Hastings River Floodplain Prioritisation Study

WRL TR 2020/08, May 2023

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UNSW Water Research Laboratory

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Executive summary

ES.1 Preamble

The NSW Marine Estate Management Strategy (MEMS) (Marine Estate Management Authority, 2018) is a NSW 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 Hastings River floodplain. To determine how water quality from the Hastings 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 developed 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).

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

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

ES.3 Study approach

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

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

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

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

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

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

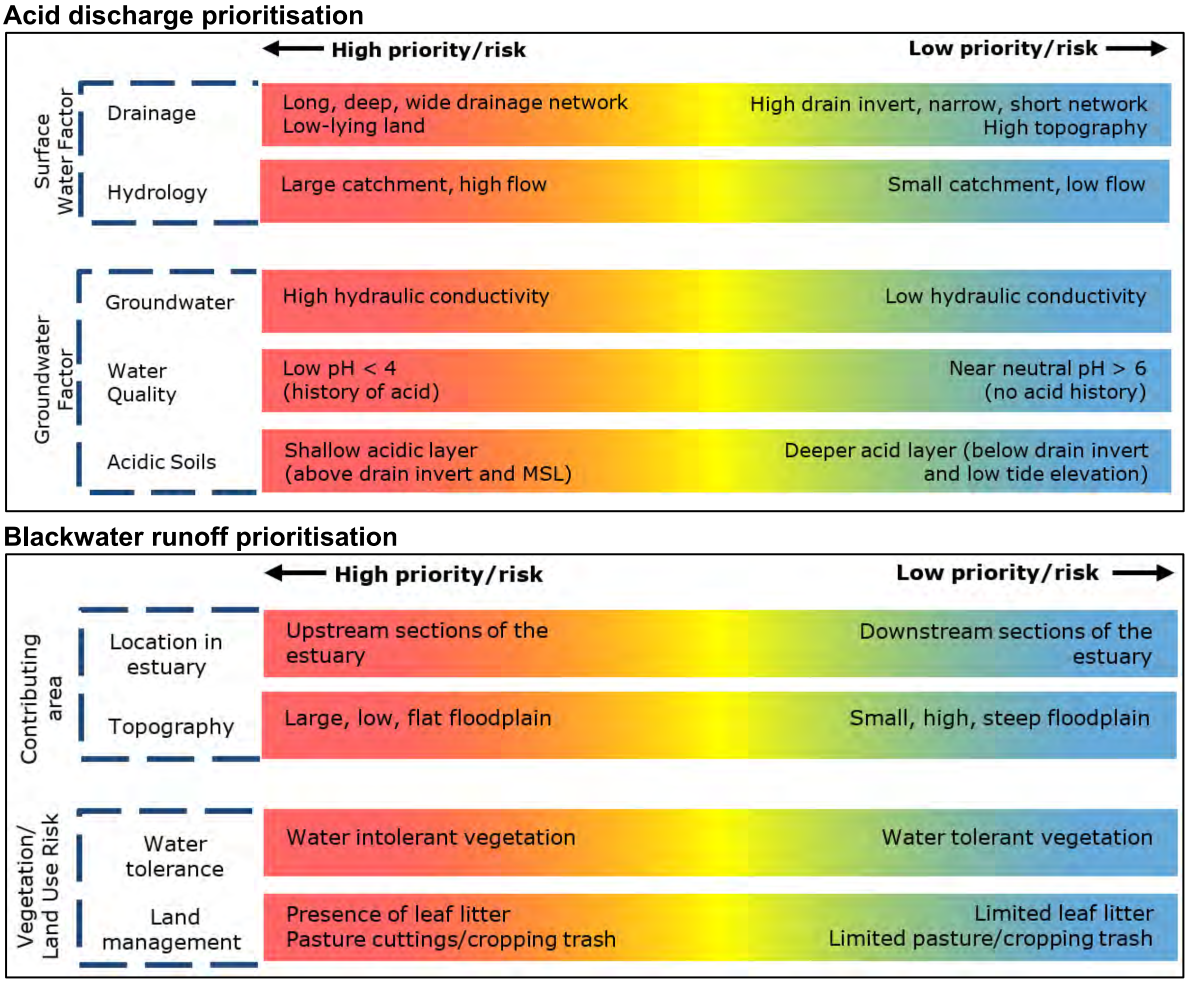

Figure ES-1: Factors influencing acid sulfate soil discharge and blackwater runoff from NSW coastal floodplain subcatchments

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

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

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

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

ES.4 Hastings River floodplain subcatchment prioritisation results

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

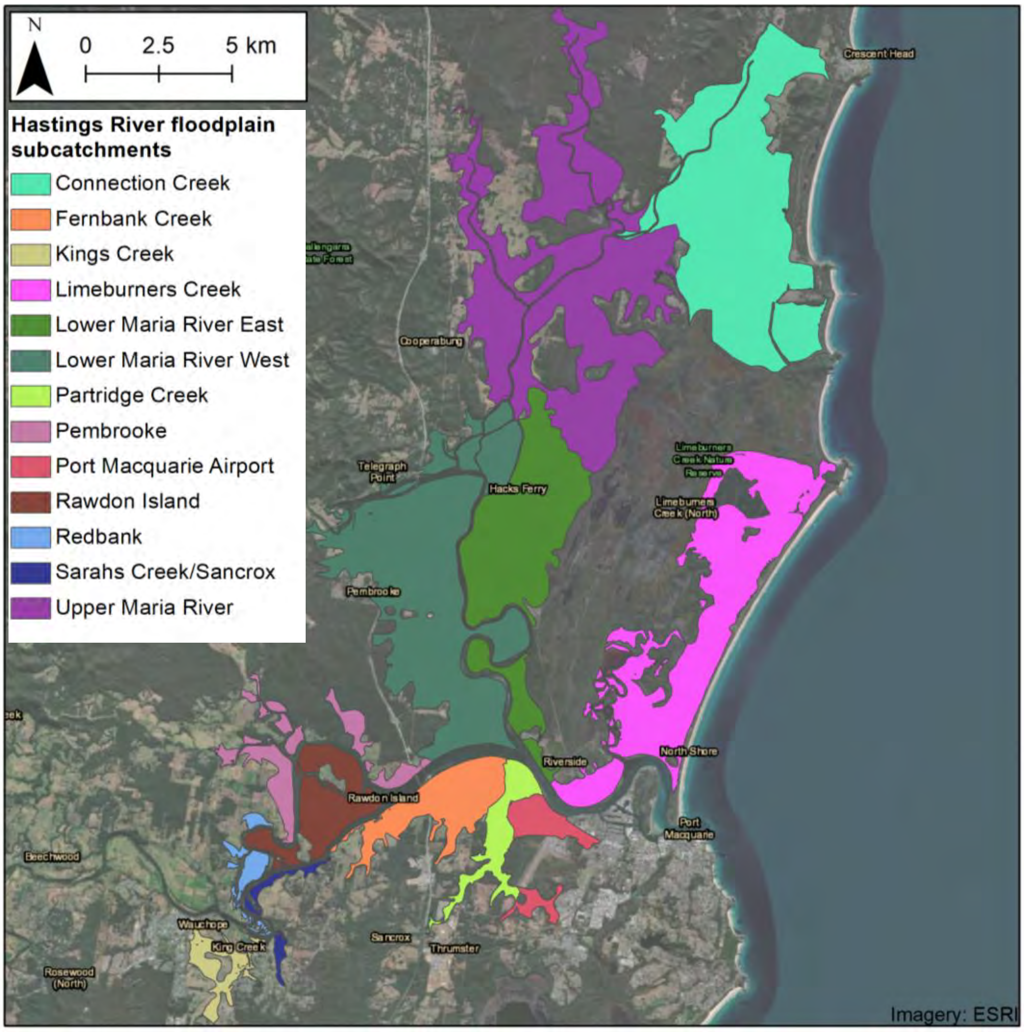

Figure ES-2: Hastings River floodplain subcatchments

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 Hastings River floodplain, the highest two (2) ranked subcatchments for acid drainage: Lower Maria River West (1) and Upper Maria River (2) were estimated to contribute over 55% of the total acid risk to the estuary. The Lower Maria River West subcatchment was estimated to individually be the source of 37% of acid risk to the estuary. High risk acid subcatchments were identified in particularly in the Maria River area, which indicates that this tributary may be particularly vulnerable to acidification (Table ES-1, Figure ES-3).

Table ES-1: Hastings River floodplain subcatchment priority ranking

Floodplain subcatchment	Acid rank	Blackwater rank
Lower Maria River West	1	3
Upper Maria River	2	2
Partridge Creek	3	13
Connection Creek	4	1
Pembrooke	5	5
Lower Maria River East	6	4
Rawdon Island	7	8
Fernbank Creek	8	6
Kings Creek	9	9
Port Macquarie Airport	10	12
Sarahs Creek/Sancrox	11	10
Limeburners Creek	12	7
Redbank	13	11

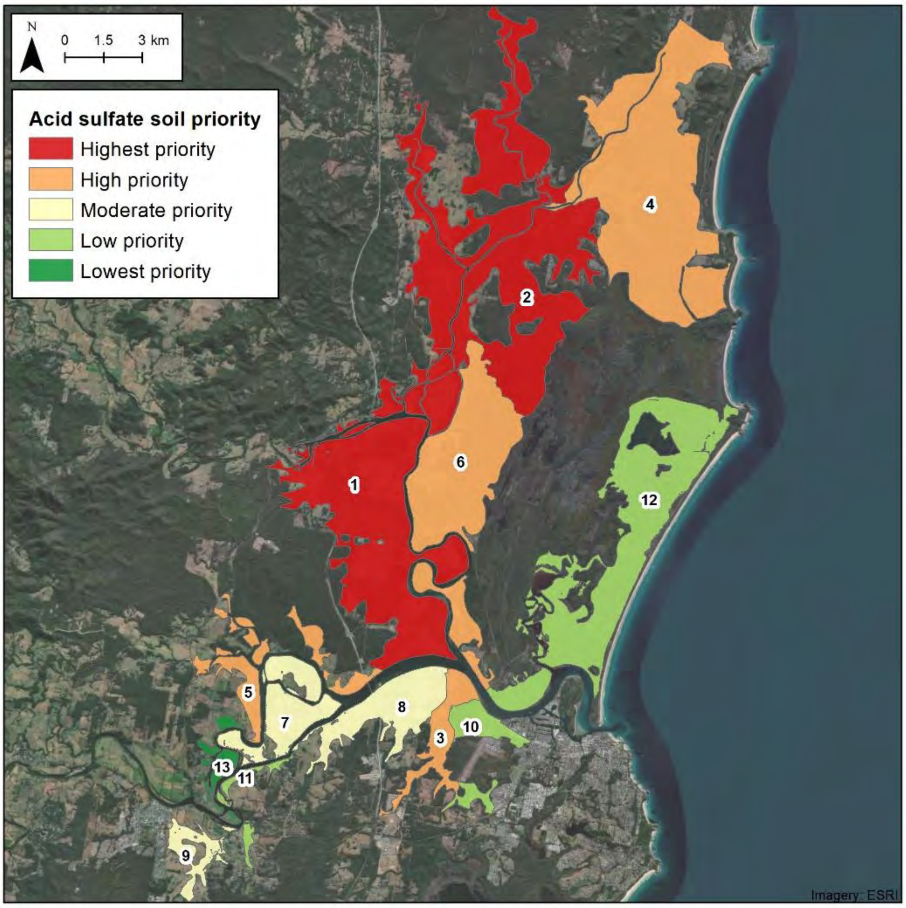

Figure ES-3: Hastings River floodplain subcatchment rankings of the acid prioritisation assessment

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 two (2) ranked subcatchments (Table ES-1), Connection Creek (1) and Upper Maria River (2), each account for 39% of the over blackwater generation potential in the Hastings River. As shown in Figure ES-4, the top four (4) ranked subcatchments for blackwater generation potential are all on the Maria River and collectively account for approximately 95% of the total blackwater generation potential in the estuary.

Note, while blackwater generation occurs in the Hastings River floodplain, it has historically not been as significant an issue compared to other large coastal floodplains in NSW (e.g. the Richmond River floodplain or the Macleay River floodplain). While ASS and blackwater risks have been individually ranked, this does not mean that the impacts of blackwater are necessarily comparable to the impacts of ASS on the Hastings River floodplain.

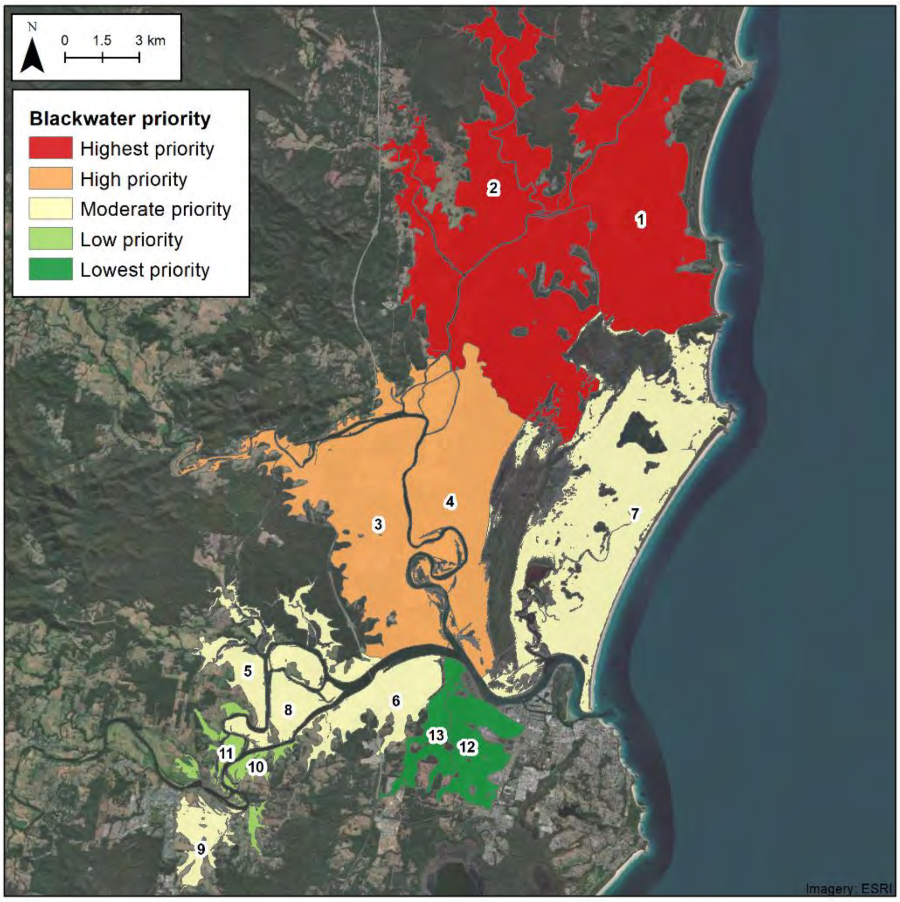

Figure ES-4: Hastings River floodplain subcatchment rankings of the blackwater prioritisation assessment

ES.5 Sea level rise & 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 environment. 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 Hastings 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.

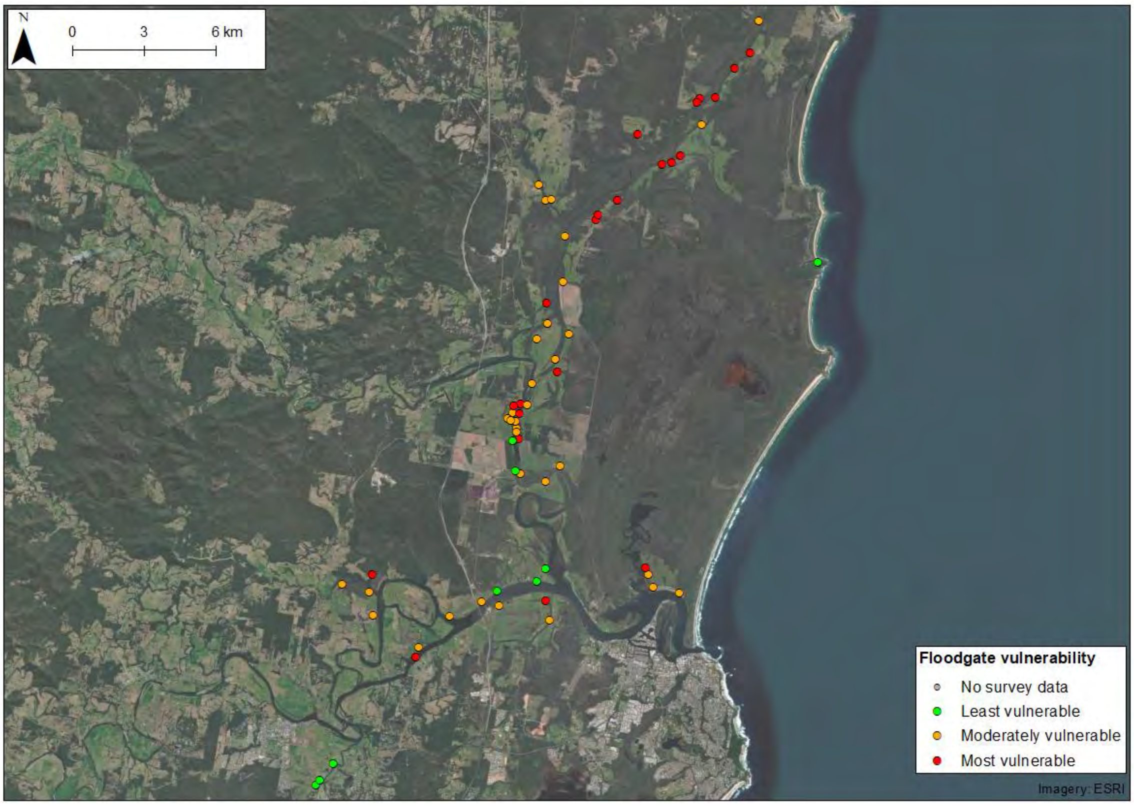

Figure ES-5: Hastings River estuary floodgate vulnerability with sea level rise (far future ~2100)

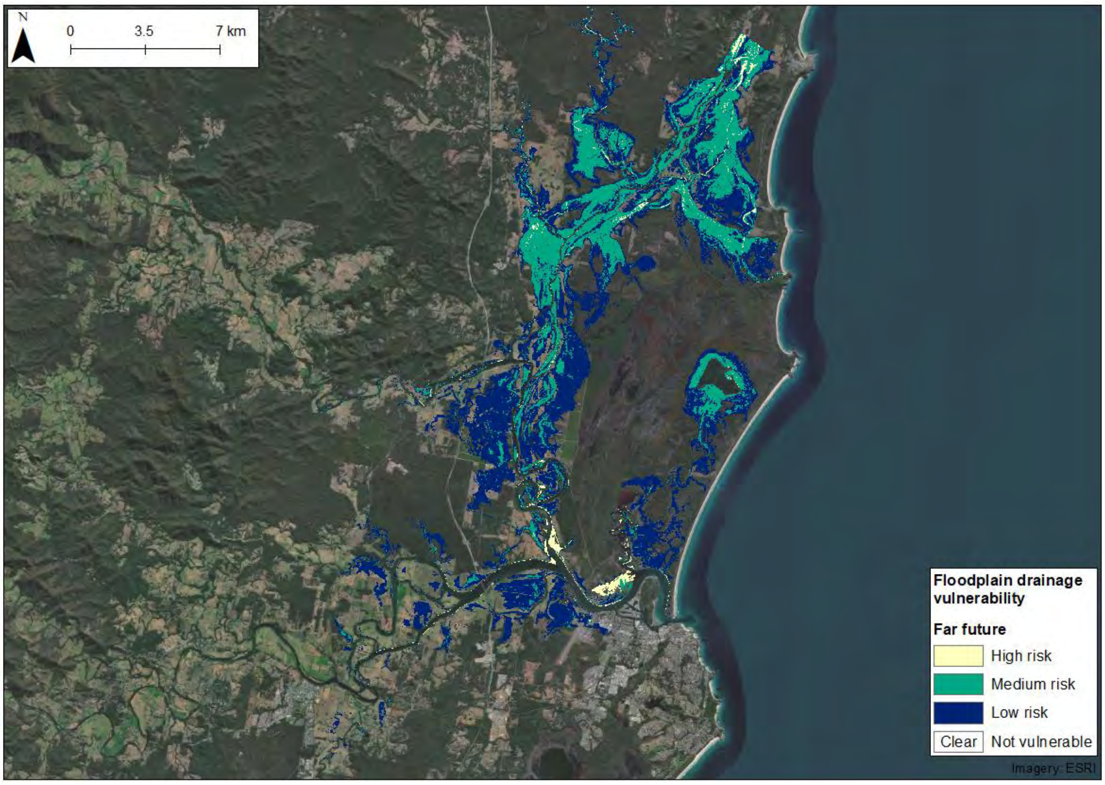

Figure ES-6: Hastings River floodplain vulnerability with sea level rise (far future ~2100)

ES.6 Recommended actions for three priority subcatchments

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

- Lower Maria River West;
- Upper Maria River; and
- Connection Creek.

It is estimated that these three (3) floodplain subcatchments account for approximately 63% and 89% of the overall acid and blackwater generation risk in the Hastings River floodplain respectively and are all situated along the Maria River tributary. Addressing water quality issues from these three (3) subcatchments would result in significant improvements in overall estuary health of the Hastings River estuary.

The prioritisation methodology is primarily based on subcatchment datasets to determine subcatchment rank within a coastal floodplain, and does not explicitly incorporate the effectiveness of existing remediation works on reducing acid discharge or blackwater generation potential. Existing remediation works are, however, considered in each subcatchment management options.

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

Lower Maria River West

The Lower Maria River West subcatchment ranked first in the ASS prioritisation, and was estimated to contribute 37% of the overall acid risk to the Hastings River estuary. It also ranked third in the blackwater prioritisation. While a substantial amount of work has already been completed by the Port Macquarie-Hastings Council and local landholders in this subcatchment (largely in the form of floodgate modifications and use of weirs), further long-term reductions in acid and blackwater discharges would result in substantial improvements in estuarine eco-health.

The existing remediation works in the Lower Maria River West subcatchment will have already addressed some of the acid discharges from the area and the options for further short-term improvements in land management without impacting existing land uses is limited. The management of dropboard weir structures should be reviewed and optimised where necessary. The use of livestock (sheep or goats) for grazing in tea tree plantations to reduce blackwater risk should also be considered.

In the long-term, remediation of low areas to freshwater and/or brackish wetlands should be prioritised in this subcatchment. This remediation would likely include:

- Infilling of the artificial drainage network to reduce drainage density;
- Reshaping of remaining drainage network to reduce interaction with acidic layers;
- Removal of floodgates; and
- Establishment of wetland habitats in low-lying areas.

This would result in a mix of freshwater and brackish wetlands and prolonged inundation in the lowest areas of the subcatchment. This would reduce acid drainage, as well as encourage water tolerant vegetation and reduce the blackwater generation potential. In higher areas, wet pasture management should be encourage through the use of stepped weirs.

Upper Maria River

The Upper Maria River subcatchment ranked second in both the ASS and blackwater prioritisation. While at least four (4) structures have been modified or constructed to manage acid discharges, the short-term management options includes additional modification of remaining floodgates along Maria River Road. These modifications would allow managed tidal flushing and maintain higher surface water levels in the drainage system upstream. The use of dropboard weirs coupled with wet pasture management should also be considered in areas that are currently actively used for grazing.

Sea level rise may impact the productivity of present day land uses in the low areas of the Upper Maria River subcatchment. If areas that are currently cleared for grazing are no longer viable due to sea level rise, low areas (below +1 m AHD) should be prioritised for remediation to increase the footprint of the Coastal Management SEPP coastal wetland areas in this subcatchment. This would reduce the impacts of ASS in the subcatchment, as well as reducing the blackwater generation potential and providing important estuarine habitat. This would likely to include:

- Restoration of natural flow paths through infilling of artificial drainage networks and reducing efficient connectivity of the floodplain to the main waterways to encourage prolonged inundation of low backswamp areas; and
- Removal or modification of floodgates to allow significant tidal flushing.

Connection Creek

The Connection Creek subcatchment ranks first in the blackwater prioritisation, and was estimated to account for approximately 39% of the blackwater generation potential in the Hastings River estuary. The subcatchment also ranked fourth in the ASS prioritisation. More than three quarters of the Connection Creek floodplain are mapped as “conservation and minimal use” or “marsh/wetland”, and a substantial area is mapped as Coastal Management SEPP coastal wetlands. While the majority of this subcatchment is not actively used for agriculture, existing artificial drainage should be investigated to ensure it is not lowering the water table in the coastal wetland areas. Short-term management may also include the use of dropboard weirs to retain water on low areas after significant rainfall to reduce acid and blackwater drainage.

In the long-term, low-lying areas in this subcatchment may also be impacted by reduced drainage as a result of sea level rise. These areas should be prioritised for remediation to freshwater or brackish wetlands to expand the existing Coastal Management SEPP coastal wetlands. Restoration of natural flow paths and prolonging inundation of the subcatchment will significantly reduce pathways for acid drainage, as well as reducing the blackwater generation potential by encouraging water tolerant vegetation. This would likely include:

- Restoration of natural flow paths with infilling of artificial drainage networks;
- Reshaping of the remainder of the drainage system to reduce interaction with acidic layers;
- Removal of floodgates; and
- Revegetation of cleared areas.

ES.7 Outcomes and conclusions

Outcomes from the Coastal Floodplain Prioritisation Study for the Hastings 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.

Across the Hastings River estuary, local government, and landholders have completed significant on-ground works to reduce the impact of acid sulfate soils on the waterway. This includes major floodplain end-of-system infrastructure being modified to allow some controlled flushing (e.g. sluice gates, auto-tidal gates and winches), improved connectivity with the estuary and large scale remediation of the Partridge Creek area. Numerous landholders have co-operated with paddock scale interventions, such as weirs or drain reshaping, with mixed success in terms of water quality improvements and maintenance/improvement of agricultural productivity. These remediation efforts should be encouraged and commended. However, the scale of on-going large event-based floodplain discharges of blackwater and acid, particularly from Maria River 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 dropboard 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.
Dropboard	Dropboards 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. Dropboards are similar to weirs in that they only allow water to flow over the top of them. Unlike weirs, dropboards are adjustable in height. Multiple boards with different heights can be used to adjust and set the weir level. Dropboards can be fitted to culverts or can be standalone structures.
Drought	A prolonged period of reduced or low precipitation resulting in a shortage of water.
Electrical conductivity (EC)	A measure of dissolved salt in water in the units of micro Siemens per centimetre (µS/cm) usually at a temperature of 25ºC.
Estuary	A semi-enclosed waterbody where fresh water from catchment runoff and saltwater from the ocean mix.
Evaporation	The process of liquid water on the land surface becoming water vapour in the atmosphere.
Evapotranspiration	The sum of evaporation and transpiration.
Exceedance per year (EY)	The likelihood that a flood or rainfall event of a predetermined size will occur a certain number of times within any one-year period.
Flood	High flow of water within a waterway that results in the overtopping of natural or artificial banks (or levees) of a waterbody and inundation of usually dry land.
Floodgate/ floodgate flap	A plate that is hinged on its top edge to cover the outlet of a culvert. The flap is positioned so that it only opens when the water level on the upstream (floodplain side) is higher that the level on the downstream (river side) of the culvert, thereby only allowing water to flow in the downstream direction effectively draining the floodplain. Floodgates often regularly open and close with fluctuating tidal water levels in the river. It is common for floodgates to have rubber seals to prevent leaking. Floodgate flaps can be made of many materials such as aluminium, plastic, fibre glass or wood.
Floodplain	The area of land adjacent to a waterbody that is often relatively flat and usually dry unless exposed to water as occurs during a flood.
Freshwater	Water that contains less than 1,000 milligrams per litre (mg/L) of dissolved solids.
Gate	A term used to describe the part of either a floodgate or sluice gate flow control structure that controls water movement.
Groundwater	Water held under the ground surface within soil and rock formations.
Groundwater table	The upper surface of soil or rock formations that is fully saturated by groundwater.
Headwall	The concrete structure surrounding and supporting a culvert. Floodgate flaps or other mechanisms are usually mounted to the headwall.
Hydraulic gradient	The difference in pressure or elevation of water over a distance. The hydraulic gradient results in the flow of water (from high elevation or pressure to low elevation or pressure).
Hydrodynamics	The branch of science concerned with the movement of, and forces acting on or exerted by fluids.
Hydrodynamic model	A numerical representation of the movement of water through a system.
Hydrograph	A graph showing the level, discharge, velocity, or other property of water with respect to time.
Hydrology	The branch of science concerned with the movement and quality of water in relation to land.
Impermeable layer	A layer of solid material, such as rock or clay, which does not allow water to pass through.
Invert	The elevation of the lowest internal point of a culvert.
Leaching	The process by which soluble materials in the soil such as salts, nutrients, pesticide chemicals or contaminants are dissolved and carried away by water.
Left bank/right bank	The side of a waterway when looking in the downstream direction (i.e. toward the ocean).
LEP	Local Environmental Plan - LEPs are planning instruments that guide planning decisions for local government areas. They do this through zoning and development controls, which provide a framework for the way land can be used. LEPs are the main planning tool to shape the future of communities and also ensure local development is completed appropriately.

LGA	Local Government Area.
Levee	An embankment that prevents or reduces flow from a waterway to the floodplain. Levees can be naturally formed as river banks or manmade for the purpose of flood mitigation or to prevent inundation of low-lying land.
Lidar	Light detection and ranging technology that can be used to measure ground surface elevations and create DEMs.
Marine estate	Tidal rivers and estuaries, the shoreline, submerged lands, offshore islands, and the waters of the coast up to three nautical miles offshore.
Management area	A subset or smaller area of a subcatchment often delineated based on floodplain tenure and ownership in addition to floodplain hydrological and geomorphological characteristics. Generally, a management area is of small enough scale that implementation of on-ground works to address water quality issues can be completed.
MBO	Mono-sulfidic black ooze – deposits in drainage channels created by iron and sulphur minerals (pyrite) within acid sulfate soils which, when mobilised, can remove oxygen from the water through a chemical reaction.
Obvert	The elevation of the highest internal point of a culvert.
Organic matter	Substances made by living organisms and based on carbon compounds.
Peak flow	The maximum instantaneous discharge of a waterway at a given location.
pH	A measure of the acidity or alkalinity of water. Water with a pH of 7 is neutral; lower pH levels indicate increasing acidity, while pH levels higher than 7 indicate increasing alkalinity
Pipe	A pipe is a circular culvert. Pipes can be made of many materials such as concrete, PVC or fibre glass.
Precipitation	Water that falls on land surfaces and open waterbodies as rain, sleet, snow, hail or drizzle.
River	A major watercourse carrying water to another river, a lake or the ocean.
Runoff	Excess rainfall that becomes streamflow.
Salinity	The total mass of dissolved salts per unit mass of water. Seawater has a salinity of about 35g/kg or 35 parts per thousand (ppt).
Sediment	Material suspended in water or deposited from suspension.
Seepage	The infiltration of water from surface waterbodies to the groundwater.
Sluice/sluice gate	A gate that operates by sliding vertically to control water flowing through or past a restriction point. Sluice gates act so that water flows underneath the 'sluice' or the sliding section of the gate. A sluice gate can be set to different levels to control the volume of water that flows. There are many different designs for sluice gates.
Soil profile	A vertical section of soil (from the ground surface downwards) where features such as layers (soil horizons), texture, structure, consistency, colour and other characteristics of the soil can be observed.
Streamflow	The flow of water in open waterbodies (such as streams, rivers or channels).
Subcatchment	A section of the floodplain that is geologically and hydrologically similar but can also be delineated based on floodplain management objectives.
Surface water	Water that flows or is stored on the Earth's surface.
Tidal exchange	The proportion of water that is flushed away and replenished with new ocean water each tidal cycle.
Tidal limit	The maximum distance upstream of a waterway where the influence of tidal variation in water levels is observed.
Tidal planes	Reference elevations that define regular tide elevations, including: MHWS - Mean High Water Springs MHW - Mean High Water MSL - Mean Sea Level MLW - Mean Low Water MLWS - Mean Low Water Springs
Tidal prism	The volume of water that flows in and out of an estuary during a tidal cycle (e.g. high tide to low tide).
Transpiration	The release of water vapour from plants to the atmosphere.
Tributary	A smaller river or stream that flows into a larger waterbody.
Watertable	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 NSW 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. Major sources of poor water quality across the marine estate include acid sulfate soil (ASS) and blackwater runoff into our estuaries. Over the past 25+ years, significant efforts to remediate ASS and blackwater drainage have been made by local councils and landholders to remediate ASS and blackwater drainage, however this has been limited by insufficient funding, resources, and community willingness. To better target remediation efforts and land management decisions, Department of Primary Industries (DPI) – Fisheries commissioned the Coastal Floodplain Prioritisation Study, based on a method detailed in Glamore and Rayner (2014) and adapted to integrate the MEMS approach for achieving environmental outcomes that consider social, cultural and economic benefits, to prioritise floodplain subcatchments in seven (7) coastal floodplains in NSW.

This report provides an evidence based assessment of floodplain subcatchment drainage areas that contribute poor water quality to the Hastings 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 outline 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 Hastings 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 staff at 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 Hastings 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:

- Hastings River floodplain (this report);
- Tweed River floodplain (WRL TR2020/04);
- Richmond River floodplain (WRL TR2020/05);
- Clarence River floodplain (WRL TR2020/06);
- Macleay River floodplain (WRL TR2020/07);
- 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 Hastings 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 study report provides a prioritised list of floodplain subcatchments from where the greatest risk of acid and blackwater within each floodplain originate. The greatest potential benefit to the estuary can be gained by reducing the sources of poor water quality from the subcatchments according to the priority order. The individual floodplain assessments and prioritisations provide subcatchment management options and data summaries to guide land managers and decision makers in implementing on-ground actions on both floodplain and paddock scales.

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

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

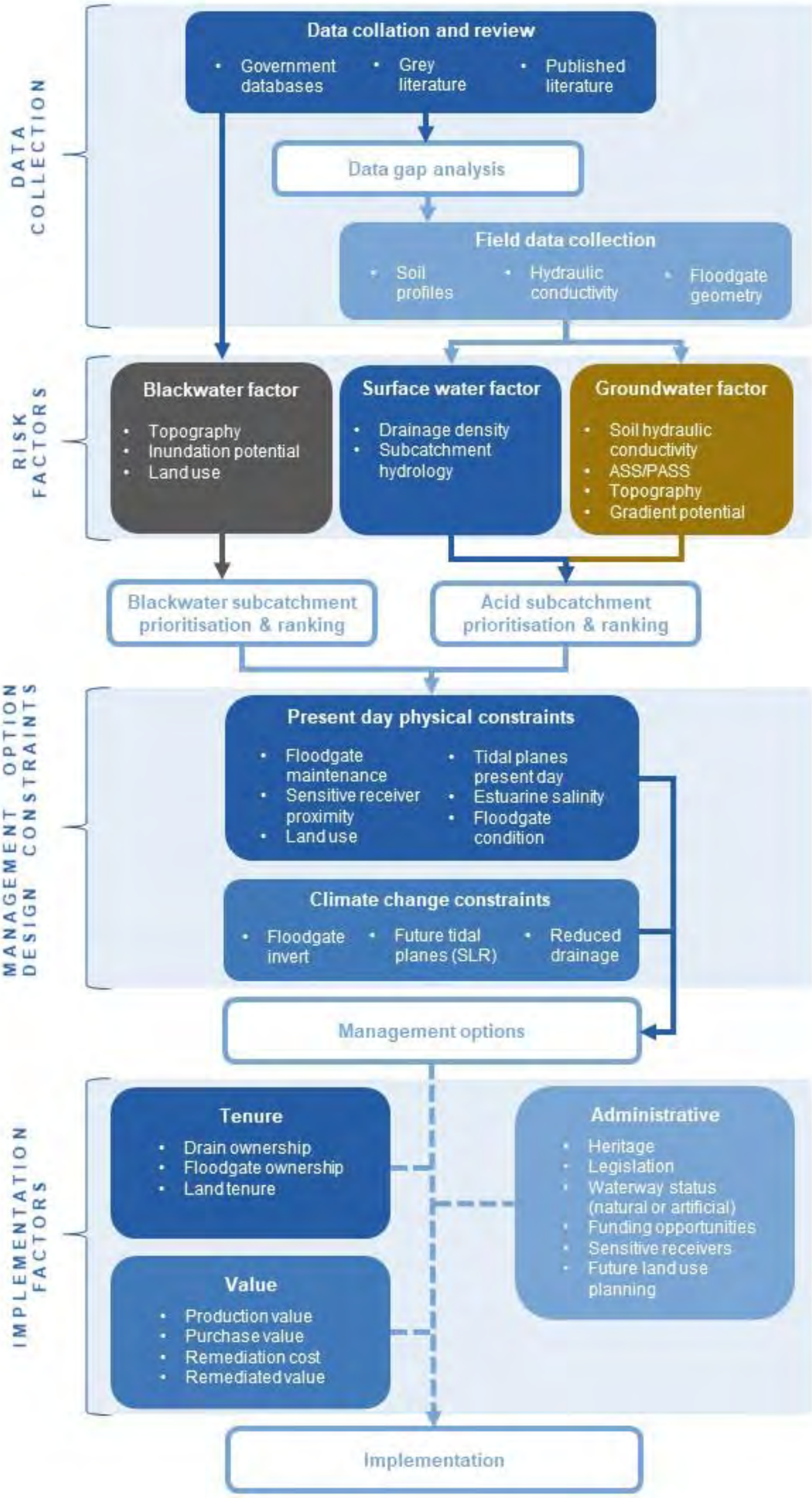

Figure 1-1: Study approach overview

1.4 Hastings River floodplain prioritisation

The Hastings River floodplain is located on the mid-north coast of NSW between the towns of Port Macquarie in the east and the town of Wauchope to the west. The Hastings region has been actively used for agriculture and aquaculture since the 1800's, including the state's first sugar cane farming in 1821 (Tulau, 2011) and oyster farming in Limeburners Creek recorded in 1886 (Dove, 2003). Major drainage works were constructed in the 1960s and 1970s to facilitate agricultural development and for flood protection purposes (Tulau, 1999). Floodplain development and drainage has had unintended impacts on estuarine water quality with the oxidation of acid sulfate soils, and the establishment of non-water tolerant vegetation in historically low-lying wetland areas (Johnston et al., 2003a; Johnston et al., 2003b). Although acid sulfate soils are naturally occurring sediments, and blackwater discharge historically occurred in undeveloped, natural floodplains, the construction of man-made drainage channels exacerbated these issues and has contributed to poor water quality throughout the greater Hastings River estuary. Discharges from ASS have also impacted in reduced productivity of oyster farming through increased mortality and disease (Dove, 2003) .

This report summarises the application of the acid sulfate soil and blackwater subcatchment prioritisation methodologies on the Hastings River estuary floodplain (defined as the area below 5 m AHD). On-ground management options have been developed for each subcatchment, based on the results of the dual prioritisation. Some remediation strategies 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 action plans 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 Hastings 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 Hastings River floodplain;
- **Chapter 3** provides background information describing the floodplain drainage and presence of ASS and blackwater in the Hastings River floodplain.
- **Chapter 4** provides an overview of the ASS and blackwater prioritisation;
- **Chapter 5** presents the outcomes of the ASS prioritisation on the Hastings River floodplain;
- **Chapter 6** presents the outcomes of the blackwater prioritisation on the Hastings River floodplain;
- **Chapter 7** provides information on the impact of climate change on floodplain drainage;
- **Chapter 8** outlines the management options developed for each subcatchment; and
- **Chapter 9** provides a summary and recommendations.

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

- **Appendix A** Floodplain 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 Hastings 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 LiDAR surveys);
- Waterway alignment data; and
- 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 delineation process as it then allows each subcatchment to be managed as a discretised unit. This typically allows for modifications to occur in one subcatchment without impacting or altering the hydrological conditions to an adjacent subcatchment. This section outlines the subcatchments developed for the Hastings River floodplain, which are used throughout this study.

2.2 Subcatchments of the Hastings River floodplain

The subcatchment delineation of the Hastings River considers the ASS priority areas identified by Tulau (1999). For the purpose of this study, the Upper Maria River – Connection Creek ASS priority area has been split into two (2) subcatchments (Upper Maria River and Connection Creek), as has the Lower Maria River ASS priority area (Lower Maria River West and Lower Maria River East). The Partridge Creek and Rawdon Island subcatchments cover a similar area to the corresponding ASS priority areas in Tulau (1999). The estuary management plan did not include floodplain subcatchment areas, so the remainder of the floodplain subcatchments were delineated based on topography and drainage.

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

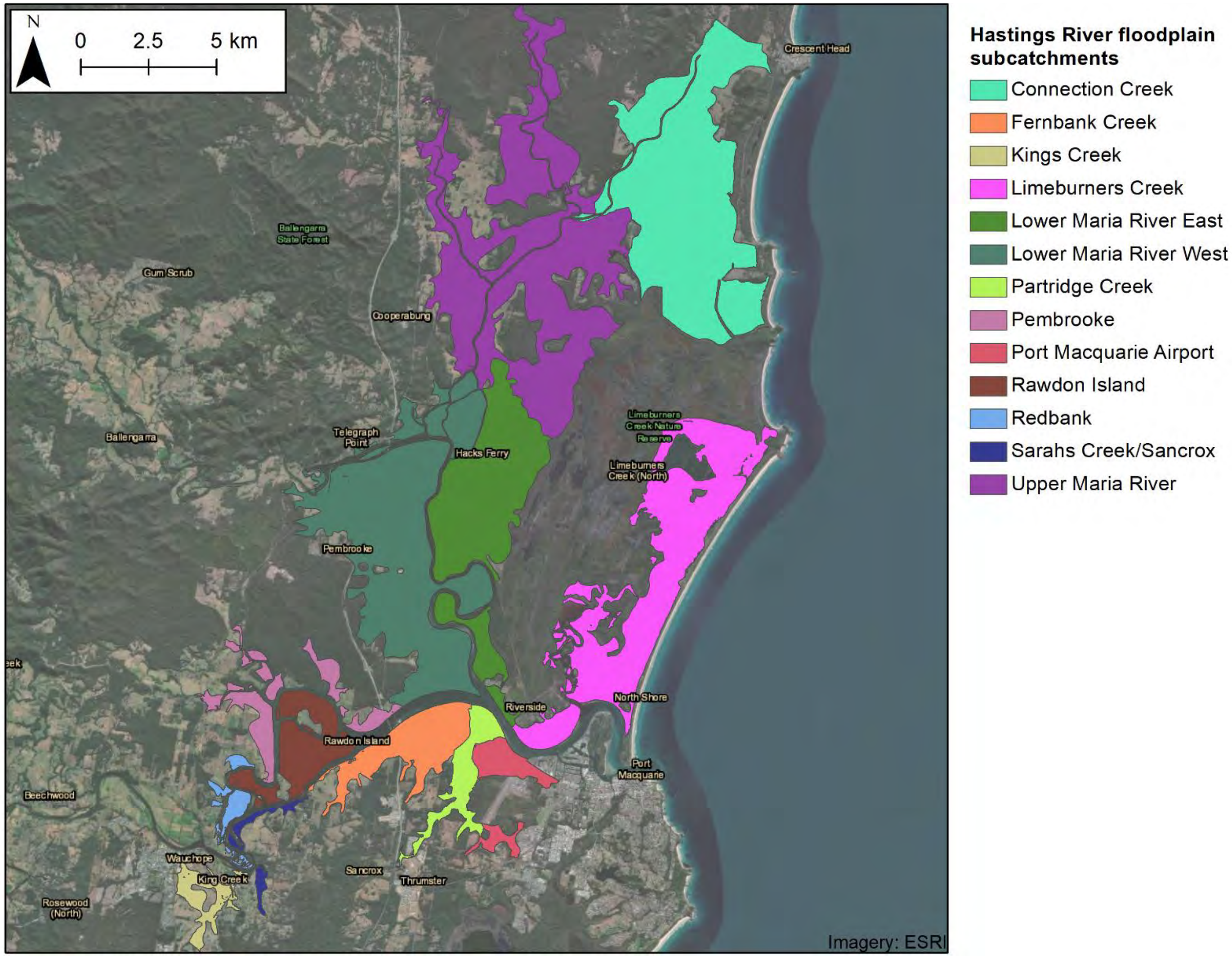

Figure 2-1: Subcatchments in the Hastings River floodplain

3 Background

3.1 Preamble

This section provides background information on the Hastings 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

Parts of the Hastings River floodplain are within the boundaries of two (2) local government areas (LGAs), shown in Figure 3-1. These include:

- Port Macquarie-Hastings Council, which includes all of the Hastings River, and the lower sections of the Maria River; and
- Kempsey Shire Council, which includes the upper sections of the Maria River, which is connected via low-lying floodplain to the Belmore River to the north (which is located within the catchment of the Macleay River).

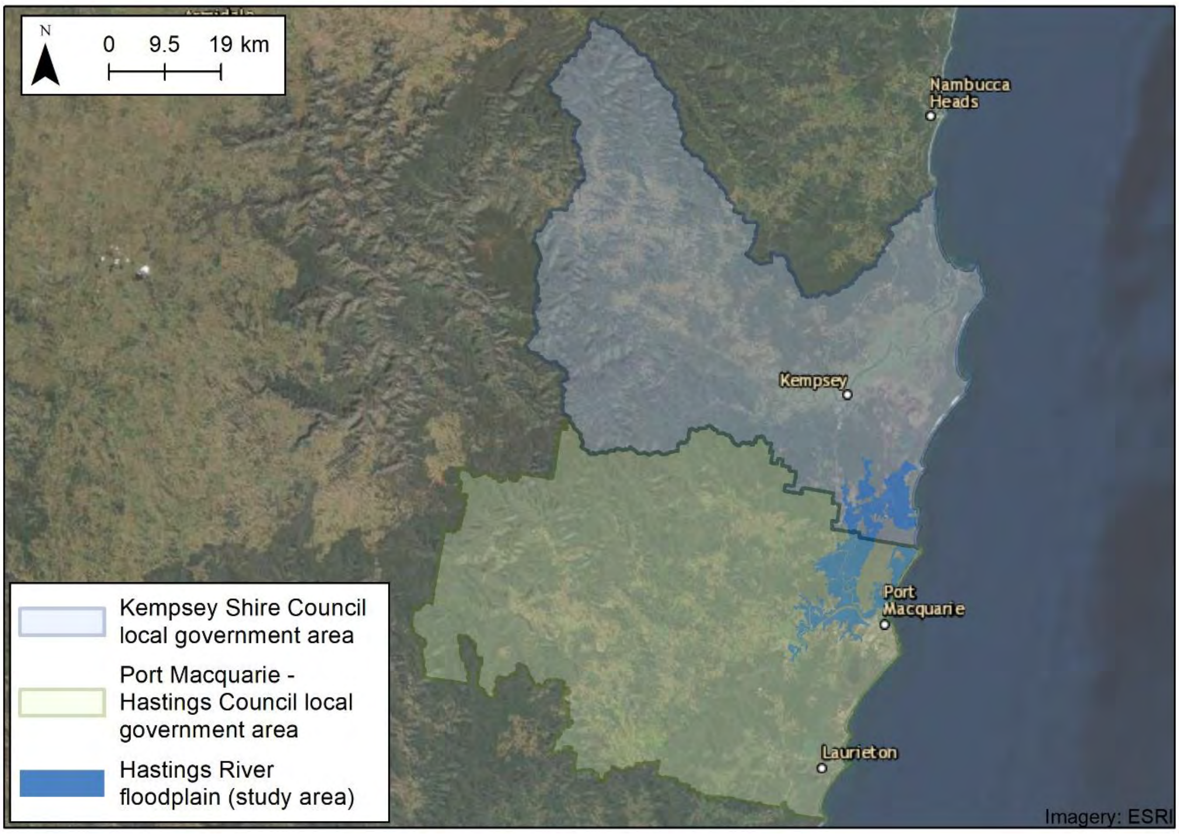

Figure 3-1: Local government areas covering the Hastings River floodplain

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

3.3 Floodplain history

The Hastings River floodplain (below 5 m AHD) covers an area of approximately 290 km^2, including the floodplain of the Maria River, a major tributary, shown in Figure 3-2. While there are some small, low elevation backswamps along the Hastings River, the larger backswamps occur along the Maria River (Figure 3-3). A number of creeks connect the backswamps of the Hastings/Maria River floodplains to the main waterways, including Connection Creek, Pipers Creek, Wilsons River, Limeburners Creek and Partridge Creek.

The town of Port Macquarie was established in 1818, and the Hastings River was among the first areas subject to artificial drainage for agriculture on the North Coast of NSW (Tulau, 2011). The majority of flood mitigation works were completed in the 1960's and 1970's, however, unlike many of the northern rivers catchments, few structural flood mitigation works were constructed with support from the Council, State or Federal funding (Tulau, 1999). This legacy remains important today, as a significant portion of the floodplain drainage infrastructure remains privately owned and managed.

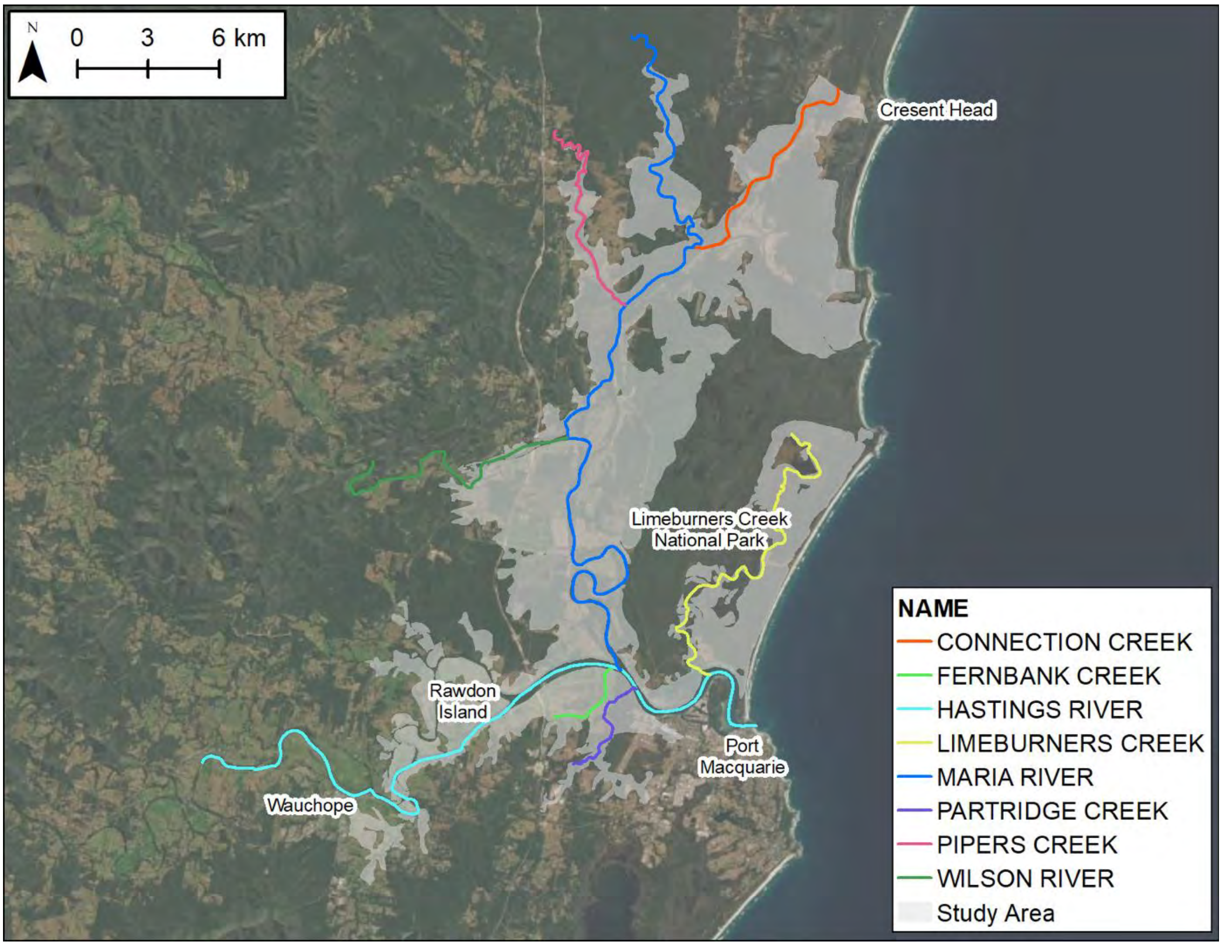

Figure 3-2: Key locations and waterways in the Hastings River floodplain

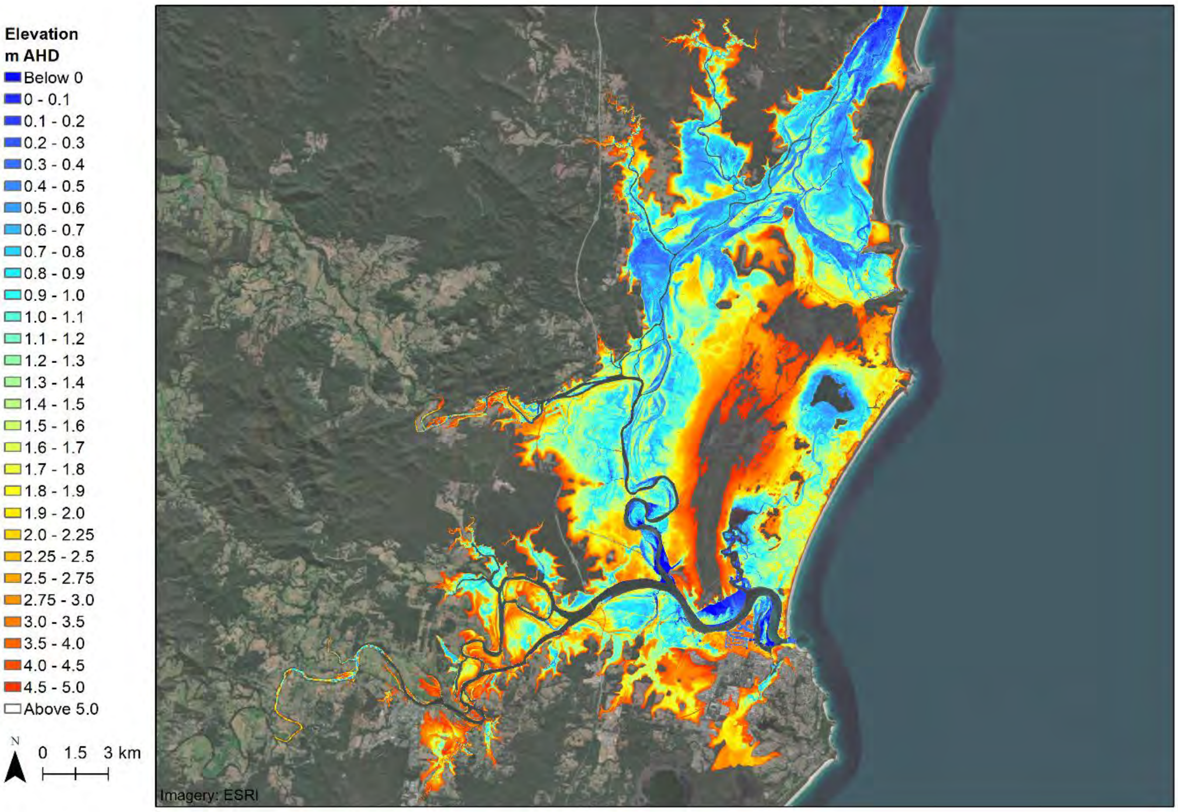

Figure 3-3: Digital elevation map of the Hastings River floodplain

A timeline of key events and drainage works on the Hastings River floodplain, as per Tulau (2011), unless otherwise stated, includes:

- 1818 – The town of Port Macquarie was established;
- 1821 – The first sugar cane in Australia was planted near Port Macquarie, likely followed by the first artificial agricultural drainage on the North Coast;
- 1860s – Agricultural expansion intensifies throughout NSW northern rivers, as a consequence of government incentives for the purchase of land;
- 1902 to 1920 – First organised attempts to coordinate drainage of North Coast floodplain backswamps;
- 1950 to 1970 – Drainage of major backswamps throughout the North Coast occurred, often through funding associated with flood mitigation policies. Tulau (2011) notes that despite the often misleading use of terminology, the 1950 to 70s ‘flood mitigation’ schemes were overwhelmingly swamp drainage schemes. On the Hastings River, flood mitigation and drainage in backswamps resulted in a change in typical drainage times from 100 days to six (6) days (Smith, 1999);
- 1960s – Major dredging of the harbour and entrance bar began (and still continues), to increase the efficiency of the entrance (Webb, McKeown & Associates Ty Ltd, 1998, as cited in Tulau, 1999);
- 1969 – The Maria River Scheme, which involved extensive flood mitigation works in the Upper Maria River/Connection Creek area, was completed. This government funded schemed resulted in the lowering of the swamp water level from about 0.4 m AHD to about -0.5 m AHD, however reclaimed land was found to have low productivity due to the impact of ASS and weed invasion (Smith, 1999);

- 1997 – Hastings Council was the first council to include map-based provisions to the Local Environmental Plan (LEP) for identification of high-risk areas of ASS;
- 1998 to 1999 – An extensive review of existing flood mitigation structures was undertaken, including recommendations for ways to reduce acid discharge, in the Hastings River floodplain by Smith (1999); and
- 2001 onwards – Port Macquarie-Hastings Council has undertaken significant remediation works to address issues associated with ASS. This includes remediation of 940 ha of acid scalds, and 5,120 ha of floodplain under voluntary plans of management (Port Macquarie Hastings Council, 2020).

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

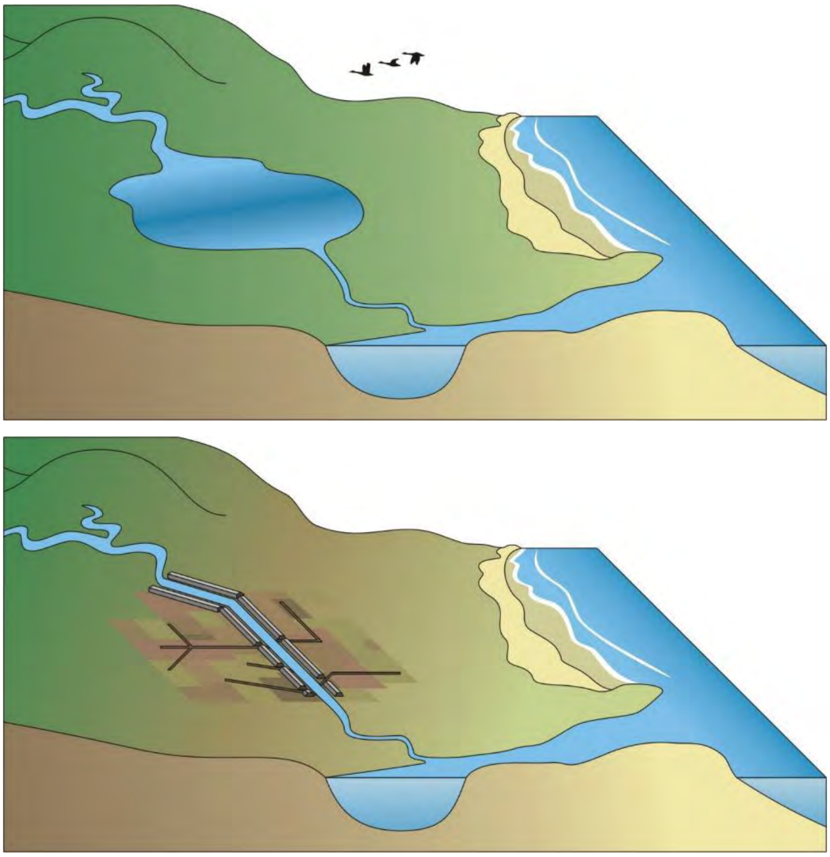

Figure 3-4: Schematic of floodplain evolution following European settlement

3.4 Land use and tenure

Land uses in the Hastings River floodplain for areas below 5 m AHD are shown in Figure 3-5 (refer to Section 9 of Methods report (Rayner et al., 2023) for more detail). The predominant agricultural land uses on the Hastings River floodplain are grazing and tea tree plantations. There are a number of areas that are owned and managed by National Parks and

Wildlife Service (NPWS) in the Hastings River floodplain, including:

- Limeburners Creek National Park; and
- Rawdon Creek Nature Reserve.

