Richmond River Floodplain Prioritisation Study

WRL TR 2020/05, May 2023

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Project details

Report title	Richmond River Floodplain Prioritisation Study
Authors(s)	A J Harrison, D S Rayner, T A Tucker, G Lumiatti, P F Rahman, D M Gilbert and W C Glamore
Report no.	2020/05
Report status	Final
Date of issue	May 2023
WRL project no.	2018064
Project manager	D S Rayner
Client	DPI Fisheries
Client address	Taylors Beach Road Taylors Beach NSW 2316
Client contact	Kylie Russell
Client reference	18-772

Document status

Version	Reviewed by	Approved by	Date issued
Preliminary Draft	GPS	GPS	25/09/20
Draft	GPS	GPS	30/09/20
Draft version 2	GPS	GPS	22/03/21
Draft version 3	GPS	GPS	24/01/22
Final	FF	BMM	22/05/23

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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 13 floodplain subcatchment drainage areas across the Richmond River floodplain. To determine how water quality from the Richmond 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 Richmond River floodplain and acid discharges have been identified as responsible for fish kill events (Dove, 2003; Sammut, 1998).

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.

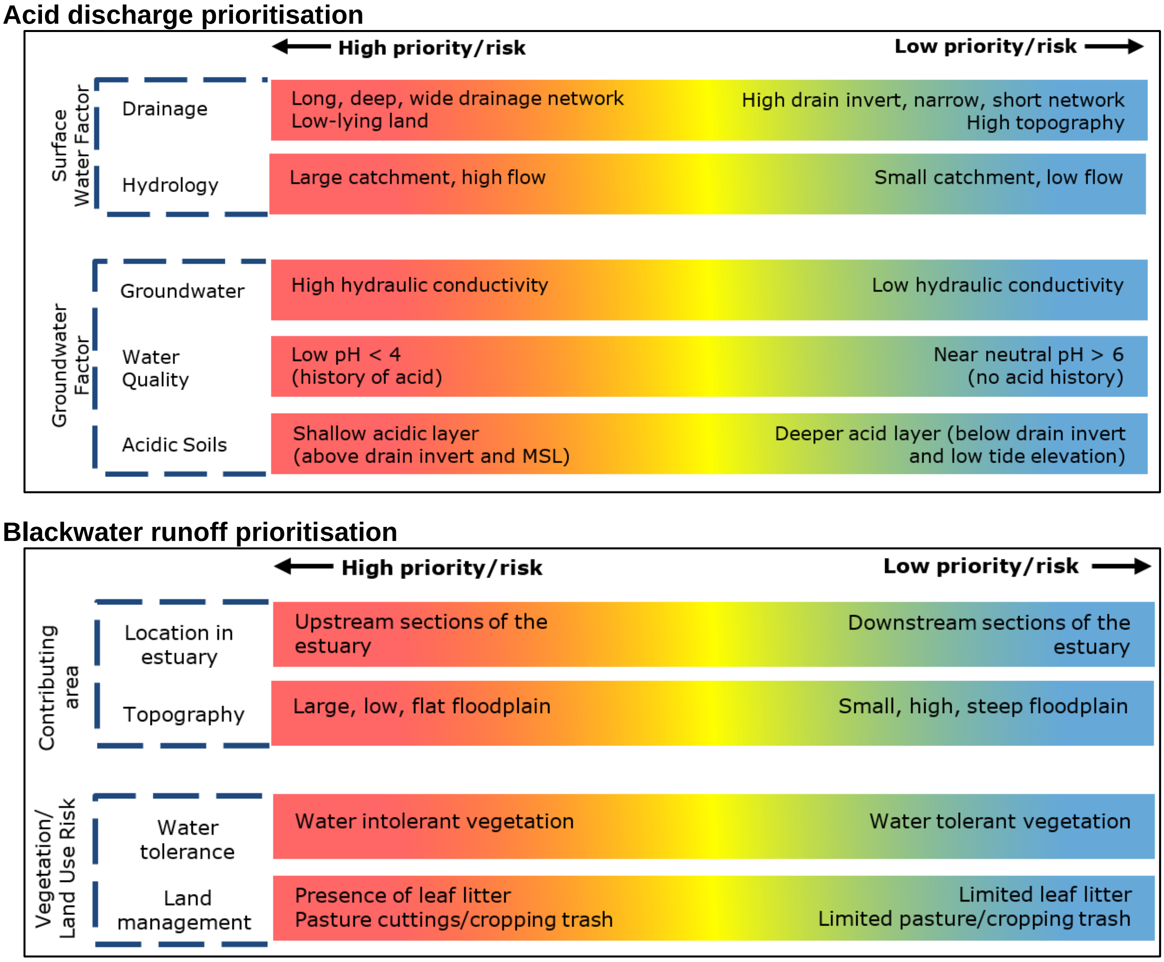

Figure ES-1: Factors influencing acid sulfate soil discharge and blackwater runoff from NSW coastal floodplain subcatchments

Following the prioritisation of subcatchments, management options have been suggested 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 suggested 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 Richmond River floodplain subcatchment prioritisation results

The multi-criteria prioritisation methodology was applied to rank subcatchment drainage areas of the Richmond 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 13 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.

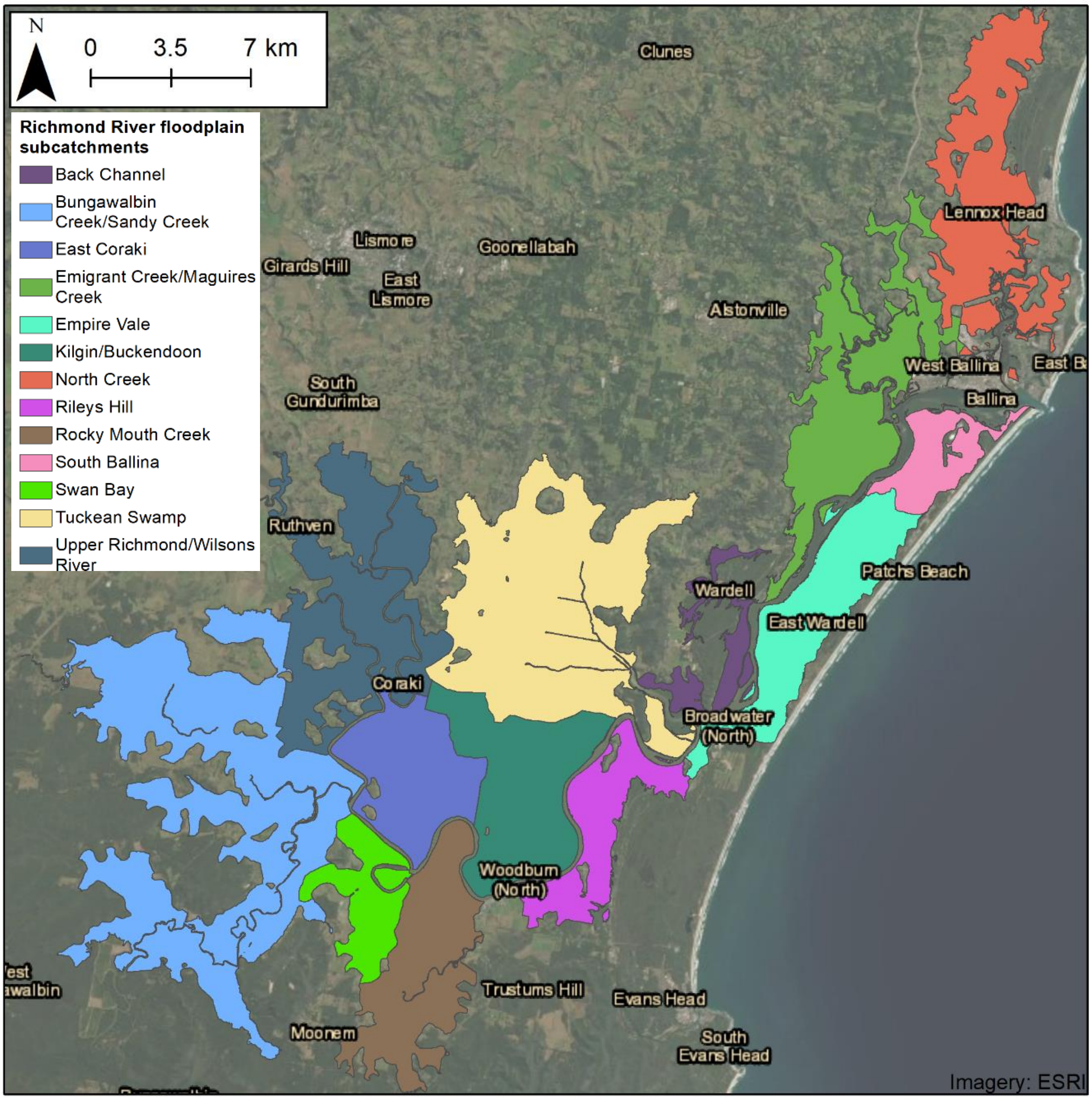

Figure ES-2: Richmond River floodplain subcatchments

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 Richmond River floodplain the five (5) highest priority subcatchments for acid drainage: Tuckean Swamp (1), Rocky Mouth Creek (2), Bungawalbin Creek/Sandy Creek (3), North Creek (4) and Emigrant Creek/Maguires Creek (5) were estimated to contribute over 82% of the total acid risk to the estuary. The Tuckean Swamp subcatchment was estimated to individually be the source of over 40% of acid risk to the estuary. High risk acid subcatchments were identified in the upper, middle, and lower reaches of the estuary, indicating that acid discharges from the floodplain have the potential to impact all areas of the Richmond River estuary (Table ES-1, Figure ES-3).

Table ES-1: Richmond River floodplain subcatchment priority ranking

Subcatchment	Acid rank	Blackwater rank
Tuckean Swamp	1	3
Rocky Mouth Creek	2	2
Bungawalbin Creek/Sandy Creek	3	1
North Creek	4	10
Emigrant Creek/Maguires Creek	5	9
Swan Bay	6	5
South Ballina	7	13
Kilgin/Buckendoon	8	6
East Coraki	9	4
Empire Vale	10	11
Upper Richmond/Wilsons River	11	7
Rileys Hill	12	8
Back Channel	13	12

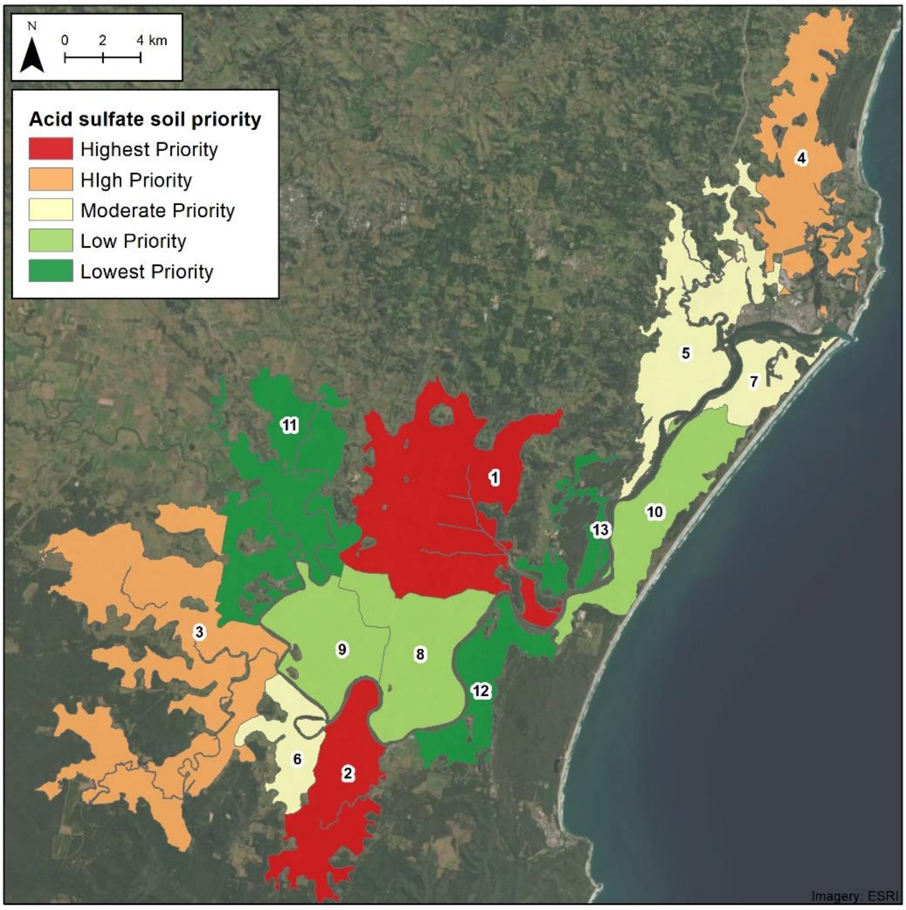

Figure ES-3: Richmond River floodplain subcatchment rankings of the acid prioritisation assessment

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. The assessment identified that the highest five (5) priority subcatchments on the Richmond River floodplain: Bungawalbin Creek/Sandy Creek (1), Rocky Mouth Creek (2), Tuckean Swamp (3), East Coraki (4) and Swan Bay (5) collectively represent over 80% of the total blackwater generation risk (Table 9.1). Over 95% of the blackwater generation risk was identified to originate from subcatchments in the mid-to-upper estuary, between Coraki and Wardell (Figure ES-2). Discharges from the highest priority subcatchments have the potential to merge in the receiving waters and collectively overwhelm the estuary, a finding confirmed by the large blackwater plumes and fish kills following major flood events in 2001, 2008, and 2020.

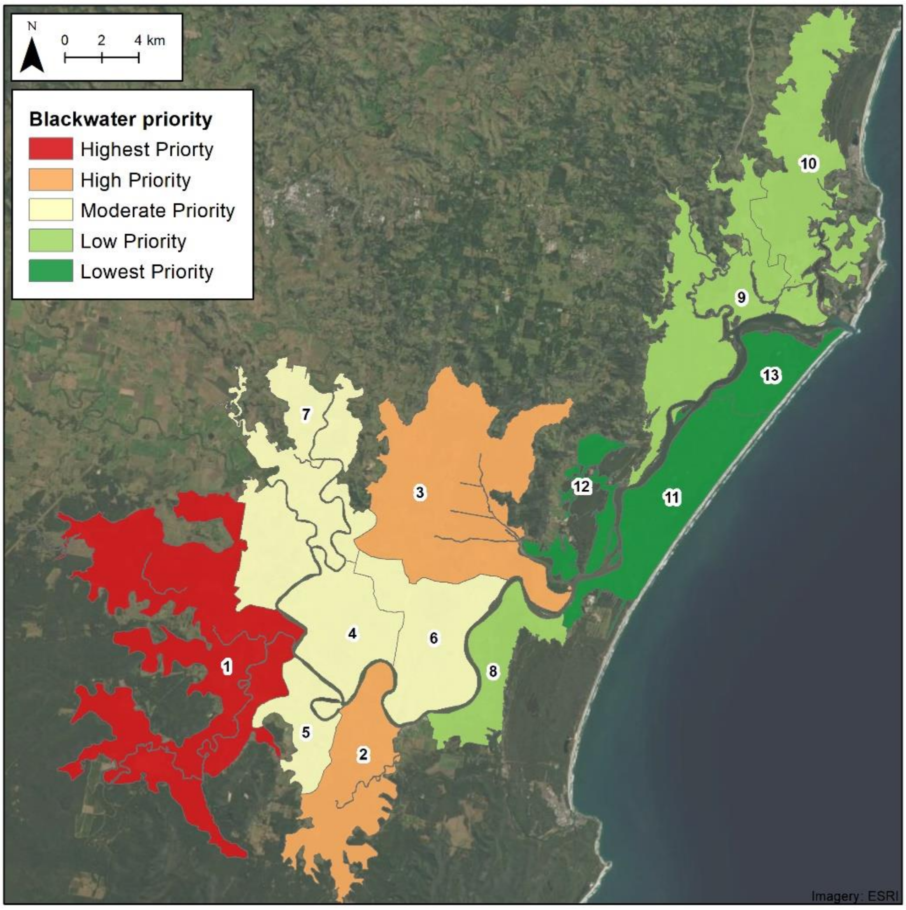

Figure ES-4: Richmond River floodplain subcatchment rankings of the blackwater prioritisation assessment

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 levels increase; and
- Floodplains – as low-lying areas are unable to be effectively drained and become increasingly wetter.

Detailed numerical modelling of the Richmond 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.

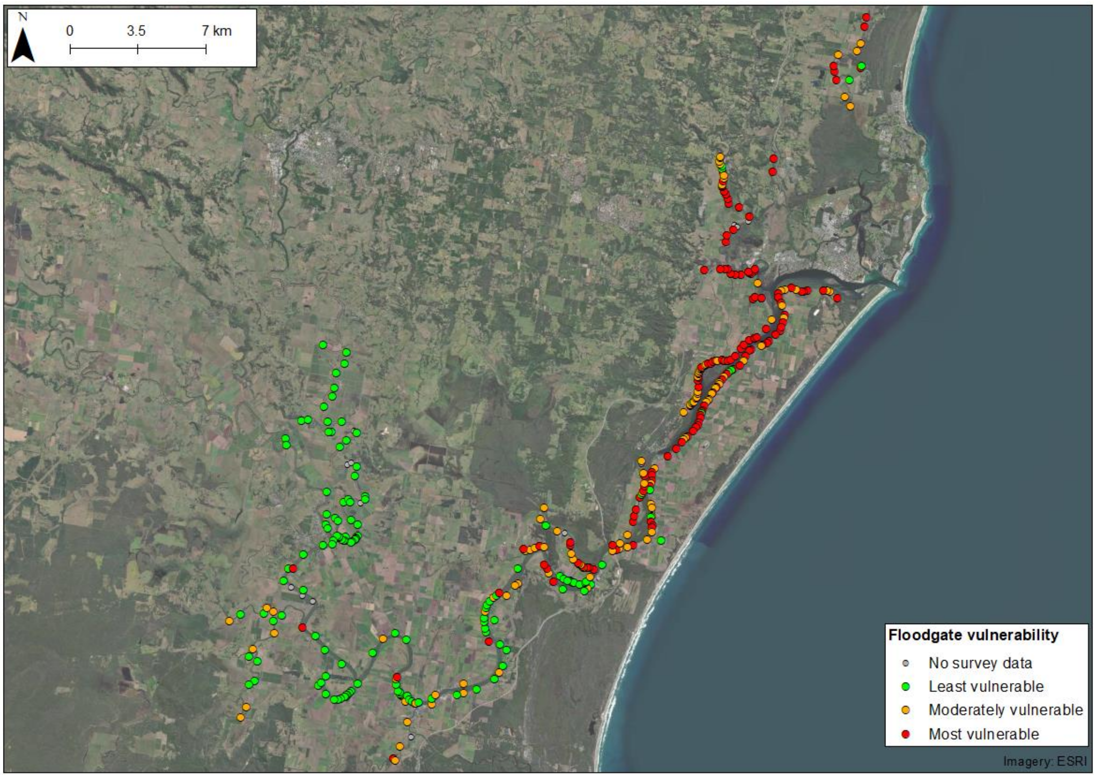

Figure ES-5: Richmond River estuary floodgate vulnerability with sea level rise (far future ~2100)

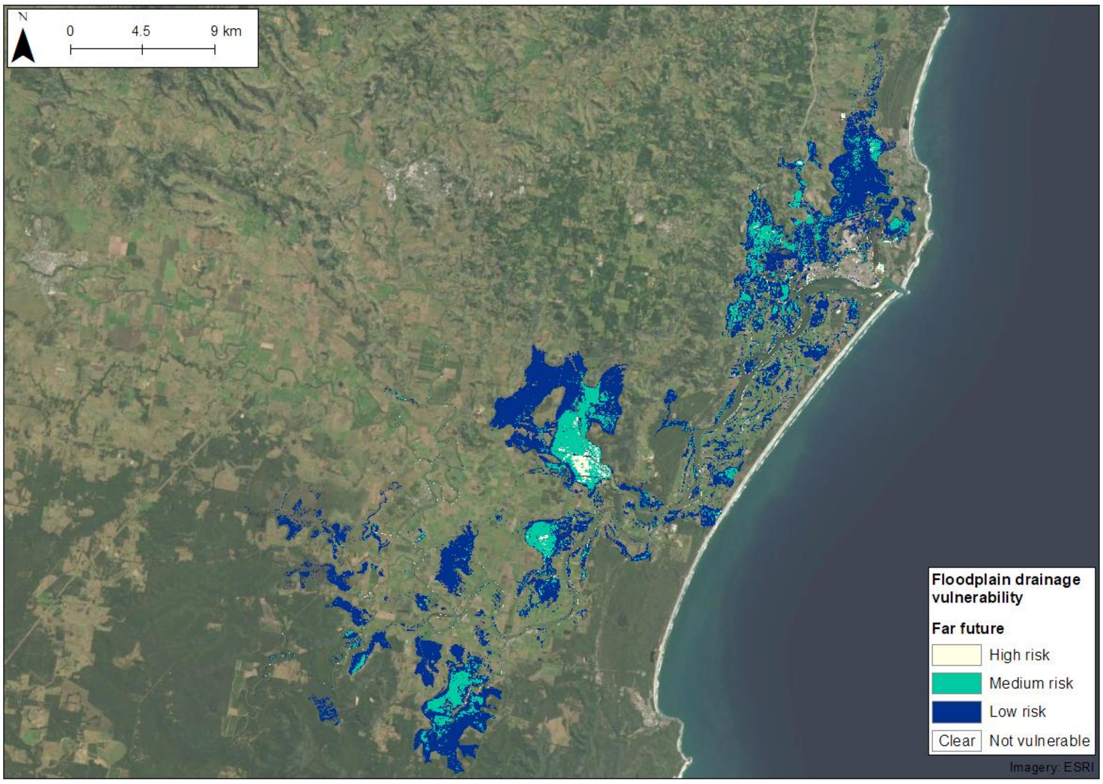

Figure ES-6: Richmond River floodplain vulnerability with sea level rise (far future ~2100)

ES.6 Top three priority subcatchments

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

- Tuckean Swamp;
- Rocky Mouth Creek; and
- Bungawalbin Creek/Sandy Creek.

It is estimated that these three (3) subcatchments account for approximately 75% of the overall acid generation risk and approximately 65% of the blackwater generation risk for the Richmond River floodplain. A significant amount of work has been done in these subcatchments to address water quality, although further remediation could result in significant improvements to the overall estuarine health of the Richmond River estuary. While paddock-scale remediation is worthwhile, broadscale restoration of natural freshwater or estuarine hydrology and changes in land use would result in the greatest improvement in water quality, particularly in the top three priority subcatchments.

However, any changes in management of these areas will require extensive 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.

Tuckean Swamp subcatchment

The Tuckean Swamp subcatchment was ranked first for acid generation and is estimated to account for approximately 40% of the total acid risk in the Richmond River floodplain, more than twice as much as the second highest ranked ASS subcatchment. It is estimated that there is enough stored acid in the Tuckean Swamp subcatchment to discharge acidic water to the marine estate for the next 1,000 years (Sammut et al., 1996). The Tuckean Swamp subcatchment also ranks third in the Richmond River floodplain for blackwater generation potential, contributing 11% of the overall blackwater risk. Combined, this highlights the scale of the water quality issues originating from this single subcatchment drainage area. Existing strategies to improve water quality are currently designed to minimise potential impacts to present day land uses, and modest improvements in water quality have been achieved. To effectively minimise acid and blackwater risks in the Tuckean Swamp subcatchment, broadscale changes in land and water management would be required.

Rocky Mouth Creek subcatchment

The Rocky Mouth Creek subcatchment ranked second in the ASS prioritisation, and second in the blackwater prioritisation. It is estimated to be the source of approximately 18% and 13% of the total acid and blackwater risk respectively in the Richmond River estuary. Significant on-ground works and active management strategies have been implemented by Rous County Council and local landholders, which have helped to mitigate some poor water quality discharges from the Rocky Mouth Creek subcatchment particularly during dry periods, however on-going impacts to the estuary remain a concern. In the long-term, reduced drainage due to sea level rise may result in prolonged inundation of large areas of the Rocky Mouth Creek subcatchment, and reduced viability of existing land uses. This may provide an opportunity to work with landholders to transition towards restoration of natural hydrology in this subcatchment.

Bungawalbin Creek/Sandy Creek subcatchment

The Bungawalbin Creek/Sandy Creek subcatchment ranked first in the Richmond River floodplain for blackwater generation and was estimated to account for 41% of the blackwater generation risk for the floodplain. It also ranked third in the ASS prioritisation, contributing approximately 12% of the total acid risk to the estuary. Rous County Council has worked extensively with local landholders to reduce the risk of acid and blackwater discharges. Many of the strategies implemented, including infilling of drains and installation of weirs were intended to reduce poor water quality discharge, while maintaining agricultural productivity. However, these strategies resulted in a shift in the vegetation towards native wetland species that have reduced grazing in this area. As the Bungawalbin Creek/Sandy Creek subcatchment is the largest single potential contributor of blackwater in the Richmond River, large scale improvements in water quality will require a significant change in land and water management in the longer term to restore the natural hydrology of the subcatchment. Such changes are only feasible with substantial input from the community and a plan to mitigate the social and economic impacts on existing landholders.

ES.7 Outcomes and conclusions

Outcomes from the Coastal Floodplain Prioritisation Study for the Richmond 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.

It is acknowledged throughout this study that substantial efforts have been made by Rous County Council, with the support of local landholders, to address poor water quality from acid sulfate soils and blackwater in the Richmond River estuary. This work has typically included modifying floodgate infrastructure and paddock scale interventions, such as liming, wet pasture management and drain management. 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 (Tuckean Swamp, Rocky Mouth Creek and Bungawalbin Creek/Sandy Creek) 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 microSiemens 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 under the ground surface within soil and rock formations that are fully saturated.
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 riverbanks 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 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 Richmond 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 Richmond 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 Richmond 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 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:

- Richmond River floodplain (this report);
- Tweed River floodplain (WRL TR2020/04);
- Clarence River floodplain (WRL TR2020/06);
- Macleay River floodplain (WRL TR2020/07);
- 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 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 Richmond 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 gained by reducing the sources of poor water quality from the subcatchments following the according to 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.

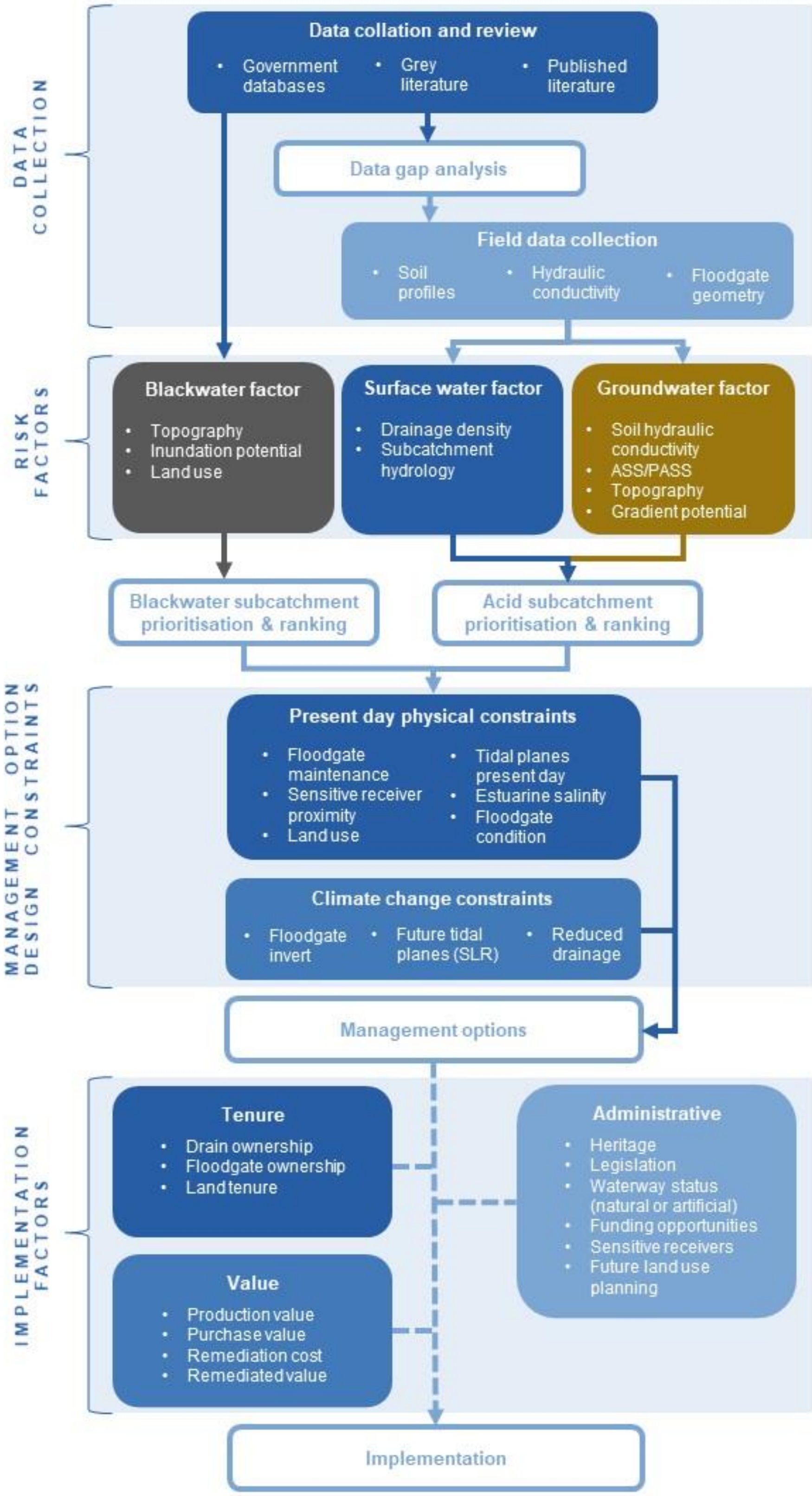

Figure 1-1: Study approach overview

1.4 Richmond River floodplain prioritisation

The Richmond River floodplain is located on the north coast of NSW between the coastal towns of Ballina in the east and Coraki to the west. European settlement of the area began in the mid-1800's. 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, 1999a). 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 Richmond River estuary (Hydrosphere Consulting, 2011; Moore, 2007).

This report summarises the application of the acid sulfate soil and blackwater subcatchment prioritisation methodologies on the Richmond River estuary floodplain (defined as the area below 5 m AHD). On-ground management options have been suggested for each subcatchment, based on the results of the dual prioritisation. 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 climate change (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 Richmond 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 environmental outcomes.

1.5 About this report

This report comprises the following sections:

- **Chapter 2** presents the drainage subcatchments considered in the Richmond River floodplain;
- **Chapter 3** provides background information describing the floodplain drainage and presence of ASS and blackwater in the Richmond River floodplain;
- **Chapter 4** provides an overview of the ASS and blackwater prioritisation;
- **Chapter 5** presents the outcomes of the ASS prioritisation in the Richmond River floodplain;
- **Chapter 6** presents the outcomes of the blackwater prioritisation in the Richmond River floodplain;
- **Chapter 7** provides information on the impact of climate change on floodplain drainage;
- **Chapter 8** outlines 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 drainage;
- **Appendix B** Catchment hydrology;
- **Appendix C** Groundwater saturated hydraulic conductivity data;
- **Appendix D** Acid sulfate soil distribution;
- **Appendix E** Blackwater elevation thresholds;
- **Appendix F** Floodplain infrastructure;
- **Appendix G** Cross sections;
- **Appendix H** Water quality;
- **Appendix I** Hydrodynamic modelling;
- **Appendix J** Sensitive environmental 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 Richmond River floodplain for areas below 5 m 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:

- Topography data (from aerial LiDAR surveys);
- Waterway alignment data;
- Management boundaries (e.g. as specified in CZMP or CMP documentation).

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 Richmond River floodplain, which are used throughout this study.

2.2 Subcatchments of the Richmond River floodplain

The subcatchments in the Richmond River floodplain have been broadly based on the management areas defined in the Coastal Zone Management Plan for the Richmond River Estuary (Hydrosphere Consulting, 2011). However, to improve relevance to the outcomes of this project, the following changes have been included in the subcatchment delineation:

- South Ballina and Empire Vale have been split into two (2) subcatchments. A substantial portion of the South Ballina catchment drains into Mobbs Bay and has been separated from the larger Empire Vale area;
- Kilgin/Buckendoon has been divided into two subcatchments to reflect the drainage to the west (East Coraki) and east (Kilgin/Buckendoon); and
- The Rocky Mouth Creek, Bungawalbin and Swan Bay subcatchments have been split in a different manner than outlined by Hydrosphere Consulting (2011). There are a number of large artificial drains that encourage floodplain drainage into Serpentine Lagoon at Swan Bay (e.g. Cambells Canal, Thearles Canal, Reardons Canal and Skinners Canal). These areas have been included within the Swan Bay subcatchment in this study.

The subcatchments in the Richmond River floodplain are shown in Figure 2-1.

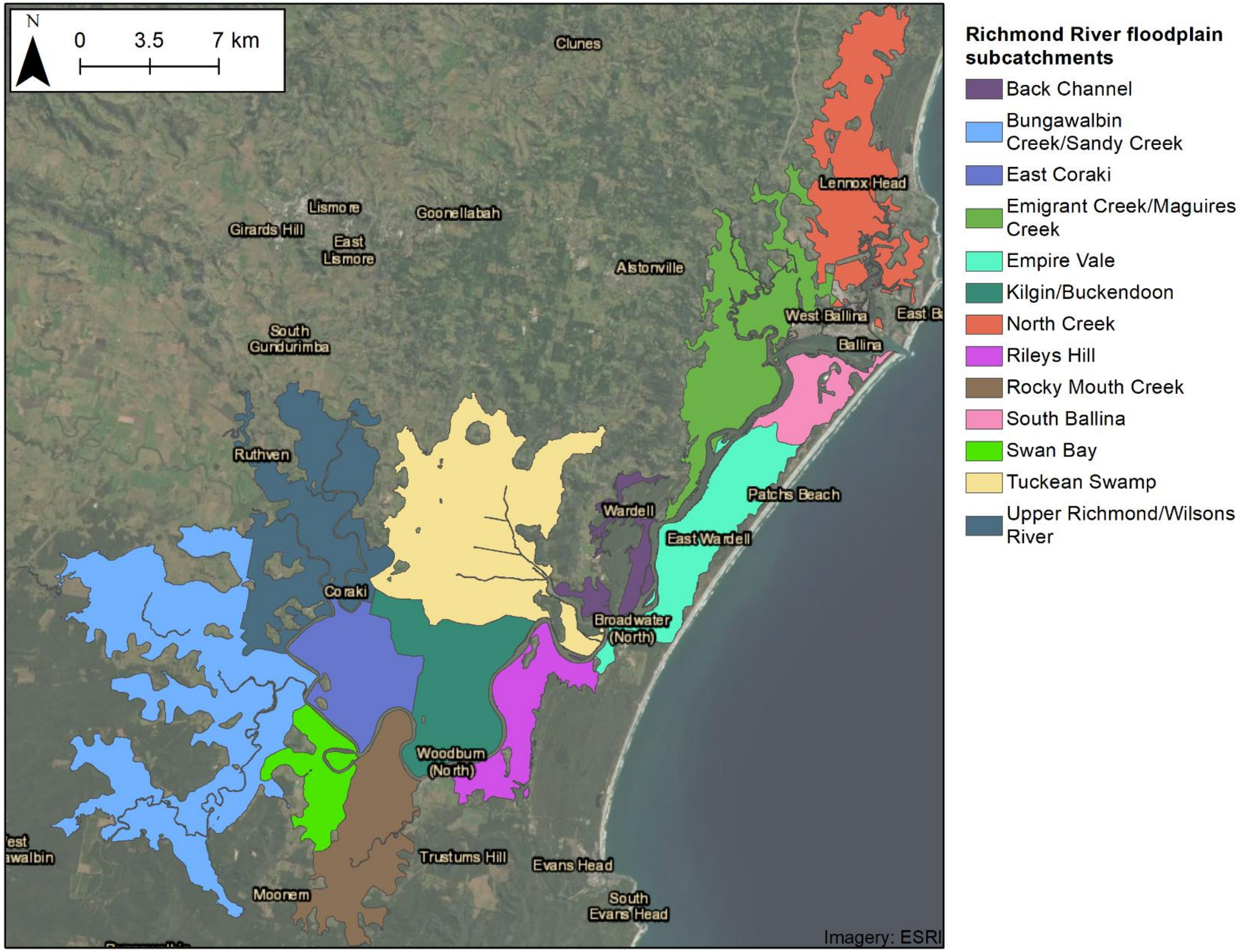

Figure 2-1: Subcatchments in the Richmond River floodplain

3 Background

3.1 Preamble

This section provides background information on the Richmond 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 areas and County Councils

Local and county government bodies play a key role in maintaining floodplain drainage assets and management of estuarine water quality. Parts of the Richmond River floodplain are within the boundaries of three (3) local government areas (LGAs), shown in Figure 3-1. These include:

- Ballina Shire Council (BSC);
- Lismore City Council (LCC); and
- Richmond Valley Council (RVC).

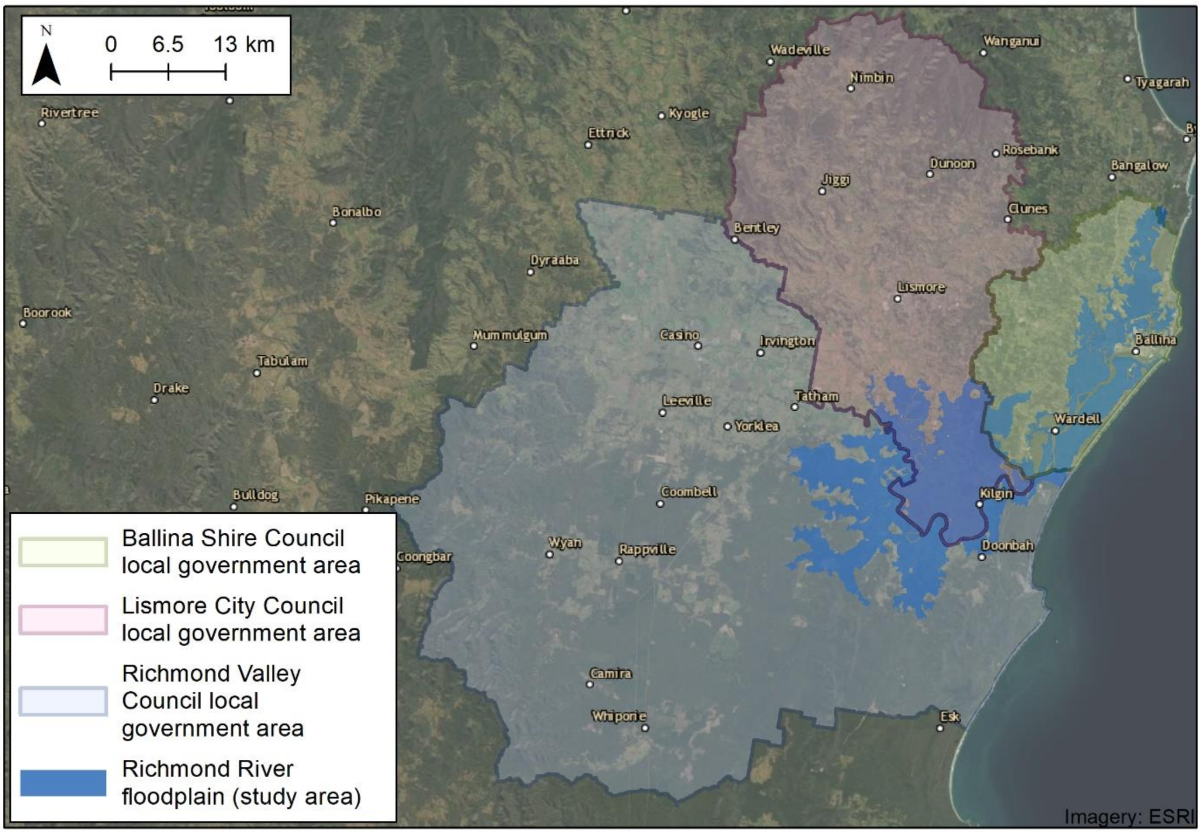

Figure 3-1: Local government areas covering the Richmond River floodplain

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 done through zoning and development controls which outline the way in which land can be used, including land on coastal floodplains.

In addition to these three (3) councils, Rous County Council (RCC) is responsible for flood mitigation, weed biosecurity, and bulk water supply across the Richmond River floodplain. RCC was formed in July 2016, as an amalgamation of three (3) historical county councils, notably Richmond River County Council (RRCC) that was formerly responsible for flood mitigation.

3.3 Floodplain history

The Richmond River floodplain (up to 5 m AHD) covers an area of approximately 620 km^2. The river is joined by numerous tributaries as it traverses downstream, including Wilsons River and Bungawalbin Creek, before discharging to the ocean near Ballina (BMTWBM, 2010; Caddis and Dearnley, 2011). Major tributary streams connect the main river to many low elevation backswamps, with substantial areas below 1 m AHD, as shown in Figure 3-3.

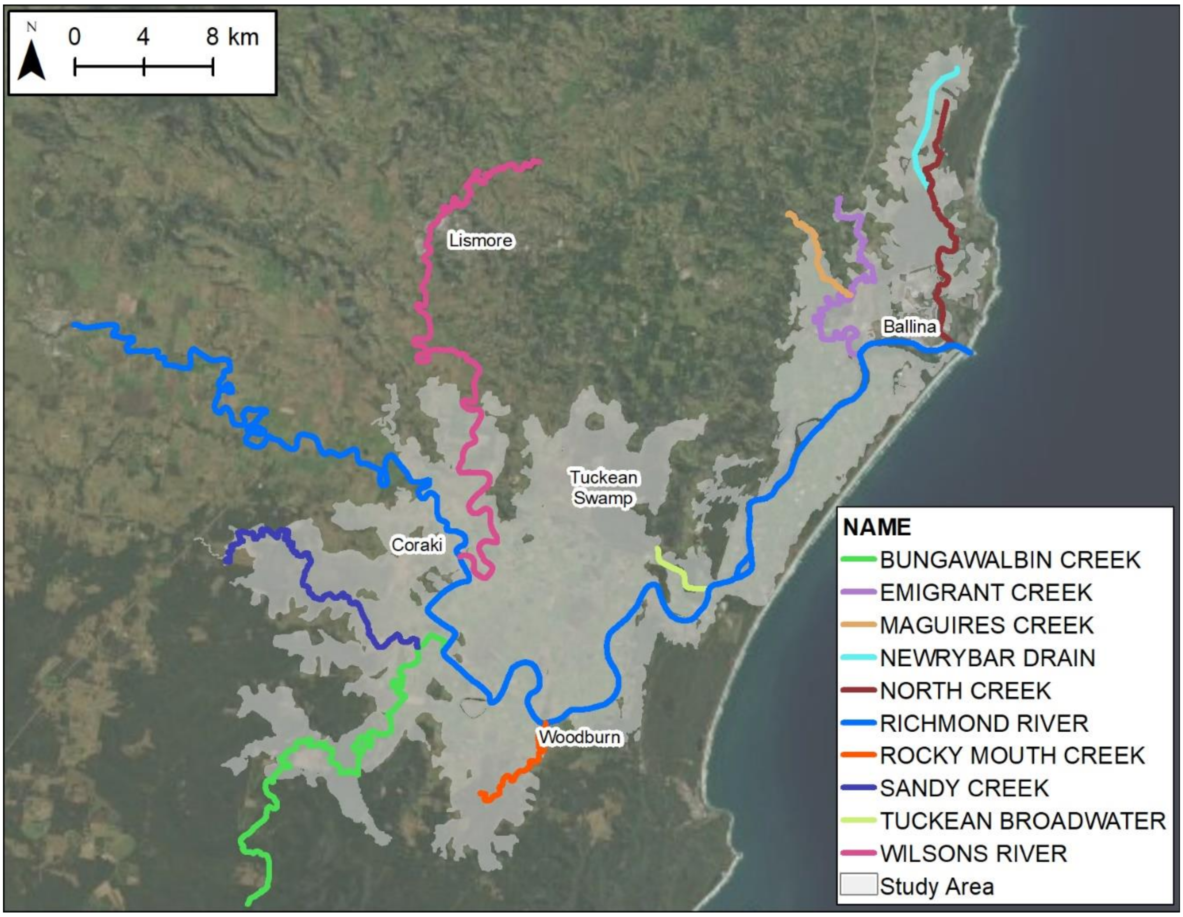

Figure 3-2: Main waterways on the Richmond River floodplain

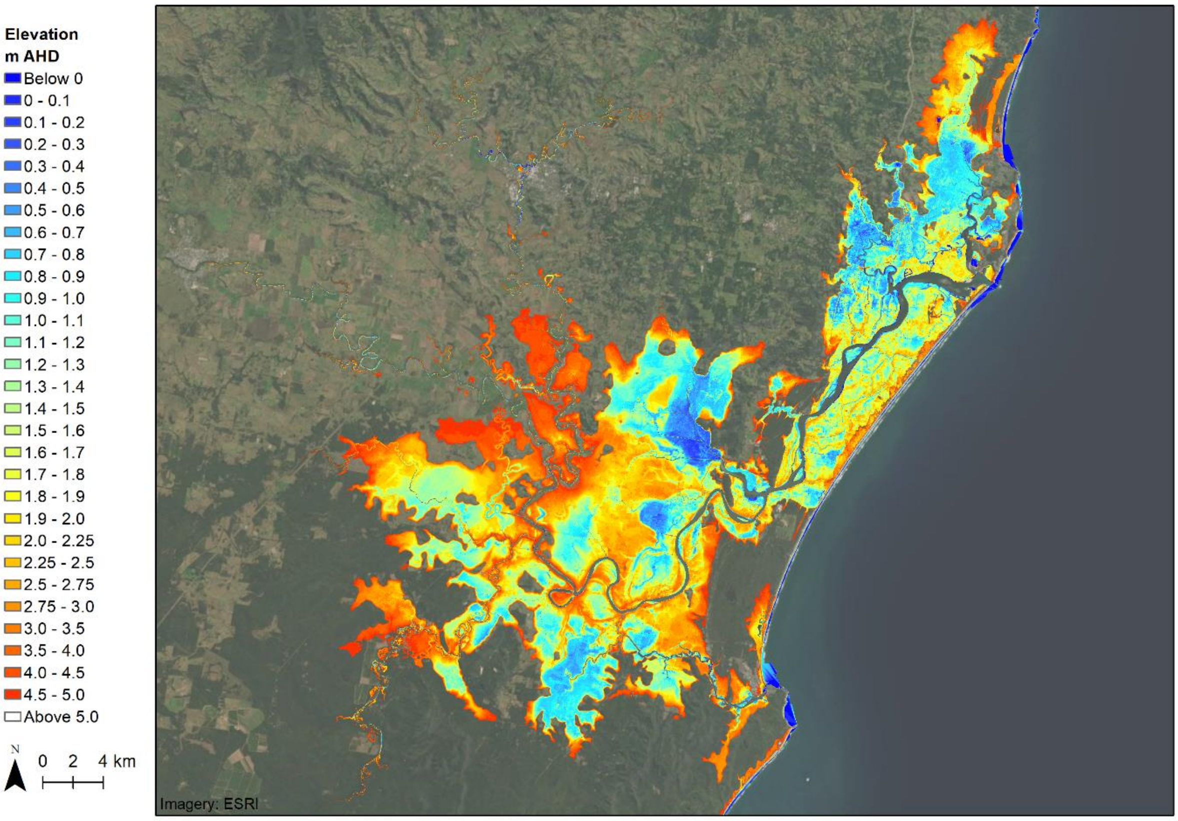

Figure 3-3: Digital elevation map of the Richmond River floodplain

In the Richmond River floodplain, the modification of the natural drainage system through the construction of drains and levees began in the 19th century and continued throughout the 20th and 21st centuries. Significant drainage works during the 20th century were primarily undertaken for flood mitigation, as well as to promote dry land agricultural production and to prevent saline intrusion onto low-lying floodplain areas (Tulau, 1999a). Tulau (2011) notes that despite the often misleading use of terminology, the 1950-70s ‘flood mitigation’ schemes were overwhelmingly swamp drainage schemes.

A timeline of key events and drainage works on the Richmond River floodplain includes (Rodgers et al., 2014; Tulau, 2011):

- Mid 1850 – Settlement of the Richmond River floodplain began. The townships of Casino and Lismore were settled in 1855 and 1856, respectively;
- 1860s – Agricultural expansion intensifies throughout NSW northern rivers, as a consequence of government incentives for the purchase of land;
- 1898 – The Tuckombil Canal was constructed to provide relief for floodwaters in the Woodburn area;
- 1902 – Newrybar Swamp, North Casino, and Tuckean Swamp were drained under the Water and Drainage Act 1902;
  1950-1970s – Extensive drainage of wetlands in NSW’s northern rivers occurred via state funded flood mitigation works. This included deepening and straightening of existing drainage systems and the installation of drainage control structures such as one-way floodgates. Richmond River County Council (RRCC) assumed responsibility of all flood mitigation activities from the Councils

of Lismore, Ballina and Richmond River to provide catchment wide flood mitigation planning. Major drainage works constructed during 1950 and 1970s included:

  - Bagotville Barrage (1968) in the Tuckean Broadwater;
  - Drainage channel from Bora Ridge to Bungawalbin Creek with headworks and floodgates installed (1961);
  - Tuckurimba area drains;
  - Drainage channels and floodgates at Keith Hall (1962);
  - Drainage channels and floodgates at West Coraki;
  - New drains and floodgates at Wyrallah, Coraki, Swan Bay, South Lismore, Bungawalbin, North Swan Bay, and Sandy Creek;
  - Installation of floodgates on existing drains at West Coraki;
  - The Tuckombil Canal was modified to increase its capacity and a weir installed at its upstream extent;
  - Further drainage works in the Tuckean Swamp.
- 1979-1980 - additional flood mitigation drainage was constructed around Newrybar Swamp to facilitate agricultural use of the area upstream of Ballina (Tulau, 1999b);
- 2001 – A concrete weir was constructed across the Tuckombil Canal replacing the existing fabridam structure; and
- 2016 - RRCC was dissolved and its functions and operations were transferred to Rous County Council (RCC). RCC is currently the primary governmental body responsible for flood mitigation throughout the Richmond River floodplain, although they work closely with the three (3) constituent councils.

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.

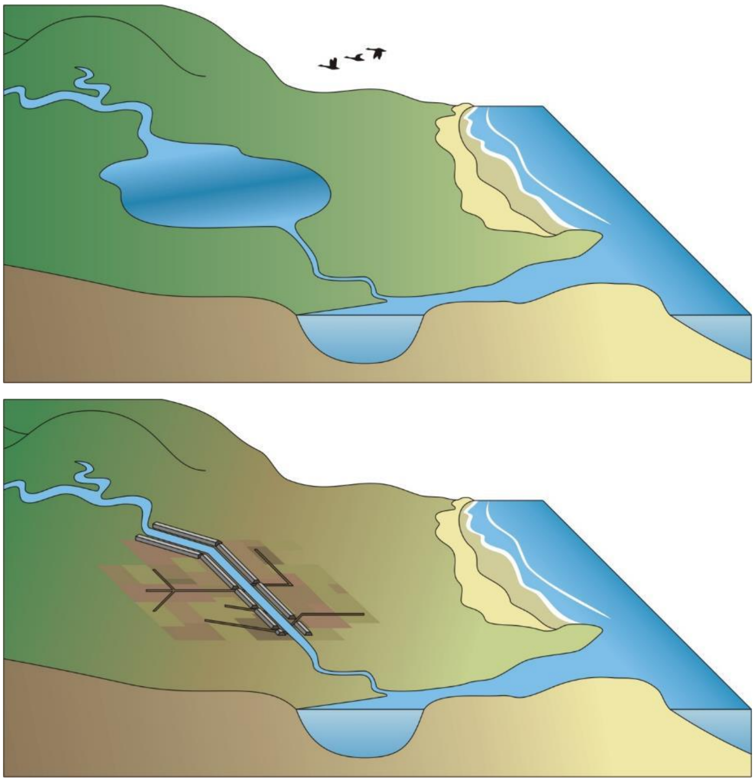

Figure 3-4: Schematic of floodplain evolution following European settlement

3.4 Land use and tenure

Land uses in the Richmond River floodplain for areas below 5 m AHD are shown in Figure 3-5 (refer to Section 9 of Methods report for more detail). Although land use in the Richmond River valley is varied, the primary agricultural use of the floodplain is sugar cane, with substantial areas also used for grazing. Over the last decade, some areas that have been historically used for sugar cane have transitioned towards macadamia farming (mapped as “Horticulture” in Figure 3-5), particularly in the north-eastern section of the floodplain, near North Creek and Emigrant/Maguires Creek subcatchments. 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 industries, including macadamia farming, have likely grown since the time of the mapping. Most areas recognised as marsh/wetland in the mid-to-upper estuary 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 Services (NPWS) in the Richmond River floodplain, including:

- Ballina Nature Reserve, north of Ballina;
- Tuckean Nature Reserve, along Hendersons Drain in Tuckean Swamp, which is largely low-lying (<0.5 m AHD) and is mapped as marsh/wetland in Figure 3-5;
- Broadwater National Park near Rileys Hill; and
- Yarringully Nature Reserve on Bungawalbin Creek.

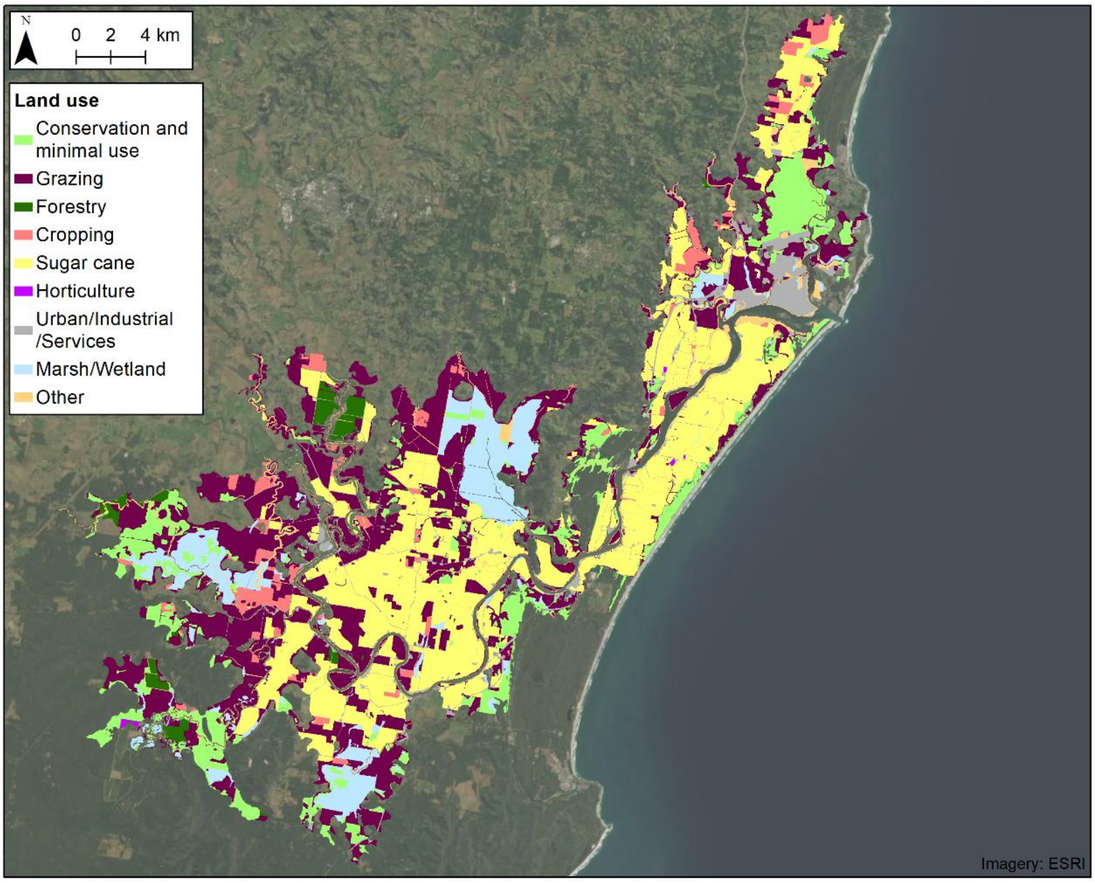

Figure 3-5: Land use in Richmond River floodplain, 2017 (DPIE, 2020)

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 Richmond 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 Richmond 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 Richmond River floodplain contains approximately 350 km^2 of high-risk ASS soil below an elevation of 5 m AHD, as shown in Figure 3-6.

The extent and severity of ASS on the Richmond River floodplain has been confirmed by numerous investigations. The following areas have been identified by various studies as acid hotspots:

- Tuckean Swamp (ABER, 2008; Moore, 2007; Tulau, 1999a);
- Rocky Mouth (ABER, 2008; Moore, 2007; Tulau, 1999a);
- North Creek (Tulau, 1999b);
- Maquires Creek - Emigrant Creek (Tulau, 1999b);
- Sandy Creek/Bungawalbin Creek (Tulau, 1999b);
- Kilgin/Buckendoon/Dungarubba (ABER, 2008; Moore, 2007);and
- Swan Bay (Moore, 2007).

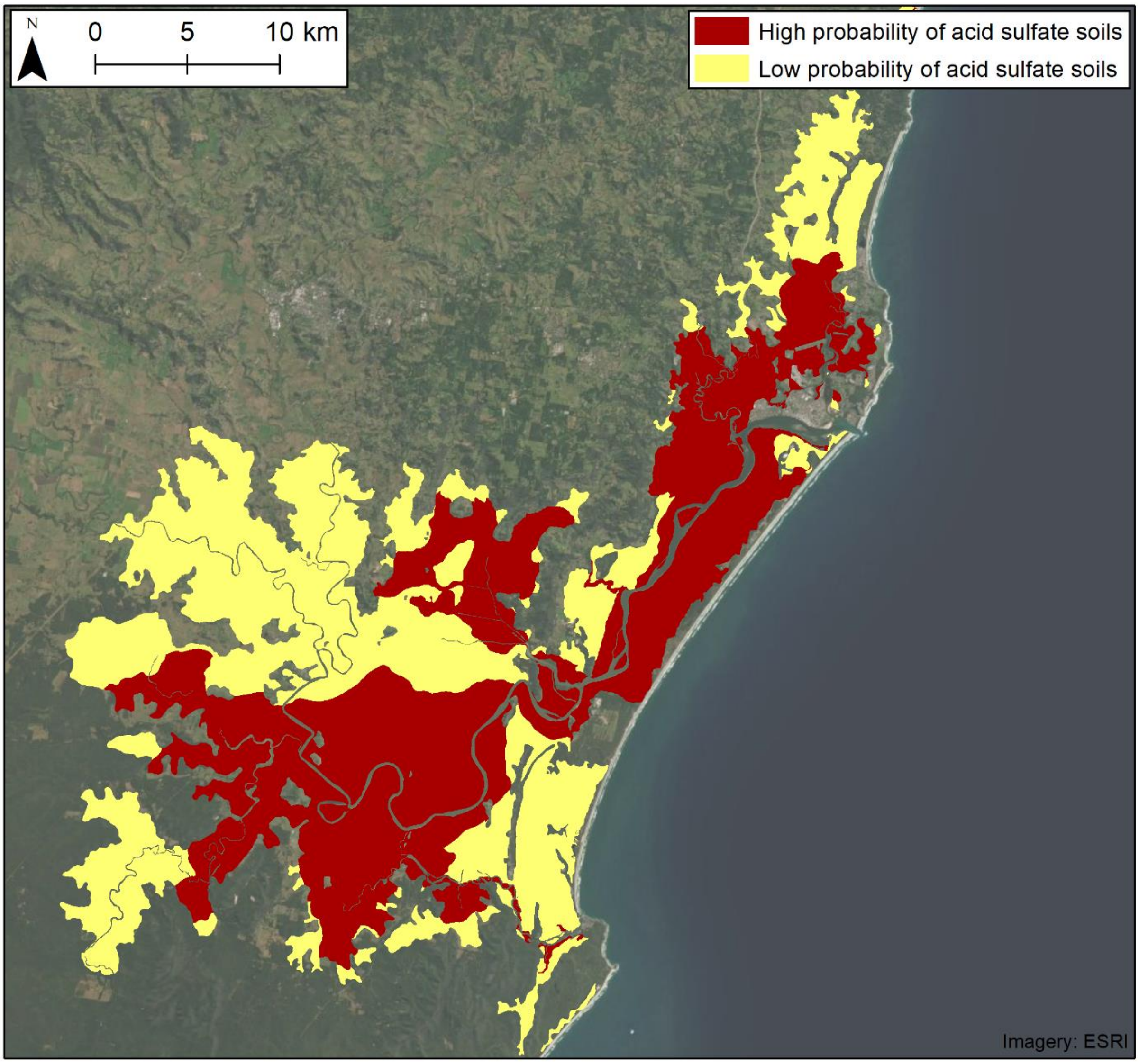

Figure 3-6: NSW Government ASS risk map of the Richmond River floodplain

Available data was analysed to describe the distribution of ASS across the Richmond River floodplain. This information was obtained from the NSW Department of Planning Industry & Environment (DPIE) eSPADE Database 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) in the soil profiles is common throughout the Richmond River floodplain, particularly in Tuckean Swamp, Rocky Mouth Creek and Sandy Creek.

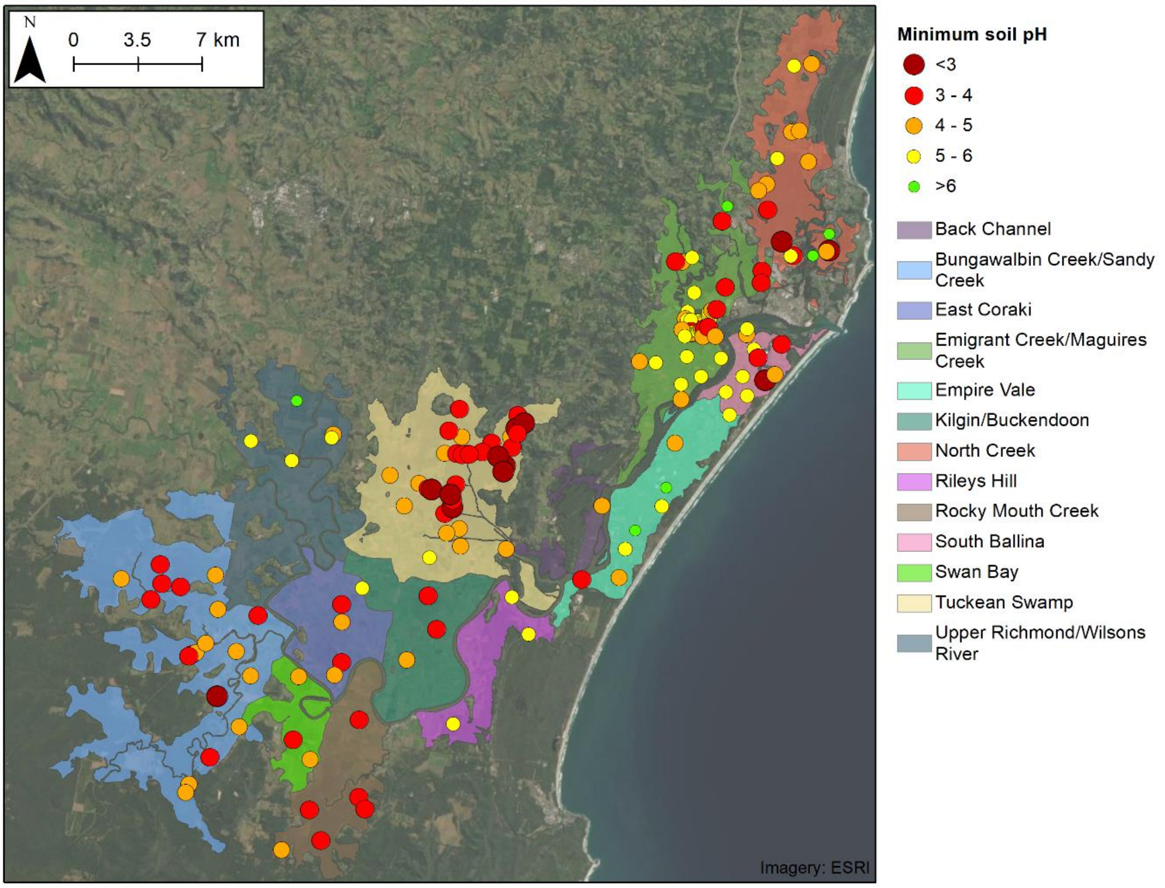

Figure 3-7: Minimum soil pH throughout the Richmond River floodplain

3.5.2 Acid discharge events in the Richmond Region

This section provides a brief overview of acid discharges that have been identified in the Richmond River. Acid discharges in the Richmond River estuary have been recorded extensively in the last three (3) decades through numerous studies and monitoring programs. A list of water quality studies completed in the Richmond River floodplain can be found in Appendix H.

