Manning River Floodplain Prioritisation Study

WRL TR 2020/09, May 2023

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UNSW
Water Research Laboratory

www.wrl.unsw.edu.au
110 King St Manly Vale NSW 2093 Australia
Tel +61 (2) 8071 9800 ABN 57 195 873 179

Executive summary

ES.1 Preamble

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

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

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

The coastal floodplain subcatchments of the Manning River were initially prioritised for acid by Glamore et al. (2016a) for the *Lower Manning River Drainage Remediation Action Plan*. Glamore et al. (2016a) ranked 15 subcatchment areas of the Manning River with respect to acid discharge potential and provided a range of short and long-term management options to address poor water quality issues. The *Lower Manning River Drainage Remediation Action Plan* (Glamore et al., 2016a) forms the basis for this report and, where applicable, the prioritisation has been updated to align with the revised approach as applied to the seven (7) study estuaries. This includes a revision of subcatchment prioritisation for acid discharge from acid sulfate soils, as well as assessing the potential for low oxygen 'blackwater' runoff to the Manning River estuary.

A new report has been developed (as opposed to providing an addendum to Glamore et al. (2016a)) to align with the format and methods of the other NSW coastal floodplains assessed as a part of the Coastal Floodplain Prioritisation Study. This report specifically provides an evidence based assessment of 17 floodplain subcatchment drainage areas across the Manning River floodplain (instead of the 15 subcatchments areas defined in Glamore et al. (2016a)). To determine how water quality from the Manning 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' (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 itself as well as the downstream estuary (Aaso, 2000). Impacts to aquatic ecology can be severe, including fish kills (Winberg and Heath, 2010) and oyster mortality (Dove, 2003). Acid sulfate soils are widespread in the Manning River floodplain and acid discharges have been responsible for degraded aquatic ecosystem health and has particularly detrimental effects on the local oyster industry (Dove, 2003; Smith et al., 1999).

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

Increasingly, the benefits of investing in coastal floodplain areas to reduce the discharge of acidic water, reduce the generation of low oxygen blackwater, and improve the overall water quality of the marine estate are being realised. The value of environmental assets within coastal floodplains are 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 to 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 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.

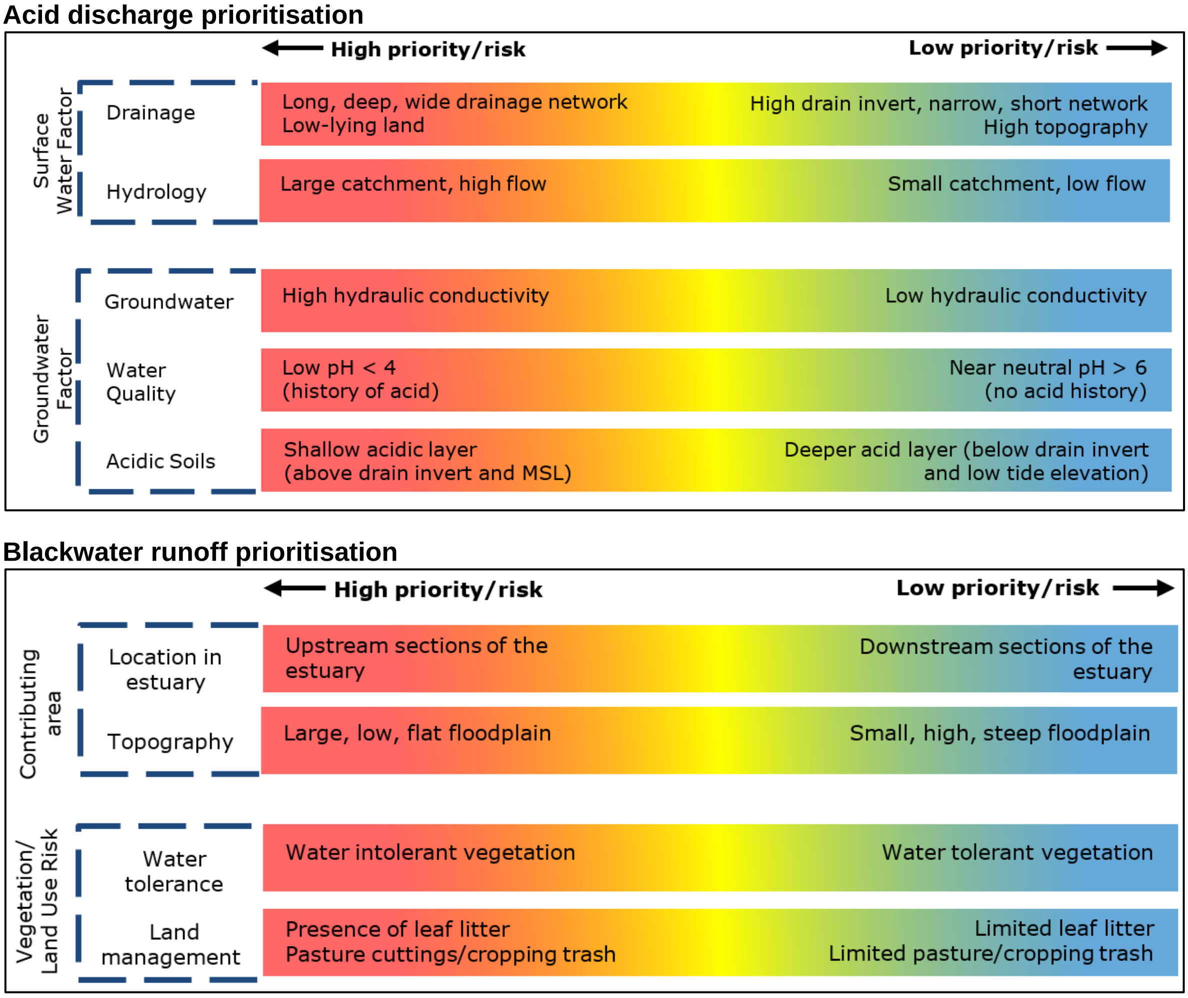

Figure ES-1: Factors influencing acid sulfate soil discharge and blackwater runoff from NSW coastal floodplain subcatchments

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:

- 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).

There are a number of factors that will influence the implementation of management options. The management options developed as part of this study are high level and designed to guide the overall strategy that should be considered by floodplain managers when addressing sources of diffuse poor water quality. It is anticipated that further detailed on-ground investigations are completed prior to the implementation of on-ground actions. While this is not specifically addressed as part of this study, a number of implementation factors have been collated to assist floodplain managers during the detailed design of works to improve water quality. Implementation factors to be considered when considering detailed design and implementation of management options 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 Manning River floodplain subcatchment prioritisation results

The multi-criteria prioritisation methodology was applied to rank subcatchment drainage areas of the Manning 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 17 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.

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 Manning River floodplain, the highest priority subcatchments for acid drainage, namely Big Swamp (1), Moto (2) and Ghinni Ghinni (3) are estimated to contribute almost 90% of the total acid risk to the estuary. The Big Swamp subcatchment was estimated to individually be the source of 38% of acid risk to the estuary (Table ES-1, Figure ES-3).

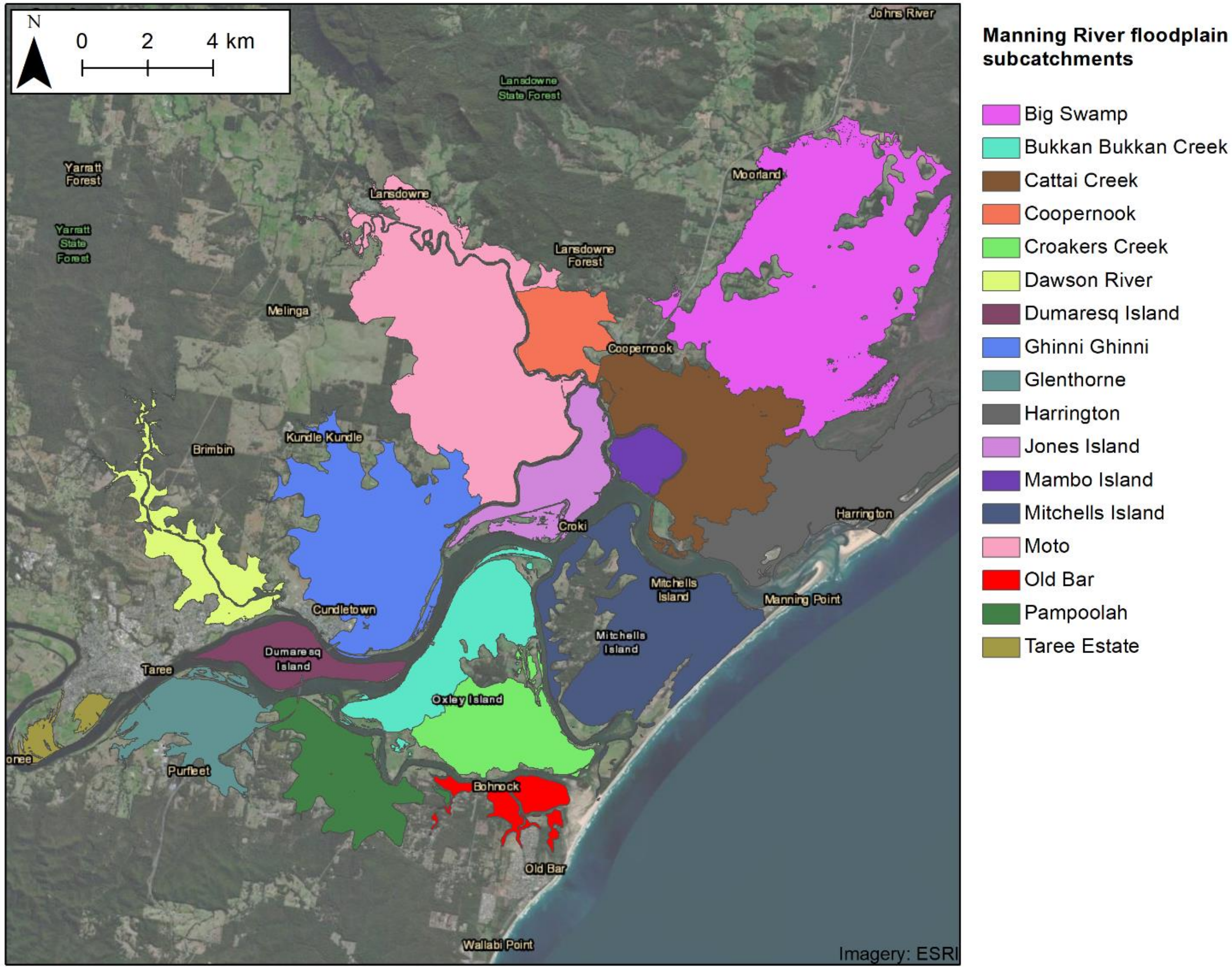

Figure ES-2: Manning River floodplain subcatchments

Table ES-1: Manning River floodplain subcatchment priority ranking

Subcatchment	Acid rank	Blackwater rank
Big Swamp	1	3
Moto	2	2
Ghinni Ghinni	3	1
Bukkan Bukkan Creek	4	5
Coopernook	5	6
Cattai Creek	6	7
Glenthorne	7	9
Jones Island	8	4
Mitchells Island	9	15
Pampoolah	10	13
Croakers Creek	11	8
Mambo Island	12	12
Dawson River	13	10
Dumaresq Island	14	11
Taree Estate	15	14
Harrington	N/A	17
Old Bar	N/A	16

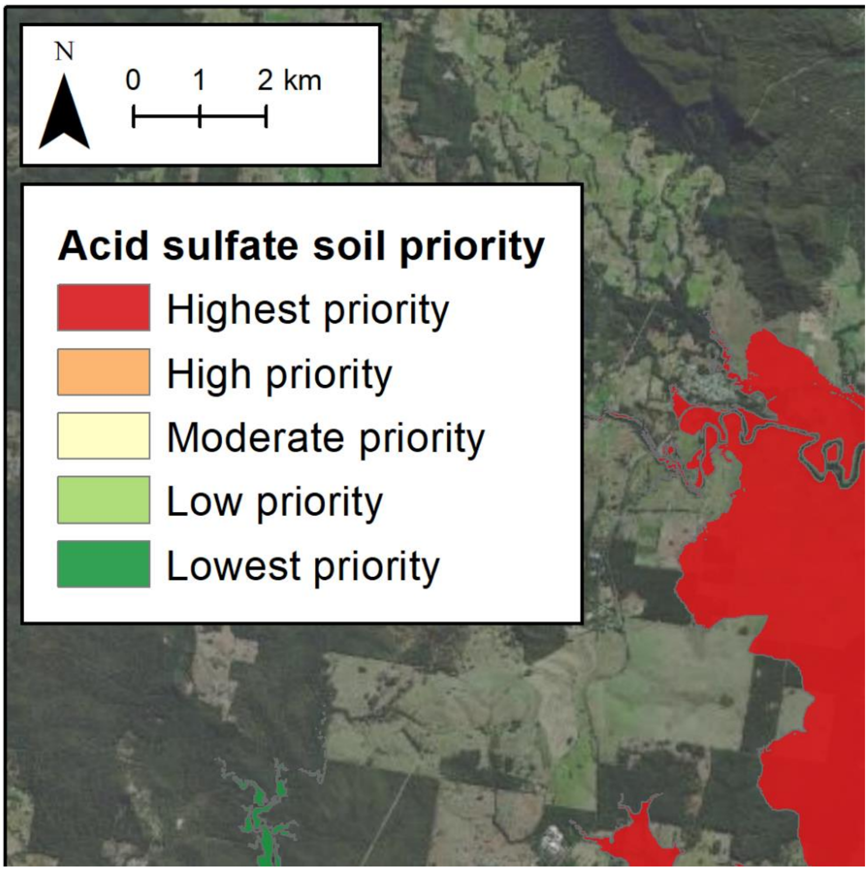

Figure ES-3: Manning River floodplain subcatchment rankings of the acid prioritisation assessment

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 four (4) priority subcatchments in the Manning River floodplain (Ghinni Ghinni, Moto, Big Swamp and Jones Island) collectively represent over 55% of the total blackwater generation risk in the Manning River estuary (Table ES-1, Figure ES-4). However, compared to other larger coastal floodplains in NSW (e.g. Clarence River, Richmond River and Macleay River), prevalence of blackwater and low dissolved oxygen associated with prolonged inundation of floodplains is not as common in the Manning River floodplain. It should be noted that the blackwater prioritisation is separate from the ASS prioritisation. Subsequently, rankings of subcatchments in terms of blackwater risk are not comparable to rankings of subcatchments in terms of ASS risk. While both mechanisms might produce poor water quality within the estuary, it is likely that estuary wide poor water quality resulting from ASS poses a higher risk to the Manning River estuary when compared to poor water quality resulting from blackwater.

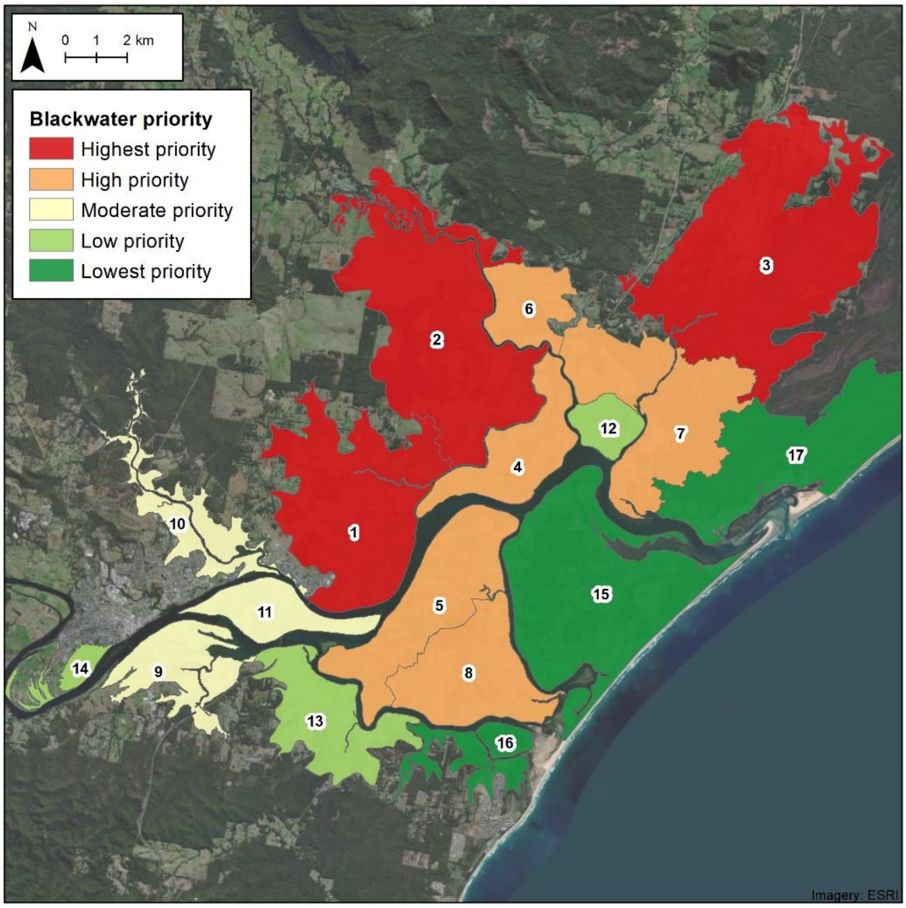

Figure ES-4: Floodplain subcatchment rankings of the blackwater prioritisation assessment

ES.5 Sea level rise and drainage vulnerability

Estuaries are situated at the interface of coastal rivers and the ocean and as a result the impacts of climate change will substantially change their physical environment (Heimhuber et al., 2019b). Sea level rise in particular will result in a significant increase in water levels within estuaries, changing the dynamics of estuarine and coastal floodplain environments . Glamore et al. (2016b) noted that since the 1960s the rate of sea level rise due to climate change has been continually increasing. 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 Manning 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.

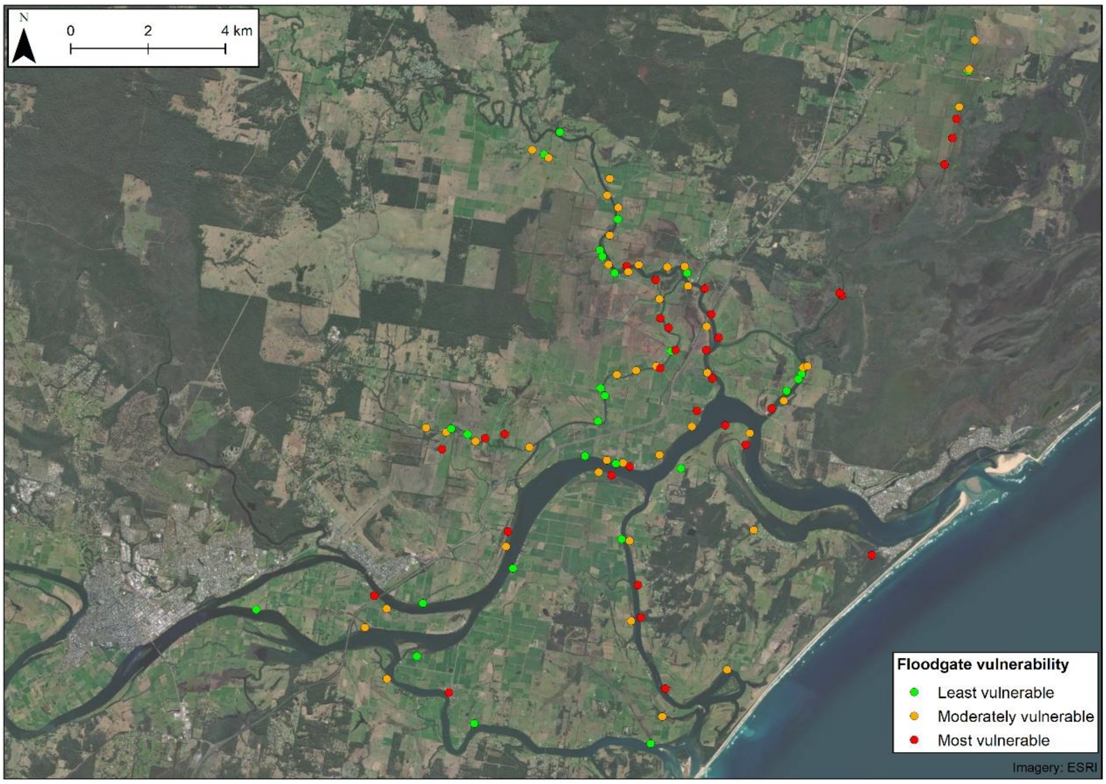

Figure ES-5: Manning River estuary floodgate vulnerability with sea level rise (far future ~2100)

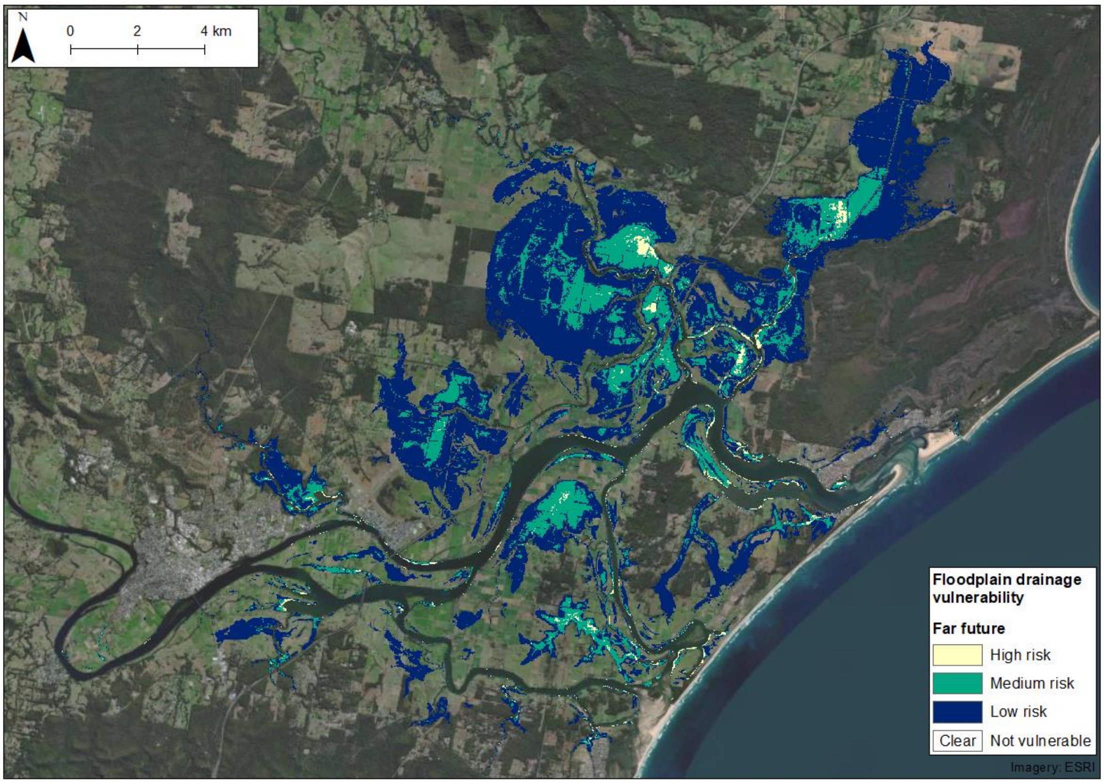

Figure ES-6: Manning River floodplain vulnerability with sea level rise (far future ~2100)

ES.6 Management options for the top three priority subcatchments

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

- Big Swamp;
- Moto; and
- Ghinni.

It is estimated that these three (3) floodplain subcatchments account for approximately 90% and 45% of the overall acid and blackwater generation risk in the Manning River floodplain respectively. Addressing water quality issues from these three (3) subcatchment would result in significant improvements in overall estuarine health.

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.