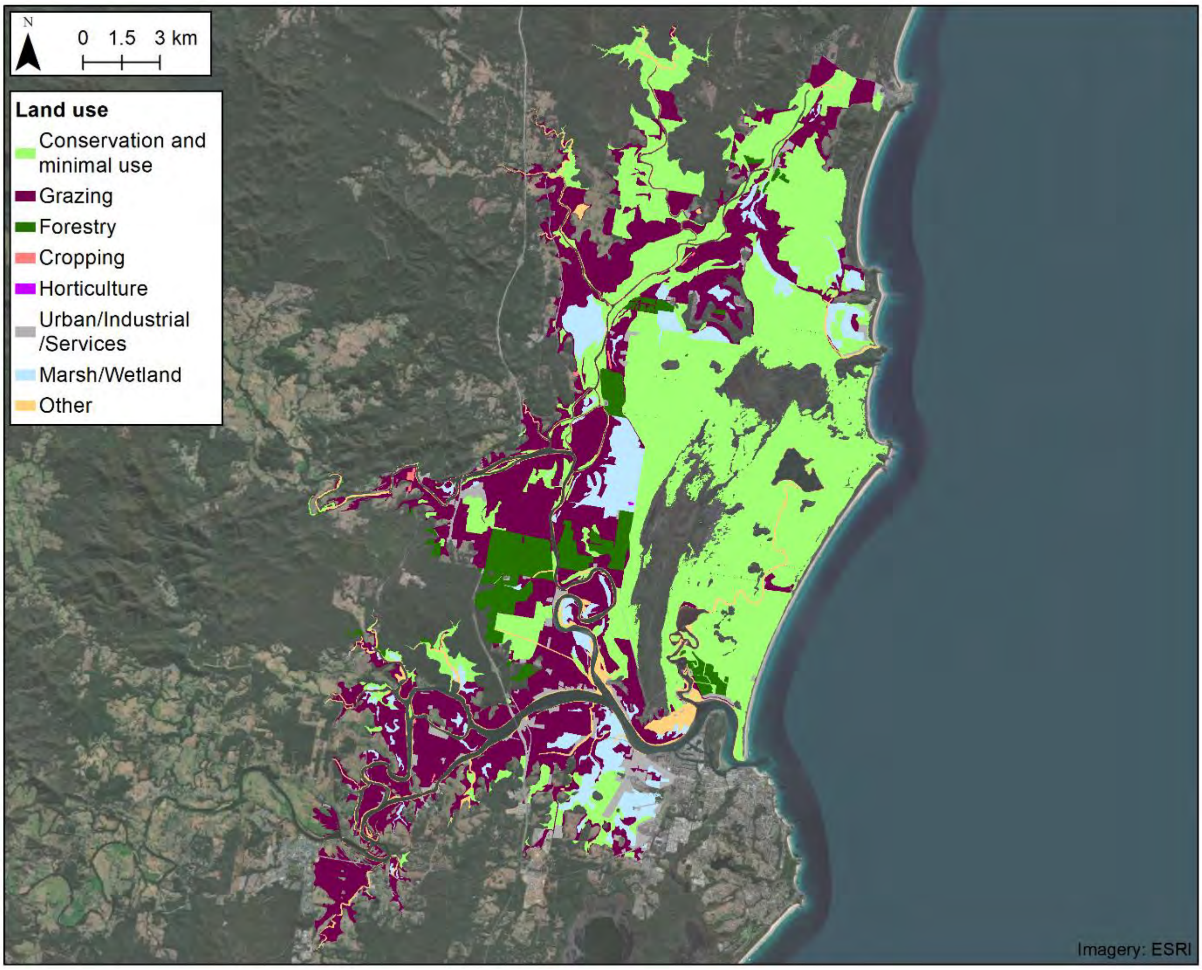

Figure 3-5: Land use in Hastings River floodplain, 2017 (DPIE, 2020)

3.5 Acid sulfate soils in the Hastings River floodplain

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 Hastings 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 Hastings Region

The acid pollution hazard in NSW was originally mapped on the Acid Sulfate Soil Risk Maps prepared by Naylor et al. (1995). The study revealed that the Hastings River floodplain contained an area of over 175 km^2 of high-risk ASS soil below an elevation of approximately 5 m AHD, as shown in Figure 3-6.

Tulau (1999) and Smith (1999) both identified high risk ASS areas/drainage networks in the Hastings River floodplain. The areas identified included (note that the ASS areas ranked 4 or 5 (out of 5) in Smith (1999) were interpreted as high risk):

- Partridge Creek/Fernbank Creek (Smith, 1999; Tulau, 1999);
- Rawdon Island (Smith, 1999; Tulau, 1999);
- Lower Maria River (Tulau, 1999) and The Hatch (North) (Smith, 1999) (largely within the Lower Maria River West subcatchment in this study, although areas in Lower Maria River East subcatchments was also included in the high priority areas in Tulau (1999));
- Maria River/Pipers Creek (referred to as Upper Maria River in this study) (Smith, 1999);
- Thompsons Creek (within the Connection Creek subcatchment in this study) (Smith, 1999); and
- Upper Maria River – Connection Creek (Tulau, 1999).

Available data was analysed to describe the distribution of ASS across the Hastings 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. Highly acidic soils (pH< 4) have been observed across the floodplain, especially in the Lower Maria River West, Partridge Creek and Rawdon Island subcatchments.

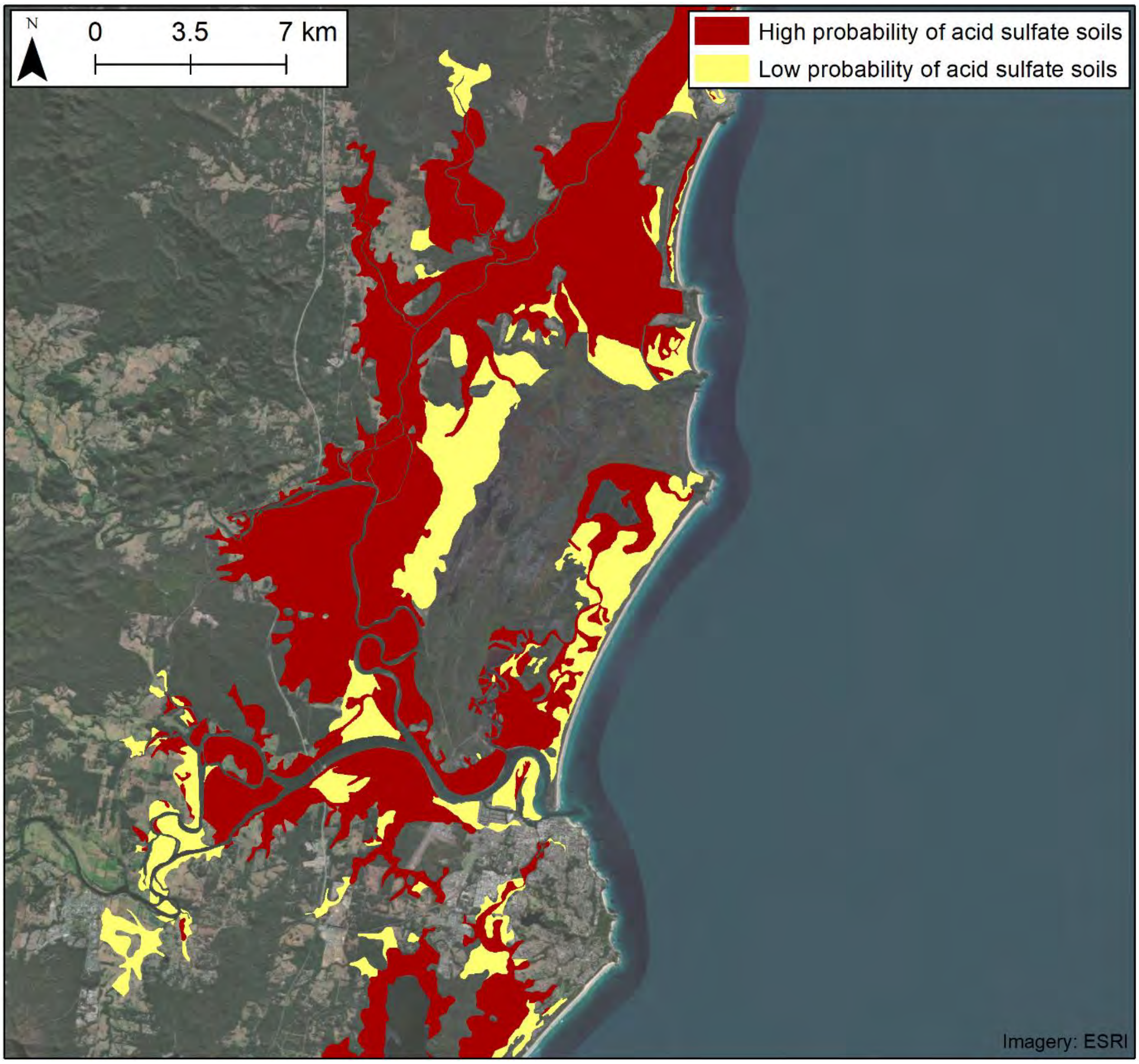

Figure 3-6: NSW Government ASS risk map of the Hastings River floodplain (Naylor et al., 1995)

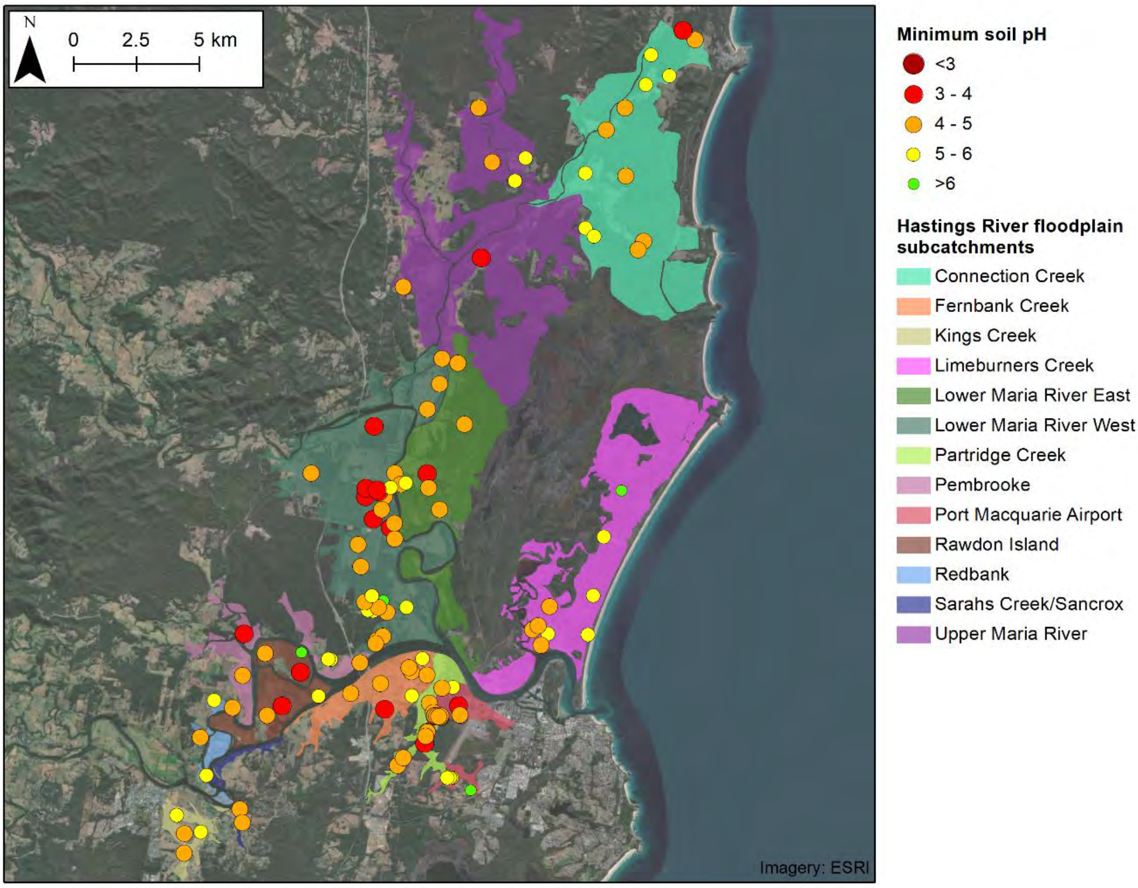

Figure 3-7: Minimum soil pH throughout the Hastings River floodplain

3.5.2 Acid discharge events in the Hastings Region

Acidification of surface waters has been observed in the Hastings River estuary since at least the 1990's (Taylor, 2000). Monitoring of acid events has been largely in the Maria River/Connection Creek system and within Partridge Creek, where high risk ASS areas had been identified by Tulau (1999).

Evidence of the impacts of ASS in the Maria River and Connection Creek waterways was observed extensively throughout the 1990s. This includes:

- Fish kills observed in February/March 1992 in the Maria River/Pipers Creek area (NSW DPI, 2020), which has been linked to high levels of acidity in the waterways and drains (Umwelt, 2000);
- Water quality monitoring by Manly Hydraulics Laboratory at Green Valley and Connection Creek in 1995 included observations of an acidification event in January to March 1995 that lasted eight (8) weeks following a rainfall event, with minimum pH values of 3.2 (Manly Hydraulics Laboratory, 1997);
- Johnston (1995) (referenced in Aaso (2000)) stated that more than half of the Maria River drainage network had discharged water with a pH less than 4.0 in 1994 and 1995; and
- Minimum pH values of 4.5 were observed near the confluence of Maria River and Pipers Creek during water quality monitoring as part of the Ecohealth project in the Hastings and Camden

Haven catchments (Ryder et al., 2011). An early study had observed pH levels of 2.4 at the same location (Smith, 1999), which indicates widespread acidification in the Upper Maria River area.

Partridge Creek is also well recognised as a high risk ASS area in the Hastings River floodplain (Smith, 1999; Tulau, 1999). Tulau (1999) summarises water quality monitoring undertaken in the 1990's, where pH levels discharging from Partridge Creek were commonly as low as 2.5 to 3.5. The Partridge Creek subcatchment underwent significant remediation between 1999 and 2004 to address poor water quality due to acid discharges (discussed in detail in Section 8.5.2). Since the remediation, acid flux from the Partridge Creek subcatchment was estimated to be reduced by 67-79% (Hastings Council, 2004).

ASS discharges in the Hastings River have also been linked to a decline in fisheries and aquaculture. Commercial fisheries and oyster production are important industries in the Hastings River estuary, estimated to be worth $7,000,000 per year in 1999 (approximately $12 million today) (Aaso, 2000). However, increased mortality and the prevalence of diseases associated with ASS have reduced fisheries and oyster yields in the estuary (Dove, 2003). Oyster farming in the estuary predominantly occurs in Limeburners Creek and the main Hastings River channel. Many oyster leases in the Maria River and near Fernbank Creek have been abandoned (Dove and Sammut, 2013). Aaso (2000) states that oyster yields between 1998 and 2000 were 50 – 80% lower than historical averages and it was estimated that 30 – 60% of these losses could be associated with ASS runoff.

Further information about water quality data related to ASS in the Hastings River floodplain can be found in Appendix H.

3.6 Blackwater

This section provides a brief overview of the formation and export of blackwater in coastal estuaries and blackwater runoff from Hastings 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, 2007). The discolouration 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;

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 (NSW DPI, 2020).

3.6.1 Blackwater runoff in the Hastings River estuary

Fish kills can be caused by a number of processes, although acid discharge and blackwater runoff are common causes in coastal estuaries in NSW (NSW DPI, 2020). Compared to other, larger coastal floodplains in NSW (e.g. Clarence River, Richmond River and Macleay River), the prevalence of blackwater and low dissolved oxygen associated with prolonged inundation of floodplains is not as common in the Hastings River floodplain. As discussed in Section 3.5.2, some fish kill events in the Maria River area have been associated with acidification. Three (3) fish kill events in the Hastings River estuary recorded in the NSW DPI (2020) database are speculated to be related to low dissolved oxygen following flood events as summarised in Table 3-1.

Table 3-1: Fish kills in the Hastings River related to low dissolved oxygen levels (NSW DPI, 2020)

Date	River/Creek	Intensity
5/1/2013	Partridge Creek (Tributary)	10 - 100 of fish
9/01/2014	Hastings River	1,000's of fish
2/1/2020	Limeburners Creek	1,000's of fish

In addition to fish kill events, water quality monitoring in the Hastings River estuary has also shown low dissolved oxygen events. Manly Hydraulics Laboratory (1997) monitored dissolved oxygen levels in Connection Creek from September 1994 to October 1995, and showed that minimum dissolved oxygen levels were 0.1 mg/L (severely hypoxic) and median dissolved oxygen was just 4.1 mg/L, below the ANZECC and ARMCANZ (2000) guidelines for protection of aquaculture species (5 mg/L). Dove (2003) also monitored water quality parameters within the Limeburners Creek between November 1997 and March 1999, showing dissolved oxygen values (<2.5 mg/L) at most upstream sample sites in the creek.

Water quality was also reported as part of a broader Ecohealth project (Ryder et al., 2011; Ryder et al., 2017). Samples were collected from a range of locations including the Hastings River, Maria River, Wilson River and Upper Limeburners Creek in 2011 and 2014/2015. Both sampling programs recorded very low dissolved oxygen values for the sampling site at Upper Maria River (downstream of the junction between Maria River and Pipers Creek), with minimum records of 0.94 mg/L.

Further information about water quality studies in the Hastings River floodplain can be found in Appendix J.

3.7 Coastal and estuary management in the Hastings River estuary

This section provides a brief overview of the major coastal and estuary management plans and projects that have been developed for the study area. This is not intended to be a comprehensive summary of coastal and estuary management in the Hastings River estuary, but rather a summary of how these plans have acknowledged and addressed issues associated with ASS and blackwater on the floodplain. Note that this report section covers floodplain wide management with specific management options for each subcatchment reported in Section 8.

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

A state-wide threat and risk assessment (TARA) was completed in 2017 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. Management of ASS in particular, has been consistently identified in coastal and estuary management priorities in the Hastings River, discussed further in the following section.

3.7.2 Improving floodgate and drain management on the Hastings floodplain (Smith, 1999)

Concerns over the impact of ASS drainage on aquaculture increased in the late 1990's when several instances of high oyster mortality and disease impacted the oyster industry. As a result, the Port Macquarie Oyster Farmers (supported by the Hastings Estuary Management Committee) initiated a study into improving floodplain management to reduce persistent acid drainage. The resulting study "Improving floodgate and drain management on the Hastings floodplain" Smith (1999) completed a comprehensive review of floodplain infrastructure and provided recommendations for 28 drain/floodgate systems to reduce the impacts of ASS. The recommendations from this report were considered in the estuary management plan that was subsequently completed as discussed in the section below.

3.7.3 Hastings Estuary Management Plan (Umwelt, 2001)

The Hastings Estuary Management Plan (EMP) (Umwelt, 2001) was completed in accordance with State wide policies to help manage estuarine resources in NSW. The EMP also included a dedicated working paper ASS management (Umwelt, 2000). The EMP explicitly states that the management of ASS and acid drainage was "the single most important threat to the health of the Hastings estuary and related community economy" and suggests that addressing ASS issues had strong support from the local community and industries (Umwelt, 2000). Blackwater and low dissolved oxygen was not identified as a key issue in the EMP and is not directly addressed by the recommended actions.

Of the actions recommended by Umwelt (2001), the most relevant to this study includes:

- Preparation of farm level management plans in areas with high risk ASS;
- Negotiating agreements with local landholders to address issues associated with ASS;
- Implementing the recommendations of Smith (1999) (refer to Section 3.7.2);
- Complete a water management plan for the Maria River (which is covered by two (2) local council areas);
- Implementing remediation of the Partridge Creek subcatchment, which was subsequently completed in 2004 (Hastings Council, 2004);
- Preparation of risk mitigation measures for the oyster and fisheries industries;
- Establishing monitoring programs;
- Active collaboration with other agencies to share data and provide consistent reporting in regards to ASS management in the Hastings region;
- Supporting and collaborating in research projects to address ASS drainage; and
- Organising and participating in educational activities to improve understanding of the issues.

The Hastings EMP demonstrates the commitment of the local Council and community to address ASS management in the Hastings River floodplain through clear and concise acknowledgement of the severity of the issue. Management of ASS has been a priority issue in the Hastings River region for a number of decades.

Since the completion of the EMP, the Port Macquarie-Hastings Council (formerly Hastings Council) and Kempsey Shire Council (in the northern section of Maria River/Connection Creek) have completed on-ground works with the assistance of local landholders. Notably, this includes extensive remediation of the Partridge Creek ASS hotspot (discussed in detail in Section 8.5), and implementation of the recommendations of Smith (1999). At least 63 structures have been modified or constructed to mitigate the impacts of acid discharges (Port Macquarie Hastings Council, 2010). This typically includes modifying existing drainage infrastructure with auto-tidal buoyancy gates to allow tidal flushing, or the use of weirs to prevent unnecessary drainage and further acidification of ASS. Since 2001, on-ground works in the Hastings River floodplain have included remediation of 940 ha of acid scalds, and 5,120 ha of floodplain under voluntary plans of management (Port Macquarie Hastings Council, 2020). The locations of these works are provided in the relevant management options for each subcatchment in Section 8.

4 Overview of prioritisation methods

4.1 Preamble

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

The prioritisation for ASS and blackwater risk within coastal floodplains is independent of one another. 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 Hastings 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.

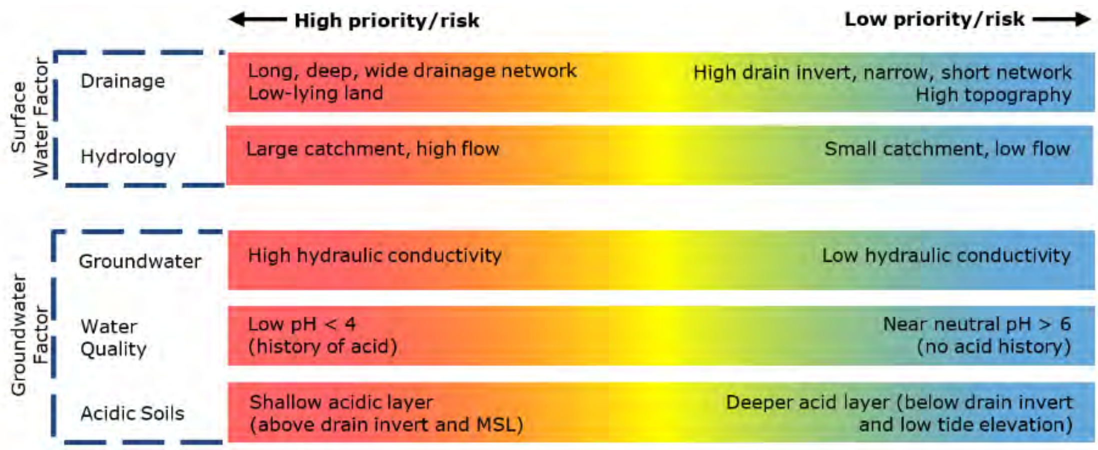

Figure 4-1: Factors influencing ASS discharge in coastal NSW that have been incorporated within the assessment method (adapted from Johnston et al. (2003a))

4.2.1 Surface water factor

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

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

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

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

4.2.2 Groundwater factor

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

The groundwater factor uses locally acquired sediment profile data and hydraulic conductivity measurements within each subcatchment. Where existing data was insufficient, additional data was collected specifically for this project, including 35 soil profiles and 26 soil hydraulic conductivity measurements on the Hastings River floodplain (see Appendix C and D for further details). 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.

$$Groundwater\ factor = hydraulic\ conductivity\ risk\ factor\ \times pH\ factor$$ **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 Hastings River floodplain during a blackwater event).

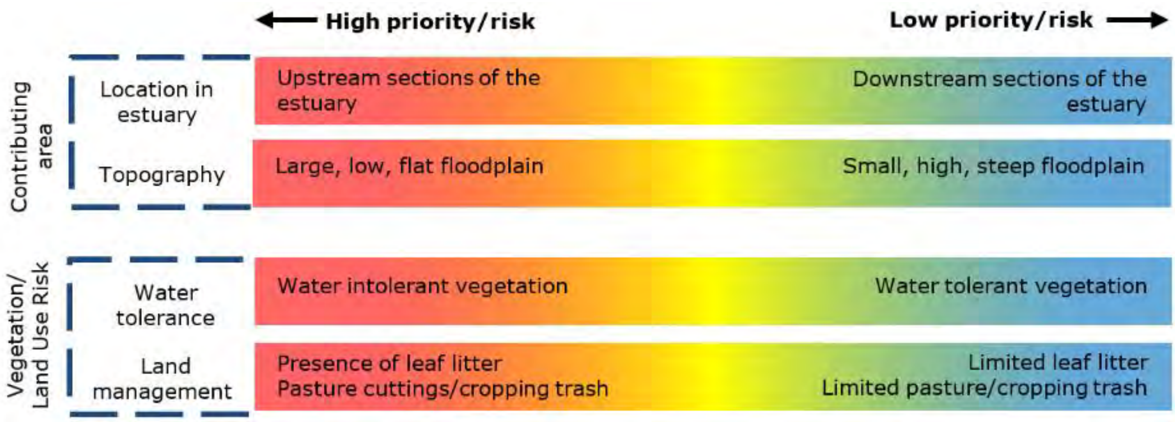

Figure 4-2: Factors influencing blackwater discharge from coastal floodplain in NSW

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 Hastings 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 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 impacts 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 Hastings 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 to 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.

5.2 ASS prioritisation of the Hastings 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 four (4) priority subcatchments (Lower Maria River West (1), Upper Maria River (2), Partridge Creek (3) and Connection Creek (4)) are all well recognised high risk ASS areas (Tulau, 1999). Figure 5-3 shows that high priority ASS sites are clustered along Maria River, which is consistent with observed acidification events in the estuary.

Table 5-1: Summary results and rankings of ASS subcatchments in the Hastings River floodplain

Subcatchment	Groundwater factor	Surface water factor	Final acid factor	Rank
Lower Maria River West	139	887	122,981	1
Upper Maria River	87	719	62,837	2
Partridge Creek	110	217	23,885	3
Connection Creek	46	497	22,940	4
Pembrooke	125	178	22,243	5
Lower Maria River East	74	294	21,797	6
Rawdon Island	151	123	18,637	7
Fernbank Creek	61	288	17,664	8
Kings Creek	31	373	11,682	9
Port Macquarie Airport	97	31	3,008	10
Sarahs Creek/Sancrox	90	31	2,815	11
Limeburners Creek	8	152	1,237	12
Redbank	16	15	235	13

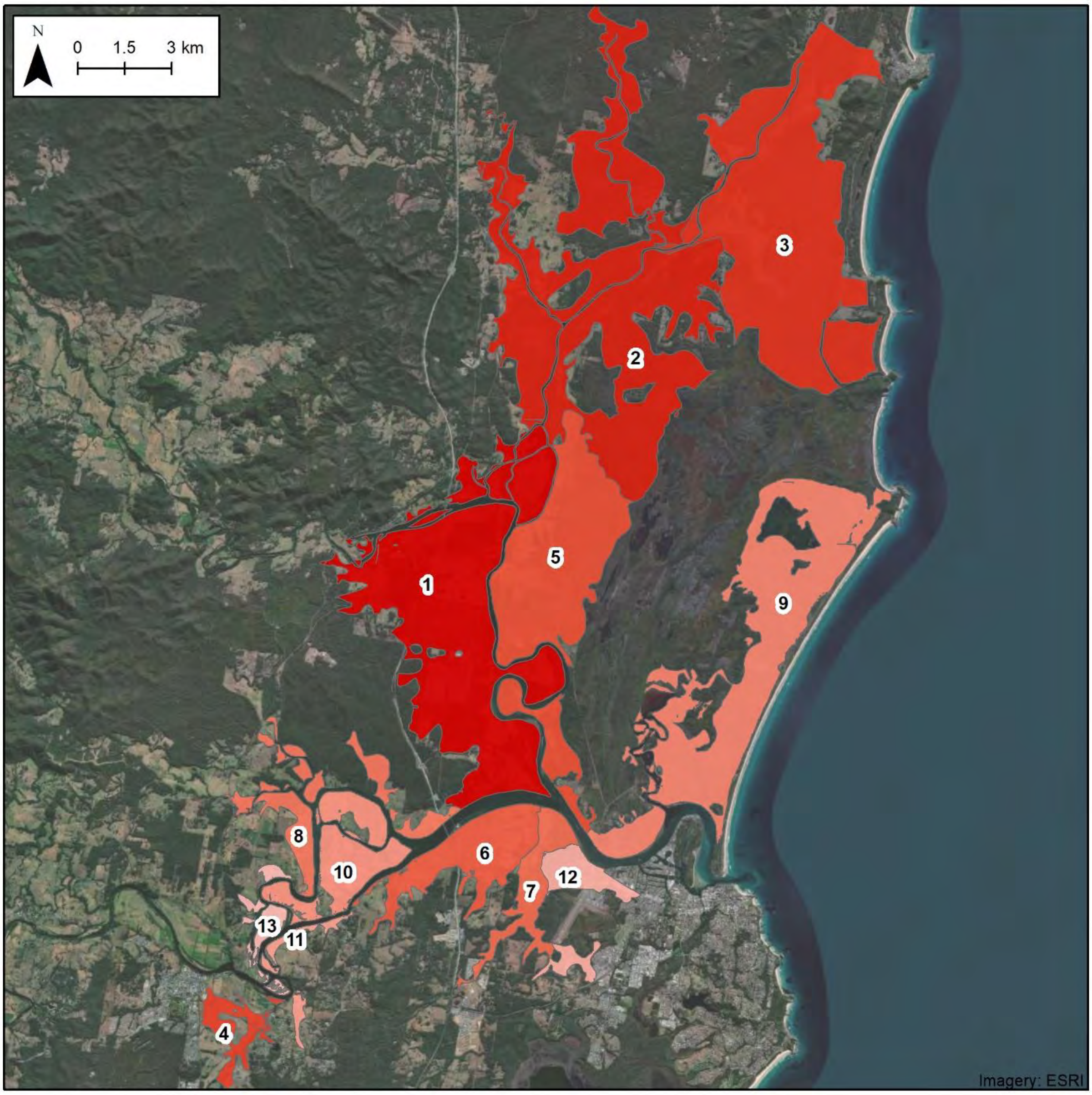

Figure 5-1: Surface water factor ranking

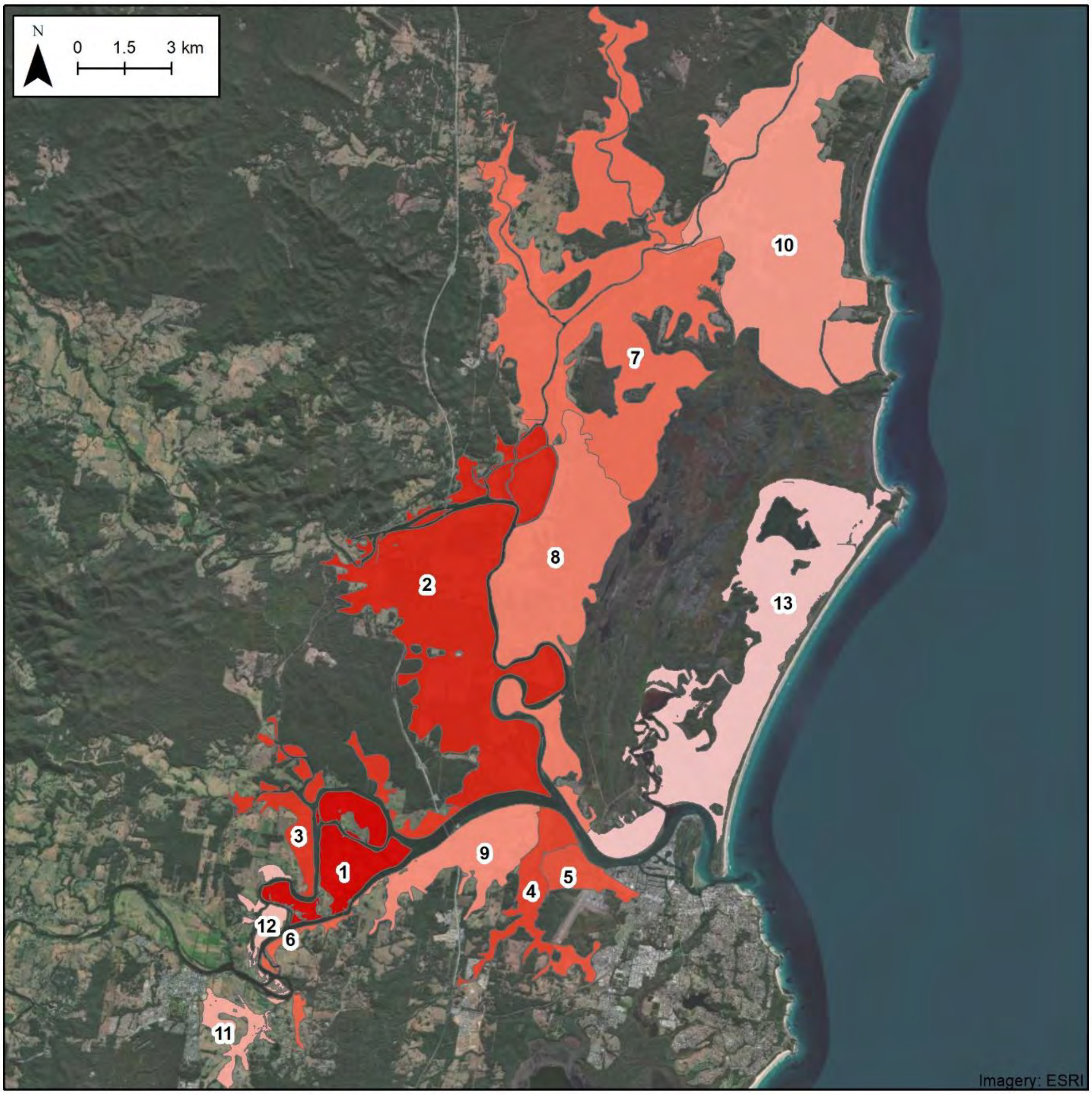

Figure 5-2: Groundwater factor ranking

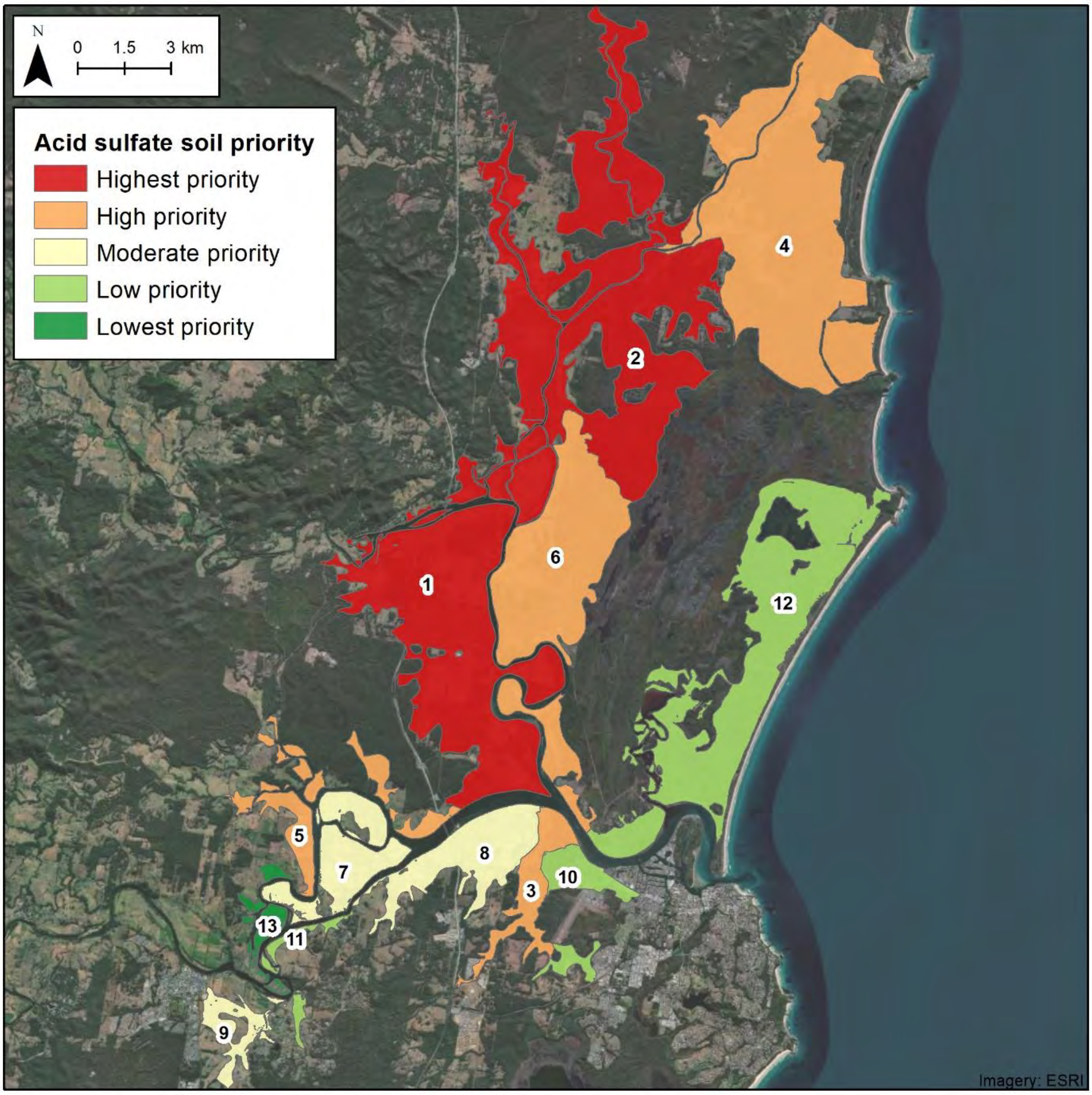

Figure 5-3: Final ranking of ASS prioritisation

6 Blackwater prioritisation assessment outcomes

6.1 Preamble

This section summarises the results of the blackwater priority assessment on the Hastings 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 Hastings River floodplain

A summary of blackwater prioritisation is provided in Table 6-1 and presented in Figure 6-1 and Figure 6-2. The top two (2) priority subcatchments, Connection Creek and Upper Maria River, have a substantially higher blackwater factor than any other subcatchment. As with the ASS prioritisation, the high risk blackwater subcatchments are all located on Maria River.

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

Subcatchment	Median blackwater elevation (m AHD)	Final blackwater factor	Rank
Connection Creek	1.0	66.8	1
Upper Maria River	1.0	66.5	2
Lower Maria River West	0.7	19.1	3
Lower Maria River East	0.7	11.4	4
Pembrooke	0.6	1.8	5
Fernbank Creek	0.5*	1.6	6
Limeburners Creek	0.4*	1.3	7
Rawdon Island	0.6	1.2	8
Kings Creek	0.7	1.1	9
Sarahs Creek/Sancrox	0.7	0.5	10
Redbank	0.7	0.5	11
Port Macquarie Airport	0.4*	0.1	12
Partridge Creek	0.5*	0.1	13

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

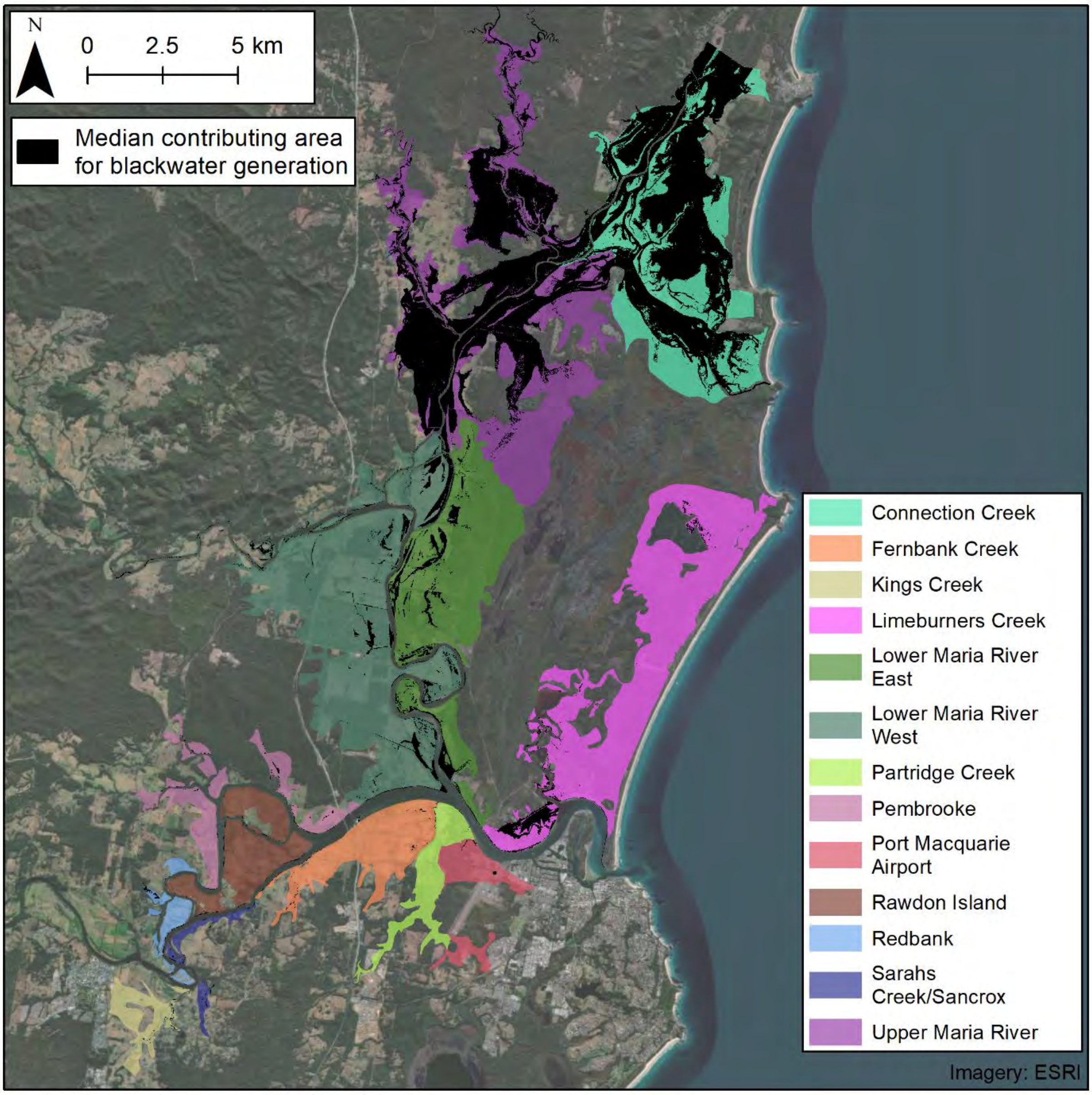

Figure 6-1: Median contributing area for blackwater generation across the Hastings River floodplain

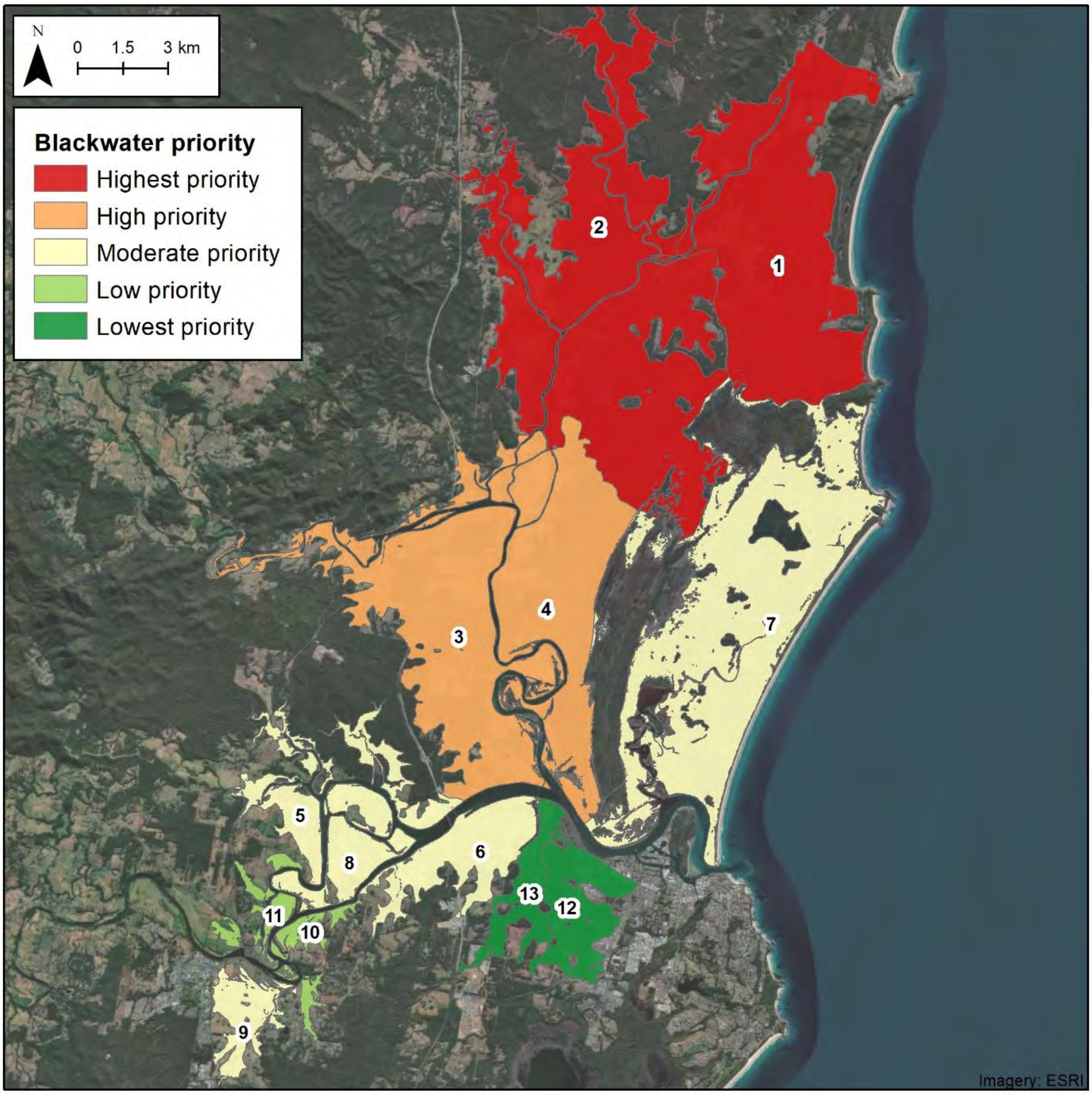

Figure 6-2: Final ranking of the blackwater prioritisation in the Hastings River floodplain

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 and 2010 in Australia was +1.4 mm/year and had accelerated to +4.5 mm/year across the country between 1993 and 2010. The rate of sea level rise is expected to continue to accelerate over the next century (IPCC, 2014). Coastal estuaries are amongst the most vulnerable areas to sea level rise due to the proximity to the ocean and level of development in Australian estuaries (OEH, 2018).

Coastal floodplains are susceptible to sea level rise as changes in sea levels and hence tidal levels, will intensify factors that currently contribute to flooding, reduced drainage efficiency, and changes to inundation extent/duration. The following section summarises the assessment completed for this study to identify floodplain areas and floodplain infrastructure in the Hastings 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, reducing the potential for blackwater generation. More research is required to model the likely changes in acid and blackwater drainage in NSW estuaries.

7.2 Changes to water levels in estuaries

Glamore et al. (2016b) detailed how water levels in estuaries are influenced by oceanic forces and climate change. In brief, tidal water levels at the entrance of an estuary influence the overall volume of water (tidal prism) moving in and out with each tide. The tidal prism, the channel bed friction, catchment inflows and the channel geometry (i.e. the depth and the shape of the estuary) influence whether the 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 of the Hastings River estuary was adopted from the most recent work of Advisian (2019). This model was slightly modified 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 Hastings 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 Hastings River estuary. Further details on the model development and calibration can be found in Appendix I.

7.2.1 Hastings 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 Hastings River estuary. The Advisian (2019) model was modified slightly and extended in areas upstream of Gulgini through Maria River. The updated model domain, shown in Figure 7-1, extends across the tidal limits of most of the major rivers, tributaries and creeks in the estuary, including the Hasting River, Limeburners Creek, Kings Creek and Maria River. The numerical model used 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 (i.e. in Maria River) and 2-D elements were used to represent the lower estuary where complex free surface flows occur.

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 about 32 km upstream from the river mouth near Crosslands. The hydrodynamic model comprised of three (3) main inputs:

1. **Channel bathymetry and geometry** were based on the previous modelling of the Hastings River (Advisian, 2019) and modified slightly based on single beam bathymetry data sourced from DPIE (formerly NSW Office of Heritage (OEH));
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 Port Macquarie (Station # 207420); and
3. **Upstream river flows** were applied as inflow hydrographs at the upstream extent of the model. These were sourced from Water NSW river gauges for:

    a. Hastings River at Ellenborough (Station # 207004); and
    b. Wilson River at Avenal (Station # 207014).

Figure 7-1: Hastings River estuary hydrodynamic model extent

Lower catchment inflows to the model were not included as sensitivity testing indicated that local floodplain runoff has a relatively small impact on the day-to-day water levels in the lower Hastings River estuary (which is dominated by the downstream tide). As such, the resulting hydrodynamic model is calibrated for everyday tides, but is not suitable for replicating catchment flood events. This is considered appropriate because the hydrodynamic model was 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 is provided in Appendix I.

The hydrodynamic model for the Hastings River estuary was calibrated to measure water level and tidal flow gauging stations along the main river channel, from a short-term tidal flow gauging exercise on the Hastings Estuary on 24 October 1999 (MHL, 1999). The locations of the water level and tidal flow gauging monitoring stations used for calibration are provided in Appendix I. The calibrated model was 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 has been detailed in Section 11 of the Methods report (Rayner et al., 2023) and are represented in Table 7-1.

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 (containing 12 individual models) ensemble that provides high resolution (10 x 10 km) climate projections for wider NSW. Heimhuber et al. (2019a) analysed the results from NARCliM modelling for near future and far future scenarios and found that rainfall is expected to stay largely the same in terms of annual totals along the NSW coast (albeit with some statistical uncertainty).

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

Table 7-1: Adopted mean sea level 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 Hastings River estuary to mitigate backwater flooding from the river, prohibit tidal water from inundating low areas of the floodplain and encourage regular tidal drainage to the low tide level upstream of the floodgate. The vulnerability of a floodgate to reduced flow efficiency due to sea level rise can be assessed by determining how frequently the floodgates are able to freely drain based on the downstream water levels and the floodgate geometry/elevation. Table 7-2 summarises the classifications applied to each floodgate. This is also presented diagrammatically in Figure 7-2. The approach to assessing floodgate vulnerability is discussed further in Section 11 of the Methods report (Rayner et al., 2023).

Table 7-2: Rules for floodgate vulnerability classification

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

Note: Obvert is the inside top of the floodgate structure

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

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

The floodgate vulnerability assessment was completed by comparing the floodgate obvert elevations to the downstream water levels statistics (i.e. the simulated water levels from the nearest numerical model node). Water level statistics were extracted for the 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 a tidal floodgate at the end of the drainage system, where the drainage system discharges into the estuary and where infrastructure survey data was available.

Figure 7-3 to Figure 7-6 present floodgate vulnerability maps for the Hastings 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, regardless of sea level rise.

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, 24 of 66 (36%) floodgates with known elevation are considered "Most Vulnerable", compared to just two (2) (<1%) in present day conditions. As shown in Figure 7-5 and Figure 7-6, Maria River is predicted to have a higher proportion of floodgate infrastructure that is identified as moderate to high vulnerability.