Many previous studies focus on acid discharges originating from Tuckean Swamp (Rayner et al., 2020a; Santos et al., 2013; Santos and Eyre, 2011; Weys et al., 2011). The typical pH of water discharging from the Bagotville Barrage (at the mouth of Tuckean Swamp) is approximately 3.5 after rain events, and surface water pH within the drainage system has been observed as low as 2 (Rayner et al., 2020a). Numerous fish kills have been observed downstream of Bagotville Barrage, which have been attributed to acid discharges as dissolved oxygen levels were observed to be non-toxic at the time of the events (Sammut, 1996).

Sammut (1998) reported 12 fish kills and two (2) disease events related to acid discharge in 1993 and 1994. Most of these events were recorded in the Tuckean Swamp region, although fish kill events were also observed in Bungawalbin Creek, Swan Lake, Empire Vale, Rocky Mouth Creek and North Creek. The pH associated with these events was typically recorded below 4.

Numerous other fish kills have occurred in the Richmond River estuary (discussed further in Section 3.6.1), although they are more commonly attributed to low oxygen levels. However, the impacts to aquatic ecosystems in these events are more likely due to a combination of acid discharges and low dissolved oxygen, which can often occur at similar times (ABER, 2007). It is likely many of the other recorded fish kills events can also be partially attributed to acid discharges from drained ASS. Acid events have also directly affected oyster growth in the Richmond River estuary (White, 2003). More generally, acid discharges (and associated discharges of heavy metals) also result in less visible impacts to estuarine ecology, including (Johnston et al., 2003a; Tulau, 2007):

- Chronic disease in aquatic life;
- Impacts to migration of fish and prawns;
- Reduced hatching and fish recruitment;
- Reduced survival and growth in many aquatic species; and
- Weed invasion of acid tolerant vegetation.

RCC have operated a network of water quality monitoring stations and sampling sites throughout the Richmond River estuary since 2004. Their monitoring program includes five (5) continuous monitoring stations at three major backswamps (Tuckean Swamp, Rocky Mouth Creek and North Creek) and manual sample points (typically collected on a weekly or monthly interval) at a number of locations throughout Richmond River. A recent analysis of this data confirmed that both Rocky Mouth Creek and Tuckean Swamp are major sources of acid on the Richmond River floodplain with both sites discharging surface water with a pH of 4.1 or less at least 10% of the time (Rayner et al., 2020b; Rayner et al., 2020c).

3.5.3 Acid sulfate soil management on sugar cane farms

While many agricultural industries have had to address the impacts of ASS and acid drainage, the sugar cane industry has been particularly active in creating formal, industry wide guidelines for ASS management. The sugar cane industry operates throughout the Northern Rivers of NSW, including on the Richmond River floodplain. Approximately 50% of sugar cane land in NSW is within areas with known occurrences of ASS (Sunshine Sugar, 2020). In 1987 mass fish kills in the Tweed River led to widespread criticism of the sugar cane industry related to the management of ASS (Beattie et al., 2001). Over the following decade, the industry took proactive steps to improve management of their soils and drainage to reduce impacts in downstream waterways. This included research, cooperation with government agencies, and the engagement of individual famers.

NSW Sugar has developed industry best practice guidelines for managing ASS on cane farms and has coordinated and participated in a number of initiatives aimed at understanding the presence and impacts of ASS (Sunshine Sugar, 2020). Note, compliance with the industry best practice guidelines has been enforced on all cane farms in NSW since a national strategy was developed in the year 2000 (White et al., 2006). The guidelines have been developed to minimise the drainage of ASS and include:

- Soil profiling of individual cane farms to confirm the presence and depth of ASS;
- Development of drainage management plans for each cane farm in NSW, including information on:
    - Depth of ASS;
    - Location and dimension of drains and how to minimises acid discharge;

    - Liming rates required when excavation is necessary; and
    - How to manage farm drainage.
- Cooperation and participation in government programs to actively manage floodgates to improve water quality and allow tidal flushing;
- Laser levelling of farms to reduce the number of drains required to provide adequate surface water drainage and minimise acidic groundwater discharges; and
- Regular auditing and reporting.

Through the development and compulsory compliance of the industry best practice guidelines, the sugar cane industry is approved to self-regulate the disturbance of ASS through normal farm practises under the relevant council LEP (Sunshine Sugar, 2020). This means that sugar cane farmers are allowed to disturb ASS material within the cane production areas of their property without prior regulatory approval, providing the disturbance is considered within their drainage management plans.

3.6 Blackwater

This section provides a brief overview of the formation and export of blackwater in coastal estuaries and blackwater runoff from Richmond 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 (Moore, 1996; 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 drains, flood mitigation works and swamp drainage works, have resulted in an increase in the frequency and magnitude of blackwater events (Eyre et al., 2006; Johnston et al., 2003b; Tulau, 2011; Wong et al., 2010a). The construction of one-way floodgates also maintains upstream surface water levels at low tide levels (during average conditions), and enables non-water tolerant vegetation, such as pasture grasses, to establish at lower elevations where they could historically not survive (Glamore, 2003). Despite the 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 Richmond River estuary

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. As discussed in Section 3.5.2, some fish kills in the Richmond River have been related solely to acid discharges (Sammut, 1998), however deoxygenated discharges have been identified as the largest cause of fish mortality in the estuary (Moore, 2007). It is likely that a combination of acid sulfate soil discharges, as well as blackwater from organic matter decomposition is responsible for these fish kill events.

Eighty-six (86) fish kill events have been recorded in the Richmond River Floodplain since 1970 (although other events are likely to have occurred but gone undocumented). For the majority of these events the cause was not confirmed, although it is likely that blackwater discharges and/or acidic discharges have contributed significantly to mortality. Table 3.1 lists the most severe recorded fish kills in the Richmond River estuary. While some fish kill events affect smaller tributaries of the Richmond River (e.g. Rocky Mouth Creek or Emigrant/Maguires Creek), the Richmond River is also prone to wide spread deoxygenation events that can cause mass fish kills across the estuary. River wide events occurred in 2001, 2007 and 2020 and were well publicised locally.

Table 3.1: Severe fish kills and blackwater events in the Richmond River floodplain

Date	River/Creek	Intensity
8/06/1993	Rocky Mouth Creek	1,000's of fish
27/04/1998	Emigrant Creek/Maguires Creek	1,000's of fish
1/11/1998	Richmond River	1,000's of fish
7/02/2001	Richmond River	100,000's of fish
9/02/2001	Bungawalbin Creek	1,000's of fish
9/02/2001	Empire Vale Creek	1,000's of fish
1/02/2006	Richmond River	1,000's of fish
18/11/2007	Pacific Ocean	100,000's of fish
9/01/2008	Richmond River	1,000's of fish
4/12/2010	Empire Vale and Reedy Creeks	1,000's of fish
13/03/2015	Richmond River Estuary	1,000's of fish
20/01/2020	Richmond River	100,000's of fish

The blackwater event that affected the Richmond River in February 2001 resulted in levels of dissolved oxygen as low as 0.03 mg/L and dissolved oxygen remained hypoxic for several weeks (Moore, 2007). Dawson (2002) added that during this episode, acidity levels were only slightly less than normal (pH of 6.3) throughout the affected area, therefore eliminating ASS as the main cause for the fish kills. As a result of this event, the whole estuary (downstream of Coraki) was closed for commercial and recreational fishing for a period of six months to allow the fisheries stock and habitat to recover (Dawson, 2002).

The impact of blackwater in the Richmond River estuary has been studied numerous times since the mass fish kills in 2001 (Moore (2007); Wong et al. (2010b); ABER (2008); Southern Cross GeoScience (2019)). The following areas have been identified as key areas for the generation of blackwater in the Richmond River floodplain:

- Tuckean Swamp (ABER, 2008; Moore, 2007; Southern Cross GeoScience, 2019);
- Rocky Mouth Creek (ABER, 2008; Moore, 2007; Southern Cross GeoScience, 2019);
- Sandy and Bungawalbin Creek (ABER, 2008; Moore, 2007; Southern Cross GeoScience, 2019);
- Kilgin/Buckendoon (ABER (2008)); and
- Lower Wilsons/Richmond (Moore, 2007),

As discussed in Section 3.5.2, RCC has collected extensive water quality data at major backswamp discharge points (Tuckean Swamp, Rocky Mouth Creek and North Creek) as well as grab samples throughout the estuary at regular intervals. Analysis by Rayner et al. (2020c) indicated that sources of deoxygenated water are concentrated in the mid-estuary, with limited evidence of blackwater discharges upstream of Coraki. The analysis suggests that dissolved oxygen throughout most of the mid Richmond River estuary (between Wardell and Coraki) can be periodically hypoxic (< 2mg/L) or anoxic (near 0 mg/L). Rocky Mouth Creek and Tuckean Swamp are often affected by low dissolved oxygen surface water (dissolved oxygen less than 4.5 mg/L more than half of the time), while dissolved oxygen in the downstream section of North Creek are typically well oxygenated (dissolved oxygen greater than 6.6 mg/L 90% of the time) (Rayner et al., 2020c).

3.7 Coastal management in the Richmond 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 Richmond River, discussed further in the following section.

3.7.2 Coastal Zone Management Plan and Estuary Management Study (Hydrosphere Consulting, 2011)

Hydrosphere Consulting (2011) completed the Coastal Zone Management Plan (CZMP), including an Estuary Management Study (EMS) for the Richmond River estuary. 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 Richmond River.

Poor water quality, fish kill events and acid discharges were all identified as key management issues of concern in the Richmond River. The top two (2) management strategies identified for implementation in the CZMP and EMS directly address the impacts of ASS and deoxygenated discharges. The first high priority strategy considered floodplain infrastructure management. This generally encourages the restoration of natural estuary flow paths to mitigate the impacts of ASS drainage and blackwater generation to reduce fish kill events and improve estuarine water quality. Implementation of this strategy includes:

- Identifying, prioritising and optimising drainage canals and levees. This includes consideration of drain infilling/reshaping and the use of weirs and sills to restore natural drainage while maintaining flood mitigation capacity. The CZMP suggests that the prioritisation of drains for modification should be completed in the short term, while implementation of changes should occur over the next 10 years; and
- Review floodgate management protocols – RCC actively manages a number of large floodgates throughout the floodplain, and have 56 active floodgate management plans in operation (p. comms C. Clay, 18/5/2021). These gates directly influence water quality, connectivity and flushing in many of the major backswamps in the Richmond River floodplain, including Tuckean Swamp, Rocky Mouth Creek, Swan Bay and Sandy Creek. These plans are updated every three (3) years, and most have been reviewed in the past 18 months. As an example, RCC have Active Floodgate Management Plans for the following ten (10) major floodgates throughout the estuary:

    - Boggy Creek;
    - Bora Creek;
    - Cambells Drain;
    - Haughwood Canal;
    - Keith Hall Drain;
    - Reardons Canal;
    - Rocky Mouth Creek;
    - Sandy Creek No. 1;
    - Wades Canal; and
    - West Coraki Canal.

Active floodgate management plans are implemented either by volunteers (typically local landholders) or RCC Operators.

Farm management was identified as the second highest priority strategy by Hydrosphere Consulting (2011). This is an acknowledgement that farm scale land management has an impact on the water quality in the estuary. This includes using farm management practises as a way to address blackwater issues in the region. Implementation of this strategy includes:

- Scientific studies to investigate strategies for retention of water in backswamps to reduce blackwater production and drainage. The report "Episodic estuarine hypoxia: resolving the geochemistry of coastal floodplain blackwaters – Summary of project findings", Southern Cross GeoScience (2019) has since been published and addresses this specific strategy. This study shows that water retention will address blackwater runoff, although it will require broad scale changes in land use and management.
- Recommendations for farm management plans to be developed for high priority areas to improve environmental outcomes in the short term and provide long-term economic planning to foster changes to land uses towards more sustainable practises and usages. This includes recommendations for wet pasture management, crop changes and buy back schemes.
- Liaising with industry groups to improve education and facilitate more environmentally friendly land practises. This includes schemes for grants or loans to assist land holders in implementing improved practises, which could address ASS, blackwater or a range of other water quality issues (such as nutrient runoff).

Medium priority strategies that would also address acid and blackwater drainage include:

- Vegetation management, including remediated native floodplain vegetation; and
- Education, which provides the community with valuable information on the impacts on the estuary and ways they can contribute to improvements.

The CZMP for the Richmond River estuary highlights that addressing poor water quality resulting from acid and blackwater drainage is a priority (Hydrosphere Consulting, 2011). Specific on-ground remediation works completed by RCC and DPIE as part of the coastal management program in the Richmond River floodplain are discussed in the history of remediation of individual subcatchments in Section 8. The prioritisation and associated management options developed in this study may be used to guide the implementation of the management strategies from the CZMP. This includes identification of additional floodplain infrastructure that may be optimised by modification or active management and identifying subcatchments where improved farm management practices may be particularly effective at reducing acid or blackwater discharges.

3.7.3 Richmond River Coastal Management Program

Rous County Council was awarded a grant under the Coastal and Estuary Grants Program to complete a scoping study for a new Coastal Management Program (CMP) for the Richmond River. The Coastal Management Program for the Richmond River estuary is currently being completed and will supersede the existing CZMP.

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. (2020d). 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 subcatchment management options in Section 8. A brief summary of these methods is provided in this section.

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 Richmond 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 subsequent 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 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.

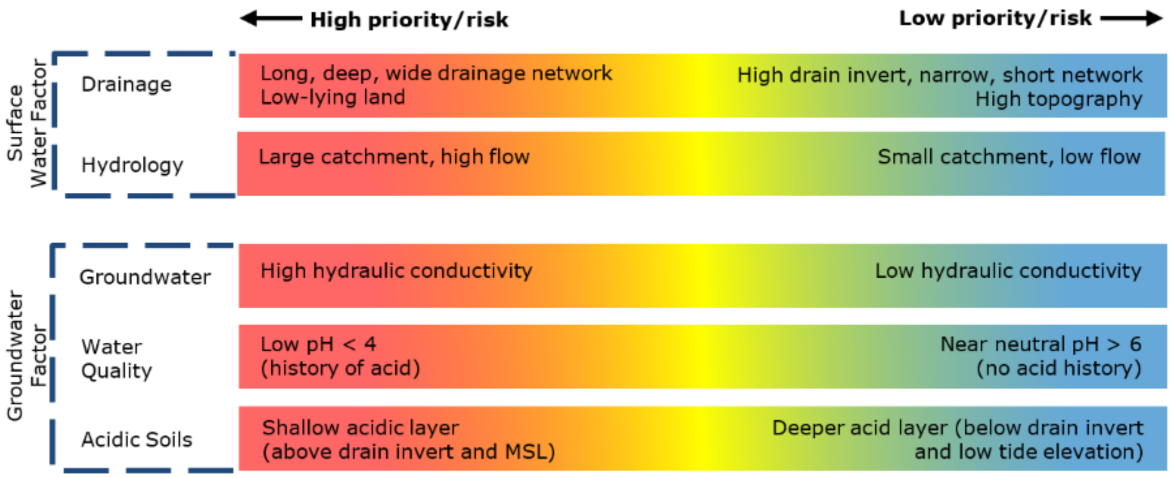

Figure 4-1: Factors influencing ASS discharge in coastal NSW that have been incorporated within the assessment method (adapted from Johnston et al. 2003)

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.

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

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 34 soil profiles and 26 soil hydraulic conductivity measurements on the Richmond 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 Richmond River floodplain during a blackwater event).

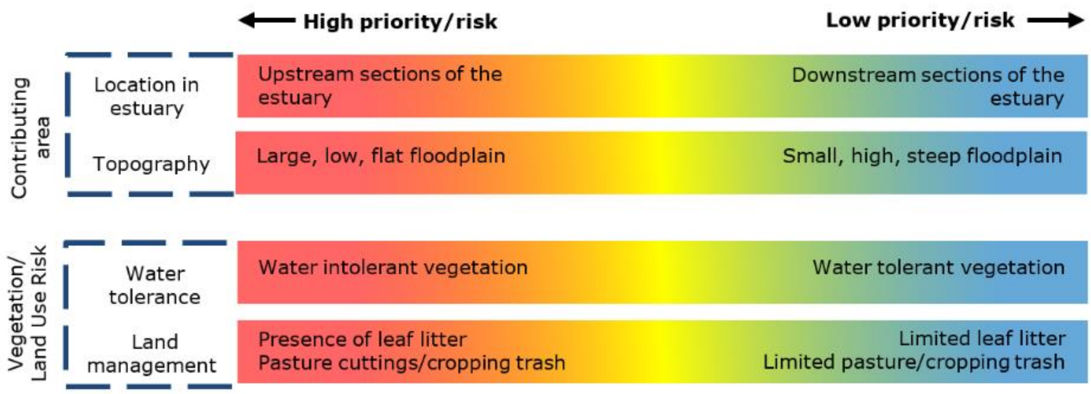

Figure 4-2: Factors influencing blackwater discharge within a coastal floodplain in NSW

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 Richmond 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, forestry, perennial horticulture (such as macadamia farming), 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 Richmond 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 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 previous remediation efforts. However, any previous remediation is considered in the individual management options in Section 8. Similarly, the prioritisation method does not consider the assimilation capacity of the river (the ability of the river to dilute or neutralise pollutants), or the presence of sensitive receivers. However, both have been considered management options in Section 8.

5.2 ASS Prioritisation of the Richmond 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 top two (2) priority subcatchments identified were Tuckean Swamp and Rocky Mouth Creek, which are recognised as ASS hotspots (Tulau, 1999a). The top five (5) priority subcatchments span across the Richmond River floodplain, which shows that impacts from acid drainage can occur throughout the estuary.

Table 5.1: Summary results and rankings of ASS subcatchments in the Richmond River floodplain

Subcatchment	Groundwater Factor	Surface Water Factor	Final Acid Factor	Rank
Tuckean Swamp	594	1,244	738,779	1
Rocky Mouth Creek	663	452	299,529	2
Bungawalbin Creek/Sandy Creek	452	455	205,639	3
North Creek	184	870	159,977	4
Emigrant Creek/Maguires Creek	76	1,033	78,129	5
Swan Bay	268	186	49,776	6
South Ballina	254	140	35,492	7
Kilgin/Buckendoon	152	202	30,788	8
East Coraki	145	151	21,865	9
Empire Vale	63	313	19,611	10
Upper Richmond/Wilsons River	9	436	4,138	11
Rileys Hill	17	138	2,334	12
Back Channel	13	102	1,351	13

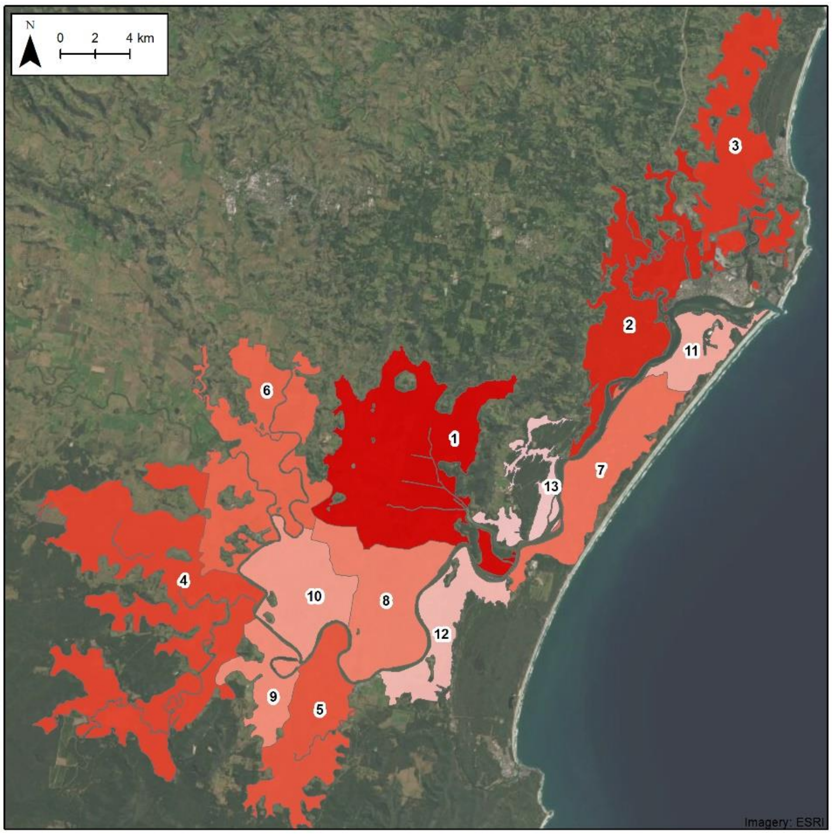

Figure 5-1: Richmond River floodplain surface water factor ranking

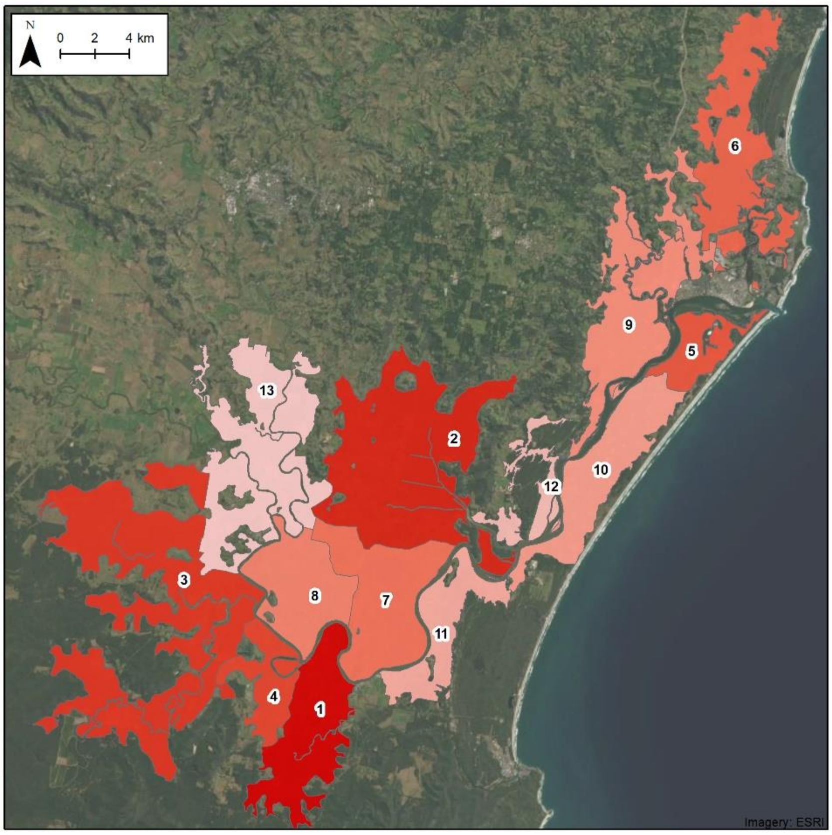

Figure 5-2: Richmond River floodplain groundwater factor ranking

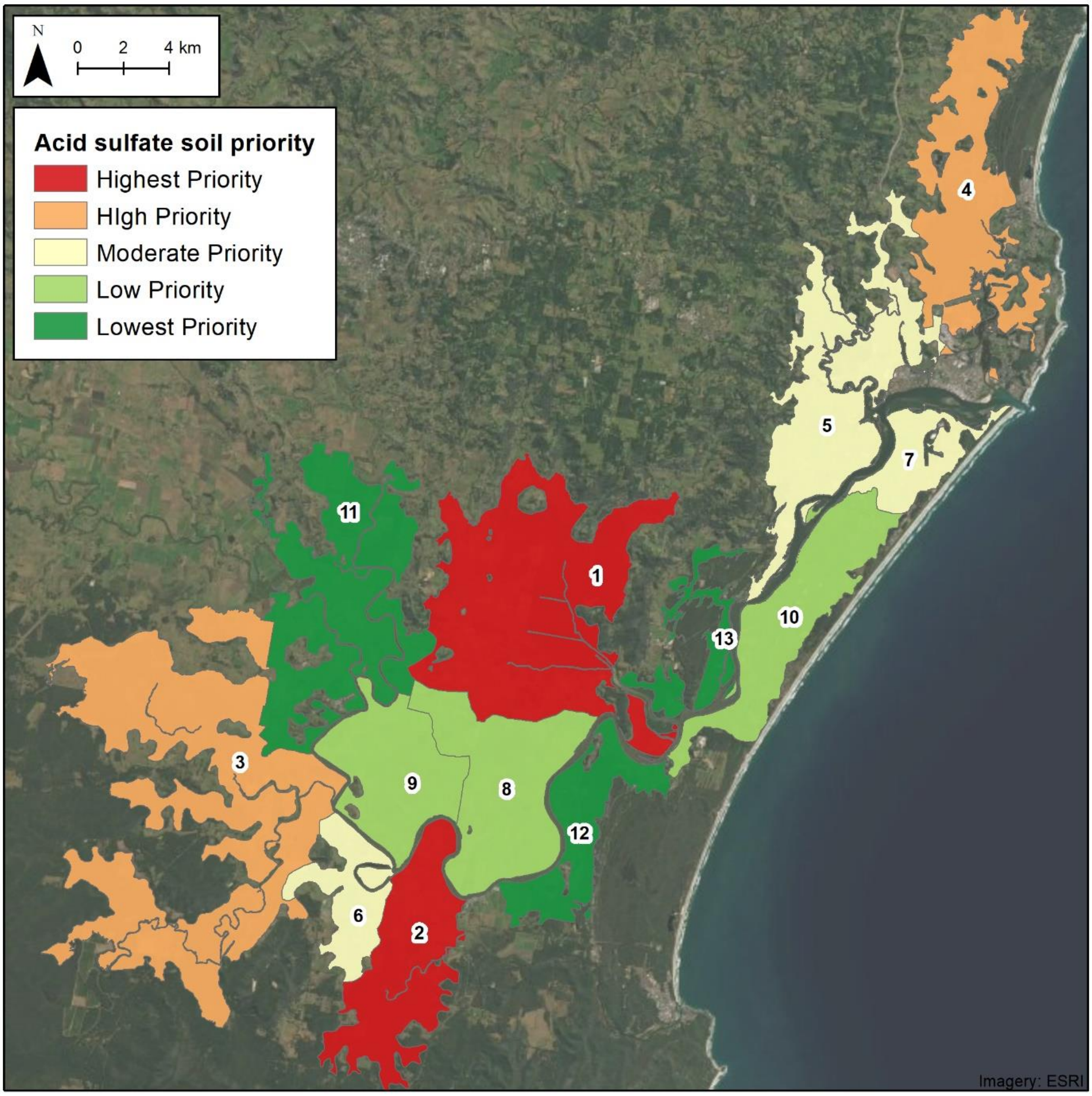

Figure 5-3: Final ranking of the ASS prioritisation for the Richmond River floodplain

6 Blackwater prioritisation assessment outcomes

6.1 Preamble

This section summarises the results of the blackwater priority assessment on the Richmond 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 Richmond 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 priority catchment, Bungawalbin/Sandy Creek, has a substantially higher blackwater factor than any other subcatchment. Figure 6-2 also shows that the top six (6) subcatchments are all in the mid-to-upper estuary, which can result in deoxygenation of the whole estuary upstream of Wardell during catchment-wide flood events. Note that while East Coraki ranked fourth in this assessment, it is likely that the blackwater risk in this subcatchment is over-estimated as there is minimal upstream catchment. While blackwater is likely to be generated at East Coraki after large floods that overtop levees, deoxygenation may be less common in minor to moderate flood events in this subcatchment.

Table 6.1: Final results and rankings of the blackwater priority assessment for the Richmond River floodplain

Subcatchment	Median blackwater elevation (m AHD)	Final blackwater factor	Rank
Bungawalbin Creek/Sandy Creek	2.9	135.4	1
Rocky Mouth Creek	1.5	44.0	2
Tuckean Swamp	1	37.4	3
East Coraki	2.5	33.4	4
Swan Bay	2.9	26.1	5
Kilgin/Buckendoon	1.5	25.6	6
Upper Richmond/Wilsons River	2.3	16.7	7
Rileys Hill	1.5	7.8	8
Emigrant Creek/Maguires Creek	0.4*	3.0	9
North Creek	0.5*	2.4	10
Empire Vale	0.5*	1.2	11
Back Channel	0.5*	0.9	12
South Ballina	0.5*	0.2	13

* Mean high water elevation. See Appendix E for details.

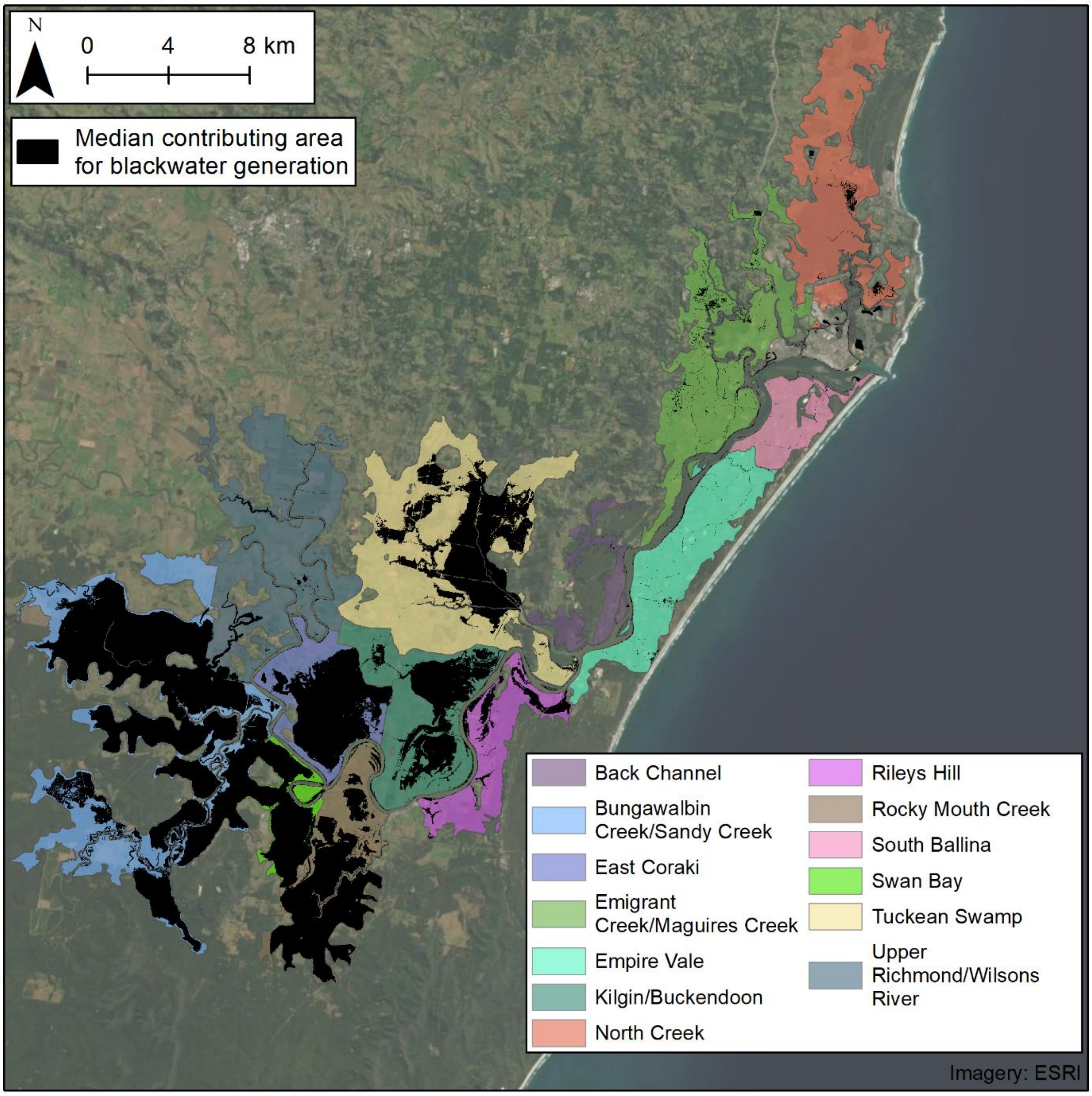

Figure 6-1: Median contributing area for blackwater generation across the Richmond River floodplain

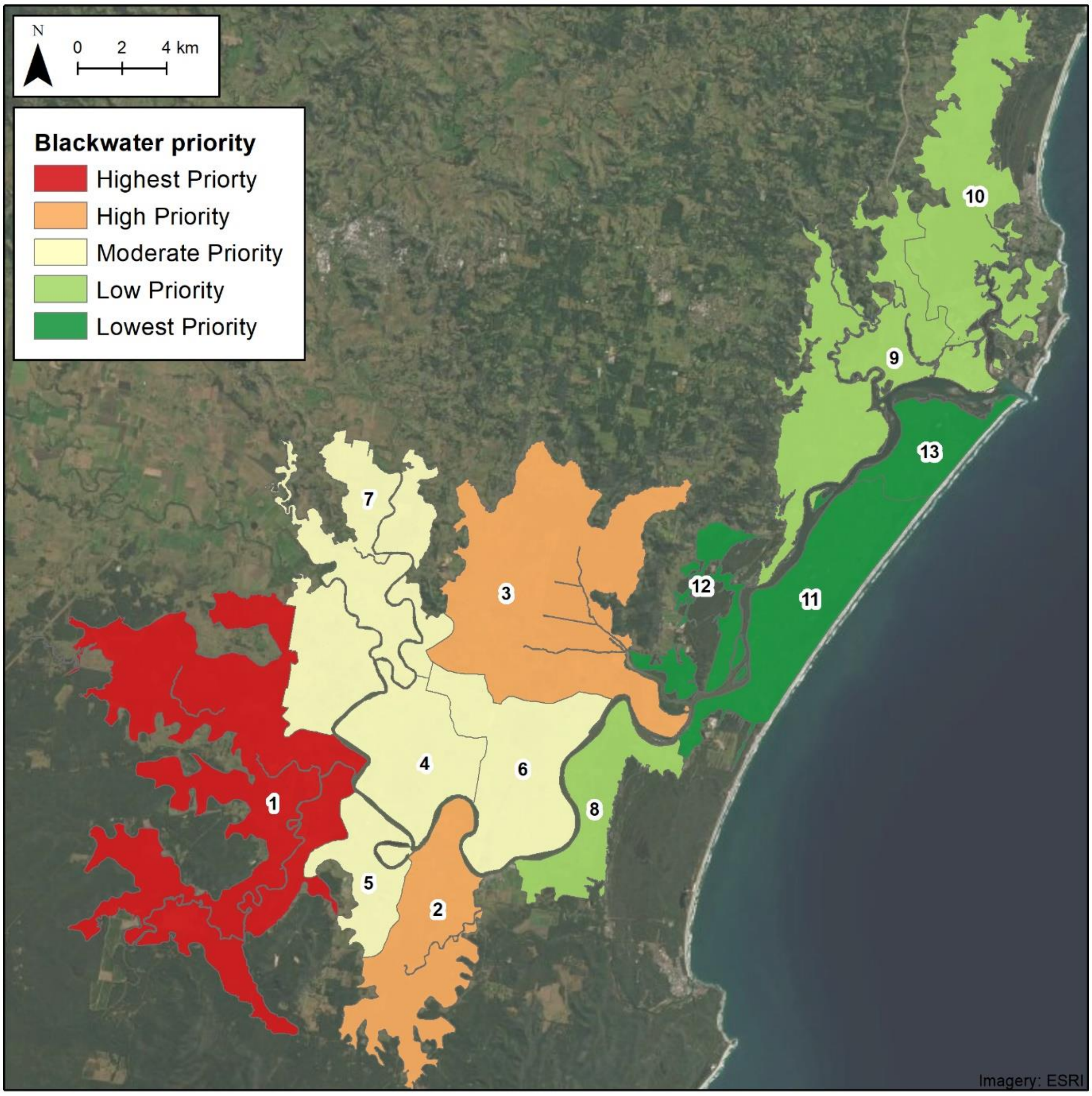

Figure 6-2: Final ranking of the blackwater prioritisation in the Richmond River floodplain

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 - 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 Richmond 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 tide levels 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, but as described above, 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 Richmond 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 Richmond 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 Richmond River estuary. Further details on the model development and calibration can be found in Appendix I.

7.2.1 Richmond 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 Richmond River estuary. The model domain, shown in Figure 7-1, extends across the tidal region of the Richmond River and its tributaries, including; Wilsons River, Bungawalbin Creek, Emigrant Creek, Maguires Creek and North Creek. The numerical model was constructed using a combination of one dimensional (1-D) and two dimensional (2-D) elements. 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-y plane).

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 at Bungawalbin, Casino, Woodlawn and Tuncester. The hydrodynamic model comprised of three (3) main inputs:

1. **Channel bathymetry and geometry** was based on the previous modelling of the Richmond River (Peirson et al., 1999) and updated with the bathymetry from the most recent flood model of the Richmond River (Caddis and Dearnley, 2011);
2. **Downstream tidal water levels** were applied at the downstream ocean boundary. This was based on the observed records from the Manly Hydraulics Laboratory water level station at Ballina Breakwell (Station # 203452); and
3. **Upstream river flow** was applied as inflow hydrographs at the upstream extent of the model. These were sourced from Water NSW river gauges for:

    a. Richmond River at Casino (Station # 203004);
    b. Shannon Brook at Yorklea (Station # 203041);
    c. Coopers Creek at Fairmeadow (Station # 203060);
    d. Wilsons River at Eltham (Station # 203014);
    e. Leycester River at Rock Valley (Station # 203010); and
    f. Goolmangar Creek at Mcnamara Bridge Weir (Station # 203061).

Figure 7-1: Richmond River estuary hydrodynamic model extent

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 Richmond 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, rather than large-scale catchment flood events. Further information on the hydrodynamic model setup and calibration are provided are Appendix I.

The hydrodynamic model of the Richmond River estuary was calibrated to measured water level monitoring stations along the main river channel for a year of average rainfall (2017). Details of the model calibration are provided in Appendix I. The calibrated model was then used to simulate a representative ‘wet’ year (i.e. more rain than average across the catchment) and a representative ‘dry’ year (i.e. less rain than average 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:

- A historic scenario (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 relative to 2020 for these periods have been detailed in Section 11 of the Methods report (Rayner et al., 2023) and are represented in Table 7.1 below.

Freshwater catchment inflows were not modified to account for changes to rainfall and catchment run-off 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 regional climate model ensemble (containing 12 individual models) that provides high resolution (10x10 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 Richmond 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 models were 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 higher 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

Tidal floodgates are used extensively throughout the Richmond 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 WL > 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 – 23 hours of the day) (Figure 7-2b).
- '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 historic (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 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 Richmond 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 over 50% of the floodplain infrastructure owned by Rous County Council is already beyond its active life (Rous County Council, 2017).

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, 132 of 376 (35%) floodgates with known elevation are considered "Most Vulnerable", compared to just 10 (3%) in present day conditions. As shown in Figure 7-5 and Figure 7-6, the lower estuary (downstream of the Tuckean Swamp subcatchment) 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 Richmond River floodplain floodgates

Floodgate Vulnerability	Historic Scenario (HS)	Present Day (PD)	Near Future (NF)	Far Future (FF)
Least Vulnerable	280	266	224	140
Moderately Vulnerable	86	97	124	104
Most Vulnerable	10	13	28	132

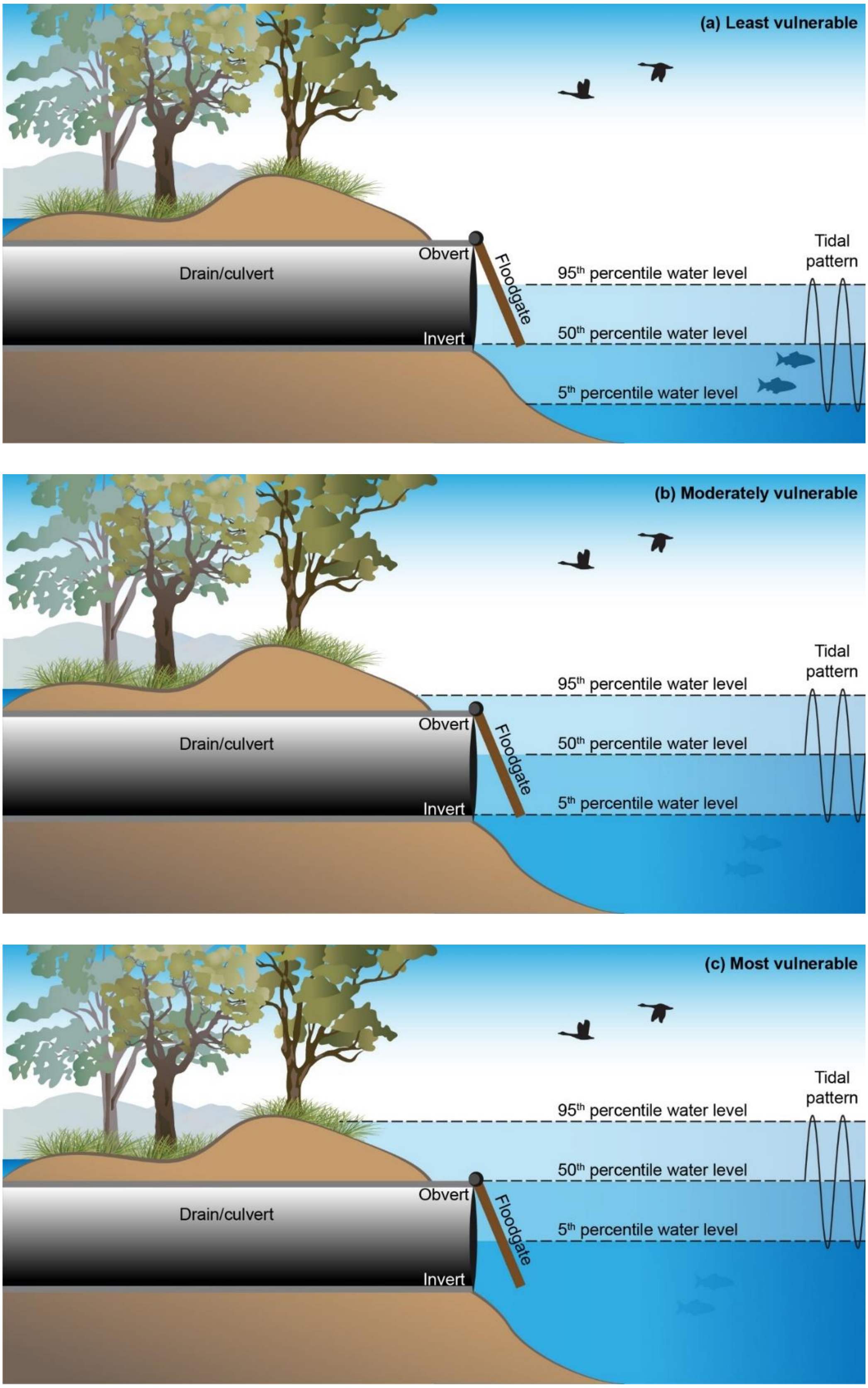

Figure 7-2: Floodgate vulnerability assessment

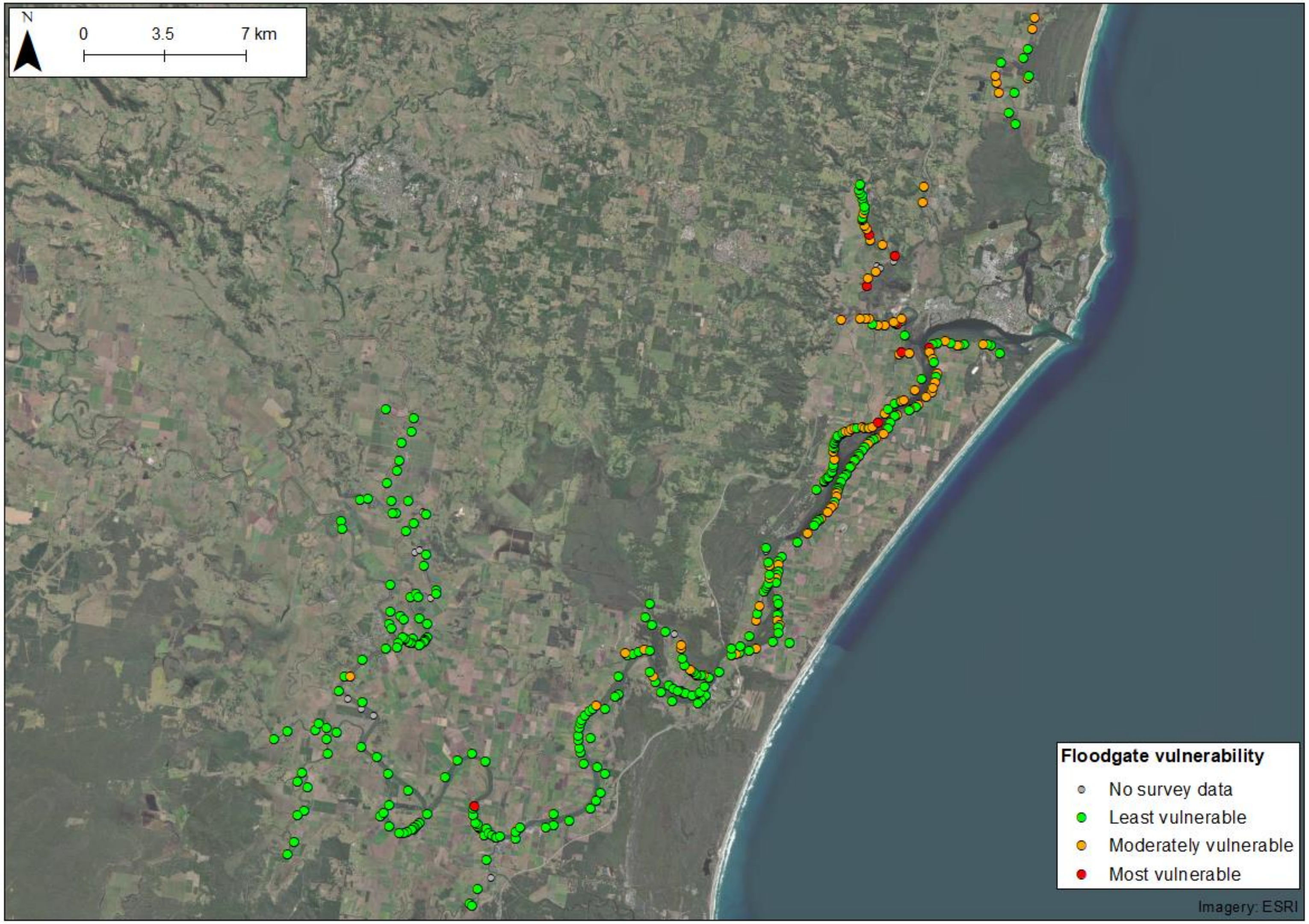

Figure 7-3: Historic floodgate vulnerability – Richmond River estuary

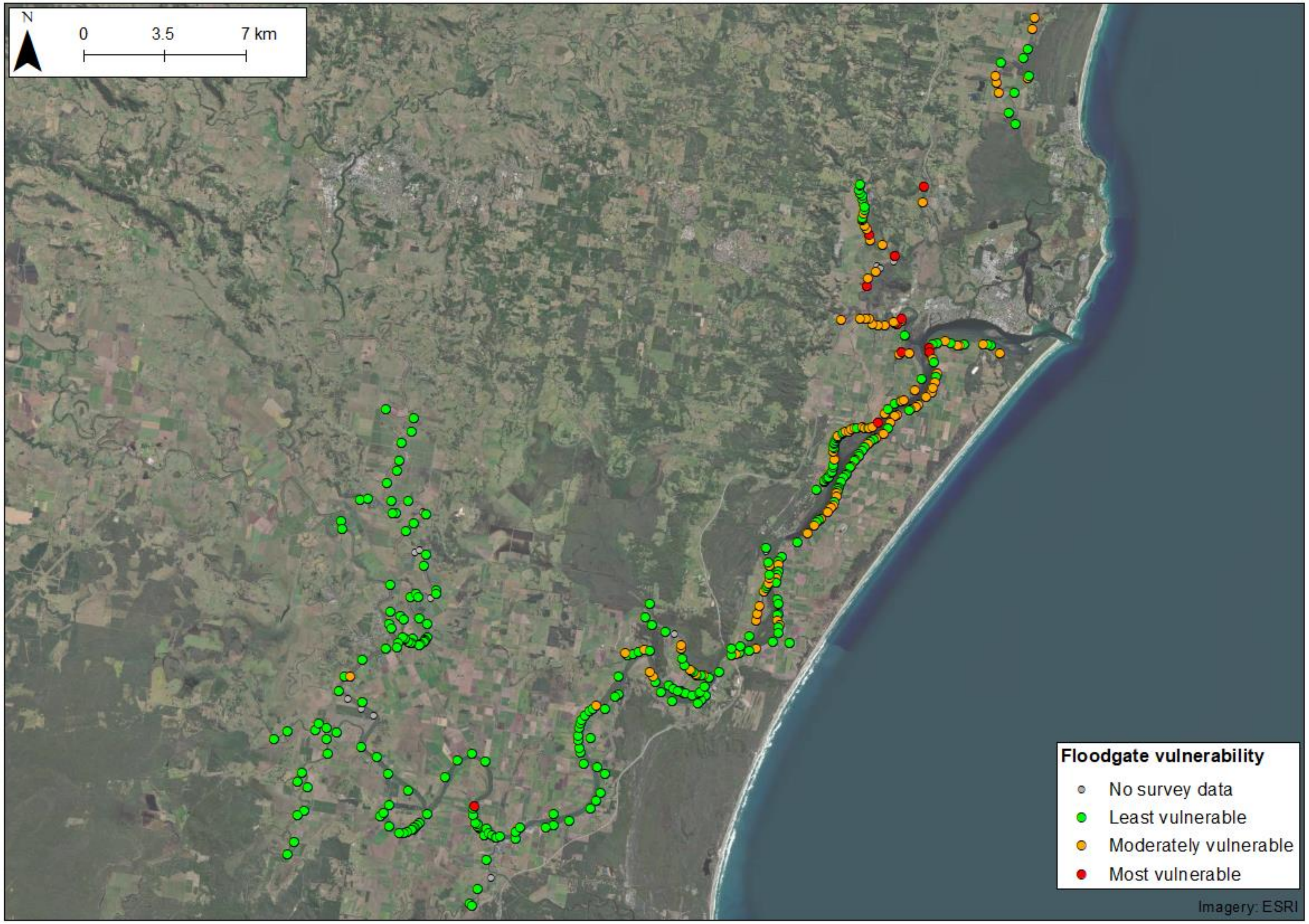

Figure 7-4: Present day floodgate vulnerability – Richmond River estuary

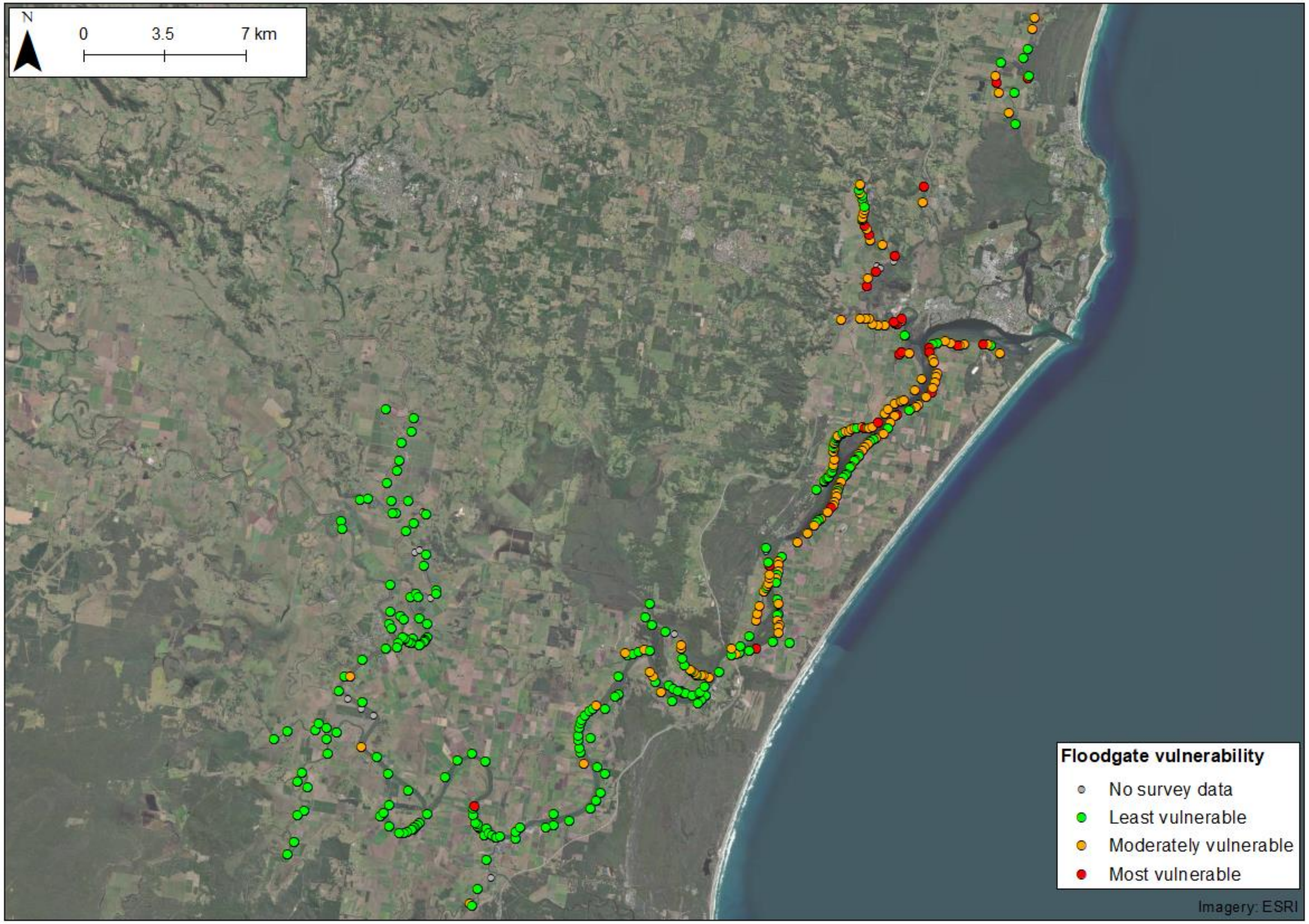

Figure 7-5: Near future (~2050) floodgate vulnerability – Richmond River estuary

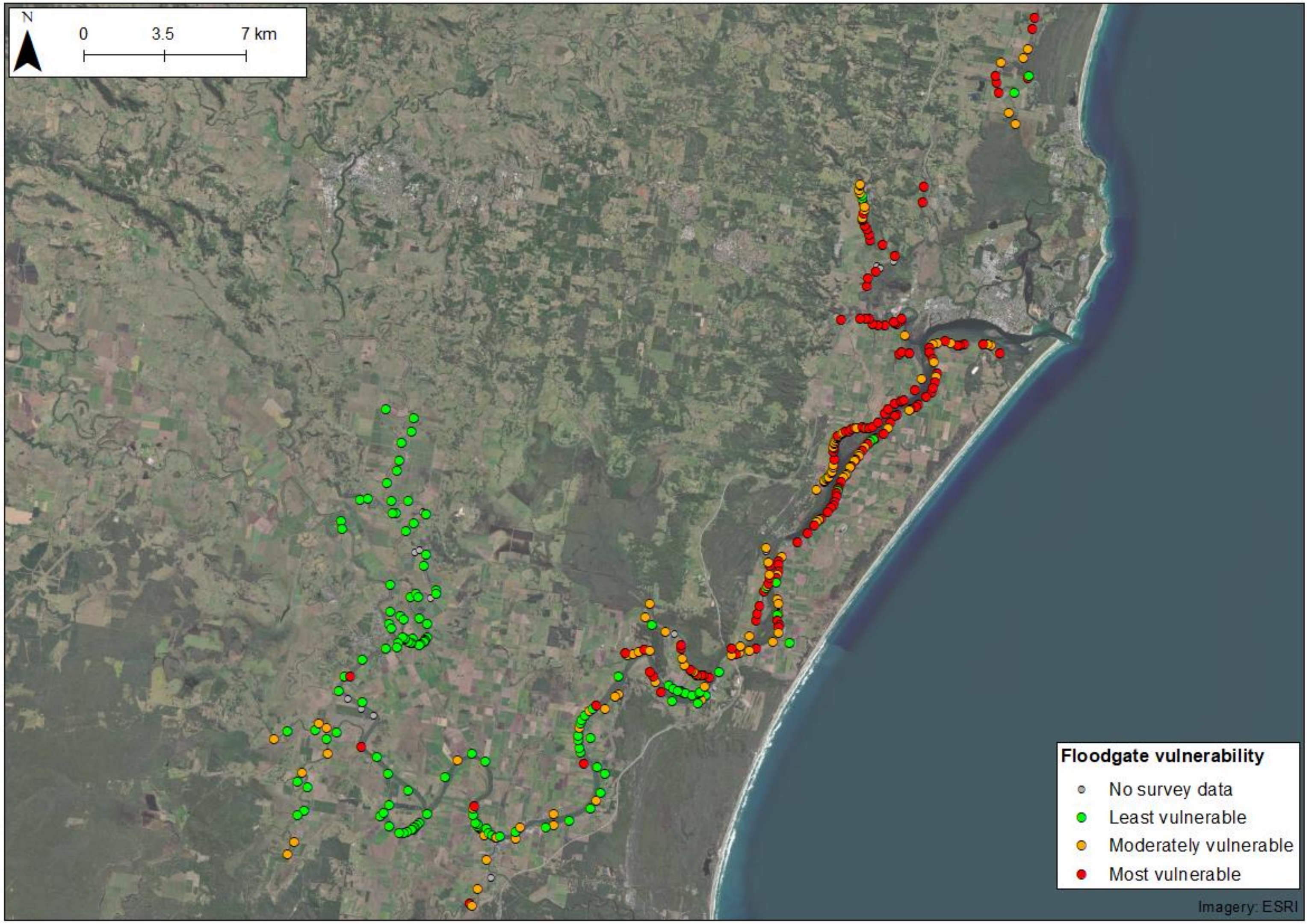

Figure 7-6: Far future (~2100) floodgate vulnerability – Richmond River estuary

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 higher 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 higher future high tides (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 higher 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 Richmond River floodplain for the historic (HS), present day (PD), near future (NF) and far future (FF) 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 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.

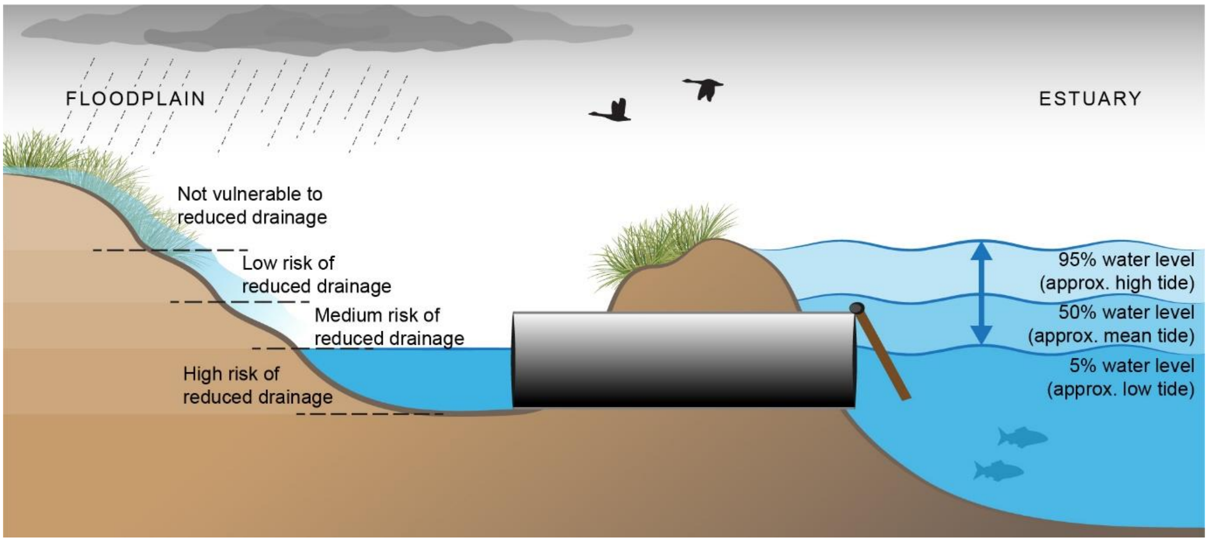

Figure 7-7:Floodplain drainage vulnerability

The total floodplain areas below the water level percentiles for the HS, PD, NF and FF sea level rise scenarios for the Richmond River are summarised in Table 7.5. While the area below the 5th percentile water level more than doubles between present day and the near future, this increases to more than 20 times in the far future to close to 400 ha. The majority of this land is located in the Tuckean Swamp subcatchment (see Figure 7-11).

