Macleay River Floodplain Prioritisation Study

WRL TR 2020/07, May 2023

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Executive summary

ES.1 Preamble

The NSW Marine Estate Management Strategy (MEMS) (Marine Estate Management Authority, 2018) is a state wide strategy to protect and manage waterways, coastlines and estuaries over a ten year period (2018 – 2028). Initiative 1 of the Strategy is focused on improving water quality. Poor water quality specifically originating from diffuse agricultural runoff has been identified as one of the highest priority threats to the environmental assets within NSW estuaries (Fletcher and Fisk, 2017). Diffuse agricultural runoff was also identified as a significant threat to the social, cultural and economic benefits derived from the marine estate. Two major sources of poor water quality impacting the NSW marine estate result from diffuse acid sulfate soil (ASS) and low oxygen 'blackwater' runoff from coastal floodplains.

Department of Primary Industries (DPI) – Fisheries commissioned the Coastal Floodplain Prioritisation Study with funding from the Marine Estate Management Strategy (MEMS) to identify priority locations across major NSW coastal floodplains where the greatest improvements in water quality can be achieved through strategic management actions that reduce the impacts of ASS and blackwater runoff. This has been completed for the following seven (7) coastal floodplains in NSW:

- Tweed River floodplain;
- Richmond River floodplain;
- Clarence River floodplain;
- Macleay River floodplain;
- Hastings River floodplain;
- Manning River floodplain; and
- Shoalhaven River floodplain.

This report specifically provides an evidence-based assessment of 11 floodplain subcatchment drainage areas across the Macleay River floodplain. To determine how water quality from the Macleay River floodplain can be improved, subcatchments have been prioritised based on the risk they pose to the marine estate through the generation of poor water quality from ASS and blackwater runoff. Following the priority risk assessment, management options for short and long-term planning horizons have been suggested outlining potential strategies for each subcatchment to improve water quality outcomes. Importantly, this study identifies localised and site specific management responses targeted to sources of poor water quality considering key environmental, social, economic, cultural, and regulatory criteria. The outcomes from the study will provide an overview of floodplain processes, collate valuable datasets, provide potential management responses to address sources of poor water quality, and facilitate the streamlined implementation of actions to improve the health of the marine estate into the future.

ES.2 Background

Coastal floodplains in NSW have been extensively developed since the turn of the 20th century (Tulau, 2011). The expansion of urban and agricultural land uses has resulted in the construction of significant floodplain drainage systems to provide flood protection and improve agricultural productivity (Johnston et al., 2003a). Although floodplain drainage has improved agricultural productivity in some areas, the over drainage of coastal backswamps and wetland areas has resulted in the oxidation of acid sulfate soils (ASS), and the establishment of non-water tolerant vegetation in low-lying areas. This has contributed to the increased frequency and magnitude of poor water quality from ASS discharge and low oxygen blackwater runoff (Johnston et al., 2003b; Naylor et al., 1998; Tulau, 2011; Wong et al., 2011).

Coastal floodplains in NSW are often founded upon ASS which, when drained and oxidised, can discharge sulfuric acid and high concentrations of metal by-products into the receiving estuarine waters (Naylor et al., 1998). In areas affected by ASS, the combination of deep drainage channels and one-way floodgates increases ASS oxidation, creates acid reservoirs, and restricts potential buffering (or neutralisation) of acid by tidal waters (Johnston et al., 2003a; Stone et al., 1998). Acidic discharge causes adverse environmental, ecological and economic impacts to the floodplain and downstream estuarine receiving waters (Aaso, 2000). Impacts to aquatic ecology can be severe, including fish kills (Winberg and Heath, 2010) and oyster mortality (Dove, 2003). Acid sulfate soils are widespread in the Macleay River floodplain and acid discharges have been identified as responsible for fish kill events (NSW DPI, 2020; Tulau, 2011; Tulau and Naylor, 1999).

Low oxygen blackwater is often generated on coastal floodplains following prolonged inundation during flood events. Blackwater is formed when floodplain inundation leads to the breakdown and decay of organic matter which consumes oxygen from the standing water column (Kerr et al., 2013). When flood levels in the river recede, low oxygen blackwater drains into the estuary, often further consuming oxygen from the river water (Eyre et al., 2006). Low oxygen blackwater impacts aquatic ecology, often resulting in large fish kill events (Moore, 2007). Although blackwater is a natural process, and blackwater runoff from floodplains has historically occurred (Wong et al., 2011), the construction of efficient floodplain drainage, combined with the establishment of non-water tolerant vegetation in low-lying floodplain areas, has increased the magnitude and frequency of blackwater runoff events (Wong et al., 2011).

Increasingly, the benefits of investing in coastal floodplain areas to reduce the discharge of acidic water, reduce the generation of low oxygen blackwater, and improve the overall water quality of the marine estate are being realised. The value of environmental assets within coastal floodplains is intrinsically linked with social, cultural, and economic benefits (Fletcher and Fisk, 2017). Improvements in floodplain management have resulted in a range of benefits from improved agricultural productivity, to improved water quality, establishment of wetland habitats, greater ecosystem services, and recovery of degraded estuarine environments. Understanding the areas that contribute the most to the generation of acid or blackwater on coastal floodplains is an important step to guide future investment and reduce the impact of poor water quality on the NSW marine estate.

ES.3 Study approach

The objective of the Coastal Floodplain Prioritisation Study was to develop a roadmap for the strategic management of ASS and blackwater runoff from NSW coastal floodplains to improve the water quality and overall health of the marine estate. This has been achieved through the development and application of an evidence based and data driven multi-criteria assessment involving:

- Application of a prioritisation methodology to rank subcatchment drainage areas within NSW coastal floodplains with regard to their contribution to acid and blackwater generation and the risk they pose to the health of the marine estate;
- A first-pass guide of management options for individual subcatchments outlining potential strategies for on-ground works to improve water quality; and
- Collation of catchment specific data relevant to the implementation of management options.

This approach enables the identification of high-priority subcatchments within coastal floodplain systems that can be targeted to improve water quality and guide floodplain management. The outcomes of the subcatchment prioritisation, development of management options, and supporting information, provide an objective prioritised list of floodplain subcatchments with a roadmap on how to achieve water quality improvements across major NSW coastal floodplains. A detailed description of the multi-criteria assessment has been outlined in a separate background and methodology report by Rayner et al. (2023) that supplements this report.

The study approach features two (2) primary prioritisation methods that assess and rank floodplain subcatchments based on the risk they pose to the marine estate relating to poor water quality due to:

1. Discharge from acid sulfate soils; and
2. Generation of low oxygen ‘blackwater’.

These methods utilise an evidence based and data driven analysis which ranks subcatchments based on the risk they pose to an estuary in terms of the generation and export of poor quality water. The greatest potential benefit to the estuary can therefore be gained by reducing the sources of poor water quality from the subcatchments following the priority rank order. Figure ES-1 provides an overview of the prioritisation approach.

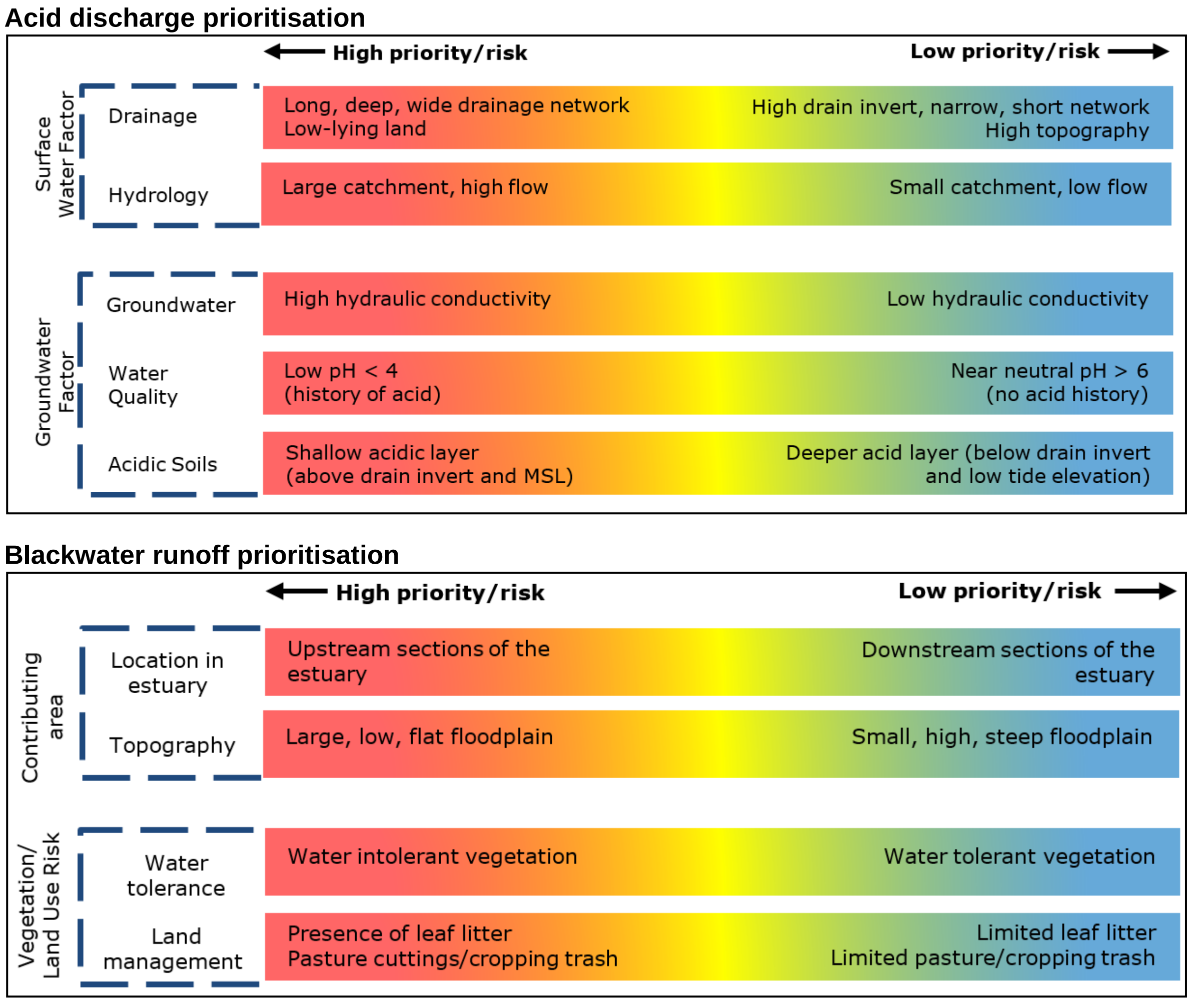

Figure ES-1: Factors influencing acid sulfate soil discharge and blackwater runoff from NSW coastal floodplain subcatchments

Following the prioritisation of subcatchments, management options have been developed to guide potential on-ground actions that could be implemented to address the sources of poor water quality from ASS and low oxygen blackwater. Management options have been proposed for the short-term, assuming existing land use practices will remain unchanged, and the long-term, where environmental stressors on subcatchments such as sea level rise may require strategic changes to floodplain management. Management options have been developed for individual subcatchments taking into consideration:

- Priority ranking for acid and blackwater;
- Proximity to sensitive receivers;
- Condition of existing floodplain infrastructure;
- Historical remediation works;
- Estuarine influence on the floodplain (e.g. tide and salinity levels);
- Current and future land uses;
- Current and future land values;
- The relative costs and benefits of remediating the floodplain; and
- Predicted vulnerability to climate change (sea level rise).

The management options suggested as part of this study are high level and intended to guide the overall strategy that should be considered by floodplain managers when addressing sources of diffuse poor water quality. It is acknowledged that further detailed on-ground investigations are required prior to the commitment to any on-ground actions, including consideration of impacts on local landholders. While this is not specifically addressed as part of this study, a range of factors which influence implementation have been collated to assist floodplain managers during the detailed design of works to improve water quality. Implementation factors to be considered when assessing changes in existing management and in detailed design include:

- Waterway status (natural or artificial);
- Infrastructure and land tenure;
- Land value (including production, purchase and remediation values);
- Future land use planning;
- Location of sensitive receivers; and
- Location of heritage items.

ES.4 Macleay River floodplain subcatchment prioritisation results

The multi-criteria prioritisation methodology was applied to rank subcatchment drainage areas of the Macleay River floodplain with respect to the risk they pose to the marine estate due to poor water quality associated with ASS discharge and blackwater runoff. The prioritisation methodology utilised a data driven approach to objectively rank the 11 floodplain subcatchments outlined in Figure ES-2. Data considered during this analysis included:

- Topography;
- Groundwater potential flow rate (i.e. hydraulic conductivity);
- Floodplain drainage;
- Subcatchment hydrology;
- Soil parameters including acid concentration;
- Land use; and
- Estuarine and tidal dynamics.

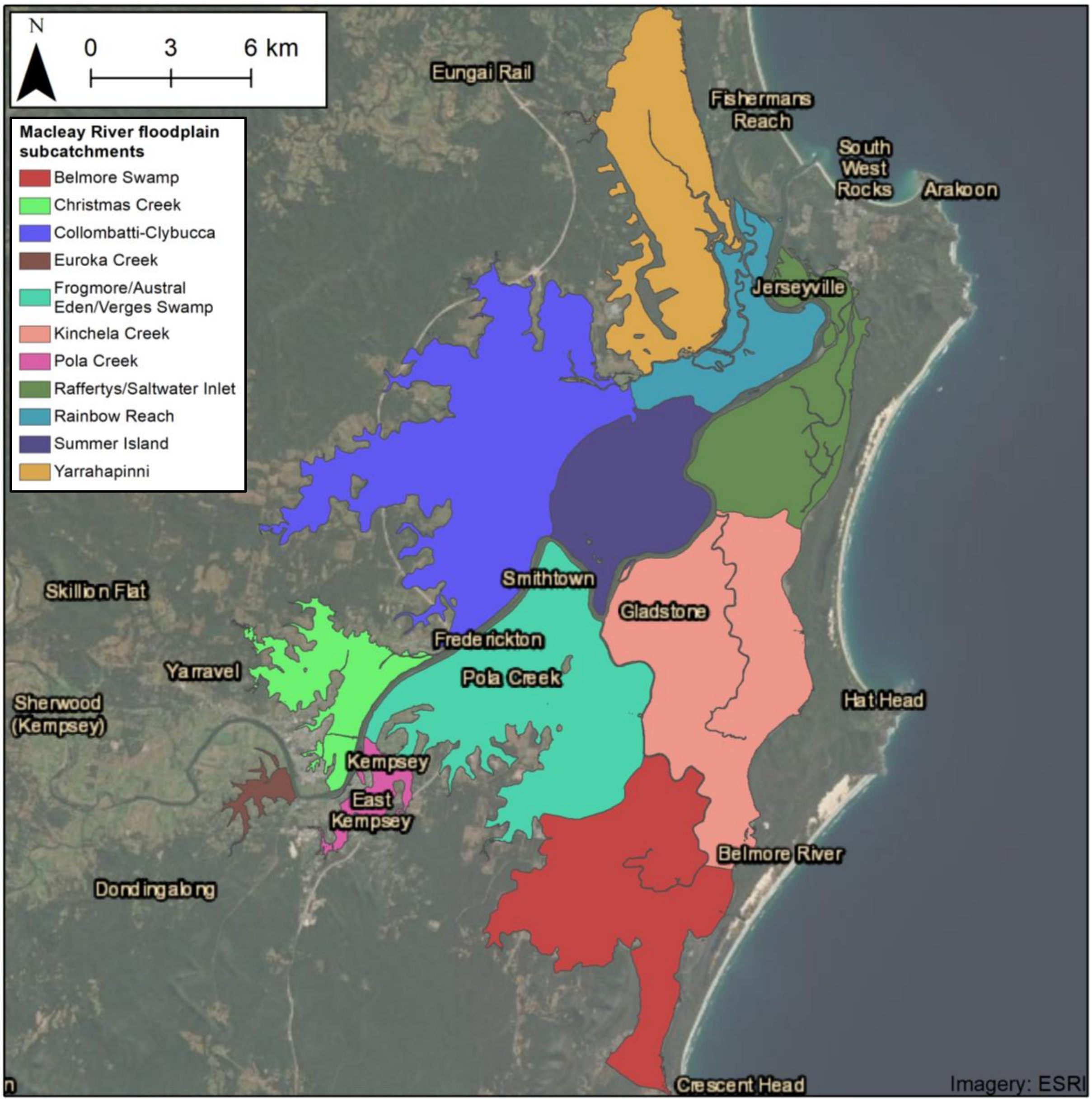

Figure ES-2: Macleay River floodplain subcatchments

The acid prioritisation assessment considers the volume of acid stored within a floodplain and the potential for it to be transported to the estuary to objectively rank subcatchment areas from the highest to lowest with respect to the risk of acid drainage to the estuary. Within the Macleay River floodplain, the highest priority subcatchment for acid drainage was Collombatti-Clybucca estimated to contribute approximately 70% of the total acid risk to the estuary (Table ES-1 and Figure ES-3). The second highest priority subcatchment was Frogmore/Austral Eden/Verges Swamp which individually contribute approximately 10% of the total acid risk for the Macleay River estuary. The upstream location of these two subcatchments highlights that acid generation and export is a risk throughout the entire Macleay River estuary. The Yarrahapinni subcatchment (ranked third) has undergone significant remediation works since 2007 including removal of floodgates to facilitate full tidal flushing.

Table ES-1: Macleay River floodplain subcatchment priority ranking

Subcatchment	Acid rank	Blackwater rank
Collombatti-Clybucca	1	3
Frogmore/Austral Eden/Verges Swamp	2	4
Yarrahapinni*	3	5
Christmas Creek	4	8
Belmore Swamp	5	2
Kinchela Creek	6	1
Raffertys/Saltwater Inlet	7	6
Pola Creek	8	10
Summer Island	9	7
Euroka Creek	10	11
Rainbow Reach	11	9

*Large scale remediation works implemented since 2007

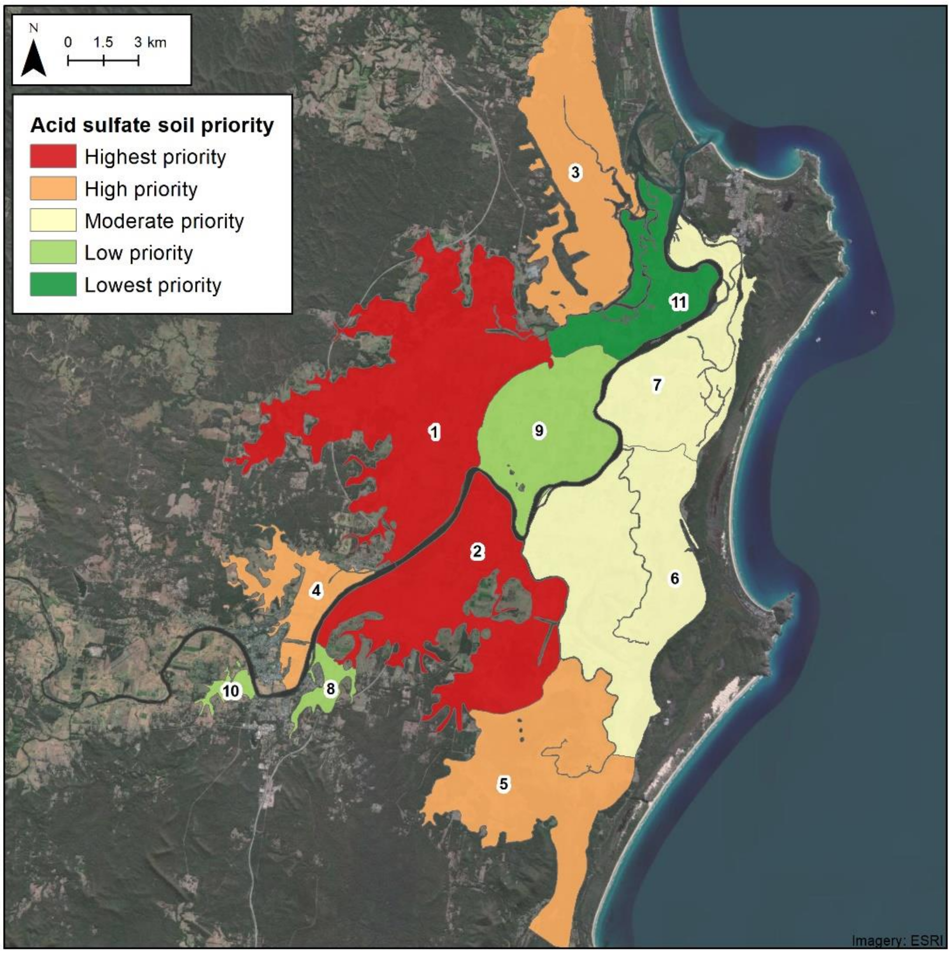

Figure ES-3: Macleay River floodplain subcatchment rankings of the acid prioritisation assessment

Application of the blackwater prioritisation methodology identified areas that are most likely to contribute to blackwater generation due to:

(i) Susceptibility to prolonged floodplain inundation following flood events; and

(ii) Distribution of water tolerant (or intolerant) vegetation.

This data was used to objectively rank subcatchments from highest to lowest based on the risk they pose to the marine estate in terms of discharging low oxygen blackwater to the estuary (Table ES-1 and Figure ES-4). The assessment identified the highest priority subcatchments, Kinchela Creek (1), Belmore Swamp (2) and Collombatti-Clybucca (3), represented approximately 55% of the total blackwater generation risk in the Macleay River estuary. It should be noted that the southern floodplain of the Macleay River includes a number of subcatchments (e.g. Belmore Swamp and Kinchela Creek) that are all hydrologically linked and altogether comprise the greatest risk within the Macleay River floodplain for blackwater generation.

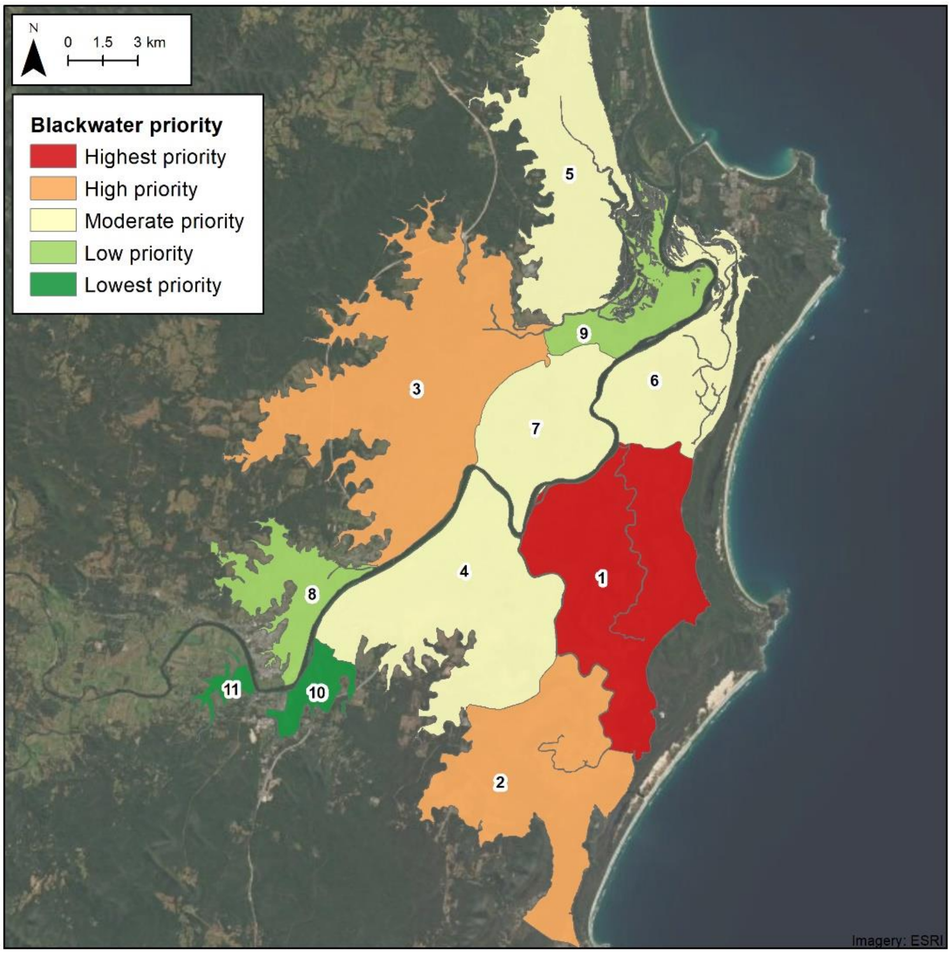

Figure ES-4: Macleay River floodplain subcatchment rankings of the blackwater prioritisation assessment

ES.5 Sea level rise and floodplain drainage vulnerability

Estuaries are situated at the interface of coastal rivers and the ocean and as a result the impacts of climate change will substantially change their physical environment (Heimhuber et al., 2019b). Sea level rise in particular will result in a significant increase in water levels within estuaries, changing the dynamics of estuarine and coastal floodplain environments. When developing management options to improve water quality of the marine estate, it is critical to incorporate the impact of sea level rise on estuarine and floodplain processes.

Assessments of sea level rise typically consider increases in the high tide levels and the subsequent inundation and flooding that may occur as a result. On coastal floodplains, however, drainage infrastructure is designed to function over a tidal cycle, preventing backwater flooding during the high tides and also allowing drainage to occur during low tides. As sea level rise occurs, the low tide level will increase which in turn will reduce the drainage potential of the floodplain and associated drainage networks. An increase in the low tide level will impact:

- Floodgates – as their effective operation is reduced as estuary water levels increase; and
- Floodplains – as low-lying areas are unable to be effectively drained and become increasingly wetter.

Detailed numerical modelling of the Macleay River estuary was completed to assess the vulnerability of floodplain drainage to sea level rise. Historical (~1960s), present day (2020), near future (~2050) and far future (~2100) sea levels were modelled and compared to floodgate infrastructure geometry and floodplain topography to assess floodplain vulnerability to reduced drainage under sea level rise. The assessment identified drainage infrastructure and floodplain areas potentially vulnerable to sea level rise as summarised in Figure ES-5 and Figure ES-6, respectively.

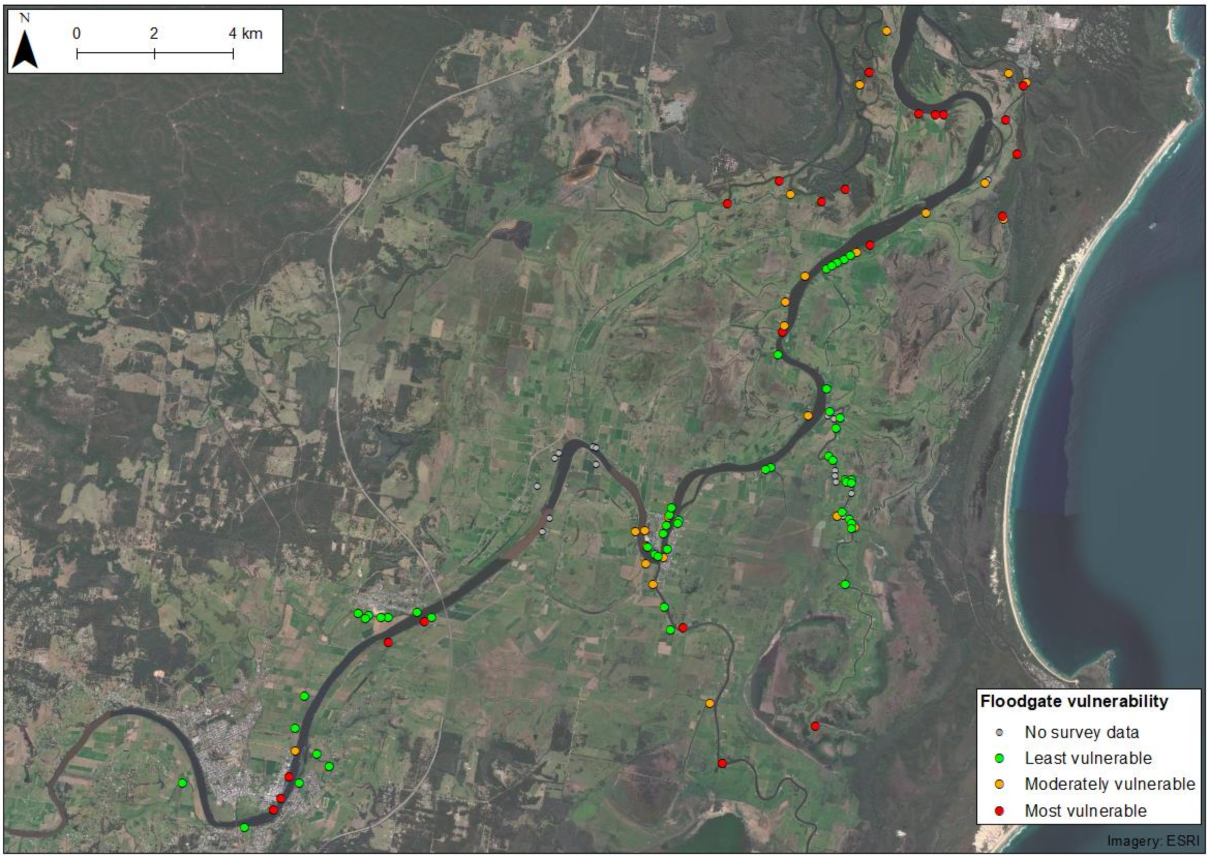

Figure ES-5: Macleay River estuary floodgate vulnerability with sea level rise (far future ~2100)

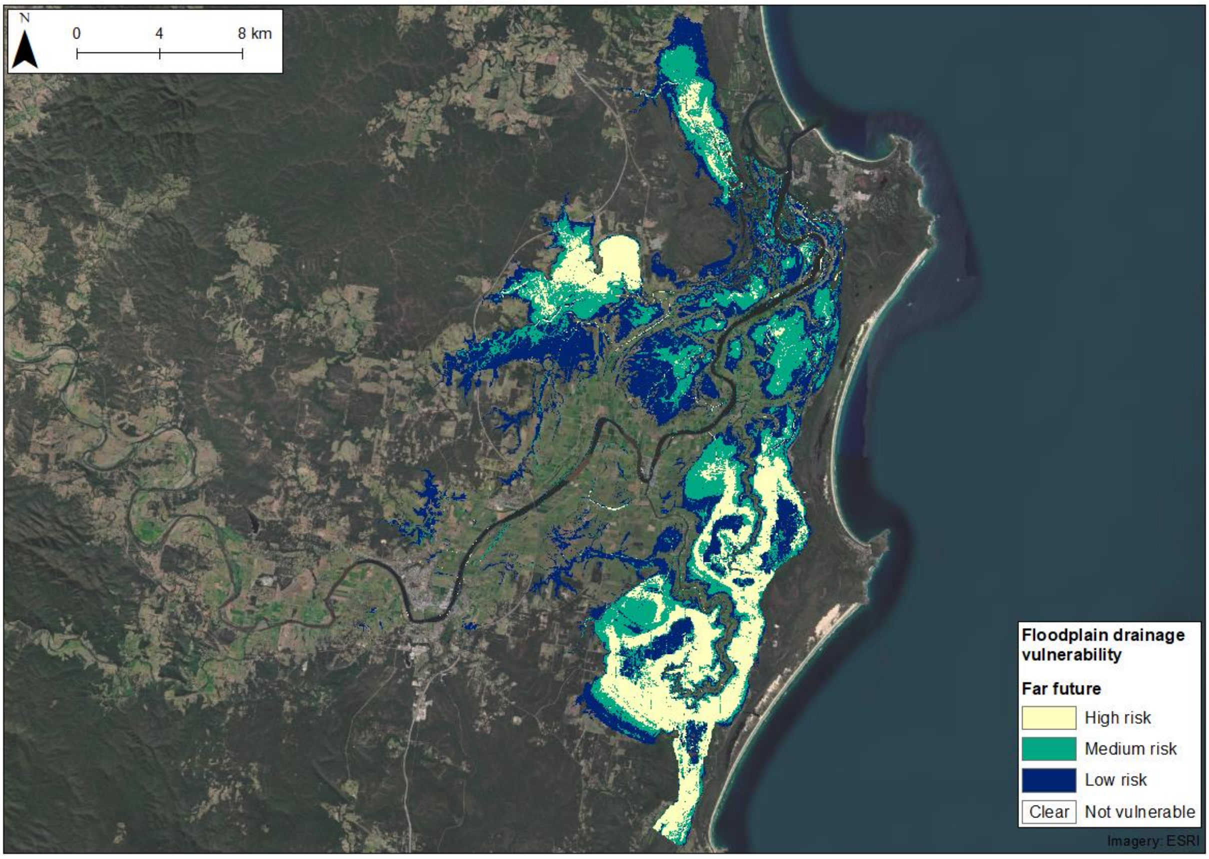

Figure ES-6: Macleay River floodplain vulnerability with sea level rise (far future ~2100)

ES.6 Management options for the top three priority subcatchments

The top three (3) highest priority subcatchments in the Macleay River floodplain were identified as:

- Collombatti-Clybucca;
- Kinchela Creek; and
- Belmore Swamp.

It is estimated that these three (3) floodplain subcatchments account for over 50% of the overall blackwater generation risk in the Macleay River floodplain. Furthermore, it is estimated that the Collombatti-Clybucca subcatchment is solely responsible for approximately 70% of the acid generation risk in the Macleay River floodplain. Addressing water quality issues from these three (3) subcatchments would result in significant improvements in the overall health of the estuary. It should be noted that the low-lying floodplains of the Kinchela Creek and Belmore Swamp subcatchments are hydrologically linked and characteristically similar. Long term management for these subcatchments may be most effective if these two subcatchments are treated as one hydrological unit in the future.

The short and long-term management options provided in this study are intended to provide a guide only, and are not intended to be implemented without further detailed investigation, design, and landholder consultation. Management options are based on existing data and may be subject to change upon further site investigation and/or additional information.

Collombatti-Clybucca subcatchment
The Collombatti-Clybucca subcatchment was ranked first for acid generation and third for blackwater generation. It is responsible for approximately 70% of the total acid risk and over 15% of the total blackwater risk for the Macleay River estuary. The Collombatti-Clybucca subcatchment has previously been identified as a priority area for improving water quality within the Macleay River floodplain and subsequently detailed investigations have been completed to identify a subcatchment wide approach to improve water quality (Glamore and Rayner, 2017; Rayner and Glamore, 2017; Rayner et al., 2020). Recommendations for management of the Collombatti-Clybucca subcatchment align with these studies.

Short-term management options for the Collombatti-Clybucca subcatchment should focus on restoring the natural wetting and drying across the floodplain. This will involve:

- Retaining freshwater on low-lying floodplain to promote the growth of water tolerant vegetation and reduce the generation and export of acid and blackwater; and
- Construction of weirs to increase the groundwater table to reduce the generation of acid.

Concept designs for this management strategy have already been developed (Rayner et al., 2020a) and detailed design investigations are currently underway. Support for the implementation of this strategy should continue.

Long-term management options for the Collombatti-Clybucca subcatchment should focus on introducing tidal waters to the backswamp. This strategy can be implemented following a gradual and deliberate stepped approach that considers sea level rise. Actions to implement this strategy include:

1. Overland controlled tidal flushing on low-lying areas through modification to the Menarcobrinni floodgates; followed by
2. Fully opening the Menarcobrinni floodgates to allow tidal flow upstream.

Benefits associated with this approach include:

- Extensive development of estuarine wetlands including water tolerant vegetation which would reduce acid and blackwater generation and export;
- Increased flushing preventing stagnation and build-up of poor quality water;
- Acid buffering capacity from tidal water; and
- Reduced generation and export of acid and acid by products (such as iron and aluminium) through increased water levels.

Kinchela Creek subcatchment

The Kinchela Creek subcatchment was ranked first for blackwater generation and was estimated to individually account for over 20% of the blackwater risk in the Macleay River floodplain. A large extent of the Kinchela Creek subcatchment is mapped as Coastal Management SEPP coastal wetlands and also includes areas within the Hat Head National Park. It is important that future management options are integrated with existing Coastal Management SEPP coastal wetland and national park areas.

Short-term management options for the Kinchela Creek subcatchment involve retaining water on the floodplain and restoring the natural backswamp hydrology. This strategy would result in the increase of water tolerant vegetation to reduce the risk of blackwater and prevent further generation and export of acid from acid sulfate soils. Implementation of this strategy could include:

- Construction of drop board and weir structures to promote the growth of water tolerant vegetation allowing wet pasture management; and
- Modification of existing structures to enhance wetland values.

Long-term management options for the Kinchela Creek subcatchment should focus on the full restoration of the low-lying backswamp that will be impacted by sea level rise to an estuarine/freshwater wetland. This strategy should focus on restoring the area’s natural hydrology to retain water on the floodplain using actions such as drain infilling, optimisation/decommissioning of structures and increasing floodplain connectivity for the following benefits:

- Reduced generation and export of acid through higher water levels;
- Increase in water tolerant vegetation reducing the severity of blackwater; and
- Increase in retention time of water following flood events resulting in blackwater being retained on the floodplain and no longer discharging to the estuary.

In the long term, management options should allow for expansion of wetland conservation areas to include existing Coastal Management SEPP coastal wetlands and the low-lying floodplain areas most likely to generate blackwater.

Belmore Swamp subcatchment

The Belmore Swamp subcatchment ranked second for blackwater generation and individually accounts for approximately 15% of the blackwater risk for the Macleay River floodplain. Similar to the Kinchela Creek subcatchment, a large extent of the Belmore Swamp subcatchment is mapped as Coastal Management SEPP coastal wetlands. It is important that future management options add value to this important ecosystem.

Short-term strategies for the remediation of the Belmore Swamp subcatchment include promoting the retention of water across the floodplain and optimising the management of existing infrastructure. The aims of these strategies are to reduce the generation of blackwater by encouraging water tolerant vegetation growth and then reduce the impact of discharge of blackwater to the Belmore River and the wider Macleay River estuary. Management options such as encouraging wet pasture through installation of weirs and drop boards have already taken place across the subcatchment, however, these practices could be more extensively implemented. Management of floodgate structures on the Belmore River could also be investigated to determine if their management in unison could achieve water quality improvements.

Long-term management options for the Belmore Swamp subcatchment should focus on the full restoration of the low-lying floodplain that will be impacted by sea level rise to a freshwater wetland by restoring the floodplains natural hydrology. This would enhance the ecological benefits of the existing Coastal Management SEPP coastal wetlands while reducing the generation and export of blackwater and acid. By managing the Belmore Swamp subcatchment as a whole unit and implementing actions such as drain infilling, optimisation/decommissioning of structures and increasing floodplain connectivity, the following benefits could be achieved:

- Reduced generation and export of acid through higher water levels;
- Increase in water tolerant vegetation reducing the severity of blackwater; and
- Increase in retention time of water following flood events resulting in blackwater being retained on the floodplain and no longer discharging to the estuary.

ES.7 Outcomes and conclusions

Outcomes from the Coastal Floodplain Prioritisation Study for the Macleay River floodplain provide a roadmap for floodplain land managers to directly improve poor water quality associated with diffuse runoff caused by acid and blackwater generation on the coastal floodplain. Specifically, this study has:

1. Ranked subcatchments on the basis of the risk they pose to the marine estate in terms of poor water quality resulting from ASS and blackwater runoff;
2. Suggested potential management options that describe the overall strategy for floodplain management to improve water quality; and
3. Identified and collated key datasets that will be valuable for floodplain management.

Substantial efforts have been put into managing water quality in the Macleay River estuary, primarily through Kempsey Shire Council with support from local landholders. Notably, a large number of major floodplain end-of-system infrastructure has been modified to allow some controlled flushing (e.g. sluice gates, and winches) and improved connectivity with the estuary. Numerous landholders have co-operated with paddock scale interventions, such as weirs or drain reshaping, with mixed success in terms of water quality improvements and maintenance/improvement of agricultural productivity. These remediation efforts should be encouraged and commended.

However, the scale of on-going large event-based floodplain discharges of blackwater and acid, particularly from the three (3) highest priority subcatchments (Collombatti-Clybucca, Kinchela Creek and Belmore Swamp) can only be substantially addressed through broadscale changes to land use and a restoration of natural floodplain hydrology. Broadscale management changes throughout the floodplain will need to consider, and have a plan to mitigate, potential social, cultural, and economic impacts to local landholders. Particularly as sea level rise impacts drainage and agricultural land uses in the lowest lying areas of the floodplain, a catchment wide strategy needs to be established to assist the community to adapt to a changing environment and to support a future that is environmentally and economically sustainable.

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Glossary of terms

Acid	A substance that has a pH less than 7 (a pH of 7 being neutral i.e. neither acidic nor alkaline). Specifically, an acid has more free hydrogen ions (H^+) than hydroxide ions (OH^-).
Acid export	The mass of acid discharged from a system (e.g. a drain or floodplain). Acid can be exported via two common mechanisms, by either a hydraulic gradient (water level or pressure head difference along a channel or pipeline) or a concentration gradient (natural mixing through a water body from a higher concentration to a lower concentration).
Acid sulfate soil (ASS)	Sediments in which iron sulfides (mainly pyrite) accumulate below the groundwater table in anaerobic conditions. The exposure of these sediments to air enables the oxidation of pyrite/sulfides to produce sulfuric acid. Oxidised acid sulfate soils are referred to as actual acid sulfate soils (AASS), unoxidised acid sulfate soils are referred to as potential acid sulfate soils (PASS).
Alkali	A substance that has a pH greater than 7 (a pH of 7 being neutral i.e. neither acidic nor alkaline). Specifically, an alkali has more free hydroxide ions (OH^-) than hydrogen ions (H^+).
Anaerobic conditions	The absence of atmospheric oxygen (often required for certain biological processes).
Annual exceedance probability (AEP)	The probability of a flood or rainfall event of a predetermined size or larger occurring in a one-year period.
Antecedent conditions	The moisture stored within a catchment prior to a rainfall event.
Australian Height Datum (AHD)	A datum surface for Australia used for measuring elevation. The zero metres AHD height at 30 tide gauges across Australia corresponds to mean sea level as measured from 1966 to 1968.
Auto-tidal gate	A mechanism whereby a small opening on a floodgate flap is allowed to let a controlled volume of water upstream of a floodgate as the water level increases on the downstream side. This can be mechanical or power driven. As the water rises to a designed level (on the downstream side) the mechanism on the gate shuts, closing the small opening on the floodgate flap. This mechanism allows for controlled flushing of waterbodies upstream of a floodgate in addition to fish passage.
Backwater	Water held up in its course (being controlled by downstream conditions) as compared with its normal or natural condition of flow.
Baseflow	Flow of a waterway sustained between periods of rainfall by groundwater discharge.
Bathymetry	The measurement of depth of water from the surface to the bottom a waterbody.
Blackwater	Deoxygenated water usually dark in colour and resulting from decomposing organic matter.
Buoyancy tidal gate	A buoyancy tidal gate (often referred to as a fish gate) is a mechanism whereby a small opening on a floodgate flap is allowed to let a controlled volume of water upstream of a floodgate as the water level increases on the downstream side. As the water rises to a designed level (on the downstream side) the buoyancy mechanism on the gate shuts, closing the small opening on the floodgate flap. This mechanism allows for controlled flushing of waterbodies upstream of a floodgate in addition to fish passage.
Catchment	The land area upstream of a particular point of interest into which precipitation drains. Each waterway has its own individual catchment. Also called a "watershed."
Climate change	A change in climate patterns as a result of increases in atmospheric carbon dioxide.
Connector watercourse	A waterway with either natural or artificial sections that provides a connection between two natural waterbodies.
Crest	The crest is the elevation at which weirs, levees or drop board structures are designed to overtop.
Culvert	Culverts are structures that allow water to move between two open waterbodies and bypass an obstruction such as a levee or road. Culverts have two open ends which do not inhibit flow. However, they can also have separate mechanisms such as floodgates or sluice gates attached to them to further control the flow of water.
Digital elevation model (DEM)	A 3D computer model of land surface elevation. A DEM is composed of a grid of cells which each represent an elevation value. The size of individual grid cells (e.g. 1 m times 1 m or 5 m times 5 m) is one measure of the accuracy of a DEM.
Discharge	Flow rate measured by volume per unit time (usually in cubic metres per second).
Dissolved organic carbon (DOC)	Organically bound carbon present in water that can pass through a membrane filter with a 0.45µm pore size.

Dissolved oxygen (DO)	Atmospheric oxygen that dissolves in water. The solubility of oxygen depends upon temperature and salinity.
Downstream/ upstream	Downstream is the location in a channel that is closest to the ocean. Upstream is the location in a channel that is furthest from the ocean.
Drop board	Drop boards are frames built across a waterway which enable the manipulation of flow and water levels by the insertion of 'boards' into specifically designed slots to act as a barrier to water movement. Drop boards are similar to weirs in that they only allow water to flow over the top of them. Unlike weirs, drop boards are adjustable in height. Multiple boards with different heights can be used to adjust and set the weir level. Drop boards can be fitted to culverts or can be standalone structures.
Drought	A prolonged period of reduced or low precipitation resulting in a shortage of water.
Electrical conductivity (EC)	A measure of dissolved salt in water in the units of micro Siemens per centimetre (µS/cm) usually at a temperature of 25ºC.
Estuary	A semi-enclosed waterbody where fresh water from catchment runoff and saltwater from the ocean mix.
Evaporation	The process of liquid water on the land surface becoming water vapour in the atmosphere.
Evapotranspiration	The sum of evaporation and transpiration.
Exceedance per year (EY)	The likelihood that a flood or rainfall event of a predetermined size will occur a certain number of times within any one-year period.
Flood	High flow of water within a waterway that results in the overtopping of natural or artificial banks (or levees) of a waterbody and inundation of usually dry land.
Floodgate/ floodgate flap	A plate that is hinged on its top edge to cover the outlet of a culvert. The flap is positioned so that it only opens when the water level on the upstream (floodplain side) is higher that the level on the downstream (river side) of the culvert, thereby only allowing water to flow in the downstream direction effectively draining the floodplain. Floodgates often regularly open and close with fluctuating tidal water levels in the river. It is common for floodgates to have rubber seals to prevent leaking. Floodgate flaps can be made of many materials such as aluminium, plastic, fibre glass or wood.
Floodplain	The area of land adjacent to a waterbody that is often relatively flat and usually dry unless exposed to water as occurs during a flood.
Freshwater	Water that contains less than 1,000 milligrams per litre (mg/L) of dissolved solids.
Gate	A term used to describe the part of either a floodgate or sluice gate flow control structure that controls water movement.
Groundwater	Water held under the ground surface within soil and rock formations.
Groundwater table	The upper surface of soil or rock formations that is fully saturated by groundwater.
Headwall	The concrete structure surrounding and supporting a culvert. Floodgate flaps or other mechanisms are usually mounted to the headwall.
Hydraulic gradient	The difference in pressure or elevation of water over a distance. The hydraulic gradient results in the flow of water (from high elevation or pressure to low elevation or pressure).
Hydrodynamics	The branch of science concerned with the movement of, and forces acting on or exerted by fluids.
Hydrodynamic model	A numerical representation of the movement of water through a system.
Hydrograph	A graph showing the level, discharge, velocity, or other property of water with respect to time.
Hydrology	The branch of science concerned with the movement and quality of water in relation to land.
Impermeable layer	A layer of solid material, such as rock or clay, which does not allow water to pass through.
Invert	The elevation of the lowest internal point of a culvert.
Leaching	The process by which soluble materials in the soil such as salts, nutrients, pesticide chemicals or contaminants are dissolved and carried away by water.
Left bank/right bank	The side of a waterway when looking in the downstream direction (i.e. toward the ocean).
LEP	Local Environmental Plan - LEPs are planning instruments that guide planning decisions for local government areas. They do this through zoning and development controls, which provide a framework for the way land can be used. LEPs are the main planning tool to shape the future of communities and also ensure local development is completed appropriately.
LGA	Local Government Area.
Levee	An embankment that prevents or reduces flow from a waterway to the floodplain. Levees can be naturally formed as river banks or manmade for the purpose of flood mitigation or to prevent inundation of low-lying land.

Lidar	Light detection and ranging technology that can be used to measure ground surface elevations and create DEMs.
Marine estate	Tidal rivers and estuaries, the shoreline, submerged lands, offshore islands, and the waters of the coast up to three nautical miles offshore.
Management area	A subset or smaller area of a subcatchment often delineated based on floodplain tenure and ownership in addition to floodplain hydrological and geomorphological characteristics. Generally, a management area is of small enough scale that implementation of on-ground works to address water quality issues can be completed.
MBO	Mono-sulfidic black ooze – deposits in drainage channels created by iron and sulphur minerals (pyrite) within acid sulfate soils which, when mobilised, can remove oxygen from the water through a chemical reaction.
Obvert	The elevation of the highest internal point of a culvert.
Organic matter	Substances made by living organisms and based on carbon compounds.
Peak flow	The maximum instantaneous discharge of a waterway at a given location.
pH	A measure of the acidity or alkalinity of water. Water with a pH of 7 is neutral; lower pH levels indicate increasing acidity, while pH levels higher than 7 indicate increasing alkalinity
Pipe	A pipe is a circular culvert. Pipes can be made of many materials such as concrete, PVC or fibre glass.
Precipitation	Water that falls on land surfaces and open waterbodies as rain, sleet, snow, hail or drizzle.
River	A major watercourse carrying water to another river, a lake or the ocean.
Runoff	Excess rainfall that becomes streamflow.
Salinity	The total mass of dissolved salts per unit mass of water. Seawater has a salinity of about 35g/kg or 35 parts per thousand (ppt).
Sediment	Material suspended in water or deposited from suspension.
Seepage	The infiltration of water from surface waterbodies to the groundwater.
Sluice/sluice gate	A gate that operates by sliding vertically to control water flowing through or past a restriction point. Sluice gates act so that water flows underneath the 'sluice' or the sliding section of the gate. A sluice gate can be set to different levels to control the volume of water that flows. There are many different designs for sluice gates.
Soil profile	A vertical section of soil (from the ground surface downwards) where features such as layers (soil horizons), texture, structure, consistency, colour and other characteristics of the soil can be observed.
Streamflow	The flow of water in open waterbodies (such as streams, rivers or channels).
Subcatchment	A section of the floodplain that is geologically and hydrologically similar but can also be delineated based on floodplain management objectives.
Surface water	Water that flows or is stored on the Earth's surface.
Tidal exchange	The proportion of water that is flushed away and replenished with new ocean water each tidal cycle.
Tidal limit	The maximum distance upstream of a waterway where the influence of tidal variation in water levels is observed.
Tidal planes	Reference elevations that define regular tide elevations, including: MHWS - Mean High Water Springs MHW - Mean High Water MSL - Mean Sea Level MLW - Mean Low Water MLWS - Mean Low Water Springs
Tidal prism	The volume of water that flows in and out of an estuary during a tidal cycle (e.g. high tide to low tide).
Transpiration	The release of water vapour from plants to the atmosphere.
Tributary	A smaller river or stream that flows into a larger waterbody.
Water table	The surface of water whether it is under or above ground.
Waterbody	Either: An artificial body of water, including any constructed waterway, canal, inlet, bay, channel, dam, pond, lake or artificial wetland, but does not include a dry detention basin or other stormwater management construction that is only intended to hold water intermittently; or A natural body of water, whether perennial or intermittent, fresh, brackish or saline, the course of which may have been artificially modified or diverted onto a new course, and includes a river, creek, stream, lake, lagoon, natural wetland, estuary, bay, inlet or tidal waters (including the sea).

Watercourse	Any river, creek, stream or chain of ponds, whether artificially modified or not, in which water usually flows, either continuously or intermittently, in a defined bed or channel, but does not include a waterbody (artificial).
Waterway	The whole or any part of a watercourse, wetland, waterbody (artificial) or waterbody (natural).
Weir	Weirs are permanent structures that block a channel and only allow water to flow over the top of them.
Winch	A mechanism used to open floodgate flaps or sluice gates. The winch system usually involves pulling the gates open via chains or cables.

1 Introduction

1.1 Preamble

The NSW Marine Estate Management Strategy (MEMS) (Marine Estate Management Authority, 2018) is a state wide strategy to protect and manage waterways, coastlines and estuaries over the ten year period 2018 – 2028. Initiative 1 of the Strategy is focused on improving water quality. Major sources of poor water quality across the marine estate include acid sulfate soil (ASS) and blackwater runoff into our estuaries. Over the past 25+ years, significant efforts to remediate ASS and blackwater drainage have been made by local councils and landholders to remediate ASS and blackwater drainage, however this has been limited by insufficient funding, resources, and community willingness. To better target remediation efforts and land management decisions, Department of Primary Industries (DPI) – Fisheries commissioned the Coastal Floodplain Prioritisation Study, based on a method detailed in Glamore and Rayner (2014) and adapted to integrate the MEMS approach for achieving environmental outcomes that consider social, cultural and economic benefits, to prioritise floodplain subcatchments in seven (7) coastal floodplains in NSW.

This report provides an evidence-based assessment of floodplain subcatchment drainage areas that contribute poor water quality to the Macleay River estuary. Poor water quality from diffuse agricultural runoff has been identified as the highest priority threat to the environmental assets within estuaries in NSW, as outlined in the threat and risk assessment (TARA) (Fletcher and Fisk, 2017). Diffuse agricultural runoff was also identified as a significant threat to the social, cultural and economic benefits derived from the marine estate. In particular, the TARA highlights the threat posed to estuaries from acid discharges and low oxygen blackwater runoff associated with modified floodplain uses and drainage. To address this, subcatchments in the Macleay River estuary have been prioritised based on the risk of generating poor water quality from ASS and blackwater drainage. Following the priority risk assessment, management options for short and long-term planning horizons have been suggested, outlining potential high level land management options for each subcatchment to address acid and blackwater drainage. This study identifies localised management responses that target sources of poor water quality throughout the floodplain. The management options in this study are intended to provide a guide to further improve water quality, although it is acknowledged that further work will be required to assess the applicability of on-ground works at a given location. Any changes in management of these areas will require consultation with local landholders and a comprehensive understanding of, and a plan to mitigate, the social and economic impacts of changes in land management on the community. The outcomes from the study will provide an overview of floodplain processes and datasets, provide potential management responses to poor water quality sources, and facilitate the streamlined implementation of management options into the future.

This study was funded by the NSW Government under the Marine Estate Management Strategy (MEMS). The ten-year Strategy was developed by the NSW Marine Estate Management Authority (MEMA) to coordinate the management of the marine estate. The study was commissioned by NSW Department of Primary Industries - Fisheries under the MEMS Stage 1 and delivered by the Water Research Laboratory (WRL) of the School of Civil and Environmental Engineering at UNSW Sydney.

1.2 Connection to other reports

The prioritisation of the Macleay River floodplain subcatchments and associated management options presented in this report are an application of the methods outlined in the Coastal Floodplain Prioritisation Study – Background and Methodology (Rayner et al., 2023) (i.e. the 'Methods report'). The Methods report (Rayner et al., 2023) outlines the theoretical processes behind the applied prioritisation approach and provides comprehensive detail and justification on the study approach and methods used in this report. The Coastal Floodplain Prioritisation Study covers seven (7) NSW coastal floodplains:

- Macleay River floodplain (this report);
- Tweed River floodplain (WRL TR2020/04);
- Richmond River floodplain (WRL TR2020/05);
- Clarence River floodplain (WRL TR2020/06);
- Hastings River floodplain (WRL TR2020/08);
- Manning River floodplain (WRL TR2020/09); and
- Shoalhaven River floodplain (WRL TR2020/10).

The subcatchment prioritisations for each of these floodplains are documented in individual reports. Note that prioritisation results between individual floodplains are not directly comparable.

1.3 Coastal floodplain prioritisation method

The Coastal Floodplain Prioritisation Method (Rayner et al., 2023) provides an objective approach to assess subcatchments within a coastal floodplain and identify areas that pose the greatest risk of poor water quality from acid sulfate soil discharges and low dissolved oxygen (DO) blackwater runoff. The method does not address additional water quality issues, such as nutrient export or catchment runoff, which may also pose a significant risk to the estuarine health of the marine estate. Instead, it focuses specifically on the generation of acid discharge and blackwater within each estuary. The present report focuses on the Macleay River estuary and adjoining floodplain subcatchments.

The study approach features two (2) primary prioritisation methods that independently assess and rank floodplain subcatchments based on the risk of:

1. Discharge from acid sulfate soils; and
2. Generation of low oxygen 'blackwater' runoff.

The prioritisation method utilises a multi-criteria analysis to assess the risk of poor water quality from floodplain subcatchments and ranks the subcatchments relative to their contribution to these key water quality issues. Figure 1-1 provides an overview of the study approach.

This report provides a prioritised list of floodplain subcatchments from where the greatest risk of acid and blackwater within each floodplain originates. The greatest potential benefit to the estuary can be logically gained by reducing the sources of poor water quality from the subcatchments according to the priority order. The individual floodplain assessments and prioritisations provide subcatchment management options and data summaries to guide land managers and decision makers in implementing on-ground actions on both floodplain and paddock scales.

In addition to the prioritisation and management options, collated in this report and the Methods report (Rayner et al., 2023) there are a number of implementation constraints. These are factors that do not necessarily influence physical processes and the development of the management plans but will influence their implementation. Implementation constraints that have been collated include:

- Waterway status (natural or artificial);
- Infrastructure and land tenure;
- Land value (including production, purchase and remediation values);
- Future land use planning;
- Location of sensitive receivers; and
- Location of heritage items.

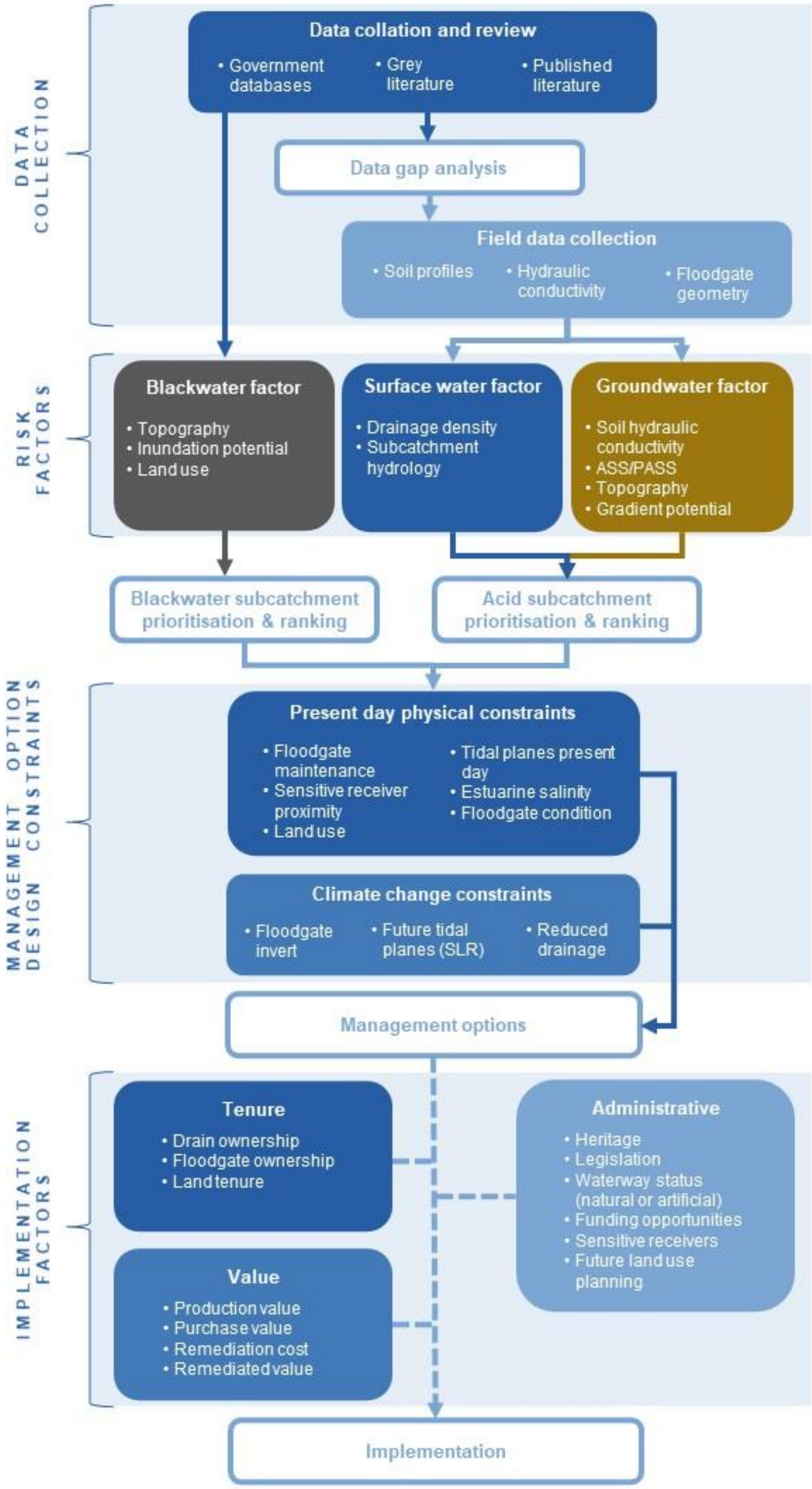

Figure 1-1: Study approach overview

1.4 Macleay River floodplain prioritisation

The Macleay River floodplain is located on the mid-north coast of NSW between the town of South West Rocks in the east and the town of Kempsey to the west. European settlement of the area began in the mid-19th century (Tulau, 2011). Extensive artificial floodplain drainage was constructed in the late 19th century and throughout the 20th century for flood protection purposes and to facilitate agricultural development (Tulau and Naylor, 1999). Floodplain development and drainage has had unintended impacts on estuarine water quality with the oxidation of acid sulfate soils, and the establishment of non-water tolerant vegetation in historically low-lying wetland areas (Johnston et al., 2003a; Johnston et al., 2003b). Although acid sulfate soils are naturally occurring sediments, and blackwater discharge historically occurred in undeveloped, natural floodplains, the construction of man-made drainage channels exacerbated these issues and has contributed to poor water quality throughout the greater Macleay River estuary.

This report summarises the application of the acid sulfate soil and blackwater subcatchment prioritisation methodologies on the Macleay River estuary floodplain (defined as the area below 5 m AHD). On-ground management options have been developed for each floodplain subcatchment and are based on site specific conditions and constraints. Some management options can be implemented in the short term with minimal impacts to existing land uses, while others require substantial changes to land management to create effective improvements in water quality outcomes. The management options provided in this study are intended to be a guide only, and no on-ground work is recommended without further studies into the applicability and potential impacts of any changes in management. The following factors were considered to develop on-ground management options for each subcatchment area:

- Priority ranking for acid and blackwater;
- Proximity to sensitive receivers;
- Condition of existing floodplain infrastructure;
- Historical remediation works;
- Estuarine influence on the floodplain (e.g. tide and salinity levels);
- Current and future land uses;
- Current and future land values;
- The relative costs and benefits of remediating the floodplain; and
- Predicted vulnerability to sea level rise.

The outcomes of this study aim to provide the basis for a strategic approach to address ASS and blackwater discharges in the Macleay River floodplain, as well as collecting and collating key datasets that will inform on-going and future decision making and design of floodplain drainage and flood mitigation infrastructure. Implementing the recommended options will ensure that subcatchments with the greatest potential impacts are prioritised for strategic land use decisions and remediation of water quality risks. As such, this will ensure that future investments in subcatchment management actions are evidence based, providing the best value for money, and the greatest environmental benefit.

1.5 About this report

This report comprises the following sections:

- **Chapter 2** presents the drainage subcatchments considered in the Macleay River floodplain;

- **Chapter 3** provides background information describing the floodplain drainage and presence of ASS and blackwater in the Macleay River floodplain;
- **Chapter 4** provides an overview of the ASS and blackwater prioritisation methods;
- **Chapter 5** presents the outcomes of the ASS prioritisation in the Macleay River floodplain;
- **Chapter 6** presents the outcomes of the blackwater prioritisation in the Macleay River floodplain;
- **Chapter 7** provides information on the impact of sea level rise on floodplain drainage;
- **Chapter 8** outlines the management options developed for each subcatchment; and
- **Chapter 9** provides a summary and recommendations.

The following appendices have also been included to provide additional information and summaries of data used and collected for the study:

- **Appendix A** Floodplain waterways;
- **Appendix B** Catchment hydrology;
- **Appendix C** Groundwater saturated hydraulic conductivity data;
- **Appendix D** Acid sulfate soil distribution;
- **Appendix E** Blackwater elevation threshold;
- **Appendix F** Floodplain infrastructure;
- **Appendix G** Cross-sections;
- **Appendix H** Water quality;
- **Appendix I** Numerical modelling;
- **Appendix J** Sensitive receivers;
- **Appendix K** Heritage; and
- **Appendix L** Soil profile data sheets.

2 Subcatchment delineation

2.1 Preamble

The prioritisation of ASS and blackwater generation potential in this study compares and ranks drainage units or subcatchments on the Macleay River floodplain for areas below 5 m Australian Height Datum (AHD). The delineation of subcatchments can influence the results of the prioritisation and requires careful consideration given the highly connected nature of low-lying coastal floodplain areas. The process of delineating the subcatchments primarily includes consideration of:

- Floodplain topography and geological features;
- Connectivity of waterways, including consideration of location of major floodplain infrastructure and drains; and
- Management areas from previous studies (e.g. estuary management plans).

The primary data used for subcatchment delineation was topographical and waterway data which allows for the determination of hydrological flow paths. Using this data allows each subcatchment to be delineated as a single hydrological unit (as far as reasonably practical). This was deemed the most important factor in the subcatchment delineation process as it then allows each subcatchment to be managed as a discrete unit. This section outlines the subcatchments developed for the Macleay River floodplain, which are used throughout this study.

2.2 Subcatchments of the Macleay River floodplain

The subcatchments in the Macleay River floodplain have been defined based on the floodplain geological and hydrological features, in addition to drainage areas identified by Geolink (2012). Coastal planning for the Macleay River estuary has previously identified six (6) high priority drainage areas for remediation works (Geolink, 2012), namely:

- Collombatti-Clybucca;
- Kinchela;
- Belmore;
- Frogmore;
- Yarrahapinni; and
- Raffertys.

These drainage areas have been utilised to guide the delineation of subcatchments and also to inform the management options for floodplain subcatchments that align with coastal planning for the Macleay River estuary (Geolink, 2012). The subcatchments in the Macleay River floodplain are shown in Figure 2-1.

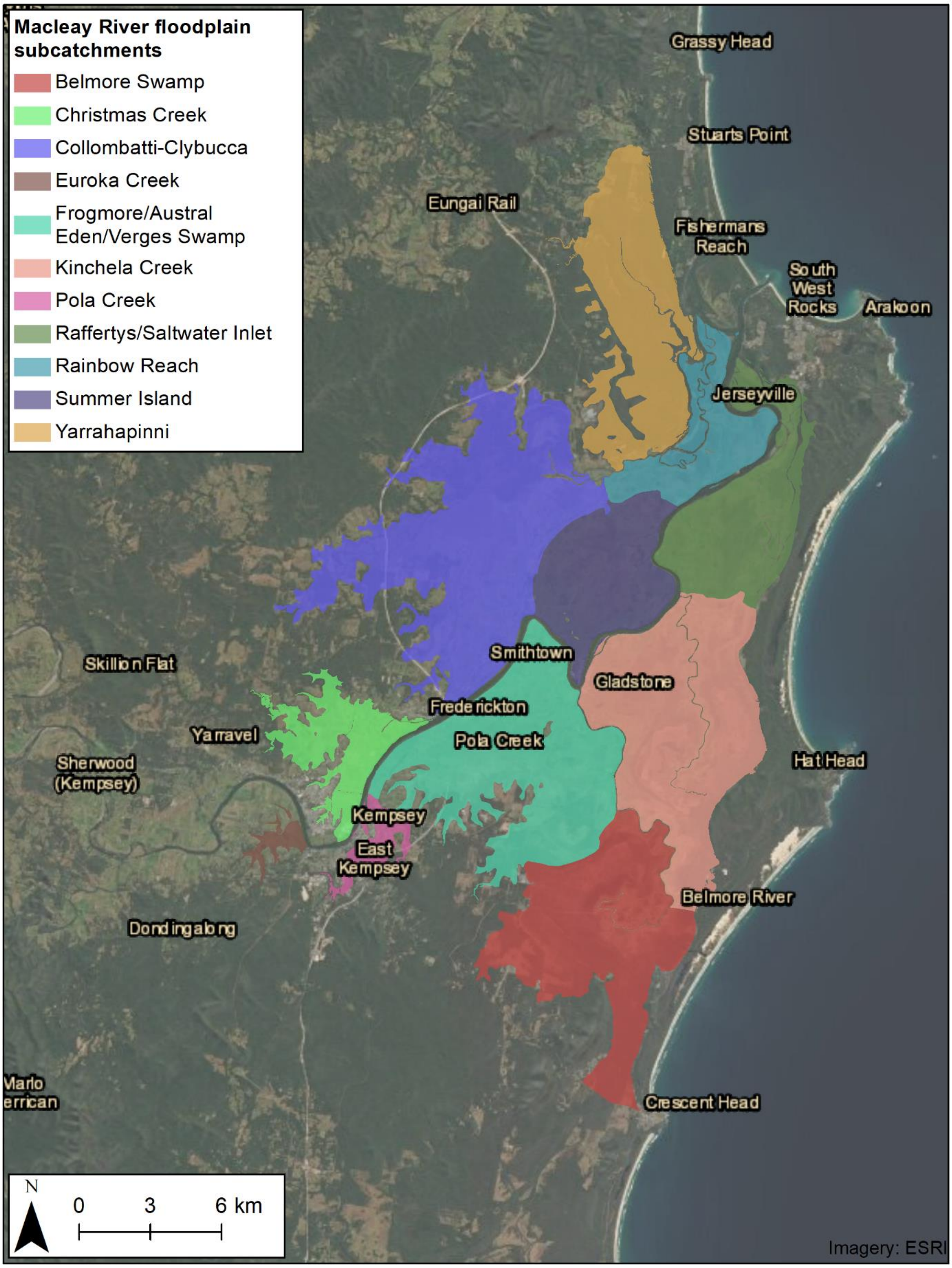

Figure 2-1: Subcatchments of the Macleay River floodplain

3 Background

3.1 Preamble

This section provides background information on the Macleay River floodplain, describing the history of the floodplain drainage, ASS distribution, blackwater runoff events, and floodplain land use and tenure. General background on ASS oxidation and blackwater formation can be found in Sections 3 and 5 of the Methods report (Rayner et al., 2023), respectively.

3.2 Local government

Local government authorities play a key role in maintaining floodplain drainage assets and the overall management of estuarine water quality. The Macleay River floodplain is located within and managed by the Kempsey Shire Council local government area (LGA). The Kempsey Shire Council LGA is shown in Figure 3-1 with respect to the Macleay River floodplain study area.

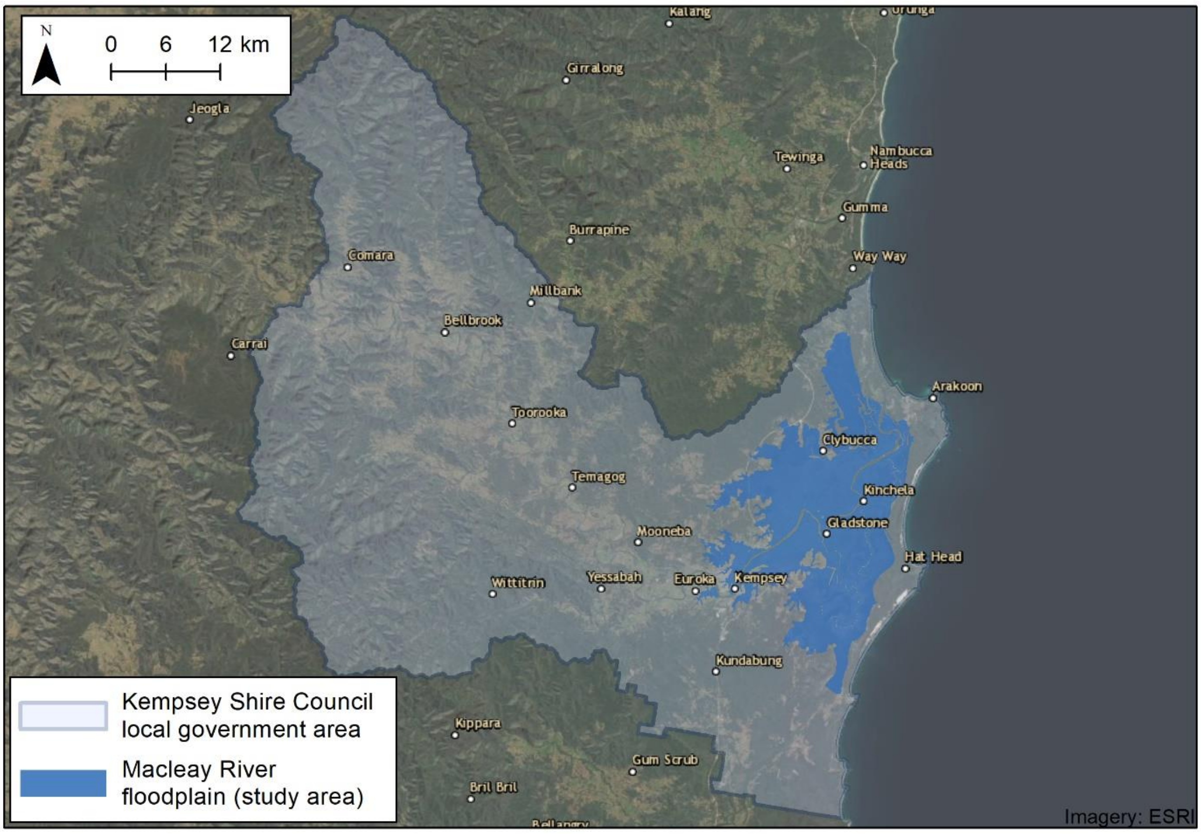

Figure 3-1: Kempsey Shire Council local government area including the Macleay River floodplain

Under the Environmental Planning and Assessment Act (1979) a Local Environmental Plan (LEP) is required for each LGA. LEPs guide the strategic planning decisions for local councils within their LGAs. This is achieved through zoning and development controls which outline the way in which land can be used, including land on coastal floodplains.