Table 7-3: Vulnerability classification of Hastings River floodgates

	Historic Scenario (HS)	Present Day (PD)	Near Future (NF)	Far Future (FF)
Least Vulnerable	50	48	35	9
Moderately Vulnerable	14	15	26	33
Most Vulnerable	2	3	5	24

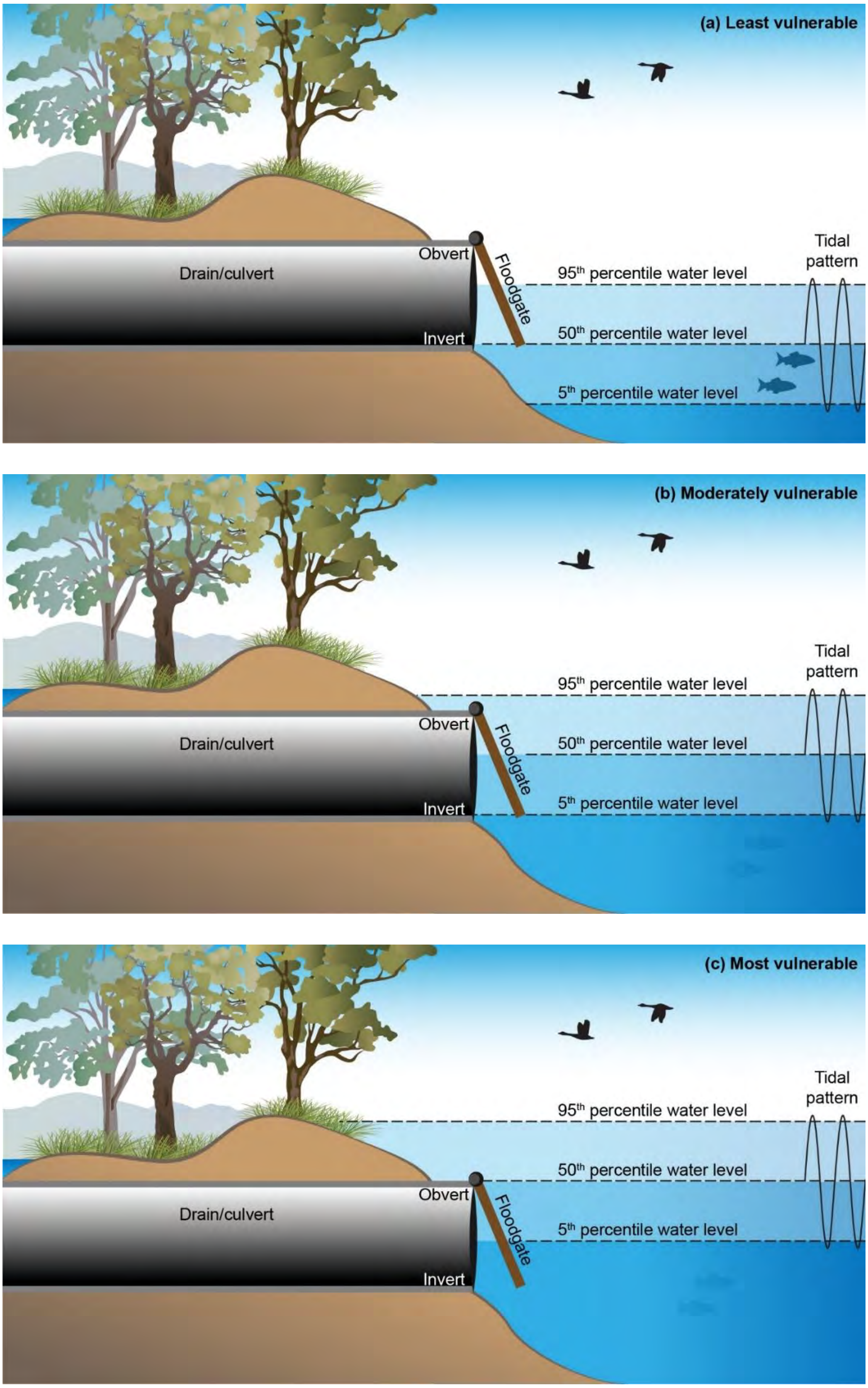

Figure 7-2: Floodgate vulnerability assessment

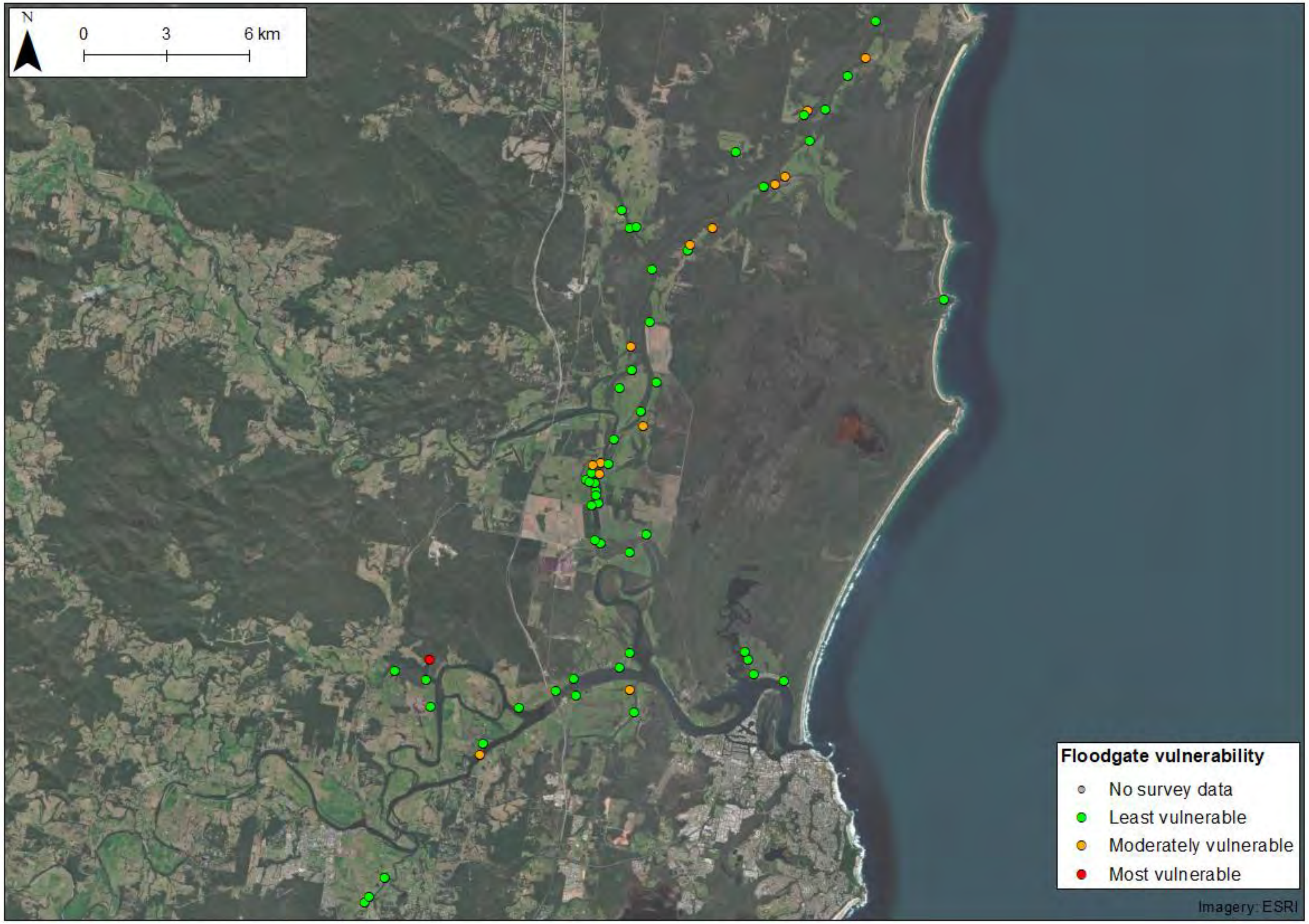

Figure 7-3: Historic (~1960s) floodgate vulnerability – Hastings River estuary

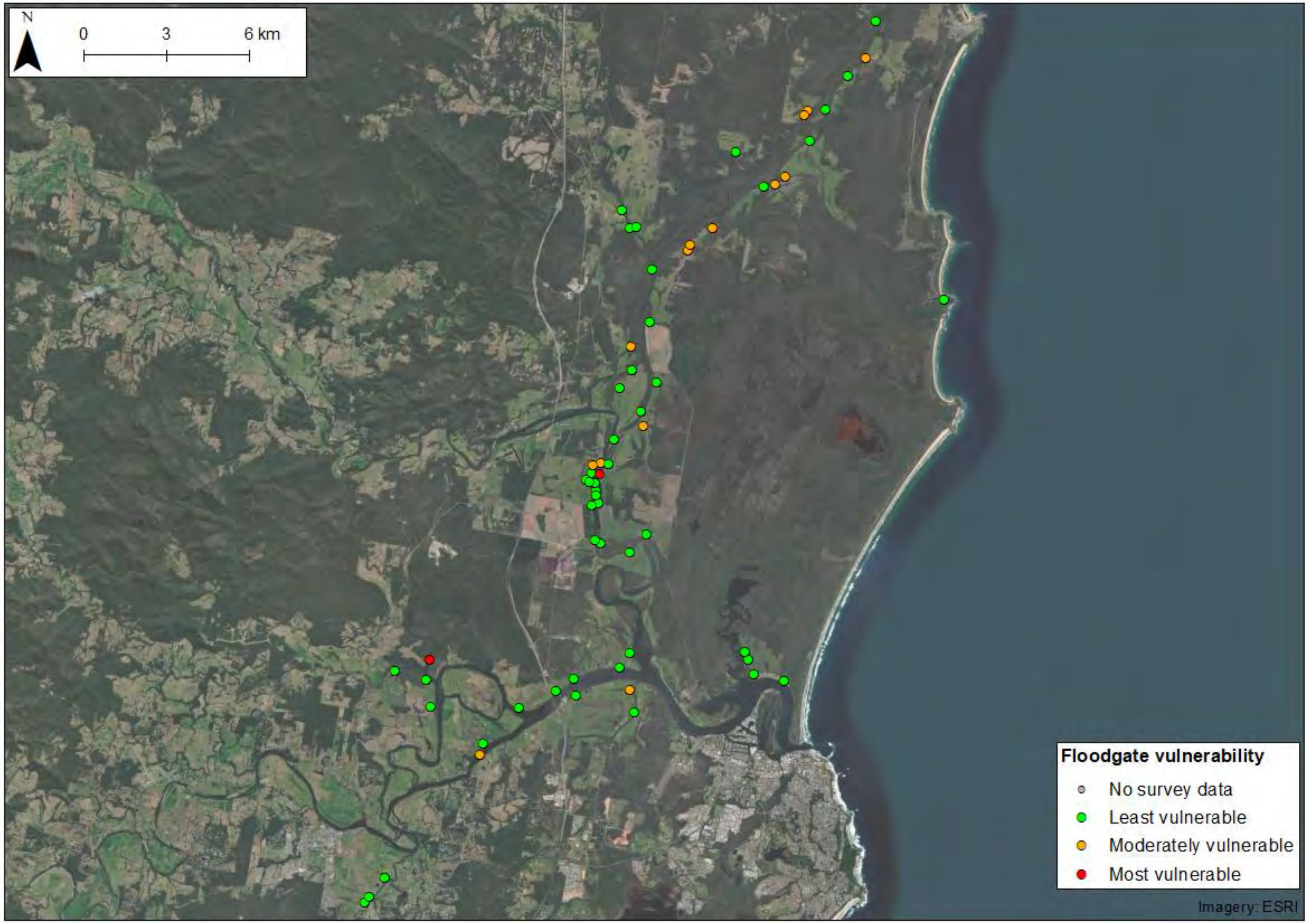

Figure 7-4: Present day floodgate vulnerability – Hastings River estuary

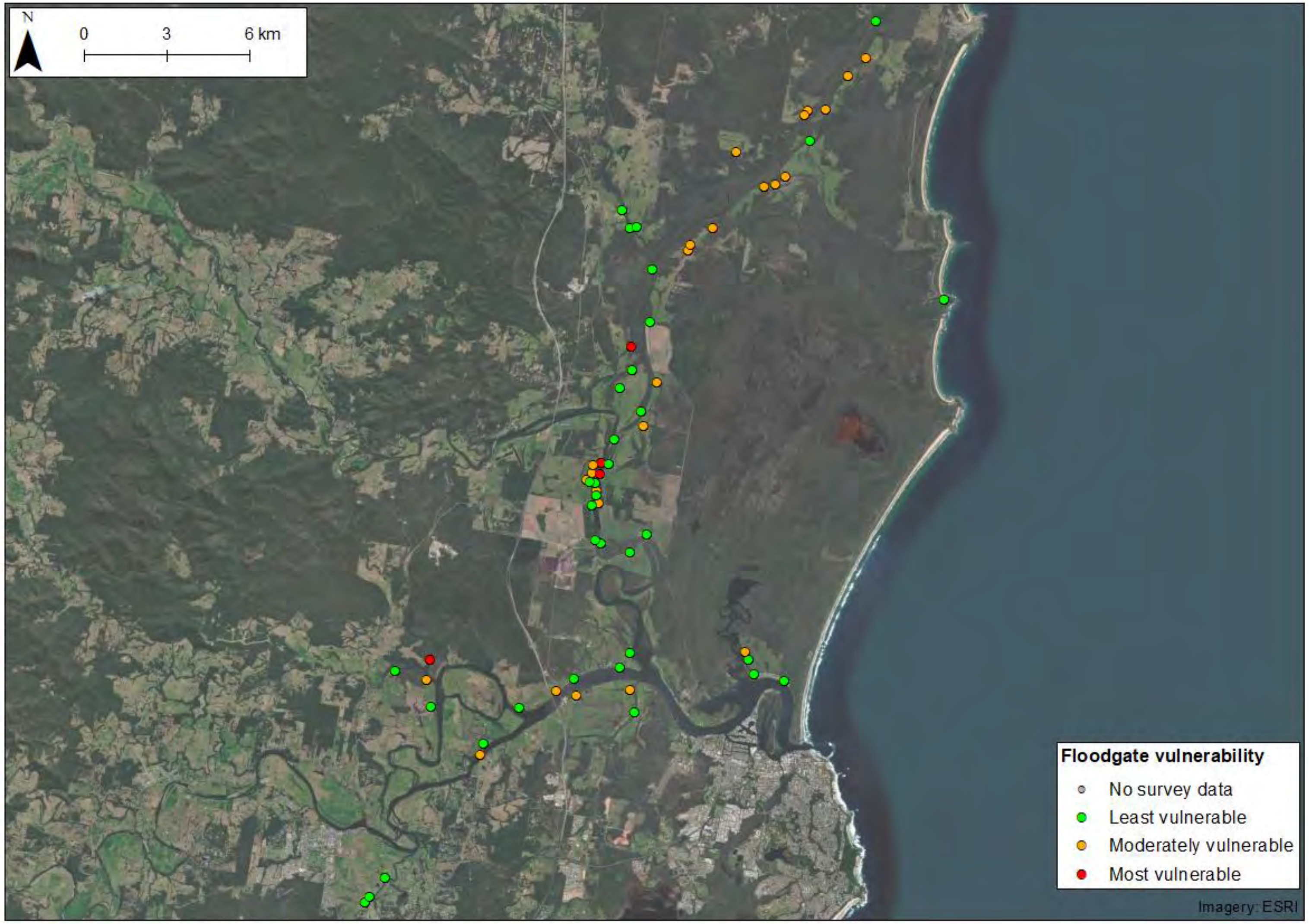

Figure 7-5: Near future (~2050) floodgate vulnerability – Hastings River estuary

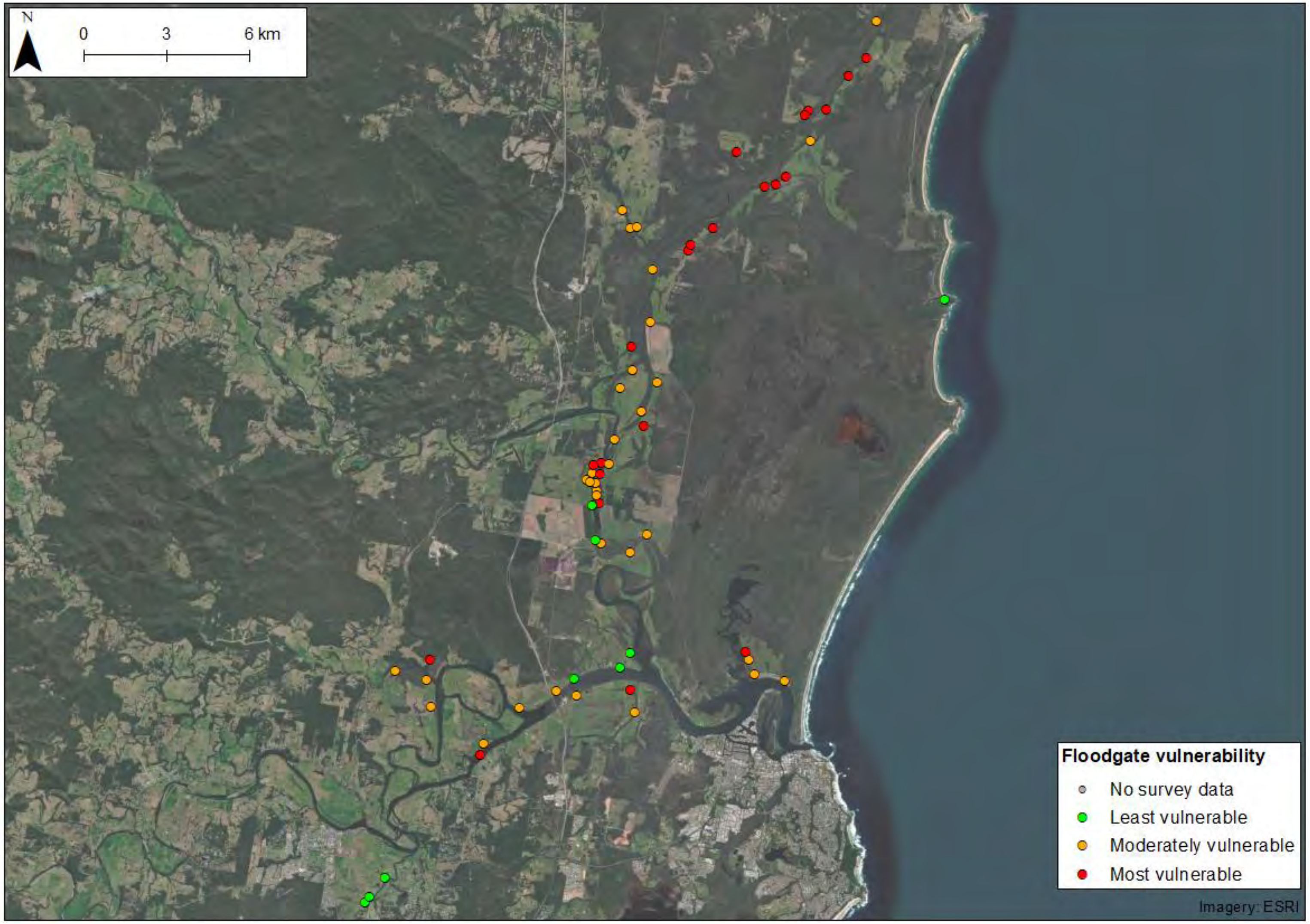

Figure 7-6: Far future (~2100) floodgate vulnerability – Hastings River estuary

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 Hastings 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 of this analysis is to highlight areas at risk of reduced drainage, rather than areas that may be actively inundated by tidal waters due to sea level rise.

The total floodplain areas below the water level percentiles for the HS, PD, NF and FF sea level rise scenarios for the Hastings River are summarised in Table 7-5. While the area below the 5^{th} percentile water level increases by over three times between present day and the near future, this increases to over 50 times in the far future to approximately 314 ha, compared to present day. The total floodplain area classified as Moderately vulnerable increases by more than 30 times in the far future, compared to present day.

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.

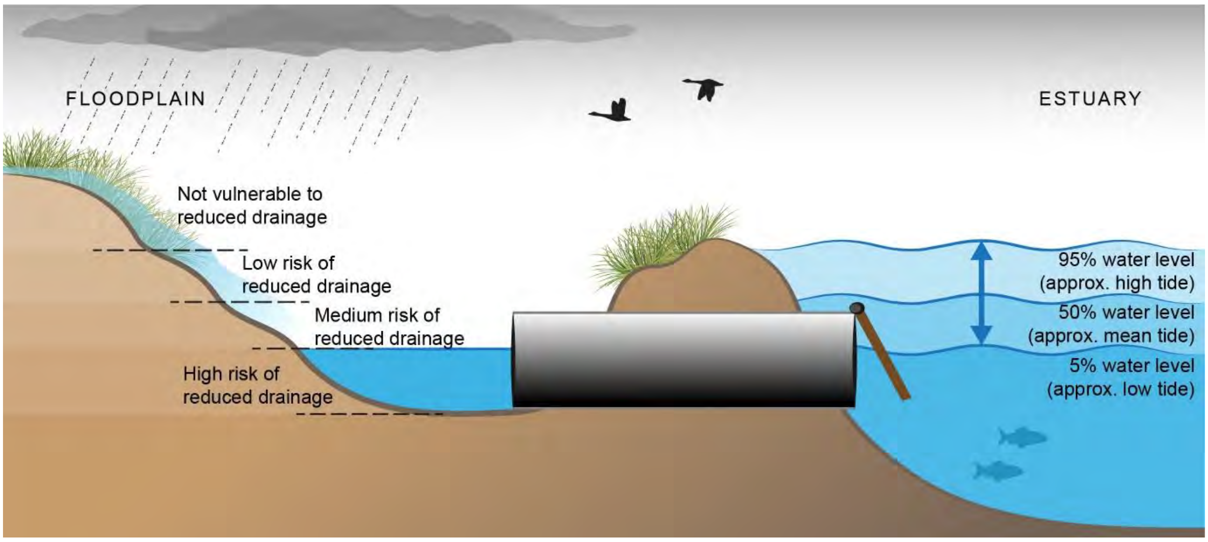

Figure 7-7:Floodplain drainage vulnerability

Table 7-5: Total area (ha) of the Hastings River floodplain vulnerable to reduced drainage

Vulnerability Status	Level criteria	Historic Scenario (HS) ~1960 (ha)	Present Day (PD) 2020 (ha)	Near Future (NF) ~2050 (ha)	Far Future (FF) ~2150 (ha)
Low	50th percentile water level < Land elevation < 95th percentile water level	2,857	3,410	5,133	7,929
Moderate	5th percentile water level < Land elevation < 50th percentile water level	89	111	257	4,260
High	Land elevation < 5th percentile water level	2	6	22	314

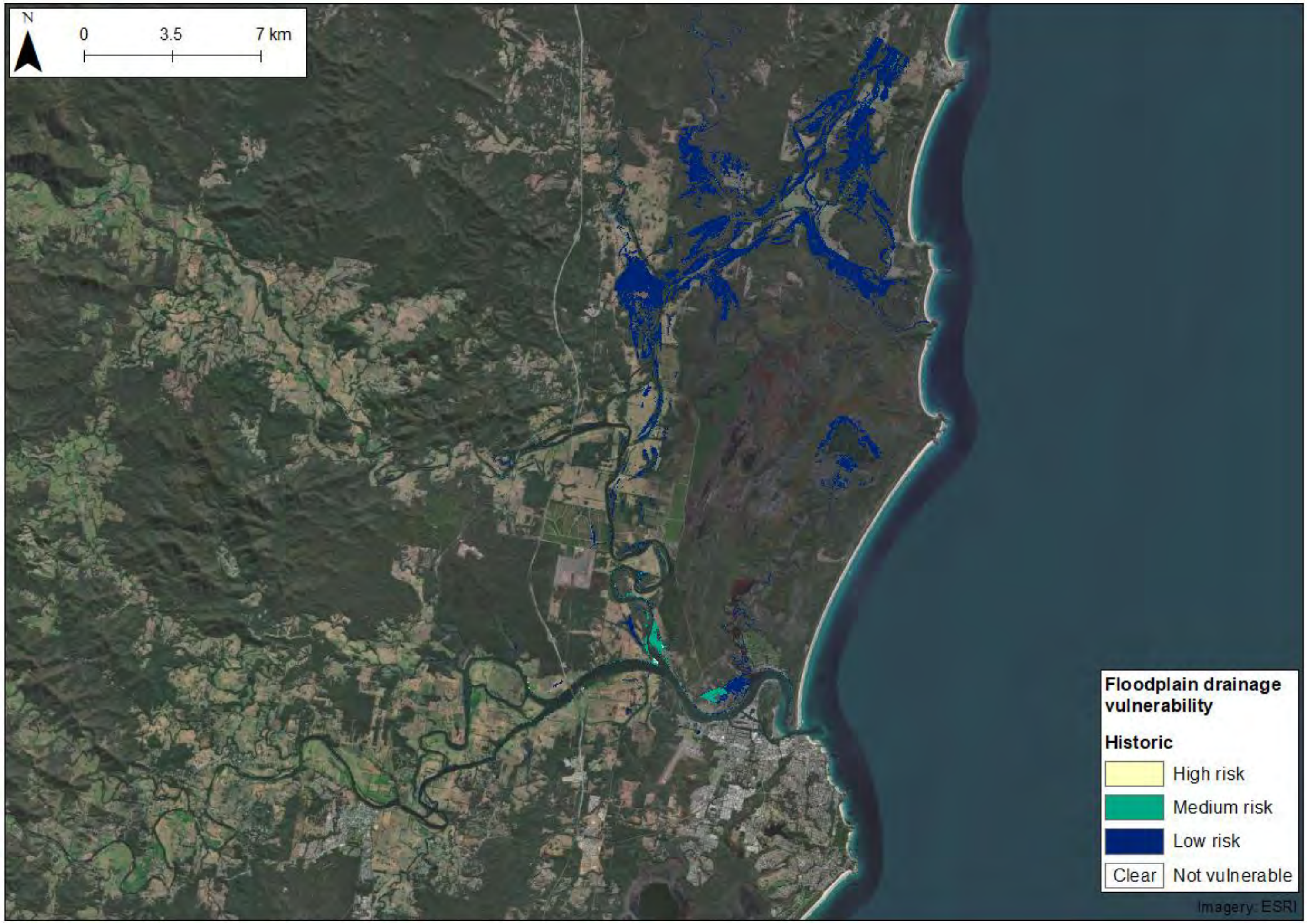

Figure 7-8: Historic (~1960s) floodplain vulnerability – Hastings River estuary

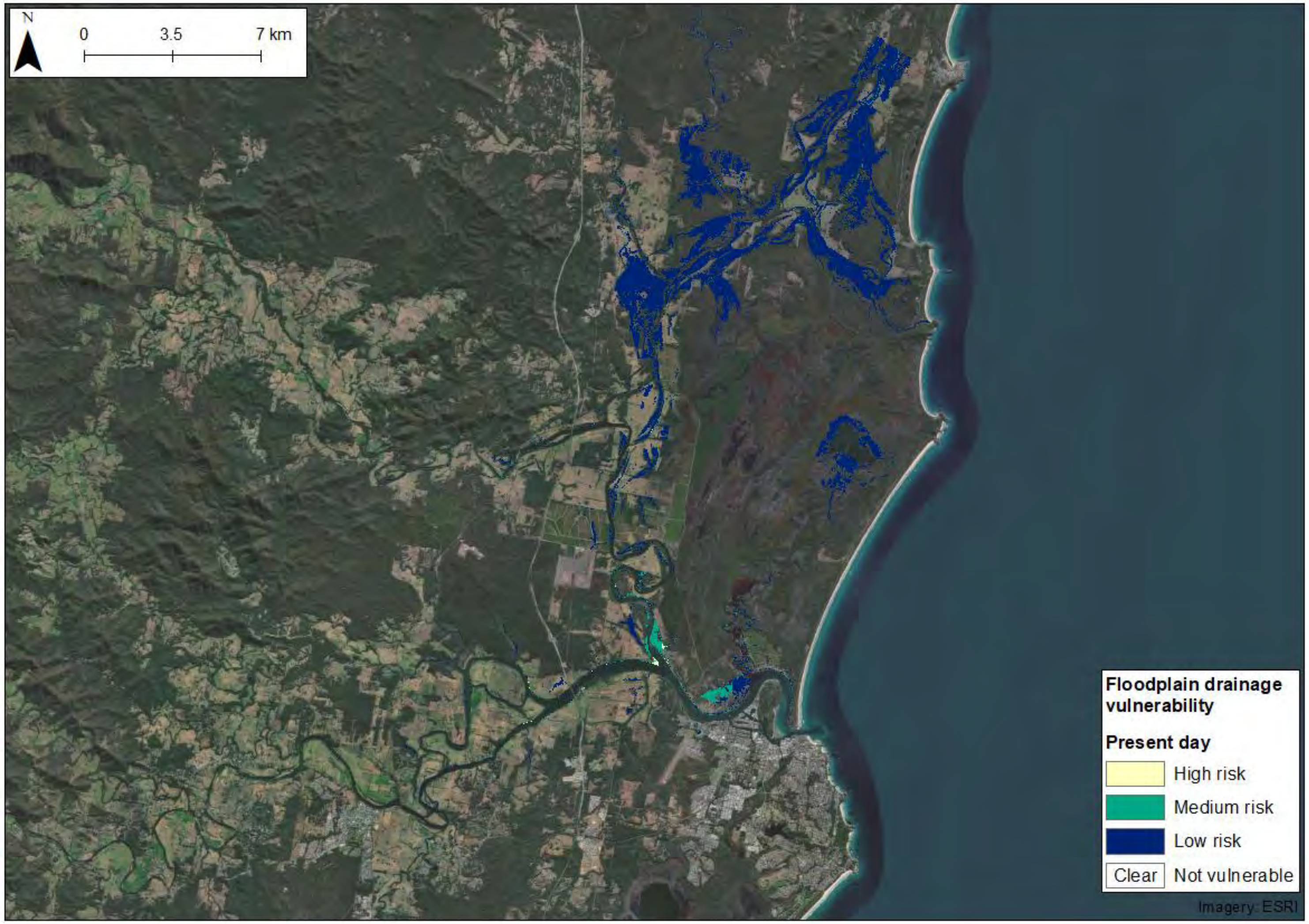

Figure 7-9: Present day floodplain vulnerability – Hastings River estuary

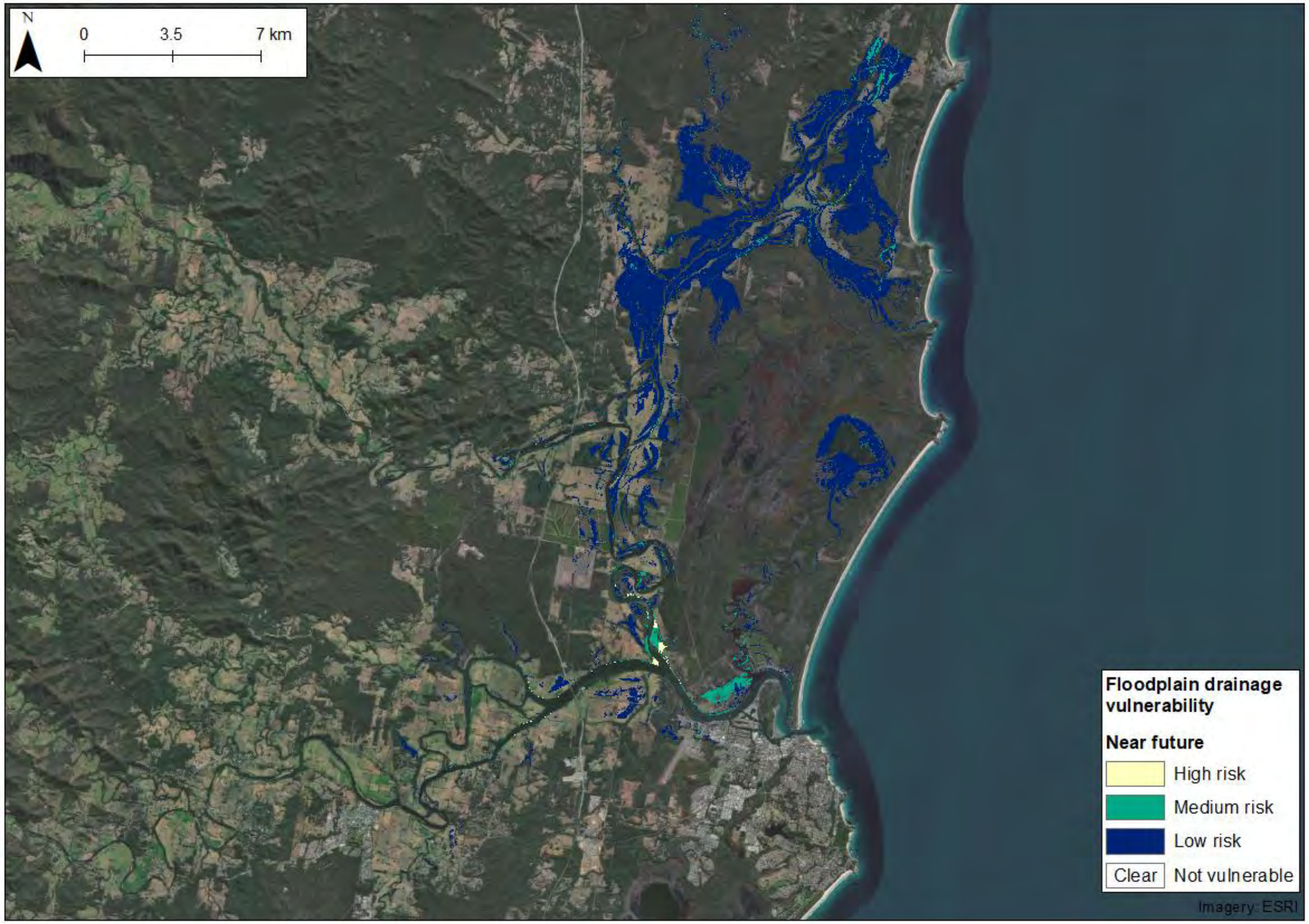

Figure 7-10: Near future (~2050) floodplain vulnerability – Hastings River estuary

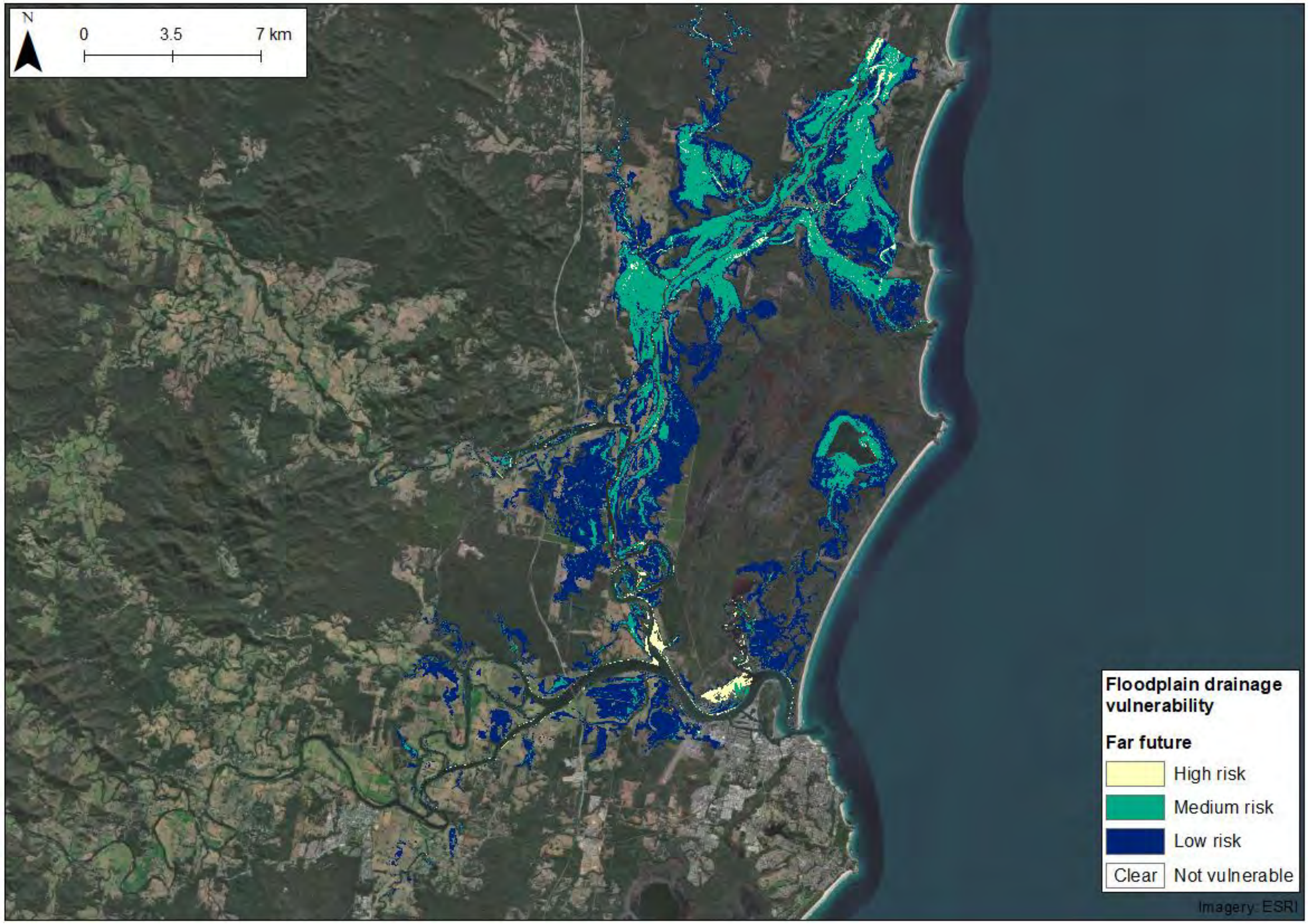

Figure 7-11: Far future (~2100) floodplain vulnerability – Hastings River estuary

8 Subcatchment management options

8.1 Preamble

Management options have been developed for each subcatchment of the Hastings River floodplain. They include options for short and long-term strategies to reduce the impact of ASS drainage and blackwater generation. Short-term management options are typically implementable within the next one (1) to ten (10) years, while long-term management targets require a longer time period for implementation or a greater upfront investment. Existing remediation has also been considered in the development of future strategies, where it is relevant.

Further information and investigation is required 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. 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**
<u>Infrastructure</u>	
Approximate waterway length (km)	Total length of waterways below 5 m AHD
# Privately owned end of system structures	Number of private floodgates (includes floodgates with unknown tenure)
# Publicly owned end of system structures	Number of public floodgates
# End of system structures within coastal wetlands	Total number of floodgates located within Coastal Management SEPP coastal wetlands
# Publicly owned end of system structures within coastal wetlands	Number of public floodgates located within Coastal Management SEPP coastal wetlands
Primary floodplain infrastructure (floodgate ID)	Floodgate ID (or name, where relevant) of the most significant infrastructure, based on Council records where possible (see Appendix F for more information)
<u>Elevations</u>	
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
<u>Proximity to sensitive receivers</u>	
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)
<u>Land use</u>	
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 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
<u>Land values</u>	
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 dynamic, and represent both wet and dry years. Mapping includes:

- **Floodgate vulnerability:** a vulnerability status (most, moderately or least vulnerable) of floodgates based on modelled downstream water levels. Vulnerability is based on water level statistics and floodgate geometry and provides an indication of a reduced drainage potential, summarised in Table 8-2. Note that this assessment considers floodgates only. Other types of end of system structures (e.g. weirs) have not been explicitly assessed but may be vulnerable to overtopping due to sea level rise. In the case of floodgated weirs (which typically have a small floodgate coupled with a weir in the same structure), the vulnerability only considers the geometry of the floodgate. Overtopping of the weir portion of these structures is not considered in the assessment. More information on this assessment can be found in Section 7.4;
- **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).

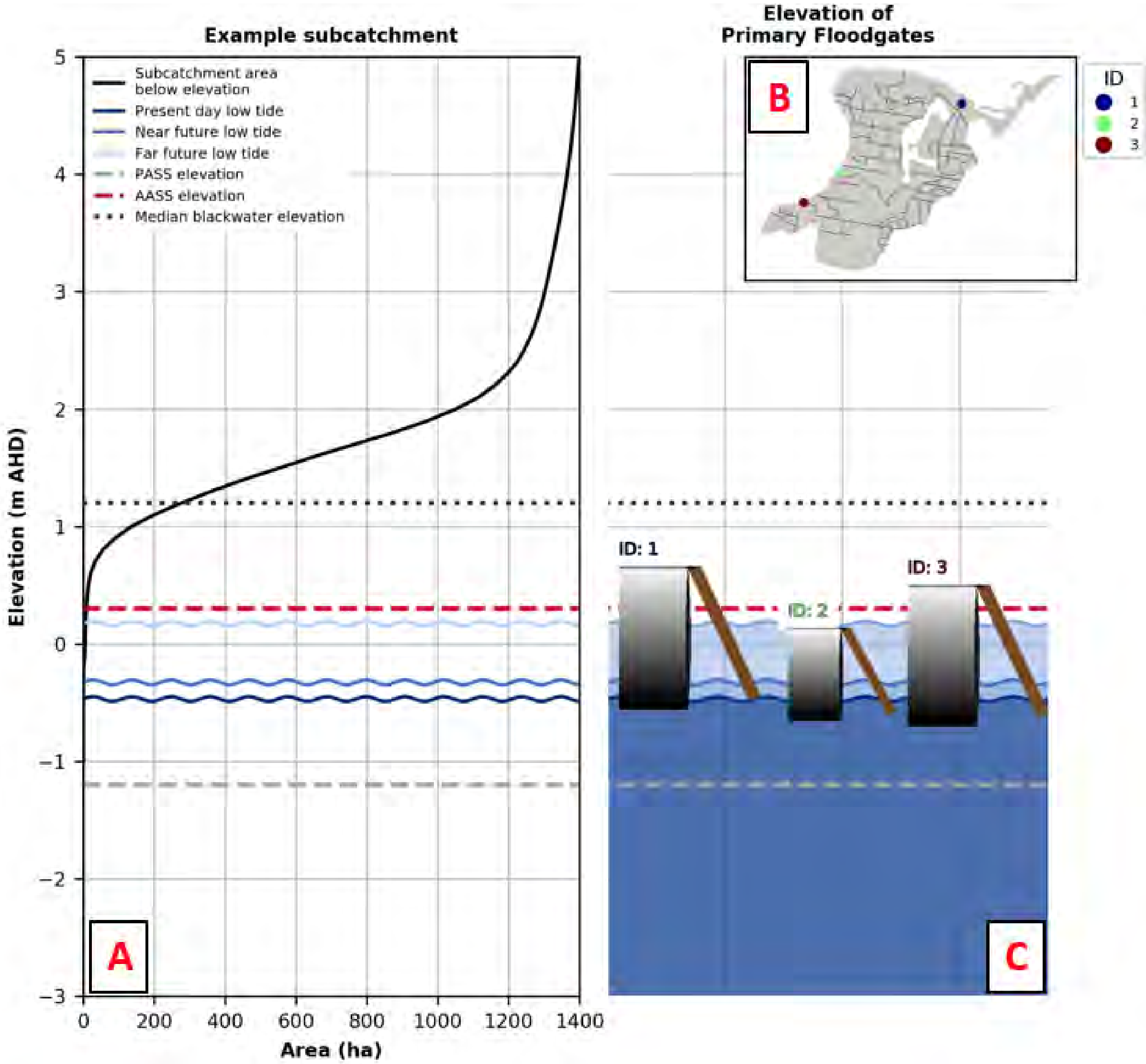

Figure 8-1: Reduced drainage vulnerability summary figure example

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** summarises key elevations in the subcatchment, including:
    - o The area of the subcatchment below 5 m AHD elevation;
    - o 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;
    - o Average subcatchment potential acid sulfate soil (PASS) and actual acid sulfate soils (AASS) elevation; and
    - o The median blackwater elevation within that subcatchment.
- **Panel B** shows the location of the primary floodplain floodgates within the subcatchment; and
- **Panel C** which shows the elevation (invert and obvert) of each primary floodgate in the relevant subcatchment, relative to the present day, near future and far future low tide conditions. Each of these are labelled with the floodgate ID. These floodgates are only designed to show elevation of the floodgate, and do not reflect other information such as the number of culverts, the shape of the culvert or the height of the headwall.

This infographic, and the sea level rise vulnerability of infrastructure more generally, focuses on the impact of reduced drainage from increasing low tides. While this provides a good indication of reduced drainage potential, it is acknowledged that high tide levels also impact floodgate functionality. The tidal range (based on the 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 is provided for:

- Land acquisition – based on NSW Valuer General database;
- Upfront costs – based on unit values of land management options (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 changes in management and average productivity for different land uses (present-day) in the catchment.

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

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

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

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

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

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

8.2.5 Waterway classification

Connected natural creeks and waterways provided important aquatic habitats prior to human intervention. In general, remediation focuses on restoration of natural waterways and flow paths and removal of constructed (artificial) drainage networks where possible. 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 outlined 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 Hastings River floodplain for:

- Lower Maria River West subcatchment;
- Upper Maria River subcatchment; and
- Connection Creek subcatchment.

8.3 Lower Maria River West subcatchment

Acid priority rank:	**1**
Blackwater priority rank:	**3**
<u>Infrastructure</u>	
Approximate waterway length (km)	109
# Privately owned end of system structures	12
# Publicly owned end of system structures	4
# End of system structures within coastal wetlands	5
# Publicly owned end of system structures within coastal wetlands	3
Primary floodplain infrastructure (floodgate ID)	FMS_26, FMS_27, FMS_29, FMS_32, ASSS_32
<u>Elevations</u>	
Invert of primary floodplain infrastructure (m AHD)	-0.3 to 0.0
Average AASS elevation (m AHD)	0.5
Average PASS elevation (m AHD)	-0.7
Median blackwater elevation (m AHD)	0.7
Present day low water level (m AHD)	-0.5
Near future low water level (m AHD)	-0.3
Far future low water level (m AHD)	0.2
<u>Proximity to sensitive receivers</u>	
Oyster Leases (km)	Within subcatchment
Saltmarsh (km)	Within subcatchment
Seagrass (km)	Within subcatchment
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
<u>Land use</u>	
Total floodplain area (ha)	4,225
Classified as conservation and minimal use (ha (%))	609 (14%)
Classified as grazing (ha (%))	2,400 (57%)
Classified as forestry (ha (%))	755 (18%)
Classified as horticulture (ha (%))	13 (0.3%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	182 (4%)
Classified as marsh/wetland (ha (%))	94 (2%)
Other (ha (%))	173 (4%)
<u>Land values</u>	
Estimated total primary production value ($/year)	$1,200,000
Average land value above 0.7 m AHD ($/ha)	$7,300
Average land value below 0.7 m AHD ($/ha)	$4,500

8.3.1 Site description

The Lower Maria River West subcatchment is on the right bank of the Maria River, situated between the Hastings River and the Wilsons River. As shown in Figure 8-2, the majority of the land in the subcatchment is privately owned. The area has been primarily used for grazing, although tea tree plantations have become increasingly more common over the previous two (2) decades. Artificial drainage of the subcatchment began in the 19th century and continued throughout the 20th century including major drainage works in the 1970's by Hastings Council (Tulau, 1999).

Currently, there is an extensive artificial drainage network that facilitates the agricultural use of the subcatchment, shown in Figure 8-3. The majority of the end of system infrastructure in this subcatchment is privately owned and managed. The Lower Maria River West subcatchment was previously identified as an acid sulfate soil priority area by Tulau (1999).

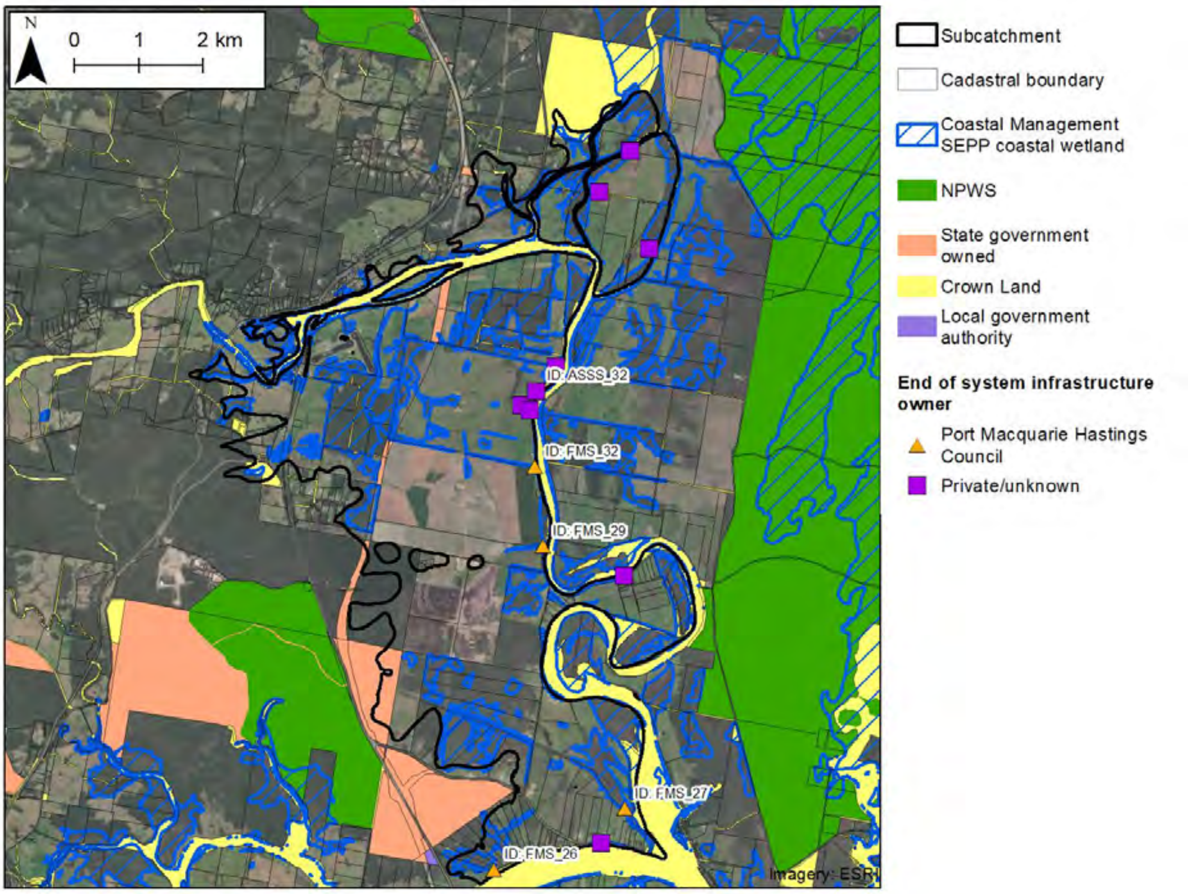

Figure 8-2: Lower Maria River West land and end of system infrastructure tenure

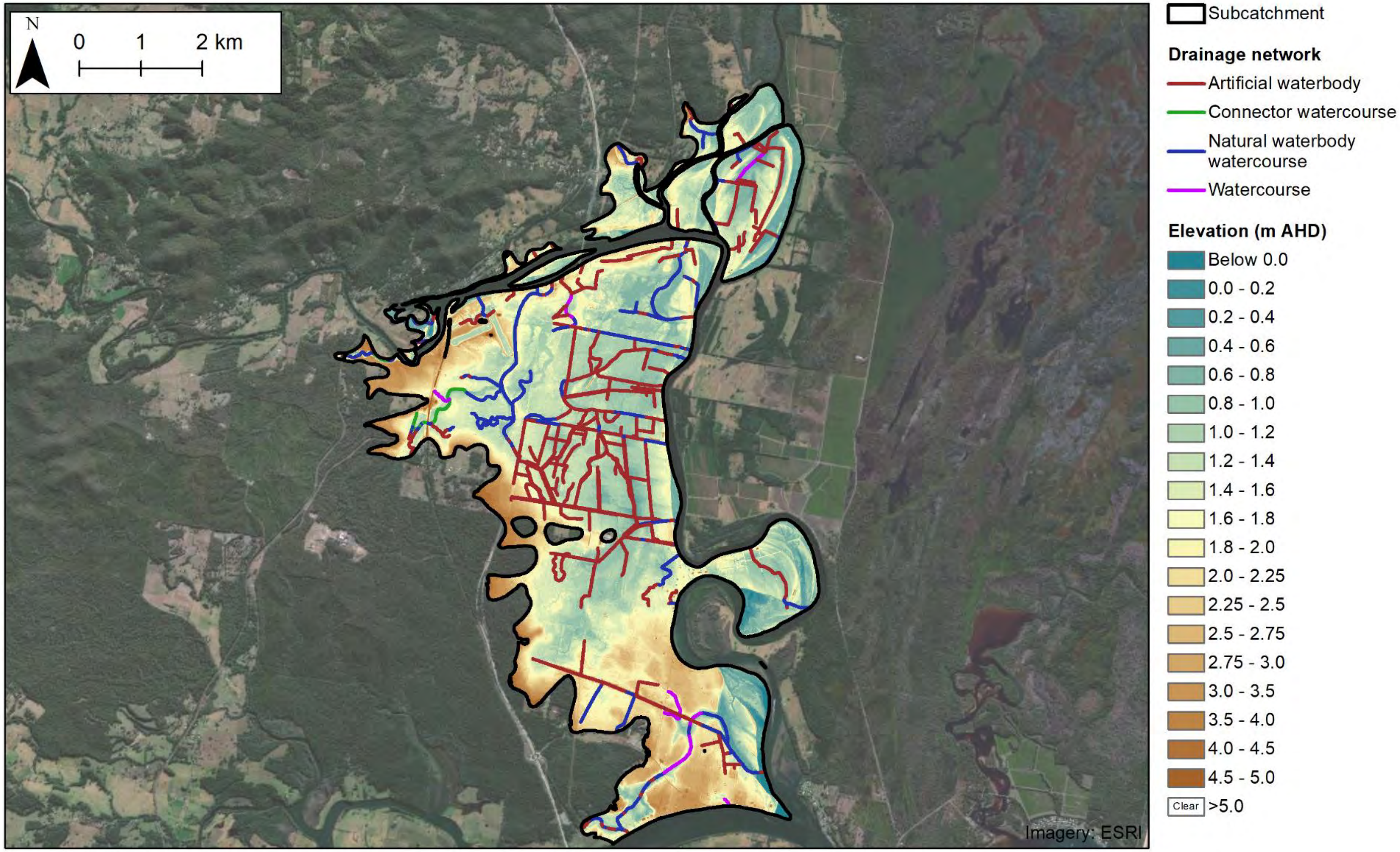

Figure 8-3: Lower Maria River West subcatchment elevation and drainage network

8.3.2 History of remediation

Extensive remediation works have been completed in the Lower Maria River West subcatchment. At least fourteen (14) structures have been modified specifically to address the impacts of ASS drainage, highlighted in Figure 8-4. Remediation of floodgates and drainage systems in this subcatchment have been undertaken by the local council with the support and cooperation of local landholders (Tulau, 1999). Modifications often involved the construction of an additional water retention structure (e.g. weirs) upstream of the original floodgate. In most cases, it is unclear whether original downstream floodgates were decommissioned or are still operational. Modified structures include:

- Three (3) floodgated weirs on Torrens Island, an example of which is shown in Figure 8-5 (floodgate ID ASSS_38, ASSS_39 and ASSS_40);
- Two (2) auto-tidal buoyancy gates in the lower reaches of the subcatchment, an example of which is shown in Figure 8-6 (floodgate ID FMS_26 and FMS_27);
- One (1) earthen weir (ID ASSS_26); and
- Nine (9) floodgates with an auto-tidal gate, with a weir behind the floodgate to maintain higher groundwater tables (floodgate ID FMS_29, FMS_32, ASSS_31, ASSS_32, ASSS_33, ASSS_59, ASSS_34).

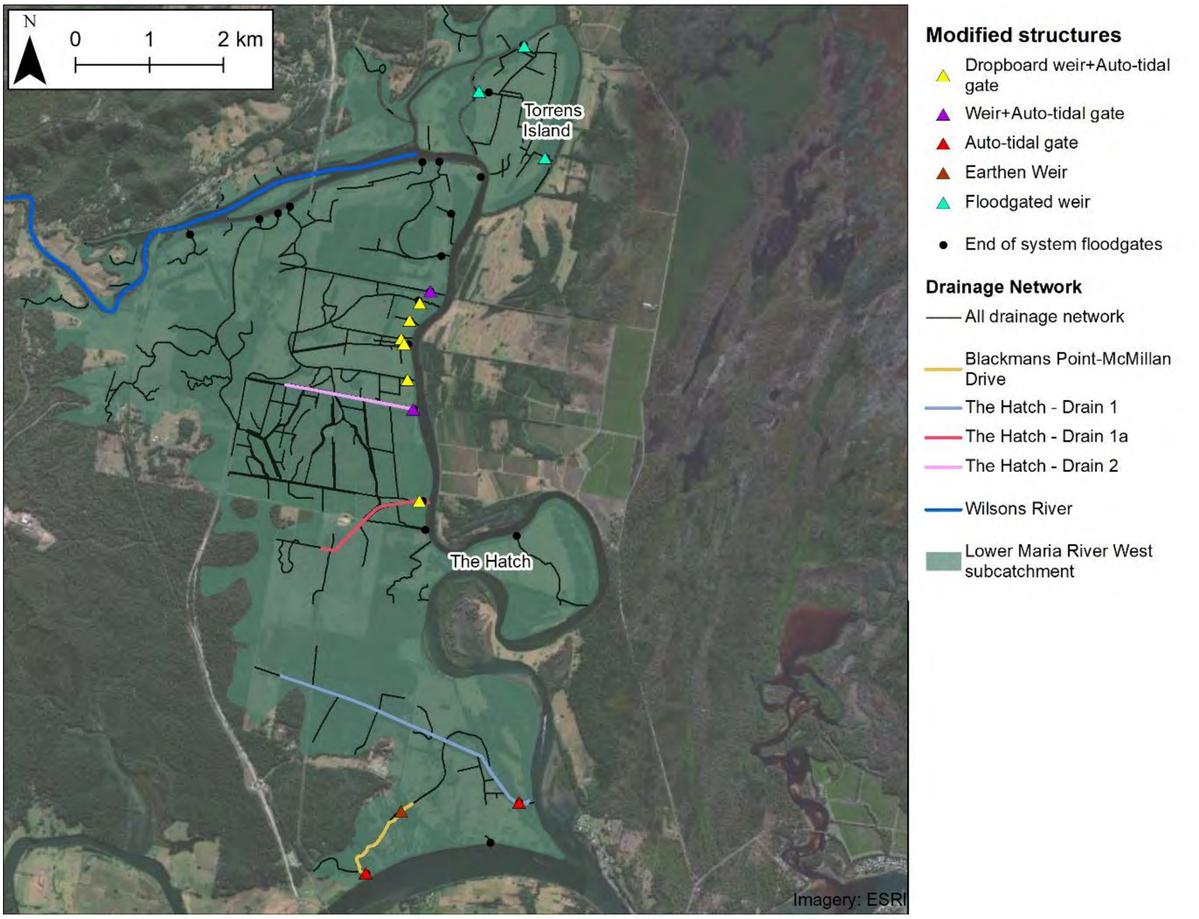

Figure 8-4: Lower Maria River West subcatchment including previous remediation actions

The water level retention level (e.g. crest of weir or bottom of floodgate) of each of the structures is presented in Table 8-3. Both the water retention level based on information provided by PMHC (Port Macquarie Hastings Council, 2010) and field investigations have been provided, which indicates some structures may have been modified or removed since their initial construction.

Table 8-3: Summary of modified floodgates in the Lower Maria River subcatchment

ID	Structure description	Water retention level (m AHD) PMHC records	Water retention level (m AHD) WRL/Abbott and Macro Survey
FMS_27	Automatic tide flushing	NA	-0.28
FMS_26	Automatic tide flushing gate	NA	
FMS_29	Automatic tide flushing dropboard weir	+0.2	-0.13
ASSS_26	Earthen Weir	+0.8	
FMS_32	Weir and automatic tide flushing	+0.2	
ASSS_30	Dropboard weir automatic tide flushing gate	+0.2	Not found
ASSS_31	Dropboard weir automatic tide flushing gate	+0.2	+0.07
ASSS_32	Dropboard weir automatic tide flushing gate	+0.2	+0.29
ASSS_33	Dropboard weir automatic tide flushing gate	+0.2	-0.16
ASSS_34	Weir automatic tide flushing gate	+0.2	-0.26
ASSS_38	Floodgated weir	+0.2	+0.51
ASSS_39	Floodgated weir	+0.2	+0.17
ASSS_40	Floodgated weir	+0.3	+0.25
ASSS_59	Dropboard weir automatic tide flushing gate	NA	-0.20

Figure 8-5: Example of a floodgated weir at ASSS_40 on Torrens Island

Figure 8-6: Example of an auto-tidal floodgate at FMS_26

8.3.3 Prioritisation of management areas in the Lower Maria River West subcatchment

The Lower Maria River West subcatchment is the highest ranked subcatchment in the Hastings River floodplain for acid generation and third highest for blackwater generation. Note that the prioritisation does not explicitly consider historical remediation, as discussed in Section 8.3.2. The subcatchment has been further divided into six (6) management areas referred to as LMW1 – LMW6 (Figure 8-7) to provide additional information on the sources of potential 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 Lower Maria River West subcatchment are shown in Figure 8-7 and summarised in Table 8-4. Management area LMW3 presents the largest risk for potential acid drainage, and has both the highest surface water factor and groundwater factor in the acid prioritisation. Management area LMW4 also contributes substantially to the risk, with a final acid factor almost three (3) times higher than the next highest management area. It is suggested that remediation efforts to improve water quality should initially focus on management areas LMW3 and LMW4, although reducing acid drainage from management areas LMW1, LMW2 and LMW6 may also result in substantial improvements in water quality.

As shown in Figure 8-7 and Table 8-4, no soil profile data was available in management area LMW5. However, this management area has a lower surface water factor (i.e. no upland catchment) and is assumed to be a low priority in this analysis. Collection of additional soil data in LMW5 is recommended to confirm these assumptions.

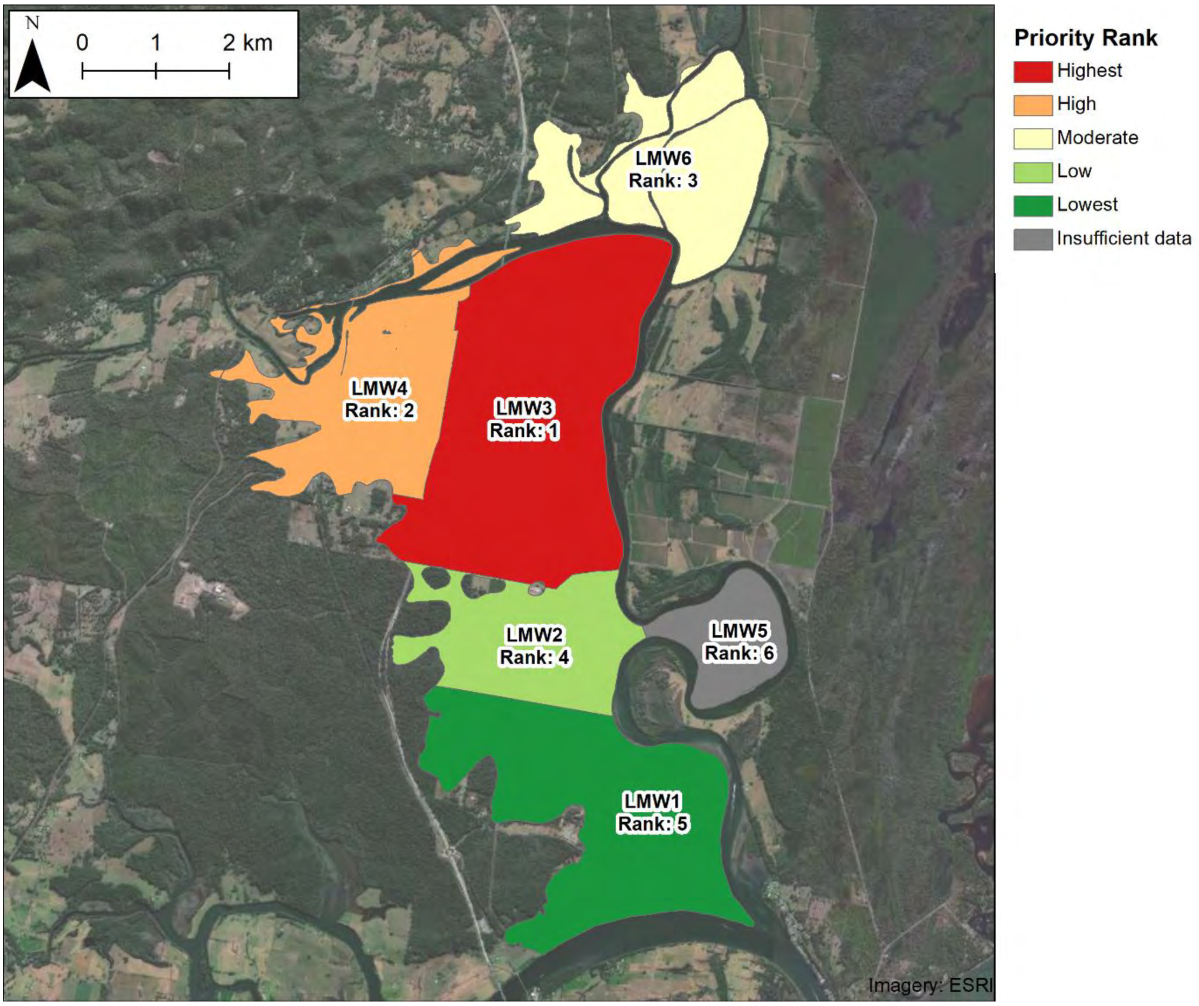

Figure 8-7: Lower Maria River West subcatchment management areas acid prioritisation

Table 8-4: Management area acid prioritisation of Lower Maria River West subcatchment

Management area	Groundwater factor	Surface water factor	Final acid factor	Final rank
LMW3	274	2,282	624,665	1
LMW4	164	871	143,290	2
LMW6	122	431	52,715	3
LMW2	100	403	40,210	4
LMW1	53	691	36,934	5
LMW5	Insufficient data	61	Insufficient data	Insufficient data

Figure 8-8 shows the management areas in the Lower Maria River West subcatchment below the median elevation for blackwater generation (+0.7 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). While Figure 8-8 shows that there is only a small area below the median blackwater elevation, it is important to recognise that the blackwater risk assessment includes levels up to +2 m AHD, which covers a substantially larger area of the floodplain (including the majority of management areas LMW3, LMW6 and LMW2). This indicates that blackwater can still be generated from this subcatchment, but it is more likely during larger, less frequent flood events. Blackwater management should focus on the lowest areas in the subcatchment, particularly in LMW3.