Table 7.5: Total area (ha) of the Richmond River floodplain vulnerable to reduced drainage

Vulnerability status	Level criteria	Historic Scenario (HS) ~1960	Present Day (PD) 2020	Near Future (NF) ~2050	Far Future (FF) ~2150
		Area (ha)			
Low	50th percentile water level < Land elevation < 95th percentile water level	2,063	2,628	4,915	12,75
Moderate	5th percentile water level < Land elevation < 50th percentile water level	85	96	247	3,340
High	Land elevation < 5th percentile water level	13	17	40	421

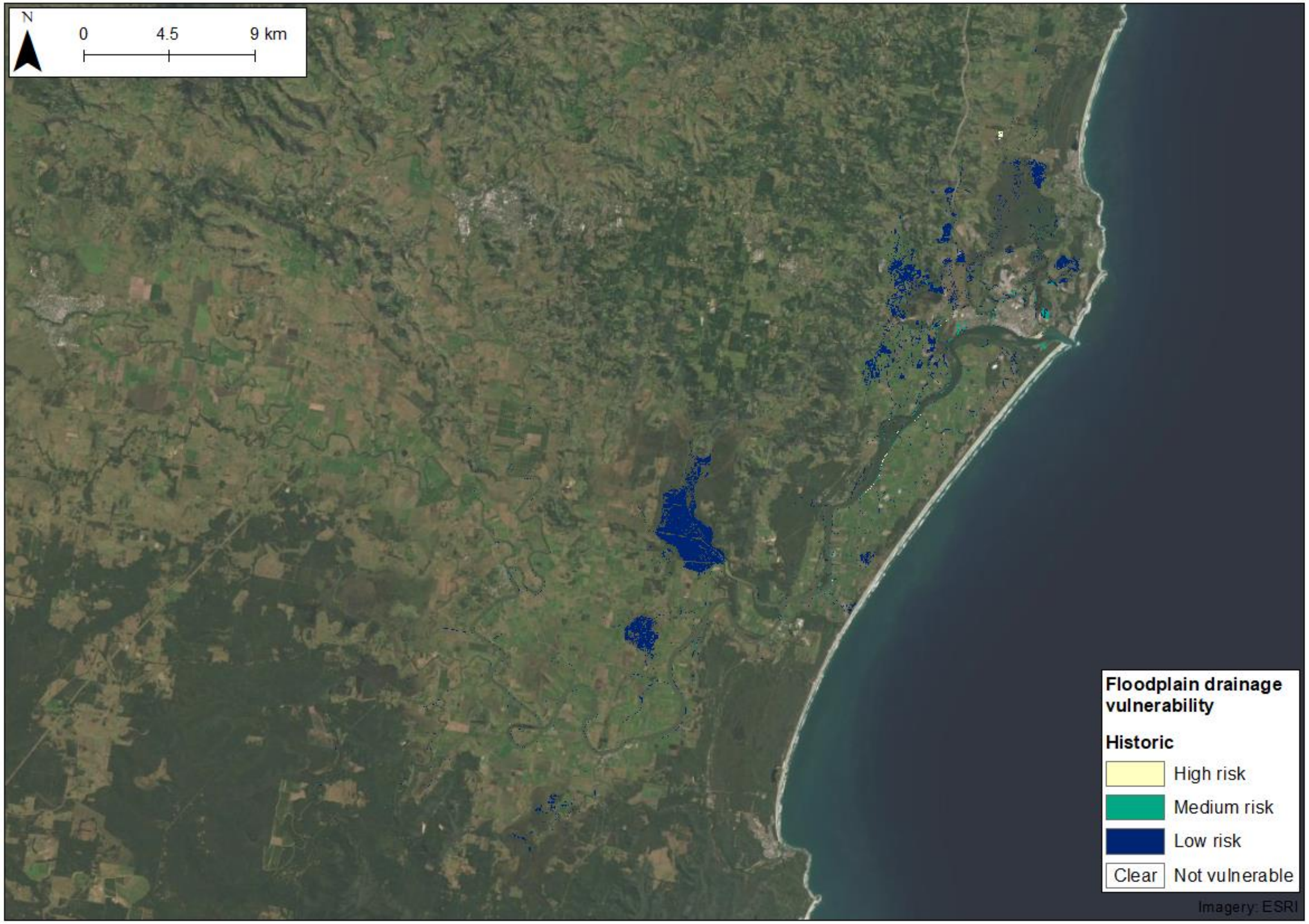

Figure 7-8: Historic (~1960) floodplain vulnerability – Richmond River estuary

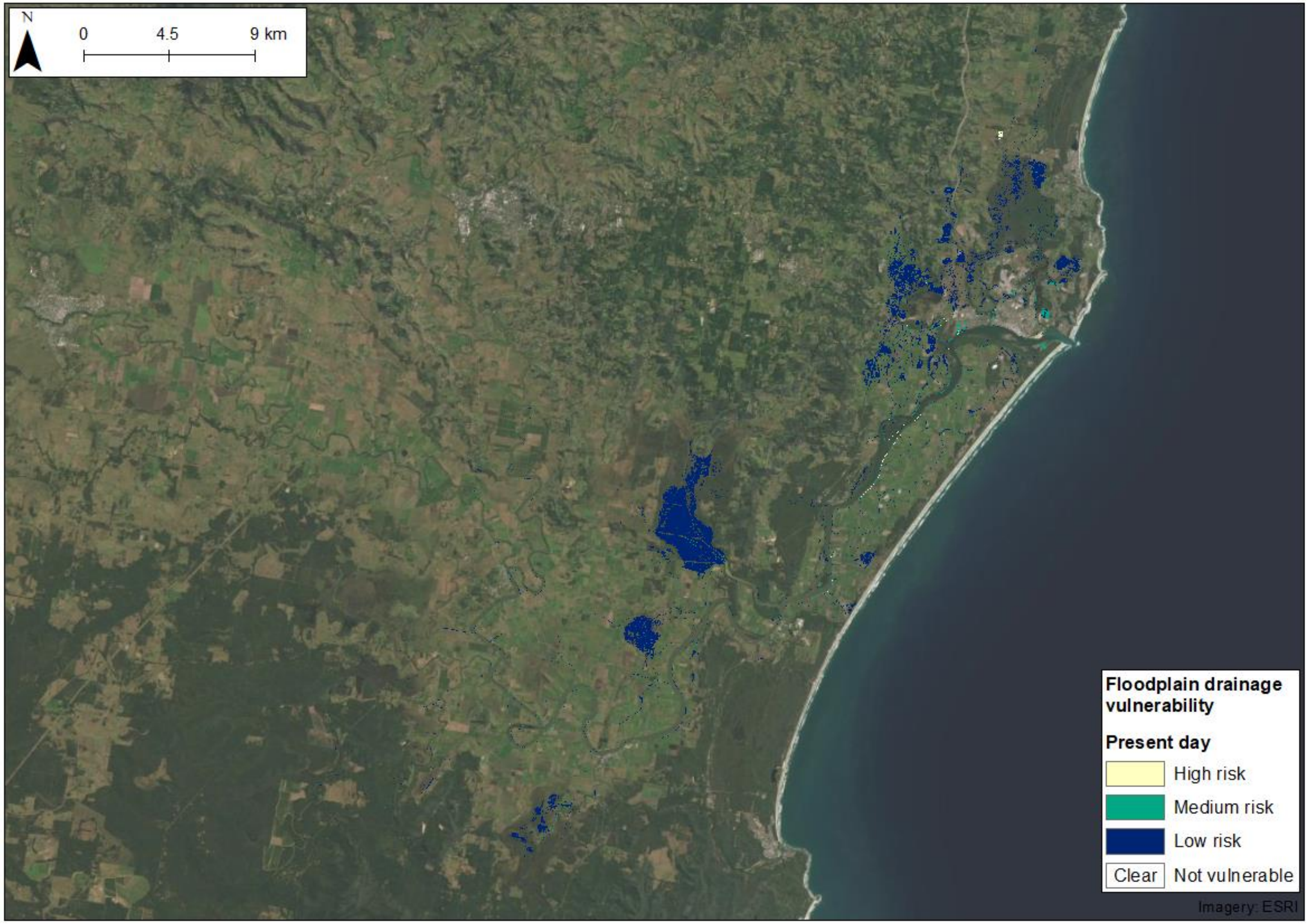

Figure 7-9: Present day floodplain vulnerability – Richmond River estuary

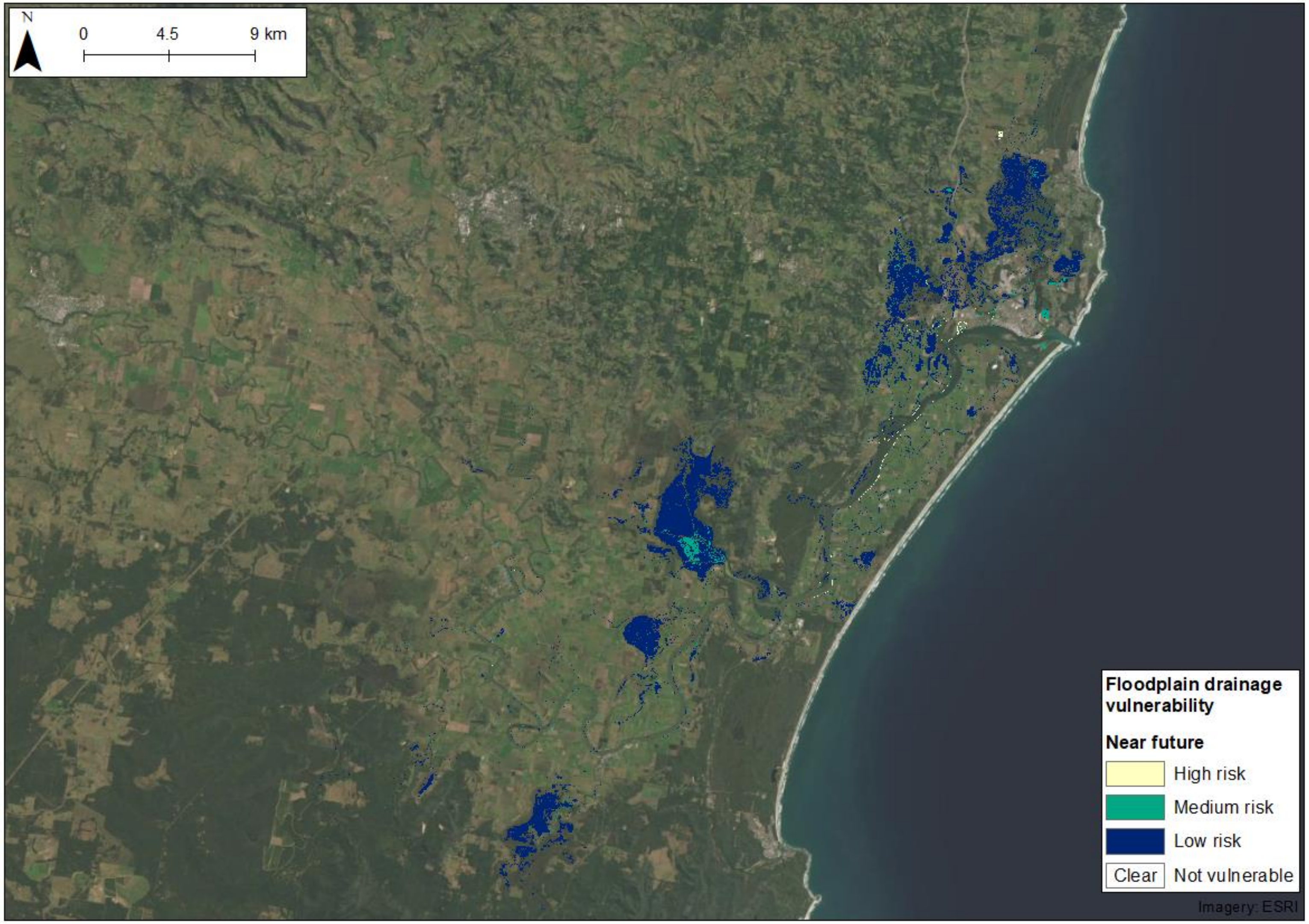

Figure 7-10: Near future (~2050) floodplain vulnerability – Richmond River estuary

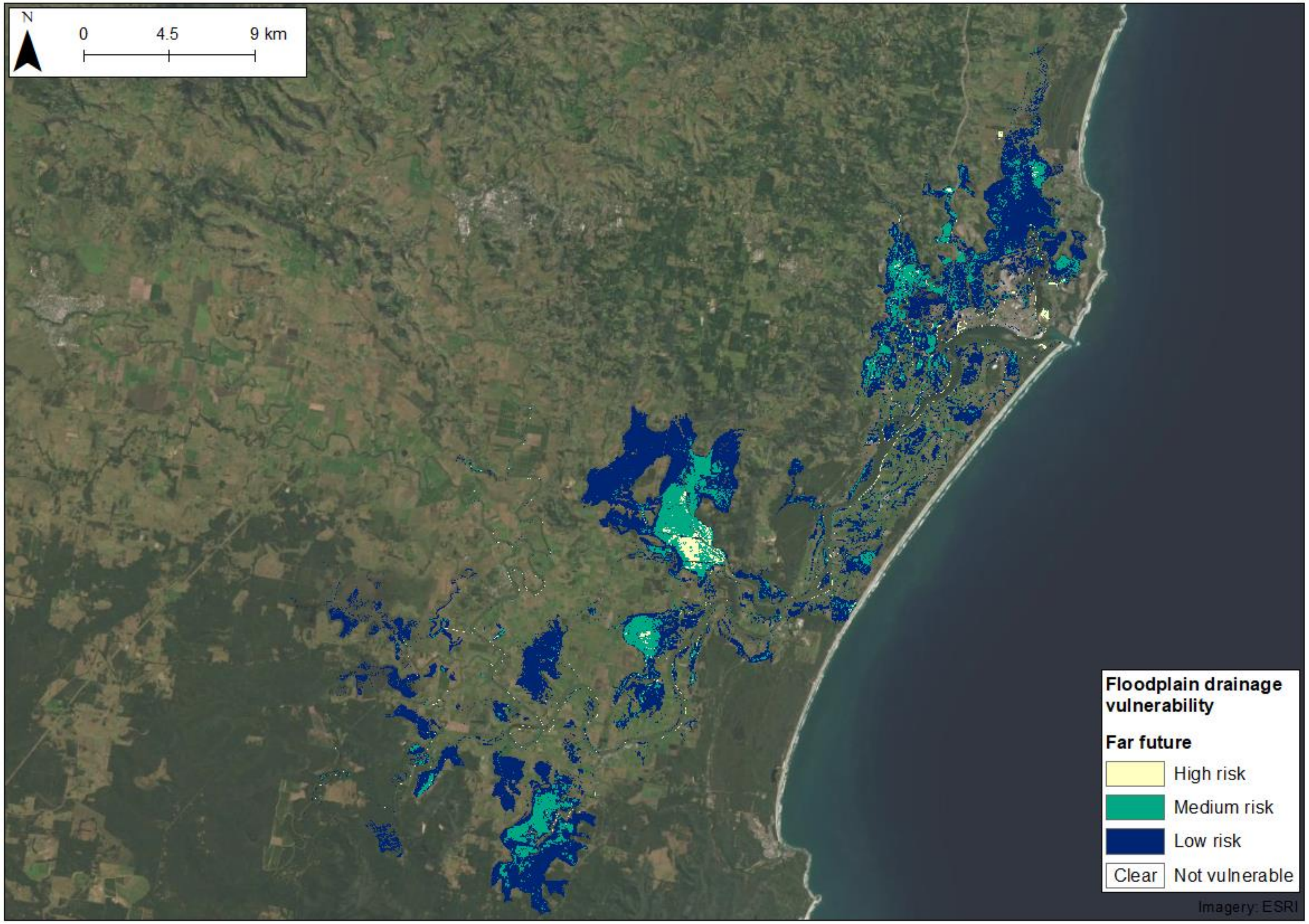

Figure 7-11: Far future (~2100) floodplain vulnerability – Richmond River estuary

8 Subcatchment management options

8.1 Preamble

Management options have been suggested for each subcatchment of the Richmond 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 and assume existing land use practices will continue, 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
# Structures to be confirmed	Number of possible end of system structures that require further confirmation of existence
# 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

8.2.3 Sea level rise vulnerability

Details of the sea level rise vulnerability assessment are provided in Section 7, but are summarised here to assist in the interpretation of the management options. 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 of 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 dynamics, 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 hours 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.

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

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 includes 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).

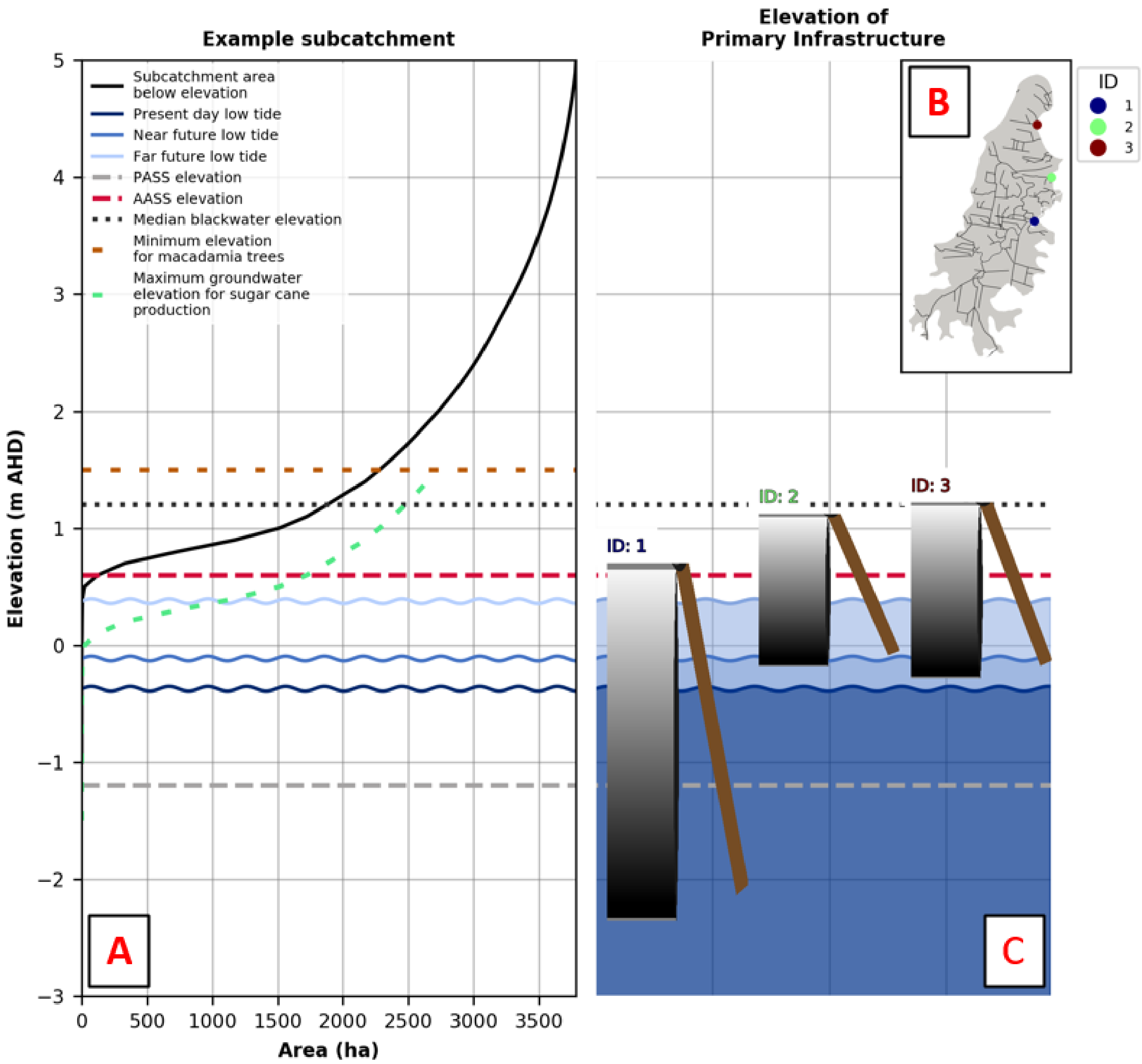

Figure 8-1: Reduced drainage vulnerability summary figure example

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** sumamrises 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;

    - The median blackwater elevation within that subcatchment;
    - The minimum recommended ground elevation for developing and managing macadamia trees (+1.5 m AHD), based on the recommendation of Bright (2020); and
    - The maximum groundwater elevation for sugar cane production (approximately 0.5 m below the ground elevation), based on the findings of Rudd and Chardon (1977). Frequent water logging resulting in higher water tables can reduce sugar cane crop yield.
- **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 5th and 95th 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 limiters 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 are 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 – estimated 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). The total on-ground costs would include 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 to inform any changes in management. 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 land management changes is important when prioritising on-ground works. In this report, benefits have been qualitatively scored (e.g. negligible, low, moderate, high) based on the effectiveness of the changed land management in regards to the effectiveness of improving wetland habitat and connectivity while reducing the impacts of ASS and blackwater. This is based on the type of remediation, experience and engineering judgement.

However, 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. Note that past experience on the Richmond River to improve water quality and provided co-benefits for agriculture (e.g. wet pasture management) have generally been unsuccessful (p.comms C. Clay 02/06/2021), and a site specific assessment on potential co-benefits would need to be considered on a site by site basis prior to any on-ground works;
- 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 into the future, which may incentive land use changes on 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 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 Richmond River floodplain for:

- Tuckean Swamp subcatchment;
- Rocky Mouth Creek subcatchment; and
- Bungawalbin Creek/Sandy Creek subcatchment.

8.3 Tuckean Swamp subcatchment

Acid priority rank:	**1**
Blackwater priority rank:	**3**
Infrastructure	
Approximate waterway length (km)	177
# Privately owned end of system structures	1
# Publicly owned end of system structures	32
# End of system structures within coastal wetlands	19
# Publicly owned end of system structures within coastal wetlands	19
Primary floodplain infrastructure (floodgate ID)	Bagotville Barrage (3830)
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-1.7
Average AASS elevation (m AHD)	0.7
Average PASS elevation (m AHD)	-1.1
Median blackwater elevation (m AHD)	1.0
Present day low water level (m AHD)	-0.35
Near future low water level (m AHD)	-0.19
Far future low water level (m AHD)	0.30
Proximity to sensitive receivers	
Oyster leases (km)	15.0
Saltmarsh (km)	11.0
Seagrass (km)	18.7
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	7,986
Classified as conservation and minimal use (ha (%))	373 (5%)
Classified as grazing (ha (%))	2,916 (37%)
Classified as forestry (ha (%))	4 (0%)
Classified as sugar cane (ha (%))	2,044 (26%)
Classified as horticulture (ha (%))	18 (0%)
Classified as other cropping (ha (%))	119 (1%)
Classified as urban/industrial/services (ha (%))	128 (2%)
Classified as marsh/wetland (ha (%))	2,164 (27%)
Other (ha (%))	220 (3%)
Land values	
Estimated total primary production value ($/year)	$5,300,000
Average land value above 1 m AHD ($/ha)	$7,700
Average land value below 1 m AHD ($/ha)	$4,900

8.3.1 Site description and brief history of drainage

Tuckean Swamp is an estuarine backswamp located on the north side of the Richmond River approximately 25 km upstream of Ballina. Since the 1880's, extensive drainage works have been completed at Tuckean Swamp providing efficient drainage of floodwaters from the naturally low-lying floodplain (Tulau, 1999b), shown in Figure 8-3. In 1971, the existing major drainage was finalised with the construction of the Bagotville Barrage (floodgate ID 3830). The structure comprises of eight (8) large culverts with one-way floodgate flaps. The floodgates enable drainage from the Tuckean Swamp subcatchment, while limiting downstream tidal waters and backwater flooding from the Richmond River.

The constructed drainage system, including the Bagotville Barrage, has facilitated agricultural development of Tuckean Swamp, mostly comprised of grazing and sugar cane. However, it has also caused unintended environmental impacts including the lowering of groundwater levels across the connected upstream floodplain, production of highly acidic discharges from the drainage of ASS, as well as 'blackwater' (low-oxygen water) runoff into the broader estuary (Moore, 2007). While the majority of the floodplain is privately owned, approximately 916 ha of the lowest lying area on the floodplain is owned and managed by National Parks and Wildlife Services (NPWS), referred to as the Tuckean Nature Reserve (TNR), shown in Figure 8-2. Elevation and drainage network information for the Tuckean Swamp subcatchment is shown in Figure 8-3.

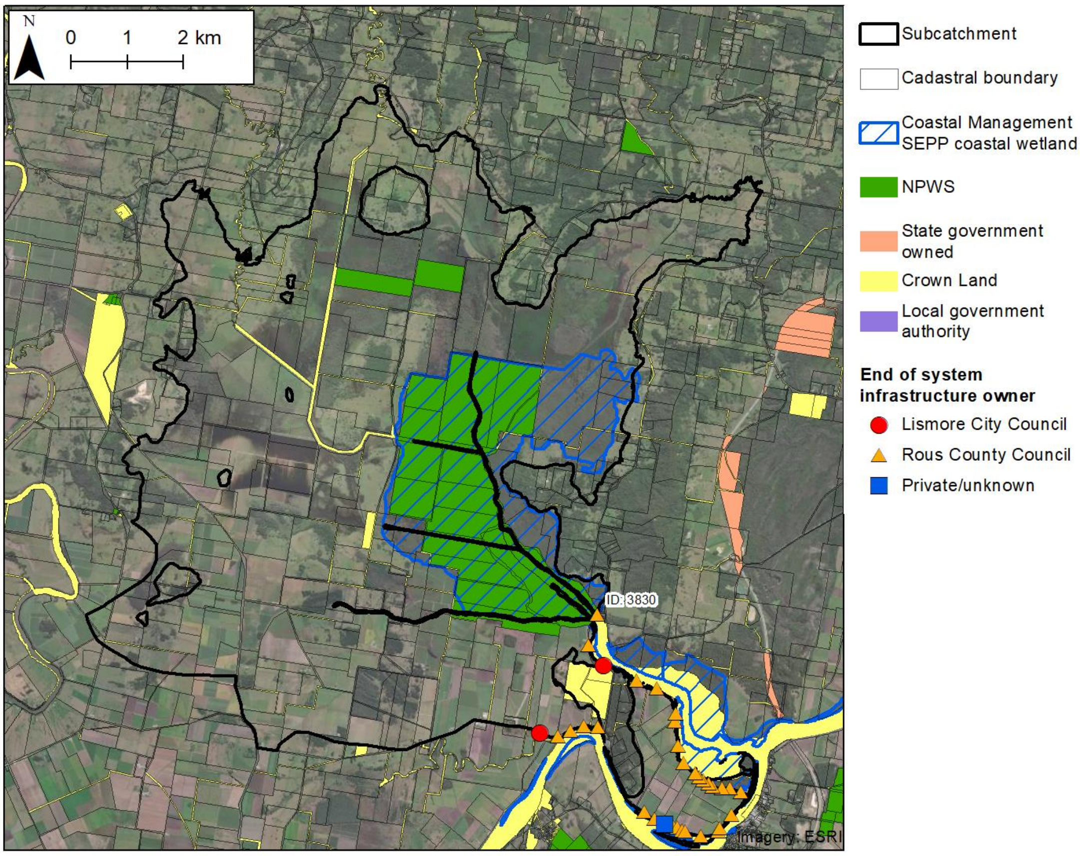

Figure 8-2: Tuckean Swamp tenure and end of system infrastructure tenure

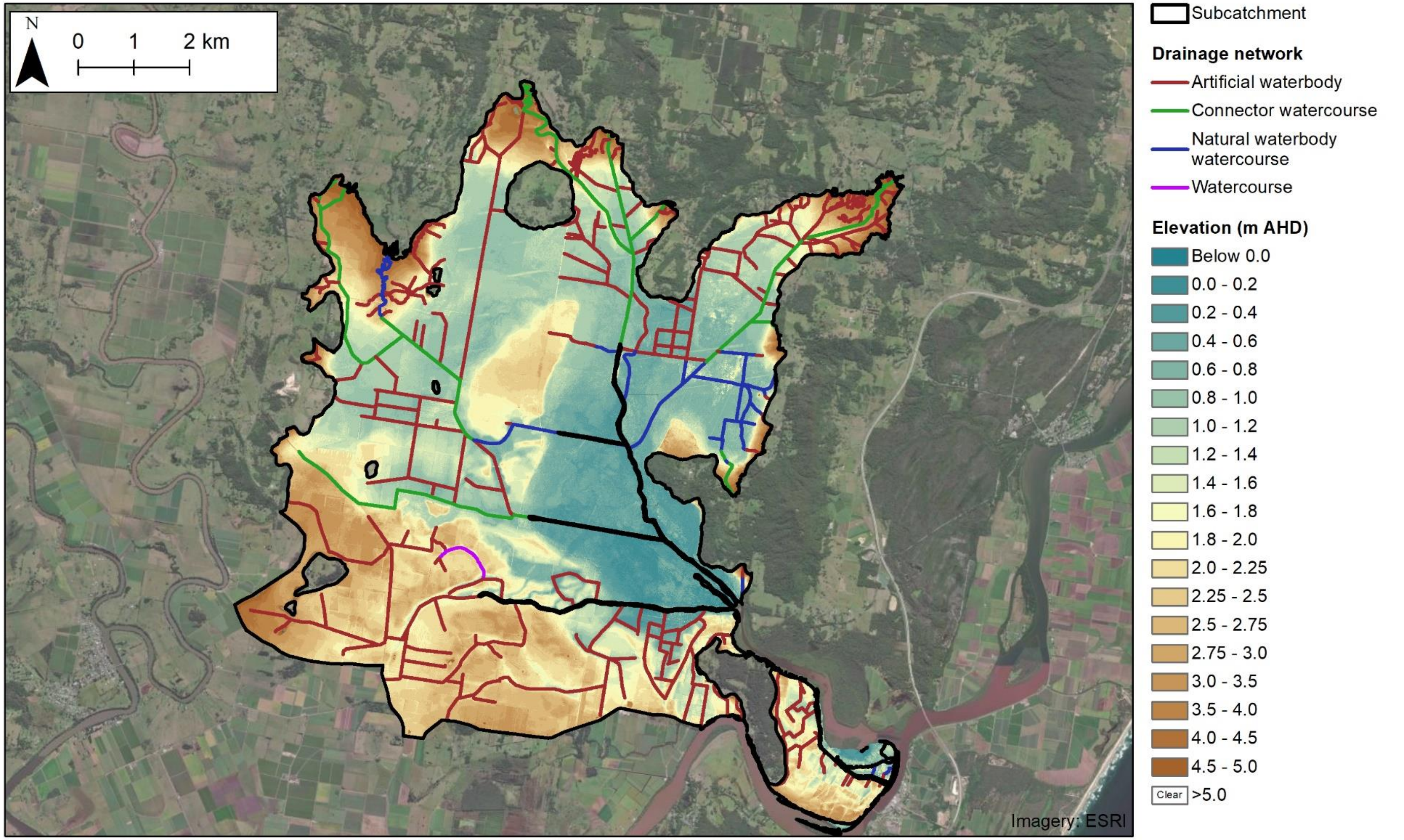

Figure 8-3: Tuckean Swamp subcatchment elevation and drainage network

8.3.2 History of remediation

A timeline of remediation works within the Tuckean Swamp subcatchment is provided below with reference to Figure 8-4. These works are described by Tulau (1999b) and Rayner et al. (2020a) unless otherwise stated, and include:

- 1982 - establishment of the Tuckean Nature Reserve, covering an area of 550 ha. The reserve forms the connection between Tuckean Swamp and the Richmond River. An additional 366 hectares of former Crown Land were added on 5 March 1999, taking the total area of the reserve to 916 hectares (NSW National Parks and Wildlife Service, 2002).
- 1993 - Tuckean Swamp Management Committee (formed in 1993) developed a Land and Water Management Plan aiming to address the improvement of agricultural, fisheries and wildlife habitat values of the area, while maintaining adequate drainage and flood protection for agricultural lands. Some of the strategies to manage ASS and their impacts included:
    - Management of ASS drain spoil by reconfiguring, liming and revegetating drain banks;
    - Management of potential acidic sediments in-drain by implementation of alternative drain maintenance procedures;
    - Management of acid scalds by liming and revegetation of these areas;
    - Management of acidic and potentially acidic soils underlain by an artificially lowered water table by reducing oxidation; and
    - Management of the impacts of ASS on water quality by assessing the operation of the Bagotville Barrage.
- 1996 - To assist in the development of the Land and Water Management Plan for the Tuckean Swamp, a number of technical investigations were completed and published. As part of those investigations, Patterson Britton & Partners (1996) developed a numerical model of the Tuckean floodplain to assess the impacts of removing the Bagotville Barrage (floodgate ID 3830). Following this modelling, a proposal to open one of the eight (8) gates in the Barrage was proposed, however landholders were concerned about the possibility of tidal inundation of land and salinity of groundwater affecting agricultural productivity.
- From 1996 to 2003 - Under the coordination of the Tuckean Landcare Group, remediation works were undertaken including liming, laser levelling, and drain re-shaping. Further, Tulau (1999b) also mentioned the installation of drop board structures to manipulate the water table, monitoring of the water table and water quality, and the establishment of trial sites to evaluate pasture production using pond pasture species. There is no further documentation of the implementation of the mentioned remediation works nor an assessment of their effectiveness for specific sites.
- 2003 - Installation of three (3) sluice gates with dimensions 1 m x 1 m on three (3) northern Bagotville Barrage gates. Flow through the sluice gates allows controlled tidal inflows into Hendersons Drain, which increases salinity within the lower Tuckean Nature Reserve and promotes better flushing. The sluice gates are typically shut prior to catchment rainfall events to maintain flood capacity.
- 2019/2020 - Rayner et al. (2020a) developed a detailed hydrodynamic and salinity model of the Tuckean floodplain to test the impact of seven (7) drainage management options proposed to mitigate ASS and improve water quality on the site. For each proposed option, potential impacts on the water quality, floodplain inundation, drainage and saltwater intrusion were investigated.

Sugar cane farms in the Richmond River floodplain operate in compliance with “the NSW sugar industry best practice guidelines for acid sulfate soils” (Sunshine Sugar, 2020). While details of specific drainage management on cane farms in the Tuckean Swamp subcatchment were not obtained, cane farms typically undertook:

- Laser levelling of farms to reduce drainage density required to allow surface water drainage;
- Construction of new drainage works to minimise the interaction with acidic soils; and
- Extensive application of liming.

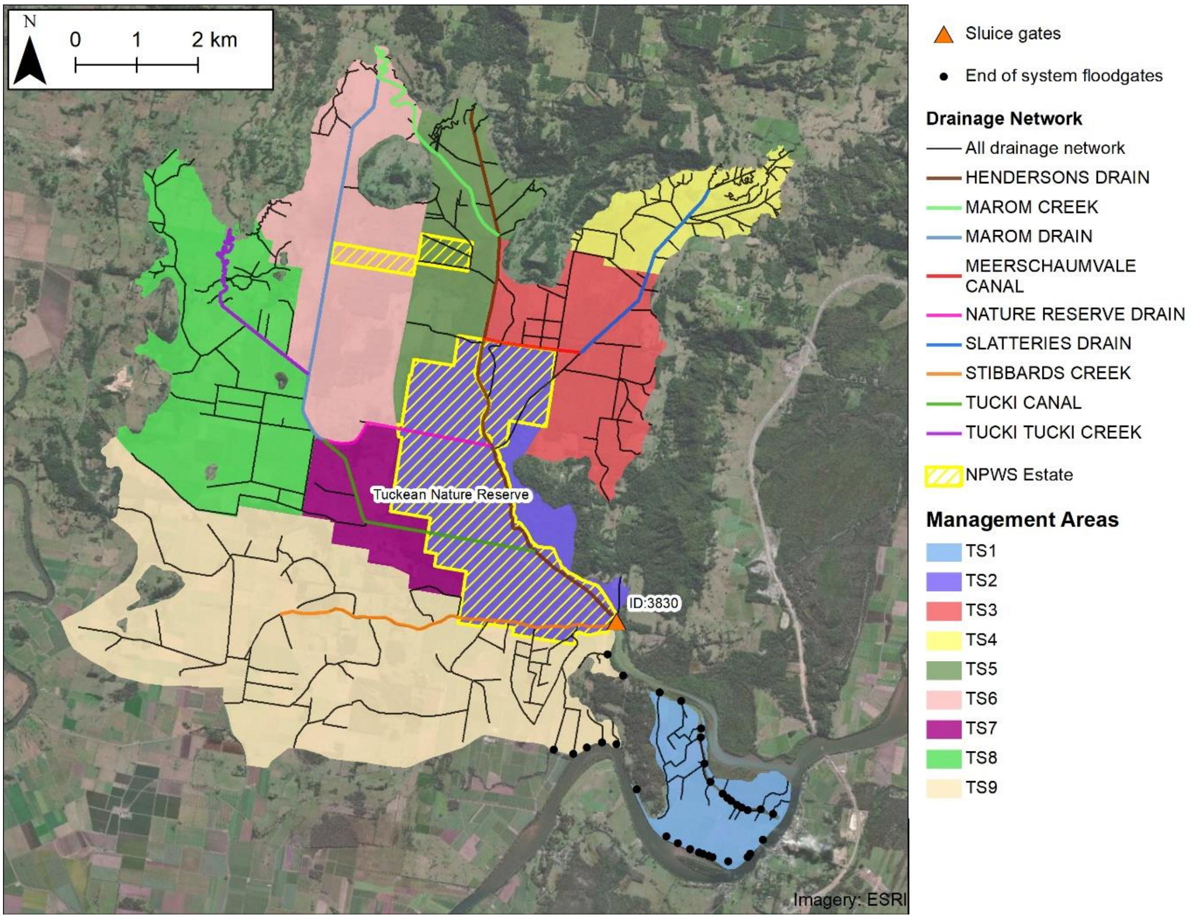

Figure 8-4: Tuckean Swamp subcatchment including previous remediation actions and further breakdown of management areas

8.3.3 Prioritisation of management areas in the Tuckean Swamp subcatchment

Tuckean Swamp is the highest ranked subcatchment in the Richmond River floodplain with regards to acid generation, and ranked third for blackwater generation. The subcatchment has been further divided into nine (9) management areas (referred to as TS1 – TS9, shown in Figure 8-4) to provide additional information on the sources of acid and blackwater in the Tuckean Swamp region. The areas have been delineated based on 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 4.2. The results of the acid prioritisation for the management areas of Tuckean Swamp are shown in Figure 8-5 and summarised in Table 8.3. The top four (4) management areas account for the majority of the water quality risk. There is insufficient soil acidity data in TS1, located downstream of the

Bagotville Barrage, to include it in the management areas prioritisation for acid generation. It is recommended that additional soil data is collected in this area to better understand the contribution of the area to acid drainage.

Figure 8-6 shows the management areas at Tuckean Swamp below the median elevation for blackwater generation (+1 m AHD). As elevation is a primary driver of the production of blackwater, the areas below this level typically have the greatest contribution to the risk of large scale deoxygenation. The management areas ranked second and fourth in the acid prioritisation (TS3 and TS2) also contain the majority of the area in the Tuckean Swamp floodplain below +1 m AHD (the median blackwater elevation).

Based on the prioritisation of management areas for acid generation, and the areas below the median elevation for blackwater generation, it is suggested that remediation efforts to improve water quality should initially focus on management areas TS7, TS3, TS4 and TS2.

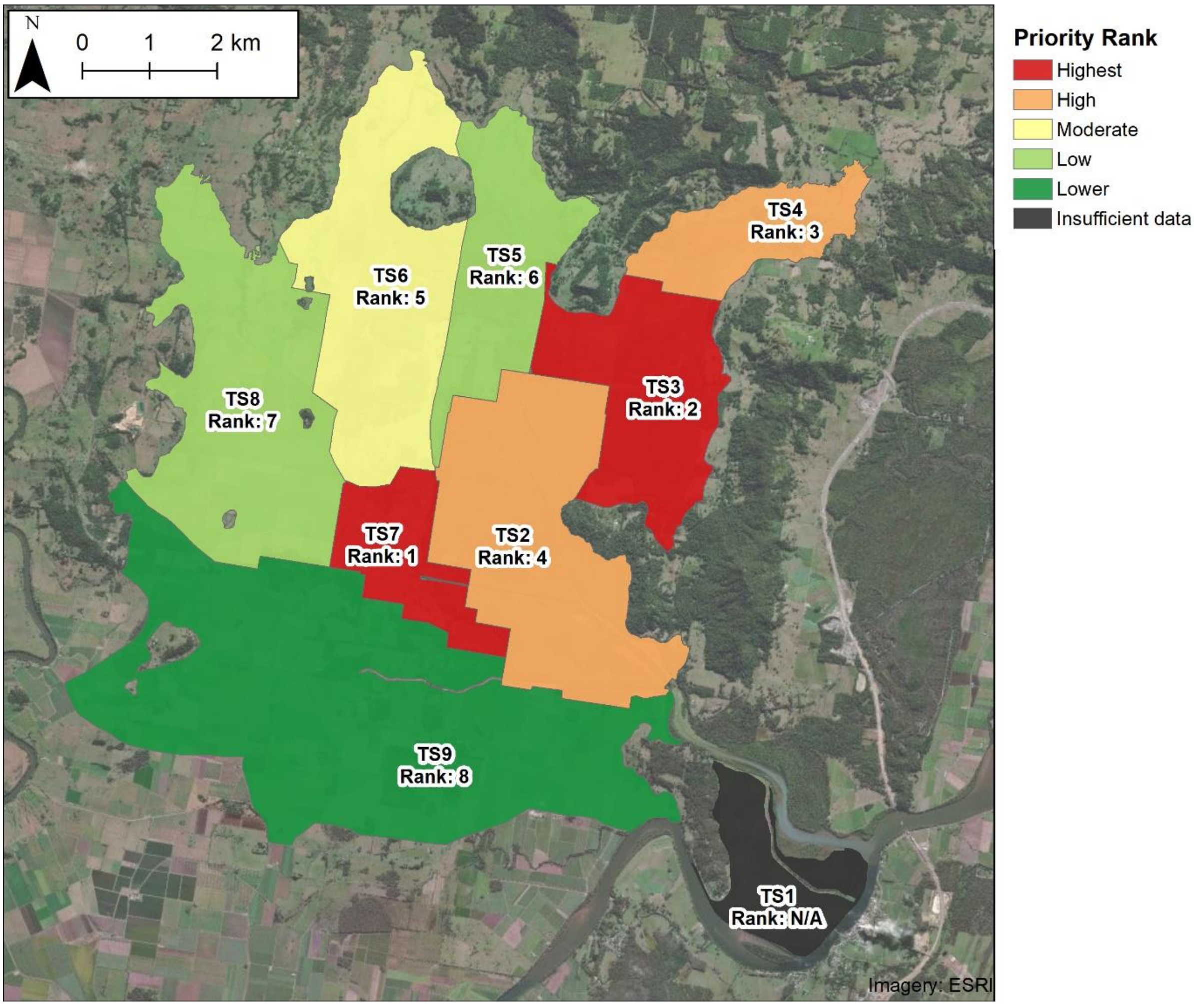

Figure 8-5: Tuckean Swamp subcatchment management areas acid prioritisation

Table 8.3: Management area acid prioritisation of Tuckean Swamp subcatchment

Management Area	Groundwater Factor	Surface Water Factor	Final Acid Factor	Final Rank
TS7	1,030	437	450,063	1
TS3	1,086	392	425,350	2
TS4	786	504	396,142	3
TS2	483	820	395,827	4
TS6	459	235	107,665	5
TS5	235	213	50,097	6
TS8	47	414	19,429	7
TS9	45	119	5,401	8
TS1	Insufficient data	22	Insufficient data	Insufficient data

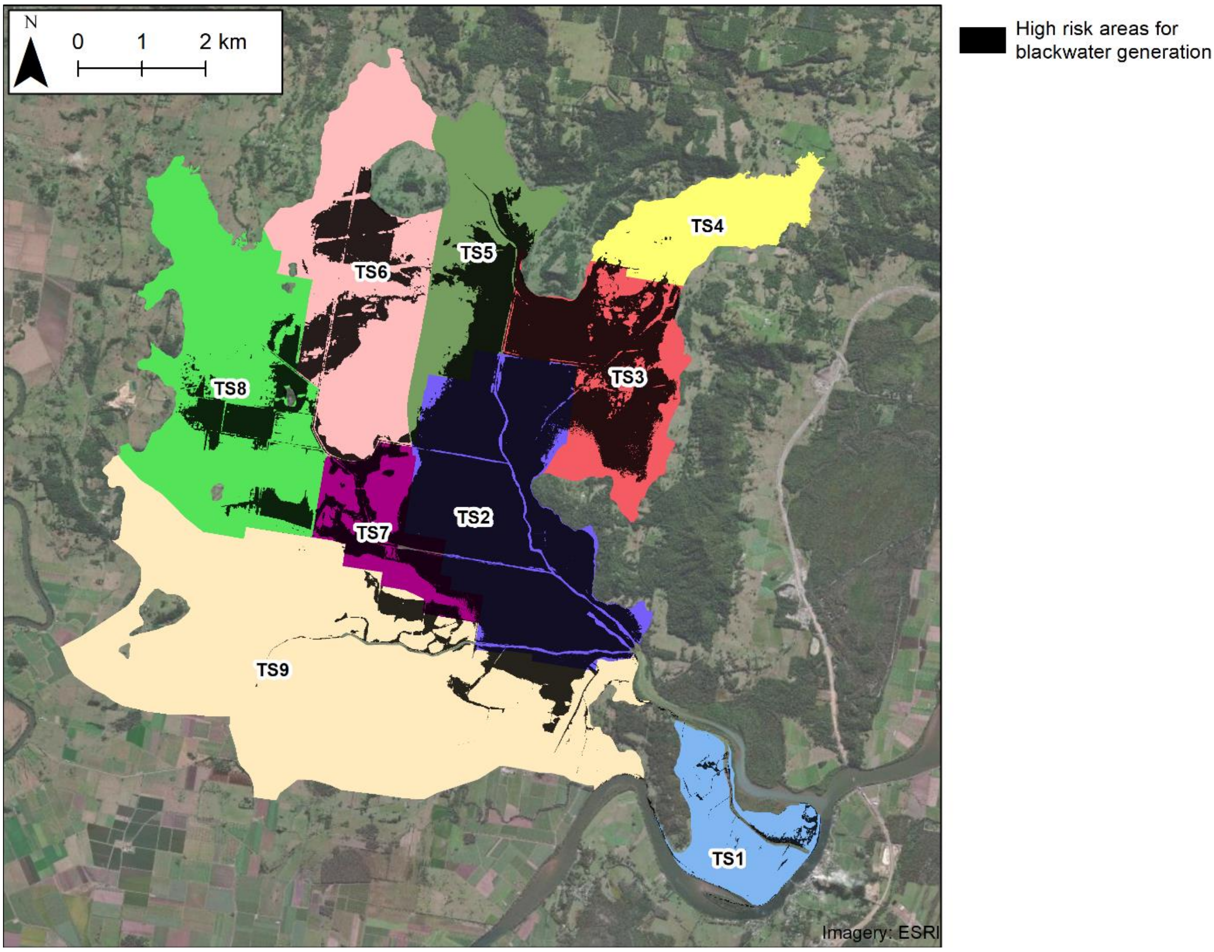

Figure 8-6: High risk areas for blackwater generation in management areas in Tuckean Swamp subcatchment (median blackwater level +1 m AHD)

8.3.4 Floodplain drainage – sea level rise vulnerability

Assessment of potential impacts of sea level rise on floodplain drainage in Tuckean Swamp in the near and far future is critical for limiting impacts on water quality and ensuring the viability of current land uses in the future. Future drainage efficiency will also influence the long-term effectiveness of potential remediation options. The vulnerability assessment (described in Section 7) is summarised in Figure 8-7.

This assessment indicated that the Tuckean Swamp subcatchment is vulnerable to reduced drainage as a result of higher water levels in the Richmond River in the near and far future. Presently, the majority of the floodplain beyond the Tuckean Nature Reserve is not considered vulnerable to reduced drainage (e.g. being located above the 95^{th} percentile downstream water level) and the floodplain generally allows for drainage of the agricultural land after small to moderate local rainfall events. However, Figure 8-7 indicates that the area classified as low risk to reduced drainage will expand significantly in the near future (particularly around management area TS3). In the far future, the Tuckean Nature Reserve and the majority of management area TS3 is assessed as moderate risk, indicating significantly reduced drainage potential. Furthermore, the area considered low risk in terms of drainage vulnerability extends extensively into every management area, except TS1.

The Bagotville Barrage, the most significant infrastructure in the Tuckean Swamp subcatchment, has a low invert elevation (-1.7 m AHD). However, due to the size of the floodgates (approximately 3 m high), the obvert is at +1.3 m AHD, which is above the 95^{th} percentile water levels in the present day and near future and just marginally below the far future 95^{th} percentile water level. The elevation of this floodgate compared to key elevations across the floodplain is shown in Figure 8-8. Due to the high obvert, this floodgate will only be moderately vulnerable to sea level rise in the far future (~2100). Note that this assessment does not consider the engineering design life of floodplain drainage infrastructure, and it is likely that the Bagotville Barrage will still require significant investment to maintain functionality over the following century.

Across the Tuckean Swamp subcatchment, ten (10) floodgates will become moderately vulnerable to sea level rise in the near future, increasing to twelve (12) moderately vulnerable and nine (9) most vulnerable floodgates in the far future. There are seven (7) floodgates along the Richmond River in management area TS1 that will become most vulnerable to sea level rise in the far future and a further six (6) that will be moderately vulnerable. This highlights the susceptibility of floodplain drainage within management area TS1 to sea level rise.

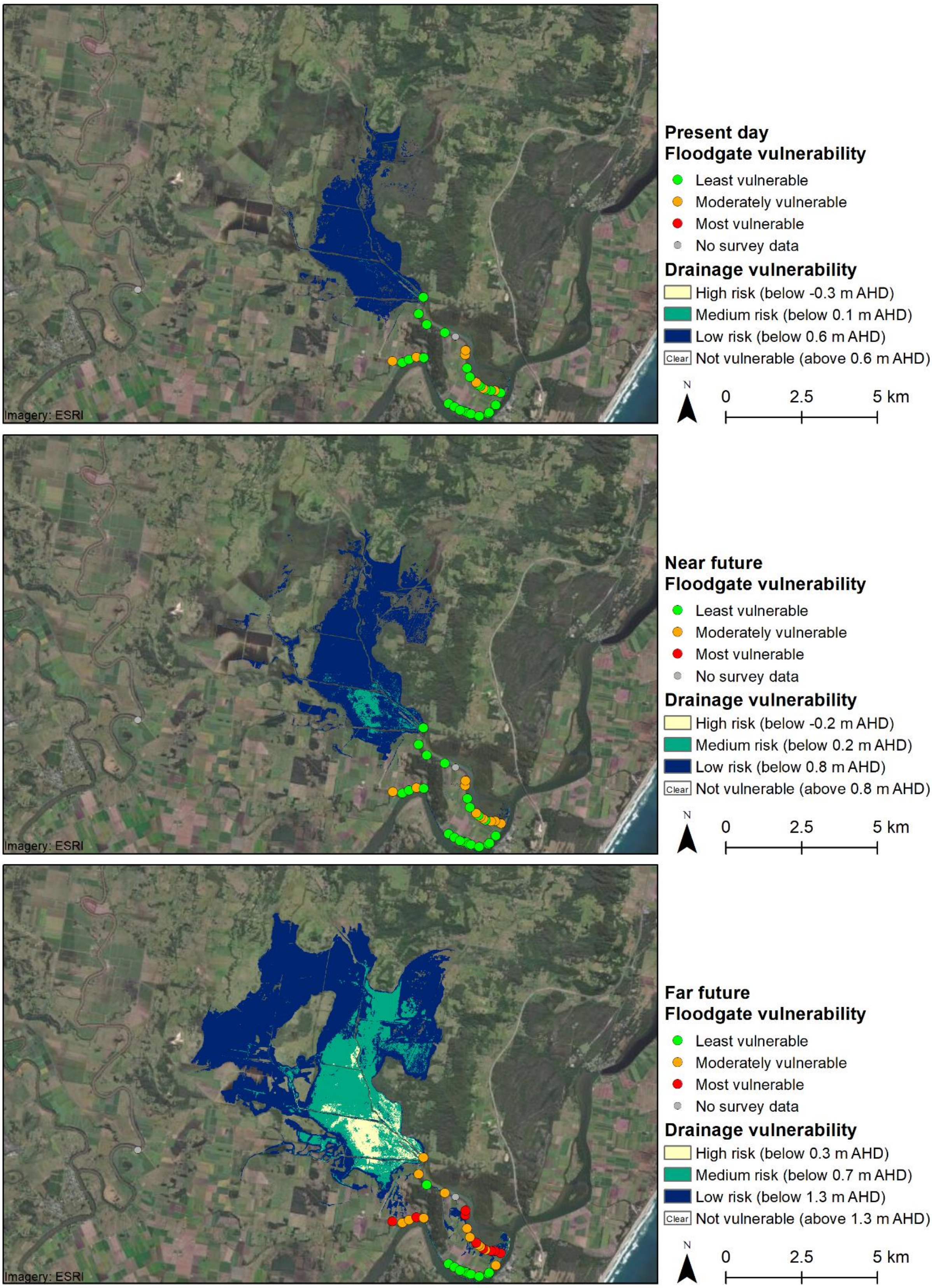

Figure 8-7: Sea level rise drainage vulnerability - Tuckean Swamp subcatchment

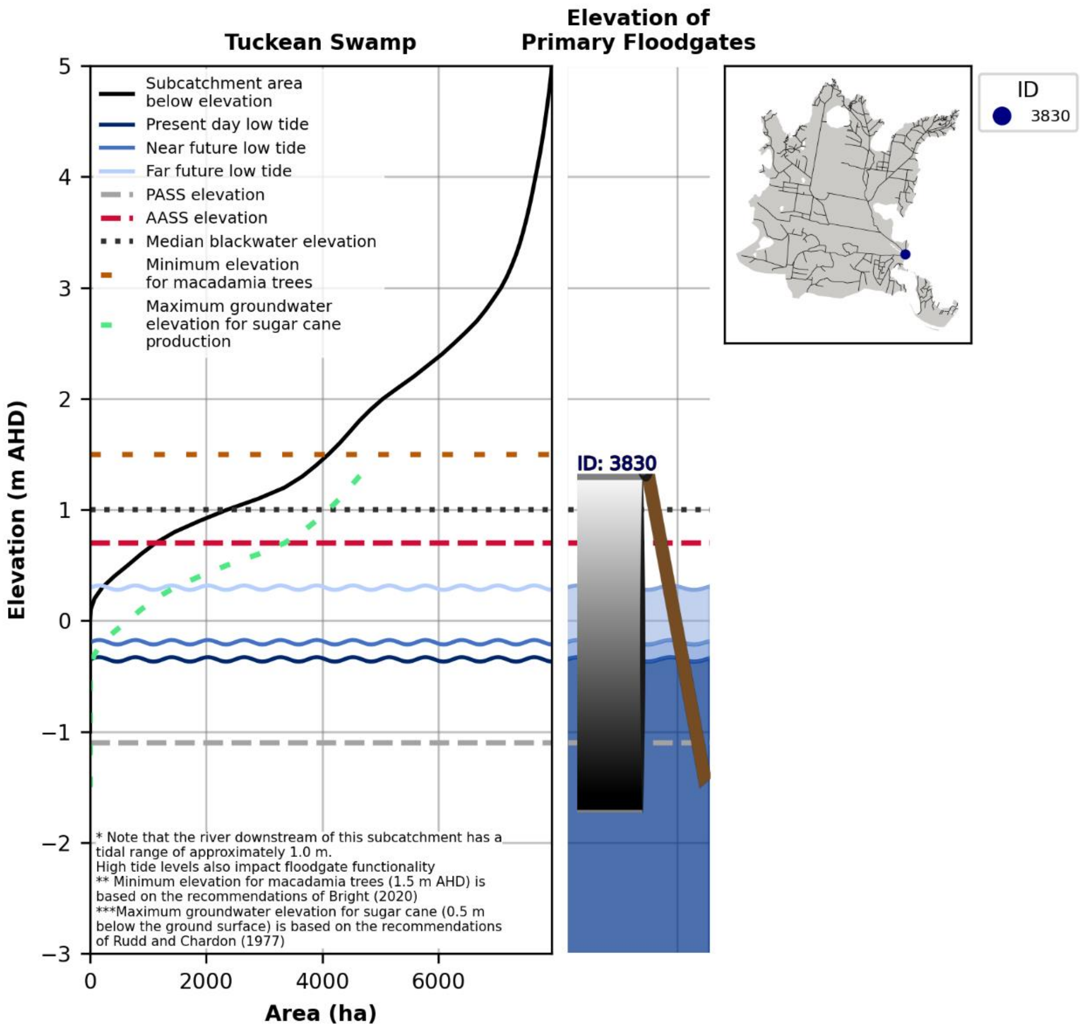

Figure 8-8: Primary floodgates and key floodplain elevations - Tuckean Swamp subcatchment

8.3.5 Management options

The prioritisation indicates that the Tuckean Swamp subcatchment accounts for approximately 45% of the acid risk in the Richmond River floodplain, more than twice as much as the second highest ranked ASS subcatchment. The Tuckean Swamp subcatchment ranks third in the Richmond River floodplain for blackwater generation risk, contributing to 11% of the risk to the overall floodplain. Combined, these highlight the scale of the water quality issues originating from this subcatchment. Strategies in the short term to improve water quality will continue to require a tailored approach so that they do not impact present day land uses, however, these strategies are likely to only have modest outcomes. To effectively minimise the acid and blackwater risks in the Tuckean subcatchment, broadscale changes in land and water management would be required. Effective and large-scale remediation of the Tuckean Swamp subcatchment would achieve the most significant improvements in estuarine health in the Richmond River and marine estate compared to any other single subcatchment. However, any remediation must be done with extensive involvement of existing landholders and consideration of potential social and economic impacts.

Short-term management options

RCC currently operates an active floodgate management plan for the major floodplain infrastructure in the Tuckean Swamp subcatchment, with the cooperation of local landholders. On-going management of these gates improves flushing and encourages natural buffering of acidic discharges from the lower floodplain during dry conditions, as well as providing some connectivity with the wider estuary for fish passage. Effective management of the existing floodgate infrastructure, as well as engagement with local landholders should be continued to assist in managing chronic acidic discharges during extended dry periods. However, it is important to recognise that the present management of this infrastructure will not prevent or even reduce large scale acid and blackwater discharges from the Tuckean Swamp subcatchment.

A summary of the short-term management options for Tuckean Swamp is provided in Table 8.4.

Long-term management options

This subcatchment includes some of the lowest elevation topography on the Richmond River floodplain. It is an area that is likely to be increasingly affected by reduced drainage due to sea level rise, and it is expected that many of the lowest areas will remain inundated due to higher low tide water levels in the near-to-far future. Present day land use and agricultural productivity may be affected by sea level rise, and options for the restoration of natural hydrology should be considered in high priority areas. On-going agricultural land uses can continue in higher areas identified as low priority although improved farm management practices (such as liming and avoiding over drainage) should be actively encouraged and supported.

The long-term management of this area is likely to include a range of strategies that can be implemented in parallel or opportunistically if reduced drainage impacts present day land uses. Potential long-term management options for Tuckean Swamp may include:

- Reshaping of major drains;
- Restoration of natural freshwater hydrology in the upper sections of Tuckean Swamp to remediate acid scalds and promote water tolerant vegetation to reduce blackwater generation potential. By increasing the time of inundation, carbon cycle processes that occur when organic

matter decomposes would be able to be completed, which would substantially reduce the generation potential of blackwater; and

- Increased tidal flushing and restoration of natural estuarine hydrology in the downstream areas of the subcatchment to reduce acid drainage during dry periods, reduce the potential for blackwater generation and create extensive intertidal habitats benefiting both terrestrial and aquatic ecology.

A summary of potential management options for Tuckean Swamp is provided in Table 8.4.

Table 8.4: Summary of management options for Tuckean Swamp

Timeframe	Strategy	Effectiveness at improving:		
		Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Floodgate management	Small	Low	Negligible
Long-term	Restore freshwater hydrology	None	Moderate	High
Long-term	Restore estuarine hydrology	Very high	High	Moderate

8.4 Rocky Mouth Creek subcatchment

Acid priority rank:	**2**
Blackwater priority rank:	**2**
Infrastructure	
Approximate waterway length (km)	85
# Privately owned end of system structures	1
# Publicly owned end of system structures	14
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (ID):	1530
Elevations	
Invert of primary floodplain infrastructure (m AHD):	-2.4
Approximate AASS elevation (m AHD)	0.6
Approximate PASS elevation (m AHD)	N/A
Median blackwater elevation (m AHD)	1.5
Present day low water level (m AHD)	-0.27
Near future low water level (m AHD)	-0.11
Far future low level (m AHD)	0.38
Proximity to sensitive receivers	
Oyster leases (km)	31.9
Saltmarsh (km)	28.0
Seagrass (km)	35.7
Mangroves (km)	0.2
Coastal Management SEPP coastal wetlands (km)	9.5
Land use	
Total floodplain area (ha)	3,805
Classified as conservation and minimal use (ha (%))	422 (11%)
Classified as grazing (ha (%))	1,364 (36%)
Classified as forestry (ha (%))	0 (0%)
Classified as sugar cane (ha (%))	972 (26%)
Classified as horticulture (ha (%))	2 (0%)
Classified as other cropping (ha (%))	54 (1%)
Classified as urban/industrial/services (ha (%))	127 (3%)
Classified as marsh/wetland (ha (%))	807 (21%)
Other (ha (%))	56 (1%)
Land values	
Estimated total primary production value ($/year)	$2,500,000
Average land value above 1.5 m AHD ($/ha)	$6,700
Average land value below 1.5 m AHD ($/ha)	$4,300

8.4.1 Site description and brief history of drainage

Rocky Mouth Creek joins the Richmond River at Woodburn (Tulau, 1999b) and is shown in Figure 8-9. In 1965, six (6) floodgates were installed in an artificially straightened section of creek, 4 km upstream of the confluence with the Richmond River to prevent inundation of the land behind the floodgates (Rous County Council, 2018). This was completed to prevent inundation of low-lying land behind the floodgates (see Figure 8-10).

The creek is connected to the upper Evans River through an artificial canal, the Tuckombil Canal, which was built in 1895 (Rous County Council, 2018). The artificial canal is located downstream of the Rocky Mouth Creek floodgates and in the past had an inflatable barrier, known as a fabridam, to avoid the influx of saline waters from the Evans River into the Rocky Mouth Creek. The fabridam was replaced by a concrete weir in 2001 (Rous County Council, 2018).