3.3 Floodplain history

The Macleay River floodplain (below 5 m AHD) covers an area of approximately 37,000 hectares. The tidal limit of the estuary is located at Belgrave Falls and the Macleay River flows from this location in a north easterly direction for approximately 55 km to South West Rocks at the ocean entrance (Geolink, 2012; Telfer, 2005). Prior to 1893, the ocean entrance of the estuary used to be located at Grassy Head, approximately 10 km north of its current location (Telfer, 2005). In 1983 a large flood resulted in the Macleay River entrance breaking through the sand barrier at South West Rocks creating a new entrance to the ocean, which was subsequently trained in 1897 becoming a permanent opening and significantly altering the tidal influence on the river (Geolink, 2012; Telfer, 2005; Tulau, 2011). The section of river to the north that became disconnected from the ocean is now known as the Macleay Arm. Other major tributaries of the Macleay River include (Figure 3-3):

- Andersons Inlet (flows into the Macleay Arm);
- Boringalla Creek (flows into Andersons Inlet);
- Clybucca Creek (flows into Andersons Inlet);
- Saltwater Inlet (to the south of the Macleay river floodplain)
- Kinchela Creek (to the south of the Macleay river floodplain);
- Belmore River (to the south of the Macleay river floodplain); and
- Christmas Creek (located on the left bank in the upper estuary).

These tributary streams connect the main river to numerous low elevation backswamps, with substantial areas below 1 m AHD, as shown in Figure 3-2.

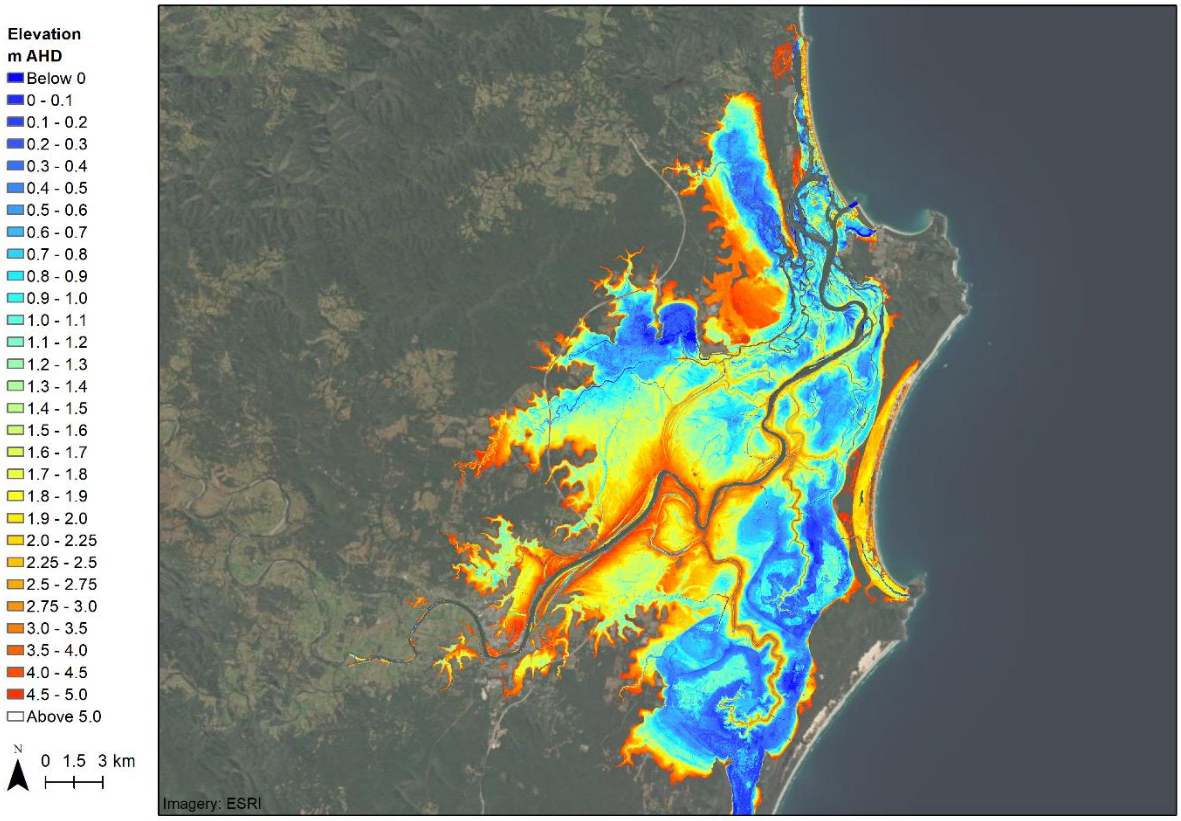

Figure 3-2: Digital elevation map of the Macleay River floodplain topography

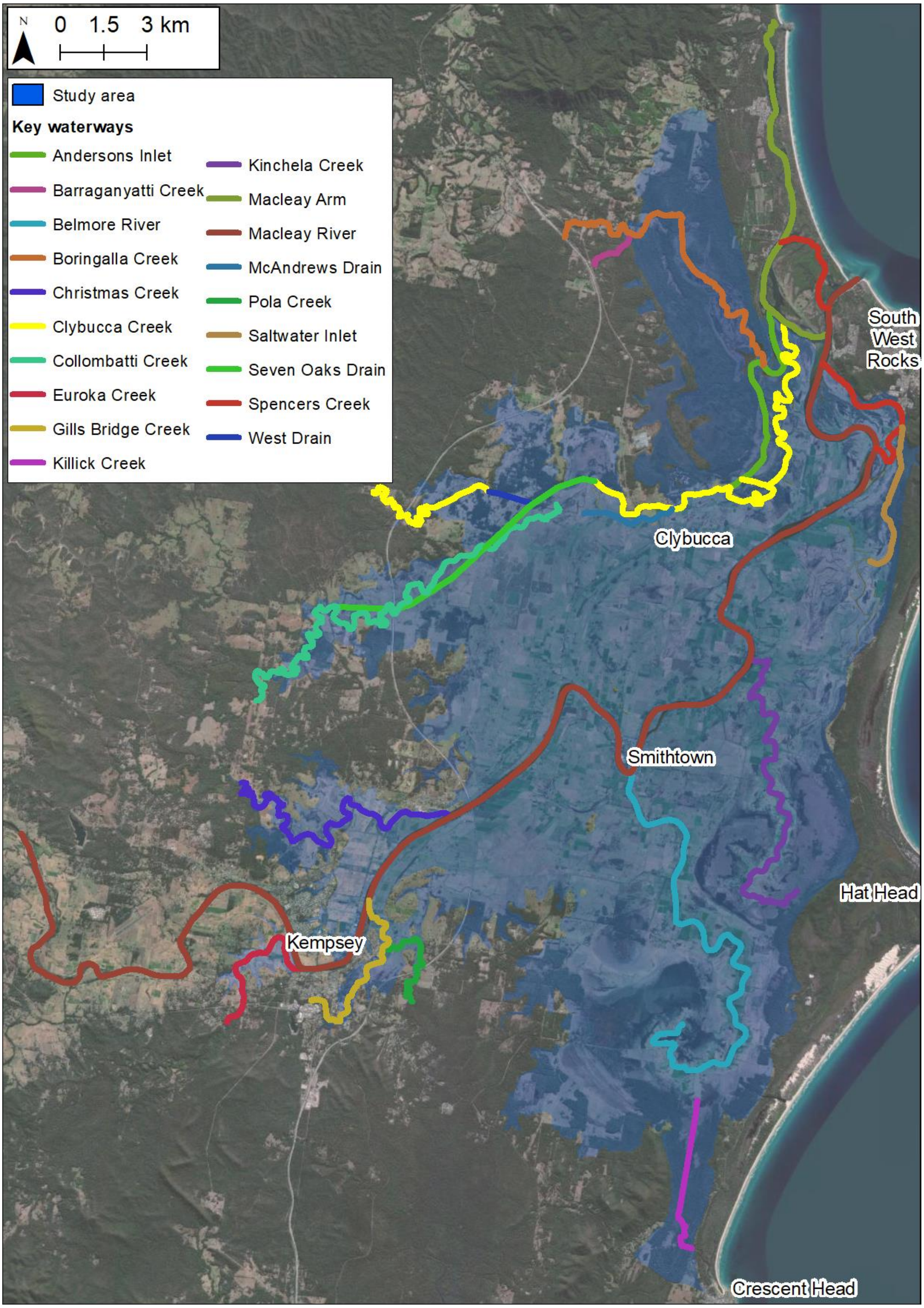

Figure 3-3: Key waterways on the Macleay River floodplain

Prior to European exploration in 1817, the Macleay River estuary was an important area described as being "full of natural bounty" (Telfer, 2005). Numerous archaeological records show the area's importance to indigenous Australians, known as the Dunghutti people, who lived throughout the region (WMA, 2009). Drainage works across the Macleay River floodplain began as early as the 1870s when areas around Belmore Swamp and Kinchela Creek were drained under the Drainage Promotion Act 1865 (Telfer, 2005). In the late 19th century and throughout the 20th century, further modifications were made to floodplain drainage to increase the extent of land available for agriculture and also to protect the low-lying floodplain from flooding. A detailed history of the settlement and drainage of the Macleay River floodplain is provided by Telfer (2005) and Tulau (2011):

- 1817 – The entrance to the Macleay River was first discovered by European settlers;
- 1827 – Timber cutters began to navigate within the Macleay River;
- 1835 – The first European settlers purchased land on the Macleay River floodplain;
- 1836 – The shipbuilding industry was established in the Macleay River;
- 1865 – The Drainage Promotion Act 1865 was enacted;
- 1870s – Drainage of the Macleay River floodplain began in the Belmore Swamp and Kinchela Creek areas;
- 1880s – drainage construction works on the Macleay River floodplain began to boom;
- Prior to 1884 – Doughboy Drain constructed in the Collombatti-Clybucca subcatchment;
- 1885 – A concrete dam headworks structure was built on Doughboy Drain. Kinchela Swamp and Swan Pool areas were first drained. The first drains were constructed at Yarrahapinni;
- Prior to 1890 – Thurgoods Drain and Verges Drains constructed;
- 1891 – A cutting connecting the Macleay River floodplain to Killick Creek that had been constructed by landholders was improved by the Public Works Department;
- 1895 – The first headworks structure was constructed across Clybucca Creek;
- 1897 – The break wall at South West Rocks began construction;
- 1901 – The Drainage Promotion Act 1901 was enacted to improve drainage and encourage establishment of drainage unions;
- 1900s – Drainage of the Frogmore and Summer Island areas began;
- 1908 – Cooroobongatti Drainage Union formed;
- 1912 – Gladstone Drainage Union formed;
- 1913 – Frogmore Drainage Union formed;
- 1922 – Glenrock – Tennessee Drainage Union formed;
- 1924 – Seven Oaks Drainage Union and Darkwater Drainage Union formed;
- 1925 – Belmore Drainage Union and Swan Pool Drainage Union formed;
- 1930 – Marriott Drainage Union formed;
- 1931 – The Lock constructed on Kinchela Creek;
- 1933 – Austral Eden Drainage Union formed;
- 1935 – Whalen Drainage Union formed;
- Prior to 1942 – Slaughterhouse Drain, Schoolhouse Drain and McNallys Drain were completed;
- 1947 – Rafferty Drainage Union formed;
- Prior to 1952 – The Clybucca Creek headworks were upgraded;
- 1951 – Macleay Flood Mitigation Committee established;
- 1953 – Saltwater Lagoon Drainage Union formed;
- 1955 – The Macleay Valley flood mitigation scheme began;
- Prior to 1956 – Buchanans Drain, Frogmore Drain, Darkwater No. 1 Drain, Reillys Drain, Worthings Drain and Scotts Drain were completed;
- 1957 – Killick Creek headworks constructed;
- Prior to 1960 – The Austral Eden and Belmore headworks constructed.

- 1960 to 1962 – Headworks structures were completed on Belmore River and Kinchela Creek;
- Prior to 1963 – Christmas Creek drains and headworks constructed. A drain was constructed between Belmore Swamp and Killick Creek;
- 1965 – Pola Creek headworks constructed and improvement works completed on the creek;
- 1966 – Andersons Inlet excavated providing increased connectivity to upstream sections of Clybucca Creek;
- 1966 to 1970 – Improvement works completed on drains at Collombatti-Clybucca including the Menarcobrinni floodgates;
- 1967 – Gladstone Drain and headworks constructed. Frogmore and Darkwater drains were extended;
- 1968 – Willows Drain and Glenrock Drain constructed. Korogoro Cut and headworks constructed creating an outlet for the Kinchela floodplain to the ocean. Lancasters Drain constructed;
- 1968 to 1969 – New headworks and floodway structures on Kinchela Creek constructed;
- Prior to 1969 – 90% of semi-permanent freshwater wetland within the Macleay River had been destroyed;
- 1969 – Yarrahapinni headworks and drains constructed. Headworks constructed on drains within Summer Island. Christmas Creek headworks and drain improvements completed; Glenrock Drain and headworks completed. Saltwater Inlet headworks completed and Saltwater Side Drain constructed. Euroka Creek headworks constructed;
- 1970 to 1971 – The first blackwater events began to be observed within Killick Creek;
- 1971 – Drop boards installed on the Killick Creek headworks to hold water back;
- 1973 – Ryans Cut created and headworks installed connecting Belmore Swamp to the ocean;
- 1974 – Headworks constructed on Scotts Drain;
- 1976 – Belmore River floodway constructed;
- 1976 – A comprehensive environmental assessment into the impacts of flood mitigation infrastructure was announced marking a shift in management of floodplains and wetlands; and
- Prior to 1980s – A total of 380 km of drains and 181 floodgate structures completed across the Macleay River estuary as part of the flood mitigation scheme.

A schematic of floodplain evolution indicating the influence of extensive drainage works and the conceptual progression from past to present hydrologic conditions is presented in Figure 3-4.

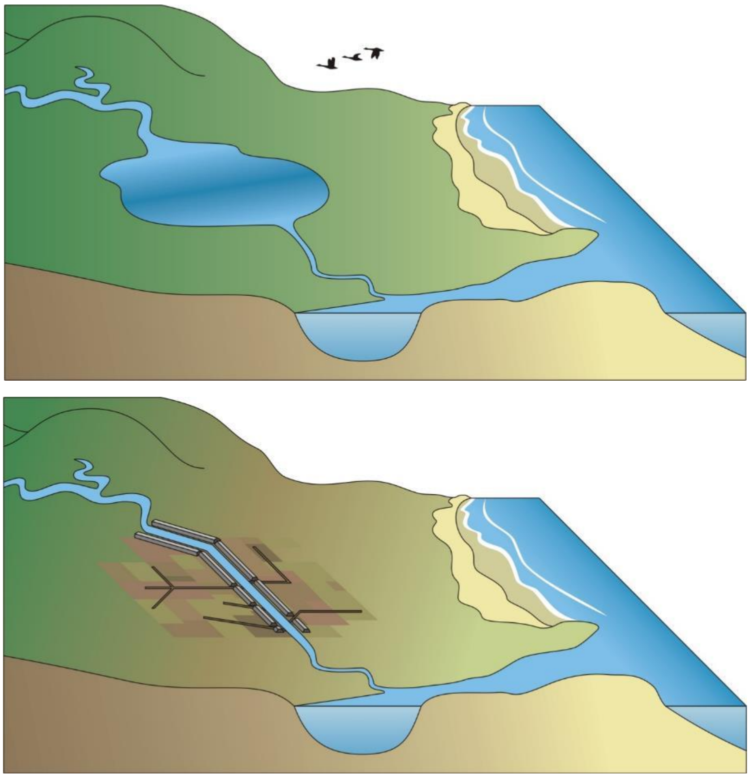

Figure 3-4: Schematic of floodplain evolution following European settlement

3.4 Land use and tenure

Although land use on the Macleay River floodplain is varied, the primary agricultural use of the floodplain is grazing, with substantial areas also classified as marsh/wetland, conservation and minimal use. Land uses in the Macleay River floodplain for areas below 5 m AHD are shown in Figure 3-5 (refer to Section 9 of Methods report (Rayner et al., 2023) for more detail). While the latest land use data has been used in this study, it is recognised that floodplain land uses are constantly evolving and that some land uses have likely changed since the time of the mapping. Note, a proportion of areas recognised as wetland/marsh in the Belmore area or conservation and minimal use in the Collombatti area are privately owned and actively grazed, particularly during drought periods.

There are a number of areas that are owned and managed by National Parks and Wildlife Service (NPWS) in the Macleay River floodplain, including:

- Arakoon National Park;
- Clybucca Aboriginal area;
- Clybucca Historic Site;
- Fishermans Bend Nature Reserve;
- Hat Head National Park; and
- Yarrahapinni Wetlands National Park.

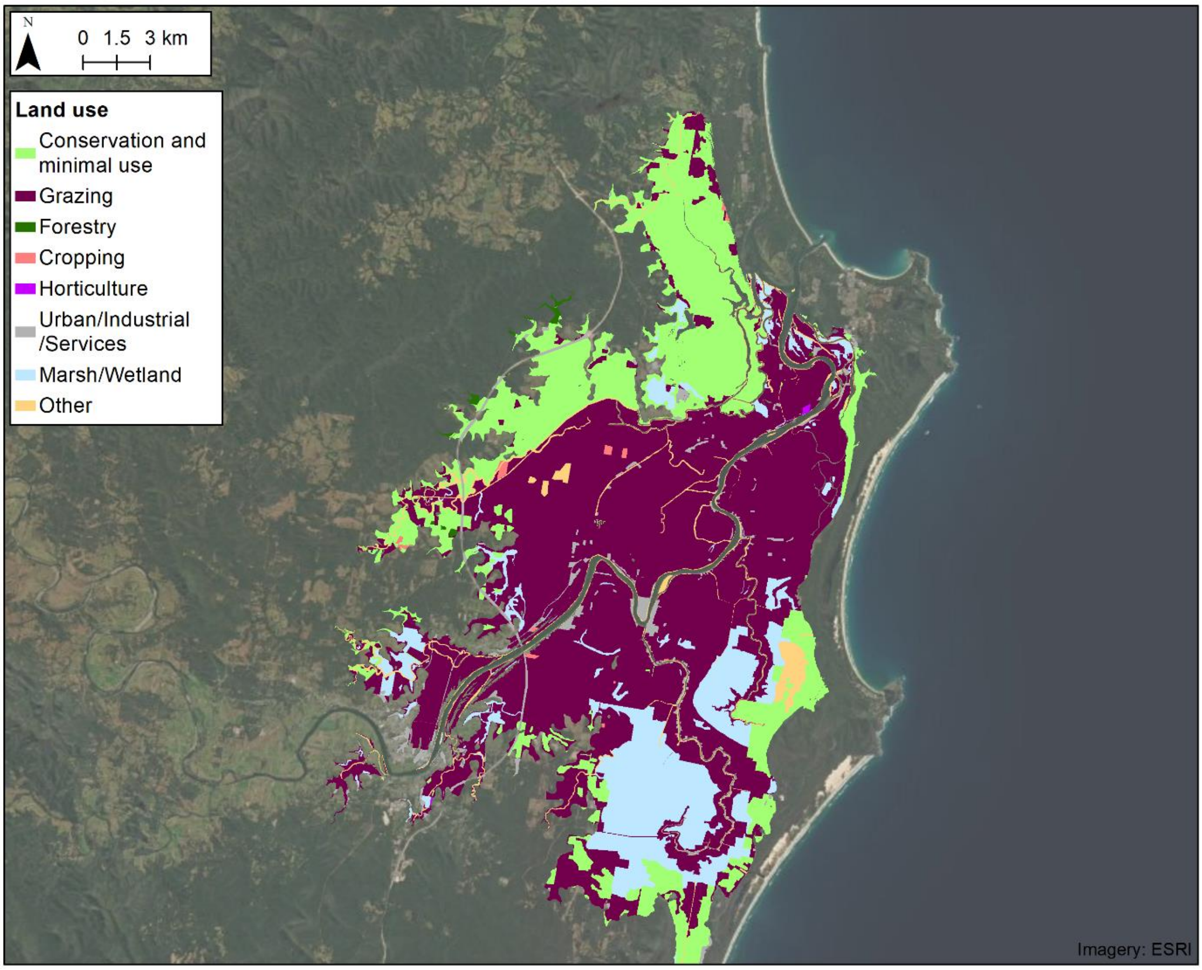

Figure 3-5: Land use in Macleay River floodplain, 2017 (DPIE, 2020)

3.5 Acid sulfate soils

This section provides a brief overview of the formation and export of acid from acid sulfate soils (ASS) in coastal floodplains and the presence of ASS on the Macleay River floodplain. Detailed information on the formation, export and impacts of ASS is provided in Section 3 of the Methods report (Rayner et al., 2023).

Acid sulfate soils (ASS) are common on coastal floodplains in NSW (Naylor et al., 1998) and were naturally deposited in low energy environments (e.g. backswamps) during the last 10,000 years. These sediments are benign when permanently inundated in natural swamp lands. However, when floodplain backswamps are drained and the sediments are exposed to oxygen, they can discharge sulfuric acid and toxic metal by-products into the receiving estuarine waters. In areas affected by ASS, the combination of deep drainage channels and one-way floodgates increase ASS oxidation, create acid reservoirs, and restrict potential buffering (or neutralisation) of acid by tidal waters (Johnston et al., 2003a; Stone et al., 1998).

Acidic discharge causes adverse environmental, ecological and economic impacts to the floodplain itself as well as the downstream estuary (Aaso, 2000). Impacts to aquatic ecology can be severe, including acid discharge events leading to fish (Winberg and Heath, 2010) and oyster mortality (Dove, 2003).

3.5.1 ASS distribution in the Macleay Region

The acid pollution hazard in NSW was originally mapped on the Acid Sulfate Soil Risk Maps prepared by Naylor et al. (1998). These maps highlight that the Macleay River floodplain contains approximately 36,000 hectares of high-risk ASS below an elevation of 5 m AHD, as shown in Figure 3-6.

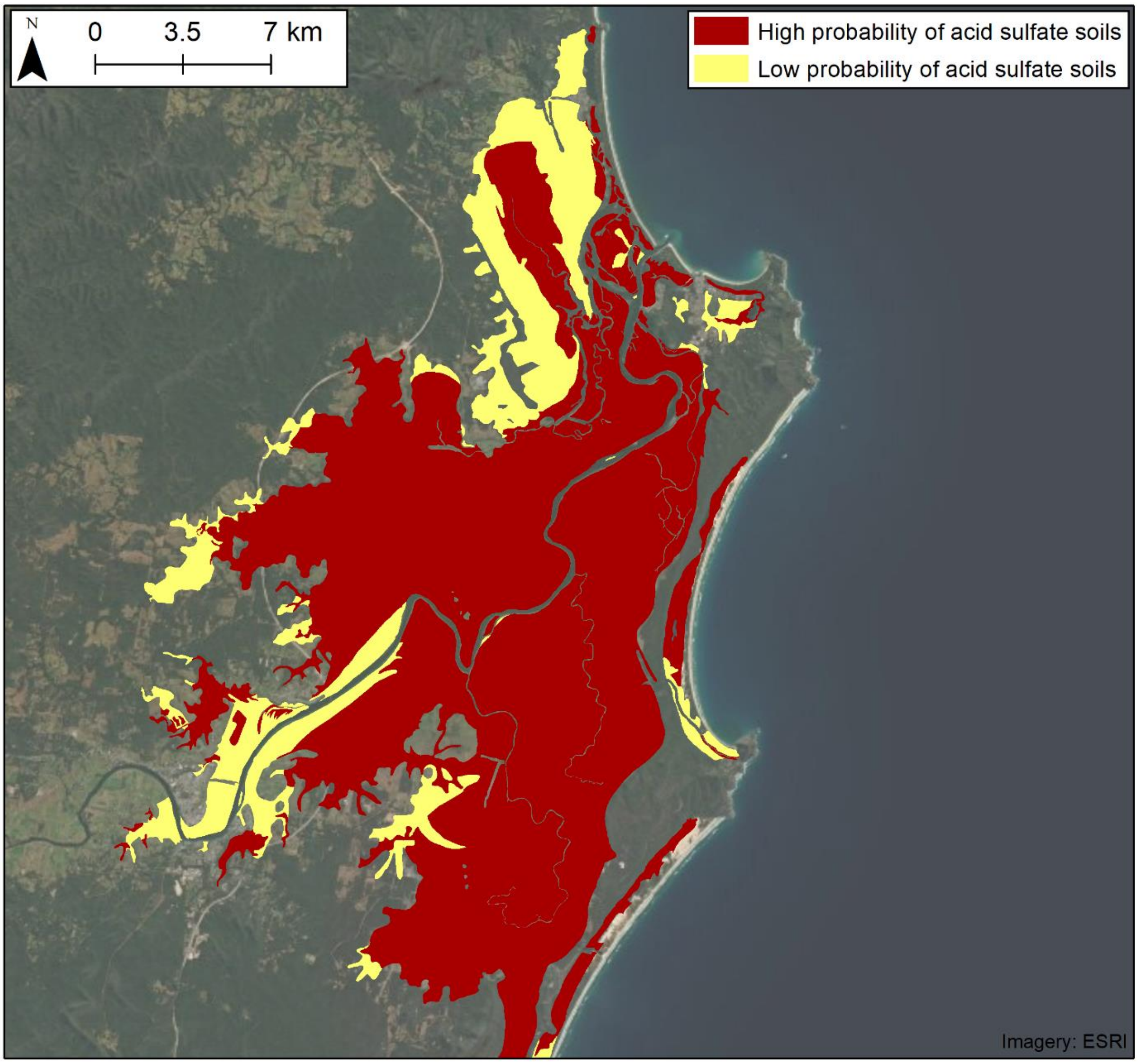

Figure 3-6: NSW Government ASS risk map of the Macleay River floodplain (Naylor et al., 1998)

The extent and severity of ASS on the Macleay River floodplain has been confirmed by numerous investigations. The following subcatchments have previously been identified by various studies as ASS priority areas by Tulau and Naylor (1999) and Geolink (2010b):

- Collombatti-Clybucca;
- Belmore Swamp;
- Frogmore/Austral Eden/Verges Swamp;
- Kinchela Creek;
- Raffertys/Saltwater Inlet; and
- Yarrahapinni.

Available data was analysed to describe the distribution of ASS across the Macleay River floodplain. This information was obtained from the NSW Department of Planning Industry & Environment (DPIE) eSPADE Database, published literature, and recent field investigations completed by WRL, as described in Appendix D. eSPADE provides access to soil profile data and information, including spatial data, reports and imagery, primarily sourced from the NSW Soil and Land Information System (SALIS). This information is useful in understanding the existing distribution and potential risk of stored acidity within floodplain sediments.

The minimum pH at each available location is shown in Figure 3-7. Low pH (<5) soil is common throughout the Macleay River floodplain. The lowest pH values were observed in the Belmore Swamp, Collombatti-Clybucca, Frogmore/Austral Eden/Verges Swamp and Yarrahapinni subcatchments.

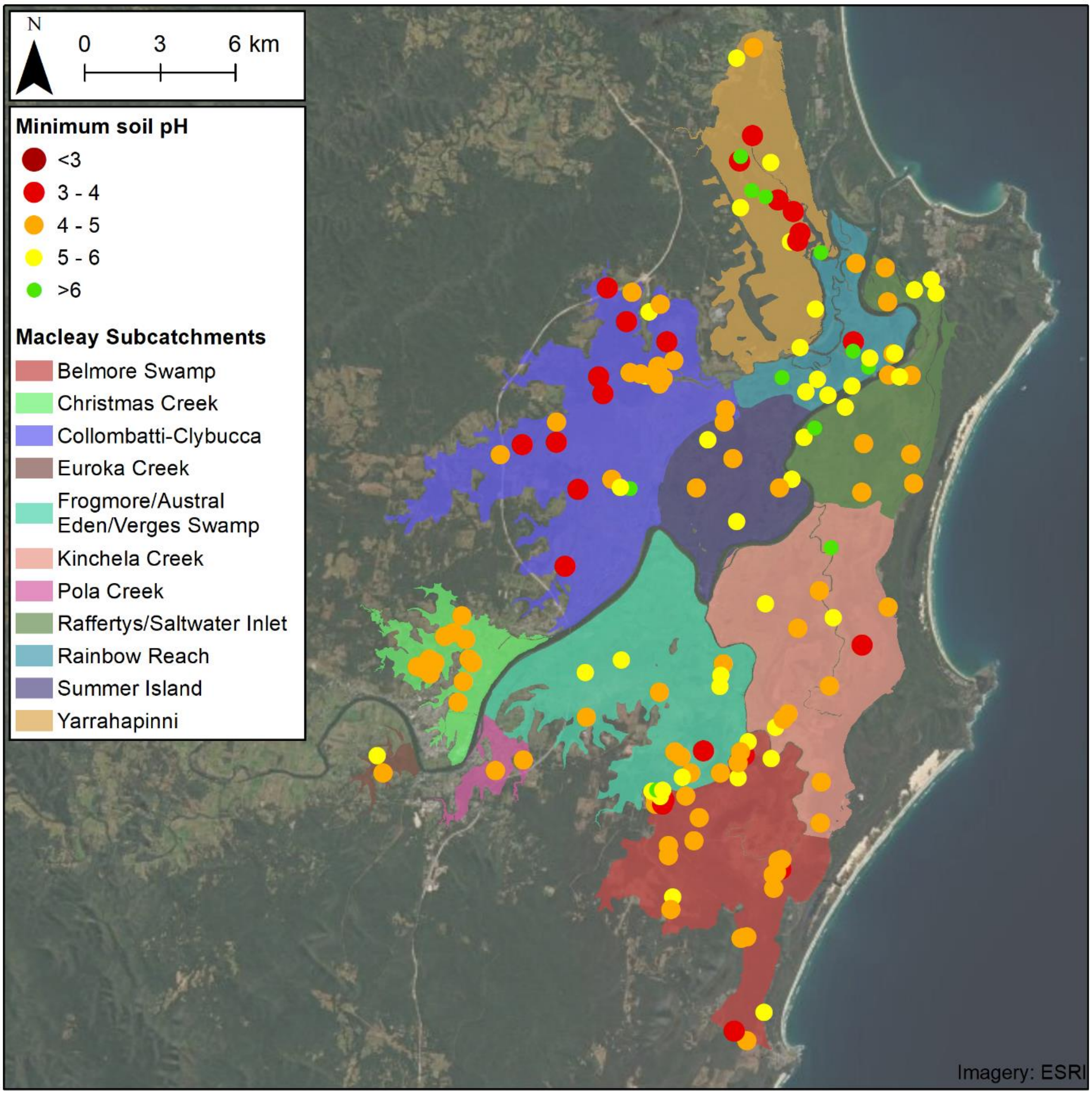

Figure 3-7: Minimum soil pH throughout the Macleay River floodplain

3.5.2 Acid discharge events in the Macleay Region

In the 1950s soil surveys were completed by CSIRO across the Macleay River floodplain that confirmed the presence of extensive ASS (Tulau, 2011). Since this discovery, monitoring of water quality across the estuary has confirmed numerous ASS discharge events. This section provides a brief overview of acid discharges within the Macleay River. A list of water quality studies completed in the Macleay River floodplain can be found in Appendix H.

In the 1960s, understanding the prevalence of ASS on the Macleay River floodplain and the potential impacts that the flood mitigation scheme would have on them, Walker (1972) measured the pH within the Belmore River and Kinchela Creek. Findings of this study found that following prolonged dry events acid would generate in low-lying floodplains and when mobilised would result in extremely acidic water (pH<3) being discharged to the estuary. It was not long before the concern raised by Walker (1972) came to fruition with acid discharge events being measured across the Macleay River estuary, including at:

- Belmore Swamp (Tulau and Naylor, 1999);
- Collombatti-Clybucca (Haskins, 1999);
- Frogmore/Austral Eden/Verges Swamp (Tulau and Naylor, 1999);
- Kinchela Creek (Tulau and Naylor, 1999); and
- Yarrahapinni (Manly Hydraulics Laboratory, 2001).

Soon, the environmental impacts of acid discharge across the Macleay River estuary began to be realised. In many instances fish kills have been attributed to the discharge of acidic water due to oxidisation of ASS (NSW DPI, 2020; Tulau, 2011; Tulau and Naylor, 1999), however blackwater is also a cause of aquatic mortality (discussed in 3.6.1). Aquaculture within the Macleay River has also been impacted by acidic discharges (Dove, 2003). An example of the impacts of acid discharges on the oyster industry can be seen from 1975 and 1977 when acid within Clybucca Creek resulted in oyster mortalities between 50% to 80% (Tulau, 2011). Other investigations have also found that discharges of heavy metals and creation of mono-sulfidic black ooze (MBO) have resulted from the drainage of ASS in the Macleay River estuary (Rayner et al., 2020).

Acknowledgment of the impacts of ASS across the Macleay River floodplain has resulted in numerous remediation investigations being completed and subsequent additional monitoring for acid discharge events (Geolink, 2010b). In particular, the Yarrahapinni and Collombatti-Clybucca subcatchments have been identified as key remediation sites within the Macleay River floodplain and subsequently extensive monitoring has been completed identifying acid discharge events and assessing options to improve water quality within the marine estate (Bush et al., 2006; Cheeseman et al., 2004; Edeson et al., 2004; Engenuity Design, 2003; Glamore and Rayner, 2017; Glamore et al., 2012; Kempsey Shire Council, 2004a; McLennan et al., 2005; Rayner et al., 2020; Smith, 2005; Wilkinson, 2014). Historic remediation actions for individual subcatchments is summarised in Section 8.

3.6 Blackwater

This section provides a brief overview of the formation and export of blackwater in coastal estuaries and blackwater runoff from Macleay River floodplain. Detailed information on the formation, export and impacts of blackwater is provided in Section 5 of the Methods report (Rayner et al., 2023).

Blackwater is a common term used to describe dark coloured waters that are characterised by high dissolved organic carbon (DOC) and reduced levels of dissolved oxygen (DO) (Moore, 2007). The discolouring of the water emanates from carbon compounds released into the water column as organic matter decays, which includes tannins (Howitt et al., 2007). Large volumes of blackwater can be generated on floodplains and are often associated with flooding, as floods act as a link between the floodplains (rich in organic matter) and the adjacent river channel (where the main impact occurs). Note, other sources of blackwater include monosulfidic black ooze (MBO) and humic blackwater. MBO and humic blackwater impact the estuary to a lesser degree in comparison to blackwater resulting from decaying organic matter (Moore, 2007). This is discussed further in Section 5 of the Methods report (Rayner et al., 2023).

Although blackwater events can be a natural part of lowland river ecosystems (Hladyz et al., 2011) and part of the floodplain carbon cycle (Wong et al., 2010b), the occurrence of blackwater events leads to low dissolved oxygen in estuarine waterways and can be fatal to fish and crustacean communities (Hladyz et al., 2011). Anthropogenic alterations to the floodplain hydrology and vegetation, mainly due to the construction of the drains and other flood mitigation works, have resulted in an increase in the frequency and magnitude of blackwater events (Eyre et al., 2006; Johnston et al., 2003b; Wong et al., 2010a). The construction of one-way floodgates also maintains upstream surface water levels at low tide levels (during average conditions) (Glamore, 2003), and enables non-water tolerant vegetation, such as pasture grasses, to establish at lower elevations where they could historically not survive (Southern Cross GeoScience, 2019). Despite extensive drainage and floodgate infrastructure, these low-lying areas remain prone to inundation during flood events, and are subject to prolonged inundation due to the relatively flat gradient between backswamp areas and river water levels. Extended inundation of non-water tolerant vegetation leads to plant die off and decay, consuming oxygen from the water column, leading to the formation of low oxygen blackwater. When flood levels in the river recede, low oxygen blackwater drains into the estuary, often further consuming oxygen from the river water (Eyre et al., 2006). Where the blackwater discharges are sufficiently large to overwhelm the receiving water system, this can result in mass fish kill events.

3.6.1 Blackwater runoff in the Macleay River estuary

Whilst the Macleay River flood mitigation scheme was still under construction, Tulau (2011) reports that from 1964 blackwater became a yearly occurrence within Killick Creek which drains the Belmore Swamp floodplain. The Belmore River, Kinchela Creek and Clybucca Creek were all identified as sources of blackwater by the early 1970s (Tulau, 2011). In 2001, a particularly severe blackwater event on the Belmore River and Kinchela Creek floodplains affected the Macleay River resulting in tens of thousands of fish being killed (NSW DPI, 2020). This triggered an investigation by NSW fisheries which found that the dissolved oxygen levels took four (4) weeks to return to normal. (Kennelly and McVea, 2002). The cause of these blackwater events within the Macleay River has been attributed to prolonged inundation across low-lying floodplain following flood events (Engenuity Design, 2003; Geolink, 2010b; Hurrell et al., 2009).

NSW DPI (2020) maintains a record of observed fish kills across the state. The scale of the recorded events range from 'less than 10 fish' to '100,000's of fish' that have been killed per event. Fish kills can be caused by a number of processes, although acid discharge and blackwater runoff are common causes in coastal estuaries in northern NSW. Since 2013, this database has included details of the suspected cause of fish kill events. Table 3-1 details the fish kill events recorded by NSW DPI (2020) that have been attributed to low dissolved oxygen events since 2013.

Table 3-1: Severe fish kills due to low dissolved oxygen events in the Macleay River estuary (NSW DPI, 2020)

Date	Waterway	Intensity
7/03/2013	Macleay River	100’s of fish
31/03/2014	Killick Creek	1,000's of fish
12/11/2014	Killick Creek	100’s of fish
31/01/2015	Yarrahapinni Broadwater	1,000's of fish
5/02/2015	Kinchela Creek	100’s of fish
22/03/2017	Macleay River	1,000's of fish
1/04/2018	Macleay River	100’s of fish
13/12/2019	Summer Island Drain	100’s of fish
11/02/2020	Clybucca Creek	1,000's of fish
18/02/2020	Belmore River and Kinchela Creek	10,000's of fish

During field investigations completed as part of this study the effects of the blackwater event that occurred on 18 February 2020 were observed almost two (2) weeks later. Water within Kinchela Creek was observed to be black and discharging into the estuary on 2 March 2020 (Figure 3-8). Measurements of dissolved oxygen confirmed that all oxygen had been stripped from the water column through the breakdown of organic matter.

Figure 3-8: Blackwater observed in Kinchela Creek on 2 March 2020 with blackwater juxtaposed against white boat wash (top) and blackwater discharging from the Kinchela creek headworks (bottom)

3.7 Coastal management in the Macleay River estuary

3.7.1 NSW Marine Estate Threat and Risk Assessment (TARA) (Fletcher and Fisk, 2017)

In 2017, a state-wide threat and risk assessment (TARA) was completed to identify and prioritise threats to the environmental, social, cultural and economic benefits derived from the NSW Marine Estate (Fletcher and Fisk, 2017). This assessment found that diffuse agricultural runoff was the single highest priority threat to the environmental assets within estuaries in NSW and also present a high threat to the social, cultural and economic benefits derived from the marine estate. While diffuse agricultural runoff can relate to a wide range of water quality stressors, the TARA specifically identifies the exacerbation of acid and blackwater drainage associated with clearing riparian vegetation and artificial drainage poses a high environmental risk to estuaries throughout the state.

Based on the TARA assessment, management of acid and blackwater drainage in estuaries in NSW is considered a priority to improve environmental, social, cultural and economic benefits associated with the marine estate. This is consistent with the existing coastal and estuary management priorities in the Macleay River, discussed further in the following section.

3.7.2 Coastal Zone Management Plan and Coastal Management Program

A Coastal Zone Management Plan (CZMP) was prepared by Geolink (2012) for the Macleay River estuary. This plan has taken into account the findings from the Macleay River Estuary Management Study (EMS) (Geolink, 2010b). The purpose of these studies is to tabulate social and environmental values and pressures on the estuary, and strategies to address the environmental issues and improve community values. This section provides a summary of how the outcomes of the EMS and CZMP have addressed acid drainage and blackwater drainage in the Macleay River. Note, presently Kempsey Shire Council are in the early stages of the development of a Coastal Management Program (CMP) with a scoping study (the first of five (5) stages) already completed (Rollason, 2020). The CMP is designed to evaluate and build upon the CZMP whilst aligning to the Coastal Management Act 2016 (Rollason, 2020).

The CZMP outlined 30 management strategies to improve the values of the Macleay River Estuary (Geolink, 2012). Of these strategies, nine (9) were identified as high priority and of these, five (5) specifically related to remediation of ASS discharge and blackwater, including (Geolink, 2012):

- Improve water quality from floodplain wetlands;
- Coordinate and prioritise drainage projects;
- Active management of floodgates;
- Conservation of floodplain wetlands; and
- Water management improvements in the Collombatti-Clybucca drainage scheme.

In addition to these, a number of medium and low priority strategies also relate to ASS and blackwater remediation. Geolink (2012) provided actions required to achieve each management strategy (high, medium or low priority). Actions that focus on the remediation of ASS and blackwater include:

- Continue encouraging wet pasture management in the Belmore Swamp, Collombatti-Clybucca and Kinchela Creek subcatchments;
- Investigate changes to the Belmore Swamp and Kinchela Creek subcatchments drainage networks to retain water on the floodplain;
- Reduce the formation of MBOs in drains across the floodplain;
- Consult stakeholders and investigate remediation options within the Kinchela Creek and Raffertys/Saltwater Inlet subcatchments;
- Identify and adopt strategies to improve management of the drainage networks in the Belmore Swamp, Collombatti-Clybucca, Frogmore/Austral Eden/Verges Swamp, Kinchela Creek, Raffertys/Saltwater Inlet and Yarrahapinni subcatchments;

- Create plans for and actively manage primary end of system structures that include considerations for before, during and after flood events;
- Assess effectiveness of all drainage infrastructure and create plans for their ongoing management;
- Encourage private conservation of wetlands particularly within the Belmore Swamp, Collombatti-Clybucca, Christmas Creek, Frogmore/Austral Eden/Verges Swamp, Kinchela Creek, Raffertys/Saltwater Inlet and Yarrahapinni subcatchments;
- Continue to improve the management of the Swan Pool wetland within the Kinchela Creek subcatchment implementing recommendations of Smith (2002) for the remediation and management of the area and inclusion of Swan Pool within the Hat Head National Park plan of management.
- Scope, investigate and implement modifications to the Collombatti-Clybucca subcatchment to improve water quality whilst ensuring flood mitigation capacity; and
- Continue rehabilitation of the Yarrahapinni subcatchment.

Since the development of the Macleay River estuary CZMP a number of these actions have already been completed (Rollason, 2020). Specific on-ground remediation works completed by Kempsey Shire Council and DPIE as part of the CZMP for the Macleay River estuary are discussed in the history of remediation of individual subcatchments in Section 8. As part of the CMP scoping study an evaluation of the existing CZMP was completed (Rollason, 2020). During this evaluation it was determined that a number of high priority strategies that focus on the remediation of ASS and blackwater have been inadequately completed for following reasons:

- Uncertainty on how to support agricultural productivity whilst improving ecological health and water quality;
- Lack of clarity regarding the area to which the CZMP applies (i.e. poor water quality originating outside the coastal zone is affecting the coastal zone); and
- Remediation approaches lack a whole of system approach for individual backswamps that can then be used to identify target areas for maximum benefit.

The CZMP for the Macleay River estuary highlights that addressing poor water quality resulting from acid and blackwater drainage is a high priority (Geolink, 2012). Despite this, there are challenges in implementing remediation actions across the Macleay River floodplain. The prioritisation and associated management options developed in this study can be used as tools to assist in the implementation of CZMP and CMP actions now and into the future. In the immediate future, the prioritisation and associated management plans can be used to guide the implementation of the CZMP strategies and in the near future they can be used to guide the development of the CMP for the Macleay River estuary. This includes implementation of a whole of system approach to identify subcatchments where on-ground actions can be targeted for the highest benefit to water quality, identification of additional floodplain infrastructure that may be optimised by either modification or active management, and identifying where improved farm management practices may be particularly effective at reducing impacts due to poor water quality.

4 Overview of prioritisation methods

4.1 Preamble

This study prioritises coastal floodplain subcatchments based on acid discharges from ASS and blackwater runoff using an objective, evidence based method as outlined in Rayner et al. (2023). The coastal floodplain prioritisation method utilises a multi-criteria analysis approach to objectively compare the risk of acid and blackwater generation using locally acquired field evidence (including field data collected for this study). Importantly, the method is applicable to all estuarine floodplains across NSW, including the seven (7) floodplains analysed for the Coastal Floodplain Prioritisation Study. The prioritisation method used in this study does not consider improvements made through historical remediation efforts. However, any previous remediation is considered in the individual management options in Section 8. A brief summary of these methods is provided below.

The prioritisation for ASS and blackwater risk within coastal floodplains is independent of each other. As such, it is possible for a subcatchment to be a low risk for ASS, but a high risk for blackwater (or vice versa). It is important to recognise that there has been no attempt to compare the prioritisation of the two issues. While a subcatchment that is ranked first for ASS can be interpreted as objectively worse for acid discharge compared to a subcatchment ranked lower for ASS, it is not also (necessarily) objectively worse than the subcatchment that ranks second for blackwater.

Both prioritisation methods have been designed to compare and rank subcatchments within an individual coastal floodplain. Therefore, the factors and subcatchment rankings in the Macleay River floodplain should not be directly compared to the prioritisation outcomes for other coastal floodplains.

4.2 Acid sulfate soil prioritisation

The ASS priority assessment undertaken for this study is an objective, benchmarked methodology used to determine the risk of acid discharges from ASS-affected estuarine floodplains in coastal NSW. The method, as developed by Glamore and Rayner (2014) and Glamore et al. (2016a), can be applied to individual drainage channels within a paddock, or across larger floodplain subcatchments. The method results in a prioritised ranking of ASS subcatchments that pose the highest risk to the ecohealth of the marine estate.

The ASS priority assessment is structured around two (2) major factors:

(i) surface water factor; and
(ii) groundwater factor.

Each factor is calculated based on local environmental processes that contribute to the risk of ASS oxidation and acid discharges to the marine estate. The risk associated with each factor is determined via a multi-criteria approach that assesses local field data and onsite environmental conditions. These factors are then combined within a calibrated algorithm to rank each subcatchment drainage area within an estuary. A summary of the risk rating, as applied to each factor, is conceptualised in Figure 4-1. Further detail on each factor is provided below.

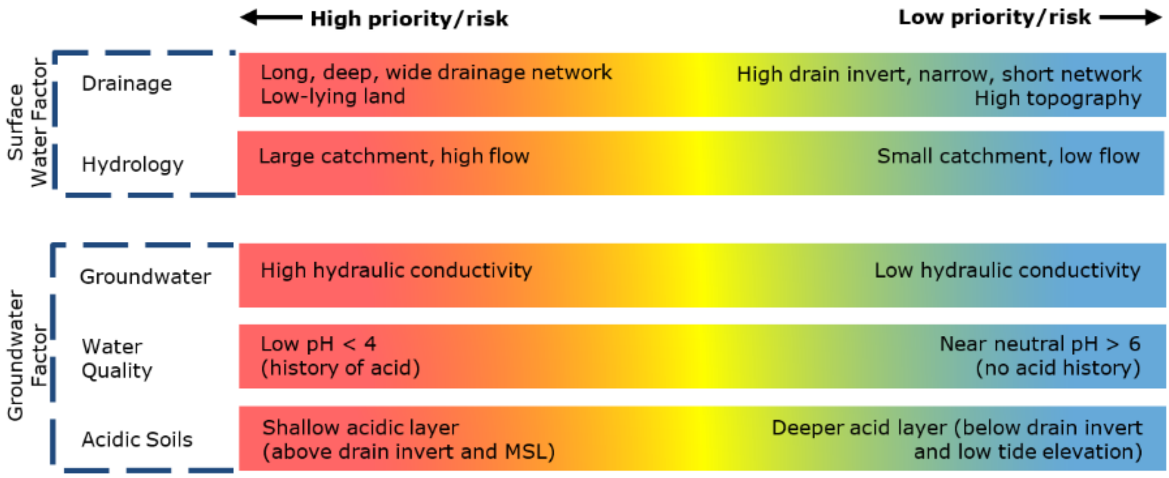

Figure 4-1: Factors influencing ASS discharge in coastal NSW that have been incorporated within the assessment method (adapted from Johnston et al. 2003a)

4.2.1 Surface water factor

Details on the calculation of the surface water factor can be found in Section 4.3 of the Methods report (Rayner et al., 2023). In summary, the surface water factor is an indication of the surface water drainage density and the catchment inflows. The surface water factor ensures that a subcatchment that is more extensively drained, or can potentially export a larger volume of acid, is ranked higher in the prioritisation method. This acknowledges that acid transport, via onsite drains and drainage flux, is a critical component towards realising acid related impacts downstream.

The surface water factor is determined by multiplying the drainage density factor by the inflow factor, as shown in Equation 4-1.

$$Surface\ water\ factor = drainage\ density\ factor\ \ x\ normalised\ inflow\ factor \qquad \textbf{Equation 4-1}$$

The drainage density factor for each subcatchment is calculated in Appendix A, while the normalised inflow factor is detailed in Appendix B.

4.2.2 Groundwater factor

The groundwater factor is designed to highlight the potential acidity that could be generated and its ability to be transported to the environment. The underpinning hypothesis is that the worst conditions are where high acidity concentrations are combined with strong groundwater transport gradients. The factor includes local information on the acidity of the sediments, the acid layer thickness, the location of the ASS layer relative to low tide levels, and the hydraulic conductivity of the sediments.

The groundwater factor uses locally acquired sediment profile data and hydraulic conductivity measurements within each subcatchment. Where existing data was insufficient, additional data was collected specifically for this project, including 23 soil profiles and 21 soil hydraulic conductivity measurements on the Macleay River floodplain. Details on the calculation of the groundwater factor can be found in Section 4.4 in the Methods report (Rayner et al., 2023).

The groundwater factor is calculated by multiplying a hydraulic conductivity risk factor by the pH factor (which accounts for the degree of acidity, acid thickness and acid layer position with respect to the lowest drain water level), as shown Equation 4-2.

$$Groundwater\ factor = hydraulic\ conductivity\ risk\ factor\ \times pH\ factor \qquad \textbf{Equation 4-2}$$

The hydraulic conductivity risk factor for each subcatchment is provided in Appendix C, while the pH factor is presented in Appendix D.

4.3 Blackwater prioritisation

The blackwater prioritisation method is independent of the ASS method and has been developed to rank subcatchments within a floodplain based on the potential for the generation of low oxygen blackwater. The blackwater prioritisation method is designed to compare blackwater risk within an estuary amongst subcatchments and is not suitable for paddock scale prioritisation due to the interconnectivity of floodplain areas during elevated flood waters. Further background on the blackwater prioritisation methods can be found in Section 6 in the Methods report (Rayner et al., 2023).

The blackwater priority assessment method is based on two (2) major factors:

(i) a contributing area of the catchment that results in blackwater production; and
(ii) the oxygen consumption risk associated with different land use and vegetation types.

These factors incorporate the key physical attributes that drive production of blackwater on coastal floodplains, discussed in detail in Section 6 of the Methods report (Rayner et al., 2023). Unlike the ASS prioritisation, the blackwater prioritisation has been undertaken with existing, catchment, or statewide datasets (i.e. no subcatchment specific data was collected for this prioritisation). A summary of how each factor affects the prioritisation is provided in Figure 4-2. Note that a range of additional factors known to contribute to blackwater risk, such as temperature and antecedent conditions, were omitted from the prioritisation methodology as these variables were assumed to be (over the long term) equally applicable across the floodplain (e.g. temperature is unlikely to be significantly different within the Macleay River floodplain during a blackwater event).

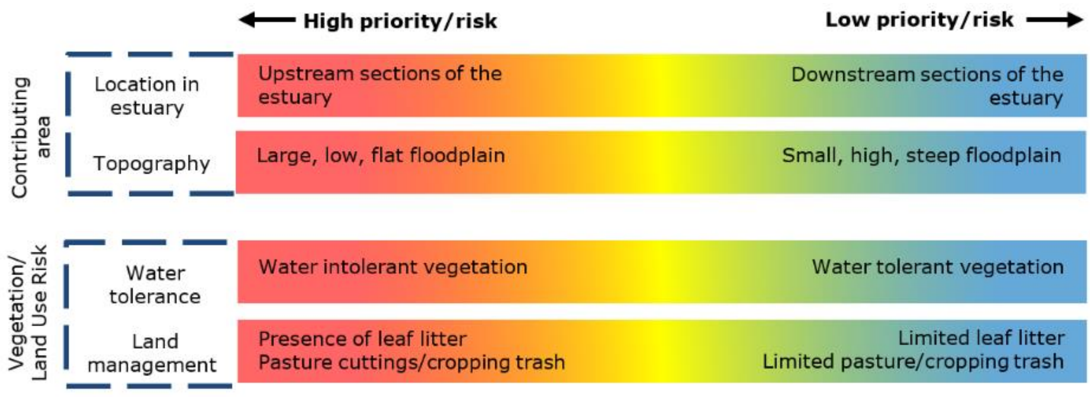

Figure 4-2: Factors influencing blackwater discharge within a coastal floodplain in NSW

4.3.1 Contributing blackwater area

The calculation of the contributing blackwater area is based on the topography of the floodplain subcatchment and an analysis of historical water level observations within the estuary to determine observed inundation frequency and duration. Since hypoxic blackwater is generated when water intolerant vegetation is inundated over an extended period, the risk of blackwater generation is greater in areas that are prone to prolonged inundation.

Long-term water levels in the main river channel were analysed to establish 25 water level thresholds relating to different periods of river water elevation (e.g. elevated over a given threshold for 1, 2, 3, 4 or 5 days) and temporal frequencies (e.g. 1, 2, 3, 4 or 5 year return intervals). Water levels in the main river channel were then projected across the adjacent floodplain subcatchments using a geospatial approach to identify areas likely to be subject to reduced drainage and prolonged inundation. These areas were identified as key contributors to blackwater generation under different flood events and flood behaviour. Appendix E provides the details of this analysis within the Macleay River estuary and floodplain. While 25 water level thresholds are used in this analysis, a median elevation has been adopted throughout this report to provide an indicative elevation for blackwater contribution in each floodplain subcatchment.

4.3.2 Land use/vegetation risk factor

Water tolerance varies between different vegetation types, with some vegetation having a higher ability to decompose, leading to a greater risk of blackwater generation. To account for differences in land use and associated vegetation types, a summary risk rating was developed. While details of the risk rating associated with all land use types can be found in Section 6.3 of the Methods report (Rayner et al., 2023), the following general rules have been applied:

- High: Areas used for grazing or forestry, or are heavily wooded, present the greatest risk;
- Moderate: Areas used for cropping, particularly sugar cane, are moderate risk; and
- Low: Areas that have are predominately covered by water tolerant vegetation (e.g. marshes or wetlands) present the lowest risk.

Areas that have been mapped as macrophytes by DPI Fisheries (2019) or as open water bodies have been excluded from contributing to blackwater risk. The land use risk factor has been combined with the contributing area factor to calculate the final blackwater risk ranking for each subcatchment. This ranking identifies areas that pose the greatest risk of blackwater generation. It is worth noting that this ranking does not consider risks to downstream sensitive receivers or to the assimilation capacity of the downstream waterway.

5 ASS prioritisation assessment outcomes

5.1 Preamble

This section summarises the results of the ASS priority assessment for the Macleay River floodplain. The summary rankings and acid prioritisation factors for each of the subcatchments are provided in Section 5.2. The final rankings in the ASS priority assessment are a function of a surface water drainage factor and a groundwater factor calculated for each subcatchment, as discussed in Section 4.2 and Appendices A - D. The highest priority subcatchments have the highest combination of the surface water and groundwater factors, thereby presenting the highest risk of acid drainage.

The prioritisation method used in this study does not consider improvements made through historical remediation efforts. However, any previous remediation is considered in the individual management options in Section 8.

5.2 ASS Prioritisation of the Macleay River floodplain

A summary of the catchment wide ASS prioritisation is provided in Table 5-1 and presented in Figure 5-1 to Figure 5-3. The highest priority area for acid generation was the Collombatti-Clybucca subcatchment which individually accounts for approximately 70% of the total acid risk on the Macleay River floodplain. The Frogmore/Austral Eden/Verges Swamp subcatchment ranked second overall for the ASS priority assessment. This indicates that poor water quality from acid discharges has the potential to occur throughout the estuary.

Table 5-1: Final results and rankings of ASS priority assessment for the Macleay River floodplain

Subcatchment	Groundwater factor	Surface water factor	Final acid factor	Rank
Collombatti-Clybucca	214	798	170,656	1
Frogmore/Austral Eden/Verges Swamp	142	175	24,745	2
Yarrahapinni	123	112	13,847	3
Christmas Creek	58	234	13,485	4
Belmore Swamp	111	77	8,532	5
Kinchela Creek	57	95	5,381	6
Raffertys/Saltwater Inlet	52	82	4,266	7
Pola Creek	28	114	3,259	8
Summer Island	31	87	2,706	9
Euroka Creek	14	161	2,203	10
Rainbow Reach	13	45	580	11

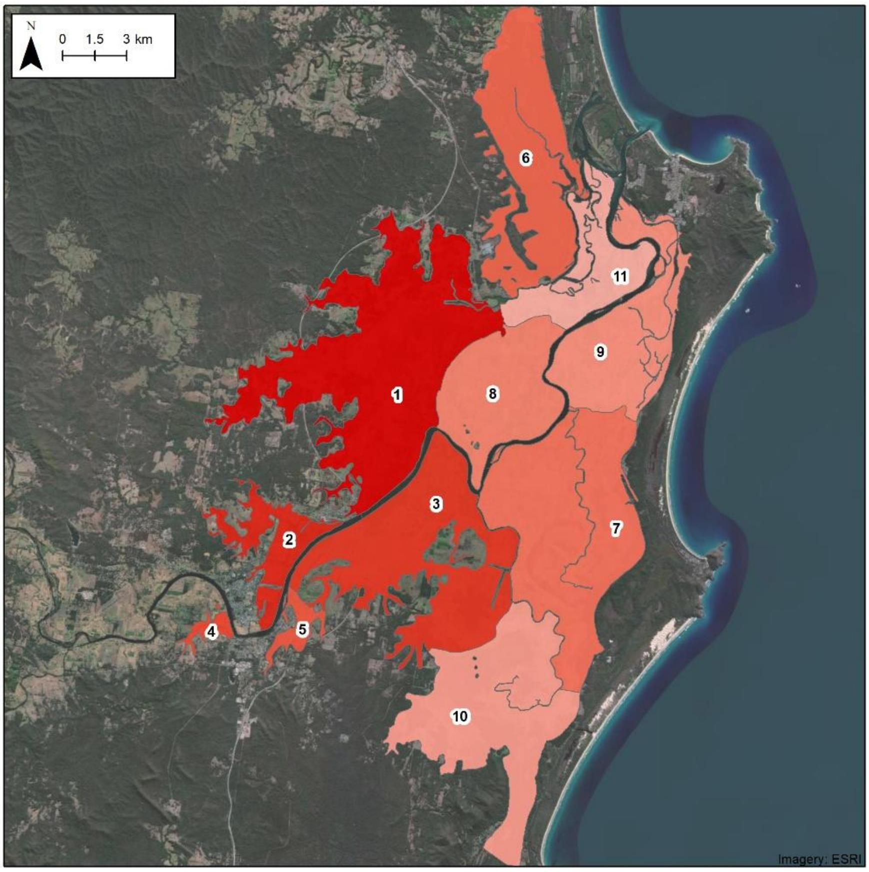

Figure 5-1: Surface water factor ranking for the Macleay River floodplain

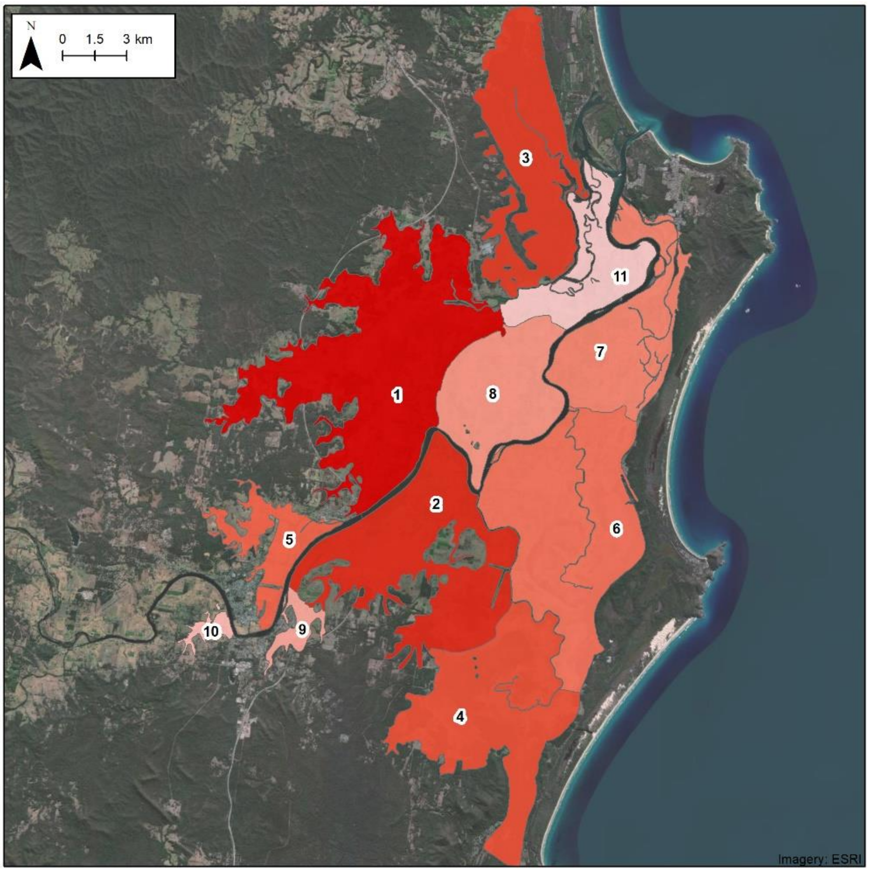

Figure 5-2: Groundwater factor ranking for the Macleay River floodplain

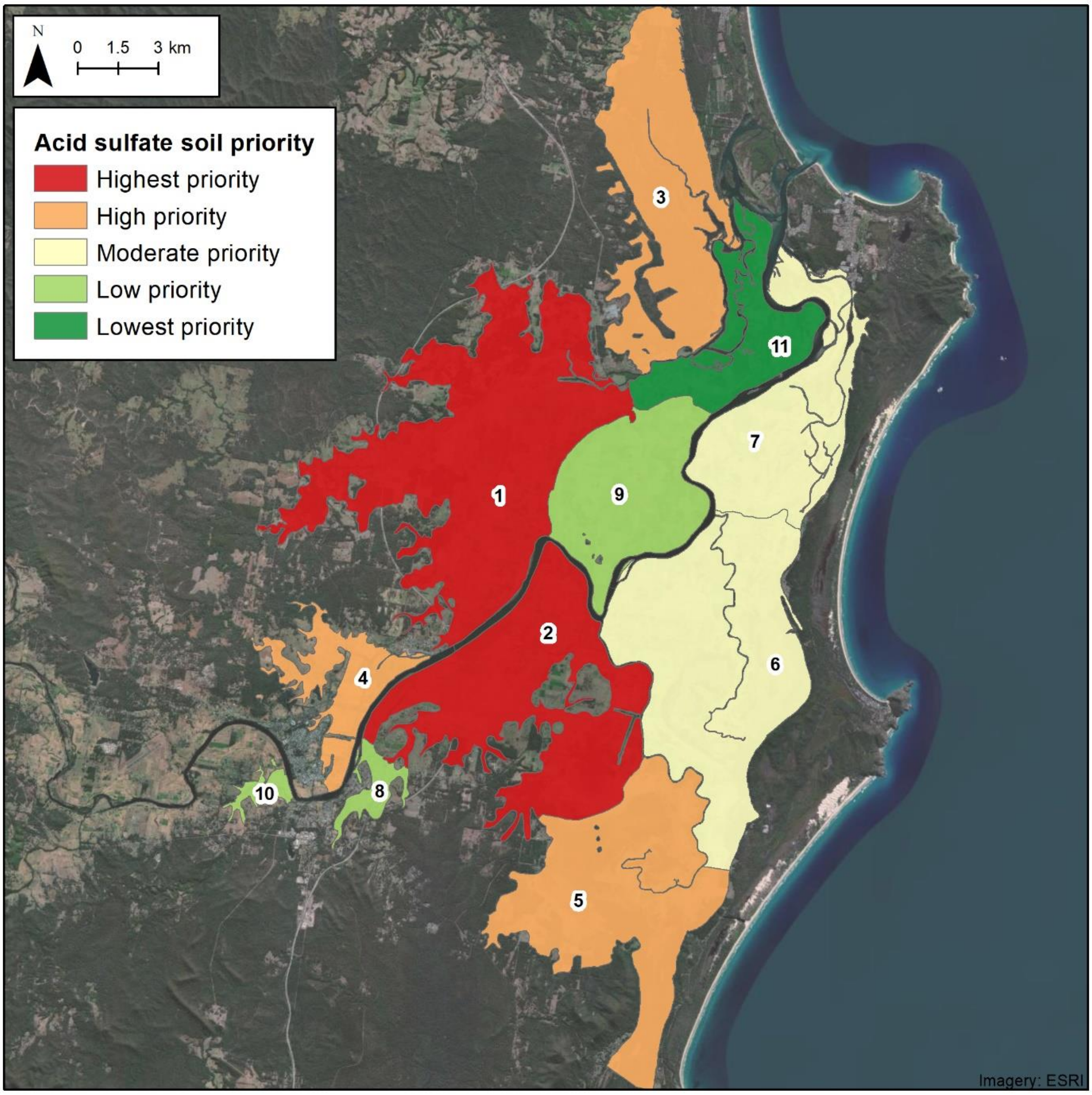

Figure 5-3: Final ranking of ASS prioritisation for the Macleay River floodplain

6 Blackwater prioritisation assessment outcomes

6.1 Preamble

This section summarises the results of the blackwater priority assessment on the Macleay River floodplain. The overall rankings and calculated prioritisation factors that contribute to the ranking of each subcatchment is provided in Section 6.2. The final rankings in the blackwater prioritisation are a function of elevation and land use factors. A summary of the elevations used to calculate the blackwater contributing area on floodplain subcatchments is provided in Appendix E.

6.2 Blackwater prioritisation of the Macleay River floodplain

A summary of blackwater prioritisation is provided in Table 6-1 and presented in Figure 6-1 and Figure 6-2. The top two (2) priority subcatchments were identified as Kinchela Creek and Belmore Swamp, both located in the floodplain to the south of the estuary. It should be noted that the Verges Swamp area in the Frogmore/Austral Eden/Verges Swamp subcatchment (ranked fourth for blackwater generation) is hydrologically linked to the Belmore Swamp and in turn the Kinchela Creek subcatchments. Combined, these three (3) areas account for the majority of blackwater risk on the Macleay River floodplain. The Collombatti-Clybucca subcatchment ranked third for blackwater risk, highlighting that blackwater can occur catchment wide within the Macleay River floodplain.

Table 6-1: Final results and rankings of blackwater priority assessment for the Macleay River floodplain

Subcatchment	Median blackwater elevation (m AHD)	Final blackwater factor	Rank
Kinchela Creek	1.0	87.0	1
Belmore Swamp	1.2	73.9	2
Collombatti-Clybucca	1.1	69.3	3
Frogmore/Austral Eden/Verges Swamp	1.2	48.6	4
Yarrahapinni	1.1	39.8	5
Raffertys/Saltwater Inlet	0.8	34.8	6
Summer Island	0.9	29.6	7
Christmas Creek	1.9	13.8	8
Rainbow Reach	0.6	9.8	9
Pola Creek	2.1	4.0	10
Euroka Creek	2.0	2.1	11

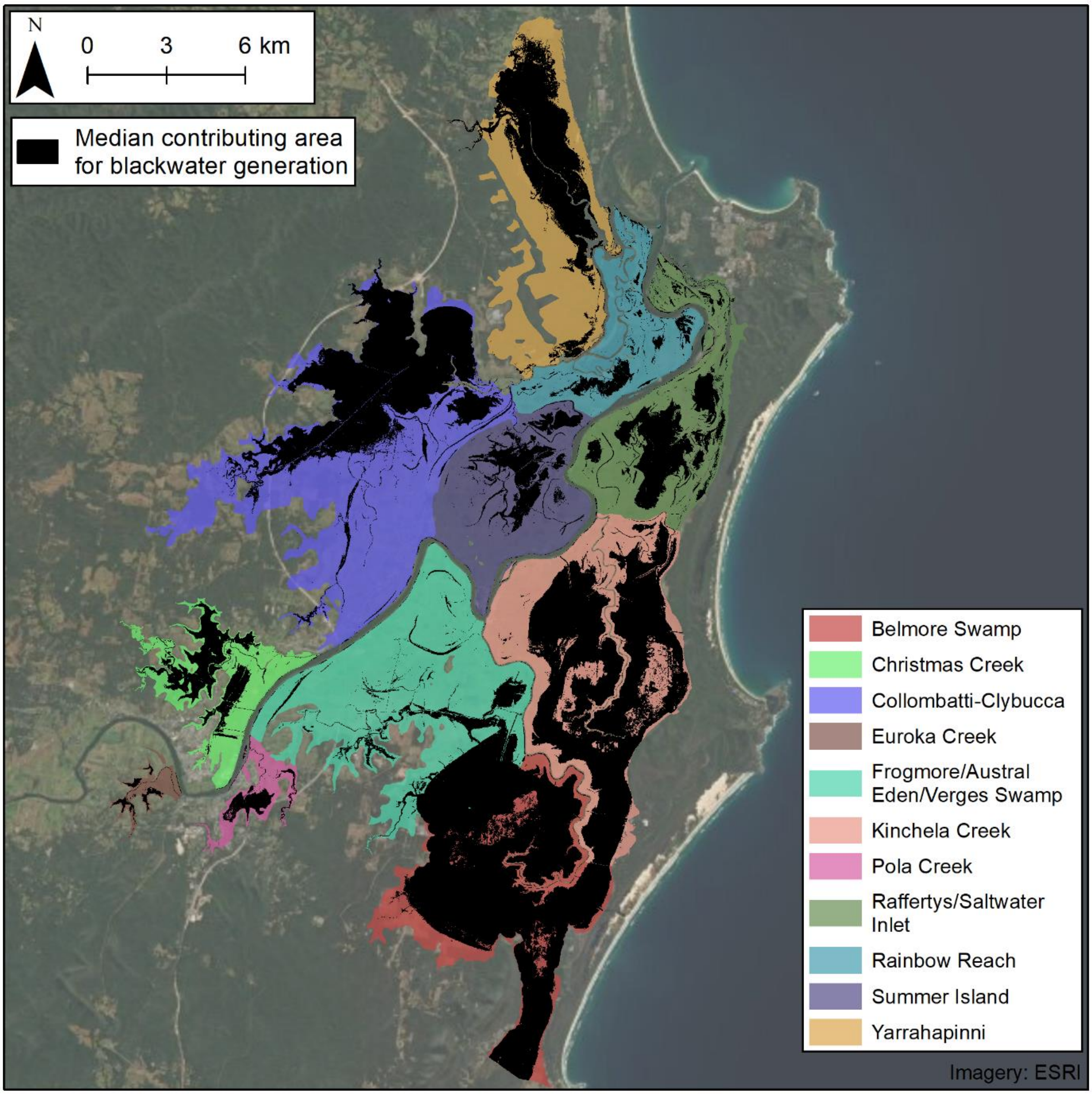

Figure 6-1: Median contributing area for blackwater generation across the Macleay River floodplain

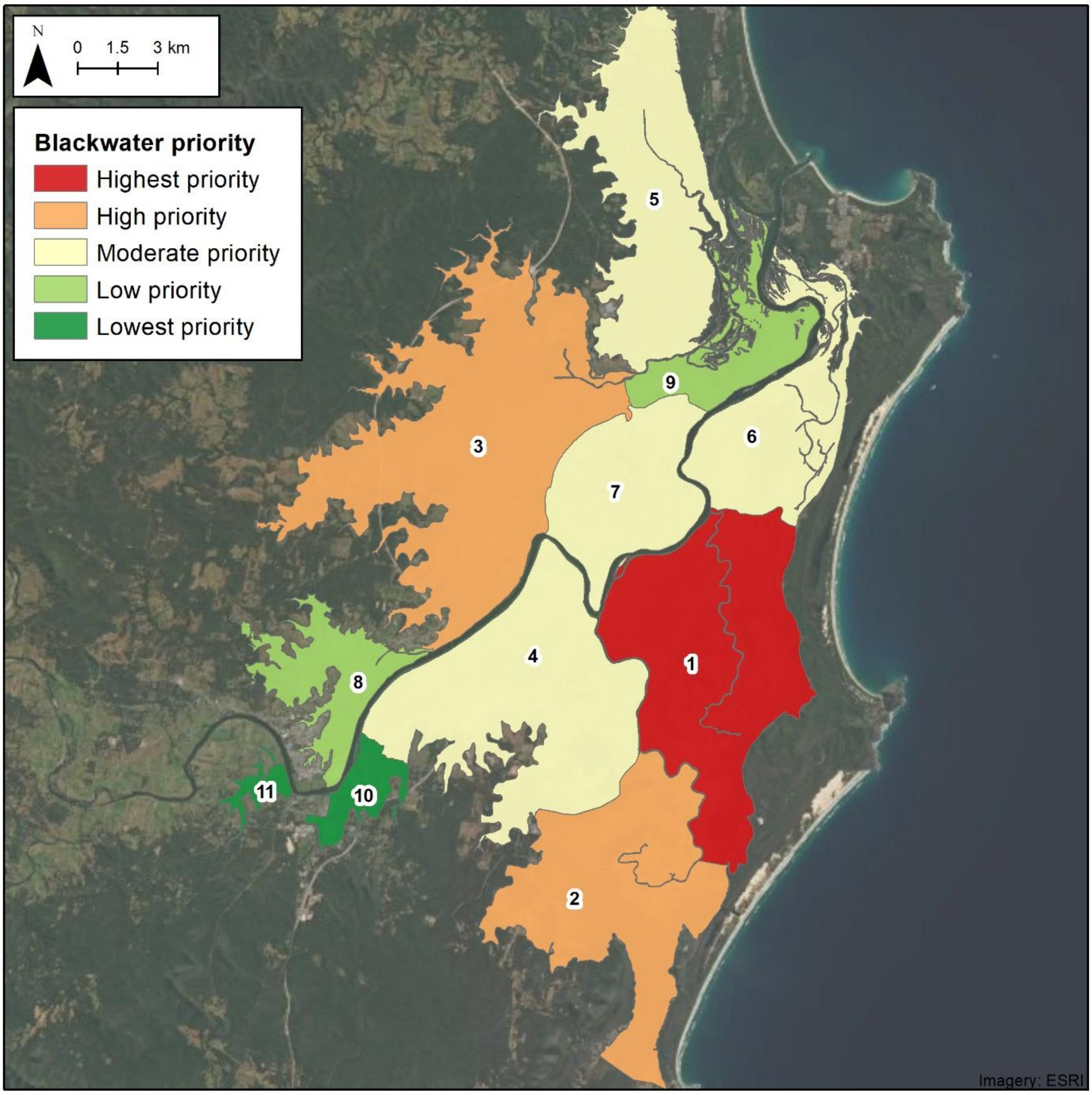

Figure 6-2: Final ranking of the blackwater prioritisation in the Macleay River floodplain

7 Sea level rise implications

7.1 Preamble

White et al. (2014) completed an analysis of tidal gauges across Australia and found that the average rate of rise in relative sea levels between 1966 - 2010 in Australia was +1.4 mm/year and had accelerated to +4.5 mm/year across the country between 1993 and 2010. The rate of sea level rise is expected to continue to accelerate over the next century (IPCC, 2014). Coastal estuaries are amongst the most vulnerable areas to sea level rise due to the proximity to the ocean and level of development in Australian estuaries (OEH, 2018).