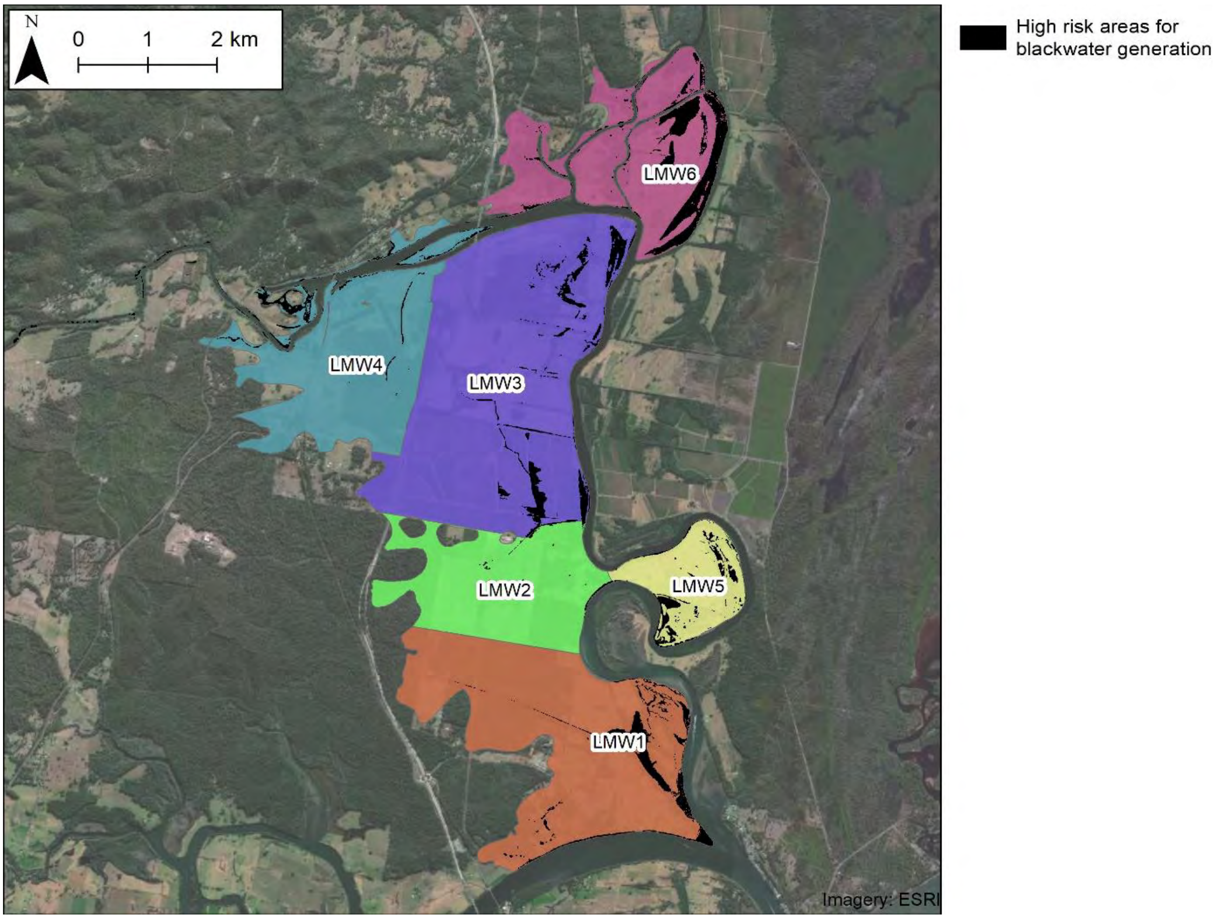

Figure 8-8: Blackwater contribution in management areas in Lower Maria River West subcatchment (median blackwater elevation +0.7 m AHD)

8.3.4 Floodplain drainage – sea level rise vulnerability

Figure 8-9 summarises the sea level rise vulnerability of the Lower Maria River West subcatchment. Under the present day and near future sea level rise scenarios, the majority of the floodplain is not considered vulnerable to reduced drainage. However, under the far future sea level rise scenario a substantial area will be considered low to medium risk. Reduced drainage may impact current land uses in the near to far future. Figure 8-10 shows the primary floodgates in this subcatchment are generally relatively high compared to present day and future low tide water levels.

Torrens Island, in the northern end of the subcatchment, will be amongst the areas most impacted by reduced drainage. Under the far future sea level rise scenario, low areas (<0.2 m AHD) will be below the median (50th percentile) water levels in the river, and all of the floodgates have been classified as “Moderately vulnerable”. Structure ASSS_32 is the only primary structure vulnerable to sea level rise, being classified as “Moderately vulnerable” in the near and far future (Figure 8-10).

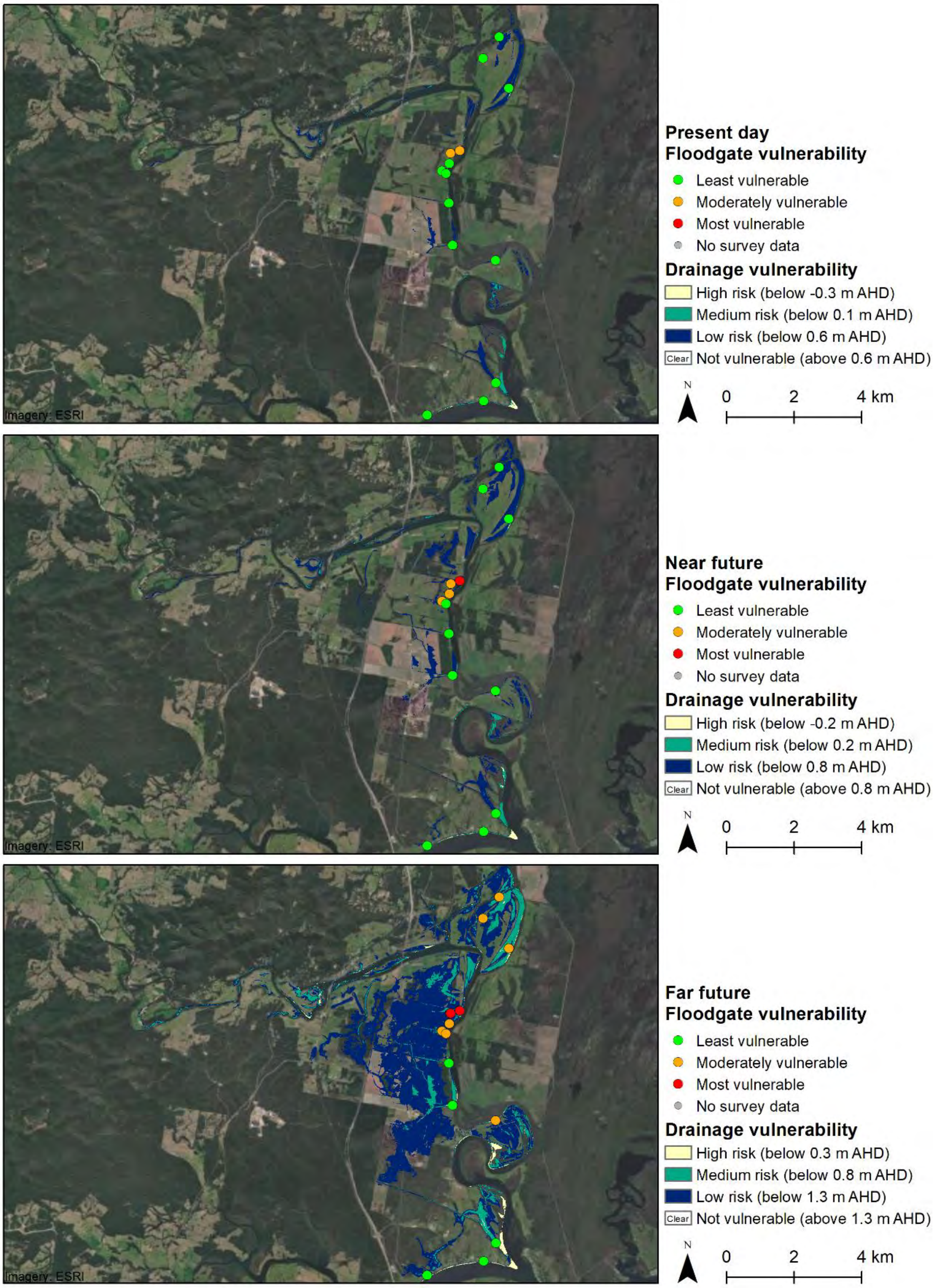

Figure 8-9: Sea level rise drainage vulnerability – Lower Maria River West subcatchment

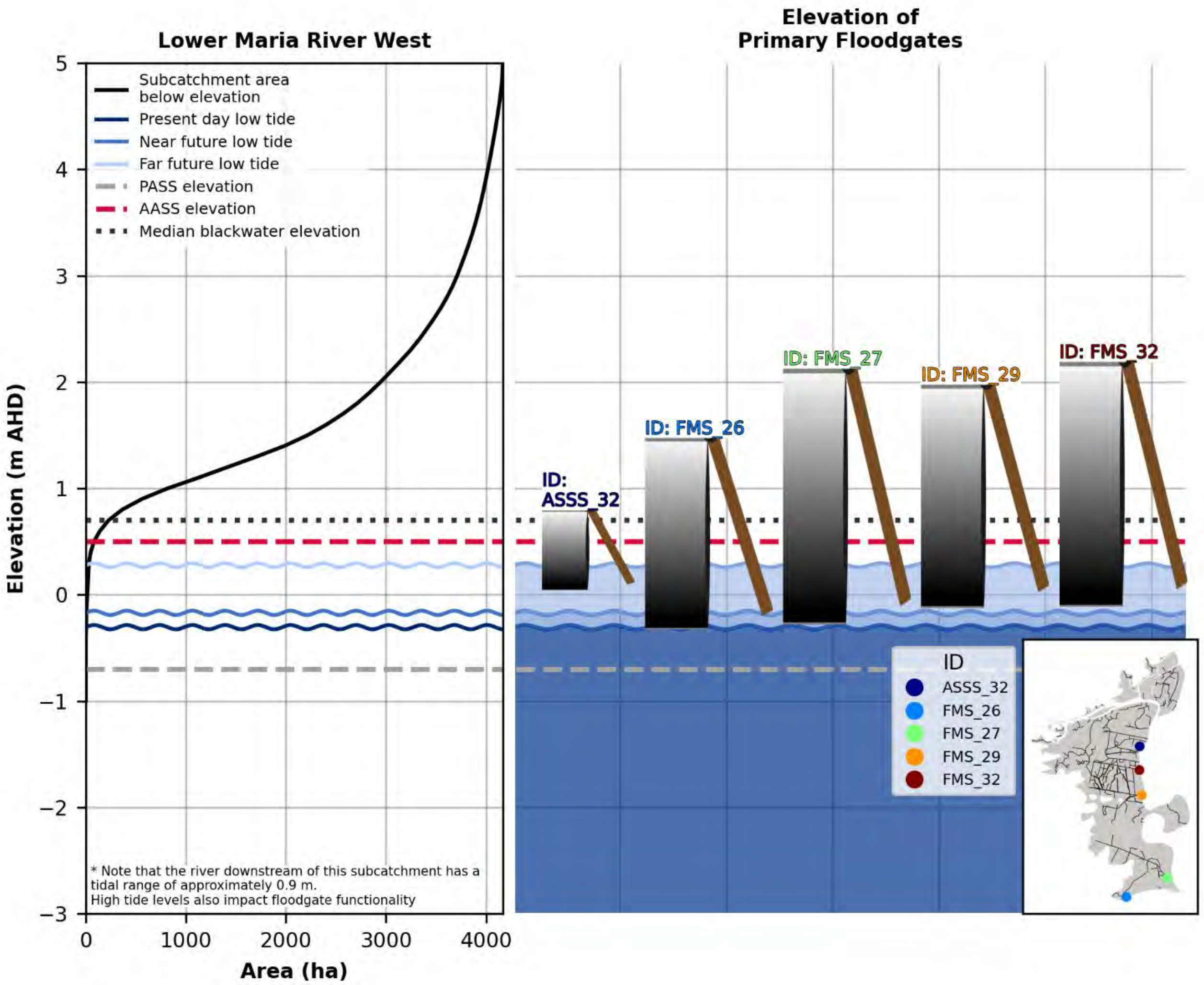

Figure 8-10: Key floodplain elevations – Lower Maria River West subcatchment

8.3.5 Management options

Potential management options for short-term and long-term planning horizons for the Lower Maria River West subcatchment include:

- Short-term: Review management of existing dropboard structures, consider using alternative vegetation management strategies (e.g. sheep or goats for grazing of grasses in tea tree plantations) to reduce the blackwater risk in management areas LMW3 and LMW2; and
- Long-term: Remediation of low areas to freshwater/brackish wetlands, consider the use of stepped weirs (weirs with increasing height installed moving upstream in a drain) to encourage wet pasture management in higher areas.

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

Short-term management options

The PMHC and local landholders in the Lower Maria River West have modified the vast majority of the end of system infrastructure in this subcatchment to manage acid discharges and improve water quality. This is mostly in the form of water retention structures combined with tidal flushing (discussed in Section 8.3.2), which reduces groundwater drawdown while also allowing tidal flushing and buffering in the drainage network. This work done to date is likely to be effective at managing acid drainage while maintaining current land uses. Other than optimising the management of the existing structures (such as ensuring dropboard weirs are being actively managed), the existing remediation actions provide adequate short-term management of acid risk in this subcatchment whilst maintaining existing land use practices.

The Lower Maria River West subcatchment ranked third for blackwater generation. While most effective blackwater management strategies would require significant water retention and land use changes, small changes in land management practices can also be effective at reducing the risk of blackwater drainage. In areas used for tea tree plantations (management areas LMW3 and LMW2), the use of grazing animals, such as sheep or goats, can be used to manage grasses and weeds between trees; additionally tea tree leaf waste can be recycled for urban mulch to reduce carbon contents on the floodplain (Eyre et al., 2006; Moore, 2007). Note that cattle on grass pasture are typically not considered an effective management option as they do not consume grass across paddocks evenly and pasture growth typically exceeds consumption (Eyre et al., 2006).

Long-term management options

In the longer term, current land uses may be impacted by reduced drainage due to sea level rise, particularly in management area LMW3 which is the lowest area in the Lower Maria River West subcatchment.

Future reduced drainage may impact existing land uses and increase the risk of blackwater generation. If current land uses cannot persist, it is recommended that land use changes be considered for the lowest areas (below +1.3 m AHD, or far future 95th percentile water levels) and restoration of natural flow paths is pursued. 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 of the artificial drainage network to reduce drainage density;
- Reshaping of remaining drainage network to wider, shallower waterways to reduce interaction with acidic layers;
- Removal of floodgates; and
- Establishment of wetland habitats in low-lying areas.

This would result in a mix of freshwater and brackish wetlands and prolonged inundation in the lowest areas of the subcatchment, which would reduce acid drainage. By facilitating prolonged drainage and an increased time of inundation, carbon processes that occur when organic matter decomposes would be able to be completed, which would reduce the impact of blackwater, particularly in management areas LMW3 and LMW2.

In other areas, stepped weirs (weirs with increasing height installed moving upstream in a drain) should be considered to encourage wet pasture management and higher water tables. This would further reduce acid and blackwater generation in this subcatchment.

Table 8-5: Summary of management options for Lower Maria River West subcatchment

Timeframe	Strategy	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing)	Indicative cost (lost productivity)	Effectiveness at improving:		
						Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Review management of existing structures	None	$5,000	$5,000	None	Limited**	Moderate**	Low**
Long-term	Stepped weir system and wet pasture management	None	$65,000	$5,000	None	None	Moderate	Moderate
Long-term	Remediate brackish/freshwater wetlands	$8,100,000	$1,000,000	Minimal	$1,700,000	High	High	High

*Costs exclude additional investigation/studies, including; REF, EIS, flood studies, and monitoring programs that may be required prior to implementation
** These benefits are already achieved through existing structures, however reviewing the management ensures outcomes are optimised

8.4 Upper Maria River subcatchment

Acid priority rank:	**2**
Blackwater priority rank:	**2**
Infrastructure	
Approximate waterway length (km)	74
# Privately owned end of system structures	7
# Publicly owned end of system structures	5
# End of system structures within coastal wetlands	4
# Publicly owned end of system structures within coastal wetlands	1
Primary floodplain infrastructure (ID):	060G1, 061G1, 076G1, 078G1
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-1.2 to -0.7
Approximate AASS elevation (m AHD)	0.6
Approximate PASS elevation (m AHD)	-0.7
Median blackwater elevation (m AHD)	1.0
Present day low water level (m AHD)	-0.3
Near future low water level (m AHD)	-0.2
Far future low level (m AHD)	0.3
Proximity to sensitive receivers	
Oyster Leases (km)	9.5
Saltmarsh (km)	3.9
Seagrass (km)	9.6
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	6,901
Classified as conservation and minimal use (ha (%))	3,886 (56%)
Classified as grazing (ha (%))	2,172 (31%)
Classified as forestry (ha (%))	146 (2%)
Classified as other cropping (ha (%))	10 (0.2%)
Classified as horticulture (ha (%))	3 (0%)
Classified as urban/industrial/services (ha (%))	70 (1%)
Classified as marsh/wetland (ha (%))	439 (6%)
Other (ha (%))	173 (3%)
Land values	
Estimated total primary production value ($/year)	$1,100,000
Average land value above 1 m AHD ($/ha)	$3,500
Average land value below 1 m AHD ($/ha)	$2,400

8.4.1 Site description

The Upper Maria River subcatchment includes Pipers Creek and the north west corner of the Limeburners Creek National Park, as shown in Figure 8-11. Unlike the majority of subcatchments in the Hastings River floodplain, this subcatchment is largely within the Kempsey Shire Council (KSC) LGA and all primary infrastructure is managed by KSC (although the majority of secondary drainage infrastructure is privately owned). The Upper Maria River includes a substantial area below 1 m AHD (shown in Figure 8-12) and the majority of the subcatchment is classified as "conservation and minimal use" (56%) or "wetland/marsh" (6%). Grazing is the primary agricultural land use, accounting for 33% of the land use in the subcatchment.

Smith (1999) states that an Upper Maria River Flood Mitigation Scheme was implemented after floods in the 1960's to allow for agricultural development of areas below 1 m AHD. However, while this resulted in a decline in water levels in swamp lands from +0.4 m to -0.5 m AHD, little agricultural productivity was gained from the scheme and it greatly exacerbated acid drainage from the area (Smith, 1999). This subcatchment is part of the Upper Maria River – Connection Creek ASS priority area identified by Tulau (1999).

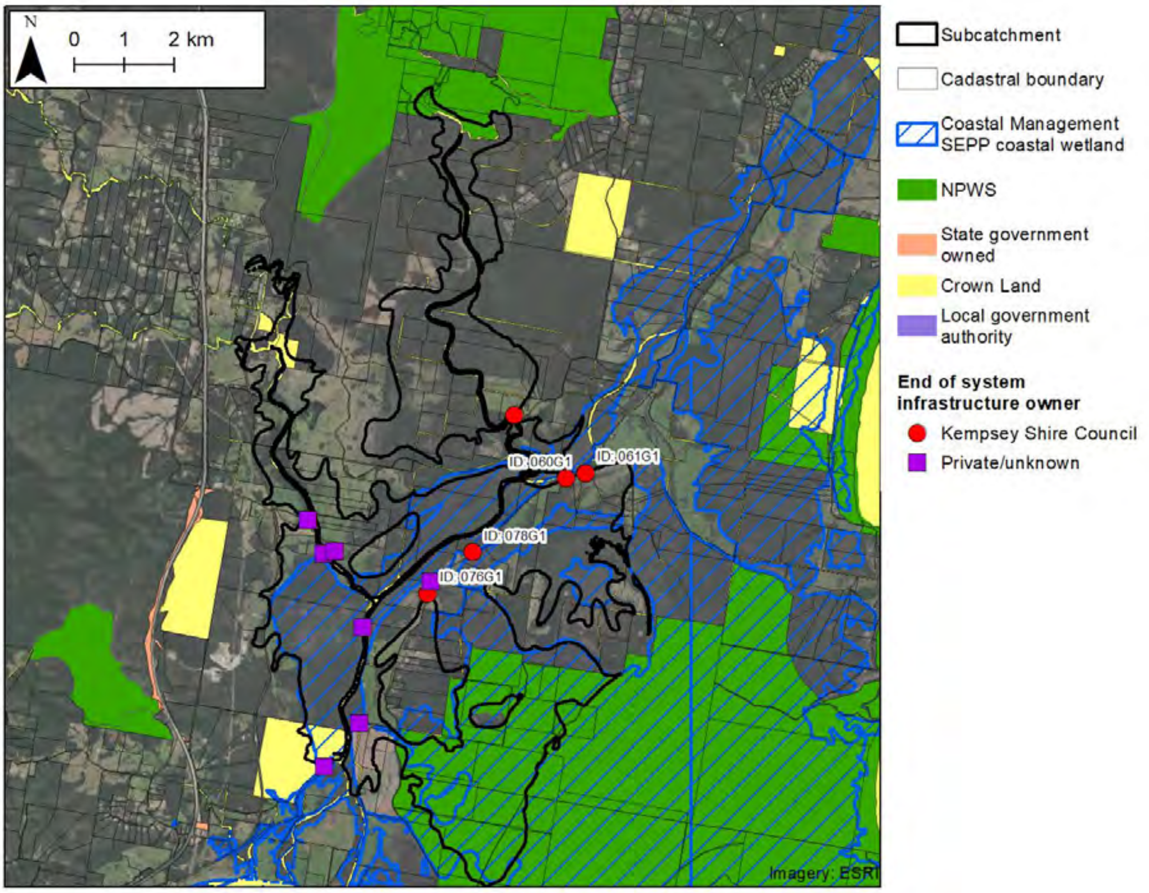

Figure 8-11: Upper Maria River subcatchment land and drainage infrastructure tenure

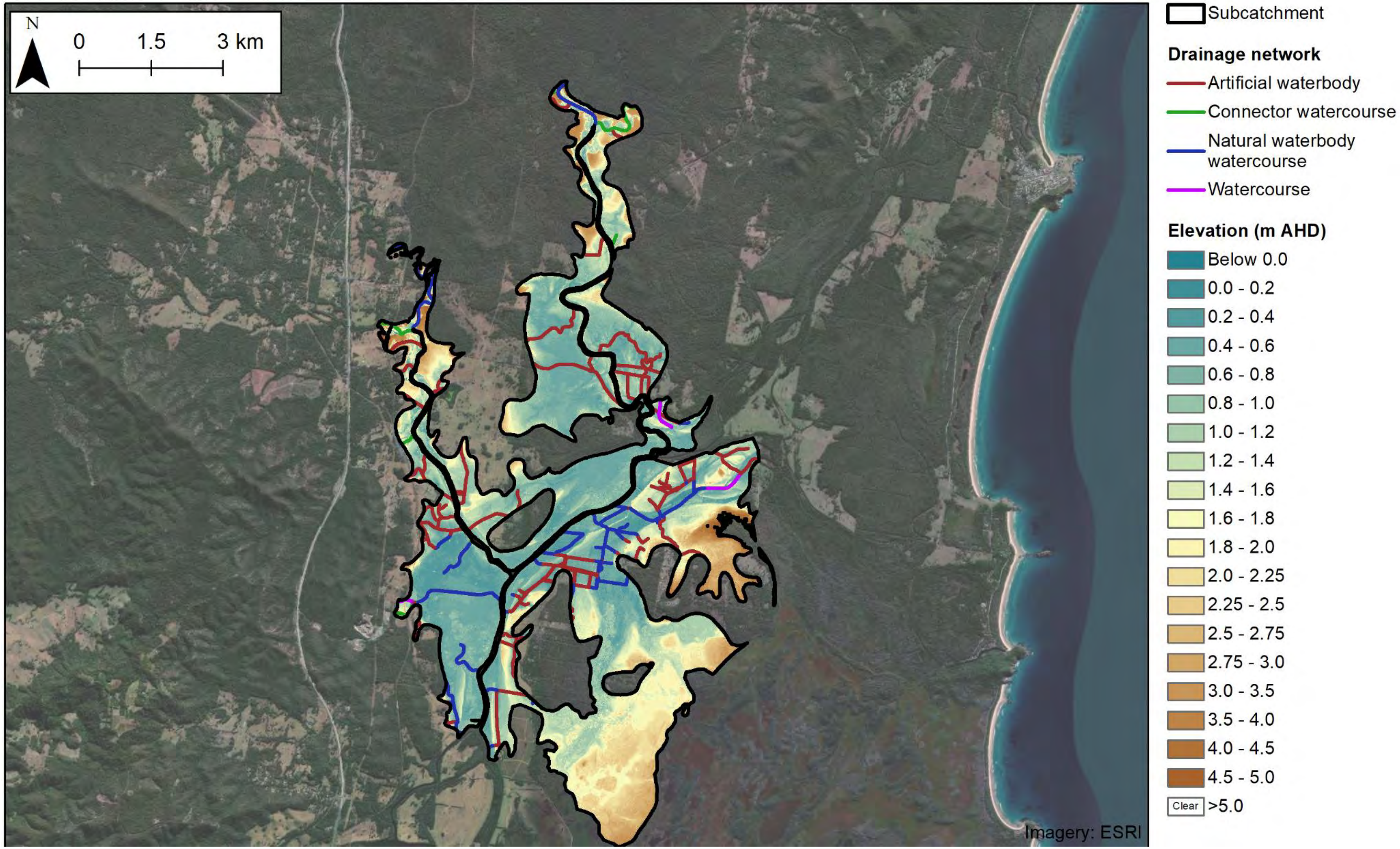

Figure 8-12: Upper Maria River subcatchment elevation and drainage network

8.4.2 History of remediation

At least four (4) structures have been modified or constructed to manage ASS drainage in the Upper Maria River subcatchment, indicated in Figure 8-13. Modifications often involved the construction of an additional water retention structure (e.g. weirs) upstream of the original floodgate. It is unclear whether original downstream floodgates were decommissioned or are still operational. This includes:

- One (1) concrete sill (ID ASSS_41) with a water retention level of 0.4 m AHD , based on Council records (Port Macquarie Hastings Council, 2010);
- One (1) floodgated weir (ID ASSS_42) with a water retention level of 0.25 m AHD, based on Council records (Port Macquarie Hastings Council, 2010); and
- Two (2) auto-tidal buoyancy floodgates (floodgate ID 076G1 and 060G1) which were identified during WRL field investigations. These floodgates allow some tidal flushing and allow fish passage upstream of the floodgates. Note that these two (2) floodgates are managed by Kempsey Shire Council. Floodgate ID 076G1 is shown in Figure 8-14.

Figure 8-13 also shows a substantial area within the Upper Maria River subcatchment is mapped as Coastal Management SEPP coastal wetlands. This classification means that the area is subject to more stringent development controls under state government legislation.

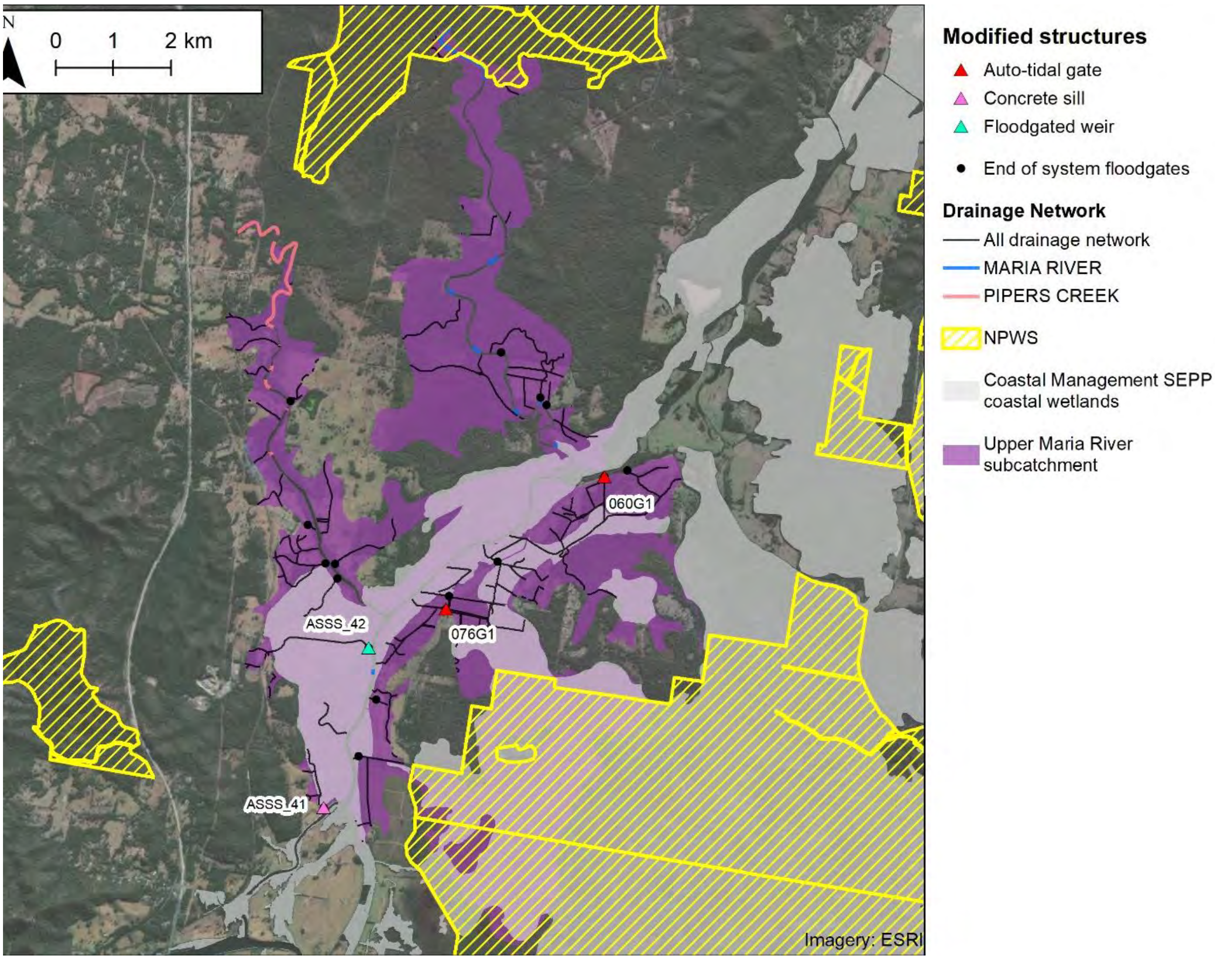

Figure 8-13: Upper Maria River subcatchment including previous remediation actions

Figure 8-14: Floodgate ID 076G1 with auto-tidal buoyancy gate on the left bank floodgate

8.4.3 Prioritisation of management areas in the Upper Maria River subcatchment

The Upper Maria River subcatchment ranked second for acid generation and second for blackwater generation, indicating that it is a high priority area. The subcatchment has been further divided into three (3) management areas referred to as UMR1, UMR2 and UMR3 (Figure 8-15) to provide additional information on potential sources of acid and blackwater. The areas have been delineated based on data availability, elevation, changes in soil acidity, and drainage units.

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 Upper Maria River subcatchment are shown in Figure 8-15 and summarised in Table 8-6. The highest ranked subcatchment is UMR1, located on the eastern side (left bank) of the Maria River. There was insufficient soil profile data available in management area UMR3 to implement the ASS prioritisation assessment methodology. Management area UMR3 has a similar surface water factor to management area UMR2, and it is assumed to be of a comparable priority. Collection of additional soil data is recommended in this management area to confirm ASS depths, extent and severity.

Figure 8-16 shows the management areas in the Upper Maria River subcatchment 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 contribute the most to the risk of large scale deoxygenation (although this can be managed through changing vegetation and land uses). All of the management areas in this subcatchment contribute to blackwater generation.

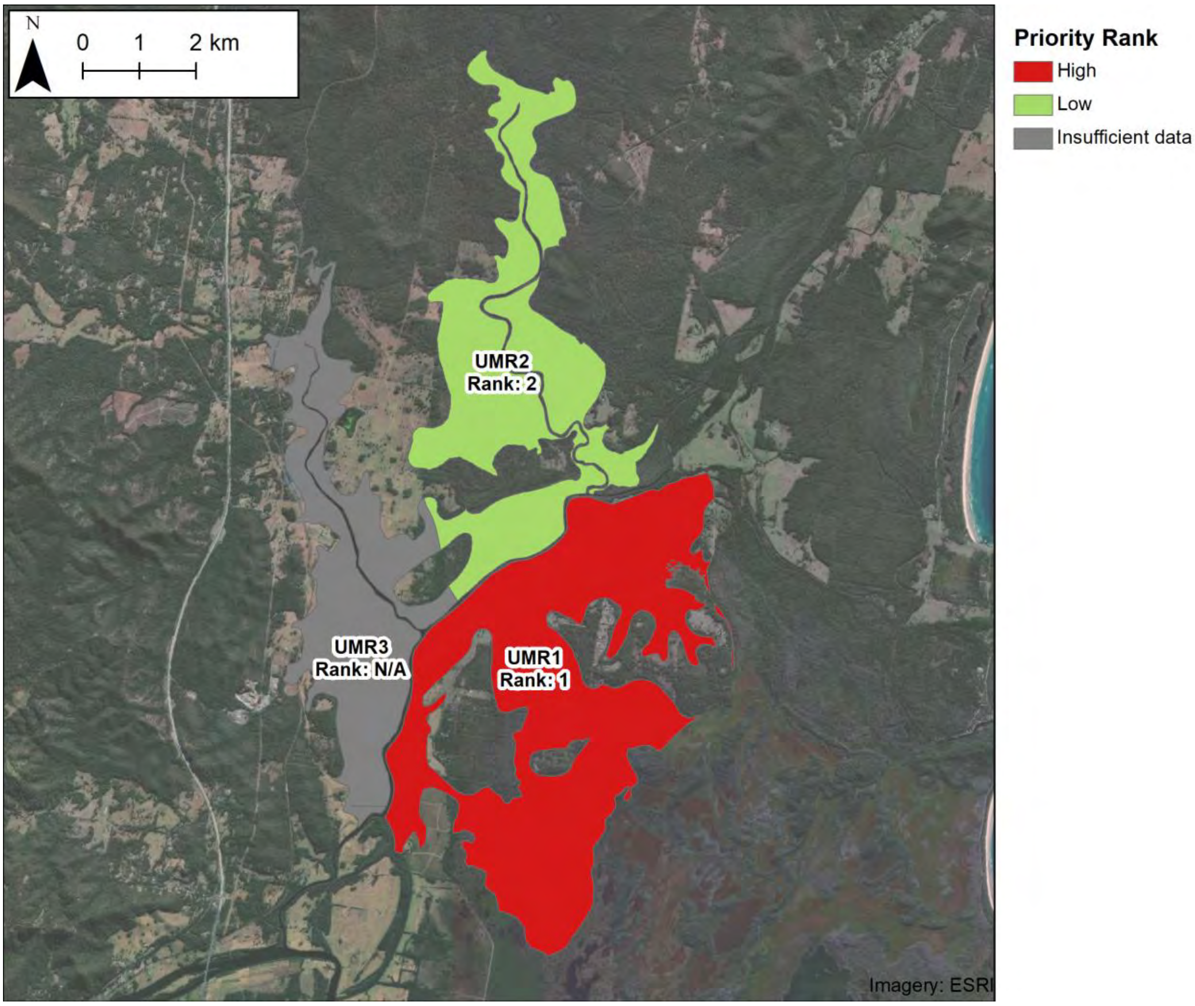

Figure 8-15: Upper Maria River subcatchment management areas acid prioritisation

Table 8-6: Management area acid prioritisation of Upper Maria River subcatchment

Management area	Groundwater factor	Surface water factor	Final acid factor	Final management area rank
UMR1	125	310	38,797	1
UMR2	51	129	6,577	2
UMR3	Insufficient data	170	Insufficient data	Insufficient data

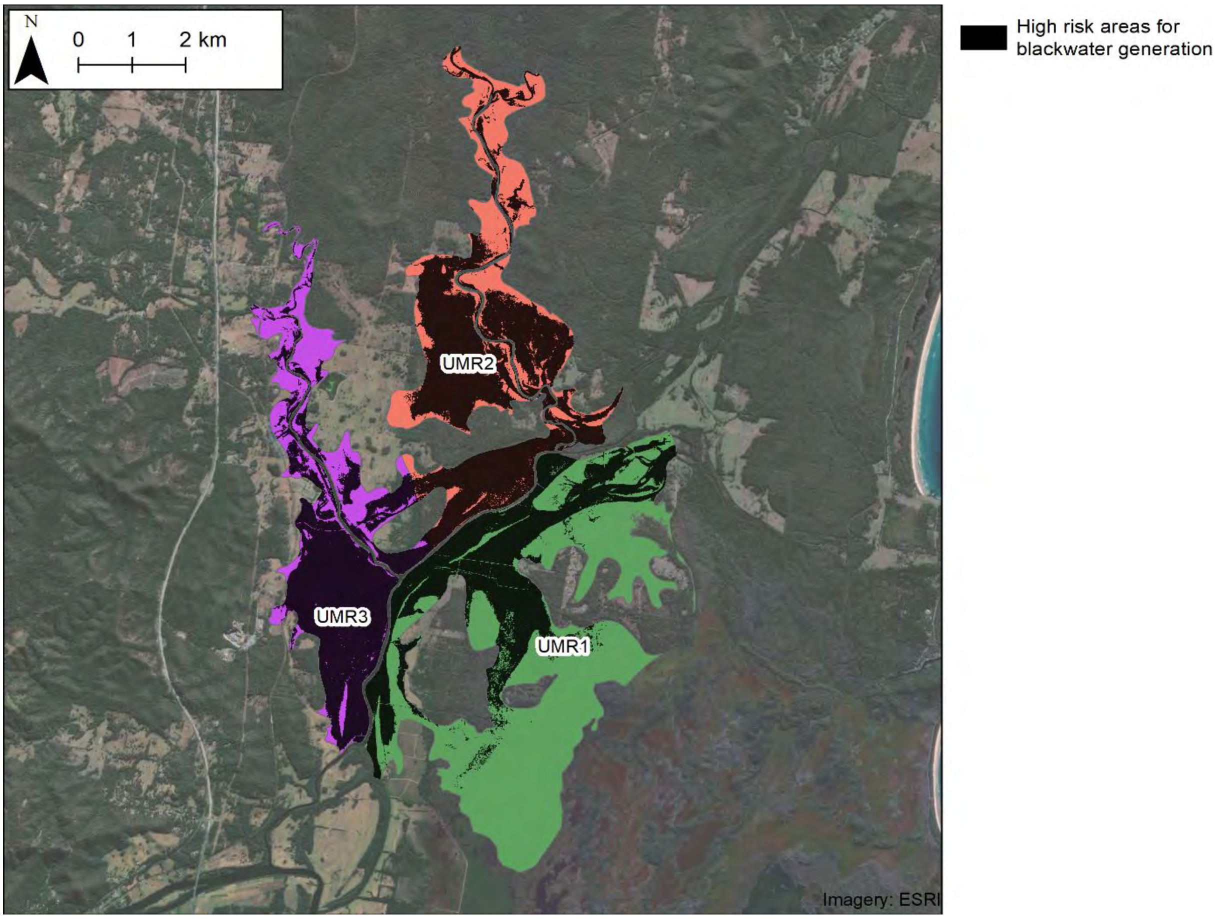

Figure 8-16: Blackwater contribution in management areas in Upper Maria River subcatchment (median blackwater elevation +1 m AHD)

8.4.4 Floodplain drainage – sea level rise vulnerability

Figure 8-17 summarises the sea level rise vulnerability of the Upper Maria River subcatchment. Even under the present day scenario, a significant area of this subcatchment is considered low risk for reduced drainage, and limited drainage has already reduced the area that can be used productively for agriculture (Smith, 1999). Under the far future sea level rise scenario, approximately 1,700 ha (or more than a third) of the subcatchment will be classified as medium risk for reduced drainage. Reduced drainage may impact agriculture land uses in this subcatchment as sea levels continue to rise in the near to far future.

The drainage infrastructure in this subcatchment will also be impacted by sea level rise. Figure 8-18 shows that the majority of the primary floodgates are relatively low compared to the far future lower tide water level. Under the far future scenario, seven (7) of the 12 (twelve) structures with survey information are classified as “Most vulnerable”, up from none in the present day scenario and one (1) in the near future scenario.

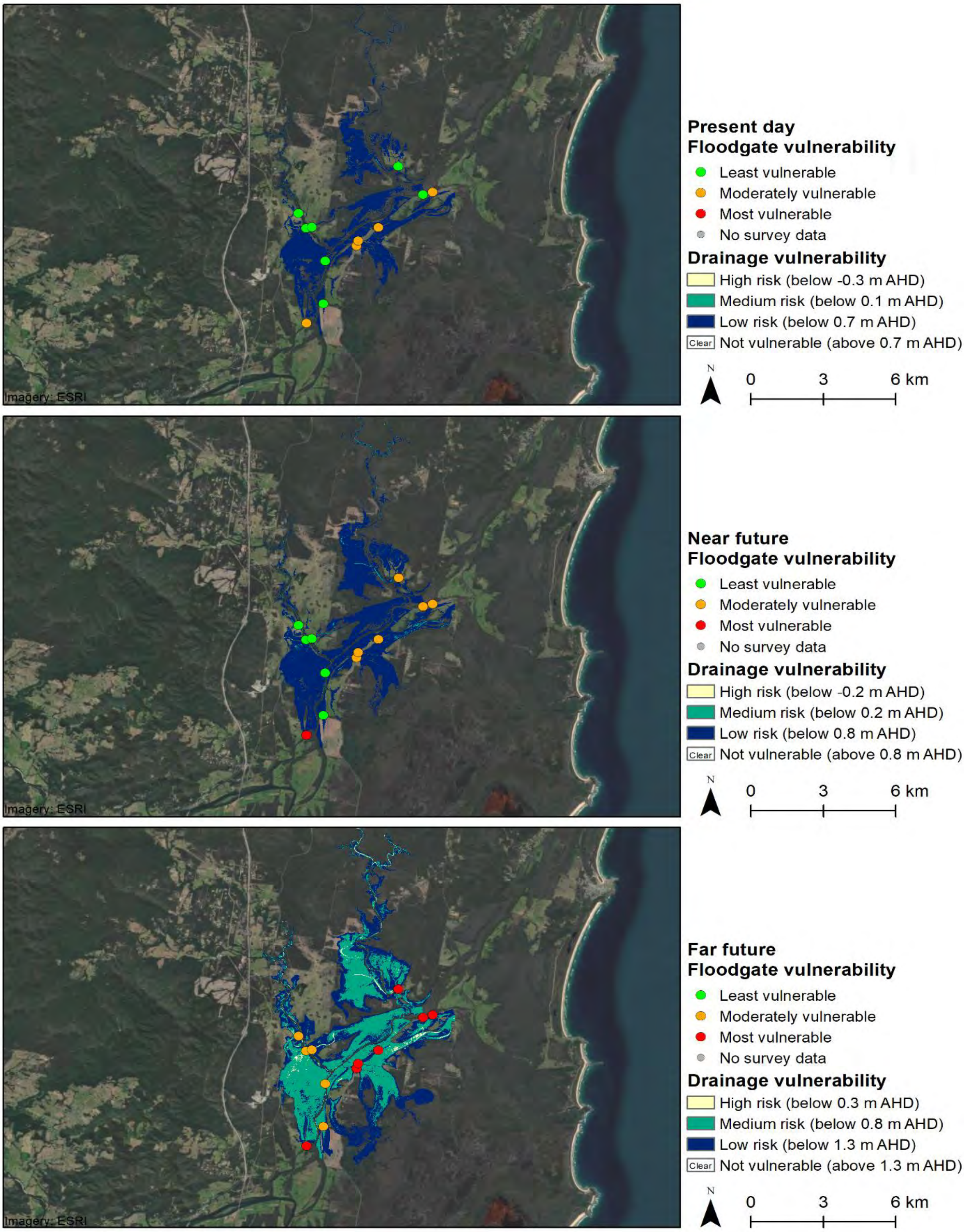

Figure 8-17: Sea level rise drainage vulnerability – Upper Maria River subcatchment

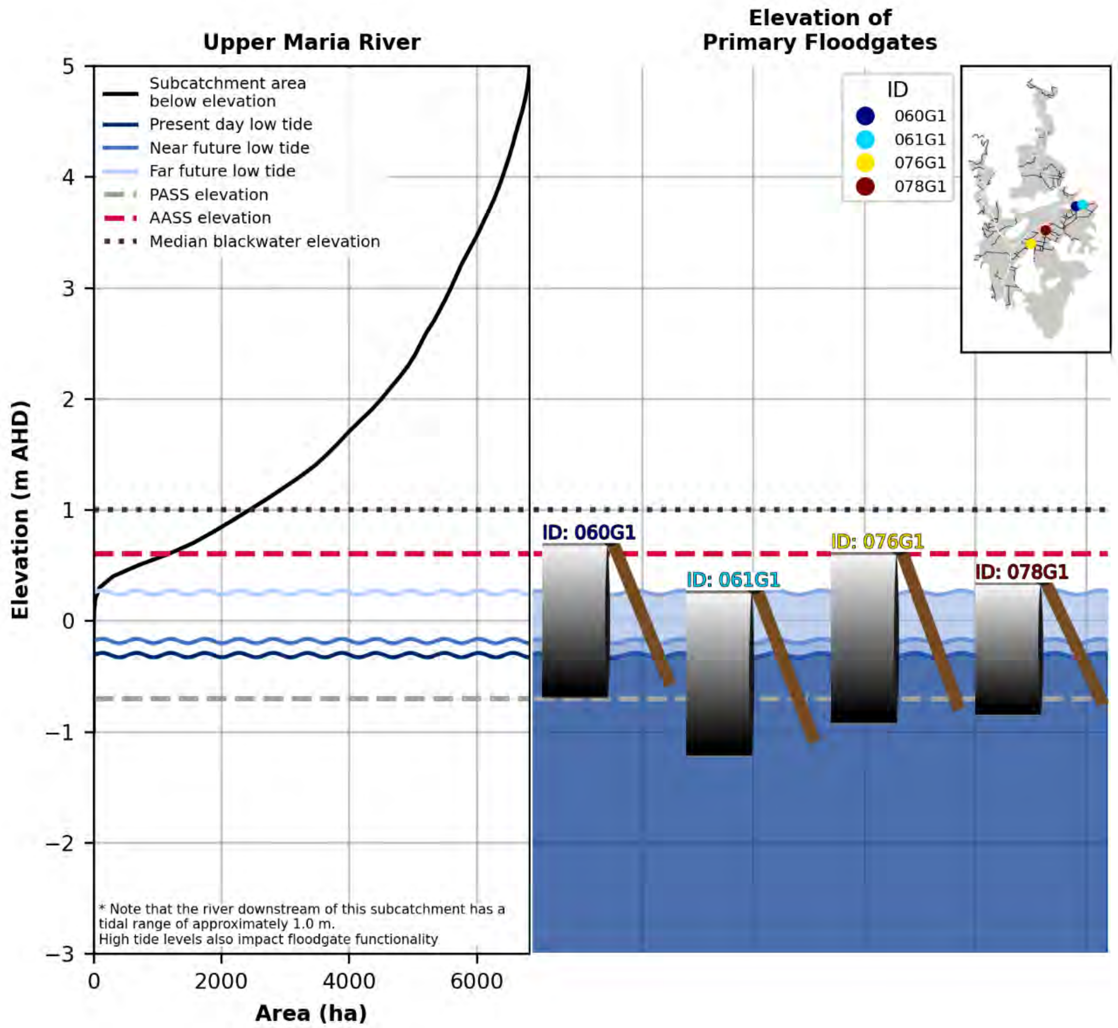

Figure 8-18: Key floodplain elevations – Upper Maria River subcatchment

8.4.5 Management options

Potential management options for short and long-term planning horizons for the Upper Maria River subcatchment include:

- Short-term: Modifying additional floodgates to allow some tidal flushing in management area UMR1, consider the use of dropboard weirs for wet pasture management in areas that are actively grazed.
- Long-term: grazing areas in low (<1 m AHD) areas of all management areas may be impacted by reduced drainage. If present day land uses are no longer viable, consider remediation and extension of coastal wetlands.

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

Short-term management options
In management area UMR1 (the highest rank subcatchment for acid drainage), two (2) of the four (4) major floodgates have been modified with an auto-tidal buoyancy gate (floodgate ID 076G1 and 060G1). The remaining two (2) primary floodgates (floodgate ID 078G1 and 061G1, shown in Figure 8-19) should be assessed if suitable for modification with auto-tidal buoyancy gates to allow managed tidal flushing and maintaining higher surface water levels in the drainage system upstream.

Figure 8-19: (Left) Floodgate ID 061G1 1.5 m culvert, invert level -1.2 m AHD, (Right) Floodgate ID 078G1 1.2 m diameter culvert, invert level -0.85 m AHD

In areas presently used for grazing (mostly in management areas UMR1 and UMR3), the use of dropboard weirs coupled with wet pasture management should be considered. This would maintain higher water tables, reduce acid drainage, and encourage water tolerant vegetation (i.e. reduce blackwater generation potential). Artificial drainage in areas mapped as Coastal Management SEPP coastal wetlands (in management areas UMR1 and UMR3) should be reviewed and reshaped, or infilling of drains should be considered.

Long-term management options
Land uses in low areas of the Upper Maria River subcatchment may be impacted by reduced drainage as sea levels continue to rise. If areas that are currently cleared for grazing are no longer viable due to

sea level rise, low areas (<1 m AHD) should be prioritised for remediation and increase the footprint of the Coastal Management SEPP coastal wetlands in this subcatchment. This could be targeted in each of the three (3) management areas and would be effective for addressing both acid and blackwater drainage. Remediation is likely to include:

- Restoration of natural flow paths through infilling artificial drainage networks and reduced connectivity of the floodplain to the main waterways to encourage prolonged inundation of low backswamp areas; and
- Removal or modification of floodgates to allow significant tidal flushing.

Note that any changes in hydrology will require studies into the impacts to flooding and land uses, and should only be implemented with extensive consultation of local landholders and consideration of the social and economic impacts of such changes. This strategy will also require further consideration and design of roads (including Maria River Road) which may be impacted if drainage is significantly altered as a result of changed flooding regimes.

Table 8-7: Summary of management options for Upper Maria River subcatchment

Timeframe	Strategy	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing)	Indicative cost (lost productivity)	Effectiveness at improving:		
						Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Modify floodgates to improve tidal flushing	None	$40,000	$5,000	None	Moderate	Moderate	Low
Short-term	Dropboard weirs and wet pasture management	None	$65,000	$5,000	None	None	Moderate	Moderate
Long-term	Remediate brackish/freshwater wetlands	$2,900,000	$650,000	Minimal	$1,700,000	High	High	High

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

8.5 Partridge Creek subcatchment

Acid priority rank:	**3**
Blackwater priority rank:	**13**
Infrastructure	
Approximate waterway length (km)	11
# Privately owned end of system structures	0
# Publicly owned end of system structures	0
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (ID):	N/A
Elevations	
Invert of primary floodplain infrastructure (m AHD):	N/A
Approximate AASS elevation (m AHD)	1.2
Approximate PASS elevation (m AHD)	-0.4
Median blackwater elevation (m AHD)	0.5
Present day low water level (m AHD)	-0.5
Near future low water level (m AHD)	-0.3
Far future low level (m AHD)	0.2
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)	557
Classified as conservation and minimal use (ha (%))	137 (25%)
Classified as grazing (ha (%))	210 (38%)
Classified as forestry (ha (%))	0 (0%)
Classified as horticulture (ha (%))	0 (0%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	48 (9%)
Classified as marsh/wetland (ha (%))	153 (28%)
Other (ha (%))	9 (2%)
Land values	
Estimated total primary production value ($/year)	$90,000
Average land value above 0.5 m AHD ($/ha)	$20,900
Average land value below 0.5 m AHD ($/ha)	No property data available

8.5.1 Site description

The Partridge Creek subcatchment is in the lower Hastings River floodplain, approximately 5 km west of Port Macquarie and includes a backswamp area that would historically have been a freshwater wetland that was poorly connected to the Hastings River. While early artificial drainage dates back to the start of the 20th century, major flood mitigation works were completed in the 1960's to 1980's, including deepening of the drainage network, a diversion of Partridge Creek into Fernbank Creek and installation of floodgates (Hastings Council, 2004). Partridge Creek was identified as an ASS priority area by Tulau (1999) and was estimated to discharge approximately 860 to 1,100 tonnes of acid annually (Hastings Council, 2004).

As shown in Figure 8-20, Hastings Council acquired a significant portion of the Partridge Creek subcatchment in 1999 as part of large scale remediation works, discussed further in Section 8.5.2. The majority of the subcatchment is classified as "marsh/wetland" or "conservation and minimal use" (55% of the subcatchment area). Grazing occurs on approximately 38% of the subcatchment, predominantly in higher areas (>2 m AHD). Subcatchment topography and drainage is shown in Figure 8-21.

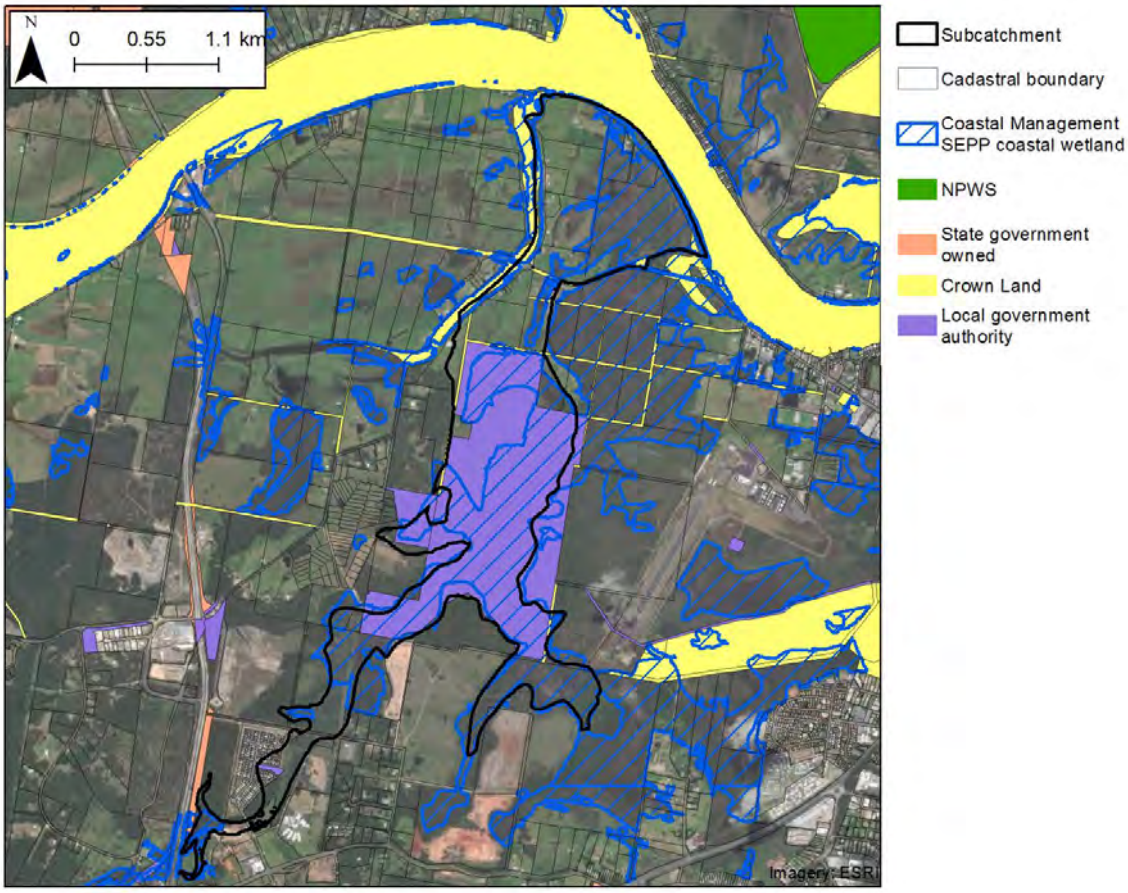

Figure 8-20: Partridge Creek subcatchment land

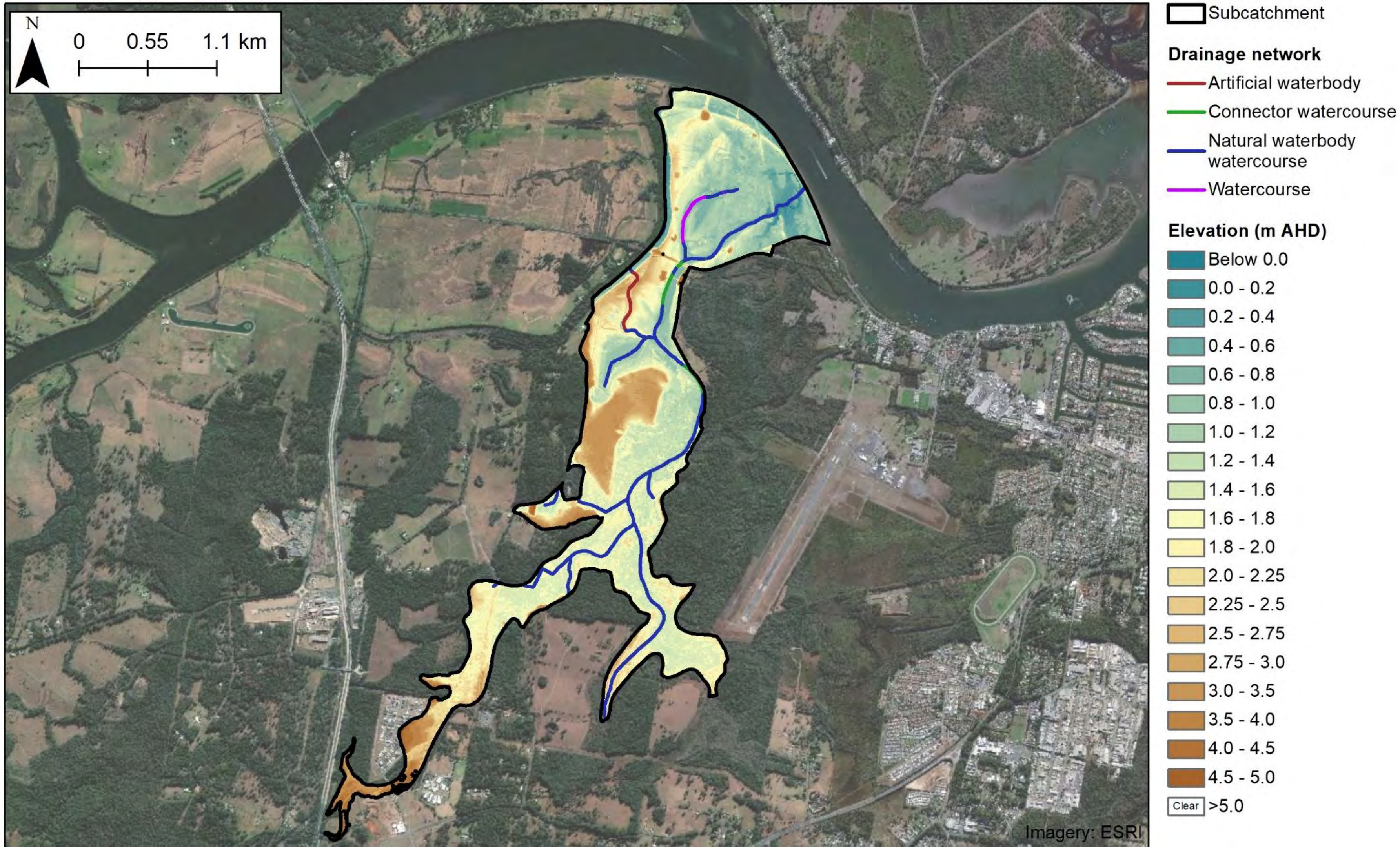

Figure 8-21: Partridge Creek subcatchment elevation and drainage network

8.5.2 History of remediation

The Partridge Creek subcatchment was the focus of substantial remediation efforts by Hastings Council, with funding from the state government ASS Hot Spot Remediation Program (Hastings Council, 2004). The timeline of remediation works includes (Aaso (2003); Hastings Council (2004)):

- 1999 – Hastings Council acquired a significant portion of the low-lying, high-risk ASS area, shown in Figure 8-22. Floodgates were opened after the land was purchased;
- 2002 – two (2) 80 m sections of the upper part of Partridge Creek were reshaped/infilled to reduce the mobilisation of monosulfidic black ooze (MBO); and
- 2003 – a hinged weir (ID ASSS_1, shown in Figure 8-23) and containment wall were installed to maintain water levels at +0.9 m AHD, prevent further oxidisation of ASS, and reduce acid drainage. The hinged weir can be manipulated to provide flood drainage after significant rainfall events.