Big Swamp subcatchment

The Big Swamp subcatchment was ranked first for acid generation, and accounts for approximately 38% of the total acid risk in the Manning River floodplain. The subcatchment also ranked third in the blackwater prioritisation. MidCoast Council has already completed substantial on-ground remediation works and has already acquired close to 900 ha of the low-lying ASS affected areas. A cost-benefit analysis (CBA) was undertaken on behalf of MidCoast Council (Harrison et al., 2019) to support state government funding for broad scale remediation of the low lying areas of the Big Swamp floodplain. This study conservatively estimated remediation works to have a benefit to cost ratio of 7:1, despite not including the costs of acid discharges in the assessment. The Council is currently seeking funding for further investigations and land acquisition.

While small scale benefits may be possible through tidal flushing via floodgate modifications in the Big Swamp subcatchment, the recommendations strongly support the Council’s plan for further acquisitions and large scale remediation. Ultimately, remediation of wetland areas in the Big Swamp subcatchment will provide large environmental benefits through reducing pathways for acid drainage, encouraging water tolerant vegetation, reducing the overall blackwater generation potential and providing aquatic and terrestrial habitat.

Moto subcatchment

The Moto subcatchment ranked second in both the ASS and blackwater prioritisation. The acid generation potential from the Moto subcatchment was found to be comparable to the Big Swamp floodplain (representing 36% of the total acid risk in the Manning River floodplain). MidCoast Council and local landholders have been actively managing acid discharges from the Moto subcatchment over the last two (2) decades, including infilling drains, encouraging wet pasture management and modifying structures.

In the short-term, water quality from the Moto subcatchment could be improved through a combination of floodgate management and drain infilling/reshaping. This would raise the local groundwater table and reduce the acid drainage from the surrounding floodplain to drains, while maintaining existing land uses. In the long-term, reduced drainage as a result of sea level rise will impact increasingly large areas on the Moto subcatchment. Without additional infrastructure the agricultural productivity of the Moto swamp is likely to become increasingly reduced and options for full remediation of poorly drained land to wet pastures (freshwater), or wetland (saline) should be investigated.

Ghinni Ghinni

The Ghinni Ghinni subcatchment was ranked first in the blackwater prioritisation and third in the ASS prioritisation. Previous on-ground works in the Ghinni Ghinni subcatchment involved installation of new water control structures (i.e. culverts and associated floodgates) on the main drains to raise the invert of the drainage points to 0.3 m AHD.

In the short-term, unused paddock drains connected to deep (>0.5 m) drains should be filled/reshaped to reduce pathways for acid drainage, and wet pasture management areas are encouraged across low-lying, boggy land to manage blackwater generation potential. Floodgate modifications, or installation of drop board weirs in the upstream section of Dickensons Creek, along with drain infilling/reshaping across the floodplain, could be used to manage dry and wet weather acid discharges. As with the Moto subcatchment, sea level rise may impact the drainage in the Ghinni Ghinni subcatchment. Without additional infrastructure the agricultural productivity of the Ghinni Ghinni floodplain is likely to become increasingly reduced. Options for remediation to wet pastures (freshwater), or wetlands (saline) should be investigated, which would be effective at reducing both acid and blackwater drainage from this subcatchment.

ES.7 Outcomes and conclusions

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

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

Substantial efforts have been put into managing water quality in the Manning River estuary, through both Council driven efforts and the cooperation of local landholders. Notably, MidCoast Council has proactively pursued large scale restoration in the Big Swamp floodplain. Numerous landholders have co-operated with paddock scale interventions, such as weirs or modified floodgates, with mixed success in terms of water quality improvements and maintenance/improvement of agricultural productivity. These remediation efforts should be encouraged and commended. However, the scale of on-going large event-based floodplain discharges of blackwater and acid, particularly from the three (3) highest priority subcatchments (Big Swamp, Moto, and Ghinni Ghinni) can only be substantially addressed through broadscale changes to land use and a restoration of natural floodplain hydrology. Broadscale management changes throughout the floodplain will need to consider, and have a plan to mitigate, potential social, cultural, and economic impacts to local landholders. Particularly as sea level rise impacts drainage and agricultural land uses in the lowest lying areas of the floodplain, a catchment wide strategy needs to be established to assist the community to adapt to a changing environment and to support a future that is environmentally and economically sustainable.

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Glossary of terms

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

Digital elevation model (DEM)	A 3D computer model of land surface elevation. A DEM is composed of a grid of cells which each represent an elevation value. The size of individual grid cells (e.g. 1 m times 1 m or 5 m times 5 m) is one measure of the accuracy of a DEM.
Discharge	Flow rate measured by volume per unit time (usually in cubic metres per second).
Dissolved organic carbon (DOC)	Organically bound carbon present in water that can pass through a membrane filter with a 0.45µm pore size.
Dissolved oxygen (DO)	Atmospheric oxygen that dissolves in water. The solubility of oxygen depends upon temperature and salinity.
Downstream/ upstream	Downstream is the location in a channel that is closest to the ocean. Upstream is the location in a channel that is furthest from the ocean.
Drop board	Drop boards are frames built across a waterway which enable the manipulation of flow and water levels by the insertion of 'boards' into specifically designed slots to act as a barrier to water movement. Drop boards are similar to weirs in that they only allow water to flow over the top of them. Unlike weirs, drop boards are adjustable in height. Multiple boards with different heights can be used to adjust and set the weir level. Drop boards can be fitted to culverts or can be standalone structures.
Drought	A prolonged period of reduced or low precipitation resulting in a shortage of water.
Electrical conductivity (EC)	A measure of dissolved salt in water in the units of micro Siemens per centimetre (µS/cm) usually at a temperature of 25ºC.
Estuary	A semi-enclosed waterbody where fresh water from catchment runoff and saltwater from the ocean mix.
Evaporation	The process of liquid water on the land surface becoming water vapour in the atmosphere.
Evapotranspiration	The sum of evaporation and transpiration.
Exceedance per year (EY)	The likelihood that a flood or rainfall event of a predetermined size will occur a certain number of times within any one-year period.
Flood	High flow of water within a waterway that results in the overtopping of natural or artificial banks (or levees) of a waterbody and inundation of usually dry land.
Floodgate/ floodgate flap	A plate that is hinged on its top edge to cover the outlet of a culvert. The flap is positioned so that it only opens when the water level on the upstream (floodplain side) is higher that the level on the downstream (river side) of the culvert, thereby only allowing water to flow in the downstream direction effectively draining the floodplain. Floodgates often regularly open and close with fluctuating tidal water levels in the river. It is common for floodgates to have rubber seals to prevent leaking. Floodgate flaps can be made of many materials such as aluminium, plastic, fibre glass or wood.
Floodplain	The area of land adjacent to a waterbody that is often relatively flat and usually dry unless exposed to water as occurs during a flood.
Freshwater	Water that contains less than 1,000 milligrams per litre (mg/L) of dissolved solids.
Gate	A term used to describe the part of either a floodgate or sluice gate flow control structure that controls water movement.
Groundwater	Water held under the ground surface within soil and rock formations.
Groundwater table	The upper surface of soil or rock formations that is fully saturated by groundwater.
Headwall	The concrete structure surrounding and supporting a culvert. Floodgate flaps or other mechanisms are usually mounted to the headwall.
Hydraulic gradient	The difference in pressure or elevation of water over a distance. The hydraulic gradient results in the flow of water (from high elevation or pressure to low elevation or pressure).
Hydrodynamics	The branch of science concerned with the movement of, and forces acting on or exerted by fluids.
Hydrodynamic model	A numerical representation of the movement of water through a system.
Hydrograph	A graph showing the level, discharge, velocity, or other property of water with respect to time.
Hydrology	The branch of science concerned with the movement and quality of water in relation to land.
Impermeable layer	A layer of solid material, such as rock or clay, which does not allow water to pass through.
Invert	The elevation of the lowest internal point of a culvert.
Leaching	The process by which soluble materials in the soil such as salts, nutrients, pesticide chemicals or contaminants are dissolved and carried away by water.
Left bank/right bank	The side of a waterway when looking in the downstream direction (i.e. toward the ocean).

LEP	Local Environmental Plan - LEPs are planning instruments that guide planning decisions for local government areas. They do this through zoning and development controls, which provide a framework for the way land can be used. LEPs are the main planning tool to shape the future of communities and also ensure local development is completed appropriately.
LGA	Local Government Area.
Levee	An embankment that prevents or reduces flow from a waterway to the floodplain. Levees can be naturally formed as river banks or manmade for the purpose of flood mitigation or to prevent inundation of low-lying land.
LiDAR	Light detection and ranging technology that can be used to measure ground surface elevations and create DEMs.
Marine estate	Tidal rivers and estuaries, the shoreline, submerged lands, offshore islands, and the waters of the coast up to three nautical miles offshore.
Management area	A subset or smaller area of a subcatchment often delineated based on floodplain tenure and ownership in addition to floodplain hydrological and geomorphological characteristics. Generally, a management area is of small enough scale that implementation of on-ground works to address water quality issues can be completed.
MBO	Mono-sulfidic black ooze – deposits in drainage channels created by iron and sulphur minerals (pyrite) within acid sulfate soils which, when mobilised, can remove oxygen from the water through a chemical reaction.
Obvert	The elevation of the highest internal point of a culvert.
Organic matter	Substances made by living organisms and based on carbon compounds.
Peak flow	The maximum instantaneous discharge of a waterway at a given location.
pH	A measure of the acidity or alkalinity of water. Water with a pH of 7 is neutral; lower pH levels indicate increasing acidity, while pH levels higher than 7 indicate increasing alkalinity
Pipe	A pipe is a circular culvert. Pipes can be made of many materials such as concrete, PVC or fibre glass.
Precipitation	Water that falls on land surfaces and open waterbodies as rain, sleet, snow, hail or drizzle.
River	A major watercourse carrying water to another river, a lake or the ocean.
Runoff	Excess rainfall that becomes streamflow.
Salinity	The total mass of dissolved salts per unit mass of water. Seawater has a salinity of about 35g/kg or 35 parts per thousand (ppt).
Sediment	Material suspended in water or deposited from suspension.
Seepage	The infiltration of water from surface waterbodies to the groundwater.
Sluice/sluice gate	A gate that operates by sliding vertically to control water flowing through or past a restriction point. Sluice gates act so that water flows underneath the 'sluice' or the sliding section of the gate. A sluice gate can be set to different levels to control the volume of water that flows. There are many different designs for sluice gates.
Soil profile	A vertical section of soil (from the ground surface downwards) where features such as layers (soil horizons), texture, structure, consistency, colour and other characteristics of the soil can be observed.
Streamflow	The flow of water in open waterbodies (such as streams, rivers or channels).
Subcatchment	A section of the floodplain that is geologically and hydrologically similar but can also be delineated based on floodplain management objectives.
Surface water	Water that flows or is stored on the Earth's surface.
Tidal exchange	The proportion of water that is flushed away and replenished with new ocean water each tidal cycle.
Tidal limit	The maximum distance upstream of a waterway where the influence of tidal variation in water levels is observed.
Tidal planes	Reference elevations that define regular tide elevations, including: MHWS - Mean High Water Springs MHW - Mean High Water MSL - Mean Sea Level MLW - Mean Low Water MLWS - Mean Low Water Springs
Tidal prism	The volume of water that flows in and out of an estuary during a tidal cycle (e.g. high tide to low tide).
Transpiration	The release of water vapour from plants to the atmosphere.

Tributary	A smaller river or stream that flows into a larger waterbody.
Water table	The surface of water whether it is under or above ground.
Waterbody	Either: An artificial body of water, including any constructed waterway, canal, inlet, bay, channel, dam, pond, lake or artificial wetland, but does not include a dry detention basin or other stormwater management construction that is only intended to hold water intermittently; or A natural body of water, whether perennial or intermittent, fresh, brackish or saline, the course of which may have been artificially modified or diverted onto a new course, and includes a river, creek, stream, lake, lagoon, natural wetland, estuary, bay, inlet or tidal waters (including the sea).
Watercourse	Any river, creek, stream or chain of ponds, whether artificially modified or not, in which water usually flows, either continuously or intermittently, in a defined bed or channel, but does not include a waterbody (artificial).
Waterway	The whole or any part of a watercourse, wetland, waterbody (artificial) or waterbody (natural).
Weir	Weirs are permanent structures that block a channel and only allow water to flow over the top of them.
Winch	A mechanism used to open floodgate flaps or sluice gates. The winch system usually involves pulling the gates open via chains or cables.

1 Introduction

1.1 Preamble

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

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

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

1.2 Lower Manning River Drainage Remediation Action Plan (Glamore et al., 2016a)

The coastal floodplain subcatchments of the Manning River were initially prioritised for acid sulfate soils by Glamore et al. (2016a) for the *Lower Manning River Drainage Remediation Action Plan*. Glamore et al. (2016a) ranked 15 subcatchment areas with respect to acid discharge potential and provided a range of short and long-term management options to address poor water quality issues. The *Lower Manning River Drainage Remediation Action Plan* (Glamore et al., 2016a) forms the basis for this report and, where applicable, the prioritisation has been updated to align with the revised approach (Rayner et al., 2023) as applied to the seven (7) study estuaries.

While the ASS prioritisation methodology used in this study is based on the same approach as Glamore et al. (2016a), some changes have been incorporated to improve the outcomes and to allow the method to be applied to each of the seven (7) study estuaries. As a result, the ASS prioritisation rankings for the subcatchments of the Manning River estuary have been updated in this report. A comparison and discussion of the differences in ranking in this report to Glamore et al. (2016a) has been provided in Section 5.3.

This present study also assesses the potential for low oxygen 'blackwater' generation from each subcatchment of the Manning River floodplain, which was not considered in Glamore et al. (2016a). The blackwater prioritisation is independent of the ASS prioritisation. While all 15 subcatchments delineated by Glamore et al. (2016a) have been maintained for the blackwater prioritisation, an additional two (2) subcatchment (Old Bar and Harrington) have been included to provide wholistic coverage of the Manning River floodplain. These additional subcatchments were not assessed in the updated ASS prioritisation as there was insufficient existing data and minimal history of ASS drainage issues within the Old Bar and Harrington subcatchments. Where required, the short and long-term management options have been updated to include actions relating to blackwater generation.

1.3 Connection to other reports

The prioritisation of the Manning 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:

- Manning 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);
- Hastings River floodplain (WRL TR2020/08); 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.

1.4 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 Manning 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 Coastal Floodplain Prioritisation Method utilises a multi-criteria analysis to assess the risk of poor water quality from floodplain subcatchments and ranks the subcatchments relative to their contribution to these key water quality issues. Figure 1-1 provides an overview of the study approach.

This report provides a prioritised list of floodplain subcatchments from where the greatest risk of acid and blackwater within each floodplain 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.

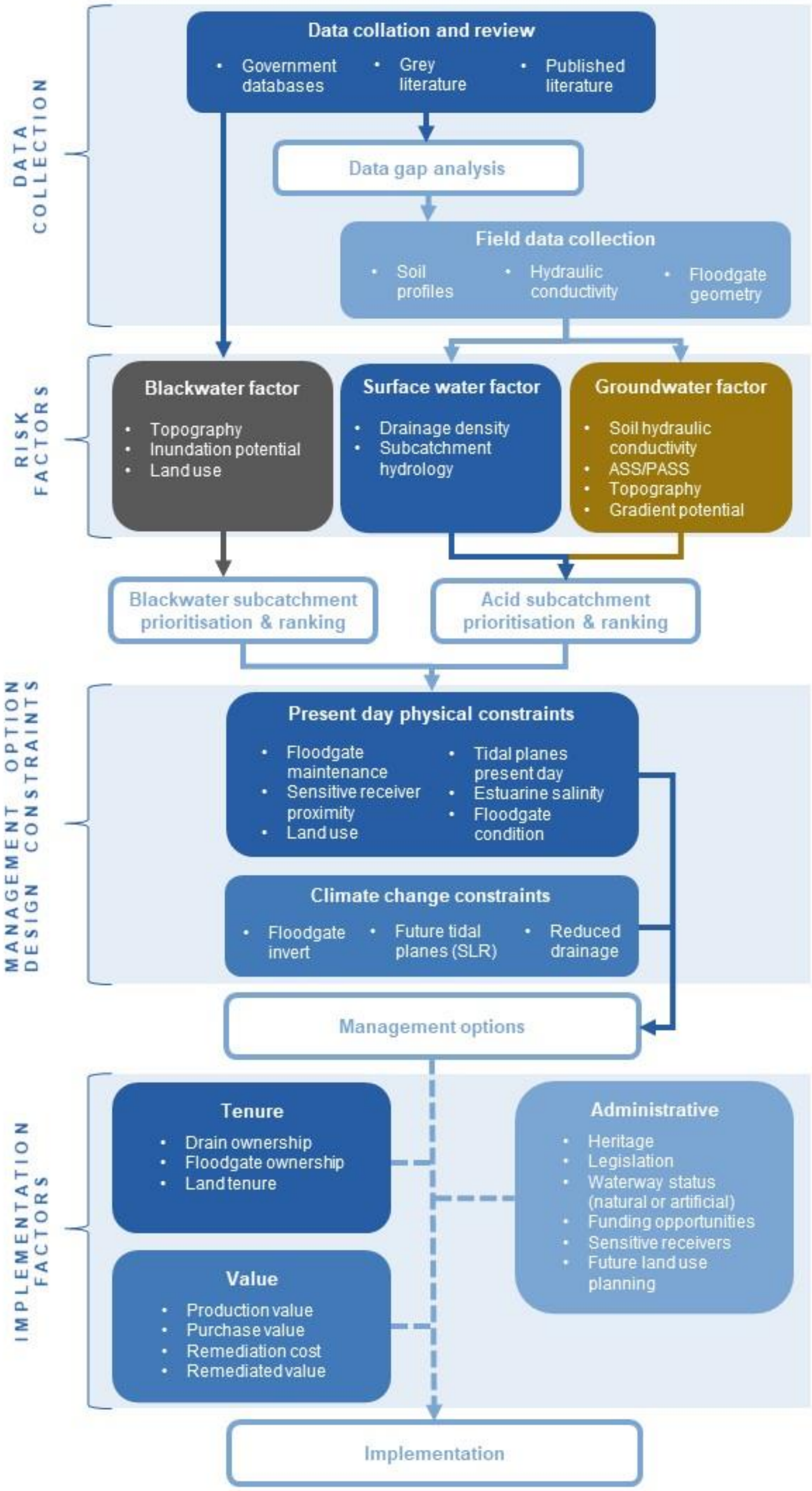

Figure 1-1: Study approach overview

1.5 Manning River floodplain prioritisation

The Manning River floodplain is located on the mid-north coast of NSW between the coastal towns of Harrington and Old Bar in the east and Taree to the west. The drainage history of the Manning River floodplain began in the early-19th century and has been continually modified until the present day. Significant floodplain drainage works throughout the 20th century were primarily undertaken for flood mitigation purposes, as well as to promote dry land agricultural production and to prevent saline intrusion onto the backswamp areas of the floodplain (Tulau, 2011). 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 across coastal NSW (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 Manning River estuary, particularly on the oyster industry (Dove, 2003; Smith et al., 1999).

This report summarises the application of the acid sulfate soil and blackwater subcatchment prioritisation methodologies on the Manning River 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 management options can be implemented in the short term with minimal impacts to existing land uses, while others require substantial changes to land management to create effective improvements in water quality outcomes. The management options provided in this study are intended to be a guide only, and no on-ground work is recommended without further studies into the applicability and potential impacts of any changes in management. The following factors were considered to develop on-ground management options for each subcatchment area:

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

The outcomes of this study aim to provide the basis for a strategic approach to address ASS and blackwater discharges in the Manning 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.

1.6 About this report

This report comprises the following sections:

- **Chapter 2** presents the drainage subcatchments considered in the Manning River floodplain;
- **Chapter 3** provides background information describing the floodplain drainage and presence of ASS and blackwater in the Manning River floodplain;
- **Chapter 4** provides an overview of the ASS and blackwater prioritisation, including a comparison with the ASS prioritisation in Glamore et al. (2016a);
- **Chapter 5** presents the outcomes of the ASS prioritisation in the Manning River floodplain;
- **Chapter 6** presents the outcomes of the blackwater prioritisation in the Manning 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 hydraulic conductivity;
- **Appendix D** Acid sulfate soil distribution;
- **Appendix E** Blackwater elevation threshold;
- **Appendix F** Floodplain infrastructure;
- **Appendix G** Water quality;
- **Appendix H** Hydrodynamic modelling ;
- **Appendix I** Sensitive environmental receivers; and
- **Appendix J** Heritage.

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 Manning River floodplain for areas below 5 m AHD. This section outlines the subcatchments developed for the Manning River floodplain, which are used throughout this study.

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

2.2 Subcatchments of the Manning River floodplain

The subcatchments used in the ASS prioritisation in this study have been sourced from Glamore et al. (2016a) and have not been modified. The previous study delineated the subcatchment areas based on historical land management areas and cadastral subdivisions, high-resolution aerial imagery (Nearmaps), topography and GIS mapping techniques.

In the blackwater prioritisation, two (2) additional subcatchments were included:

- Harrington; and
- Old Bar.

The inclusion of these two (2) subcatchments provides holistic consideration of the risk of blackwater generation throughout the floodplain. These subcatchments were not included in the ASS prioritisation as no soil profile data was available. While neither of these (2) subcatchments has been historically identified as a priority area for assessing impacts of ASS, more field data should be collected in these areas to confirm they are low risk for ASS.

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

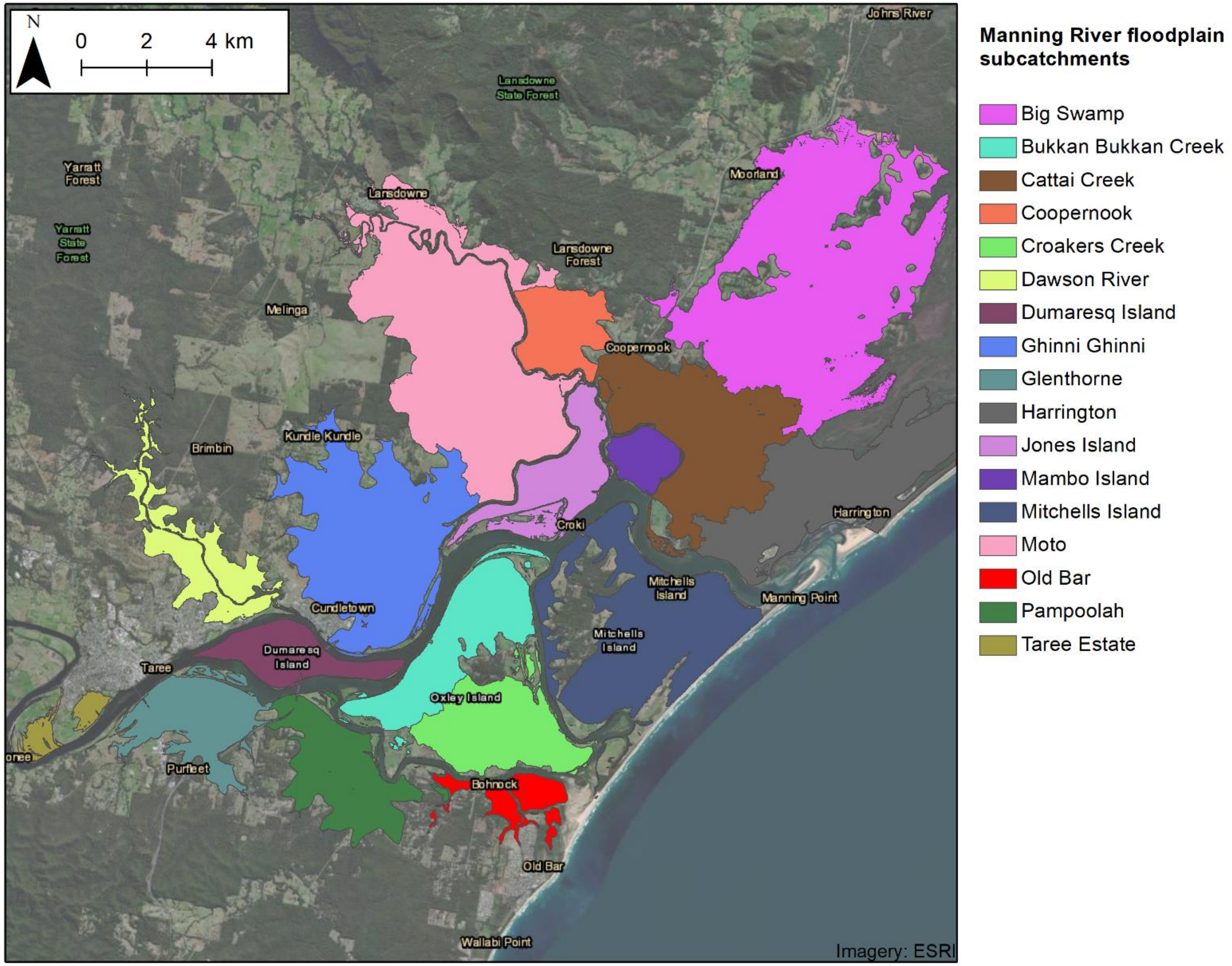

Figure 2-1: Subcatchments in the Manning River floodplain

3 Background

3.1 Preamble

This section provides background information on the Manning 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 area

The Manning River floodplain is within the MidCoast Council local government area (Figure 3-1). However, until 2016, the floodplain was situated within the Greater Taree City Council (GTCC) local area who were responsible for much of the previous remediation. GTCC was amalgamated with Gloucester Shire Council and Great Lakes Council to form MidCoast Council in May 2016.