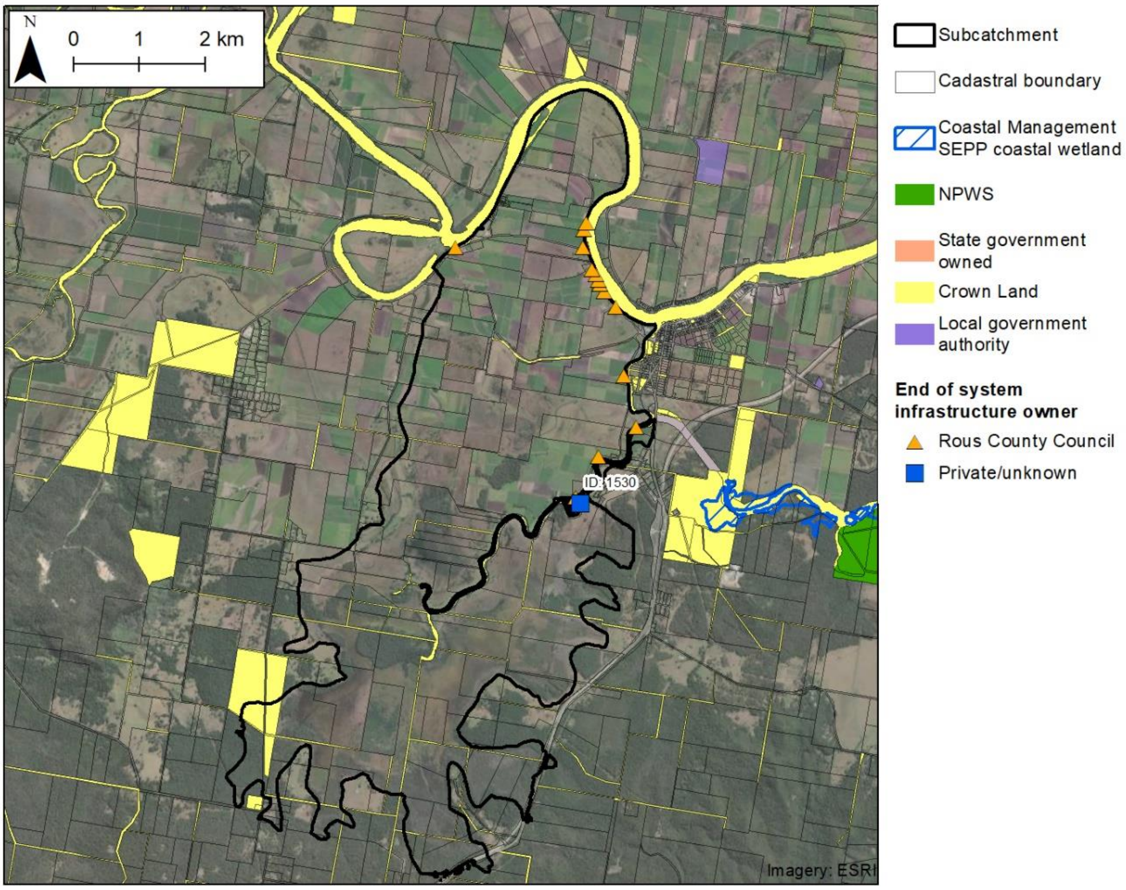

Figure 8-9: Rocky Mouth Creek subcatchment land and drainage infrastructure tenure

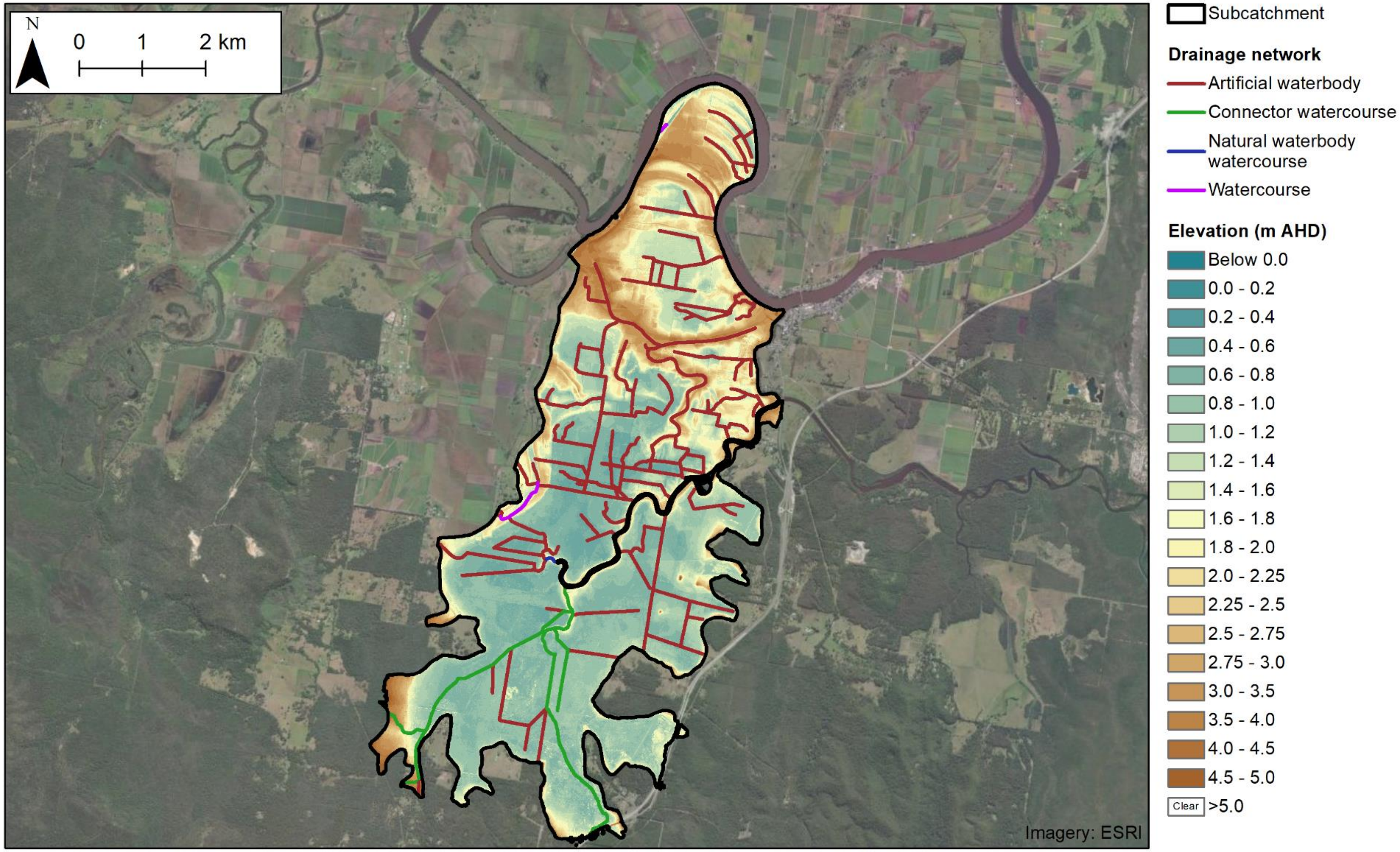

Figure 8-10: Rocky Mouth Creek subcatchment elevation and drainage network

8.4.2 History of remediation

Rous County Council (RCC) (and formerly Richmond River Country Council (RRCC)), in conjunction with local landholders, have been actively managing and remediating the Rocky Mouth Creek subcatchment since 1985. This includes the active management of the Rocky Mouth Creek floodgates (floodgate ID 1530, location shown in Figure 8-11). A brief timeline of the management of these gates is listed below, based on Rous County Council (2018), and Tulau (1999b):

- 1965 – The main floodgates were installed and the creek straightened to reduce flood impacts. The natural creek alignment was disconnected;
- Prior 1985 - Rocky Mouth Creek floodgates were opened to flush the upstream area of acid. After 1985, the Tuckombil fabridam wore out and a temporary sheet piling coffer dam was put in place until 1988, when the structure was removed. The Rocky Mouth Creek floodgates remained closed to prevent the intrusion of the salt water from the Evans River during this period;
- 1994 - A new fabridam was installed and a temporary part-opening of the gates was trialled to renew tidal flushing to the upstream reaches of Rocky Mouth Creek;
- 1995 - A formal active management plan for the Rocky Mouth Creek floodgates was established in 1995, to encourage the floodgates to be open in non-flood periods;
- 1998 to 2001 – The Tuckombil fabridam failed a number of times, requiring Rocky Mouth Creek floodgates to be closed during this period to prevent saltwater intrusion;
- 2001 – Following the failure of the Tuckombil fabridam, a fixed weir was installed on Tuckombil Canal, preventing saltwater connectivity between Rocky Mouth Creek and the Evans River;
- 2001 to present – Active management of the gates by the RCC ensures that all six (6) floodgates are winched open during non-flood periods. The gates are lowered when heavy rainfall or flooding is predicted to prevent backwater flooding of the Rocky Mouth Creek subcatchment; and
- 2013 – After a blackwater event caused the death of 1,000 fish in one section of Rocky Mouth Creek, construction of an emergency fish passage was completed. An escape channel was constructed through the earthen embankment of an end section of the creek and a 1.2 m diameter floodgated culvert was installed (see Figure 8-12 and Figure 8-13). This floodgate is actively managed alongside the main Rocky Mouth Creek floodgates.

Since the early 2000's, Rocky Mouth Creek has also been remediated by DPI Fisheries (with the assistance of RRC and local landholders) with funding from the North Rivers Catchment Management Authority (NRMCA) and NSW Government Environmental Trust Grants. While the exact location of these works are unknown, the works have included (Rous County Council, 2018):

- 2005 – Laser levelling of 80 ha of cane land in the north-west of the catchment, and reshaping or removal of 2.5 km of drains in the same area. While the location of this is not certain, it is assumed to be in the northern section of management area RMC3 (Figure 8-11);
- 2005 – Four (4) sluice windows installed on private floodgates on cane land to improve flushing; and
- 2007 – Four (4) drop board weirs installed in major private drains in the south-eastern section of the catchment. While the location of this is not certain, it is assumed to be in management area RMC4 (Figure 8-11).

There are also two (2) other floodgates (floodgate ID 1650 and 1630) in the Rocky Mouth Creek subcatchment north of the Woodburn-Coraki Road that have auto-tidal buoyancy gates installed to allow tidal flushing and connectivity for fish habitat.

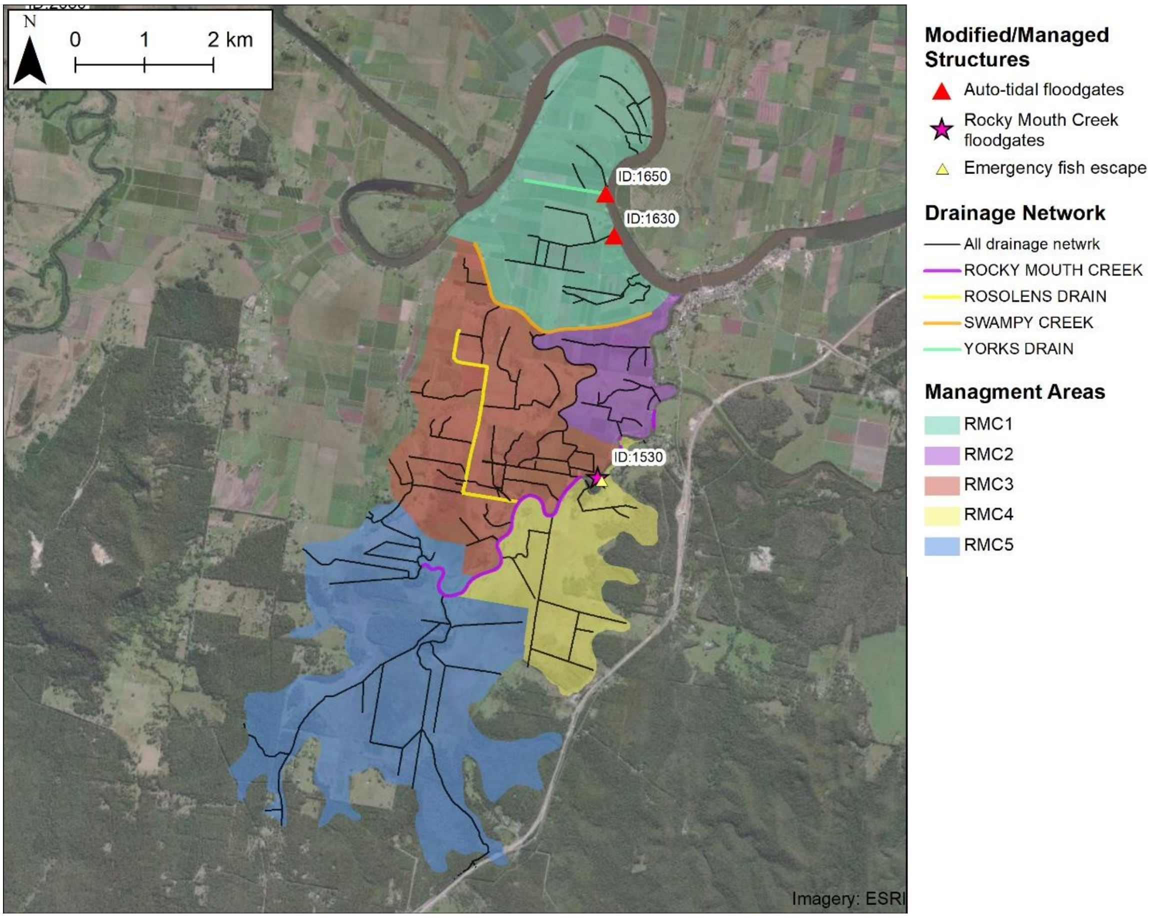

Figure 8-11: Rocky Mouth Creek subcatchment including previous remediation actions and further breakdown of management areas

Note additional remediation has been undertaken, although the location is uncertain, it likely included laser levelling and drain reshaping in RMC3 and drop board weirs in RMC4.

Sugar cane farms in the Richmond River floodplain operate in compliance with "The NSW sugar industry best practice guidelines for acid sulfate soils" (Sunshine Sugar, 2020). While details of specific drainage management on cane farms in the Rocky Mouth Creek subcatchment were not obtained (other than those mentioned above), cane farms typically:

- Laser level farms to reduce the drainage density required to allow surface water drainage;
- Construct new drainage works that are designed to minimise the interaction with acidic soils; and
- Complete extensive liming.

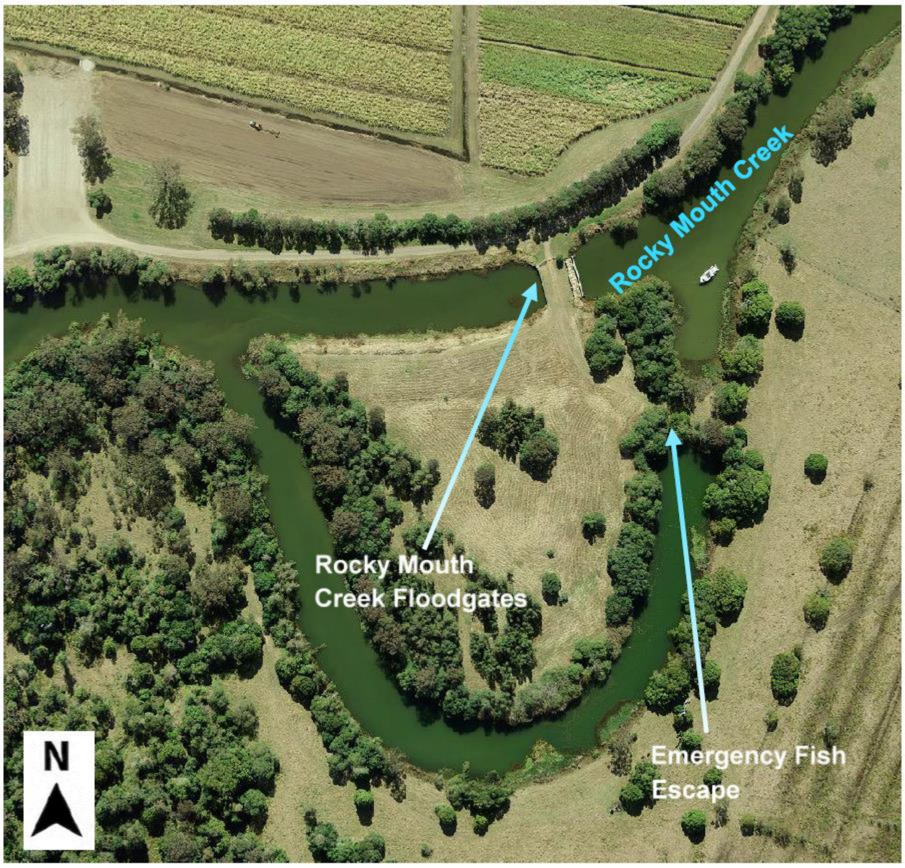

Figure 8-12: Aerial location of Rocky Mouth Creek floodgates and emergency fish escape (Rous County Council, 2018)

Figure 8-13: Rocky Mouth Creek emergency fish escape (Rous County Council, 2018)

8.4.3 Prioritisation of management areas in the Rocky Mouth Creek subcatchment

Rocky Mouth Creek ranked second in the acid prioritisation, and second in the blackwater prioritisation, indicating that it is overall a high priority for remediation. The Rocky Mouth Creek subcatchment has been further delineated into five (5) smaller management areas (referred to as RMC1 – RMC5, shown in Figure 8-11) to provide additional information on the sources of acid and blackwater. These areas have been delineated based on data availability, topography, soil acidity and drainage connectivity.

The management areas have been prioritised for acid generation using the method described in Section 4.2. The results of the acid prioritisation for the management areas of Rocky Mouth Creek are shown in Figure 8-14 and Table 8.5. Due to the limited availability of soil profile data across all management areas, the groundwater factor cannot be calculated in RMC3 and RMC2. However, Table 8.5 shows that RMC3 has the second highest surface water factor, while RMC2 has the lowest. Figure 8-10 also shows that the topography in management area RMC2 is relatively high (similar to RMC1), while RMC3 is low and appears to be highly connected to RMC5. As a result, it is assumed that RMC2 is likely to be low priority, while RMC3 is more likely to be moderate-to-high priority. This assumption has been used to guide development of the subcatchment management options (Section 8.4.5).

Figure 8-15 shows the management areas at Rocky Mouth Creek with respect to the median elevation for blackwater generation (1.5 m AHD). Due to the higher elevations in management areas RMC1 and RMC2, these areas are considered a lower risk for the generation of blackwater. The majority of the blackwater risk comes from areas that drain into Rocky Mouth Creek upstream of the main floodgates (RMC3, RMC4 and RMC5).

Based on Figure 8-14 and Figure 8-15 (and assumptions on acid generation in areas with incomplete data), it is suggested that remediation in the Rocky Mouth Creek subcatchment focus on management areas RMC3, RMC4 and RMC5.

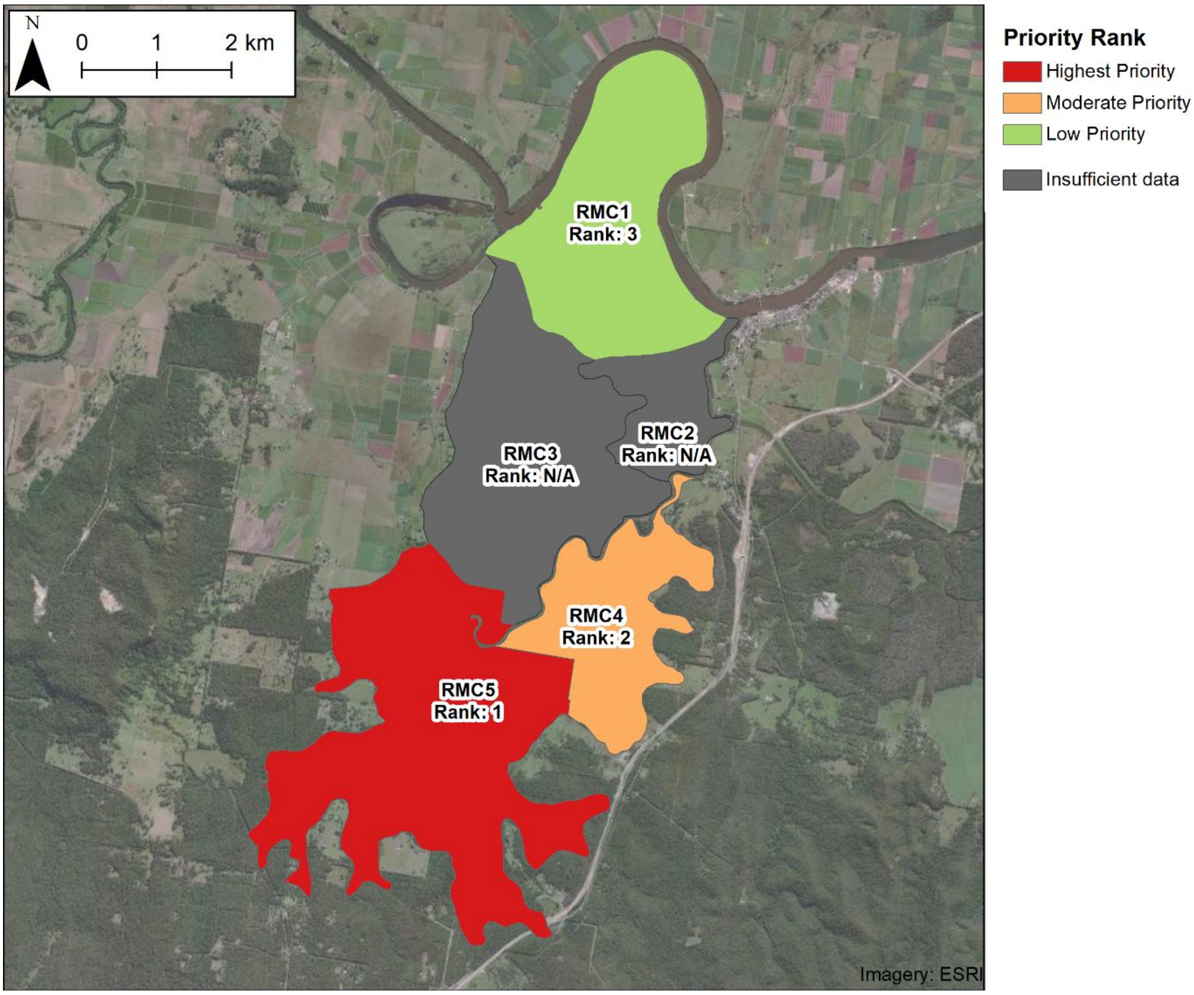

Figure 8-14: Rocky Mouth Creek subcatchment management areas acid prioritisation

Table 8.5: Management area acid prioritisation of Rocky Mouth Creek subcatchment

Management Area	Groundwater Factor	Surface Water Factor	Final Acid Factor	Final Management Area Rank
RMC5	640	1,106	707,213	1
RMC4	860	140	120,165	2
RMC1	153	163	25,012	3
RMC3	Insufficient data	311	Insufficient data	N/A
RMC2	Insufficient data	79	Insufficient data	N/A

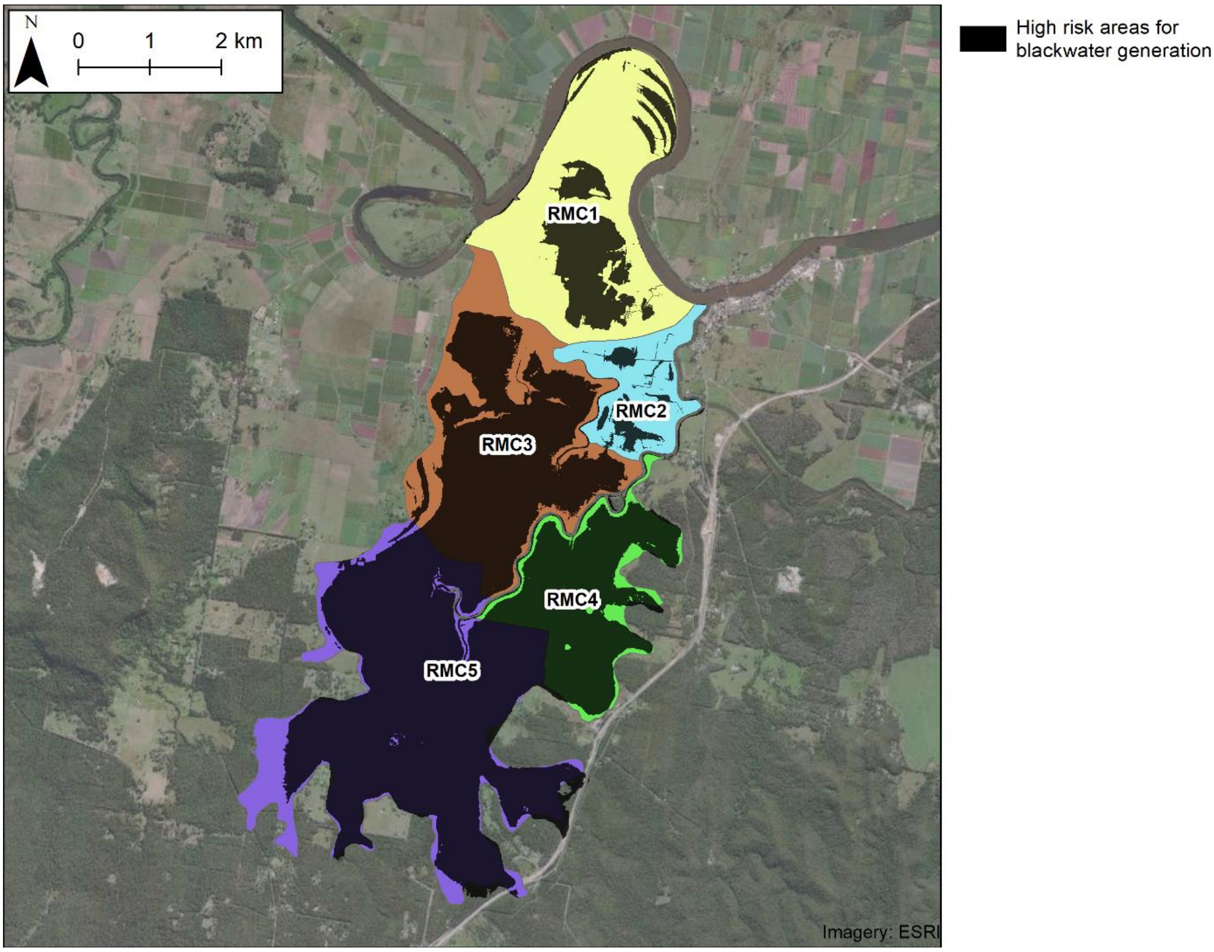

Figure 8-15: High risk areas for blackwater generation in management areas in Rocky Mouth Creek subcatchment (median blackwater elevation 1.5 m AHD)

8.4.4 Floodplain drainage – sea level rise vulnerability

Figure 8-16 summarises the climate change vulnerability assessment of the Rocky Mouth Creek subcatchment. Presently, the majority of the floodplain is not considered vulnerable to reduced drainage (e.g. below the 95th percentile downstream water level), however this will change under predicted near and far future sea level rise scenarios. The lowest areas of the subcatchment are likely to be affected by reduced drainage due to sea level rise in the near future, and this will be extended to the majority of the southern portion of the floodplain in the far future. This includes a substantial area that will become considered as moderate risk to reduced drainage in the far future. The management areas RMC1 and RMC2 are higher than the remainder of the subcatchment and may not be as severely affected by reduced drainage as a result of sea level rise.

The floodgates in the Rocky Mouth Creek subcatchment will also become increasingly vulnerable as sea level rise occurs, as shown in Figure 8-16 and Figure 8-17. Significantly, the Rocky Mouth Creek main floodgate (floodgate ID 1530) is considered most vulnerable in the far future, along with secondary floodgate 1660 which is most vulnerable in all scenarios. Five (5) other secondary floodgates are moderately vulnerable to sea level rise in the far future.

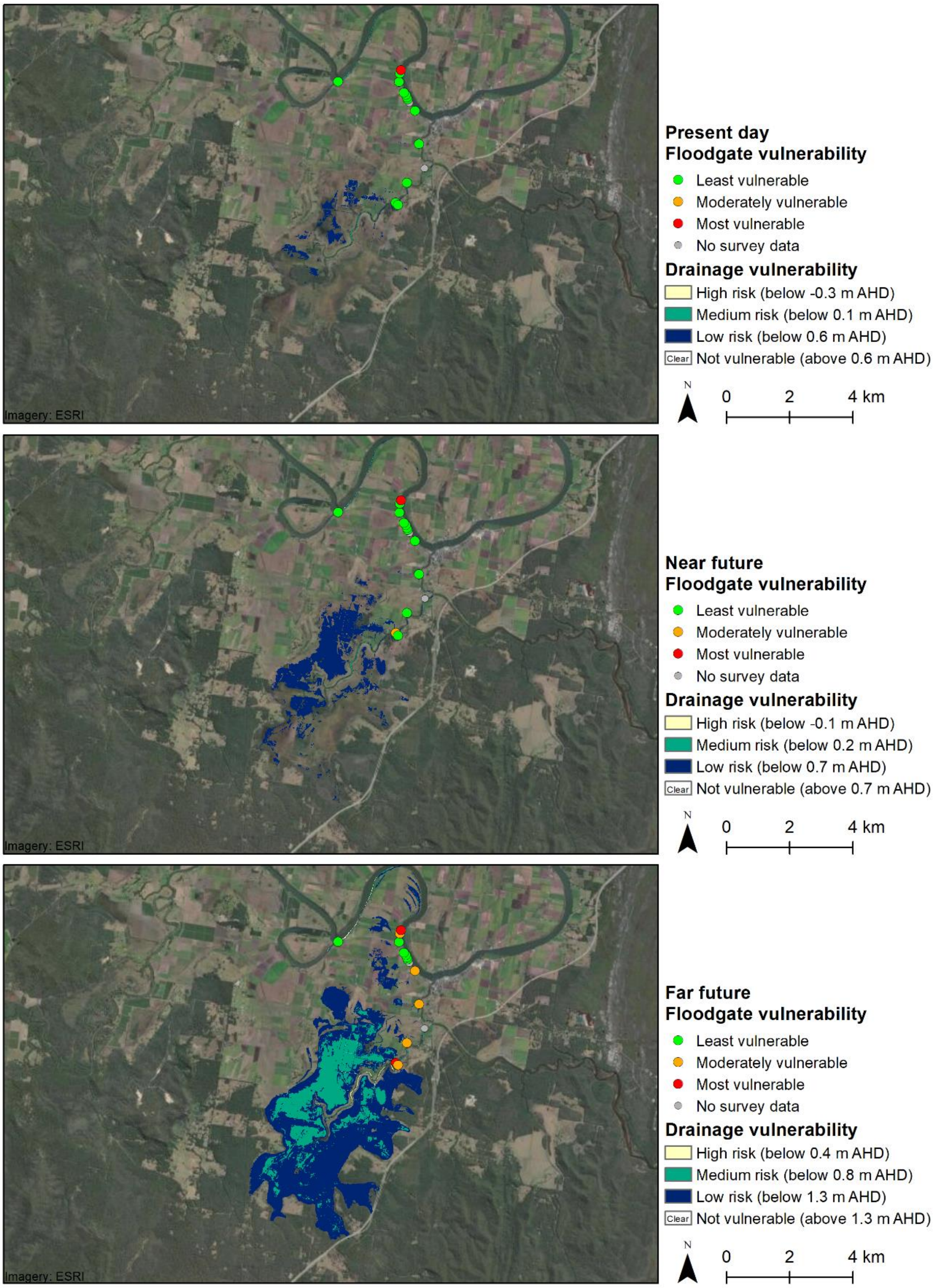

Figure 8-16: Sea level rise drainage vulnerability – Rocky Mouth Creek subcatchment

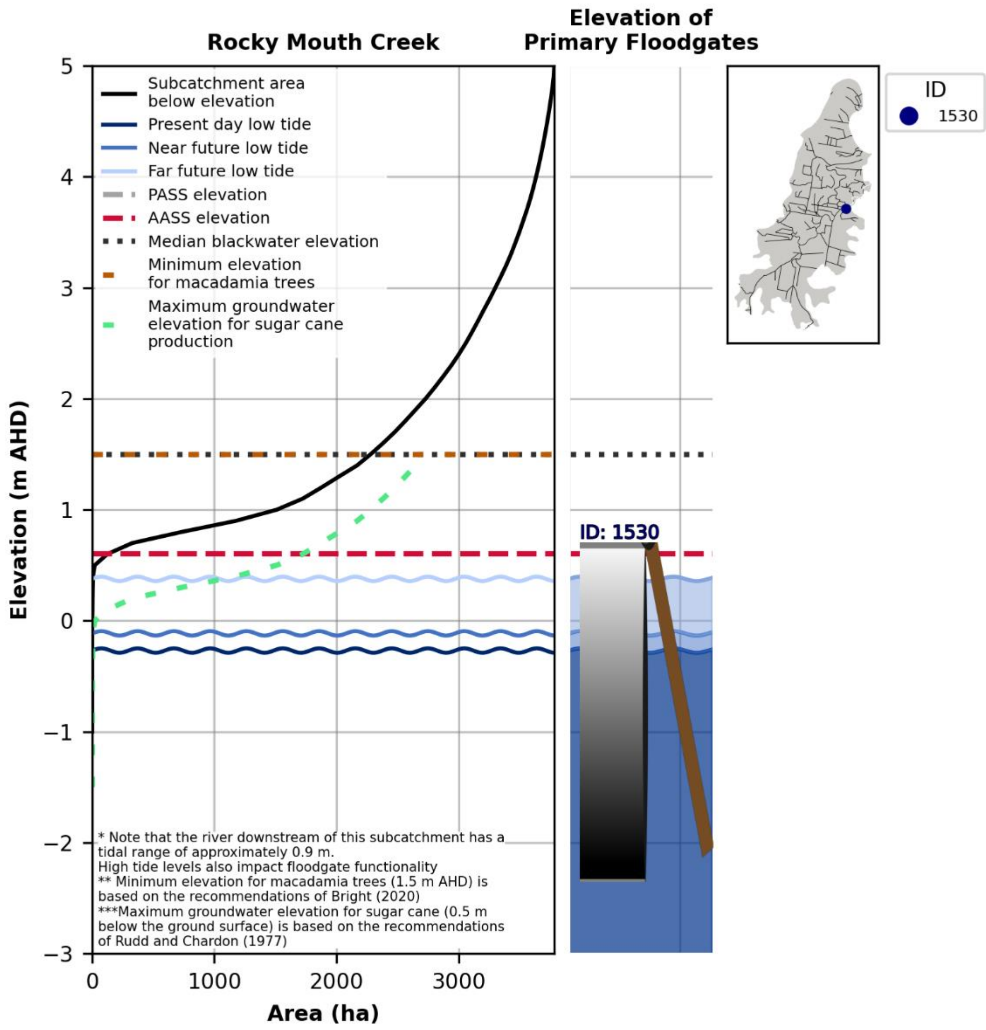

Figure 8-17: Primary floodgates and key floodplain elevations – Rocky Mouth Creek subcatchment

8.4.5 Management options

Short-term management options

The management of the Rocky Mouth Creek floodgates undertaken by RCC already provides substantial improvements in water quality through improved flushing, reduction in acid drainage, and also allows significant fish habitat to be connected to the main estuary. Opening the primary floodgates provides substantial benefits, and the continued active management of those gates should be maintained. Continued management of these gates with the cooperation of local landholders is essential to minimising poor water quality from this subcatchment and should be prioritised.

Historical remediation in the Rocky Mouth Creek subcatchment included drain infilling/reshaping in some parts of the subcatchment, and it is recommended that secondary drains are reviewed and assessed to determine if additional drains can be reshaped to reduce interaction with underlying acid soil layers and to prevent unnecessary groundwater drawdown. Ineffective drains should be infilled entirely where possible to reduce drainage density. Similarly, in grazing areas, use of drop board weirs on private drainage channels will increase the surface water and groundwater tables, thereby reducing acid discharge. Existing drop board structures should be assessed and optimised, and investigations for additional locations for weirs should be considered. Investigations must include the input of local landholders to ensure potential impacts to agricultural productivity can be effectively managed.

Long-term management options

Land uses in the low-lying backswamp areas upstream of the main Rocky Mouth Creek floodgates are likely to be impacted by reduced drainage due to sea level rise in the near-to-far future. As present day land uses become less productive, remediation of the natural hydrology of the lowest areas (below 1.5 m AHD) should be considered. Broadscale management changes in this subcatchment will need to consider, and have a plan to mitigate, potential social, cultural and economic impacts to local landholders. Restoration of natural hydrology may include:

- Infilling drains;
- Restoring natural levees and connectivity; and
- Allowing widespread freshwater inundation which would increase the time it takes for water to drain from the floodplain, allowing carbon cycle processes that occur when organic matter decomposes to complete and result in a significant reduction in poor water quality. A reduction in the rate and volume of runoff also provides a greater opportunity for the downstream estuary to assimilate blackwater discharges.

Table 8.6: Summary of management options for Rocky Mouth Creek subcatchment

Timeframe	Strategy	Effectiveness at improving: Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Installation of drop board weir structures	None	Moderate	Low
Short-term	Drain infilling/reshaping	None	Moderate	Negligible
Long-term	Restoration of natural hydrology	High	High	High

8.5 Bungawalbin Creek/Sandy Creek subcatchment

Acid priority rank:	**3**
Blackwater priority rank:	**1**
<u>Infrastructure</u>	
Approximate waterway length (km)	115
# Privately owned end of system structures	0
# Publicly owned end of system structures	19
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (ID):	1890, 1900, 1940, 1960, 1990, 2010, 2030, 2050
<u>Elevations</u>	
Invert of primary floodplain infrastructure (m AHD):	-1.0 to 0.2
Approximate AASS elevation (m AHD)	1.1
Approximate PASS elevation (m AHD)	-0.4
Median blackwater elevation (m AHD)	2.9
Present day low water level (m AHD)	-0.21
Near future low water level (m AHD)	-0.06
Far future low level (m AHD)	0.42
<u>Proximity to sensitive receivers</u>	
Oyster leases (km)	35.2
Saltmarsh (km)	31.3
Seagrass (km)	39.0
Mangroves (km)	9.8
Coastal Management SEPP coastal wetlands (km)	12.8
<u>Land use</u>	
Total floodplain area (ha)	10,801
Classified as conservation and minimal use (ha (%))	2,402 (22%)
Classified as grazing (ha (%))	4,405 (41%)
Classified as forestry (ha (%))	439 (4%)
Classified as sugar cane (ha (%))	807 (7%)
Classified as horticulture (ha (%))	57 (1%)
Classified as other cropping (ha (%))	509 (5%)
Classified as urban/industrial/services (ha (%))	139 (1%)
Classified as marsh/wetland (ha (%))	1,368 (13%)
Other (ha (%))	674 (6%)
<u>Land values</u>	
Estimated total primary production value ($/year)	$4,600,000
Average land value above 2.9 m AHD ($/ha)	$3,100
Average land value below 2.9 m AHD ($/ha)	$2,800

8.5.1 Site description and brief history of drainage

The Bungawalbin Creek/Sandy Creek subcatchment is situated in the mid-to-upper estuary and discharges into the Richmond River approximately 5 km downstream of Coraki and is shown in Figure 8-18. The subcatchment includes the town of Coraki and drains a large upstream catchment. Bungawalbin Creek alone drains an upstream catchment of 1,400 km^2, approximately 20% of the catchment of the greater Richmond River. Bungawalbin Creek has been identified as having high regional conservation value for river biodiversity (DECCW, 2010), and is considered as an important tributary for fish habitat in the Richmond River estuary. Note that the Richmond River at Sandy Creek has low-to-freshwater salinity levels for the majority of the time, with brackish salinities occurring occasionally during extended dry periods (Herold et al., 2021; Rayner et al., 2020b; Rayner et al., 2020c).

There are seven (7) main floodgates in the Bungawalbin Creek/Sandy Creek subcatchment, some of which have been modified to allow some tidal flushing (shown in Figure 8-20). This includes:

- Floodgate 1950 – which drains the natural waterway Boggy Creek. These gates were first installed in 1929 (Rous County Council, 2019a);
- Floodgate 1940 – draining Wades Canal, which is thought to have been constructed in the 1960s/70s (Rous County Council, 2019d);
- Floodgate 1960 – draining Haughwood Canal which was constructed in 1964 as major flood mitigation works (Rous County Council, 2019c);
- Floodgate 1980 – which drains Bora Creek, constructed in the 1960s through the levee that otherwise disconnected Bora Creek from Bungawalbin Creek for flood mitigation purposes;
- Floodgate 2030 – on Sandy Creek No. 1 drain which was installed in 1968 (although it is likely that it replaced a smaller, ad hoc structure at that time);
- Floodgate 2010 – on Sandy Creek No. 2; and
- Floodgate 2050 – on Seelim Canal.

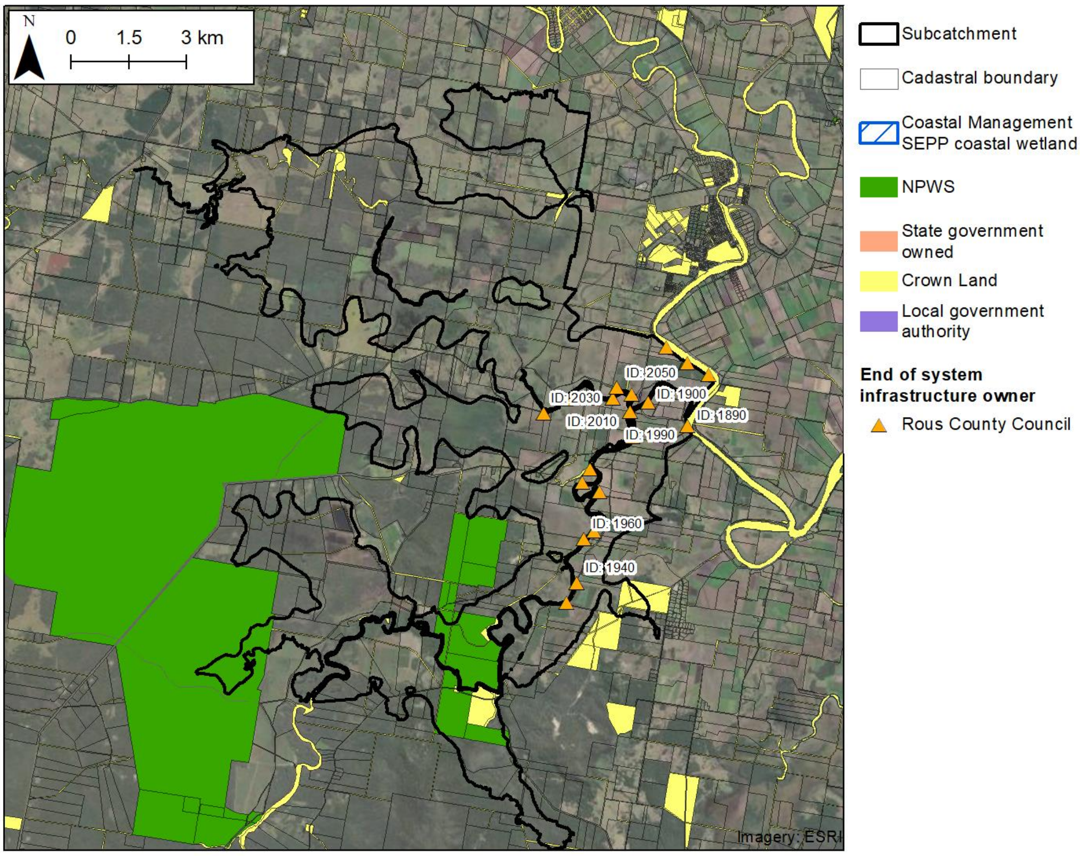

Figure 8-18: Sandy Creek subcatchment land and end of system infrastructure tenure

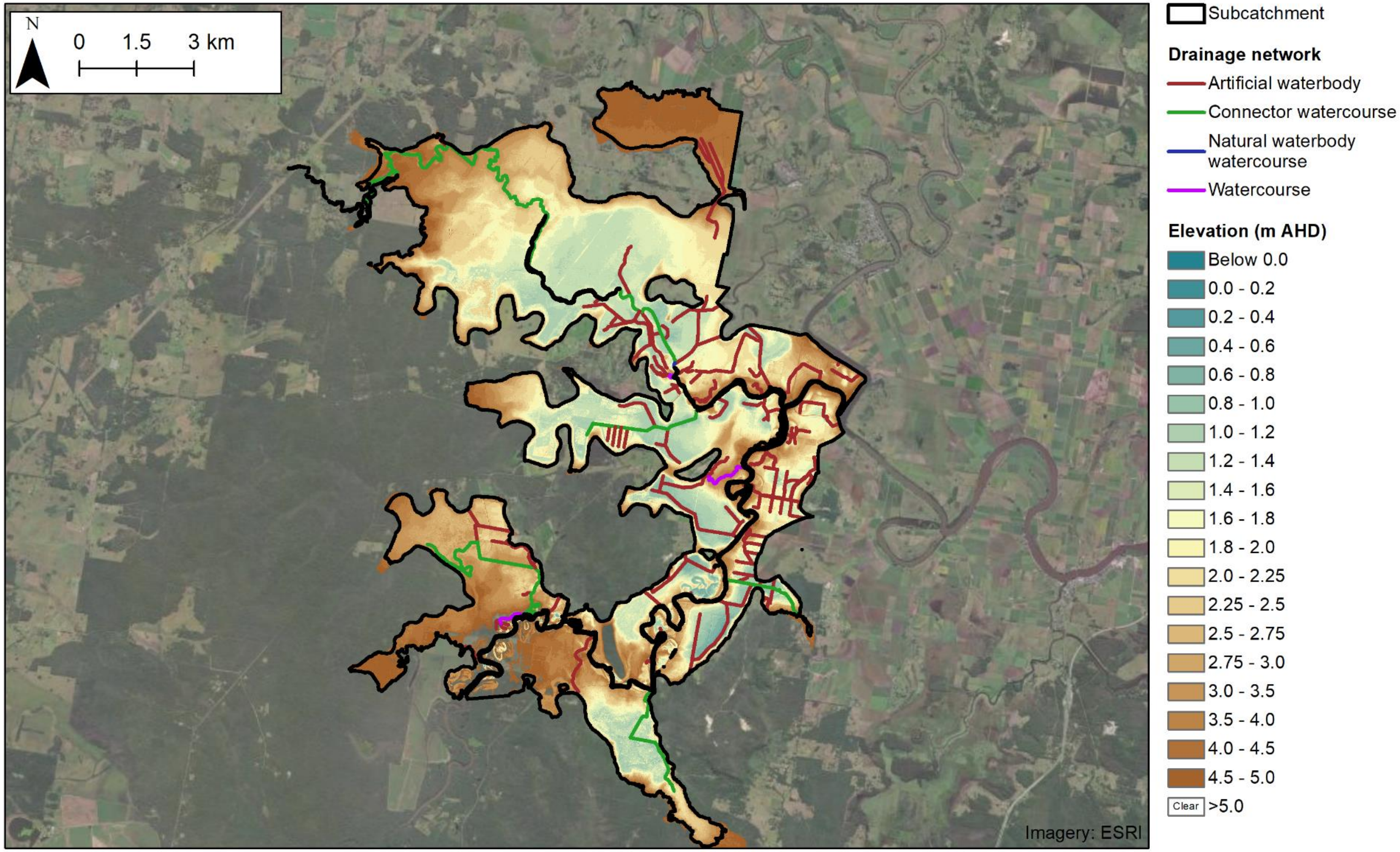

Figure 8-19: Sandy Creek subcatchment elevation and drainage network

8.5.2 History of remediation

There have been substantial remediation works in the Sandy Creek subcatchment to reduce acid and blackwater discharges from the area, summarised in Figure 8-20. The seven (7) main floodgates in Bungawalbin Creek/Sandy Creek subcatchment have been modified to allow tidal flushing, six (6) of which have detailed active floodgate management plans managed by RCC. These floodgates include:

- Floodgate 1950 on Boggy Creek - which has a sluice gate which is open in non-flood periods (Rous County Council, 2019a);
- Floodgate 1940 on Wades Canal - which has a sluice gate which is open in non-flood periods (Rous County Council, 2019d);
- Floodgate 1960 on Haughwood Canal - which has two sluice gates which are open in non-flood periods (Rous County Council, 2019c);
- Floodgate 1980 on Bora Gully – which is winched open entirely during non-flood periods (Rous County Council, 2019b);
- Floodgate 2050 on Seelim Canal - which has a sluice gate which is open in non-flood periods;
- Floodgate 2010 on Sandy Creek No. 2 - which has a sluice gate installed and managed by RCC; and
- Floodgate 2030 on Sandy Creek No. 1 - which has a sluice gate. The active floodgate management plan for this gate states that the sluice gate should be open when the area is not expecting or experiencing flooding to reduce the impact of acid drainage (Rous County Council, 2020d).

In addition to the management of floodgates, a number of weirs and drop board structures have been installed on Haughwood Canal, Boggy Creek and Wades Canal to maintain higher groundwater tables and reduced acid transport. The approximate locations of these structures are shown in Figure 8-20.

The weir on Haughwood Canal was constructed in 2003 by NSW Agriculture, in management area BSC1. A second weir was installed upstream, but has since been removed. In 2008, RRC reshaped the western half of Haughwood Canal, significantly shallowing and narrowing the drain with funding from Northern Rivers CMA. The eastern half of the drain was also reshaped by RCC in 2009. Stock exclusion fencing has also been erected along both sides of the drain (Rous County Council, 2019c). The works undertaken to date have resulted in a change in vegetation on the western half of the floodplain drained by Haughwood Canal towards native wetland species and a reduction in grazing productivity.

The structures on Boggy Creek include weirs and drop board structures that were installed between 2003 and 2016 with funding from NSW Agriculture, NSW Department of Primary Industry (Fisheries), Wetland Care Australia and North Coast Local Land Services and support from local land holders. There is presently support for the local land holders to maintain the structures to ensure continued functionality (Rous County Council, 2019a).

A drop board structure was also constructed on Wades Canal by NSW DPI (Fisheries) with support from NRCMA and local land holders to reduce acid drainage (Rous County Council, 2019d).

The area drained by the Sandy Creek No 1 drain (floodgate ID 2030), referred to as management area BSC3 in Figure 8-20, is recognised as having chronic issues with acidic discharges and contributes to blackwater drainage after flooding (Rous County Council, 2020d). To address these issues, Rous

County Council has completed a series of on-ground works with local landholders to increase surface water and groundwater tables in the management area. This includes:

- Installation of three (3) weirs in the western portion of the management area BSC1 in 2006;
- A large rock weir installed 40 m upstream of the main floodgate (ID 2030) in 2008, which allows larger tides to still flow into the drainage system, but limits low tide drainage. This weir was topped up in 2014 after it had eroded; and
- Drainage density has been reduced and drains were swaled in 2006 in the western portion of the management area. The exact location of this work is not clear, however it appears to have been in the area west of the three (3) weirs on the upstream section of Sandy Creek No. 1 drain. Rous County Council (2020d) suggests that this has resulted in a shift in vegetation towards native wetland species and reduced acid scalds, however it has also greatly reduced agricultural productivity.

RCC (and formerly RRCC) have also been implementing remediation works in the upper Sandy Creek area, referred to as management area BSC1 in Figure 8-20, particularly with respect to the drainage of Kookami Swamp which is recognised as an acid and blackwater hotspot (Richmond River County Council, 2014). The main rock weir (shown in green in Figure 8-20 and Figure 8-21) was built in 2013 with support from local landholders, RRCC and Local Land Services, resulting in the water table being approximately 300 mm higher (Richmond River County Council, 2014). Three (3) other weirs/drop board structures were constructed in the lower sections of management area BSC1 through funding from Wetland Care Australia. Another drop board structure was also observed by WRL during site inspections in the upper section of management area BSC1 (the most northern yellow structure in Figure 8-20). Another water control structure was also constructed within Kookami Swamp by DPI – Agriculture in 2007 (p. comms, C. Clay 02/06/2021). Works undertaken in this management area have generally targeted higher water tables to encourage water tolerant vegetation to flourish and reduce acid drainage by maintaining higher groundwater tables. However, RCC has indicated that the water control structures in BSC1 typically only hold water back immediately following flood events, and have limited effectiveness maintaining high water levels in the medium to long term (p. comms C. Clay 02/06/2021).

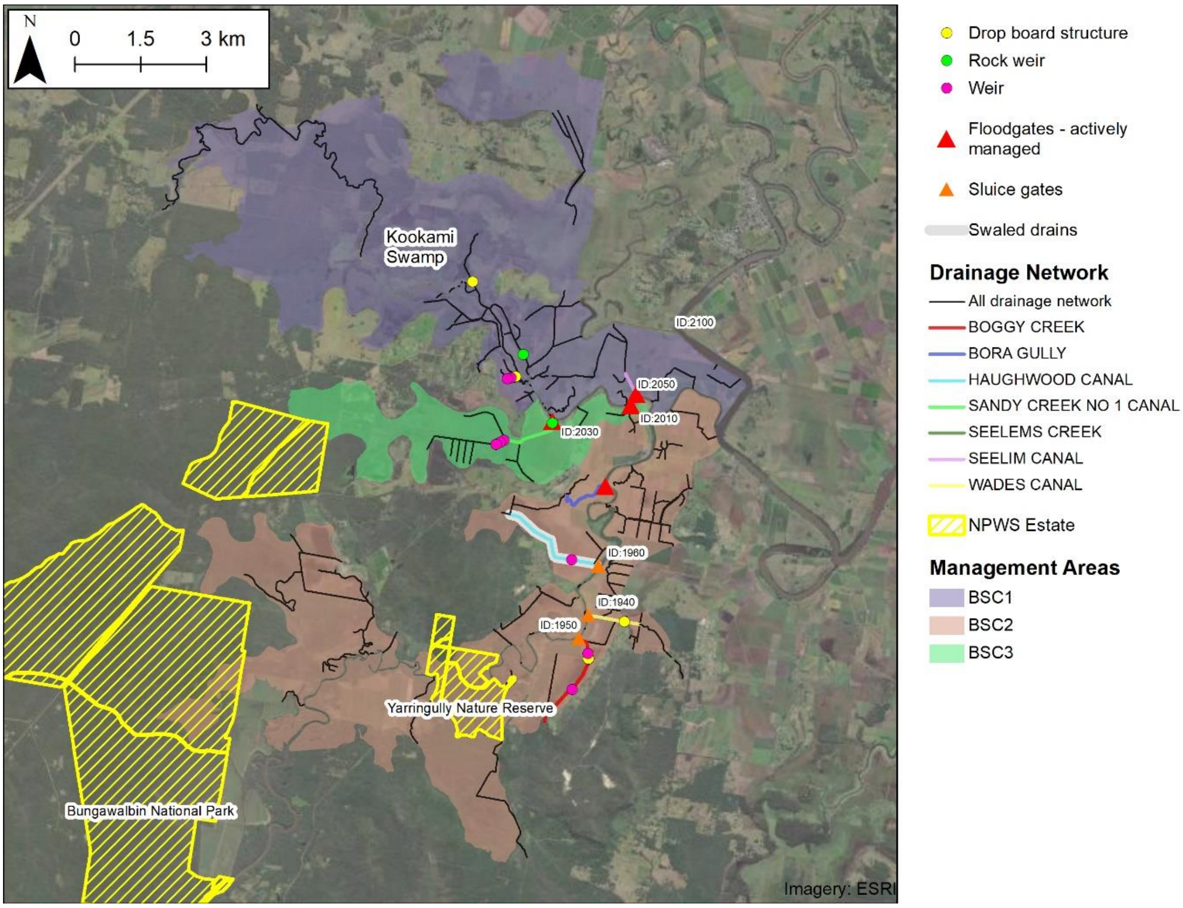

Figure 8-20: Sandy Creek subcatchment including previous remediation actions and further breakdown of management areas

Figure 8-21: (left) Major rock weir at the downstream discharge point of Kookami Swamp (Source: Richmond River County Council (2014)) (right) drop board structure observed by WRL further upstream

8.5.3 Prioritisation of management areas in Bungawalbin Creek/Sandy Creek subcatchment

The Bungawalbin Creek/Sandy Creek subcatchment ranked third for acid generation and first for blackwater generation, indicating that it is a high priority for remediation. The subcatchment has been further divided into three (3) management areas (referred to as BSC1, BSC2 and BSC3, shown in Figure 8-20) to provide additional information on the sources of acid and blackwater. The areas have been delineated based on 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 4.2. The results of the acid prioritisation for the management areas of the Bungawalbin Creek/Sandy subcatchment are shown in Figure 8-22 and summarised in Table 8.7. The two highest ranked management areas, BSC2 (Bungawalbin Creek) and BSC3 (Sandy Creek No. 1) were found to be of very similar risk for acid generation in this subcatchment.

Figure 8-6 shows the management areas in the Bungawalbin Creek/Sandy subcatchment below the median elevation for blackwater generation (2.9 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). All three management areas have a high capacity to generate blackwater, although it should be noted that natural water tolerant vegetation in Kookami Swamp is likely to decrease blackwater generated from BSC1.

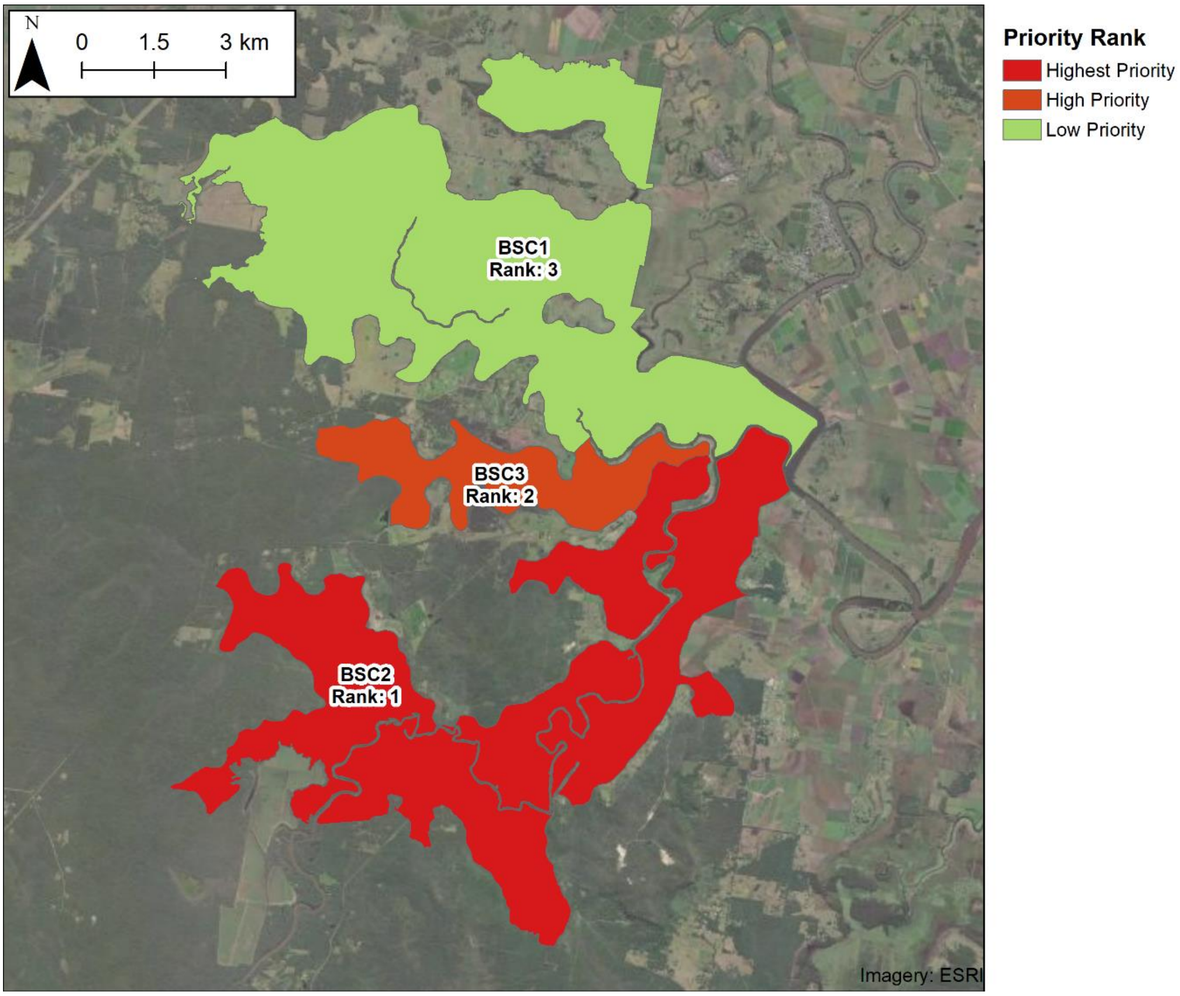

Figure 8-22: Bungawalbin Creek/Sandy Creek subcatchment management areas acid prioritisation

Table 8.7: Management area acid prioritisation of Bungawalbin Creek/Sandy Creek subcatchment

Management Area	Groundwater Factor	Surface Water Factor	Final Acid Factor	Final Rank
BSC2	367	779	285,556	1
BSC3	568	483	274,311	2
BSC1	237	498	118,011	3

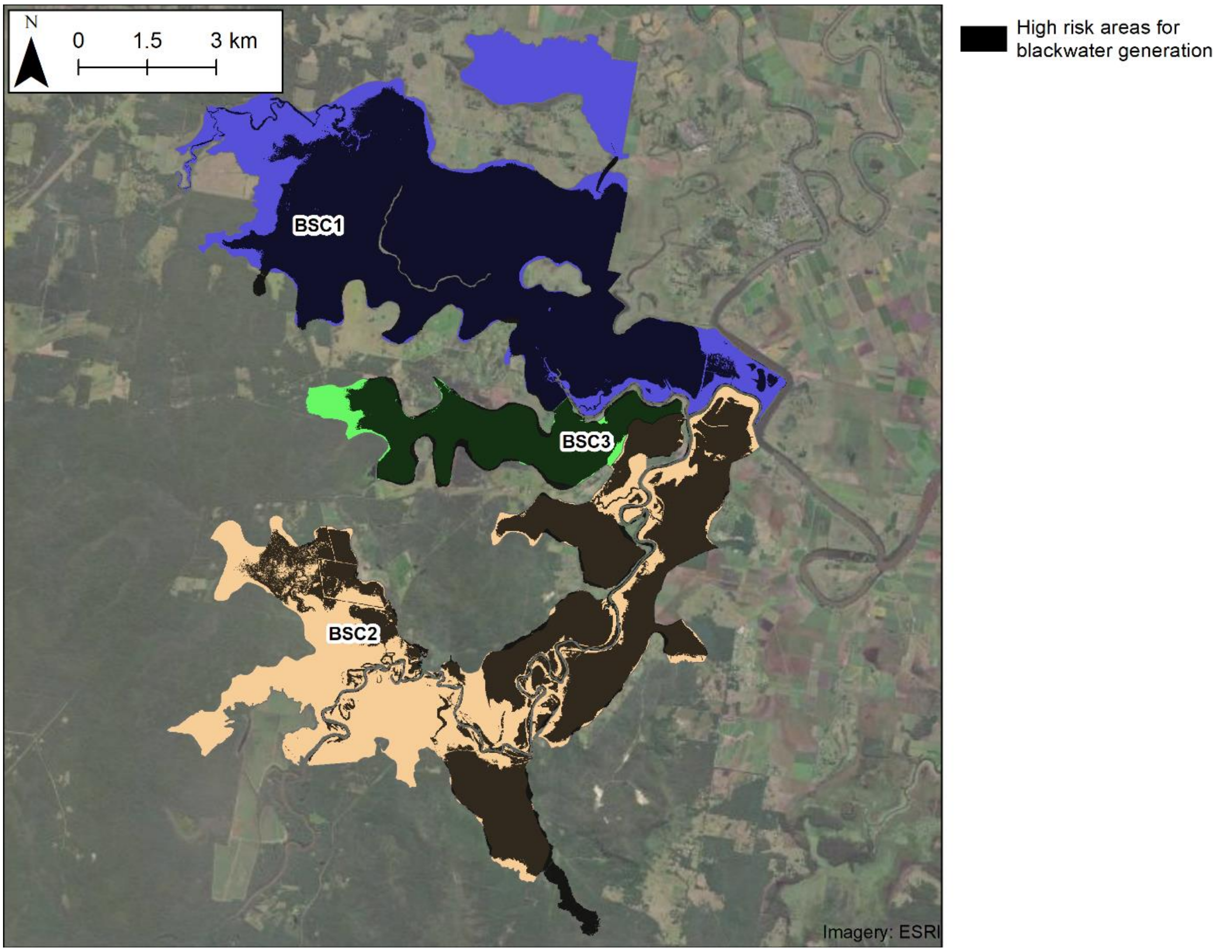

Figure 8-23: High risk areas for blackwater generation in management areas in Bungawalbin Creek/Sandy Creek subcatchment (median blackwater level 2.9 m AHD)

8.5.4 Floodplain drainage – sea level rise vulnerability

The floodplain and floodgate vulnerability assessment of the Bungawalbin Creek/Sandy Creek subcatchment is summarised in Figure 8-24. The subcatchment is mostly above 1 m AHD and will only begin to be impacted by reduced drainage under the far future sea level rise scenario. Similarly, the floodgates in the area are generally large and only one (1) of the floodgates is predicted to become moderately vulnerable in the near future (floodgate ID 1890, shown in Figure 8-25). This structure is also predicted to become most vulnerable in the far future. Reduced drainage may impact the lowest elevation area of this subcatchment in the far future. This analysis of sea level rise vulnerability does not consider increased risk related to flood events, which may impact the Bungawalbin Creek/Sandy Creek subcatchment.