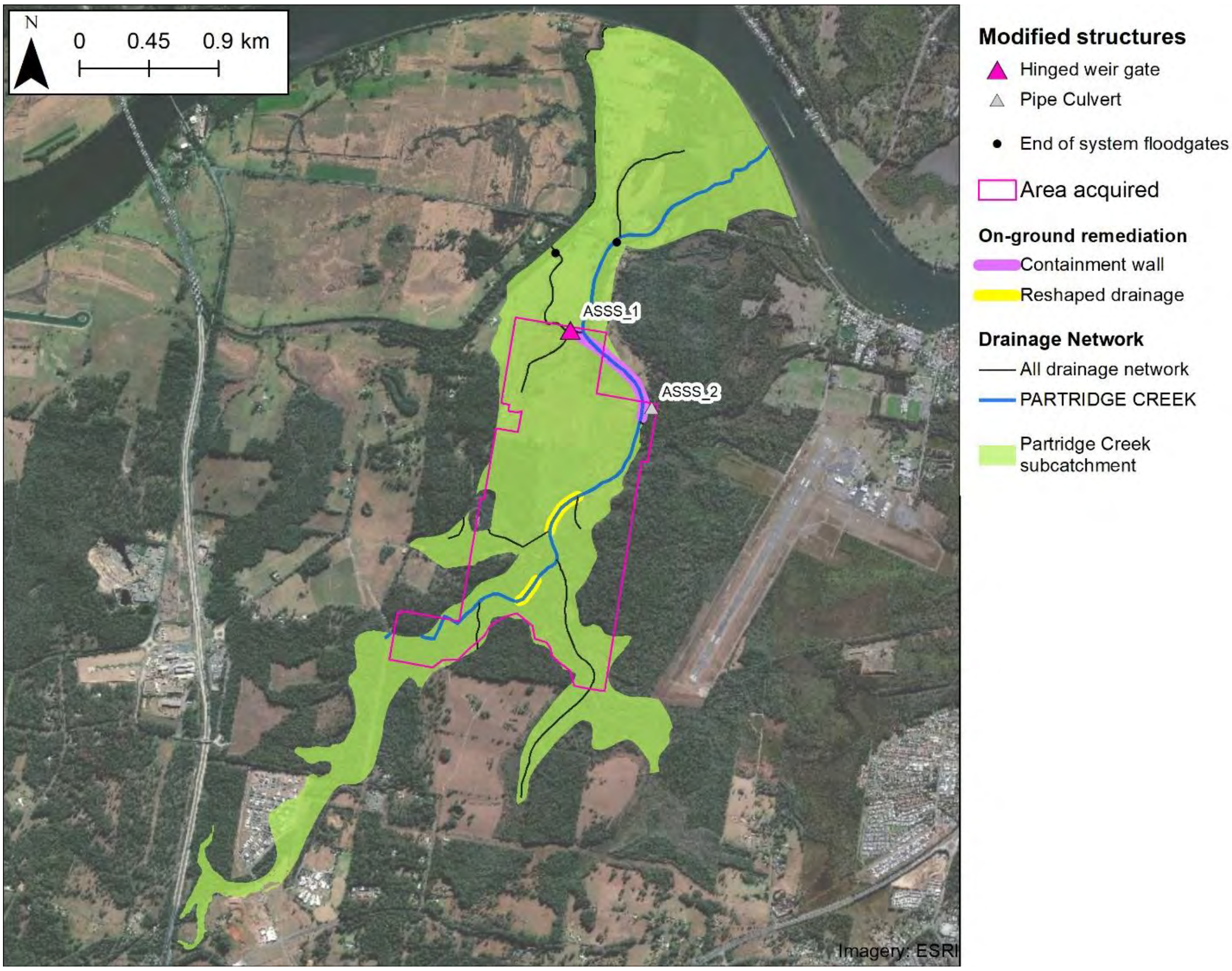

Figure 8-22: Partridge Creek subcatchment including previous remediation actions

Partridge Creek was also part of a lime dosing system trial as part of the Commonwealth Acid Sulfate Soils Program (CASSP) from 2002 onwards (Hastings Council, 2004). In addition, a pipe culvert (ID ASSS_2) was closed as part of remediation works, and is only used to convey flow during periods of high rainfall (Port Macquarie Hastings Council, 2010). The remediation works resulted in the remediation of 420 ha of wetland area, and modelling has suggested that the on-ground works resulted in a reduction in acid flux by 67-79% (Hastings Council, 2004). The project also resulted in fish passage being reinstated to 850 m of waterway.

Figure 8-23: ID ASSS_01 hinged weir (Source: Hastings Council (2004))

8.5.3 Floodplain drainage – sea level rise vulnerability

The vulnerability of the Partridge Creek subcatchment to sea level rise is summarised in Figure 8-24. The Partridge Creek subcatchment has relatively high elevation compared to other parts of the Hastings River floodplain. The areas that are most likely to be impacted by reduced drainage are currently classified as wetland or minimal use. The agricultural uses in this subcatchment tend to be in higher areas (elevation > 2 m AHD) and are not considered significantly vulnerable to sea level rise.

The main Partridge Creek structure is a weir and is not considered in the floodgate vulnerability assessment, however the hinged weir is at an elevation of +0.9 m AHD when closed. This is significantly lower than the far future high tide water level (+1.3 m AHD), which may significantly change the hydrology of the wetland area upstream. Remediation works in Partridge Creek may need to be adapted to accommodate the potential impacts of sea level rise.

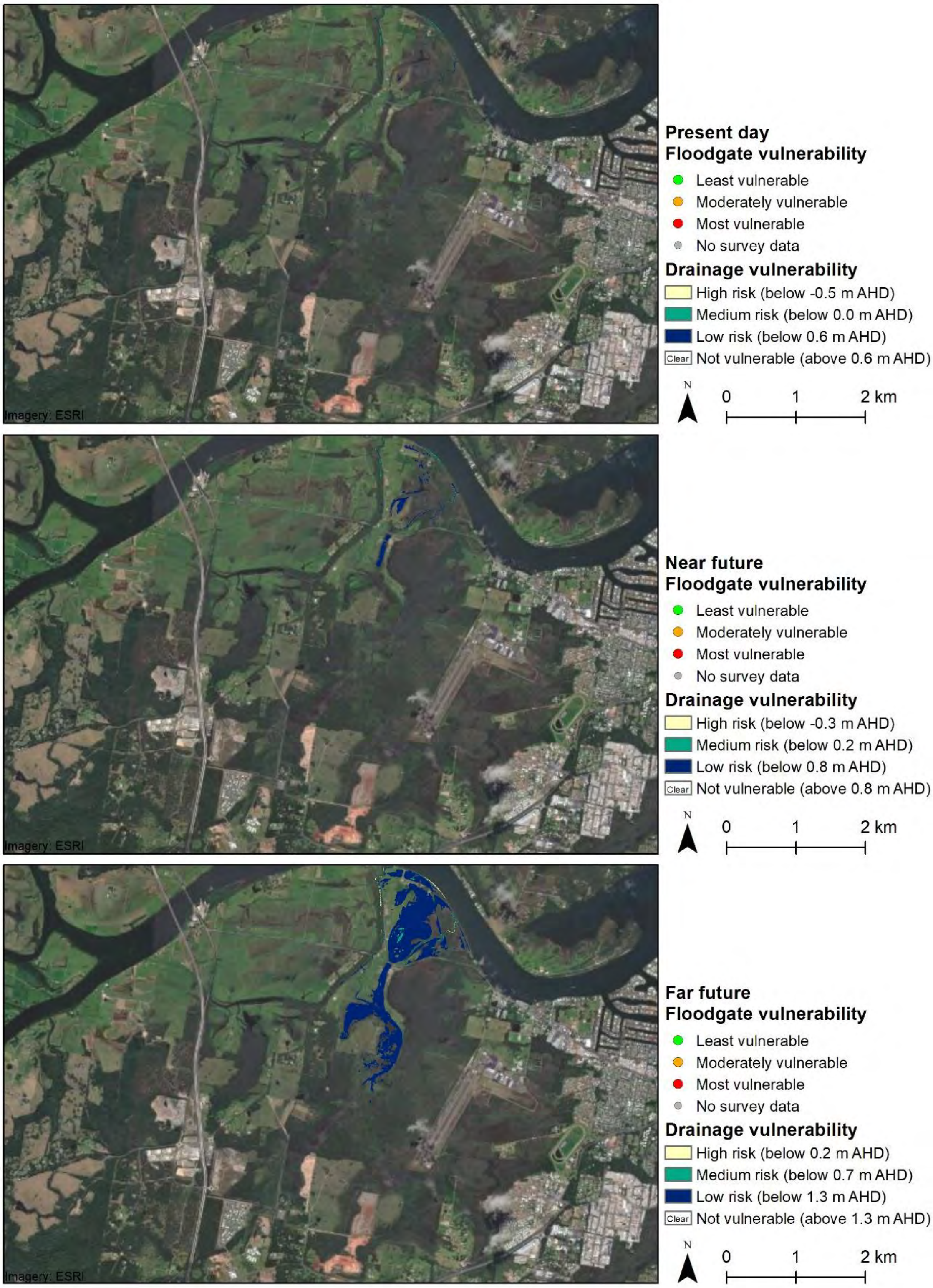

Figure 8-24: Sea level rise drainage vulnerability – Partridge Creek subcatchment

8.5.4 Management options

The ASS prioritisation ranked the Partridge Creek subcatchment third, however it is important to acknowledge that the prioritisation is based on historical data and does not consider the efficacy of previous remediation works. While Partridge Creek still has a high acid generation potential due to the on-going presence of ASS, the on-ground works to date prevent the mobilisation of a significant proportion of this acid. Further potential management options for short and long-term planning horizons for the Partridge Creek subcatchment include:

- Short-term: continue active management of hinged weir, and continued management of remediated area; and
- Long-term: consider the need to raise the weir or containment wall (or change management of the wetland area) in response to sea level rise.

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

Short-term management options
PMHC has undertaken substantial remediation works in the Partridge Creek subcatchment which have been effective at significantly reducing acid drainage. Council assigned an annual budget of $7,000/yr for infrastructure maintenance and management. The active management of the hinged weir and remediated area should be continued and supported to ensure acid drainage is minimised.

Long-term management options
While the Partridge Creek subcatchment has been largely remediated, the impacts of sea level rise on the current management strategy should be considered. As sea level rise continues to occur, the high tide levels downstream of the hinged weirs will increase. This may require the weir and containment wall to be risen and continued management of the backswamp as a freshwater wetland continued. Alternatively, consideration of incorporating tidal inflows into the remediated area could be considered.

Table 8-8: Summary of management options for Partridge Creek subcatchment

Timeframe	Strategy	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing)	Indicative cost (lost productivity)	Effectiveness at improving:		
						Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	On-going management of existing infrastructure	None	None	$7,000**	None	Low**	High**	High**
Long-term	Upgrade of existing infrastructure for sea level rise	None	Depends on work required	$7,000**	None	Low**	High**	High**

*Costs exclude additional investigation/studies, including; REF, EIS, flood studies, and monitoring programs that may be required prior to implementation
** Benefits and costs already applicable based on existing remediation

8.6 Connection Creek subcatchment

Acid priority rank:	**4**
Blackwater priority rank:	**1**
<u>Infrastructure</u>	
Approximate waterway length (km)	62
# Privately owned end of system structures	0
# Publicly owned end of system structures	9
# End of system structures within coastal wetlands	3
# Publicly owned end of system structures within coastal wetlands	3
Primary floodplain infrastructure (ID):	062G1, 063G1, 064G1, 065G1, 066G1, 067G1, 079G1, 094G1
<u>Elevations</u>	
Invert of primary floodplain infrastructure (m AHD)	-1.2 to 0.0
Approximate AASS elevation (m AHD)	N/A
Approximate PASS elevation (m AHD)	0
Median blackwater elevation (m AHD)	1.0
Present day low water level (m AHD)	-0.3
Near future low water level (m AHD)	-0.2
Far future low level (m AHD)	0.2
<u>Proximity to sensitive receivers</u>	
Oyster Leases (km)	207
Saltmarsh (km)	12.3
Seagrass (km)	20.9
Mangroves (km)	4.8
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
<u>Land use</u>	
Total floodplain area (ha)	4,594
Classified as conservation and minimal use (ha (%))	3,048 (66%)
Classified as grazing (ha (%))	995 (22%)
Classified as forestry (ha (%))	48 (1%)
Classified as horticulture (ha (%))	1 (0%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	90 (2%)
Classified as marsh/wetland (ha (%))	360 (8%)
Other (ha (%))	52 (1%)
<u>Land values</u>	
Estimated total primary production value ($/year)	$400,000
Average land value above 1 m AHD ($/ha)	$6,900
Average land value below 1 m AHD ($/ha)	$4,500

8.6.1 Site description

Connection Creek connects the Hasting River floodplain to the Macleay River floodplain near Crescent Head Road. While most of the subcatchment is privately owned (shown in Figure 8-25), the majority of the area is classified as "conservation and minimal use" (66% of the subcatchment) or as a "marsh/wetland" (8 % of the subcatchment). The primary agricultural land use in this subcatchment is grazing, occurring over 22% of the area.

Like the Upper Maria River subcatchment, the Connection Creek subcatchment is within the LGA boundary of Kempsey Shire Council (KSC). All nine (9) of the floodgates in this subcatchment are managed by KSC. This subcatchment is part of the Upper Maria River – Connection Creek ASS priority area identified by Tulau (1999). Thompsons Creek in the south-west of the subcatchment (see Figure 8-27) was a very high priority acid drainage area by Smith (1999), while Connection Creek itself was identified as moderate priority.

While the majority of flows in this subcatchment pass through Connection Creek to the Maria River, it is also connected directly to the ocean during flood events through the Big Hill drainage works (shown in Figure 8-27), on the south-eastern edge of the subcatchment. This was constructed in 1975 to mitigate the impacts of medium – large floods (Tulau, 2011). A fish kill event was observed in this drainage network in July 2016, which was thought to be associated with ASS drainage (NSW DPI, 2020). This hydraulic connection to the ocean has not been directly considered in the blackwater prioritisation method.

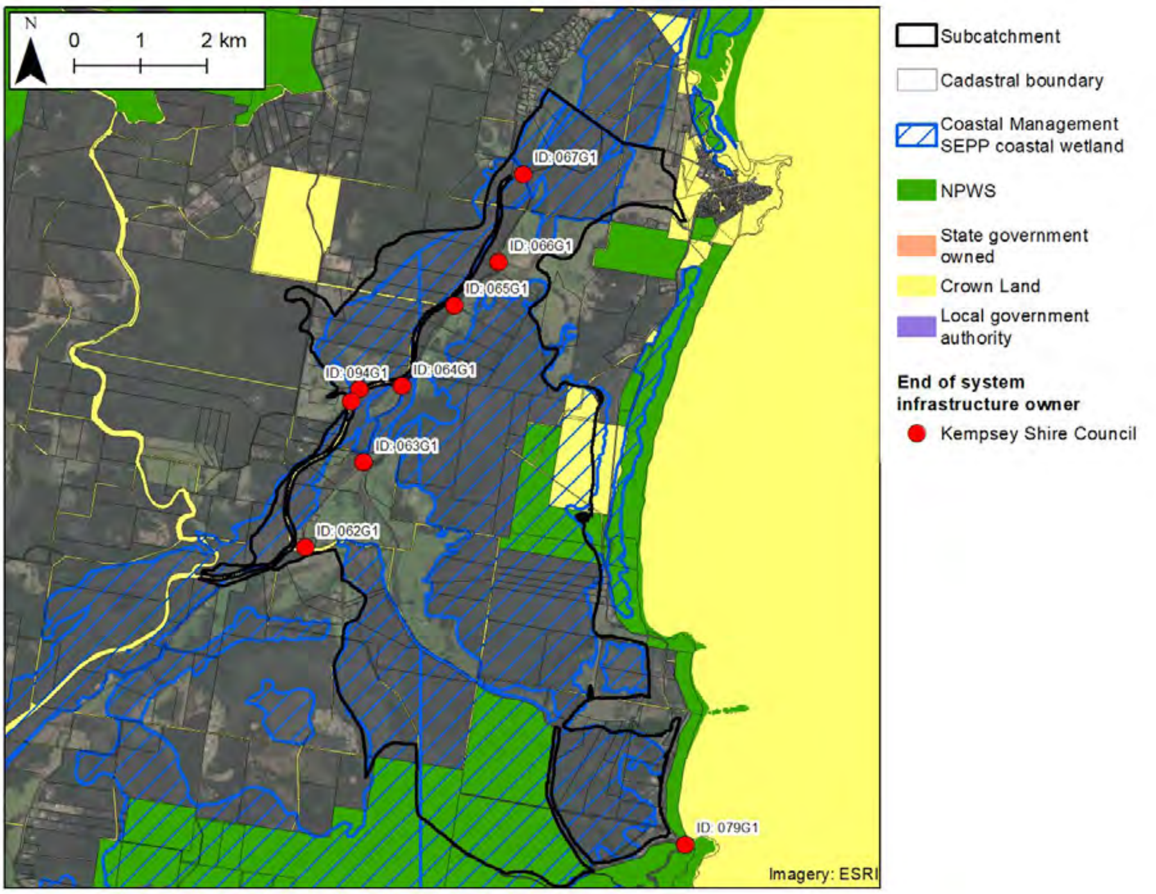

Figure 8-25: Connection Creek subcatchment land and end of system infrastructure tenure

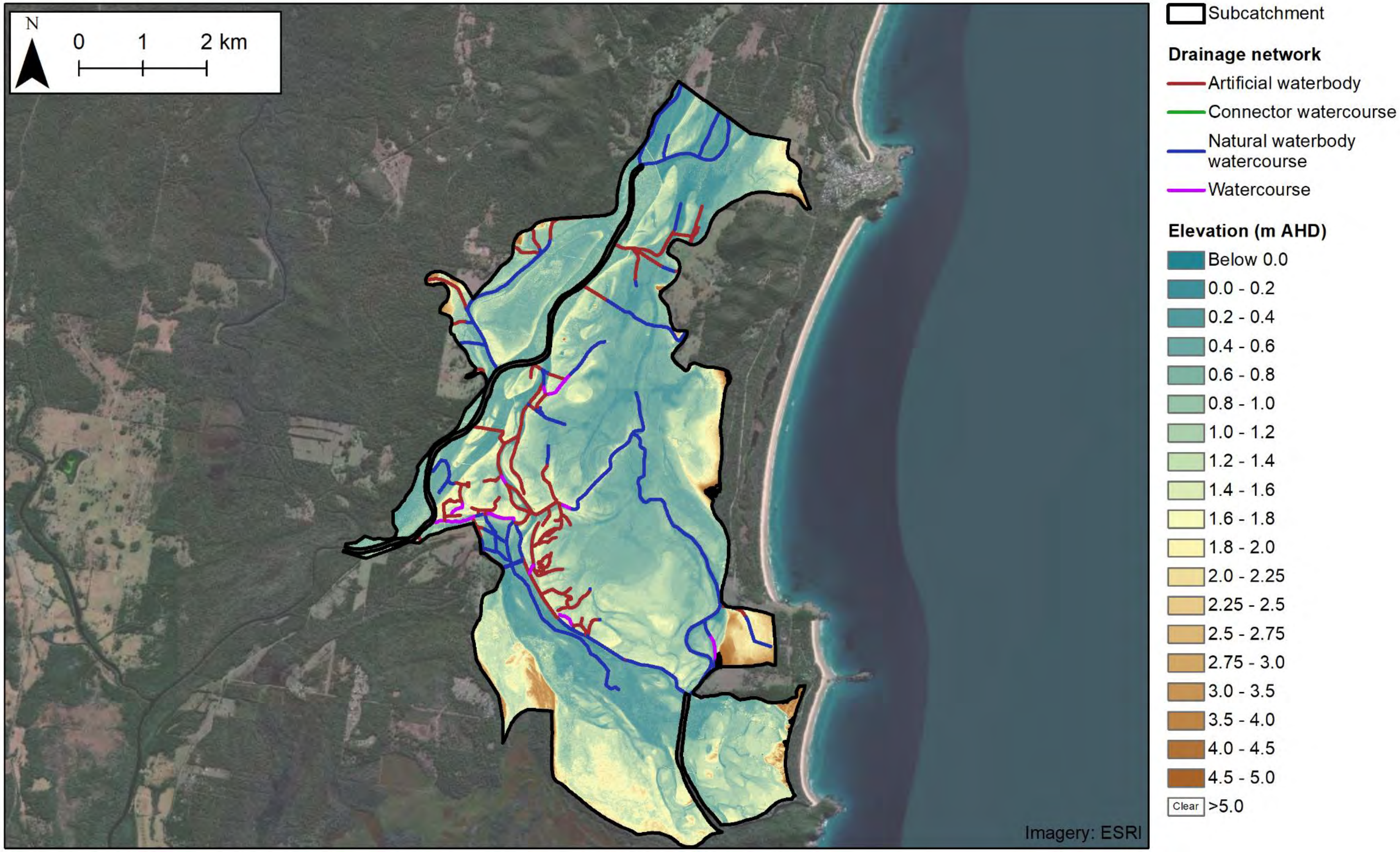

Figure 8-26: Connection Creek subcatchment elevation and drainage network

8.6.2 History of remediation

During field investigations, WRL observed three (3) floodgates in the Connection Creek subcatchment that had been modified to allow controlled tidal flushing, which has benefits for water quality and fish passage (Figure 8-27). This included:

- Two (2) floodgates fitted with auto-tidal buoyancy gates (floodgate ID 066G1 and 067G1) in the Upper Connection Creek area.
- One (1) floodgate fitted with a sluice gate (floodgate ID 063G1, shown in Figure 8-28). The management plan for this floodgate indicates that a dropboard weir was also installed upstream that is managed by the local landholder. The sluice window is generally not open when salinity in Connection Creek is greater than 10 mS/cm (approximately 20% ocean salinity) (Kempsey Shire Council, n.d.), which was observed to occur during dry periods (Manly Hydraulics Laboratory, 1997).

Figure 8-27 also shows a substantial area within the Connection Creek subcatchment is mapped as Coastal Management SEPP coastal wetlands. This classification means that the area is subject to more stringent development controls under state government legislation.

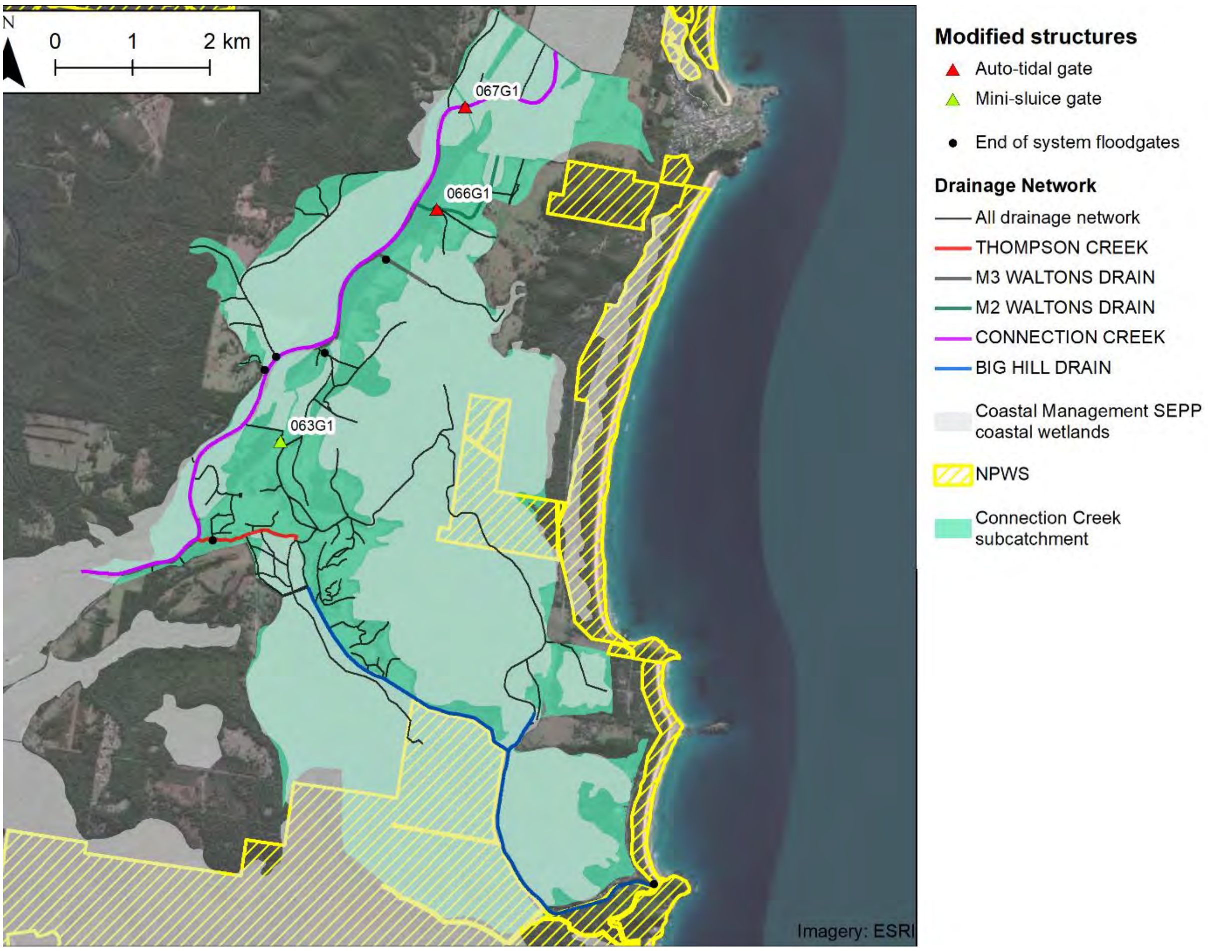

Figure 8-27: Connection Creek subcatchment including previous remediation actions

Figure 8-28: Floodgate ID 063G1 with sluice gate open

8.6.3 Prioritisation of management areas in Connection Creek subcatchment

The Connection Creek subcatchment ranked first for blackwater generation and fourth in regards to acid generation. The subcatchment has been further divided into four (4) management areas referred to as CC1, CC2, CC3 and CC4 (Figure 8-29) to provide additional information on the sources of acid and blackwater. In this subcatchment, the delineation of management areas has considered drainage, elevation and location of mapped Coastal Management SEPP coastal wetlands. The majority of the area used for agriculture is in management areas CC1 and CC2 (although there is also clearing in grazing in some limited areas of CC3 and CC4).

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 Connection Creek subcatchment are shown in Figure 8-29 and summarised in Table 8-9. The majority of the acid risk is assessed to be originating from management areas CC1 and CC3 (based on available data), although there was insufficient data to apply the prioritisation methodology in management area CC4. More soil profile data is recommended in management area CC4 to confirm the presence of ASS. Changes in land management targeting reducing acid drainage should focus initially on management areas CC1 and CC3.

The median elevation for blackwater generation (+1 m AHD) in the Connection Creek subcatchment has been superimposed on the management areas in Figure 8-30. As elevation is a primary driver of the production of blackwater, the areas below this level typically contribute the most to the risk of large scale deoxygenation (although this can be managed through changing vegetation, land uses and hydrology). Every management area, except management area CC1 which has a slightly higher elevation, has a substantial area contributing to blackwater generation.

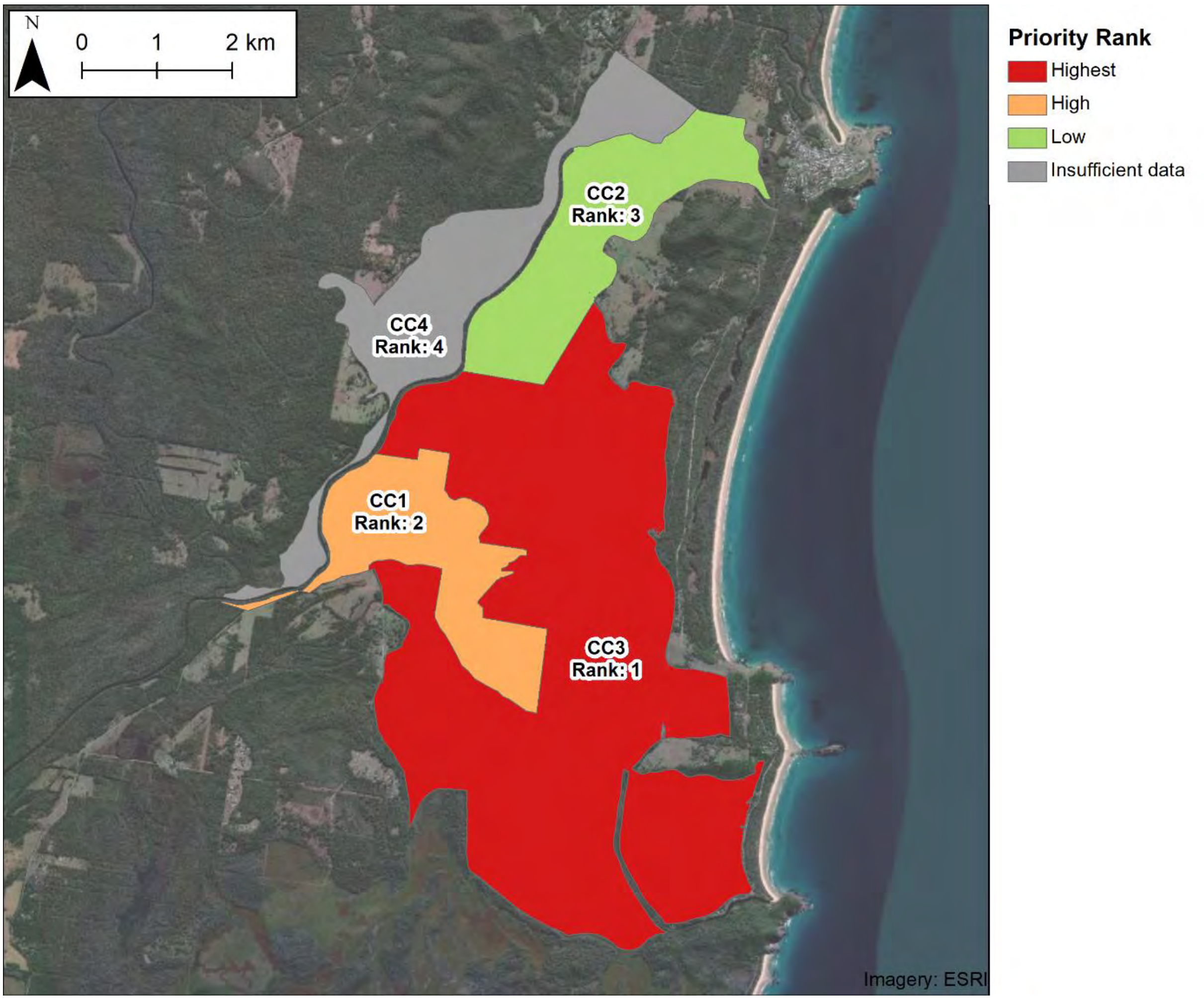

Figure 8-29: Connection Creek subcatchment management areas acid prioritisation

Table 8-9: Management area acid prioritisation of Connection Creek subcatchment

Management Area	Groundwater Factor	Surface Water Factor	Final Acid Factor	Final Rank
CC3	40	409	16,359	1
CC1	7	1,781	13,196	2
CC2	43	155	6,638	3
CC4	Insufficient data	408	Insufficient data	Insufficient data

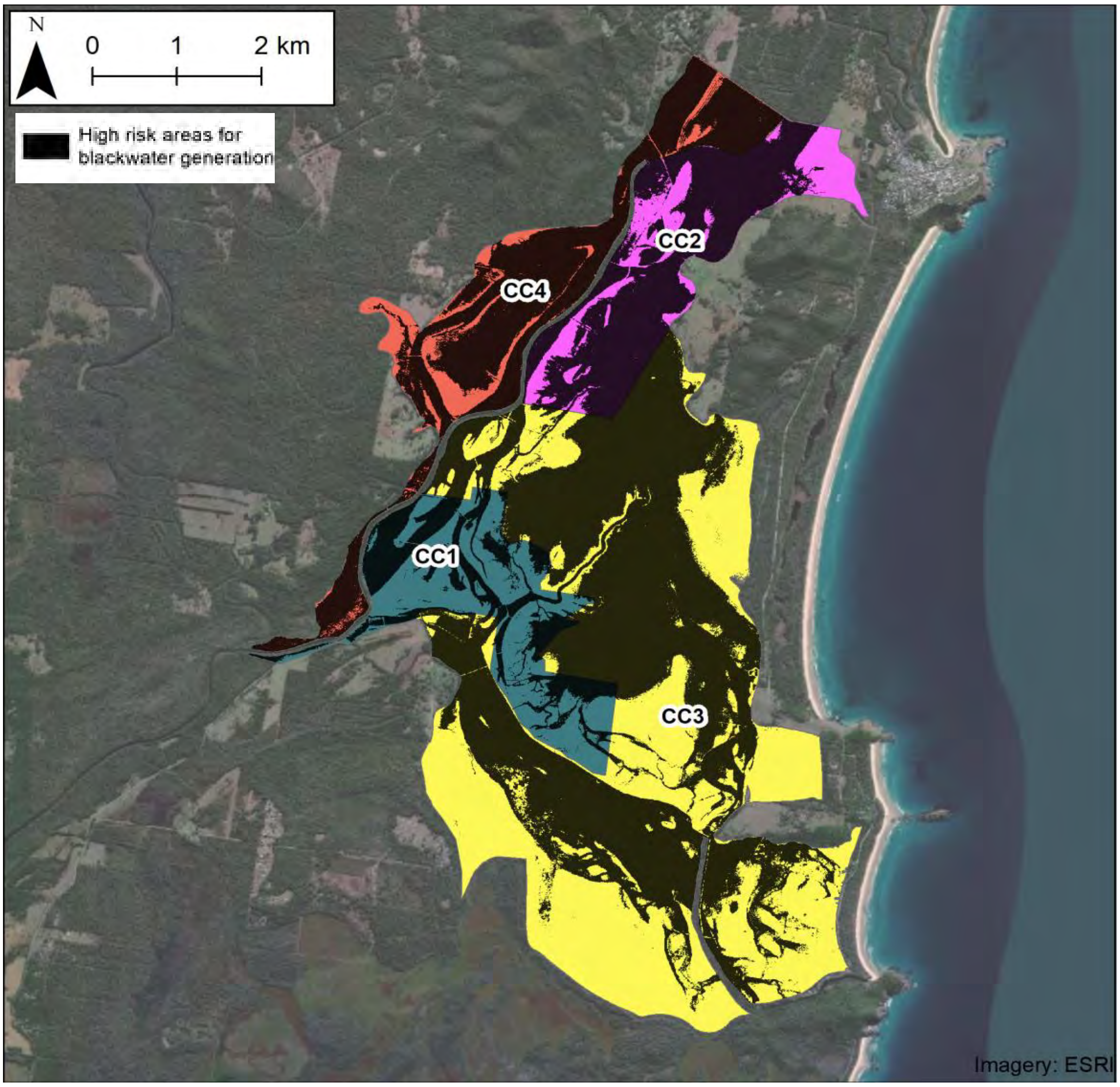

Figure 8-30: Blackwater contribution in management areas in Connection Creek subcatchment (median blackwater level +1 m AHD)

8.6.4 Floodplain drainage – sea level rise vulnerability

Figure 8-31 summarises the sea level rise vulnerability of the Connection Creek floodplain and floodplain infrastructure. The Connection Creek subcatchment has a significant area classified as low risk for reduced drainage, although the majority of this area is not actively used for agriculture and is mapped as Coastal Management SEPP coastal wetlands. Under the far future sea level rise scenario, over 1,700 ha (or more than 40% of the subcatchment area) will be classified as medium risk, and almost 80% of the subcatchment will be low or medium risk. Reduced drainage may impact agricultural productivity in this subcatchment in the near-to-far future.

Figure 8-32 summarises the elevation of primary floodgates compared to key floodplain elevations. Under present day conditions, four (4) of the nine (9) floodgates with survey information are classified as "Moderately vulnerable". This increases to six (6) floodgates in the near future sea level rise scenario. Under the far future sea level rise scenario, six (6) of the floodgates are classified as "Most vulnerable", meaning that downstream water levels have the potential to restrict drainage more than 50% of the time.

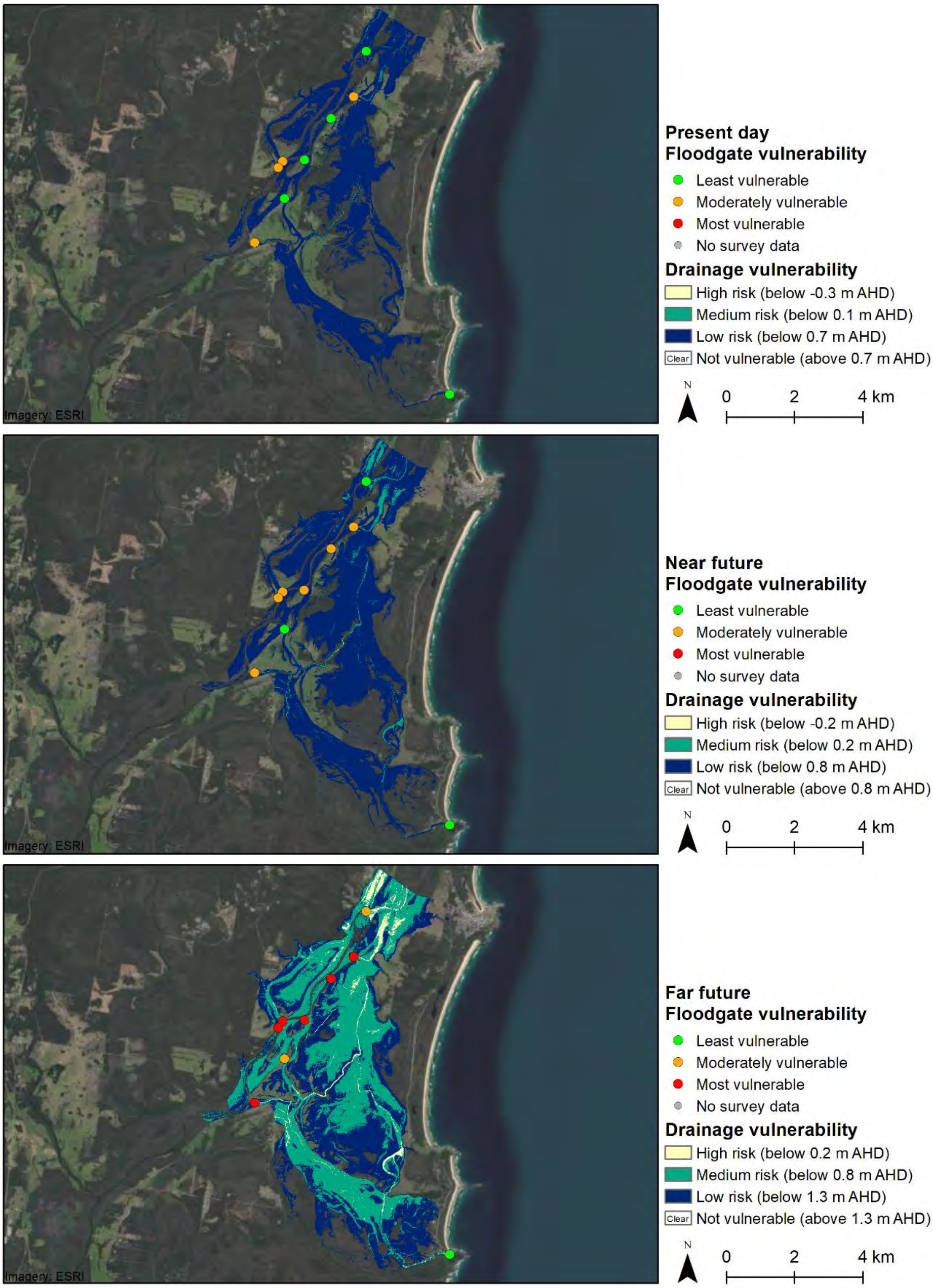

Figure 8-31: Sea level rise drainage vulnerability – Connection Creek subcatchment

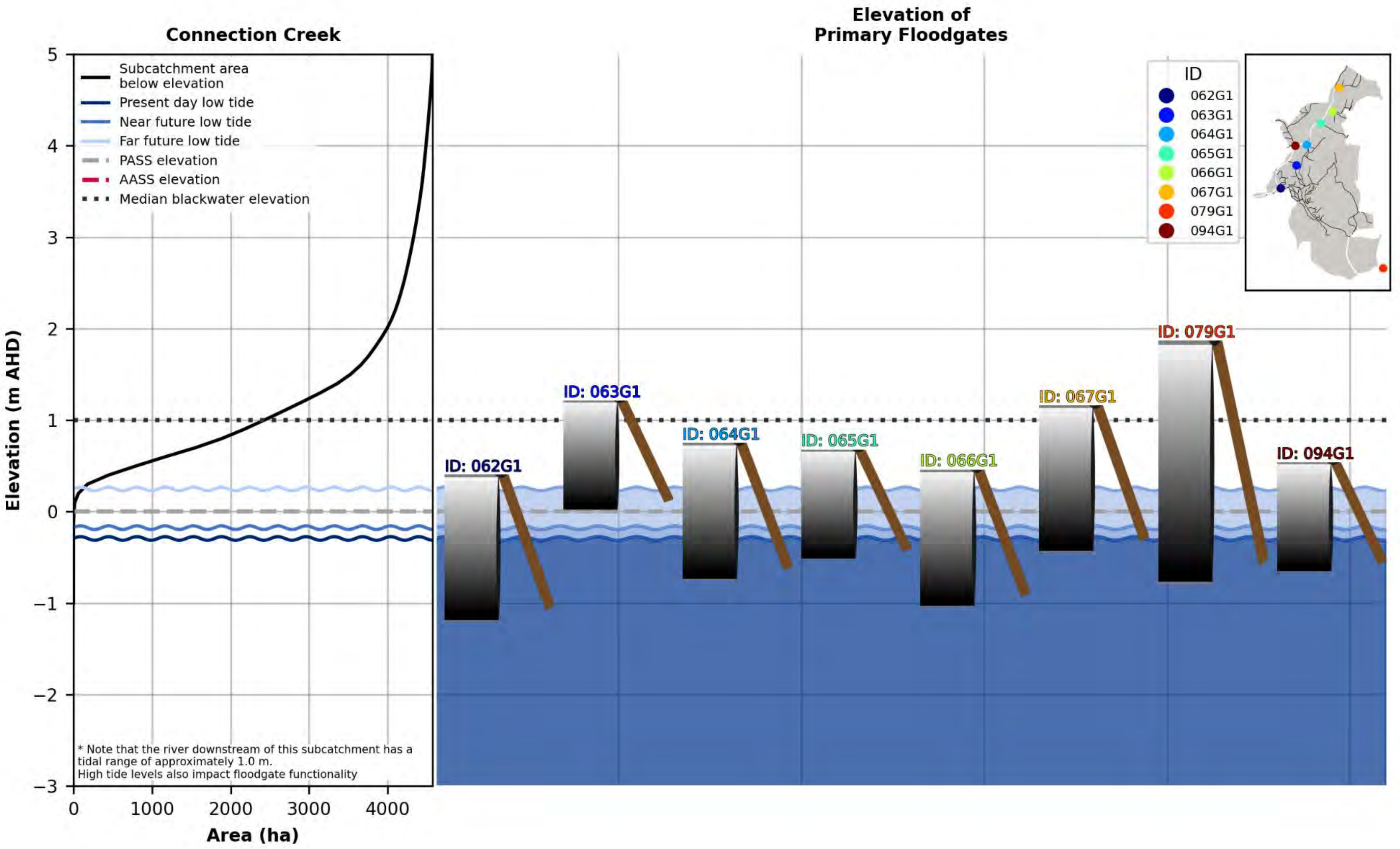

Figure 8-32: Key floodplain elevations – Connection Creek subcatchment

8.6.5 Management options

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

- Short-term: Ensure constructed drainage does not impact water table in areas mapped as Coastal Management SEPP coastal wetlands, consider using dropboard weirs to encourage ponding on coastal wetland areas; and
- Long-term: Transition towards freshwater wetlands where current land uses are impacted by sea level rise and reduced drainage, or consider reshaping artificial drains in management areas CC1 and CC2,.

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

Short management options

A significant portion of this subcatchment is mapped as Coastal Management SEPP coastal wetlands, meaning it is an area of environmental significance. While the majority of this subcatchment is not actively used for agriculture, it is important to investigate whether artificial drainage in surrounding areas (particularly management area CC1 and CC2) is lowering the water table in the Coastal Management SEPP coastal wetland areas. Dropboard weirs may be able to be used to retain water on low areas after significant rainfall to reduce acid and blackwater drainage.

An example of a location where a dropboard weir may be able to be used is west of Nevertire Road at a causeway (location shown in Figure 8-33). After rainfall, the dropboard weir could be used to maintain higher water levels in the Coastal Management SEPP coastal wetlands to the south-west and reduce acid drainage.

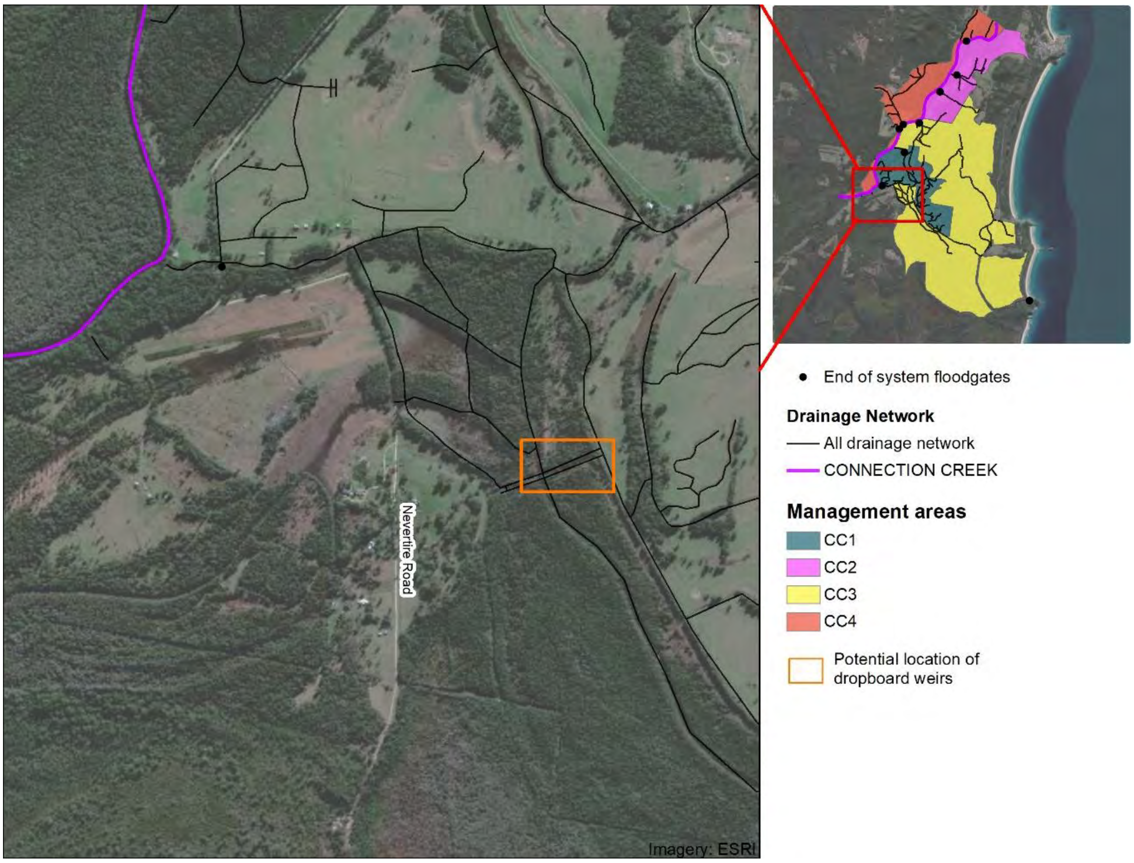

Figure 8-33: Example location where a dropboard weir could be considered

Long-term management options

In areas where grazing is expected to continue in the long term, it is recommended that the artificial drainage network be investigated and drain reshaping should be considered where possible to reduce groundwater drawdown and acid drainage. This is most likely to be applicable in major drains in management areas CC1 and CC2.

However, as discussed in Section 8.6.4, the low areas (particularly below +0.8 m AHD) may be impacted by reduced drainage in the near to far future as sea level rise occurs. Where grazing is no longer viable, remediation to freshwater or brackish wetlands and extension of existing coastal wetland areas should be considered. This would likely include:

- Restoration of natural flow paths with infilling of artificial drainage networks to encourage prolonged inundation and ponding of freshwater;
- Potential reshaping of the remainder of the drainage system to reduce interaction with acidic layers;
- Removal of floodgates; and
- Revegetation of cleared areas.

Restoration of natural flow paths and prolonging inundation on low-lying subcatchment areas will significantly reduce pathways for acid drainage, as well as reducing the blackwater generation potential by encouraging water tolerant vegetation and reducing the overall drainage potential.

Table 8-10: Summary of management options for Connection Creek subcatchment

Timeframe	Strategy	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing)	Indicative cost (lost productivity)	Effectiveness at improving:		
						Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Dropboard weirs to encourage ponding on minimal use areas	None	$65,000	$5,000	None	None	Moderate	Moderate
Long-term	Remediate freshwater wetlands	$3,900,000	$650,000	Minimal	$360,000	High	High	High

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

8.7 Pembrooke subcatchment

Acid priority rank:	**5**
Blackwater priority rank:	**5**
Infrastructure	
Approximate waterway length (km)	21
# Privately owned end of system structures	6
# Publicly owned end of system structures	0
# End of system structures within coastal wetlands	2
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (ID):	ASSS_61
Elevations	
Invert of primary floodplain infrastructure (m AHD)	0.6
Approximate AASS elevation (m AHD)	0.4
Approximate PASS elevation (m AHD)	-1.0
Median blackwater elevation (m AHD)	0.6
Present day low water level (m AHD)	-0.4
Near future low water level (m AHD)	-0.3
Far future low level (m AHD)	0.2
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)	921
Classified as conservation and minimal use (ha (%))	206 (22%)
Classified as grazing (ha (%))	531 (58%)
Classified as forestry (ha (%))	24 (3%)
Classified as horticulture (ha (%))	0 (0%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	13 (1%)
Classified as marsh/wetland (ha (%))	55 (6%)
Other (ha (%))	91 (10%)
Land values	
Estimated total primary production value ($/year)	$200,000
Average land value above 0.6 m AHD ($/ha)	$7,500
Average land value below 0.6 m AHD ($/ha)	No property data available

8.7.1 Site description

The Pembrooke subcatchment is in the middle Hastings River floodplain, north of Rawdon and Little Rawdon Islands, shown in Figure 8-34. It includes the low areas (< 5 m AHD) around Rawdon Creek to the east and Balyngara Creek and Stony Creek to the west. The primary land use in this subcatchment is grazing, accounting for 58% of the total area.

Artificial drainage networks, shown in Figure 8-35, provide drainage to low areas to facilitate agricultural land uses in the Pembrooke subcatchment. While there are at least five (5) floodgates in this subcatchment, none are located on major waterways and typically provide drainage to small, paddock scale drainage systems.

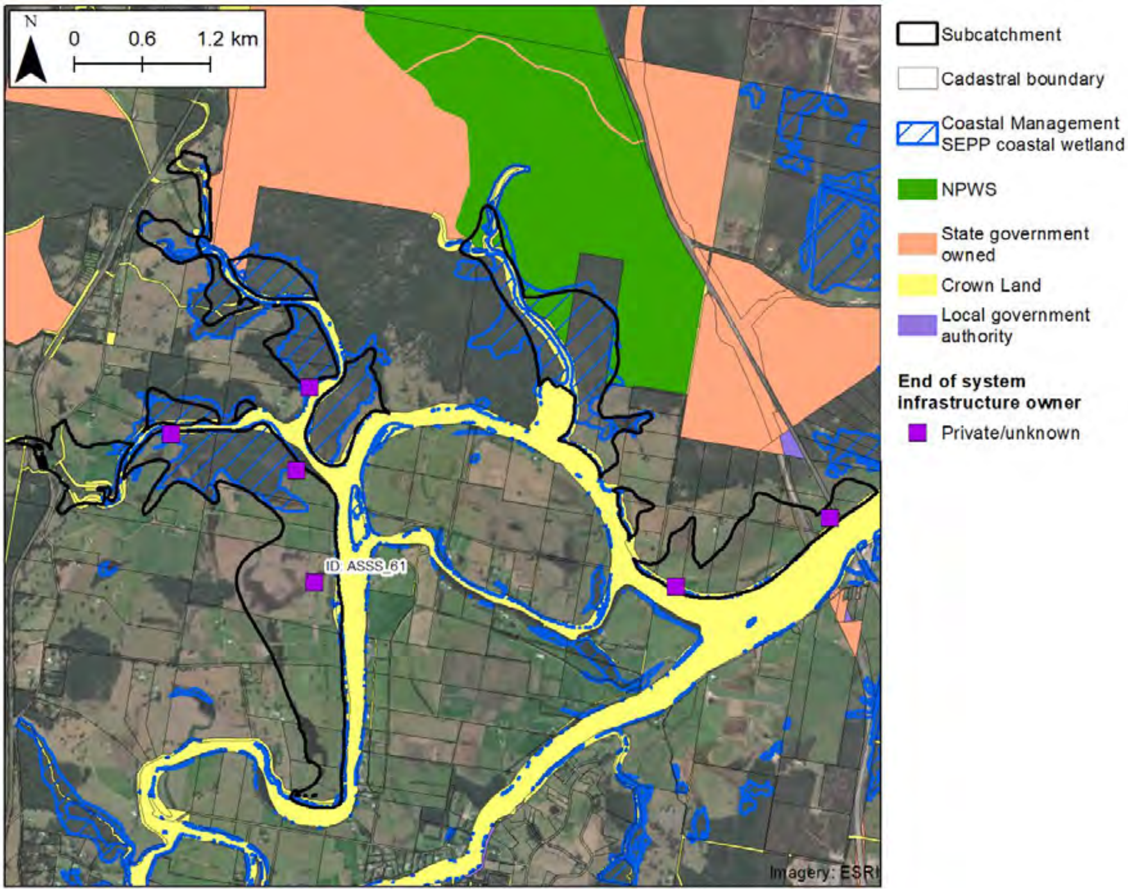

Figure 8-34: Pembrooke subcatchment land and end of system infrastructure tenure

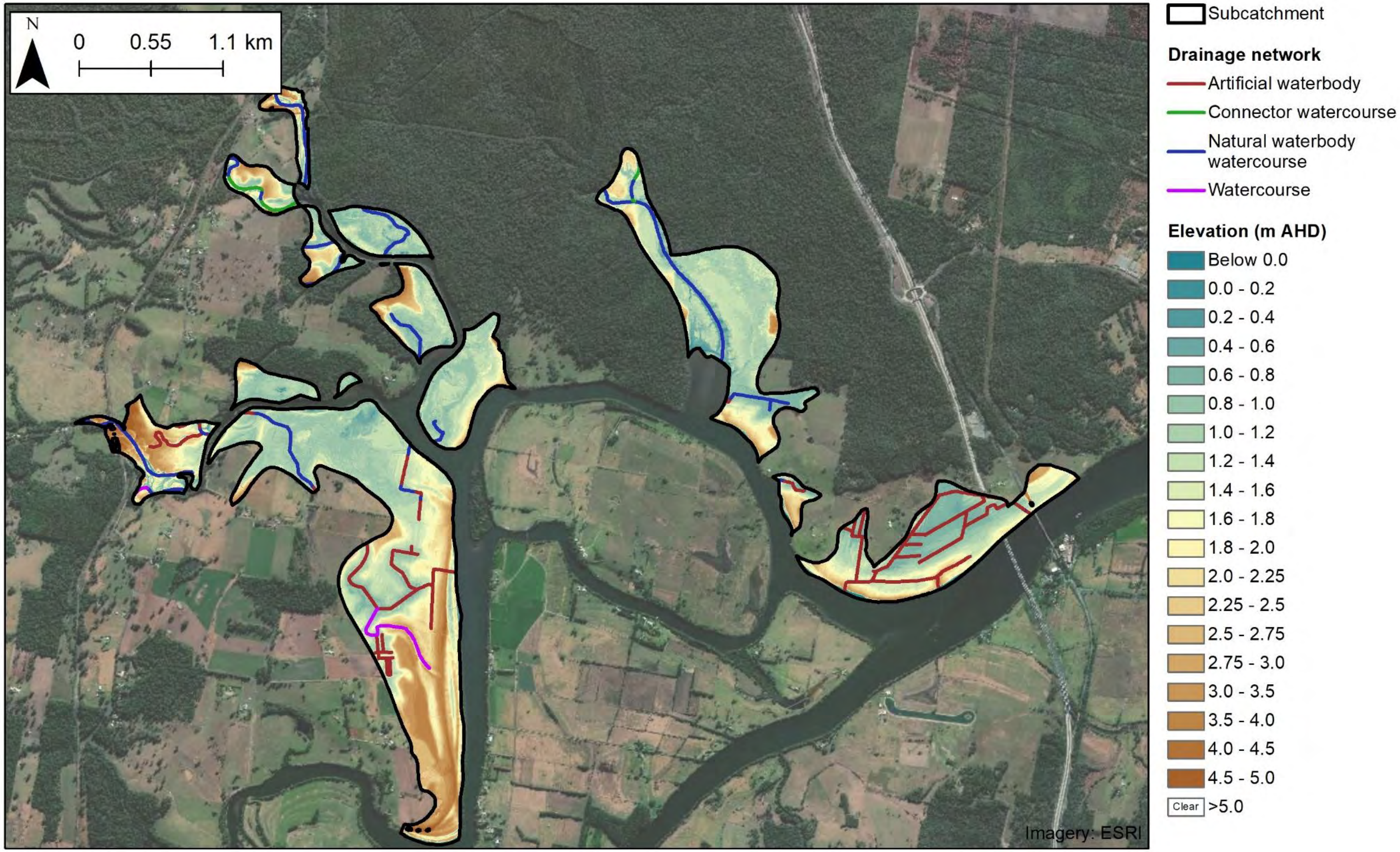

Figure 8-35: Pembrooke subcatchment elevation detail and drainage network

8.7.2 History of remediation

Based records from PMHC (Port Macquarie Hastings Council, 2010), at least five (5) structures in the Pembrooke subcatchment have been modified by Council to address the impacts of ASS drainage, shown in Figure 8-36. Modifications often involved the construction of an additional water retention structure (e.g. weirs) upstream of the original floodgate. It is unclear whether original downstream floodgates were decommissioned or are still operational. This includes:

- One (1) floodgate that has been modified with an auto-tidal buoyancy gates (floodgate ID ASSS_53);
- One (1) structure that is a weir with auto-tidal buoyancy gates on top (ID ASSS_61, shown in Figure 8-37). Based on WRL surveys, this structure retains water on low-lying backswamp areas upstream to a level of approximately +0.6 m AHD; and
- Three (3) pipe culverts that have had dropboard weirs installed to allow removable water retention. These structures are often used to promote wet pasture management on grazing land, while allowing the weirs to be removed for flood mitigation purposes. PMHC records indicate these structures can retain water up to a level of +0.5 m AHD (Port Macquarie Hastings Council, 2010).