Figure 3-1: MidCoast Council local government area

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 Manning River floodplain covers an area of approximately 450 km^2, shown in Figure 3-2. The most noticeable feature of the Manning River region is the proliferation of connecting channels that trace across the floodplain, dividing it into a number of low islands and backswamp areas (Tulau, 2011). Across coastal floodplains in NSW, large areas that were once open swampland dominated by reeds or open water have been artificially drained to facilitate agricultural land uses (Tulau, 2011). The lowest point of the floodplain is found at Coopernook Swamp, an eastern section of the Moto basin at Coopernook, and is situated near 0 m Australian Height Datum (AHD), as shown in Figure 3-3. However, most backswamp areas of the floodplain are located well above mean high tide (> 0.5 m AHD at the Harrington ocean entrance), including most of the former Big Swamp area upstream of Cattai Creek. Note that AHD is approximately equal to mean sea level.

The drainage history of the Manning River floodplain began in the early-19th century and has been continually modified until the present day (Tulau, 1999). Significant floodplain drainage works throughout the 20th century were primarily undertaken for flood mitigation, as well as to promote dry land agricultural production and to prevent saline intrusion onto the backswamp areas of the floodplain.

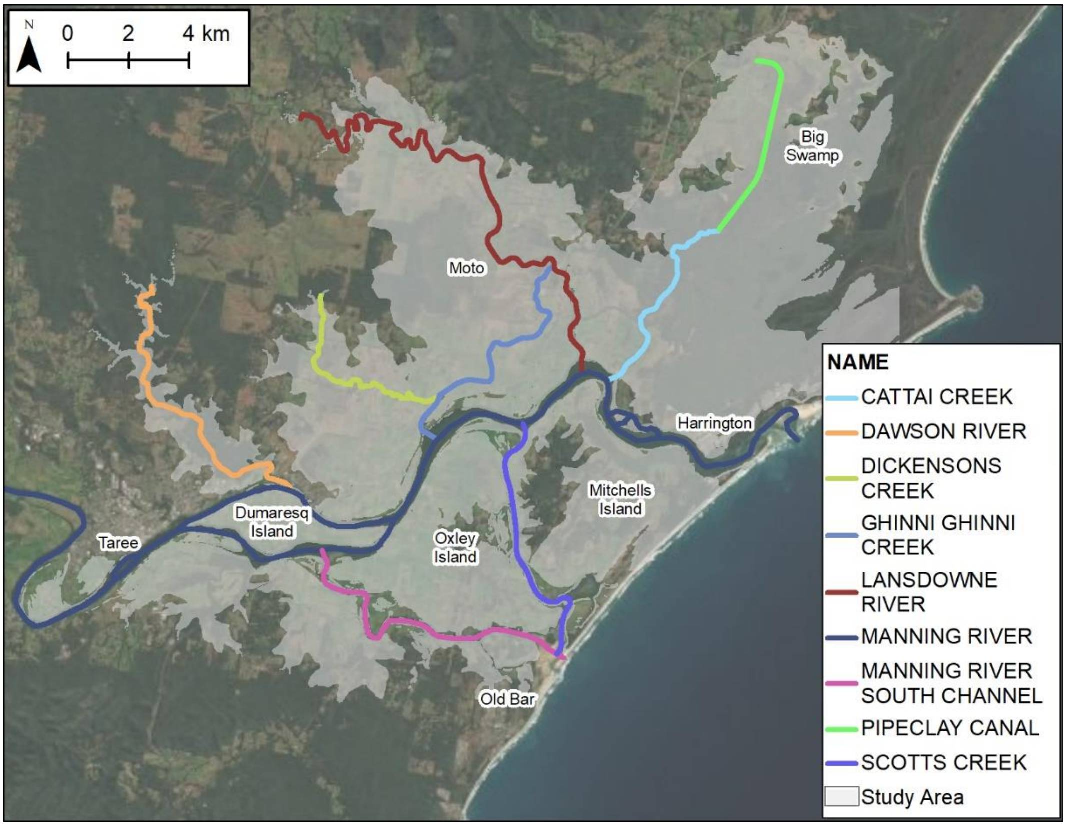

Figure 3-2: Major waterways on the Manning River floodplain

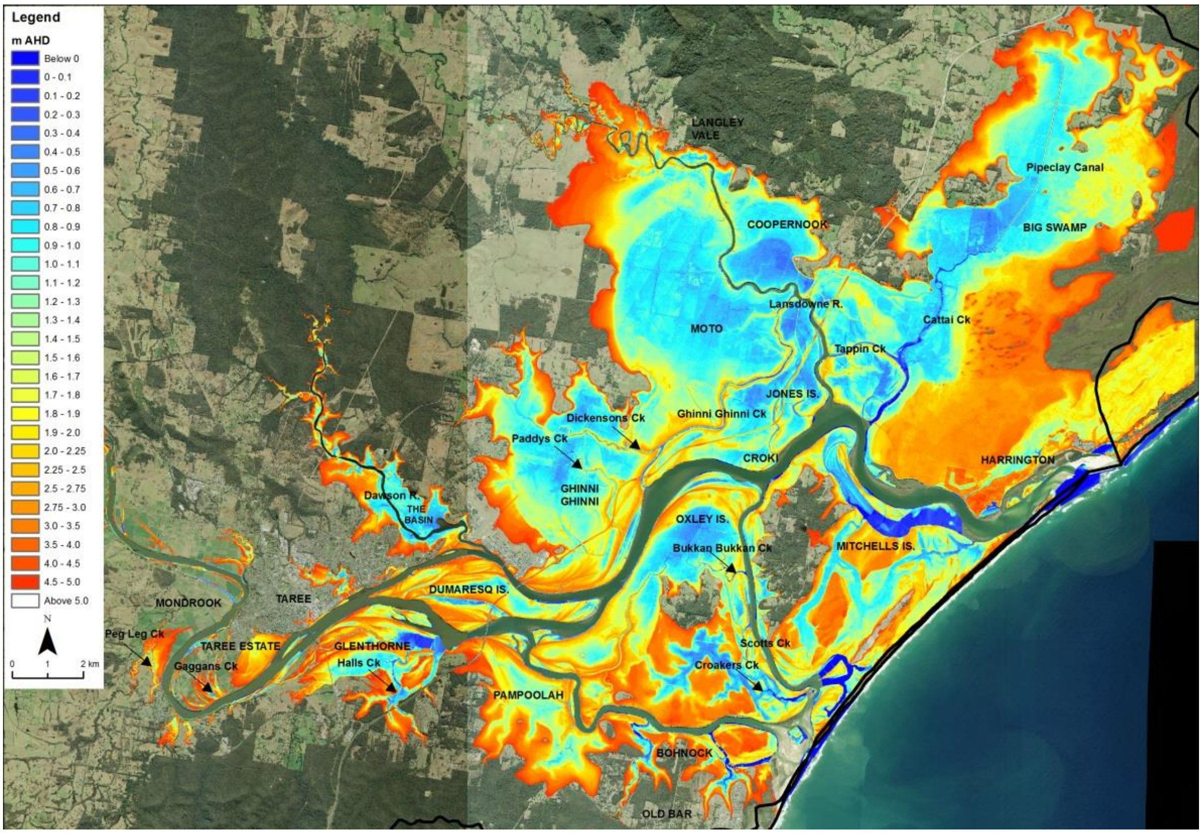

Figure 3-3: Digital Elevation Map of the Manning River floodplain

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

- 1824 – Moto swamp became the first backswamp drained, farmed and settled on the north coast of NSW;
- 1852 – The first wave of small-holding settlers began to purchase land on the Manning floodplain, selecting the higher, well drained alluvial soil on the levees on which to grow maize;
- 1856 – Most of the prime agricultural land on the floodplain had been subdivided and the higher levees alienated, including on Oxley Island, leaving only small areas of brush-covered land and the wet backswamps for later settlers. Extensive drainage works commenced across the Ghinni Ghinni and Moto floodplain areas to open up the swamp land to dry land agricultural production;
- 1861 – The swampy central portions of Oxley and Mitchells Islands, and on the north side of the river, the Big Swamp, were the only large areas of the floodplain not yet drained;
- 1898 – Big Swamp Project prepared and was the first major drainage scheme in NSW carried out under the Public Works Act of 1888;
- 1904 – Big Swamp Drainage Scheme completed and was designed to pass upland catchment inflows from Pipeclay Creek (and local catchment inflows draining from the floodplain) directly to Cattai Creek. This relied on the construction of Pipeclay Canal (approximately 6.5 km long, 15 m wide and 1.2 m deep) through the Big Swamp floodplain, separating the catchment into two halves. In addition, Coopernook Swamp Drainage Scheme was completed;
- 1911 to 1970s – Limited literature is available about drainage works carried out in the Manning Region. However, following the floods of the 1950s, the response of successive Local and State governments facilitated the construction of extensive drainage systems by drainage unions and private landholders;

- 1950 to 1970s – Despite the often misleading use of terminology, the ‘flood mitigation’ schemes of the 1950s to 70s were overwhelmingly swamp drainage schemes, whereby additional deepening, straightening and drainage control (i.e. floodgates) was carried out in accordance with flood mitigation policy funding;
- 1960s – Sections of Dickensons Creek were straightened;
- Late 1970s – Marked the end of new, large-scale drainage works in NSW coastal floodplain backswamps. However, by this stage the Manning floodplain landscape had been transformed and backswamp wetlands were all but gone, apart from a few diminished and temporary remnants;
- 1997 – The last approved major excavation works of Pipeclay Canal (MidCoast Council, 2010); and
- 2010 – MidCoast Council had introduced clause 7.1 on Acid Sulfate Soils into the Greater Taree LEP which stated that consent would be required for drainage undertaken by drainage unions, flood mitigation works undertaken by councils and county councils, and drain ‘cleaning’ by farmers. This was generally consistent with other north coast council LEPs, except the Greater Taree LEP included an allowance for ploughing of land >0.7 m AHD.

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.

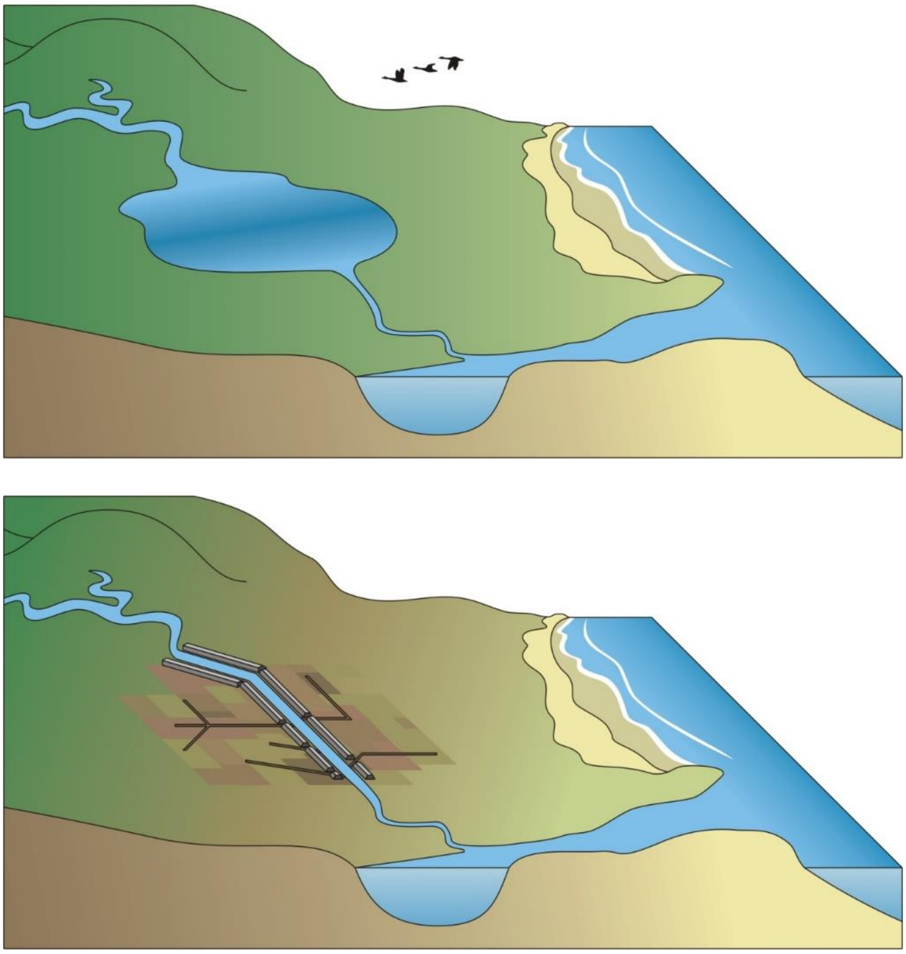

Figure 3-4: Schematic of floodplain evolution following European settlement

3.4 Land use and tenure

Grazing is the major agricultural land use in the Manning River floodplain. Land uses in the Manning 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).

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

- Crowdy Bay National Park north of Harrington; and
- Brimbin Nature Reserve at Dawsons River.

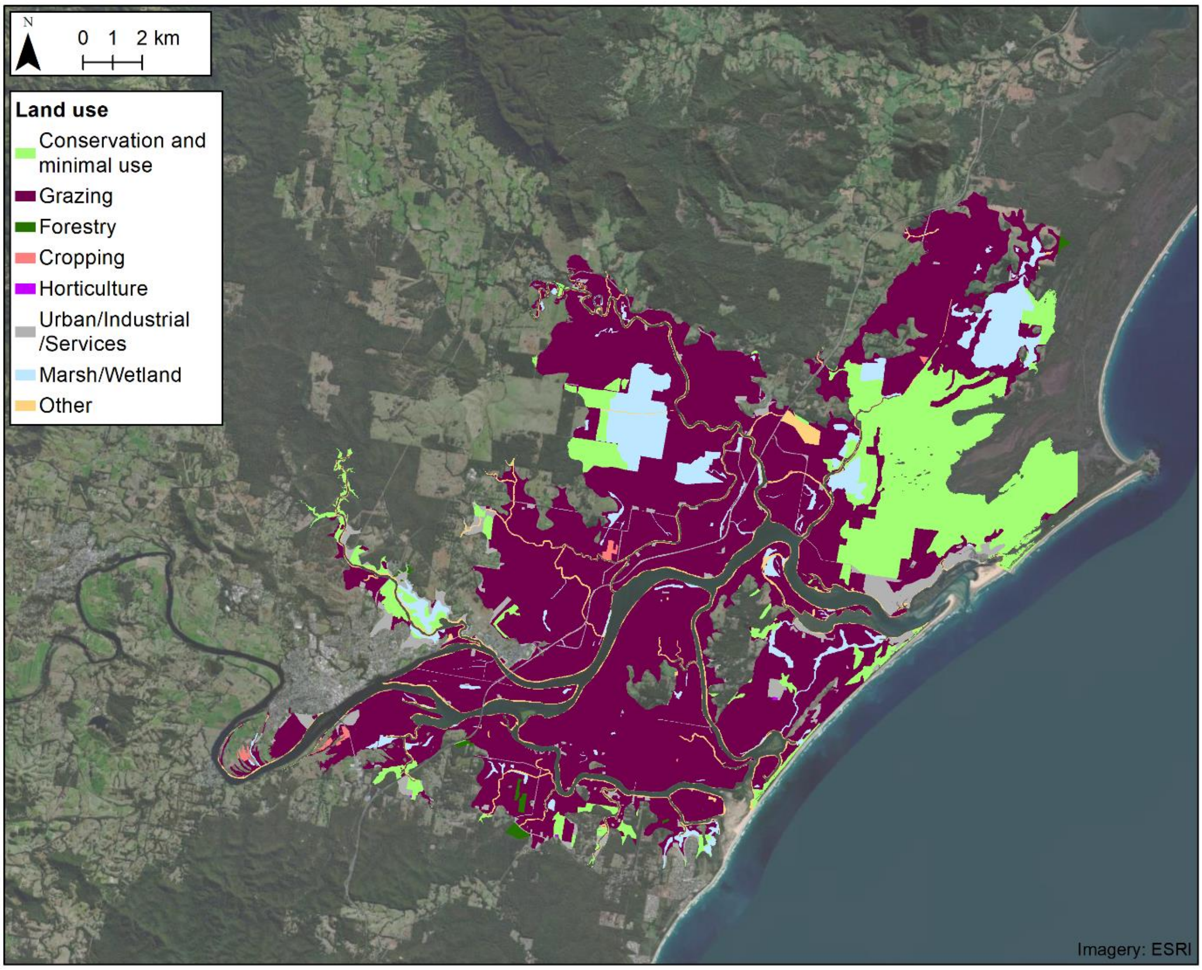

Figure 3-5: Land use in Manning River floodplain, 2017 (DPIE, 2013; DPIE, 2020)

3.5 Acid sulfate soils

This section provides a brief overview of the formation and export of acid from acid sulfate soils (ASS) in coastal floodplains and the presence of ASS on the Manning 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 Manning Region

The acid pollution hazard in NSW was originally mapped on the Acid Sulfate Soil Risk Maps prepared by Naylor et al. (1998). The study revealed that the Manning River floodplain contained an area of over 200 km^2 of high-risk ASS soil up to an elevation of approximately 5 m AHD as shown in Figure 3-6. The extent and severity of ASS on the Manning River floodplain has since been confirmed by several investigations, including Sonter (1999), Smith et al. (1999), Dove (2003), Johnston (2007), and Glamore et al. (2014).

In 1999, the NSW Department of Land and Water Conservation (DLWC) identified twenty-six ASS hotspots in NSW, four (4) of which were located in the Manning area (Tulau, 1999), including:

- Cattai Creek-Pipeclay Canal (included in the Big Swamp subcatchment in this study);
- Lower Lansdowne-Moto-Ghinni Ghinni Creek (within the Moto and Coopernook subcatchments in this study);
- North Oxley Island (within the Bukkan Bukkan Creek subcatchment in this study); and
- Dickensons Creek (within the Ghinni Ghinni subcatchment in this study).

The Cattai Creek-Pipeclay Canal area was generally recognised as one of the very worst areas for ASS pollution on the entire NSW coast.

Available data was analysed to describe the distribution of ASS across the Manning 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 profile is shown in Figure 3-7. Extremely low pH (<4) have been observed in the Manning River floodplain, particularly near Big Swamp, Moto, Coopernook, Ghinni

Ghinni and Bukkan Bukkan Creek, which is consistent with the ASS priority areas identified by Tulau (1999).

Impacts of acid drainage flowing from drains and floodgates in high-risk ASS landscapes include the extensive impacts on fish (Sammut, 1998) and oyster industries (Dove, 2003). In the Manning River floodplain, the oyster industry was estimated to be worth approximately $2 million a year in 1999 (approximately $3.3 million today), although increased disease and mortality is reducing the productivity of the industry (Dove, 2003).