Coastal floodplains are susceptible to sea level rise as changes in sea levels and hence tidal levels, will intensify factors that currently contribute to flooding, reduced drainage efficiency, and changes to inundation extent/duration. The following section summarises the assessment completed for this study to identify floodplain areas and floodplain infrastructure in the Macleay River floodplain that are vulnerable to future sea level rise. Detailed information on how climate change will likely influence estuaries in NSW can be found at: http://estuaries.wrl.unsw.edu.au/index.php/climate-change/ (accessed 23/09/2020).

Note, acid and blackwater generation and drainage are intrinsically linked to water levels in the main estuary and will be affected by sea level rise. Sea level rise will likely reduce the impact of ASS discharges in estuaries, due to (but not limited to):

- Greater neutralisation capacity (through natural bicarbonates available in sea water) of the mid-upper estuary associated with greater penetration of the tide; and
- Reduced groundwater drainage due to higher average surface water levels throughout the drainage network.

The impact of sea level rise on blackwater drainage is less well understood and dependent on a number of factors. In the short-term, proliferation of non-water tolerant vegetation across the floodplain will likely result in an increased blackwater risk as a result of greater and more frequent flooding due to sea level rise. However, in the long-term, sea level rise will result in reduced drainage and prolonged inundation across the floodplain. This will mean it is likely for water tolerant vegetation to grow and establish in areas susceptible to reduced drainage, reducing the potential for blackwater generation. More research is required to model the likely changes in acid and blackwater drainage in NSW estuaries under future sea levels.

7.2 Changes to water levels in estuaries

Glamore et al. (2016b) detailed how water levels in estuaries are influenced by oceanic forces and climate change. In brief, tidal water levels at the entrance of an estuary influence the overall volume of water (tidal prism) moving in and out with each tide. The tidal prism, the channel bed friction, catchment inflows and the channel geometry (i.e. the depth and the shape of the estuary) influence whether the tidal planes amplify (increase), remain constant or attenuate (decrease) as the tide travels upstream. With sea level rise, tidal levels at the entrance of an estuary will increase, however, the impact on tidal water levels within the estuary is dynamic and non-linear, and therefore not intuitively relatable to the sea level rise changes in the ocean.

Numerical models enable the behaviour and response of estuaries to sea level rise to be investigated. Section 11 of the Methods report (Rayner et al., 2023) discusses the different types of numerical models and their merit for use in dynamic estuarine systems. For this study, a hydrodynamic numerical model was constructed of the Macleay River estuary, and calibrated to present day tidal levels throughout the estuary. The tidal levels at the oceanic boundary of the estuary were then altered to predict the impact of sea level rise throughout the estuary. The aim of the numerical modelling analysis was to establish water level statistics for past, present-day, near-future and far future planning horizons throughout the Macleay River estuary and detail hydrodynamic processes such as tidal attenuation and amplification.

The following section outlines the numerical modelling approach used to investigate sea level rise in the Macleay River estuary. Further details on the model development and calibration can be found in Appendix I.

7.2.1 Macleay River estuary hydrodynamic model

A hydrodynamic model was constructed using the finite element model RMA-2 (King, 2015) to simulate the tidal currents and freshwater inflows to the Macleay River estuary. The model domain, shown in Figure 7-1, extends across the tidal region of the Macleay Arm, Clybucca Creek, Kinchela Creek and Belmore River. The numerical model was constructed using a combination of one dimensional (1-D) and two dimensional (2-D) elements. One dimensional (1-D) elements were used in areas where flow occurs perpendicular to the cross section and 2-D elements were used to represent the lower estuary where complex free surface flows occur (i.e. where the flow can occur in both the x and y planes).

The model was developed to ensure coverage of the areas of interest (i.e. major floodgate infrastructure) in the lower estuary and extends up to the tidal limit approximately 32 km upstream from the river mouth. The hydrodynamic model comprised of three (3) primary inputs:

1. **Channel bathymetry and geometry** utilised the same data as previous modelling of the Macleay River developed by WMA (2009). This was based on the 2003 survey of the Macleay River estuary bathymetry;
2. **Downstream tidal water levels** were applied at the ocean boundary. This was based on the observed records from the NSW DPIE Manly Hydraulics Laboratory (MHL) offshore water level station at the Port Macquarie (station number 207450); and
3. **Upstream river flows** were applied as inflow hydrographs at the upstream extent of the model. This was sourced from the Water NSW river gauge for Macleay River at Turners Flat (station number 206011).

Lower catchments inflows to the model were not included as sensitivity testing indicated that floodplain runoff has a relatively small impact on the day-to-day water levels in the lower Macleay River estuary (which is dominated by the downstream tide). As such, the resulting hydrodynamic model is calibrated for everyday tides, but is not suitable to replicate catchment flood events. This is considered to be appropriate because the hydrodynamic model has been used in this study as a tool to assess the vulnerability of end of drainage system infrastructure, and floodplains subject to day-to-day drainage conditions, rather than large-scale catchment flood events. Further information on the hydrodynamic model setup and calibration is provided are Appendix I.

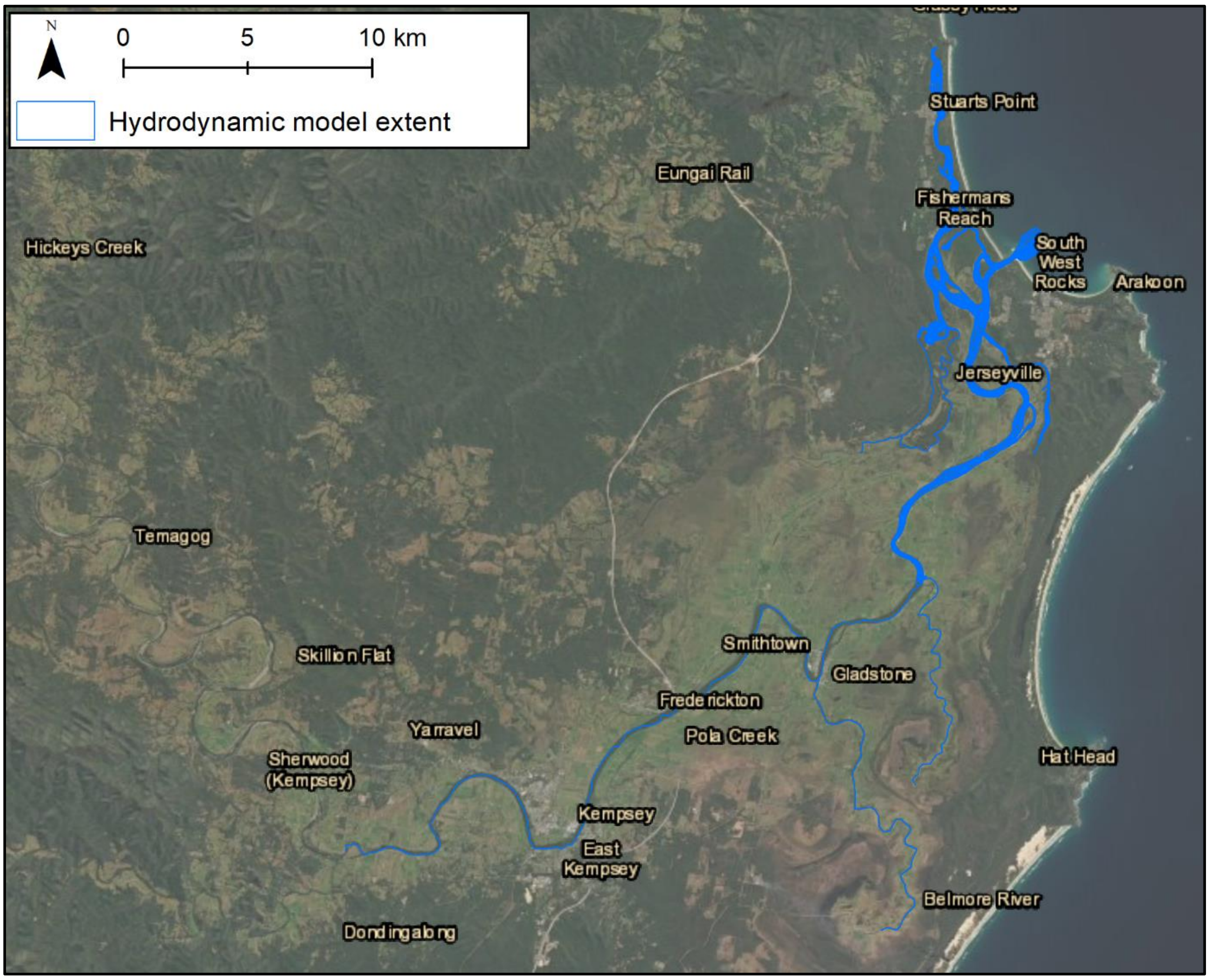

Figure 7-1: Macleay River estuary hydrodynamic model extent

The hydrodynamic model of the Macleay River estuary was calibrated to measured water level monitoring stations along the main river channel for 2003. This year was selected due to the availability of short-term tidal flow gauging at various locations on the Macleay River taken on 16 April 2003 (MHL, 2003). The locations of the water level and tidal flow gauging monitoring stations used for calibration are provided in Appendix I. The calibrated model was then used to simulate a representative 'wet' year (i.e. above average rainfall across the catchment) and a representative 'dry' year (i.e. below average rainfall across the catchment) based on analysis of rainfall records in Northern NSW. For this project, 2013 and 2019 were selected as the wet and dry years, respectively based on long term rainfall monitoring by the Bureau of Meteorology. The model results from these simulations were then used to verify the tidal water level patterns throughout the estuary.

7.2.2 Historic and future sea level rise

Four (4) time periods have been identified to simulate how sea level rise influences estuarine water levels:

- Historical (HS) (~1960);
- Present day (PD (~2020);
- Near future (NF) (~2050); and
- Far future (FF) (~2100).

Sea level rise scenarios were based on scenarios from Glamore et al. (2016b). The adopted changes in mean sea level (MSL) relative to 2020 for these periods has been detailed in Section 11 of the Methods report (Rayner et al., 2023) and are presented in Table 7-1.

Freshwater catchment inflows were not modified to account for changes to rainfall and catchment runoff as a result of climate change. Global climate models typically cannot resolve hydrological processes (i.e. catchment rainfall and runoff) with enough detail. The NSW and ACT Regional Climate Modelling (NARCliM) Project is a 12-member regional climate model ensemble (containing 12 individual models) that provides high resolution (10 by 10 km) climate projections for wider NSW. Heimhuber et al. (2019a) analysed the results from NARCliM modelling for near future and far future scenarios and found that rainfall is expected to stay largely the same in terms of annual totals along the NSW coast (albeit with some statistical uncertainty).

In a recent study undertaken by Nguyen et al. (2020) it was shown that mean annual streamflow is expected to reduce by -20% to -30% for most catchments by the end of the century largely due to increased evaporation resulting from increased temperatures. This may result in an increase in tidal influence in the upper sections of the estuary but is unlikely to influence estuary wide water levels as significantly as sea level rise and has therefore not been included in modelling for this study. The results of the modelling in this study should be seen as a 'first-pass' assessment of sea level rise impacts on the Macleay River estuary.

Table 7-1: Adopted mean sea level (MSL) relative to present-day (2020)

Time period	Adopted change in MSL relative to 2020 (m)
HS - Historical (circa 1960)	-0.05
PD - Present day (circa 2020)	0
NF - Near future (circa 2050)	+0.16
FF - Far future (circa 2100)	+0.67

7.3 Water level statistics

The hydrodynamic model was run for two (2) years for each of the four (4) sea level rise scenarios (Table 7-1). Water levels were extracted at the locations of interest and statistical analysis used to assess floodplain vulnerability. Increasing water levels, particularly an increase in low tide levels, will significantly impact the drainage potential (i.e. hydraulic gradient) of coastal floodplains.

Three (3) main statistical water levels have been used to assess floodplain vulnerability:

- **5th percentile water level** (water levels are below this level 5% of the time, or around 1 hour a day) – this represents a low tide water level at a given location. Areas below the 5th percentile water level are typically permanently inundated and difficult to drain without additional mechanical assistance (i.e. pumping);
- **50th percentile water level** (water levels are above/below this level 50% of the time) – this is a median water level. Areas below the 50th percentile water level can be difficult to drain

efficiently, although the use of one-way floodgates has allowed agricultural development on low-lying land; and

- **95th percentile water level** (water levels are below this level 95% of the time, or around 23 hours a day) – this represents a high tide water level at a given location. While these areas are commonly used for agriculture, areas below the 95th percentile water level may be impacted by reduced drainage, particularly after flood events.

7.4 Floodgate vulnerability

One-way tidal floodgates are used extensively throughout the Macleay River estuary to mitigate backwater flooding from the river, prohibit tidal water from inundating low areas of the floodplain and encourage regular tidal drainage to the low tide level upstream of the floodgate. The vulnerability of a floodgate to reduced flow efficiency due to sea level rise can be assessed by determining how frequently the floodgates are able to freely drain based on the downstream water levels and the floodgate geometry/elevation. Table 7-2 summarises the classifications applied to each floodgate. This is also presented diagrammatically in Figure 7-2. The approach to assessing floodgate vulnerability is discussed further in Section 11 of the Methods report (Rayner et al., 2023).

Table 7-2: Rules for floodgate vulnerability classification

Colour	Classification	Criteria
Green	Least Vulnerable	Obvert > 95th percentile water level
Orange	Moderately Vulnerable	95th percentile water level > Obvert > 50th percentile water level
Red	Most Vulnerable	Obvert < 50th percentile water level

Note: Obvert is the inside top of the floodgate structure.

The classification developed identifies floodgates that will not allow efficient drainage of surface water (either now or into the future). Based on this classification, a floodgate is classified as:

- 'Least Vulnerable' if the structure can drain effectively for at least 95% of the time (approximately 23 hours in a day) (Figure 7-2a);
- 'Moderately Vulnerable' if the structure can drain effectively between 50% – 95% of the time (i.e. between 12 and 23 hours of the day) (Figure 7-2b); and
- 'Most Vulnerable' if the structure can drain effectively for less than 50% of the time (i.e. for less than 12 hours of the day) (Figure 7-2c).

The floodgate vulnerability assessment was completed by comparing the floodgate obvert elevations to the downstream water levels statistics (i.e. the simulated water levels from the nearest numerical model node). Water level statistics were extracted for the historical (HS), present day (PD), near future (NF) and far future (FF) simulations for the 5th, 50th and 95th percentile exceedances and compared to the floodgate elevation. Note that the floodgate vulnerability assessment could only be applied to a tidal floodgate at the end of the drainage system, where the drainage system discharges into the estuary and where infrastructure survey data was available.

Figure 7-3 to Figure 7-6 present floodgate vulnerability maps for the Macleay River estuary for the scenarios tested. Detailed mapping for each floodplain subcatchment is provided in Section 8. This assessment does not consider the design life of floodplain infrastructure or the additional vulnerability expected from aging infrastructure and has been completed only considering present day floodgate geometry. A significant portion of the infrastructure considered is likely to require substantial capital expenditure to maintain functionality over the next century, given that approximately 70% of floodgates owned by Kempsey Shire Council were constructed prior to 1970 and they generally have a useful life of 60 years (Kempsey Shire Council, 2014).

Table 7-3 presents a summary of the number of floodgates which are classified as 'Most vulnerable', 'Moderately vulnerable' and 'Least vulnerable' for each of the simulated scenarios. By the far future, 23 of 97 (24%) floodgates with known elevation are considered "Most vulnerable", compared to just one (1) (1%) in present day conditions. As shown in Figure 7-5 and Figure 7-6, the lower estuary has a higher proportion of floodgate infrastructure that is identified as moderate to high vulnerability versus the upper estuary.

Table 7-3: Vulnerability classification of Macleay River floodgates

	Historical (HS)	Present day (PD)	Near future (NF)	Far future (FF)
Least vulnerable	82	81	73	49
Moderately vulnerable	14	15	23	25
Most vulnerable	1	1	1	23

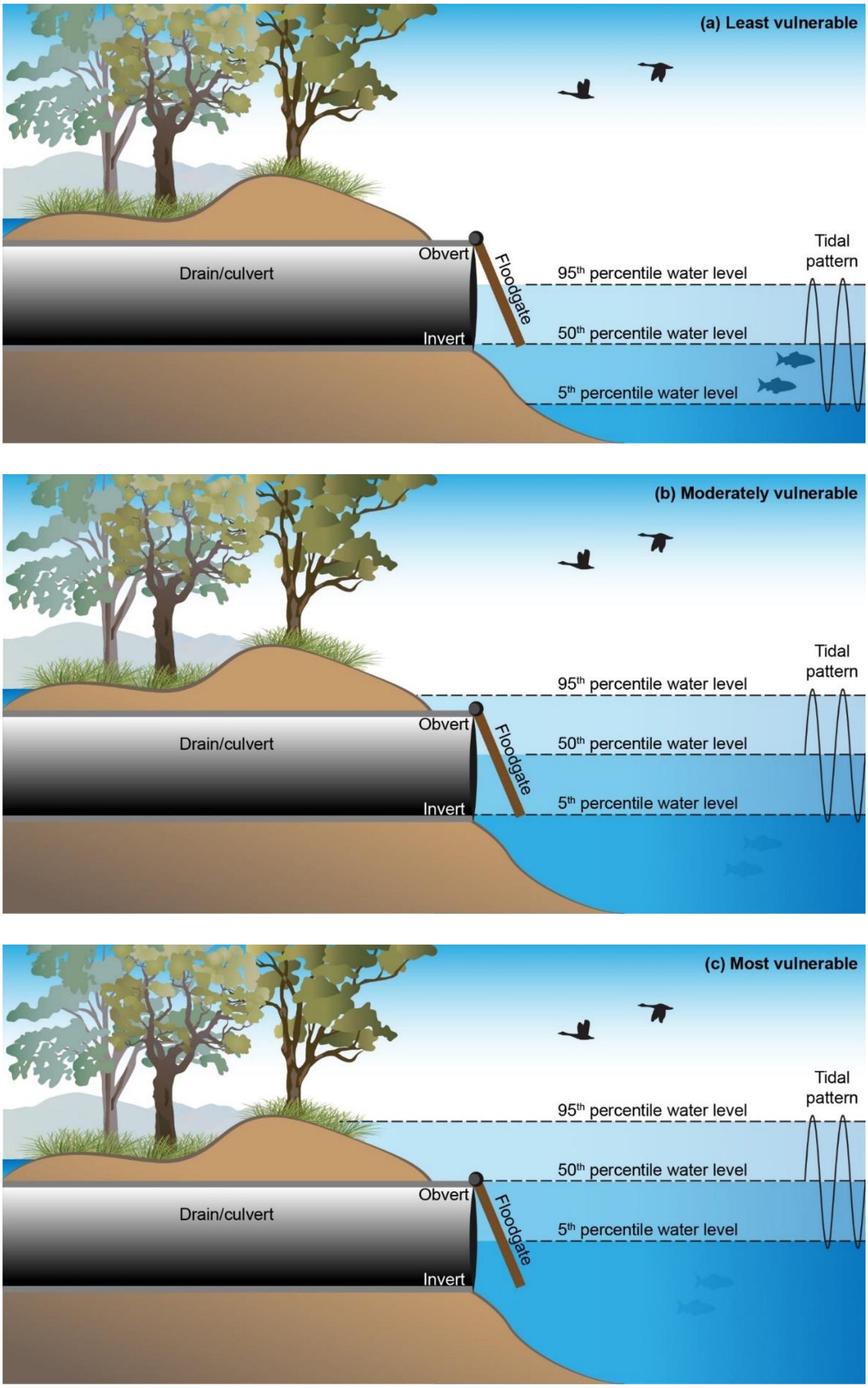

Figure 7-2: Floodgate vulnerability assessment

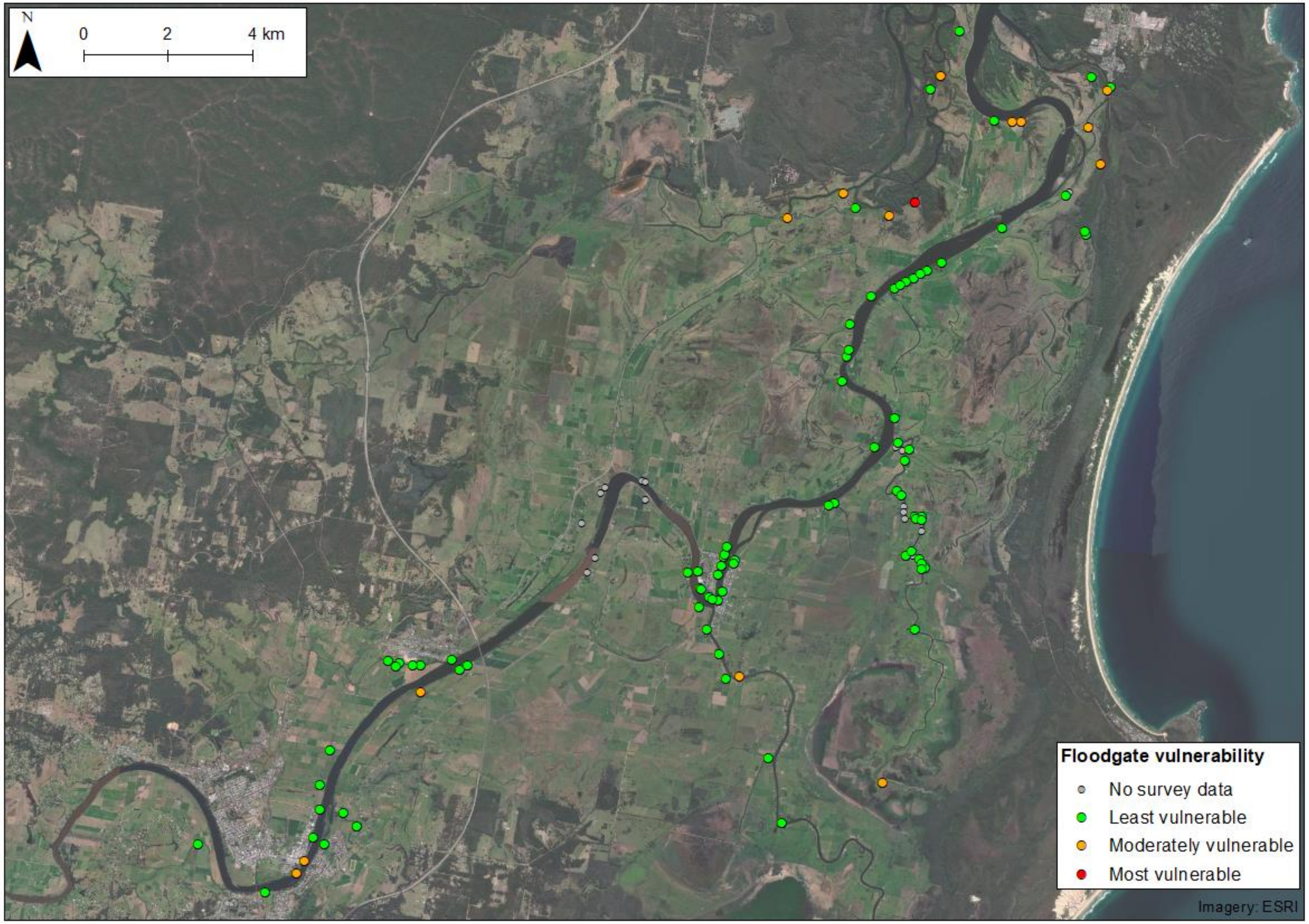

Figure 7-3: Historic (~1960s) floodgate vulnerability – Macleay River estuary

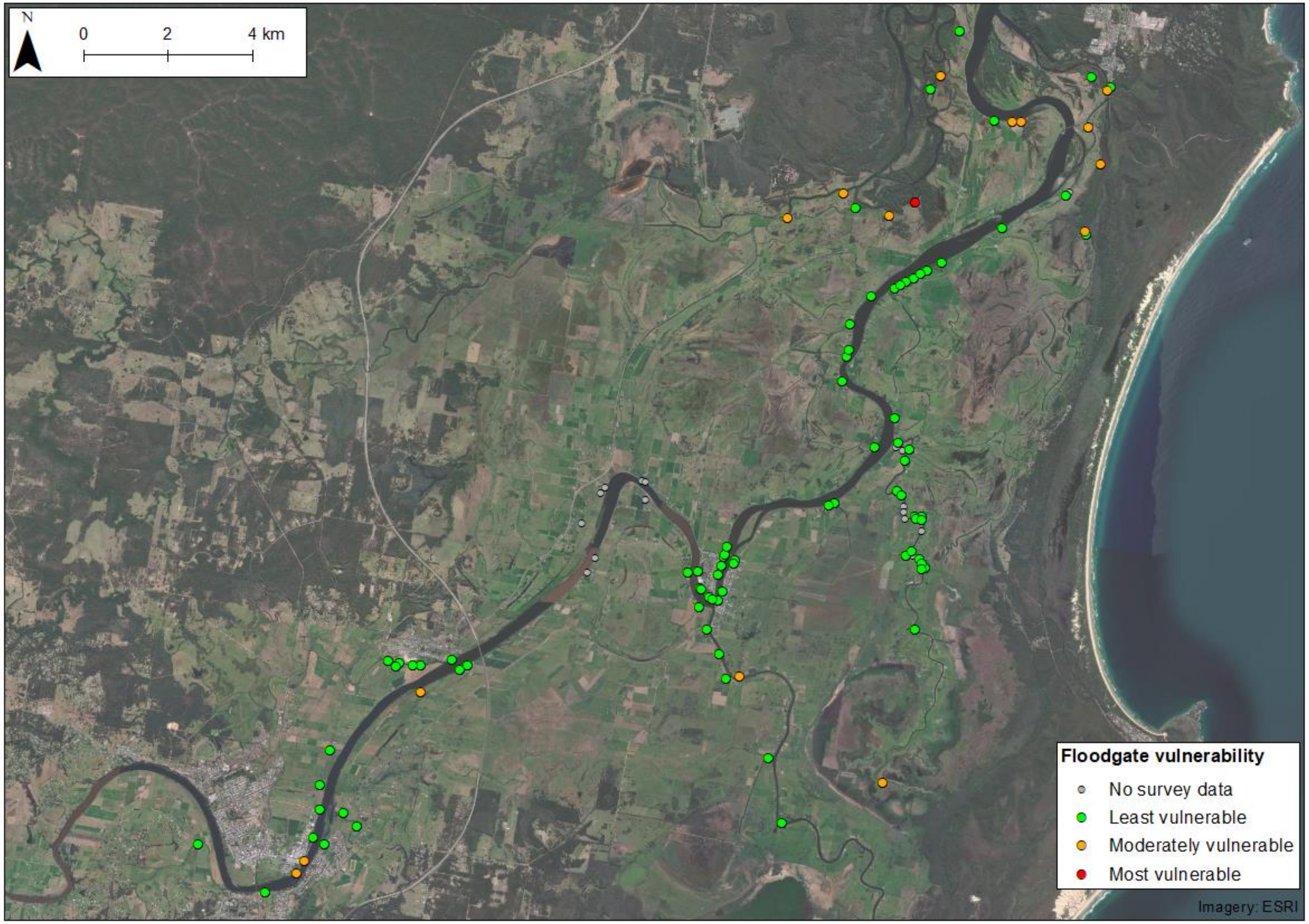

Figure 7-4: Present day (2020) floodgate vulnerability – Macleay River estuary

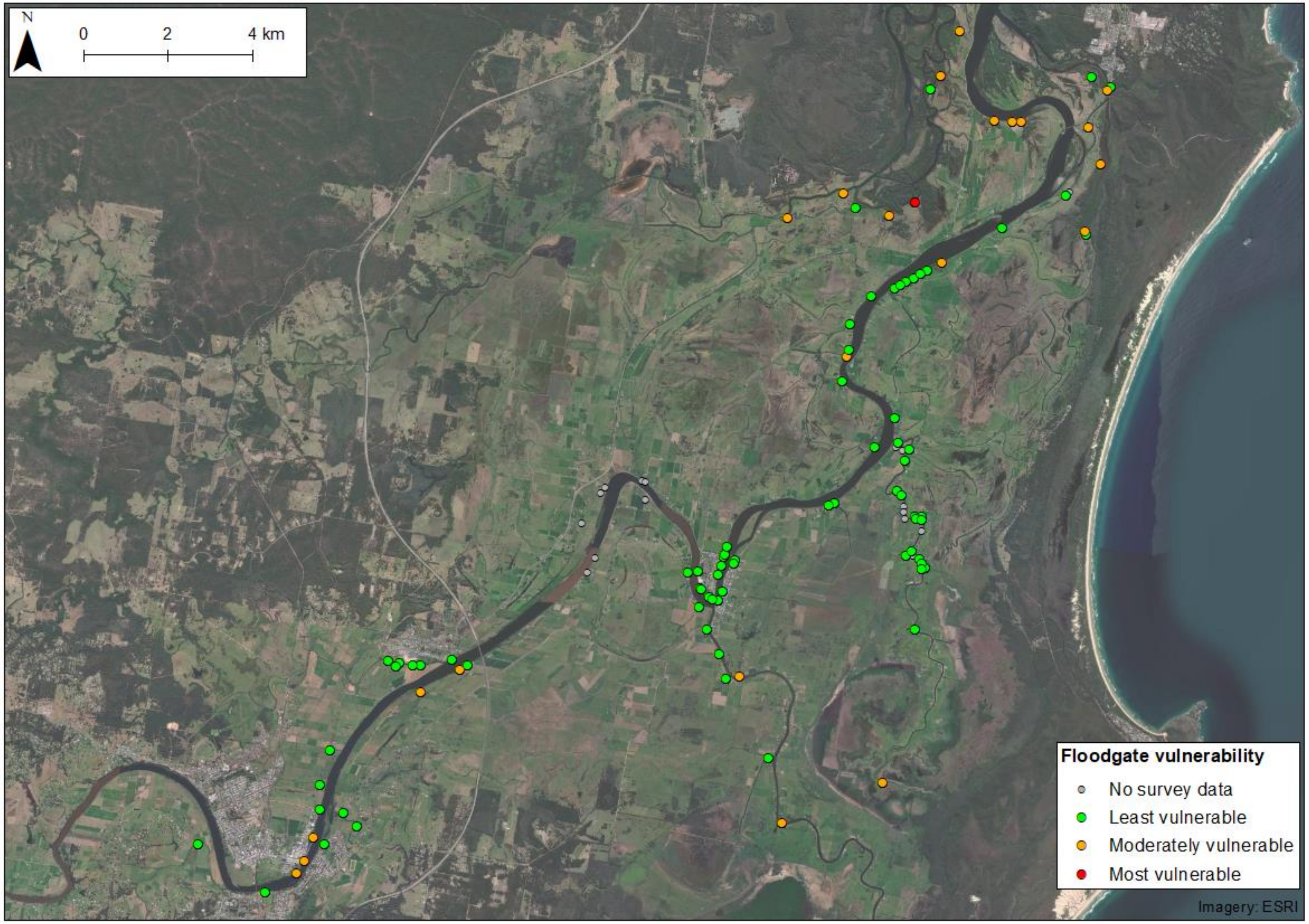

Figure 7-5: Near future (~2050) floodgate vulnerability – Macleay River estuary

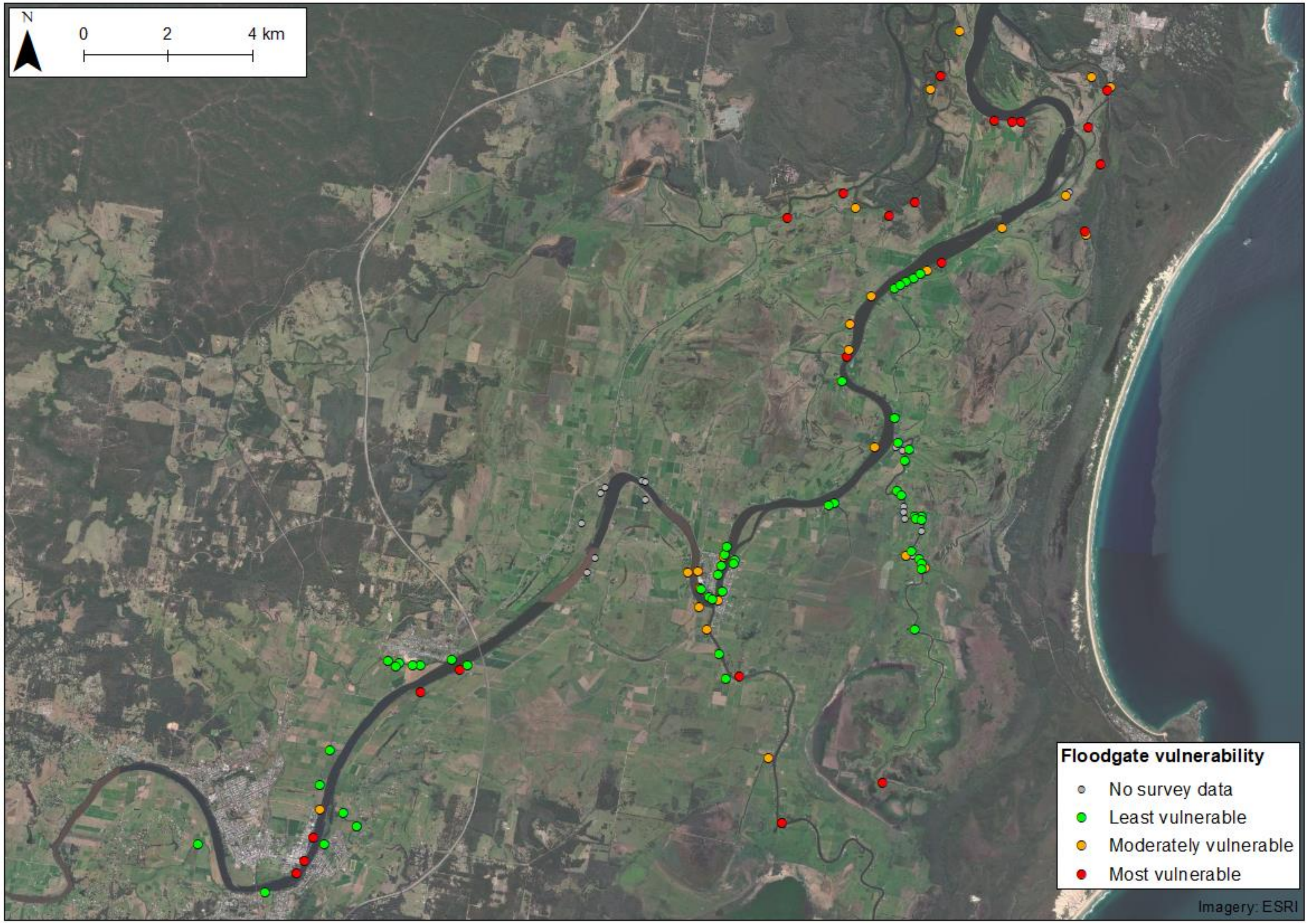

Figure 7-6: Far future (~2100) floodgate vulnerability – Macleay River estuary

7.5 Floodplain vulnerability

Coastal floodplains are vulnerable to sea level rise as they are susceptible to increased inundation times (Glamore et al., 2016b). Inundation can increase for a number of reasons, including increased flooding due to higher ocean levels, tidal inundation due to higher king tides, and reduced drainage due to an increase in the average low tide levels. Impacts of sea level rise to flooding are typically assessed in floodplain flood studies by increasing ocean boundary conditions during periods of high catchment inflows (OEH, 2015). Similarly, tidal inundation assessments consider areas at risk of inundation due to an increase in future high tide levels (OEH, 2018) which may directly inundate floodplain areas immediately adjacent to water ways, or overtop infrastructure.

In this study, floodplain vulnerability has been assessed with respect to the potential impacts of reduced drainage only. Elevated tidal levels will result in an increase in low tide elevations and subsequently reduced drainage. This is particularly relevant to low-lying areas where prolonged periods of inundation following wet weather events are expected. Rather than assessing which areas may be directly inundated (as per a tidal inundation assessment), this assessment identifies areas which may be subject to reduced drainage due to low gradients between the floodplain and estuary water levels. Reduced day-to-day drainage has the potential to significantly impact future floodplain land uses and productivity. The floodplain vulnerability assessment presented here is a first pass assessment that identifies floodplain infrastructure and areas that may be impacted by reduced drainage due to sea level rise in the near to far future.

The floodplain vulnerability assessment methodology, as described in the Section 11 of the Methods report (Rayner et al., 2023), provides an indication of the floodplain areas that are likely to be most impacted by reduced drainage. This analysis translates the predicted water level statistics in the estuary, to the floodplain subcatchment topography. Note, this analysis only considers the risk to floodplain drainage that may arise from catchment inflows and does not consider other modes of floodplain inundation such as movement of estuarine water through underground aquifers to the floodplain. The three (3) key water level statistics described in Section 7.3 have been used in this analysis (5^{th}, 50^{th} and 95^{th} percentile water levels). The floodplain areas above the 95^{th} percentile water levels are not considered to be vulnerable under this assessment. These are outlined in Table 7.4 and Figure 7-7.

Figure 7-8 to Figure 7-11 illustrate the floodplain vulnerability of the Macleay River floodplain for the historical, present day, near future and far future sea level rise scenarios. Detailed mapping for each floodplain subcatchment is provided in Section 8. Note that these figures may not be indicative of the actual areas to be inundated due to sea level rise as they do not account for localised impediments to flow (such as levee banks, culverts, floodgates or hydraulic losses) or any localised dampening/amplification of tides that may occur through the smaller drainage channels. The purpose of this analysis is to highlight areas at risk of reduced drainage, rather than areas that may be actively inundated by tidal waters due to sea level rise.

Table 7.4: Rules for floodplain drainage vulnerability

Classification	Criteria	Description
High risk	Land with an elevation below the 5th percentile water level (approximate low tide level)	Water can only drain from this land effectively 5% of the time, or for around 1 hour in a day. These areas are typically permanently inundated and difficult to drain without additional mechanical assistance (i.e. pumping).
Medium risk	Land with an elevation below the 50th percentile water level (median water level)	Water can drain from this land effectively 50% of the time, or for around 12 hours in a day. These areas are generally difficult to drain efficiently .
Low risk	Land with an elevation below the 95th percentile water level (approximate high tide level)	Water can drain from this land effectively 95% of the time, or for around 23 hours in a day. These areas can be impacted by inefficient drainage, particularly after flood events.
Not vulnerable	Land with an elevation above the 95th percentile water level (approximate high tide level)	Water can drain from this land effectively more than 95% of the time, or for more than 23 hours in a day. These areas are generally not impacted by reduced drainage.

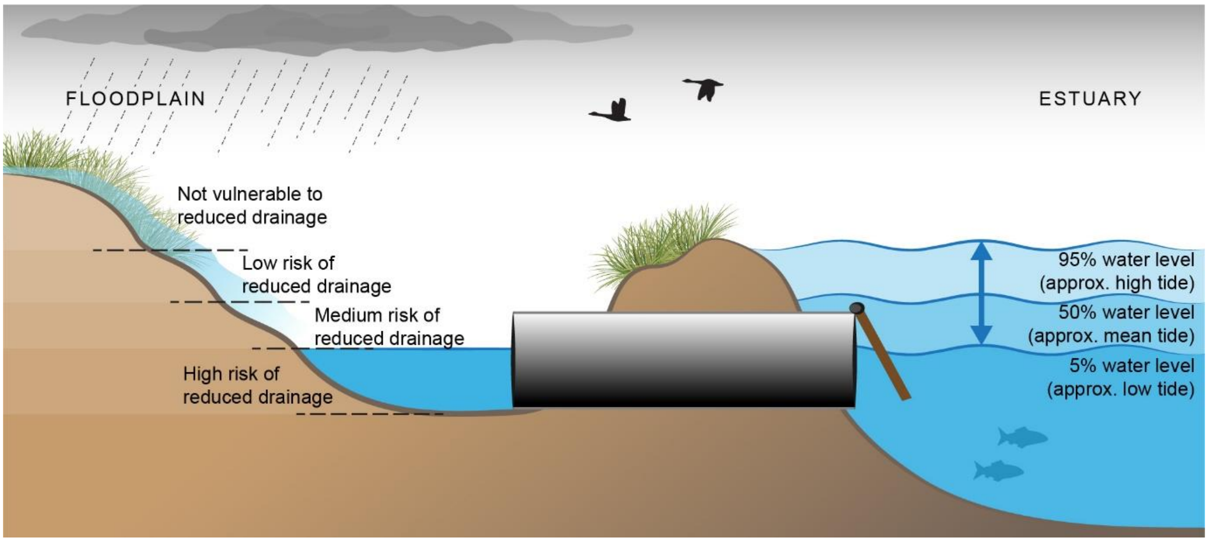

Figure 7-7:Floodplain drainage vulnerability

The total floodplain areas below the water level percentiles for the historical, present day, near future and far future sea level rise scenarios for the Macleay River are summarised in Table 7-5. Between present day and the near future, the area below the 5th percentile water level increases by over 100 hectares. This increases significantly further in the far future by over 5,000 ha.

Table 7-5: Total area of the Macleay River floodplain vulnerable to reduced drainage

Vulnerability status	Level criteria	Historical (HS) ~1960 (ha)	Present day (PD) 2020 (ha)	Near future (NF) ~2050 (ha)	Far future (FF) ~2150 (ha)
Low	50th percentile water level < Land elevation < 95th percentile water level	7,962	8,363	8,579	14,515
Moderate	5th percentile water level < Land elevation < 50th percentile water level	726	1,186	3,466	6,539
High	Land elevation < 5th percentile water level	36	81	211	5,513

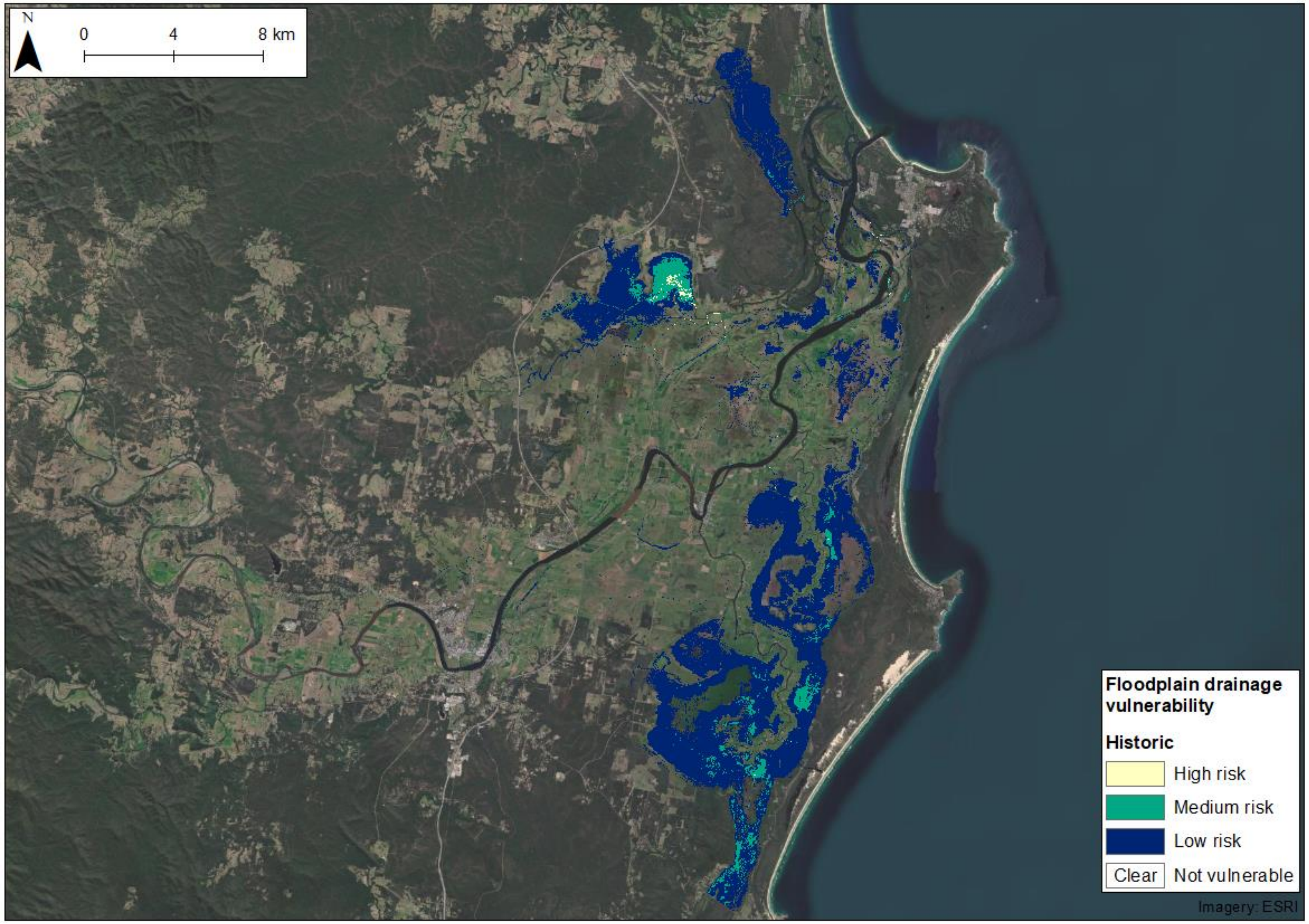

Figure 7-8: Historic (~1960s) floodplain vulnerability – Macleay River estuary

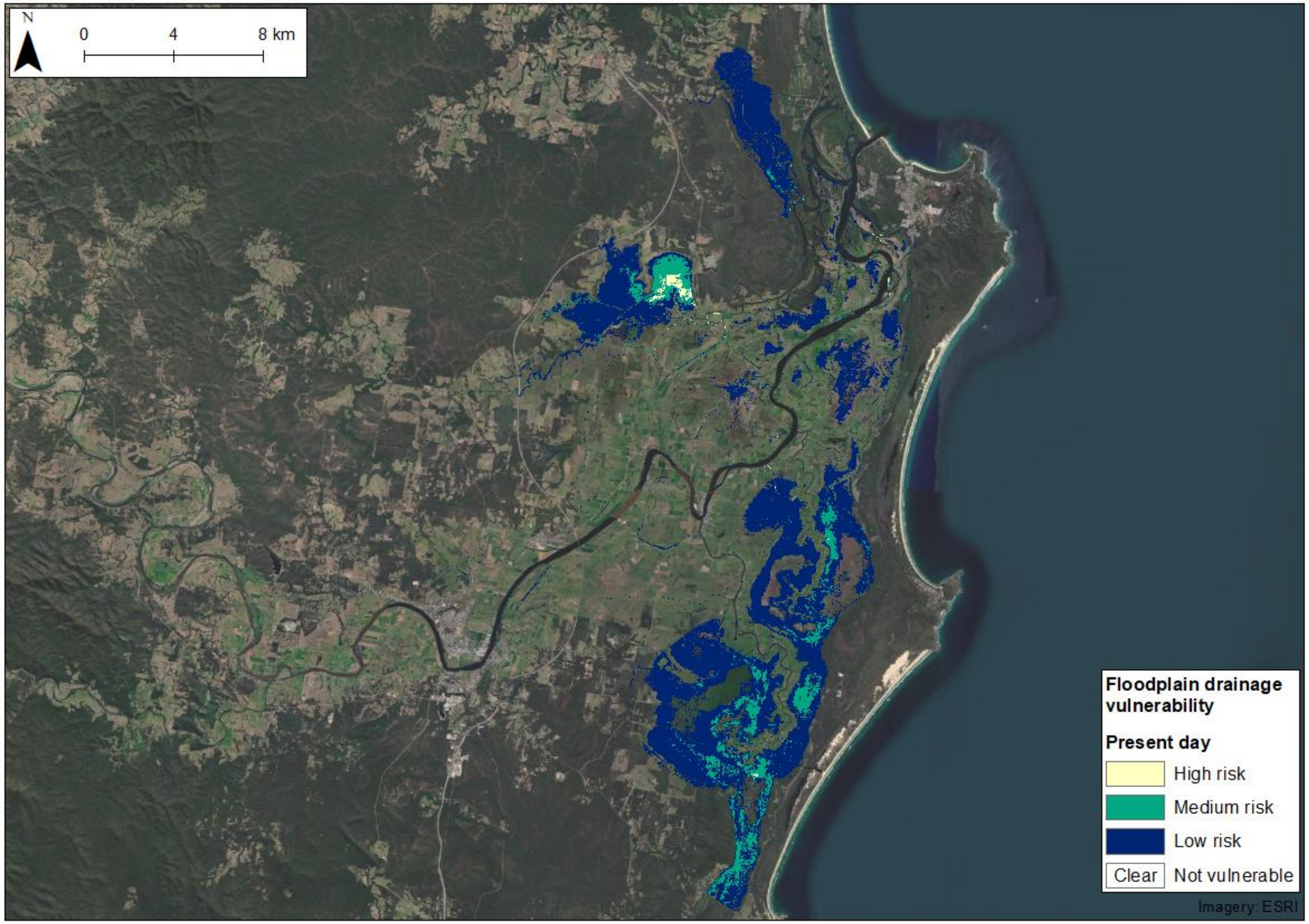

Figure 7-9: Present day (2020) floodplain vulnerability – Macleay River estuary

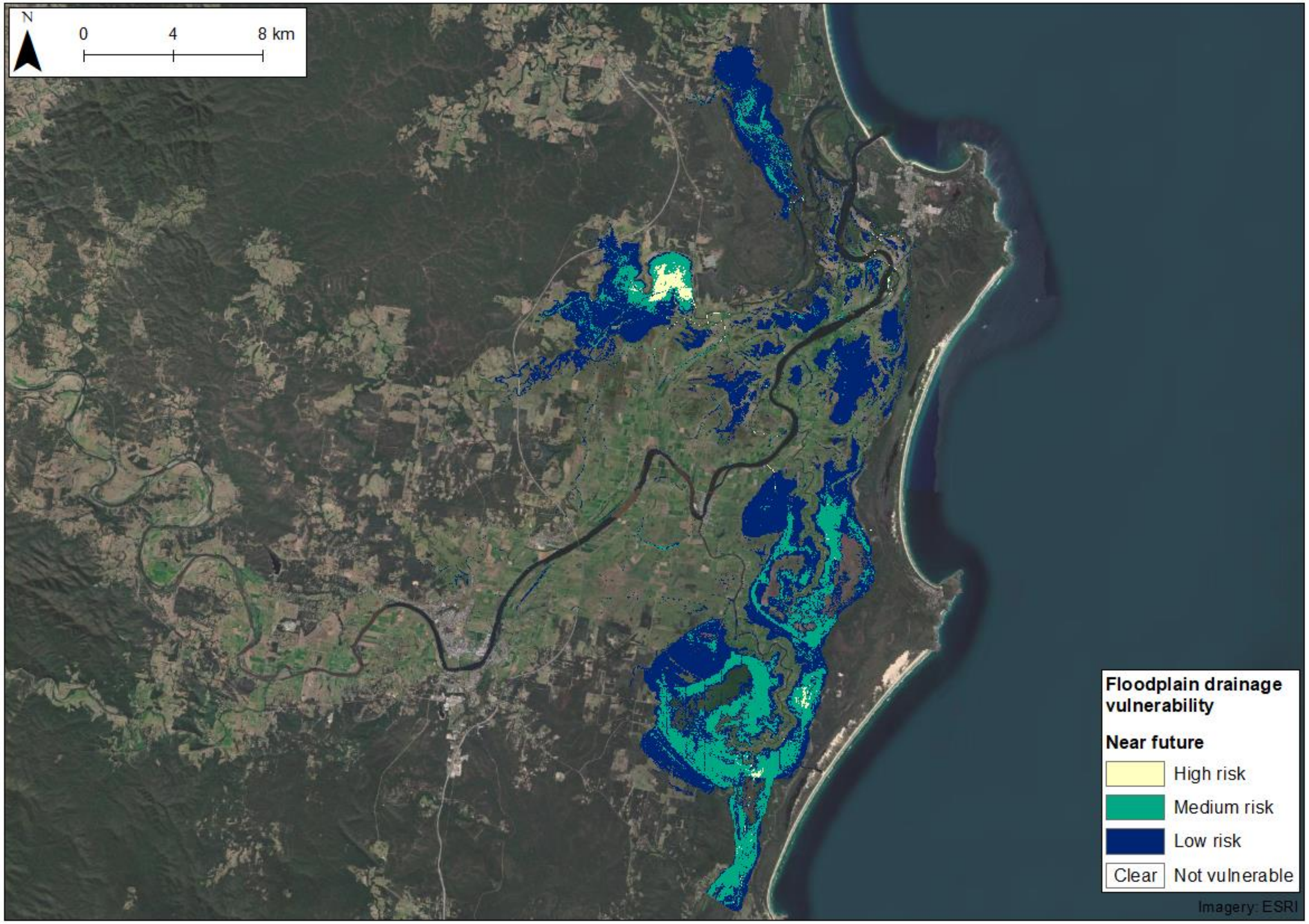

Figure 7-10: Near future (~2050) floodplain vulnerability – Macleay River estuary

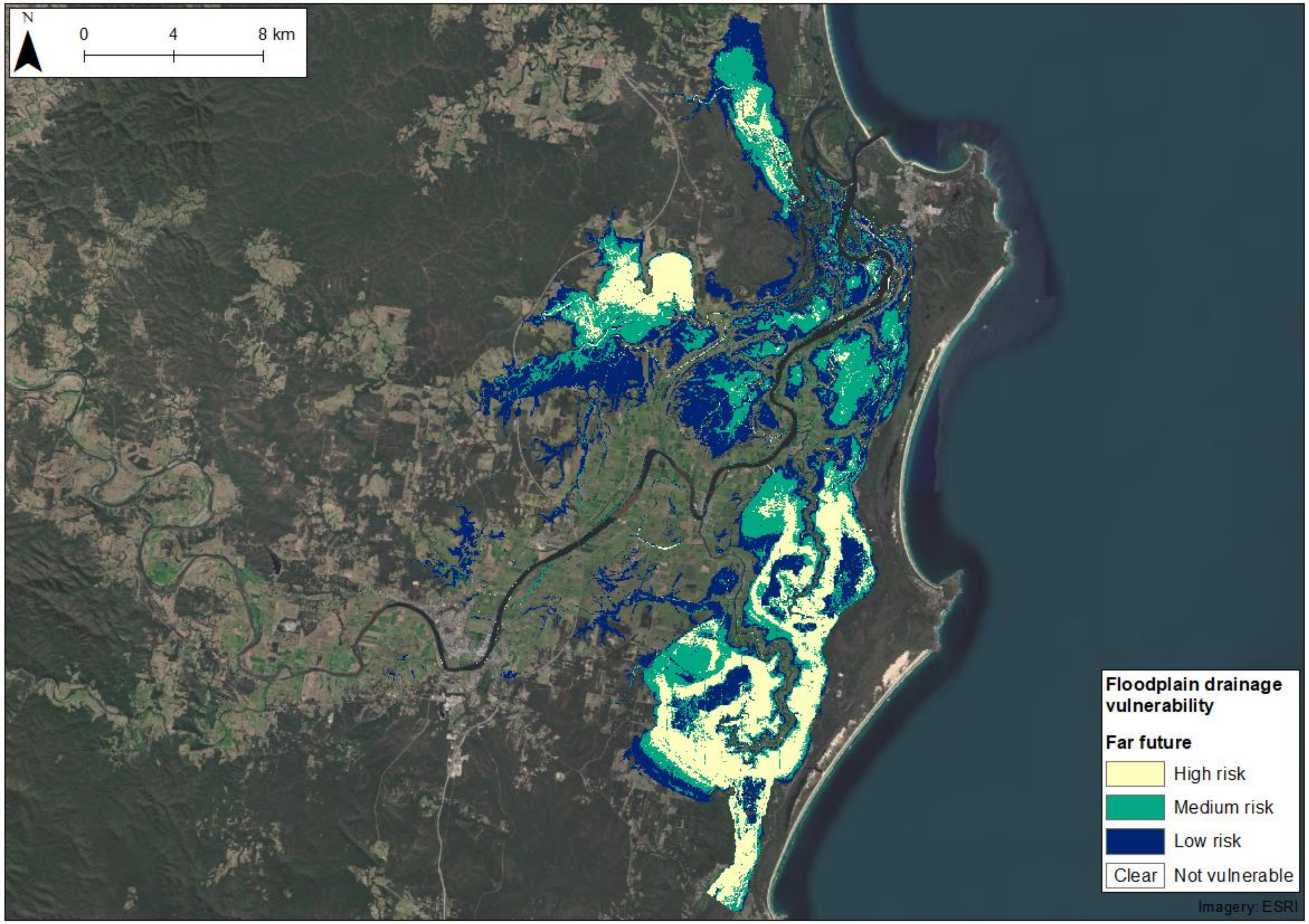

Figure 7-11: Far future (~2100) floodplain vulnerability – Macleay River estuary

8 Subcatchment management options

8.1 Preamble

Management options have been developed for each subcatchment of the Macleay River floodplain. They include options for short and long-term strategies to reduce the impact of ASS drainage and blackwater generation. Short-term management options are typically implementable within the next one (1) to ten (10) years, while long-term management targets require a longer time period for implementation or a greater upfront investment.

The management options provided in this section are intended as a guide only. Further information and investigation, including incorporation of current on-ground works and management initiatives will be required to confirm any on-ground works are applicable, and to determine the required engineering specifications prior to implementing any remedial works. Site investigations should adequately consider the potential impact of any remedial work on existing ecological values, as well as the impact on upstream and adjacent landholders. Any changes in management of these areas will require consultation with local landholders and a comprehensive understanding of, and a plan to mitigate, the social and economic impacts of changes in land management on the community. Additional detailed site investigations required may include - subcatchment hydrological assessments, data collection and monitoring, additional ASS sampling and analysis, and detailed design. Community, landholder, and stakeholder consultation and engagement will also be required.

8.2 Explanation of key information

8.2.1 Summary table

A summary table is provided for each floodplain subcatchment which includes information on priority rankings (for blackwater and acid), drainage and infrastructure, ASS elevations, sea level rise predictions, land uses, proximity to sensitive receivers, and a brief summary of land value and productivity. An example of the summary table provided is shown in Table 8-1, including an explanation of each value.

8.2.2 Floodgates and tenure

The location/number of known end of system floodgates is provided in mapping and the summary tables. In this project, ‘end of system’ is used to refer to any infrastructure that discharges directly into a river, creek or drain that is unrestricted by other infrastructure (i.e. there are no other floodgates located downstream). Infrastructure that is upstream of another floodgate is not included in mapping or the infrastructure counts.

Tenure is provided where known information is available. Information for privately owned infrastructure is difficult to determine as there is no central database. Where the tenure is unknown, it is classified as ‘Private/Unknown’. A summary of all known infrastructure is provided in Appendix F.

Table 8-1: Subcatchment data summary table

Value	Description
Acid priority rank: #	**Final rank in floodplain for acid generation**
Blackwater priority rank: #	**Final rank in floodplain for blackwater generation**
Infrastructure	
Approximate waterway length (km)	Total length of waterways below 5 m AHD
# Privately owned end of system structures	Number of private floodgates* (includes floodgates with unknown tenure)
# Publicly owned end of system structures	Number of public floodgates*
# End of system structures within coastal wetlands	Total number of floodgates* located within Coastal Management SEPP coastal wetlands
# Publicly owned end of system structures within coastal wetlands	Number of public floodgates* located within Coastal Management SEPP coastal wetlands
Primary floodplain infrastructure (floodgate ID)	Floodgate* ID (or name, where relevant) of the most significant infrastructure, based on Council records where possible (see Appendix F for more information)
Elevations	
Invert of primary infrastructure (m AHD)	Invert level(s) of significant infrastructure (may be a range)
Average AASS elevation (m AHD)	Approximate elevation of AASS across catchment
Average PASS elevation (m AHD)	Approximate elevation of PASS across catchment
Median blackwater elevation (m AHD)	Median elevation from blackwater prioritisation analysis
Present day low water level (m AHD)	5^{th} percentile water level from present day estuary model
Near future low water level (m AHD)	5^{th} percentile water level from near future estuary model
Far future low water level (m AHD)	5^{th} percentile water level from far future estuary model
Proximity to sensitive receivers	
Oyster leases (km) Saltmarsh (km) Seagrass (km) Mangroves (km) Coastal Management SEPP coastal wetlands (km)	Distance (along the river channel) to sensitive receivers from any discharge point (may be within catchment)
Land use	
Total floodplain area (ha)	Total floodplain area below 5 m AHD excluding tidal waterways
Classified as conservation/minimal use (ha (%)) Classified as grazing (ha (%)) Classified as forestry (ha (%)) Classified as sugar cane (ha (%)) Classified as horticulture (ha (%)) Classified as other cropping (ha (%)) Classified as urban/industrial/services (ha (%)) Classified as marsh/wetland (ha (%)) Other (ha (%))	Area (percentage of floodplain) classified for various land uses below 5 m AHD
Land values	
Estimated total primary production value ($/year):	Total estimated production value of floodplain below 5 m AHD, based on ABS data from the region
Average land value above X m AHD ($/ha) Average land value below X m AHD ($/ha)	Average land value above/below the median blackwater elevation (X m AHD), based on NSW Valuer General data Rural properties only included, below 5 m AHD

* Major floodway control structures, such as sluice gates, have been included due to their significance.

8.2.3 Sea level rise vulnerability

Historic measured tidal records show that mean sea levels off the NSW coast are increasing (e.g. Glamore et al., 2016b; White et al., 2014). Climate scientists project that sea levels will continue to rise and that the rate of rise is likely to accelerate. Increased mean sea levels will have implications for the drainage of all NSW estuaries and floodplains, with reduced drainage efficiency resulting in higher floodplain inundation levels during flood events and increased inundation durations.

Acknowledging the potential impacts of sea level rise on each floodplain subcatchment informs potential management options. For each subcatchment, mapping on drainage vulnerability is presented for the present day (2020), near future (~2050), and far future (~2100) based on the results of hydrodynamic modelling of estuarine water levels. Water level statistics are based on 24 months of predicted tidal dynamic, and represent both wet and dry years. Mapping includes:

- **Floodgate vulnerability:** a vulnerability status (most, moderately or least vulnerable) of floodgates based on modelled downstream water levels. Vulnerability is based on water level statistics and floodgate geometry and provides an indication of a reduced drainage potential, summarised in Table 8-2. More information on this assessment can be found in Section 7.4, see Figure 7-2;
- **Floodplain vulnerability:** represented as downstream water level statistics (5th, 50th and 95th percentile) translated directly onto upstream floodplain topography. Note that this simplified 'bath tub' approach does not take into account floodgates, hydraulic losses, or dampening/amplification through floodplain drainage channels. The purpose of the floodplain vulnerability analysis is to identify areas likely to be directly impacted by higher estuarine water levels and reduced drainage, rather than areas that may be actively inundated by tidal waters due to sea level rise. The relevance of each of the water level statistics is:
    - **5th percentile water level** (water levels are below this 5% of the time, or around 1 hour a day) – this represents a low tide water level at a given location. Areas below the 5th percentile water level are typically permanently inundated and difficult to drain without additional mechanical assistance (i.e. pumping);
    - **50th percentile water level** (water levels are below this 50% of the time) – this is a median water level. Areas below the 50th percentile water level are generally difficult to drain efficiently; and
    - **95th percentile water level** (water levels are below this 95% of the time, or around 23 hrs a day) – this represents a high tide water level at a given location. Areas below the 95th percentile water level can be impacted by inefficient drainage, particularly after flood events and one-way floodgates are often installed to improve drainage of these areas.

Table 8-2: Assessment of floodgate vulnerability, based on downstream water levels (see Figure 7-2)

Colour	Classification	Criteria
Green	Least Vulnerable	Obvert > 95th percentile water level
Orange	Moderately Vulnerable	95th percentile water level > Obvert > 50th percentile water level
Red	Most Vulnerable	Obvert < 50th percentile water level

Note: Obvert is the inside top of the floodgate structure.

As part of the sea level rise vulnerability assessment, an infographic (example shown in Figure 8-1) has been provided to summarise the vulnerability of primary floodplain infrastructure. Note that this does not include all floodplain drainage infrastructure. Primary floodplain floodgates include infrastructure that plays a significant role in draining the floodplain catchment (e.g. drains a high order floodplain waterway and/or provides drainage for a significant area of the subcatchment).

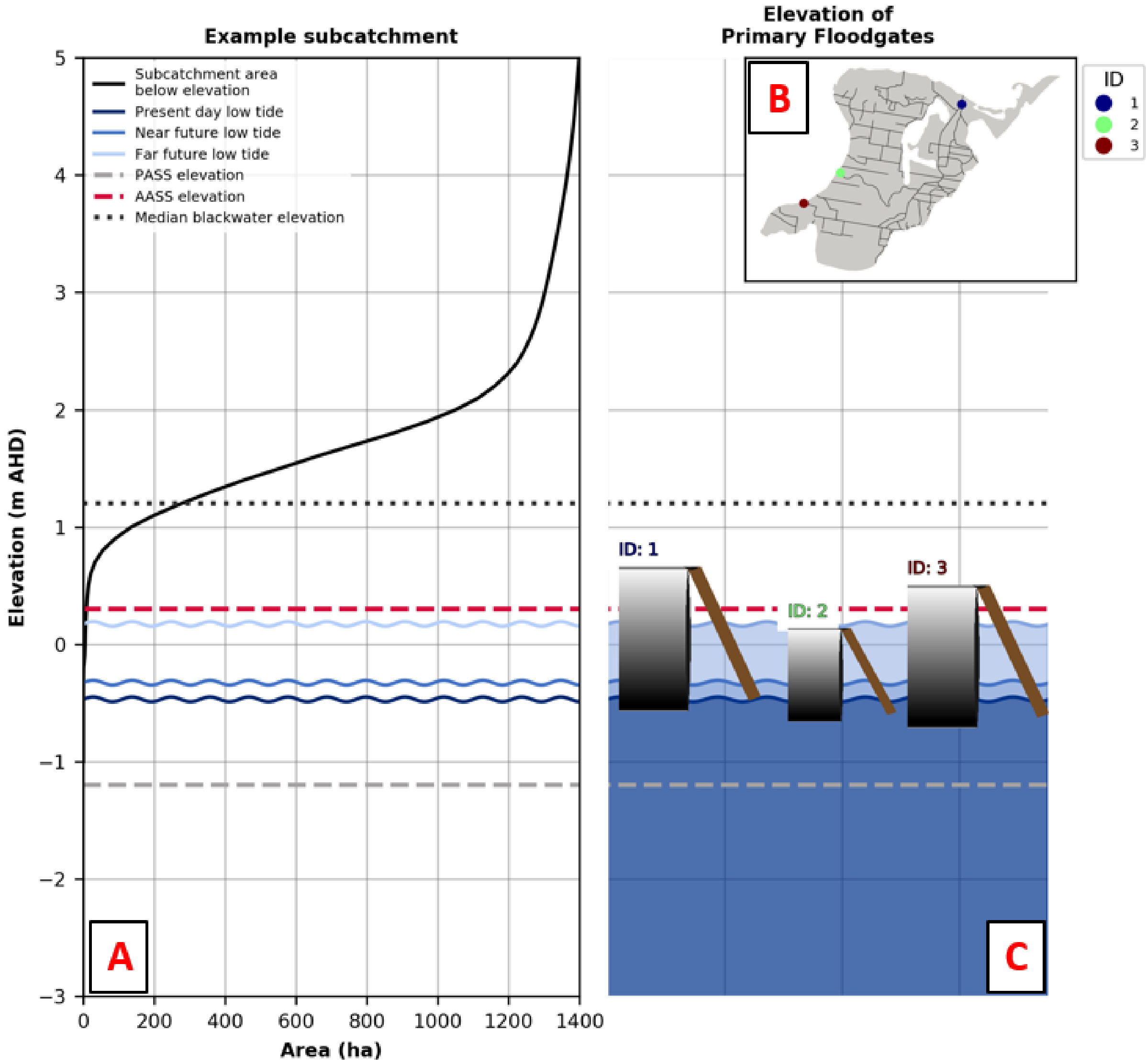

Figure 8-1: Reduced drainage vulnerability summary figure example

These figures are separated into three (3) panels (highlighted in red as "A", "B" and "C" in Figure 8-1), which include the following key information:

- **Panel A** summarises key elevations in the subcatchment, including:
  - The area of the subcatchment below 5 m AHD elevation;
  - The present day, near future and far future low tide levels (approximated by the 5th percentile water levels) modelled in the main river channel immediately downstream of the subcatchment;
  - Average subcatchment potential acid sulfate soil (PASS) and actual acid sulfate soils (AASS) elevation; and
  - The median blackwater elevation within that subcatchment.

- **Panel B** shows the location of the primary floodplain floodgates within the subcatchment; and
- **Panel C** which shows the elevation (invert and obvert) of each primary floodgate in the relevant subcatchment, relative to the present day, near future and far future low tide conditions. Each of these are labelled with the floodgate ID. These floodgates are only designed to show elevation of the floodgate, and do not reflect other information such as the number of culverts, the shape of the culvert or the height of the headwall.

This infographic, and the sea level rise vulnerability of infrastructure more generally, focuses on the impact of reduced drainage from increasing low tides. While this provides a good indication of reduced drainage potential, it is acknowledged that high tide levels also impact floodgate functionality. The tidal range (based on the 5^{th} and 95^{th} percentile modelled water levels) in the main river channel downstream of the subcatchment is provided on each figure for reference.

8.2.4 Costs and benefits of changes in land management

Changes to land management and remediation of coastal floodplains can have substantial environmental benefits including improved water quality, however there are also costs associated with capital works and changing land use. The cost of on-ground works, including factors such as compensation for changes in land use, and how to acquire funding are often key factors to whether environmental remediation is pursued. To provide land managers with an order of magnitude cost estimate associated with the proposed management options, a first-pass estimate of costs is provided for:

- Land acquisition – based on NSW Valuer General database;
- Upfront costs – based on unit values for restoration (e.g. drain infilling per km) presented in Section 10 of the Methods report (Rayner et al., 2023); and
- Lost productivity – estimate based on the area of land impacted by proposed remediation and average productivity for different land uses (present day) in the catchment.

More information on the cost estimates used in this study is presented in Section 10 of the Methods report (Rayner et al., 2023). Costs provided exclude additional investigation/studies, including (but not limited to) environmental assessments, landholder negotiations, flood studies, possible legal costs, and monitoring programs that may be required prior to implementation. Note, these studies/investigations will need to be considered during the planning phase for implementation of management options. They will need to consider requirements, such as Coastal Management SEPP coastal wetland mapping, which may trigger certain development pathways and/or additional expenses.

Similarly, understanding the relative benefits of the proposed management options is important when prioritising on-ground works. The effectiveness of the management options at reducing the impacts of ASS and blackwater and improving wetland habitat and aquatic connectivity, is assessed using a qualitative score (e.g. negligible, low, moderate, high). This is based on the type of remediation, experience and engineering judgement.

Note, the benefits of land management changes and/or remediation of wetland areas can include other aspects, including:

- Agricultural benefits – such as reduced weed/drain maintenance costs associated with saline flushing of drains, improved productivity through well designed drainage, better drought resilience or improved water quality;

- Reduced vulnerability of land uses to sea level rise – sea level rise may impact the productivity of existing land uses through reduced drainage and changes in salinity. Some proposed land management strategies may be better suited to adapt to changing environmental stressors; and
- Reduced maintenance costs - it is important to recognise continuing with current floodplain management is not without cost. Floodplain infrastructure throughout estuaries requires significant capital expenditure to maintain and replace damaged infrastructure or infrastructure that has come to the end of its functional life. Some changes to land management may reduce the need for on-going maintenance expenditure (e.g. floodgate removal).

There are also emerging markets that may allow landholders to pursue environmental remediation on private land in an economically viable way, as the value of biodiversity, conservation and carbon sequestration is realised. Examples of such pathways currently include Biodiversity Stewardship Agreements under the NSW Biodiversity Offset Scheme, or the Australian Government Clean Energy Regulator emissions reduction fund. It is anticipated that such pathways may become increasingly common in the future, which may encourage land use changes in some areas of coastal floodplains.

While the dollar value of benefits has not been provided for the recommended management options, a number of studies on remediation of ASS affected areas in NSW have shown that the benefits of remediation outweighed the costs. These include:

- A cost-benefit analysis of a large scale restoration of the Big Swamp floodplain on the Manning River was conservatively estimated to have a benefit to cost ratio of 7:1 (Harrison et al., 2019), despite not including the costs of acid discharges in the assessment;
- A cost-benefit analysis of modifications of the Bagotville Barrage to allow tidal flushing and implement works to reduce acid drainage from Tuckean Swamp showed the benefit-cost ratio would range from 1.1:1 to 5.7:1 (Read Sturgess and Associates, 1996) considering improvements to fishing only (variations considered a pessimistic scenario with higher than expected costs and lower than expected benefits, and an optimistic scenario with lower than expected costs and higher than expected benefits for improved fishing opportunities); and
- A cost-benefit analysis of remediating ASS affected areas on the Maria River floodplain was estimated to have a benefit-cost ratio of 1.1:1 to 3:1 (Aaso, 2000) (using a pessimistic and optimistic scenario), before considering any non-market ecosystem service benefits from remediation works.