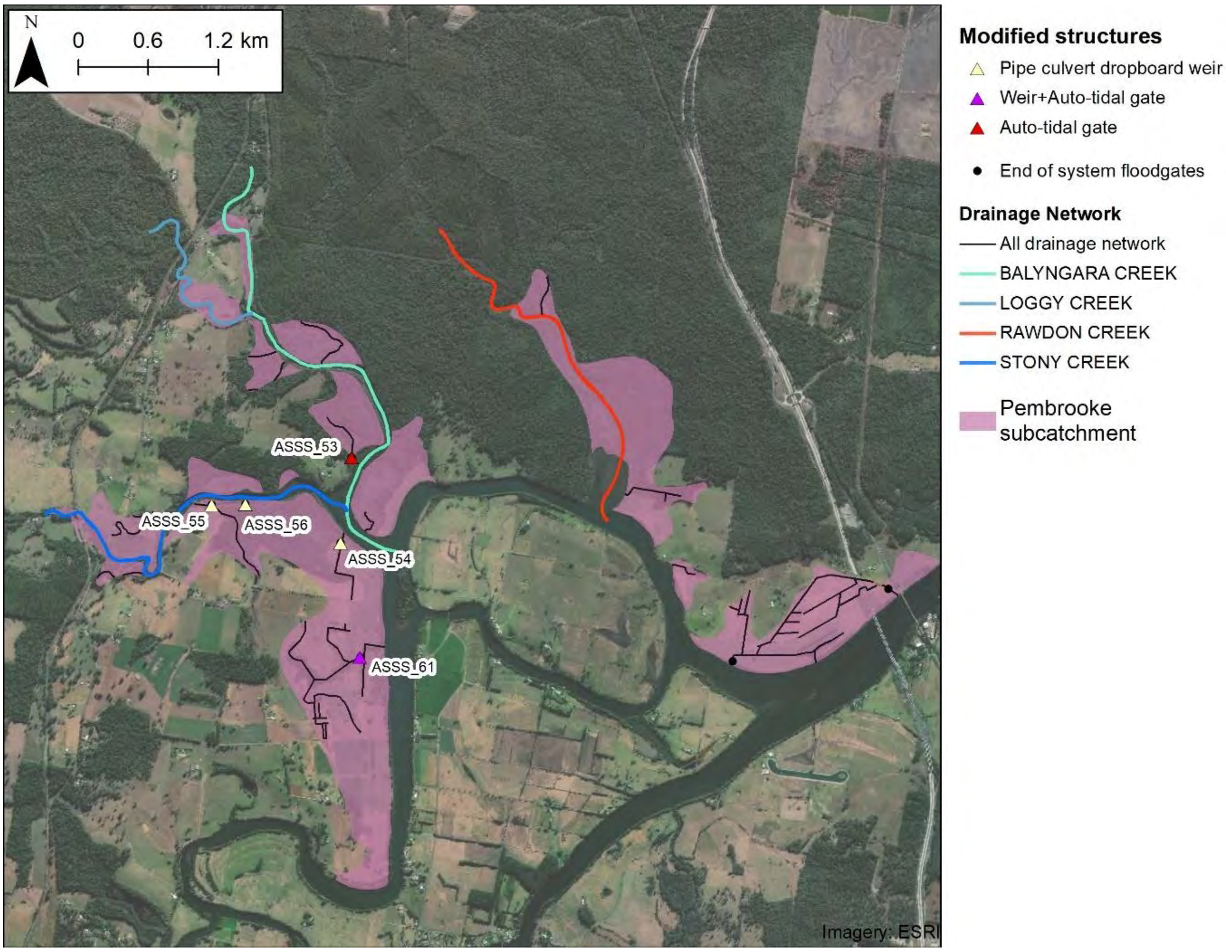

Figure 8-36: Pembrooke subcatchment including previous remediation actions

Figure 8-37: ID ASSS_61 - weir with auto-tidal gates

8.7.3 Floodplain drainage – sea level rise vulnerability

The sea level rise vulnerability of the Pembrooke subcatchment is summarised in Figure 8-38. Under present day conditions and the near future sea level rise scenario, the majority of the subcatchment is above the 95th percentile water levels in the Hastings River, except for a limited area upstream of floodgate ID UNK03. However, under the far future sea level rise scenario more than 50% of the subcatchment is classified as low risk for reduced drainage, including areas used for grazing along Stony Creek and upstream of floodgate ID UNK03 and ASSS_61. Reduced drainage in these areas may impact productivity of present day land uses.

Of the six (6) floodgates with survey information, one (1) is classified as “most vulnerable” under present day conditions, while the other five (5) structures are classified as “least vulnerable”. Under the far future sea level rise scenario, all six (6) of the floodgates are classified as either moderately or most vulnerable. While floodgate ID ASSS_61, shown in Figure 8-37, is only classified as “Moderately vulnerable” under the far future scenario, this assessment was designed for standard floodgate structures that do not act as a weir. This structure would be overtopped by the 95th percentile water levels under the far future scenario, which may have implications for the land upstream.

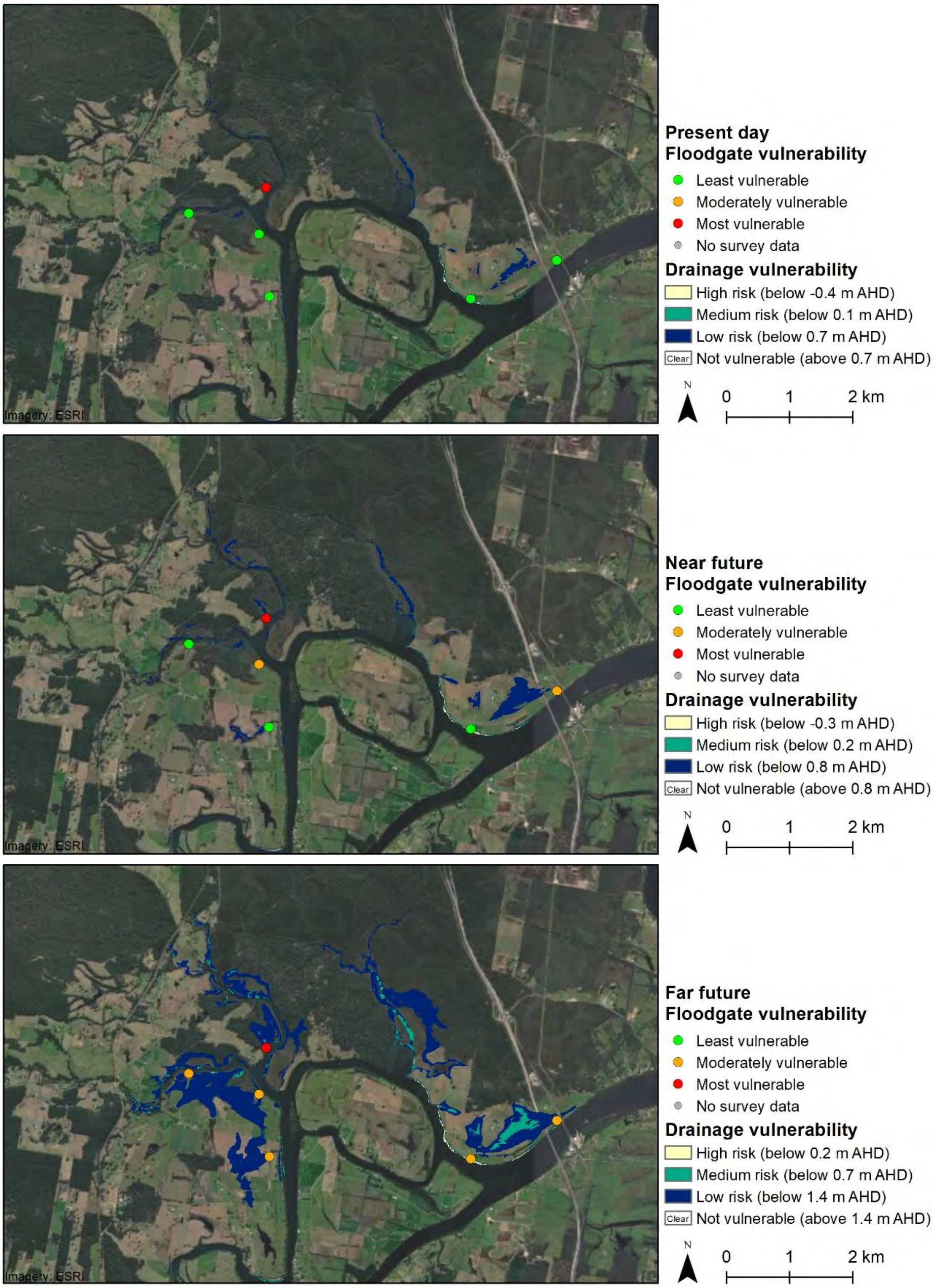

Figure 8-38: Sea level rise drainage vulnerability – Pembrooke subcatchment

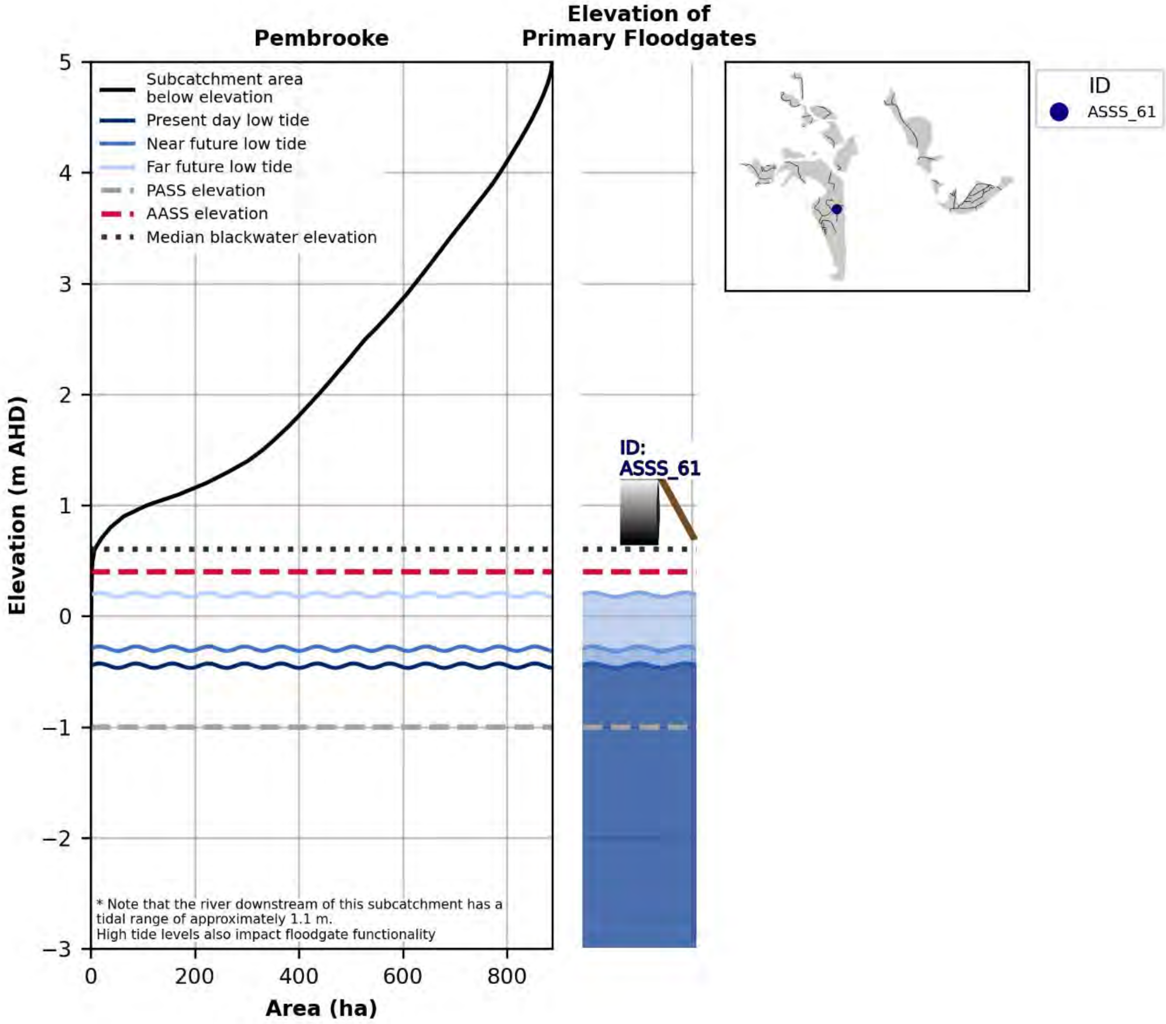

Figure 8-39: Key floodplain elevations – Pembrooke subcatchment

8.7.4 Management options

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

- Short-term: Wet pasture management in the grazing area between the Pacific Highway and Rawdon Creek; and
- Long-term: localised remediation of freshwater or brackish wetlands in low lying areas.

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

Short-term management options

PMHC has actively remediate five (5) structures in the western half of the Pembrooke subcatchment. Further management in this area is unlikely to be effective without impacting present day land uses/productivity. The management of the existing dropboard weirs should be reviewed and optimised.

In addition, dropboard weirs in the drainage network of the grazing area between the Pacific Highway and Rawdon Creek in the east of the subcatchment (upstream of floodgate ID UNK03 and UNK16) should be considered alongside wet pasture management and will reduce unnecessary groundwater drawdown and further acidification of the soils.

Long-term management options

Reduced drainage may impact grazing in the lowest areas of this subcatchment. Where this occurs, remediation and transition to wetland environments should be considered. It is recommended that the drain upstream of floodgate ID ASSS_61 be significantly reshaped or infilled and water retention be encouraged in the small backswamp area. This will create a freshwater (or brackish, depending on the downstream tide levels) wetland, and wet pasture management may be feasible along the fringes. Any changes in land use would need to consider the impacts to the social, cultural and economic well-being of local landholders.

Similarly, the grazing area on the eastern side of the subcatchment (upstream of floodgate ID UNK03 and UNK16) may also be impacted by reduced drainage. If present day land uses cannot persist in this area, the artificial drainage network should be infilled and water should be allowed to pond in low lying areas to reduce potential for ASS oxidisation, reduce the risk of blackwater generation, and establish wetland habitats.

Table 8-11: Summary of management options for Pembrooke subcatchment

Timeframe	Strategy	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing)	Indicative cost (lost productivity)	Effectiveness at improving:		
						Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Dropboard weirs to encourage ponding on minimal use areas	None	$65,000	$5,000	None	None	Moderate	Moderate
Long-term	Remediate localised freshwater/brackish wetlands	$600,000	$210,000	Minimal	$35,000	Moderate	Moderate	Moderate

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

8.8 Lower Maria River East subcatchment

Acid priority rank:	**6**
Blackwater priority rank:	**4**
Infrastructure	
Approximate waterway length (km)	47
# Privately owned end of system structures	11
# Publicly owned end of system structures	0
# End of system structures within coastal wetlands	5
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (ID):	ASSS_37, ASSS_48, ASSS_50
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-0.1 to 0.2
Approximate AASS elevation (m AHD)	0.1
Approximate PASS elevation (m AHD)	-0.9
Median blackwater elevation (m AHD)	0.7
Present day low water level (m AHD)	-0.3
Near future low water level (m AHD)	-0.2
Far future low level (m AHD)	0.3
Proximity to sensitive receivers	
Oyster Leases (km)	Within subcatchment
Saltmarsh (km)	Within subcatchment
Seagrass (km)	Within subcatchment
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	2,726
Classified as conservation and minimal use (ha (%))	819 (30%)
Classified as grazing (ha (%))	845 (31%)
Classified as forestry (ha (%))	405 (15%)
Classified as horticulture (ha (%))	3 (0.1%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	36 (1%)
Classified as marsh/wetland (ha (%))	543 (20%)
Other (ha (%))	75 (3%)
Land values	
Estimated total primary production value ($/year)	$400,000
Average land value above 0.7 m AHD ($/ha)	$5,800
Average land value below 0.7 m AHD ($/ha)	No property data available

8.8.1 Site description

The Lower Maria River East subcatchment is on the left bank of the Maria River and the eastern edge of the subcatchment is in the Limeburners Creek National Park, shown in Figure 8-40. The majority of the subcatchment is below +1.5 m AHD, shown in Figure 8-41.

A network of artificial drainage was constructed in the subcatchment throughout the 20th century (Tulau, 1999). Grazing and tea tree plantations are the predominant agricultural land use. The northern half of this subcatchment was identified as part of the Lower Maria River ASS Priority area by Tulau (1999).

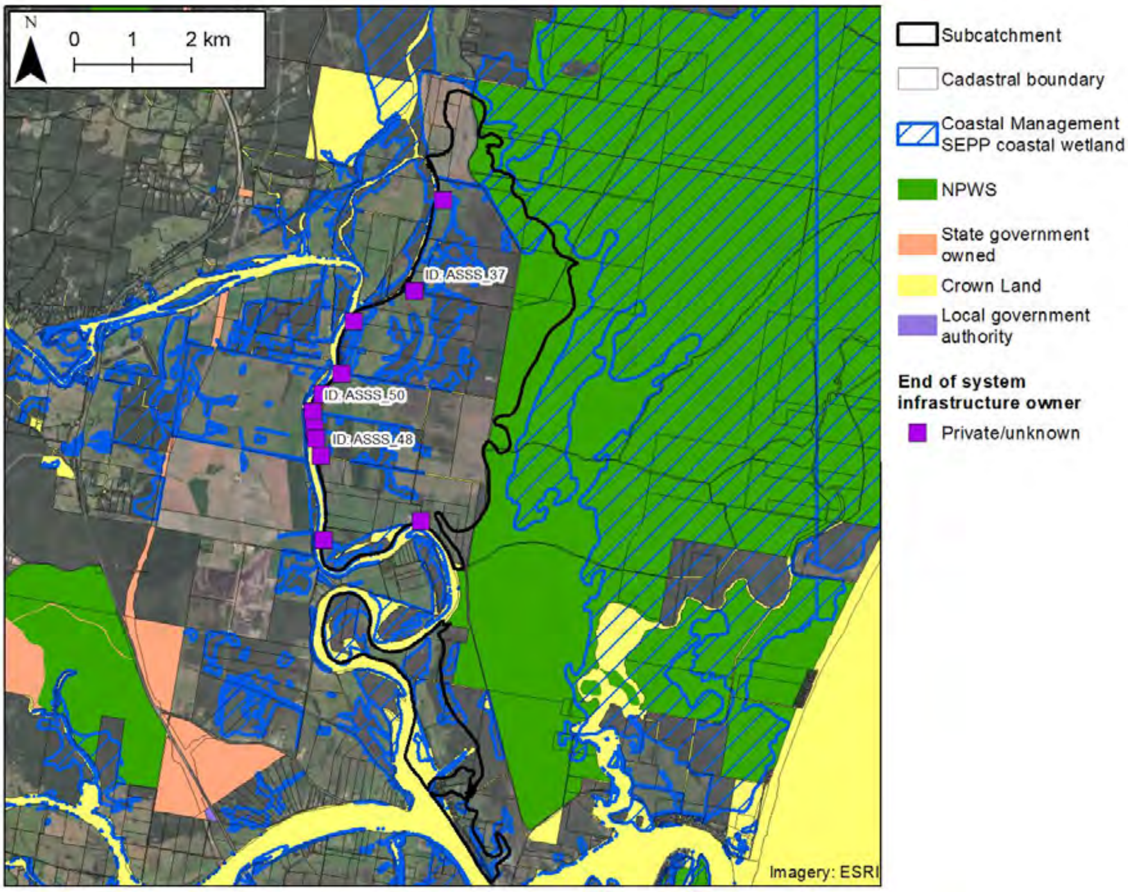

Figure 8-40: Lower Maria River East subcatchment land and end of system infrastructure tenure

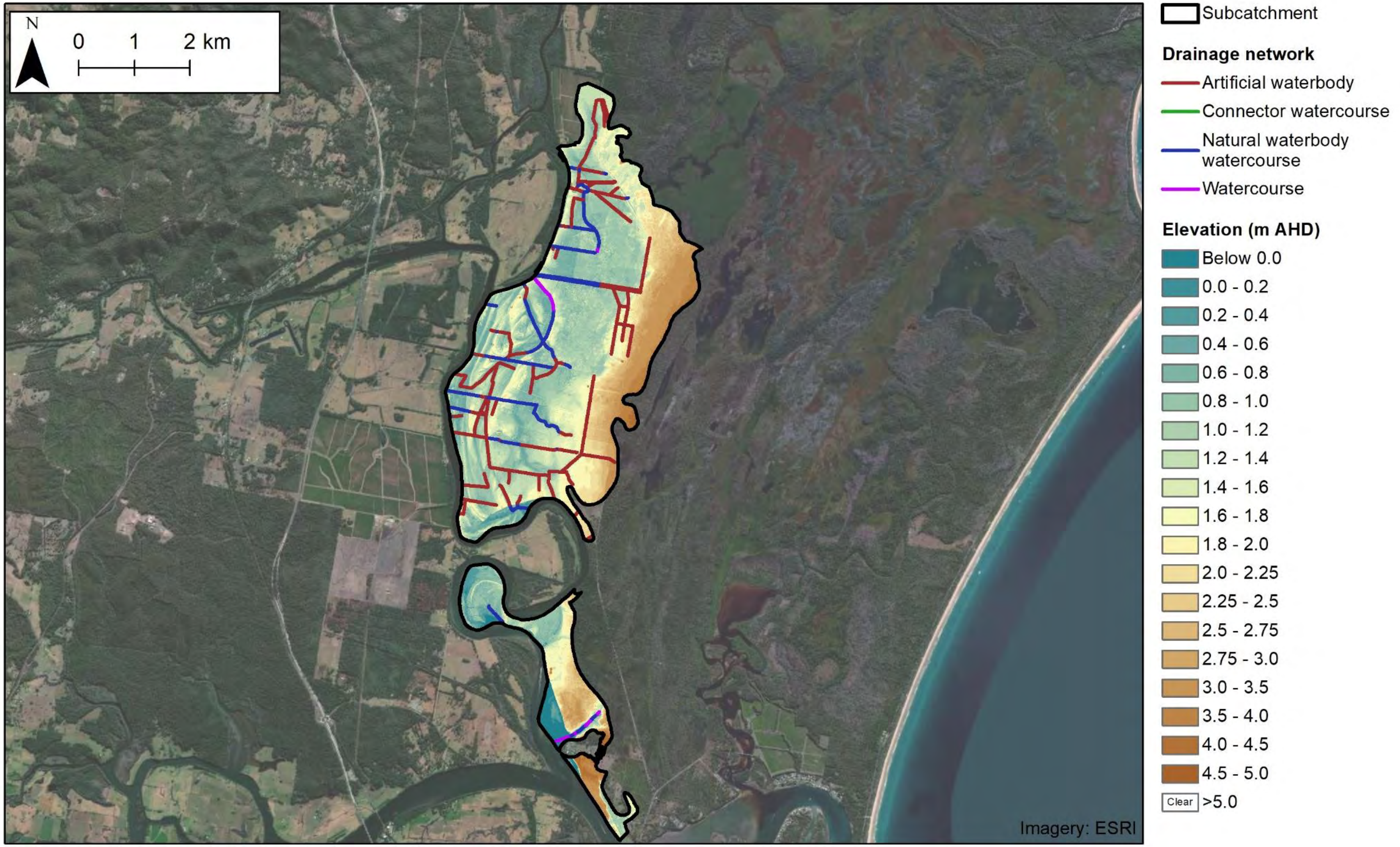

Figure 8-41: Lower Maria River East subcatchment elevation and drainage network

8.8.2 History of remediation

All 15 of the main end-of-system structures in the Lower Maria River East subcatchment have been modified to reduce acid drainage from ASS, shown in Figure 8-42. Modifications often involved the construction of an additional water retention structure (e.g. weirs) upstream of the original floodgate. It is unclear whether original downstream floodgates were decommissioned or are still operational. The structures include:

- Two (2) floodgated concrete weirs (ID ASSS_35 and ASSS_36). Note ASSS_36 was not found during inspections by Abbott and Macro in 2022, while ASSS_35 was estimated to retain water to a level of approximately +0.3 m AHD;
- 13 structures that are floodgated weirs, such as ID ASSS_45 shown in Figure 8-43.

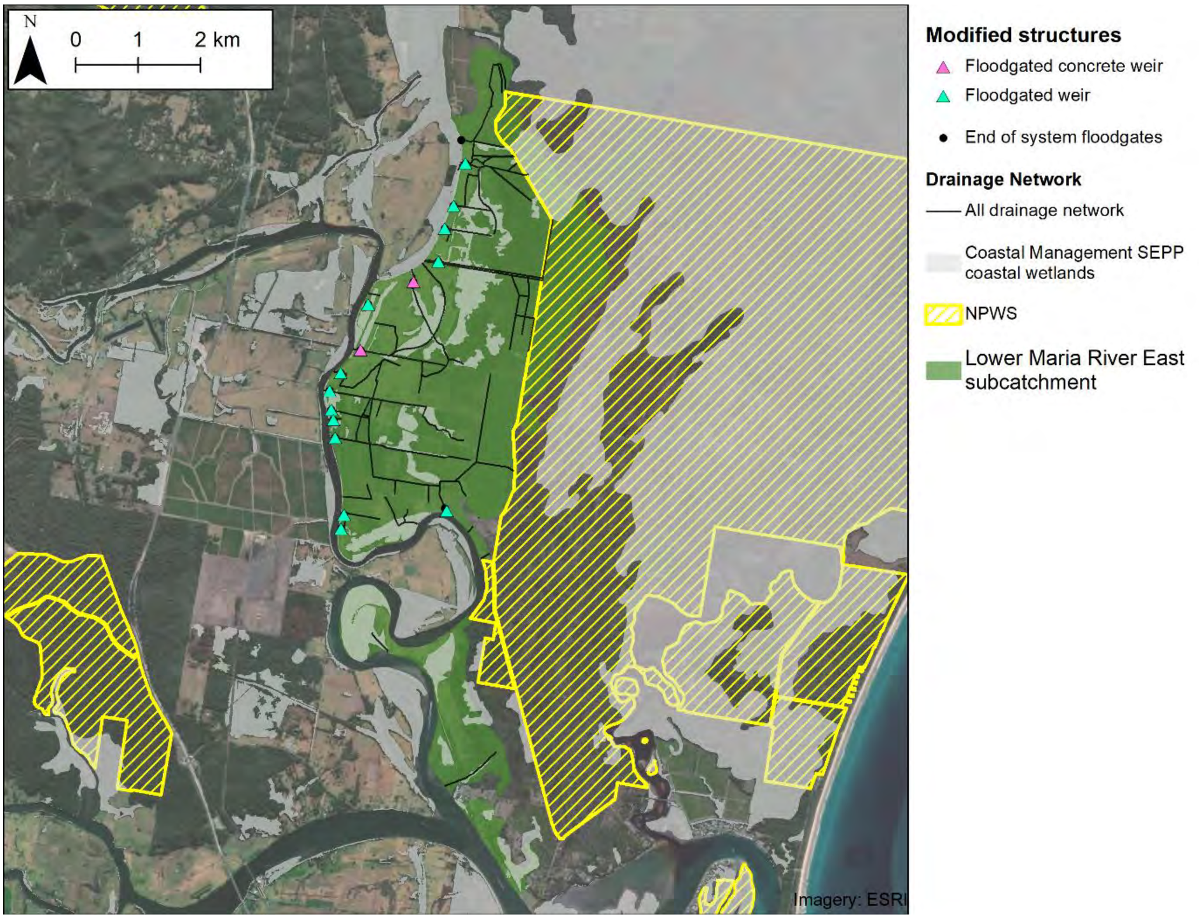

Figure 8-42: Lower Maria river East subcatchment including previous remediation actions

The water level retention level (e.g. crest of weir or bottom of floodgate) of each of the structures is presented in Table 8-12. Both the water retention level based on information provided by PMHC (Port Macquarie Hastings Council, 2010) and field investigations have been provided, which indicates some structures may have been modified or removed since their initial construction. The structures in this subcatchment were designed to maintain high surface water tables to reduce unnecessary groundwater drawdown and acid export.

The only structure inspected by WRL (ID ASSS_45 shown in Figure 8-43) also had a dropboard weir structure immediately downstream of the main floodgated weir. It is unclear whether the dropboards are still in active use.

Figure 8-42 also shows a localised area within the Lower Maria River East subcatchment is mapped as Coastal Management SEPP coastal wetlands. This classification means that the area is subject to more stringent development controls under state government legislation.

Table 8-12: Summary of modified infrastructure in the Lower Maria River East subcatchment

ID	Structure description	Water retention level (m AHD) PMHC records	Water retention level (m AHD) WRL/Abbott and Macro Survey
ASSS_35	Floodgated concrete weir	+0.35	+0.29
ASSS_36	Floodgated concrete weir	+0.35	Not found
ASSS_37	Floodgated weir	+0.3	-0.12
ASSS_43	Floodgated weir	+0.3	+0.26
ASSS_44	Floodgated weir	+0.3	Not found
ASSS_45	Floodgated weir	+0.7*	+0.65
ASSS_46	Floodgated weir	+0.6	+0.1 (floodgate only found)
ASSS_47	Floodgated weir	+0.4	-0.12 (culvert only found)
ASSS_48	Floodgated weir	+0.4	+0.06
ASSS_49	Floodgated weir	+0.4	+0.17
ASSS_50	Floodgated weir	+0.4	+0.20
ASSS_51	Floodgated weir	+0.35	+0.32
ASSS_52	Floodgated weir	+0.35	-0.40 (floodgate only found)
ASSS_57	Floodgated weir	+0.3	-0.25 (culvert only found)
ASSS_58	Floodgated weir	+0.4	+0.28

*Surveyed by WRL, invert updated (compared to +0.7 m AHD in PMHC records)

Figure 8-43: ID ASSS_45 floodgated weir with an invert of approximately 0.65 m AHD – note that upstream there is a dropboard weir structure downstream (with no boards in at the time of inspection)

8.8.3 Floodplain drainage – sea level rise vulnerability

Figure 8-44 summarises the vulnerability of the Lower Maria River subcatchment to sea level rise. While small areas of the subcatchment are classified as low risk for reduced drainage under the present day and near future sea level rise scenarios, the area likely to be impacted by reduced drainage increases significantly, with more than 50% of the subcatchment area classified as at risk. This includes a substantial portion of the subcatchment that is presently used for agriculture. Sea level rise may impact productivity in these areas.

Of the 11 floodgates with survey information, only one (1) is classified as "most vulnerable" in present day conditions (ASSS_52), and a second structure (ASSS_37) is classified as "moderately vulnerable". In the far future, all 11 floodgates are classified as either moderately or most vulnerable. Note that many of the structures in this subcatchment are floodgated weirs, which do not have a headwall, are predicted to be regularly overtopped in the far future sea level rise scenario.

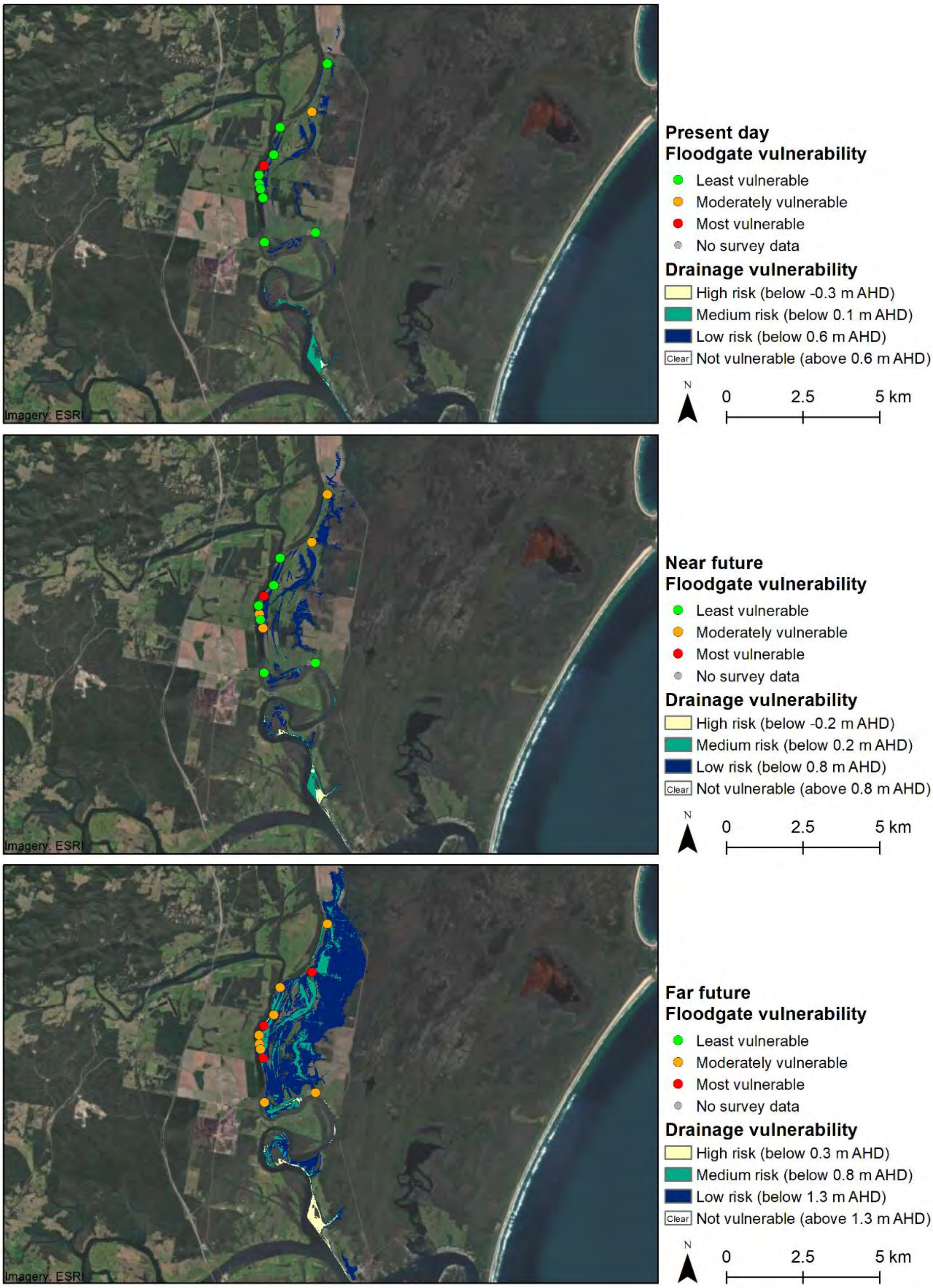

Figure 8-44: Sea level rise drainage vulnerability – Lower Maria River East subcatchment

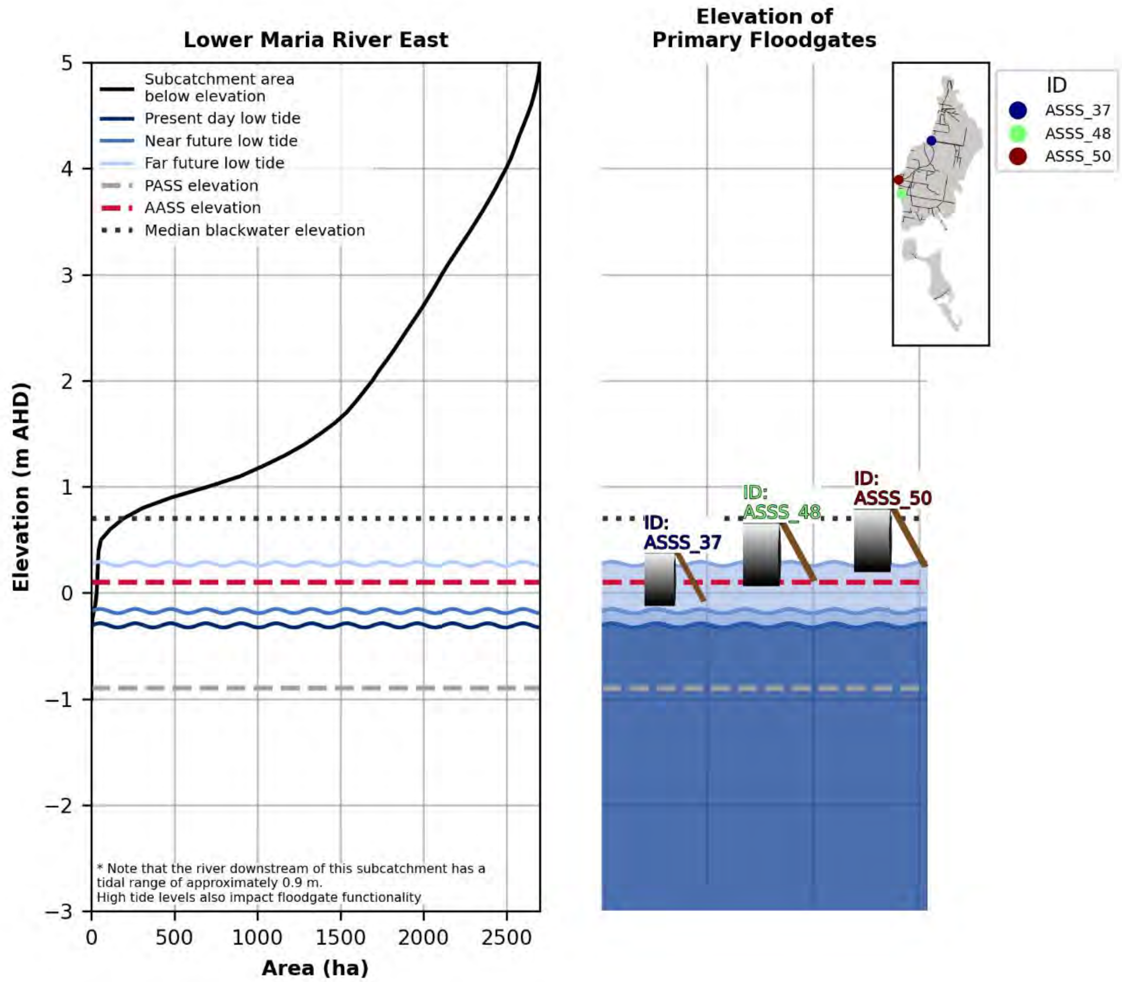

Figure 8-45: Key floodplain elevations – Lower Maria River East subcatchment

8.8.4 Management options

Potential management options for short and long-term planning horizons for the Lower Maria River East subcatchment include:

- Short-term: Review management of existing ASS mitigation structures, consider using alternative vegetation management strategies (e.g. sheep or goats for grazing of grasses in tea tree plantations) to reduce the blackwater risk; and
- Long-term: Investigate localised remediation to wetlands in low areas where present day land uses are impacted by reduced drainage.

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

Short-term management options
As described in Section 8.8.2, a substantial amount of work has been completed in the Lower Maria River East subcatchment by PMHC and local landholders to manage acidic discharges. This is mostly in the form of water retention structures that maintain higher water levels within drains and reduce groundwater drawdown. Regular maintenance and review of these structures is recommended to ensure they are operating effectively. Significant additional changes to land management in this subcatchment is unlikely to be achievable without impact to present day land uses. Works completed to date is considered to be effective at managing ASS discharges.

The Lower Maria River East subcatchment ranked fourth for blackwater generation. While most effective blackwater management strategies require significant water retention and land use changes, small changes in land management practices can also be effective at reducing the risk of blackwater drainage during frequent inundation events. In areas used for tea tree plantations, the use of grazing animals, such as sheep or goats can be used to manage grasses and weeds between trees, or tea tree trash can be recycled for urban mulch to reduce carbon contents on the floodplain (Eyre et al., 2006; Moore, 2007). Note that cattle do not provide the same management of grass as they do not consume paddocks evenly and pasture growth typically exceeds consumption (Eyre et al., 2006).

Long-term management options
In the longer term, agricultural land uses in low areas (particularly below +1.3 m AHD) may be impacted by reduced drainage due to sea level rise. Where present day land uses cannot persist, it is recommended that the existing Coastal Management SEPP coastal wetlands be extended and localised remediation of natural inundation and flow paths. While the design of this remediation will change depending on the areas considered, it is likely to include:

- Infilling of artificial drainage network to reduce efficient drainage and reduce groundwater drawdown which will reduce acid drainage and encourage water tolerant vegetation;
- Possible installation of new flood mitigation/tidal exclusion structures to protect land used for agriculture upstream; and
- Removal or redesign of existing infrastructure to allow tidal flushing and buffering.

The restoration of natural flow paths would result in freshwater to brackish wetland that would significantly reduce the potential for acid drainage and reduce the blackwater generation potential by encouraging water tolerant vegetation. Note that any changes in hydrology will require studies into the impacts to flooding and land uses and should only be implemented with extensive consultation of local landholders and consideration of the social and economic impacts of such changes.

Table 8-13: Summary of management options for Lower Maria River East subcatchment

Timeframe	Strategy	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing)	Indicative cost (lost productivity)	Effectiveness at improving:		
						Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Review management of existing structures	None	$5,000	$5,000	None	None	Moderate**	Low**
Long-term	Localised remediation brackish/freshwater wetlands	$5,800,000	$640,000	Minimal	$1,300,000	High	High	High

*Costs exclude additional investigation/studies, including; REF, EIS, flood studies, and monitoring programs that may be required prior to implementation
** These benefits are already achieved through existing structures, however reviewing the management ensures outcomes are optimised

8.9 Rawdon Island subcatchment

Acid priority rank:	**7**
Blackwater priority rank:	**8**
Infrastructure	
Approximate waterway length (km)	22
# Privately owned end of system structures	2
# Publicly owned end of system structures	0
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (ID):	N/A
Elevations	
Invert of primary floodplain infrastructure (m AHD)	N/A
Approximate AASS elevation (m AHD)	0.6
Approximate PASS elevation (m AHD)	-0.5
Median blackwater elevation (m AHD)	0.6
Present day low water level (m AHD)	-0.4
Near future low water level (m AHD)	-0.3
Far future low level (m AHD)	0.2
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)	760
Classified as conservation and minimal use (ha (%))	3 (0%)
Classified as grazing (ha (%))	647 (85%)
Classified as forestry (ha (%))	0 (0%)
Classified as horticulture (ha (%))	3 (0.4%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	53 (7%)
Classified as marsh/wetland (ha (%))	16 (2%)
Other (ha (%))	38 (5%)
Land values	
Estimated total primary production value ($/year)	$300,000
Average land value above 0.6 m AHD ($/ha)	$13,600
Average land value below 0.6 m AHD ($/ha)	No property data available

8.9.1 Site description

The Rawdon Island subcatchment includes Rawdon Island and Little Rawdon Island, shown in Figure 8-46. The centre of Rawdon Island was historically a low elevation peat swamp (the low area in Figure 8-47), although a peat fire in the 1920's changed the hydrology of the area (Tulau, 1999). Small backswamps also exist on Little Rawdon Island to the north.

The Rawdon Island subcatchment has had a substantial artificial drainage network constructed to facilitate agricultural expansion in low areas. The majority of the subcatchment is used for grazing (accounting for 85% of the subcatchment area). Rawdon Island was identified as an ASS priority area by Tulau (1999).

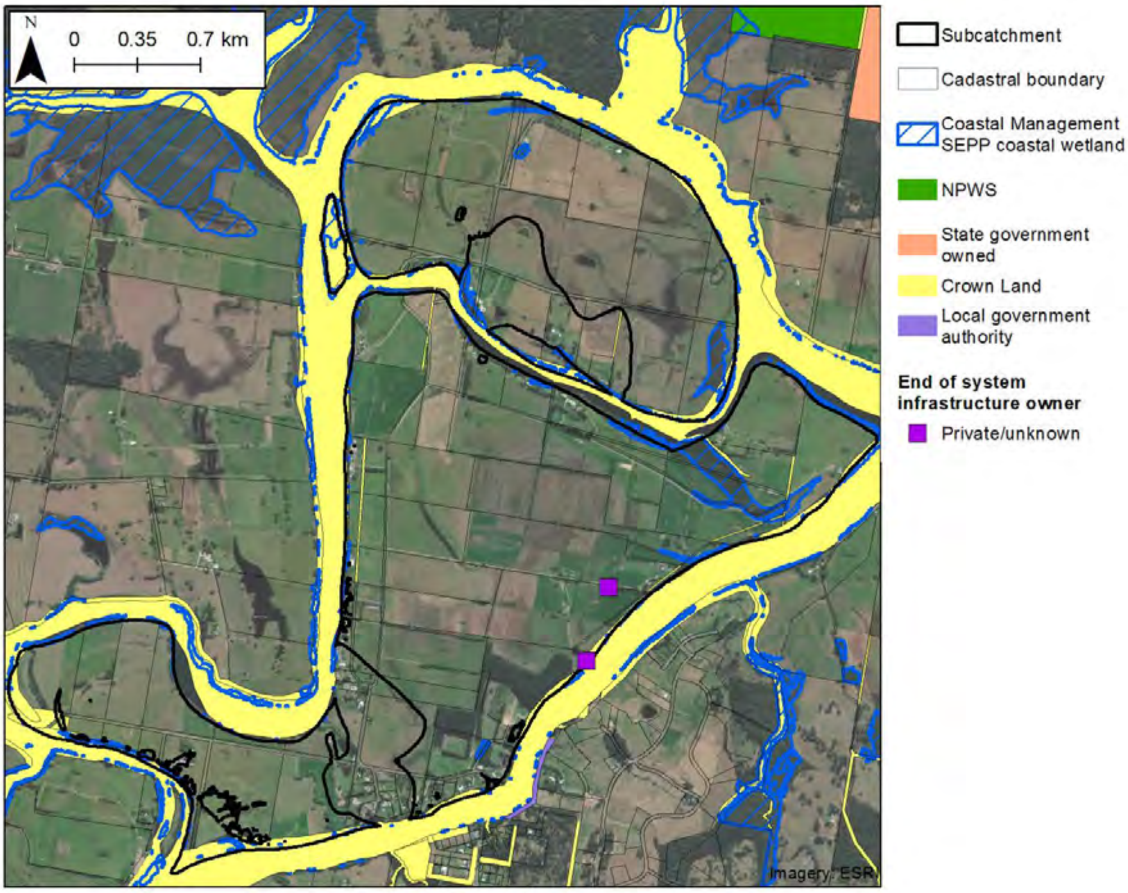

Figure 8-46: Rawdon Island subcatchment - land and end of system infrastructure tenure

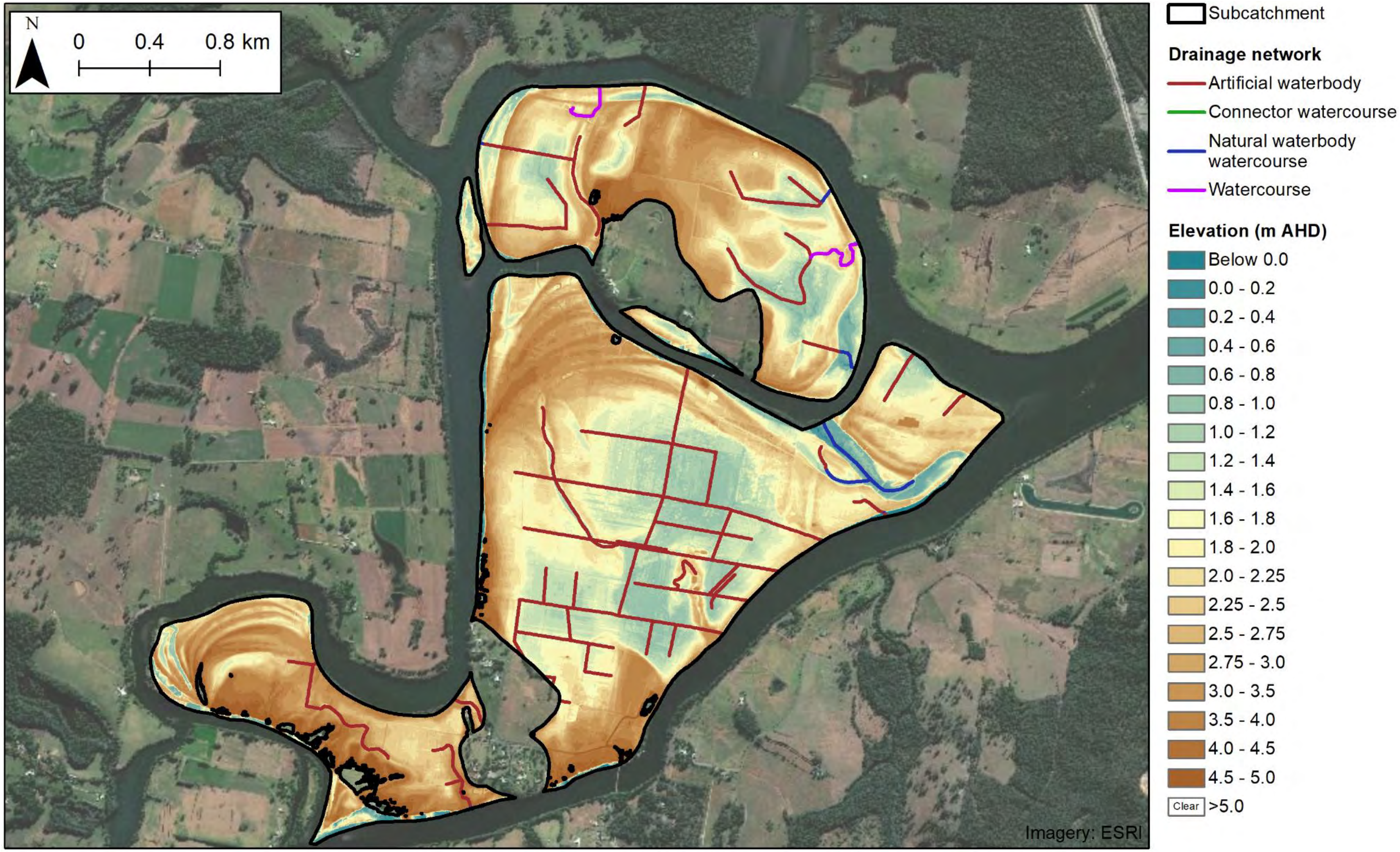

Figure 8-47: Rawdon Island elevation and drainage network

8.9.2 History of remediation

Based on PMHC records (Port Macquarie Hastings Council, 2010), five (5) structures have been constructed or modified in the Rawdon Island subcatchment to retain water on the land and reduce acid drainage, shown in Figure 8-48. These structures include (Port Macquarie Hastings Council, 2010):

- One (1) pipe culvert that has been modified to allow wet pasture management of adjacent land (ID ASS_25). While this structure was not inspected during this study, it is assumed that it is a dropboard structure or similar that is designed to maintain water levels upstream at a level of +0.9 m AHD; and
- Four (4) concrete spillways that act as weirs to maintain higher surface water levels upstream. ID ASSS_21 and ASSS_22 retains water to a level of +0.8 m AHD, while ID ASSS_23 and ASSS_24 retain water to +0.6 m AHD based on PMHC records.

The structures limit the drainage and groundwater drawdown in the low-lying areas in the centre of Rawdon Island, shown in Figure 8-47.

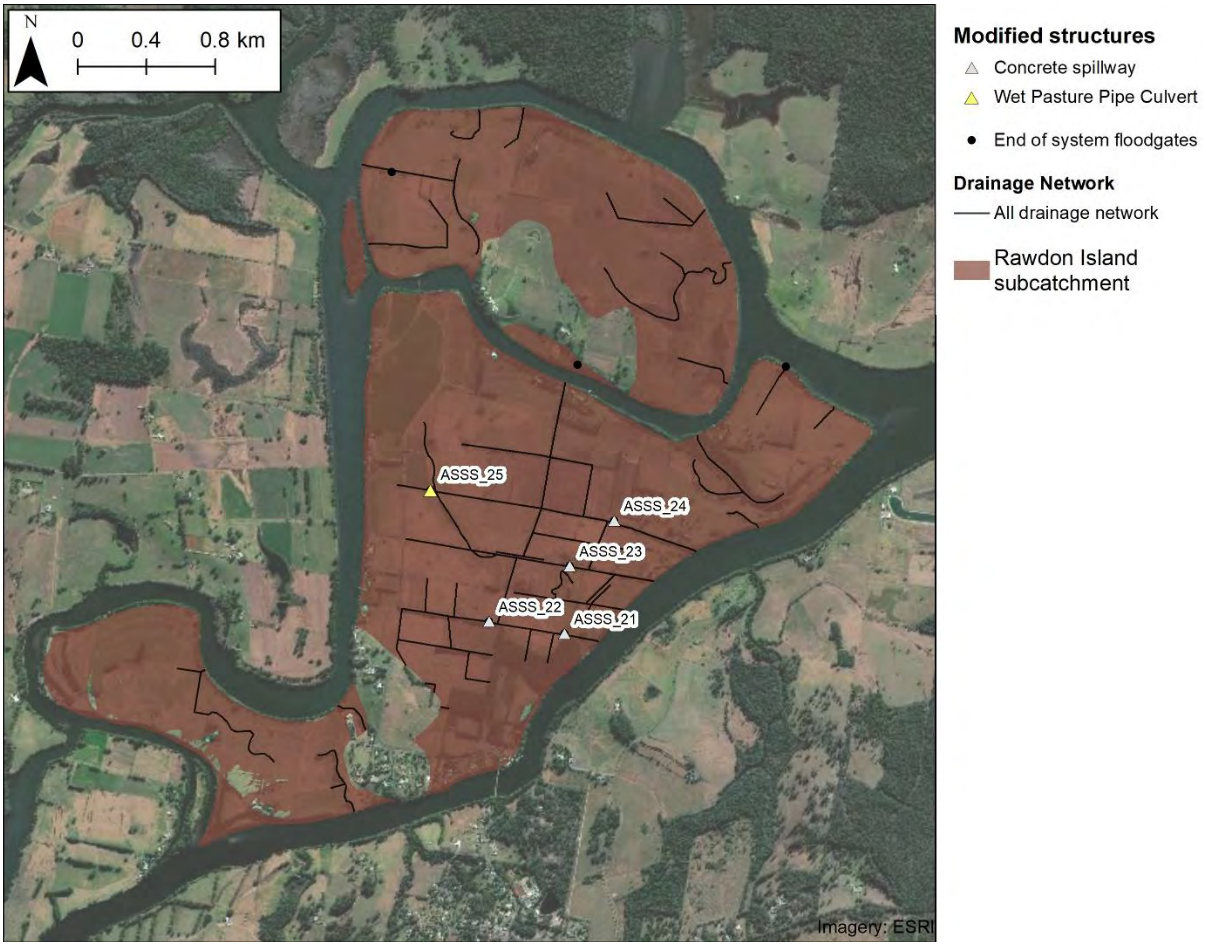

Figure 8-48: Rawdon Island subcatchment including previous remediation actions

8.9.3 Floodplain drainage – sea level rise vulnerability

Figure 8-49 summarises the sea level rise vulnerability of the Rawdon Island subcatchment. The subcatchment is relatively high, with the majority of areas well above 1 m AHD. Reduced drainage may affect drainage in the lowest areas (below +1.4 m AHD) in the far future. Of the two floodgates with survey data, ASSS_21 is presently classified as "moderately vulnerable", while it is classified as "most vulnerable" under the far future sea level rise scenario. In addition, the crests of the concrete weirs (discussed in Section 8.9.2) may also be overtopped by tides in the near to far future. Further investigation of these structures is recommended to confirm sea level rise vulnerability.