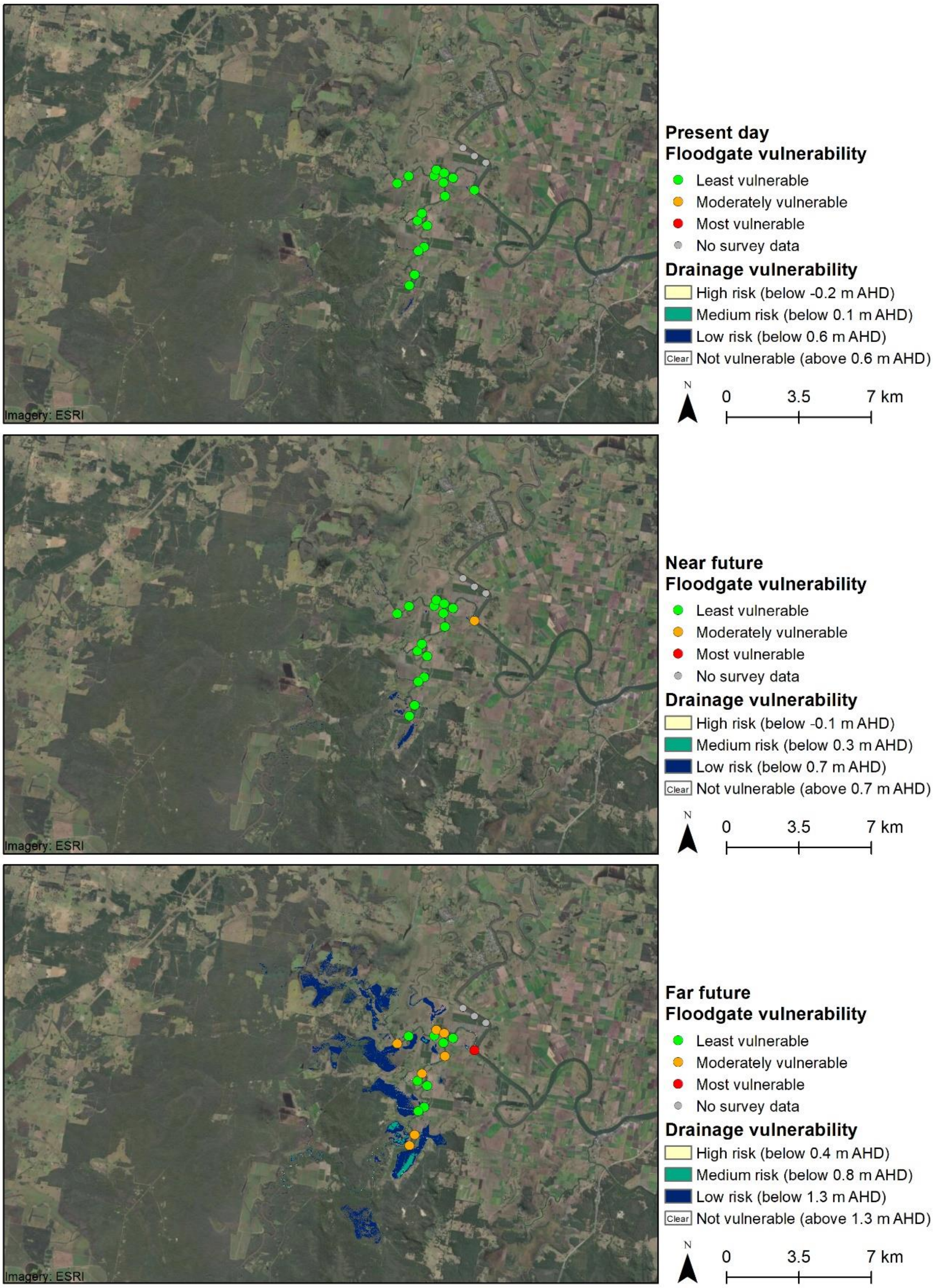

Figure 8-24: Sea level rise drainage vulnerability – Bungawalbin Creek/Sandy Creek subcatchment

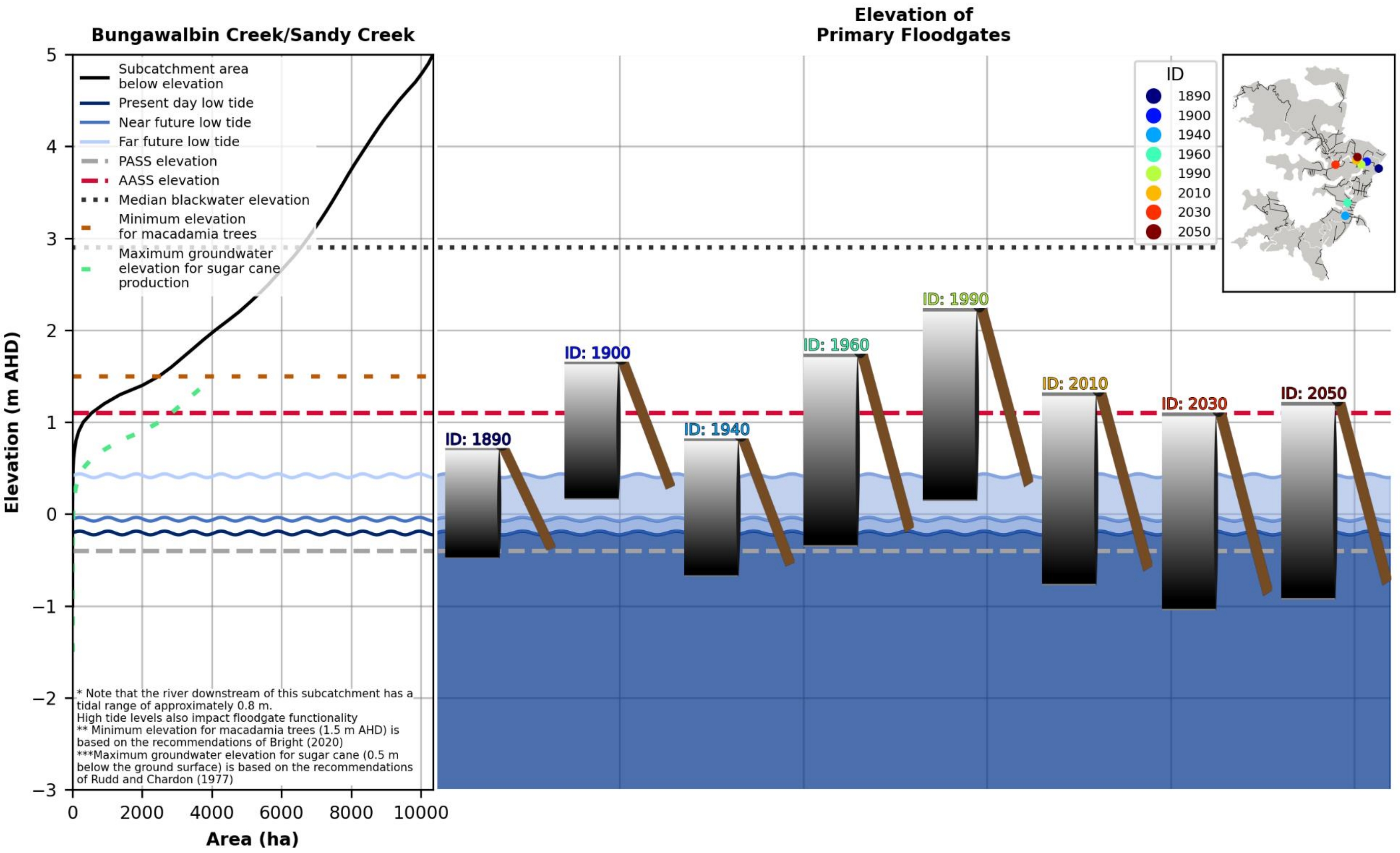

Figure 8-25: Primary floodgates and key floodplain elevations – Bungawalbin Creek/Sandy Creek subcatchment

8.5.5 Management options

Short-term management options

As discussed in Section 8.5.2, RCC and local landholders have been actively remediating the Bungawalbin Creek/Sandy Creek subcatchment since the early 2000s. At this stage, the majority of the work within management area BSC2 (with the exception of Haughwood Canal) has focussed on installing weirs and drop board structures that increase the groundwater table and reduce acid drainage. However, the impact of these structures on reducing blackwater generation is limited. The drain reshaping in Haughwood Canal (BSC2) to be shallower and narrower (reducing its efficiency) resulted in a change in the floodplain vegetation towards more water tolerant native species which would have reduced blackwater risk, but has also negatively impacted the agricultural productivity. These changes in agricultural productivity limits the ability to implement a drain reshaping and wet pasture management strategy elsewhere without willingness and/or compensation for local landholders.

In management area BSC3, the works done to date are designed to reduce acid and blackwater discharges while allowing agricultural use and productivity to continue. Continued maintenance of the existing structures is recommended (such as ensuring rock weirs do not become eroded).

In management area BSC1, remediation works have included the installation of a number of rock weirs and drop board weir structures. In this area, expanding the present strategy of working with individual landholders to allow paddock scale retention of freshwater, such as drop board weirs is recommended to encourage more water tolerant vegetation within the management area. However, it is acknowledged that the implementation of such structures may be difficult in this area, as wet pasture management has not previously been successful at maintaining agricultural productivity.

The existing management in the Bungawalbin Creek/Sandy Creek subcatchment has involved significant effort and will have reduced acid export from the area, particularly during dry periods. However, it is acknowledged that there is limited ability to implement larger-scale improvement without more significant changes in land management, including changes in land uses, in this subcatchment.

Long-term management options

Bungawalbin Creek/Sandy Creek is the largest potential contributor of blackwater in the Richmond River, with the analysis indicating that it contributes significantly more than any other subcatchment considered (see Table 6.1) and is also a major contributor of acid discharge. In the long-term, remediation of the natural freshwater hydrology in each of the three management areas should be considered to achieve significant improvements in water quality. Note that any changes in hydrology will require extensive studies into the impacts to flooding and land uses, and should only be implemented with extensive consultation of local landholders and extensive consideration of the social and economic impacts of such changes.

Floodwaters could be strategically held on the low areas to allow carbon cycle processes that occur when organic matter decomposes to be complete and prevent blackwater discharges from this subcatchment impacting the greater Richmond River estuary. This will have a particularly large impact on reducing blackwater drainage following flood events.

Table 8.8: Summary of management options for Bungawalbin Creek/Sandy Creek subcatchment

Timeframe	Strategy	Effectiveness at improving:		
		Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Installation of drop board structures	None	Moderate	Low
Short-term	Reshape drains	None	Moderate	Low
Long-term	Restore natural freshwater hydrology	Limited	High	High

8.6 North Creek subcatchment

Acid priority rank:	**4**
Blackwater priority rank:	**10**
Infrastructure	
Approximate waterway length (km)	173
# Privately owned end of system structures	4
# Publicly owned end of system structures	9
# End of system structures within coastal wetlands	1
# Publicly owned end of system structures within coastal wetlands	1
Primary floodplain infrastructure (ID):	5800, 5810
Elevations	
Invert of primary floodplain infrastructure (m AHD):	-1.2 to -1.1
Approximate AASS elevation (m AHD)	0.4
Approximate PASS elevation (m AHD)	-0.5
Median blackwater elevation (m AHD)	0.5
Present day low water level (m AHD)	-0.52
Near future low water level (m AHD)	-0.36
Far future low level (m AHD)	0.14
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)	5,401
Classified as conservation and minimal use (ha (%))	1,485 (27%)
Classified as grazing (ha (%))	1,133 (21%)
Classified as forestry (ha (%))	0 (0%)
Classified as sugar cane (ha (%))	1,301 (24%)
Classified as horticulture (ha (%))	337 (6%)
Classified as other cropping (ha (%))	4 (0%)
Classified as urban/industrial/services (ha (%))	862 (16%)
Classified as marsh/wetland (ha (%))	51 (1%)
Other (ha (%))	228 (4%)
Land values	
Estimated total primary production value ($/year)	$5,700,000
Average land value above 0.5 m AHD ($/ha)	$39,500
Average land value below 0.5 m AHD ($/ha)	No property data available

8.6.1 Site description and brief history of drainage

North Creek joins the Richmond River at Ballina, approximately 1 km from the ocean entrance. The subcatchment includes the Ballina Nature Reserve in its lower reaches, shown in Figure 8-26. The upstream area, which is now primarily used for sugar cane and macadamia farming, is known as Newrybar Swamp and was naturally a semi-permanently inundated swampland (Tulau, 1999b). Extensive drainage of the catchment began in the late 1800's and the main Union Drain (now referred to as Newrybar Drain) was constructed in the early 1900's. To address issues of flooding, additional flood mitigation drains were constructed, formalising the connection of this drain to North Creek in 1980 (BMT WBM, 2013).

The North Creek subcatchment includes a substantial area below 1 m AHD (Figure 8-27), including the majority of the Ballina Nature Reserve. Outside the Ballina Nature Reserve, the majority of the low land (<1 m AHD) is used for grazing, while the northern half of the catchment has been historically used for sugar cane, although recently some of the cane paddocks have been converted to macadamias.

Discharges and runoff from the North Creek subcatchment have a limited impact to the wider Richmond River estuary, however impacts to the North Creek waterway itself have been noted (e.g. Alluvium, 2019); Rayner et al. (2020b); (Rayner et al., 2020c). Although the sources of acid and blackwater have been broadly identified, the relative contribution of poor water quality from different subcatchment areas has yet to be quantified.

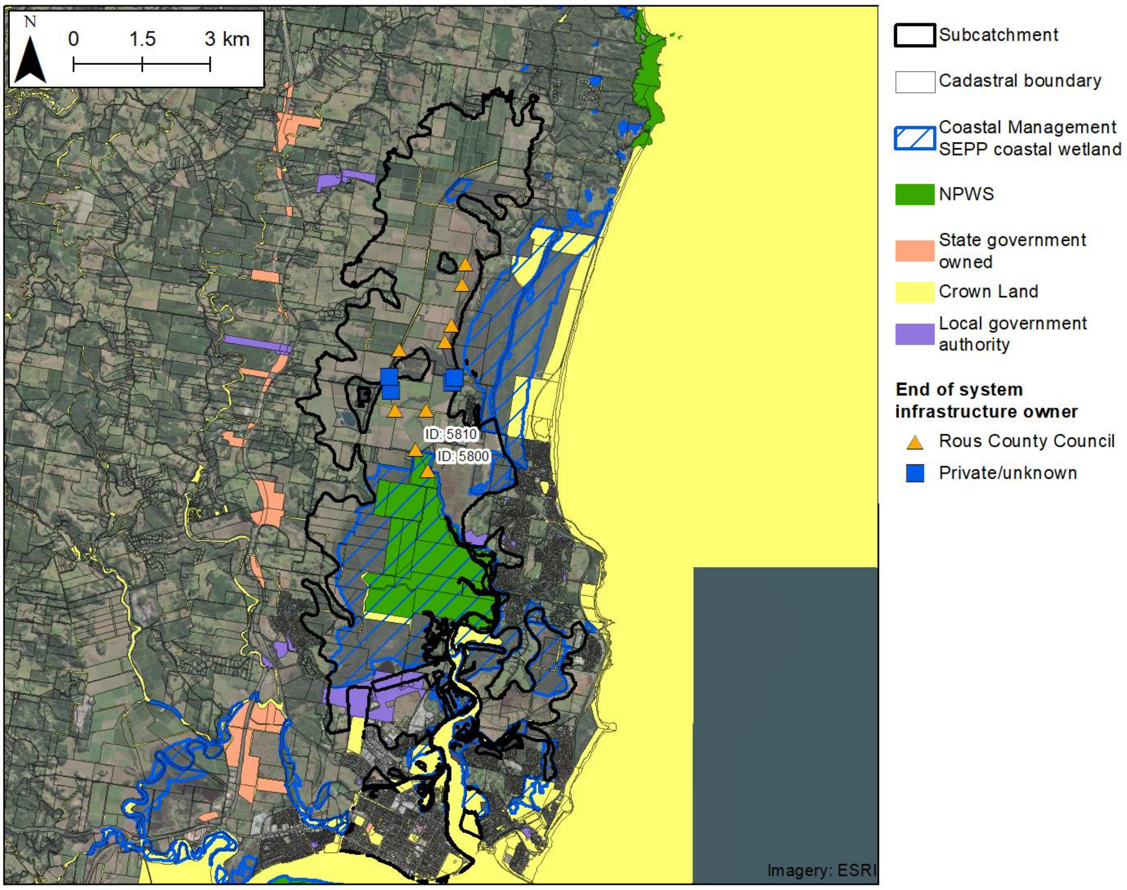

Figure 8-26: North Creek subcatchment land and end of system infrastructure tenure

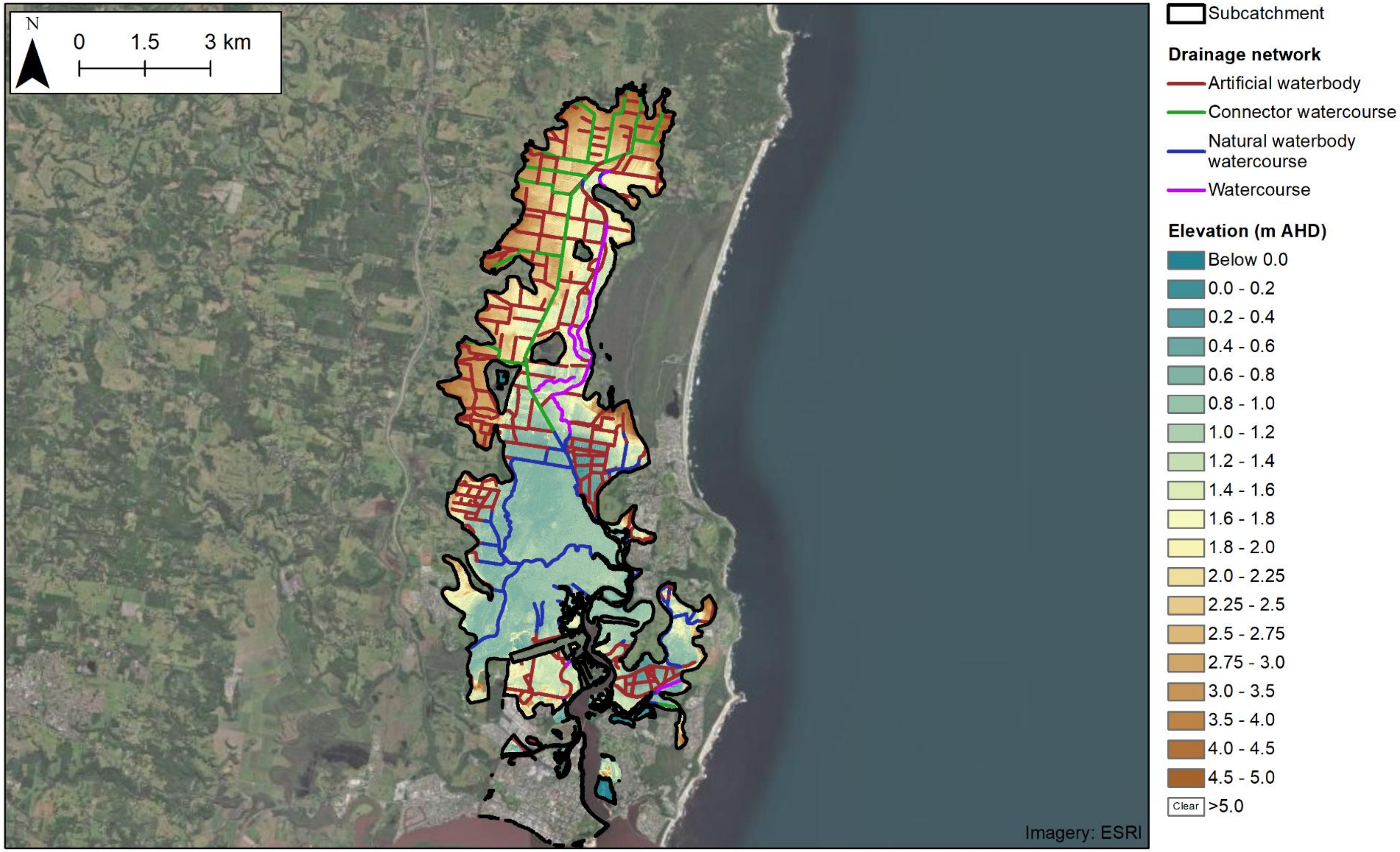

Figure 8-27: North Creek subcatchment elevation detail and drainage network

8.6.2 History of remediation

Three (3) of the floodgates in the North Creek subcatchment are known to have been modified through the installation of auto-tidal buoyancy gates (floodgate ID 5800, 5820, 7000). The largest of these, floodgate 5800, is on the main drain at the northern end of the Ballina Nature Reserve. In addition, a rock weir was installed on one of the secondary drains that flows into the National Park Drain to maintain higher water levels in the Nature Reserve to improve ecological values, identified in Figure 8-28.

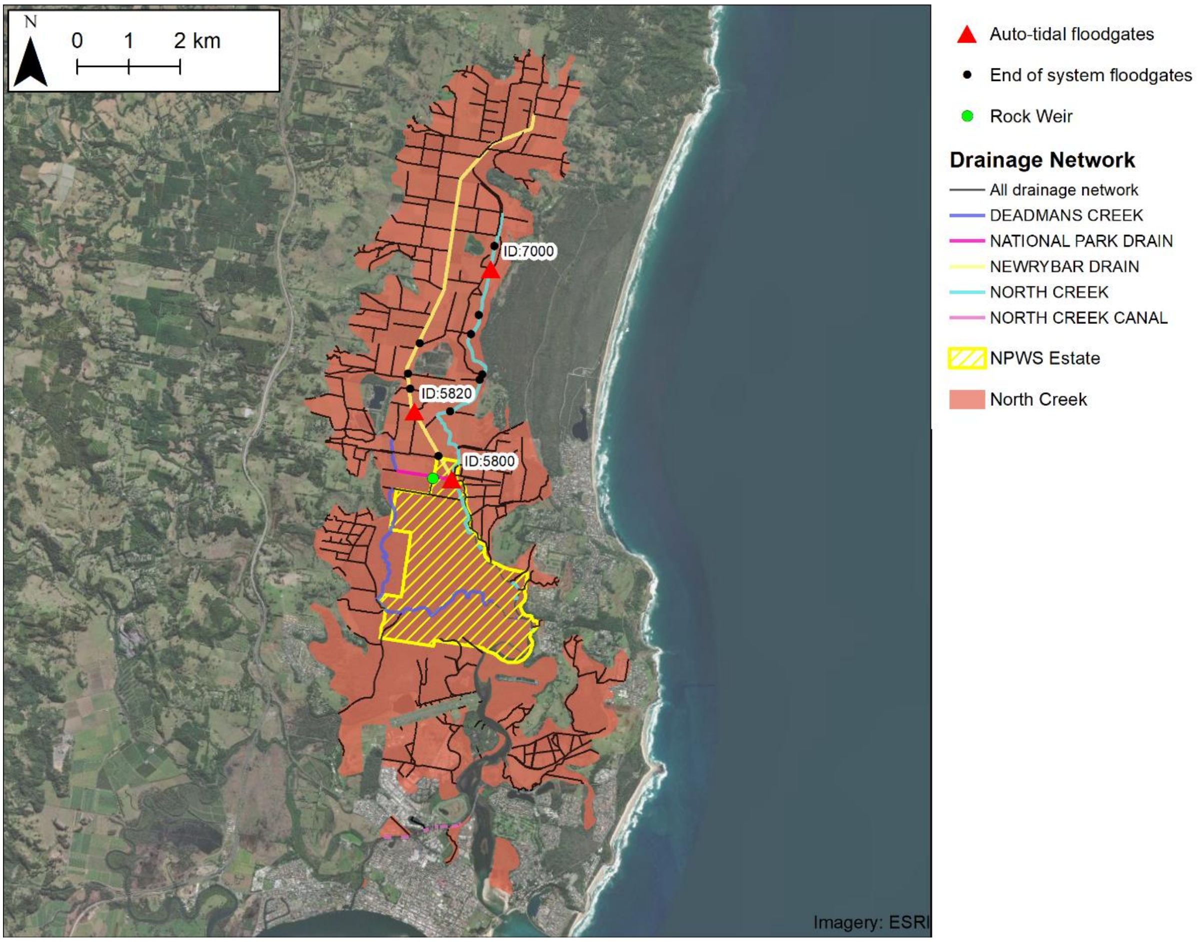

Figure 8-28: North Creek subcatchment including previous remediation actions

Sugar cane farms in the Richmond River floodplain operate in compliance with “The NSW sugar industry best practice guidelines for acid sulfate soils” (Sunshine Sugar, 2020). While details of specific drainage management on cane farms in the North Creek subcatchment were not obtained, cane farms typically:

- Laser level farms to reduce the drainage density required to allow surface water drainage;
- Construct new drainage works that are designed to minimise the interaction with acidic soils; and
- Complete extensive liming.

8.6.3 Floodplain drainage – sea level rise vulnerability

Figure 8-29 summarises the vulnerability of floodplain drainage in North Creek due to sea level rise. Note that improved certainty in the sea level rise vulnerability would require additional field data collection, including survey of private infrastructure and confirmation of ground topography. However, using the data available, under the near future sea level rise scenario, substantial sections of the Ballina Nature Reserve are expected to be considered at low risk for reduced drainage, as well as the low lying grazing land west of the Nature Reserve, immediately north of East Ballina and west of Lennox Head. Under the far future sea level rise scenario, these grazing areas will likely be at moderate risk of reduced drainage (e.g. they are below the median water levels downstream). Drainage in these areas is likely to be progressively limited as sea levels rise in future decades.

The main floodgate on the National Park Drain (floodgate ID 5800) is classified as moderately vulnerable in the far future, indicating that areas upstream of this floodgate may experience reduced drainage as shown in Figure 8-30. The floodgates that are identified as most vulnerable in the near future (one floodgate, ID WRL_RICH_46) and far future (six floodgates) are all privately owned.

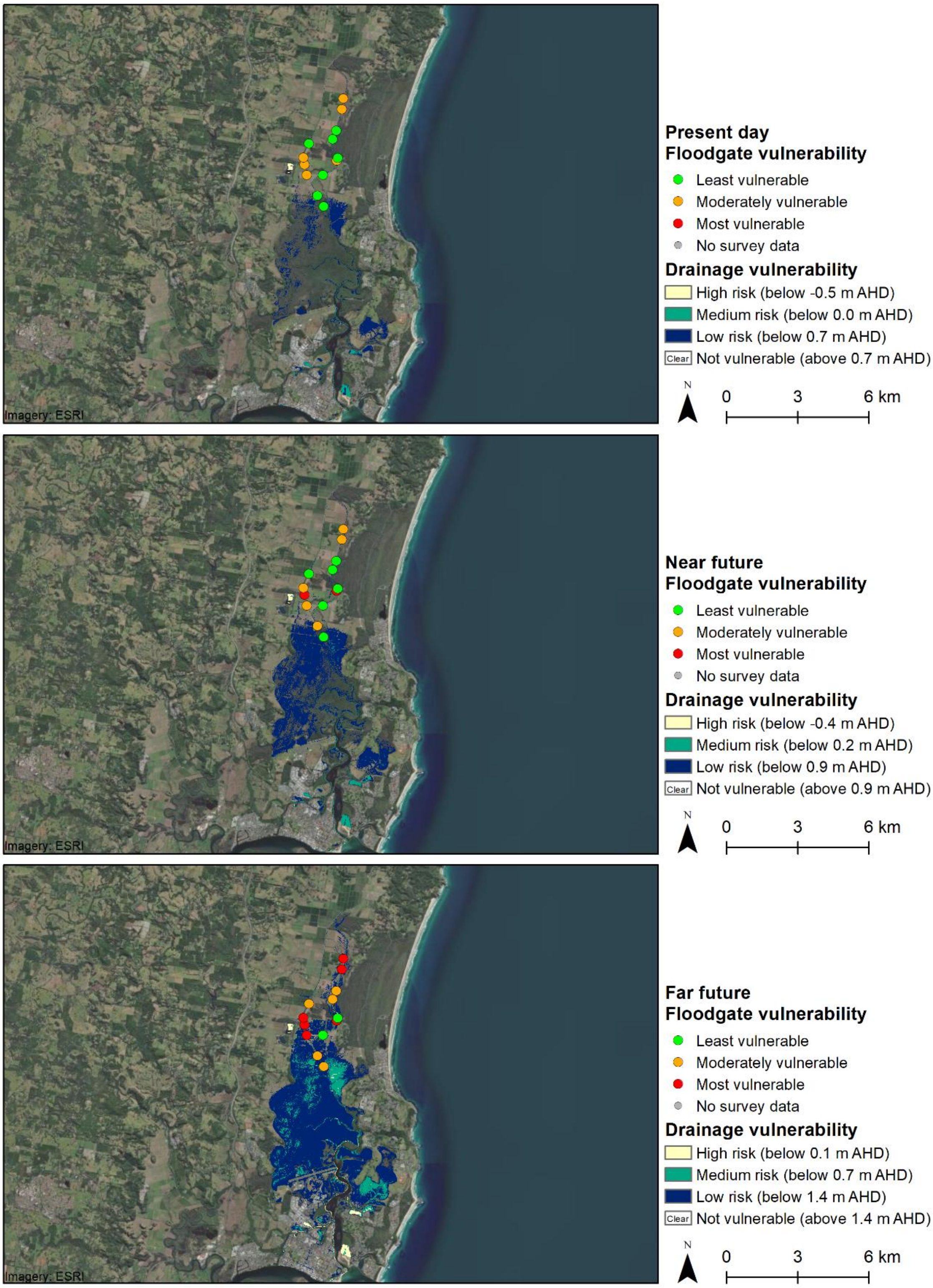

Figure 8-29: Sea level rise drainage vulnerability – North Creek subcatchment

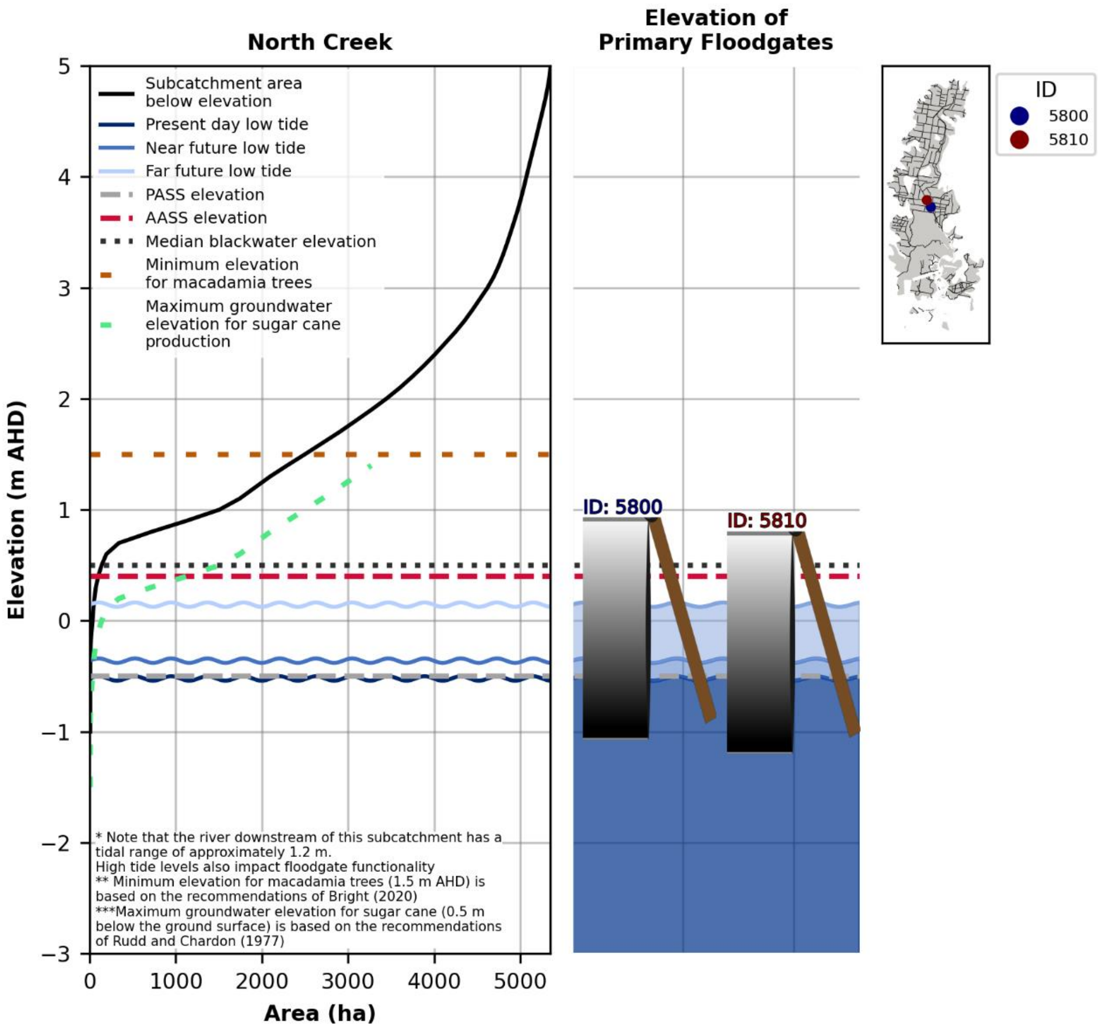

Figure 8-30: Primary floodgates and key floodplain elevations – North Creek subcatchment

8.6.4 Management options

Short-term management options

The source, generation mechanism and relative contribution of poor water quality from different subcatchment areas should be investigated. Routine monitoring across the subcatchment combined with event based monitoring would enable poor water quality sources and generation mechanisms to be identified, and targeted management actions to be implemented. It is understood that a monitoring program will be implemented as part of the Coastal Management Program for the Richmond River estuary.

Where possible, it is recommended that larger drains should be investigated for feasibility to be reshaped to reduce groundwater drawdown and acid discharge. Where grazing is already practiced, opportunities for wet pasture management may be able to be investigated in the lowest lying areas of this subcatchment through the installation of drop board weirs. It is acknowledged, however, that salinity levels in North Creek are near marine levels and salt transport through surface water or groundwater systems may limit wet pasture management and impact freshwater land uses. Similarly, previous experience in the Richmond River has shown wet pasture management has had limited success in maintaining agricultural productivity, which would need to be addressed for this to be viable.

Ballina Nature Reserve is the lowest lying elevation area in the North Creek subcatchment. RRCC (now RCC) have previously installed weirs in the Ballina Nature Reserve to encourage water retention on the nature reserve. Investigations should be completed to establish whether additional freshwater retention could be encouraged in Ballina Nature Reserve through the installation of weirs to reduce acid discharge and blackwater runoff.

Long-term management options

The lowest lying land in the downstream sections of the North Creek subcatchment may be impacted by reduced drainage under the near-to-far future sea level rise scenarios. Low areas (below +0.7 m AHD) may be subject to reduced drainage and prolonged inundation, which is likely to impact existing land uses, and these areas could be considered transition to wetland habitats. Land to the downstream of Ballina Nature Reserve may be able to be targeted for intertidal wetlands due to the proximity to the ocean and relatively low land elevation in relation to tidal water levels. Secondary drains could be infilled, and main truck drains could be swaled/reshaped to reduce acid drainage and promote wetland environments. This area could be expected to become an ideal habitat migration area for mangrove, saltmarsh and other coastal wetland ecosystems under future sea level rise scenarios. Low-lying areas adjacent to the existing Nature Reserve may be able to be amalgamated into the Ballina Nature Reserve. Artificial drainage channels should be infilled and semi-permanent wetland areas should be encouraged. Areas to the west of the Nature Reserve are likely to be predominantly freshwater systems, while areas adjacent to North Creek may be brackish.

Some areas north of Ballina Nature Reserve and Ross Lane are generally higher in elevation than the lower reaches of the North Creek subcatchment, which may limit the impacts of reduced drainage. However, if reduced drainage due to sea level rise does impact productivity in these areas, wet pasture management could be considered.

Table 8.9: Summary of management options for North Creek subcatchment

Timeframe	Strategy	Effectiveness at improving:		
		Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Drain swaling/ reshaping	None	Moderate	Low
Short-term	Wet pasture management	None	Moderate	Moderate
Long-term	Restoration of natural hydrology of low lying areas	Moderate	High	High

8.7 Emigrant Creek/Maguires Creek subcatchment

Acid priority rank:	**5**
Blackwater priority rank:	**9**
Infrastructure	
Approximate waterway length (km)	230
# Privately owned end of system structures	5
# Publicly owned end of system structures	84
# End of system structures within coastal wetlands	12
# Publicly owned end of system structures within coastal wetlands	11
Primary floodplain infrastructure (ID):	4280, 4410, 4590, 4800, 4830, 5410, 5500, 5570
Elevations	
Invert of primary floodplain infrastructure (m AHD):	-1.7 to -0.8
Approximate AASS elevation (m AHD)	0.5
Approximate PASS elevation (m AHD)	-0.2
Median blackwater elevation (m AHD)	0.4
Present day low water level (m AHD)	-0.44
Near future low water level (m AHD)	-0.28
Far future low level (m AHD)	0.21
Proximity to sensitive receivers	
Oyster leases (km)	0.6
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)	5,136
Classified as conservation and minimal use (ha (%))	193 (4%)
Classified as grazing (ha (%))	1,294 (25%)
Classified as forestry (ha (%))	19 (0%)
Classified as sugar cane (ha (%))	2,184 (43%)
Classified as horticulture (ha (%))	212 (4%)
Classified as other cropping (ha (%))	118 (2%)
Classified as urban/industrial/services (ha (%))	663 (12%)
Classified as marsh/wetland (ha (%))	187 (4%)
Other (ha (%))	298 (6%)
Land values	
Estimated total primary production value ($/year)	$6,300,000
Average land value above 0.4 m AHD ($/ha)	$19,700
Average land value below 0.4 m AHD ($/ha)	No property data available

8.7.1 Site description

The Emigrant Creek/Maguires Creek subcatchment (shown in Figure 8-31) discharges into the Richmond River approximately 6.5 km upstream of the ocean entrance and is located west of Ballina. As shown in Figure 8-32, this subcatchment is the most highly drained area in the Richmond River floodplain. There are over 88 end-of-system floodgates operating in Emigrant Creek/Maguires Creek, most of which are owned and maintained by Rous County Council (RCC).

The land uses of this subcatchment are primarily sugar cane and grazing, although macadamia farms are becoming increasingly common. The area identified as Crown land within the subcatchment in Figure 8-31 is operated as a research station by DPI Fisheries, and the State Government owned land is adjacent to the new Pacific Highway alignment.

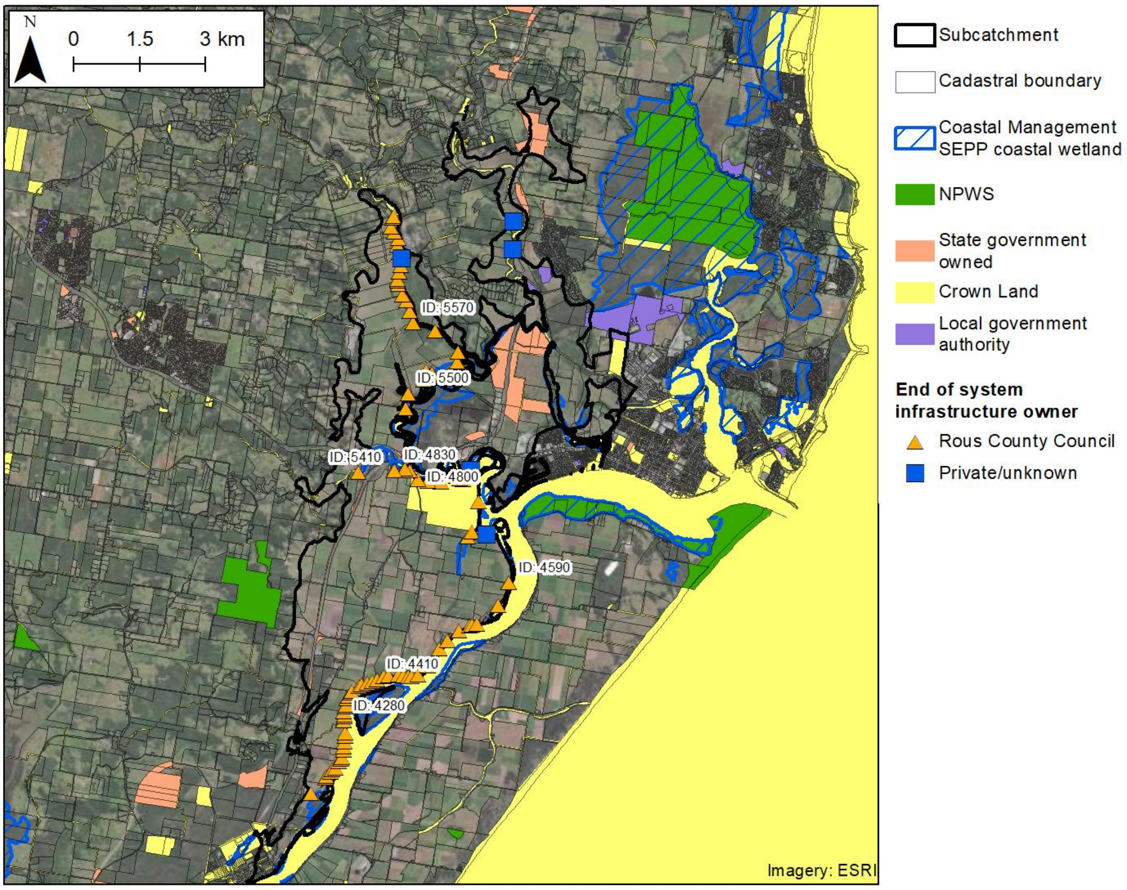

Figure 8-31: Emigrant Creek/Maguires Creek subcatchment - land and end of system infrastructure tenure

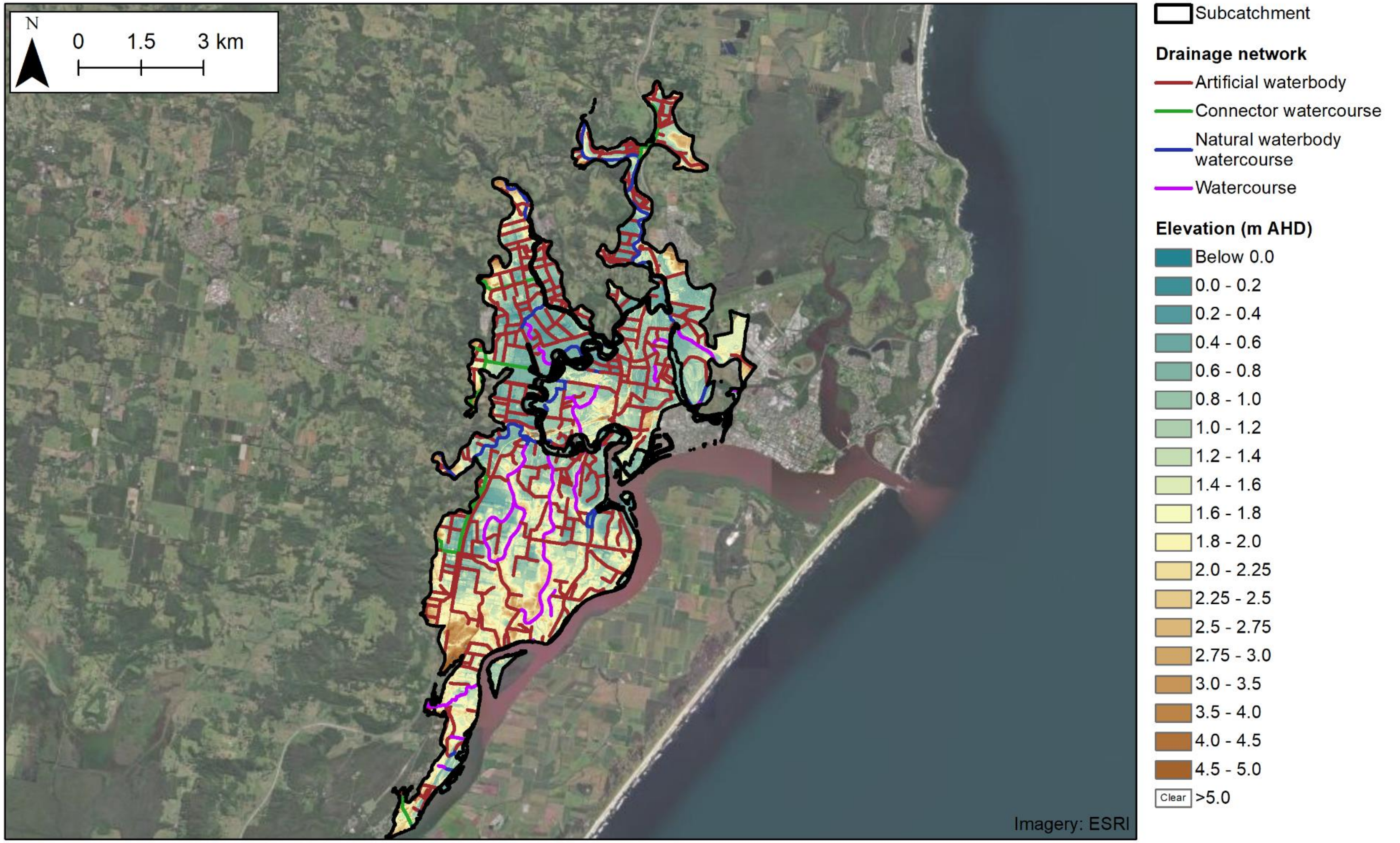

Figure 8-32: Emigrant Creek/Maguires Creek elevation and drainage network

8.7.2 History of remediation

The Emigrant Creek/Maguires Creek subcatchment includes three (3) floodgates that have been modified with sluice gates to allow limited tidal flushing and connectivity for fish passage (Figure 8-33). Management of the sluice gate is held by RCC, although the day-to-day operation of the sluice gates is unknown. These include:

- Floodgate ID 4280 – on Saltwater Creek;
- Floodgate ID 5410 – on Duck Creek West Canal; and
- Floodgate ID 4830 – on Duck Creek East Canal.

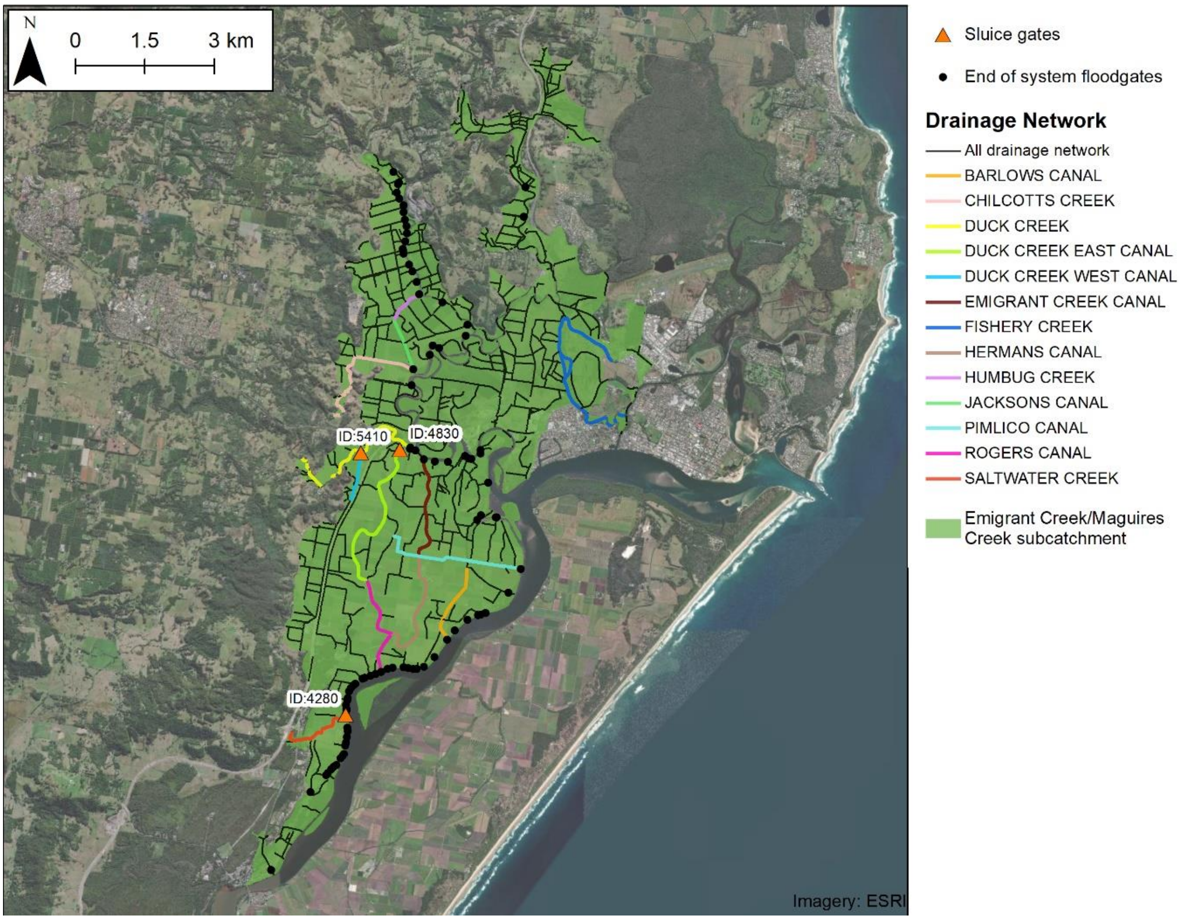

Figure 8-33: Emigrant Creek/Maguires Creek subcatchment including previous remediation actions

Sugar cane farms in the Richmond River floodplain operate in compliance with "The NSW sugar industry best practice guidelines for acid sulfate soils" (Sunshine Sugar, 2020). While details of specific drainage management on cane farms in the Emigrant Creek/Maguires Creek subcatchment were not obtained, cane farms typically:

- Laser level farms to reduce the drainage density required to allow surface water drainage;
- Construct new drainage works that are designed to minimise the interaction with acidic soils; and
- Complete extensive liming.

8.7.3 Floodplain drainage – sea level rise vulnerability

The sea level rise vulnerability analysis of the floodplain and floodplain infrastructure in the Emigrant Creek/Maguires Creek subcatchment is presented in Figure 8-34 and Figure 8-35 (primary floodgates only). Many floodgates (37 out of 83) in the Emigrant Creek/Maguires Creek subcatchment are moderately vulnerable under present day water levels, meaning that the obvert of the floodgate is below the downstream water level more than 5% of the time (but less than 50% of the time). In the near future, 16 of the 83 floodgates (with survey data) are classified as most vulnerable, meaning the obvert is below the water level more than 50% of the time. This increases to 52 floodgates, or 63%, in the far future, including 7 out of 8 primary floodplain structures (Figure 8-35). Floodplain infrastructure will likely be impacted by reduced drainage capacity as sea level rise continues to occur.

Figure 8-34 also shows that the Emigrant Creek/Maguires Creek floodplain will also be impacted by sea level rise in the future due to the low-lying elevation of areas of the subcatchment. In the near future, lower areas of the subcatchment will become low risk for reduced drainage, meaning that they are situated below the (near future) 95th percentile downstream water level. However, under the far future sea level rise scenario, a substantial portion of the subcatchment is classified as moderate risk and may be highly vulnerable to reduced drainage and prolonged inundation.

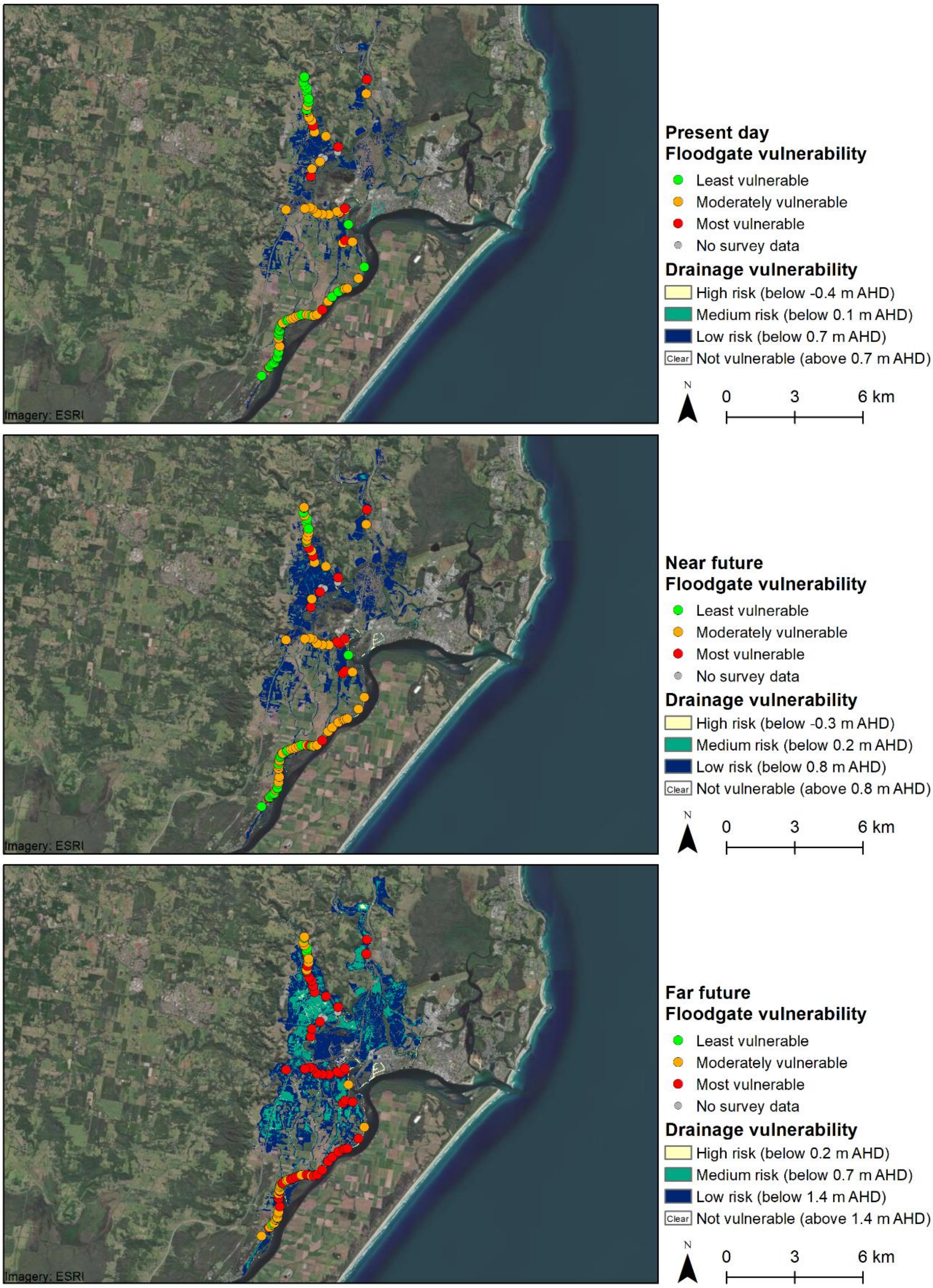

Figure 8-34: Sea level rise drainage vulnerability – Emigrant Creek/Maguires Creek subcatchment

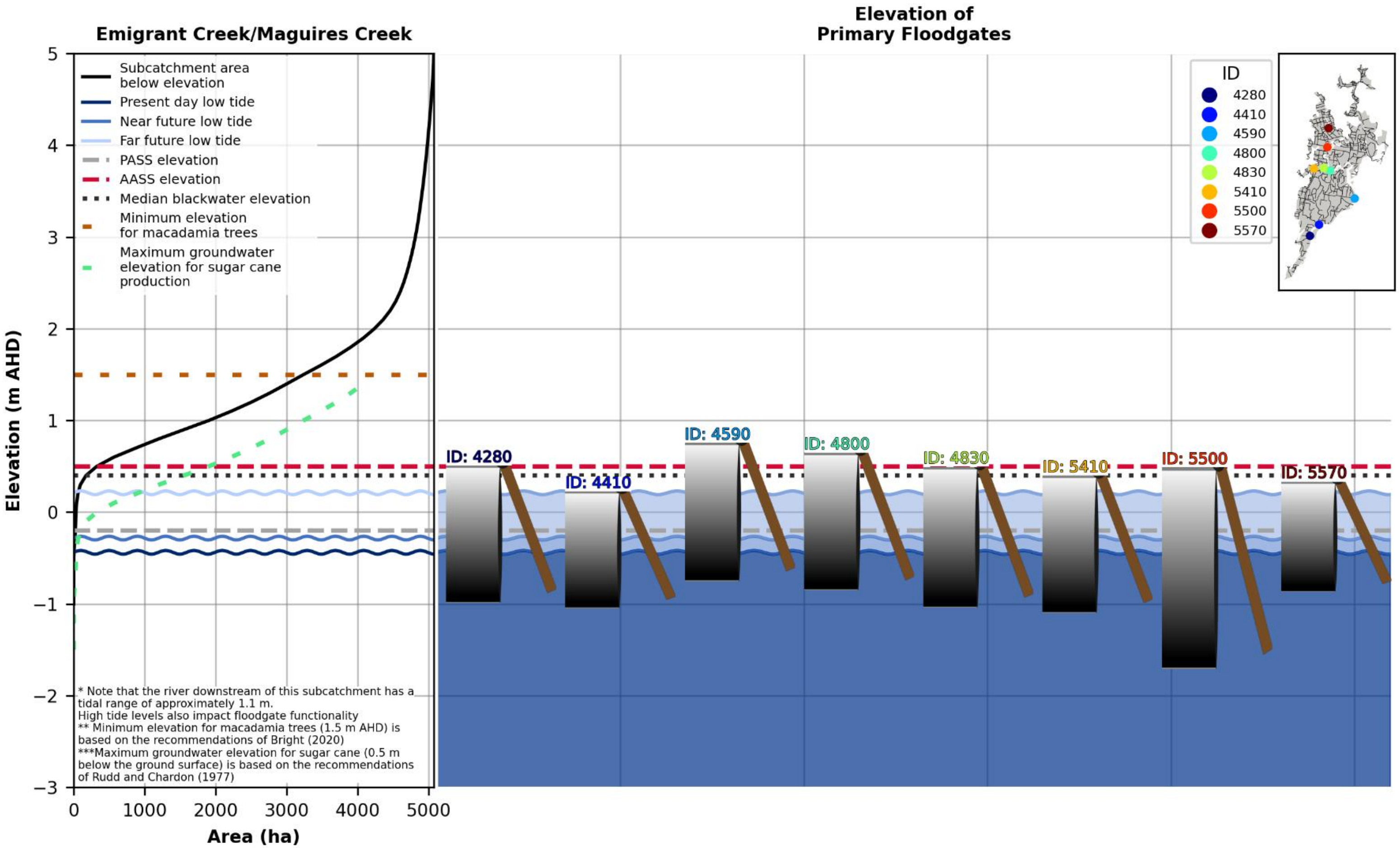

Figure 8-35: Primary floodgates and key floodplain elevations – Emigrant Creek/Maguires Creek subcatchment

8.7.4 Management options

Short-term management options

RCC has already modified numerous floodgates in this subcatchment, however further improvements in tidal flushing on major floodgates along the Richmond River would improve overall water quality and estuarine habitat in this subcatchment. Where floodgates have not been modified, consideration of sluice gate or auto-tidal buoyancy gates is suggested. Management of these gates would require consideration of land uses and consultation with surrounding landholders.

Reshaping of secondary floodplain drains should be investigated to raise the drain invert to be above PASS layers (approximately -0.1 m AHD, although this should be confirmed locally). Reducing drain depth and drainage density will reduce the risk of further oxidisation of the soils and reduce overall acid drainage. If possible, larger trunk drains should also be reshaped, although it is unlikely that drain reshaping to -0.1 m AHD could be achieved in major drains without impacting present day drainage and land use. Low-lying areas that are currently used for grazing may also be able to be targeted for wet pasture management strategies through the installation of drop board weirs to raise the overall groundwater table and promote water tolerant vegetation.

Long-term management options

As discussed in Section 8.7.3, low-lying areas, particularly areas below +0.7 m AHD, will likely be impacted by reduced drainage under near-to-far future sea level rise scenarios. Where present day land uses are impacted by sea level rise, it is suggested that natural estuarine hydrology is restored in low-lying areas. Restoration of the hydrology in this subcatchment may include:

- Allowing significant tidal flushing;
- Infilling and shallowing of existing drainage systems to reduce acid drainage, while maintaining flood mitigation capacity; and
- Removing impediments to floodplain inundation (such as farm scale levees).

Table 8.10: Summary of management options for Emigrant Creek/Maguires Creek

Timeframe	Strategy	Effectiveness at improving: Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Floodgate management	Moderate	Moderate	Negligible
Short-term	Drain reshaping and infilling	None	Moderate	Negligible
Short-term	Wet pasture management	None	Moderate	Moderate
Long-term	Restoration of estuarine hydrology	High	Moderate	Moderate

8.8 Swan Bay subcatchment

Acid priority rank:	**6**
Blackwater priority rank:	**5**
<u>Infrastructure</u>	
Approximate waterway length (km)	49
# Privately owned end of system structures	0
# Publicly owned end of system structures	17
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (ID):	1780, 1790, 1820, 1860, 1880
<u>Elevations</u>	
Invert of primary floodplain infrastructure (m AHD):	-1 to -0.1
Approximate AASS elevation (m AHD)	0.6
Approximate PASS elevation (m AHD)	-0.5
Median blackwater elevation (m AHD)	2.7
Present day low water level (m AHD)	-0.23
Near future low water level (m AHD)	-0.08
Far future low level (m AHD)	0.41
<u>Proximity to sensitive receivers</u>	
Oyster leases (km)	35.3
Saltmarsh (km)	31.3
Seagrass (km)	39.0
Mangroves (km)	5.5
Coastal Management SEPP coastal wetlands (km)	12.8
<u>Land use</u>	
Total floodplain area (ha)	1,593
Classified as conservation and minimal use (ha (%))	4 (0%)
Classified as grazing (ha (%))	540 (34%)
Classified as forestry (ha (%))	38 (2%)
Classified as sugar cane (ha (%))	866 (54%)
Classified as horticulture (ha (%))	2 (0%)
Classified as other cropping (ha (%))	57 (4%)
Classified as urban/industrial/services (ha (%))	57 (4%)
Classified as marsh/wetland (ha (%))	1 (0%)
Other (ha (%))	28 (2%)
<u>Land values</u>	
Estimated total primary production value ($/year)	$1,800,000
Average land value above 2.7 m AHD ($/ha)	$4,900
Average land value below 2.7 m AHD ($/ha)	$6,300

8.8.1 Site description

The Swan Bay subcatchment is located on the right bank of the Richmond River, and the majority of the subcatchment discharges into a partially disconnected ox-bow lake (called Swan Bay) shown in Figure 8-36, and it only connected to the Richmond River on the southern side through a 20 m wide canal. The main drainage channels in the subcatchment were first constructed in the 1920's, although RRCC undertook additional major drainage works (including construction of the majority of the existing floodgate structures and headwalls) during the 1960s and 1970s (Rous County Council, 2020a). There are few natural watercourses in the subcatchment and the limited natural gradient of the floodplain means that the area would have likely been near-permanently inundated prior to artificial drainage (Rous County Council, 2020a). The majority of the subcatchment is situated around 1 m AHD and is mostly drained through artificial drainage networks (shown in Figure 8-37).