More details on the benefits of changes in land management are provided in Section 10 of the Methods report (Rayner et al., 2023).

8.2.5 Waterway classification

Connected natural creeks and waterways provided important aquatic habitats prior to human intervention. Waterways below a 5 m AHD elevation have been categorised as part of this project into one of four categories to describe if a waterway is natural or artificial. Descriptions for each of the four categories (natural waterbody watercourse, artificial waterbody, watercourse and connector watercourse) are outlined in Appendix A. Details on how waterways have been categorised are provided in Chapter 12 of the Methods report (Rayner et al., 2023).

Waterway categorisations of all identified drainage lines are provided within the management options for each subcatchment. Where possible, management options focus on improving aquatic habitat in natural waterways (i.e. natural waterbody watercourses, watercourses or connector watercourses) which would have historically been connected. Drain modifications (e.g. infilling or reshaping) are typically only recommended in artificial waterbodies (or connector watercourses, if appropriate).

8.2.6 Subcatchment management areas

Subcatchments that are identified to have significantly higher ASS or blackwater factors have been further delineated into separate management areas based on geology and drainage. Where there is sufficient data, the ASS prioritisation methodology is repeated within the subcatchment to identify high priority management areas and indicate the potential sources of acid drainage within a subcatchment. Similarly, the median blackwater elevation is superimposed to the management areas to indicate areas associated with high blackwater risk. The reanalysis of management areas is provided in the management options in the Macleay River floodplain for:

- Collombatti-Clybucca subcatchment (ASS and blackwater);
- Frogmore/Austral Eden/Verges Swamp subcatchment (ASS and blackwater);
- Belmore Swamp subcatchment (blackwater only); and
- Kinchela Creek subcatchment (blackwater only).

8.3 Collombatti-Clybucca subcatchment

Acid priority rank:	**1**
Blackwater priority rank:	**3**
Infrastructure	
Approximate waterway length (km)	198
# Privately owned end of system structures	0
# Publicly owned end of system structures	4
# Jointly owned end of system structures	0
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (floodgate ID)	001G1 (Menarcobrinni Floodgates)
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-2.3
Average AASS elevation (m AHD)	0.6
Average PASS elevation (m AHD)	-0.6
Median blackwater elevation (m AHD)	1.1
Present day low water level (m AHD)	-0.2
Near future low water level (m AHD)	0.0
Far future low water level (m AHD)	0.4
Proximity to sensitive receivers	
Oyster leases (km)	5.8
Saltmarsh (km)	2.8
Seagrass (km)	8.6
Mangroves (km)	0.7
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	8,422
Classified as conservation and minimal use (ha (%))	2,792 (33%)
Classified as grazing (ha (%))	4,719 (56%)
Classified as forestry (ha (%))	90 (1%)
Classified as horticulture (ha (%))	20 (0.2%)
Classified as other cropping (ha (%))	49 (1%)
Classified as urban/industrial/services (ha (%))	239 (3%)
Classified as marsh/wetland (ha (%))	157 (2%)
Other (ha (%))	355 (4%)
Land values	
Estimated total primary production value ($/year)	$2,700,000
Average land value above 1.1 m AHD ($/ha)	$4,900
Average land value below 1.1 m AHD ($/ha)	$1,700

8.3.1 Site description and brief history of drainage

The Collombatti-Clybucca subcatchment is located to the north west of the Macleay River floodplain. A complex network of natural and artificial waterways drain across the subcatchment to its most downstream point at Clybucca Creek which flows into the Macleay Arm, and in turn to the Macleay River near its entrance to the ocean at South West Rocks, approximately 15 km downstream of the subcatchment (Rayner et al., 2020). There is a large headworks structure (001G1) known as the Menarcobrinni floodgates, located on Clybucca Creek at the downstream boundary of the subcatchment which acts as a barrier preventing tidal egress to the upstream floodplain (Figure 8-2).

Figure 8-2: Menarcobrinni floodgates (Rayner et al., 2020)

There are three significant natural waterways within the Collombatti-Clybucca subcatchment:

- Collombatti Creek;
- Clybucca Creek; and
- Johnsons Creek.

Of the three, Collombatti Creek is the largest and flows from west to east across the floodplain. There is a large low-lying area in the north-east of the floodplain which includes areas known as Mayes Swamp and Doughboy Swamp. It is here that the three (3) waterways meet before flowing to Clybucca Creek and discharge to the Macleay River estuary. Historically, Mayes Swamp and Doughboy Swamp contained extensive freshwater wetlands, however, in the last 150 years the area has been extensively drained for agricultural practices.

Drainage of the Collombatti-Clybucca subcatchment began in the 1880s with the construction of Doughboy Drain which passes through Mayes Swamp and Doughboy Swamp (Tulau, 2011).

Further drainage works occurred in the 1960s and 1970s as part of a flood mitigation scheme in response to extensive flooding across the Macleay River floodplain (Tulau and Naylor, 1999). Note, Tulau (2011) identified that despite the often misleading use of terminology, the 1950-70s ‘flood mitigation’ schemes were overwhelmingly swamp drainage schemes. These works included (PWD, 1978):

- Construction of Seven Oaks Drain;
- Construction of West Drain;
- Construction of East Drain;
- Construction of McAndrews Drain;
- Construction of Shackles Drain;
- Construction of the Menarcobrinni floodgates; and
- Excavation of Andersons Inlet.

For more information, a detailed history of the drainage across the Collombatti-Clybucca subcatchment is provided by Rayner et al. (2020). Across the Collombatti-Clybucca subcatchment maintenance of drainage infrastructure is split between private landholders, Kempsey Shire Council and Seven Oaks Drainage Union (Figure 8-3). Union and Council owned drains are maintained through methods such as weed spraying and clearing out of weeds, although this no longer occurs for East Drain (also referred to as Union Drain) (Rayner et al., 2020).

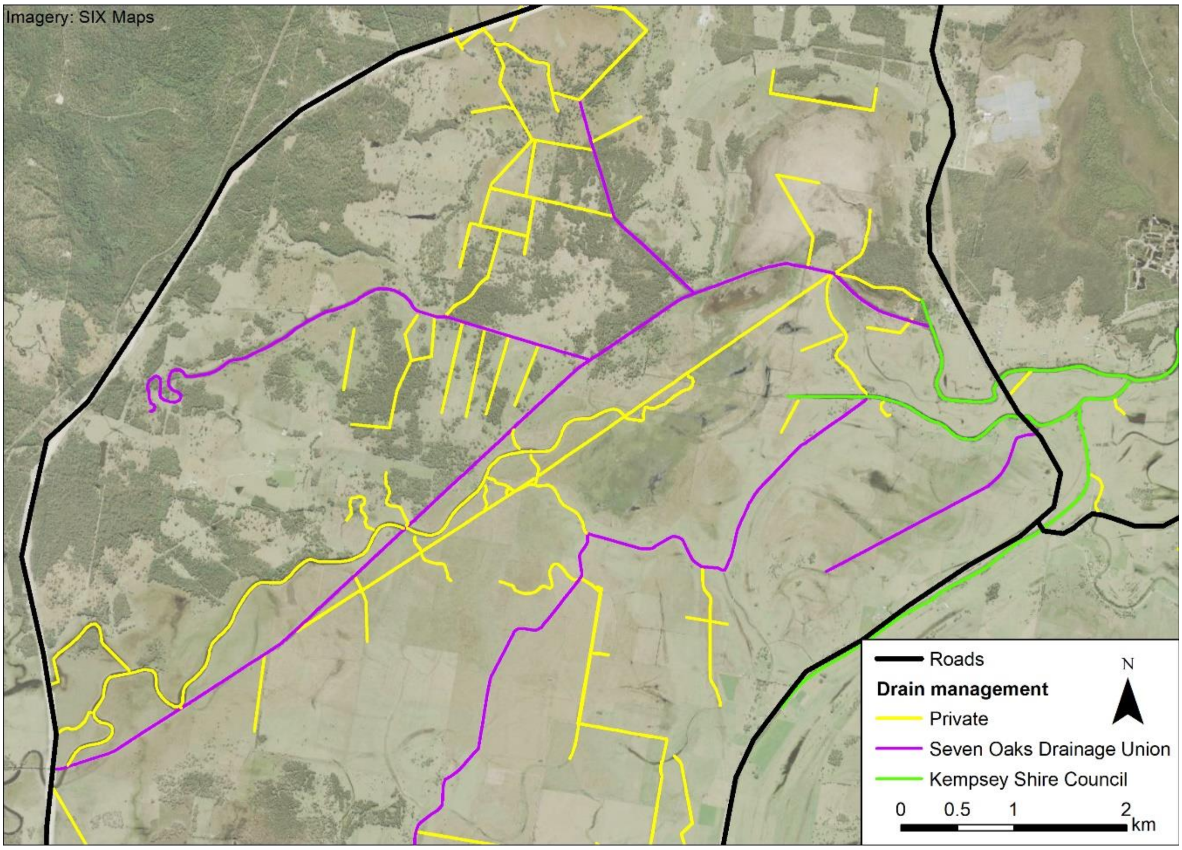

Figure 8-3: Collombatti-Clybucca subcatchment drainage management (Geolink, 2012; Rayner et al., 2020)

Land tenure across the Collombatti-Clybucca floodplain is split between private landholders, Crown lands and the NSW state government, specifically Transport for NSW (TfNSW, formerly NSW Roads and Maritime Services (RMS)). Transport for NSW has purchased a large area of land across the north-eastern area floodplain as part of the Oxley to Kempsey Pacific Highway upgrade project which includes low-lying areas within Mayes Swamp and Doughboy Swamp, that has been approved by the NSW Environment Protection Authority to fulfill biodiversity offset requirements (Glamore and Rayner, 2017; Rayner and Glamore, 2017; Rayner et al., 2020). Details on land and end of system structure tenure for the Collombatti-Clybucca subcatchment is shown in Figure 8-4.

The Collombatti-Clybucca subcatchment is the largest on the Macleay River floodplain with a total area of approximately 8,500 hectares. Almost 200 km of artificial and natural waterways span the subcatchments floodplain. The Collombatti-Clybucca subcatchment drainage network is shown in Figure 8-5 alongside elevation information.

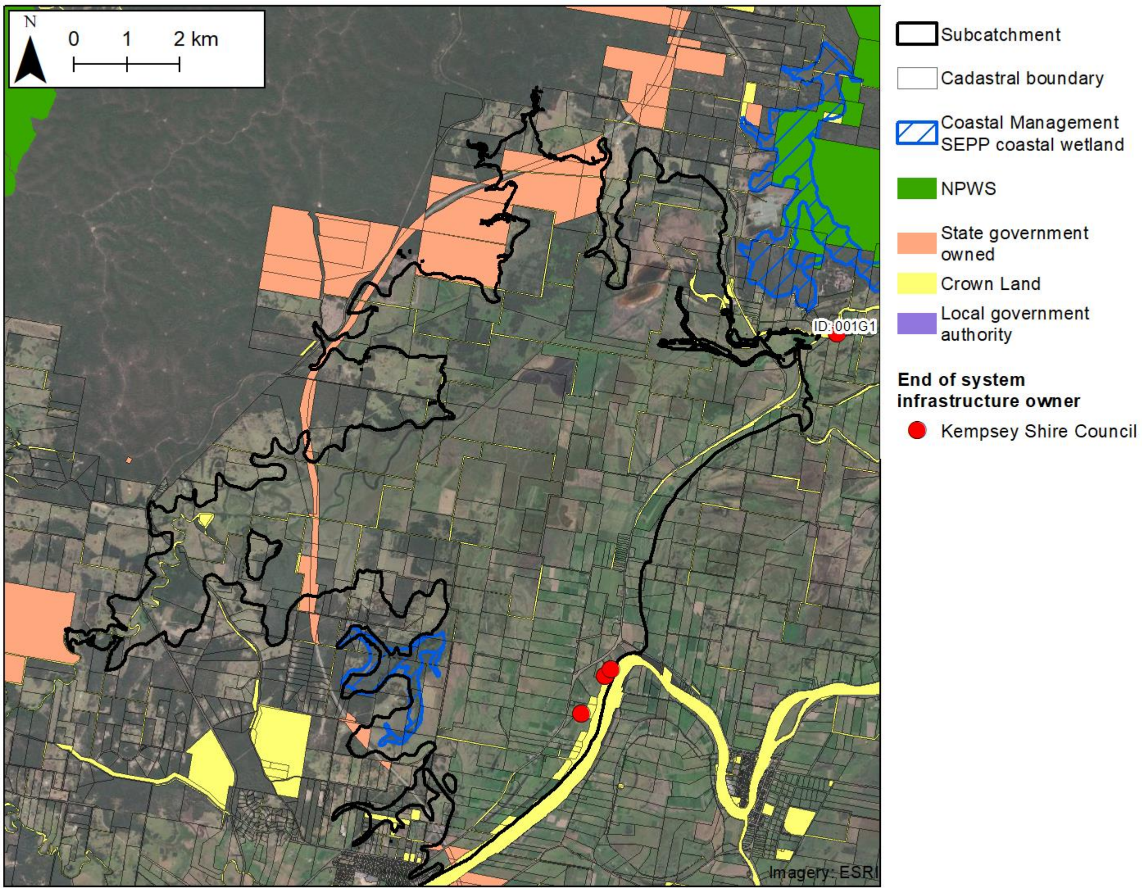

Figure 8-4: Collombatti-Clybucca subcatchment land and end of system infrastructure tenure

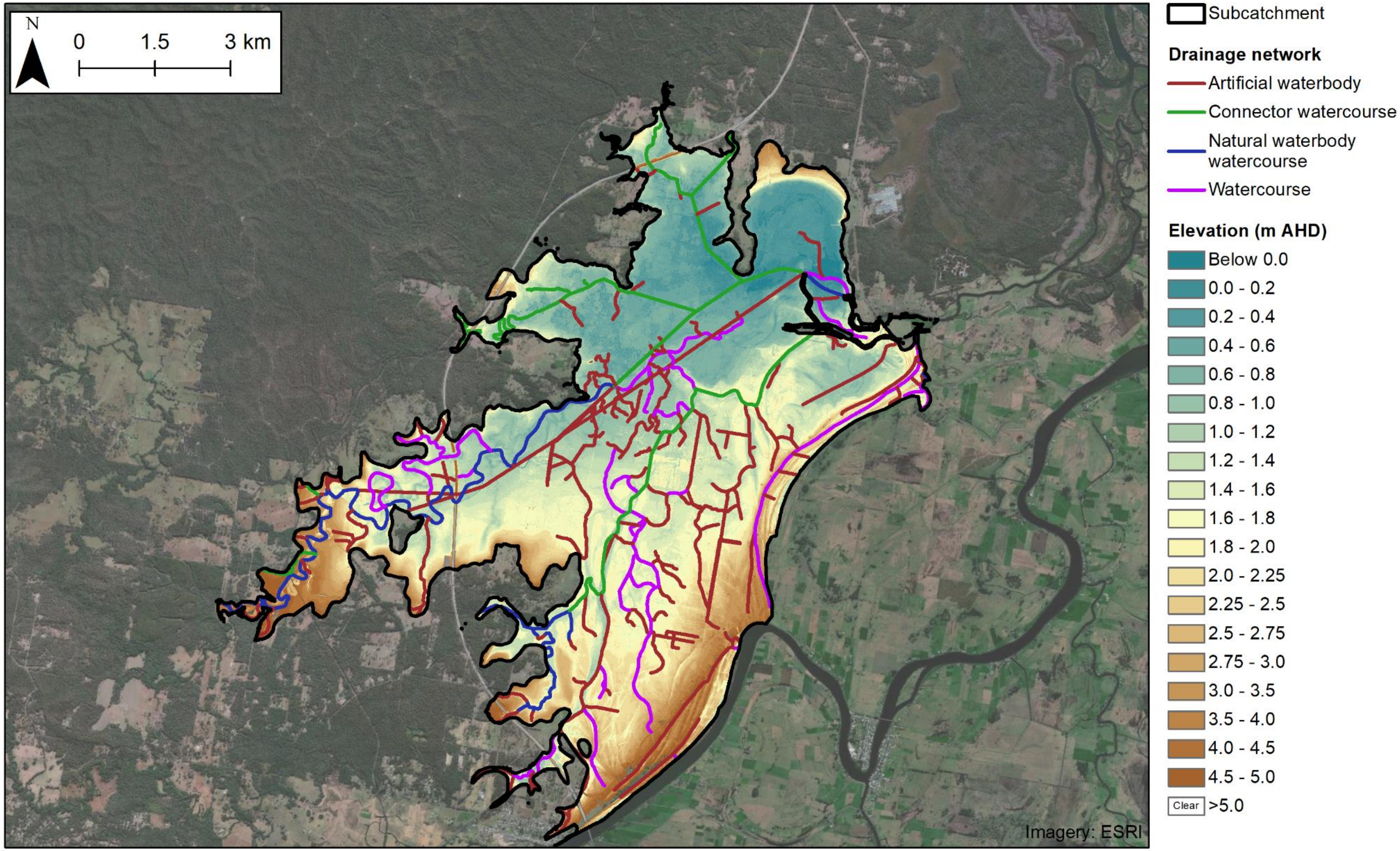

Figure 8-5: Collombatti-Clybucca subcatchment elevation and drainage network

8.3.2 History of remediation

The Collombatti-Clybucca subcatchment has historically been a known source of poor water quality within the Macleay River estuary as a result of acid sulfate soil runoff and blackwater generation (Engenuity Design, 2003; Kempsey Shire Council, 2004a; NSW DPI, 2020; Rayner et al., 2020; Tulau and Naylor, 1999). This has resulted in numerous investigations that have been completed with the goal of improving water quality (Andrews et al., 2005; Bush et al., 2006; Chartres et al., 2005; Cheeseman et al., 2004; Edeson et al., 2004; Engenuity Design, 2003; Glamore and Rayner, 2017; Kempsey Shire Council, 2004a; McLennan et al., 2005; Rayner and Glamore, 2017; Rayner et al., 2020; Wetland Care Australia, 2010). Early records of remediation efforts include the construction of bunds along drainage lines and sills within drains on the south of Mayes Swamp, with the aim to provide wet pasture during dry times and reduce the export of acid (Tulau and Naylor, 1999). Other works that were completed in the 1990s are summarised by Rayner et al. (2020) and include:

- Installation of a weir known as "Yerbury's Sill" on the downstream of Seven Oaks Drain;
- Installation of four (4) additional low-level earthen sills/weirs on upstream sections of Seven Oaks Drain;
- Construction of drop boards on levee cut out points at Mayes Swamp;
- Installation of two (2) sluice gates on the Menarcobrinni floodgates (which have since been removed);
- Remediation of acid scalds; and
- Enhancing wetland values.

In 1998, the NSW Department of Planning, Industry and Environment (DPIE, formerly the Department of Land and Water Conservation) mapped areas in the Collombatti-Clybucca subcatchment as an acid sulfate soil hotspot which resulted in an increase in investment to reduce the impacts of acid sulfate soils and the beginning of the Collombatti-Clybucca Acid Sulfate Soil Hotspot Program (Edeson et al., 2004; Kempsey Shire Council, 2004a). During the hotspot program additional works were completed to reduce the impact of acid sulfate soils including (Kempsey Shire Council, 2004a):

- Fencing of two acid scalds (Yerbury's Scald to the south of Seven Oaks Drain and Latham's Scald to the east of East Drain);
- Revegetation of acid scalds;
- Liming of acid scalds; and
- Installation of one (1) weir on East Drain and two (2) weirs on West Drain.

Since the acid sulfate soil hotspot works were completed, numerous studies have been conducted to further improve water quality within the Collombatti-Clybucca subcatchment. A summary of these is outlined by Rayner et al. (2020) and includes:

- Cheeseman et al. (2004) – A case study testing the effectiveness of the NSW Environmental Services Scheme in combatting environmental degradation due to ASS;
- Edeson et al. (2004) – A study into the effects of freshwater ponding on ASS;
- Andrews et al. (2005) – A study of surface vegetation impacts on ASS;
- Chartres et al. (2005) – A study investigating how sub-surface shell material effects ASS;
- McLennan et al. (2005) – A study assessing the variability of surface water chemistry in relation to vegetation across Mayes Swamp;
- Bush et al. (2006) – A study of the historical datasets to determine the effectiveness of monitoring at ASS hotspots;

- Wetland Care Australia (2010) – A concept plan for promoting the best management of the Clybucca wetlands;
- Glamore and Rayner (2017) – A feasibility study looking at the feasibility and constraints with regards to the remediation of the Clybucca wetlands;
- Rayner and Glamore (2017) – A preliminary draft lot-by-lot management plan developed for low-lying property on the Clybucca floodplain; and
- Rayner et al. (2020) – Detailed site investigation and numerical modelling of various management options.

In addition to these studies, Kempsey Shire Council developed a drainage management plan for Doughboy Drain and a weir modification management plan for West Drain. The drainage management plan for Doughboy Drain included drain reshaping and management of drop boards on culverts within the drain (Kempsey Shire Council, 2005a). The management plan for the weir on West Drain included installing a culvert under the weir with a drop board to actively manage flow during flooding (Kempsey Shire Council, 2006i). Field investigations to inspect these structures did not indicate any active management of the drop board structures.

Generally, remediation efforts across the Collombatti-Clybucca subcatchment have been at a farm/paddock scale and while small improvements have reduced the impacts of acid sulfate soils, poor water quality across the subcatchment still persists (Bush et al., 2006; Kempsey Shire Council, 2004a). In recent years there has been a shift in the management approach taken for remediating the water quality issues within the Collombatti-Clybucca subcatchment. The acquisition of large areas of some of the lowest-lying and worst acid sulfate soil affected land by Transport for NSW, has meant that large scale remediation and restoration of wetland areas can be considered across hydrologically connected areas. This has resulted in detailed investigations conducted by Rayner et al. (2020) to develop options to improve water quality within the Collombatti-Clybucca subcatchment on a large scale.

Initial investigations were completed by Glamore and Rayner (2017) to assess the feasibility of large scale remediation of the Collombatti-Clybucca subcatchment. Findings of the study included recommendations to investigate the potential for introduction of tidal water to the lowest-lying floodplain areas to provide the maximum environmental outcomes. Three (3) additional land acquisition areas were recommended that would assist in achieving improved environmental outcomes across the floodplain. This has since resulted in an additional purchase of land within priority Area 1 by Transport for NSW.

Recently, a detailed study was completed by Rayner et al. (2020) which included the development of six (6) management options for the Collombatti-Clybucca subcatchment (Table 8-3). As part of the study, Rayner et al. (2020) completed detailed numerical modelling of the management options to determine their viability. Management options were designed to have a staged implementation with option 1 being implemented immediately, and options 2 or 3 in the near future. Long-term management options (4 to 6) are dependent upon the future tenure of the Transport for NSW land, the maintenance requirements for the Menarcobrinni floodgates and the future of the floodplain in the context of a changing climate.

Table 8-3: Potential management options for the Collombatti-Clybucca subcatchment outlined by Rayner et al. (2020)

Option number	Management option	Planning horizon	Kilometres of drain remediated	Drain remediation strategy	Wetland Area (ha)	Wetland type
1	Land management only	Immediate	None	-	None	-
2	Freshwater on low-lying wetland areas	Short term	12.5	Fresh	285	Fresh
3	Freshwater on low-lying wetland areas with extension of McAndrews Drain to Seven Oaks Drain	Short term	12.5	Fresh	285	Fresh
4a	Modified floodgates to allow controlled in-drain tidal flushing	Short term	13.0	Tidal	None	Mixed Tidal/fresh
4b	Modified floodgates to allow controlled overland tidal flushing	Long-term	22.5	Tidal	240	Mixed Tidal/fresh
5a	Decentralise floodgates to multiple locations with overland inundation	Long-term	16.0	Tidal	115	Mixed Tidal/fresh
5b	Decentralise floodgates to multiple locations – in-drain flow only	Long-term	6.6	Tidal	None	Mixed Tidal/fresh
6	Fully open floodgates	Long-term	51.5	Tidal	725	Tidal

Option 2 was identified as the preferred option for further investigation. This includes the installation of a weir on Clybucca Creek at the southern end of Mayes Swamp, designed to restore natural wetting and drying of low-lying historical wetland areas, as well as reduce the export of acid sulfate soils by raising the water table.

A summary of the existing remediation actions that have taken place across the Collombatti-Clybucca subcatchment is provided in Figure 8-6.

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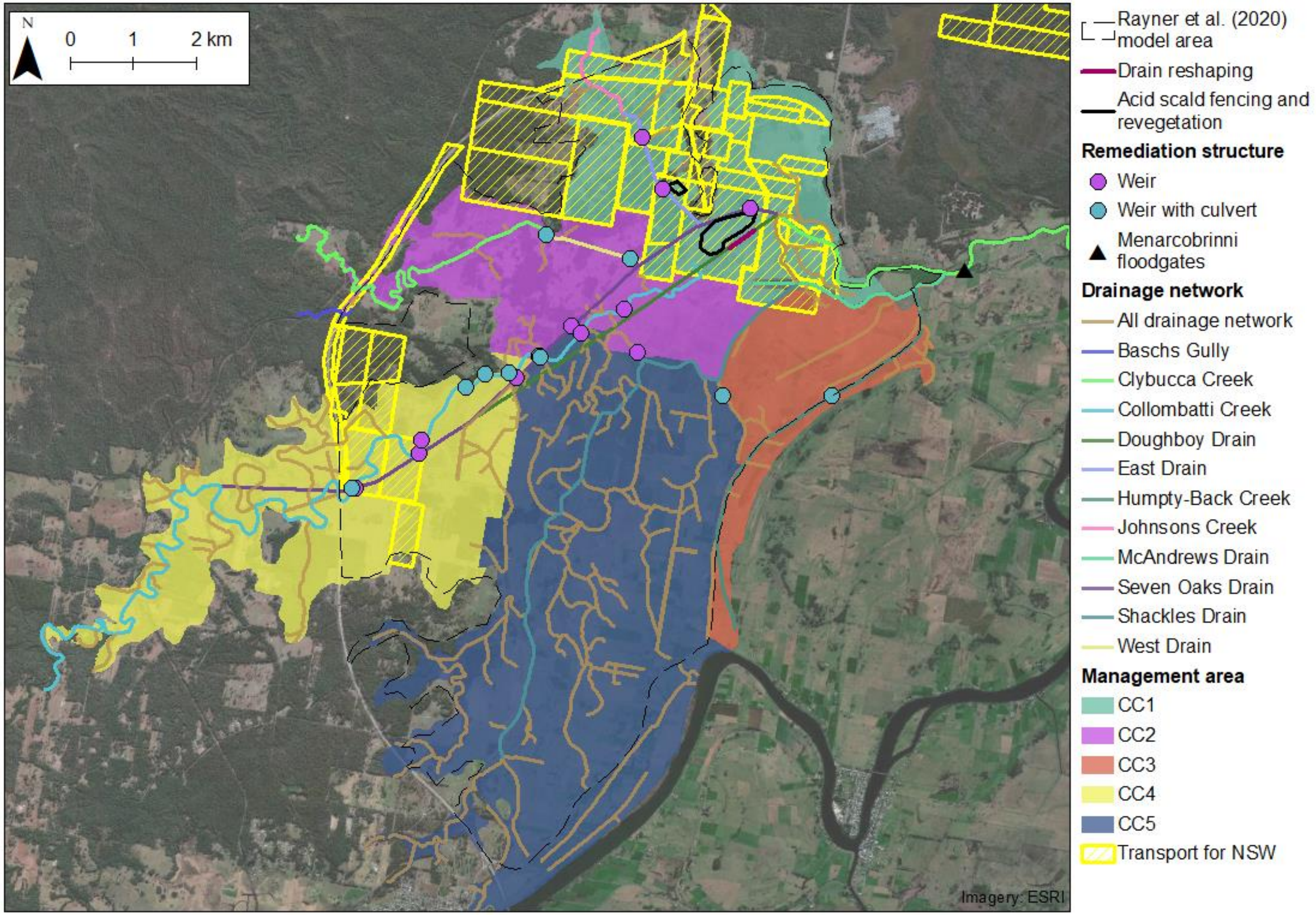

Figure 8-6: The Collombatti-Clybucca subcatchment including previous remediation actions

8.3.3 Prioritisation of management areas in the Collombatti-Clybucca subcatchment

The Collombatti-Clybucca subcatchment ranked first in the acid prioritisation, and third in the blackwater prioritisation. The subcatchment has been further delineated into five (5) smaller management areas (referred to as CC1 to CC5, shown in Figure 8-7) to provide additional information on the sources of acid and blackwater. The areas have been delineated based on land tenure, data availability, elevation, changes in soil acidity, and drainage units.

The management areas have been prioritised based on acid generation potential using the method described in Section 4. The results of the acid prioritisation for the management areas of the Collombatti-Clybucca subcatchment are shown in Figure 8-7 and Table 8-4. The largest source of acid risk was found in the lowest-lying floodplain management areas CC1 and CC2. Additional site investigation (e.g. soil profiling) would further improve the delineation of acid risk within the subcatchment.

Figure 8-8 shows the management areas for the Collombatti-Clybucca subcatchment below the median elevation for blackwater generation (+1.1 m AHD). As elevation is a primary driver of the production of blackwater, the areas below this level typically contribute the most to the risk of large scale deoxygenation (although this risk can be mitigated through changing vegetation and land uses). The majority of blackwater risk in the Collombatti-Clybucca subcatchment can be found in management areas CC1 and CC2.

Based on the findings from the management area prioritisation shown in Figure 8-7 and Figure 8-8 it is suggested that improvements in water quality in the Collombatti-Clybucca subcatchment focus on management areas CC1, CC2 and CC4.

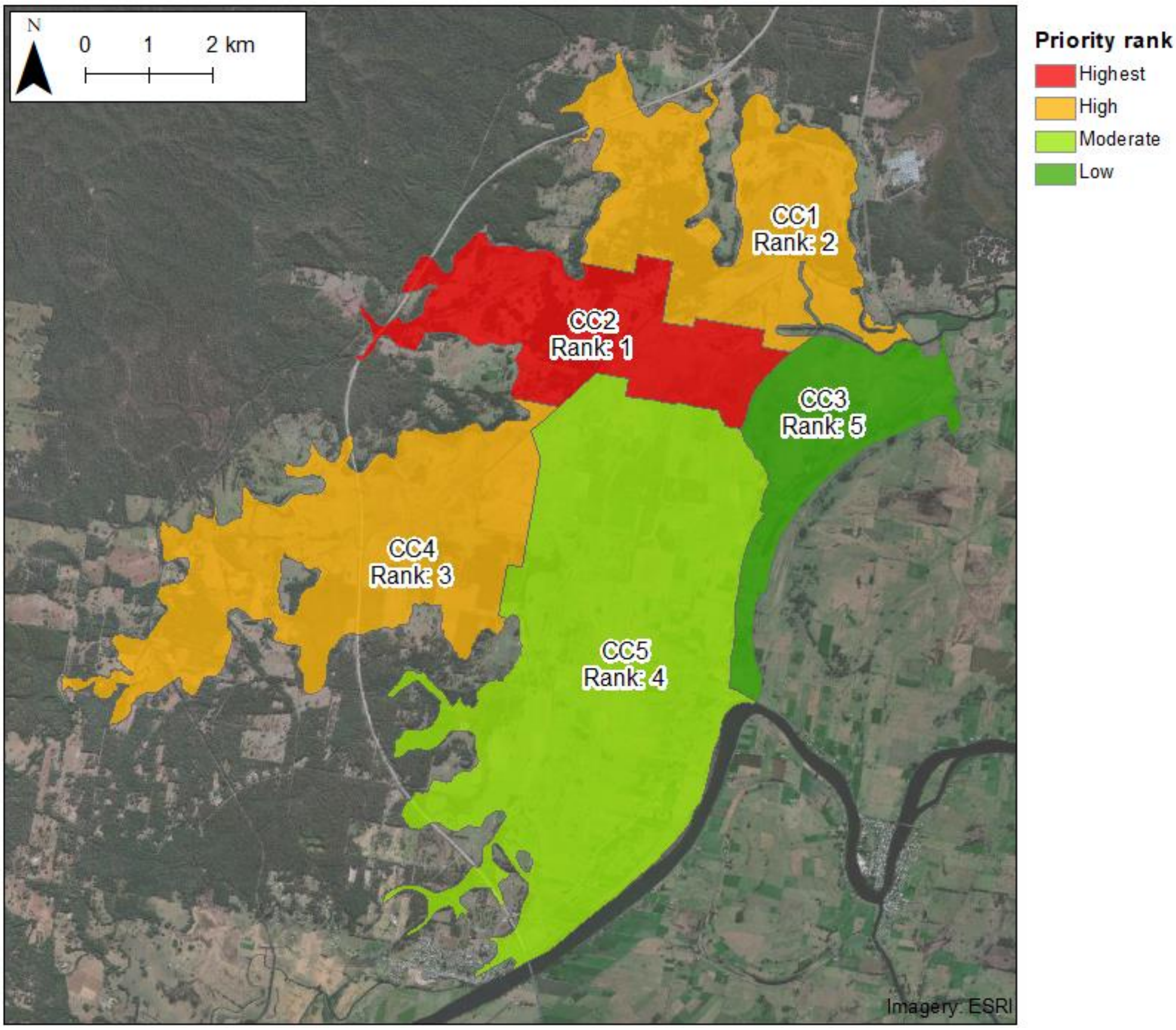

Figure 8-7: Collombatti-Clybucca subcatchment management areas acid prioritisation

Table 8-4: Management area acid prioritisation of Collombatti-Clybucca subcatchment

Management area	Groundwater factor	Surface water factor	Final acid factor	Final rank
CC2	246	578	142,540	1
CC1	182	414	75,504	2
CC4	122	603	73,509	3
CC5	208	165	34,346	4
CC3	100	189	18,899	5

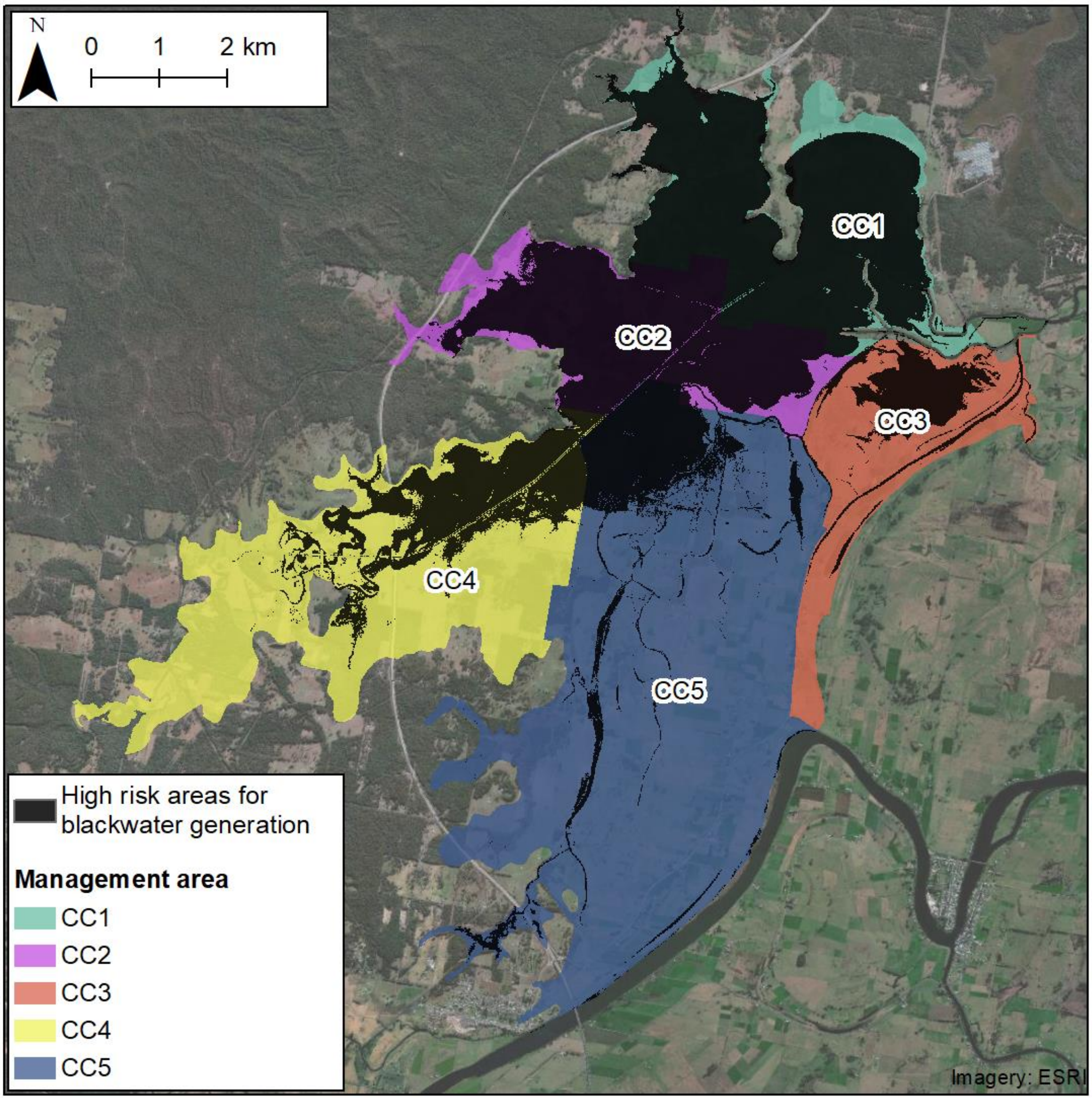

Figure 8-8: Blackwater contribution for management areas in the Collombatti-Clybucca subcatchment (median blackwater level +1.1 m AHD)

8.3.4 Floodplain drainage – sea level rise vulnerability

The sea level rise vulnerability assessment of the Collombatti-Clybucca subcatchment is summarised in Figure 8-10. In present day conditions, the lowest-lying floodplain areas are impacted by reduced drainage. Areas within Mayes Swamp and Doughboy Swamp are situated at, or below mean sea level (0 m AHD) and are the most severely impacted. There is limited change in drainage vulnerability based on the near future sea level rise modelling, however, predictions of far future sea level rise indicates large areas of the floodplain will be situated below the future approximate mean tide water level (i.e. at medium risk of reduced drainage), and the lowest areas in Mayes Swamp and Doughboy Swamp will be below the approximate low tide water level (i.e. at high risk to reduced drainage).

Primary floodgates and key floodplain elevations have been compared to the elevation of the Menarcobrinni floodgates (001G1) and are shown in Figure 8-11. Under present day conditions the Menarcobrinni floodgates (001G1) are classified as moderately vulnerable meaning their obvert level is below the approximate high tide water level. This remains the same in the near future modelling scenario. In the far future scenario, the floodgates are classified as most vulnerable with an obvert level below the approximate mean tide water level.

Note, Rayner et al. (2020) also completed investigations to determine the extent of reduced drainage across the Collombatti-Clybucca subcatchment as the result of sea level rise induced by climate change. Their modelling indicated that in the far future sea level rise scenario, the average inundation depth across the floodplain will increase by 0.3 m in key areas due to reduced drainage following a two (2) exceedance per year (2EY) event (6 month event) (Figure 8-9).

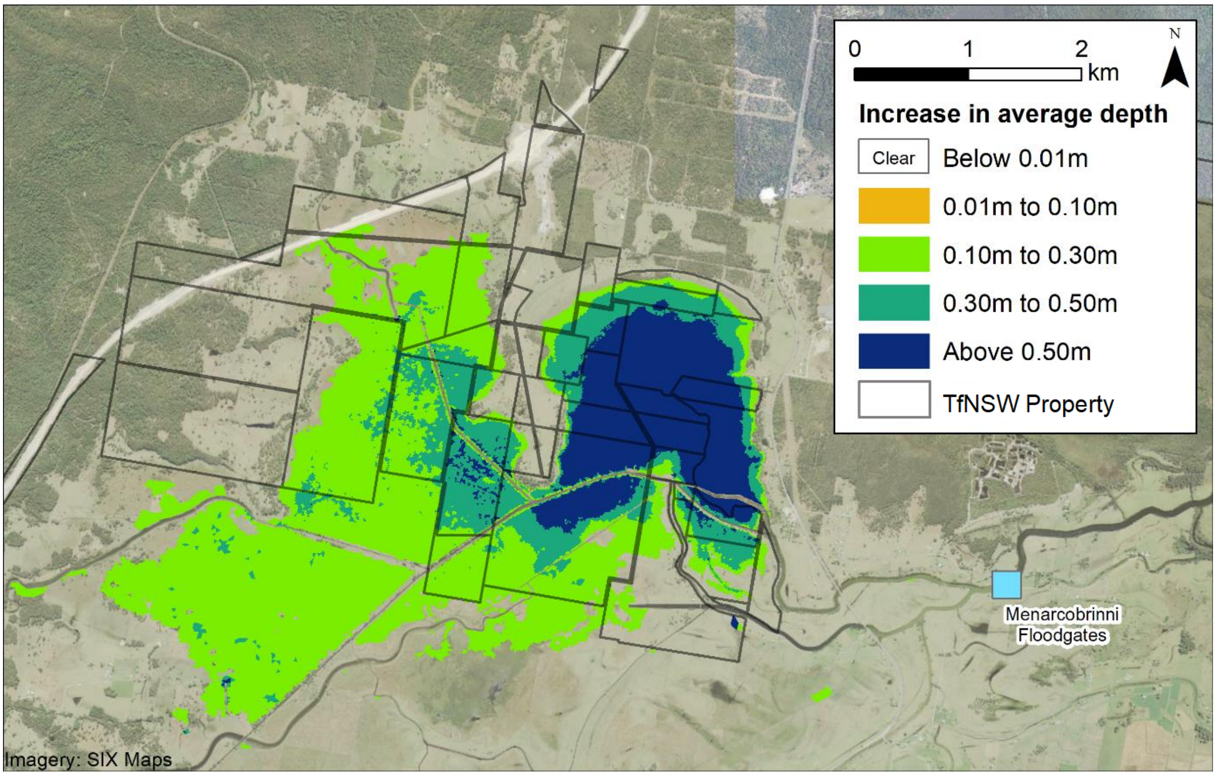

Figure 8-9: Numerical modelling completed by Rayner et al. (2020) showing the average increase in depth due to reduced drainage in the far future following a 2EY event

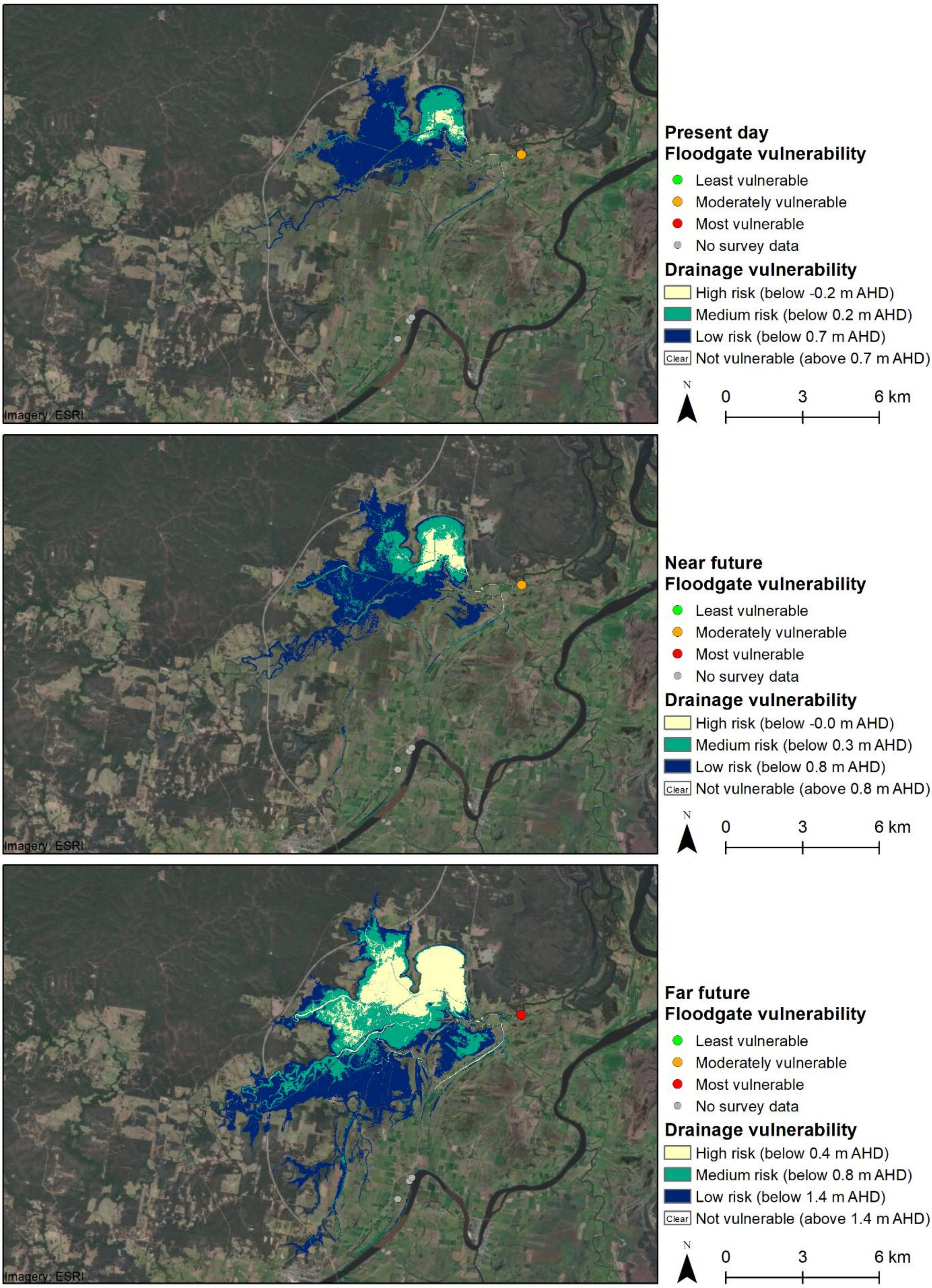

Figure 8-10: Sea level rise drainage vulnerability – Collombatti-Clybucca subcatchment

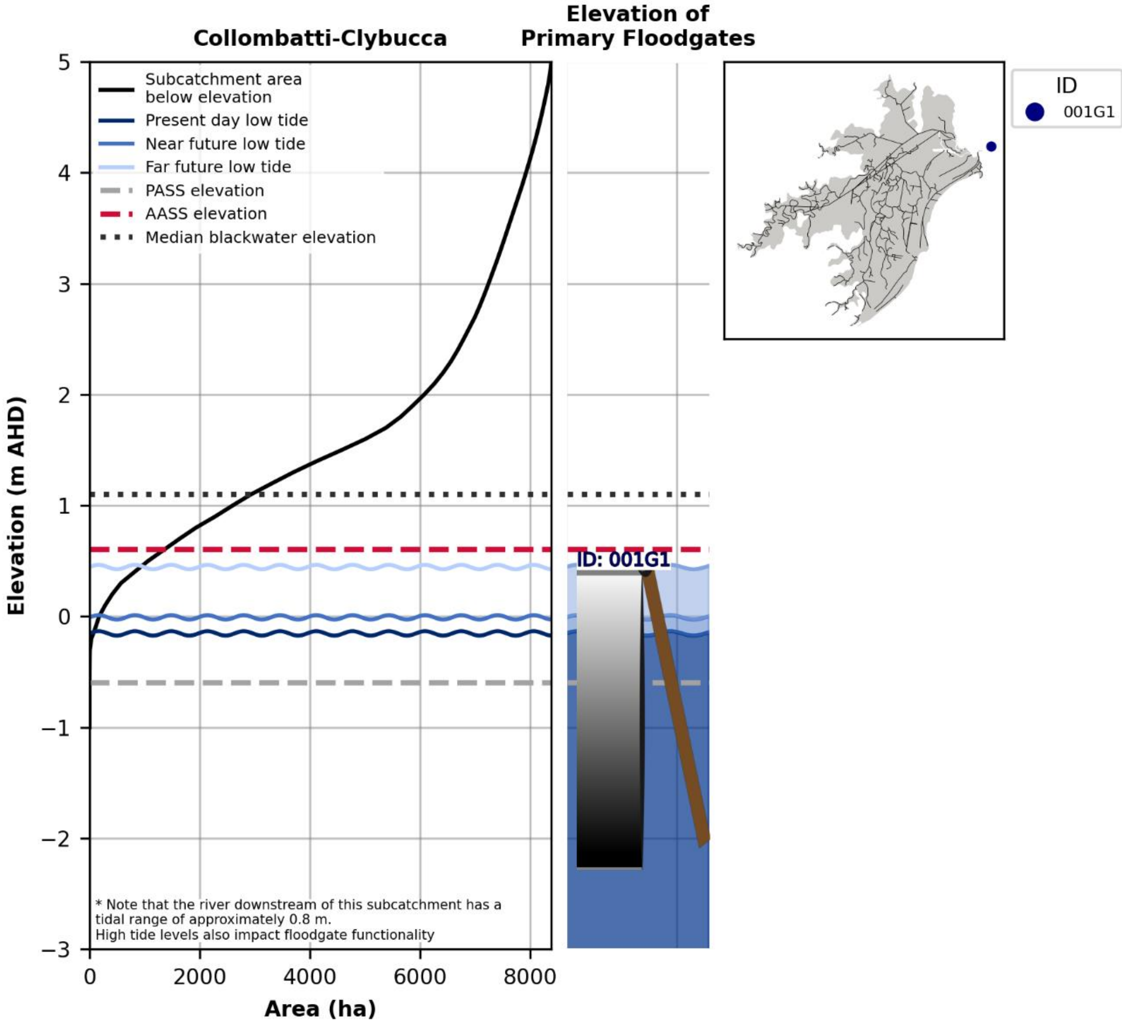

Figure 8-11: Primary floodgates and key floodplain elevations – Collombatti-Clybucca subcatchment

8.3.5 Management options

Management options for short and long-term planning horizons for the Collombatti-Clybucca subcatchment include:

- Short-term: Restore natural wetting and drying across low-lying wetlands by modifying drainage and installing weirs; and
- Long-term: Introduction of tidal water to the subcatchment waterways through modification of the Menarcobrinni floodgates.

Note that these options align with management options investigated by Rayner et al. (2020) who have conducted a detailed and thorough assessment of potential Collombatti-Clybucca subcatchment management options. Rayner et al. (2020) also included an assessment of the qualitative cost and benefit appraisals of multiple management options.

Short-term management options

Short term strategies for the Collombatti-Clybucca floodplain should consider works to restore the natural wetting and drying to the low-lying floodplain areas, specifically focussing on Transport for NSW land which is located within management area CC1. Works required for this include installing low-level weirs on Clybucca Creek and the left bank of McAndrews Drain, installing a low-level weir on East Drain immediately upstream of its confluence with Seven Oaks Drain and removing levee banks along downstream sections of Seven Oaks Drain. These modifications to the drainage network are outlined in Figure 8-12.

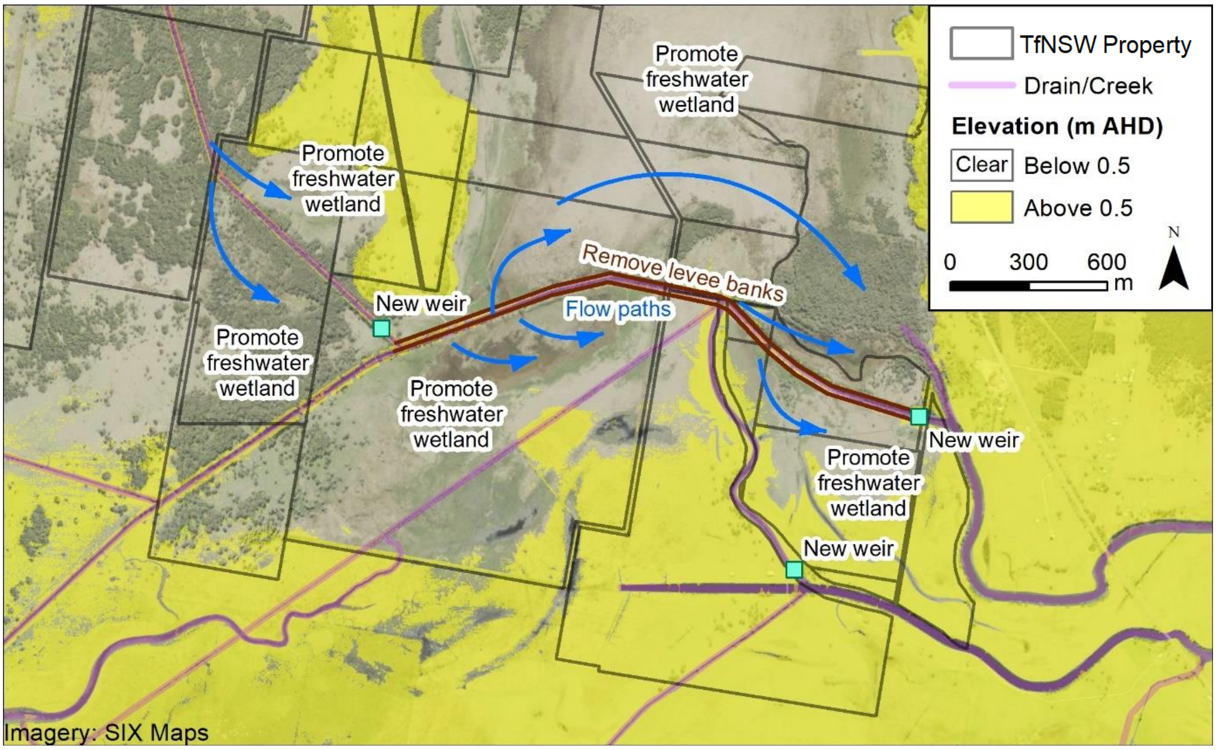

Figure 8-12: Works required to restore natural wetting and drying in management area CC1 (Rayner et al., 2020)

These modifications will have two outcomes:

1. An increased water table within the drainage network and surrounding land; and
2. An increase in wetland extent in key low-lying floodplain areas.

An increased water table will primarily influence management areas CC1 and CC2 with management area CC4 receiving the benefits of this outcome to a lesser degree. An increase in wetland extent will primarily occur within management area CC1. Benefits of this option, as outlined by Rayner et al. (2020), include:

- Reduced acidic runoff;
- Minimise potential for further oxidisation of acid sulfate soils;
- Containment of iron, aluminium and other metals by reducing their transport; and
- Increase in water tolerant vegetation in wetland areas which will reduce the risk of blackwater.

Existing weir structures constructed on upstream sections of Seven Oaks Drain and Collombatti Creek were observed and inspected by Rayner et al. (2023) within management area CC4. These structures should continue to be maintained.

The existing land use within management areas CC3 and CC5 will be sustainable in the short-term due to the generally higher elevation and lower acid risk when compared to the rest of the subcatchment. To improve water quality within these areas consideration should be given to introduce wet pasture management practices in low-lying areas to reduce the impacts of blackwater. This could be supported with strategic construction of paddock water retention structures which would also assist in raising the groundwater table and reducing acid export.

As recommended by Rayner et al. (2020), land management practices which reduce the impacts of acid sulfate soils and blackwater, as well as improving wetland and habitat values, could be implemented immediately across the entire Collombatti-Clybucca subcatchment. Examples of works that could be completed include:

- Fencing to exclude stock from remediation areas;
- Pest and weed management;
- Wet pasture management;
- Fire risk management;
- Access control;
- Native bush regeneration; and
- Acid scald remediation.

Long-term management options

Rayner et al. (2020) noted that the long term management of the Collombatti-Clybucca subcatchment is dependent upon a number of management decisions including:

- Future land acquisitions by state authorities;
- Long-term tenure of Transport for NSW land;
- Long-term maintenance of the Menarcobrinni floodgates; and
- Stakeholder consultation.

These decisions will also need to consider the impacts of climate change that will have significant influence upon management across the subcatchment. Sea level rise will likely reduce the drainage potential across the floodplain and result in the current land use in low-lying sections of the floodplain becoming untenable.

Management options modelled by Rayner et al. (2020) found that the highest benefit for water quality will be achieved with:

- Controlled tidal flushing through modification to the Menarcobrinni floodgates; followed by
- Large scale restoration of wetland habitats.

The strategy for long-term implementation of these management options will need to assess the long-term ownership of land acquired by Transport for NSW. An ideal outcome for the site would be long term management as a conservation area (National Park or similar). Landholders who own low-lying land, particularly within Mayes Swamp and Doughboy Swamp, should be consulted regarding land management practices to improve water quality and biodiversity. Mechanisms for this could include:

- Land use change (via acquisition);
- Participation in a biodiversity offset scheme; or
- Other programs designed to compensate private landholders.

In addition to the land management issues, the ongoing maintenance of the Menarcobrinni floodgates will need to be considered in consultation with its owner (Kempsey Shire Council) and other major stakeholders such as Seven Oaks Drainage Union. The current condition of the floodgates is such that, in the long-term, significant maintenance works will need to be completed (Kempsey Shire Council, 2018). Strategic maintenance and improvements to the floodgate infrastructure will allow for the roadmap presented by Rayner et al. (2020) to be implemented.

Rayner et al. (2020) investigated a range of longer-term management options (Table 8-3) including controlled and uncontrolled tidal flushing. These options target daily flushing of waterways, with mechanisms to establish intertidal habitats on low-lying areas. A full assessment of the impacts and benefits of each option, in conjunction with land use planning and consultation on a subcatchment scale, would be required to determine the optimal pathway for long-term management.

Management recommendations outlined by Rayner et al. (2020) have focused on actions that can be completed within the low-lying areas of Mayes Swamp and Doughboy Swamp (management area CC1) due to the ownership of this land by the NSW Government. Management areas CC3, CC4 and CC5 are all located on higher elevated land, however, there are still actions that can be implemented to improve water quality in these areas in the long term.

Within management area CC4, strategic management of weirs and drop board structures for environmental outcomes should continue. As sea level rise impacts drainage there is potential for low-lying areas to be used for wet pasture management. Alternatively, migration of downstream freshwater wetlands further upstream to this management area could be considered.

The north western section of management areas CC3 and the centre of management area CC5 will be impacted in the long-term by reduced drainage. In these areas wet pasture management should be implemented to reduce the impact of blackwater. Furthermore shallowing and widening of key drains in this area (such as Shackles Drain) and infilling of unnecessary drains will provide further improvements in water quality.

A summary of the potential management options for the Collombatti-Clybucca subcatchment including indicative costs is provided in Table 8-5.

Table 8-5: Summary of management options for Collombatti-Clybucca

Timeframe	Strategy	Target management area(s)	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing per year)	Indicative cost (lost productivity per year)	Effectiveness at improving:		
							Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Install weirs	CC1, CC2	None	$400,000	$25,000	Minimal	None	High	Moderate
Short-term	Remove levees	CC1, CC2	None	$100,000	$5,000	None	None	Moderate	Moderate
Short-term	Wet pasture management	CC3, CC4, CC5	None	$60,000	Minimal	Minimal	None	Low	Moderate
Long term	Tidal flushing	CC1, CC2, CC3	$200,000	$500,000	$5,000	$50,000	Very high	Moderate	Moderate
Long term	Drain reshaping/infilling	CC3, CC5	None	$100,000	None	Minimal	None	Moderate	Low
Long-term	Restoration of wetlands	CC1	$350,000	$750,000	Minimal	$80,000	Very High	High	High

*Costs exclude additional investigation/studies, including; REF, EIS, flood studies, and monitoring programs that may be required prior to implementation.

8.4 Frogmore/Austral Eden/Verges Swamp subcatchment

Acid priority rank:	**2**
Blackwater priority rank:	**4**
Infrastructure	
Approximate waterway length (km)	102
# Privately owned end of system structures	0
# Publicly owned end of system structures	13
# Jointly owned end of system structures	0
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (floodgate ID)	014G1, 015G1 (Union Drain floodgates), 016G1, 031G1, 082G1
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-1.8 to -0.2
Average AASS elevation (m AHD)	0.4
Average PASS elevation (m AHD)	-1.0
Median blackwater elevation (m AHD)	1.2
Present day low water level (m AHD)	-0.2
Near future low water level (m AHD)	0.0
Far future low water level (m AHD)	0.5
Proximity to sensitive receivers	
Oyster leases (km)	16.7
Saltmarsh (km)	13.7
Seagrass (km)	17.6
Mangroves (km)	11.4
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	5,550
Classified as conservation and minimal use (ha (%))	235 (4%)
Classified as grazing (ha (%))	4,100 (74%)
Classified as forestry (ha (%))	0 (0%)
Classified as horticulture (ha (%))	4 (0.1%)
Classified as other cropping (ha (%))	10 (0.2%)
Classified as urban/industrial/services (ha (%))	150 (3%)
Classified as marsh/wetland (ha (%))	941 (17%)
Other (ha (%))	110 (2%)
Land values	
Estimated total primary production value ($/year)	$1,900,000
Average land value above 1.2 m AHD ($/ha)	$8,000
Average land value below 1.2 m AHD ($/ha)	$2,500

8.4.1 Site description and brief history of drainage

The Frogmore/Austral Eden/Verges Swamp subcatchment is located on the right bank of the Macleay River upstream of its confluence with the Belmore River. There is extensive drainage infrastructure across the subcatchment which includes multiple works that were completed as part of the Macleay River flood mitigation scheme (Tulau, 2011):

- Austral Eden Drain and headworks (1959);
- Frogmore Drain and the Union Drain floodgates (015G1) (1959);
- Barnetts Drain and floodgates (1960)
- Friths Drain and floodgates (1960)
- Buchanans Drain and floodgates (1960)
- Whalens Drain and floodgates (1960)
- Darkwater Drain (1967);
- Lancasters Drain (1968); and
- Belmore River floodway and headworks (sluice gate 016G1) (1976).

The majority of catchment inflow within the Frogmore/Austral Eden/Verges Swamp subcatchment comes from the south and is directed to the Belmore River via Frogmore Drain, which runs from west to east across the floodplain, and Darkwater Drain, which drains the low-lying south eastern floodplain (Figure 8-13). Lancasters Drain and Barnetts Drain also assist in draining the northern areas of the subcatchment.

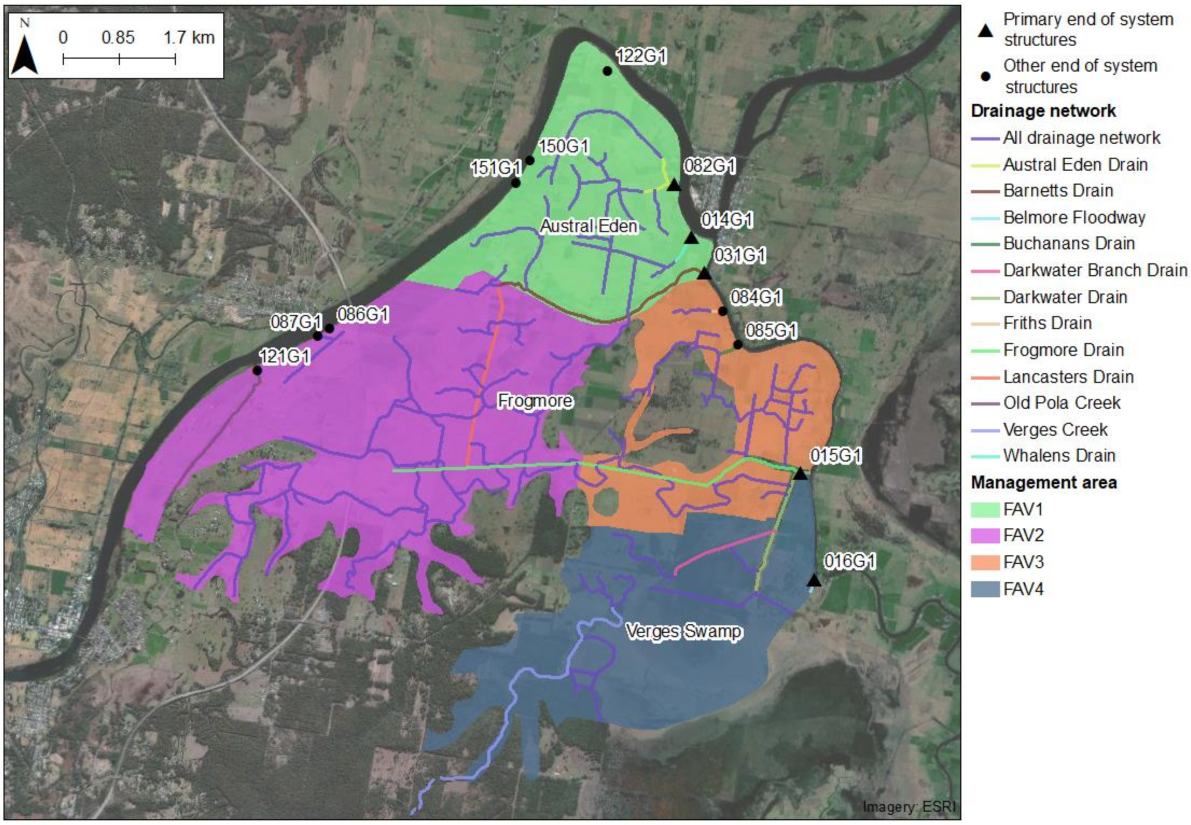

Figure 8-13: Flood mitigation structures in the Frogmore/Austral Eden/Verges Swamp subcatchment

Land tenure information for the Frogmore/Austral Eden/Verges Swamp subcatchment is shown in Figure 8-14. Land tenure across the subcatchment is predominantly grazing and all end of system infrastructure for the subcatchment is managed by Kempsey Shire Council. The lowest lying land within the subcatchment is located in Verges Swamp to the south east of the floodplain. Information on drainage and floodplain elevation for the Frogmore/Austral Eden/Verges Swamp subcatchment is shown in Figure 8-15.

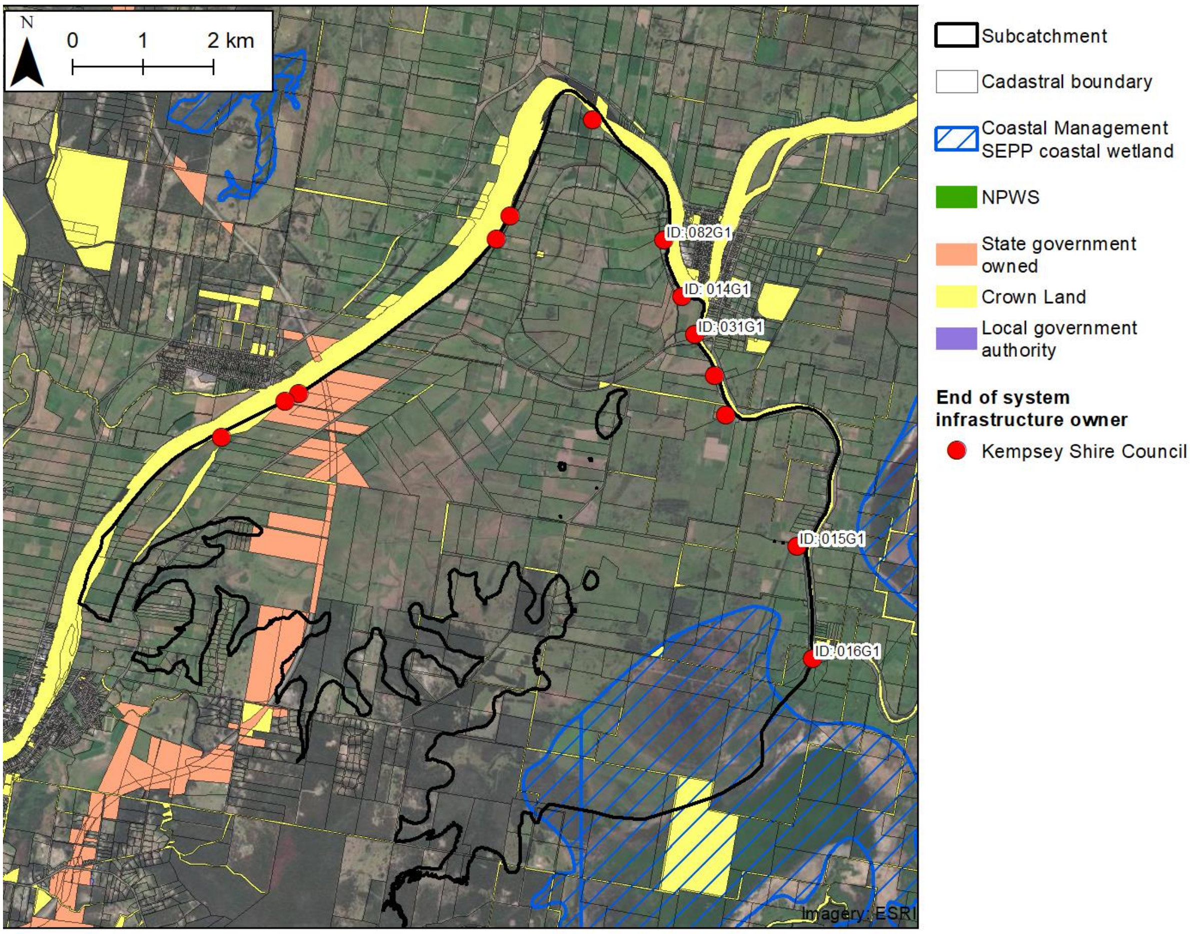

Figure 8-14: Frogmore/Austral Eden/Verges Swamp subcatchment land and end of system infrastructure tenure

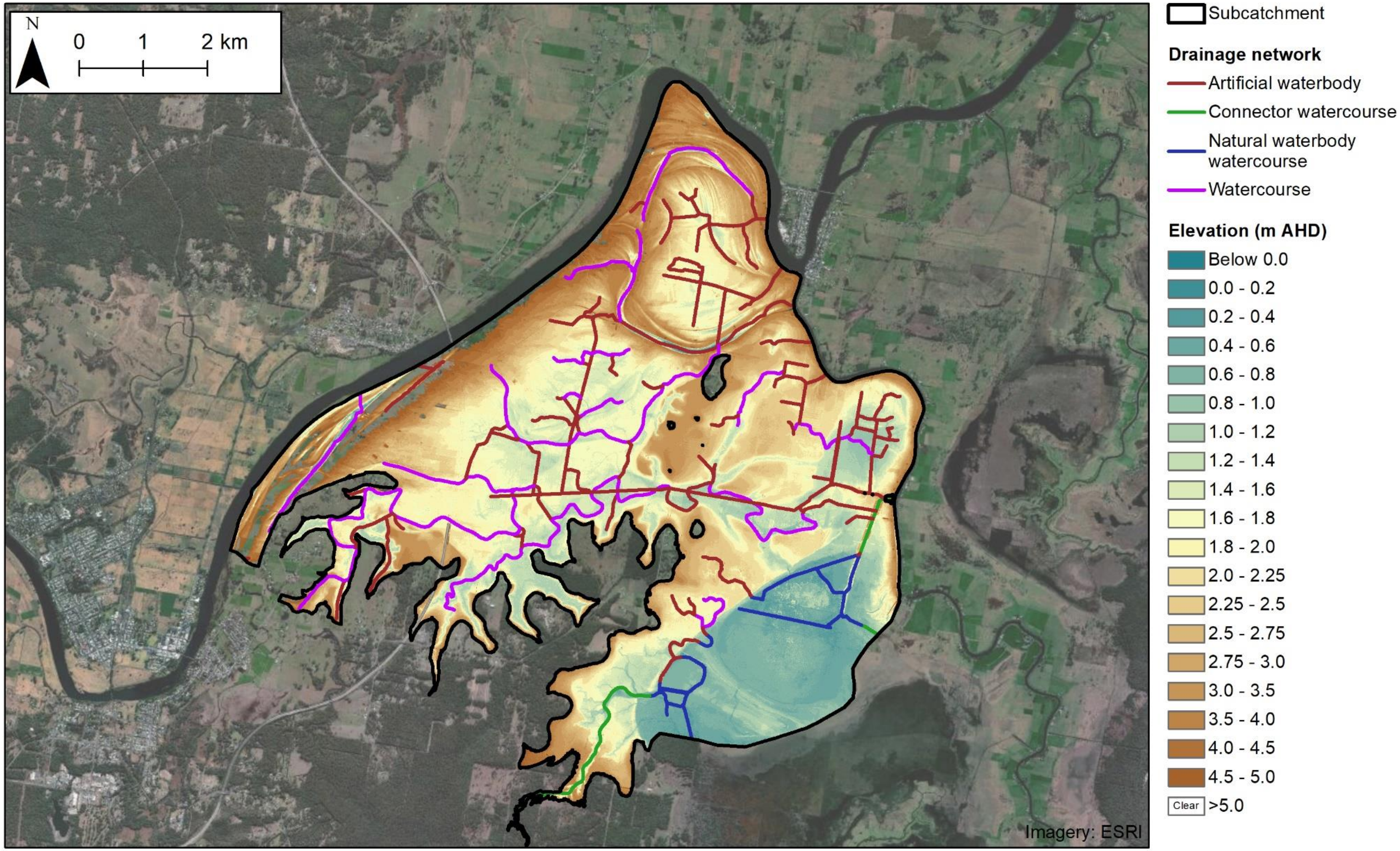

Figure 8-15: Frogmore/Austral Eden/Verges Swamp subcatchment elevation and drainage network

8.4.2 History of remediation

Prior to the early 2000s there were no attempts for remediating acid sulfate soils or blackwater generation risk within the Frogmore/Austral Eden/Verges Swamp subcatchment (Tulau and Naylor, 1999). The first account of remediation occurred in 2002 when Kempsey Shire Council developed a floodgate management plan for the Union Drain floodgates (015G1) (Kempsey Shire Council, 2002b). This plan outlined the approach that would be taken to open one (1) of the floodgates to allow controlled tidal flushing upstream of the headworks during non-flood periods. Recent inspection of the floodgates completed during this study found that, in addition to this management strategy, two buoyancy controlled auto-tidal gates have been installed on floodgate flaps that would allow aquatic connectivity and controlled tidal flushing upstream of the floodgates.

Kempsey Shire Council have also developed a management strategy for Darkwater Drain and Darkwater Branch Drain (Kempsey Shire Council, 2006b). As part of the development of this plan, modifications were completed on Darkwater Branch Drain to install two (2) drop board structures on existing culverts. Three (3) new drop board structures were also constructed on side drains on the left bank of Darkwater Drain. These structures retain water and enable wet pasture management upstream.