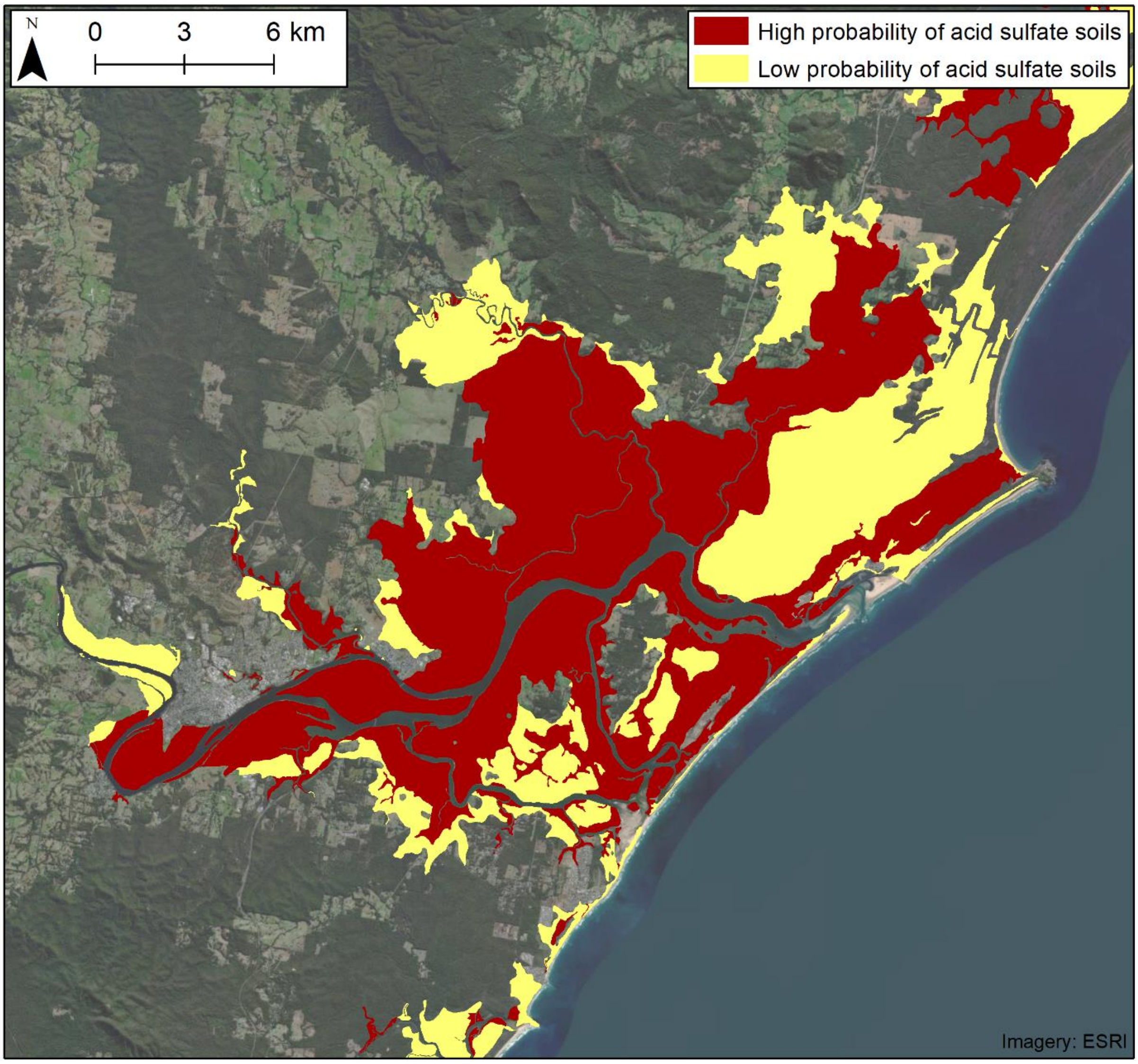

Figure 3-6: NSW Government ASS Risk Map of the Manning River floodplain

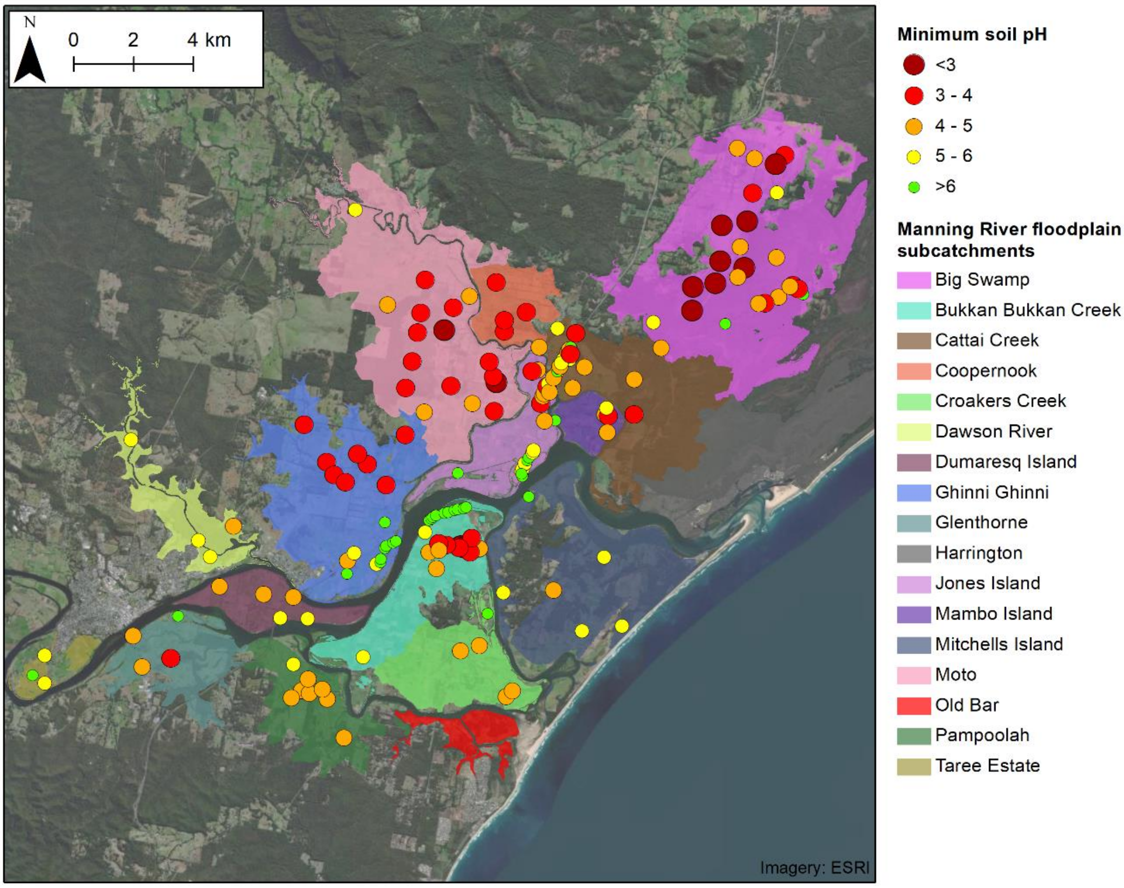

Figure 3-7: Minimum soil pH throughout the Manning River floodplain

3.6 Blackwater

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

Blackwater is a common term used to describe dark coloured waters that are characterised by high dissolved organic carbon (DOC) and reduced levels of dissolved oxygen (DO) (Moore, 1996). The discolouring of the water emanates from carbon compounds released into the water column as organic matter decays, which includes tannins (Howitt et al., 2007). Large volumes of blackwater can be generated on floodplains and are often associated with flooding, as floods act as a link between the floodplains (rich in organic matter) and the adjacent river channel (where the main impact occurs). Note, other sources of blackwater include monosulfidic black ooze (MBO) and humic blackwater. MBO and humic blackwater impact the estuary to a lesser degree in comparison to blackwater resulting from decaying organic matter (Moore, 2007). This is discussed further in Section 5 of the Methods report (Rayner et al., 2023).

Although blackwater events can be a natural part of lowland river ecosystems (Hladyz et al., 2011) and part of the floodplain carbon cycle (Wong et al., 2010b), the occurrence of blackwater events leads to low dissolved oxygen in estuarine waterways and can be fatal to fish and crustacean communities

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

3.6.1 Fish kills and blackwater in the Manning River estuary

NSW DPI (2020) maintains a record of observed fish kills across the state. The scale of the recorded events range from 'less than 10 fish' to '100,000's of fish' that have been killed per event. Fish kills can be caused by a number of processes, although acid discharge and blackwater runoff are common causes in coastal estuaries in northern NSW. It is likely that a combination of acid sulfate soil discharges, as well as blackwater from organic matter decomposition is responsible for these fish kill events.

Twenty-three (23) fish kill events have been recorded in the Manning River estuary since 1992 (although other events are likely to have occurred but gone undocumented). For the majority of these events the cause was not confirmed, although it is likely that blackwater discharges and/or acidic discharges have contributed significantly to mortality. Documented fish kills in the Manning River estuary are summarised in Table 3-1.

Table 3-1: Severe fish kills in the Manning River floodplain

Date	River/Creek	Intensity
31/01/1992	Manning River	100s of fish
1/03/1992	Lansdowne River	100s of fish
1/03/1992	Cattai Creek	1,000's of fish
12/10/1994	Manning River	100s of fish
30/01/1997	Lansdowne River	100s of fish
1/04/2004	Ghinni Ghinni Creek	1,000's of fish
18/09/2006	Cattai Creek, Lansdowne River, Ghinni Creek	100s of fish
14/12/2007	Dawson River	1,000's of fish
23/03/2017	Lansdown River	100s of fish
9/01/2020	Manning River & Barnard River	1,000's of fish
19/02/2020	Unnamed lagoon	100s of fish

Localised generation of blackwater has been identified by MidCoast Council (formerly Greater Taree City Council) in several of their ASS drainage management plans. Areas identified in these plans to have issues associated with blackwater include:

- The Moto subcatchment (Greater Taree City Council, 2009b) where breaches of levees were constructed to aid surface water drainage for the southern sections of the subcatchment (although this had unintended impacts on adjacent landholders);
- Oxley Island (largely within the Bukkan Bukkan Creek subcatchment in this study) (Greater Taree City Council, 2008e) where poor surface water drainage was seen to result in increased ponding during rain events, subsequently causing blackwater generation; and
- The Dickensons Creek area (referred to as Ghinni Ghinni in this study) (Greater Taree City Council, 2009a) where insufficient surface water drainage through floodplain infrastructure was seen to be the cause of a blackwater event originating in this area.

Consistent with the floodplain prioritisation approach outlined by Rayner et al. (2023) and the broader strategy for identifying key sources of poor water quality within NSW estuaries, the high risk areas for blackwater generation have been identified within the Manning River estuary. It should be noted that the blackwater prioritisation is separate from the ASS prioritisation. Subsequently, rankings of subcatchments in terms of blackwater risk are not comparable to rankings of subcatchments in terms of ASS risk. While both mechanisms might produce poor water quality within the estuary, it is likely that poor water quality resulting from ASS may present a higher risk to the Manning River estuary when compared to poor water quality resulting from blackwater. However, localised impacts due to blackwater runoff have been observed from low-lying backswamp areas, presenting a particular risk to immediate downstream tributary waterways.

3.7 Coastal management on the Manning River estuary

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

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

Based on the TARA assessment, management of acid and blackwater drainage in estuaries in NSW is considered a priority to improve environmental, social, cultural and economic benefits associated with the marine estate.

3.7.2 Manning River estuary management plan (Worley Parsons, 2009)

The Manning River estuary management plan (EMP) identified acid sulfate soils as key management issues affecting the systems fisheries and water quality (Worley Parsons, 2009). Subsequently, two priority strategies were outlined to address the issues associated with acid sulfate soils:

- "*Incorporate provisions to address acid sulfate soils (ASS) management and rehabilitation into the new 'Local Plan 2008' (LEP), currently being prepared by Greater Taree Council;" and*
- *"Continue investigations into management of acid sulfate soils (ASS) and drainage from areas of ASS."*

Since the development of these strategies have been implemented with provisions being added to the Greater Taree LEP (2010) and numerous investigations into acid sulfate soil management and drainage being completed (Glamore et al., 2016a; Ruprecht et al., 2020a; Ruprecht et al., 2020b).

3.7.3 Manning River estuary coastal management program

MidCoast Council has completed a coastal management program (CMP) scoping study and is currently developing a CMP for the Manning River estuary (Bettink et al., 2020). The scoping study has identified acid runoff due to floodplain drainage and climate change stressors as one of the key threats to the ecological health of the Manning River estuary that will need to be addressed when considering coastal management. The CMP for the Manning River estuary is currently being developed and will supersede the existing EMP.

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

The prioritisation for ASS and blackwater risk within coastal floodplains is independent of 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 Manning 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.

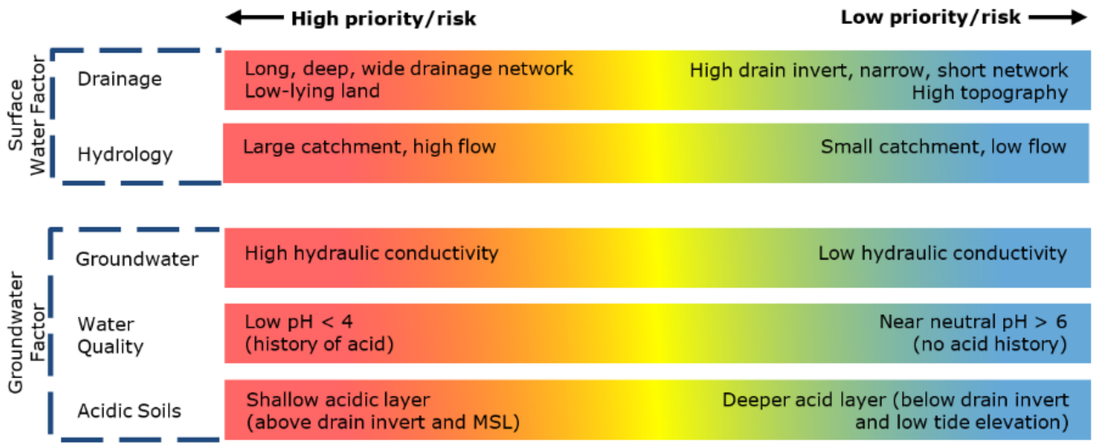

Figure 4-1: Factors influencing ASS discharge in coastal NSW that have been incorporated within the assessment method (adapted from Johnston et al. (2003a))

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. 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 Manning River floodplain during a blackwater event).

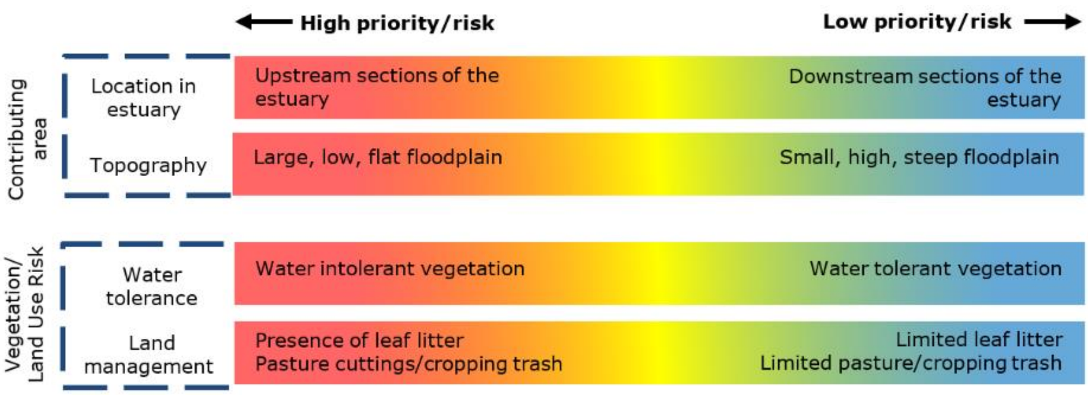

Figure 4-2: Factors influencing blackwater discharge within a coastal floodplain in NSW

4.3.1 Contributing blackwater area

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

Long-term water levels in the main river channel were analysed to establish 25 water level thresholds relating to different periods of river water elevation (e.g. elevated over a given threshold for 1, 2, 3, 4 or 5 days) and temporal frequencies (e.g. 1, 2, 3, 4 or 5 year return intervals). Water levels in the main river channel were then projected across the adjacent floodplain subcatchments using a geospatial approach to identify areas likely to be subject to reduced drainage and prolonged inundation. These areas were identified as key contributors to blackwater generation under different flood events and flood behaviour. Appendix E provides the details of this analysis within the Manning 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 are moderate risk; and,
- Low: Areas that have are predominately covered by water tolerant vegetation (e.g. marshes or wetlands) present the lowest risk.

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

5 ASS prioritisation assessment outcomes

5.1 Preamble

This section summarises the results of the ASS priority assessment for the Manning River floodplain. The summary rankings and acid prioritisation factors for each of the subcatchments are provided in Section 5.2. The final rankings in the ASS priority assessment are a function of a surface water drainage factor and a groundwater factor calculated for each subcatchment, as discussed in Section 4 and Appendices A – D. The highest priority subcatchments have the highest combination of the surface water and groundwater factors, thereby presenting the highest risk of acid drainage.

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

5.2 ASS Prioritisation of the Manning 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 five (5) subcatchments identified were Big Swamp (1), Moto (2), Ghinni Ghinni (3), Bukkan Bukkan Creek (4) and Coopernook (5) have all been historically identified as ASS priority areas (Tulau, 1999). The top three (3) subcatchments alone were estimated to account for 90% of the acid risk in the Manning River floodplain.

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

Subcatchment	Groundwater factor	Surface water factor	Final acid factor	Rank
Big Swamp	952	1,046	995,018	1
Moto	697	1,334	930,033	2
Ghinni Ghinni	257	1,580	406,503	3
Bukkan Bukkan Creek	285	335	95,285	4
Coopernook	247	325	80,212	5
Cattai Creek	140	261	36,596	6
Glenthorne	133	185	24,586	7
Jones Island	37	232	8,653	8
Mitchells Island	14	520	7,401	9
Pampoolah	60	123	7,367	10
Croakers Creek	19	168	3,201	11
Mambo Island	17	94	1,598	12
Dawson River	9	79	680	13
Dumaresq Island	4	131	479	14
Taree Estate	5	12	56	15

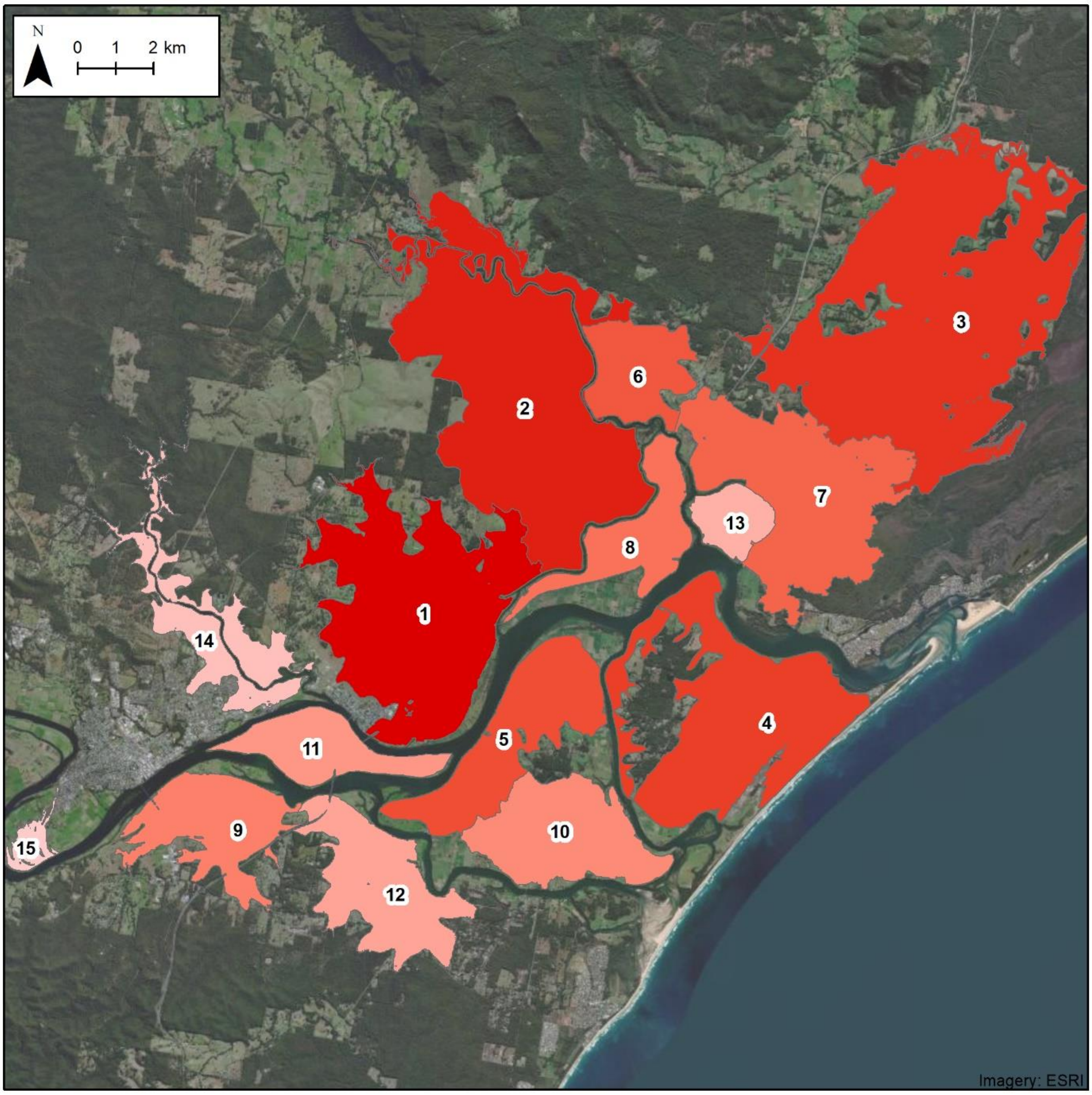

Figure 5-1: Surface water factor ranking

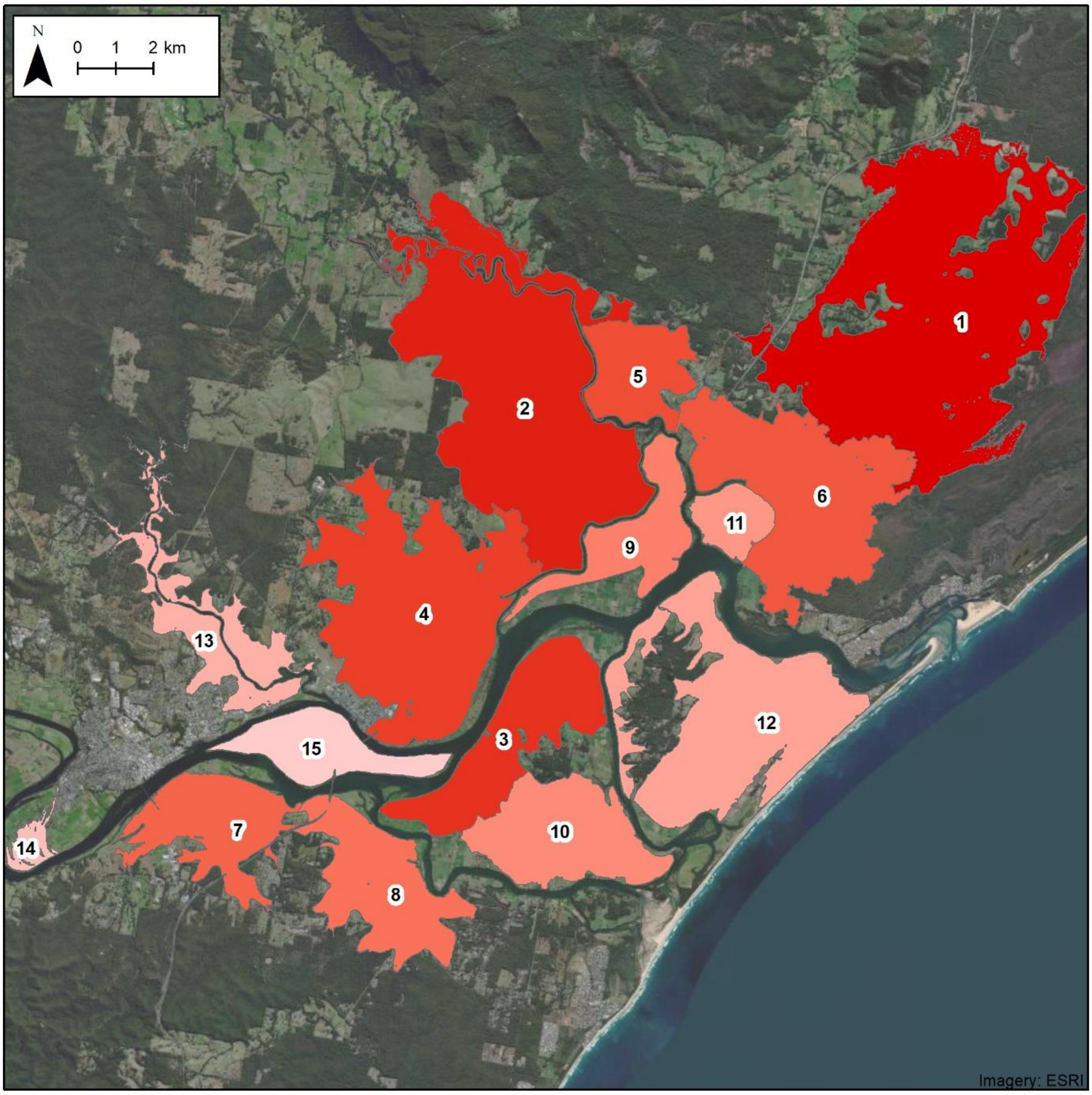

Figure 5-2: Groundwater factor ranking

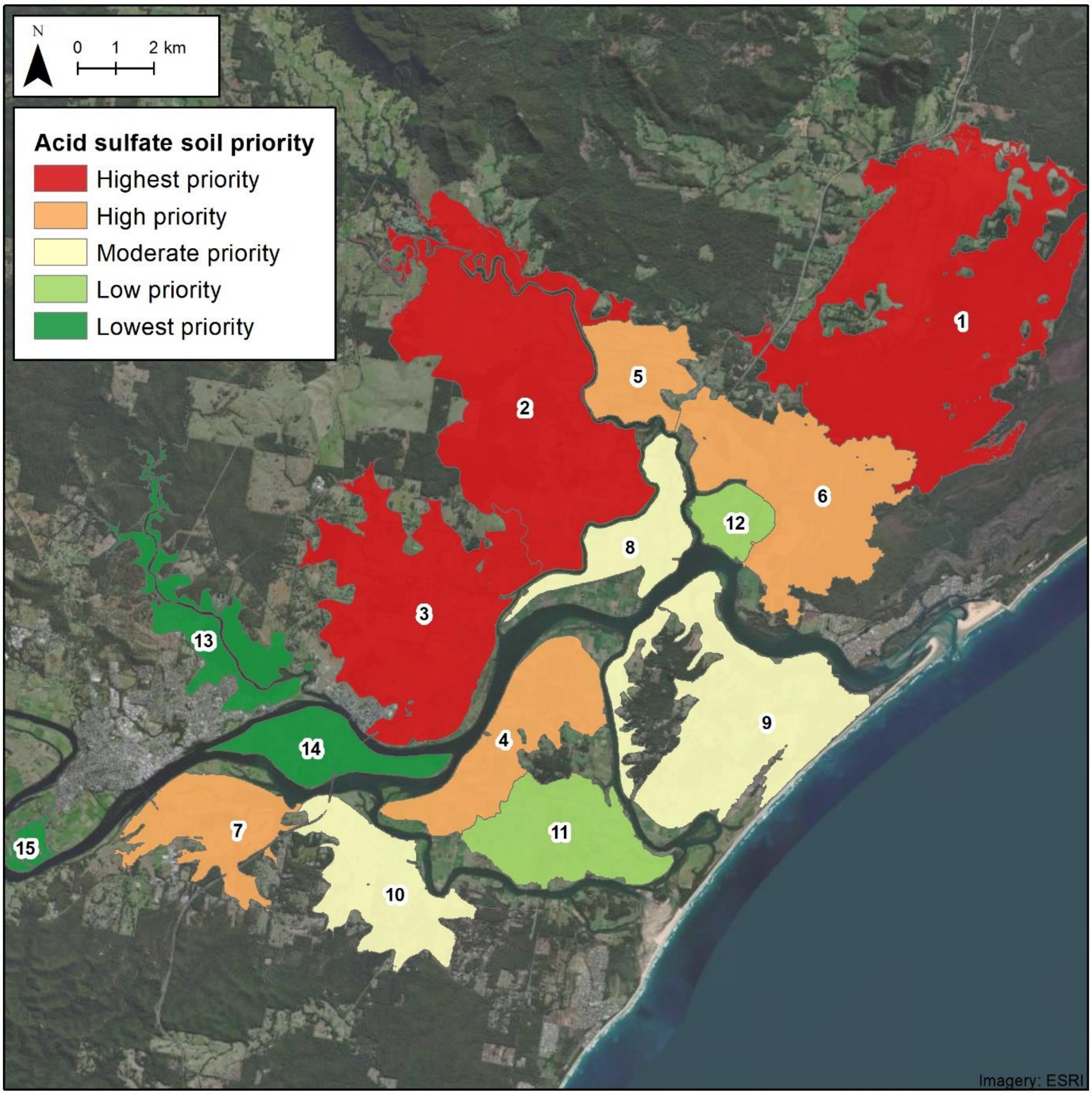

Figure 5-3: Final ranking of ASS prioritisation

5.3 Comparison to previous ranking

Table 5-2 summarises the differences in the surface water factor, groundwater factor and final ASS priority rank for the Manning River floodplain in this study compared to Glamore et al. (2016a). There are number of reasons the factors and rankings have changed, including:

- Use of different datasets in calculating factors, including:
    - New soil profile and hydraulic conductivity data in the Big Swamp subcatchment from WRL (2019);
    - New soil profile data in the Pampoolah subcatchment from Ruprecht et al. (2020b); and
    - A new floodplain drainage GIS layer was developed that provided more consistent mapping of the drainage network across the floodplain (see Section 12 of the Methods

report (Rayner et al., 2023)). This has resulted in changes in surface water factors across all subcatchments. This included large increases in drainage length within the subcatchments of Bukkan Bukkan Creek (106% increase), Coopernook (150% increase) and Jones Island (110% increase) and significant decreases in drainage length in Taree Estate (65% decrease) and Dawsons River (64% decrease).