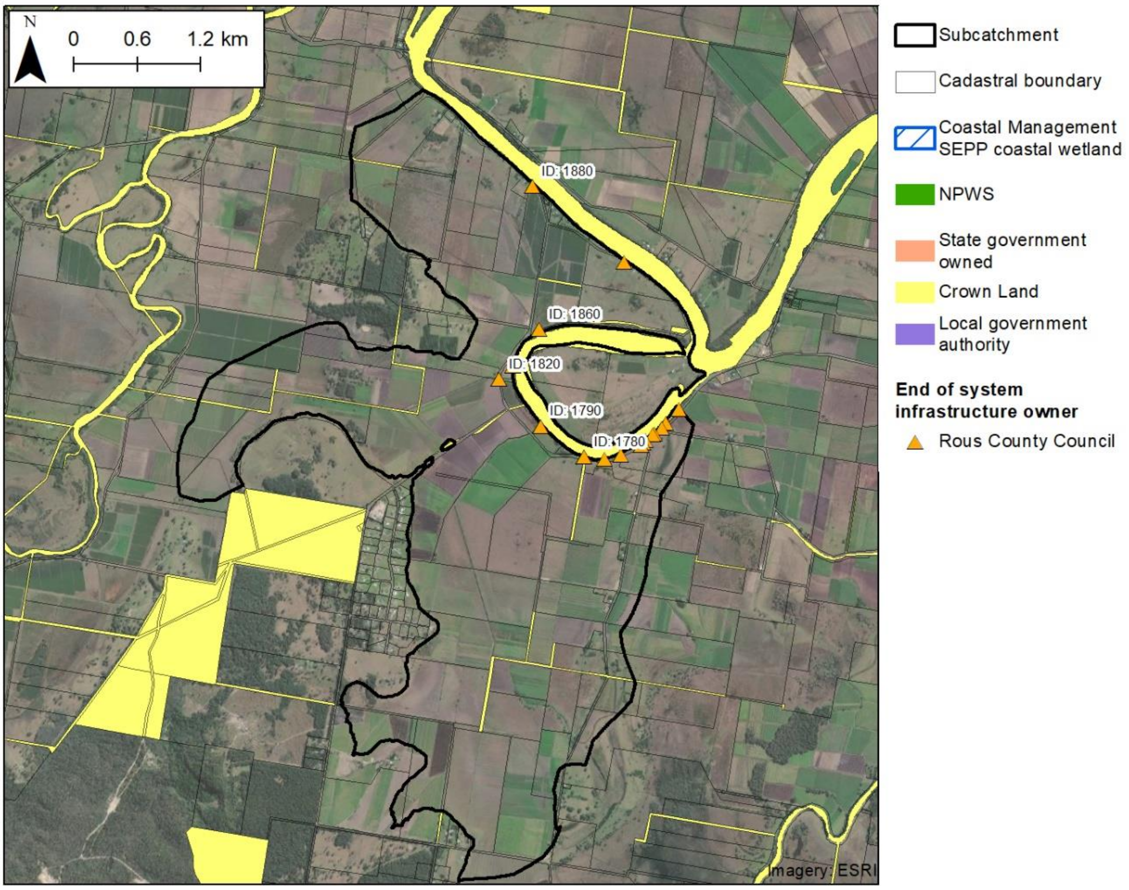

Figure 8-36: Swan Bay subcatchment - land and end of system infrastructure tenure

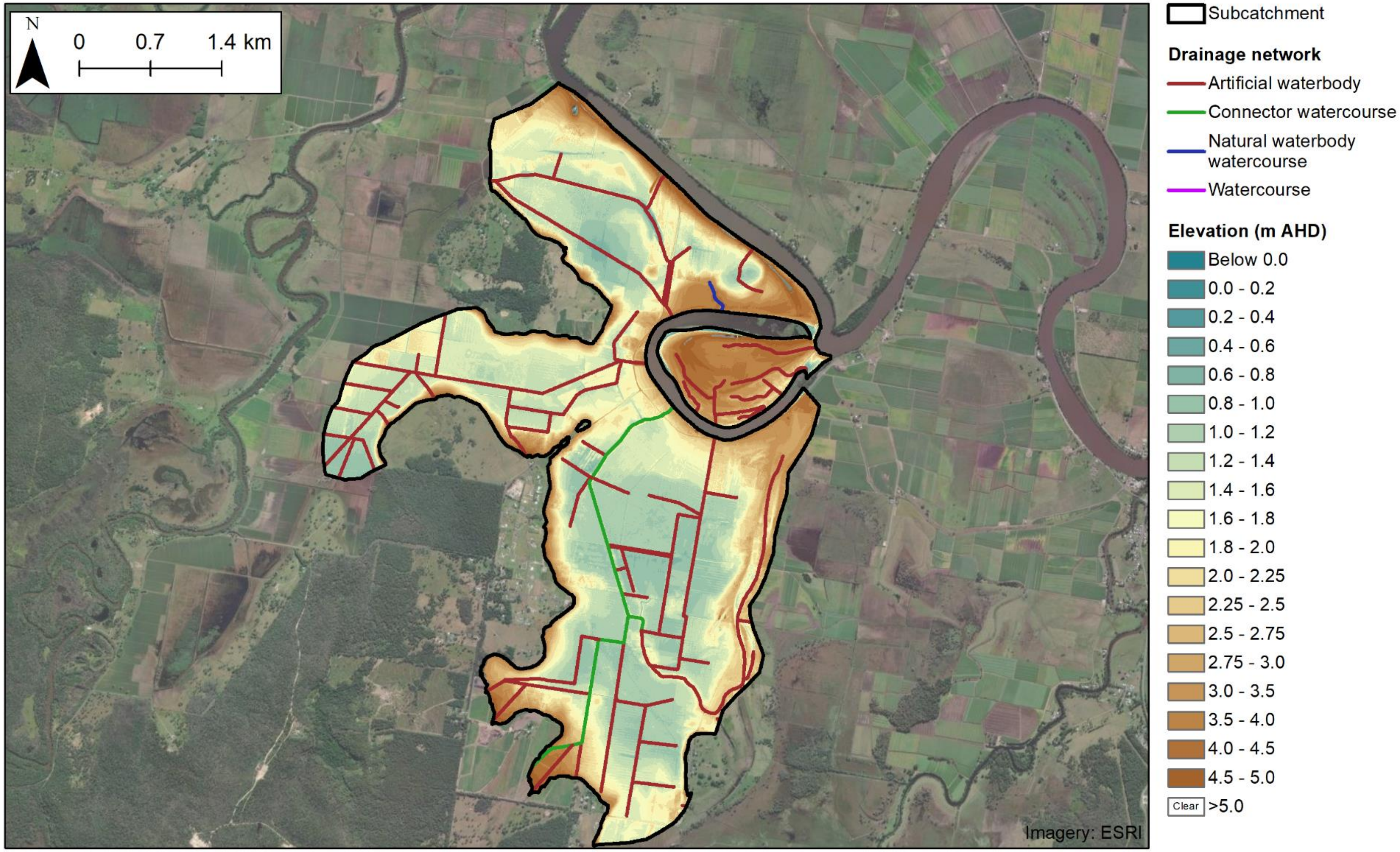

Figure 8-37: Swan Bay subcatchment elevation and drainage network

8.8.2 History of remediation

The five (5) major floodgates in the Swan Bay subcatchment have been modified to allow some tidal flushing, shown in Figure 8-38. This includes:

- Floodgate ID 1880 on Bungawalbyn Hall Canal, which has been modified with an auto-tidal buoyancy gate;
- Floodgate ID 1860 on Skinners Canal, which has a sluice gate. The management of this sluice gate is unknown, although it was observed to be shut in August 2019 by WRL;
- Floodgate ID 1820 on Reardons Canal, which has a sluice gate that is actively managed by RCC and remains open in non-flood periods (Rous County Council, 2020c);
- Floodgate ID 1790 on Thearles Canal, which has a sluice gate. The management of this sluice gate is unknown; and
- Floodgate ID 1780 on Cambells Canal, which has a sluice gate that is actively managed by RCC and remains open in non-flood periods (Rous County Council, 2020a).

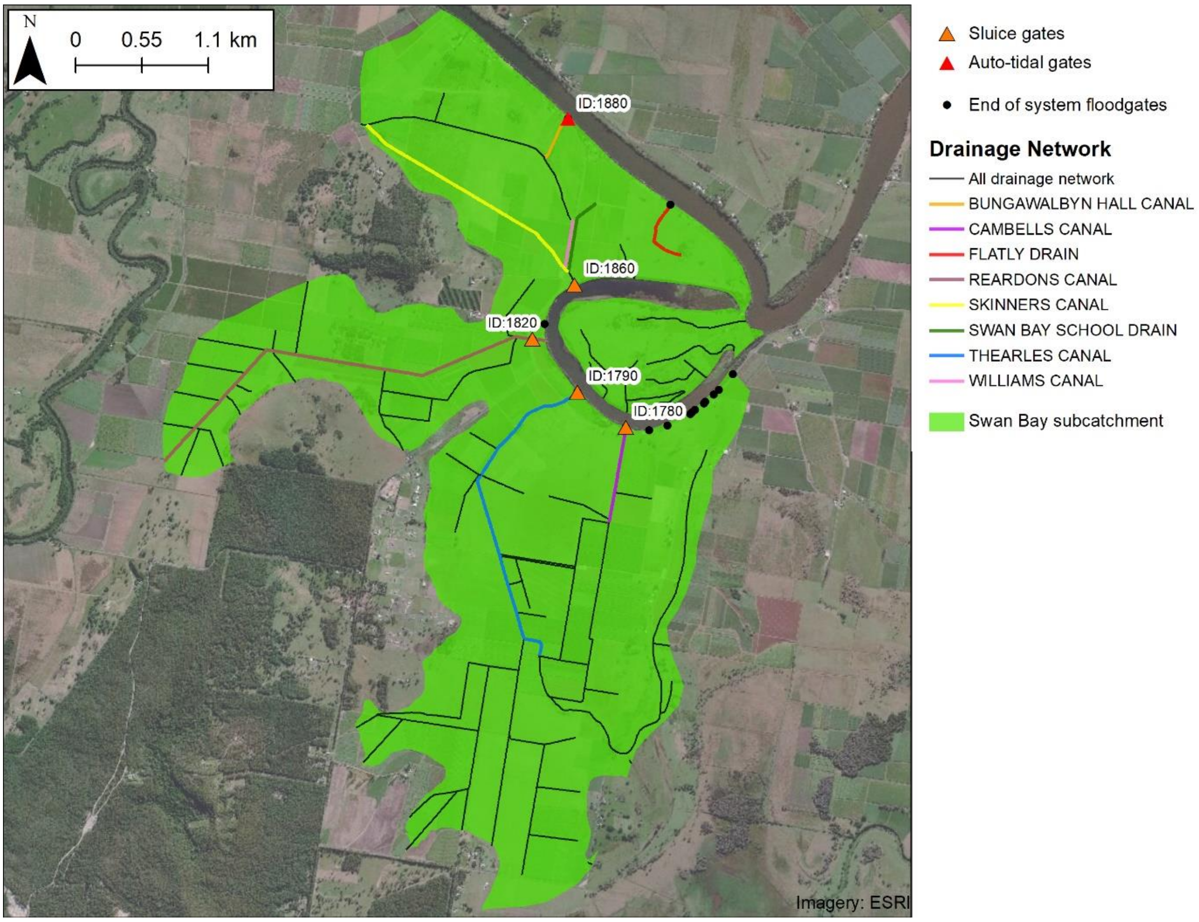

Figure 8-38: Swan Bay subcatchment including previous remediation actions

Note: Drain reshaping has also occurred in secondary drains near Thearles and Cambells Canal, but the exact location is unclear and has therefore been omitted.

RCC and DPI Fisheries, with funding from the NRCMA, also reshaped and shallowed 5.1 km of private drains near Cambells and Thearles Canals. The exact location of this work is unknown, but the purpose of the works was to reduce acid drainage from the area (Rous County Council, 2020a).

Sugar cane farms in the Richmond River floodplain operate in compliance with “The NSW sugar industry best practice guidelines for acid sulfate soils” (Sunshine Sugar, 2020). While details of specific drainage management on cane farms in the Swan Bay subcatchment were not obtained, cane farms typically:

- Laser level farms to reduce the drainage density required to allow surface water drainage;
- Construct new drainage works that are designed to minimise the interaction with acidic soils; and
- Complete extensive liming.

8.8.3 Floodplain drainage – sea level rise vulnerability

The floodplain vulnerability to sea level rise in Swan Bay is summarised in Figure 8-39. None of the major floodgates are identified as vulnerable for the near or far future sea level rise scenarios (Figure 8-40), although a large area of the floodplain (particularly in the southern area drained by Cambells and Thearles Canals) is predicted to be low risk under far future water levels, which may result in reduced drainage due to sea level rise.

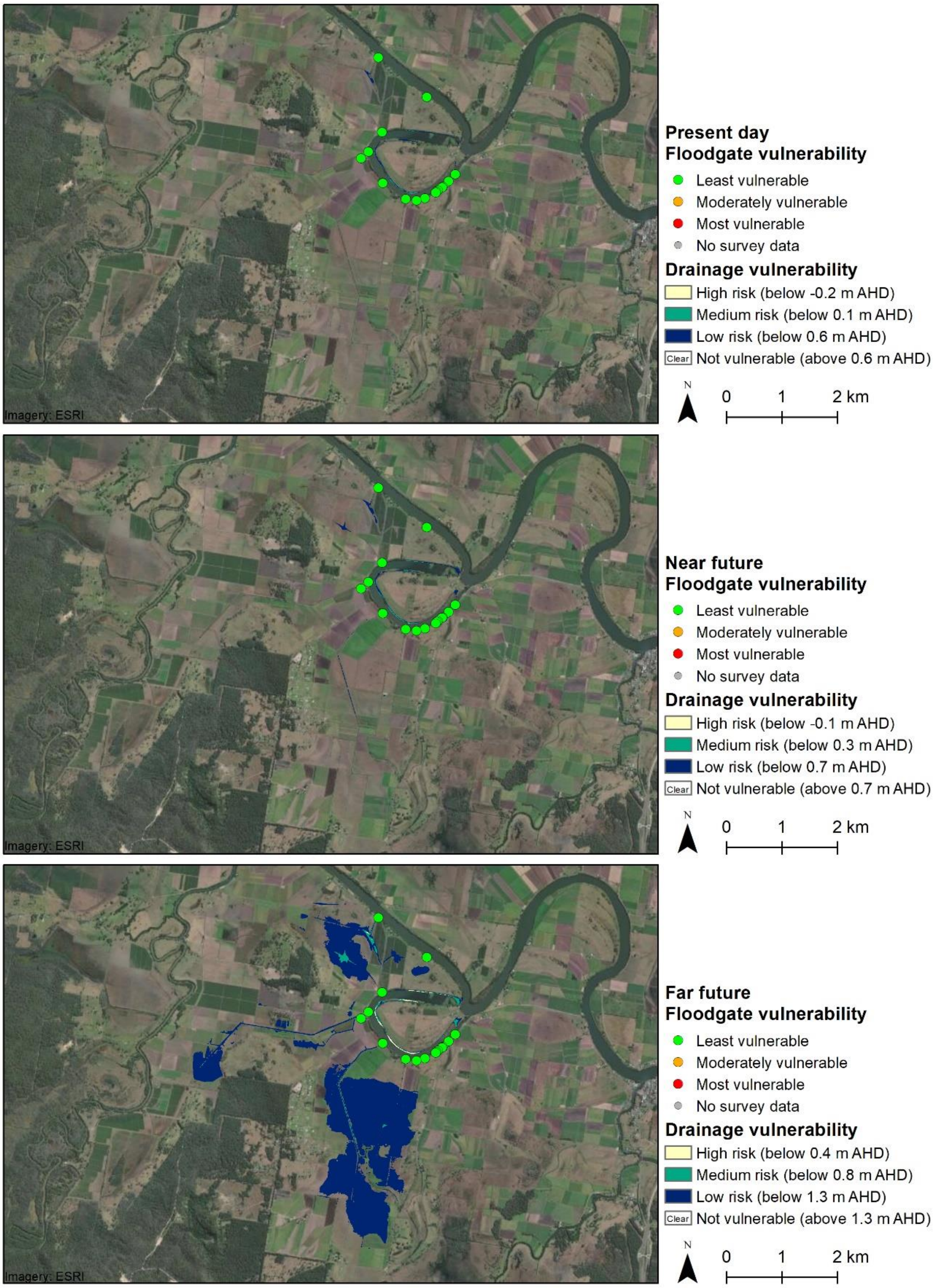

Figure 8-39: Sea level rise drainage vulnerability – Swan Bay subcatchment

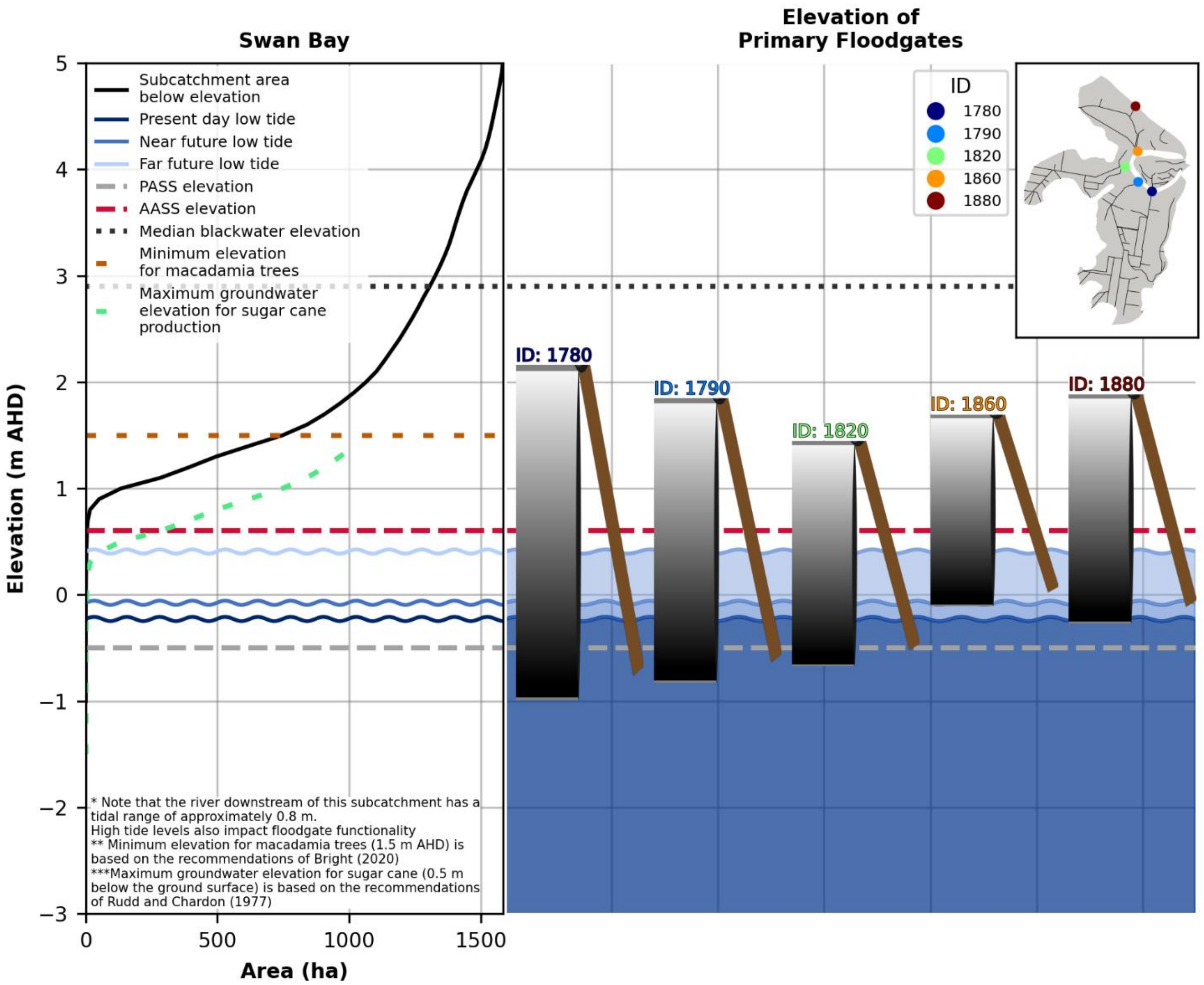

Figure 8-40: Primary floodgates and key floodplain elevations – Swan Bay subcatchment

8.8.4 Management options

Short-term management options

Two (2) of the five (5) modified floodgates have current active management plans implemented by RCC (Cambells and Reardons Canals). This flushing strategy reduces acid discharge (by promoting higher average water levels, and buffering during dry periods) and promotes aquatic connectivity. Continued management of these floodgates is recommended to allow some flushing in the drainage network and, if opportunities arise, additional flushing through increased floodgate modifications should be investigated. While this management will improve estuarine connectivity and results small improvements in water quality, addressing poor water quality from blackwater and event based acid discharges will not be addressed without larger scale changes in drainage in this subcatchment.

In areas currently used for grazing, wet pasture management could be encouraged through the infilling of secondary drains and installation of drop board weirs to hold freshwater back. This would allow for water tolerant vegetation to establish and reduce the risk of blackwater generation. However, it is acknowledged that the implementation of such structures may be difficult in Swan Bay, as wet pasture management has not previously been successful at maintaining agricultural productivity near Bungawalbin Creek, adjacent to Swan Bay.

Long-term management options

Although Figure 8-39 indicates that sea level rise is unlikely not to have a large direct impact on reduced drainage in the near future, areas within this subcatchment currently experience poor drainage and prolonged inundation due to low topography and limited natural gradients in the floodplain. If reduced drainage affects current land uses into the future, it is recommended that these areas be investigated for alternative land uses, including transition to backswamp wetland systems by restoring the natural hydrology. This would require redesigning the existing drainage system, infilling drains where possible, and reshaping drains that are required for flood mitigation. Where drains are still required for flood mitigation, end of system infrastructure may also be able to be modified to allow controlled tidal flushing. Note that any changes in hydrology will require extensive studies into the impacts to flooding and land uses and should only be implemented with extensive consultation of local landholders and extensive consideration of the social and economic impacts of such changes.

By facilitating prolonged drainage and an increased time of inundation, carbon cycle processes that occur when organic matter decomposes would be able to be completed, which would substantially reduce the impact of blackwater from this subcatchment on Swan Bay and the greater Richmond River.

Table 8.11: Summary of management options for Swan Bay

Timeframe	Strategy	Effectiveness at improving:		
		Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Active floodgate management	Moderate	Moderate	Negligible
Short-term	Wet pasture management	None	Moderate	Moderate
Long-term	Restoration of freshwater wetlands	Limited	High	High

8.9 South Ballina subcatchment

Acid priority rank:	**7**
Blackwater priority rank:	**13**
Infrastructure	
Approximate waterway length (km)	51
# Privately owned end of system structures	1
# Publicly owned end of system structures	27
# End of system structures within coastal wetlands	4
# Publicly owned end of system structures within coastal wetlands	4
Primary floodplain infrastructure (ID):	110, 290, 330
Elevations	
Invert of primary floodplain infrastructure (m AHD):	-0.7 to -0.6
Approximate AASS elevation (m AHD)	0.3
Approximate PASS elevation (m AHD)	-0.5
Median blackwater elevation (m AHD)	0.5
Present day low water level (m AHD)	-0.49
Near future low water level (m AHD)	-0.33
Far future low level (m AHD)	0.17
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)	1,409
Classified as conservation and minimal use (ha (%))	151 (11%)
Classified as grazing (ha (%))	156 (11%)
Classified as forestry (ha (%))	0 (0%)
Classified as sugar cane (ha (%))	999 (71%)
Classified as horticulture (ha (%))	0 (0%)
Classified as other cropping (ha (%))	**8** (1%)
Classified as urban/industrial/services (ha (%))	42 (3%)
Classified as marsh/wetland (ha (%))	0 (0%)
Other (ha (%))	51 (4%)
Land values	
Estimated total primary production value ($/year)	$1,800,000
Average land value above 0.5 m AHD ($/ha)	$17,500
Average land value below 0.5 m AHD ($/ha)	No property data available

8.9.1 Site description

The South Ballina subcatchment is in the lower Richmond River estuary and has many discharge points via numerous floodgates directly into the estuary, shown in Figure 8-41. The northern boundary encompasses the Richmond River Nature Reserve and Mobbs Bay. A large portion of this subcatchment (referred to as the Keith Hall drainage system) discharges directly into Mobbs Bay, which is enclosed by submerged breakwaters. This area is recognised as high ecological and amenity value, and includes oyster leases, mangroves and Coastal Management SEPP coastal wetlands.

The primary agricultural use of the subcatchment is sugar cane, except for the lowest sections (see Figure 8-42), which are used for grazing. The higher area in the centre of the subcatchment is used as a sand mine.

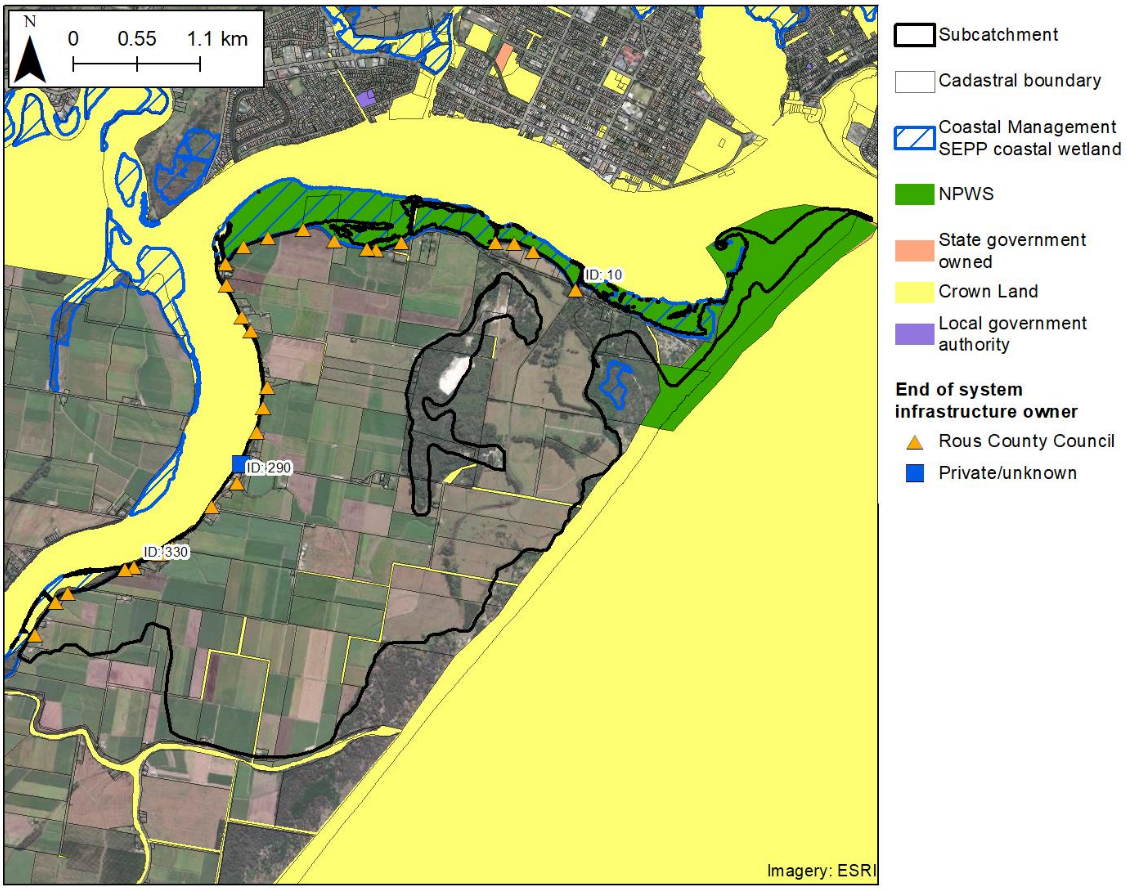

Figure 8-41: South Ballina subcatchment land and end of system infrastructure tenure

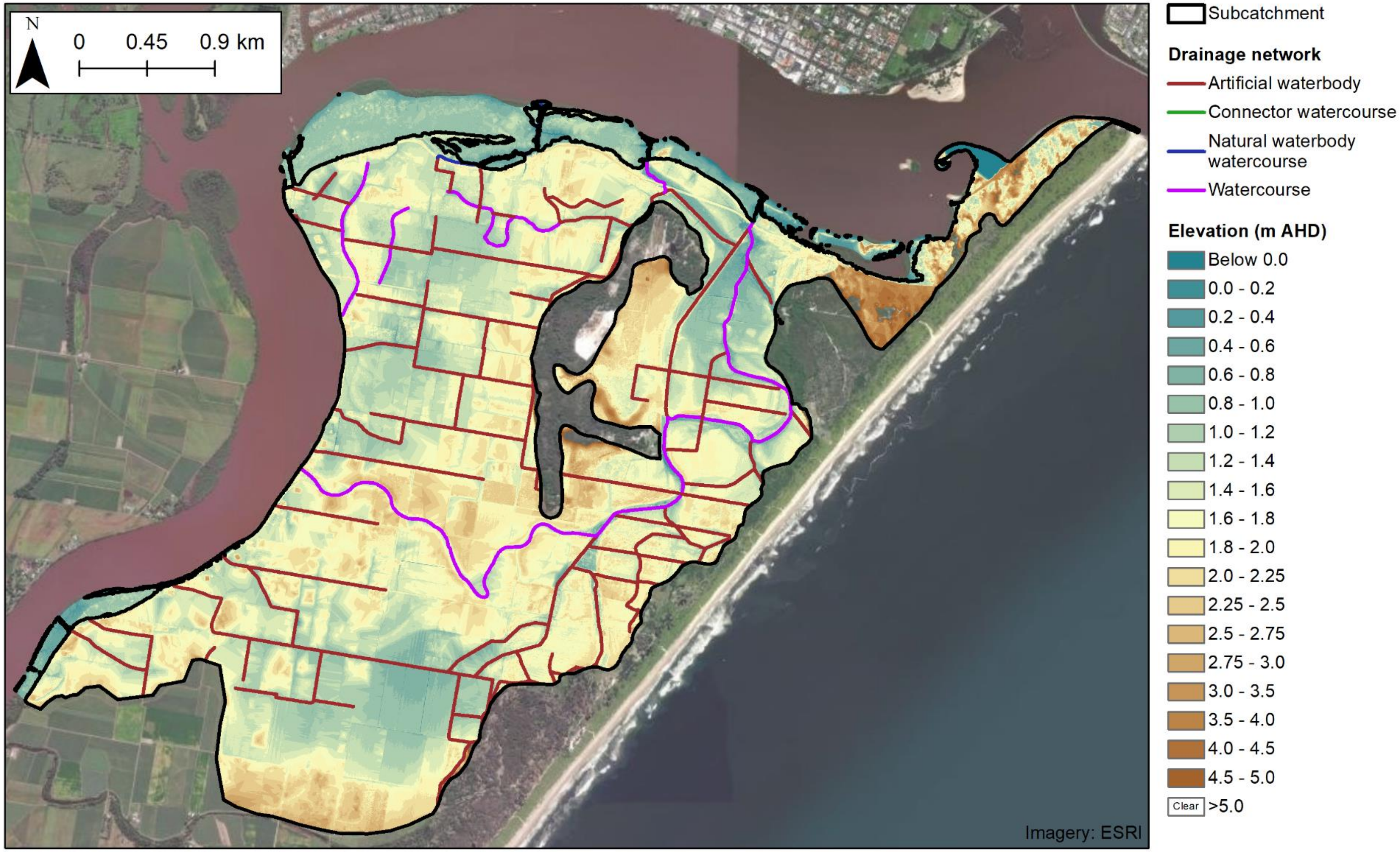

Figure 8-42: South Ballina subcatchment elevation and drainage network

8.9.2 History of remediation

There are 28 floodgates that connect the South Ballina subcatchment to the Richmond River. The majority of these are relatively small (e.g. 750 mm diameter culvert or smaller). Five (5) of the larger floodgates, identified in Figure 8-43, in the subcatchment have been modified with auto-tidal buoyancy gates to allow controlled tidal flushing and to improve connectivity for fish habitat. This includes the floodgate at the end of the Keith Hall drainage system (floodgate ID 10) which flows directly into Mobbs Bay which is fitted with one (1) buoyancy gate and one (1) sluice gate (shown in Figure 8-44).

RCC has recently been investigating ways to improve water quality in Mobbs Bay through the management of the Keith Hall drainage system. This has included a survey of the drains, soil profiles and water quality measurements (WRL, 2019). The main Keith Hall floodgate (floodgate ID 10) was fitted with two (2) auto-tidal gates until 2019, when RCC converted one of the gates to a sluice gate as part of a trial allowing additional tidal flushing. RCC's current active floodgate management plan states that this sluice is to be open 200 mm in non-flood times to improve flushing (Rous County Council, 2020b). Tucker et al. (2021) completed a study to identify options to improve water quality, while improving drainage efficiency and reducing maintenance requirements. This identified strategies including improved tidal flushing, reshaping of major drains and construction of an additional drain connecting Keith Hall Number 2 drain into Mobbs Bay.

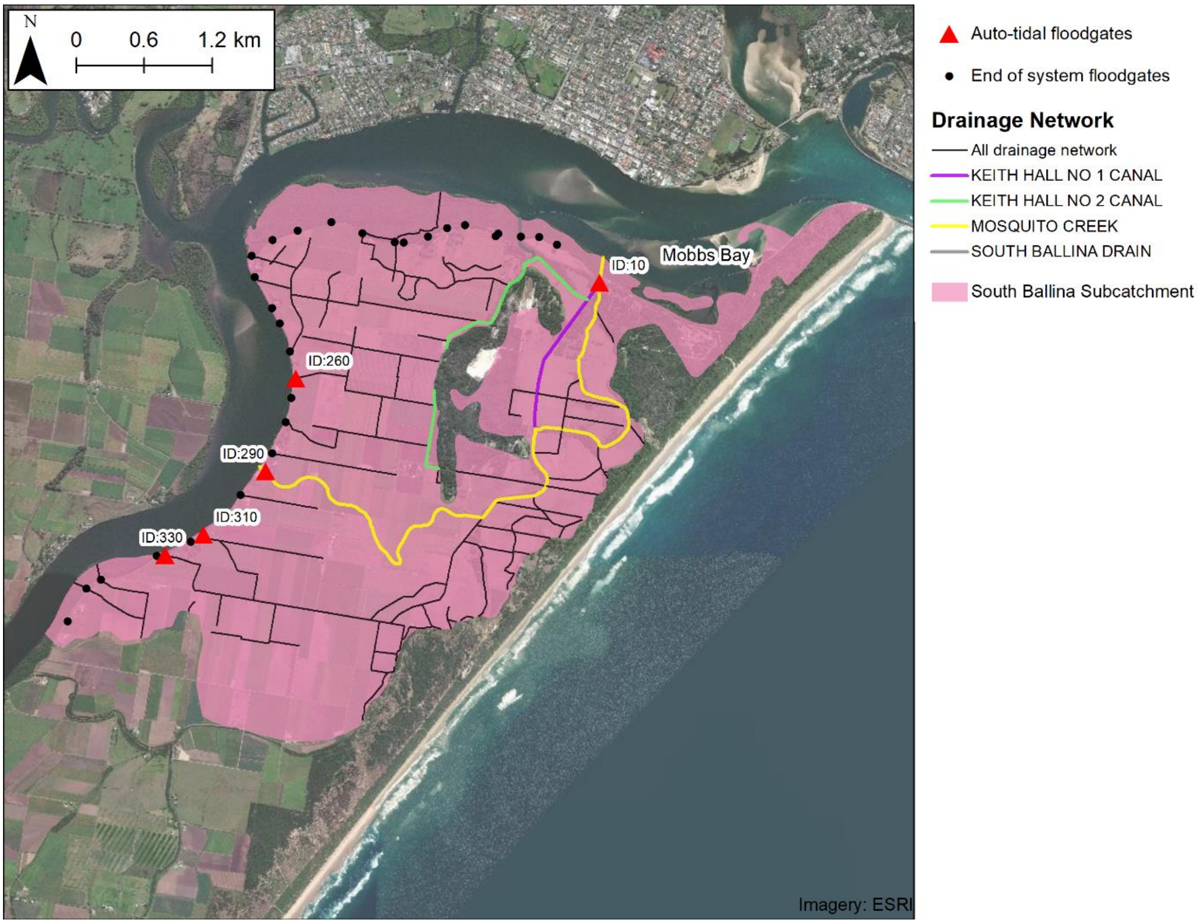

Figure 8-43: South Ballina subcatchment including previous remediation actions

Figure 8-44: Floodgate ID 10 – at the end of the Keith Hall Drainage system (Photo: WRL, 2020)

Sugar cane farms in the Richmond River floodplain operate in compliance with “The NSW sugar industry best practice guidelines for acid sulfate soils” (Sunshine Sugar, 2020). While details of specific drainage management on cane farms in the South Ballina subcatchment were not obtained, cane farms typically:

- Laser level farms to reduce the drainage density required to allow surface water drainage;
- Construct new drainage works that are designed to minimise the interaction with acidic soils; and
- Complete extensive liming.

8.9.3 Floodplain drainage – sea level rise vulnerability

Figure 8-45 summarises the floodplain and floodgate vulnerability to sea level rise in the South Ballina subcatchment. Many of the floodgates (17 out of 28) are considered ‘moderately vulnerable’ in present day sea levels, meaning that downstream water levels prevent drainage from these floodgates more than 5% of the time. This includes the major floodgate (ID 10) at the end of the Keith Hall drainage system shown in Figure 8-46. As discussed in Section 8.4.2, the majority of the floodgates in this subcatchment are small (<750 mm diameter) and provide local drainage on a paddock scale, however all five (5) of the larger modified floodgates (identified in Figure 8-43) are also classified as moderately vulnerable. All primary floodgates become ‘most vulnerable’ in the near future, along with 17 out of 25 secondary floodgates. All remaining secondary floodgates are classified as ‘moderately vulnerable’ in the far future. A classification of ‘most vulnerable’ indicates the top of the floodgate is underwater approximately half of the time, significantly reducing its efficiency. The infrastructure in the South Ballina subcatchment is likely to be a major restriction for drainage as sea levels continue to rise.

The topography of the South Ballina floodplain is mostly above 1 m AHD and not considered vulnerable to reduced drainage in the present day and near future. In the near future, the lowest sections of the Keith Hall drainage system may be affected by reduced drainage due to sea level rise. However, reduced drainage may become a widespread issue across the subcatchment in the far future scenario.

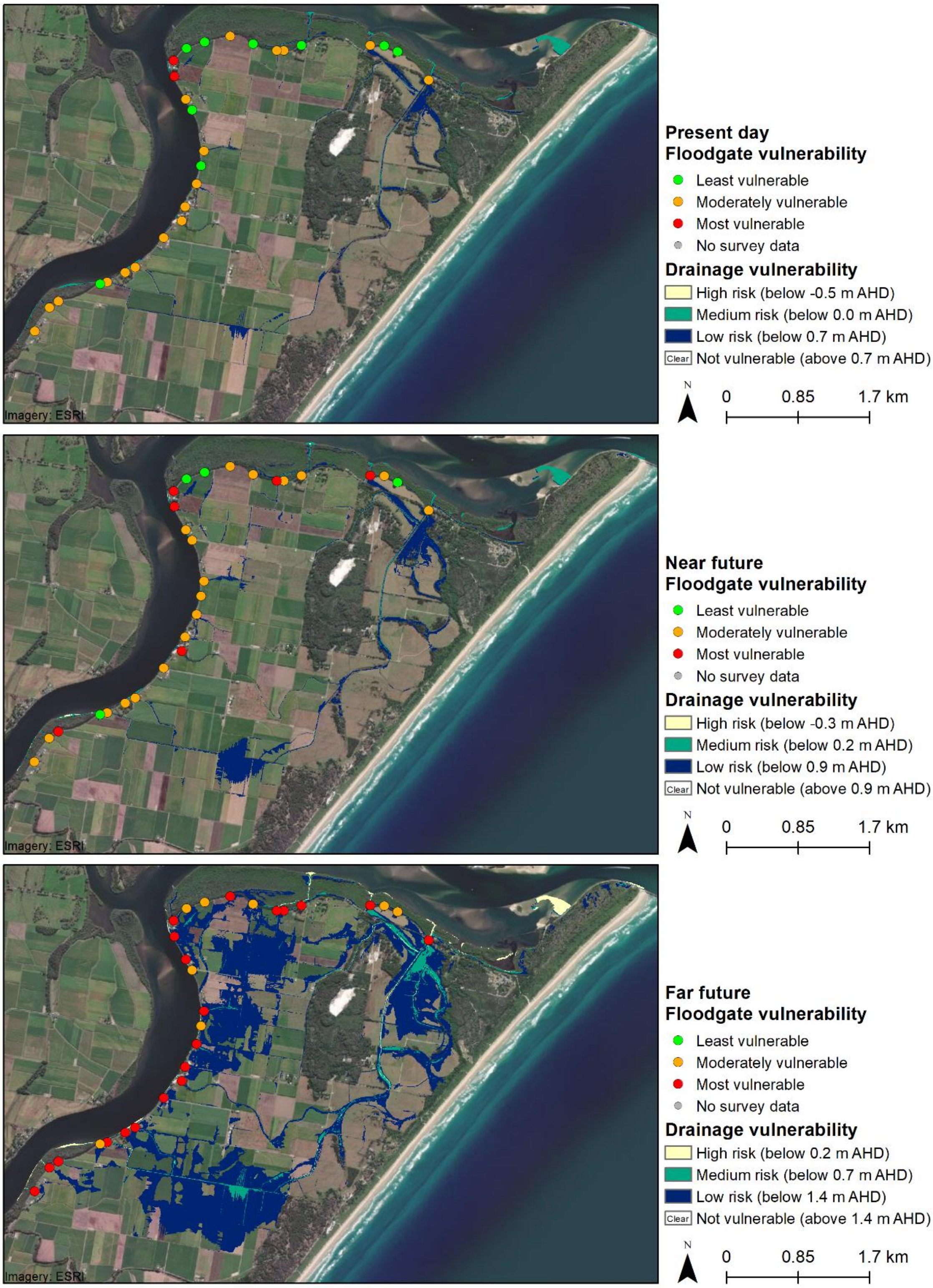

Figure 8-45: Sea level rise drainage vulnerability – South Ballina subcatchment

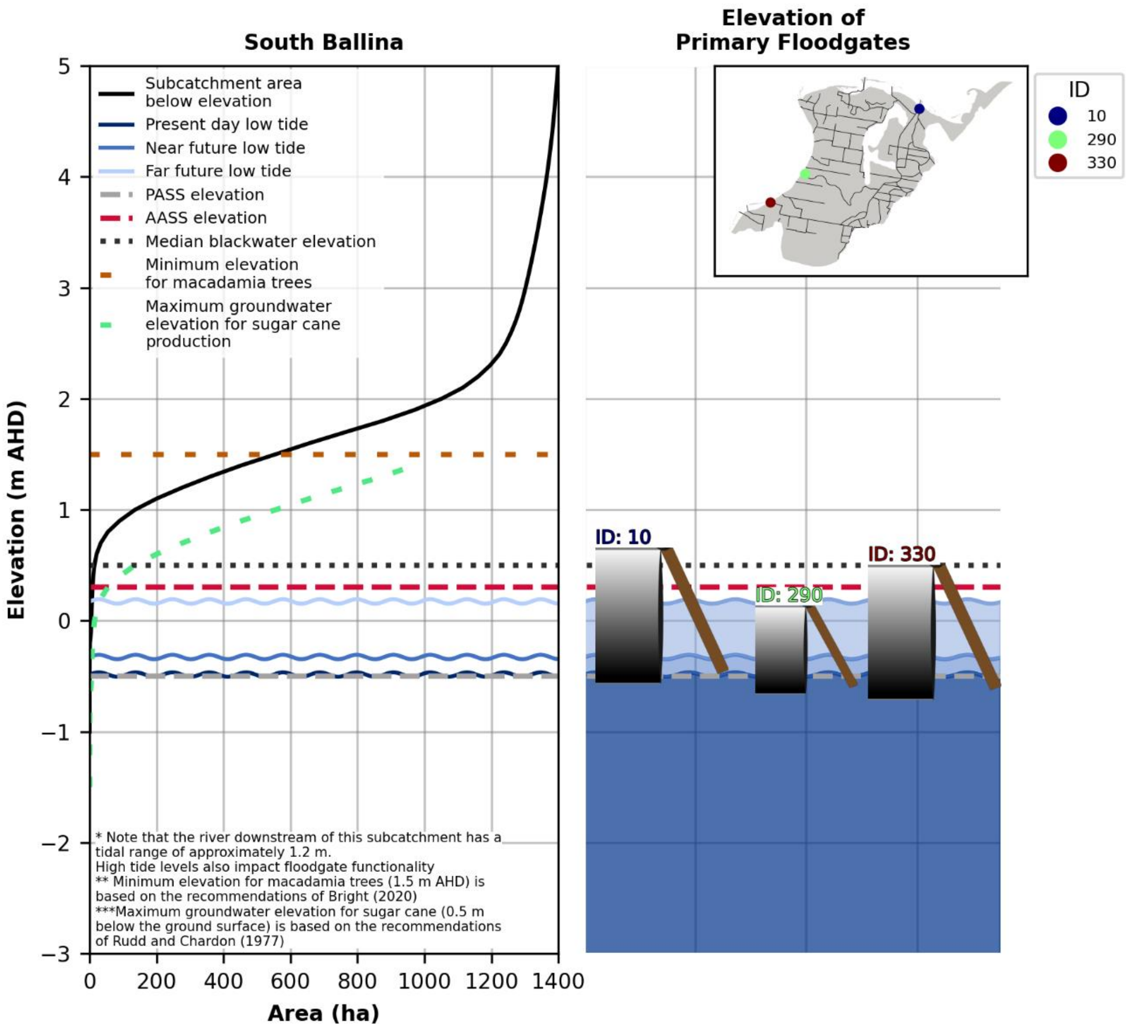

Figure 8-46: Primary floodgates and key floodplain elevations – South Ballina subcatchment

8.9.4 Management options

Short-term management options

Discharges from the Keith Hall drainage system flow into Mobbs Bay, which contains high ecological and community values. Poor water quality has been observed from Keith Hall, with potential impacts to Mobbs Bay. RCC is currently undertaking detailed investigations into the Keith Hall drainage system to improve water quality management of the area. Some of the suggested remediation options in the short-term include investigating increased tidal flushing through the floodgates 10, 290 and 330 which form an interconnected system through the drainage network. RCC has already trialled increased connectivity through floodgate 10 by modifying one of the existing buoyancy gates to a sluice gate. Depending on the success of this trial, further modifications to floodgates to increase tidal flushing will improve acid buffering and estuarine connectivity. In addition, options to infill or reshape the main drains in the subcatchment to the invert of the main infrastructure should be investigated to limit the drain interaction with acid soils and prevent groundwater drawdown.

Long-term management options

As discussed in Section 8.9.3, reduced drainage may impact current land uses in the South Ballina subcatchment. Where present day land uses are impacted, it is suggested that the opportunity to restore natural estuarine hydrology should be considered in low areas (below 1 m AHD). Any changes to the drainage system will need to be completed with consideration of the potential social and economic impacts on local landholders. This may include:

- Significant tidal flushing; and
- Redesigning the drainage network to low density, wide and shallow drains that enable tidal inundation of the lowest lying areas. There may be some opportunities to expand the area within the Richmond River Nature Reserve, which has significant intertidal habitat (including saltmarsh and mangroves) already.

Remaining floodgates are likely to be impacted by reduced drainage as a result of sea level rise. Adaptive management of these structures as they reach the end of their design lives by increasing the floodgate obvert, would provide improved resilience to changing sea levels.

Table 8.12: Summary of management options for South Ballina subcatchment

Timeframe	Strategy	Effectiveness at improving: Wetland habitat and fish passage	Effectiveness at improving: Impacts of ASS	Effectiveness at improving: Impacts of blackwater
Short-term	Floodgate management	Moderate	Moderate	Low
Short-term	Drain reshaping	Moderate	Moderate	Negligible
Long-term	Small scale restoration of estuarine hydrology	Low	Moderate	Moderate

8.10 Kilgin/Buckendoon subcatchment

Acid priority rank:	**8**
Blackwater priority rank:	**6**
Infrastructure	
Approximate waterway length (km)	67
# Privately owned end of system structures	0
# Publicly owned end of system structures	24
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (ID):	3120, 3170, 3370, 3390
Elevations	
Invert of primary floodplain infrastructure (m AHD):	-0.9 to -0.6
Approximate AASS elevation (m AHD)	0.6
Approximate PASS elevation (m AHD)	-0.6
Median blackwater elevation (m AHD)	1.5
Present day low water level (m AHD)	-0.31
Near future low water level (m AHD)	-0.15
Far future low level (m AHD)	0.34
Proximity to sensitive receivers	
Oyster leases (km)	20.7
Saltmarsh (km)	16.7
Seagrass (km)	24.4
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	0.2
Land use	
Total floodplain area (ha)	3,784
Classified as conservation and minimal use (ha (%))	52 (1%)
Classified as grazing (ha (%))	723 (23%)
Classified as forestry (ha (%))	0 (0%)
Classified as sugar cane (ha (%))	2,650 (70%)
Classified as horticulture (ha (%))	58 (1%)
Classified as other cropping (ha (%))	18 (0%)
Classified as urban/industrial/services (ha (%))	113 (3%)
Classified as marsh/wetland (ha (%))	70 (2%)
Other (ha (%))	100 (3%)
Land values	
Estimated total primary production value ($/year)	$5,500,000
Average land value above 1.7 m AHD ($/ha)	$11,600
Average land value below 1.7 m AHD ($/ha)	$7,500

8.10.1 Site description

The Kilgin/Buckendoon subcatchment discharges over a significant section of the left bank of the mid-upper Richmond River estuary, from Dungarubba to Wyrallah Road (Figure 8-47). The primary agricultural land use is sugar cane, although grazing also occurs in some of the lower lying areas. Figure 8-48 shows that while a large portion of the subcatchment is relatively high (above +1.5 m AHD), there is a distinct, low backswamp that is drained by Dungarubba Canal and Blazers Drain in the north-east of the subcatchment.

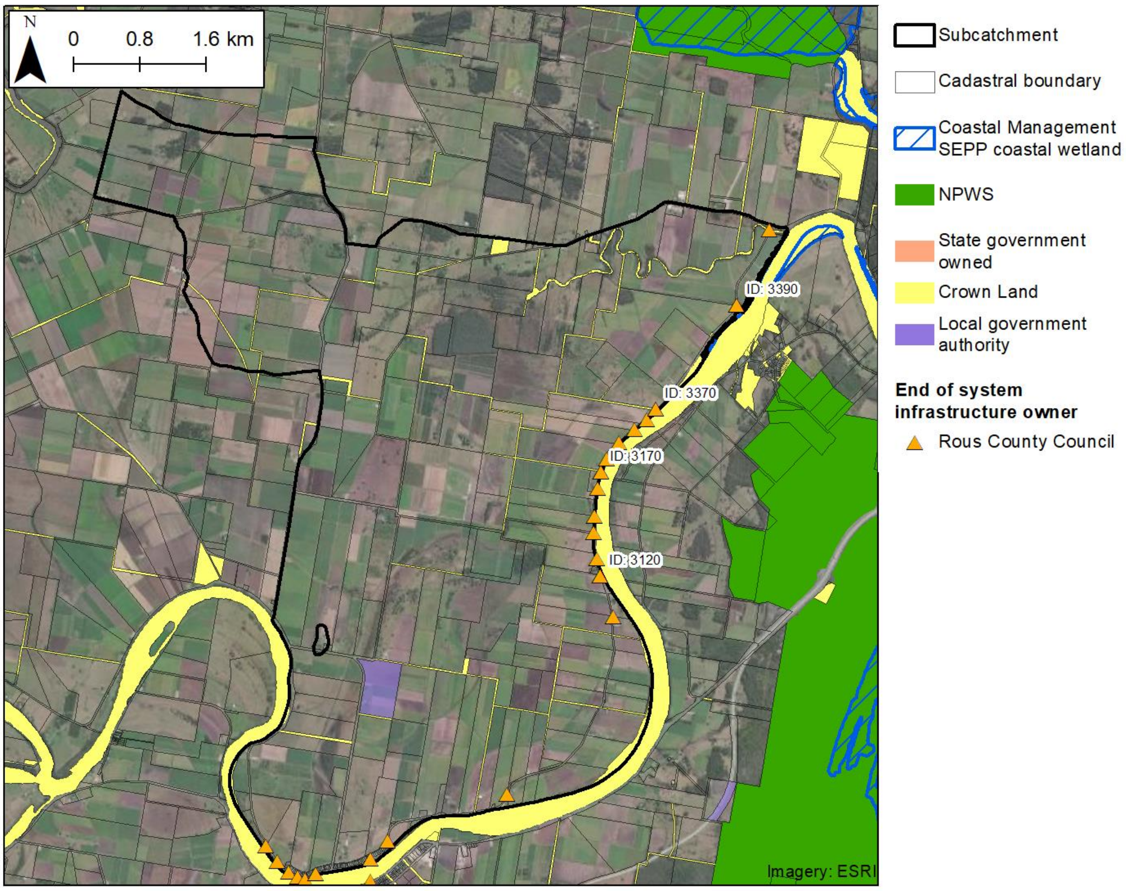

Figure 8-47: Kilgin/Buckendoon subcatchment – land and end of system infrastructure tenure

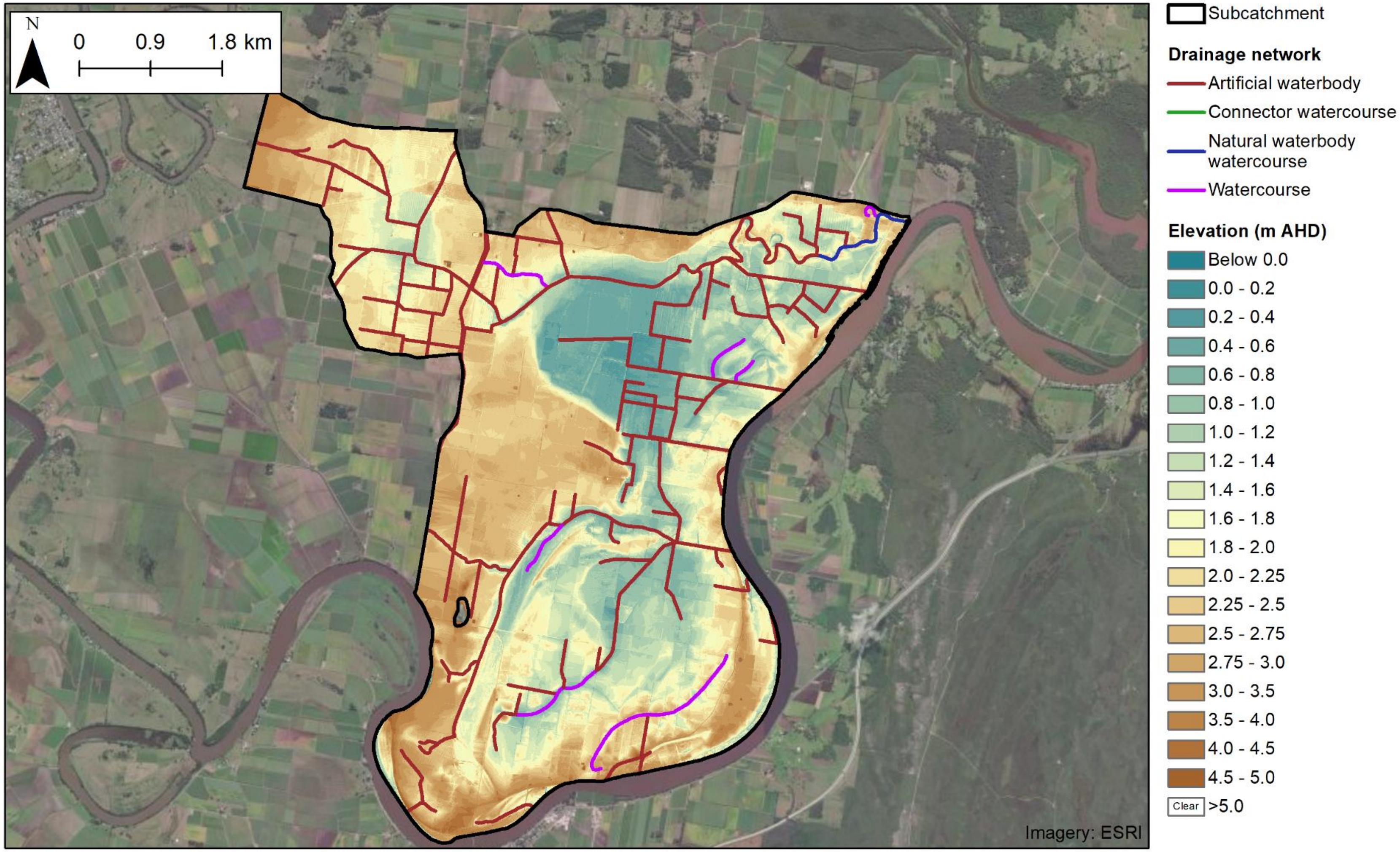

Figure 8-48: Kilgin/Buckendoon Creek elevation and drainage network

8.10.2 History of remediation

The Kilgin/Buckendoon subcatchment includes several large artificial drains and canals, shown in Figure 8-49, and Dungarubba Creek is the only major creek line in the subcatchment. Two (2) of the main floodgates have been modified to allow some tidal flushing, including:

- Floodgate ID 3510 on Dungarubba Creek which has a sluice gate; and
- Floodgate ID 3170 on Kilgin North Woodburn Canal, which has a sluice gate that is managed by a local landholder and predominantly kept open in non-flood periods (per comms J. Sykes).

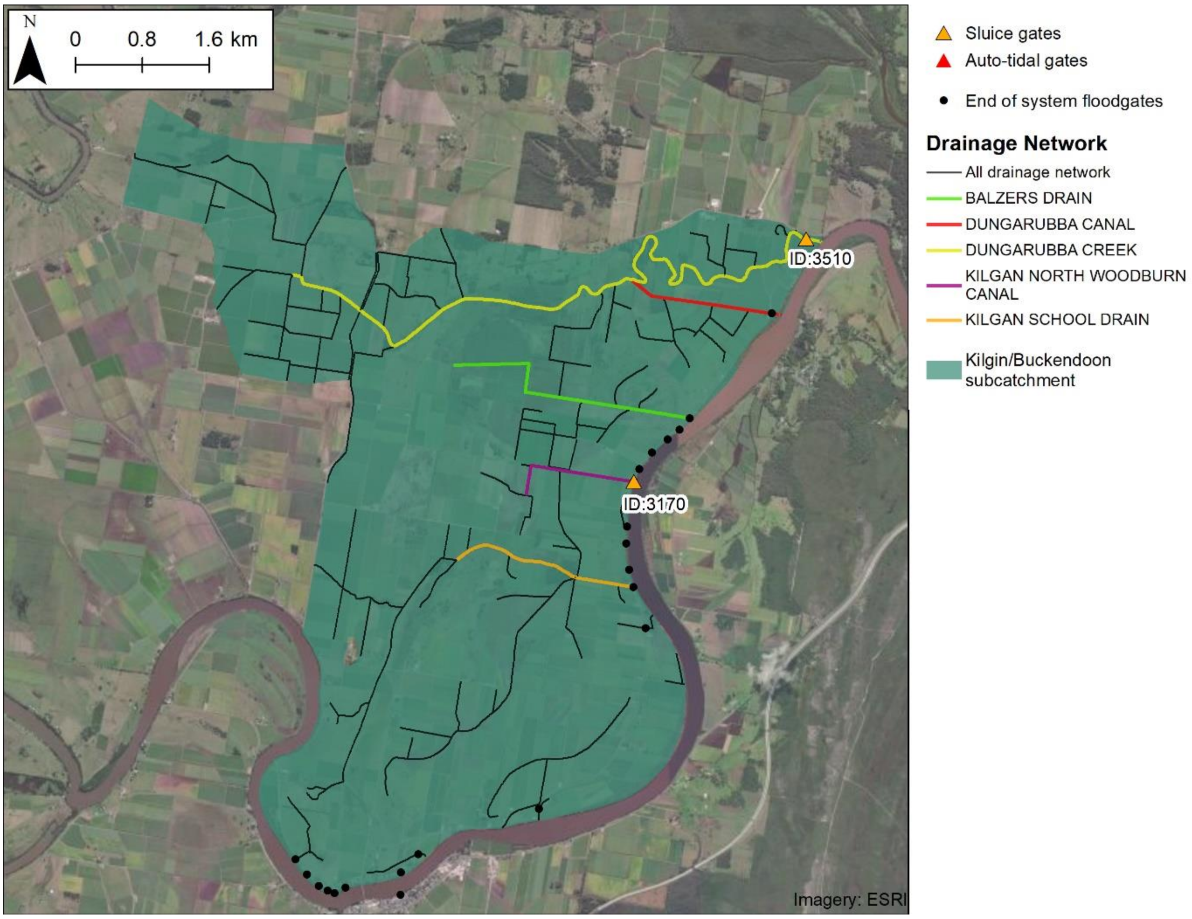

Figure 8-49: Kilgin/Buckendoon subcatchment including previous remediation actions

Sugar cane farms in the Richmond River floodplain operate in compliance with "The NSW sugar industry best practice guidelines for acid sulfate soils" (Sunshine Sugar, 2020). While details of specific drainage management on cane farms in the Kilgin/Buckendoon subcatchment were not obtained, cane farms typically:

- Laser level farms to reduce the drainage density required to allow surface water drainage;
- Construct new drainage works that are designed to minimise the interaction with acidic soils; and
- Complete extensive liming.