There is no record of other structures that have been modified within the Frogmore/Austral Eden/Verges Swamp subcatchment, however, the Belmore River floodway structure, which consists of three (3) large sluice gates, is actively managed for flooding purposes (Geolink, 2012). Remediation for the Frogmore/Austral Eden/Verges Swamp subcatchment is summarised in Figure 8-16.

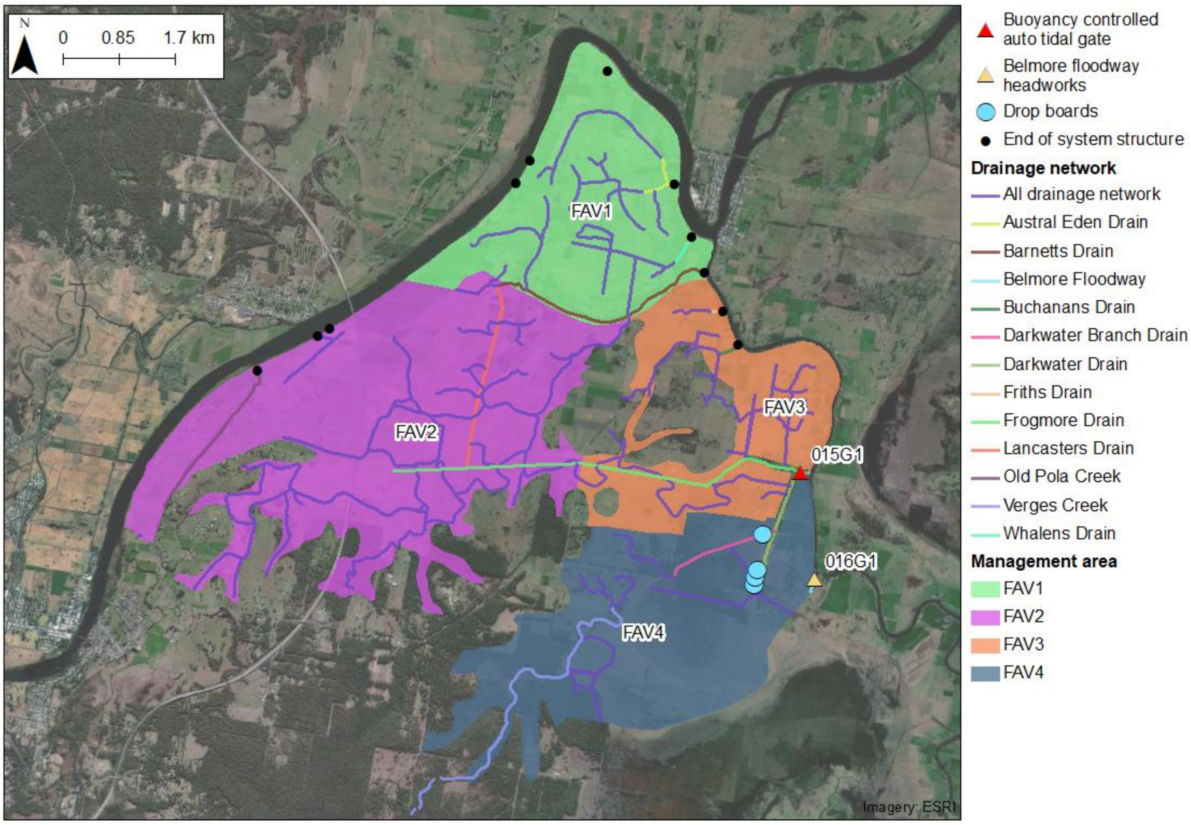

Figure 8-16: The Frogmore/Austral Eden/Verges Swamp subcatchment including previous remediation actions

8.4.3 Prioritisation of management areas in the Frogmore/Austral Eden/Verges Swamp subcatchment

The Frogmore/Austral Eden/Verges Swamp subcatchment ranked second in the acid prioritisation, and fourth in the blackwater prioritisation. The subcatchment has been further delineated into four (4) smaller management areas (referred to as FAV1 to FAV4, shown in Figure 8-17) to provide additional information on the sources of acid and blackwater. The areas have been delineated based on land tenure, data availability, elevation, changes in soil acidity and drainage units.

The management areas have been prioritised for acid generation using the method described in Section 4. The results of the acid prioritisation for the management areas of the Frogmore/Austral Eden/Verges Swamp subcatchment are shown in Figure 8-17 and Table 8-6. The largest source of acid risk was found to be in management areas FAV2 and FAV3, which are both serviced by Frogmore Drain. Limited soil profile data was available for the management area FAV1. It was therefore compared with the remaining management areas qualitatively based upon drainage and hydrology.

Figure 8-18 shows the management areas for the Frogmore/Austral Eden/Verges Swamp subcatchment below the median elevation for blackwater generation (+1.2 m AHD). As elevation is a primary driver of the production of blackwater, the areas below this level typically contribute the most to the risk of large scale deoxygenation (although this can be managed through changing vegetation and land uses). The majority of blackwater risk in the Frogmore/Austral Eden/Verges Swamp subcatchment can be found in management area FAV4, with a small contribution from management area FAV3.

Based on the findings from the management area prioritisation shown in Figure 8-17 and Figure 8-18 and analysis of drainage and hydrology data, it is suggested that water quality improvements in the Frogmore/Austral Eden/Verges Swamp subcatchment focus on management areas FAV2, FAV3 and FAV4.

Table 8-6: Management area acid prioritisation of Frogmore/Austral Eden/Verges Swamp subcatchment

Management Area	Groundwater Factor	Surface Water Factor	Final Acid Factor	Final Rank
FAV3	107	851	91,177	1
FAV2	111	330	36,535	2
FAV4	96	162	15,536	3
FAV1	Insufficient data	415	Insufficient data	N/A

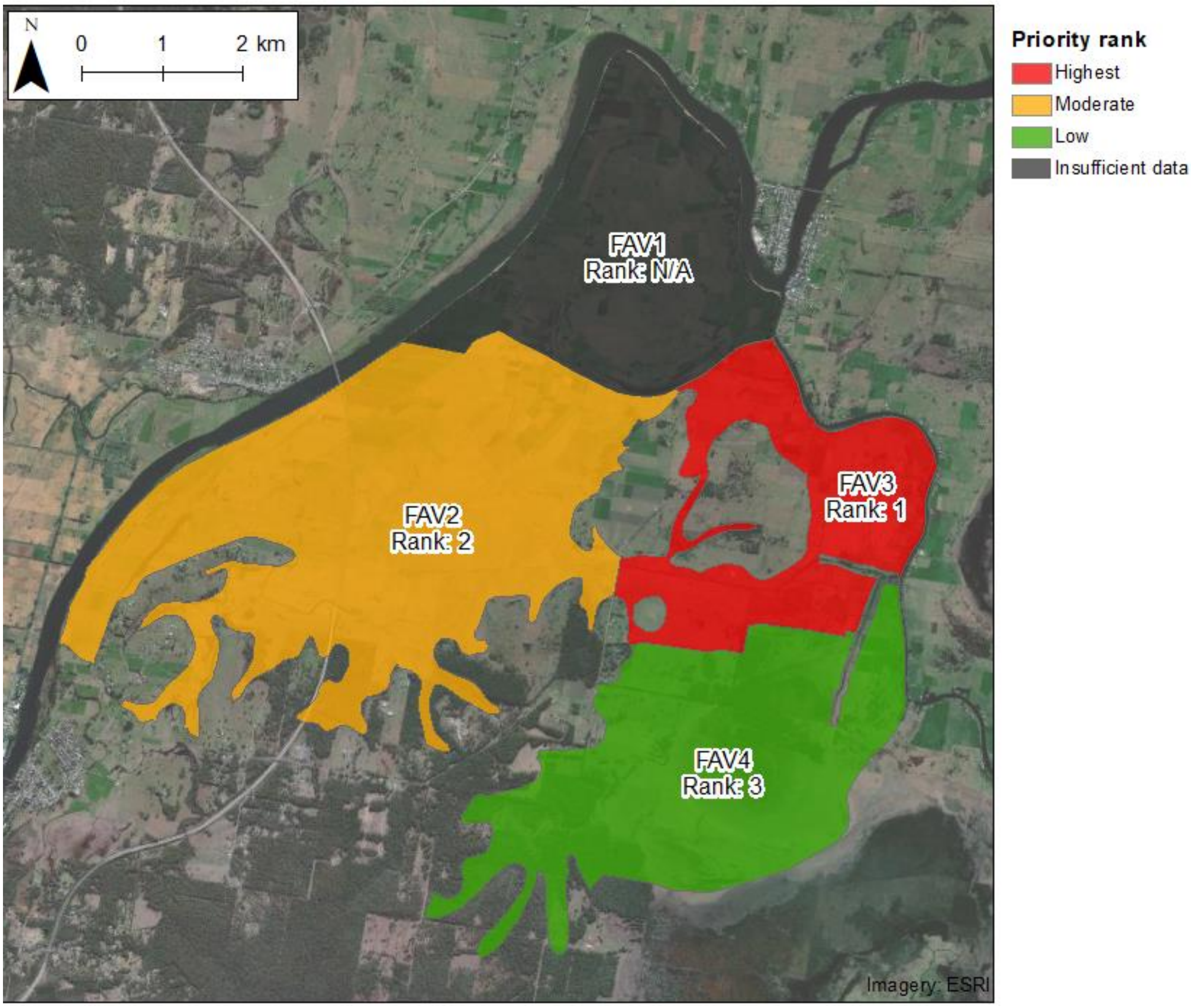

Figure 8-17: Frogmore/Austral Eden/Verges Swamp subcatchment management areas acid prioritisation

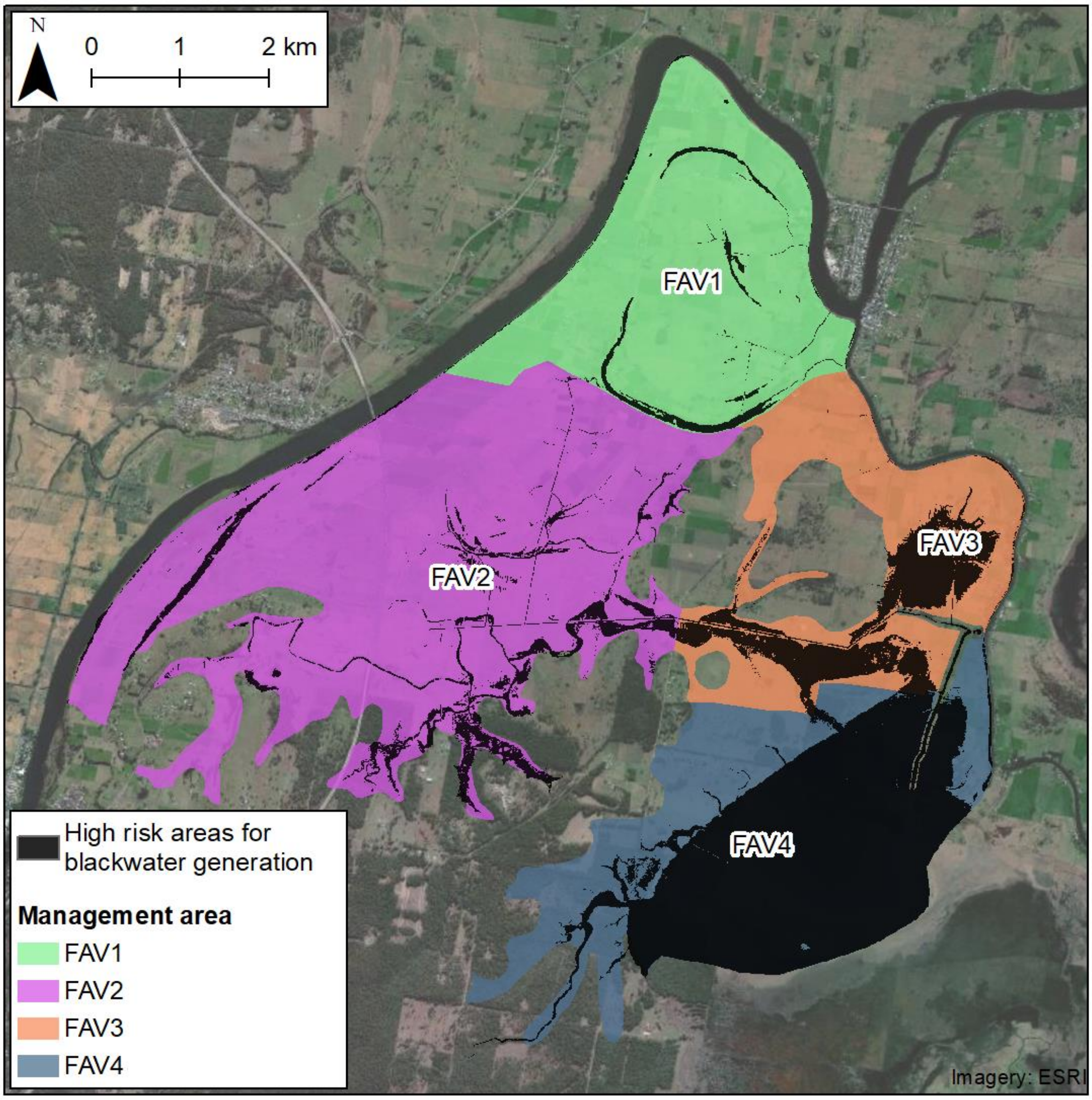

Figure 8-18: Blackwater contribution for management areas in the Frogmore/Austral Eden/Verges Swamp subcatchment (median blackwater level +1.2 m AHD)

8.4.4 Floodplain drainage – sea level rise vulnerability

The sea level rise vulnerability assessment of the Frogmore/Austral Eden/Verges Swamp subcatchment is summarised in Figure 8-19, while primary floodgates and key floodplain elevations are compared to the geometry of the primary floodgates in Figure 8-20. Simulation of present day conditions indicated that the floodplain drainage is only impacted at locations in the lowest-lying floodplain within Verges Swamp in management area FAV4, where modelling of far future sea level rise scenarios indicated that the majority of FAV4 will be situated below the approximate mean tide water level (i.e. at medium risk to reduced drainage). Low lying land in management area FAV3 and along Frogmore Drain may also be potentially impacted by reduced drainage under far future water levels.

The floodgate draining Old Pola Creek (121G1) to the west of the subcatchment is currently moderately vulnerable to sea level rise, becoming most vulnerable in the far future modelling along with structure 087G1 as the approximate mean tide water level exceeds the obverts of these structures. Additionally, four (4) other floodgates are predicted to become moderately vulnerable in the far future, including primary floodgates 014G1 and the Union Drain floodgates (015G1).

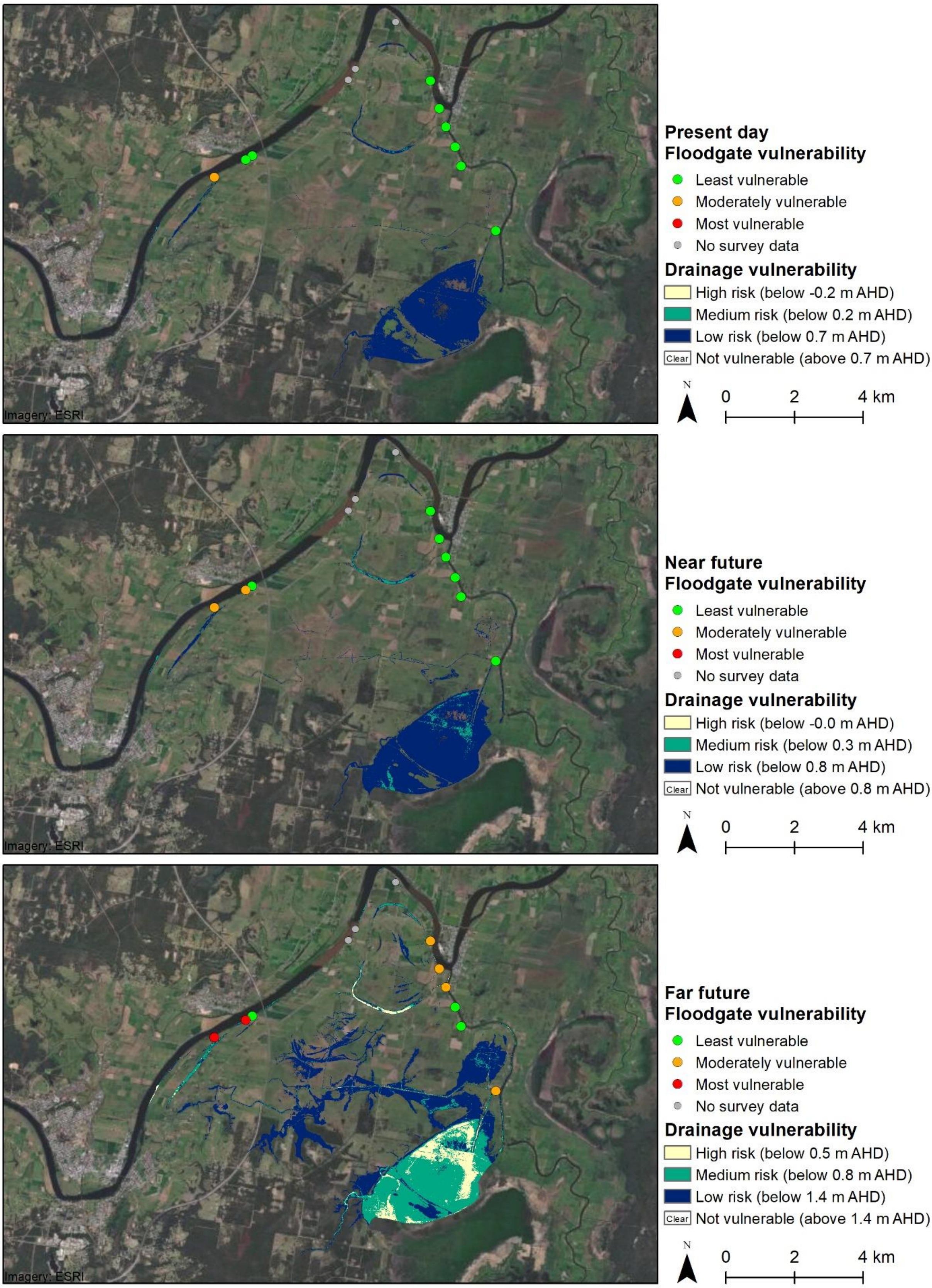

Figure 8-19: Sea level rise drainage vulnerability – Frogmore/Austral Eden/Verges Swamp subcatchment

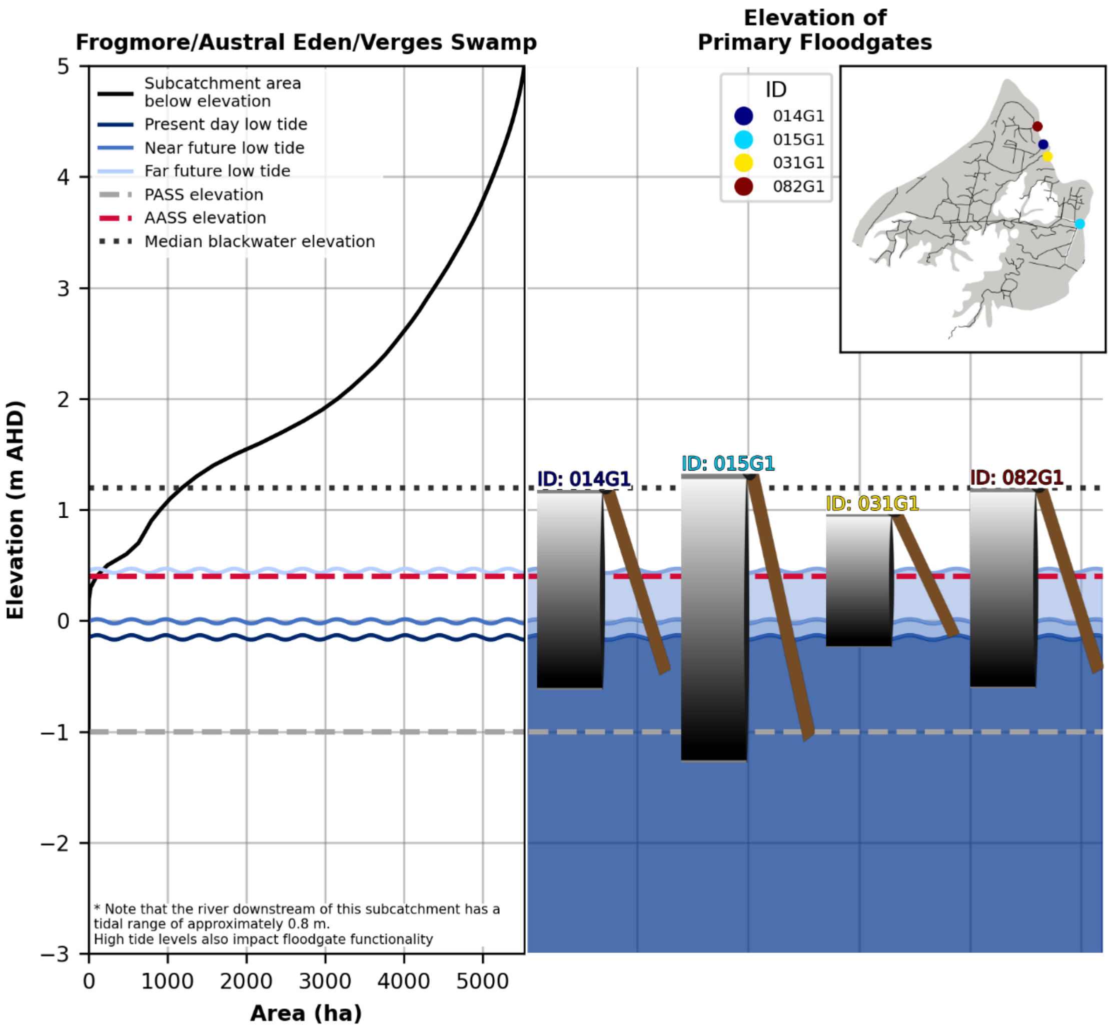

Figure 8-20: Primary floodgates and key floodplain elevations – Frogmore/Austral Eden/Verges Swamp subcatchment

8.4.5 Management options

Potential management options for short and long-term planning horizons for the Frogmore/Austral Eden/Verges Swamp subcatchment include:

- Short-term: Optimise tidal flushing through structures, drain reshaping/infilling, installing drop board structures, wet pasture management, and protection of existing Coastal Management SEPP coastal wetlands.
- Long-term: Installing weirs, drain reshaping/infilling, wet pasture management, creation and protection of freshwater wetland and existing Coastal Management SEPP coastal wetlands.

Note that short and long-term management options are based on existing data and may be subject to change upon detailed site investigation and/or additional information. The options tabled are intended to provide a range of potential options that could be investigated further as required.

Short-term management options

The Union Drain floodgates (015G1) control the drainage of management areas FAV2, FAV3 and FAV4. Active management of the Union Drain floodgates is currently not in place (p.comms R. Kemsley, 2021). The active management of these floodgates should be reinstated, including opening of one floodgate flap during dry times as per the floodgate management plan. Detailed investigations could be completed to optimise tidal flushing through this structure.

Within management areas FAV1 and FAV3, floodgates on structures 031G1, 084G1 and 085G1 have winches installed on them but are not actively managed. A management plan could be developed whereby these floodgates are opened during dry periods. Alternatively these floodgates (031G1, 084G1 and 085G1) and structures 014G1, 031G1 and 082G1 could be modified with buoyancy controlled auto-tidal gates or similar to allow controlled in-drain tidal flushing. This strategy would reduce the impacts of acid sulfate soils during dry periods and improve aquatic connectivity.

Installing of water retention structures (drop board weirs) at strategic locations in management area FAV2 could be utilised to retain water and raise the water table. This would reduce the export of acid water while allowing the land to be effectively managed during flood times.

The drainage density could be reduced in management area FAV3 by infilling small paddock scale drains in the low-lying areas, provided existing land productivity is maintained. This could be implemented alongside wet pasture management practices to minimise pasture die off following prolonged inundation and reduce the generation of blackwater.

The side drains at the southern extent of Darkwater Drain (upstream of Darkwater Branch Drain) within management area FAV4 could be infilled/reshaped decreasing the connectivity across the floodplain. Active management of existing drop board structures in management area FAV4 as per the drain management plan should continue. These actions would assist wet pasture management which could be encouraged across the broader management area by promoting the growth of water tolerant pasture species to help minimise the risk of blackwater. Note, there is a large area of Coastal Management SEPP coastal wetland within management area FAV4 which should continue to be protected.

Long-term management options

Management area FAV1 has a higher elevation in comparison to the other management areas and is unlikely to be severely impacted by sea level rise due to climate change. Further investigations should be completed to confirm that the acid sulfate soil risk for this management area is low. Continued management of tidal flushing within the drainage network (as outlined in the Short-term management options) should continue.

In management area FAV2, investigations could be completed to determine if Lancasters Drain can be reshaped (shallowed and widened) to reduce intersection with acid sulfate soils while maintaining floodwater drainage. Currently there is no cross-section data available for Lancasters Drain and limited localised information on the acid sulfate soil layer depth adjacent to the drain. LiDAR measurements indicate that the invert of the drain may be around 0.4 to 0.5 m AHD which may mean that it is already above the acid layer (which has an average depth of 0.4 m AHD for the subcatchment), in which case, no changes would be required. In addition to this, detailed hydrological investigations across this section of the floodplain could identify the strategic optimisation of drainage channels to reduce the risk of acid export and blackwater.

Frogmore Drain (which drains management areas FAV2 and FAV3) could be reshaped to reduce intersection with acid sulfate soils. Furthermore, construction of weirs along Frogmore Drain that rise in elevation the further they are from Belmore River, would assist in reducing the acid export. Strategic placement of weirs could also enable the restoration of historic drainage pathways through management areas FAV2 and FAV3.

There is presently limited information on the levels of acid sulfate soils within management area FAV3 to guide management options. Investigations could be completed to identify the extent and elevation of acid sulfate soils and inform drain reshaping design. Far future sea level rise predictions indicate that there may be an overall reduction in drainage potential for this management area, which may support wet pasture management as a strategy to reduce the blackwater generation potential.

In the long-term, the natural freshwater wetland hydrology within Management area FAV4 could be remediated. This could be achieved by disconnecting man-made connections between FAV4 and the remainder of the Frogmore/Austral Eden/Verges Swamp subcatchment. Actions such as infilling Darkwater Drain and Darkwater Branch Drain could be completed to create freshwater wetland and allow for the expansion and protection of the existing Coastal Management SEPP coastal wetland within management area FAV4. Note that management area FAV4 is hydrologically linked with the Belmore Swamp subcatchment and long-term management should be aligned between the two areas (see Section 8.7.5 for greater details). Impacts of flood connectivity between FAV4 and the remainder of the Frogmore/Austral Eden/Verges Swamp subcatchment would also need to be investigated. Any changes in hydrology will require studies into the impacts to land uses and should only be implemented with extensive consultation of local landholders and consideration of the social and economic impacts of such changes.

A summary of the potential management options for the Frogmore/Austral Eden/Verges Swamp subcatchment including indicative costs is provided in Table 8-7.

Table 8-7: Summary of management options for Frogmore/Austral Eden/Verges Swamp

Timeframe	Strategy	Target management area(s)	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing per year)	Indicative cost (lost productivity per year)	Effectiveness at improving:		
							Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Optimise tidal flushing	FAV1, FAV2, FAV3	None	$100,000	$15,000	Minimal	Moderate	Low	Negligible
Short-term	Drain infilling	FAV3, FAV4	None	$150,000	None	None	None	Moderate	Low
Short-term	Install drop boards	FAV2	None	$35,000	$2,000	Minimal	None	Moderate	Low
Long-term	Wet pasture management	FAV2, FAV3, FAV4	None	$60,000	None	Minimal	None	Low	Moderate
Long-term	Install weirs	FAV2, FAV3	None	$200,000	$40,000	Minimal	None	Moderate	Moderate
Long-term	Drain reshaping/infilling	FAV2, FAV3	None	$500,000	None	Minimal	None	Moderate	Low
Long-term	Restoration of wetlands	FAV4	$1,750,000	$75,000	Minimal	$300,000	Moderate	High	High

*Costs exclude additional investigation/studies, including; REF, EIS, flood studies, and monitoring programs that may be required prior to implementation.

8.5 Yarrahapinni subcatchment

Acid priority rank:	**3**
Blackwater priority rank:	**5**
<u>Infrastructure</u>	
Approximate waterway length (km)	42
# Privately owned end of system structures	0
# Publicly owned end of system structures	0
# Jointly owned end of system structures	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (floodgate ID)	NA
<u>Elevations</u>	
Invert of primary floodplain infrastructure (m AHD)	NA
Average AASS elevation (m AHD)	1.9
Average PASS elevation (m AHD)	1.3
Median blackwater elevation (m AHD)	1.1
Present day low water level (m AHD)	-0.2
Near future low water level (m AHD)	-0.1
Far future low water level (m AHD)	0.3
<u>Proximity to sensitive receivers</u>	
Oyster leases (km)	Within subcatchment
Saltmarsh (km)	Within subcatchment
Seagrass (km)	Within subcatchment
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
<u>Land use</u>	
Total floodplain area (ha)	4,555
Classified as conservation and minimal use (ha (%))	3,824 (84%)
Classified as grazing (ha (%))	410 (9%)
Classified as forestry (ha (%))	1 (0.02%)
Classified as horticulture (ha (%))	11 (0.2%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	34 (1%)
Classified as marsh/wetland (ha (%))	197 (4%)
Other (ha (%))	77 (2%)
<u>Land values</u>	
Estimated total primary production value ($/year)	$400,000
Average land value above 1.1 m AHD ($/ha)	$6,200
Average land value below 1.1 m AHD ($/ha)	$3,400

8.5.1 Site description and brief history of drainage

The Yarrahapinni subcatchment is located on the left bank of Andersons Inlet approximately seven km upstream of the entrance of the Macleay River estuary to the ocean at South West Rocks. It is the most northern subcatchment on the Macleay River floodplain. A key feature of the subcatchment is the Yarrahapinni Broadwater. The main flow path through the subcatchment is via Boringalla Creek which runs from north to south before joining Andersons Inlet at the Yarrahapinni Broadwater.

Historically the Yarrahapinni Broadwater was connected to Andersons Inlet, however, during the late 1960s, during the Macleay River flood mitigation program, a levee was constructed across the connection and a floodgate structure installed (009G1) (Glamore and Timms, 2009). Other modifications to the subcatchment included the construction of a drain on sections of Kings Creek and excavation of channels (Wilkinson, 2014). Drainage works resulted in the oxidation of highly acidic soils and the impacts of acid discharges from Yarrahapinni were severely detrimental to downstream aquatic flora and fauna, as well as wetland habitats within the subcatchment (Manly Hydraulics Laboratory, 2001; Telfer, 2005). Since 2007, restoration of the Yarrahapinni subcatchment has been completed to restore tidal connectivity by removal of floodgates and breaching of levee banks (Glamore et al., 2012; Wilkinson, 2014). During field investigations it was observed that all floodgate flaps have been removed on structure 009G1 and the levee separating Andersons Inlet and the Yarrahapinni Broadwater is breached, now allowing tidal exchange between the two (2) waterbodies.

The prioritisation approach utilises historical drainage and soil datasets to identify the potential risk of poor water quality from acid sulfate soils and blackwater. Remediation works that have been implemented are considered when developing potential short and long-term management options for the subcatchment.

The majority of the Yarrahapinni subcatchment has been gazetted as the Yarrahapinni Wetlands National Park and this area in addition to the Clybucca Aboriginal Area and Clybucca Historic Site are now managed by the NSW National Parks and Wildlife Service (Office of Environment and Heritage, 2013). Some grazing does occur to the north of the subcatchment on private land. Tenure information for the Yarrahapinni subcatchment is shown in Figure 8-21. Information on drainage and floodplain elevation is shown in Figure 8-22.

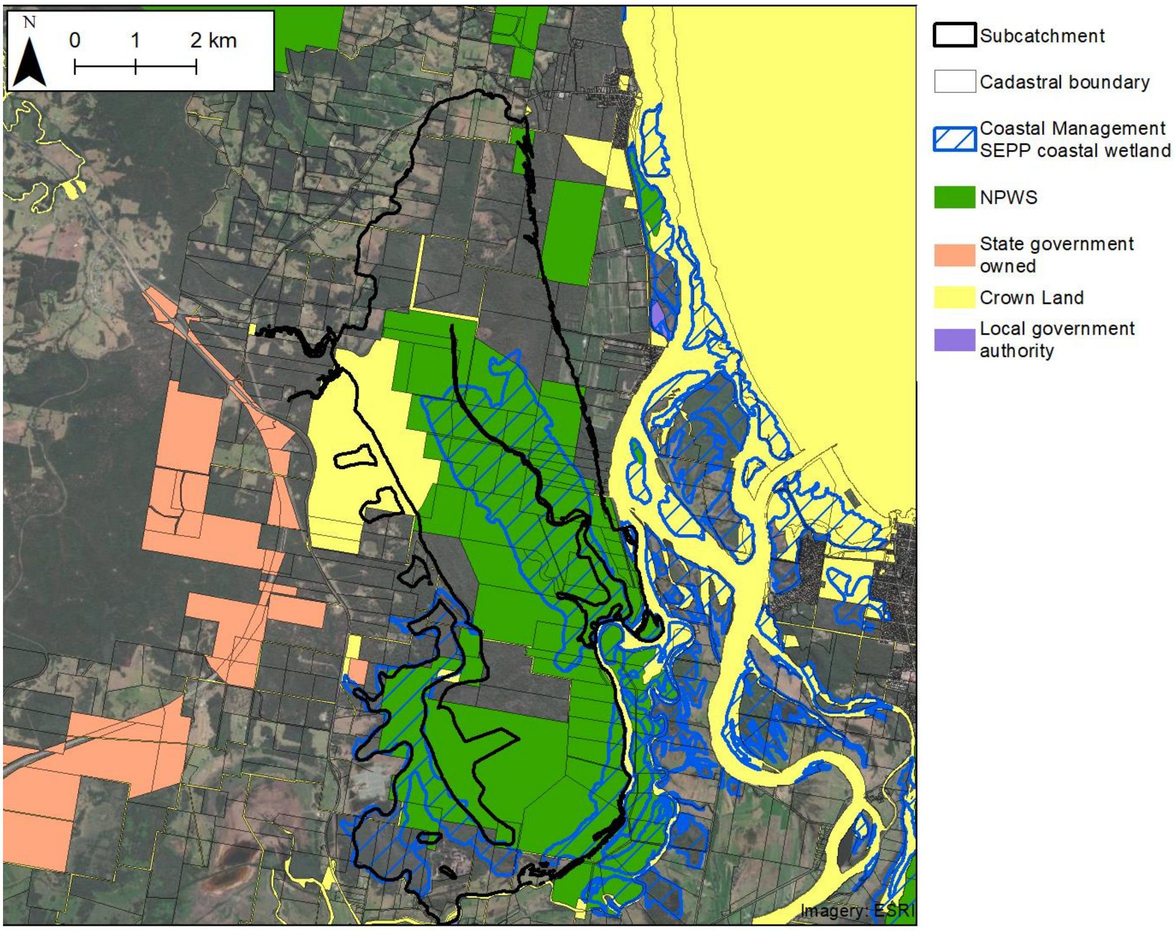

Figure 8-21: Yarrahapinni subcatchment land use

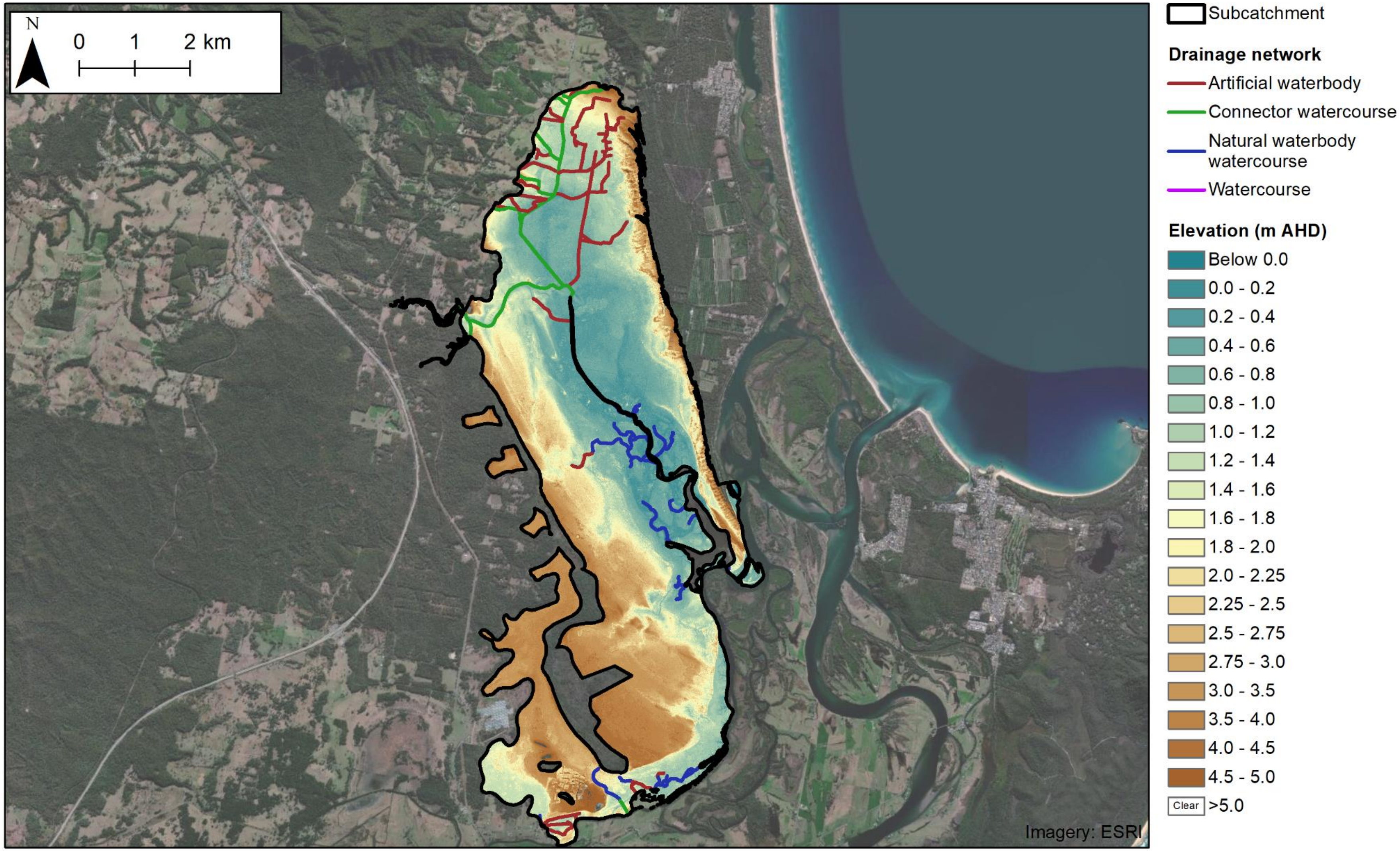

Figure 8-22: Yarrahapinni subcatchment elevation and drainage network

8.5.2 History of remediation

In 1996 the Yarrahapinni Wetlands Reserve Trust was established with the objective to restore 600 hectares of degraded wetland habitat within the Yarrahapinni subcatchment (Tulau and Naylor, 1999). This resulted in a number of studies between 1999 and 2004, summarised by Glamore and Timms (2009), to investigate potential remediation options for the subcatchment. These studies failed to produce any on-ground action, however, in 2007 the 600 hectare area was gazetted as the Yarrahapinni Wetlands National Park. In the same year two (2) buoyancy controlled auto-tidal gates were installed on floodgate flaps of structure 009G1 to initiate the restoration process (Industry and Investment NSW, 2009; Wilkinson, 2014).

In 2009, Glamore and Timms (2009) outlined five stages required for the restoration of the Yarrahapinni subcatchment:

1. Establish trigger points and management protocols;
2. Onsite preparatory work and design;
3. Initial on-ground works;
4. Initial restoration works; and
5. Incremental implementation of full restoration works.

This study outlined the detailed approach required for on-ground actions to begin at Yarrahapinni and as a result, Glamore et al. (2012) completed detailed numerical modelling simulating the staged restoration process outlined by Glamore and Timms (2009).

During this time the staged remediation of the Yarrahapinni Subcatchment had already begun. In 2008 the buoyancy controlled auto-tidal gates were removed allowing free flow of tidal water into the subcatchment through their two (2) openings (Wilkinson, 2014). This work was further progressed in 2010 when one of the floodgate flaps was completely removed, and again in 2011 when two more floodgate flaps were removed (Wilkinson, 2014).

In 2013, the NSW Office of Environment and Heritage (2013) developed a plan of management for the Yarrahapinni Wetlands National Park. This document outlined actions required to achieve the following goals:

- Protect the natural environment;
- Complete staged restoration of the natural hydrology of the Yarrahapinni Wetlands;
- Revegetate previously cleared areas;
- Remediate saltmarsh; and
- Management of weeds, pests and fire.

Implementation of the restoration plan as outlined by Glamore and Timms (2009) and the NSW Office of Environment and Heritage (2013) has been successful in remediating the Yarrahapinni subcatchment. Field investigations completed in March 2020 found that tidal exchange between the Yarrahapinni Broadwater and Andersons Inlet through multiple breakthroughs in the levee and structure 009G1 which now no-longer has any floodgate flaps (see Figure 8-23 and Figure 8-24). While the restoration plan recommended complete removal of the levee structure, it has become evident that this is occurring due to natural processes and no further major works are required to restore the Yarrahapinni Wetlands. Figure 8-25 shows the location of structure 009G1 and the levee that formerly separated Yarrahapinni Broadwater and Andersons Inlet.

Figure 8-23: Structure 009G1 allowing full tidal flow between Yarrahapinni Broadwater and Andersons Inlet (March 2020)

Figure 8-24: A breakthrough in the levee allowing tidal exchange between Yarrahapinni Broadwater and Andersons Inlet (March 2020)

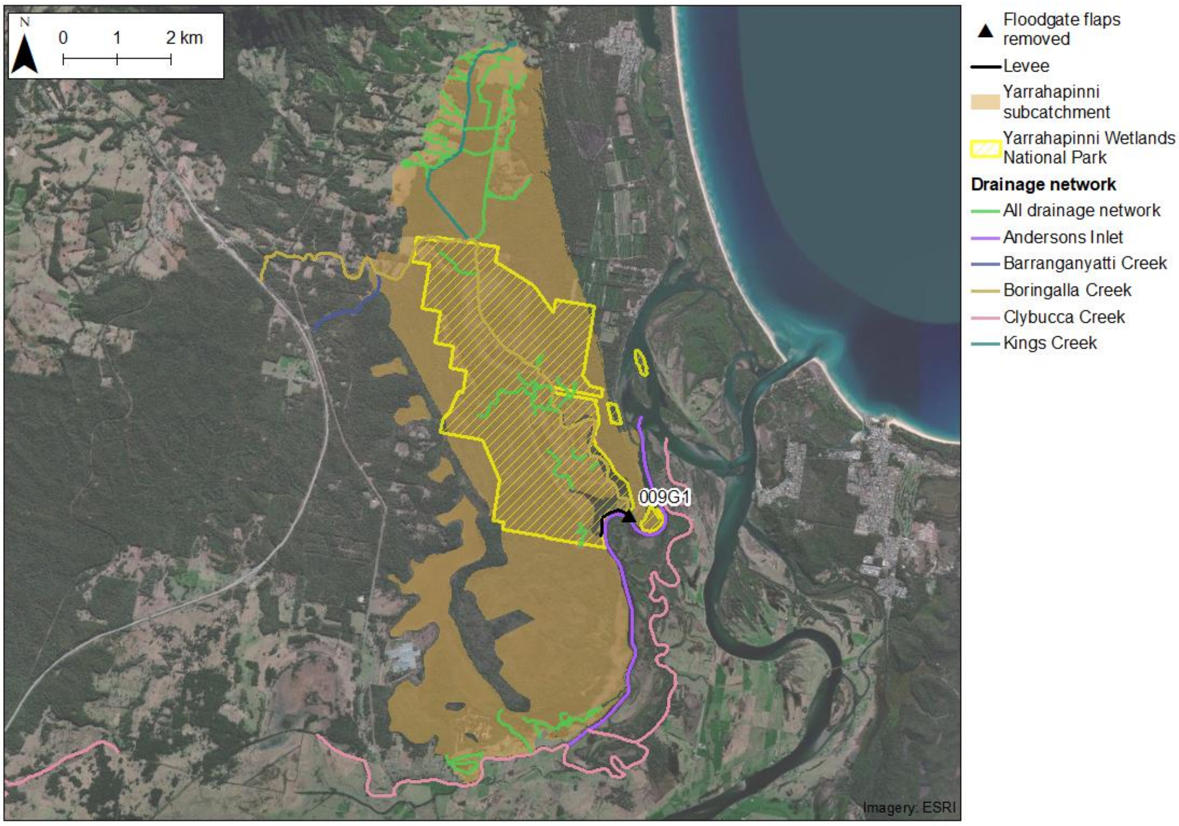

Figure 8-25: The Yarrahapinni subcatchment including previous remediation actions

8.5.3 Floodplain drainage – sea level rise vulnerability

The sea level rise vulnerability assessment of the Yarrahapinni subcatchment is summarised in Figure 8-26. Modelling shows that most of the land that will be affected by reduced drainage is within the Yarrahapinni Wetlands National Park. There are areas in the north of the subcatchment used for grazing that will also be affected. These areas are presently affected by the approximate high tide water level (i.e. low risk to reduced drainage) and will become affected by the approximate mean tide water level in the far future (i.e. medium risk to reduced drainage). Note, there are no known floodgates within the Yarrahapinni Subcatchment.

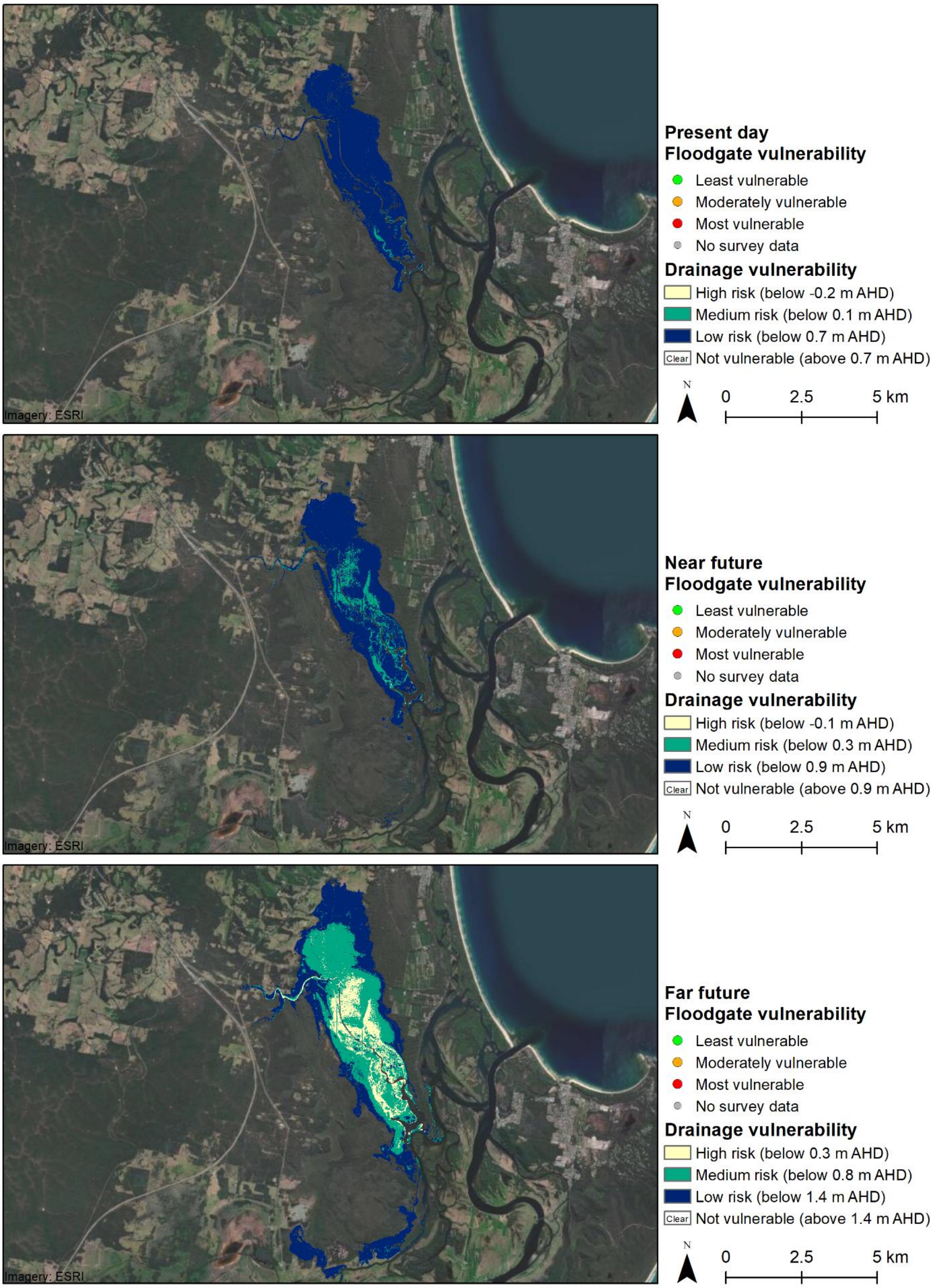

Figure 8-26: Sea level rise drainage vulnerability – Yarrahapinni subcatchment

8.5.4 Management options

The Yarrahapinni Subcatchment is ranked third in the acid prioritisation, and fifth in the blackwater prioritisation. This is because the prioritisation methodology does not analytically incorporate remediation efforts that have already taken place, as is based on historical datasets. Management of the Yarrahapinni Wetlands National Park has included restoration of the Yarrahapinni subcatchment over the past 15 years. These works have re-established the former Yarrahapinni Wetlands which are now thriving and include a diverse ecological community (Wilkinson, 2014). Continued support and protection of these wetlands should continue in perpetuity.

Since remediation of the majority of this subcatchment has already been completed, the focus of management options will be on areas in the north of the Yarrahapinni Subcatchment where land use has resulted in drainage of the floodplain. Potential strategies for short and long-term planning horizons for this area within the Yarrahapinni subcatchment include:

- Short-term: Reshaping/infilling of drains and wet pasture management.
- Long-term: Incorporation of hydrologically connected low-lying areas into the wider Yarrahapinni Wetlands National Park.

Note that short and long-term management options are based on existing data and may be subject to change upon detailed site investigation and/or additional information. The options tabled are intended to provide a range of potential options that could be investigated further as required.

Short-term management options
Investigations into the contribution of acid discharges from upstream areas could be completed to determine the relative contribution (if any) of poor water quality. Potential options for these areas may include reshaping of major drainage channels that pass through farmland and do not have natural wetland/riparian vegetation growth around them, and strategic infilling of secondary drains coupled with wet pasture management (as existing land uses permit).

Long-term management options
In the long-term, low-lying areas to the north of the Yarrahapinni Subcatchment will be impacted by reduced drainage. As present day land uses become untenable, low-lying connected areas could be integrated into the existing Yarrahapinni Wetland Nation Park.

A summary of the potential management options for the Yarrahapinni subcatchment including indicative costs is provided in Table 8-8.

Table 8-8: Summary of management options for Yarrahapinni

Timeframe	Strategy	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing per year)	Indicative cost (lost productivity per year)	Effectiveness at improving:		
						Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Drain infilling/reshaping	None	$300,000	None	Minimal	None	Moderate	Low
Short-term	Wet pasture management	None	$20,000	None	Minimal	None	Low	Moderate
Long-term	Restoration of wetlands	$6,200,000	$125,000	Minimal	$415,000	High	High	High

*Costs exclude additional investigation/studies, including; REF, EIS, flood studies, and monitoring programs that may be required prior to implementation.

8.6 Christmas Creek subcatchment

Acid priority rank:	**4**
Blackwater priority rank:	**8**
<u>Infrastructure</u>	
Approximate waterway length (km)	42
# Privately owned end of system structures	0
# Publicly owned end of system structures	12
# Jointly owned end of system structures	0
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (floodgate ID)	011G1, 013G1, 096G1
<u>Elevations</u>	
Invert of primary floodplain infrastructure (m AHD)	-1.3 to -0.2
Average AASS elevation (m AHD)	0.8
Average PASS elevation (m AHD)	-0.5
Median blackwater elevation (m AHD)	1.9
Present day low water level (m AHD)	-0.1
Near future low water level (m AHD)	0.0
Far future low water level (m AHD)	0.4
<u>Proximity to sensitive receivers</u>	
Oyster leases (km)	22.2
Saltmarsh (km)	19.2
Seagrass (km)	25.0
Mangroves (km)	17.1
Coastal Management SEPP coastal wetlands (km)	14.4
<u>Land use</u>	
Total floodplain area (ha)	1,564
Classified as conservation and minimal use (ha (%))	112 (7%)
Classified as grazing (ha (%))	963 (62%)
Classified as forestry (ha (%))	0 (0%)
Classified as horticulture (ha (%))	0 (0%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	109 (7%)
Classified as marsh/wetland (ha (%))	271 (17%)
Other (ha (%))	109 (7%)
<u>Land values</u>	
Estimated total primary production value ($/year)	$400,000
Average land value above 1.9 m AHD ($/ha)	$7,700
Average land value below 1.9 m AHD ($/ha)	$6,800

8.6.1 Site description and brief history of drainage

The Christmas Creek subcatchment is located on the left bank of the Macleay River immediately north of Kempsey. Christmas Creek is the primary waterway for the subcatchment and flows from west to east across the subcatchment. The southern section of the floodplain, including Kempsey, drains via Willows Creek which flows from south-to-north and into Christmas Creek (see further details in Section 8.6.2 and Figure 8-27).

A large headworks structure (013G1) was constructed on Christmas Creek approximately 1.5 km upstream from the Macleay River in 1963 as part of the Macleay River flood mitigation scheme (Tulau, 2011). Other works that were completed within the Christmas Creek subcatchment as part of the flood mitigation scheme include (Tulau, 2011):

- Verges Drain and headworks (096G1) (pre-1962);
- Willows Drain (1968); and
- Glenrock Drain and headworks (011G1) (1968).

The major land use for the Christmas Creek subcatchment is grazing which accounts for 62% of land use. Tenure information for the Christmas Creek subcatchment is shown in Figure 8-27. Information on drainage and floodplain elevation is shown in Figure 8-28.

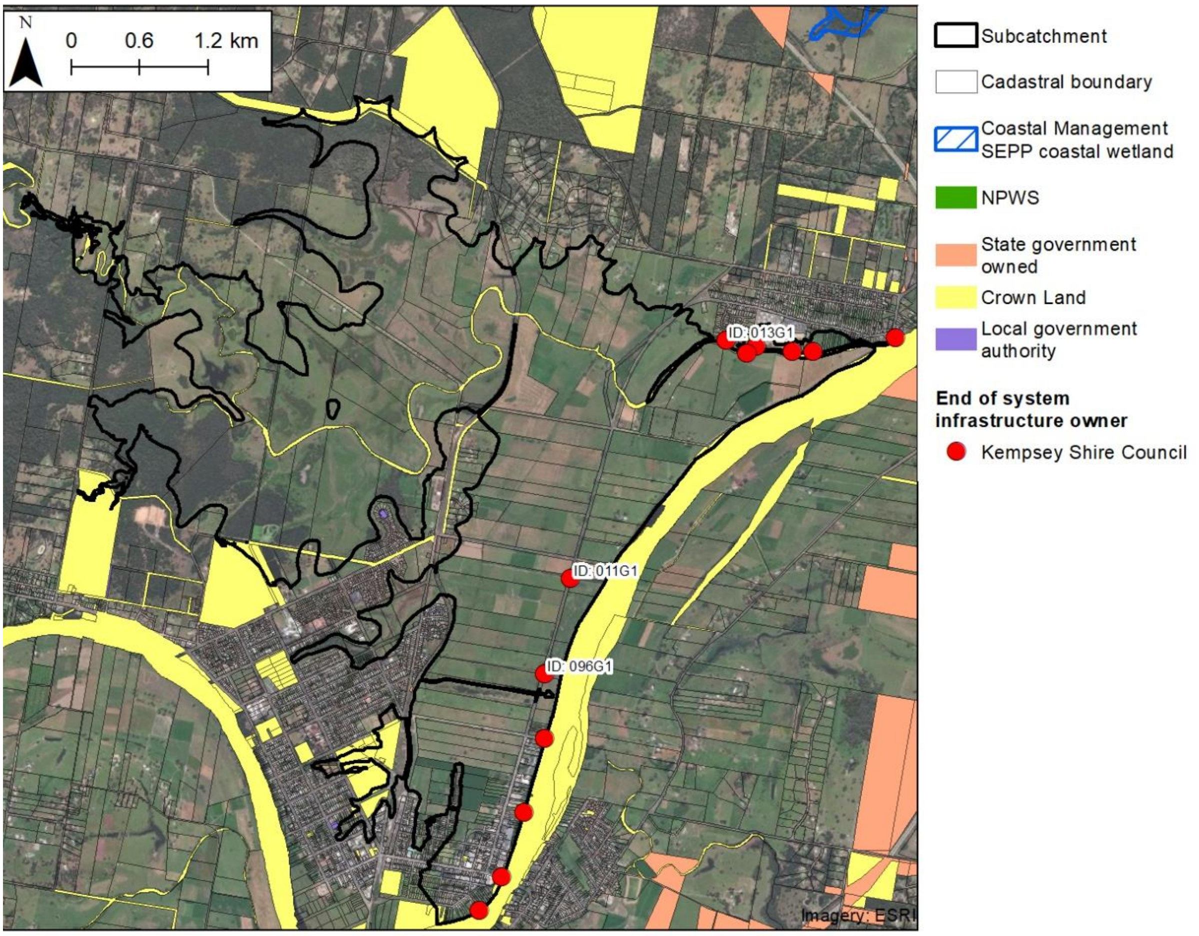

Figure 8-27: Christmas Creek subcatchment land and end of system infrastructure tenure

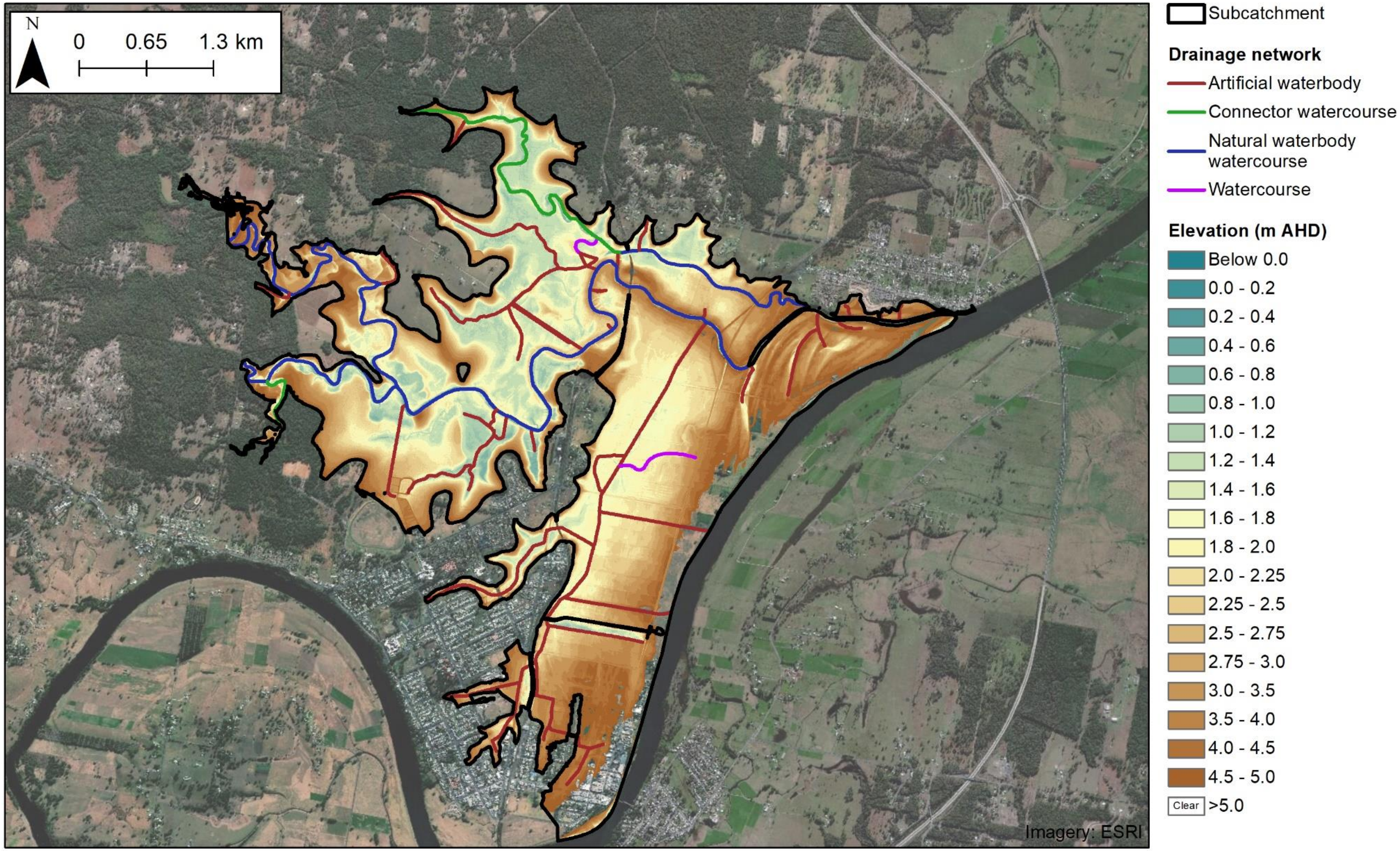

Figure 8-28: Christmas Creek subcatchment elevation and drainage network

8.6.2 History of remediation

Remediation actions within the Christmas Creek subcatchment include:

- Active floodgate management; and
- Construction of a weir and wet pasture management.

Kempsey Shire Council (N.D.-a) has developed a floodgate management plan for the Christmas Creek headworks (structure 013G1). This plan includes instructions for the floodgate flaps on the headworks structure to be winched open to allow improved aquatic habitat and passage, and improved water quality during non-flood periods.

In addition to this, Kempsey Shire Council (2006a) also constructed a weir on a secondary floodplain drain that connects to the right bank of Christmas Creek. A historic drain formerly connected what is now West Kempsey Sewage Treatment Plant to Christmas Creek. This drain has now been remediated by Kempsey Shire Council through installing a weir with the following objectives:

- Wet pasture management;
- Stock exclusion;
- Creation of freshwater wetland habitat; and
- Reduce the impacts of acid sulfate soils.

Kempsey Shire Council have a floodgate management plan for the headworks structure on Glenrock Drain (structure 011G1), however, Geolink (2012) stated that the floodgates were not actively managed. Field investigations completed in March 2020 for this study found lifting devices installed on structures 011G1 and 096G1, and the floodgates were in a closed position. It is understood that lifting devices for structures 011G1 and 096G1 are only used for maintenance activities (p.comms R. Kemsley, 2021). Figure 8-29 summarises the remediation actions that have been completed within the Christmas Creek subcatchment.

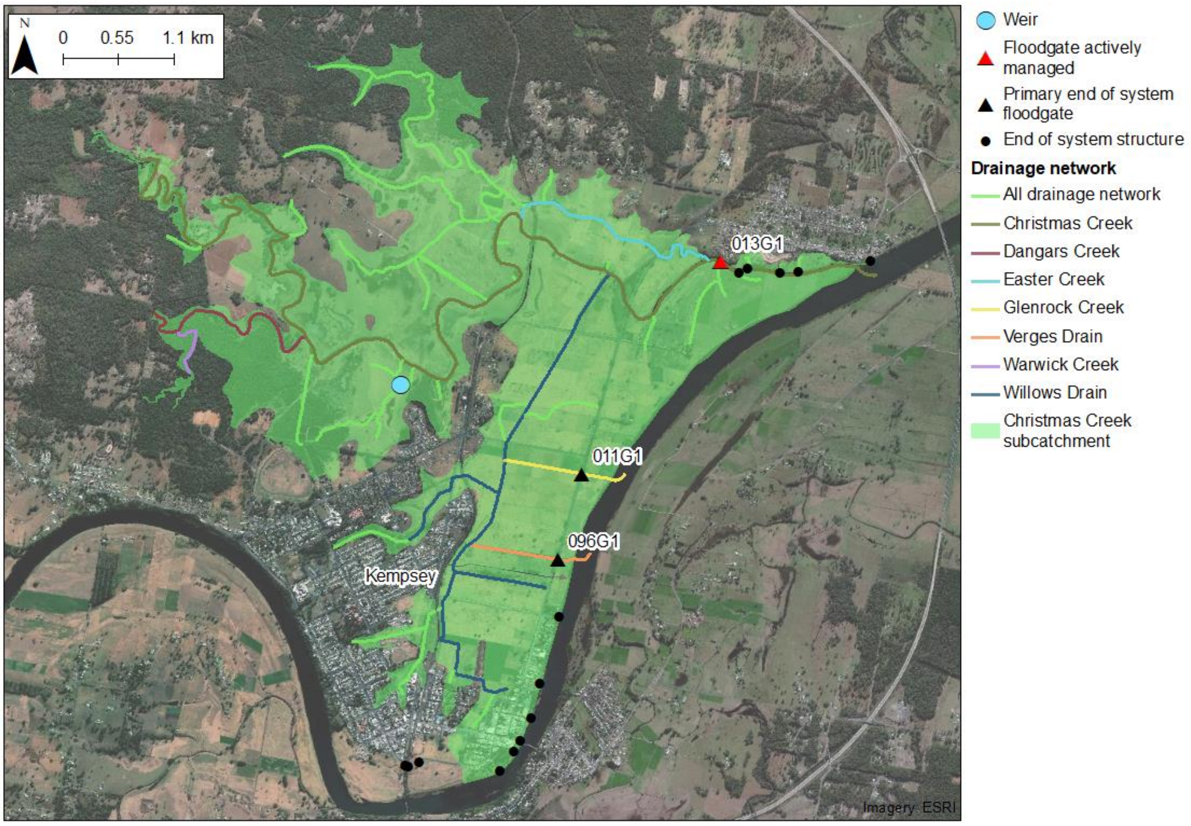

Figure 8-29: The Christmas Creek subcatchment including previous remediation actions

8.6.3 Floodplain drainage – sea level rise vulnerability

The sea level rise vulnerability assessment of the Christmas Creek subcatchment is summarised in Figure 8-30. Sea level rise modelling indicates that drainage within the Christmas Creek subcatchment will only become impacted due to sea level rise in the far future sea level rise scenario. The largest impact will be in the upstream sections of Christmas Creek which will eventually be situated below the approximate high tide water level during ~2100 estuarine tidal levels (i.e. at low risk to reduced drainage).

Figure 8-31 summarises the elevation of the primary floodgates compared to present day and modelled future low tide levels. In the present day and near future sea level rise scenarios, the primary end of system infrastructure will not be impacted due to sea level rise. This will change in the far future scenario when the Christmas Creek headworks (013G1) will become moderately vulnerable. Three (3) smaller floodgates closer to the urban area of Kempsey will be some of the most vulnerable to sea level rise (structures 099G1, 101G1 and 102G1, see Appendix F).

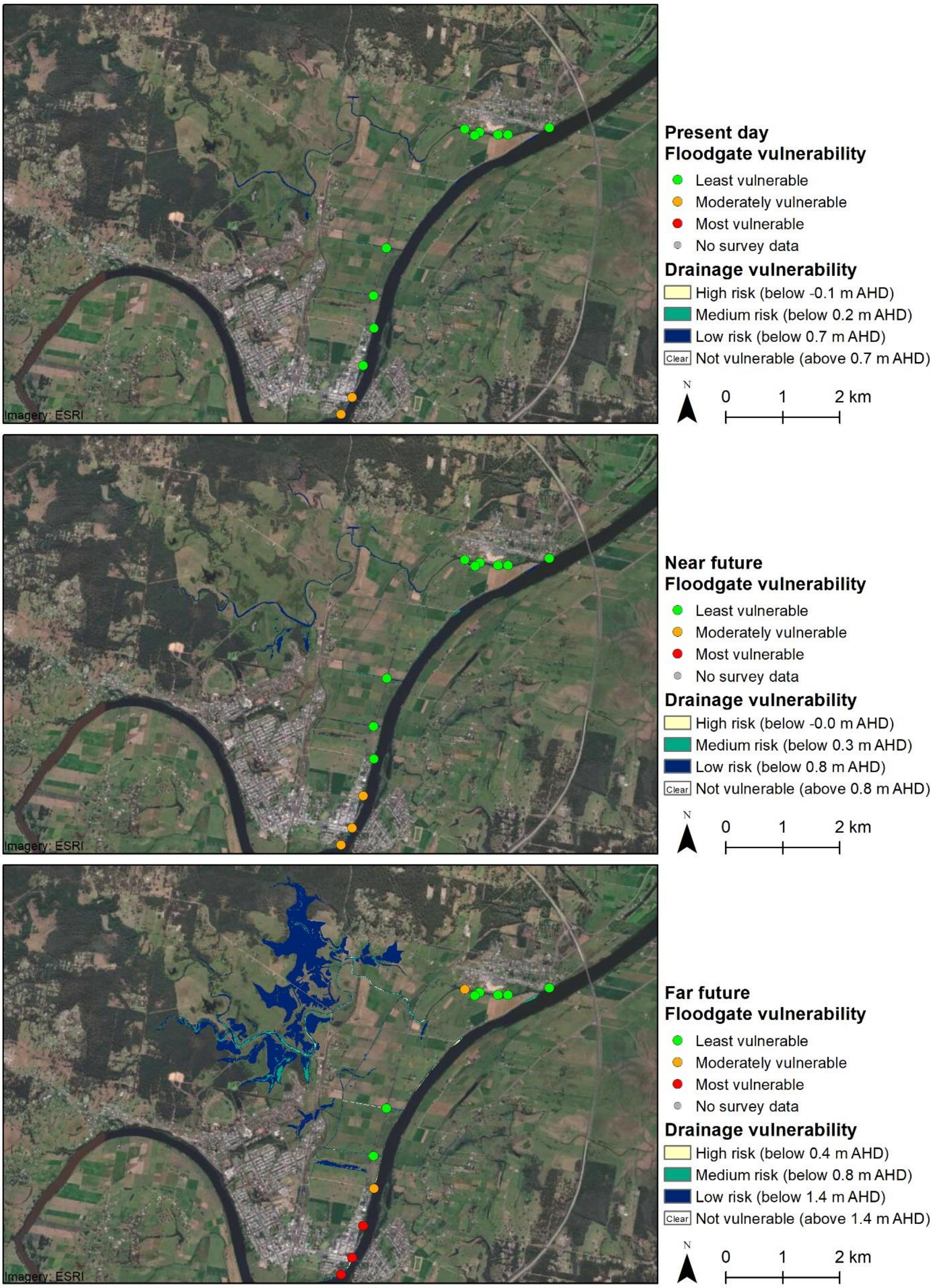

Figure 8-30: Sea level rise drainage vulnerability – Christmas Creek subcatchment

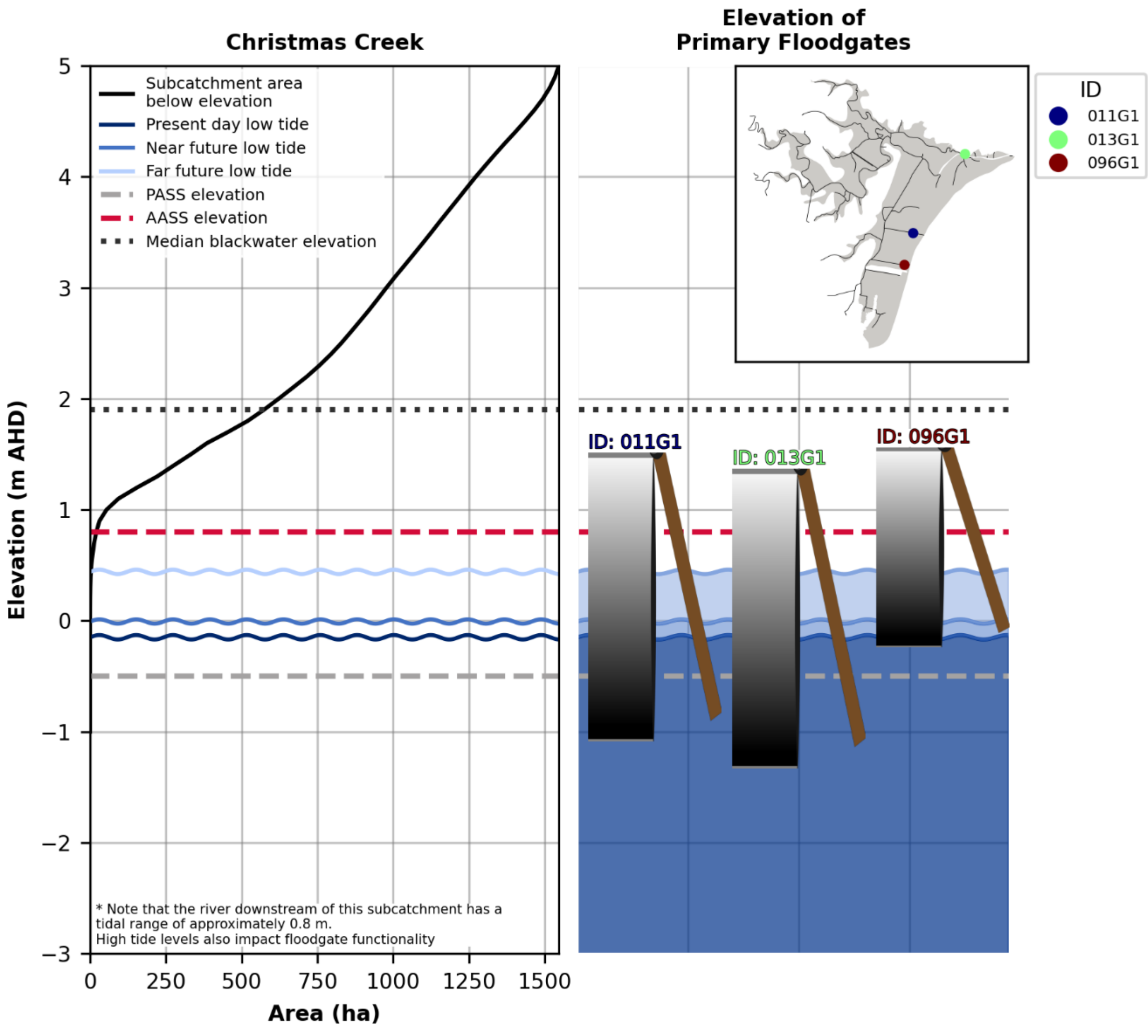

Figure 8-31: Primary floodgates and key floodplain elevations – Christmas Creek subcatchment

8.6.4 Management options

Potential management options for short and long-term planning horizons for the Christmas Creek subcatchment include:

- Short-term: Optimise in-drain tidal flushing, install drop boards, and utilise wet pasture management.
- Long-term: Protection and expansion of existing freshwater wetlands, wet pasture management and drain infilling/reshaping.