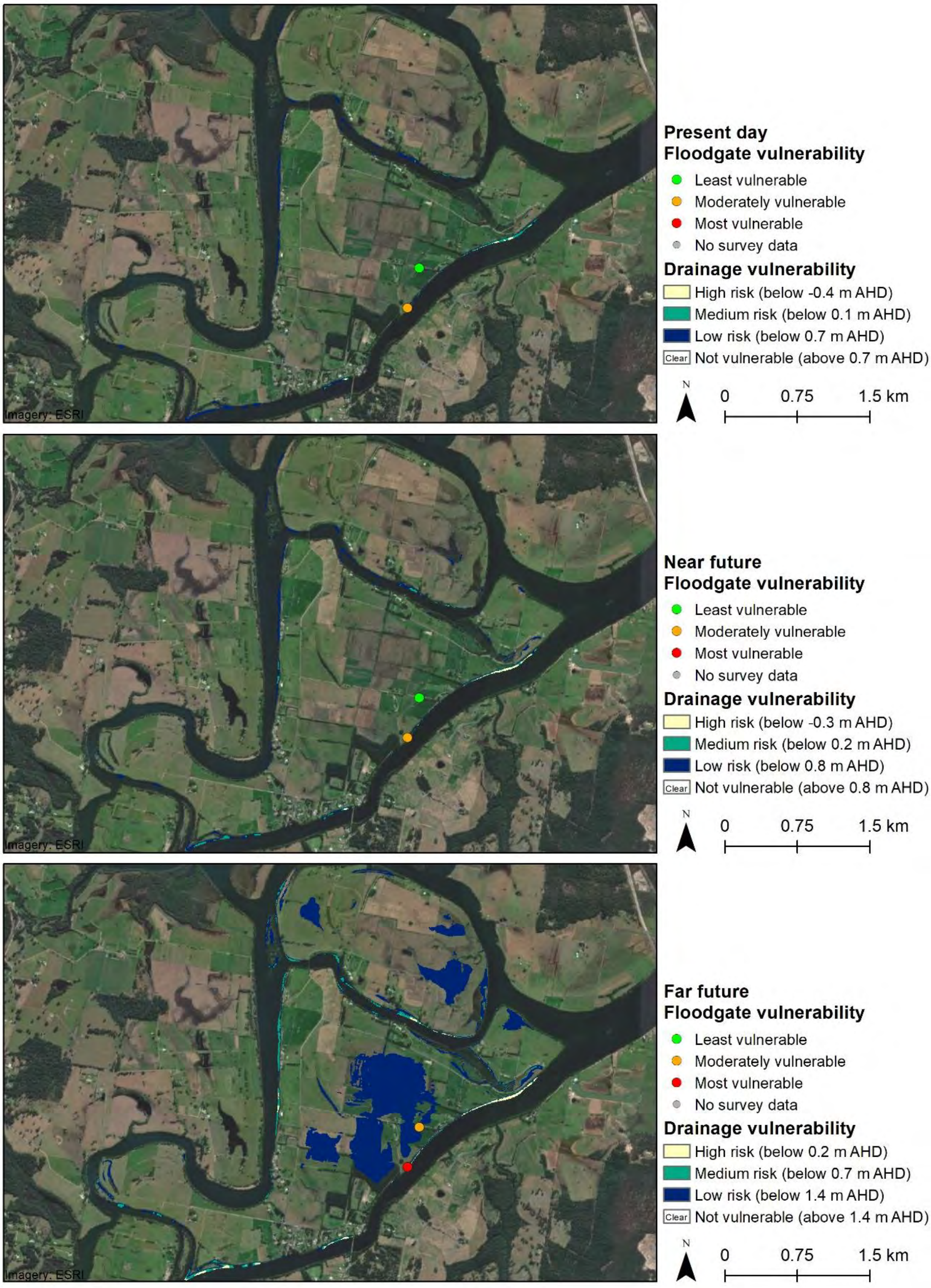

Figure 8-49: Sea level rise drainage vulnerability – Rawdon Island subcatchment

8.9.4 Management options

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

- Short-term: Review levels of existing water retention structures, investigate whether drains could be swaled/reshaped to raise channel invert.
- Long-term: Reduce drainage density on Rawdon Island and encourage wet pasture management, infill drains and encourage small, localised wetlands on Little Rawdon Island.

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

Short-term management options
At least five (5) water retention structures have been previously installed on Rawdon Island by PMHC to manage acid discharges from this subcatchment. It is recommend that structure levels are reviewed to assess whether the crest elevation could be raised to further improve retention of acidic groundwater without impacting land use/productivity. The drainage system should be assessed to investigate whether drains on both Rawdon and Little Rawdon Island could be reshaped to reduce interaction with acidic soil layers. While local soil profiles should be gathered, WRL profiles indicate that the PASS layer is typically between -0.5 and -0.1 m AHD and all drainage should be situated above this elevation, where practical, to prevent further acidification of the soils.

Long-term management options
As sea level rise reduces drainage in this subcatchment, it is recommended that the drainage density is reduced on Rawdon Island and land practices transition towards wet pasture management. This will reduce pathways for acid drainage while maintain agricultural land use and productivity on the island.

If sea level rise impacts land uses on Little Rawdon Island, it is recommended that artificial drainage networks be infilled in the backswamp areas and wetlands be restored. 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 the drain through the low (below +1.5 m AHD) area on the eastern side of Little Rawdon Island, shown in Figure 8-50. A soil profile in this area (WRL profile HA_21_P, see Appendix L for more details) show acidic soils (pH = 3.7) occur in this area, and infilling the drains through the area will prevent mobilisation of acid from the area.

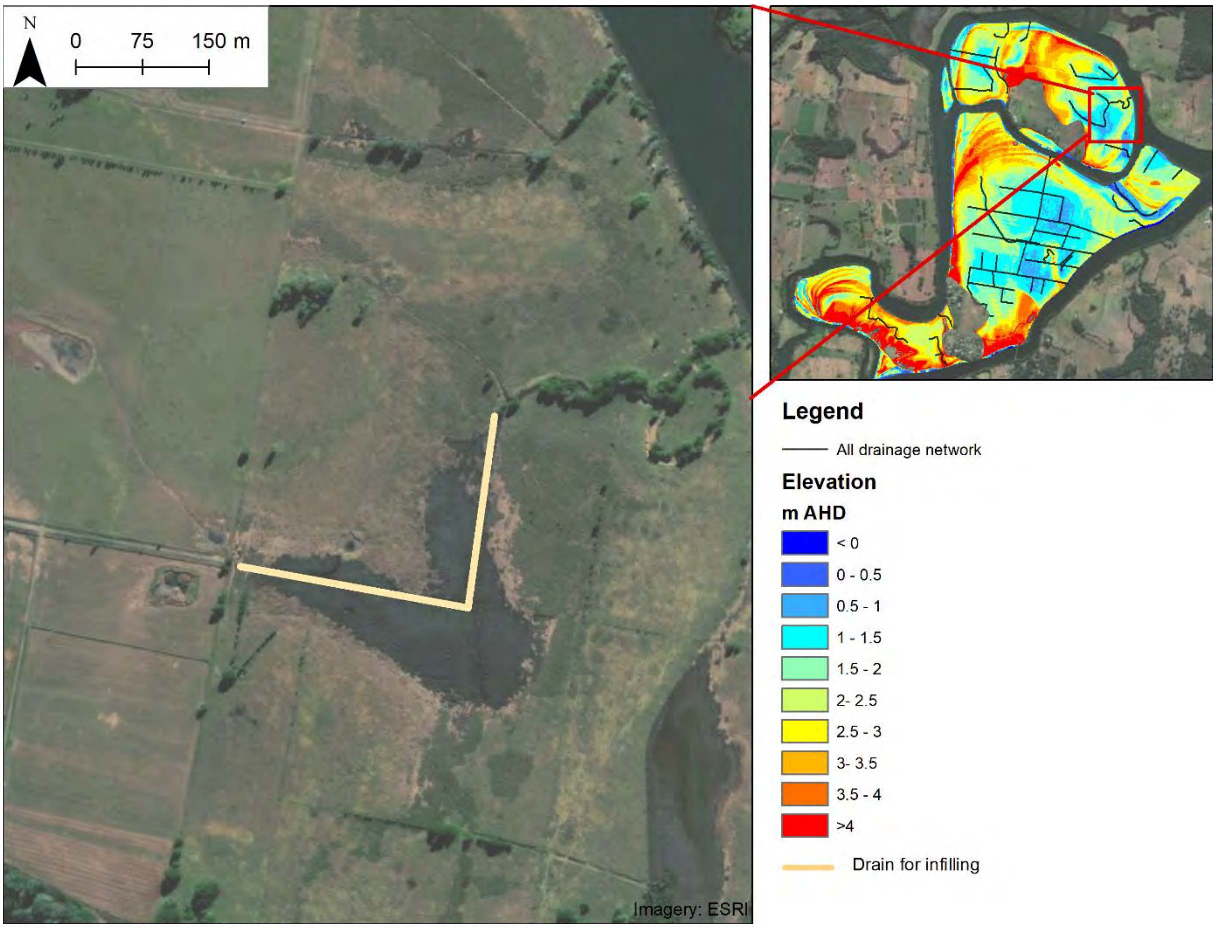

Figure 8-50: Example of drain through wetland area on Little Rawdon Island

Table 8-14: Summary of management options for the Rawdon Island subcatchment

Timeframe	Strategy	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing)	Indicative cost (lost productivity)	Effectiveness at improving:		
						Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Drain reshaping	None	$70,000	None	None	None	Moderate	None
Long-term	Reduce drain density	None	$140,000	None	None	None	Moderate	Moderate
Long-term	Localised restoration of wetlands	$410,000	$100,000	Minimal	$13,000	Moderate	Moderate	Moderate

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

8.10 Fernbank Creek subcatchment

Acid priority rank:	**8**
Blackwater priority rank:	**6**
Infrastructure	
Approximate waterway length (km)	30
# Privately owned end of system structures	3
# Publicly owned end of system structures	0
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (ID)	ASSS_19
Elevations	
Invert of primary floodplain infrastructure (m AHD)	0.0
Approximate AASS elevation (m AHD)	0.4
Approximate PASS elevation (m AHD)	-0.3
Median blackwater elevation (m AHD)	0.5
Present day low water level (m AHD)	-0.4
Near future low water level (m AHD)	-0.3
Far future low level (m AHD)	0.2
Proximity to sensitive receivers	
Oyster Leases (km)	0.1
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)	994
Classified as conservation and minimal use (ha (%))	95 (10%)
Classified as grazing (ha (%))	696 (70%)
Classified as forestry (ha (%))	0 (0%)
Classified as horticulture (ha (%))	1 (0.1%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	94 (9%)
Classified as marsh/wetland (ha (%))	62 (6%)
Other (ha (%))	46 (5%)
Land values	
Estimated total primary production value ($/year)	$300,000
Average land value above 0.5 m AHD ($/ha)	$12,100
Average land value below 0.5 m AHD ($/ha)	

8.10.1 Site description

The Fernbank Creek subcatchment is located in the lower-mid Hastings River floodplain and is primarily used for grazing. The majority of the subcatchment is private owned, as shown in Figure 8-51, apart from a small area that appears to have been purchased by the NSW State Government as part of the Pacific Highway upgrade.

The majority of the subcatchment is situated below +1.5 m AHD elevation, as shown in Figure 8-52. The natural drainage networks have been modified and additional artificial drainage constructed to allow agricultural land uses. Acidification events have been recorded in Fernbank Creek (e.g. Smith (1999); Umwelt (2001)), although these are typically thought to be related to discharges from the Partridge Creek subcatchment (the Fernbank Creek waterway forms the eastern border of Fernbank Creek subcatchment, with the Partridge Creek subcatchment located immediately to the east).

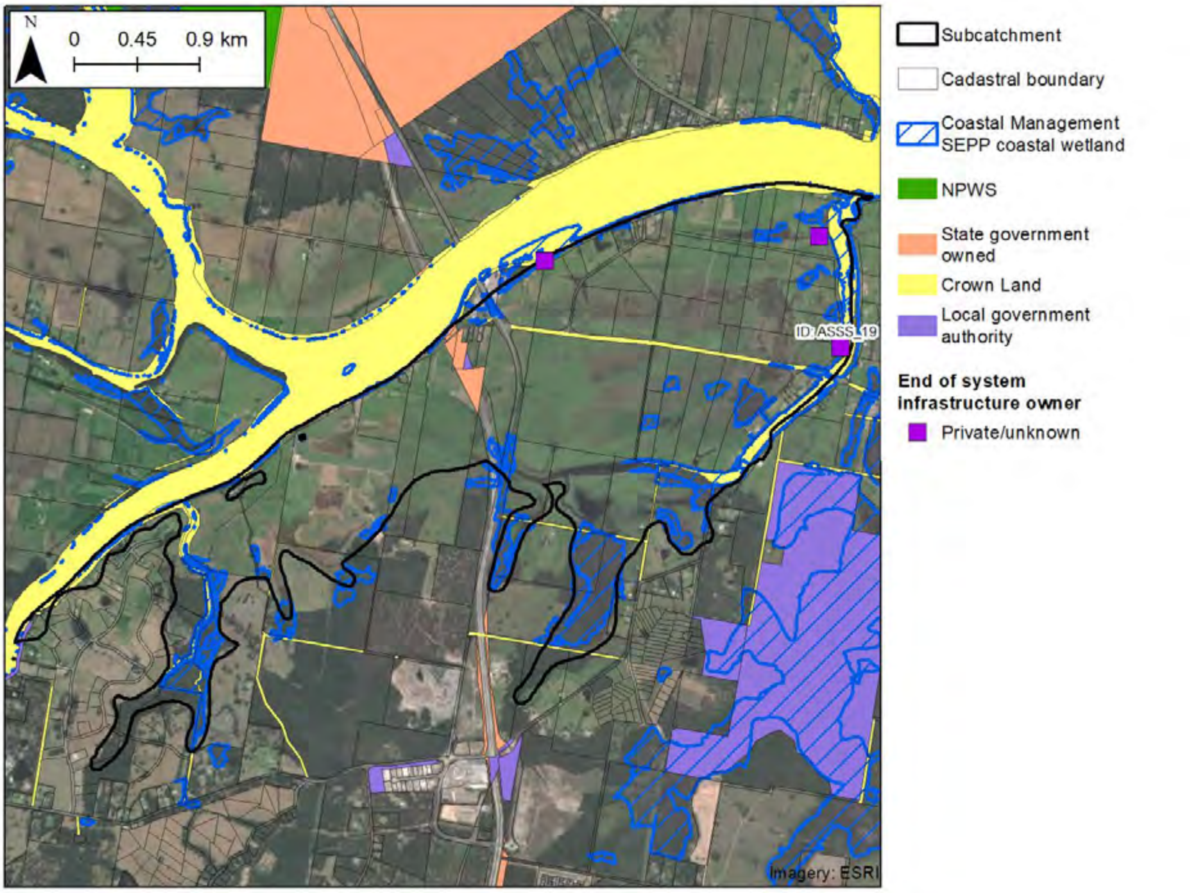

Figure 8-51: Fernbank Creek subcatchment – land and end of system infrastructure tenure

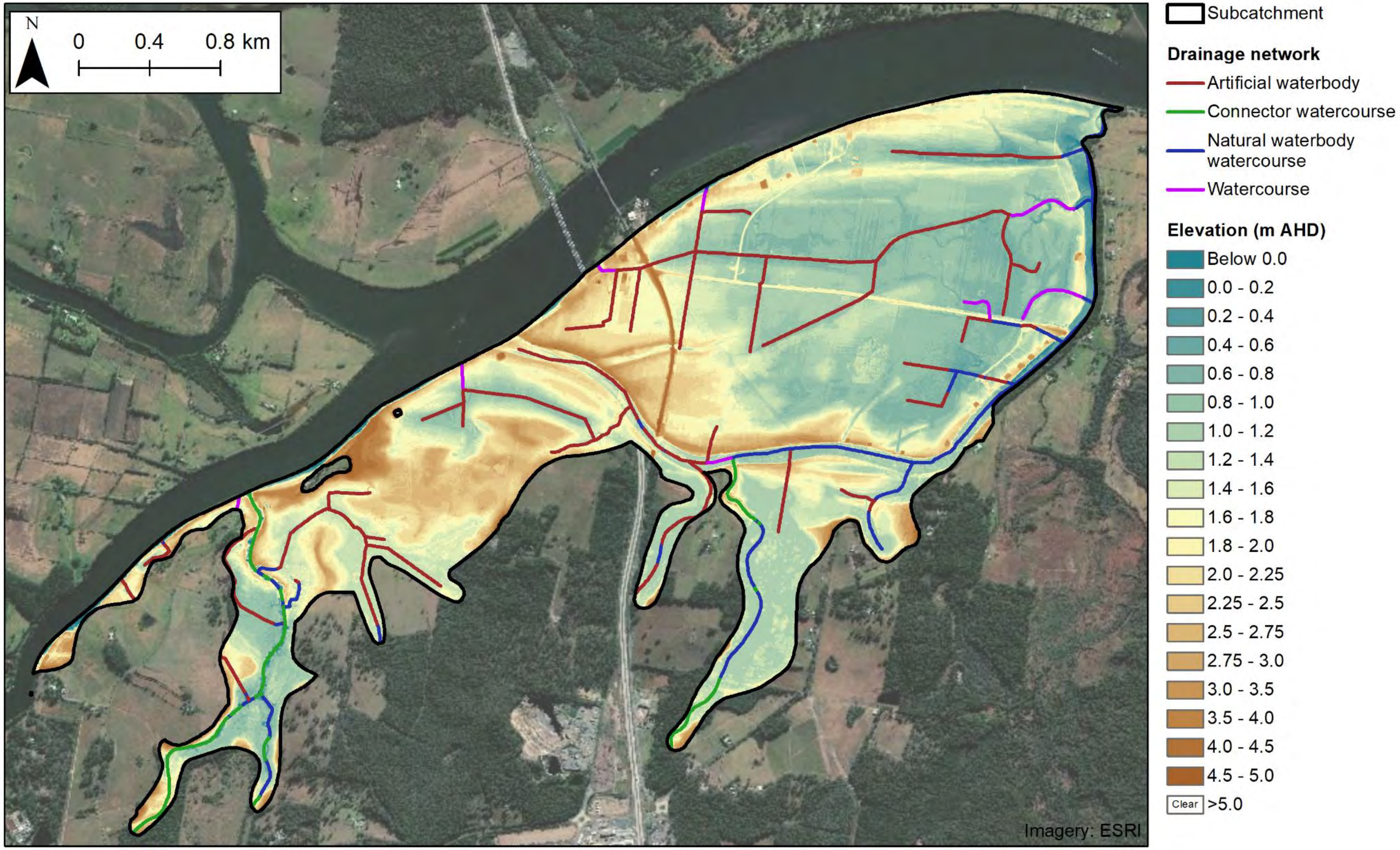

Figure 8-52: Fernbank Creek elevation and drainage network

8.10.2 History of remediation

Data from PMHC records in the Fernbank Creek subcatchment indicated that at least five (5) drainage structures had been constructed or modified to manage acidic discharges and improve water quality. However, during WRL field investigations in 2019, three (3) of the structures were observed to be different from the description in Council records (Port Macquarie Hastings Council, 2010). Table 8-15 summarises the structures in the Council records, as well as the structures observed by WRL in 2019 (where applicable). The locations are also shown in Figure 8-53. Note that field investigations may not have identified all water control structures, and water retention structures may have been in place upstream of the locations investigated.

In addition to the structures in PMHC records, WRL also observed a rock weir/crossing at the upstream end of Fernbank Creek (shown as WRL_HA_02 in Figure 8-53). While the creek line was dry at the time of survey (shown in Figure 8-55), the crest of the structure was at +0.99 m AHD.

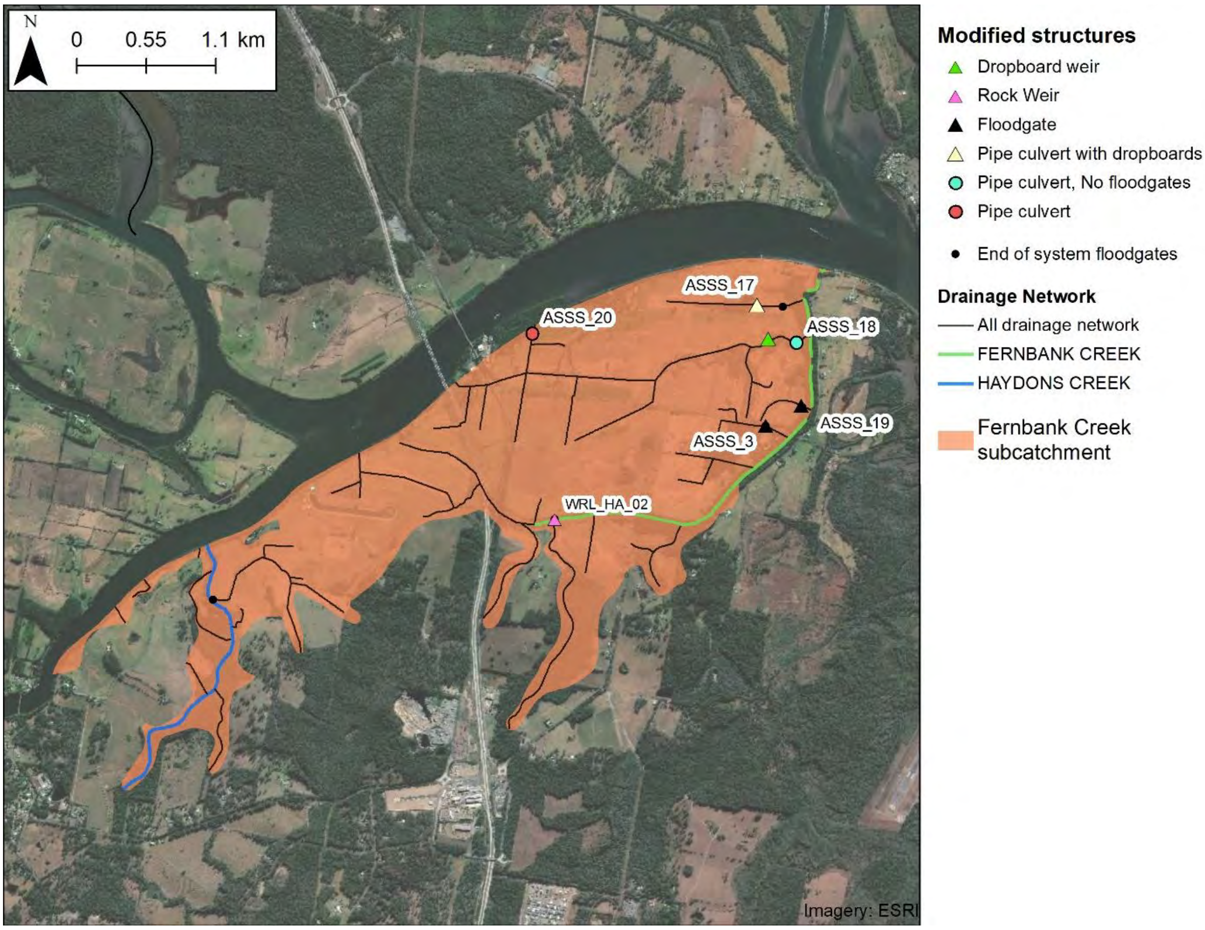

Figure 8-53: Fernbank Creek subcatchment including previous remediation actions

Table 8-15: Comparison of structures from PMHC records and WRL field investigations

ID	Description in PMHC records (Port Macquarie Hastings Council, 2010)	WRL Field Investigations (2019)
ASSS_3	Aluminium floodgate Retains water to +0.6 m AHD	N/A
ASSS_17	Pipe culvert, automatic tide flushing Retains water to +0.3 m AHD	Pipe culvert with dropboards, invert at +0.2 to +0.3 m AHD, shown in Figure 8-54. Another conventional floodgate (ID WRL_HA_01) was observed downstream
ASSS_18	Dropboard weir, automatic tide flushing Retains water to +0.3 m AHD (installed 320 m upstream (Kroon et al., 2004))	Pipe culvert with no floodgate. Dropboard weir structure was not investigated, but appears to still be in place based on aerial imagery
ASSS_19	Automatic tide gate	Floodgate with invert at 0 m AHD
ASSS_20	Pipe Culvert Retains water to+ 0.3 m AHD	N/A
WRL_HA_02	N/A	Rock weir, crest at ~1 m AHD, shown in Figure 8-55

Figure 8-54: ID ASSS_17 - pipe culvert with dropboards (not in place)

Figure 8-55: ID WRL_HA_02 - rock weir/crossing

8.10.3 Floodplain drainage – sea level rise vulnerability

The vulnerability of the Fernbank Creek subcatchment is summarised in Figure 8-57. While the majority of the subcatchment is not considered vulnerable to reduced drainage under the present day scenario, even under the near future sea level rise scenario more than 10% of the subcatchment is below the 95th percentile water levels, mostly in the eastern section of the subcatchment. Under the far future sea level rise scenario, approximately 50% of the subcatchment is considered at risk of reduced drainage. Reduced drainage may impact productivity of present day land uses as sea level rise continues to occur.

Three (3) of the floodgates in this catchment have survey information including invert levels. Of these Three (3) structures, floodgate ID WRL_HA_01 is considered "Moderately vulnerable" under present day conditions and near future sea level rise scenarios and "Most vulnerable" under the far future scenario. The other two (2) floodgates , including Floodgate ID ASSS_19 (shown in Figure 8-56) are classified as "Moderately vulnerable" under the far future sea level rise scenario.

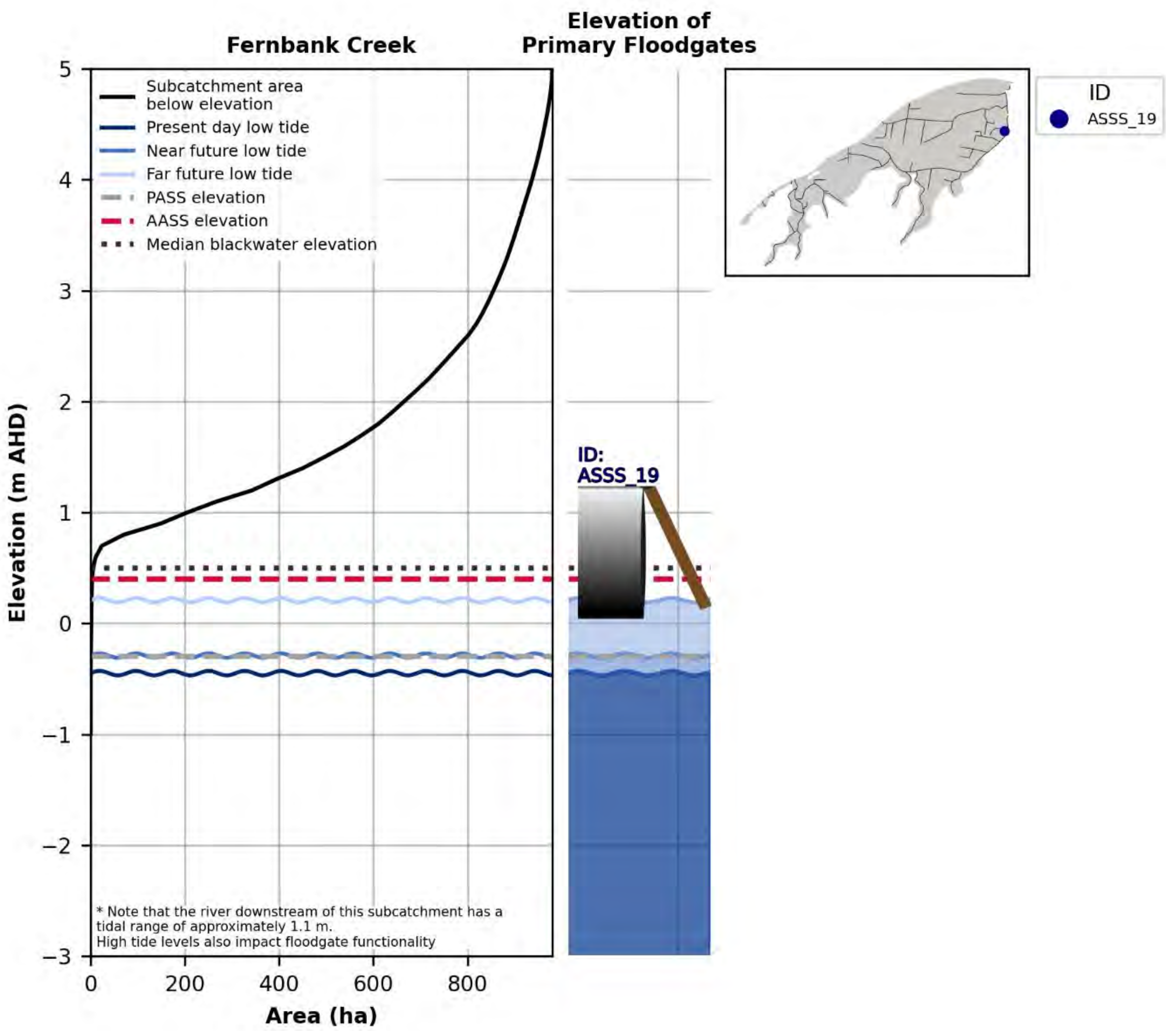

Figure 8-56: Key floodplain elevations – Fernbank Creek subcatchment

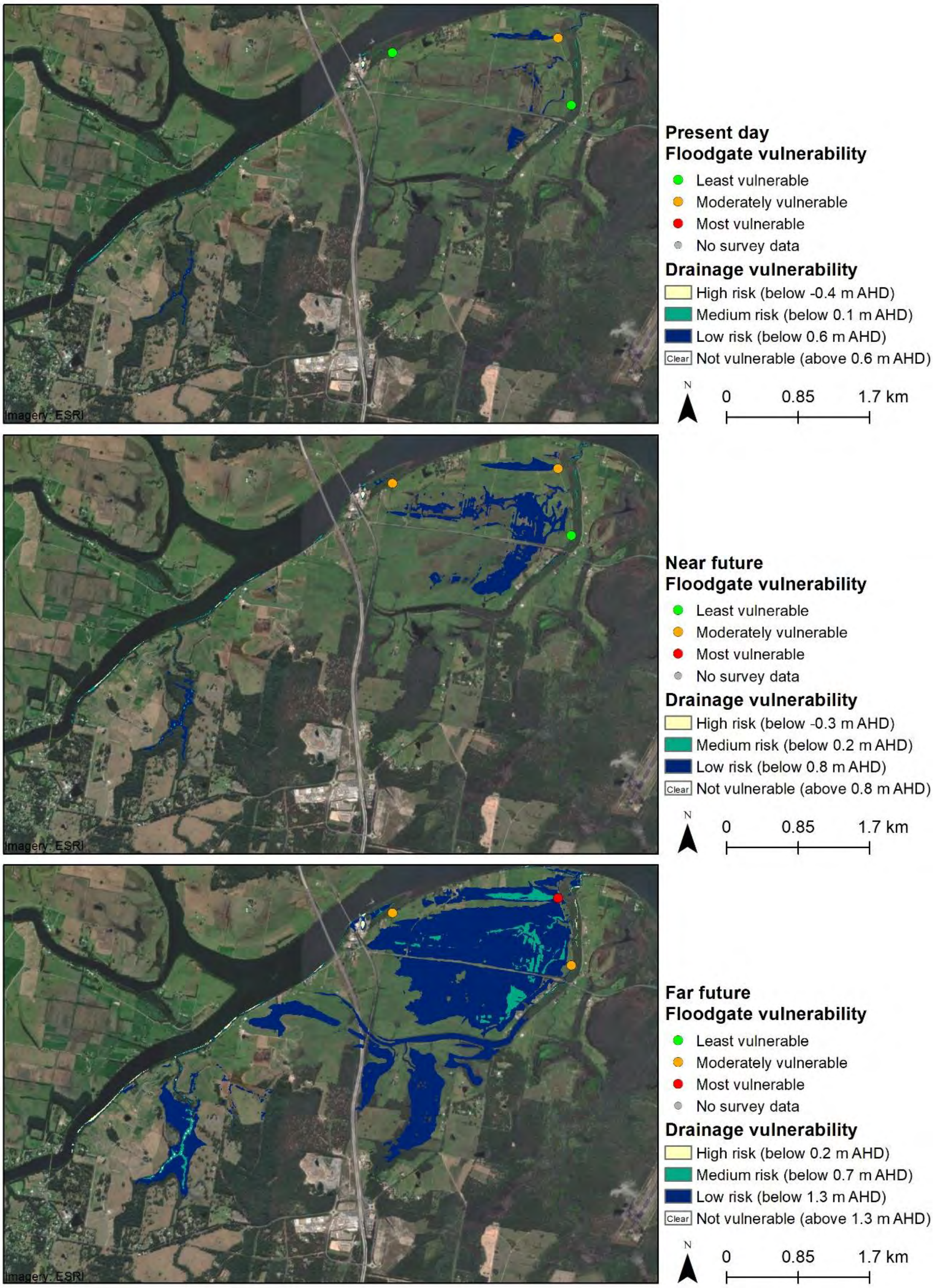

Figure 8-57: Sea level rise drainage vulnerability – Fernbank Creek subcatchment

8.10.4 Management options

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

- Short-term: Assess the feasibility of re-instating tidal flushing through floodgate ID ASSS_19 and consider reshaping drains where possible; and
- Long-term: As sea level rise impacts present day land use, consider change of land use in low areas (below +1.3 m AHD) north of Fernbank Creek and restore as a brackish wetland.

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

Short-term management options
A significant number of structures have been modified or constructed to manage acidic discharges in this subcatchment. It is recommended that, in addition to the work done to date, further modifications be considered including:

- Re-instating tidal flushing through floodgate ID ASSS_19 to provide natural buffering capacity. If previous modifications resulted in issues for landholders, the modifications could be designed to manage the impacts. This may include changing buoyancy gate designs to reduce the amount of time it is open to tide; and
- Drainage systems to be assessed and swaled/reshaped where possible to reduce interaction with acidic soils.

Long-term management options
As shown in Figure 8-57, the low area (below +1.3 m AHD) north-west of Fernbank Creek may be impacted by reduced drainage due to sea level rise. If grazing of this area becomes unproductive, this area should be considered for changed land use and remediation as a brackish wetland. Any changes to the drainage system will need to be completed with consideration of the potential social and economic impacts on local landholders. This would include:

- Infilling or reshaping of the artificial drainage network and restoration of natural flow paths. This would reduce pathways for acid drainage and promote longer inundation time of the low areas; and
- Removal of existing floodgates and structures to allow tidal flushing and buffering.

Due to the location of this subcatchment in the lower estuary, high salinity levels and a large tidal range means that this area will likely become an estuarine wetland with salt tolerant vegetation.

Table 8-16: Summary of management options for Fernbank Creek subcatchment

Timeframe	Strategy	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing)	Indicative cost (lost productivity)	Effectiveness at improving:		
						Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Drain reshaping	None	$70,000	None	None	None	Moderate	None
Short-term	Modifying floodgates for tidal flushing	None	$40,000	$5,000	None	Moderate	Moderate	Low
Long-term	Restoration of brackish wetland	$3,800,000	$400,000	Minimal	$130,000	High	High	High

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

8.11 Kings Creek subcatchment

Acid priority rank:	**9**
Blackwater priority rank:	**9**
Infrastructure	
Approximate waterway length (km)	15
# Privately owned end of system structures	0
# Publicly owned end of system structures	3
# End of system structures within coastal wetlands	2
# Publicly owned end of system structures within coastal wetlands	2
Primary floodplain infrastructure (ID)	FMS_05, FMS_12, FMS_15
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-0.2 to 0.3
Approximate AASS elevation (m AHD)	0
Approximate PASS elevation (m AHD)	-0.8
Median blackwater elevation (m AHD)	0.7
Present day low water level (m AHD)	-0.5
Near future low water level (m AHD)	-0.3
Far future low level (m AHD)	0.2
Proximity to sensitive receivers	
Oyster Leases (km)	8.1
Saltmarsh (km)	7.7
Seagrass (km)	6.7
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	479
Classified as conservation and minimal use (ha (%))	2 (0%)
Classified as grazing (ha (%))	431 (90%)
Classified as forestry (ha (%))	0 (0%)
Classified as horticulture (ha (%))	0 (0%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	19 (4%)
Classified as marsh/wetland (ha (%))	0 (0%)
Other (ha (%))	28 (6%)
Land values	
Estimated total primary production value ($/year)	$200,000
Average land value above 0.7 m AHD ($/ha)	$19,300
Average land value below 0.7 m AHD ($/ha)	No property data available

8.11.1 Site description

The Kings Creek subcatchment is in the upper Hastings River floodplain, with the town of Wauchope immediately to the west of the subcatchment and the town of Kings Creek to the east. As shown in Figure 8-58, it is a small subcatchment that is primarily used for grazing. Kings Creek flows through the subcatchment and has natural levees, as shown in Figure 8-59. While natural creek lines exist throughout the subcatchment, large artificial drains have been constructed to provide flood mitigation drainage to the surrounding towns.

Soil profiles in the Kings Creek subcatchment indicate that ASS are present (minimum soil pH observed was 4.4 at profile HA_34_P). However, the small catchment area and low hydraulic conductivity resulted in a low ranking in the ASS prioritisation.

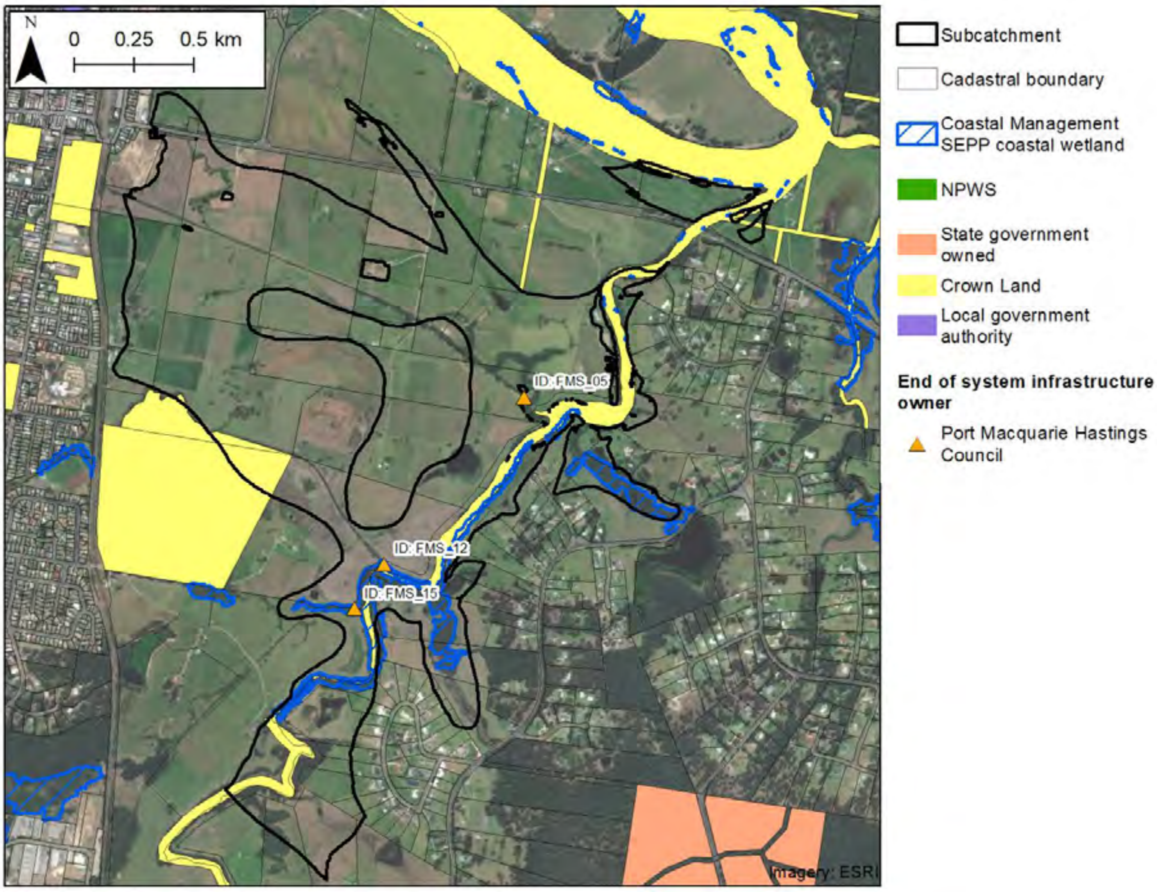

Figure 8-58: Kings Creek subcatchment - land and end of system infrastructure tenure

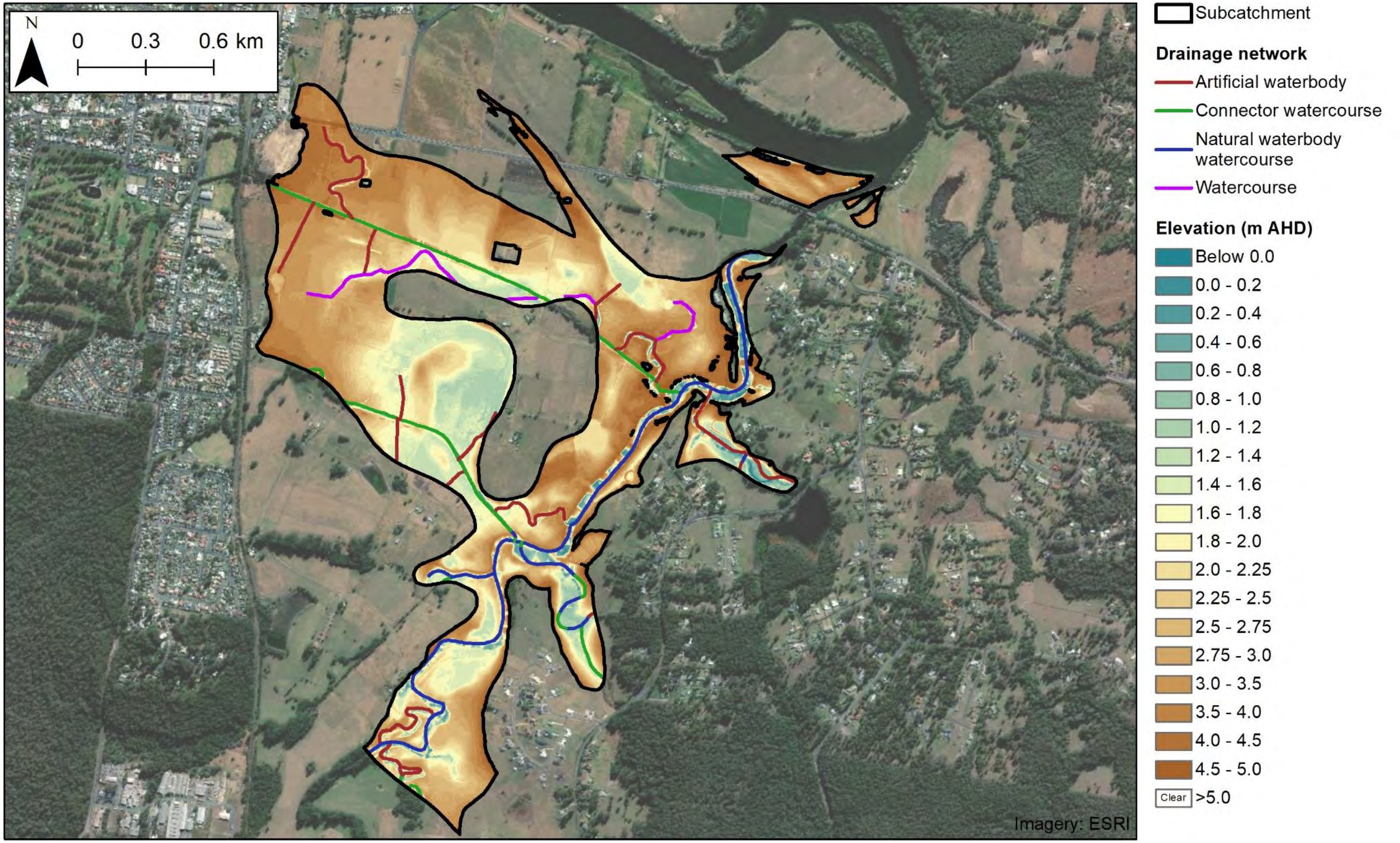

Figure 8-59: Kings Creek subcatchment elevation and drainage network

8.11.2 History of remediation

Two (2) of the three (3) floodgates in the Kings Creek subcatchment have lifting devices fitted that allows the gates to be winched open. The management of the winches is unknown. The locations are shown in Figure 8-60 and includes floodgate ID FMS_12 and FMS_05.

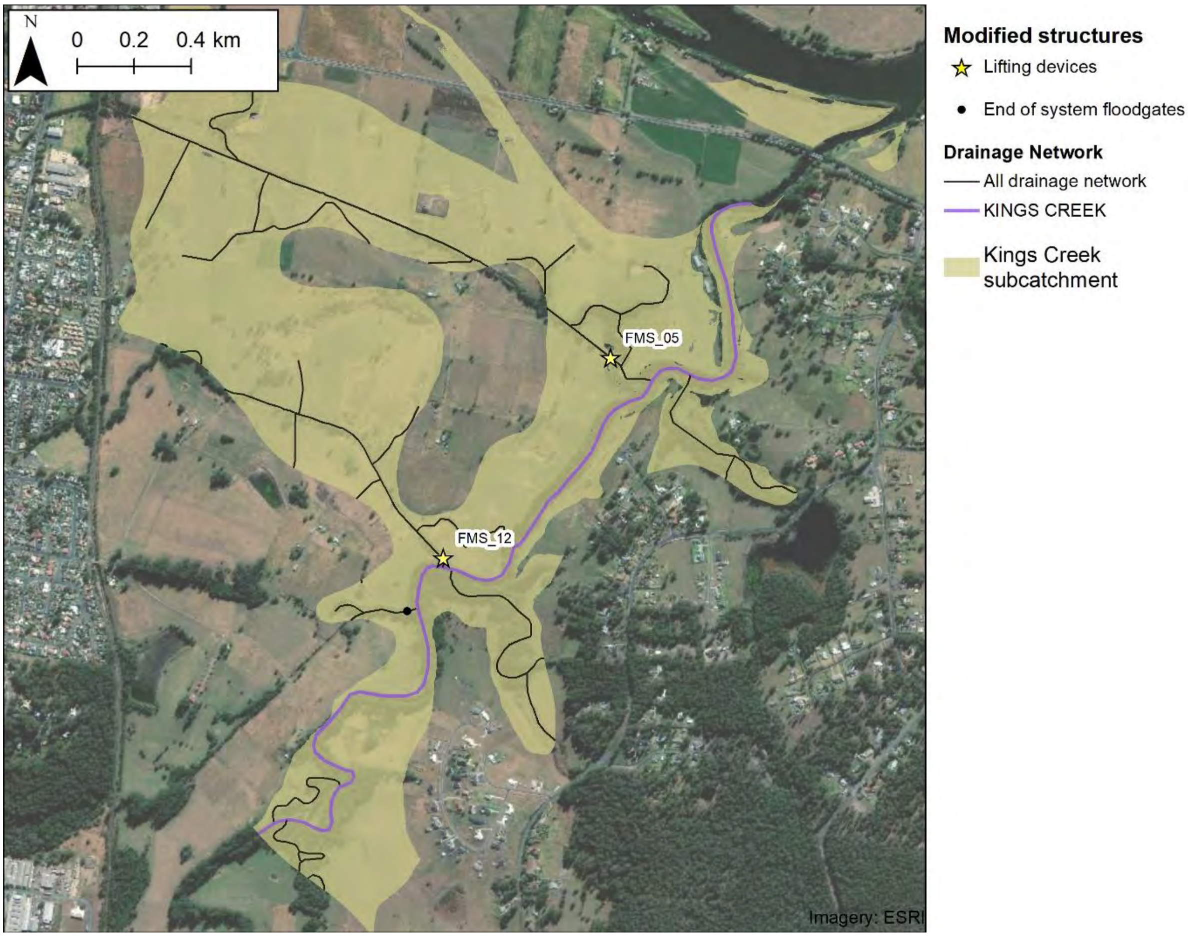

Figure 8-60: Kings Creek subcatchment including previous remediation actions

8.11.3 Floodplain drainage – sea level rise vulnerability

The vulnerability of the floodplain and floodplain infrastructure in the Kings Creek floodplain is shown in Figure 8-61. Due to the elevation of this subcatchment and the size/elevation of the primary floodplain infrastructure (shown in Figure 8-62), the impact of sea level rise on drainage is predicted to be limited.

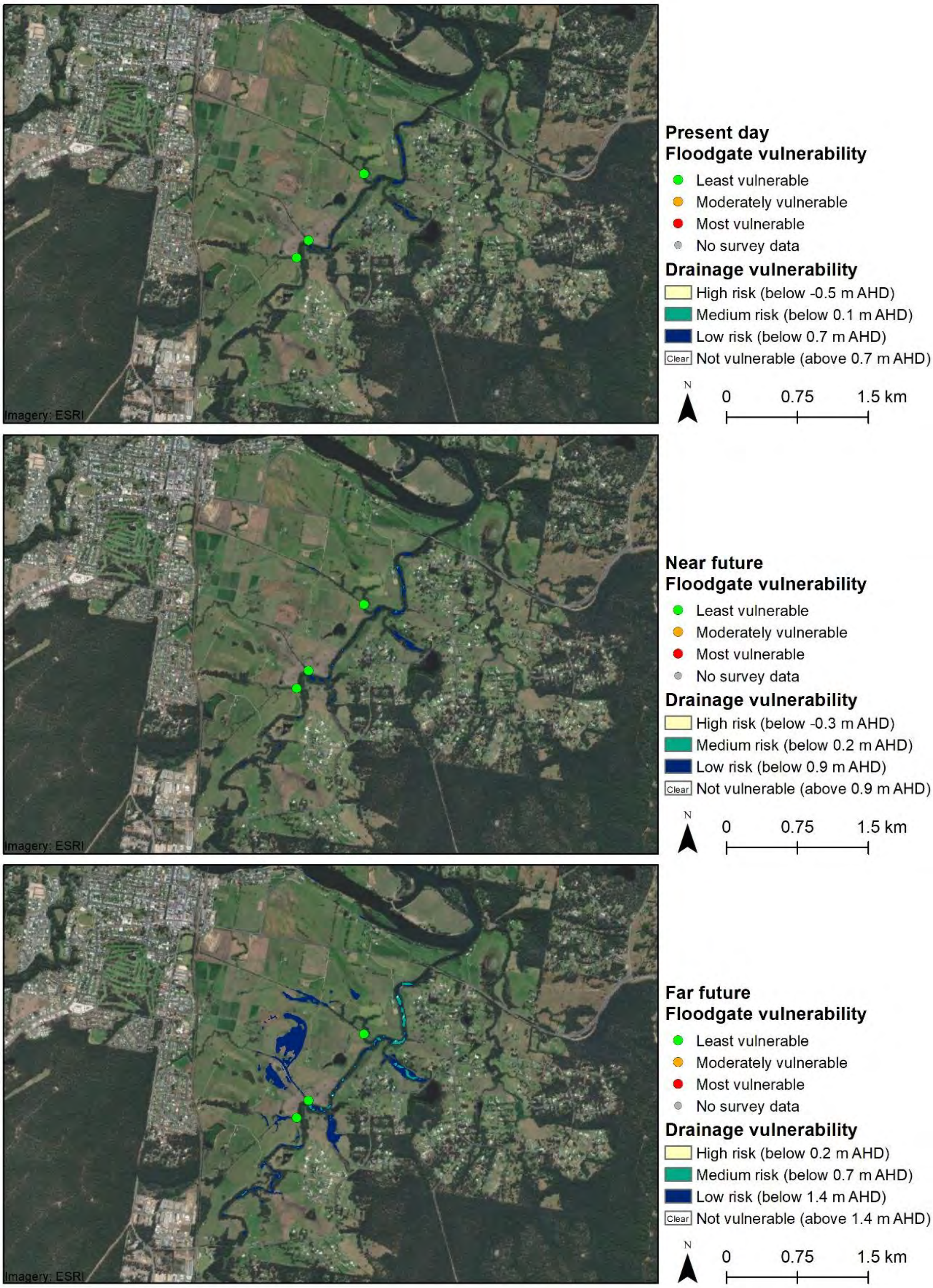

Figure 8-61: Sea level rise drainage vulnerability – Kings Creek subcatchment

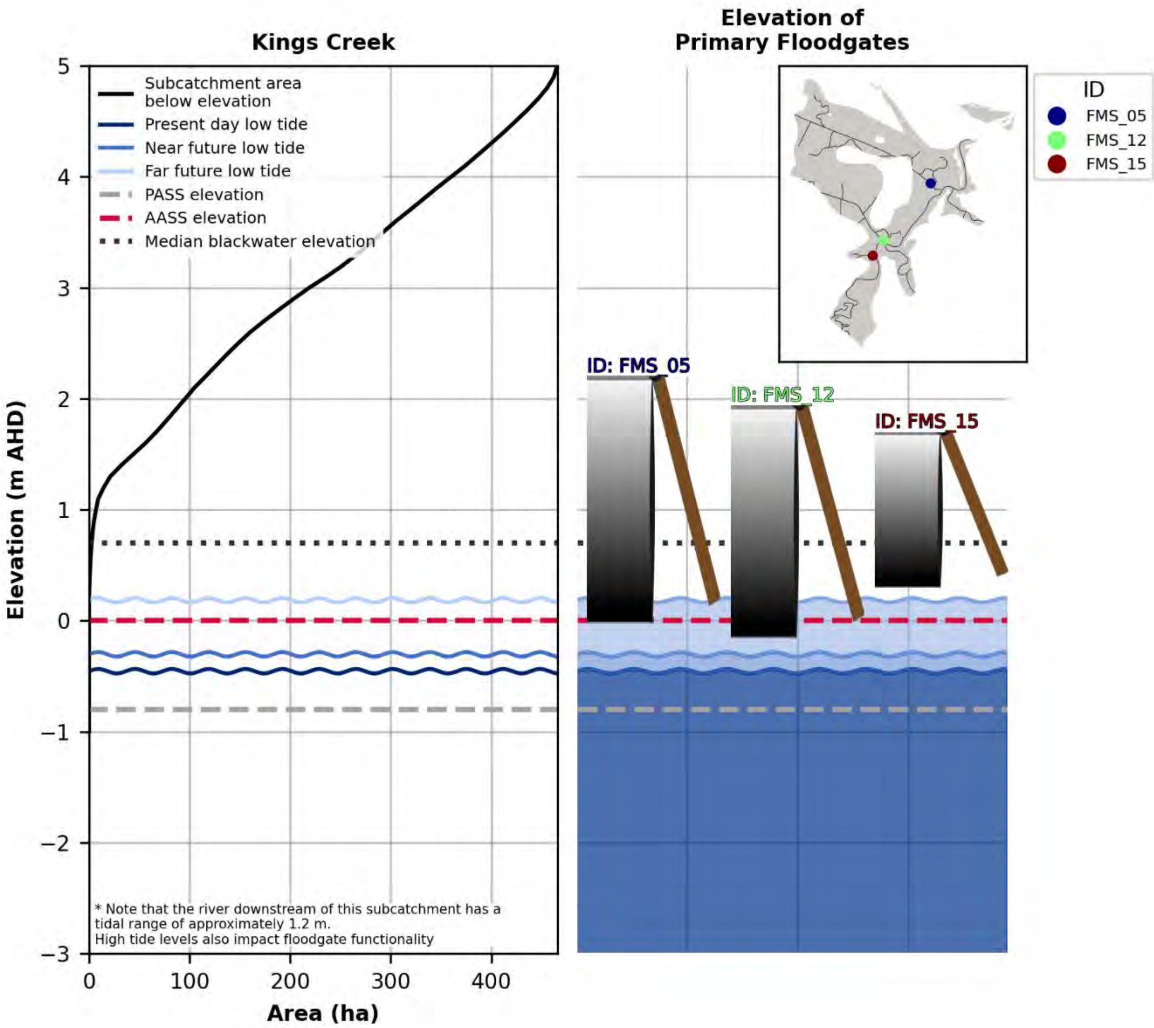

Figure 8-62: Key floodplain elevations – Kings Creek subcatchment

8.11.4 Management options

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

- Short-term: Consider opening floodgates during non-flood periods (floodgate ID FMS_05, FMS_12) to allow tidal flushing; and
- Long-term: As sea level rise occurs, levee or weirs may be required to manage tidal flows while keeping the main floodgates open during non-flood periods.

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

Short-term management options

The two (2) main floodgates in this subcatchment (floodgate ID FMS_05, FMS_12) are fitted with winches. The management of the floodgates is unknown, but it is recommended that winching open the floodgates is considered to allow tidal flushing during dry periods. While the Kings Creek subcatchment was identified as relatively low risk for both acid and blackwater drainage, increased flushing and decreased residence time in the drainage system will likely improve overall water quality throughout the drainage system. Salinity levels may need to be monitored to prevent impacts to surrounding landholders.

Long-term management options

Long term, it is recommended that winching open floodgates is continued. However, additional structures may be required to manage tidal inflows including potentially improving levees or installation of weirs. This should be considered as required as sea level rise continues to occur.

Table 8-17: Summary of management options for Kings Creek

Timeframe	Strategy	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing)	Indicative cost (lost productivity)	Effectiveness at improving:		
						Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Active management of floodgate winches	None	None	$5,000	None	High	High	Low
Long-term	Possible installation of weirs	None	$25,000	$5,000	None	None	Moderate	Low

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

8.12 Port Macquarie Airport subcatchment

Acid priority rank:	**10**
Blackwater priority rank:	**12**
Infrastructure	
Approximate waterway length (km)	6
# Privately owned end of system structures	0
# Publicly owned end of system structures	0
# Structures to be confirmed	0
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (ID)	N/A
Elevations	
Invert of primary floodplain infrastructure (m AHD)	N/A
Approximate AASS elevation (m AHD)	N/A
Approximate PASS elevation (m AHD)	N/A
Median blackwater elevation (m AHD)	0.4
Present day low water level (m AHD)	-0.5
Near future low water level (m AHD)	-0.3
Far future low level (m AHD)	0.2
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)	886
Classified as conservation and minimal use (ha (%))	169 (19%)
Classified as grazing (ha (%))	138 (16%)
Classified as forestry (ha (%))	0 (0%)
Classified as horticulture (ha (%))	0 (0%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	271 (31%)
Classified as marsh/wetland (ha (%))	304 (34%)
Other (ha (%))	4 (0%)
Land values	
Estimated total primary production value ($/year)	$100,000
Average land value above 0.4 m AHD ($/ha)	$13,400
Average land value below 0.4 m AHD ($/ha)	No property data available

8.12.1 Site description

The Port Macquarie Airport subcatchment is a small area immediately adjacent to the town of Port Macquarie, shown in Figure 8-63. The majority of the subcatchment is classified as conservation and minimal use or marsh/wetland (a combined total of 53% of the subcatchment). A small area of grazing (less than 100 ha) also occurs in the subcatchment.