- Changes in surface water factor calculation, particularly in the measurement of upstream catchment areas. In this study, only catchments upstream of floodgates were included in the surface water factor (see Section 4.3.2 of the Methods report (Rayner et al., 2023)). In the Glamore et al. (2016a) prioritisation, all upstream catchments were included. This change has resulted in a large reduction in upstream catchment area for the Big Swamp, Moto and Dawsons River subcatchments for the present study;
- Changes in the calculation of the groundwater factor, particularly the pH factor (see Section 4.4.2 of the Methods report (Rayner et al., 2023)). The updated method uses a representative soil profile between the elevation of the local mean low water level and 1 m AHD to assess the risk of acid drainage which better accounts for the location of acidic layers, and reduces error due to the location of soil data within an individual subcatchment.

Table 5-2: Comparison of ASS prioritisation in this study and Glamore et al. (2016a)

Subcatchment	Glamore et al. (2016a)			This Study			Change in rank
	Ground water Factor	Surface Water Factor	Rank	Ground water Factor	Surface Water Factor	Rank	
Big Swamp	158	1,018	3	952	1,046	1	+2
Moto	297	1,117	1	697	1,334	2	-1
Ghinni Ghinni	388	685	2	257	1,580	3	-1
Bukkan Bukkan Creek	111	91	7	285	335	4	+3
Coopernook	352	48	5	247	325	5	No change
Cattai Creek	11	179	9	140	261	6	+3
Glenthorne	207	617	4	133	185	7	-3
Jones Island	4	57	13	37	232	8	+5
Mitchells Island	6	297	10	14	520	9	+1
Pampoolah	61	182	6	60	123	10	-4
Croakers Creek	5	83	11	19	168	11	No change
Mambo Island	3	33	14	17	94	12	+2
Dawson River	4	1,294	8	9	79	13	-5
Dumaresq Island	1	59	15	4	131	14	+1
Taree Estate	11	20	12	5	12	15	-3

6 Blackwater prioritisation assessment outcomes

6.1 Preamble

This section summarises the results of the blackwater priority assessment on the Manning 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 Manning 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 three (3) ranked subcatchments for blackwater generation (Ghinni Ghinni, Moto, and Big Swamp) were also all ranked in the top three (3) in the ASS prioritisation.

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

Subcatchment	Median blackwater elevation (m AHD)	Final blackwater factor	Rank
Ghinni Ghinni	0.7	9.5	1
Moto	0.6	7.7	2
Big Swamp	0.5	6.4	3
Jones Island	0.6	5.4	4
Bukkan Bukkan Creek	0.6	4.5	5
Coopernook	0.6	4.1	6
Cattai Creek	0.5	3.1	7
Croakers Creek	0.5	2.8	8
Glenthorne	0.7	1.8	9
Dawson River	0.7	1.6	10
Dumaresq Island	0.7	1.4	11
Mambo Island	0.5	1.2	12
Pampoolah	0.6	1.1	13
Taree Estate	0.7	0.4	14
Mitchells Island	0.5	0.4	15
Old Bar	0.5	0.2	16
Harrington	0.4*	0.03	17

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

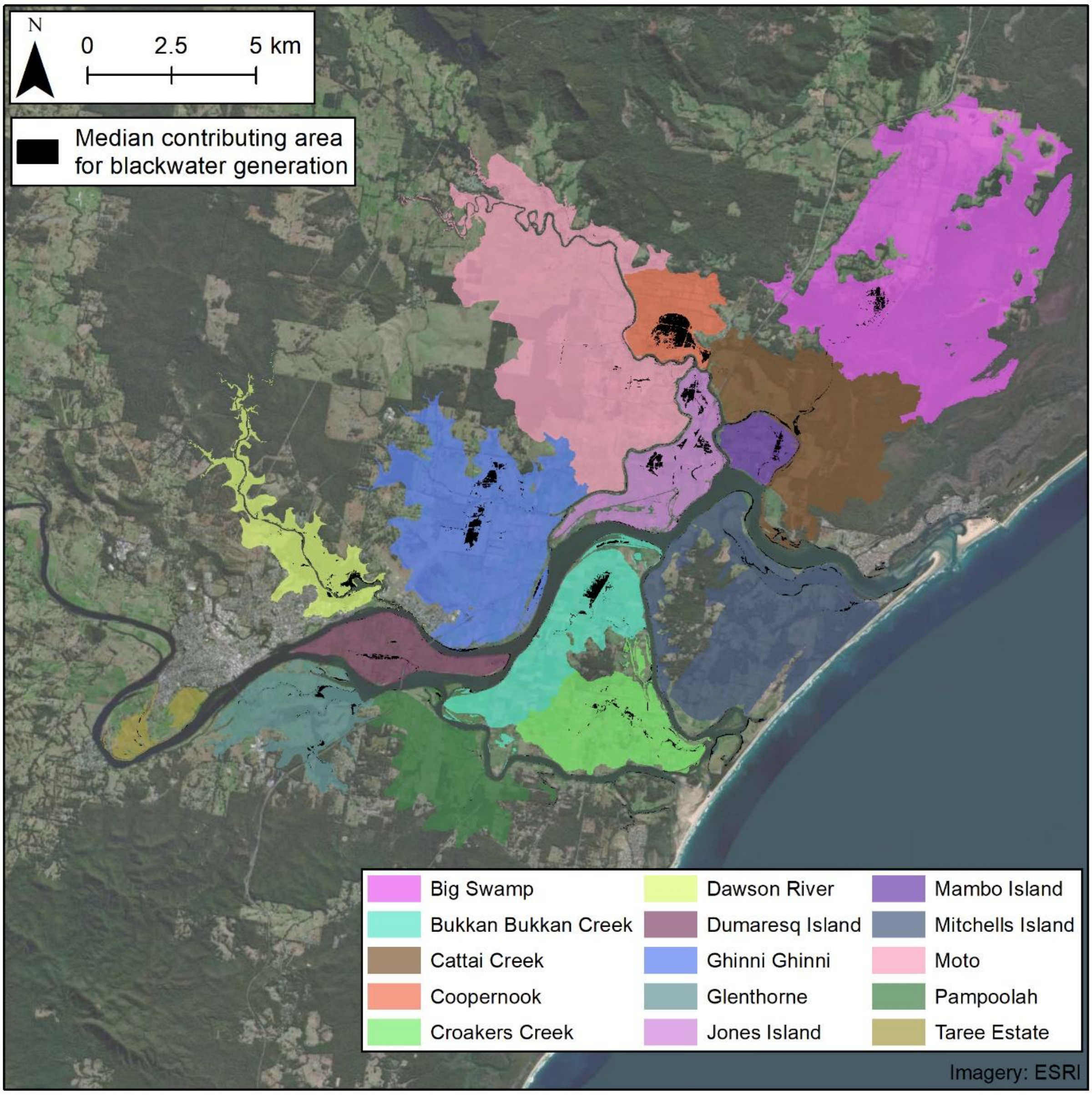

Figure 6-1: Median contributing area for blackwater generation across the Manning River floodplain

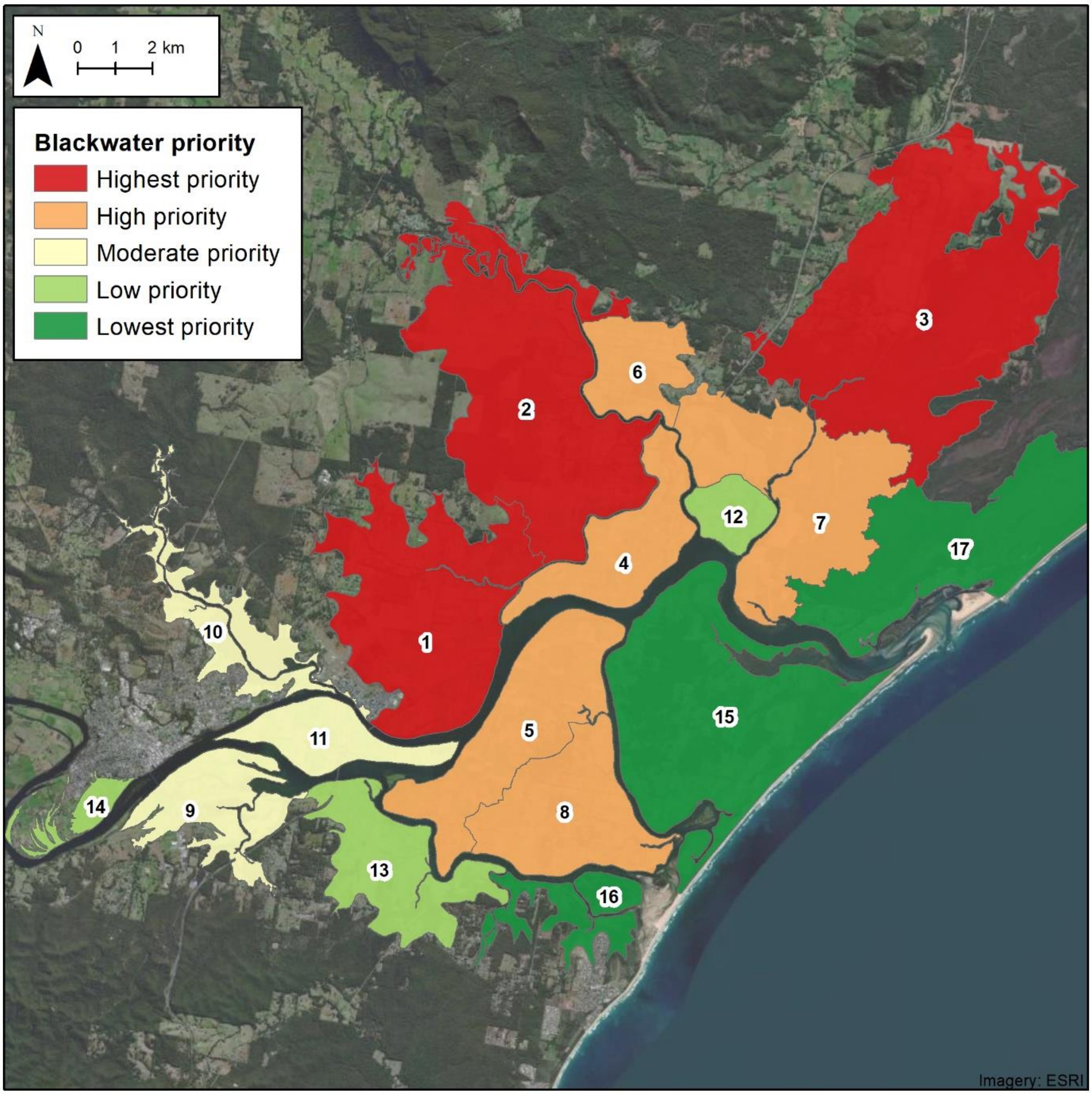

Figure 6-2: Final ranking of the blackwater prioritisation in the Manning River floodplain

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 inundation extent/duration. The following section summarises the assessment completed for this study to identify floodplain areas and floodplain infrastructure in the Manning River floodplain that are vulnerable to future sea level rise. Detailed information on how climate change will likely influence estuaries in NSW can be found at: http://estuaries.wrl.unsw.edu.au/index.php/climate-change/ (accessed 23/09/2020).

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

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

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

7.2 Changes to water levels in estuaries

Glamore et al. (2016b) detailed how water levels in estuaries are influenced by oceanic forces and climate change. In brief, tidal water levels at the entrance of an estuary influence the overall volume of water (tidal prism) moving in and out with each tide. The tidal prism, the channel bed friction, catchment inflows and the channel geometry (i.e. the depth and the shape of the estuary) influence whether the tidal planes amplify (increase), remain constant or attenuate (decrease) as they propagate 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 Manning River estuary was adopted from Miller and Tarrade (2010). This model was extended to ensure all end-of-system floodgate structures were captured, 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 Manning 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 Manning River estuary. Further details on the model development and calibration can be found in Appendix H.

7.2.1 Manning 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 Manning River estuary. The Miller and Tarrade (2010) model was modified slightly and extended through Cattai Creek. 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 Lansdowne River and Dawson 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 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 60 km upstream from the river mouth to the tidal limit near Abbott’s Falls at Killawarra. The hydrodynamic model comprised of three (3) main inputs:

1. **Channel bathymetry and geometry** are based on the previous hydrodynamic model by Miller and Tarrade (2010) and updated using bathymetry data from the Manning River Flood Study (BMT WBM, 2016). The model was also refined near the Harrington entrance using single beam bathymetry data sourced from NSW Office of Heritage (OEH);
2. **Downstream tidal water levels** are applied at the downstream ocean boundary. This was based on the observed records from the Manly Hydraulic Laboratory water level station at Harrington (Station # 208425); and
3. **Upstream river flows** are applied as inflow hydrographs at the upstream extent of the model. These were sourced from Water NSW river gauges for:

    a. Manning River at Killawarra (Station # 208004); and
    b. Lansdowne River at Lansdowne (Station # 208015).

Figure 7-1: Manning River estuary hydrodynamic model extent

Lower catchment inflows to the model were not included as sensitivity testing indicated that floodplain runoff has a relatively small impact on the day-to-day water levels in the lower Manning River estuary (which is dominated by the downstream tide and entrance conditions). As such, the resulting hydrodynamic model is calibrated for everyday tides, but is not suitable to replicate design catchment flood events. This is considered to be appropriate as the hydrodynamic model has been used in this study as a tool to assess the sea level rise 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 H.

The hydrodynamic model for the Manning River estuary was calibrated to measure water level and tidal flow gauging stations along the main river channel for 1998. The year 1998 was selected based on short-term tidal flow gauging of the Manning Estuary at various locations within the estuary during 3 November 1998 (MHL, 1999). The locations of the water level and tidal flow gauging monitoring stations used for calibration are provided in Appendix H. The calibrated model was then used to simulate a representative 'wet' year (i.e. more rain than average across the catchment) and a representative 'dry' year (i.e. less rain than average across the catchment) based on analysis of rainfall records in Northern NSW. For this project, 2013 and 2019 were selected as the wet and dry years, respectively based on long term rainfall monitoring by the Bureau of Meteorology. The model results from these simulations were then used to verify the tidal water level patterns throughout the estuary.

7.2.2 Historic and future sea level rise

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

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

Sea level rise scenarios were based on scenarios from Glamore et al. (2016b). The adopted changes in mean sea level relative to 2020 for these periods 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 ensemble (containing 12 individual models) 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 Manning River estuary.

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

Time period	Adopted change in mean sea level 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 Manning 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 7-4Figure 7-3 to Figure 7-6 present floodgate vulnerability maps for the Manning 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, 32 of 104 (31%) floodgates with known elevation are considered 'Most Vulnerable', compared to just 4 (4%) in present day conditions.

Table 7-3: Vulnerability classification of Manning River floodgates

	Historic Scenario (HS) ~1960	Present Day (PD) 2020	Near Future (NF) ~2050	Far Future (FF) ~2150
Least Vulnerable	88	87	73	27
Moderately Vulnerable	15	13	25	45
Most Vulnerable	1	4	6	32