Note that short and long-term management options are based on existing data and may be subject to change upon detailed site investigation and/or additional information. The options tabled are intended to provide a range of potential options that could be investigated further as required.

Short-term management options
Structures 011G1 and 096G1 could be actively managed to allow controlled tidal flushing to improve water quality during dry periods and provide aquatic connectivity. This would involve creating/updating floodgate management plans for these structures. The floodgate management plans could be similar to the existing one for the Christmas Creek headworks (structure 013G1) which allows the floodgates to be winched open during non-flood times. Some additional smaller upstream structures or levee upgrade works could be investigated to provide additional protection for private land upstream of the floodgates from large rainfall and spring tide events. Continued active management of the Christmas Creek headworks (structure 013G1) should continue.

Drop board structures could be installed within private property on secondary drainage channels in upstream sections of Christmas Creek to encourage freshwater retention on the low-lying land during non-flood times. This could be implemented alongside wet pasture management practices.

Continued adaptive management of rehabilitation works completed by Kempsey Shire Council at the Belmore Street site downstream of the Kempsey Sewage Treatment Works should continue. As part of these works the existing weir constructed for the Belmore Street drainage system management plan (Kempsey Shire Council, 2015a) could also be reviewed and updated (if required).

Long-term management options
The existing freshwater wetlands upstream of the weir constructed for the Belmore Street drainage system management plan (Kempsey Shire Council, 2015a) could be expanded and protected. This would include fencing of wetland areas and stock exclusion.

Secondary floodplain drains could be infilled, natural flow paths restored and wet pasture management practices adopted. By facilitating prolonged drainage and an increased time of shallow depth inundation, the export of acid and blackwater would be reduced.

Glenrock Drain, Verges Drain and Willows Drain could all be reshaped (shallowed and widened) so that their intersection with acid sulfate soils is reduced. An assessment should be completed to ensure these works do not impact flooding within the local area, in particular for Kempsey.

A summary of the potential management options for the Christmas Creek subcatchment including indicative costs is provided in Table 8-9.

Table 8-9: Summary of management options for Christmas Creek

Timeframe	Strategy	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing per year)	Indicative cost (lost productivity per year)	Effectiveness at improving:		
						Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Optimise tidal flushing	None	None	$5,000	None	Moderate	Moderate	Negligible
Short-term	Install drop boards	None	$50,000	20,000	Minimal	None	Moderate	Low
Short-term	Wet pasture management	None	$40,000	None	Minimal	None	Low	Moderate
Long-term	Drain infilling/reshaping	None	$500,000	None	Minimal	None	Moderate	Moderate

*Costs exclude additional investigation/studies, including; REF, EIS, flood studies, and monitoring programs that may be required prior to implementation.

8.7 Belmore Swamp subcatchment

Acid priority rank:	**5**
Blackwater priority rank:	**2**
Infrastructure	
Approximate waterway length (km)	44
# Privately owned end of system structures	0
# Publicly owned end of system structures	2
# Jointly owned end of system structures	0
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (floodgate ID)	016G1, 017G1
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-1.9 to -1.8
Average AASS elevation (m AHD)	-0.3
Average PASS elevation (m AHD)	-1.1
Median blackwater elevation (m AHD)	1.2
Present day low water level (m AHD)	-0.2
Near future low water level (m AHD)	0.0
Far future low water level (m AHD)	0.4
Proximity to sensitive receivers	
Oyster leases (km)	23.5
Saltmarsh (km)	20.5
Seagrass (km)	24.2
Mangroves (km)	18.0
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	5,109
Classified as conservation and minimal use (ha (%))	1,217 (24%)
Classified as grazing (ha (%))	1,560 (31%)
Classified as forestry (ha (%))	0 (0%)
Classified as horticulture (ha (%))	0 (0%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	71 (1%)
Classified as marsh/wetland (ha (%))	2,206 (43%)
Other (ha (%))	54 (1%)
Land values	
Estimated total primary production value ($/year)	$700,000
Average land value above 1.2 m AHD ($/ha)	$6,200
Average land value below 1.2 m AHD ($/ha)	$2,400

8.7.1 Site description and brief history of drainage

The Belmore Swamp subcatchment is located at the southern extent of the Belmore River. It is the most southern subcatchment in the Macleay River floodplain. The main hydrological features of this subcatchment include the Belmore River which originates in the centre of the floodplain, Ryans Cut which discharges water directly from the floodplain to the ocean during large flood events, Killick Creek which flows from south-to-north through the floodplain, and Connection Creek which connects the Macleay River floodplain to the Hastings River floodplain (see further details in Section 8.7.2 and Figure 8-36). The flow direction through Killick Creek varies, and water can either be transported to the Belmore River via Scotts Drain or to the ocean via Killick Creek's ocean entrance located at Crescent Head. Similarly, the flow direction of Connection Creek can vary depending upon different catchment influences within the Macleay River catchment and the Hastings River catchment (Chong, 2019).

As part of the Macleay River flood mitigation scheme a large number of works were completed within the Belmore Swamp subcatchment between the 1950s and 1970s (Tulau, 2011):

- Channelisation of Killick Creek (1955);
- Killick Creek headworks (068G1) (1957);
- Belmore River headworks (017G1) (1959);
- Thurgoods Drain modification and headworks (021G1) (pre-1962);
- Worthings Drain and headworks (020G1) (pre-1962);
- Scotts Drain (1964);
- Ryans Cut and headworks (069G1) (1973);
- Scotts Drain headworks (088G1) (1974); and
- Belmore River floodway and headworks (sluice gate 016G1) (1976).

Note, Killick Creek headworks (068G1) and Ryans Cut headworks (069G1) are managed only to allow flow out of the Belmore Swamp subcatchment and subsequently the Belmore River headworks (017G1) are the primary end of system structures for the Belmore Swamp subcatchment. Only when the Belmore River headworks (017G1) are open can water flow upstream to other flood mitigation structures within the Belmore Swamp subcatchment.

Management of the Belmore River headworks (017G1) (Figure 8-32) and the Belmore floodway structure (016G1) (Figure 8-33) play an important role in the management of the Belmore Swamp subcatchment. During day-to-day conditions, the flood control structures (017G1 and 016G1) are opened (Kempsey Shire Council, 2015a). Note, the floodway structure (016G1) has an impoundment area upstream which protects the floodplain from inundation (p.comms R. Kemsley, 2021). The day-to-day operational rules for Belmore floodway structure (016G1) has changed over time. Historically, Webb McKeown and Associates Pty Ltd. (2000) stated that during day-to-day conditions the floodway is kept closed, however, when inspected during non-flood conditions it was observed to be open. It is understood that currently during non-flood periods, once the water level has dropped below the crest level of the levee which surrounds the upstream impoundment area, the structure is allowed to open (p.comms R. Kemsley, 2021). When a flood is predicted in the Macleay River, both the Belmore River headworks (017G1) and the Belmore floodway structure (016G1) are closed (Chong, 2019; Webb McKeown and Associates Pty Ltd., 2000). This protects the low-lying land in the Belmore Swamp subcatchment from inundating during nuisance flood events. During large flood events, when the Belmore River begins to overtop its levees (at approximately +3.8 m AHD) the Belmore floodway structure (016G1) is opened and the floodplain is allowed to inundate (Chong, 2019; Webb McKeown and Associates Pty Ltd., 2000). The purpose of this is to utilise the Belmore Swamp floodplain as a retention basin to reduce flood levels across the wider Macleay River floodplain (McDonald, 1967). Once floodwaters begin to recede the Belmore floodway structure (016G1) is then closed (Chong, 2019) and water is allowed to drain through the Belmore River headworks (017G1).

Figure 8-32: Belmore River headworks (017G1) winched open when inspected in March 2020

Figure 8-33: Belmore floodway structure (016G1) open when inspected in September 2019 (top) and March 2020 (bottom)

The major land uses for the Belmore Swamp subcatchment are marsh/wetland (43%), grazing (31%) and conservation/minimal use (24%). Tenure information for the Belmore Swamp subcatchment is shown in Figure 8-34. Information on drainage and floodplain elevation is shown in Figure 8-35.

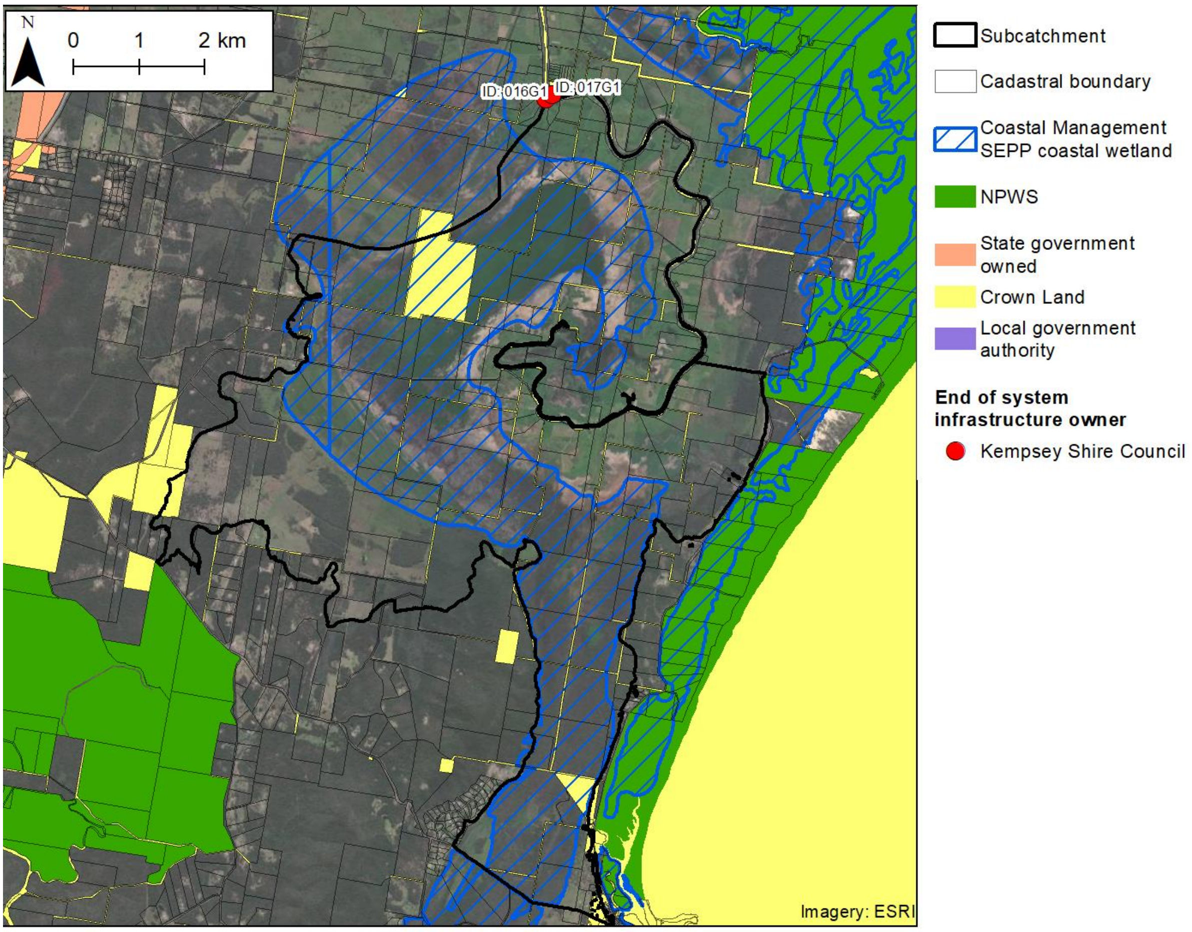

Figure 8-34: Belmore Swamp subcatchment land and end of system infrastructure tenure

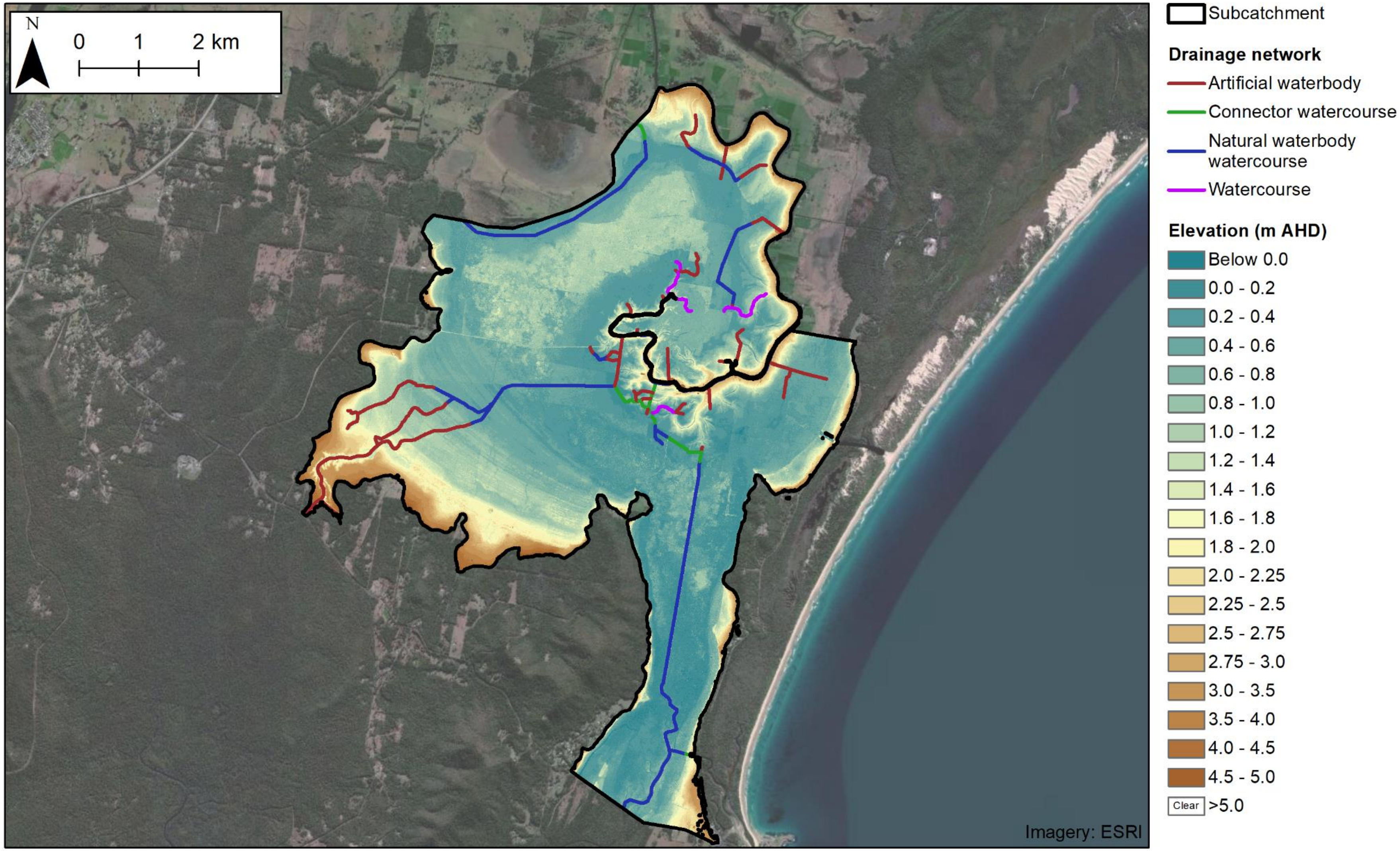

Figure 8-35: Belmore Swamp subcatchment elevation and drainage network

8.7.2 History of remediation

Early remediation strategies for the Belmore Swamp subcatchment involved the partial opening of floodgates for the purpose of remediating acid scalds and to raise the water table to assist with the growth of pasture (Tulau and Naylor, 1999). In 2000, the Upper Belmore Floodplain Management Strategy was developed with the objective of reducing the environmental impact of the flood mitigation scheme while ensuring flood protection was maintained (Gibbs and Bodycott, 2000). The Upper Belmore Floodplain Management Strategy outlined the following implementation strategy to achieve these objectives (Webb McKeown and Associates Pty Ltd., 2000):

1. Divide the floodplain in management areas;
2. Determine a desired water table for each management area;
3. Manage floodgates to achieve individual management area objectives;
4. Ensure flood protection is not inhibited; and
5. Minimise the exposure of acid sulfate soils.

To assist with the management of the floodplain, Kempsey Shire Council has completed numerous modifications to floodplain infrastructure and developed a number of floodgate management plans. Note the Belmore River headworks and floodway (017G1 and 016G1) are the only end of system structures for the Belmore Swamp subcatchment as all other structures within this subcatchment are located upstream. While this is the case, the Belmore River headworks (017G1) are often kept open meaning upstream structures become tidal barrier and as such their management remains important. Within the Belmore Swamp subcatchment, floodgate management plans have been developed for the following flood mitigation structures outlining how they should be managed:

- Belmore River headworks (017G1) (Kempsey Shire Council, 2015a);
- Sillitoe Drain headworks (018G1) (Kempsey Shire Council, 2005c);
- Worthings Drain headworks (020G1) (Kempsey Shire Council, 2015e);
- Thurgood Drain headworks (021G1) (Kempsey Shire Council, 2007a);
- Killick Creek headworks (068G1) (Kempsey Shire Council, 2015b) and
- Scotts Drain headworks (088G1) (Kempsey Shire Council, N.D.-c).

The management plan for the Killick Creek headworks (structure 068G1) outlines the use of drop board structures on the upstream side of the structure to retain water levels within the western section of Killick Creek to prevent acid sulfate soil oxidisation and to prevent drainage of environmentally sensitive freshwater wetlands upstream. Active management for the remaining flood mitigation structures involves winching the floodgate flaps open during non-flood periods. Note, the Belmore River floodway structure (016G1), which consists of four large sluice gates, does not have a management plan but is actively managed for flooding purposes (Geolink, 2012).

In addition to management of flood mitigation structures, Kempsey Shire Council have also modified the following privately owned floodgates to allow active management in a similar manner:

- Ptolemys Drain floodgates (Kempsey Shire Council, 2004b);
- McCuddens Drain floodgates (Kempsey Shire Council, 2002a);
- Fischer No 2 Drain Floodgates (Kempsey Shire Council, 2006g); and
- Eakins Drain floodgates (Kempsey Shire Council, 2006f).

Other works that have been completed within the Belmore Swamp subcatchment include:

- Drop boards installed on the Fischer No 2 Drain floodgates and Eakins Dain floodgates (Geolink, 2010b; Kempsey Shire Council, 2006g);
- Drop board structures installed on Scotts Drain, McCuddens Drain and upstream of Thurgoods Drain to allow wet pasture management of these sections of floodplain (Kempsey Shire Council, 2006d; Kempsey Shire Council, 2006e; Kempsey Shire Council, 2007a);
- A high level culvert (with an invert of +0.4 m AHD) known as Traceys culvert installed on land previously prone to drying out (Kempsey Shire Council, 2006c); and
- A levee modified on the left bank of Thurgoods Drain and high level floodgates (+1.0 m AHD) installed to allow for the opening of the Thurgood Drain headworks (021G1) without inundating private land with saline water (Kempsey Shire Council, 2007a).

Geolink (2010b) has reported that large areas of scalds have become revegetated upstream of drop board structures on Scotts Drain, McCuddens Drain and Ptolmeys Drain. Extensive freshwater wetlands have established upstream of Fischers No 2 Drain floodgates as a result of these works Geolink (2010b). A summary of remediation actions completed in the Belmore Swamp subcatchment is shown in Figure 8-36.

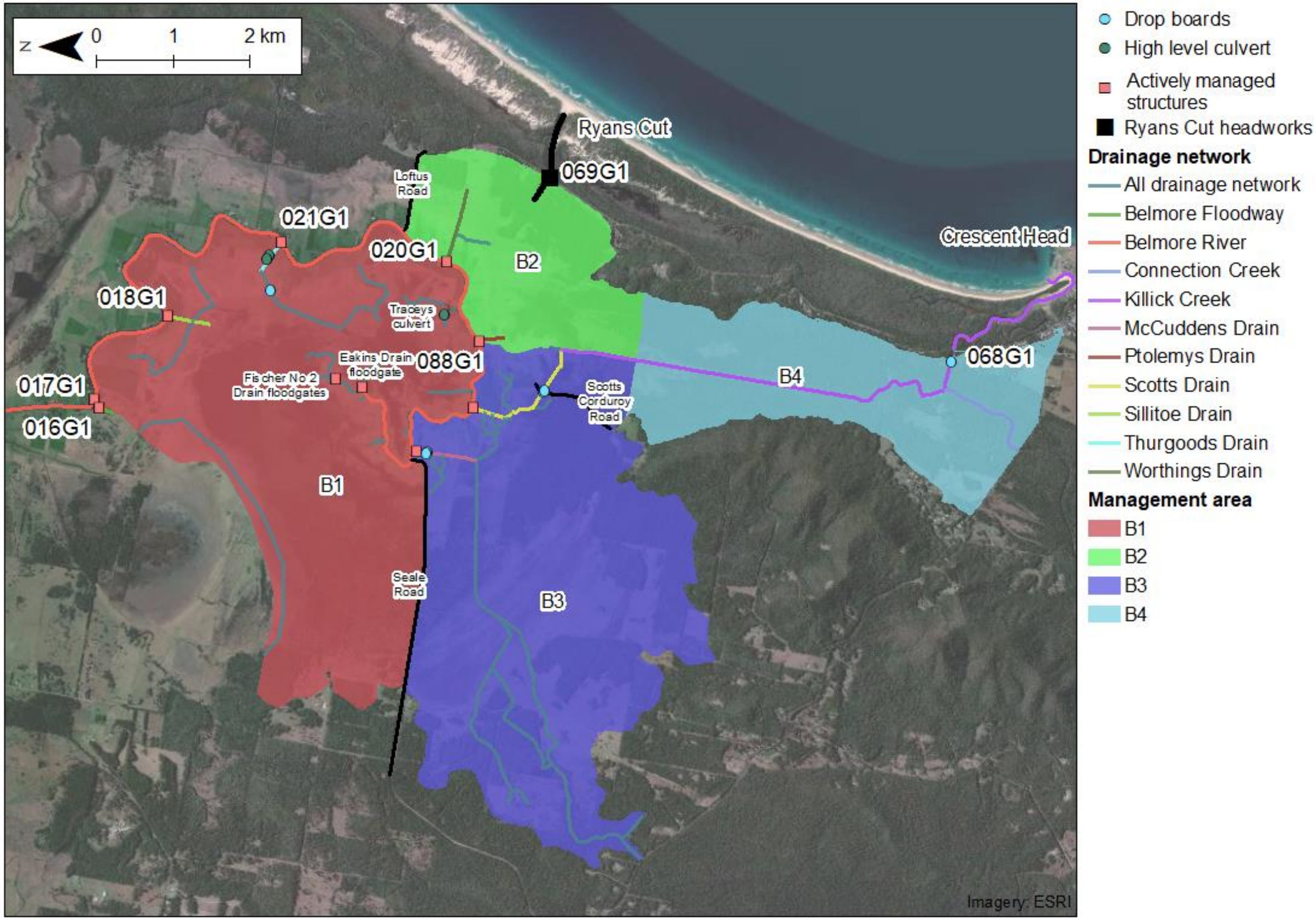

Figure 8-36: The Belmore Swamp subcatchment including previous remediation actions

8.7.3 Prioritisation of management areas in the Belmore Swamp subcatchment

The Belmore Swamp subcatchment is ranked fifth in the acid prioritisation, and second in the blackwater prioritisation. The subcatchment has been further delineated into four (4) smaller management areas (referred to as B1 to B4, shown in Figure 8-37) to provide additional information on the sources of blackwater. The areas have been delineated based on land tenure, data availability, elevation and drainage units. Note, acid risk has only been considered on the subcatchment scale.

Figure 8-37 shows the management areas for the Belmore Swamp subcatchment below the median elevation for blackwater generation (+1.2 m AHD). As elevation is a primary driver of the production of blackwater, the areas below this level typically contribute the most to the risk of large scale deoxygenation (although this can be managed through changing vegetation, land use, and subcatchment hydrology). It is evident that blackwater risk is an issue for the entire subcatchment. Based on these findings the management areas have been used to detail targeted management options for the Belmore Swamp subcatchment.

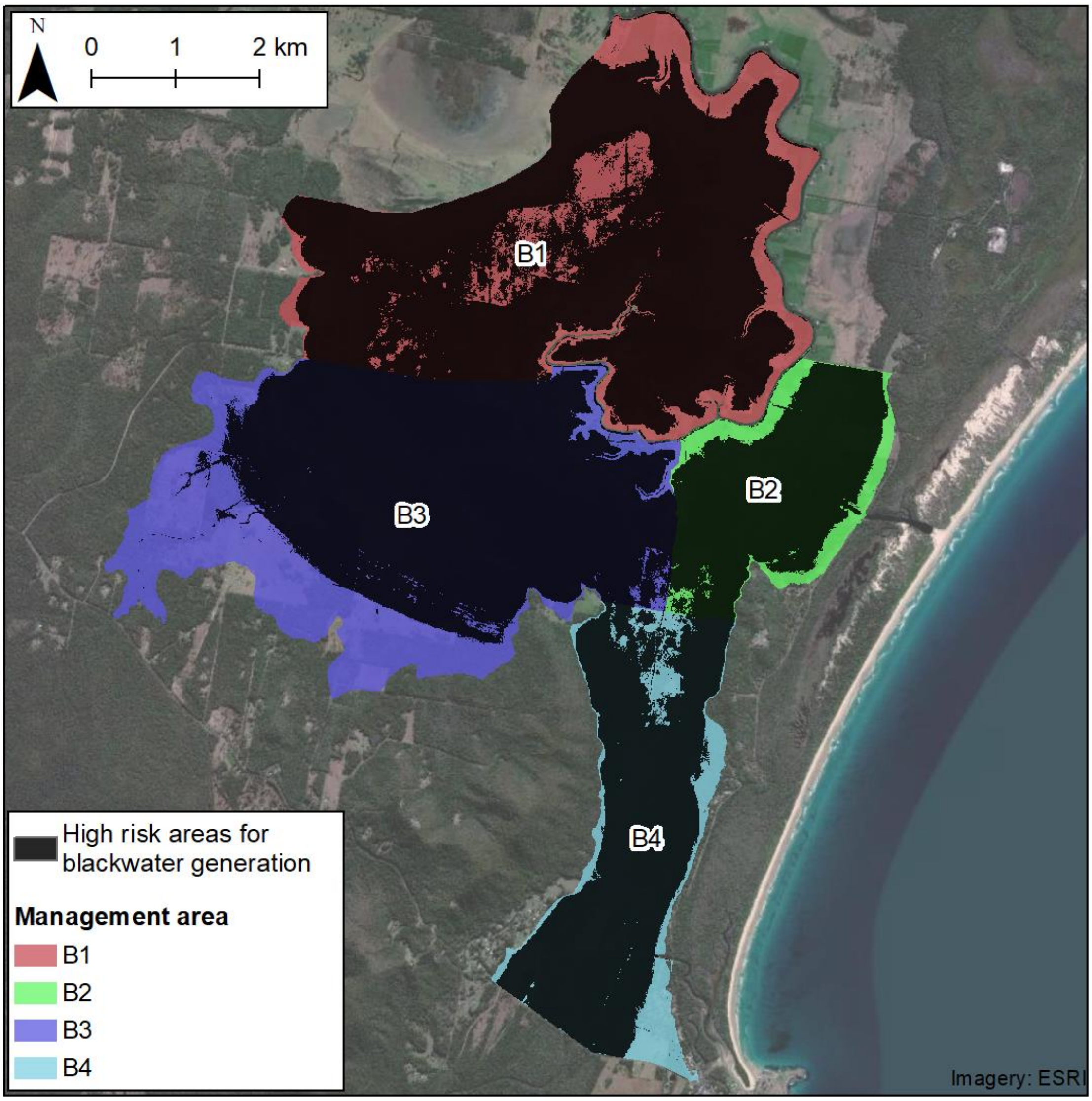

Figure 8-37: Blackwater contribution for management areas in the Belmore Swamp subcatchment (median blackwater level +1.2 m AHD)

8.7.4 Floodplain drainage – sea level rise vulnerability

The sea level rise vulnerability assessment of the Belmore Swamp subcatchment is summarised in Figure 8-39. Present day modelling shows that areas of the Belmore Swamp already have limited drainage with the lowest-lying land along Killick Creek already below the approximate mean tide water level (i.e. at medium risk to reduced drainage). In the future modelling shows that drainage across the floodplain will be significantly reduced. In the far future scenario large areas of the floodplain will be below the approximate low tide water level (+0.4 m AHD) (i.e. at high risk of reduced drainage).

The Belmore River headworks (017G1) is the only end of system structure which acts as a floodgate in the Belmore Swamp subcatchment and is depicted in Figure 8-38 (note, the Belmore River floodway (016G1) is a sluice gate structure). Sea level rise modelling indicates that this floodgate will be moderately vulnerable in the near future, and most vulnerable in the far future.

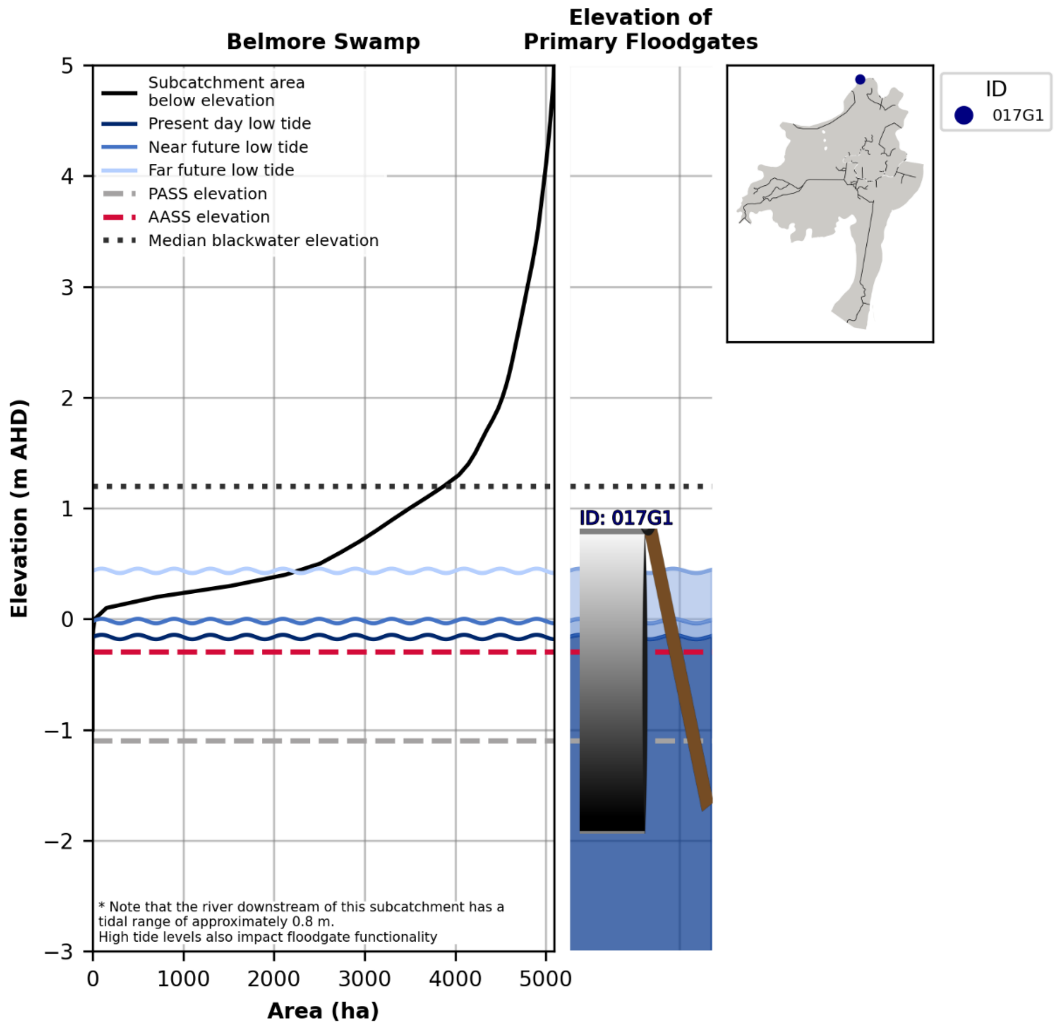

Figure 8-38: Primary floodgates and key floodplain elevations – Belmore Swamp subcatchment

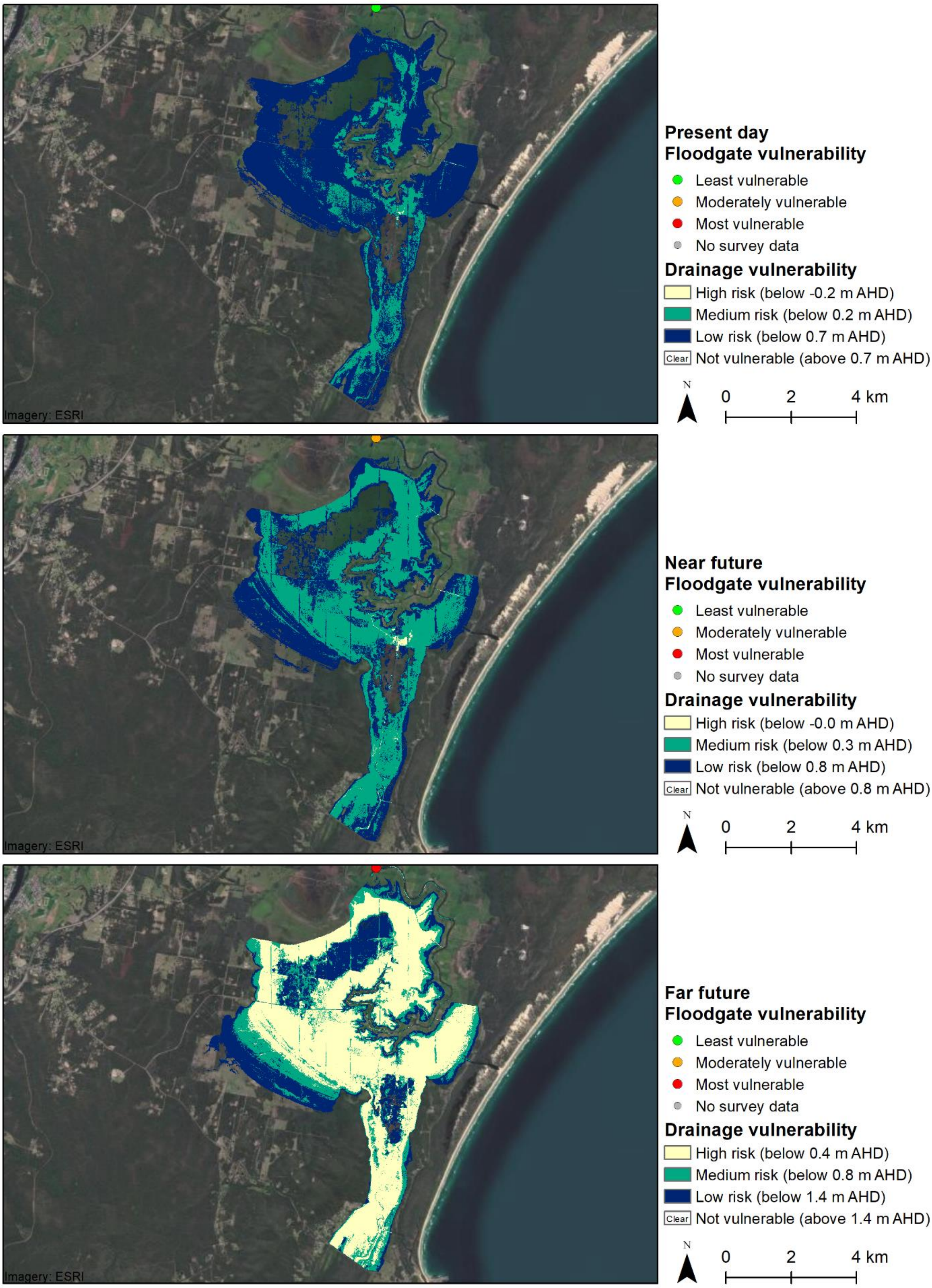

Figure 8-39: Sea level rise drainage vulnerability – Belmore Swamp subcatchment

8.7.5 Management options

Potential management options for short and long-term planning horizons for the Belmore Swamp subcatchment include:

- Short-term: Optimise floodplain infrastructure management, reduce drainage density, reshape drains and install drop board or weir structures to promote wet pasture management and freshwater wetland.
- Long-term: Full restoration to a freshwater wetland and encourage floodwater retention particularly during summer months to reduce blackwater generation and runoff.

For the Belmore Swamp subcatchment extensive remediation works have already been completed attempting to remediate acid sulfate soils and blackwater risk. Due to the existing floodplain hydrology, these actions have resulted in localised improvements only. Similarly, short-term management options will only provide localised small scale benefits to the environment. To achieve tangible improvements to water quality discharging from the Belmore Swamp subcatchment, large scale remediation efforts that treat the subcatchment as a single hydrological unit will be required. Subsequently, these types of remediation options are provided for the long-term planning horizon when the subcatchment will be impacted by reduced drainage due to sea level rise requiring a change in land use.

Note that short and long-term management options are based on existing data and may be subject to change upon detailed site investigation and/or additional information. The options tabled are intended to provide a range of potential options that could be investigated further as required.

Short-term management options

Extensive works have been completed across the Belmore Swamp subcatchment to remediate acid sulfate soils and reduce the risk of blackwater. The short-term management options for the subcatchment should aim to continue this work by seeking to promote the growth of water tolerant vegetation either as wet pasture, or by protecting freshwater wetland areas. Actions that could assist with this include infilling of unnecessary drains, excluding stock from wetland areas, and installing drop board or weir structures to maintain higher water tables. Note, short-term management options will only result in localised, small scale improvements to water quality.

Present day tidal levels influence drainage within the Belmore Swamp subcatchment. Where it is not already taking place, grazing practises should shift towards wet pasture management techniques. It is likely that use of this land for grazing will be limited during wet periods.

It should be noted that a large extent of the Belmore Swamp subcatchment is mapped as Coastal Management SEPP coastal wetlands. Wherever possible, protection of existing wetlands and modification of waterways to restore natural flow paths should be encouraged within this area.

To reduce the risk of blackwater, investigations could be completed to optimise the management of floodplain infrastructure. Current management plans for floodgates, while overseen by Kempsey Shire Council, are independent of one another and generally managed and operated by different landholders. Investigations could be completed whereby a single management strategy for all floodplain infrastructure in unity could reduce the impacts of blackwater in a more effective manner.

Long-term management options

In the future, sea level rise will have a significant impact for drainage across the floodplain, and large scale changes to management of the entire Belmore Swamp subcatchment will need to be considered. It is unlikely that grazing land use across the floodplain that currently takes place will be able to continue in the future to the same degree as the present day land use. In the far-future management options should focus on large scale efforts to restore the natural hydrology to the floodplain including promotion of freshwater wetland and wet pasture management.

Broad scale improvements in water quality from the Belmore Swamp subcatchment could be achieved through rehabilitation of the natural hydrology, which could include infilling drains, restoring natural levees, and removing flow obstructions. A rise in the water table will benefit acid sulfate soils by reducing oxidisation of sulfides. It is likely that blackwater will be an ongoing issue unless significant changes to floodplain management are implemented. There are two strategies to effectively manage blackwater generation:

1. Prevent prolonged inundation of the floodplain that causes vegetation to die, which has limited applicability in low-lying areas of this subcatchment due to the low land elevation; or
2. Retaining deoxygenated floodwaters on the floodplain until the vegetation breakdown process (i.e. carbon cycle) has completed (Southern Cross GeoScience, 2019).

The inundation level within the Belmore Swamp subcatchment during flood events is controlled by water levels in the wider Macleay River. Traditionally, an inability to drain the floodplain has been blamed on inefficiencies in the flood mitigation and drainage network (Webb McKeown and Associates Pty Ltd., 2000). However, while the effect of flood mitigation works on the drainage of the Belmore Swamp subcatchment has resulted in increased drainage efficiency, drainage times for larger flood events are longer than the (approximately) four (4) day period required for standing water to become deoxygenated (see Figure 8-40) (Johnston et al., 2003a). Inundation duration will likely increase significantly into the future due to sea level rise. Restoration of the natural backswamp hydrology and retention of floodwaters are a potential management option to reduce the generation and impact of blackwater runoff.

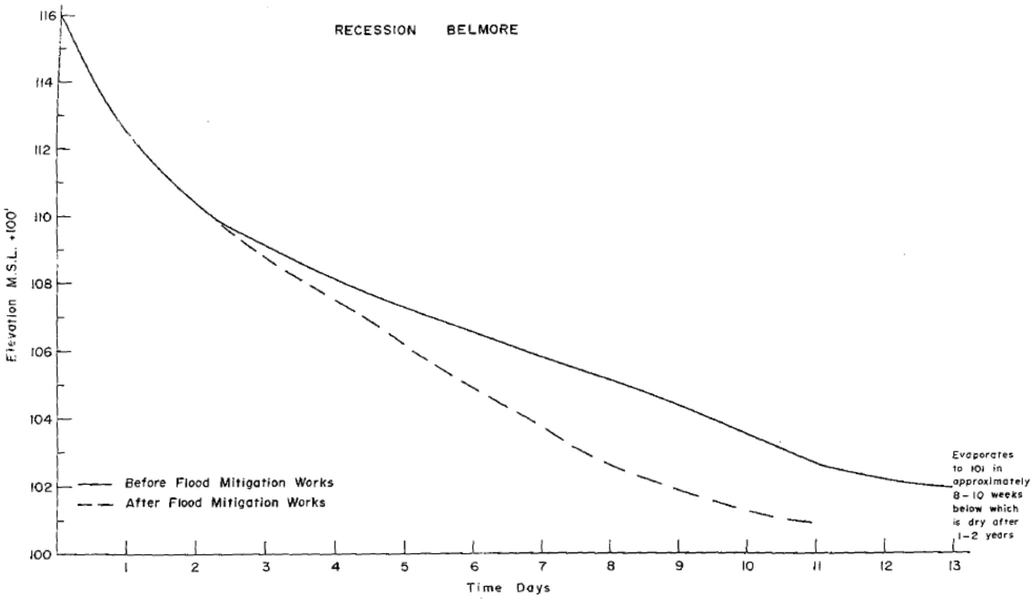

Figure 8-40: Effect of flood mitigation works on flood recession at Belmore Swamp (McDonald, 1967)

Potential works that could be completed (at a conceptual level) to restore the natural hydrology to the Belmore Swamp subcatchment are outlined for each management area below. Note, success in restoring the natural hydrology and improving water quality would be unlikely to result from any single remediation action, rather a whole-of-system remediation approach comprising multiple actions is required.

Within management area B1, recommended management actions would include:

- Infilling of Sillitoe Drain and Thurgoods Drain;
- Infilling of secondary floodplain drains;
- Closure of the Belmore Floodway structure during non-flood times (016G1);
- Permanent opening of Fishers No 2 Drain floodgates (and floodgates upstream);
- Permanent opening of the Belmore River headworks (017G1);
- Decommissioning of floodgates connecting artificial channels to the Belmore River (to prevent flow through them); and
- Review capacity of existing culverts under Seale Road and add new culverts (if required) to increase connectivity with management area B3.

Within management area B2, recommended management actions would include:

- Infilling of Worthings Drain and Ptolemys Drain;
- Infilling of secondary floodplain drains;
- Decommissioning of floodgates connecting artificial channels to the Belmore River (to prevent flow through them); and
- Consider installing culverts under Loftus Road to increase connectivity with the Kinchela Creek subcatchment.

Within management area B3, recommended management actions would include:

- Infilling of Scotts Drain and McCuddens Drain;
- Infilling of secondary floodplain drains;
- Decommissioning of floodgates connecting artificial channels to the Belmore River (to prevent flow through them);
- Review capacity of existing culverts under Seale Road and add new culverts (if required) to increase connectivity with management area B1; and
- Install culverts to increase connectivity with management area B4 under Scotts Corduroy Road.

Within management area B4:

- Infilling of modified sections of Killick Creek;
- Infilling of secondary floodplain drains;
- Install culverts to increase connectivity with management area B3 under Scotts Corduroy Road; and
- Continued management of drop boards on Killick Creek headworks (068G1).

The aim of these works would be to restore the natural backswamp hydrology to the Belmore Swamp subcatchment to prompt the expansion of freshwater wetlands. This strategy is conceptual and requires further investigation including but not limited to:

- Extensive consultation of local landholders and extensive consideration of the social and economic impacts of the strategy;
- Detailed assessment of the impacts to overall flooding for the Macleay River should be completed;
- Determine if saline intrusion from the estuary would impact the floodplain. Historically, high tides in the Belmore River would result in overtopping of the floodplain with freshwater (Webb McKeown and Associates Pty Ltd., 2000). It is unclear how sea level rise would impact this;
- Assessment of impacts of sea level rise to Ryans Cut and Killick Creek; and
- Assessment of how the strategy would be implemented alongside those for the Frogmore/Austral Eden/Verges Swamp subcatchment and Kinchela Creek subcatchment.

A summary of the potential management options for the Belmore Swamp subcatchment including indicative costs is provided in Table 8-10.

Table 8-10: Summary of management options for Belmore Swamp

Timeframe	Strategy	Target management area(s)	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing per year)	Indicative cost (lost productivity per year)	Effectiveness at improving:		
							Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Drain infilling/reshaping	Entire subcatchment	None	$900,000	None	Minimal	None	Moderate	Low
Short-term	Install water retention structures	Entire subcatchment	None	$125,000	25,000	Minimal	None	Moderate	Low
Short-term	Wet pasture management	Entire subcatchment	None	$100,000	None	Minimal	None	Low	Moderate
Long-term	Restoration of wetlands	Entire subcatchment	$13,000,000	$650,000	Minimal	$1,800,000	Very high	High	High

*Costs exclude additional investigation/studies, including; REF, EIS, flood studies, and monitoring programs that may be required prior to implementation

8.8 Kinchela Creek subcatchment

Acid priority rank:	**6**
Blackwater priority rank:	**1**
<u>Infrastructure</u>	
Approximate waterway length (km)	77
# Privately owned end of system structures	2
# Publicly owned end of system structures	30
# Jointly owned end of system structures	0
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (floodgate ID)	017G1, 019G1, 023G1, 024G1, 027G1, The Lock
<u>Elevations</u>	
Invert of primary floodplain infrastructure (m AHD)	-1.9 to -0.3
Average AASS elevation (m AHD)	-0.3
Average PASS elevation (m AHD)	-0.7
Median blackwater elevation (m AHD)	1.0
Present day low water level (m AHD)	-0.2
Near future low water level (m AHD)	0.0
Far future low water level (m AHD)	0.4
<u>Proximity to sensitive receivers</u>	
Oyster leases (km)	12.5
Saltmarsh (km)	7.8
Seagrass (km)	11.6
Mangroves (km)	5.4
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
<u>Land use</u>	
Total floodplain area (ha)	6,054
Classified as conservation and minimal use (ha (%))	1,012 (17%)
Classified as grazing (ha (%))	3,357 (55%)
Classified as forestry (ha (%))	0 (0%)
Classified as horticulture (ha (%))	2 (0.03%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	117 (2%)
Classified as marsh/wetland (ha (%))	1,197 (20%)
Other (ha (%))	370 (6%)
<u>Land values</u>	
Estimated total primary production value ($/year)	$1,500,000
Average land value above 1.0m AHD ($/ha)	$10,600
Average land value below 1.0 m AHD ($/ha)	$4,200

8.8.1 Site description and brief history of drainage

The Kinchela Creek subcatchment is located on the right bank of the Macleay River and the Belmore River. The subcatchment is hydrologically linked to the Raffertys/Saltwater Inlet subcatchment to the north, however, Loftus Road acts as a levee, separating it from the Belmore Swamp subcatchment to the south. Kinchela Creek is the main waterway for the subcatchment and flows from south-to-north into the Macleay River. Some areas of the subcatchment drain via the Belmore River which forms the western boundary of the subcatchment.

Drainage of the Kinchela Creek subcatchment began in the 1880s, although extensive drainage did not occur until the 1960s when flood mitigation works were completed across the subcatchment (Tulau, 2011). Major works that were completed across the Kinchela Creek subcatchment include (Smith, 2002; Tulau, 2011).

- The Lock headworks on upper Kinchela Creek (1931);
- Belmore River headworks (017G1) (1959);
- Kinchela No 2 Drain (1961);
- Reillys Drain and headworks (021G1) (pre 1962);
- Schoolhouse Drain and headworks (027G1) (pre 1962);
- Slaughterhouse Drain and headworks (028G1) (pre 1962);
- Hoffmans Drain and headworks (029G1) (pre 1962);
- McNallys Drain and headworks (032G1) (pre 1962);
- Gladstone Drain and headworks (019G1) (1967);
- Korogoro Cut and headworks (033G1) connecting the floodplain to Korogoro Creek which has an entrance to the ocean at the town of Hat Head (1968);
- Kinchela Creek headworks (sluice gates 025G1) (1968);
- Kinchela Creek west floodway (sluice gates 025G1) (1968); and
- Kinchela Creek east floodway (sluice gates 026G1) (1968).

Two large floodway structures (sluice gates 025G1 and 026G1) on Kinchela Creek and the Kinchela Creek headworks (024G1) are utilised to manage flooding in the Macleay River (Figure 8-41). During day-to-day conditions, the Kinchela headworks (024G1) and floodway structures (sluice gates 025G1 and 026G1) are opened to allow tidal flushing upstream (Geolink, 2012; Kempsey Shire Council, 2015c). When a flood is predicted in the Macleay River the Kinchela Creek headworks (024G1) and the floodway structures (sluice gates 025G1 and 026G1) are all closed (Chong, 2019). This protects the low-lying land in the Kinchela Creek subcatchment from inundation during minor flood events. During large flood events, when the Kinchela Creek levees begin to overtop its levees (at approximately +3m AHD) the Kinchela Creek floodway structures (sluice gates 025G1 and 026G1) are opened and the floodplain is allowed to inundate (Chong, 2019). The purpose of this is to utilise Kinchela Creek floodplain as a flood retention basin to reduce flood levels across the wider Macleay River floodplain (Walker, 1962). Once floodwaters begin to recede, the Kinchela Creek floodway structures (sluice gates 025G1 and 026G1) are then closed (Chong, 2019) and water is allowed to drain through the Kinchela Creek headworks (024G1). Once water levels have returned to their normal levels and the flood risk is reduced the Kinchela Creek headworks (024G1) are then reopened (Kempsey Shire Council, 2015c). It is worth noting that the Belmore River headworks (017G1) are managed in a similar manner to the Kinchela Creek headworks and affect drainage from Reillys Drain in the south of the Kinchela Creek subcatchment (Kempsey Shire Council, 2015a).

Figure 8-41: Major end of system flood control structures on Kinchela Creek including the Kinchela Creek headworks (024G1) (top), Kinchela Creek west floodway (025G1) (bottom left) and Kinchela Creek east floodway (026G1) (bottom right)

An area known as Swan Pool is located on the south east of the Kinchela Creek subcatchment and was one of the first areas to be drained (Tulau, 2011). The NSW National Parks and Wildlife Service now own a large portion of this land which forms part of the Hat Head National Park. The major land use for the Kinchela Creek subcatchment is grazing which accounts for 55% of the land use across the subcatchment. Tenure information for the Kinchela Creek subcatchment is shown in Figure 8-42. Information on drainage and floodplain elevation is shown in Figure 8-43.

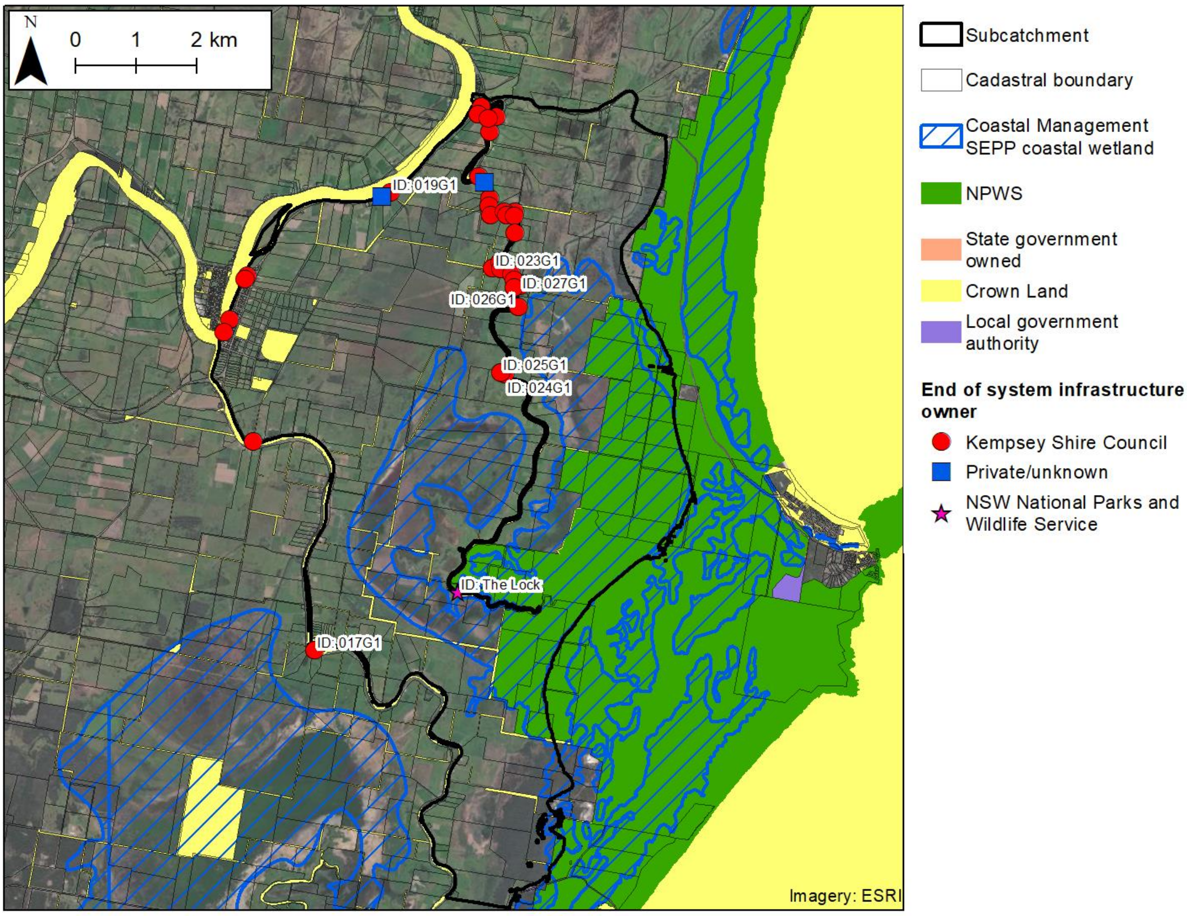

Figure 8-42: Kinchela Creek subcatchment land and end of system infrastructure tenure

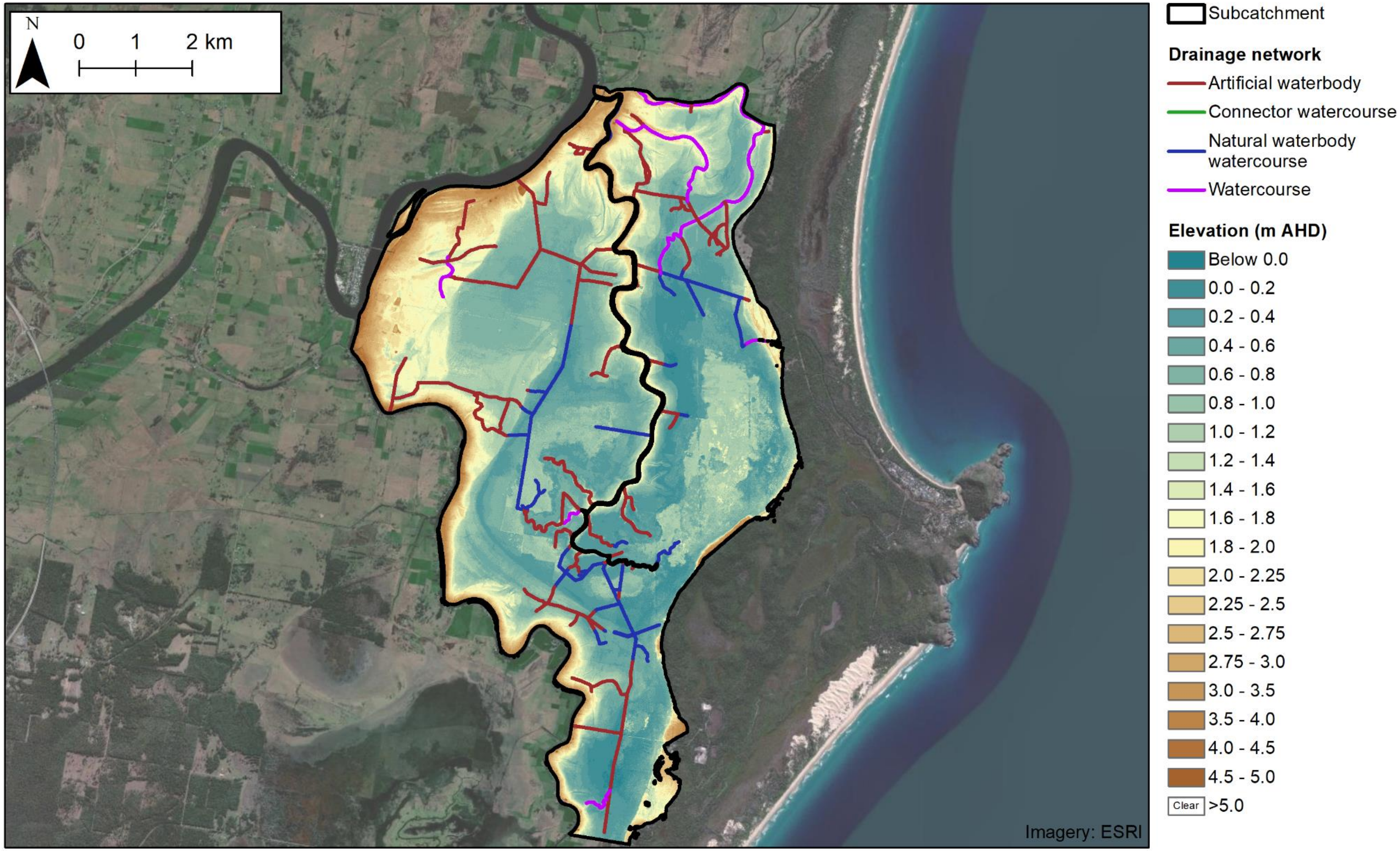

Figure 8-43: Kinchela Creek subcatchment elevation and drainage network

8.8.2 History of remediation

Flood mitigation plan drawings for the Belmore-Kinchela area outline modifications to floodgate structures including the installation of drop boards on McNallys Drain headworks (032G1) and Schoolhouse Drain headworks (027G1) (Macleay River County Council, 1960). Despite this, it is understood that the provision to install drop boards on these structures is only for maintenance purposes (p.comms R. Kemsley, 2021). Other early records of remediation attempts within the Kinchela Creek subcatchment describe the use of water retention structures to maintain higher water levels within waterways and the adjacent land (Geolink, 2010b; Tulau and Naylor, 1999). Tulau and Henderson (2000) specifically noted a number of these remediation efforts including the installation of:

- A lifting device on Wilsons Drain floodgates (Figure 8-44);
- A sluice gate on Wilsons Drain floodgates (Figure 8-44);
- Drop boards on Wilsons Drain;
- Drop boards on Kinchela No. 2 Drain (Note, these have since been replaced by a floodgate with a high level invert) (Figure 8-45);
- Lifting devices and bucket weirs on Irwins Drain floodgates; and
- A lifting device on one floodgate on Bradleys Drain floodgates.

In addition to these works, plastic floodgates that had lifting devices were installed on the Lock in 2002 (Kempsey Shire Council, 2007c). Further works were completed in 2007 with the aim of extending the floodgates life for an additional 20 years. This resulted in the installation of a buoyancy controlled auto-tidal gate on one floodgate flap, a weir on the upstream side of the floodgates with an elevation of 0.0 m AHD, and an earthen sill/weir (the North Drain Weir) located approximately one (1) kilometre upstream of the floodgates with a crest elevation of 0.0 m AHD (Kempsey Shire Council, 2007c). Field investigations completed by Tucker and Rayner (2021) in June 2021 found that the auto-tidal gate on The Lock had been removed (Figure 8-46), the low level weir immediately upstream of The Lock had been removed, and the North Drain Weir no longer existed (only remnants of the weir were found).

Figure 8-44: Lifting device installed on Wilsons Drain in 2000 (Tulau, 2011)

Figure 8-45: Floodgate on Kinchela No. 2 Drain (Source: Ron Kemsley, Kempsey Shire Council)

Figure 8-46: The Lock without auto-tidal floodgates (June, 2021) (Tucker and Rayner, 2021)

In 2002, Smith (2002) completed a review of the drainage management of the Swan Pool area and proposed the following seven (7) recommendations:

1. Adopt a 5-10 year strategy to reinstate the natural hydrology of the area;
2. Ensure wetland values are included in maintenance and management strategies for floodgates;
3. Adopt best management practices for floodgate management to allow improved communication with stakeholders;

4. Explore options to incorporate private land below +0.5 m AHD into the Hat Head National Park;
5. Modify Korogoro Cut to reduce groundwater draw down;
6. Acquire existing wetland that remains freehold for incorporation to the Hat Head National Park; and
7. Replace the Lock with a new structure on Kinchela Drain No. 2 to reinstate tidal flows in upstream Kinchela Creek.

Kempsey Shire Council (2006h) noted the recommendations were never adopted by stakeholders and it is also understood that NPWS never formally adopted or endorsed the recommendations (p.comms R. Kemsley, 2021). Geolink (2010b) found that by 2010 some progressive implementation of the recommendations had taken place including modifications to the Lock, changes in land use practises and land acquisitions. Tucker and Rayner (2021) recently reviewed the implementation of these actions and found that the modifications to The Lock have since been removed. They also found that none of the other recommendations were successfully implemented. Land acquisitions only occurred to the south of the floodplain and did not include key locations on the floodplain required to reinstate the natural floodplain hydrology.

Since 2003, Kempsey Shire Council had created a number of plans to assist with the management of floodplain infrastructure. Specifically, these included plans for:

- The active management of Irwins Drain floodgates (Kempsey Shire Council, 2003);
- The active management of a sluice gate installed on the Kinchela No 2 Drain floodgates (030G1) (Kempsey Shire Council, 2006h);
- The active management of buoyancy controlled auto-tidal gates on the Lock (Kempsey Shire Council, 2007c);
- The active management of the Reillys Drain floodgate (022G1) (Kempsey Shire Council, 2015d);
- The active management of the Kinchela Creek headworks structure (024G1) (Kempsey Shire Council, 2015c); and
- The active management of the Belmore River headworks structure (017G1) (Kempsey Shire Council, 2015a).

Other remediation efforts were noted by Geolink (2010a) and include wet pasture management and stock exclusion from an acid scald adjacent to Schoolhouse Drain. There was also a plan to install a low level weir on Gladstone Drain which was not implemented (Geolink, 2012). During field investigations completed for this study, lifting devices were observed on the Gladstone Drain headworks (019G1) and Hoffmans Drain headworks (029G1) but were not open at the time of inspection. Geolink (2012) indicated that these structures are not actively managed. A summary of the remediation works that have been completed on the Kinchela Creek subcatchment is shown in Figure 8-47.

Recently, Tucker and Rayner (2021) completed a detailed investigation that reviewed the remediation of the East Kinchela (Swan Pool) floodplain. Their study found that in order to remediate the Swan Pool floodplain and improve water quality, the Swan Pool system needs to be restored as a single hydrological unit. This would require the change in floodplain land use from agriculture such as grazing to environmental protection.

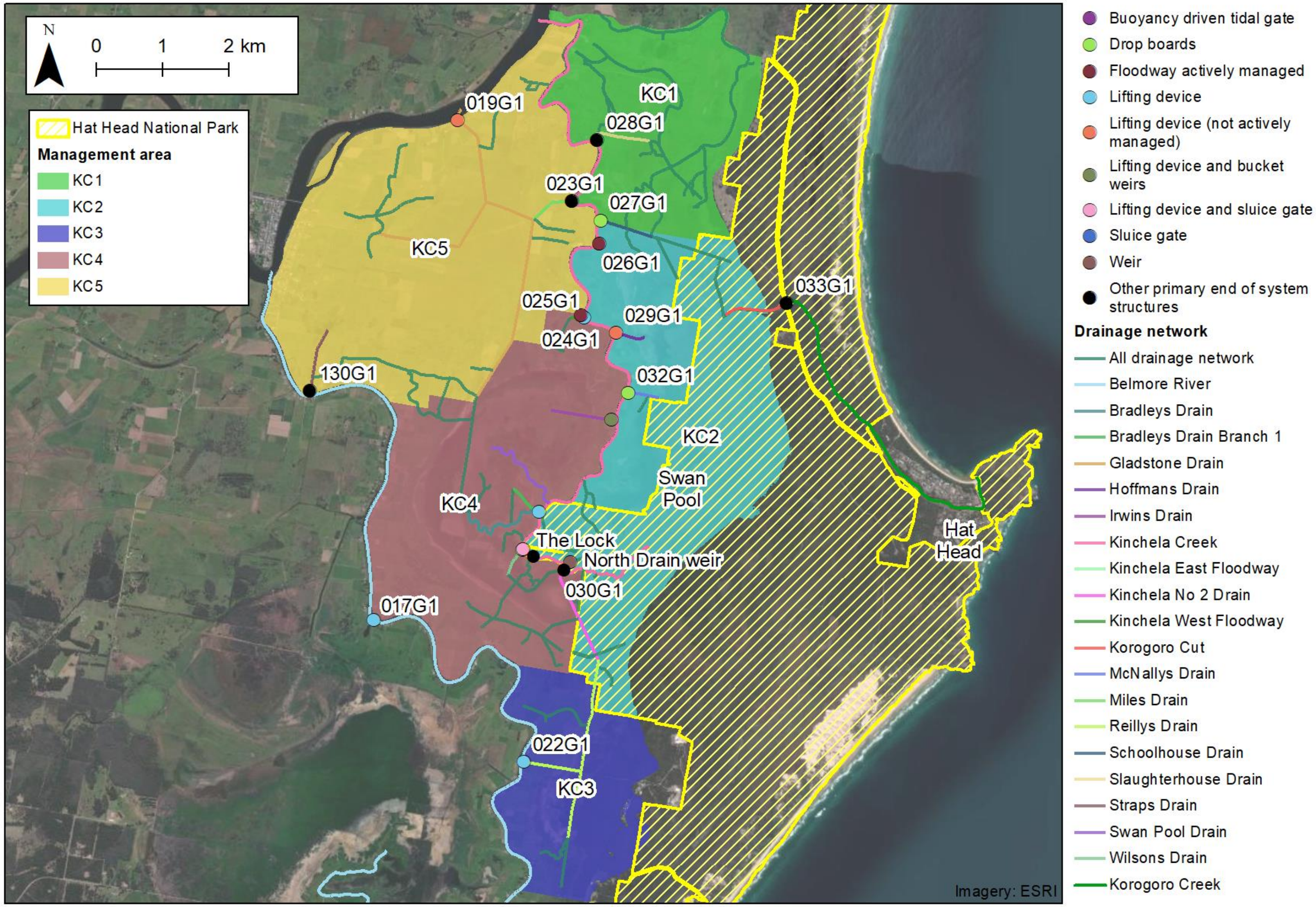

Figure 8-47: The Kinchela Creek subcatchment including previous remediation actions

8.8.3 Prioritisation of management areas in the Kinchela Creek subcatchment

The Kinchela Creek subcatchment is ranked sixth in the acid prioritisation, and first in the blackwater prioritisation. The subcatchment has been further delineated into five (5) smaller management areas (referred to as KC1 to KC5, shown in Figure 8-48) to provide additional information on the sources of blackwater. The areas have been delineated based on land tenure, data availability, elevation and drainage units. Note, acid risk has only been considered on the subcatchment scale as this subcatchment ranked sixth in that assessment.

Figure 8-48 shows the management areas for the Kinchela Creek subcatchment below the median elevation for blackwater generation (+1.0 m AHD). As elevation is a primary driver of the production of blackwater, the areas below this level typically contribute the most to the risk of large scale deoxygenation (although this can be managed through changing vegetation and land uses). It is evident that blackwater risk is an issue for the entire subcatchment. Based on these findings the management areas have been used to detail targeted management options for the Kinchela Creek subcatchment.

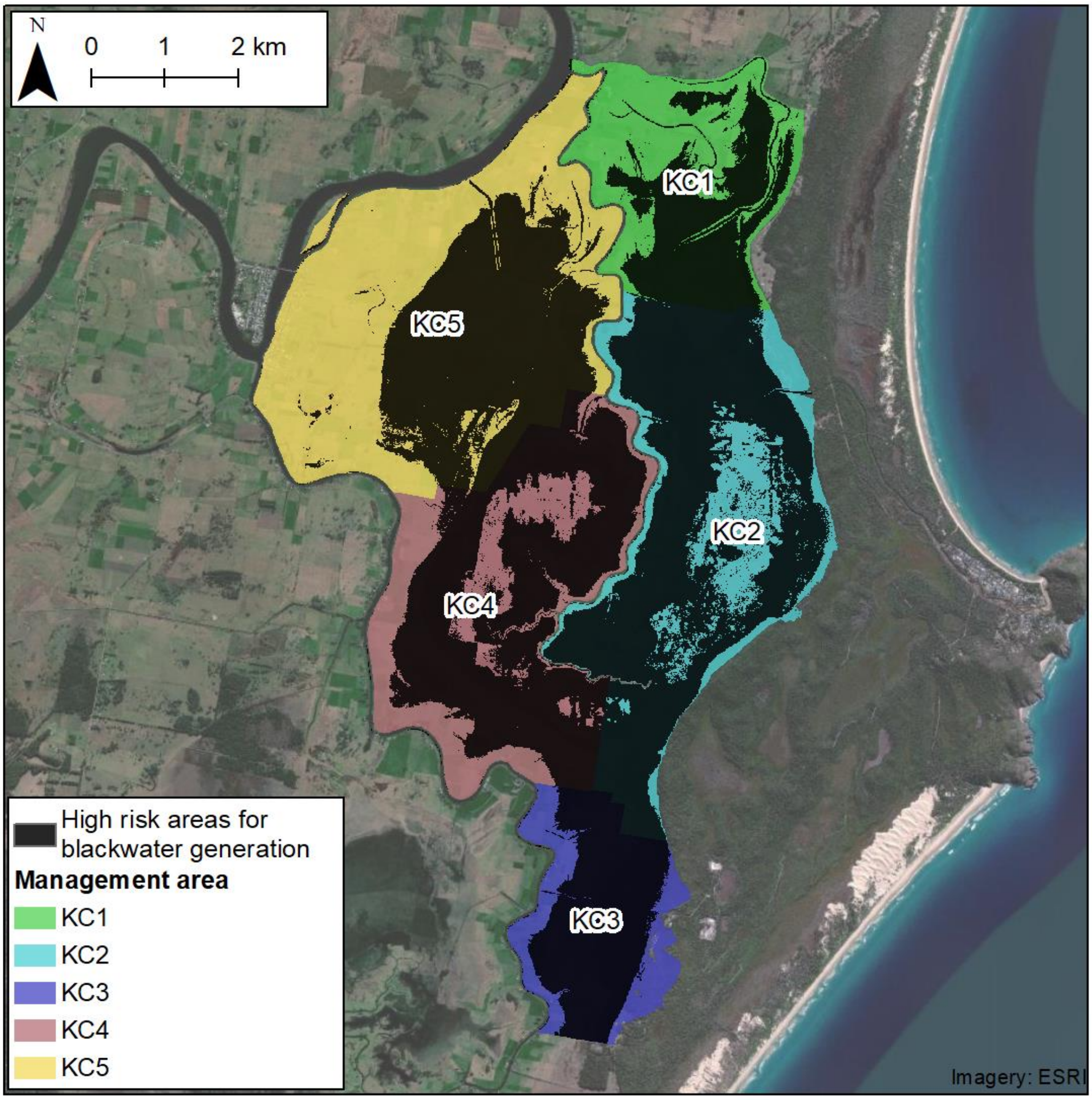

Figure 8-48: Blackwater contribution for management areas in the Kinchela Creek subcatchment (median blackwater level +1.0 m AHD)

8.8.4 Floodplain drainage – sea level rise vulnerability

The sea level rise vulnerability assessment of the Kinchela Creek subcatchment is summarised in Figure 8-49. Present day modelling indicated that large areas of Kinchela Creek subcatchment is currently susceptible to reduced drainage. This includes areas around Reillys Drain in the south of the subcatchment and low-lying area on the right bank of Kinchela Creek. In the far future sea level rise scenario, drainage of the floodplain is likely to be severely impacted by sea level rise, with large extents of the floodplain being predicted to be situated below the approximate future low tide water level (+0.4 m AHD) (i.e. at high risk to reduced drainage by ~2100).