8.10.3 Floodplain drainage – sea level rise vulnerability

The floodplain and floodgate vulnerability to sea level rise in the Kilgin/Buckendoon subcatchment is summarised in Figure 8-50. The low area drained by Balzers Drains and Dungarubba Canal on the northern side of the subcatchment is the only area at low risk of reduced drainage under present day conditions and the near future sea level rise scenario. This area is predicted to be below the 50^{th} percentile water levels (moderate risk) in the far future, indicating that this area will become increasingly susceptible to reduced drainage into the future.

Several of the primary floodgates in the Kilgin/Buckendoon subcatchment will be impacted by reduced drainage in the near to far future, as shown in Figure 8-51. The floodgate on Balzers Drains (floodgate ID 3370) has been identified as the most vulnerable primary infrastructure in this subcatchment. Reduced drainage efficiency of infrastructure will impact drainage from the low areas of this subcatchment.

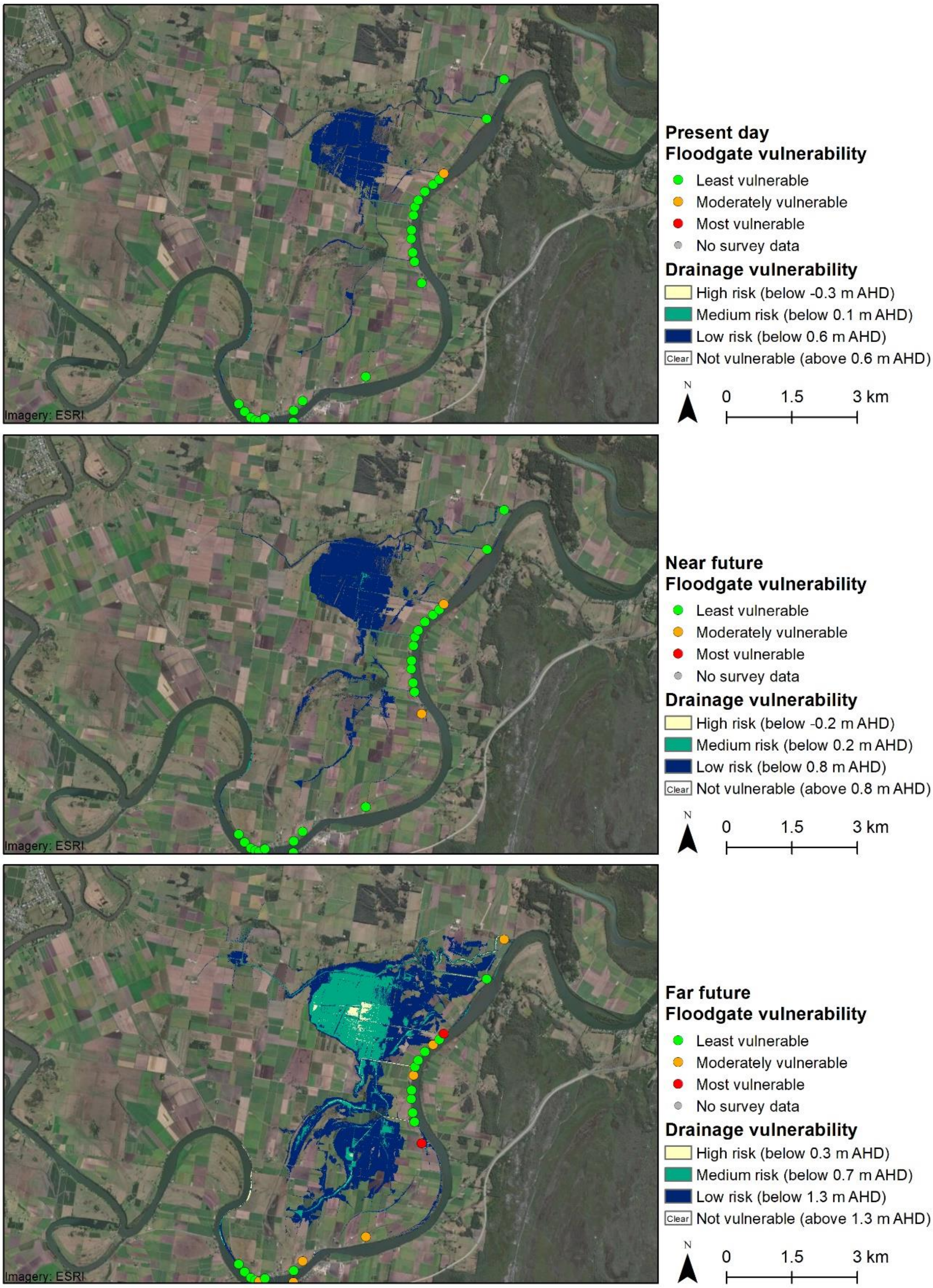

Figure 8-50: Sea level rise drainage vulnerability – Kilgin/Buckendoon subcatchment

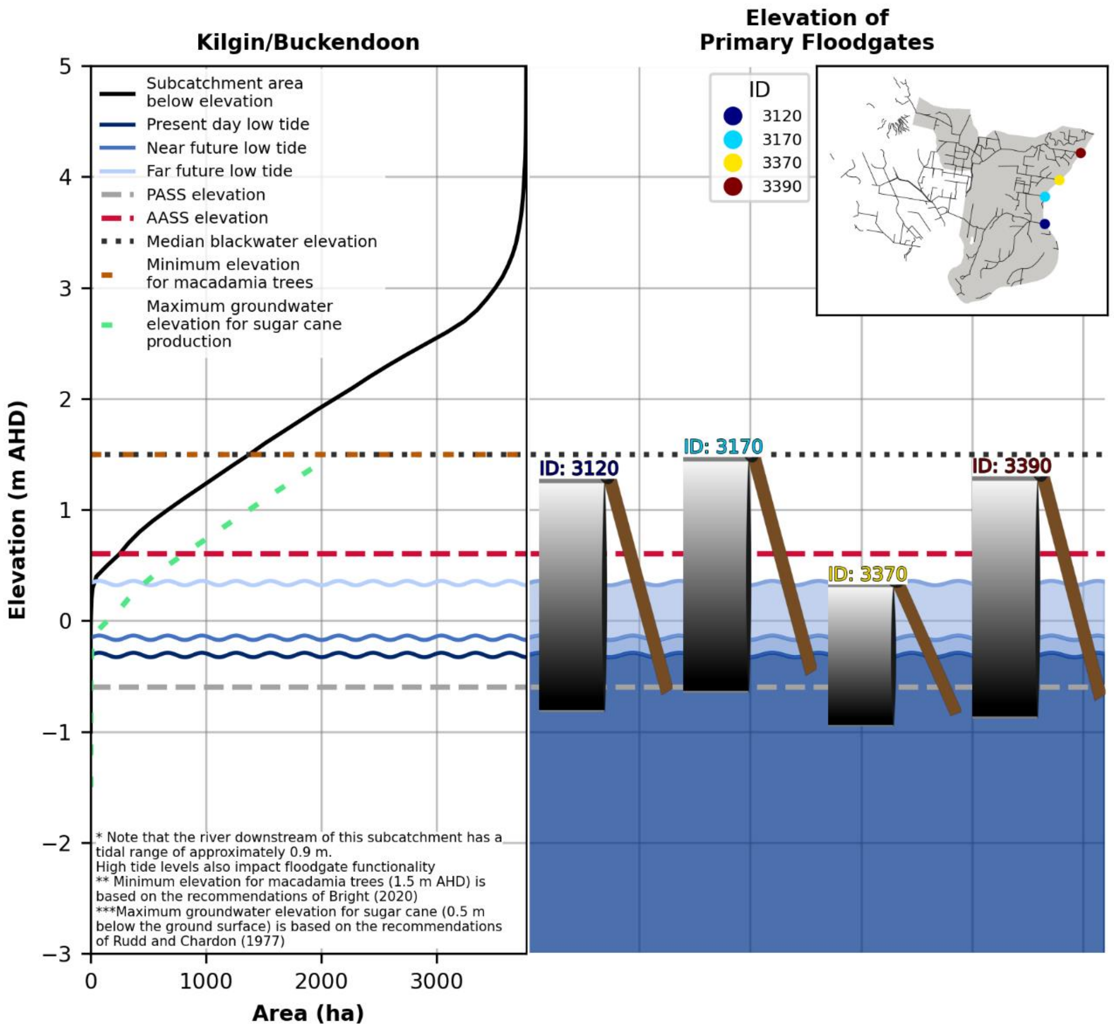

Figure 8-51: Primary floodgates and key floodplain elevations – Kilgin/Buckendoon subcatchment

8.10.4 Management options

Short-term management options

RCC has already modified two (2) floodgates in this subcatchment, and in the short term, it is suggested that additional tidal flushing via floodgate modification is considered in other drains within the Kilgin/Buckendoon subcatchment. This is particularly recommended on the major drains and waterways to improve water quality and increase fish habitat. Modifications may include auto-tidal gates buoyancy gates or sluice gates. Connectivity and potential impacts to low-lying elevation land should be considered and land holder consultation would be required to implement any changes.

Where possible, the invert of secondary floodplains drains in the lowest areas should be increased to encourage higher water tables and a change of vegetation towards native water tolerant species. Note that this may also impact present day land uses, and should only be completed with an adequate plan to mitigate impacts to local landholders.

Long-term management options

Reduced drainage may impact present day land uses in the near-to-far future in the low-lying areas of this subcatchment. In the near future, wet pasture may allow continued agricultural productivity which could be achieved by infilling secondary drains and encouraging water tolerant grasses. However, previous experience in the Richmond River has shown wet pasture management has had limited success at maintain agricultural productivity.

Long-term agricultural productivity in this area may decline into the future as average water levels in the estuary rise. If this occurs, the natural hydrology of the floodplain could be restored in the lowest areas (e.g. below +0.7 m AHD) to gain the greatest ecological outcomes. While some drains will be required to continue to operate as flood mitigation drains, there may be opportunities to redesign major drains to be shallower and wider, with the majority of non-flood flows to be redirected via the natural watercourses where possible. This would reduce the connectivity of the low-lying area with the main river and reduce the risk of regular blackwater discharges from this subcatchment as water tolerant vegetation would establish in areas subjected to prolonged inundation. Any changes in hydrology will require extensive studies into the impacts to flooding and land uses and should only be implemented with extensive consultation of local landholders and extensive consideration of the social and economic impacts of such changes.

Table 8.13: Summary of management options for Kilgin/Buckendoon River

Timeframe	Strategy	Effectiveness at improving: Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Improve tidal flushing	Moderate	Moderate	Negligible
Short-term	Drain reshaping	None	Moderate	Low
Long-term	Restoration of natural hydrology	Limited	High	High

8.11 East Coraki subcatchment

Acid priority rank:	**7**
Blackwater priority rank:	**4**
Infrastructure	
Approximate waterway length (km)	80
# Privately owned end of system structures	0
# Publicly owned end of system structures	27
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (ID):	2940, 2960, 2970, 2980
Elevations	
Invert of primary floodplain infrastructure (m AHD):	-0.8 to -0.2
Approximate AASS elevation (m AHD)	1.1
Approximate PASS elevation (m AHD)	0.5
Median blackwater elevation (m AHD)	2.5
Present day low water level (m AHD)	-0.25
Near future low water level (m AHD)	-0.10
Far future low level (m AHD)	0.39
Proximity to sensitive receivers	
Oyster leases (km)	31.3
Saltmarsh (km)	27.3
Seagrass (km)	35.0
Mangroves (km)	1.5
Coastal Management SEPP coastal wetlands (km)	8.8
Land use	
Total floodplain area (ha)	2,893
Classified as conservation and minimal use (ha (%))	5 (0%)
Classified as grazing (ha (%))	740 (26%)
Classified as forestry (ha (%))	4 (0%)
Classified as sugar cane (ha (%))	1,803 (62%)
Classified as horticulture (ha (%))	1 (0%)
Classified as other cropping (ha (%))	**8** (0%)
Classified as urban/industrial/services (ha (%))	77 (3%)
Classified as marsh/wetland (ha (%))	15 (1%)
Other (ha (%))	242 (8%)
Land values	
Estimated total primary production value ($/year)	$3,500,000
Average land value above 1.7 m AHD ($/ha)	$12,400
Average land value below 1.7 m AHD ($/ha)	$7,500

8.11.1 Site description

The East Coraki subcatchment discharges over a significant section of the left bank of the mid-upper Richmond River estuary, from Wyrallah Road to Coraki (Figure 8-47). The primary agricultural land use is sugar cane. Although topographic data (Figure 8-48) shows that a significant portion of the subcatchment is relatively high (above +1.5 m AHD), there are some low-lying drained areas within the subcatchment. This subcatchment ranked fourth in the blackwater prioritisation, however the small upstream catchment means that the risk of blackwater from smaller rain events may be over-estimated. The risk of blackwater generation from large scale blackwater events is still potentially significant from this subcatchment.

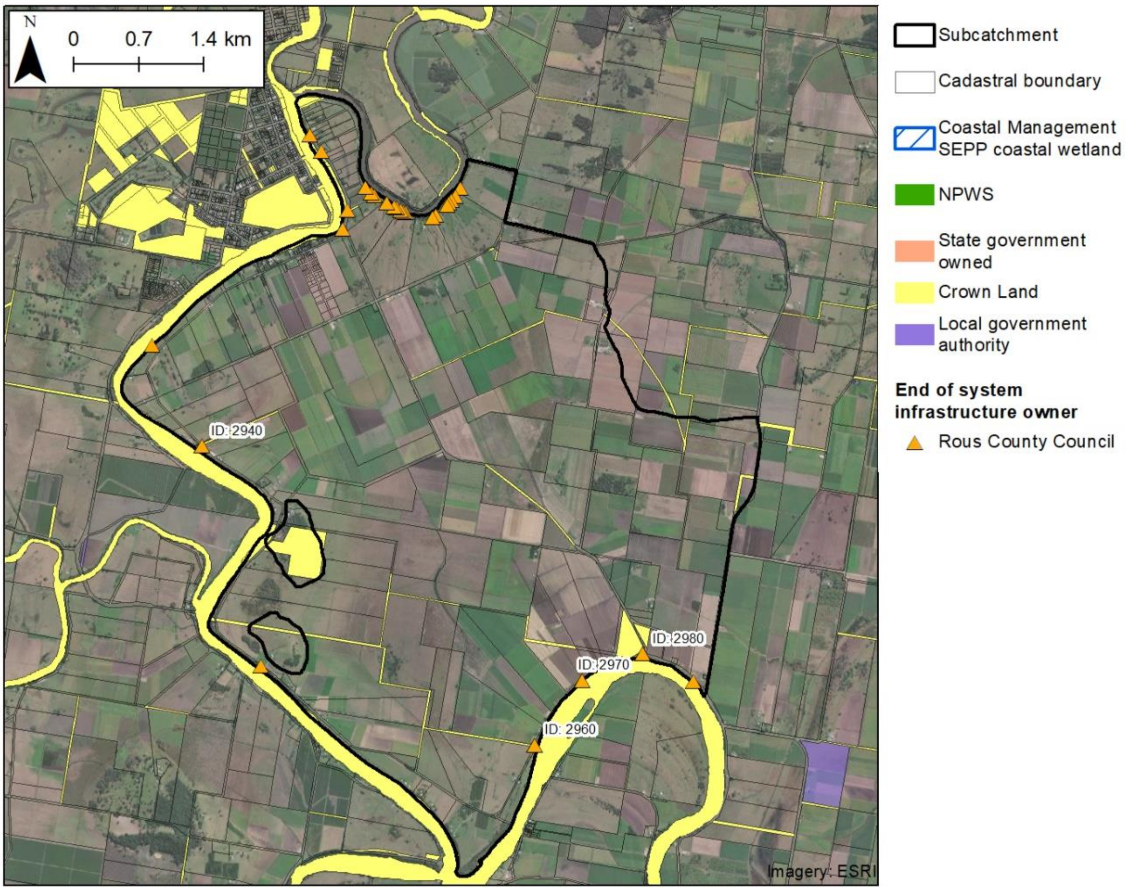

Figure 8-52: East Coraki subcatchment – land and end of system infrastructure tenure

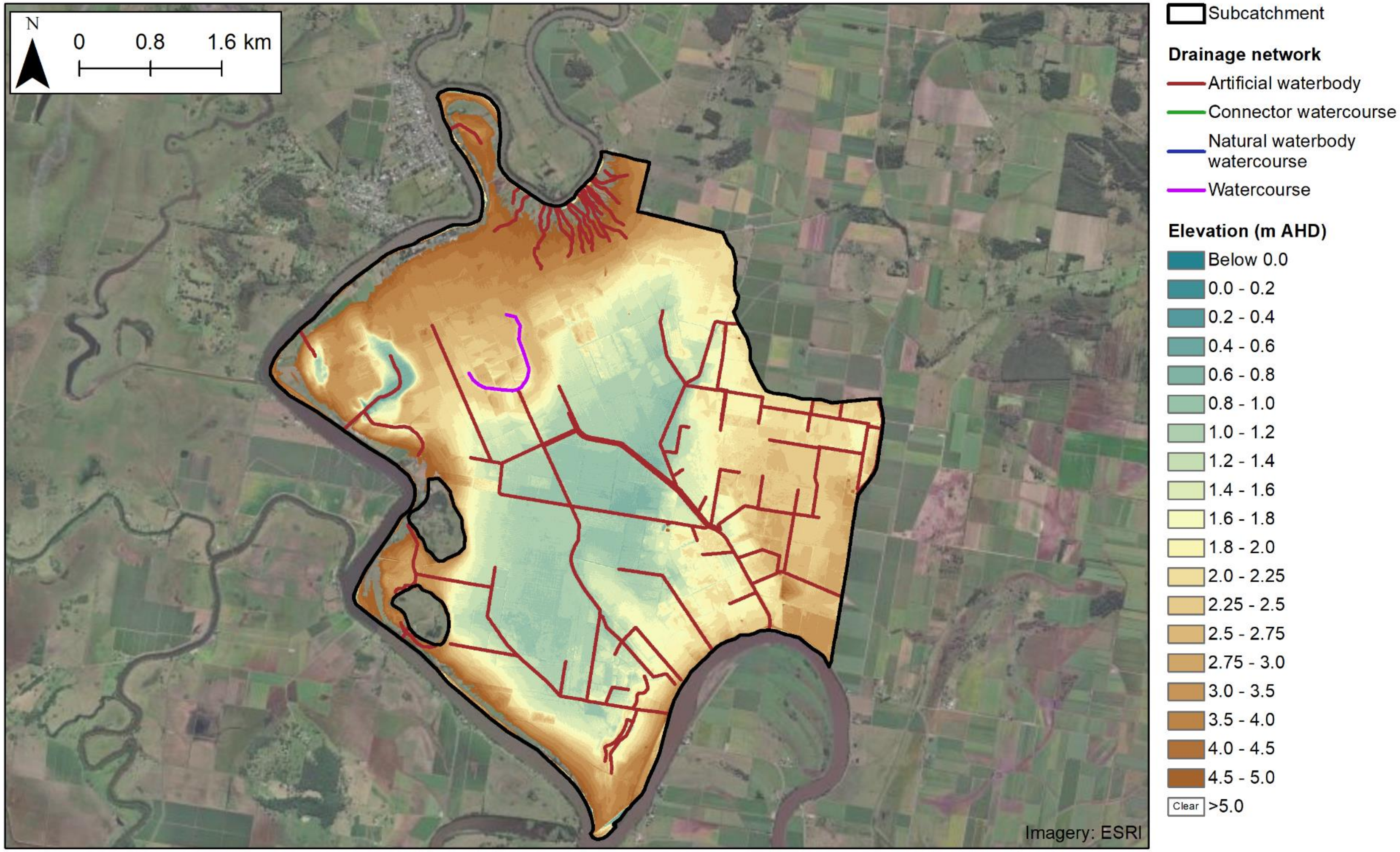

Figure 8-53: East Coraki elevation and drainage network

8.11.2 History of remediation

The East Coraki subcatchment includes several large artificial drains and canals, shown in Figure 8-49, and with minimal natural drainage. Three (3) of the main floodgates have been modified to allow some tidal flushing, including:

- Floodgate ID 2980 on Yeagers Drain, which has a sluice gate;
- Floodgate ID 2960 on McPhersons Canal, which has a sluice gate; and
- Floodgate ID 2970 on O'Connors Canal, which has an auto-tidal buoyancy gate.

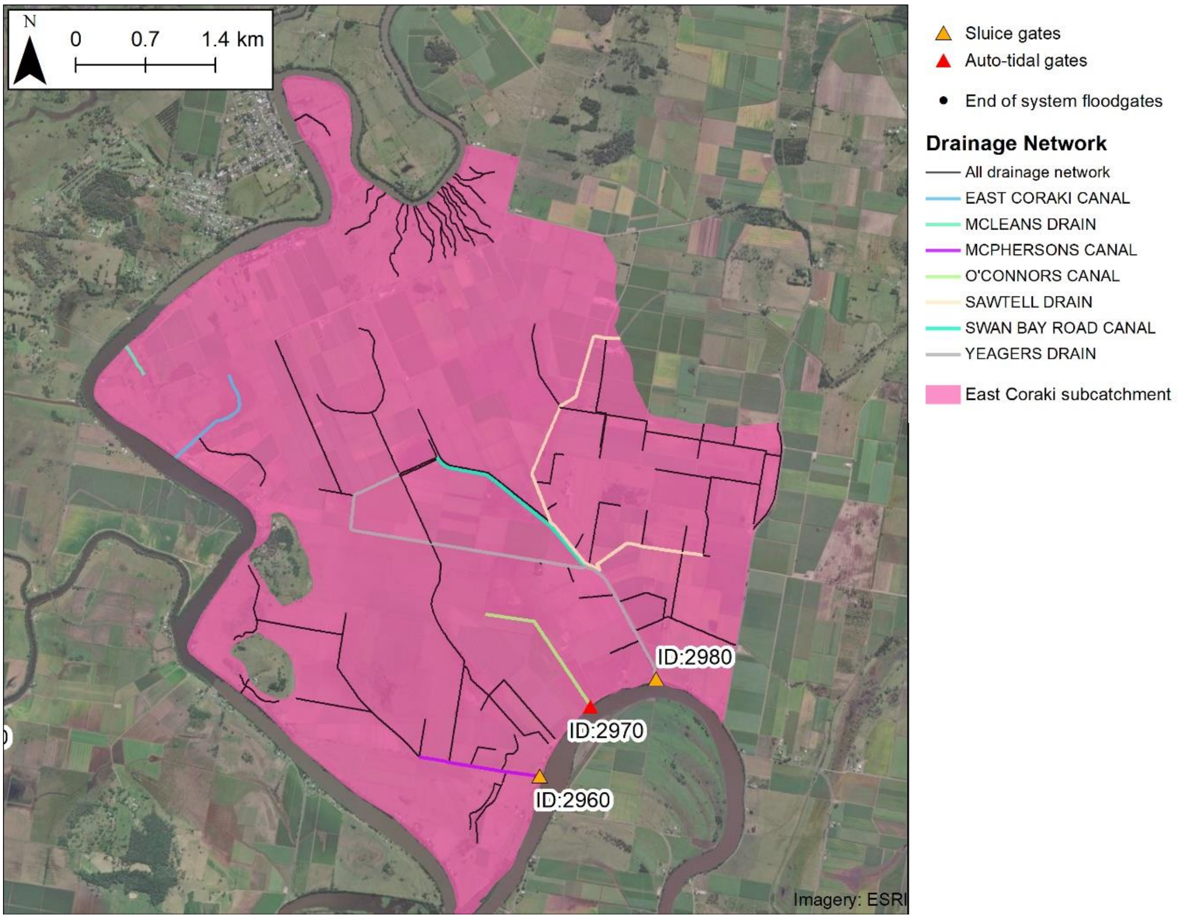

Figure 8-54: East Coraki subcatchment including previous remediation actions

Sugar cane farms in the Richmond River floodplain operate in compliance with "The NSW sugar industry best practice guidelines for acid sulfate soils" (Sunshine Sugar, 2020). While details of specific drainage management on cane farms in the East Coraki subcatchment were not obtained, cane farms typically:

- Laser level farms to reduce the drainage density required to allow surface water drainage;
- Construct new drainage works that are designed to minimise the interaction with acidic soils; and
- Complete extensive liming.

8.11.3 Floodplain drainage – sea level rise vulnerability

The floodplain and floodgate vulnerability to sea level rise in the Kilgin/Buckendoon subcatchment is summarised in Figure 8-50. A large, low lying area on the southern side of the subcatchment drained by Yeager Drain begins to be classified as low risk for reduced drainage as sea levels continue to rise.

The floodgates in the East Coraki subcatchment are generally relatively large and high, as shown in Figure 8-51. All but two (2) floodgates are classified as least vulnerable in the far future, except floodgate 2930 which is most vulnerable and floodgate 2970 which is moderately vulnerable.

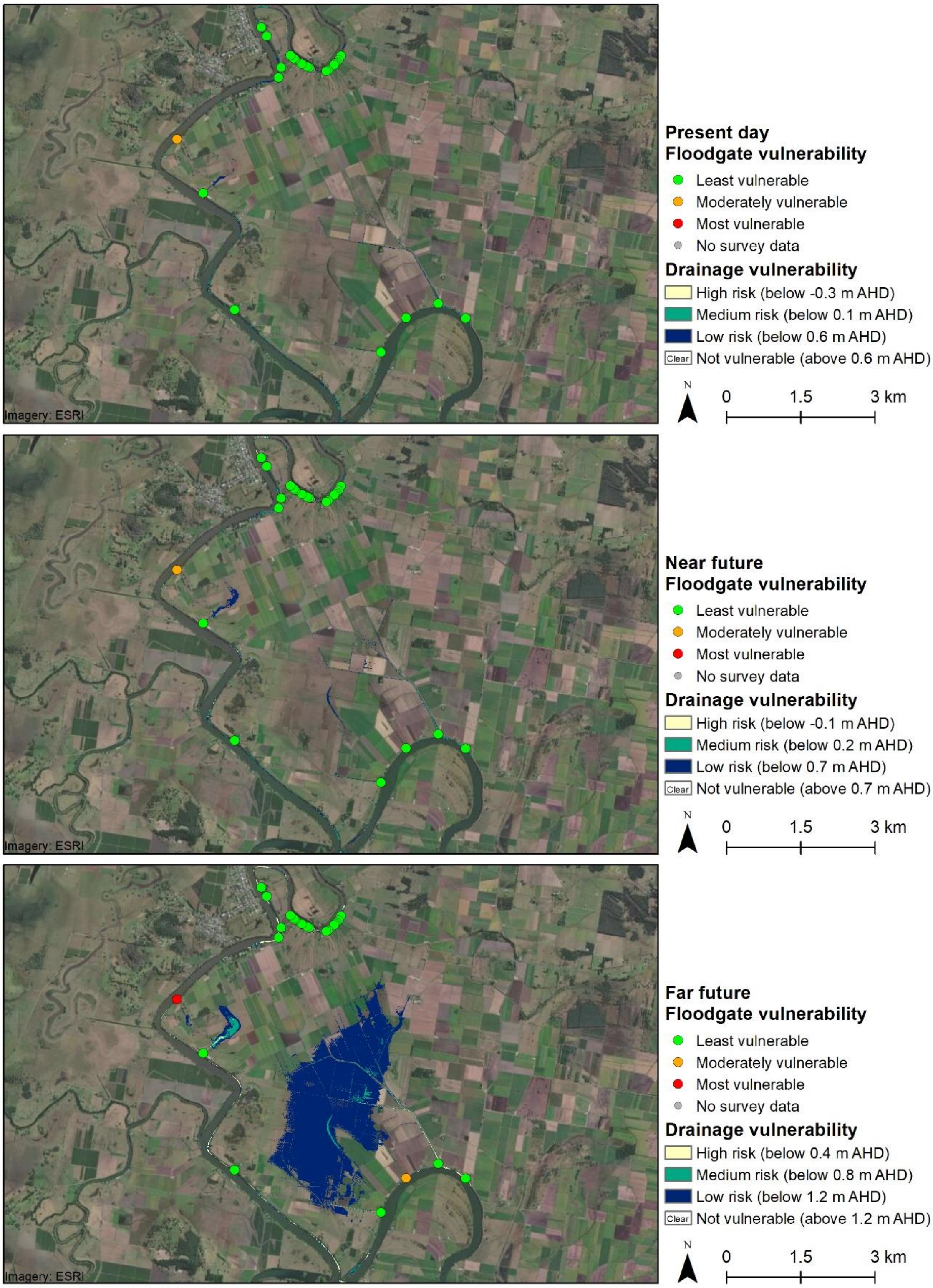

Figure 8-55: Sea level rise drainage vulnerability – East Coraki subcatchment

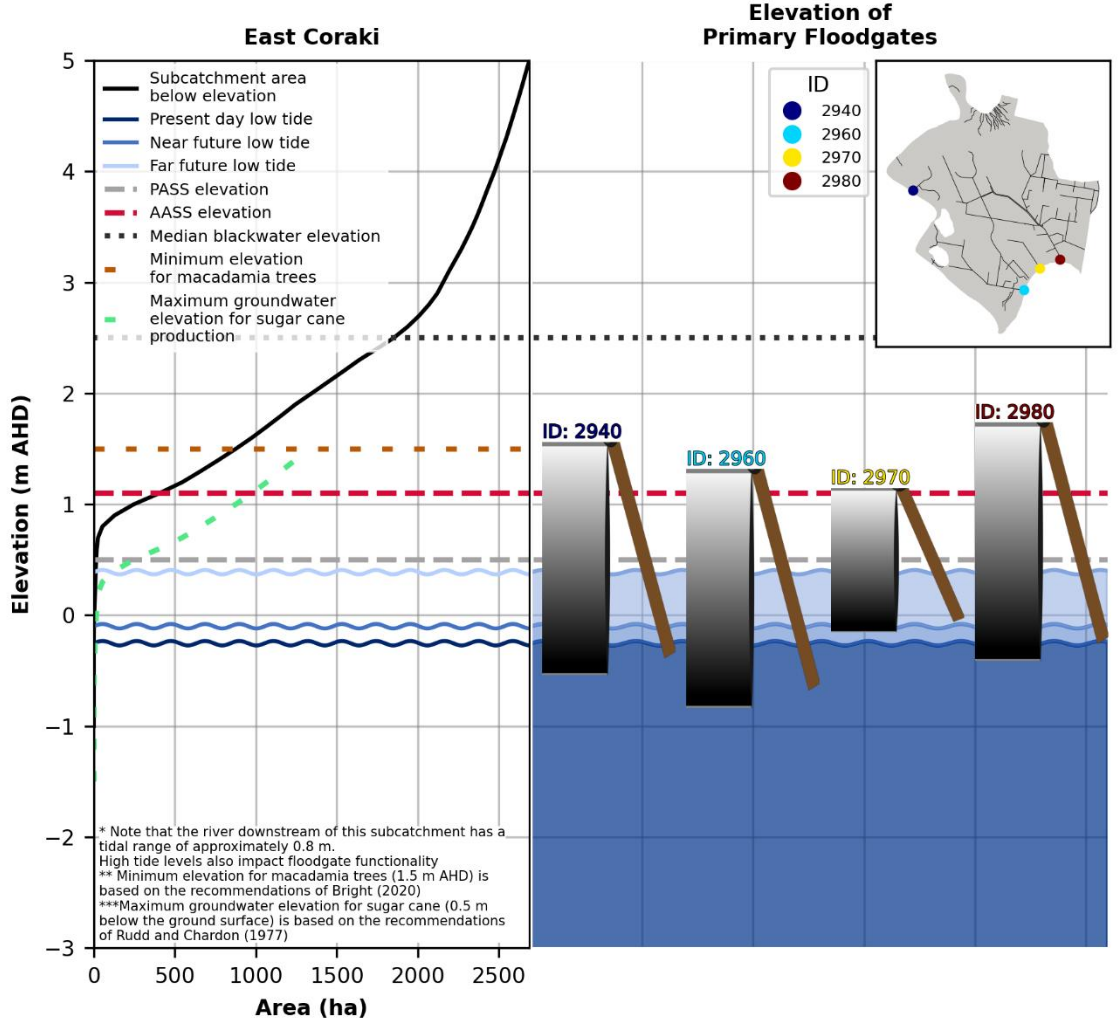

Figure 8-56: Primary floodgates and key floodplain elevations – East Coraki subcatchment

8.11.4 Management options

Short-term management options

Floodgate modifications have been completed by RCC on all three (3) major floodgates in this subcatchment and are managed in accordance with a floodgate management plan. Continued encouragement of tidal flushing and connectivity is recommended, and where possible further modifications maybe able to be considered. Active floodgate management should continue to address the concerns of local landholders (e.g. shutting prior to possible flood events), while maximising flushing where possible.

Long-term management options

Long-term agricultural productivity in the lowest areas of this subcatchment (below +0.7 m AHD) maybe impacted by reduced drainage as a result of sea level rise. Where this occurs, there may be opportunities to restore the natural backswamp hydrology in the low areas of East Coraki. This may include:

- Drain infilling;
- Floodwater retention; and
- Restoration of natural levees.

Note that any changes in hydrology will require investigation into the impacts to flooding and land use and should only be implemented with extensive consultation of local landholders and extensive consideration of the social and economic impacts of such changes. By facilitating prolonged drainage and an increased time of inundation, carbon cycle processes that occur when organic matter decomposes would be able to be completed, which would substantially reduce the impact of blackwater drainage from this subcatchment.

Table 8.14: Summary of management options for East Coraki River

Timeframe	Strategy	Effectiveness at improving: Wetland habitat and fish passage	Effectiveness at improving: Impacts of ASS	Effectiveness at improving: Impacts of blackwater
Short-term	Floodgate management	Moderate	Moderate	Negligible
Long-term	Restoration of natural backswamp hydrology	Limited	High	High

8.12 Empire Vale subcatchment

Acid priority rank:	**10**
Blackwater priority rank:	**11**
<u>Infrastructure</u>	
Approximate waterway length (km)	104
# Privately owned end of system structures	0
# Publicly owned end of system structures	59
# End of system structures within coastal wetlands	3
# Publicly owned end of system structures within coastal wetlands	3
Primary floodplain infrastructure (ID):	390, 540, 620, 690, 1040, 1080, 1200
<u>Elevations</u>	
Invert of primary floodplain infrastructure (m AHD):	-1.1 to -0.5
Approximate AASS elevation (m AHD)	0.5
Approximate PASS elevation (m AHD)	-0.2
Median blackwater elevation (m AHD)	0.5
Present day low water level (m AHD)	-0.38
Near future low water level (m AHD)	-0.22
Far future low level (m AHD)	0.27
<u>Proximity to sensitive receivers</u>	
Oyster leases (km)	1.1
Saltmarsh (km)	Within subcatchment
Seagrass (km)	4.9
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
<u>Land use</u>	
Total floodplain area (ha)	3,761
Classified as conservation and minimal use (ha (%))	411 (11%)
Classified as grazing (ha (%))	231 (6%)
Classified as forestry (ha (%))	0 (0%)
Classified as sugar cane (ha (%))	2,802 (74%)
Classified as horticulture (ha (%))	13 (0%)
Classified as other cropping (ha (%))	8 (0%)
Classified as urban/industrial/services (ha (%))	170 (5%)
Classified as marsh/wetland (ha (%))	4 (0%)
Other (ha (%))	121 (3%)
<u>Land values</u>	
Estimated total primary production value ($/year)	$5,100,000
Average land value above 0.5 m AHD ($/ha)	$18,100
Average land value below 0.5 m AHD ($/ha)	No property data available

8.12.1 Site description

The Empire Vale subcatchment is located in the lower Richmond River estuary between the towns of Broadwater in the south-west and Empire Vale in the north-east. The subcatchment lies between the Richmond River in the west and the Pacific Ocean in the east, and is shown in Figure 8-57. Sugar cane is the primary agricultural land use in the subcatchment, covering 74% of the area.

As shown in Figure 8-58, the majority of the subcatchment is above +1.5 m AHD and generally well drained, although there are localised low areas. While there is a substantial artificial drainage network, there are also several natural watercourses that flow through the subcatchment.

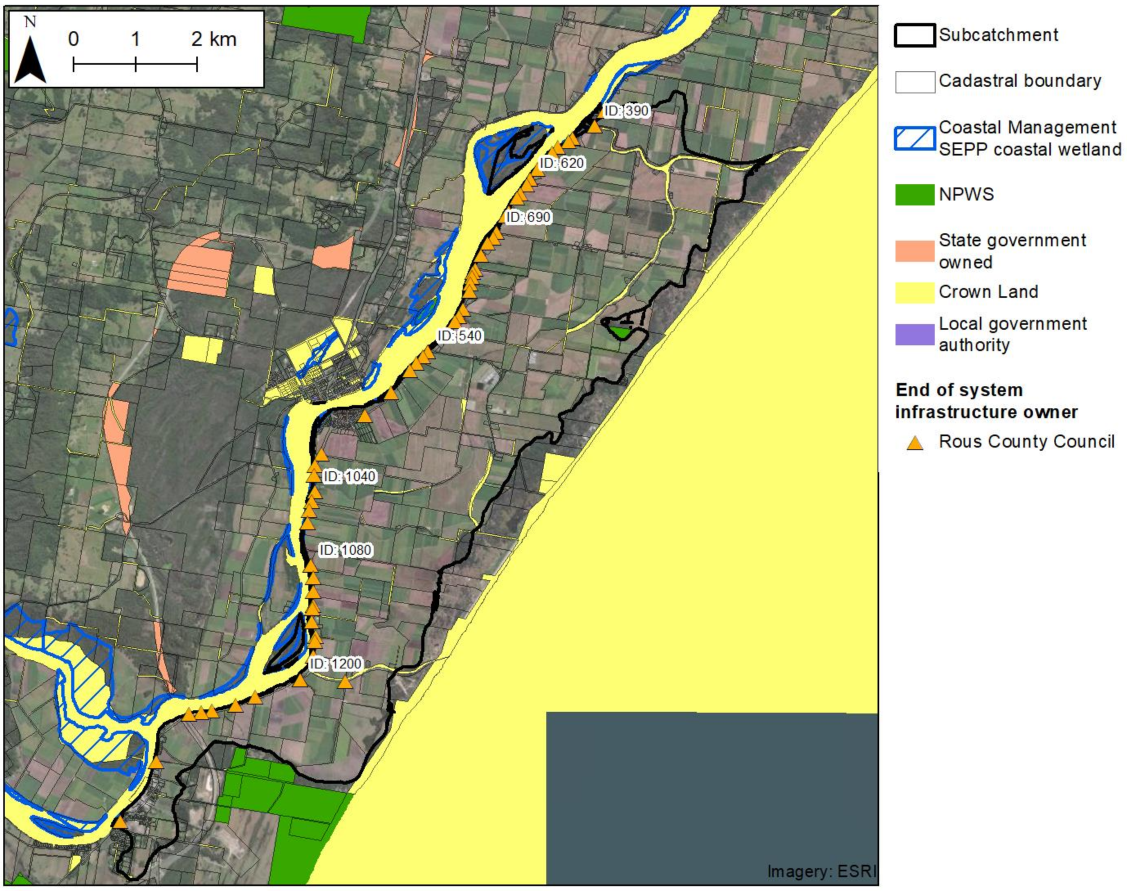

Figure 8-57: Empire Vale subcatchment - land and end of system infrastructure tenure

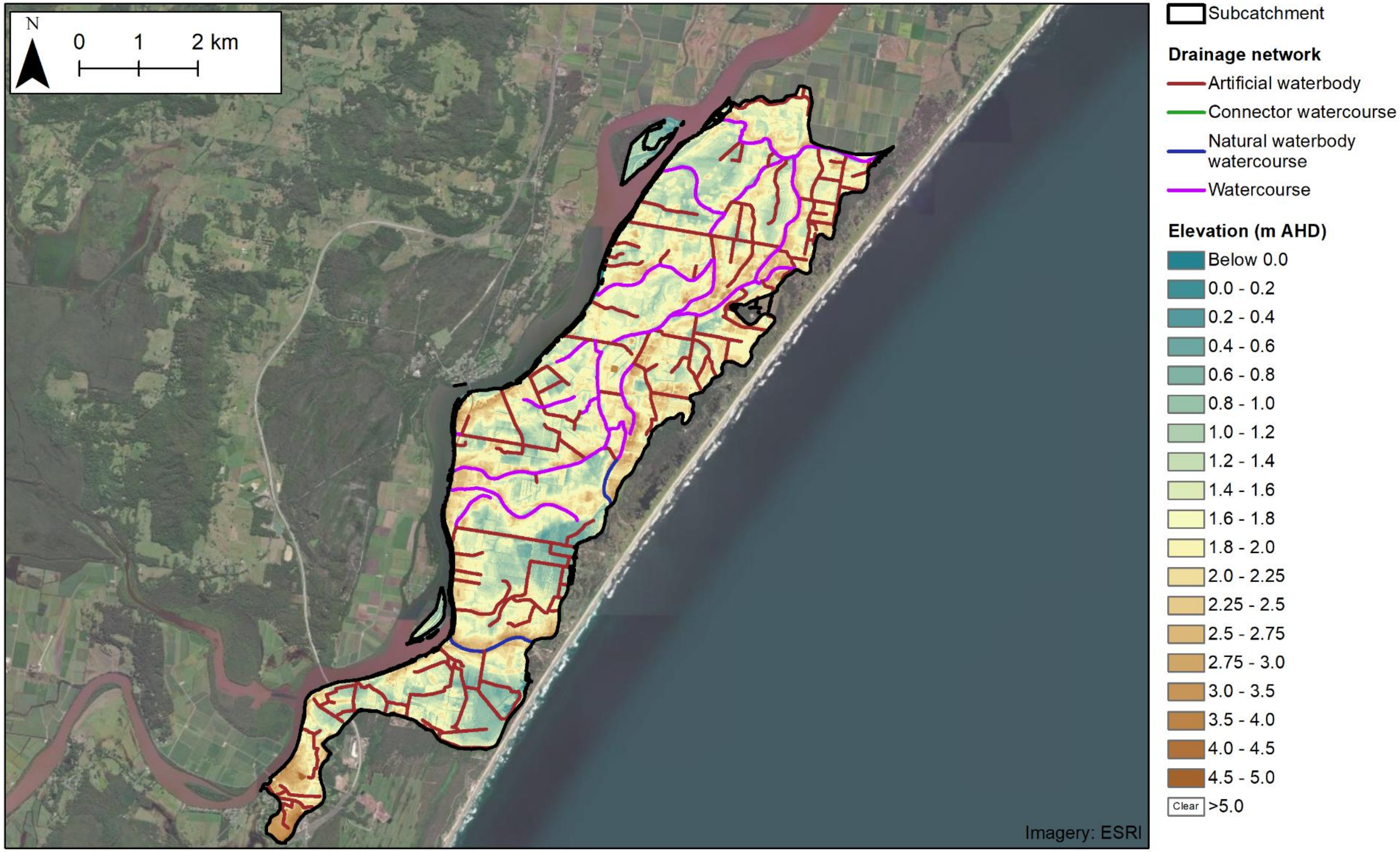

Figure 8-58: Empire Vale elevation and drainage network

8.12.2 History of remediation

At least eight (8) of the major floodgates in the Empire Vale have been modified to allow some tidal flushing, as shown in Figure 8-59. This includes:

- Floodgate ID 390 on Empire Vale Creek, which is fitted with a sluice gate that was installed to improve fish passage and prevent fish kills in the creek (Johnston et al., 2003a). The current management of this sluice gate is unknown;
- Floodgate ID 830, which is fitted with an auto-tidal buoyancy gate;
- Floodgate ID 540, on a drain at Sneesbys Lane which is fitted with a sluice gate. The current management of this sluice gate is unknown;
- Floodgate ID 1080 on Walshs Canal which is fitted with an auto-tidal buoyancy gate;
- Floodgate ID 1180 on Boundary Creek Canal which is fitted with a sluice gate. The current management of this sluice gate is unknown; and
- Floodgate ID 1230 on Eversons Creek which is fitted with an auto-tidal buoyancy gate.

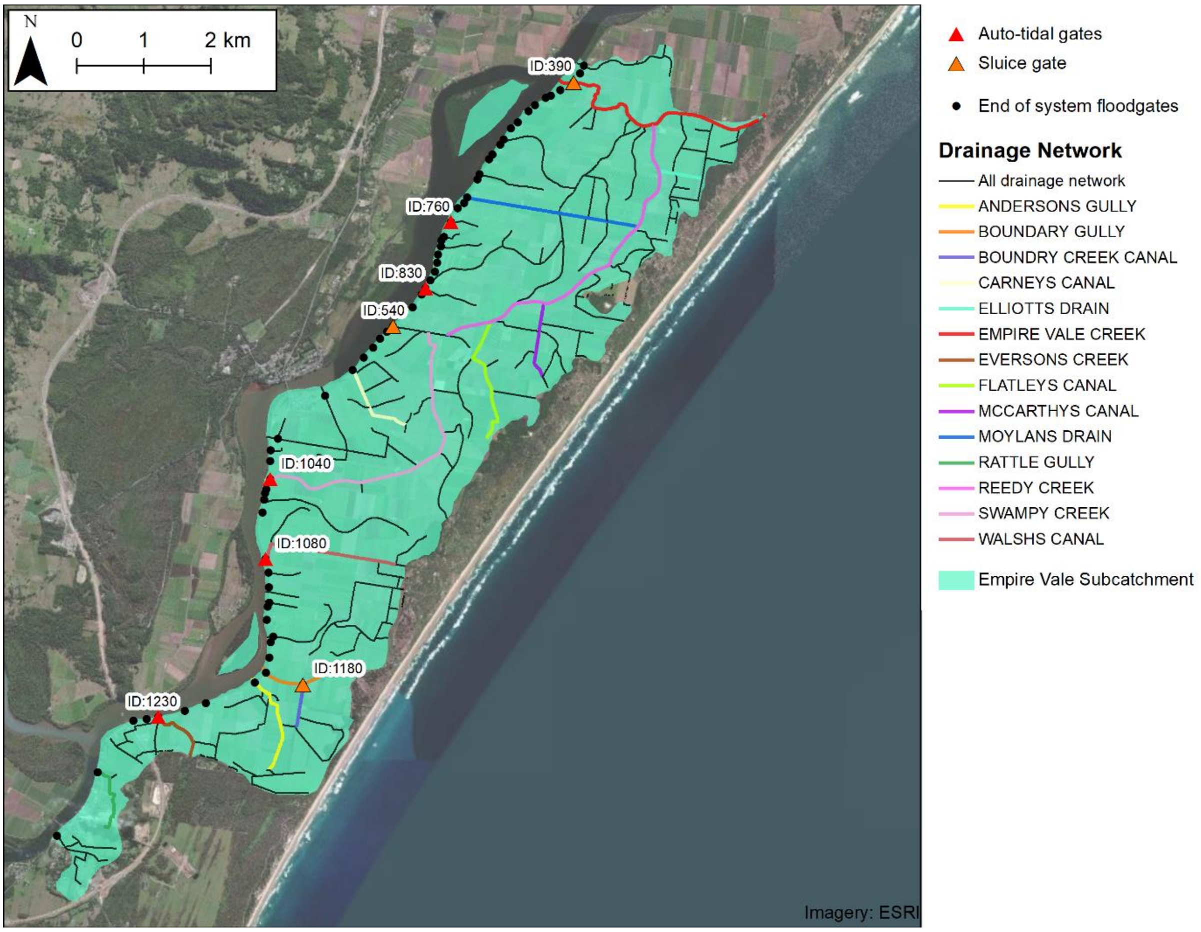

Figure 8-59: Empire Vale subcatchment including previous remediation actions

Sugar cane farms in the Richmond River floodplain operate in compliance with “The NSW sugar industry best practice guidelines for acid sulfate soils” (Sunshine Sugar, 2020). While details of specific drainage management on cane farms in the Empire Vale subcatchment were not obtained, cane farms typically:

- Laser level farms to reduce the drainage density required to allow surface water drainage;

- Construct new drainage works that are designed to minimise the interaction with acidic soils; and
- Complete extensive liming.

8.12.3 Floodplain drainage – sea level rise vulnerability

The sea level rise vulnerability of the Empire Vale subcatchment is summarised in Figure 8-60. While only two (2) of the floodgates with survey data are identified as most vulnerable in the near future (floodgate ID 840), 50% of the floodgates with data become most vulnerable under far future sea level rise, including primary floodgates 390, 540 and 1040 (Figure 8-61). The floodgate infrastructure in this subcatchment may be insufficient to maintain efficient drainage in the far future.

Similarly, the floodplain itself does not appear to be highly vulnerable to sea level rise in the near future, with the vast majority of the area not considered to be vulnerable to reduced drainage. However, reduced drainage under far future sea level rise may impact present day land uses that are sensitive to a high/shallow groundwater table.

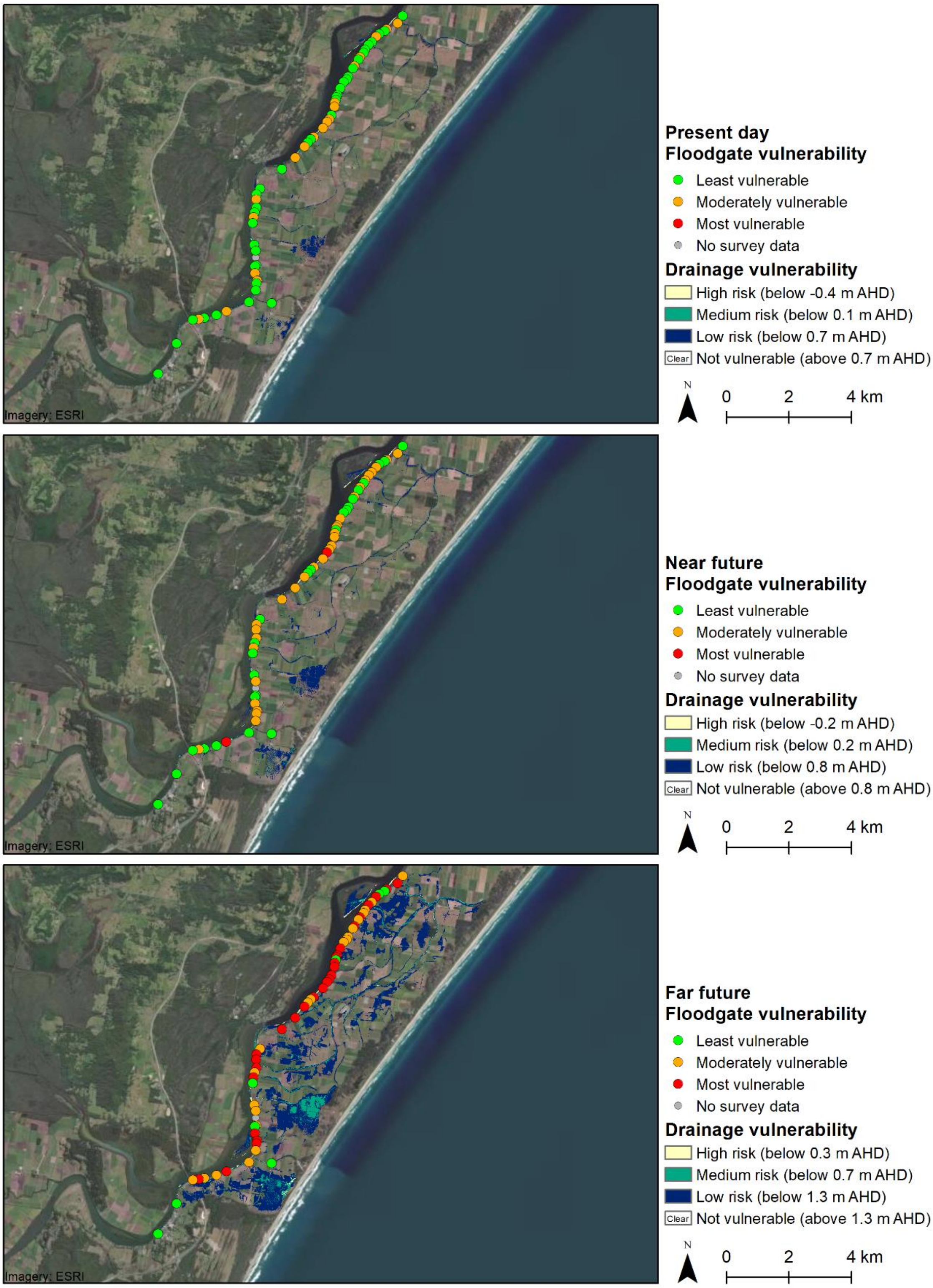

Figure 8-60: Sea level rise drainage vulnerability – Empire Vale subcatchment

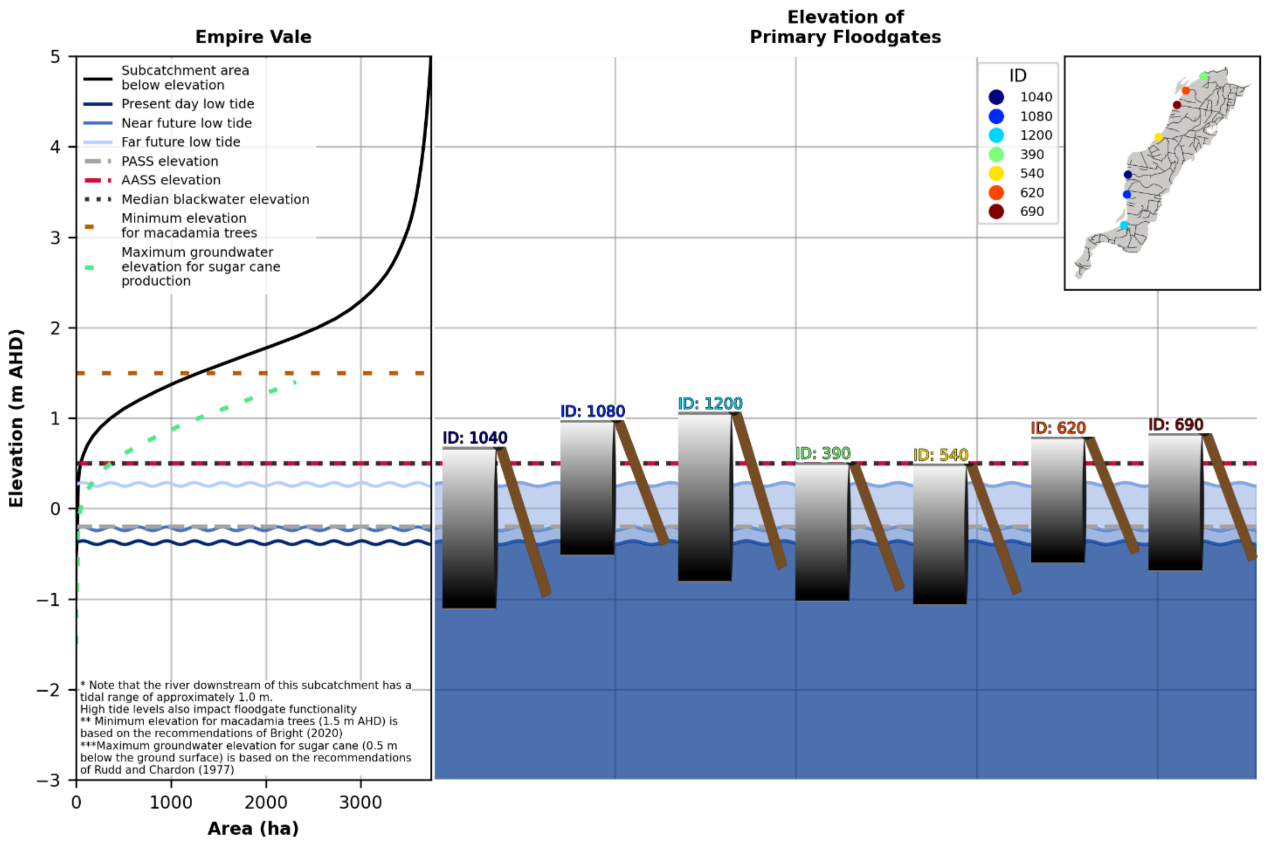

Figure 8-61: Primary floodgates and key floodplain elevations – Empire Vale subcatchment

8.12.4 Management options

Short-term management options

A significant number of the floodgates in this subcatchment have been modified to allow controlled tidal flushing and fish passage by RCC. Continued active management should be encouraged, and it is recommended that the management of these structures is reviewed and assessed as to whether tidal flushing could be increased/optimised with the existing infrastructure (e.g. ensuring sluice gates are open as much as possible). Additional modifications could be considered on larger floodgates that have not yet been modified to optimise tidal flushing. Any changes to management of existing infrastructure will need to consider, and have a plan to mitigate, any potential impacts to local landholders.

Long-term management options

Present day land uses in low areas of the Empire Vale subcatchment may be impacted by reduced drainage in the future due to sea level rise. If existing land uses cannot persist in these areas, localised restoration of natural estuarine hydrology through increased tidal flushing and drain infilling/reshaping could be investigated. Reducing drainage density throughout the rest of the subcatchment, as land management allows, would also help to reduce potential acid drainage. Changes to localised hydrology will need to consider potential impacts to adjacent landholders, including groundwater connectivity and salinity.

Table 8.15: Summary of management options for Empire Vale

Timeframe	Strategy	Effectiveness at improving:		
		Wetland habitat and fish passage	**Impacts of ASS**	**Impacts of blackwater**
Short-term	Improve tidal flushing	Moderate	Moderate	Negligible
Long-term	Restoration of natural estuarine hydrology	High	Moderate	Moderate

8.13 Upper Richmond/Wilsons River subcatchment

Acid priority rank:	**11**
Blackwater priority rank:	**7**
<u>Infrastructure</u>	
Approximate waterway length (km)	100
# Privately owned end of system structures	0
# Publicly owned end of system structures	41
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (ID):	2100, 2190, 2380, 2390, 2400, 2410, 2540, 2580, 2640, 2670
<u>Elevations</u>	
Invert of primary floodplain infrastructure (m AHD):	-0.1 to 3.0
Approximate AASS elevation (m AHD)	-0.1
Approximate PASS elevation (m AHD)	-0.2
Median blackwater elevation (m AHD)	2.3
Present day low water level (m AHD)	-0.22
Near future low water level (m AHD)	-0.08
Far future low level (m AHD)	0.39
<u>Proximity to sensitive receivers</u>	
Oyster leases (km)	42.7
Saltmarsh (km)	38.7
Seagrass (km)	46.4
Mangroves (km)	17.3
Coastal Management SEPP coastal wetlands (km)	20.3
<u>Land use</u>	
Total floodplain area (ha)	2,944
Classified as conservation and minimal use (ha (%))	41 (1%)
Classified as grazing (ha (%))	1,492 (51%)
Classified as forestry (ha (%))	463 (16%)
Classified as sugar cane (ha (%))	568 (19%)
Classified as horticulture (ha (%))	0 (0%)
Classified as other cropping (ha (%))	152 (5%)
Classified as urban/industrial/services (ha (%))	88 (3%)
Classified as marsh/wetland (ha (%))	1 (0%)
Other (ha (%))	139 (5%)
<u>Land values</u>	
Estimated total primary production value ($/year)	$1,900,000
Average land value above 2.3 m AHD ($/ha)	$8,400
Average land value below 2.3 m AHD ($/ha)	No property data available

8.13.1 Site description

The Upper Richmond/Wilsons River subcatchment is the upstream extent of the Richmond River floodplain below 5 m AHD and is shown in Figure 8-62. While there are a significant number of floodgates, the majority of those surveyed were high (invert higher than +0.5 m AHD) and do not interact with tidal water levels and provide flood drainage. Floodgate 2100 is amongst the lowest of the floodgates in this subcatchment, which is on the West Coraki Canal and was installed (and the associated canal dug) in 1963, which is important for managing flooding at Coraki.

Figure 8-63 shows that there is a significant artificial drainage network in the subcatchment which provides drainage for the grazing and sugar cane agricultural land use. Floodplain topography is significantly higher than other subcatchments considered in the Richmond River floodplain, with the majority of the subcatchment situated above +2.5 m AHD.

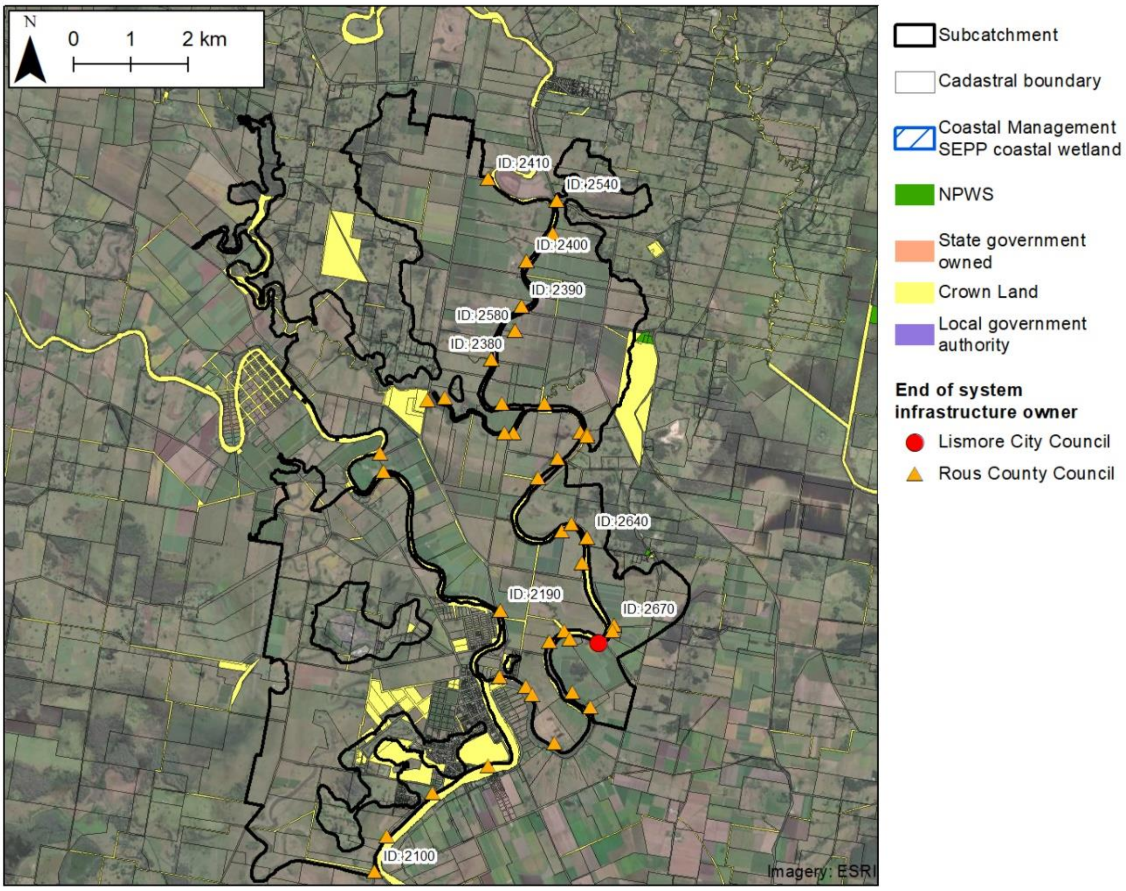

Figure 8-62: Upper Richmond/Wilsons subcatchment - land and end of system infrastructure tenure

8.13.2 History of remediation

One of the major floodgates in this subcatchment has an active management plan operated by Rous County Council to improve water quality:

- Floodgate 2100 is on the West Coraki Canal: which has a sluice gate. The active floodgate management plan for this gate states that the sluice gate should be open when the area is not expecting or experiencing flooding to reduce the impact of blackwater and nutrient discharges, manage weeds and improve connectivity and habitat (Rous County Council, 2020e).