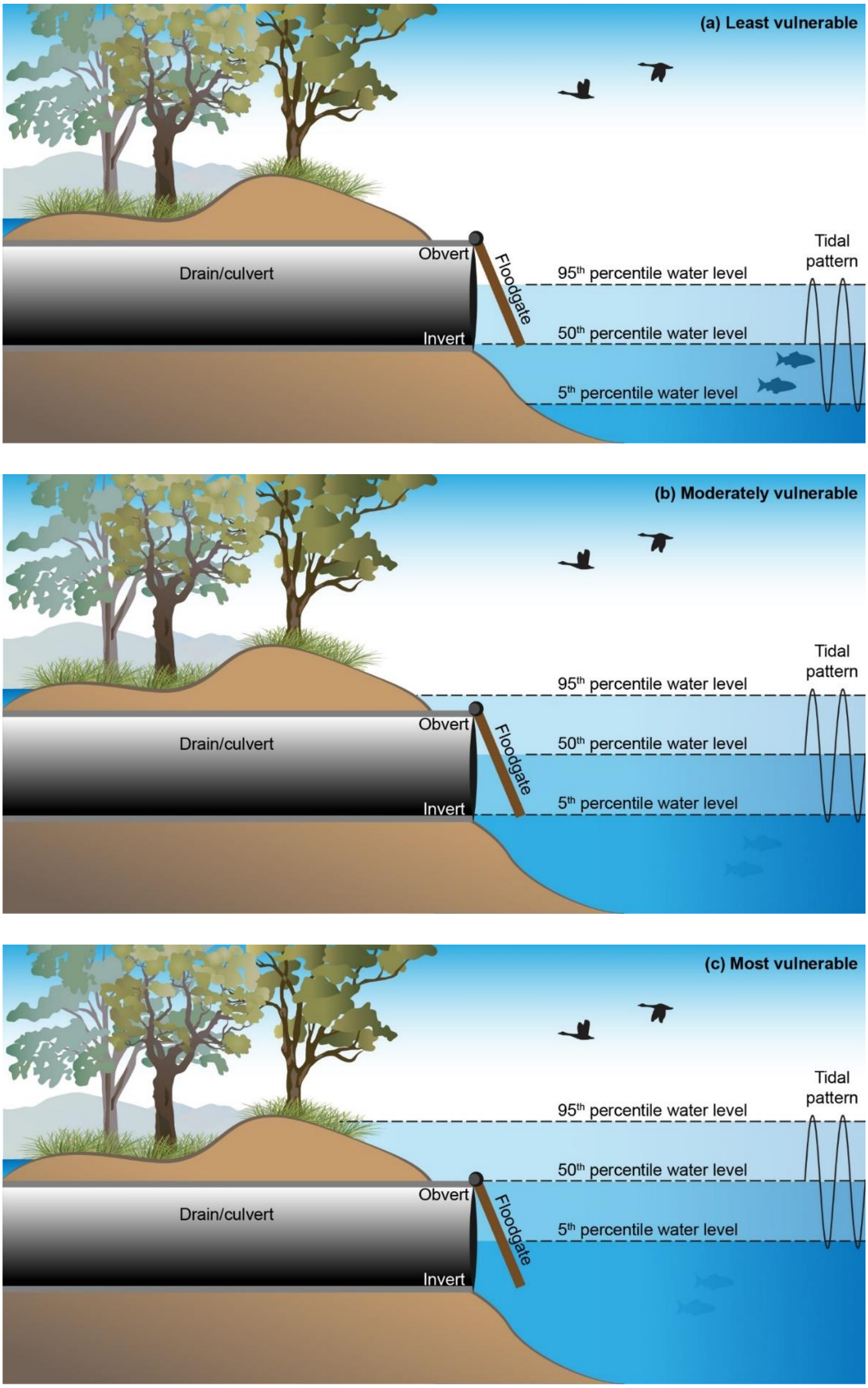

Figure 7-2: Floodgate vulnerability assessment

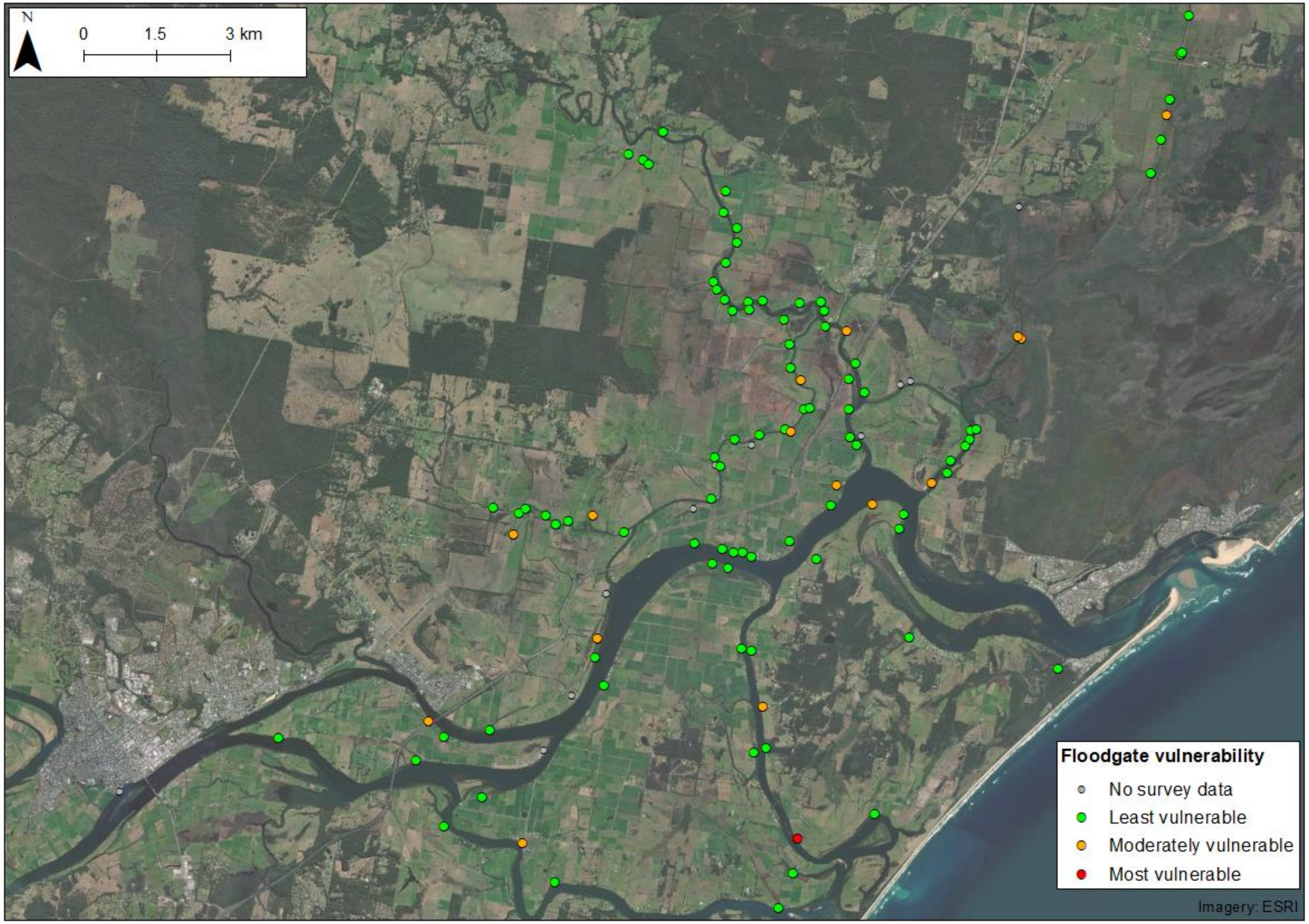

Figure 7-3: Historic (~1960) floodgate vulnerability – Manning River estuary

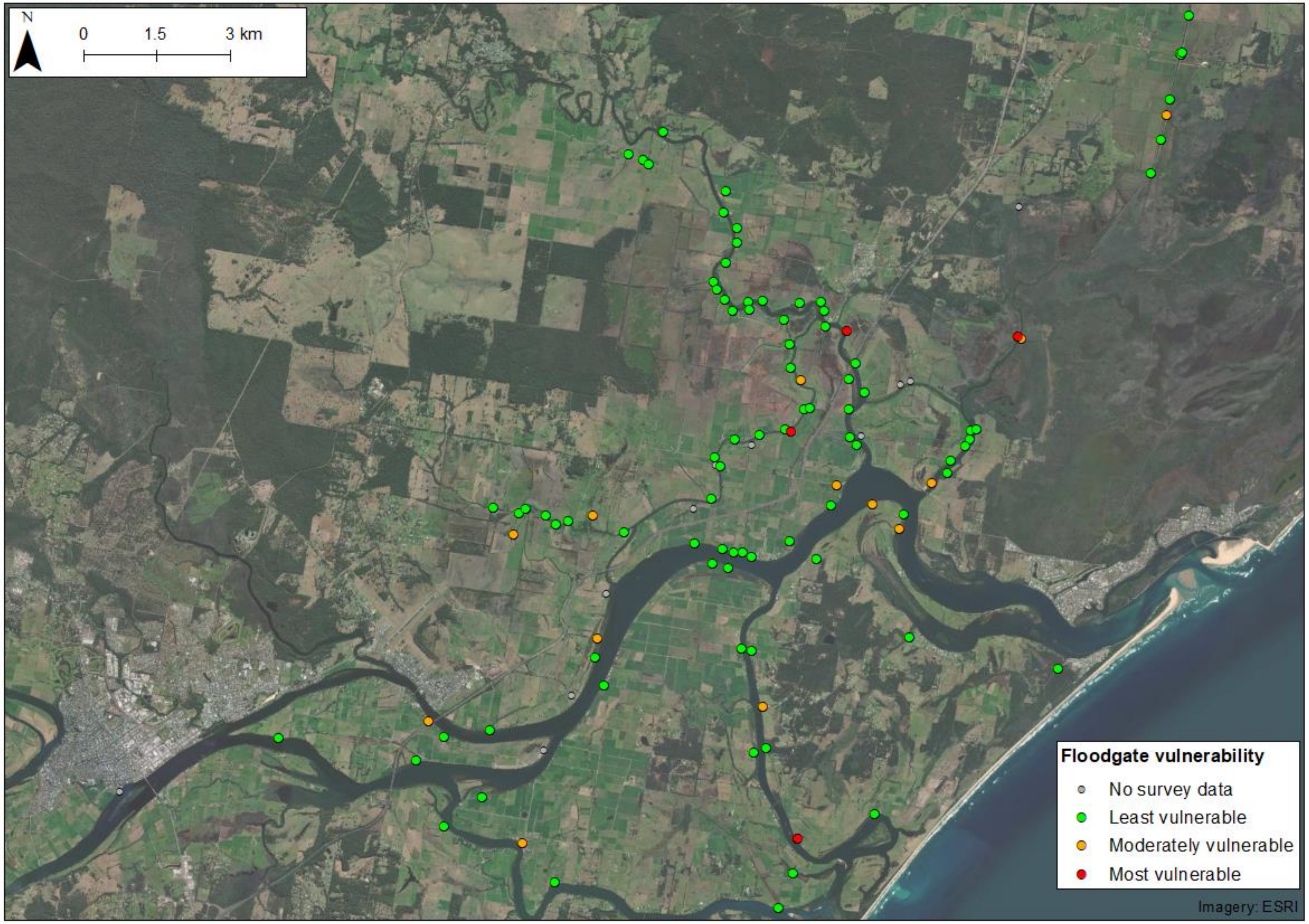

Figure 7-4: Present day floodgate vulnerability – Manning River estuary

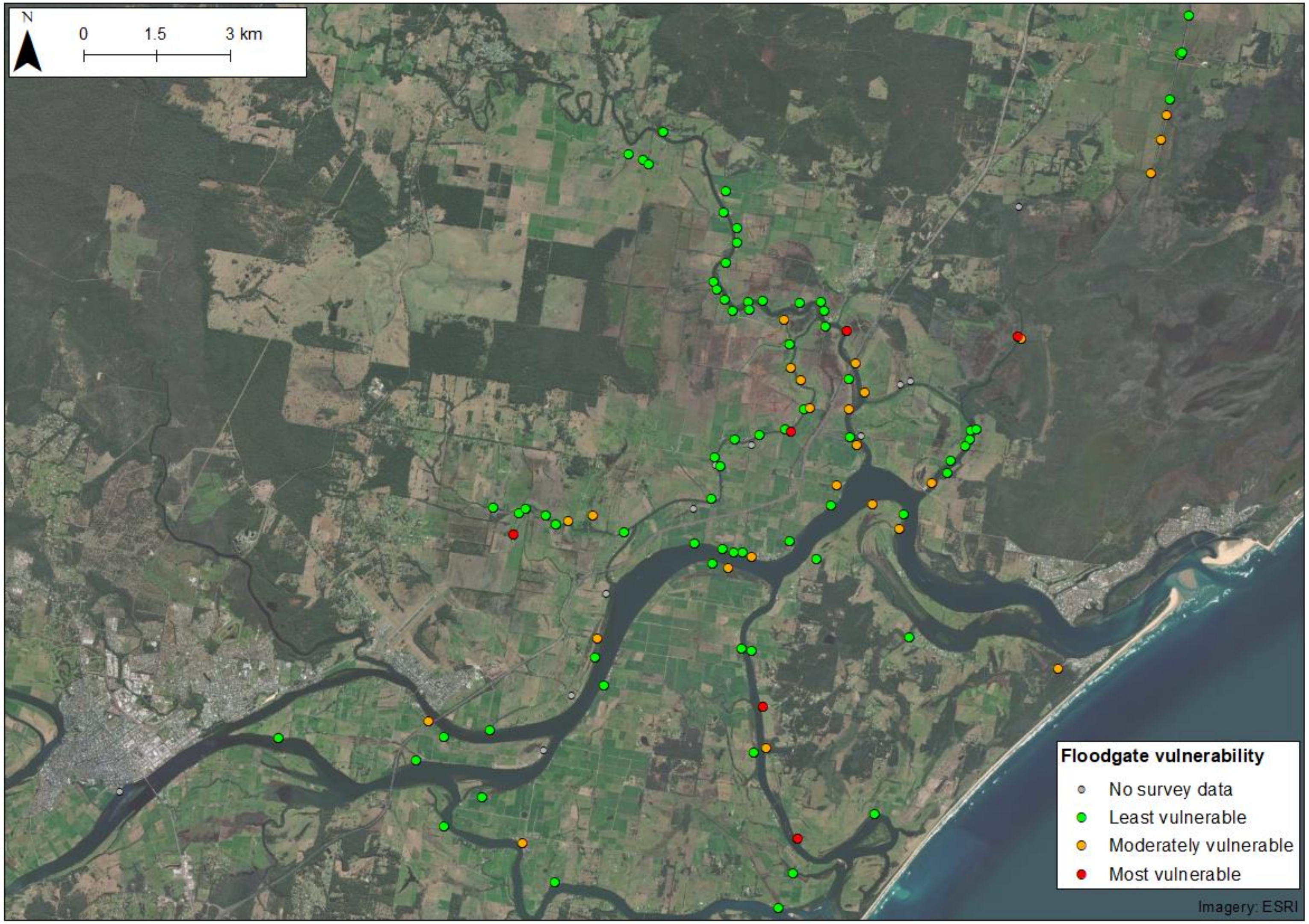

Figure 7-5: Near future (~2050) floodgate vulnerability – Manning River estuary

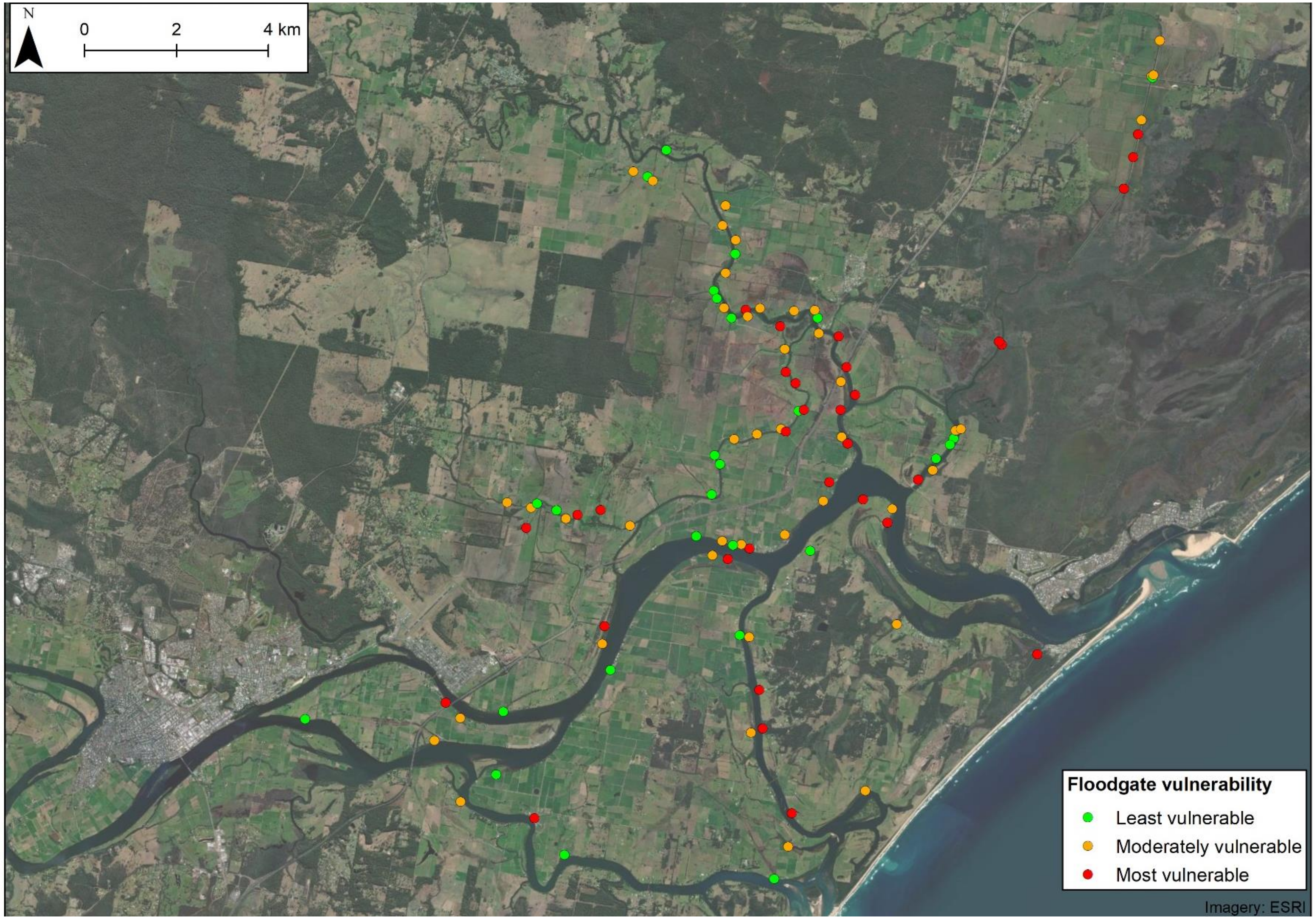

Figure 7-6: Far future (~2100) floodgate vulnerability – Manning River estuary

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

Table 7.4: Rules for floodplain drainage vulnerability

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

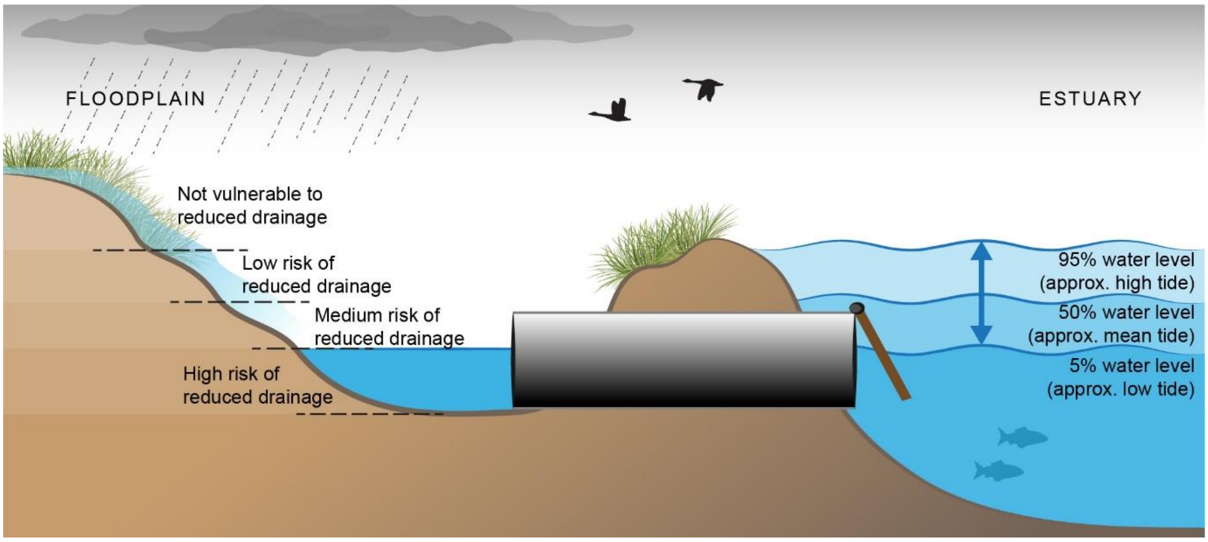

Figure 7-7:Floodplain drainage vulnerability

The total floodplain areas below the water level percentiles for the HS, PD, NF and FF sea level rise scenarios for the Manning River are summarised in Table 7-5. While the area below the 5th percentiles water level (e.g. highly vulnerable areas) increases by four (4) times between present day and the near future, this increases to more than 60 times in the far future to approximately 182 ha.

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

Vulnerability Status	Level criteria	Historic Scenario (HS) ~1960	Present Day (PD) 2020	Near Future (NF) ~2050	Far Future (FF) ~2150
		Area (ha)			
Low	50^{th} percentile water level < Land elevation < 95^{th} percentile water level	266	444	1,393	6,504
Moderate	5^{th} percentile water level < Land elevation < 50^{th} percentile water level	15	18	32	1,822
High	Land elevation < 5^{th} percentile water level	2	3	10	182

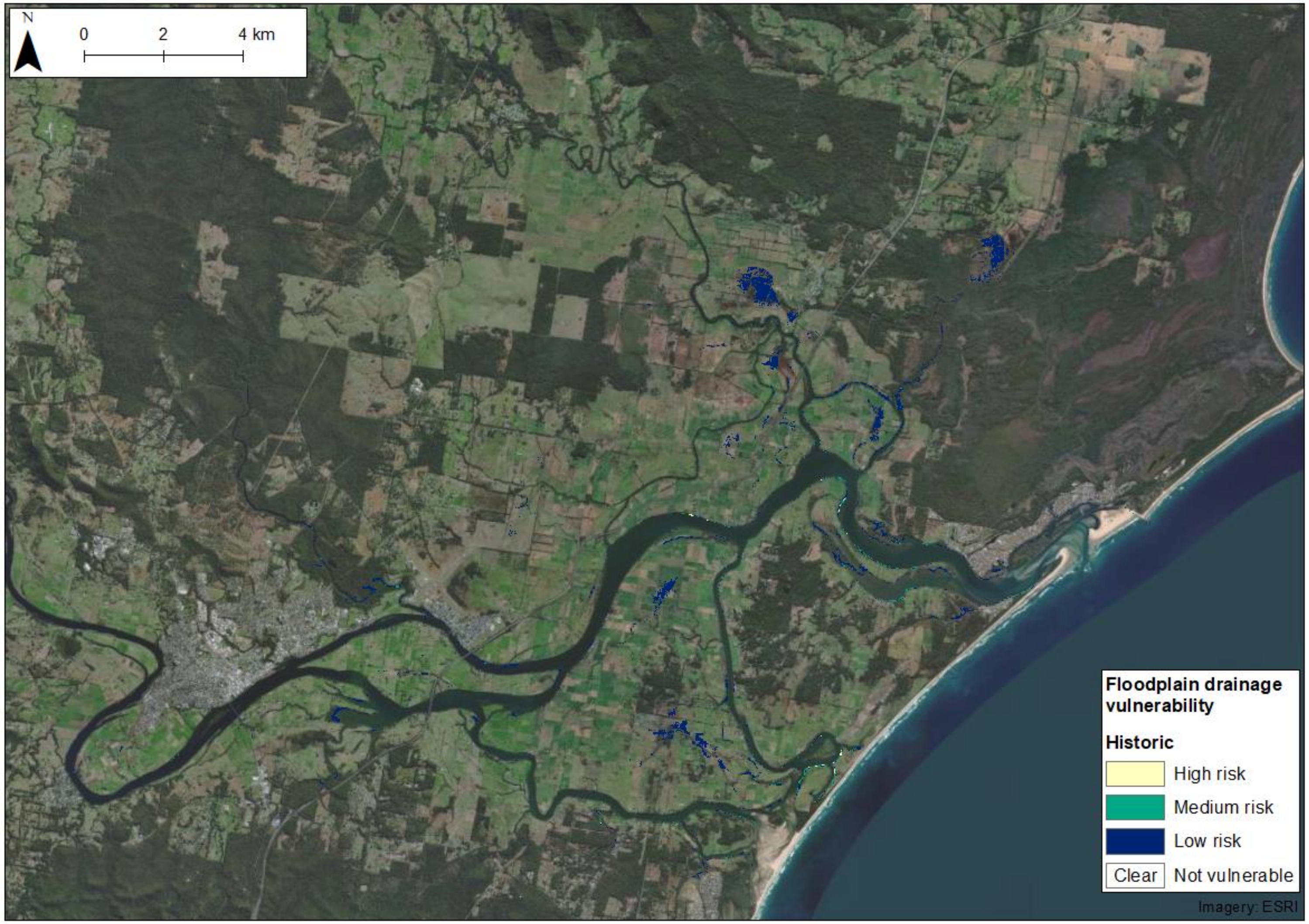

Figure 7-8: Historic (~1960) floodplain vulnerability – Manning River estuary

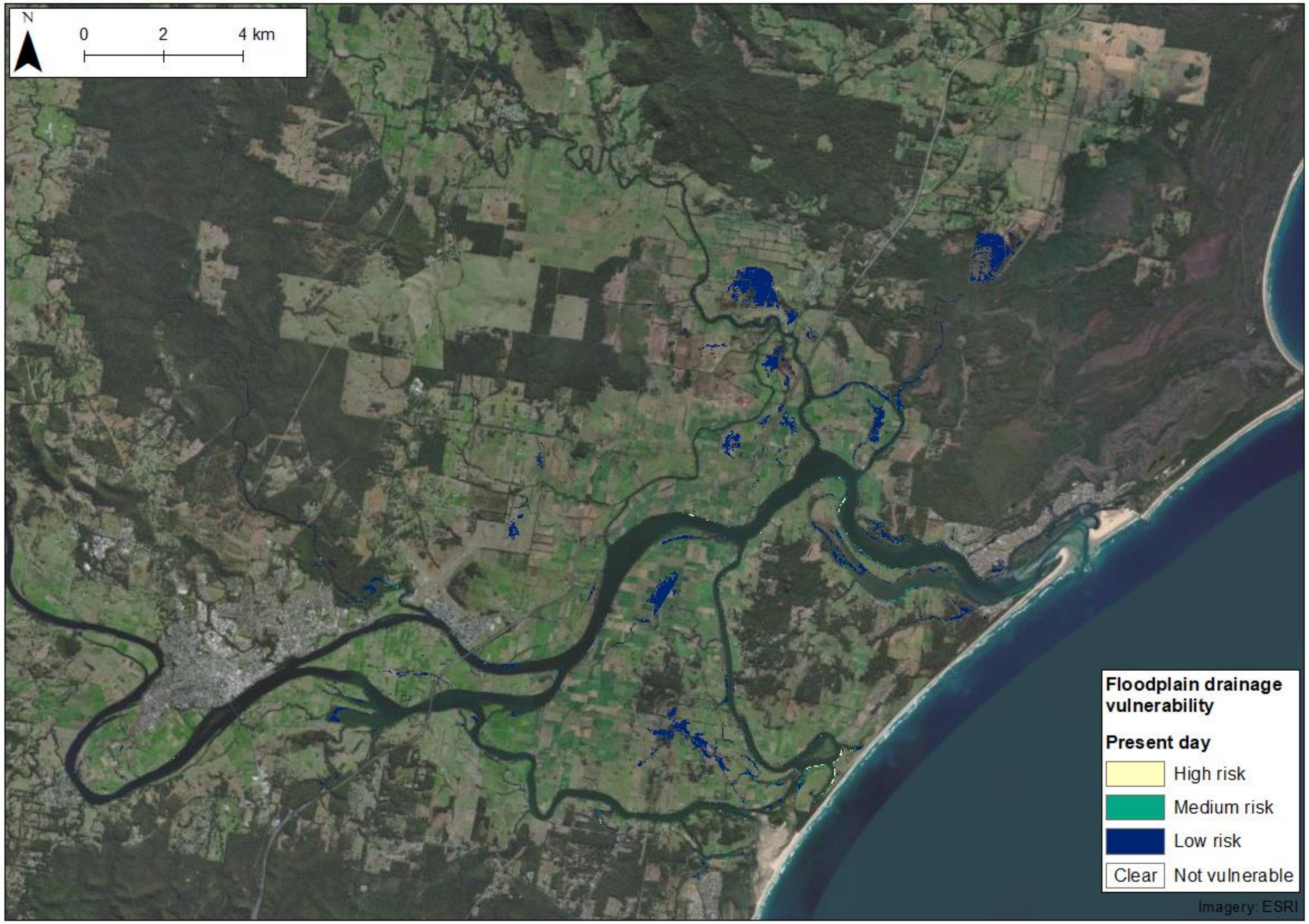

Figure 7-9: Present day floodplain vulnerability – Manning River estuary

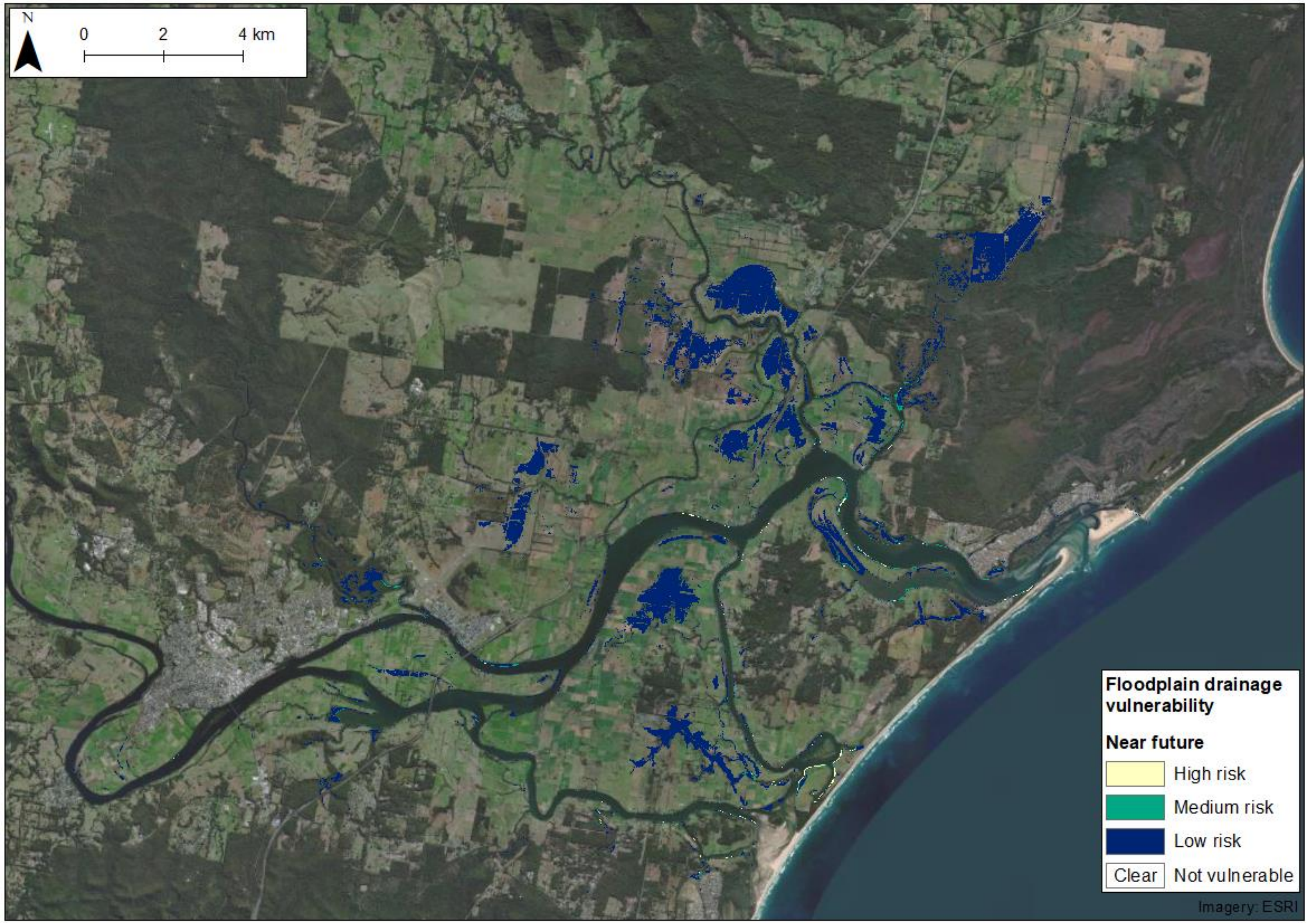

Figure 7-10: Near future (~2050) floodplain vulnerability – Manning River estuary