The vulnerability of floodplain infrastructure in the Kinchela Creek subcatchment is summarised in Figure 8-49 and Figure 8-50 (primary floodgates only). Within Kinchela Creek, most end of system structures were classified as least vulnerable due to sea level rise in the near future, except for The Lock, which was considered moderately vulnerable. Two (2) structures will become classified as most vulnerable under the far future sea level rise scenario, including The Lock. Within the Belmore River, modelling indicated two floodgates (130G1 and 017G1) will be most vulnerable due to sea level rise in the far future. The Belmore River headworks (017G1) is a primary end of system structure for the subcatchment and is classified as moderately vulnerable in the near future, and most vulnerable in the far future scenario.

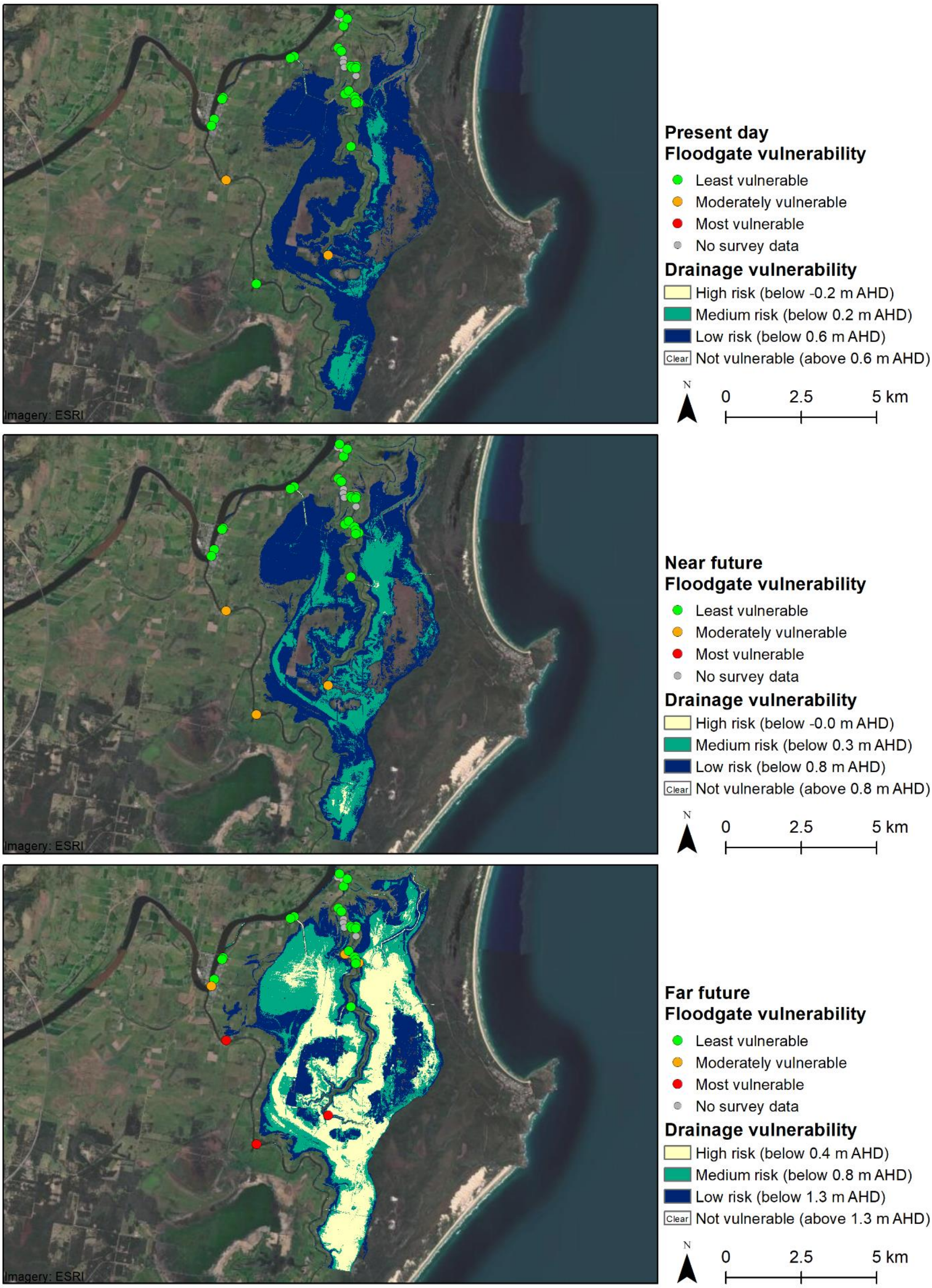

Figure 8-49: Sea level rise drainage vulnerability – Kinchela Creek subcatchment

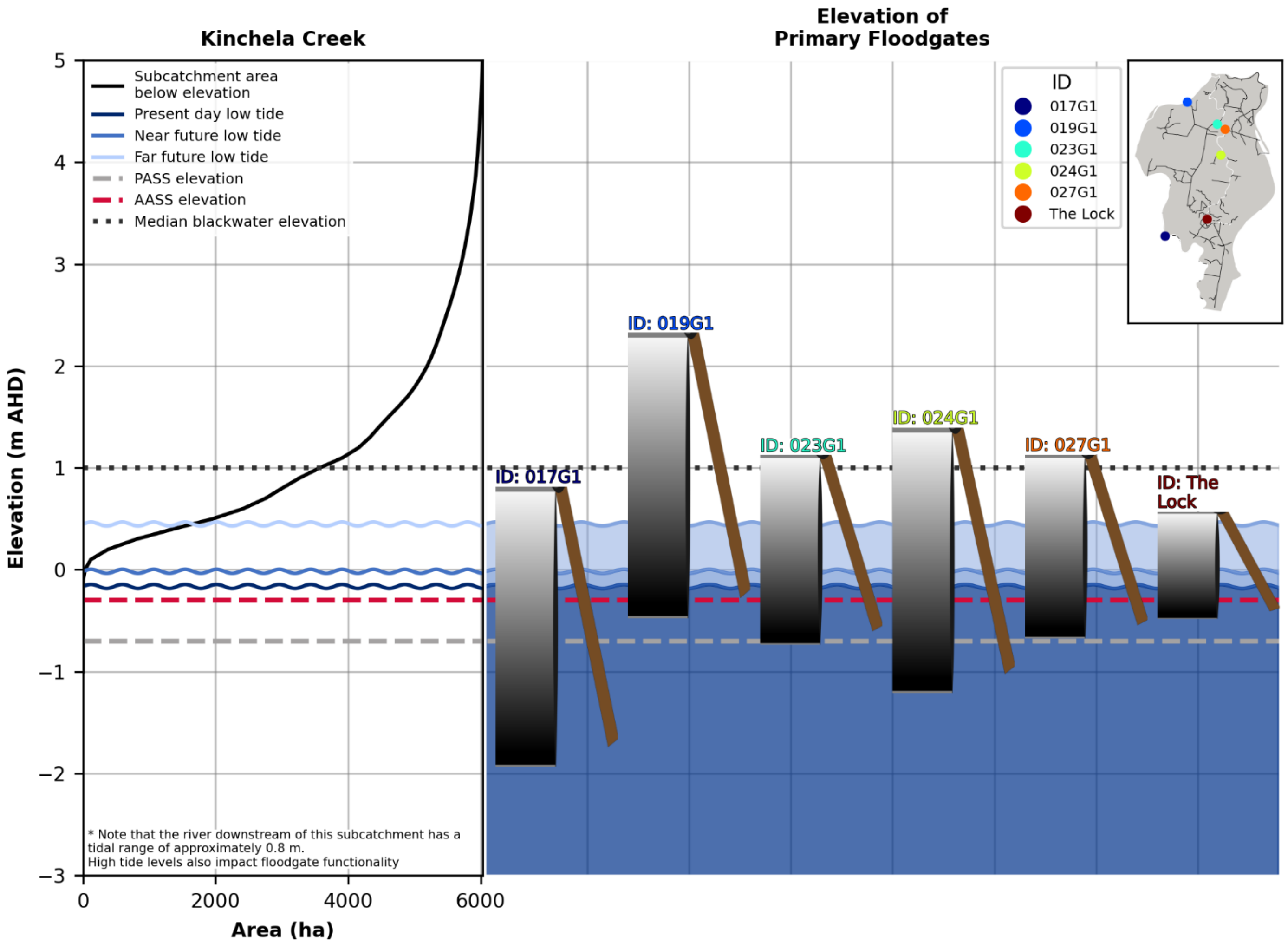

Figure 8-50: Primary floodgates and key floodplain elevations – Kinchela Creek subcatchment

8.8.5 Management options

Potential management options for short and long-term planning horizons for the Kinchela Creek subcatchment include:

- Short-term: Optimise active management of floodplain structures, install drop boards and weirs, promote wet pasture management, and protect existing wetlands.
- Long-term: Investigate full restoration to wetlands and encourage floodwater retention, particularly during summer months to reduce blackwater generation and runoff.

Extensive remediation work has already been completed in the Kinchela Creek subcatchment, attempting to remediate acid sulphate soils and blackwater risk. Due the existing floodplain hydrology, these actions have resulted in localised improvements only. Similarly, short-term management options will only provide localised small scale benefits to the environment. To achieve tangible improvements to water quality discharging from the Kinchela Creek subcatchment, large scale remediation efforts that treat the subcatchment as a single hydrological unit will be required (Tucker and Rayner 2021). Subsequently, these types of remediation options are provided for the long-term planning horizon when the subcatchment will be impacted by reduced drainage due to sea level rise requiring a change in land use.

Note that short and long-term management options are based on existing data and may be subject to change upon detailed site investigation and/or additional information. The options tabled are intended to provide a range of potential options that could be investigated further as required.

Short-term management options

Tulau and Henderson (2000) identified water retention across the floodplain as the most effective management strategy for the Kinchela Creek subcatchment. This strategy would result in reduced export of acidic water, reduced oxidisation of acid sulfate soils, as well as encouraging the growth of water tolerant vegetation that would reduce the risk of blackwater. Water retention can be implemented by installing weirs or drop board structures and infilling secondary floodplain drains. This strategy could be implemented across all management areas within the Kinchela Creek subcatchment. Consultation with stakeholders and landholders would be required to determine a feasible management plan for the subcatchment.

Within management area KC1, the Slaughterhouse Drain headworks (028G1) could be modified to allow in-drain tidal flushing to improve water quality and aquatic connectivity. The upstream section of Slaughterhouse Drain could have a weir or drop board structure installed to retain water and promote for wet pasture management. Note, benefits provided through modifications to Slaughterhouse Drain are likely to only provide localised benefits to water quality and aquatic connectivity.

Recommendations outlined by Smith (2002) should be considered for the Swan Pool area (within management area KC2) (listed in Section 8.8.2). Note that the plan of management for Hat Head National Park is being currently revised (NSW National Parks and Wildlife Service, 2020). Updates to the plan of management should consider specific actions for the Swan Pool wetland area within management area KC2 including those outlined by Smith (2002). Actions that could be considered include the permanent opening of the Lock instead of the new floodgate structure located on Kinchela No 2 Drain, modifications to Korogoro Cut, and infilling of sections of Schoolhouse Drain that extend into the low-lying wetland areas. Installing drop board structures on the Korogoro Drain headworks (033G1) could be considered to help reduce drainage of the groundwater within Swan Pool, similar to those for Killick Creek headworks (see Section 8.7.2). Note, while actions have been identified to improve the KC2 management area, Tucker and Rayner (2021) identified that agricultural and conservation objectives for this area are mutually exclusive and cannot occur concurrently.

Large areas of the Kinchela Creek subcatchment are mapped as Coastal Management SEPP coastal wetlands, particularly within management areas KC2 and KC4. Wherever possible, protection of existing wetlands and modification of waterways to restore natural flow paths should be encouraged.

Active management of floodgates (as per the corresponding floodgate management plan) should continue across the Kinchela Creek subcatchment. New plans could be developed to allow for active management of the Gladstone Drain, Miles Drain, and Slaughterhouse Drain headworks structures (019G1, 023G1 and 028G1). Use of the drop board structures on Schoolhouse Drain and McNallys Drain headworks (027G1 and 032G1) could be considered to retain water levels within management area KC2 and more specifically the Swan Pool wetland area. A similar structure (i.e. a drop board or weir) could be considered on the Hoffmans Drain headworks (029G1) for the same purpose. Alternatively, drop board or weir structures could be installed on the upstream sections of these drains to promote the growth of water tolerant vegetation within the Swan Pool wetland and allow for wet pasture management of agricultural land. Previous attempts to modify the management of Gladstone Drain, Miles Drain and Hoffmans Drain have been unsuccessful due to the lack of landowner support (p.comms R. Kemsley, 2021). Any modifications to these systems in the short term would need to be completed in conjunction with extensive community engagement to ensure existing agricultural practices are not impacted by works that improve water quality.

Within management area KC3, drop board or weir structures could be installed to prevent drainage of low-lying land and allow for wet pasture management. This could be implemented alongside the Reillys Drain Floodgate Management Plan (Kempsey Shire Council, 2015d).

Within management area KC5, existing plans to construct a weir structure within Gladstone Drain was put on hold after consultation with stakeholders (Geolink, 2012). Modifications to Gladstone Drain to improve water quality was identified by Geolink (2012) as a high priority. Options such as installing drop boards or sluice gates could be considered to allow landholders to have control over water levels and ensure that they are not adversely affected by increased inundation. It should be noted that the use of low-lying land for grazing within management area KC5 will be limited during wet periods and adopting wet pasture management practices should be considered in these areas.

Long-term management options

In the long term, sea level rise is likely to significantly impact the Kinchela Creek subcatchment, reducing the drainage potential of the subcatchment floodplain. A rise in water levels will assist in management of acid sulfate soils, however, blackwater is likely to be an ongoing issue that will be exacerbated by sea level rise unless managed appropriately. Far-future management options should focus on large scale rehabilitation of the natural hydrology including the promotion of historical wetland areas. This will mitigate the impact of blackwater by facilitating prolonged drainage and an increased time of inundation, allowing carbon processes that occur when organic matter decomposes to be completed.

Within management area KC1, the low-lying land on the east of the floodplain should be considered for inclusion within the Hat Head National Park and managed with the Swan Pool wetland. In this area drains could be infilled and natural flow paths restored. Impacts on the Raffertys/Saltwater Inlet subcatchment to the north will need to be considered. Higher elevated land within management area KC1 is unlikely to be impacted by sea level rise.

Within management area KC2, low-lying land could be incorporated into the Hat Head National Park as per the recommendations outlined by Smith (2002) and Tucker and Rayner (2021). Extension of the proposed extent of the wetland to areas above +0.5 m AHD (as proposed by Smith (2002)) should be considered. Within the national park, artificial drains should be infilled and natural flow paths reinstated. Investigations should be completed to determine how Korogoro Cut should be managed in alignment with the national park and flood mitigation needs.

Due to the impacts of sea level rise, it is likely significant changes will need to be considered for the current land management within management area KC3. One option for this area could be the implementation of wet pasture management, however, due to an increase in sea level it is unclear if this will be sustainable. Alternatively, management area KC3 could be managed along with management area KC2 as an estuarine/freshwater wetland. To achieve the greatest environmental outcomes, drains within this management area could be infilled, the Reillys Drain floodgates (022G1) could be decommissioned and natural flow paths across the management area could be reinstated. This would include installing culverts underneath Loftus Road (which runs along the subcatchment boundary to the south) to increase connectivity with the Belmore Swamp subcatchment. Note this is dependent on the long-term management strategy adopted for the Belmore Swamp subcatchment.

Management area KC4, has a similar elevation to management areas KC2 and KC3. Historically, these areas were linked and formed a large wetland backswamp complex with the adjacent Belmore Swamp subcatchment (Tulau, 2011). Options for management area KC4 could consider the restoration of this historical connection. This would include infilling sections of Kinchela Creek's natural levee at locations where cut outs have been created, such as decommissioning the Irwins Drain floodgates, infilling of artificial drains, and shallowing of natural drains where additional excavation has occurred for drainage purposes. Management of this land could consider either wet pasture management, acknowledging the land will be wet for significant periods of time, or conversion of the area to estuarine/freshwater wetland, which could also be managed with the Swan Pool wetland in management area KC2.

Management area KC5, includes higher elevation land along the bank of the Macleay River which slopes into a low-lying floodplain surrounding Kinchela Creek to the southeast. In the future, it is unlikely that higher elevation land will be significantly impacted by reduced drainage due to sea level rise. Investigations could be completed to assess the elevation of the potential acid sulfate soils layer and reshape drains to be above this elevation. Lower-lying floodplain land in management area KC5 could be utilised as wet pasture by promoting the growth of water tolerant pasture species. This could be assisted by infilling artificial drains and reinstating the natural flow paths. Promotion of water tolerant vegetation and holding of water on the floodplain would reduce the risk of blackwater. Any changes in hydrology will require studies into the impacts to flooding and land uses, and should only be implemented with extensive consultation of local landholders and consideration of the social and economic impacts of such changes.

Note, detailed investigations will need to be completed to assess the following items in the far-future:

- Long-term management of flood mitigation infrastructure;
- The interaction of estuarine and freshwater wetlands; and
- The interaction of the Kinchela Creek subcatchment and adjacent subcatchments (Belmore Swamp and Raffertys/Saltwater Inlet).

The implementation of different floodplain management strategies will have varying implications for flood mitigation infrastructure. A detailed assessment will be required to determine management plans for flood mitigation assets into the future that will align with water quality objectives for the Kinchela Creek subcatchment.

Presently, during dry conditions, tidal water is able to reach the upper extent of Kinchela Creek and Swan Pool (Smith, 2002). It is unclear how future sea level rise will affect salinity levels within Kinchela Creek and this may impact the viability of different management options. Detailed assessment will be required to determine the likely extent and concentration of saline intrusion to Kinchela Creek and across the floodplain due to sea level rise.

The Kinchela Creek subcatchment is hydrologically linked to the Belmore Swamp subcatchment to the south, and the Raffertys/Saltwater Inlet subcatchment to the north, particularly during flood events. The management strategy adopted for the Kinchela Creek subcatchment will need to consider the impacts of any actions to these subcatchments.

A summary of the potential management options for the Kinchela Creek subcatchment including indicative costs is provided in Table 8-11.

Table 8-11: Summary of management options for Kinchela Creek

Timeframe	Strategy	Target management area(s)	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing per year)	Indicative cost (lost productivity per year)	Effectiveness at improving:		
							Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Optimise tidal flushing	KC1, KC2, KC5	None	$200,000	$50,000	None	Moderate	Moderate	Negligible
Short-term	Install water retention structures	KC2, KC3, KC5	None	$300,000	$50,000	Minimal	None	Moderate	Low
Short-term	Wet pasture management	Entire subcatchment	None	$100,000	None	Minimal	None	Low	Moderate
Long-term	Restoration of wetlands	KC2, KC3, KC4	$15,500,000	$1,000,000	Minimal	$1,200,000	Very high	High	High

*Costs exclude additional investigation/studies, including; REF, EIS, flood studies, and monitoring programs that may be required prior to implementation.

8.9 Raffertys/Saltwater Inlet subcatchment

Acid priority rank:	**7**
Blackwater priority rank:	**6**
Infrastructure	
Approximate waterway length (km)	73
# Privately owned end of system structures	3
# Publicly owned end of system structures	15
# Jointly owned end of system structures	0
# End of system structures within coastal wetlands	1
# Publicly owned end of system structures within coastal wetlands	1
Primary floodplain infrastructure (floodgate ID)	008G1, 070G1, 073G1
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-1.1 to -0.3
Average AASS elevation (m AHD)	0.5
Average PASS elevation (m AHD)	-0.4
Median blackwater elevation (m AHD)	0.8
Present day low water level (m AHD)	-0.2
Near future low water level (m AHD)	0.0
Far future low water level (m AHD)	0.4
Proximity to sensitive receivers	
Oyster leases (km)	Within subcatchment
Saltmarsh (km)	Within subcatchment
Seagrass (km)	Within subcatchment
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	2,987
Classified as conservation and minimal use (ha (%))	225 (8%)
Classified as grazing (ha (%))	2,475 (83%)
Classified as forestry (ha (%))	3 (0.1%)
Classified as horticulture (ha (%))	2 (0.1%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	92 (3%)
Classified as marsh/wetland (ha (%))	109 (4%)
Other (ha (%))	82 (3%)
Land values	
Estimated total primary production value ($/year)	$1,100,000
Average land value above 0.8 m AHD ($/ha)	$5,700
Average land value below 0.8 m AHD ($/ha)	$5,700

8.9.1 Site description and brief history of drainage

The Raffertys/Saltwater Inlet subcatchment is located on the right bank of the lower Macleay River estuary. To the north of the subcatchment is Pelican Island which is bounded to the east by Spencers Creek and west by the Macleay River. Saltwater Inlet flows along the eastern side of the subcatchment draining into Spencers Creek.

There are three (3) major drainage lines for the south western section of the subcatchment. Rafterys Drain, originally constructed in the 1940s and later modified in the 1960s and then again in the 2000s, is the largest of these with an approximate length of 3.8 km (Kempsey Shire Council, 2005b). Back Creek and Marriotts Drain are other major waterways which drain the land to the west of Raffertys Drain and have floodgates fitted to end of system drainage structures (see further details in Section 8.9.2 and Figure 8-53).

The Raffertys/Saltwater Inlet subcatchment is predominantly used for grazing (83%) with some conservation occurring across the floodplain, including sections of Hat Head National Park which borders the subcatchment to the east. Tenure information for the Raffertys/Saltwater Inlet subcatchment is shown in Figure 8-51. Information on drainage and floodplain elevation is shown in Figure 8-52.

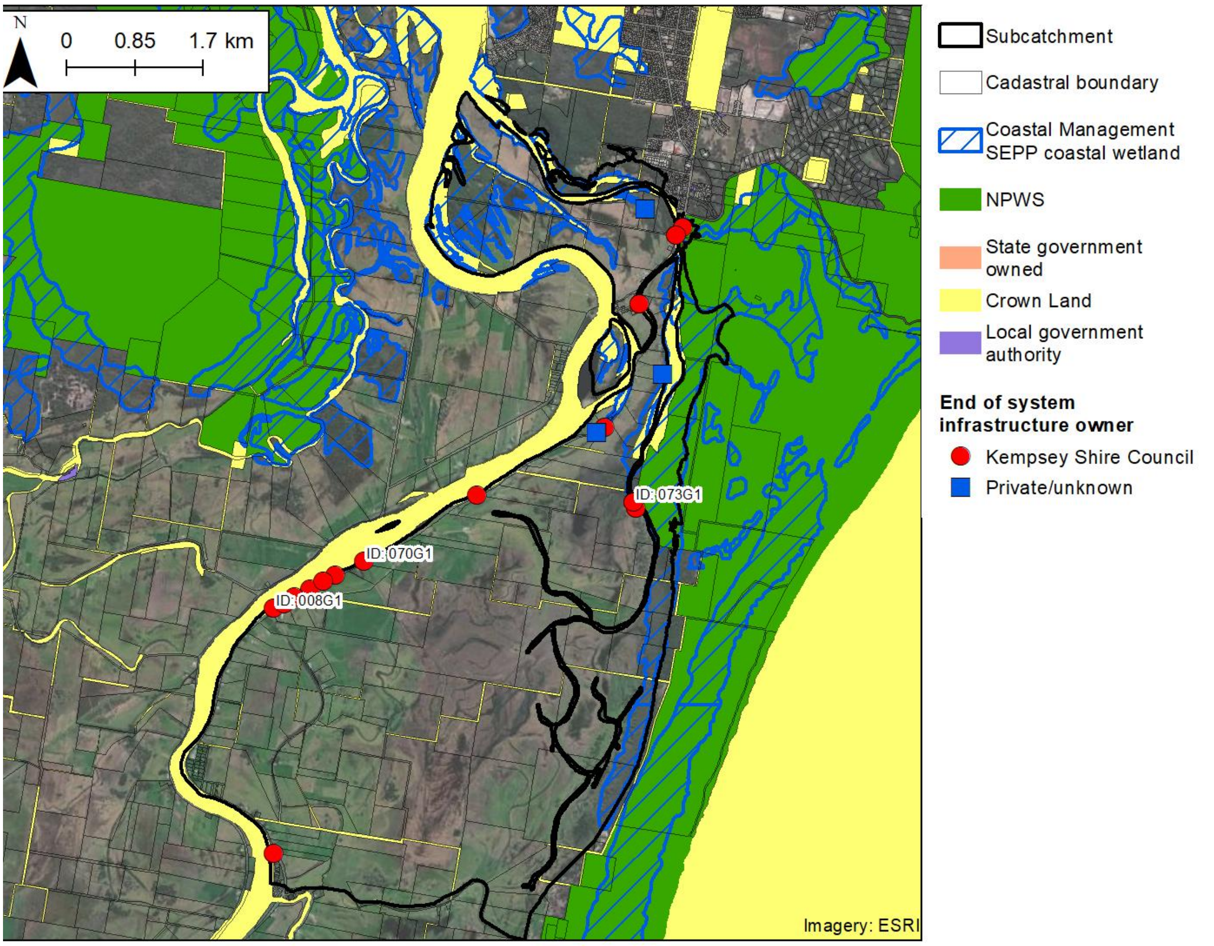

Figure 8-51: Raffertys/Saltwater Inlet subcatchment land and end of system infrastructure tenure

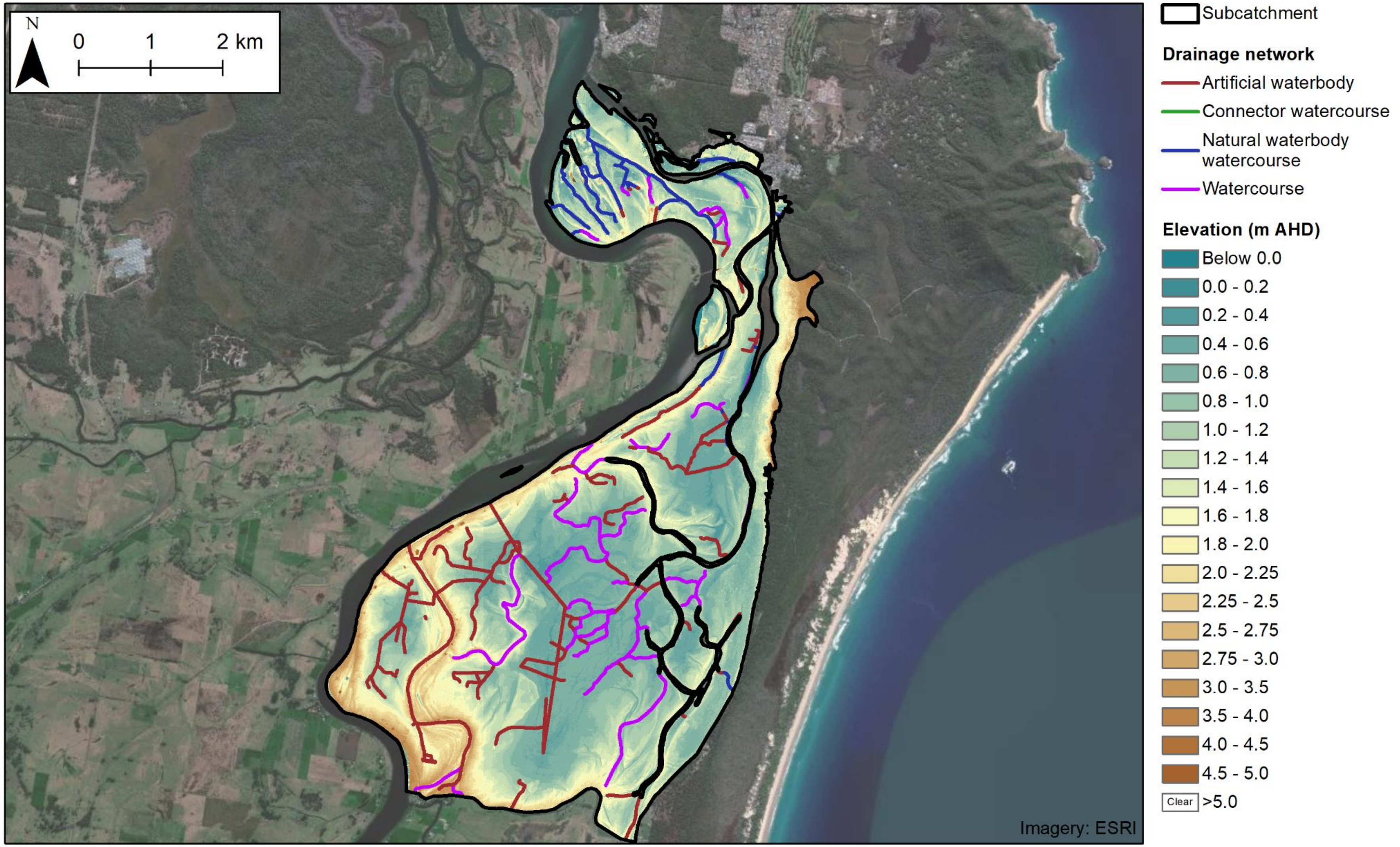

Figure 8-52: Raffertys/Saltwater Inlet subcatchment elevation and drainage network

8.9.2 History of remediation

There were no known attempts of remediation within the Raffertys/Saltwater Inlet subcatchment prior to 2000 (Tulau and Naylor, 1999). The first recorded remediation attempt was to install a lifting device to the Marriotts Drain floodgates (007G1). In 2000, Kempsey Shire Council developed a plan outlining the active management of these floodgates that included recommendations for landholders to alter land management practices to improve water quality (Kempsey Shire Council, 2000). Inspections completed in 2012 by Kempsey Shire Council showed that the floodgate was not being actively managed, however, field investigations completed in November 2019 as part of this study found that the floodgate flap has been removed and only an open culvert exists.

Buoyancy controlled auto-tidal gates were installed on two structures in the Raffertys/Saltwater inlet subcatchment by Kempsey Shire Council. The Saltwater Inlet floodgate structure (073G1) and the Raffertys Drain headworks structure (070G1) have both been modified to allow controlled tidal flushing. Kempsey Shire Council has also developed management plans for these floodgates for the purpose of flood mitigation, water quality and weed control (Kempsey Shire Council, 2004c; Kempsey Shire Council, 2005b). During field inspections the Raffertys Drain floodgates (070G1) were found to provide aquatic connectivity to upstream sections of the drain.

Raffertys Drain is the major drainage pathway for the south west of the Raffertys/Saltwater Inlet subcatchment (Tulau and Naylor, 1999). In 2005, works were completed for the remediation of Raffertys Drain (Kempsey Shire Council, 2005b). These works included the creation of a new 3 km long section of drain that was wide and shallow (reducing its intersection with and drainage of ASS) and infilling of 3 km of the former upstream extent of Raffertys Drain. In addition to these works, Kempsey Shire Council has assisted one landholder to install drop board structures on private waterways that drain into the downstream section of Raffertys Drain (Kempsey Shire Council, 2007d). A subsequent plan of management was developed for these structures with the purpose of improving water quality and encouraging wet pasture management, as well as wetland habitat whilst not impacting on flooding of the surrounding land (Kempsey Shire Council, 2007d).

In addition to the Hat Head National Park which is being managed by NSW National Parks and Wildlife Service for protection and conservation objectives (National Parks and Wildlife Service, 1998) there is a section of floodplain on Pelican Island that is being managed as a wetland. The landholder indicated management objectives for the site included encouraging freshwater wetland habitat to attract bird life (Whitehead, 2019, personal communication).

Figure 8-53 summarises the remediation actions that have been completed within the Raffertys/Saltwater Inlet subcatchment.

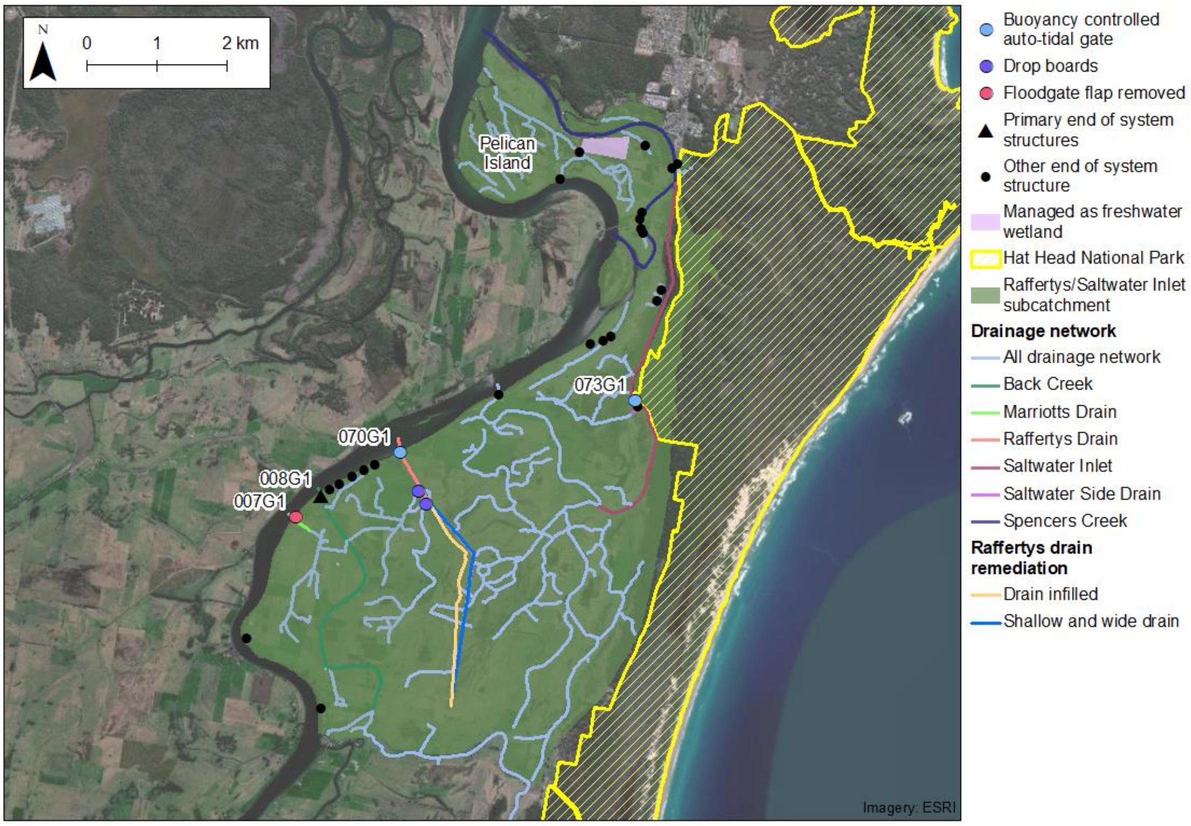

Figure 8-53: The Raffertys/Saltwater Inlet subcatchment including previous remediation actions

8.9.3 Floodplain drainage – sea level rise vulnerability

The sea level rise vulnerability assessment of the Raffertys/Saltwater Inlet subcatchment is summarised in Figure 8-54. Under present day conditions, modelling indicates that low-lying sections of the floodplain that drain via Raffertys Drain and Saltwater Inlet are below the approximate high tide water level (i.e. at low risk of reduced drainage). With sea level rise, the extent of the floodplain where drainage will be impacted will increase, with the lowest floodplain areas being below the approximate mean tide water level under far future water levels (i.e. at medium risk of reduced drainage).

The sea level rise vulnerability assessment completed for floodgates indicated that only a small number of secondary floodgates are vulnerable to sea level rise during present day conditions. In the near future, five (5) floodgates, including the Raffertys Dain headworks (070G1) and primary structure 073G1, will become moderately vulnerable, as they are the lowest of the primary floodgates (see Figure 8-55). Both of these floodgate vulnerability categorisation will change to most vulnerable in the far future sea level rise scenario, along with three (3) other secondary floodgates (structures 074G1, 142G1 and UNK01N, see Appendix F).

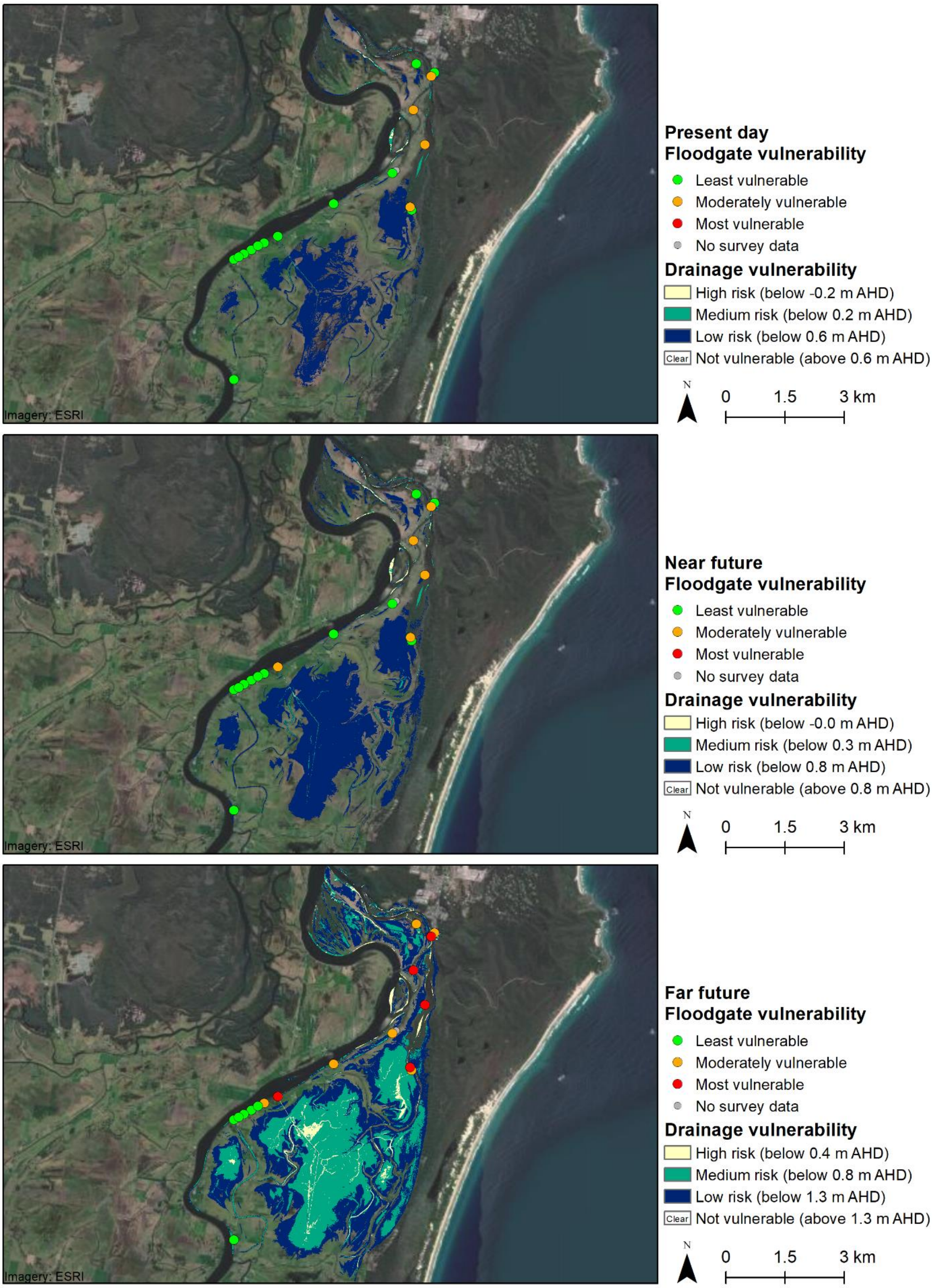

Figure 8-54: Sea level rise drainage vulnerability – Raffertys/Saltwater Inlet subcatchment

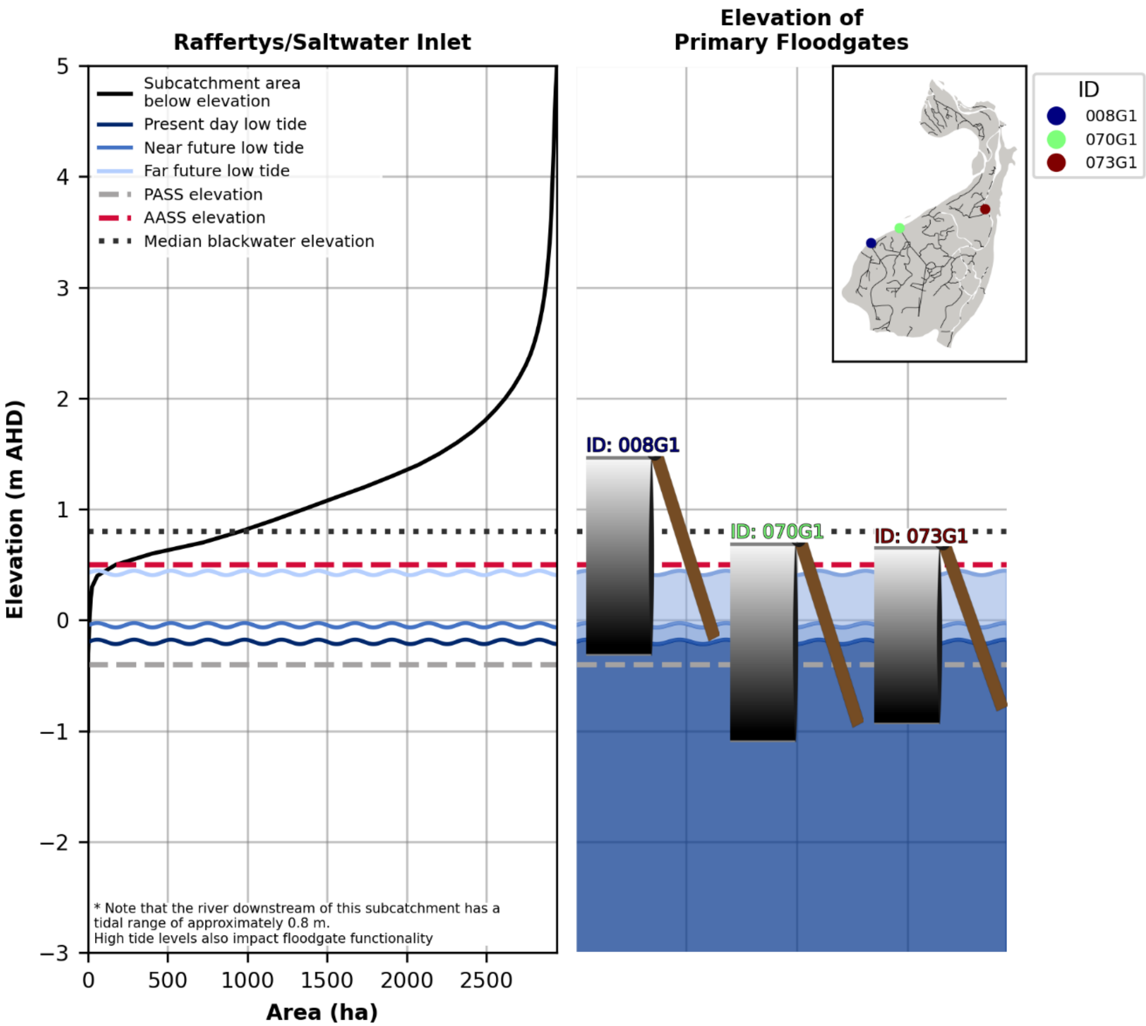

Figure 8-55: Primary floodgates and key floodplain elevations – Raffertys/Saltwater Inlet subcatchment

8.9.4 Management options

Potential management options for short and long-term planning horizons for the Raffertys/Saltwater Inlet subcatchment include:

- Short-term: Continue and optimise in-drain tidal flushing, install drop board structures, and encourage wet pasture management.
- Long-term: Investigate full restoration of low-lying floodplain areas to wetland, and utilise wet pasture management practices on higher areas.

Note that short and long-term management options are based on existing data and may be subject to change upon detailed site investigation and/or additional information. The options tabled are intended to provide a range of potential options that could be investigated further as required.

Short-term management options

Existing remediation actions completed for the Raffertys/Saltwater Inlet subcatchment should continue, including the active management of the Raffertys Drain headworks (070G1) and Saltwater Inlet floodgates (073G1) as per their management plans. Modifications could be considered for structure 008G1 to allow in-drain tidal flushing to improve surface water quality.

Installation of drop board structures on secondary drains, as has occurred for some drains that flow into Raffertys Drain, could be considered across the subcatchment. This management action could be implemented alongside wet pasture management practices.

It should be noted that a large extent of the Raffertys/Saltwater Inlet subcatchment is mapped as Coastal Management SEPP coastal wetlands. Wherever possible, protection of existing wetlands and modification of waterways to restore natural flow paths should be encouraged within this area.

Long-term management options

In the long term, large areas within the Raffertys/Saltwater Inlet subcatchment will be impacted by reduced drainage. In these areas wet pasture management or conversion to wetland could be considered. This would be assisted by infilling selected drains and restoring natural flow paths. Note that any changes in hydrology will require studies into the impacts to flooding and land uses, and should only be implemented with extensive consultation of local landholders and consideration of the social and economic impacts of such changes.

Investigations could be completed for further modification to the Saltwater Inlet floodgates (073G1). By increasing flow through these floodgates large areas of the subcatchment could be restored to estuarine wetlands.

A summary of the potential management options for the Raffertys/Saltwater Inlet subcatchment including indicative costs is provided in Table 8-12.

Table 8-12: Summary of management options for Raffertys/Saltwater Inlet

Timeframe	Strategy	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing per year)	Indicative cost (lost productivity per year)	Effectiveness at improving:		
						Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Optimise tidal flushing	None	$30,000	$2,000	None	Moderate	Moderate	Negligible
Short-term	Install drop boards	None	$250,000	$50,000	Minimal	None	Moderate	Low
Short-term	Wet pasture management	None	$80,000	None	Minimal	None	Low	Moderate
Long-term	Restoration of wetlands	$3,500,000	$100,000	Minimal	$250,000	High	High	High

*Costs exclude additional investigation/studies, including; REF, EIS, flood studies, and monitoring programs that may be required prior to implementation.

8.10 Pola Creek subcatchment

Acid priority rank:	**8**
Blackwater priority rank:	**10**
<u>Infrastructure</u>	
Approximate waterway length (km)	14
# Privately owned end of system structures	1
# Publicly owned end of system structures	5
# Jointly owned end of system structures	0
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (floodgate ID)	012G1
<u>Elevations</u>	
Invert of primary floodplain infrastructure (m AHD)	0.0
Average AASS elevation (m AHD)	N/A
Average PASS elevation (m AHD)	N/A
Median blackwater elevation (m AHD)	2.1
Present day low water level (m AHD)	-0.1
Near future low water level (m AHD)	0.0
Far future low water level (m AHD)	0.4
<u>Proximity to sensitive receivers</u>	
Oyster leases (km)	26.2
Saltmarsh (km)	23.3
Seagrass (km)	29.0
Mangroves (km)	21.1
Coastal Management SEPP coastal wetlands (km)	11.7
<u>Land use</u>	
Total floodplain area (ha)	446
Classified as conservation and minimal use (ha (%))	6 (1%)
Classified as grazing (ha (%))	303 (68%)
Classified as forestry (ha (%))	0 (0%)
Classified as horticulture (ha (%))	3 (1%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	58 (13%)
Classified as marsh/wetland (ha (%))	28 (6%)
Other (ha (%))	49 (11%)
<u>Land values</u>	
Estimated total primary production value ($/year)	$200,000
Average land value above 1.2 m AHD ($/ha)	$6,400
Average land value below 1.2 m AHD ($/ha)	$4,400

8.10.1 Site description and brief history of drainage

Pola Creek is located on the right bank of the upper Macleay River estuary. Gills Bridge Creek and Pola Creek are the main tributaries for the subcatchment. Pola Creek flows from the south to north and into Gills Bridge Creek which flows from the south west of the subcatchment to the north. A large headworks structure (0132G1) was built on Gills Bridge Creek in 1965 when some drain improvement works were also completed (Tulau, 2011).

The major land use for the Pola Creek subcatchment is grazing which accounts for 68% of land use. The subcatchment is bounded by the South Kempsey urban area to the west which drains via Gills Bridge Creek. The Pacific Highway runs along the southern side of the subcatchment and has resulted in state government acquiring land within the Pola Creek subcatchment. Tenure information for the Pola Creek subcatchment is shown in Figure 8-56. Information on drainage and floodplain elevation is shown in Figure 8-57.

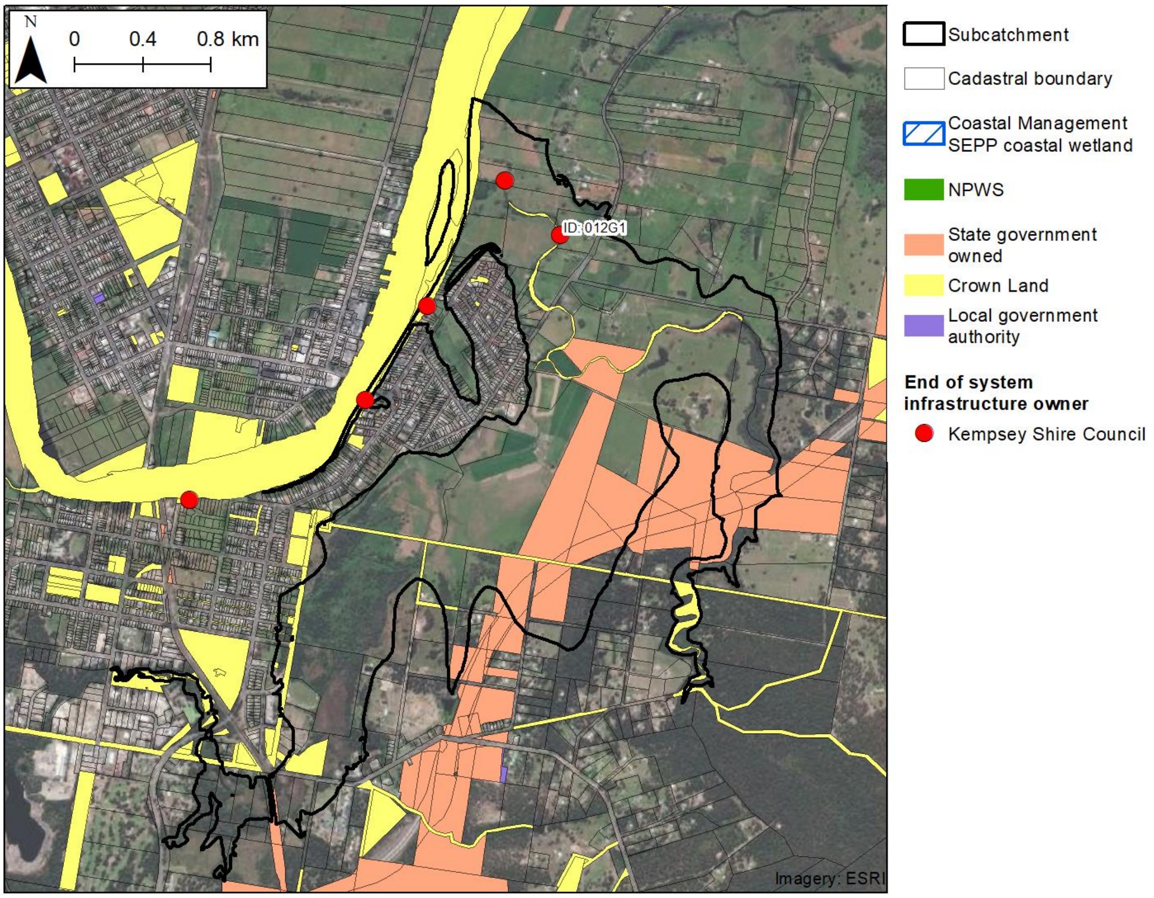

Figure 8-56: Pola Creek subcatchment land and end of system infrastructure tenure

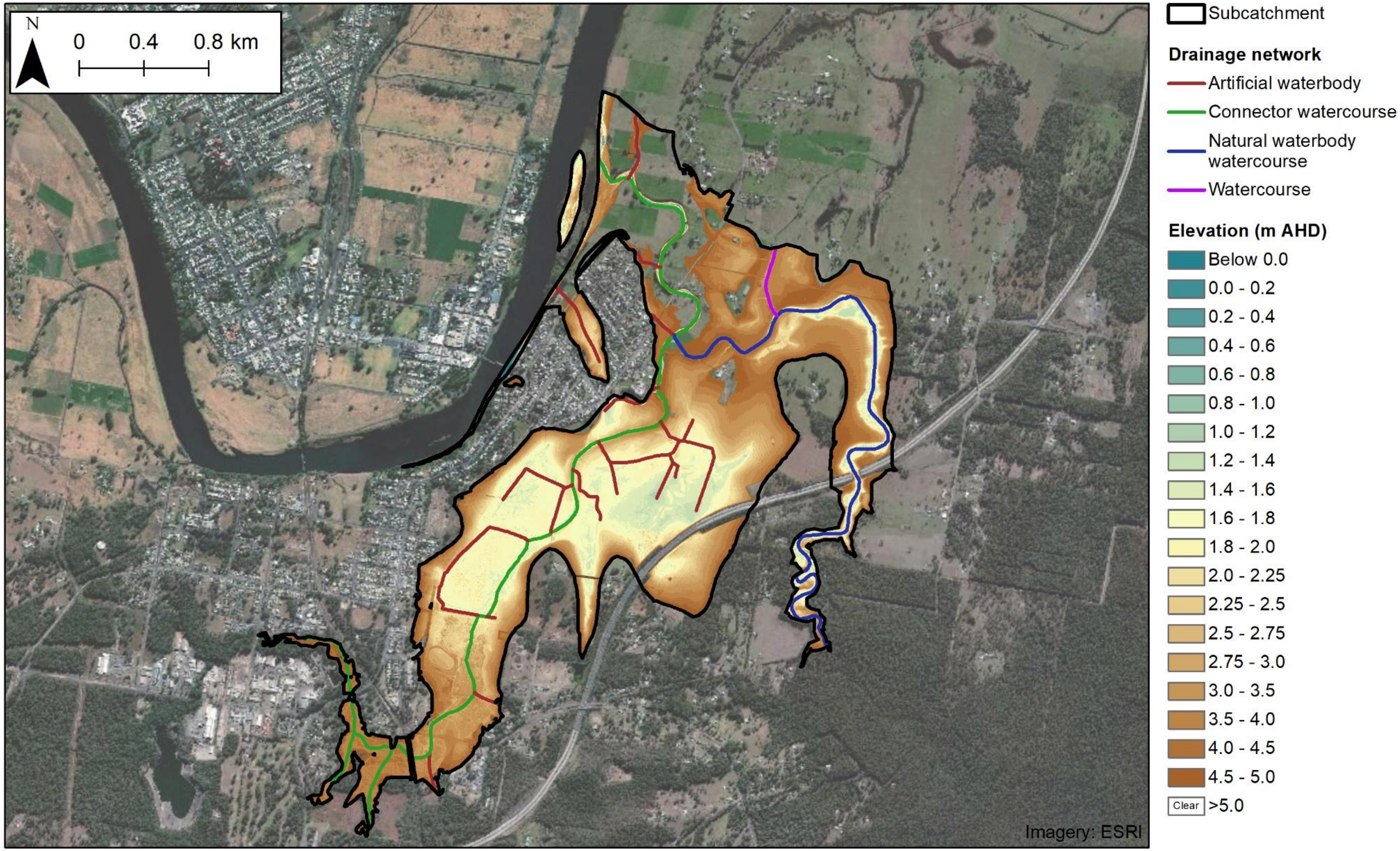

Figure 8-57: Pola Creek subcatchment elevation and drainage network

8.10.2 History of remediation

Geolink (2012) indicated that one set of floodgates (120G1) on the side of Gills Bridge Creek have a floodgate management plan but are not actively managed. Similarly, lifting devices (winches) are installed on the Gills Bridge Creek headworks (012G1) but there is no record of active management. Locations of these structures is shown in Figure 8-58.

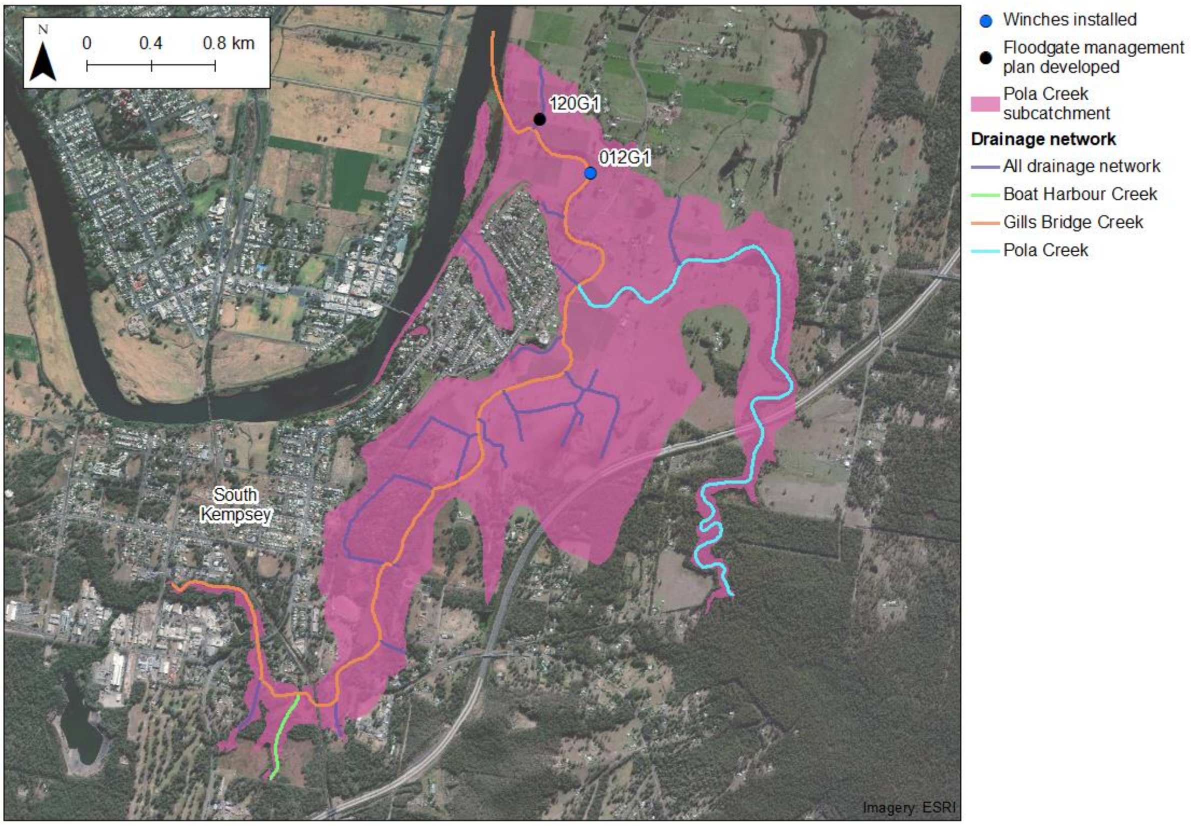

Figure 8-58: The Pola Creek subcatchment including previous remediation actions

8.10.3 Floodplain drainage – sea level rise vulnerability

The sea level rise vulnerability assessment of the Pola Creek subcatchment is summarised in Figure 8-59. Modelling did not indicate that the Pola Creek subcatchment will be impacted by reduced drainage in the near future. The far future scenario modelling indicated small areas of low-lying floodplain will be below the 95th percentile water level. The floodgate vulnerability assessment classified all floodgates in the Pola Creek subcatchment as least vulnerable to sea level rise in the far future scenario, including the primary floodgate, the Pola Creek Headworks (012G1), shown in Figure 8-60.

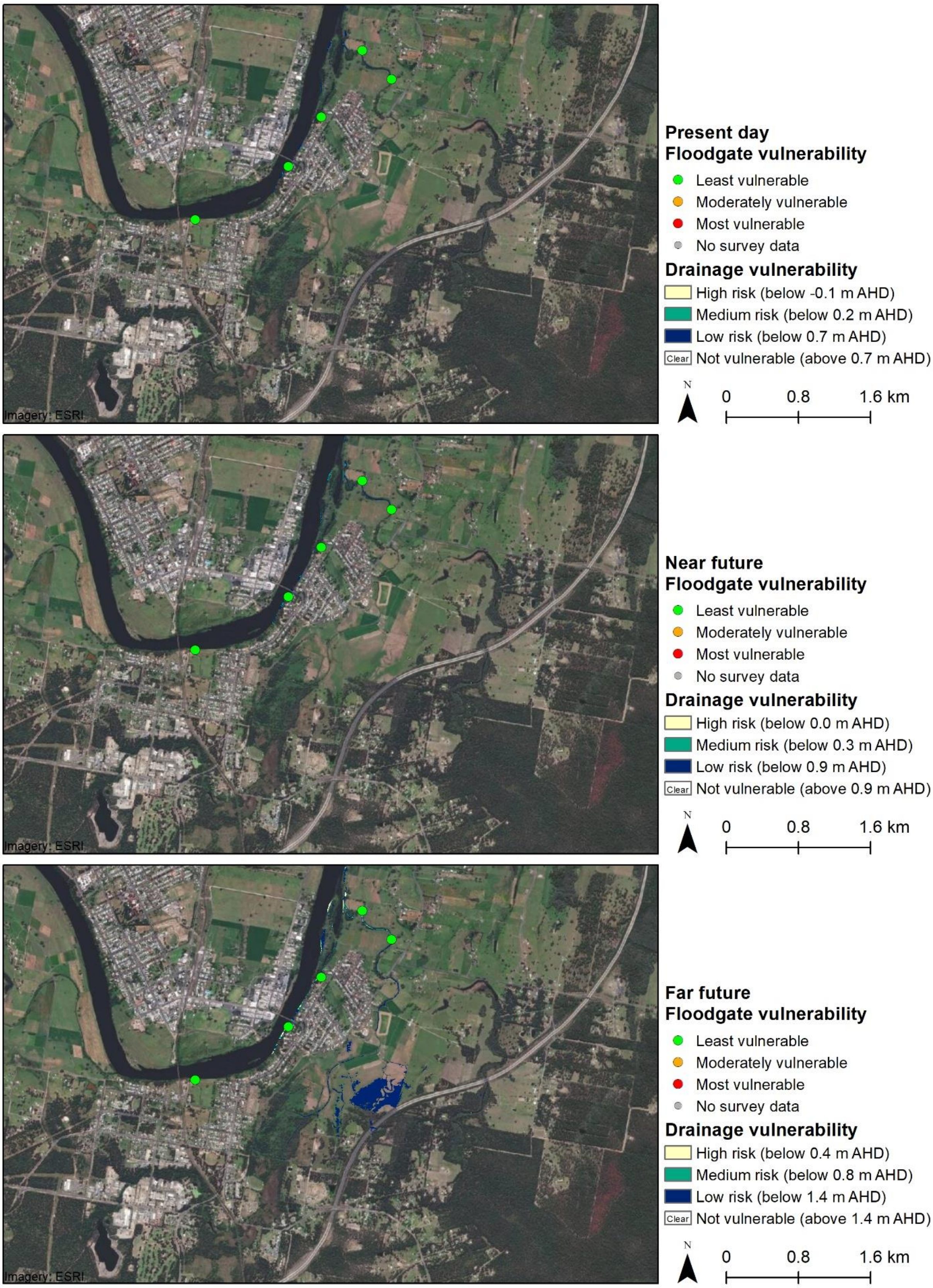

Figure 8-59: Sea level rise drainage vulnerability – Pola Creek subcatchment

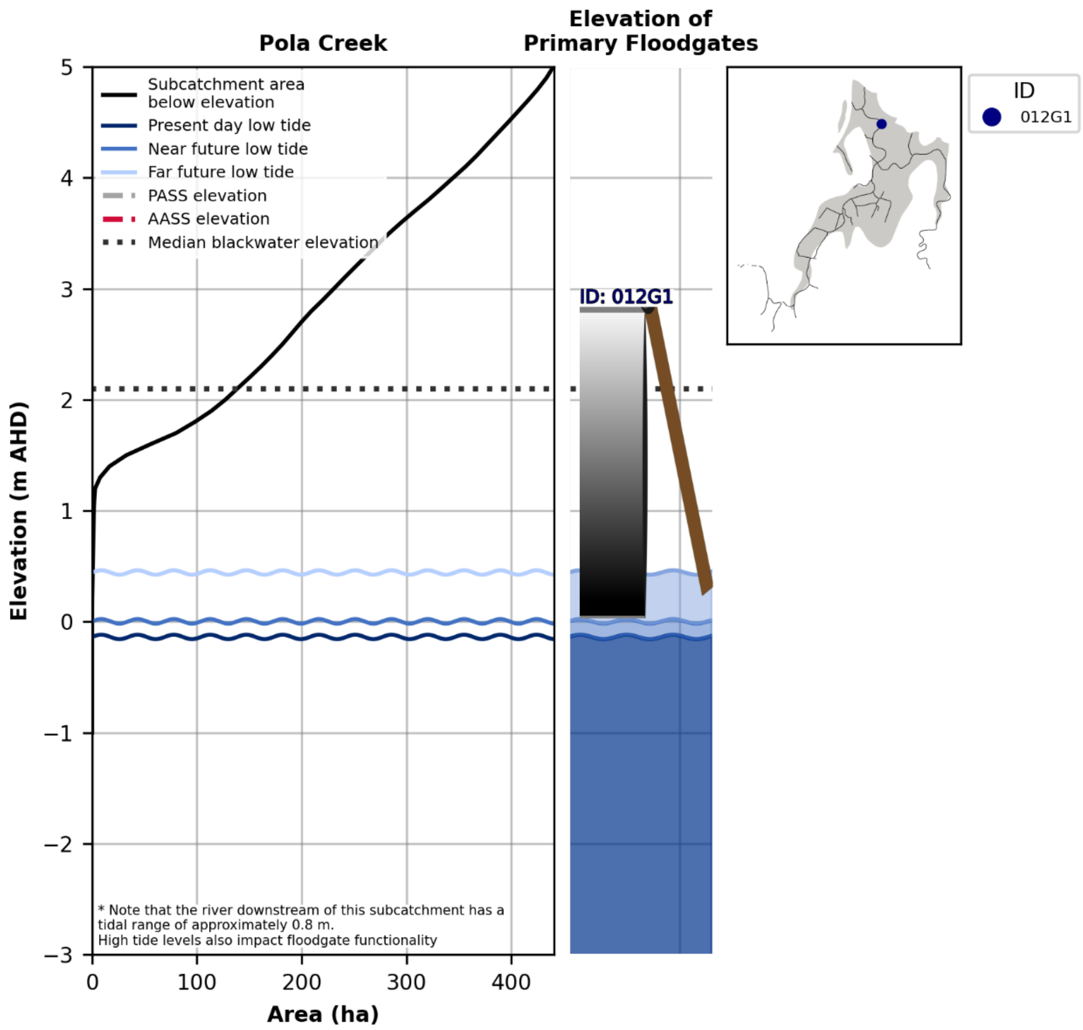

Figure 8-60: Primary floodgates and key floodplain elevations – Pola Creek subcatchment

8.10.4 Management options

Potential management options for short and long-term planning horizons for the Pola Creek subcatchment include:

- Short-term: Controlled in-drain tidal flushing.
- Long-term: Controlled in-drain tidal flushing and drain reshaping.

Note that short and long-term management options are based on existing data and may be subject to change upon detailed site investigation and/or additional information. The options tabled are intended to provide a range of potential options that could be investigated further as required.

Short-term management options

In the short-term, a plan of management could be developed for the Gills Bridge headworks structure (012G1). This could include the winching open of the floodgates during day-to-day conditions to allow tidal flushing upstream of the floodgates. During floods the gates could still be utilised to prevent backwater flooding of the Pola Creek subcatchment. Note, winches have been previously installed on the floodgates.

Long-term management options

In the long-term, in addition to continued implementation of short-term strategy, an assessment could be completed to ensure that all drains within the Pola Creek subcatchment are shallow and wide, thereby limiting their intersection with acid sulfate soils.

A summary of the potential management options for the Pola Creek subcatchment including indicative costs is provided in Table 8-13.

Table 8-13: Summary of management options for Pola Creek

Timeframe	Strategy	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing per year)	Indicative cost (lost productivity per year)	Effectiveness at improving:		
						Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Optimise tidal flushing	None	$30,000	$5,000	None	Moderate	Moderate	Negligible
Long-term	Drain reshaping	None	$250,000	None	None	None	Moderate	Low

*Costs exclude additional investigation/studies, including; REF, EIS, flood studies, and monitoring programs that may be required prior to implementation

8.11 Summer Island subcatchment

Acid priority rank:	**9**
Blackwater priority rank:	**7**
Infrastructure	
Approximate waterway length (km)	80
# Privately owned end of system structures	2
# Publicly owned end of system structures	17
# Jointly owned end of system structures	0
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (floodgate ID)	003G1, 004G1, 005G1, 006G1
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-1.7 to -0.3
Average AASS elevation (m AHD)	0.9
Average PASS elevation (m AHD)	0
Median blackwater elevation (m AHD)	0.9
Present day low water level (m AHD)	-0.2
Near future low water level (m AHD)	0.0
Far future low water level (m AHD)	0.4
Proximity to sensitive receivers	
Oyster leases (km)	7.2
Saltmarsh (km)	4.2
Seagrass (km)	7.3
Mangroves (km)	1.1
Coastal Management SEPP coastal wetlands (km)	3.2
Land use	
Total floodplain area (ha)	2,817
Classified as conservation and minimal use (ha (%))	1 (0.05%)
Classified as grazing (ha (%))	2,616 (93%)
Classified as forestry (ha (%))	0 (0%)
Classified as horticulture (ha (%))	0 (0%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	98 (3%)
Classified as marsh/wetland (ha (%))	3 (0.1%)
Other (ha (%))	98 (3%)
Land values	
Estimated total primary production value ($/year)	$1,100,000
Average land value above 0.9 m AHD ($/ha)	$7,300
Average land value below 0.9 m AHD ($/ha)	$5,600

8.11.1 Site description and brief history of drainage

The Summer Island subcatchment is located on the left bank of the Macleay River approximately 15 km upstream of the ocean entrance at South West Rocks. The area drains from west to east into the Macleay River via a number of drains that were constructed between 1986 and 1970 (Tulau, 2011), including (see further details in Section 8.11.2 and Figure 8-63):

- Clancys Drain;
- Collins Drain;
- McCabes Drain; and
- Summer Island Drain.

Floodgates have been installed on each of these structures. During flood events northern sections of the floodplain can become hydrologically connected with the adjacent Collombatti-Clybucca subcatchment to the north west.

The primary land use within the Summer Island subcatchment is grazing which accounts for 93% of land use. Smithtown urban area is located on the left bank of the Macleay River at the southern extent of the subcatchment. Tenure information for the Summer Island subcatchment is shown in Figure 8-61. Information on drainage and floodplain elevation is shown in Figure 8-62.