8.13.3 Floodplain drainage – sea level rise vulnerability

The vulnerability of the floodplain and floodplain infrastructure in the Upper Richmond/Wilsons River floodplain is shown in Figure 8-64 and Figure 8-65. Due to the elevation of this subcatchment, the impact of reduced drainage will be limited.

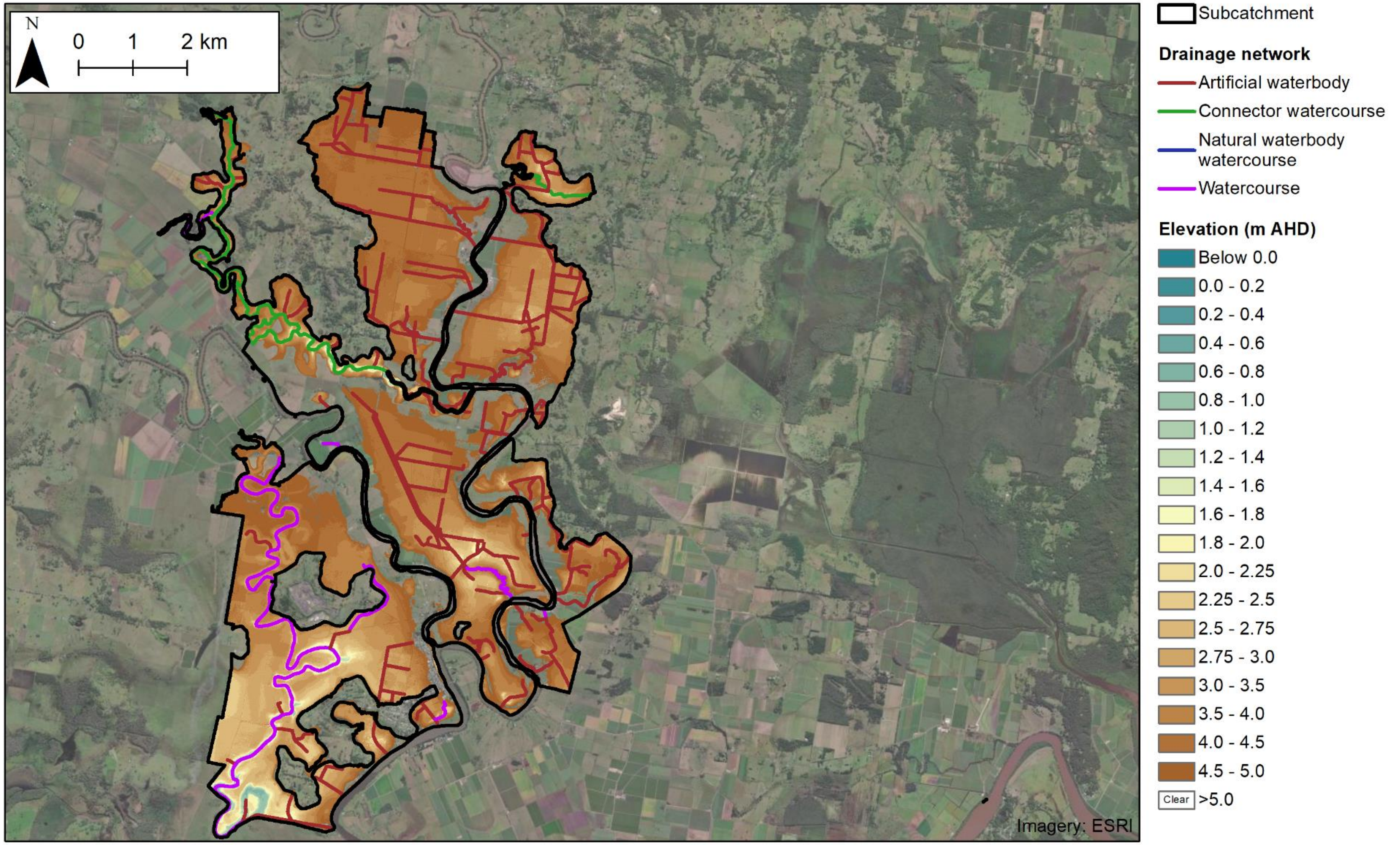

Figure 8-63: Upper Richmond/Wilsons River subcatchment elevation and drainage network

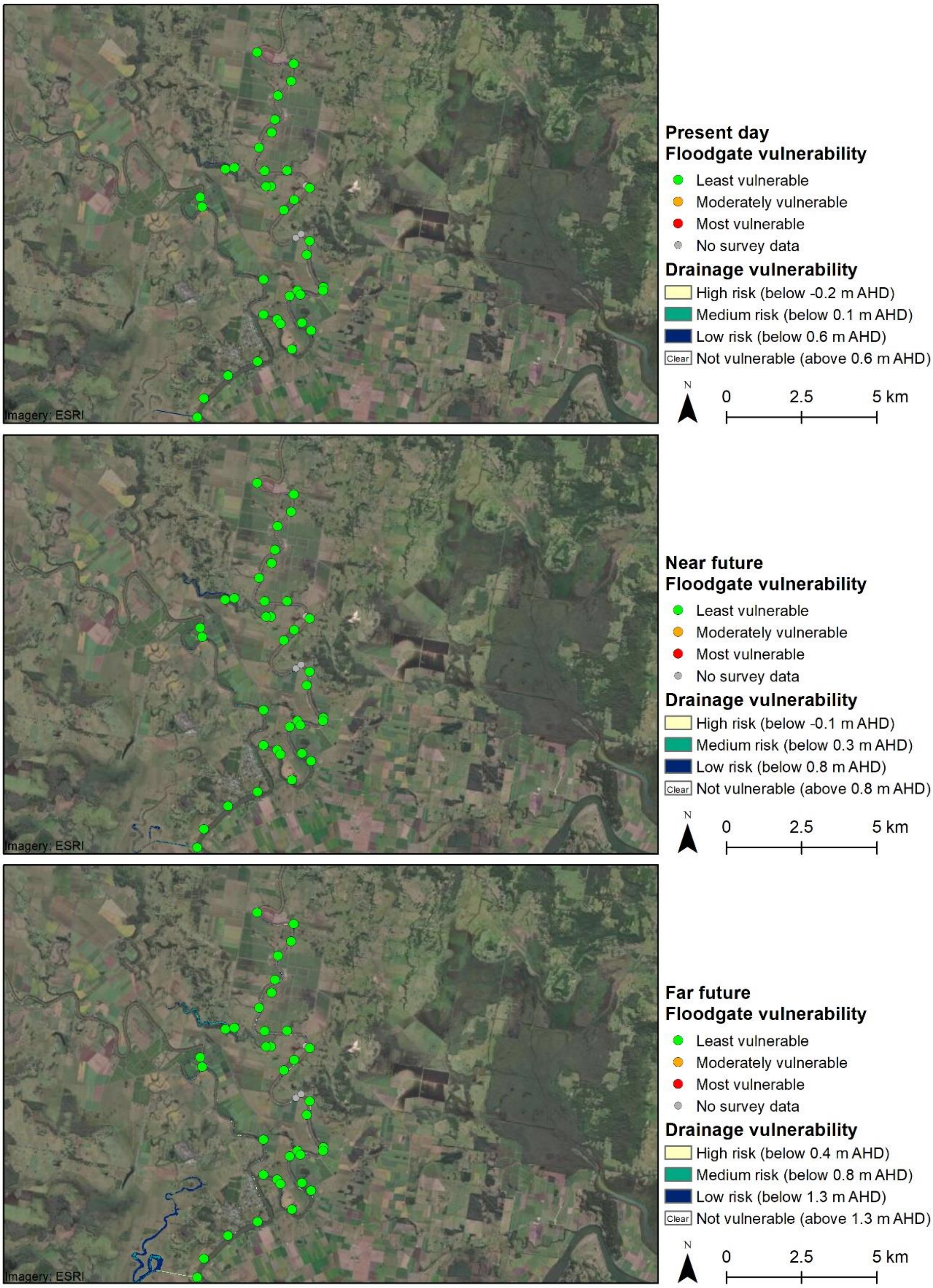

Figure 8-64: Sea level rise drainage vulnerability – Upper Richmond/Wilsons River subcatchment

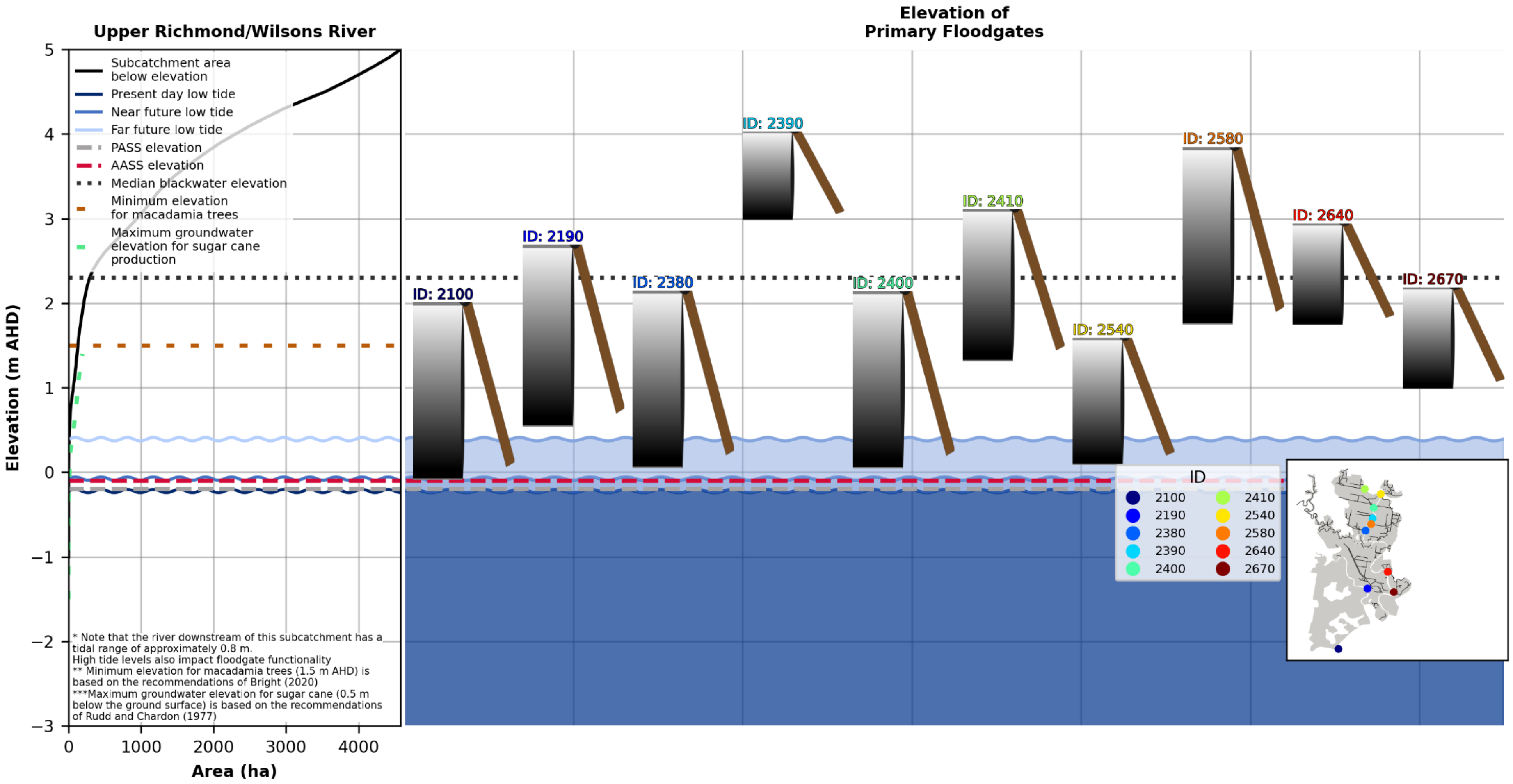

Figure 8-65: Primary floodgates and key floodplain elevations – Upper Richmond/Wilsons River subcatchment

8.13.4 Management options

Short-term management options

The risk of acid and blackwater drainage from the Upper Richmond/Wilsons subcatchment is relatively low. However, allowing limiting tidal flushing in the main drainage system may still provide other water quality benefits (by reducing residence time) and allow fish passage and aquatic connectivity. Note that benefits of tidal flushing for reducing any potential acidity are limited in the upper estuary, due to the low salinity concentrations (and therefore natural buffering capacity). Increasing acid export via tidal pumping of groundwater should be considered and avoided, however this is generally a risk in areas where soil acidity and groundwater hydraulic conductivity is high. Soil acidity was observed to be moderate (pH = 4 to 6) and groundwater hydraulic conductivity was measured to be low.

Of the nine (9) floodgates surveyed for this project, only three (3) had inverts within the present day tidal range in this section of the estuary. It is recommended that flushing through these floodgates be considered to improve surface water quality and fish habitat.

Long-term management options

This subcatchment is low risk for acid drainage and blackwater drainage, and is unlikely to be severely impacted by reduced drainage due to sea level rise. As a result, no large scale, long-term management options to mitigate acid and blackwater discharge is recommended in this subcatchment. Note that this does not consider other water quality issues (such as nutrient and sediment runoff), which may still need to be addressed.

Table 8.16: Summary of management options for Upper Richmond/Wilsons River

Timeframe	Strategy	Effectiveness at improving:		
		Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Floodgate management	Moderate	Moderate	Negligible

8.14 Rileys Hill subcatchment

Acid priority rank:	**12**
Blackwater priority rank:	**8**
Infrastructure	
Approximate waterway length (km)	36
# Privately owned end of system structures	0
# Publicly owned end of system structures	19
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (ID):	1280, 1330, 1400, 1410
Elevations	
Invert of primary floodplain infrastructure (m AHD):	-1.2 to -0.2
Approximate AASS elevation (m AHD)	N/A
Approximate PASS elevation (m AHD)	N/A
Median blackwater elevation (m AHD)	1.5
Present day low water level (m AHD)	-0.30
Near future low water level (m AHD)	-0.15
Far future low level (m AHD)	0.34
Proximity to sensitive receivers	
Oyster leases (km)	16.5
Saltmarsh (km)	12.5
Seagrass (km)	20.2
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	2,091
Classified as conservation and minimal use (ha (%))	651 (31%)
Classified as grazing (ha (%))	454 (22%)
Classified as forestry (ha (%))	5 (0%)
Classified as sugar cane (ha (%))	680 (32%)
Classified as horticulture (ha (%))	7 (0%)
Classified as other cropping (ha (%))	2 (0%)
Classified as urban/industrial/services (ha (%))	159 (8%)
Classified as marsh/wetland (ha (%))	103 (5%)
Other (ha (%))	31 (1%)
Land values	
Estimated total primary production value ($/year)	$1,500,000
Average land value above 1.5 m AHD ($/ha)	$7,600
Average land value below 1.5 m AHD ($/ha)	$10,000

8.14.1 Site description

The Rileys Hill subcatchment is on the right bank of the Richmond River between Woodburn and Broadwater and is shown in Figure 8-66. The subcatchment includes a small portion of the Broadwater National Park. As shown in Figure 8-67, most of the subcatchment is higher than 2 m AHD, with localised, small backswamps near the riverbank.

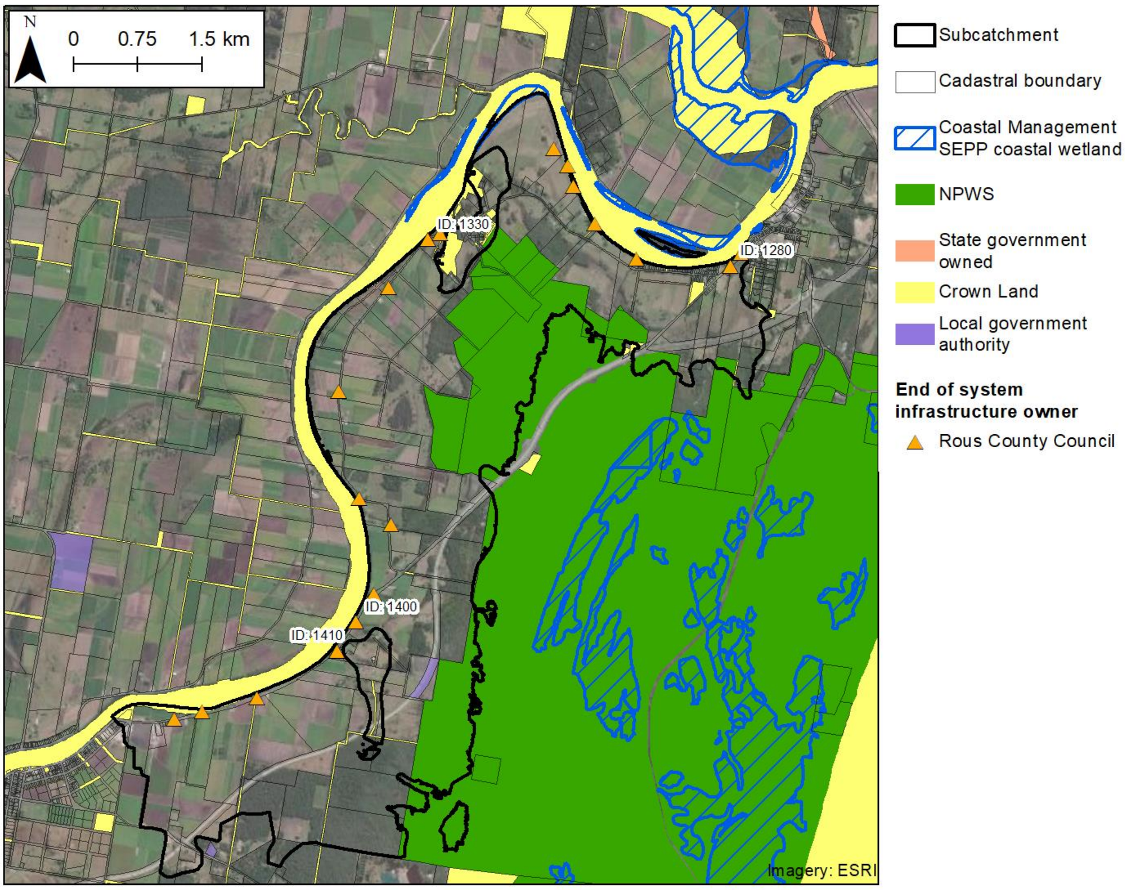

Figure 8-66: Rileys Hill subcatchment - land and end of system infrastructure tenure

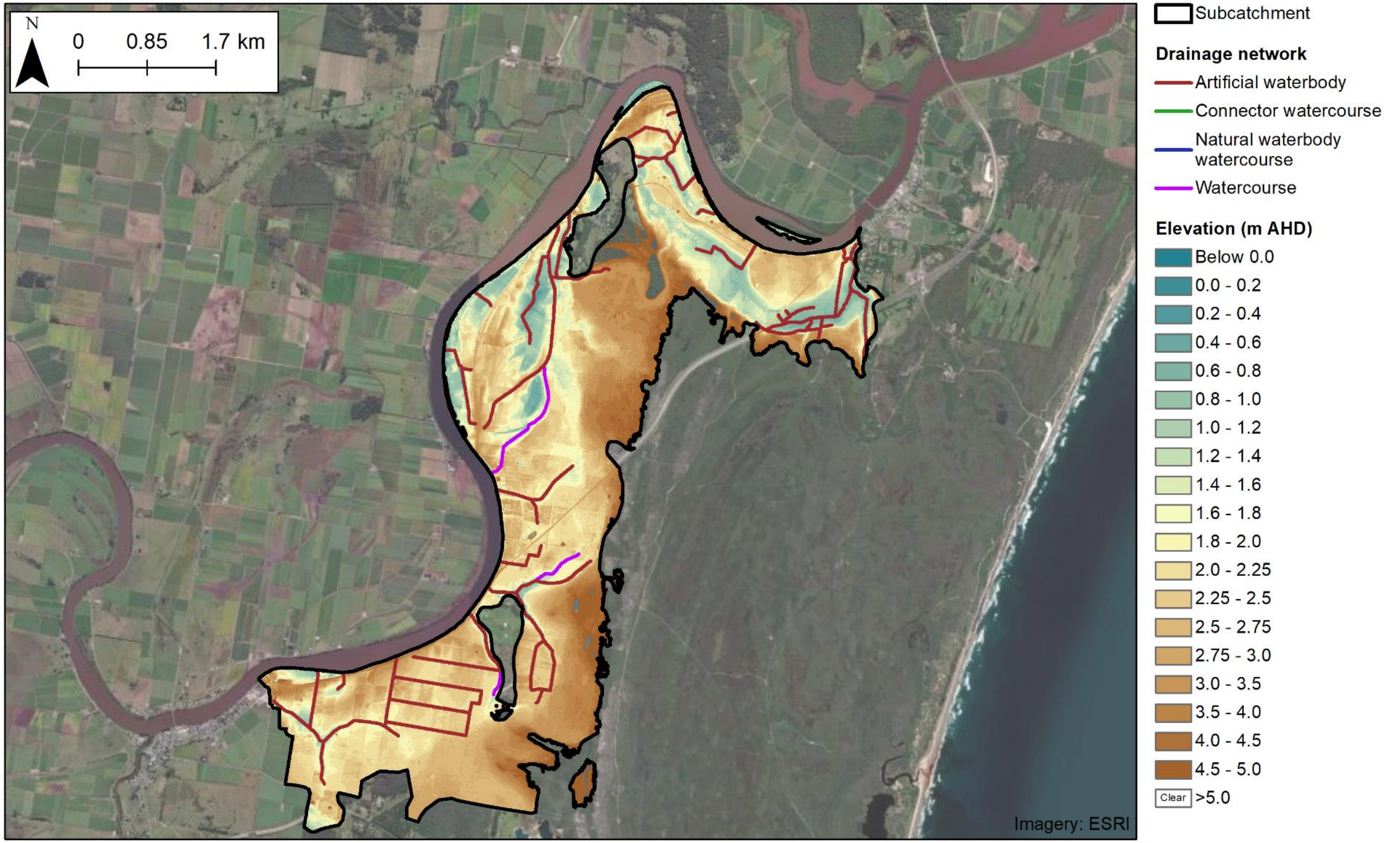

Figure 8-67: Rileys Hill subcatchment elevation and drainage network

8.14.2 History of remediation

One of the floodgates in the Rileys Hill subcatchment has been modified and fitted with an auto-tidal buoyancy gate (floodgate ID 1280), shown in Figure 8-68 and Figure 8-69. This gate provides aquatic connectivity and tidal flushing of Montis Gully. Several other floodgates have been fitted with winches, but no active management plans were identified.

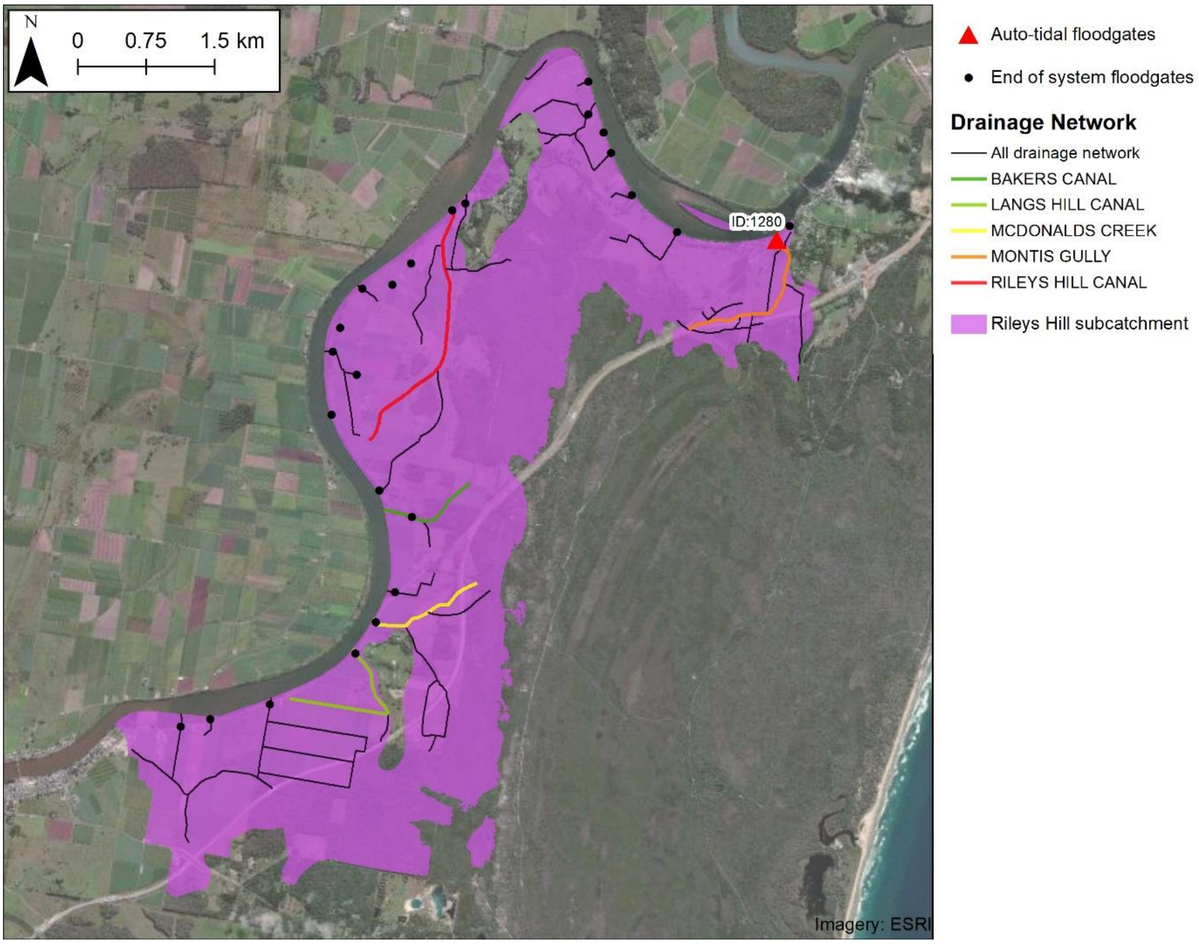

Figure 8-68: Rileys Hill subcatchment including previous remediation actions

Sugar cane farms in the Richmond River floodplain operate in compliance with "The NSW sugar industry best practice guidelines for acid sulfate soils" (Sunshine Sugar, 2020). While details of specific drainage management on cane farms in the Rileys Hill subcatchment were not obtained, cane farms typically:

- Laser level farms to reduce the drainage density required to allow surface water drainage;
- Construct new drainage works that are designed to minimise the interaction with acidic soils; and
- Complete extensive liming.

Figure 8-69: Buoyancy auto-tidal gate on floodgate 1280 at Montis Gully

8.14.3 Floodplain drainage – sea level rise vulnerability

The vulnerability of the floodplain and floodplain infrastructure in the Rileys Hill floodplain is shown in Figure 8-70. Subcatchment elevation is relatively high and it is therefore unlikely to be impacted by reduced drainage in the near future. Land uses in the small, low backswamps near Montis Gully and Rileys Hill Canal may be impacted under far future sea level rise. Drainage efficiency of ten (10) of the floodgates will be reduced in the far future, including primary structure 1330 which provides the majority of the drainage on Rileys Hill Canal (shown in Figure 8-71) and primary structure 1400.

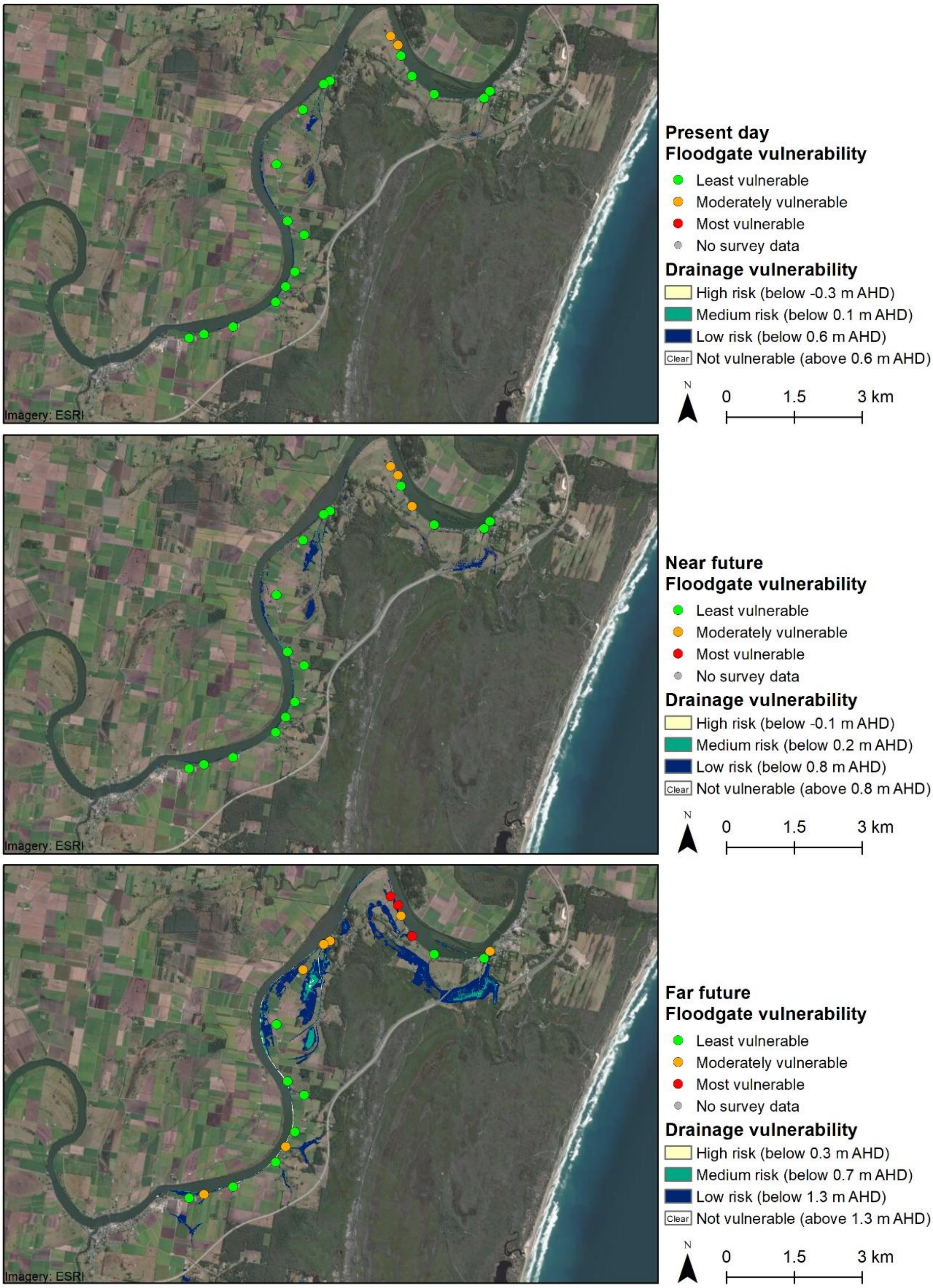

Figure 8-70: Sea level rise drainage vulnerability – Rileys Hill subcatchment

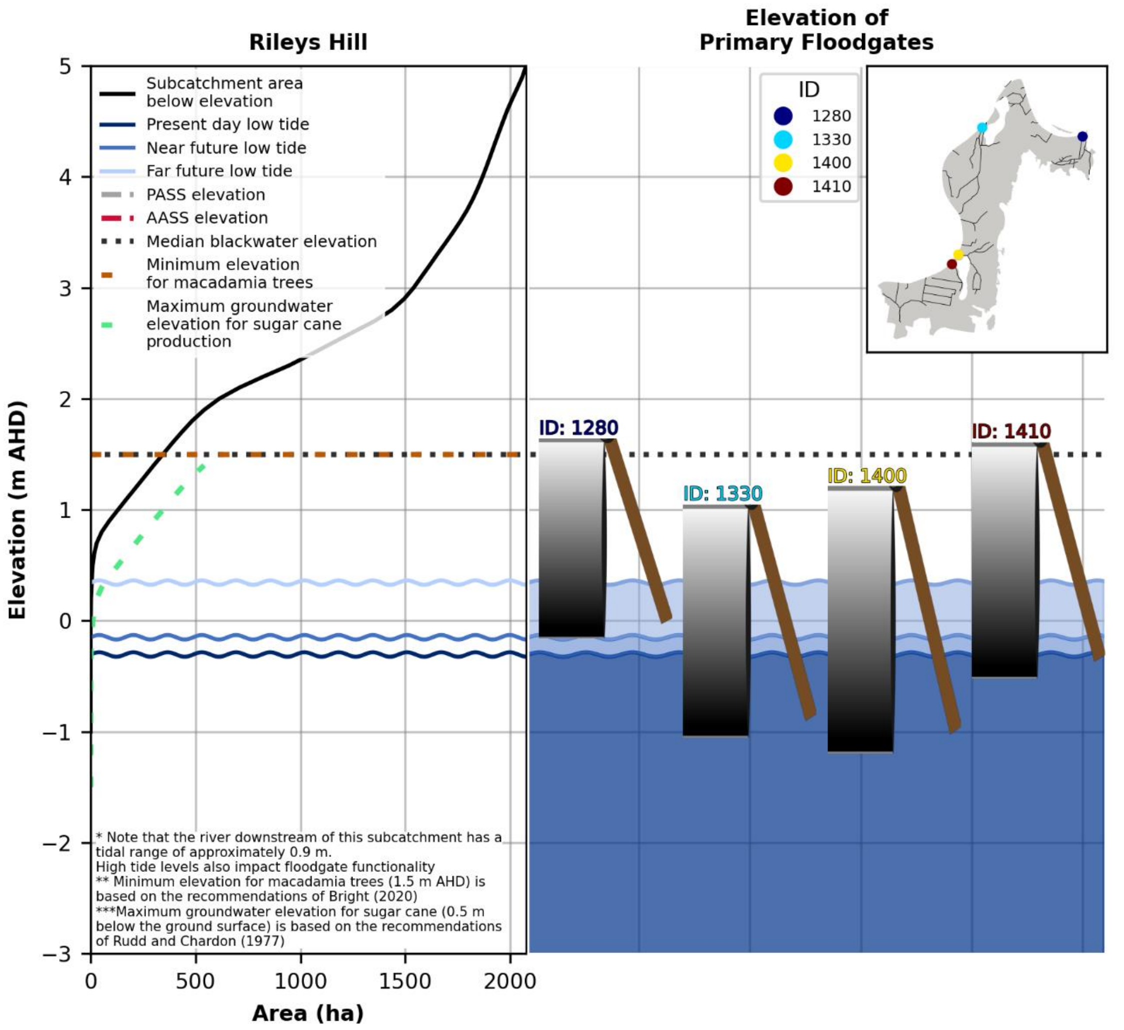

Figure 8-71: Primary floodgates and key floodplain elevations – Rileys Hill subcatchment

8.14.4 Management options

Short-term management options

The blackwater and acid generation potential from the Rileys Hill subcatchment is low, relative to other subcatchments in the Richmond River. Therefore, improving tidal flushing of floodplain drainage in this subcatchment would aim to improve general water quality and aquatic connectivity, rather than specifically mitigating acid and blackwater discharge. Investigating increased tidal flushing and connectivity through existing major floodgates would improve general water quality through increased flushing and provide fish habitat and passage. This may include auto tidal buoyancy gates, sluice gates, or winching floodgates open during extended dry periods.

Long-term management options

Reduced drainage may impact present day land uses in areas below +1.3 m AHD. If present day land uses are no longer viable, artificial drainage channels should be infilled and rehabilitation of natural flow paths and wetland areas could be encouraged to reduce the risk of blackwater generation under future sea level rise scenarios.

Table 8.17: Summary of management options for Rileys Hill

Timeframe	Strategy	Effectiveness at improving:		
		Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Improve tidal flushing	Moderate	Moderate	Negligible
Long-term	Freshwater wetland remediation	None	High	High

8.15 Back Channel subcatchment

Acid priority rank:	**13**
Blackwater priority rank:	**12**
<u>Infrastructure</u>	
Approximate waterway length (km)	34
# Privately owned end of system structures	0
# Publicly owned end of system structures	16
# End of system structures within coastal wetlands	6
# Publicly owned end of system structures within coastal wetlands	6
Primary floodplain infrastructure (ID):	4120
<u>Elevations</u>	
Invert of primary floodplain infrastructure (m AHD):	-0.7
Approximate AASS elevation (m AHD)	N/A
Approximate PASS elevation (m AHD)	0.2
Median blackwater elevation (m AHD)	0.5
Present day low water level (m AHD)	-0.37
Near future low water level (m AHD)	-0.21
Far future low level (m AHD)	0.28
<u>Proximity to sensitive receivers</u>	
Oyster leases (km)	7.8
Saltmarsh (km)	3.9
Seagrass (km)	11.6
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
<u>Land use</u>	
Total floodplain area (ha)	1,275
Classified as conservation and minimal use (ha (%))	474 (37%)
Classified as grazing (ha (%))	302 (24%)
Classified as forestry (ha (%))	0 (0%)
Classified as sugar cane (ha (%))	407 (32%)
Classified as horticulture (ha (%))	0 (0%)
Classified as other cropping (ha (%))	14 (1%)
Classified as urban/industrial/services (ha (%))	42 (3%)
Classified as marsh/wetland (ha (%))	0 (0%)
Other (ha (%))	35 (3%)
<u>Land values</u>	
Estimated total primary production value ($/year)	$750,000
Average land value above 0.5 m AHD ($/ha)	$9,600
Average land value below 0.5 m AHD ($/ha)	No property data available

8.15.1 Site description

Back Channel is a small floodplain on the north side of the Richmond River, immediately upstream of Wardell. It includes the area of Cabbage Tree Island and a substantial area of high conservation value land owned and managed by the Jali Local Aboriginal Land Council. Some of the floodplain has also been acquired by the State Government (Roads and Maritime Services) as part of the Pacific Highway upgrade, as shown in Figure 8-72. The primary agricultural use of the floodplain is sugar cane. Elevation and drainage network information for the subcatchment is shown in Figure 8-73.

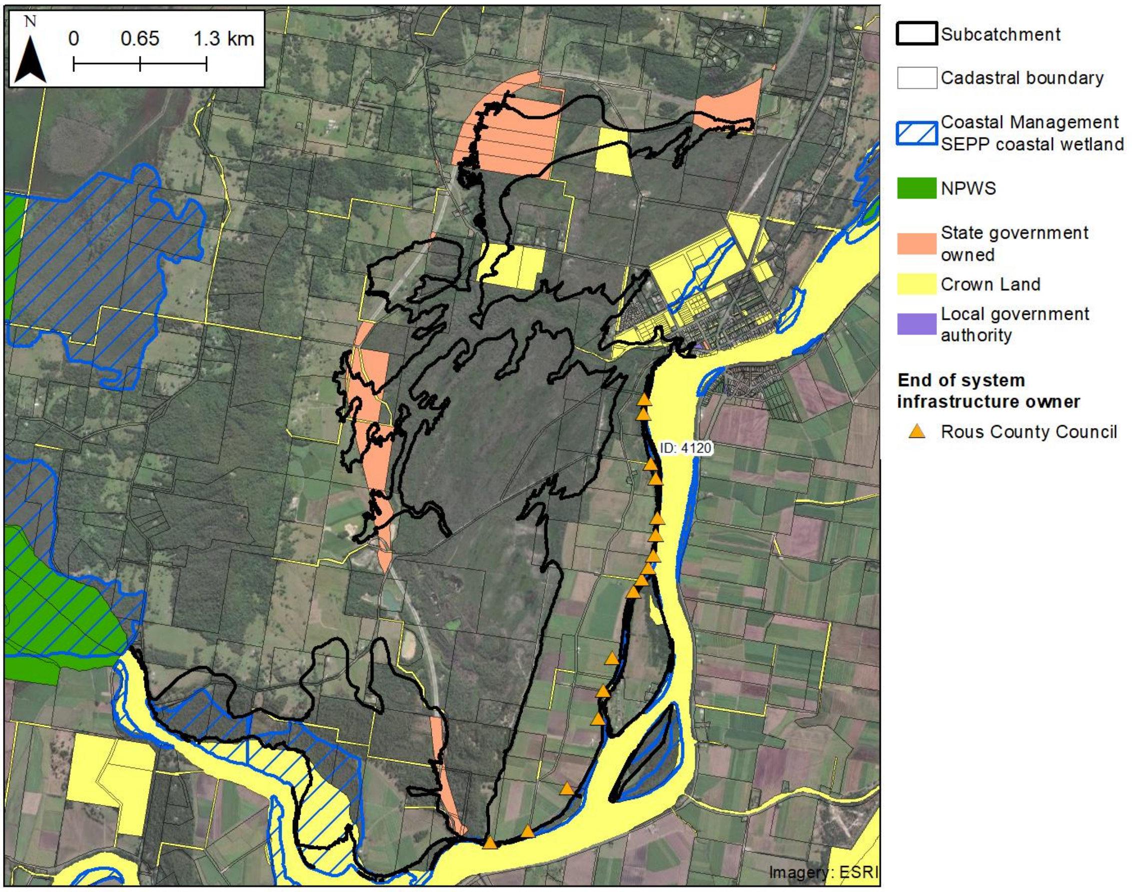

Figure 8-72: Back Channel subcatchment - land and end of system infrastructure tenure

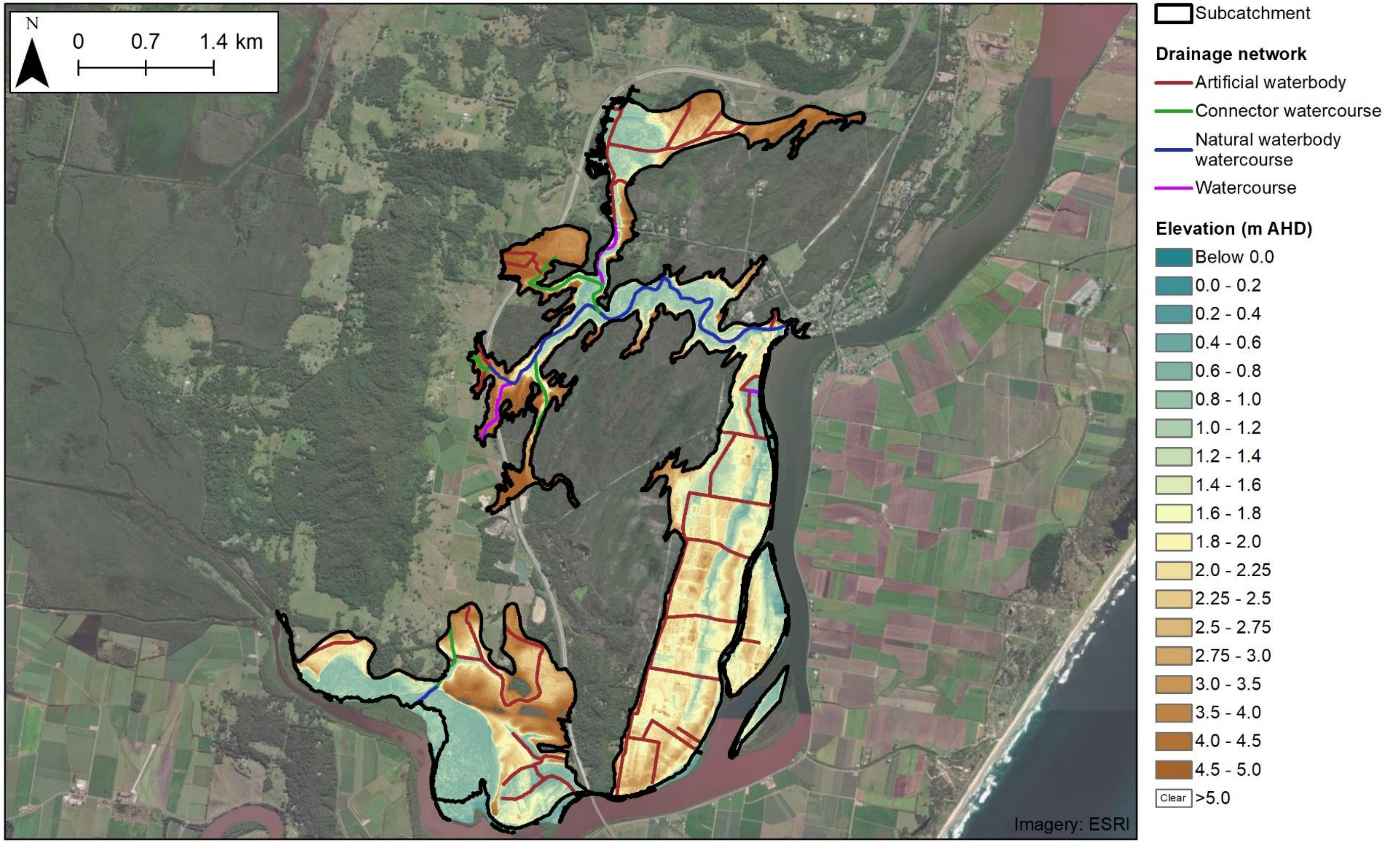

Figure 8-73: Back Channel subcatchment elevation and drainage network

8.15.2 History of remediation

Between 2012 – 2014, the remediation of Jali LALC Lands in the Back Channel floodplain was supported by a NSW Environmental Trust grant targeting the management of 815 ha of high conservation value vegetation. The Trust enabled a program that supported the local Aboriginal community to manage extensive weed control, planting of native vegetation, removal of rubbish and environmental management. By providing appropriate training and education to the indigenous owners and managers of this land, this grant aimed to ensure long-term improvements within the area.

RCC has also modified three (3) of the floodgates to promote tidal flushing, shown in Figure 8-74. Tidal flushing floodgates that are actively managed are indicated on the RCC floodgate layer and are presented in Figure 8-74. The northern most structure with tidal flushing capabilities (floodgate ID 4120) is the largest floodgate in the area, and is fitted with one (1) auto-tidal floodgate. The other two (2) gates are fitted with sluice gates, although details of the sluice gates are unknown.

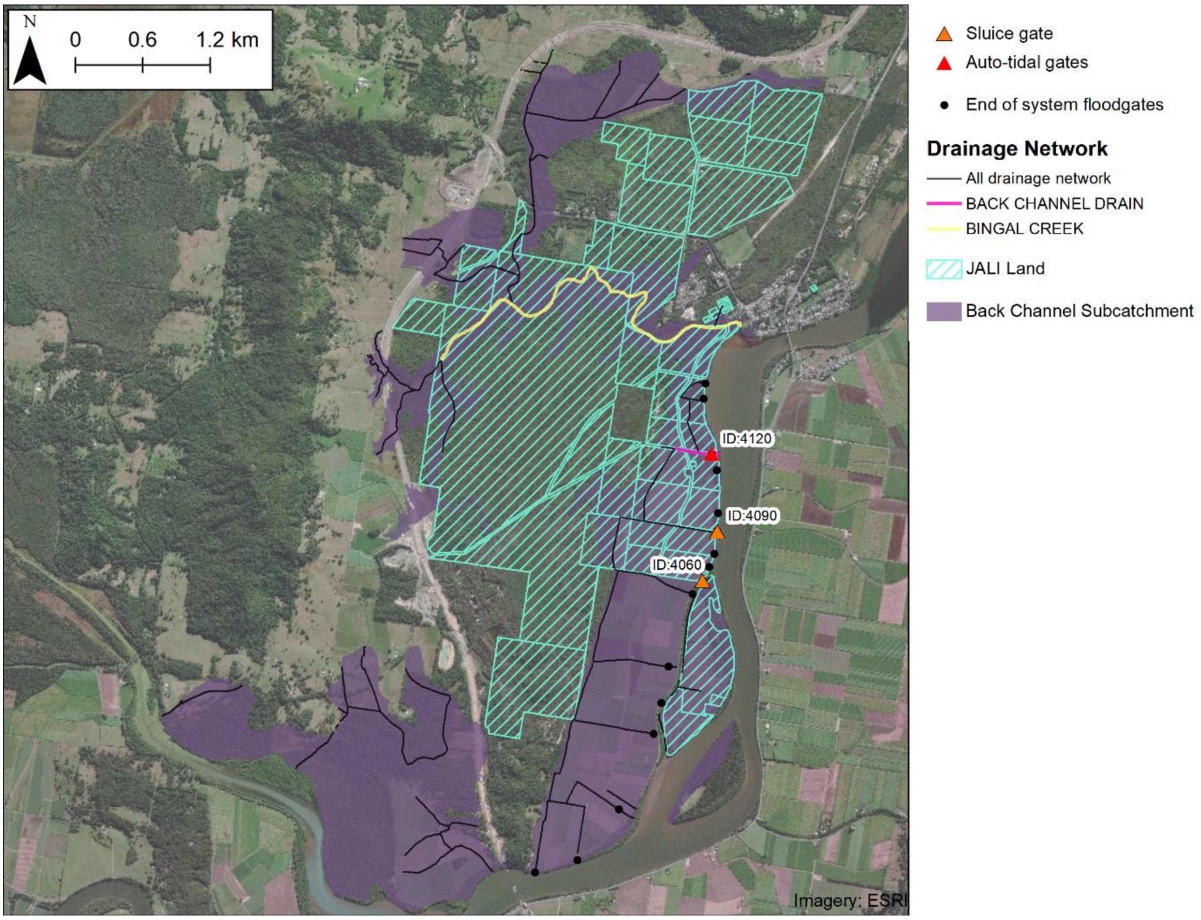

Figure 8-74: Back Channel subcatchment including previous remediation actions

Sugar cane farms in the Richmond River floodplain operate in compliance with "The NSW sugar industry best practice guidelines for acid sulfate soils" (Sunshine Sugar, 2020). While details of specific drainage management on cane farms in the Back Channel subcatchment were not obtained, cane farms typically:

- Laser level farms to reduce the drainage density required to allow surface water drainage;

- Construct new drainage works that are designed to minimise the interaction with acidic soils; and
- Complete extensive liming.

8.15.3 Floodplain drainage – sea level rise vulnerability

The vulnerability of the floodplain and floodplain infrastructure in the Back Channel floodplain is shown in Figure 8-75. The majority of the Back Channel floodplain elevation is above +1 m AHD. Reduced drainage on the floodplain is unlikely to cause substantial additional flooding on agricultural land in the near future, however reduced drainage will become more significant in the far future.

The floodgates in the Back Channel subcatchment are mostly smaller than 750 mm diameter. As a result, Figure 8-75 shows that a number of the floodgates in the region will be impacted by reduced drainage efficiency under near and far future sea levels including the primary floodgate (ID 4120, shown in Figure 8-76). All but one structure will be at least moderately vulnerable in the far future scenario, with six (6) structures classified as moderately vulnerable and eight (8) structures classified as most vulnerable.

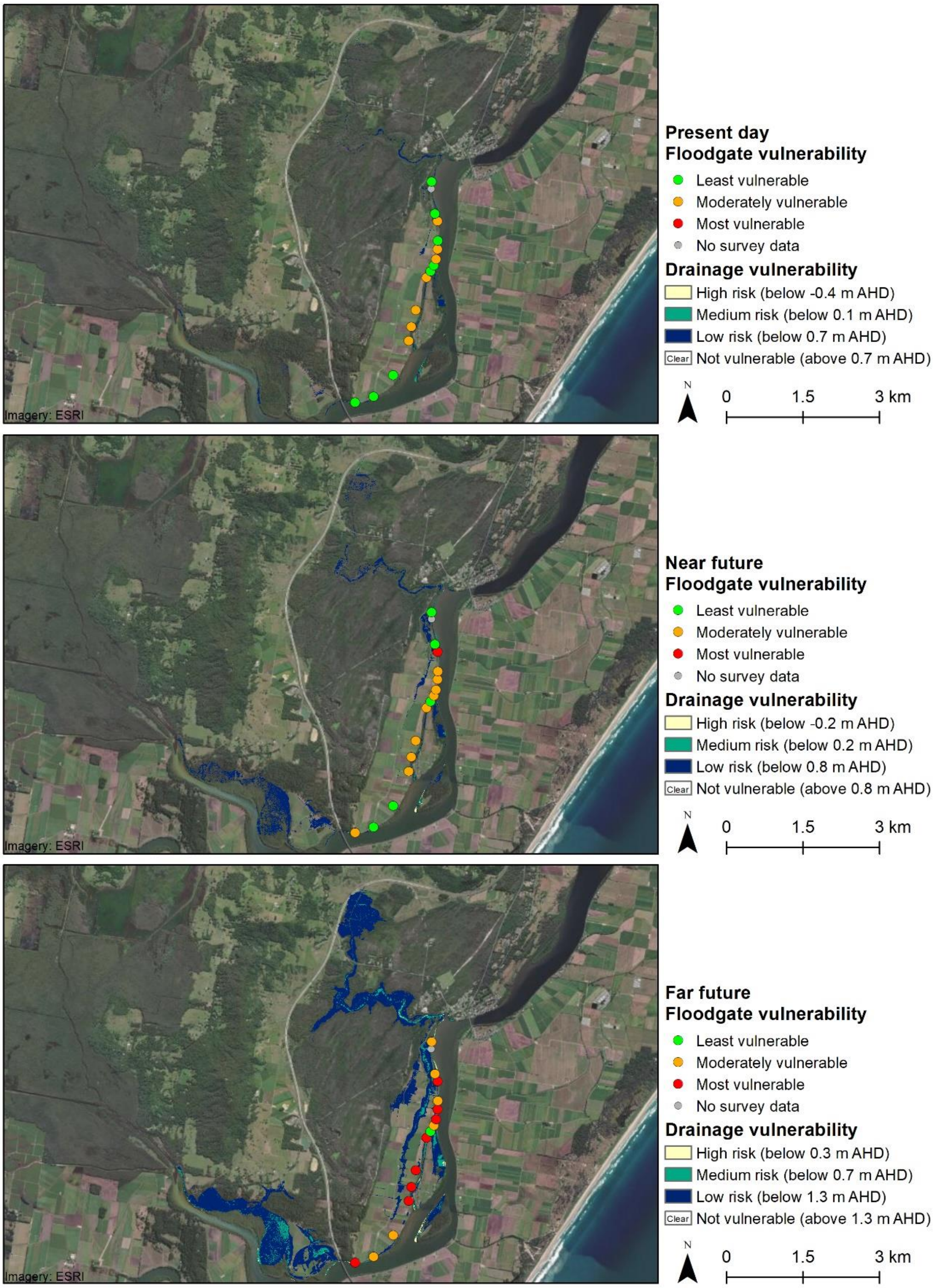

Figure 8-75: Sea level rise drainage vulnerability – Back Channel subcatchment

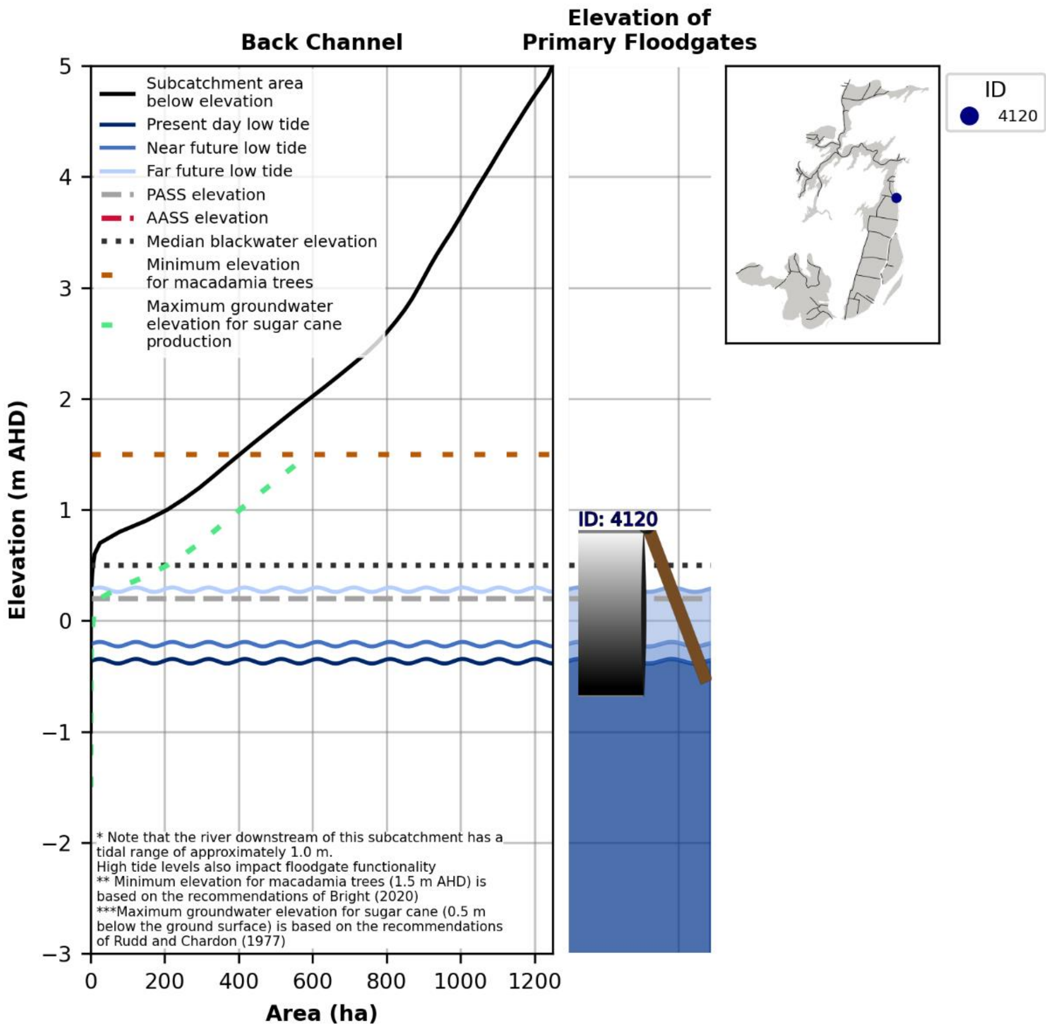

Figure 8-76: Primary floodgates and key floodplain elevations – Back Channel subcatchment

8.15.4 Management options

Short-term management options

The available information suggests that the Back Channel subcatchment is a low risk for acid and blackwater generation in the Richmond River estuary. During field investigations, numerous floodgates were observed to be in poor condition. A number of these were partially open and some had mangroves growing on the upstream side, as shown in Figure 8-77. These should be investigated to see whether the gates could be removed to encourage improved flushing without adverse impacts upstream. Existing weed and environmental management by the local community should continue to be supported and encouraged, particularly in the areas of high conservation value.

Figure 8-77: Example of floodgates wedged open in the Back Channel floodplain (floodgate ID: 4140 (left), 4100 (right))

Long-term management options

In the longer term, higher estuarine water levels due to sea level rise are likely to reduce drainage efficiency to the majority of the floodgates in the Back Channel subcatchment and the lowest lying sections of the floodplain will be at risk of increased inundation due to reduced drainage potential (Figure 8-75). The opportunity to provide funding to existing landholders to promote improved management of the land to achieve positive environmental outcomes should be investigated. Particularly in the areas around the floodgates mentioned above, options for remediation by encouraging estuarine wetland should be investigated. This would include the complete removal of floodgates and reshaping drains within this area to promote inundation and connectivity. A summary of the immediate and long-term management options for Back Channel are provided in Table 8.18.

Table 8.18: Summary of management options for Back Channel

Timeframe	Strategy	Effectiveness at improving:		
		Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Remove floodgates	Small	Small	Negligible
Long-term	Restore natural estuarine hydrology	Moderate	Small	Small

9 Outcomes and conclusions

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 through the development and application of an evidence based and data driven multi-criteria assessment involving:

- Application of a prioritisation methodology to rank 13 subcatchments on the Richmond River floodplain with regard to their contribution to acid and blackwater generation and the risk they pose to the health of the marine estate;
- Suggested 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 Richmond River coastal floodplain system to allow targeted floodplain management to improve water quality. The outcomes of the subcatchment prioritisation and supporting information provide an objectively prioritised list of 13 floodplain subcatchments with a roadmap on how to achieve water quality improvements across the Richmond 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 Outcomes

The multi-criteria prioritisation methodology was applied to rank the 13 subcatchment drainage areas of the Richmond 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 an estuary, to objectively rank floodplain subcatchments from highest to lowest priority with respect to the risk due to acid discharges. Within the Richmond River floodplain the five (5) highest priority subcatchments for acid drainage: Tuckean Swamp (1), Rocky Mouth Creek (2), Bungawalbin Creek/Sandy Creek (3), North Creek (4) and Emigrant Creek/Maguires Creek (5) were estimated to contribute over 85% of the total acid risk to the estuary. The Tuckean Swamp subcatchment was estimated to individually be the source of over 40% of acid risk to the estuary. High risk acid subcatchments were identified in the upper, middle, and lower reaches of the estuary, indicating that acid discharges from the floodplain have the potential to impact all areas of the Richmond River estuary (Table 9.1).

Table 9.1: Richmond River floodplain subcatchment priority ranking

Subcatchment	Acid rank	Blackwater rank
Tuckean Swamp	1	3
Rocky Mouth Creek	2	2
Bungawalbin Creek/Sandy Creek	3	1
North Creek	4	10
Emigrant Creek/Maguires Creek	5	9
Swan Bay	6	5
South Ballina	7	13
Kilgin/Buckendoon	8	6
East Coraki	9	4
Empire Vale	10	11
Upper Richmond/Wilsons River	11	7
Rileys Hill	12	8
Back Channel	13	12

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 across the floodplain.

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 exporting poor quality low oxygen blackwater to the estuary. The assessment identified that the highest five (5) priority subcatchments on the Richmond River floodplain: Bungawalbin Creek/Sandy Creek (1), Rocky Mouth Creek (2), Tuckean Swamp (3), East Coraki (4) and Swan Bay (5) collectively represent over 80% of the total blackwater generation risk (Table 9.1). Over 95% of the blackwater generation risk was identified to originate from subcatchments in the mid-to-upper estuary, between Coraki and Wardell. Discharges from the highest priority subcatchments have the potential to merge in receiving waters and collectively overwhelm the estuary, a finding confirmed by the large blackwater plumes and fish kills following flood events in 2001, 2008, and 2020.

Following the prioritisation of subcatchments, management options have been suggested 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 suggested 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 Richmond 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 is Table 9.2. This information was 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: Richmond River drainage vulnerability under sea level rise

Vulnerability Status	Historic Scenario (HS)	Present Day (PD)	Near Future (NF)	Far Future (FF)
Floodgates (number of)				
Least vulnerable floodgates	280	266	224	140
Moderately vulnerable floodgates	86	97	124	104
Most vulnerable floodgates	10	13	28	132
Floodplain area (hectares)				
Low vulnerability area	2,063	2,628	4,915	12,75
Moderate vulnerability area	85	96	247	3,340
High vulnerability area	13	17	40	421

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 Richmond 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 floodplain management.

9.3 Conclusions

Substantial efforts have been made in the Richmond River estuary to address poor water quality from acid sulfate soils and blackwater, mainly led by Rous County Council with the support of 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, auto-tidal gates and winches) and improved connectivity with the estuary. Numerous landholders have co-operated with trials of liming, wet pasture management, and drainage management to reduce acid drainage from the floodplain, 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 (Tuckean Swamp, Rocky Mouth Creek and Bungawalbin Creek/Sandy Creek) 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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