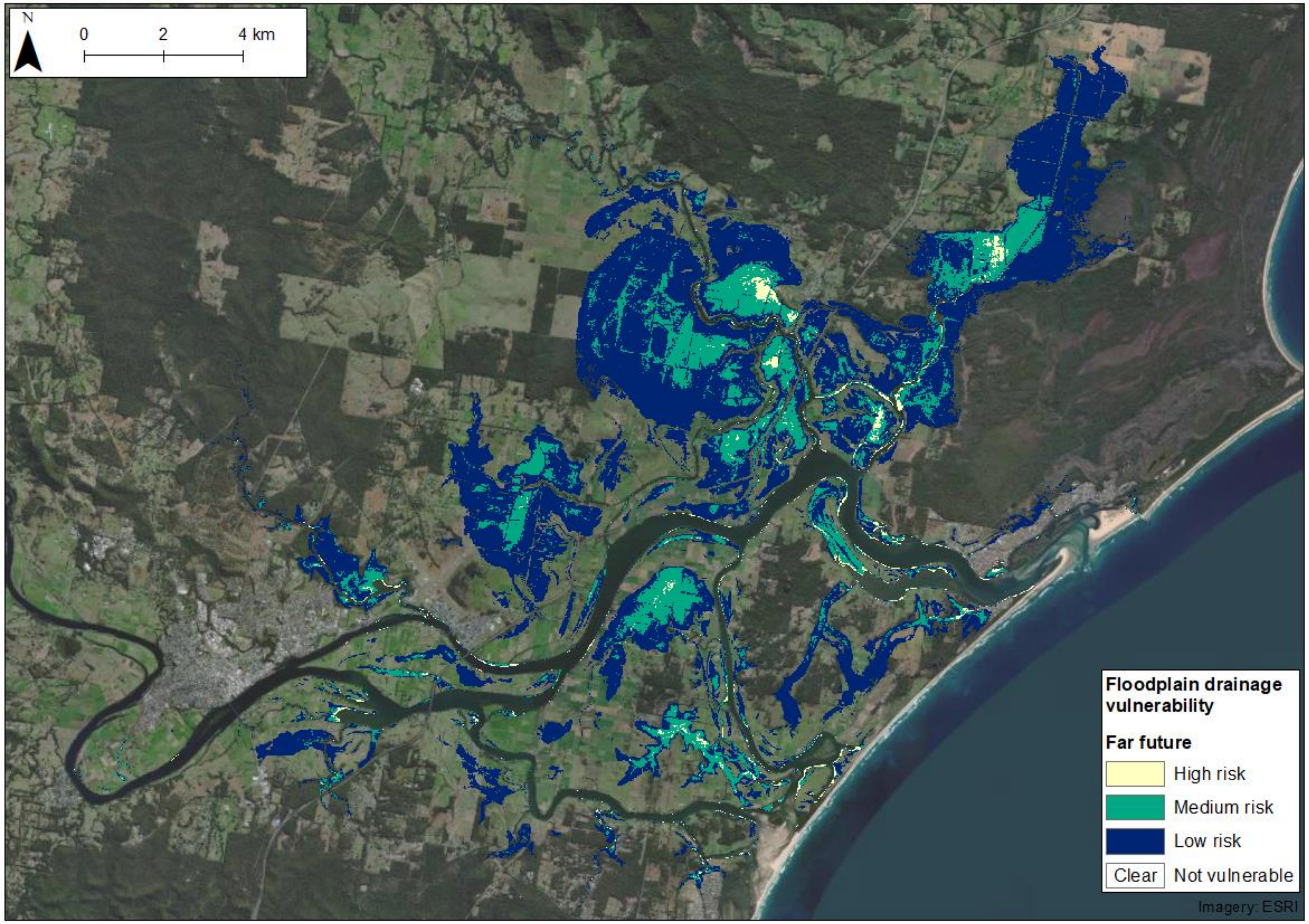

Figure 7-11: Far future (~2010) floodplain vulnerability – Manning River estuary

8 Subcatchment management options

8.1 Preamble

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

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

8.2 Explanation of key information

8.2.1 Summary table

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

8.2.2 Floodgates and tenure

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

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

Table 8-1: Subcatchment data summary table

Value	Description
Acid priority rank: #	**Final rank in floodplain for acid generation**
Blackwater priority rank: #	**Final rank in floodplain for blackwater generation**
<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. More information on this assessment can be found in Section 7.4, see Figure 7-2; and
- **Floodplain vulnerability:** represented as downstream water level statistics (5th, 50th and 95th percentile) translated directly onto upstream floodplain topography. Note that this simplified 'bath tub' approach does not take into account floodgates, hydraulic losses, or dampening/amplification through floodplain drainage channels. The purpose of the floodplain vulnerability analysis is to identify areas likely to be directly impacted by higher estuarine water levels and reduced drainage, rather than areas that may be actively inundated by tidal waters due to sea level rise. The relevance of each of the water level statistics is:
    - **5th percentile water level** (water levels are below this 5% of the time, or around 1 hour a day) – this represents a low tide water level at a given location. Areas below the 5th percentile water level are typically permanently inundated and difficult to drain without additional mechanical assistance (i.e. pumping);
    - **50th percentile water level** (water levels are below this 50% of the time) – this is a median water level. Areas below the 50th percentile water level are generally difficult to drain efficiently; and
    - **95th percentile water level (**water levels are below this 95% of the time, or around 23 hours a day) – this represents a high tide water level at a given location. Areas below the 95th percentile water level can be impacted by inefficient drainage, particularly after flood events.

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

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

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

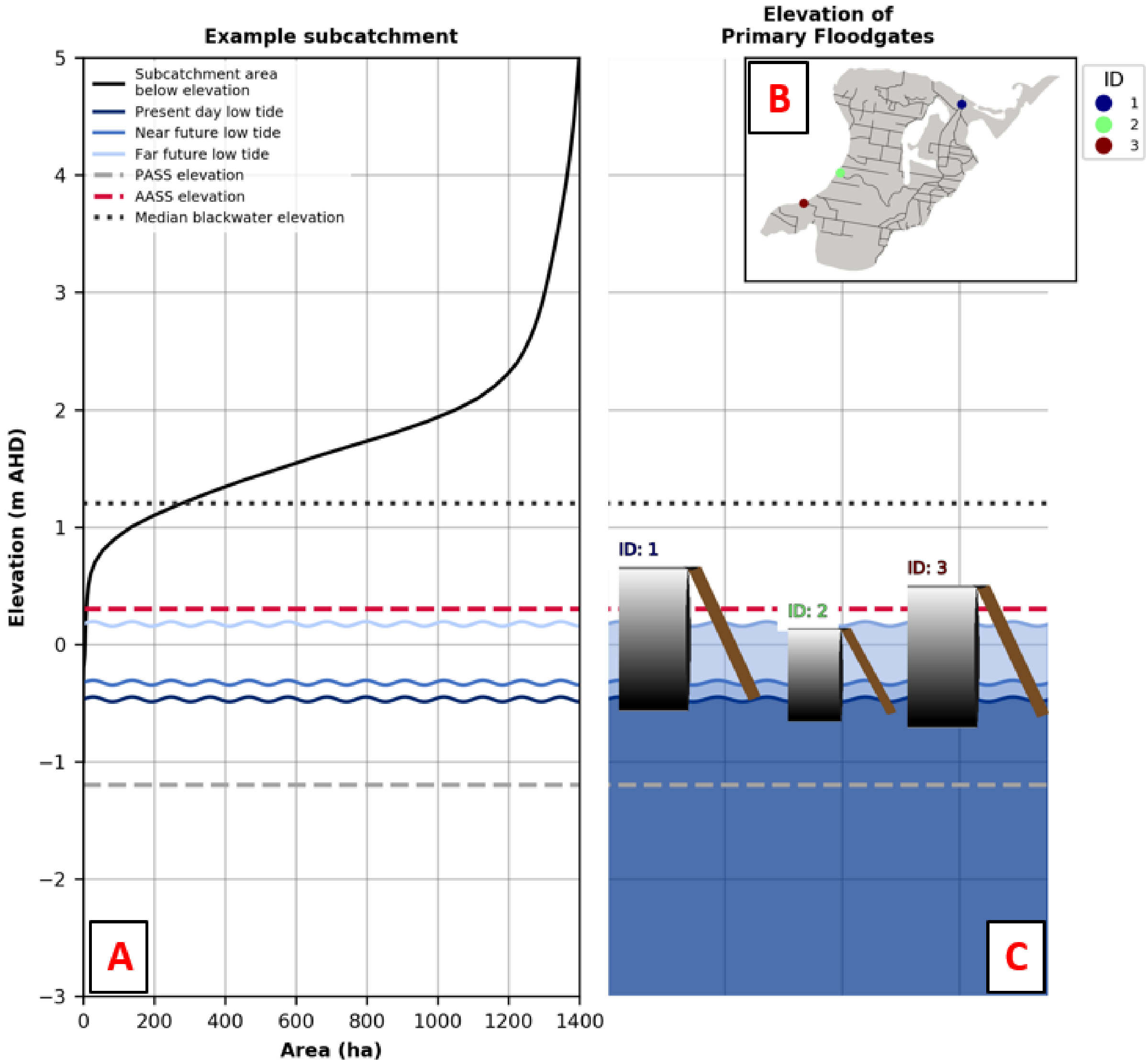

Figure 8-1: Reduced drainage vulnerability summary figure example

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

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

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

This infographic, and the sea level rise vulnerability of infrastructure more generally, focuses on the impact of reduced drainage from increasing low tides. While this provides a good indication of reduced drainage potential, it is acknowledged that high tide levels also impact floodgate functionality. The tidal range (based on the 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 to 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 for remediation (e.g. drain infilling per km) presented in Section 10 of the Methods report (Rayner et al., 2023) ; and
- Lost productivity – estimated based on the area of land impacted by proposed remediation and average productivity for different land uses (present-day) in the catchment.

More information on the cost estimates used in this study is presented in Section 10 of the Methods report (Rayner et al., 2023). 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 regards to the effectiveness of improving wetland habitat and connectivity while reducing the impacts of ASS and blackwater. This is based on the type of works proposed, 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 that the benefits of remediation outweighed the costs. These include:

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

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

8.2.5 Waterway classification

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

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

8.2.6 Subcatchment management areas

Subcatchments that are identified to have significantly higher ASS factors have been further delineated into separate management areas based on geology and drainage. The management areas were then re-analysed to identify high priority management areas and indicate the potential sources of acid drainage within a subcatchment. In the Manning River floodplain, the reanalysis of subcatchment management areas is provided in the management options in the Manning River floodplain for:

- Big Swamp subcatchment;
- Moto subcatchment; and
- Ghinni Ghinni subcatchment.

The reanalysis of management areas in this study for these three (3) subcatchments has been replicated from Glamore et al. (2016a). Catchment delineation of the drains, structures, or land management sub-divisions within the priority areas was based on high-resolution aerial photographs, LiDAR survey data, location of floodgate structures and main drains, potential flow paths, as well as on-site experience from recent investigations. Floodplain areas for the reanalysis of management areas was estimated based on the 2 m AHD contour. The 2 m AHD contour was used to define the reanalysed areas as it:

- Includes land that is frequently inundated in the catchment, given flood levels at Harrington can reach 2.3 m AHD;
- Captures the majority of the mapped high-risk ASS; and
- Provides a uniform approach for MidCoast Council to determine the potentially affected landowners and is consistent with work undertaken as part of the Big Swamp Hydrologic Study (Glamore et al. 2014),

Available soil profile data, including soil acidity, were used to assign typical values to the reanalysis management areas. Most sites across each subcatchment had at least one (1) data point within the reanalysis management area. If data was not available within each management area, values were assigned to that management area based on an average of the nearest two (2) or three (3) data points from adjacent management areas (where possible). Note that for all management areas, catchment areas, hydraulic conductivity, and the lowest drainage elevation of each management area, was based on values used for the catchment-wide assessment of the priority subcatchments.

8.3 Big Swamp subcatchment

Acid priority rank:	**1**
Blackwater priority rank:	**3**
Infrastructure	
Approximate waterway length (km)	107
# Privately owned end of system structures	10
# Publicly owned end of system structures	0
# End of system structures within coastal wetlands	1
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (floodgate ID)	MANN121, MANN123, UNK13, UNK14
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-0.5 to 0.3
Average AASS elevation (m AHD)	0.9
Average PASS elevation (m AHD)	0.2
Median blackwater elevation (m AHD)	0.5
Present day low water level (m AHD)	-0.1
Near future low water level (m AHD)	0
Far future low water level (m AHD)	0.5
Proximity to sensitive receivers	
Oyster leases (km)	4.2
Saltmarsh (km)	Within subcatchment
Seagrass (km)	3.6
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	3,904
Classified as conservation and minimal use (ha (%))	1166 (30%)
Classified as grazing (ha (%))	2150 (55%)
Classified as forestry (ha (%))	12 (0%)
Classified as horticulture (ha (%))	1 (0%)
Classified as other cropping (ha (%))	5 (0%)
Classified as urban/industrial/services (ha (%))	11 (0%)
Classified as marsh/wetland (ha (%))	539 (14%)
Other (ha (%))	20 (1%)
Land values	
Estimated total primary production value ($/year)	$1,000,000
Average land value above 0.5 m AHD ($/ha)	$4,900
Average land value below 0.5 m AHD ($/ha)	No property data available

8.3.1 Site description

The Big Swamp subcatchment is a large backswamp and associated floodplain located in the northern-eastern part of the Manning River floodplain. Pipeclay Canal flows into Cattai Creek, a north bank tributary of the Manning River, and is located 15 km upstream of the northern entrance of the Manning River. As shown in Figure 8-2, MidCoast Council owns a significant portion of the Big Swamp subcatchment, which has been acquired and remediated since 2003 to address ASS drainage.

Draining into Pipeclay Canal, the Big Swamp floodplain includes approximately 3,900 ha below 5 m AHD (shown in Figure 8-3) and is located immediately north of Cattai Wetlands. Several sensitive receivers are located downstream of the Big Swamp subcatchment, including key fisheries habitat, priority oyster leases and seagrass, that are impacted by acid discharges from the Cattai Creek-Pipeclay Canal region. The Big Swamp subcatchment was also identified as an ASS priority area in Tulau (1999).

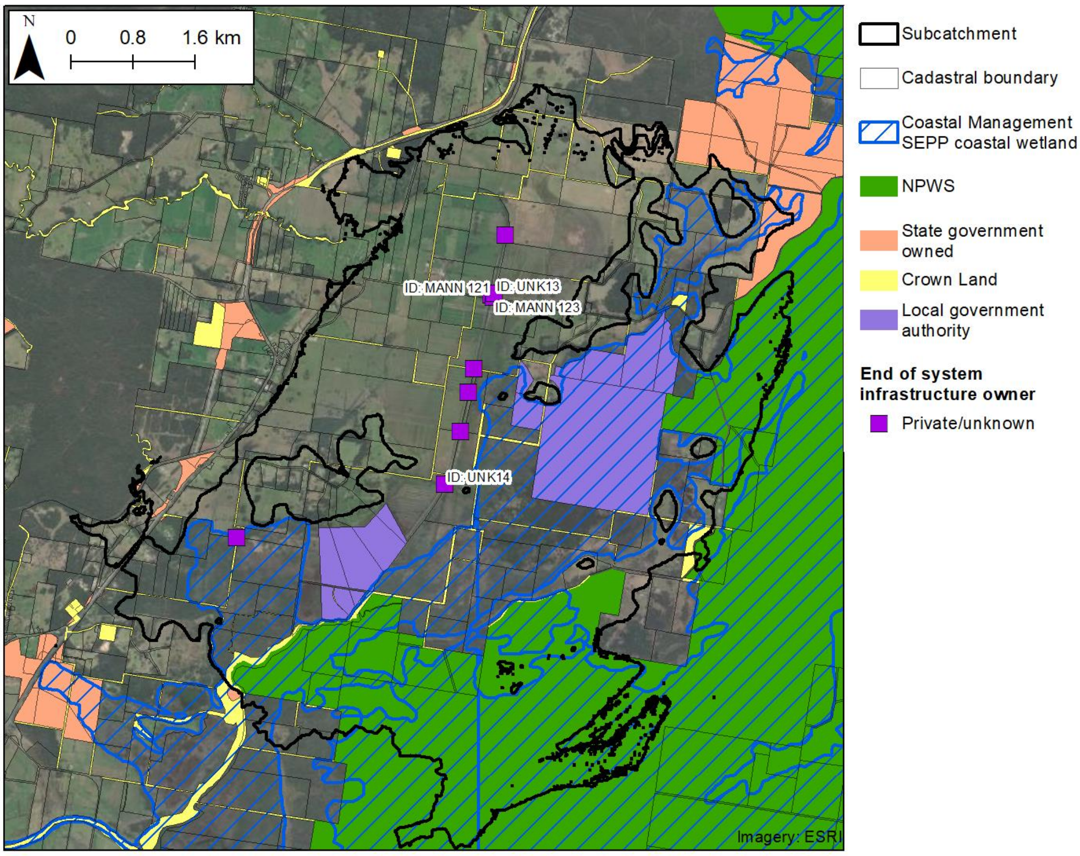

Figure 8-2: Big Swamp tenure and end of system infrastructure tenure

Note the area owned by MidCoast Council is based on data available from https://maps.six.nsw.gov.au/clipnship.html, accessed September 2020 and may not include all areas that have been purchased

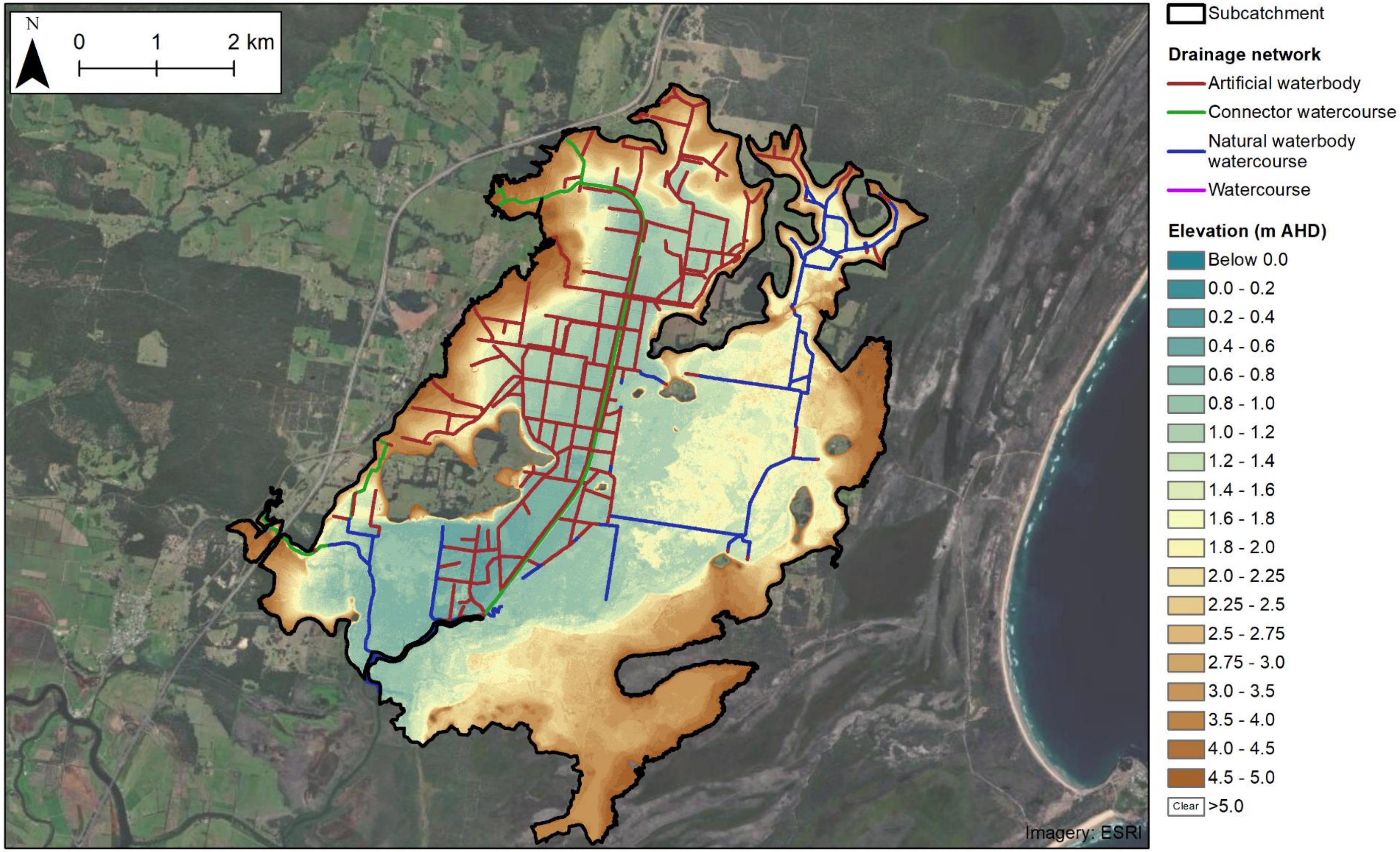

Figure 8-3: Big Swamp subcatchment elevation and drainage network

8.3.2 History of remediation

A timeline of remediation works within the Big Swamp subcatchment (including a portion of Cattai Wetlands) is provided below with reference to Figure 8-4. The works included:

- 2003 – Public acquisition of approximately 500 ha of land along the right-bank of Cattai Creek to restore an area of Manning River floodplain known as Cattai Wetlands. The Plan of Management recommended decommissioning a non-functional floodgate, as well as drain and levee structures. The objective of the project was to acquire the portions of the floodplain with wetland habitat values, develop and dispose of the remaining higher-elevated land as hobby farms, and retain the wetland areas (approximately 400 ha);
- 2014 – Following a comprehensive hydrological study conducted by WRL (Glamore et al., 2014), MidCoast Council acquired land and implemented the on-ground works program recommended by WRL as part of a $2 million Federal Government grant in 2011 to reduce acid runoff into the Manning River estuary. On-ground outcomes included:
    - Public acquisition of 700 ha of private land (parts of BS_10 and BS_11);
    - Conversion of agricultural land into an 80 ha tidal wetland by infilling/reshaping several main drains, construction of low profile levees (crest height approximately 1 m AHD), decommissioning several floodgates and associated infrastructure; and
    - Elevation of ground water levels above the acidic soil layer over the remaining 620 ha of drained floodplain.
- 2016 – MidCoast Council received further funding of $350,000 through the NSW Estuary Management Program to purchase and rehabilitate an additional degraded farmland across the Big Swamp floodplain; and
- 2017 – MidCoast Council purchased an additional 170 ha on the Big Swamp floodplain in management area B_1; and
- 2019 – A cost-benefit analysis (CBA) was undertaken on behalf of MidCoast Council (Harrison et al., 2019) to support state government funding for broad scale remediation of the low lying areas of the Big Swamp floodplain. This study conservatively estimated to have a benefit to cost ratio of 7:1, despite not including the costs of acid discharges in the assessment. The Council is currently seeking funding for further investigations and land acquisition.