Soil profiles in this subcatchment indicates that ASS with high acidity do exist, particularly in the low, undeveloped area in the north-west of the subcatchment (minimum soil pH of 4.5 observed). There is minimal artificial drainage in this area and acid discharges are likely to be small. Water quality monitoring in the Hastings River downstream of this subcatchment did not indicate issues with acidity or low dissolved oxygen originating from this subcatchment (Ryder et al., 2011), although the lower estuary is likely to be well flushed.

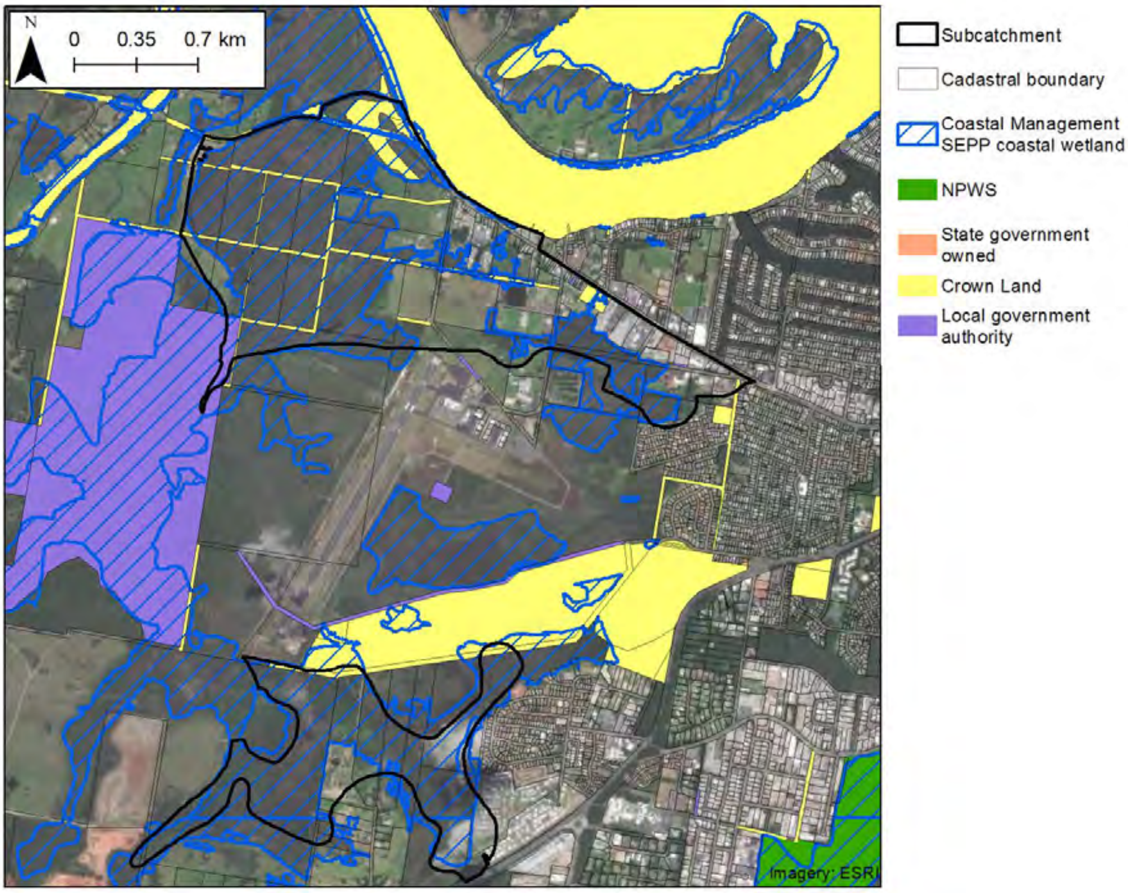

Figure 8-63: Port Macquarie Airport subcatchment land tenure

8.12.2 History of remediation

No attempts of remediation have been identified in the Port Macquarie Airport subcatchment.

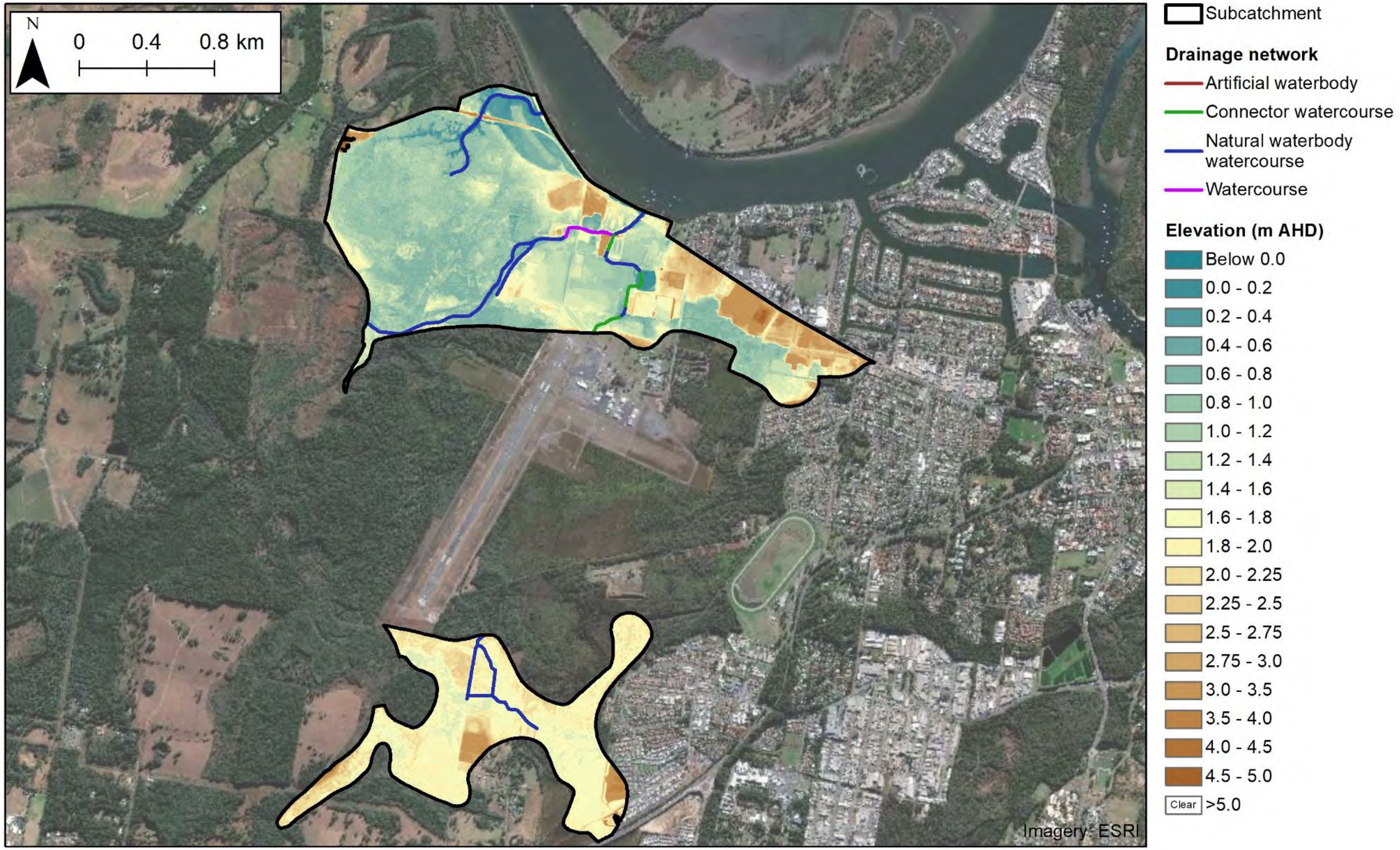

Figure 8-64: Port Macquarie Airport elevation and drainage network

8.12.3 Floodplain drainage – sea level rise vulnerability

Figure 8-65 summarises the sea level rise vulnerability in the Port Macquarie Airport subcatchment. The wetland area in the north west of the subcatchment is low lying and the intertidal area is likely to increase in the near to far future due to sea level rise. The adjacent area to the east that is used for grazing was predicted to be partially at low risk of reduced drainage under the far future sea level rise scenario. Reduced drainage may impact the small area that is currently maintained for agriculture in this subcatchment.

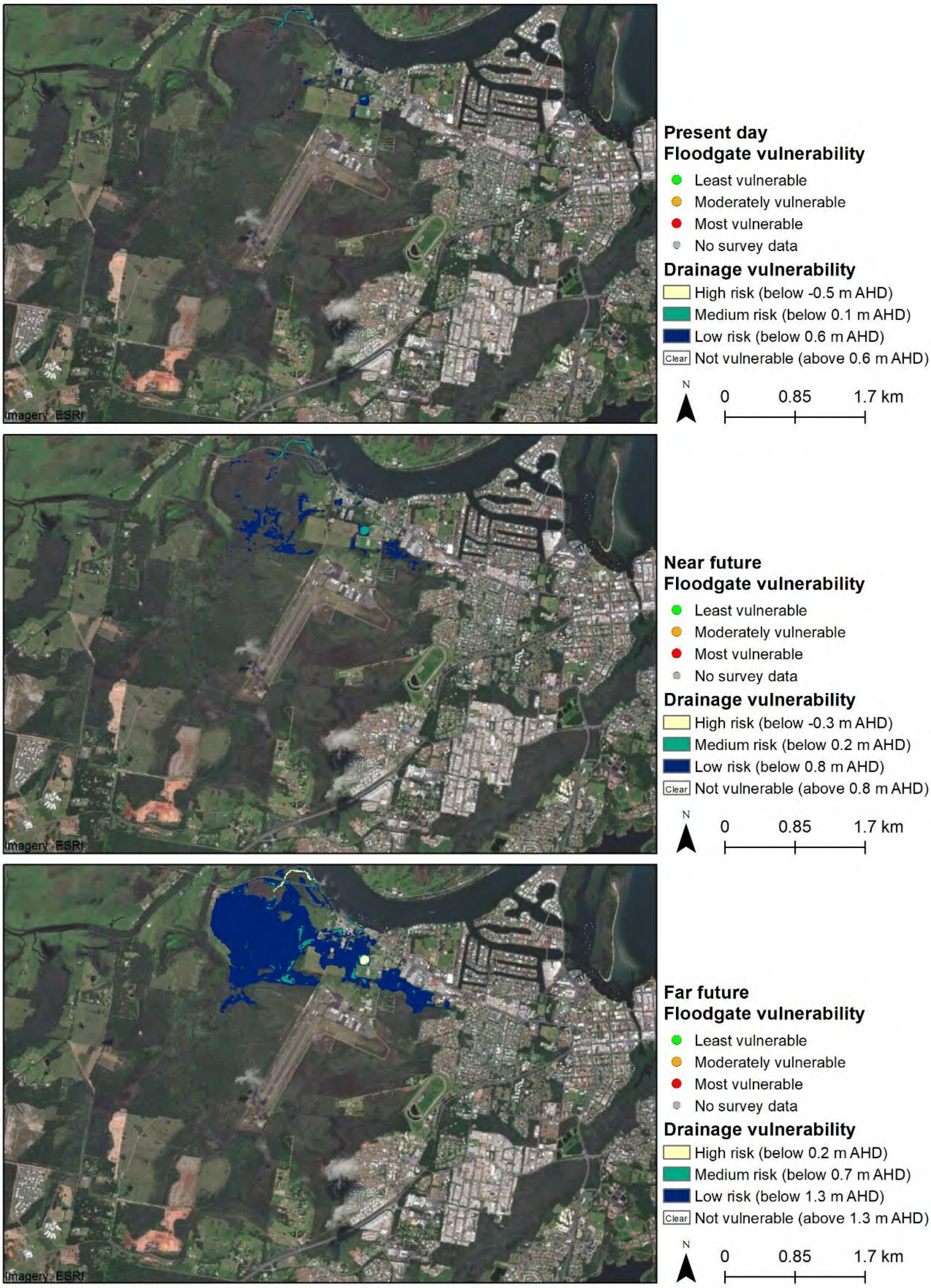

Figure 8-65: Sea level rise drainage vulnerability – Port Macquarie Airport subcatchment

8.12.4 Management options

Potential management options for short and long-term planning horizons for the Port Macquarie Airport subcatchment include:

- Short-term: Ongoing management and protection of existing Coastal Management SEPP coastal wetlands; and
- Long-term: Ensure continued protection of coastal wetland if urban pressures on the subcatchment increases.

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

Short-term management options
The acid and blackwater risk from this subcatchment was found to be relatively low and no changes to existing land or drainage management is recommended. However, the management and protection of existing Coastal Management SEPP coastal wetland areas should be prioritised to maintain habitat and prevent the disturbance of ASS.

Long-term management options
If urban pressures increase around Port Macquarie, the on-going protection and management of Coastal Management SEPP coastal wetland areas should be prioritised to ensure habitats are protected and no ASS are disturbed.

8.13 Sarahs Creek/Sancrox subcatchment

Acid priority rank:	**11**
Blackwater priority rank:	**10**
<u>Infrastructure</u>	
Approximate waterway length (km)	6
# Privately owned end of system structures	0
# Publicly owned end of system structures	0
# Structures to be confirmed	0
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (ID)	N/A
<u>Elevations</u>	
Invert of primary floodplain infrastructure (m AHD)	N/A
Approximate AASS elevation (m AHD)	-0.4
Approximate PASS elevation (m AHD)	Insufficient information
Median blackwater elevation (m AHD)	0.7
Present day low water level (m AHD)	-0.5
Near future low water level (m AHD)	-0.3
Far future low level (m AHD)	0.2
<u>Proximity to sensitive receivers</u>	
Oyster Leases (km)	2.4
Saltmarsh (km)	2.0
Seagrass (km)	1.1
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
<u>Land use</u>	
Total floodplain area (ha)	245
Classified as conservation and minimal use (ha (%))	10 (4%)
Classified as grazing (ha (%))	178 (73%)
Classified as forestry (ha (%))	0 (0%)
Classified as horticulture (ha (%))	0 (0%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	18 (7%)
Classified as marsh/wetland (ha (%))	20 (8%)
Other (ha (%))	19 (8%)
<u>Land values</u>	
Estimated total primary production value ($/year)	$100,000
Average land value above 0.7 m AHD ($/ha)	$30,000
Average land value below 0.7 m AHD ($/ha)	No property data available

8.13.1 Site description

The Sarahs Creek/Sancrox subcatchment is a small floodplain area in the upper Hastings River floodplain, shown in Figure 8-66, which is primarily used for grazing. There is low elevation land around Sarahs Creek in the west of the subcatchment, while the Sancrox area is higher, as shown in Figure 8-67. There are no floodgates in this subcatchment, and the area has minimal artificial drainage.

Soil profiles in the Sarahs Creek/Sancrox subcatchment shows that ASS do occur (minimum pH observed was 4.2 at soil profile HA_19_P). However, the small catchment area without floodgates resulted in a low ranking in the ASS prioritisation.

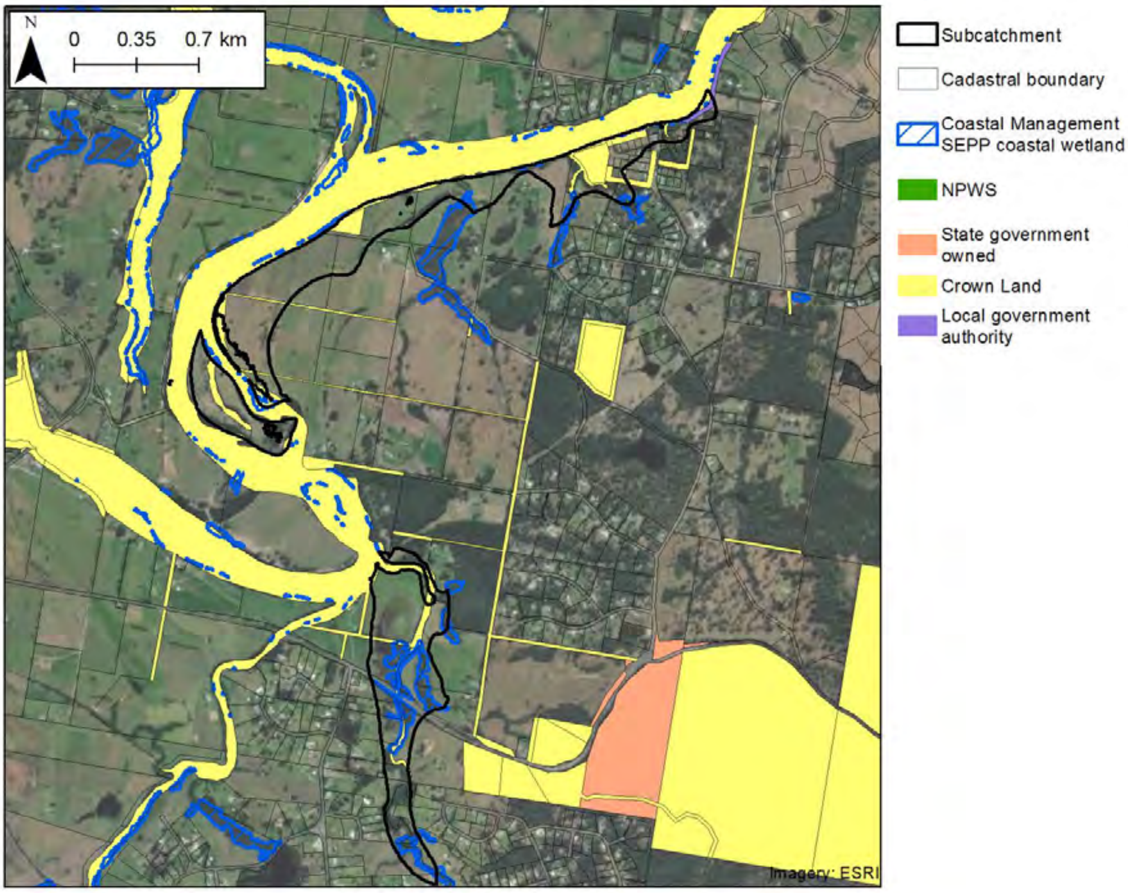

Figure 8-66: Sarahs Creek/Sancrox subcatchment - land tenure

8.13.2 History of remediation

No attempts of remediation have been identified in the Sarahs Creek/Sancrox subcatchment.

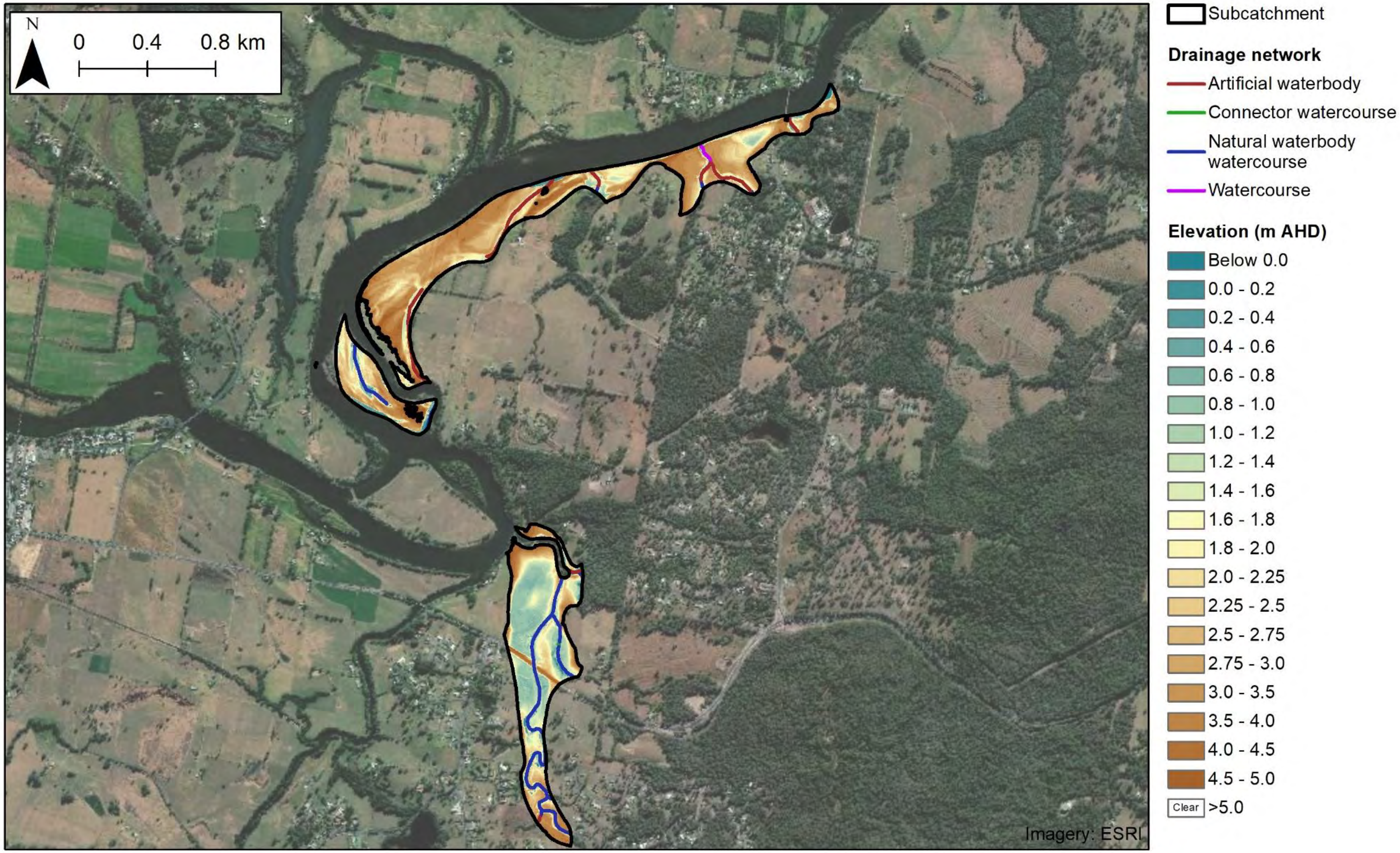

Figure 8-67: Sarahs Creek/Sancrox subcatchment elevation and drainage network

8.13.3 Floodplain drainage – sea level rise vulnerability

The vulnerability of the Sarahs Creek/Sancrox subcatchment to sea level rise is summarised in Figure 8-68. There is a small area adjacent to Sarahs Creek which may be impacted by reduced drainage under the far future sea level rise scenario.

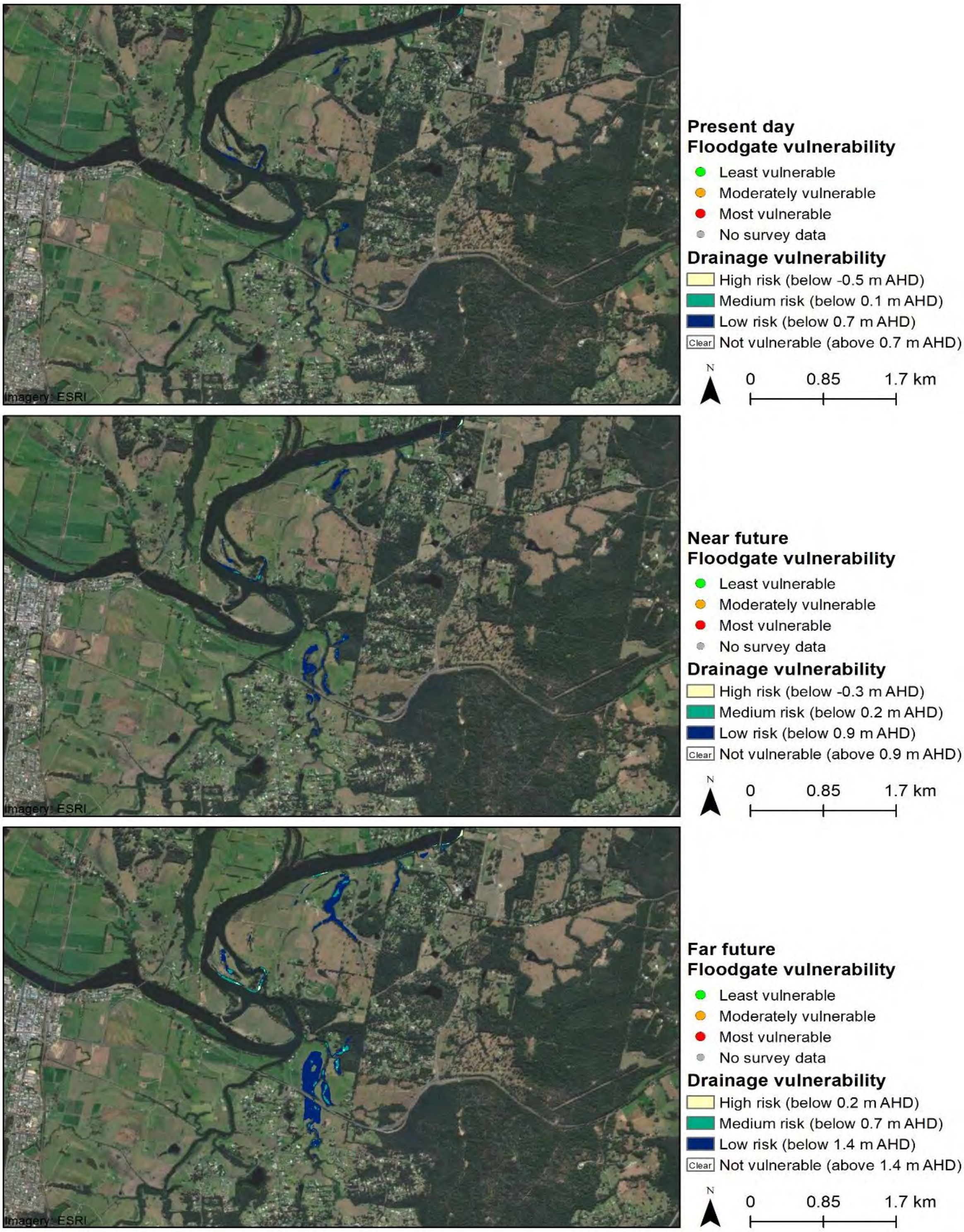

Figure 8-68: Sea level rise drainage vulnerability – Sarahs Creek/Sancox subcatchment

8.13.4 Management options

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

- Short-term: No short-term changes to land management are required; and
- Long-term: If reduced drainage due to future sea level rise impacts land uses in low-lying areas, consider encouraging establishment of wetland habitats.

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

Short-term management options
Due to the low risk of both acid and blackwater generation and minimal floodplain infrastructure, no short-term management options have been recommended.

Long-term management options
In the long term, reduced drainage may impact the lowest areas. If present day land uses cannot persist, any impediments to overland flows and ponding should be removed, and small wetland areas encouraged.

8.14 Limeburners Creek subcatchment

Acid priority rank:	**12**
Blackwater priority rank:	**7**
Infrastructure	
Approximate waterway length (km)	24
# Privately owned end of system structures	2
# Publicly owned end of system structures	2
# Structures to be confirmed	0
# End of system structures within coastal wetlands	3
# Publicly owned end of system structures within coastal wetlands	1
Primary floodplain infrastructure (ID)	FMS_01, FMS_02
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-0.4 to 0.1
Approximate AASS elevation (m AHD)	N/A
Approximate PASS elevation (m AHD)	-0.3
Median blackwater elevation (m AHD)	0.4
Present day low water level (m AHD)	-0.5
Near future low water level (m AHD)	-0.3
Far future low level (m AHD)	0.2
Proximity to sensitive receivers	
Oyster Leases (km)	Within subcatchment
Saltmarsh (km)	Within subcatchment
Seagrass (km)	Within subcatchment
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	2,847
Classified as conservation and minimal use (ha (%))	4683 (91%)
Classified as grazing (ha (%))	110 (2%)
Classified as forestry (ha (%))	124 (2%)
Classified as horticulture (ha (%))	0 (0%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	39 (1%)
Classified as marsh/wetland (ha (%))	5 (0%)
Other (ha (%))	205 (4%)
Land values	
Estimated total primary production value ($/year)	$50,000
Average land value above 0.4 m AHD ($/ha)	$5,300
Average land value below 0.4 m AHD ($/ha)	No property data available

8.14.1 Site description

The Limeburners Creek subcatchment in the Lower Hastings River floodplain, approximately 1 km from the mouth of the estuary. As shown in Figure 8-69, the majority of the subcatchment is within the Limeburners Creek National Park and a small amount of the lower subcatchment is used for grazing near North Shore. A small number of artificial drains have been constructed where the grazing occurs, shown in Figure 8-70. Oyster leases are also maintained in the lower Limeburners Creek.

Water quality monitoring after a high rainfall event in 1997 by Dove (2003) showed that pH decreased in Limeburners Creek moving upstream, however minimum pH levels still remained above six (6) (compared to around eight (8) during a dry period throughout the whole creek). Soil profile data available indicates that minimum soil pH differs throughout the subcatchment (in the range 4.5 to 6), however the location of the subcatchment in the lower estuary near the entrance means that high tidal buffering capacity is likely to prevent widespread acidification of Limeburners Creek (Dove, 2003).

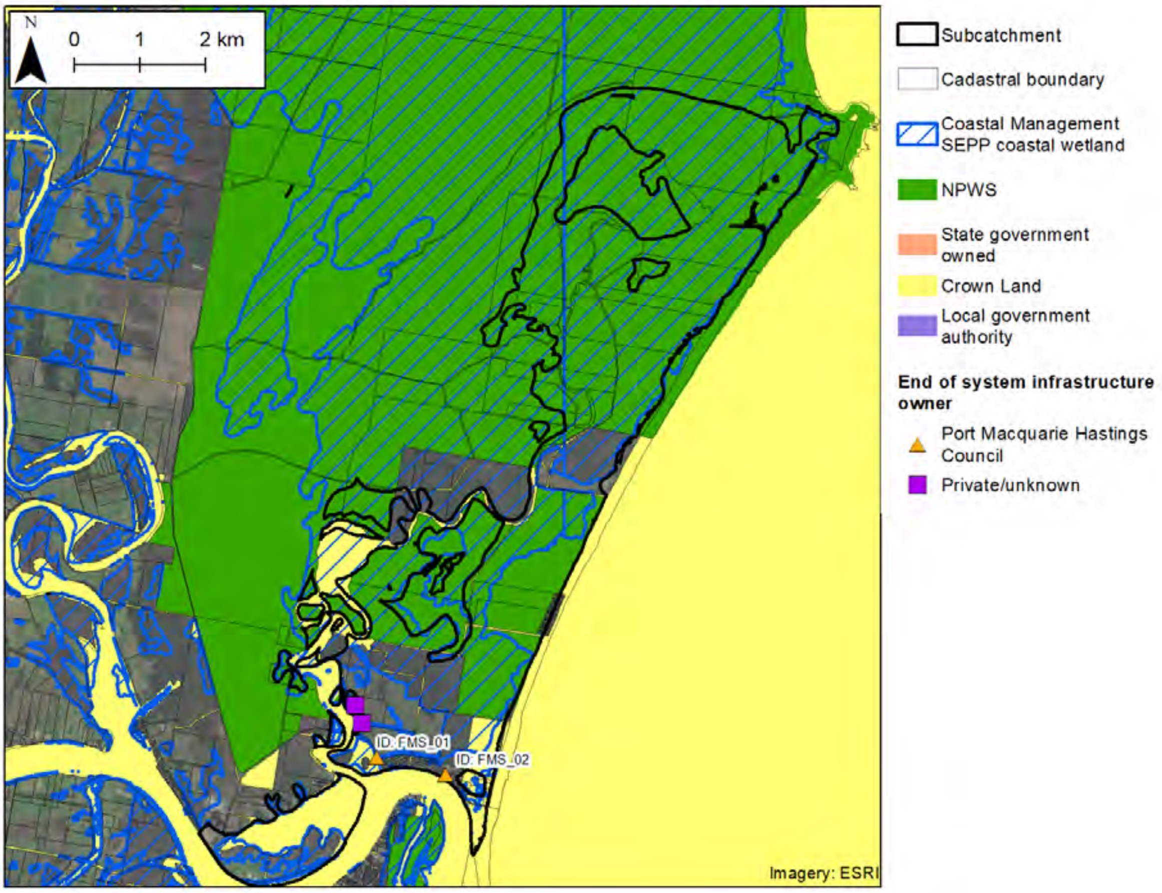

Figure 8-69: Limeburners Creek subcatchment - land and end of system infrastructure tenure

Figure 8-70: Limeburners Creek subcatchment elevation and drainage network

8.14.2 History of remediation

The four (4) floodgates in the Limeburners Creek subcatchment (floodgate ID ASSS_6, ASSS_7, ASSS_27 and ASSS_28) have all been modified with auto-tidal buoyancy gates that allow tidal flushing and provide fish passage. In addition, Figure 8-71 shows that the majority of the subcatchment is within the Limeburners Creek National Park and is largely undeveloped.

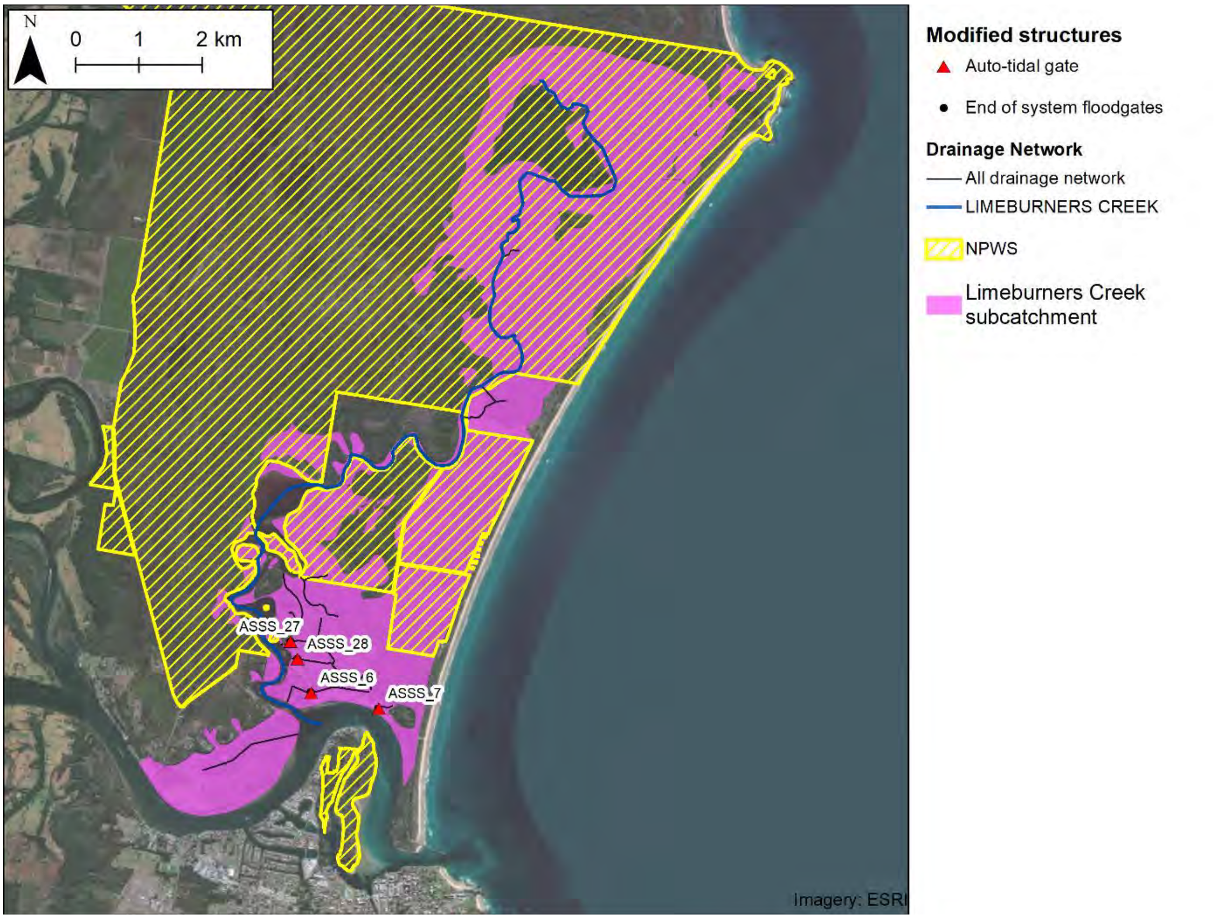

Figure 8-71: Limeburners Creek subcatchment including previous remediation actions

8.14.3 Floodplain drainage – sea level rise vulnerability

Figure 8-72 and Figure 8-73 (primary floodgates only) summarises the sea level rise vulnerability of the Limeburners Creek subcatchment. Of the four (4) floodgates, floodgate ID ASSS_27 was classified as "Moderately vulnerable" under the near future sea level rise scenario and "Most vulnerable" under the far future sea level rise scenario. The other three (3) floodgates were classified as "Moderately vulnerable" under the far future scenario only. In the areas used for grazing, the reduced drainage efficiency of these floodgates may impact the long-term productivity of the land.

Sea level rise may also change the tidal influx within Limeburners Creek National Park in the near to far future. This may result in a transition of vegetation towards salt tolerant species.

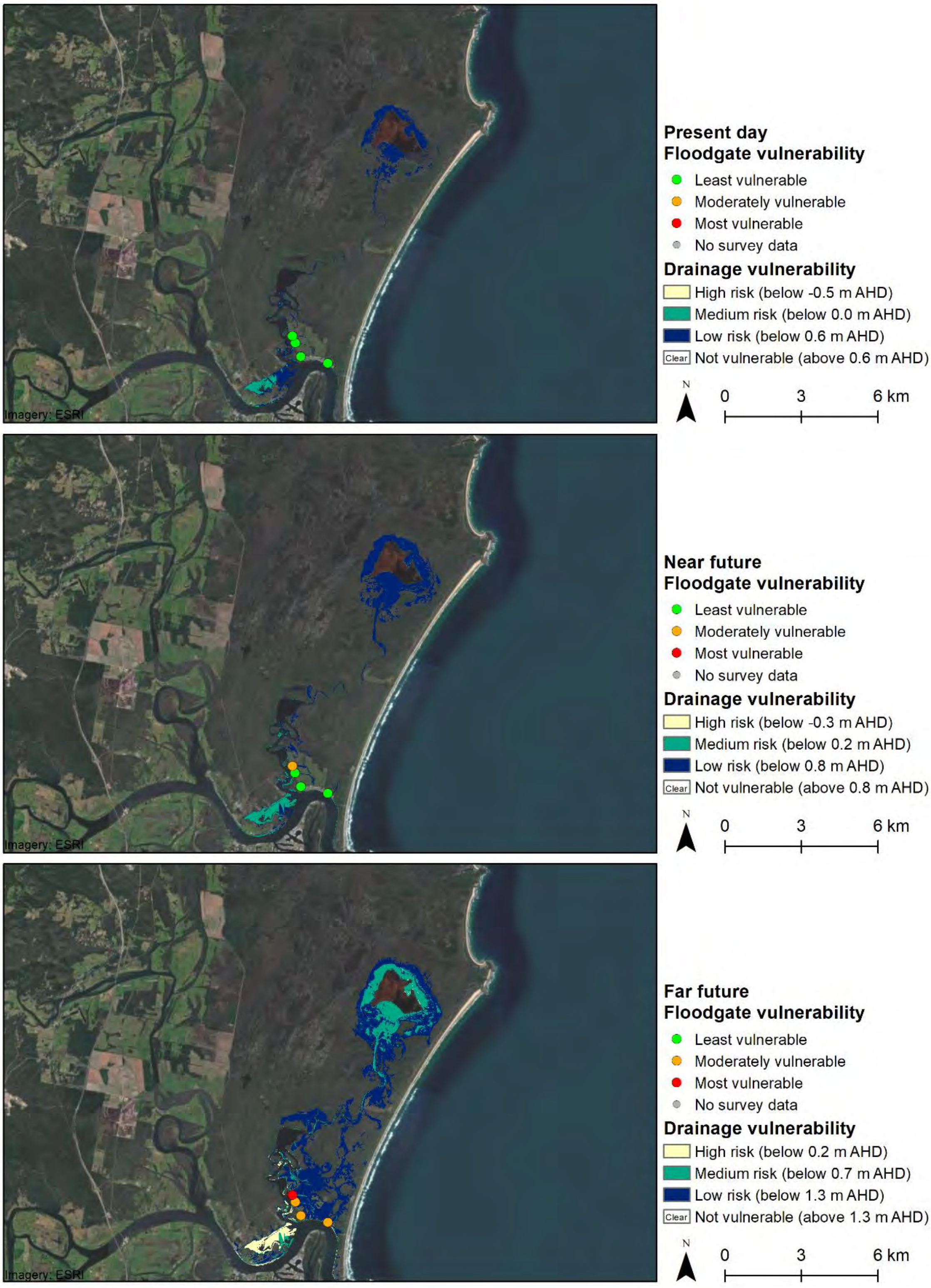

Figure 8-72: Sea level rise drainage vulnerability – Limeburners Creek subcatchment

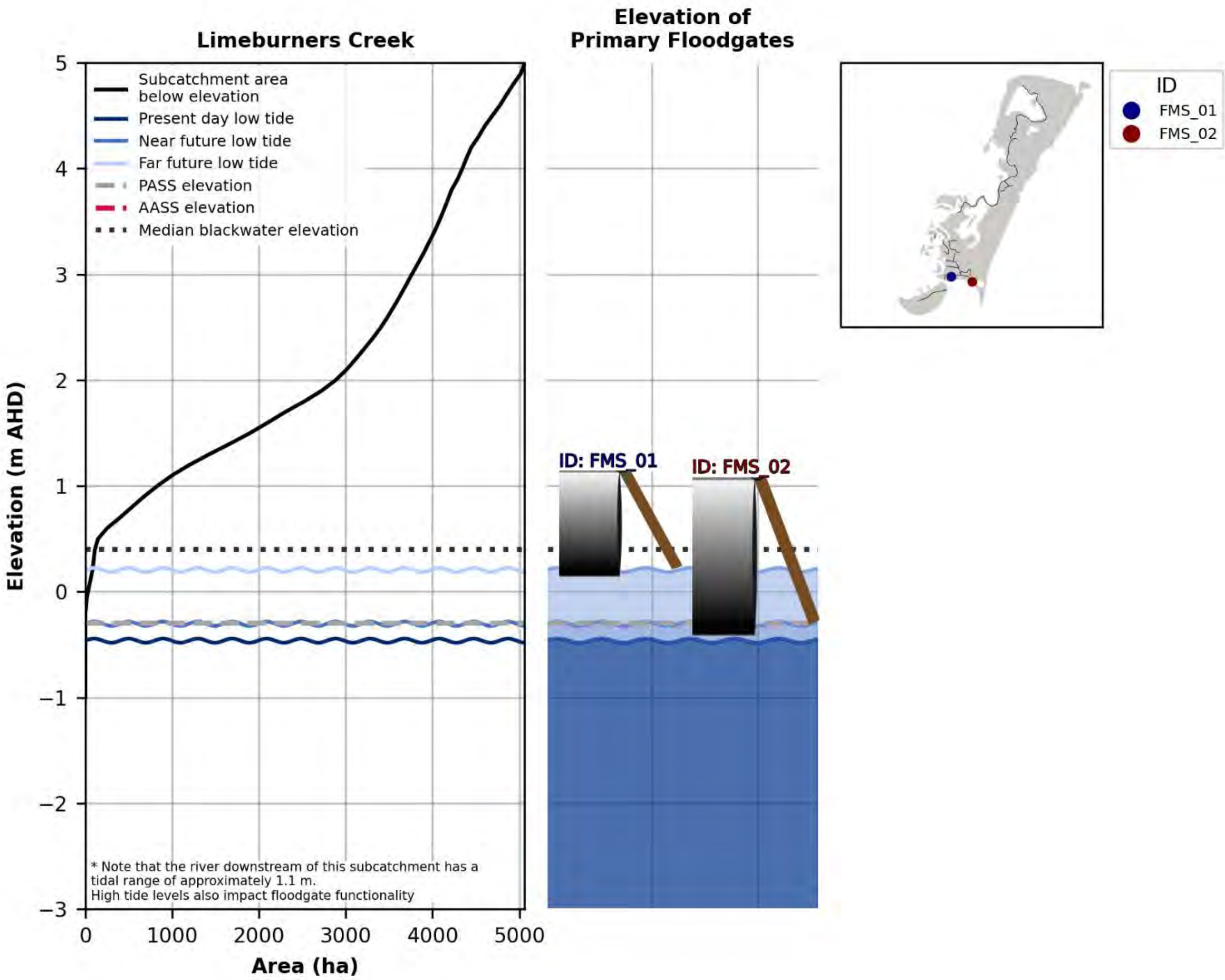

Figure 8-73: Key floodplain elevations – Limeburners subcatchment

8.14.4 Management options

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

- Short-term: Continued support for National Park management; and
- Long-term: Ensure continued protection of Coastal Management SEPP coastal wetlands if urban pressures on the subcatchment increases.

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

Short-term management options
The on-going management of Limeburners Creek National Park should be supported. No other changes to management is recommended to address acid and blackwater discharges.

Long-term management options
If urban pressures increase along North Shore, the on-going protection and management of Coastal Management SEPP coastal wetland areas should be prioritised to ensure habitat remains and no ASS are disturbed.

8.15 Redbank subcatchment

Acid priority rank:	**13**
Blackwater priority rank:	**11**
Infrastructure	
Approximate waterway length (km)	3
# Privately owned end of system structures	0
# Publicly owned end of system structures	0
# Structures to be confirmed	0
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (ID):	N/A
Elevations	
Invert of primary floodplain infrastructure (m AHD)	N/A
Approximate AASS elevation (m AHD)	N/A
Approximate PASS elevation (m AHD)	1.5
Median blackwater elevation (m AHD)	0.7
Present day low water level (m AHD)	-0.4
Near future low water level (m AHD)	-0.3
Far future low level (m AHD)	0.2
Proximity to sensitive receivers	
Oyster Leases (km)	4.6
Saltmarsh (km)	3.8
Seagrass (km)	2.4
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	280
Classified as conservation and minimal use (ha (%))	0 (0%)
Classified as grazing (ha (%))	232 (83%)
Classified as forestry (ha (%))	0 (0%)
Classified as horticulture (ha (%))	0 (0%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	12 (4%)
Classified as marsh/wetland (ha (%))	6 (2%)
Other (ha (%))	30 (11%)
Land values	
Estimated total primary production value ($/year)	$100,000
Average land value above 0.7 m AHD ($/ha)	$9,000
Average land value below 0.7 m AHD ($/ha)	No property data available

8.15.1 Site description

The Redbank subcatchment is in the upper Hastings River estuary. The floodplain area is privately owned (shown in Figure 8-74) and used for grazing. While some small, paddock scale drains have been constructed to facilitate agricultural land use, there are few large scale artificial drains, as shown in Figure 8-75 and the majority of the subcatchment is situated above +1.5 m AHD.

Soil profiles in the Redbank subcatchment shows that ASS do occur (minimum pH observed was 4.7 at soil profile HA_30_A). However, the small catchment area with no floodgates and low hydraulic conductivity resulted in the lowest ranking in the ASS prioritisation.

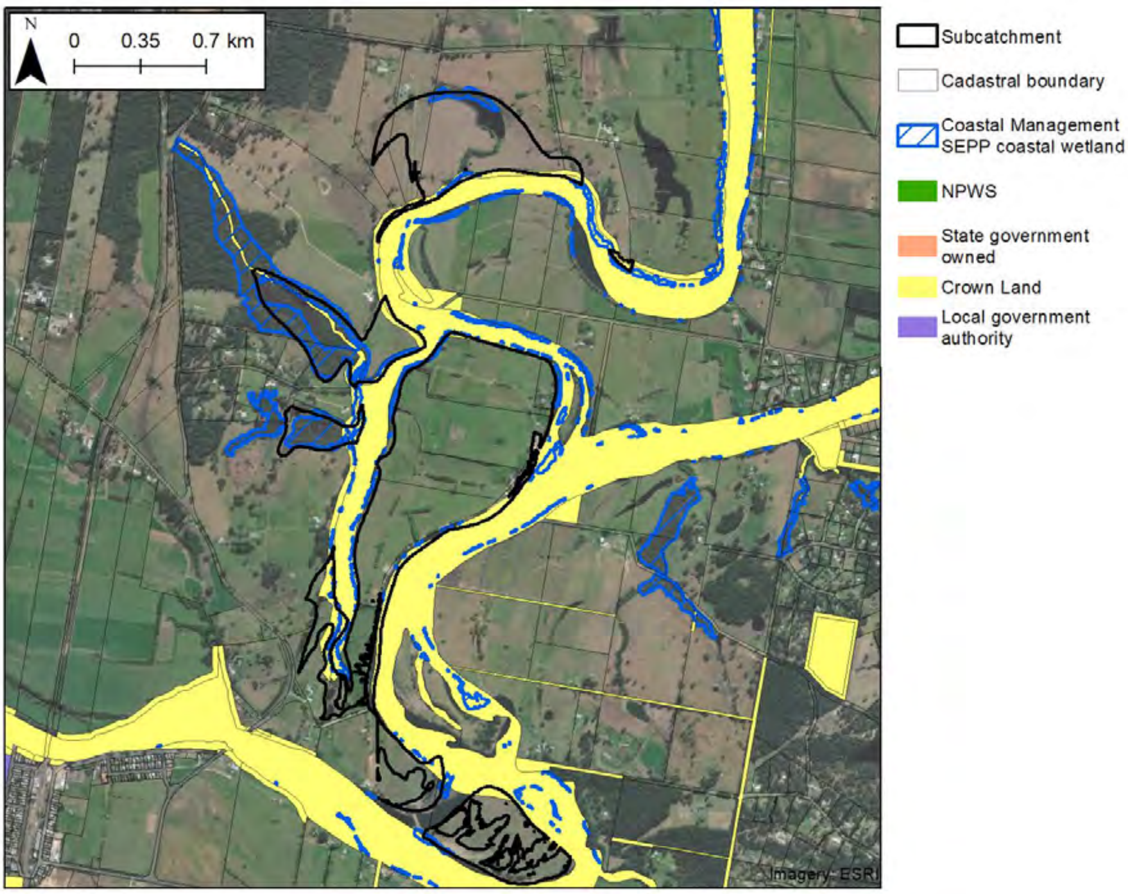

Figure 8-74: Redbank subcatchment - land and end of system infrastructure tenure

8.15.2 History of remediation

No attempts of remediation have been identified in the Redbank subcatchment.

Figure 8-75: Redbank subcatchment elevation and drainage network

8.15.3 Floodplain drainage – sea level rise vulnerability

Figure 8-76 summarises the sea level rise vulnerability in the Redbank subcatchment. Apart from a small area around Horsley Creek (which is already managed as a wetland), the majority of this subcatchment is relatively high and is unlikely to be severely impacted by reduced drainage.

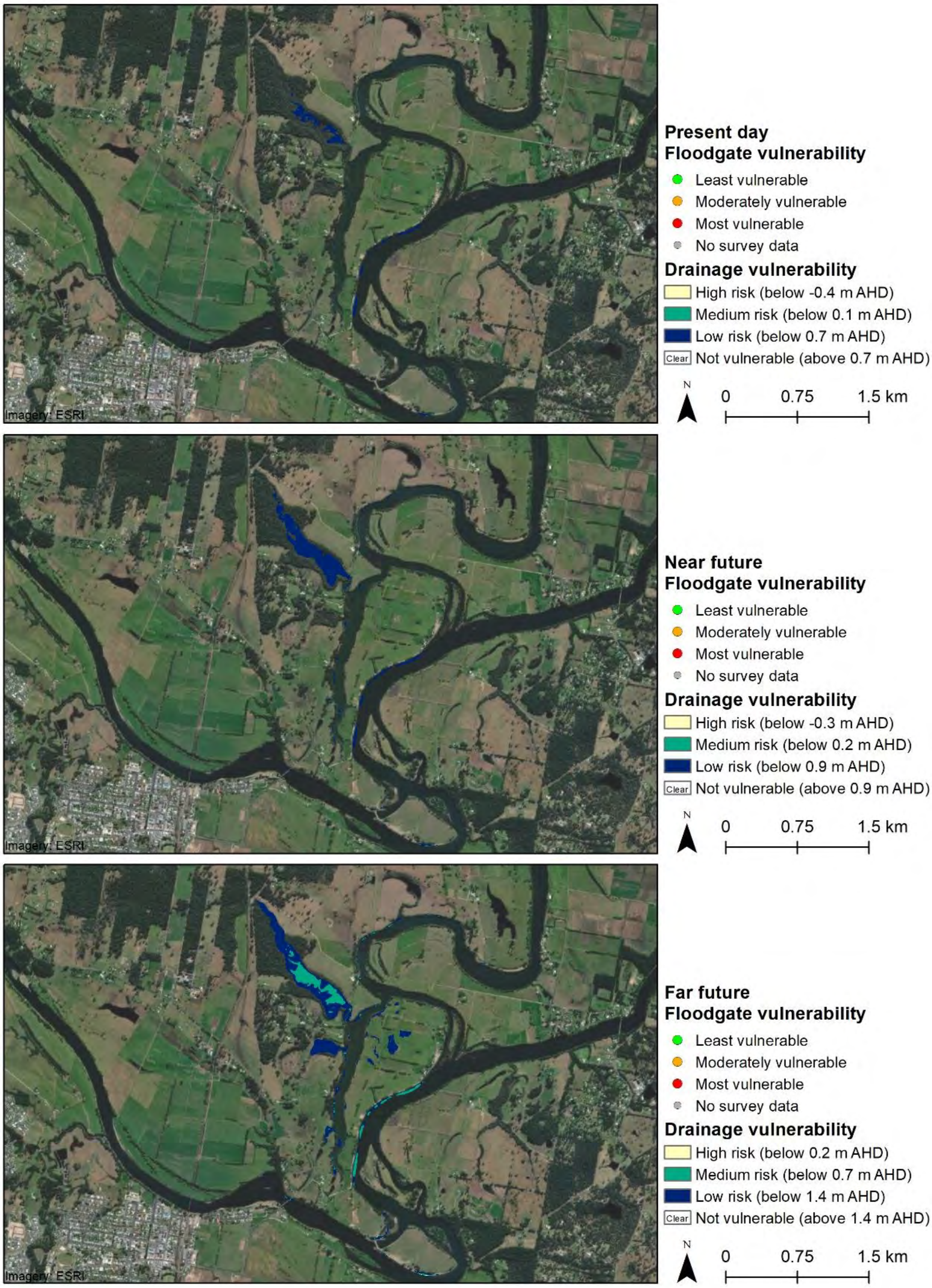

Figure 8-76: Sea level rise drainage vulnerability – Redbank subcatchment

8.15.4 Management options

Due to the low risk of acid and blackwater generation in the Redbank subcatchment, no specific changes to land management is recommended, other than continued management and protection of existing Coastal Management SEPP coastal wetland areas.

9 Outcomes and recommendations

9.1 Preamble

The objective of the Coastal Floodplain Prioritisation Study was to provide a roadmap for the strategic management of acid sulfate soils (ASS) and low oxygen blackwater runoff from seven (7) major coastal floodplains in NSW, to improve the water quality and overall health of the marine estate. This has been achieved 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 Hastings River floodplain with regard to their contribution to acid and blackwater generation and the risk they pose to the health of the marine estate;
- Development of management options for individual subcatchments outlining potential strategies for on-ground works to improve water quality; and
- Collation of catchment specific data relevant to the implementation of management options.

This approach has identified high-priority subcatchments within the Hastings River coastal floodplain system to allow targeted floodplain management to improve water quality. The outcomes of the subcatchment prioritisation, management option development and supporting information, provide an objective prioritised list of 13 floodplain subcatchments with a roadmap on how to achieve water quality improvements across the Hastings 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 Hastings 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 Hastings River floodplain, the highest two (2) ranked subcatchments for acid drainage: Lower Maria River West (1) and Upper Maria River (2) were estimated to contribute over 55% of the total acid risk to the estuary. The Lower Maria River West subcatchment was estimated to individually be the source of 37% of acid risk to the estuary. High risk acid subcatchments were identified across the whole Maria River area, indicating that this tributary may be particularly vulnerable to acidification (Table 9-1). Significant remediation actions have been implemented across the floodplain, with observed benefits in reducing acid discharge and improving estuarine water quality. A significant number of drainage structures have been modified to promote tidal flushing of surface waters, and/or installation of water retention structures to raise upstream groundwater tables to reduce acid drainage.

Table 9-1: Hastings River floodplain subcatchment priority ranking

Floodplain subcatchment	Acid rank	Blackwater rank
Lower Maria River West	1	3
Upper Maria River	2	2
Partridge Creek	3	13
Connection Creek	4	1
Pembrooke	5	5
Lower Maria River East	6	4
Rawdon Island	7	8
Fernbank Creek	8	6
Kings Creek	9	9
Port Macquarie Airport	10	12
Sarahs Creek/Sancrox	11	10
Limeburners Creek	12	7
Redbank	13	11

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 two (2) ranked subcatchments (Table 9-1), Connection Creek (1) and Upper Maria River (2), each account for 39% of the over blackwater generation potential in the Hastings River. The top four (4) ranked subcatchments for blackwater generation potential are all on the Maria River and collectively account for approximately 95% of the total blackwater generation potential in the estuary.

While blackwater runoff occurs in the Hastings River floodplain, it has historically not been as significant an issue compared to other large coastal floodplains in NSW (e.g. Richmond River or Macleay River floodplains). While ASS and blackwater risks have been individually ranked, this does not mean that the impacts of blackwater are necessarily comparable to the impacts of ASS on the Hastings River floodplain.

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

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

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

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.

Table 9-2: Floodplain vulnerability under sea level rise

Vulnerability Status	Historic scenario (HS) ~1960	Present Day (PD) 2020	Near Future (NF) ~2050	Far Future (FF) ~2100
Floodgates (number of)				
Least vulnerable floodgates	50	48	35	9
Moderately vulnerable floodgates	14	15	26	33
Most vulnerable floodgates	2	3	5	24
Floodplain Area (hectares)				
Low vulnerability area	2,857	3,410	5,133	7,929
Moderate vulnerability area	89	111	257	4,260
High vulnerability area	2	6	22	314

Outcomes from the Coastal Floodplain Prioritisation Study for the Hastings 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 flood mitigation drainage areas and subcatchments on the basis of the risk they pose to the marine estate in terms of poor water quality resulting from ASS and blackwater runoff;
2. Developed potential management options that describe the overall strategy for floodplain management to improve water quality; and
3. Identified and collated key datasets that will be valuable for the implementation of management options.

9.3 Conclusions

Across the Hastings River estuary, local government, and landholders have completed significant on-ground works to reduce the impact of acid sulfate soils on the waterway. This includes major floodplain end-of-system infrastructure being modified to allow some controlled flushing (e.g. sluice gates, auto-tidal gates and winches), improved connectivity with the estuary and large scale remediation of the Partridge Creek area. Numerous landholders have co-operated with paddock scale interventions, such as weirs or drain reshaping, with mixed success in terms of water quality improvements and maintenance/improvement of agricultural productivity. These remediation efforts should be encouraged and commended. However, to address water quality issue on a large scale in the Hastings River, broadscale changes to land use and a restoration of natural floodplain hydrology will be required. 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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