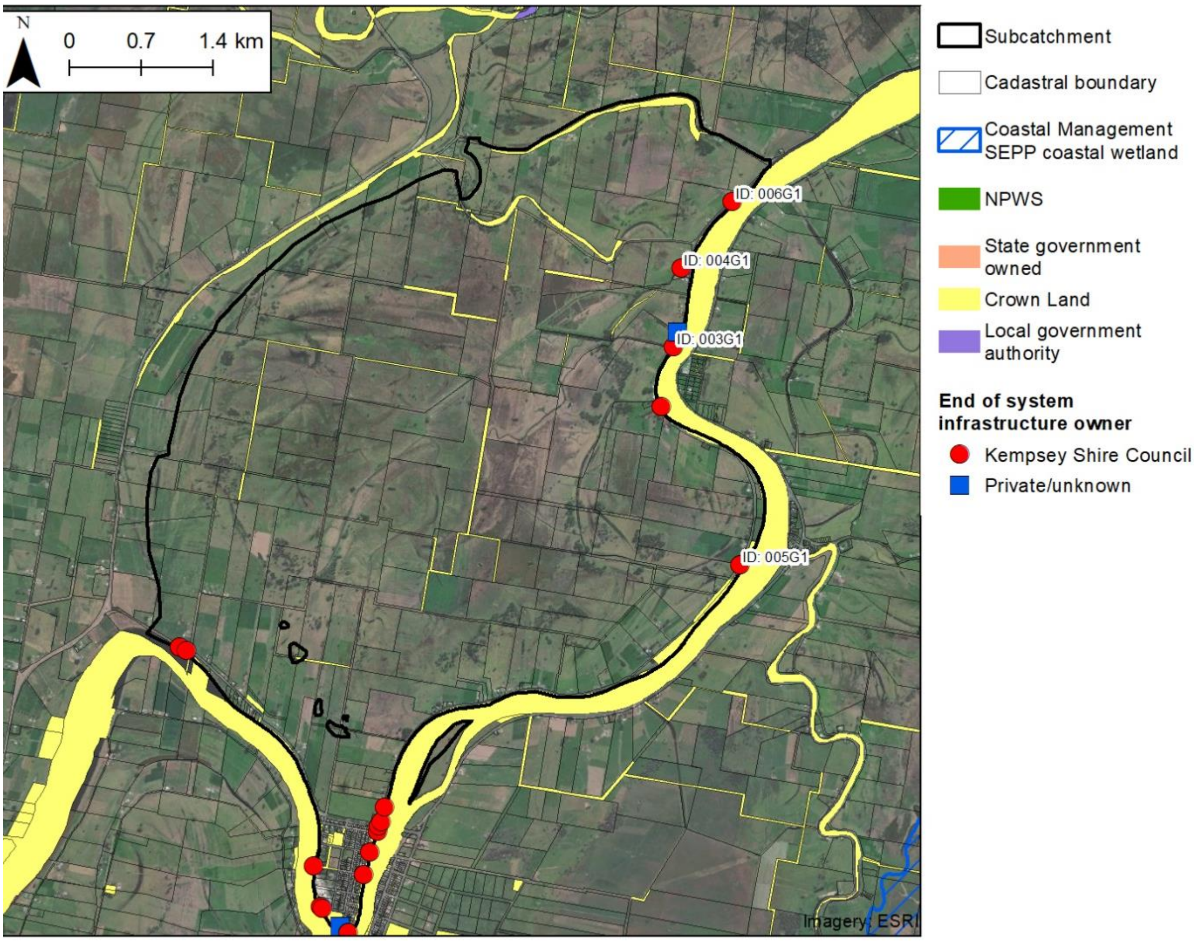

Figure 8-61: Summer Island subcatchment land and end of system infrastructure tenure

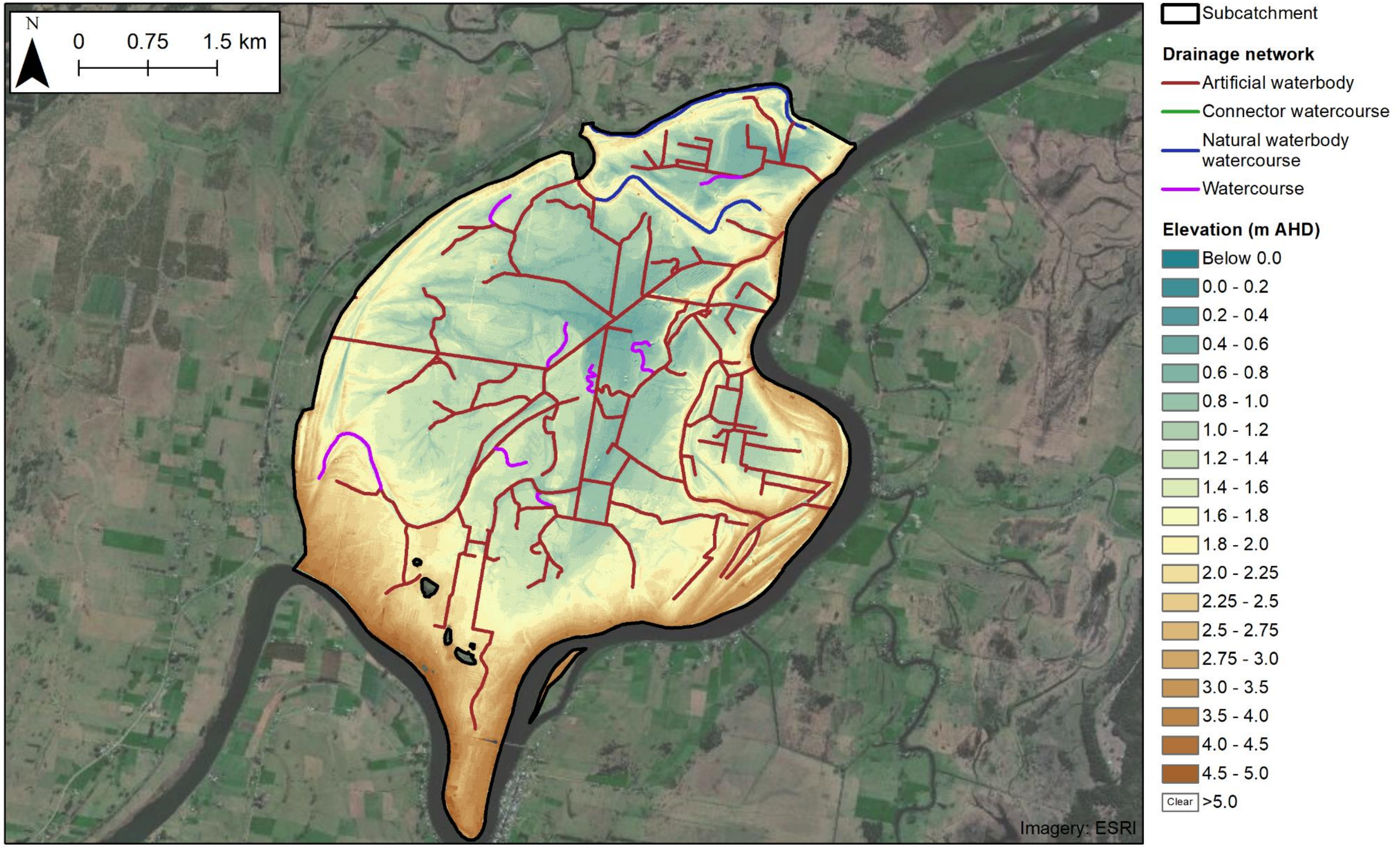

Figure 8-62: Summer Island subcatchment elevation and drainage network

8.11.2 History of remediation

The Clancys Drain headworks (005G1) and Summer Island Drain headworks (003G1) both have slots on the upstream side of the floodgate structures to allow drop boards to be inserted. The original flood mitigation drawings for these structures show that they have always had this capability (Macleay River County Council, 1968). When constructed, the structures also had a lifting mechanism (winch) installed to enable the floodgates to be opened.

Clancys Drain was one of the first floodgates in the Macleay River subcatchment to be actively managed with the Clancy Drain headworks (005G1) being used as an example for how do develop a floodgate management plan for active management (Geolink, 2010b). The original management plan included recommendations for the upgrade of the floodgate winch mechanism to allow safe opening of the floodgates (NSW Fisheries, 2002). Kempsey Shire Council updated the plan shortly after its creation and included the installation of two water retention structures in the drain upstream, in addition to the upgrade of the existing winch (Kempsey Shire Council, 1999). The exact location of the water retention structures is unknown, however, aerial imagery indicates that one weir was installed at some point prior to 2009 on upstream sections of the drain. In 2007, another plan was developed to further modify Clancys Drain and install a drop board structure to allow wet pasture management (Kempsey Shire Council, 2007b). Geolink (2010b) noted that a weir on Clancys Drain had been modified to install drop boards. It is possible that this is the same drop board structure and also the location of the second weir. Geolink (2010b) also noted that culverts with floodgates and drop boards were installed throughout the drain but did not specify the number or location. During field inspections it was noted that the Collins Drain headworks (006G1) also have winches installed.

Figure 8-63 shows the location of remediation structures for the Summer Island subcatchment.

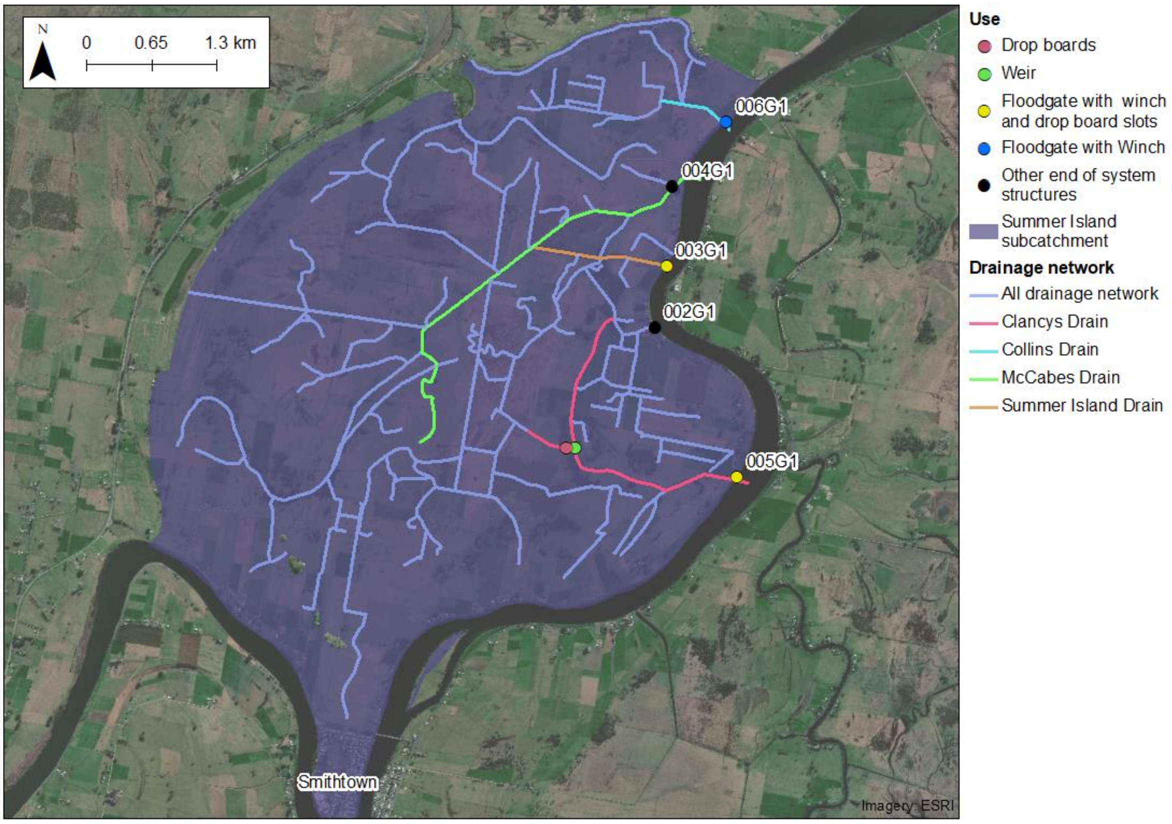

Figure 8-63: The Summer Island subcatchment including previous remediation actions

8.11.3 Floodplain drainage – sea level rise vulnerability

The sea level rise vulnerability assessment of the Summer Island subcatchment is summarised in Figure 8-64. The present day and near future sea level rise assessment indicates that small areas of the lowest-lying sections of the floodplain will be potentially susceptible to reduced drainage during high tides (i.e. at low risk of reduced drainage). In the far future scenario, modelling indicated a larger area will be impacted by reduced drainage, mainly within the centre of the floodplain, with some areas being below the approximate mean tide water level (i.e. at medium risk of reduced drainage).

The elevation of the primary floodgates compared to key floodplain elevations is shown in Figure 8-65. In the floodgate vulnerability assessment, all floodgates were classified as least vulnerable for the present-day scenario and near future, except the Summer Island Drain headworks (003G1). This primary structure is classified as moderately vulnerable in the near future, and most vulnerable in the far future. All other primary infrastructure (004G1, 005G1, 006G1) is classified as moderately vulnerable in the far future, as are four (4) other secondary floodgates (113G1, 117G1, 148G1 and UNK26, see Appendix F).

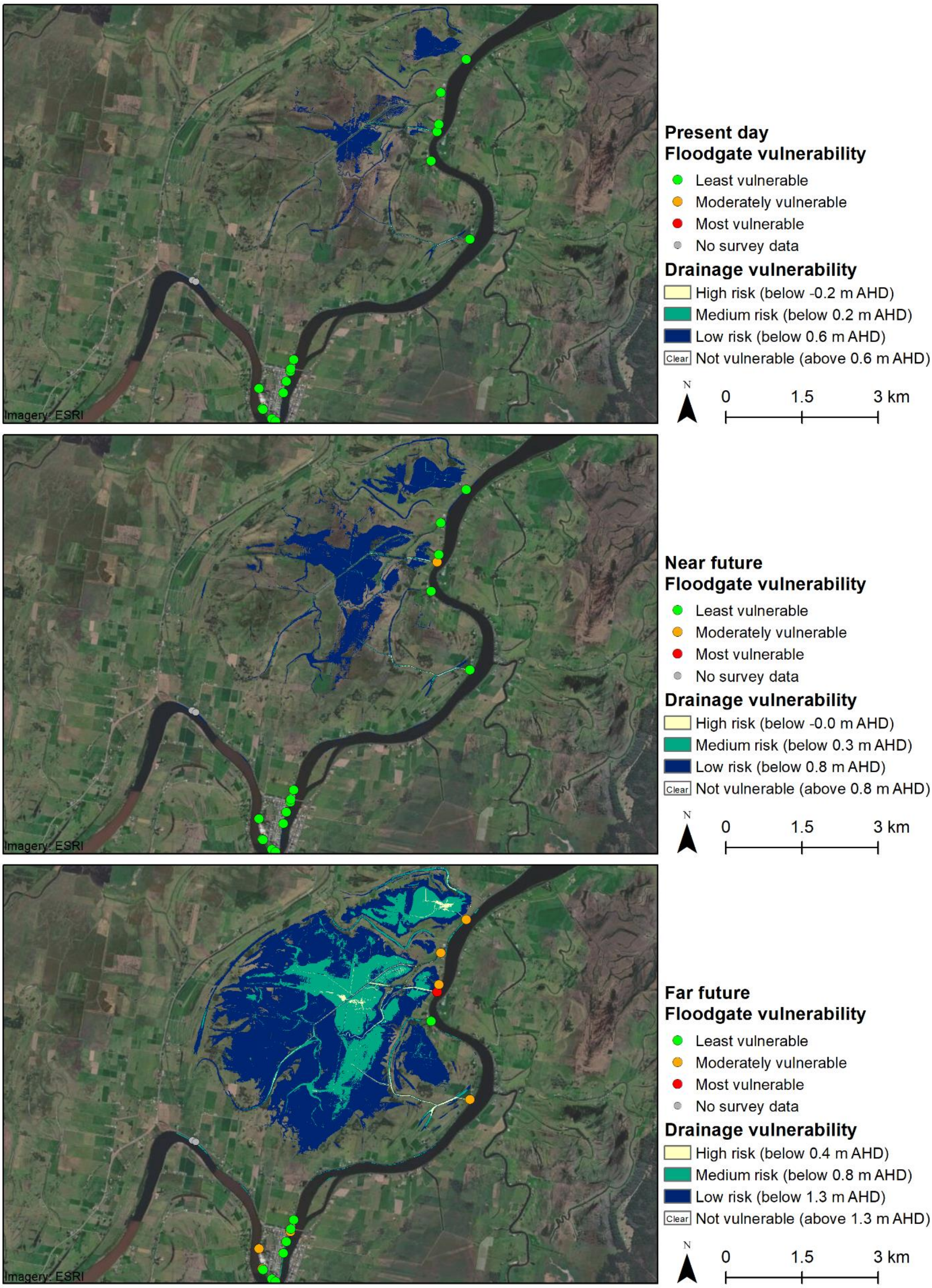

Figure 8-64: Sea level rise drainage vulnerability – Summer Island subcatchment

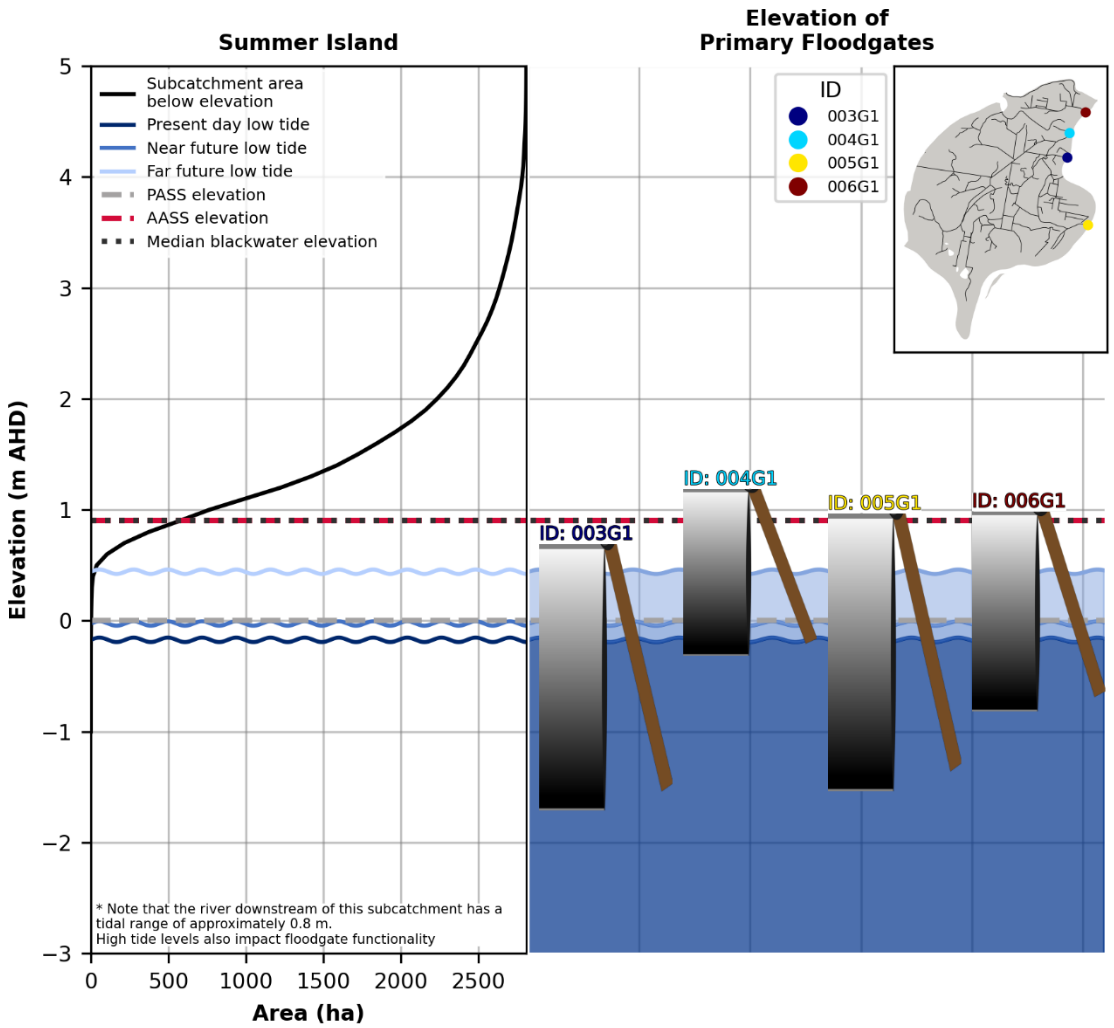

Figure 8-65: Primary floodgates and key floodplain elevations – Summer Island subcatchment

8.11.4 Management options

Potential management options for short and long-term planning horizons for the Summer Island subcatchment include:

- Short-term: Optimise controlled in-drain tidal flushing, and utilise wet pasture management.
- Long-term: Infilling and reshaping of drains in addition to wet pasture management.

Note that short and long-term management options are based on existing data and may be subject to change upon detailed site investigation and/or additional information. The options tabled are intended to provide a range of potential options that could be investigated further as required.

Short-term management options

Floodgates could be actively managed to allow controlled in-drain tidal flushing of the waterways where it is not already taking place. Structures such as buoyancy controlled auto-tidal gates could be utilised to provide more control on the level of flushing. Investigations would need to be completed to optimise the extent of tidal flushing.

Within the Summer Island subcatchment there is an extensive network of secondary floodplain drains in some areas. At these locations the drainage density could be reduced and wet pasture management practises utilised. Construction of drop board structures could assist with this.

Long-term management options

In the long term, consider further reducing the drainage density within the Summer Island subcatchment and transitioning to wet pasture management as sea level rise reduces the drainage potential. This would involve the retention of water through the use of weirs, drop board structures, or by infilling drains and promoting the growth of water tolerant vegetation. This will be particularly relevant for some of the lowest-lying areas in the floodplain that will be impacted by reduced drainage and help reduce poor water quality resulting from acid sulfate soils and blackwater.

To further reduce the risk of acid sulfate soils, consider modifying existing primary drains to make them shallower and wider. This will reduce their intersection with acid sulfate soils and the subsequent export of acidic water.

A summary of the potential management options for the Summer Island subcatchment including indicative costs is provided in Table 8-14.

Table 8-14: Summary of management options for Summer Island

Timeframe	Strategy	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing per year)	Indicative cost (lost productivity per year)	Effectiveness at improving:		
						Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Optimise tidal flushing	None	$200,000	$10,000	None	High	Moderate	Negligible
Short-term	Wet pasture management	None	$20,000	None	Minimal	None	Low	Moderate
Long-term	Drain infilling/reshaping	None	$900,000	None	Minimal	None	Moderate	Low

*Costs exclude additional investigation/studies, including; REF, EIS, flood studies, and monitoring programs that may be required prior to implementation.

8.12 Euroka Creek subcatchment

Acid priority rank:	**10**
Blackwater priority rank:	**11**
Infrastructure	
Approximate waterway length (km)	9
# Privately owned end of system structures	0
# Publicly owned end of system structures	1
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (floodgate ID)	010G1
Elevations	
Invert of primary floodplain infrastructure (m AHD)	0.1
Average AASS elevation (m AHD)	-0.2
Average PASS elevation (m AHD)	N/A
Median blackwater elevation (m AHD)	2.0
Present day low water level (m AHD)	-0.1
Near future low water level (m AHD)	0.0
Far future low water level (m AHD)	0.4
Proximity to sensitive receivers	
Oyster leases (km)	30.1
Saltmarsh (km)	27.2
Seagrass (km)	32.9
Mangroves (km)	25.0
Coastal Management SEPP coastal wetlands (km)	19.6
Land use	
Total floodplain area (ha)	201
Classified as conservation and minimal use (ha (%))	0 (0%)
Classified as grazing (ha (%))	149 (74%)
Classified as forestry (ha (%))	0 (0%)
Classified as horticulture (ha (%))	0 (0%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	16 (8%)
Classified as marsh/wetland (ha (%))	15 (8%)
Other (ha (%))	21 (11%)
Land values	
Estimated total primary production value ($/year)	$100,000
Average land value above 2.0 m AHD ($/ha)	$16,000
Average land value below 2.0 m AHD ($/ha)	$14,900

8.12.1 Site description and brief history of drainage

The Euroka Creek subcatchment is located on the right bank of the upper Macleay River estuary. It is the furthest upstream subcatchment in the Macleay River floodplain assessed as a part of this study. The main waterway for the subcatchment is Euroka Creek which flows from the south west to east through the subcatchment. There is minimal artificial drainage across the subcatchment. Floodgates were installed on Euroka Creek in 1969 as part of the Macleay River flood mitigation scheme (Tulau, 2011). Water quality monitoring completed by Kempsey Shire Council (2019) indicated both low dissolved oxygen (<3 mg/L) and low pH (<3) events have occurred within the subcatchment, however, it is unclear if these are the result of prolonged floodplain inundation or acid sulfate soils.

The primary land use across the Euroka Creek subcatchment is grazing which accounts for 74% of the area. The South Kempsey urban area is located to the east of the subcatchment. Tenure information for the Euroka Creek subcatchment is shown in Figure 8-66. Information on drainage and floodplain elevation is shown in Figure 8-67.

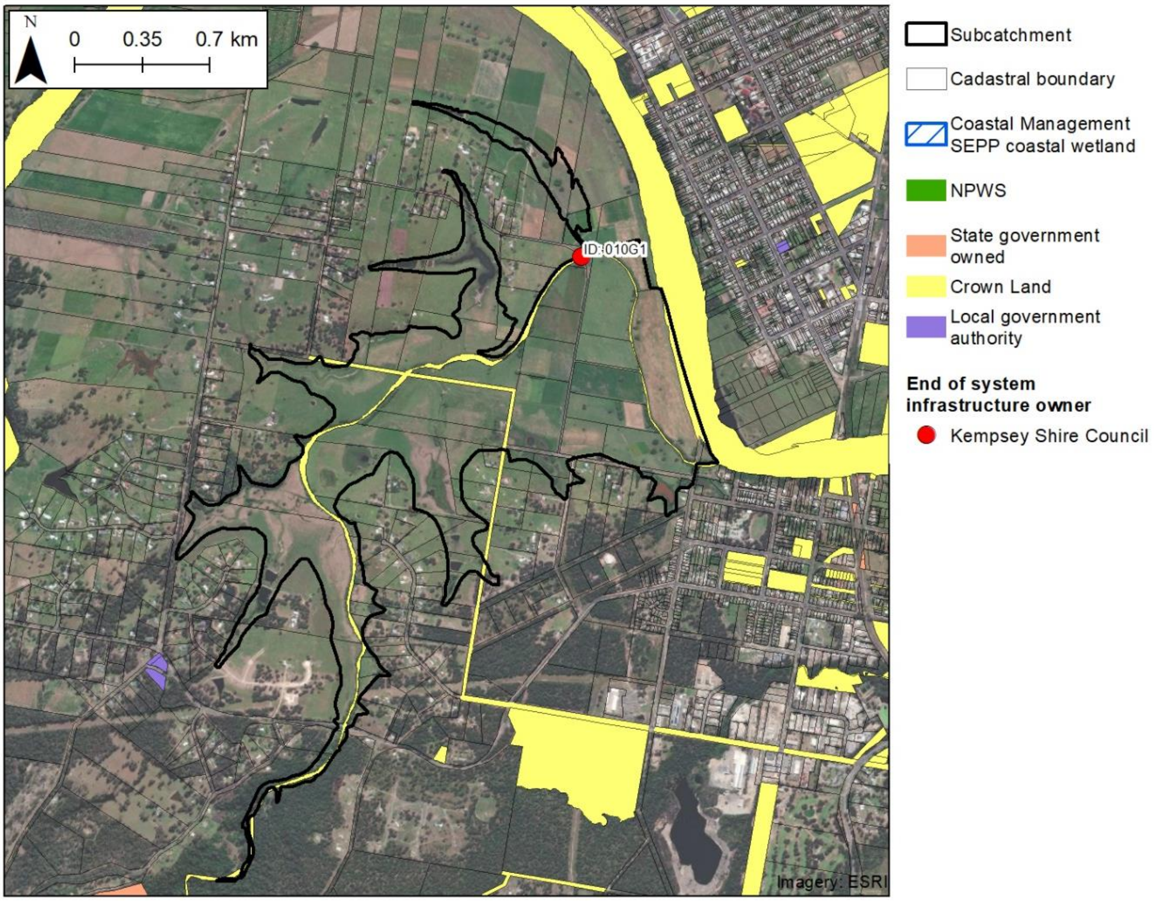

Figure 8-66: Euroka Creek subcatchment land and end of system infrastructure tenure

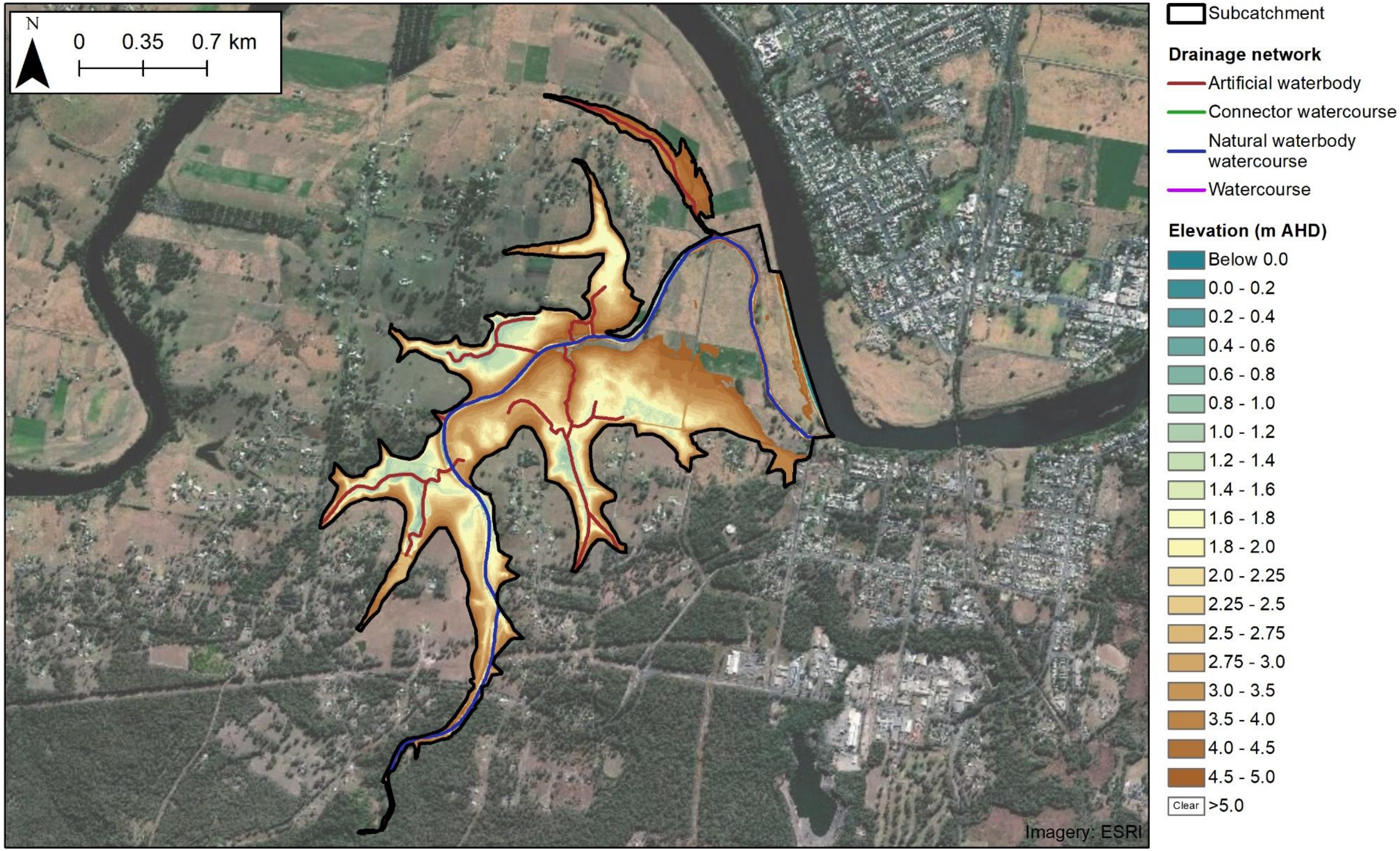

Figure 8-67: Euroka Creek subcatchment elevation and drainage network

8.12.2 History of remediation

A management plan has been developed for the active management of the Euroka Creek headworks (010G1) (Kempsey Shire Council, N.D.-b). The headworks structure has two large floodgates which are winched open to allow flow upstream (Figure 8-68). The aims of the floodgate management plan developed by Kempsey Shire Council (N.D.-b) are:

- Flood mitigation control;
- Improved weed control;
- Improved aquatic habitat; and
- Improved water quality.

The location of the Euroka Creek headworks is shown in Figure 8-69.

Figure 8-68: Euroka Creek floodgates (010G1) observed to be winched open during field investigations in September 2019

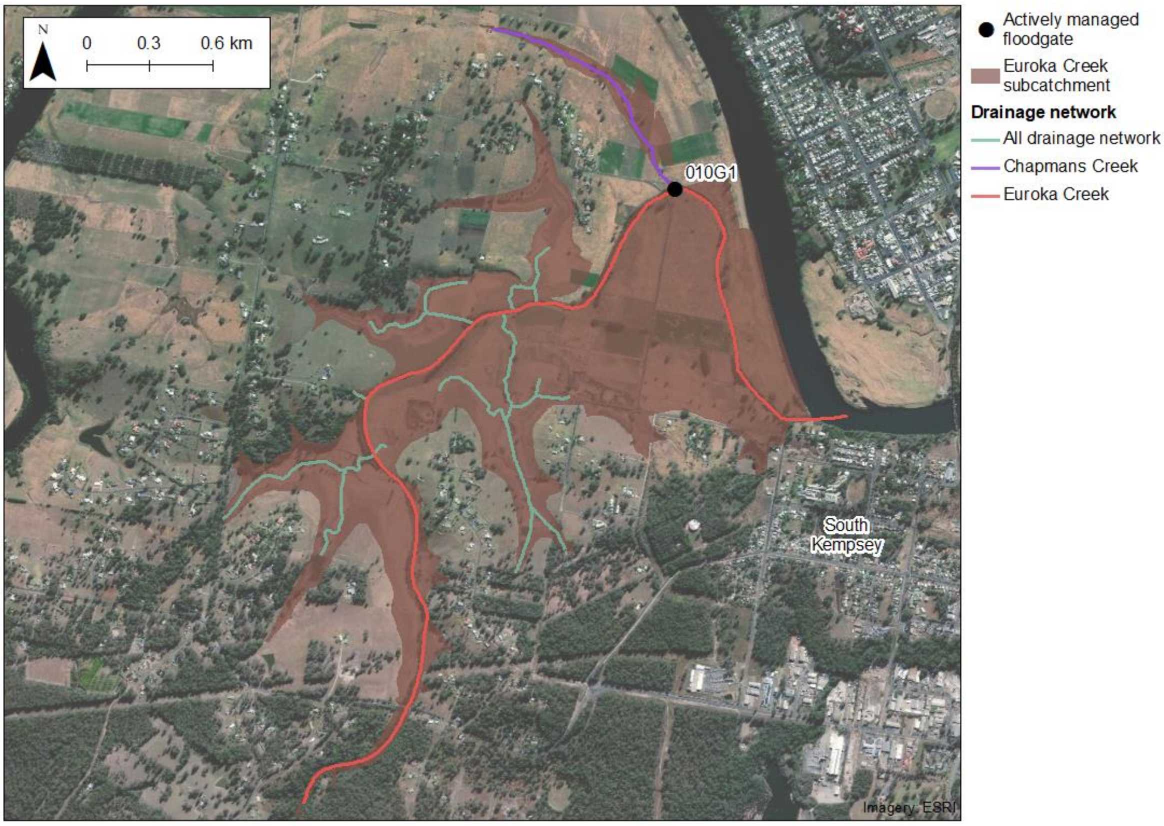

Figure 8-69: The Euroka Creek subcatchment including previous remediation actions

8.12.3 Floodplain drainage – sea level rise vulnerability

The sea level rise vulnerability assessment of the Euroka Creek subcatchment is summarised in Figure 8-70. Modelling indicated that subcatchment drainage is unlikely to be significantly impacted under future sea level rise. Assessment of floodgate vulnerability also indicated no impact on the Euroka Creek headworks (010G1). The invert of this floodgate is only marginally below the far future low tide level (Figure 8-71).

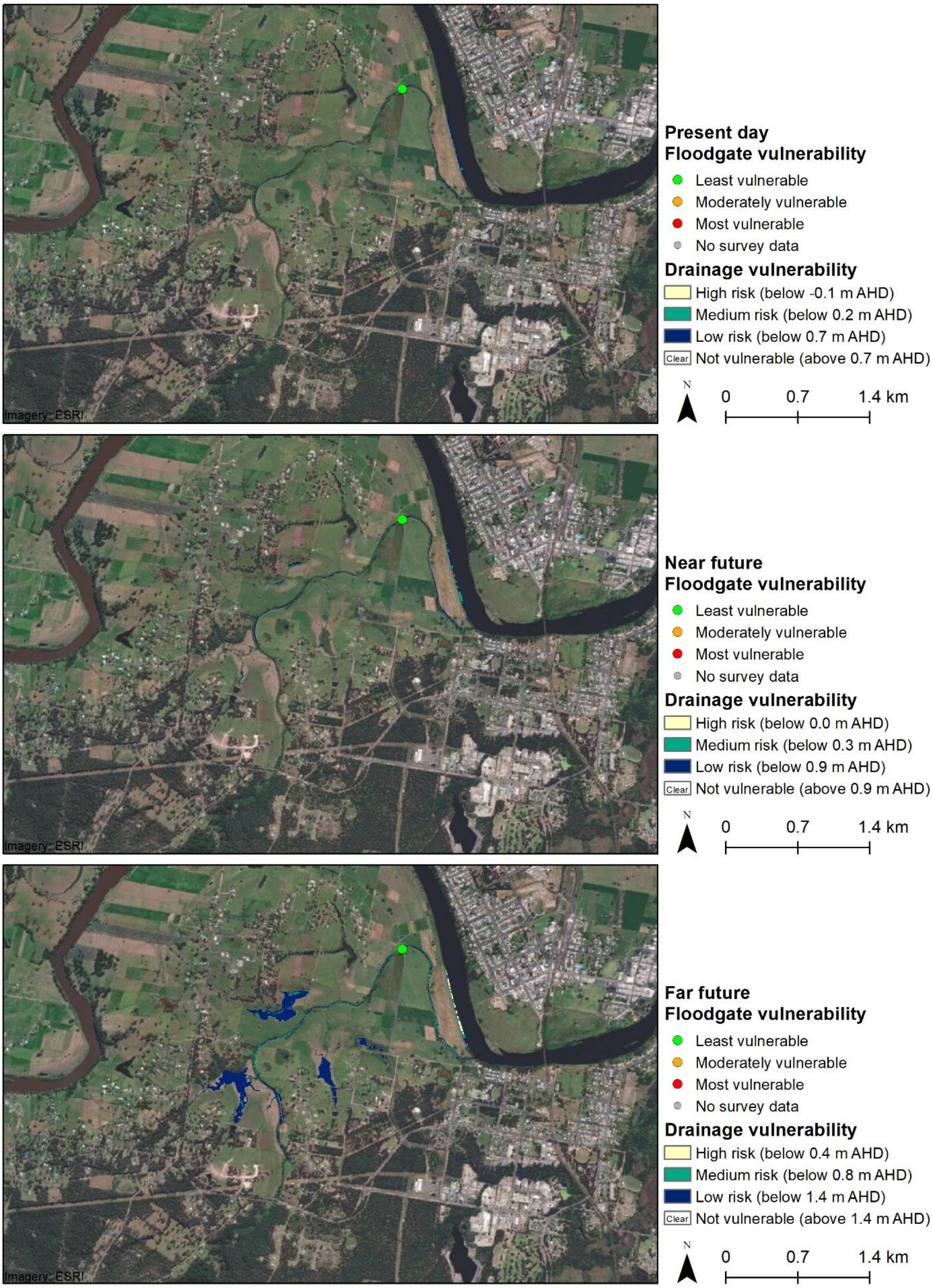

Figure 8-70: Sea level rise drainage vulnerability – Euroka Creek subcatchment

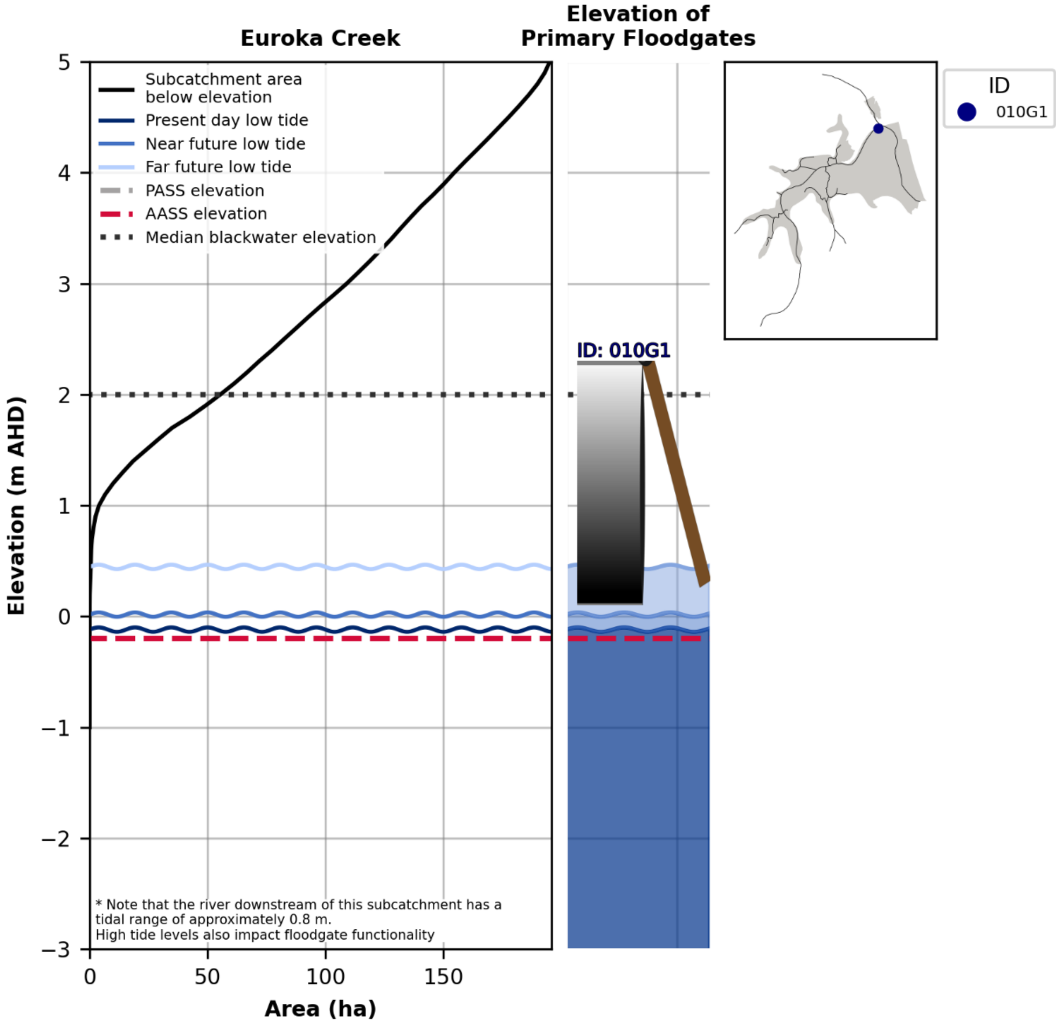

Figure 8-71: Primary floodgates and key floodplain elevations – Euroka Creek subcatchment

8.12.4 Management options

Potential management options for short and long-term planning horizons for the Euroka Creek subcatchment include:

- Short-term: Continued active management of floodgates and wet pasture management.
- Long-term: Continuation of the short-term strategy.

Note that short and long-term management options are based on existing data and may be subject to change upon detailed site investigation and/or additional information. The options tabled are intended to provide a range of potential options that could be investigated further as required.

Short-term management options

Active management of the Euroka Creek headworks (010G1) should continue into the future. Water quality benefits achieved by this could be supplemented by the use of drop boards or weirs to retain water on the low-lying areas of the floodplain to allow for wet pasture management. Wet pasture management practices can reduce the risk of blackwater generation and also limit the creation and transport of acidic runoff from acid sulfate soils.

Long-term management options

No additional strategies should be implemented for the long-term. Continuation of the short-term strategies would allow for the reduction of risks associated with acid sulfate soils and blackwater.

A summary of the potential management options for the Euroka Creek subcatchment including indicative costs is provided in Table 8-15.

Table 8-15: Summary of management options for Euroka Creek

Timeframe	Strategy	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing per year)	Indicative cost (lost productivity per year)	Effectiveness at improving:		
						Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short and long-term	Wet pasture management	None	$20,000	None	Minimal	None	Low	Moderate

*Costs exclude additional investigation/studies, including; REF, EIS, flood studies, and monitoring programs that may be required prior to implementation.

8.13 Rainbow Reach subcatchment

Acid priority rank:	**11**
Blackwater priority rank:	**9**
<u>Infrastructure</u>	
Approximate waterway length (km)	42
# Privately owned end of system structures	5
# Publicly owned end of system structures	2
# Jointly owned end of system structures	3
# End of system structures within coastal wetlands	2
# Publicly owned end of system structures within coastal wetlands	1
Primary floodplain infrastructure (floodgate ID)	075G1, 083G1, 128G1
<u>Elevations</u>	
Invert of primary floodplain infrastructure (m AHD)	-0.9 to -0.4
Average AASS elevation (m AHD)	N/A
Average PASS elevation (m AHD)	N/A
Median blackwater elevation (m AHD)	0.6
Present day low water level (m AHD)	-0.3
Near future low water level (m AHD)	-0.1
Far future low water level (m AHD)	0.4
<u>Proximity to sensitive receivers</u>	
Oyster leases (km)	Within subcatchment
Saltmarsh (km)	Within subcatchment
Seagrass (km)	Within subcatchment
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
<u>Land use</u>	
Total floodplain area (ha)	1,628
Classified as conservation and minimal use (ha (%))	160 (10%)
Classified as grazing (ha (%))	1,275 (78%)
Classified as forestry (ha (%))	0 (0%)
Classified as horticulture (ha (%))	11 (1%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	32 (2%)
Classified as marsh/wetland (ha (%))	59 (4%)
Other (ha (%))	90 (6%)
<u>Land values</u>	
Estimated total primary production value ($/year)	$800,000
Average land value above 0.6 m AHD ($/ha)	$8,100
Average land value below 0.6 m AHD ($/ha)	$5,400

8.13.1 Site description and brief history of drainage

The Rainbow Reach subcatchment is located on the left bank of the lower Macleay River estuary. The Macleay Arm bounds the subcatchment to the north and Andersons Inlet and Clybucca Creek bound the subcatchment to the west. A number of artificial drains with small floodgate structures have been constructed across the subcatchment which provide drainage of low-lying agricultural land.

On the west of the subcatchment, Clybucca Creek and Anderson Inlet separate a number of small islands from the rest of the Rainbow Reach subcatchment, all of which form part of the Clybucca Aboriginal Area managed by the NSW National Parks and Wildlife Service. This area is predominantly estuarine wetland and is managed to conserve biodiversity and cultural heritage (NSW National Parks and Wildlife Service, 2009). Grazing is the predominant land use accounting for 78% of the subcatchments area. Tenure information for the Rainbow Reach subcatchment is shown in Figure 8-72. Information on drainage and floodplain elevation is shown in Figure 8-73.

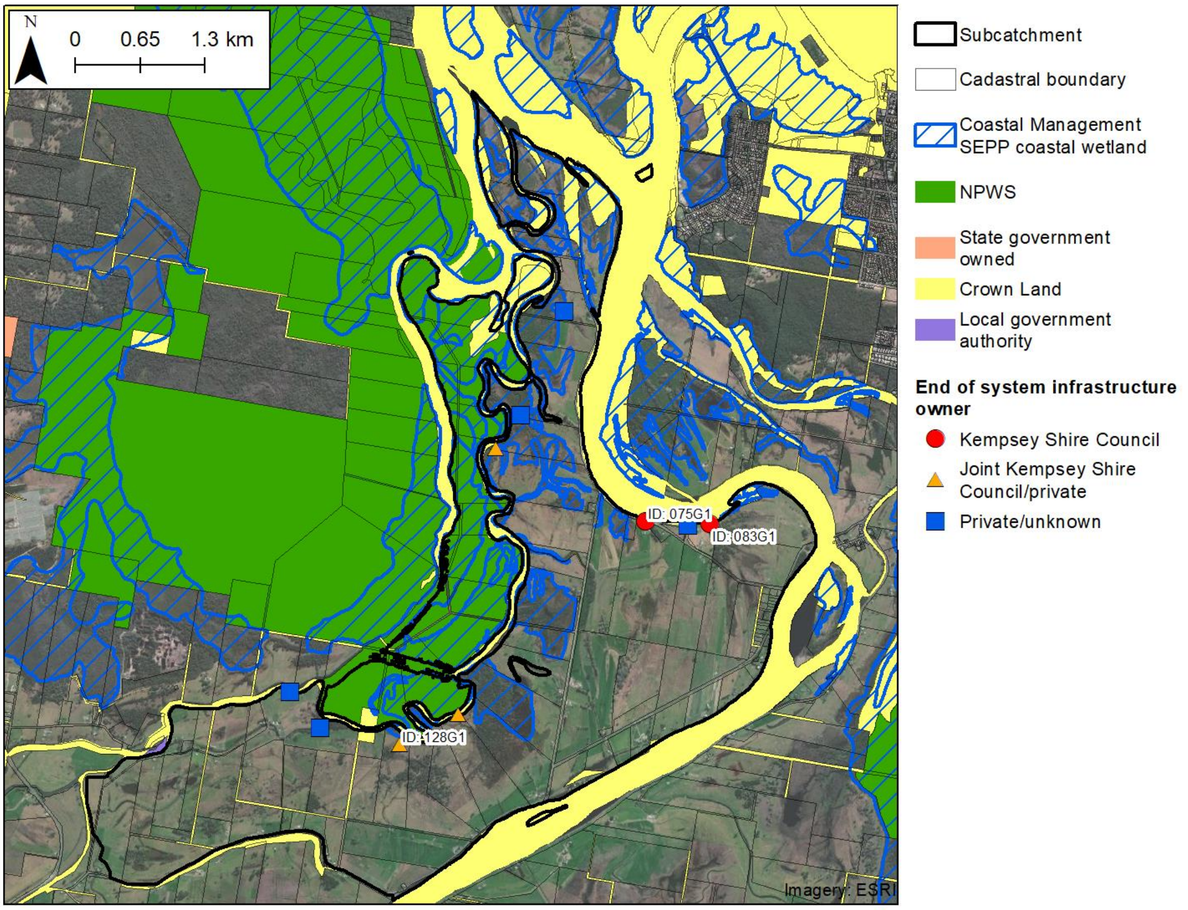

Figure 8-72: Rainbow Reach subcatchment land and end of system infrastructure tenure

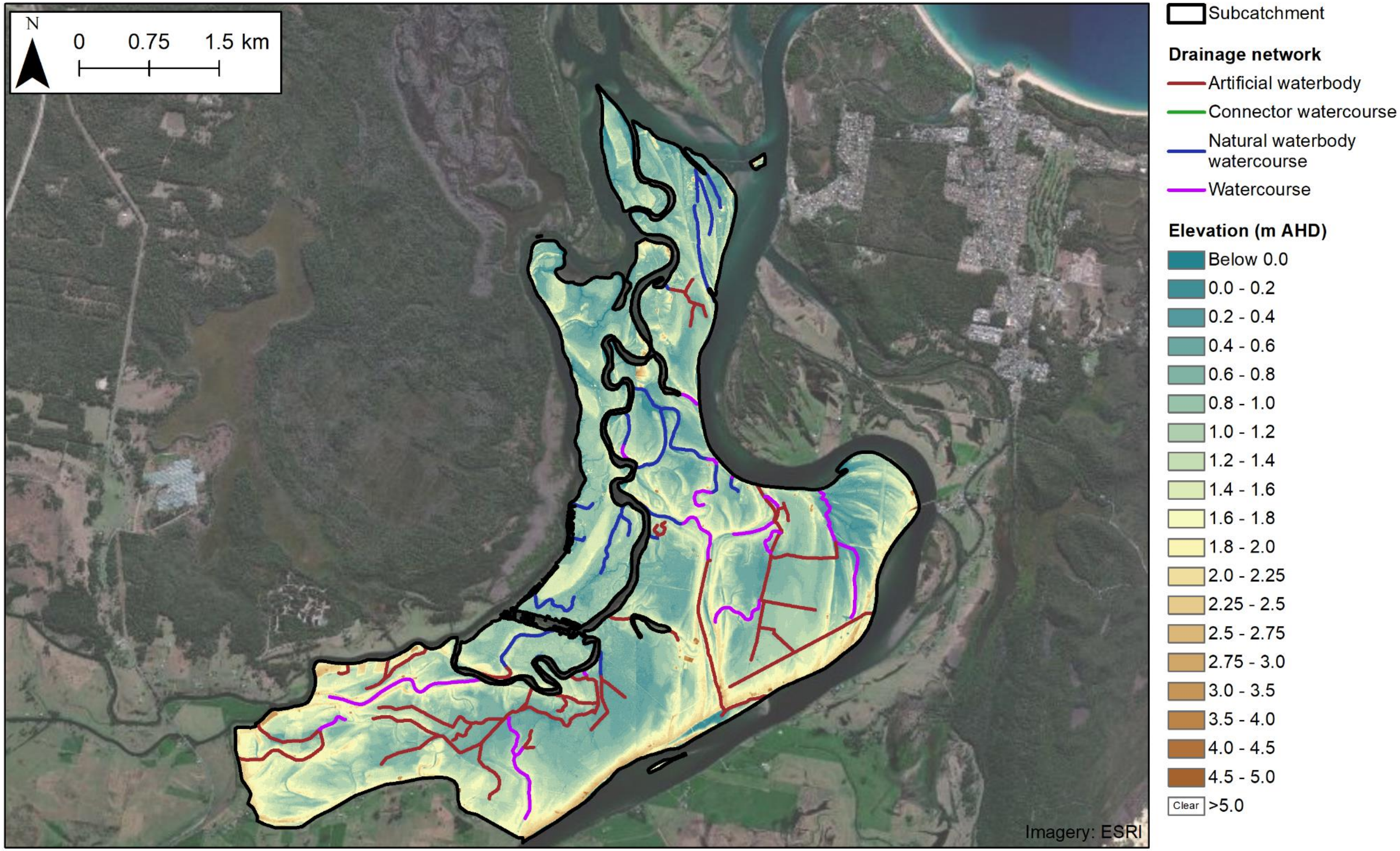

Figure 8-73: Rainbow Reach subcatchment elevation and drainage network

8.13.2 History of remediation

There are no records of remediation attempts within the Rainbow Reach subcatchment. During field investigations completed for this study, one landholder stated that the floodgate flaps on structure 127G1 had either been removed or permanently opened (Figure 8-74) (Brady, 2019, personal communication). While inspection of the floodgate was not possible, levels of salinity and the presence of intertidal vegetation observed upstream of the floodgates indicated tidal inundation of some low-lying areas of the subcatchment.

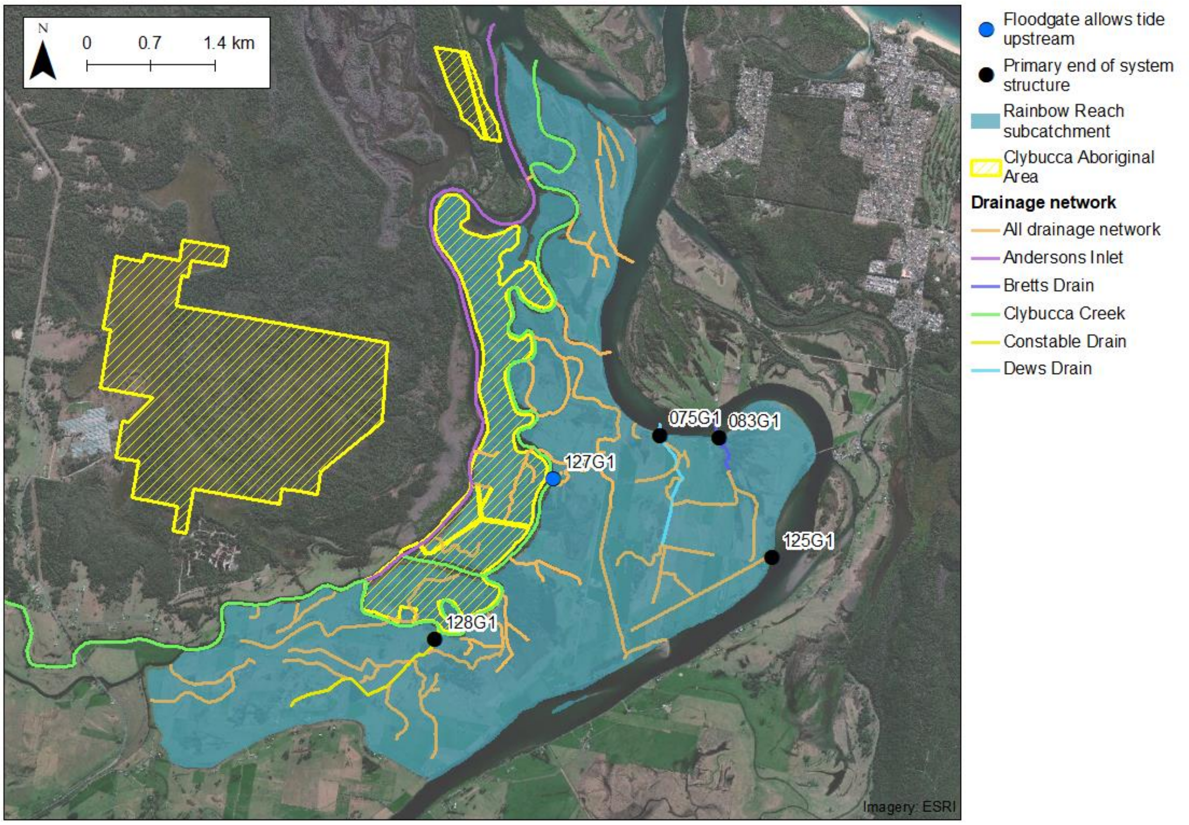

Figure 8-74: The Rainbow Reach subcatchment including previous remediation actions

8.13.3 Floodplain drainage – sea level rise vulnerability

The sea level rise vulnerability assessment of the Rainbow Reach subcatchment is summarised in Figure 8-75. Modelling of present day water conditions indicated that large areas of the floodplain are currently impacted by reduced drainage during certain water level conditions (i.e. spring tides). Sea level rise is likely to increase impact drainage into the future, with far future sea level rise modelling indicating that large areas of the floodplain will be situated below the approximate mean tide water level (i.e. at medium risk of reduced drainage).

Figure 8-76 shows the primary floodgates in this subcatchment relative to primary floodgates and key floodplain elevations. The floodgate vulnerability assessment indicated that primary structures 083G1 and 128G1 are moderately vulnerable under present day conditions, while secondary floodgate126JG1 is classified as most vulnerable. All primary floodgates are classified as moderately vulnerable in the near future scenario and most vulnerable in the far future scenario. Additionally, four (4) secondary floodgates are classified as most vulnerable in the far future and the remaining floodgates are all moderately vulnerable.

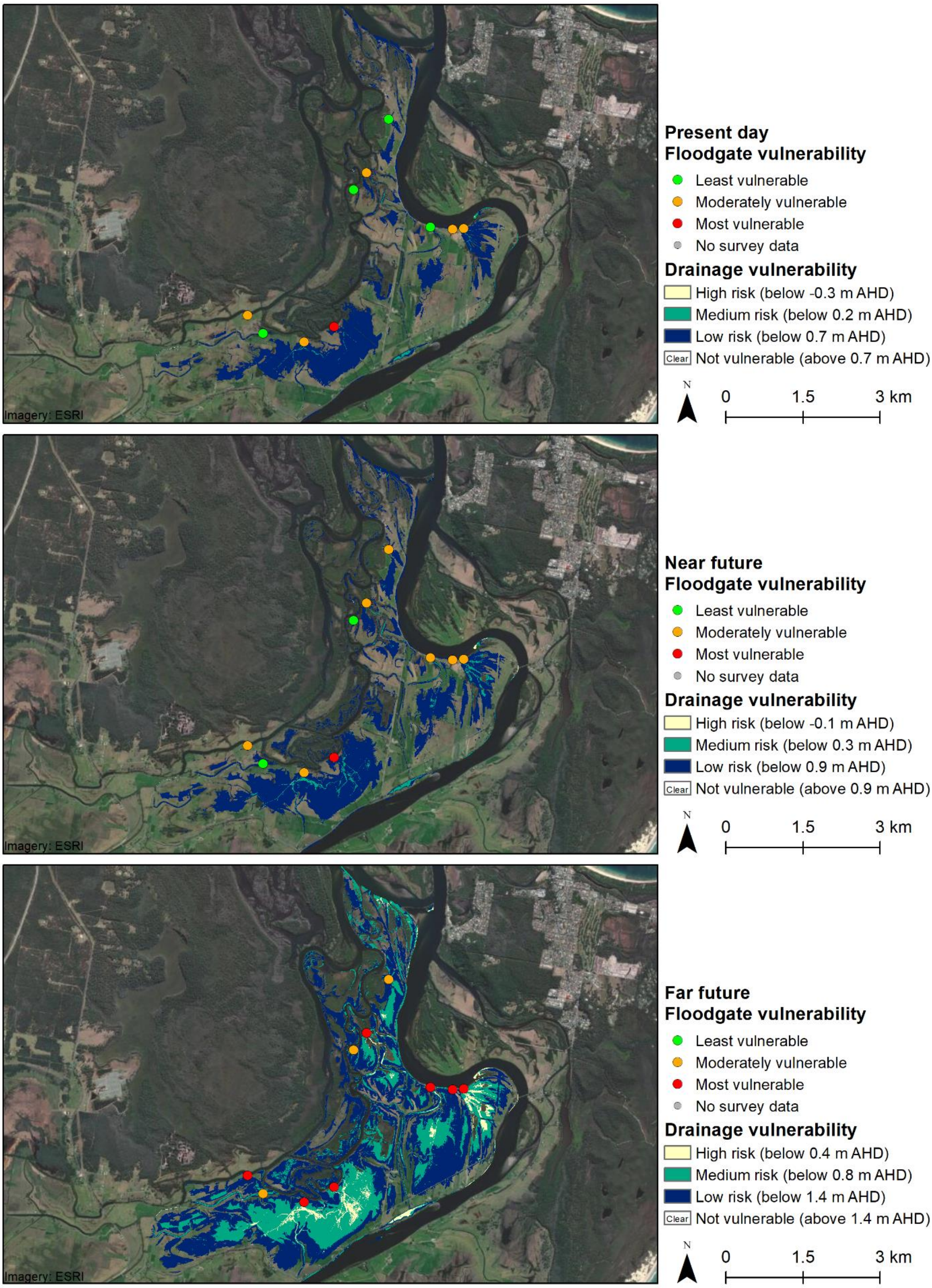

Figure 8-75: Sea level rise drainage vulnerability – Rainbow Reach subcatchment

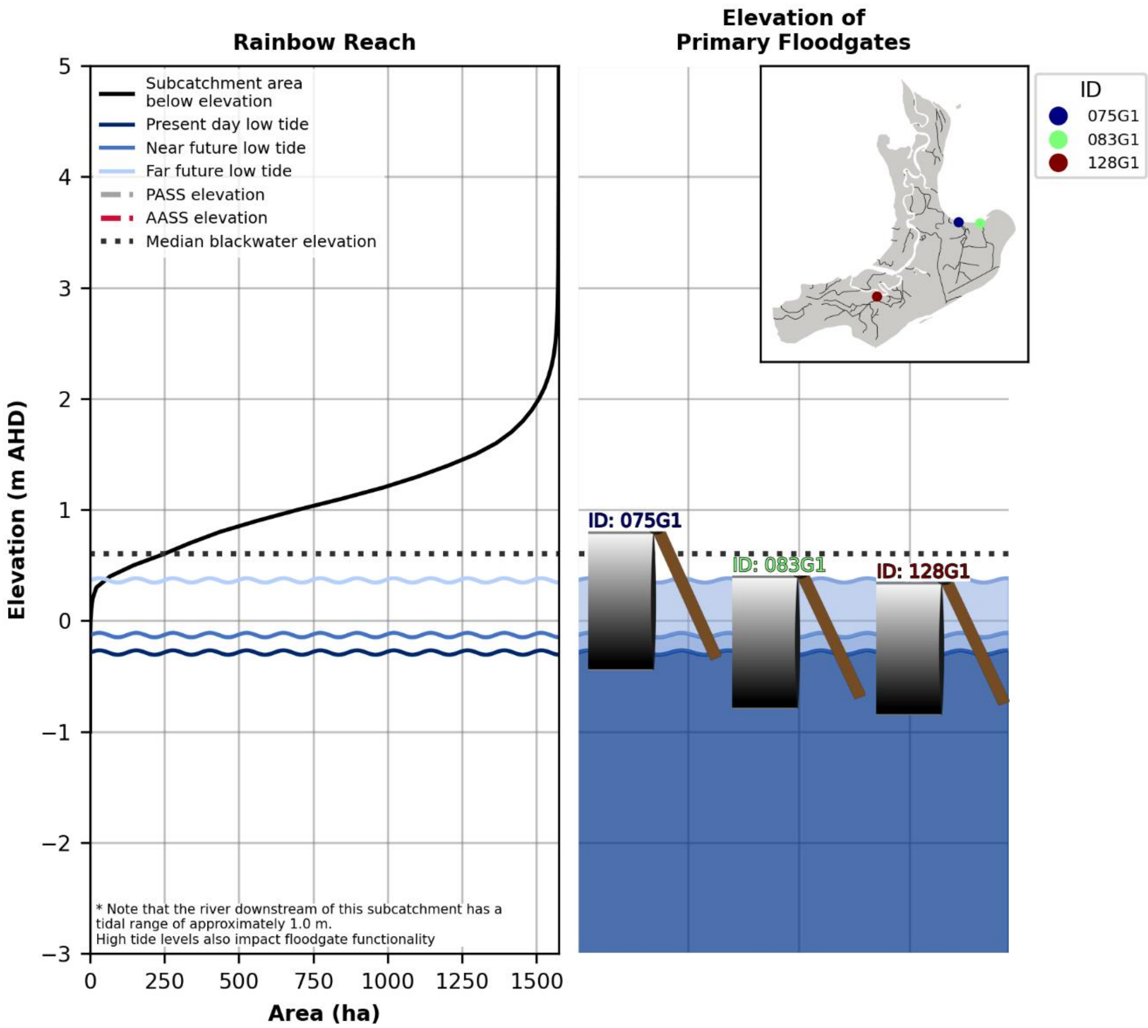

Figure 8-76: Primary floodgates and key floodplain elevations – Rainbow Reach subcatchment

8.13.4 Management options

Potential management options for short and long-term planning horizons for the Rainbow Reach subcatchment include:

- Short-term: Promote controlled in-drain tidal flushing, reshaping of drains, and protection of existing coastal wetland.
- Long-term: Investigate full restoration to estuarine wetland.

Note that short and long-term management options are based on existing data and may be subject to change upon detailed site investigation and/or additional information. The options tabled are intended to provide a range of potential options that could be investigated further as required.

Short-term management options
The short term management options for the Rainbow Reach subcatchment could investigate the modification of end of system structures to allow controlled in-drain tidal flushing. This would reduce the risk of acidic runoff and create new habitat. Deep drains in this area could be shallowed and widened to further reduce their interaction with potential acid sulfate soil layers.

It should be noted that a large extent of the Rainbow Reach subcatchment is mapped as Coastal Management SEPP coastal wetlands. Wherever possible, protection of existing wetlands and modification of waterways to restore natural flow paths should be encouraged within this area.

Long-term management options
In the long term, the Rainbow Reach subcatchment will be significantly impacted by reduced drainage due to sea level rise. Due to the location of the subcatchment in the lower Macleay River estuary and the subcatchments individual hydrology (such as its limited catchment area), it is unlikely that wet pasture management would be effective for this subcatchment. Consideration should be given for converting low-lying floodplain areas to estuarine wetlands as sea level rise impacts land use and agricultural productivity.

A summary of the potential management options for the Rainbow Reach subcatchment including indicative costs is provided in Table 8-16.

Table 8-16: Summary of management options for Rainbow Reach

Timeframe	Strategy	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing per year)	Indicative cost (lost productivity per year)	Effectiveness at improving:		
						Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Promote tidal flushing	None	$300,000	$20,000	None	High	Moderate	Negligible
Short-term	Drain reshaping	None	$450,000	None	None	None	Moderate	Low
Long-term	Restoration of wetlands	$9,000,000	$40,000	Minimal	$350,000	Very high	High	High

*Costs exclude additional investigation/studies, including; REF, EIS, flood studies, and monitoring programs that may be required prior to implementation.

9 Outcomes and recommendations

9.1 Preamble

The objective of the Coastal Floodplain Prioritisation Study was to provide a roadmap for the strategic management of acid sulfate soils (ASS) and low oxygen blackwater runoff from seven (7) major coastal floodplains in NSW, to improve the water quality and overall health of the marine estate. This has been achieved for the Macleay River floodplain through the development and application of an evidence based and data driven multi-criteria assessment involving:

- Application of a prioritisation methodology to rank 11 subcatchments on the Macleay River floodplain with regard to their contribution to acid and blackwater generation and the risk they pose to the health of the marine estate;
- Development of management options for individual subcatchments outlining potential strategies for on-ground works to improve water quality; and
- Collation of catchment specific data relevant to the implementation of management options.

This approach has identified high-priority subcatchments within the Macleay Rivers coastal floodplain system to allow targeted floodplain management to improve water quality. The outcomes of the subcatchment prioritisation, management option development and supporting information, provide an objective prioritised list of 11 floodplain subcatchments with a roadmap on how to achieve water quality improvements across the Macleay River coastal floodplain. This can be used by floodplain managers to directly reduce the environmental threats posed to the marine estate by diffuse runoff associated with acid sulfate soil discharges and blackwater generation, and will allow for the subsequent social, cultural and economic benefits to be fully realised.

9.2 Summary

The multi-criteria prioritisation methodology was applied to rank the 11 subcatchment drainage areas of the Macleay River floodplain with respect to the risk they pose to the marine estate due to poor water quality associated with ASS and blackwater runoff. The prioritisation methodology utilised a data driven approach to objectively rank the subcatchments. It is strongly recommended that this data, as well as additional data collected into the future be collated into an estuary wide database that is readily accessible to land managers. Data considered during this analysis included:

- Topography;
- Groundwater potential flow rate (i.e. hydraulic conductivity);
- Floodplain drainage;
- Catchment hydrology;
- Soil parameters including acid concentration;
- Land use; and
- Estuarine and tidal dynamics.

The acid prioritisation assessment considers the volume of acid stored within a floodplain and the potential for it to be transported to the estuary, and to objectively rank subcatchment areas from the highest to lowest with respect to the risk of acid drainage to the estuary. Within the Macleay River floodplain, the highest priority subcatchment for acid drainage was Collombatti-Clybucca estimated to contribute approximately 70% of the total acid risk to the estuary (Table 9-1). The second highest priority subcatchments was Frogmore/Austral Eden/Verges Swamp which individually contribute approximately 10% of the total acid risk for the Macleay River Estuary. The location of these two subcatchments highlights that acid generation and export is a risk throughout the entire Macleay River estuary. The Yarrahapinni subcatchment (ranked third) has undergone significant remediation works since 2007 including removal of floodgates to facilitate full tidal flushing.

Table 9-1: Macleay River floodplain subcatchment priority ranking

Subcatchment	Acid rank	Blackwater rank
Collombatti-Clybucca	1	3
Frogmore/Austral Eden/Verges Swamp	2	4
Yarrahapinni*	3	5
Christmas Creek	4	8
Belmore Swamp	5	2
Kinchela Creek	6	1
Raffertys/Saltwater Inlet	7	6
Pola Creek	8	10
Summer Island	9	7
Euroka Creek	10	11
Rainbow Reach	11	9

*Large scale remediation works implemented since 2007

Application of the blackwater prioritisation methodology identified areas that are most likely to contribute to blackwater generation due to:

(i) Susceptibility to prolonged floodplain inundation following flood events; and
(ii) Distribution of water tolerant (or intolerant) vegetation.

This data was used to objectively rank subcatchments from highest to lowest based on the risk they pose to the marine estate in terms of discharging low oxygen blackwater to the estuary (Table 9-1). The assessment identified the highest priority subcatchments, Kinchela Creek (1), Belmore Swamp (2) and Collombatti-Clybucca (3), accounted for approximately 55% of the total blackwater generation risk in the Macleay River estuary. Note, the southern floodplain of the Macleay River includes a number of subcatchments that are all hydrologically linked and together comprise the greatest risk within the Macleay River floodplain for blackwater generation.

Following the prioritisation of subcatchments, management options have been developed to guide the potential on-ground actions that could be completed to address the impacts of poor water quality associated with ASS and blackwater runoff. Management options have been proposed for the short-term, assuming existing land use practices will remain unchanged across the floodplain, and the long-term, where environmental stressors on subcatchments such as sea level rise may require strategic changes to floodplain management. Any changes in management of these areas will require consultation with local landholders and a comprehensive understanding of, and a plan to mitigate, the social and economic impacts of changes in land management on the community. Management options have been developed for individual subcatchments taking into consideration:

- Priority ranking for acid and blackwater;
- Proximity to sensitive receivers;
- Condition of existing floodplain infrastructure;
- Historical remediation works;
- Estuarine influence on the floodplain (e.g. tide and salinity levels);
- Current and future land uses;
- Current and future land values; and
- The relative costs and benefits of remediating the floodplain.

Management options have also considered the impacts that sea level rise will have on floodplain drainage. To complete this assessment, detailed numerical modelling of the Macleay River estuary was completed to assess the vulnerability of floodplain drainage to sea level rise. Historical (~1960s), present day (2020), near future (~2050) and far future (~2100) sea levels were modelled and compared to floodgate infrastructure geometry and floodplain topography to assess floodplain vulnerability to reduced drainage under future sea levels. The assessment identified floodplain infrastructure and areas potentially vulnerable to sea level rise as summarised in Table 9-2. This information was then used to inform the development of management options which are designed to guide the future strategy adopted by floodplain managers to improve the health of the marine estate.

Table 9-2: Macleay River drainage vulnerability under sea level rise

Vulnerability status	Historical (HS)	Present day (PD)	Near future (NF)	Far future (FF)
Floodgates (number of)				
Least vulnerable floodgates	82	81	73	49
Moderately vulnerable floodgates	14	15	23	25
Most vulnerable floodgates	1	1	1	23
Floodplain area (hectares)				
Low vulnerability area	7,962	8,363	8,579	14,515
Moderate vulnerability area	726	1,186	3,466	6,539
High vulnerability area	36	81	211	5,513

The management options suggested as part of this study are high level and intended to guide the overall strategy that should be considered by floodplain managers when addressing sources of diffuse poor water quality. It is acknowledged that further detailed on-ground investigations are required prior to the commitment to any on-ground actions, including consideration of impacts on local landholders. While this is not specifically addressed as part of this study, a range of factors which influence implementation have been collated to assist floodplain managers during the detailed design of works to improve water quality. Implementation factors to be considered during detailed design and changes to existing management include:

- Waterway status (natural or artificial);
- Infrastructure and land tenure;
- Land value (including production, purchase and remediation values);
- Future land use planning;
- Location of sensitive receivers; and
- Location of heritage items.

Outcomes from the Coastal Floodplain Prioritisation Study for the Macleay River floodplain provide a roadmap for floodplain land managers to directly improve poor water quality associated with diffuse runoff caused by acid and blackwater generation on the coastal floodplain. Specifically, this study has:

1. Ranked subcatchments on the basis of the risk they pose to the marine estate in terms of poor water quality resulting from ASS and blackwater runoff;
2. Developed potential management options that describe the overall strategy for floodplain management to improve water quality; and
3. Identified and collated key datasets that will be valuable for the implementation of management options.

9.3 Conclusions

Substantial efforts have been put into managing water quality in the Macleay River estuary, primarily through Kempsey Shire Council with support from local landholders. Notably, a large number of major floodplain end-of-system infrastructure has been modified to allow some controlled flushing (e.g. sluice gates, and winches) and improved connectivity with the estuary. Numerous landholders have co-operated with paddock scale interventions, such as weirs or drain swaling, with mixed success in terms of water quality improvements and maintenance/improvement of agricultural productivity. These remediation efforts should be encouraged and commended. However, the scale of on-going large event-based floodplain discharges of blackwater and acid, particularly from the three (3) highest priority subcatchments (Collombatti-Clybucca, Kinchela Creek and Belmore Swamp) can only be substantially addressed through broadscale changes to land use and a restoration of natural floodplain hydrology. Broadscale management changes throughout the floodplain will need to consider, and have a plan to mitigate, potential social, cultural, and economic impacts to local landholders.

Sufficient scientific and technical understanding exists to identify, address, and mitigate many of the environmental issues that coastal floodplains and estuaries face, both now and into the future. Particularly as sea level rise impacts drainage and agricultural land uses in the lowest lying areas of the floodplain, a catchment wide strategy needs to be established to assist the community adapting to a changing environment and supporting a future that is environmentally and economically sustainable. This will require cooperation between all levels of government, the local community, and industry, to ensure long-term management of coastal floodplains and estuaries is proactive and adaptive. The implementation of scientific knowledge and technical solutions is impeded by political, social, and economic barriers, which will need to be overcome if our estuaries are to thrive into the future.

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