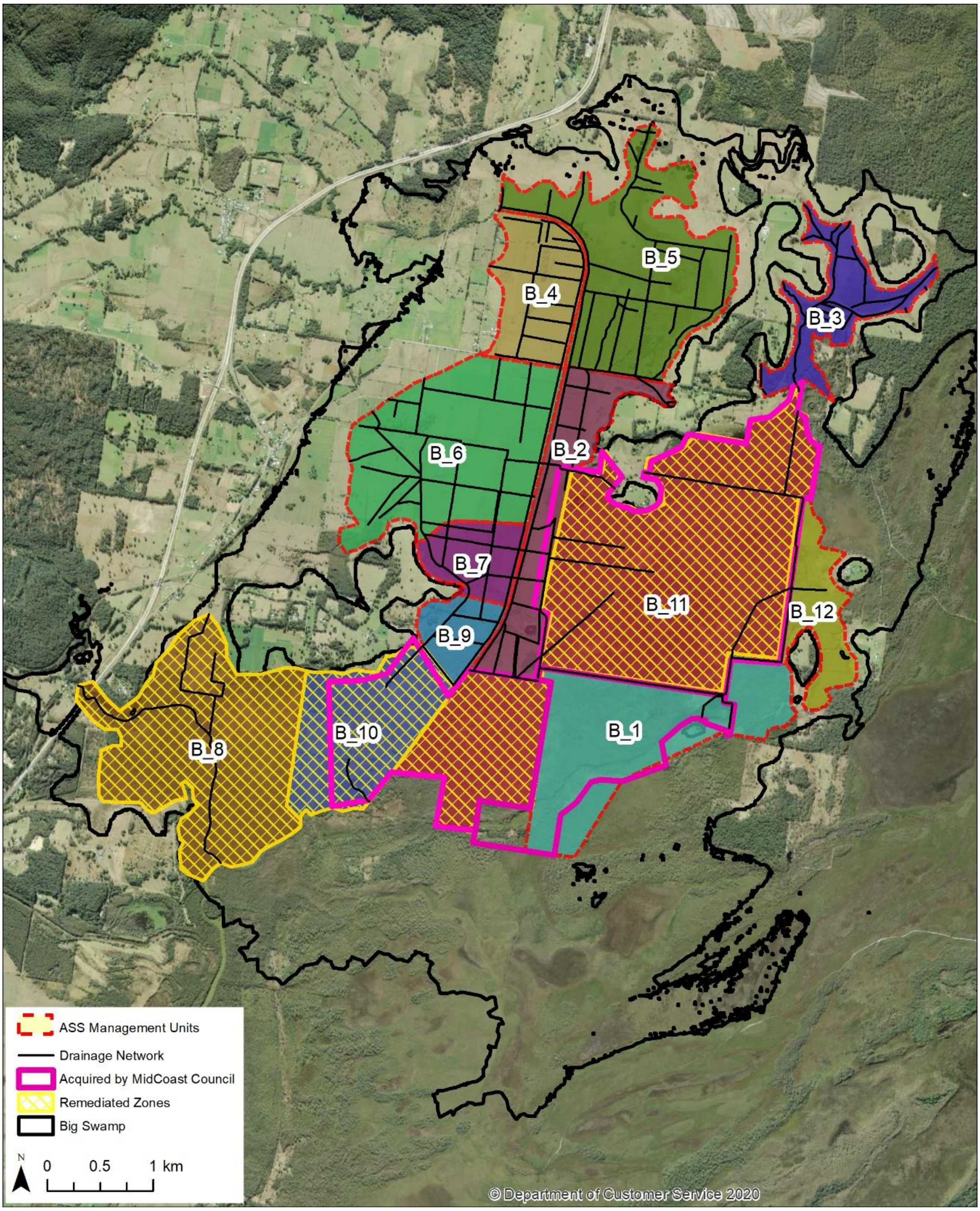

Figure 8-4: Management areas of the Big Swamp subcatchment including previous remediation target areas

8.3.3 Prioritisation of management areas in the Big Swamp subcatchment

At Big Swamp, the reanalysis assessment identified the highest priority areas for remediation adjacent to existing MidCoast Council owned land and along the eastern-side Pipeclay Canal. These areas have a soil acidity below pH 4.5 and also correspond to the lowest lying areas of the site (generally <1.0 m AHD). On the Big Swamp floodplain, the two (2) highest priority areas account for approximately 60%

of the acid risk to the broader catchment. Note that previously remediated sites in the Cattai Creek-Pipeclay Canal area, including upstream areas of the Cattai Wetlands, and publicly acquired land on the south-west and eastern side of Pipeclay Canal at Big Swamp, were included in the reanalysis assessment. The results of the reanalysis assessment supports the ongoing management and objectives of the site, providing opportunities to expand existing wetland areas without impacting drainage across the site or adjacent land-holdings.

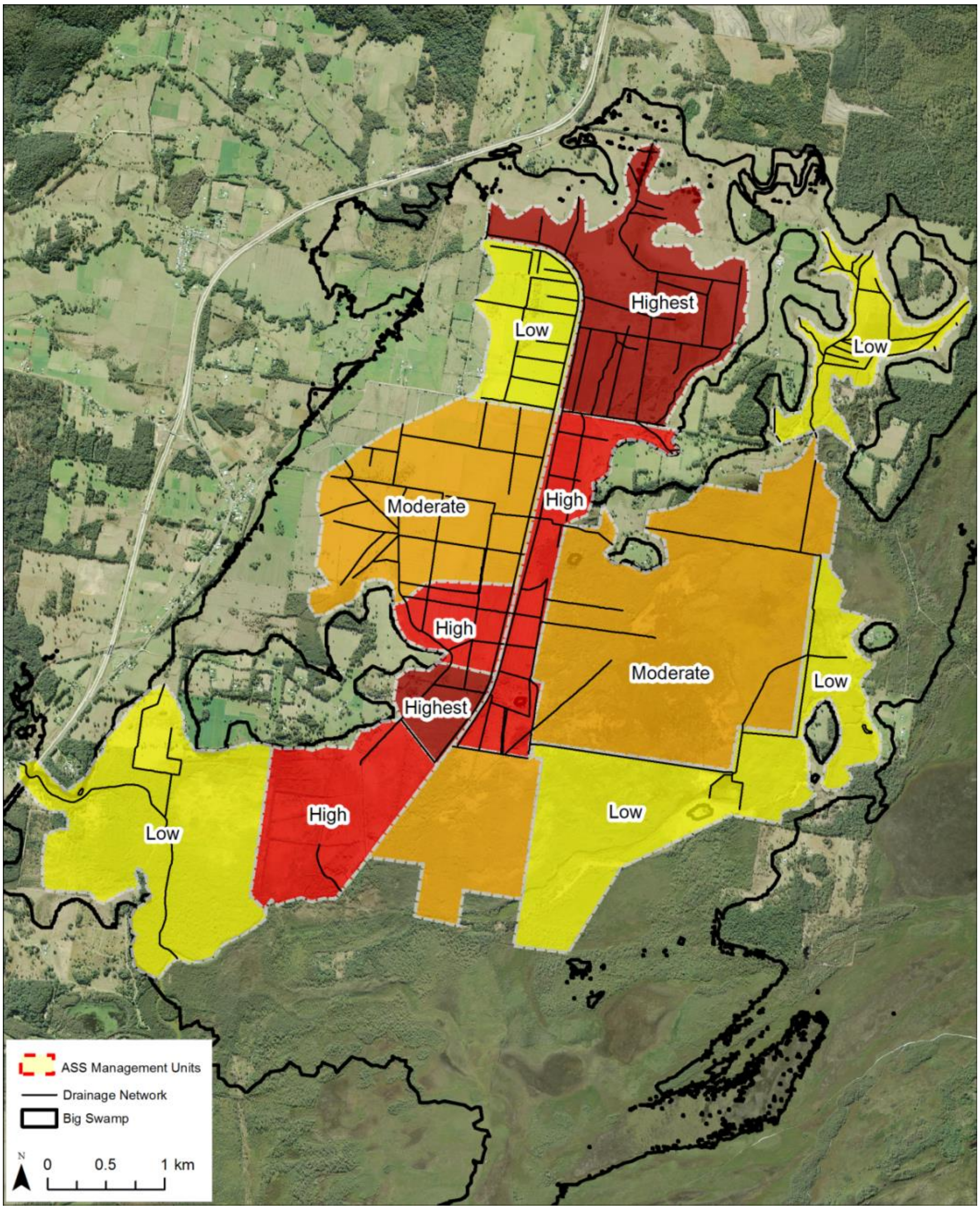

Figure 8-5: Reanalysis of ASS prioritisation of management areas in the Big Swamp subcatchment (Glamore et al., 2016a)

The Big Swamp subcatchment also ranked third in the blackwater prioritisation. While blackwater has generally not been identified as a key issue on the Manning River floodplain, the analysis suggests that areas below 1.3 m AHD (and particularly those areas below 0.5 m AHD) in the Big Swamp subcatchment may contribute to blackwater generation after flood events. In the lowest areas of this subcatchment, changes in land management should also consider reducing the blackwater generation potential through encouraging water tolerant vegetation.

8.3.4 Floodplain drainage – sea level rise vulnerability

Figure 8-6 summarises the vulnerability of the Big Swamp subcatchment to sea level rise. The lowest areas of the subcatchment are classified as low risk for reduced drainage under the near future sea level rise scenario. This area increases significantly under the far future sea level rise scenario, to everything below 1.3 m AHD. While the lowest areas are within the areas that have already been remediated to brackish wetlands by MidCoast Council, some of the area below 1.3 m AHD are currently used for grazing. These areas may be impacted by reduced drainage as sea levels continue to rise.

Figure 8-6 and Figure 8-7 (primary floodgates only) also summarises the vulnerability of floodgates in the Big Swamp subcatchment. One (1) of nine (9) floodgates with survey information is classified as 'moderately vulnerable' in present day conditions (floodgate ID MANN 128). This increases to three (3) out of nine (9) floodgates classified as 'moderately vulnerable' under near future sea level rise conditions. In the far future, three (3) floodgates are classified as most vulnerable, and five (5) floodgates are classified as 'moderately vulnerable', including primary floodgates MANN121, UNK13 and UNK14. Reduced capacity of floodplain infrastructure may also impact productivity of present day land uses into the future.

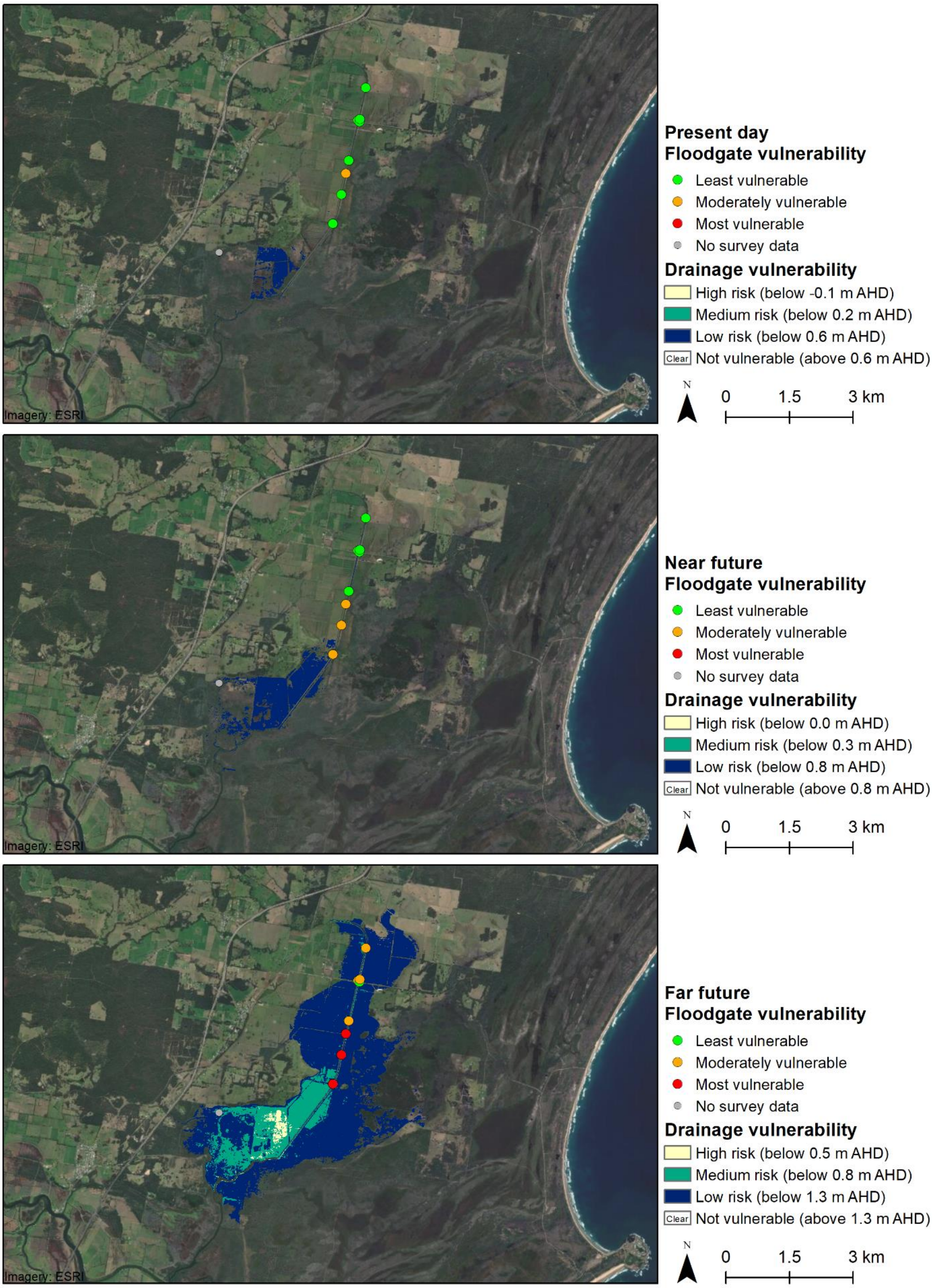

Figure 8-6: Sea level rise drainage vulnerability - Big Swamp subcatchment

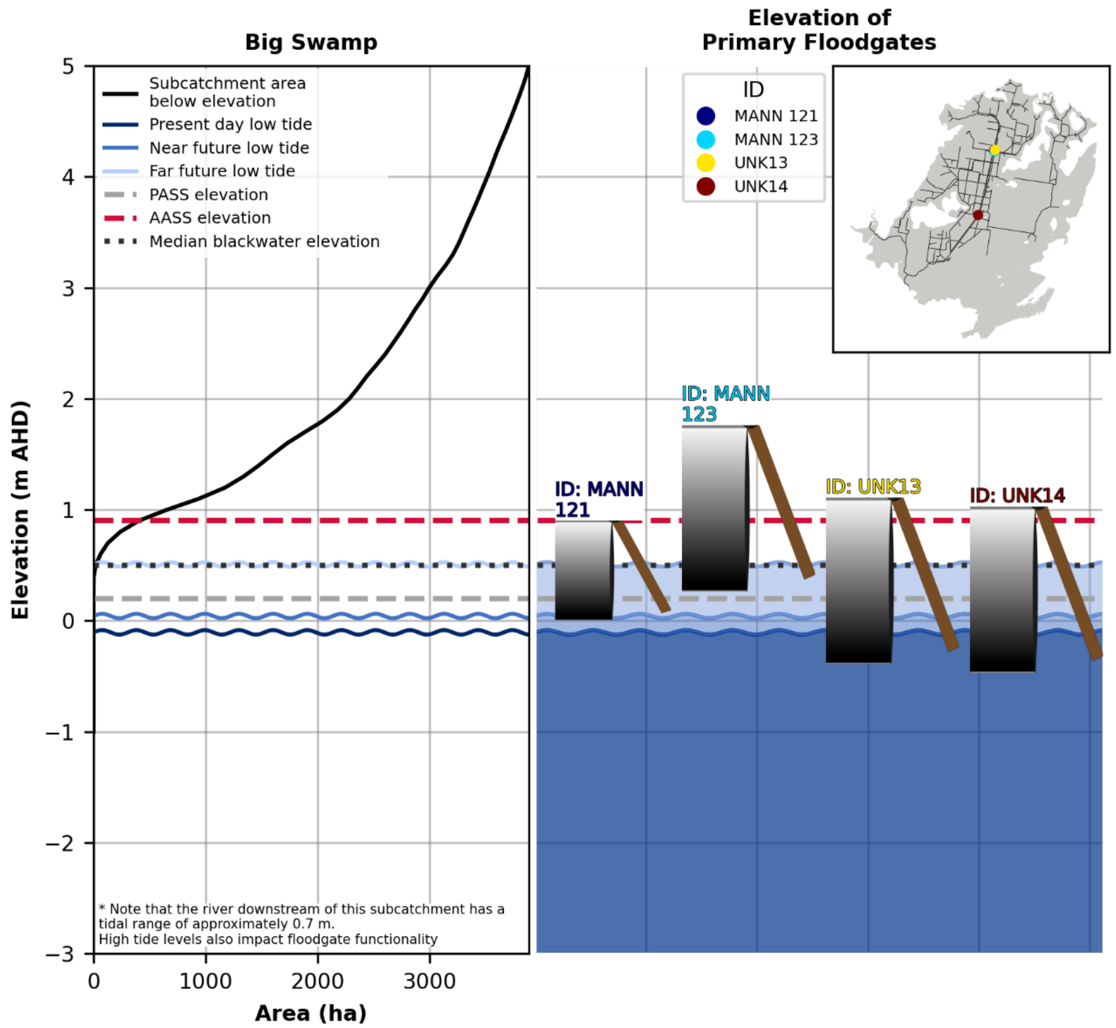

Figure 8-7: Key floodplain elevations – Big Swamp subcatchment

8.3.5 Management options

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

- Short-term: Tidal flushing via floodgate modification, expansion of current MidCoast Council remediation zone; and
- Long-term: Full remediation of low lying land to estuarine and/or freshwater wetland.

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

A significant portion of the Big Swamp subcatchment (approximately 700 ha) was previously targeted for remediation as part of the MidCoast Council ASS Drainage Management Plan (details are provided in Section 8.3.2). Previous on-ground works have focused on full remediation in Big Management Areas B_8 and B_10, and groundwater manipulation/wet pasture management within Big Swamp Management Area B_11. The on-ground works in these areas involved decommissioning several large deep (>0.5 m) drains, removing floodgates, and notching levees. The works were completed with an objective of maintaining the flood mitigation capacity of adjacent landholders via the construction of new wide shallow drains (with an equivalent hydraulic capacity to the original drain), and neutralising existing acidity by promoting shallow tidal inundation (and buffering). New perimeter fences were installed to restrict livestock access to remediated areas, allowing land regeneration. While the majority of the B_1 Management Area was purchased, on-ground investigations showed that infilling drains in the area purchased was not immediately feasible due to the reliance of upstream properties on the drainage network situated within B_1 (WRL, 2019).

Where applicable, other areas of the Big Swamp floodplain should be targeted for remediation to support the outcomes of the previous ASS Drainage Management Plan of the region by further land acquisition, groundwater manipulation, and tidal wetland or wet pasture (freshwater) creation. This would reduce acid drainage, soil acidification and blackwater generation originating from the Big Swamp subcatchment. In particular, it is recommended that MidCoast Council acquire Big Swamp Priority Areas B_2 and B_9 to expand the existing remediation areas. However, acquisition of Big Swamp Management Areas B_2 and B_9 would require further detailed design to assess impacts to adjacent private land. In addition to drain infilling/reshaping, it is also recommended that low-level concrete causeways are used (where necessary) to raise local groundwater levels, while maintaining access along the existing levees flanking Pipeclay Canal.

Following on from previous remediation efforts at Big Swamp, the next highest priority management area nominated for the region is B_5, situated in the north-eastern portion of the floodplain. Management area B_5 is extensively drained and has one of the largest stores of soil acidity in the subcatchment. Since the land topography is generally above 1.0 m AHD, in-drain tidal buffering through floodgate modification or groundwater manipulation are encouraged where salinity levels allow. Low-lying areas of the landscape could also be remediated by encouraging wet pasture management via installation of drop board weirs on main drains, which would also reduce the potential for blackwater generation and acid export. It is also recommended that unused drains are infilled and reshaped to create shallow, wide swale drains as used in other areas of the site. Swale drains can be effectively designed to maintain existing surface water removal capacity. Further detailed surveys, investigation, and design would be required before the implementation of any on-ground works.

Long-term management options

The Big Swamp subcatchment features some of the lowest-lying topography on the entire Manning River floodplain. Low-lying portions of the floodplain, particularly along the western side of Pipeclay Canal (management areas B_6, B_7, and B_9), are likely to be increasingly affected by reduced drainage in the near future, with large areas remaining inundated under the far future sea level rise scenario due to increases in low and mid tide levels. Without additional infrastructure, the agricultural productivity of the Big Swamp backswamp is likely to become increasingly reduced and options for full remediation of poorly drained land to wet pastures (freshwater), or wetland (saline) should be investigated. Remediation of permanent or near permanent inundation across the lowest sections of the Big Swamp floodplain would reduce pathways for acid drainage, as well as encouraging water tolerant vegetation and reducing the overall blackwater generation potential. As the Big Swamp subcatchment ranked first in the ASS prioritisation and was estimated to account for approximately 38% of the overall acid risk in the Manning River estuary, large scale remediation of this subcatchment would result in significant improvements in overall estuary health. 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.

Indicative costs and qualitative benefits associated with the management options in the Big Swamp subcatchment is provided in Table 8-3.

Table 8-3: Summary of management options for Big Swamp

Timeframe	Strategy	Targeted area(s)	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	Groundwater manipulation	B_5	None	$40,000	$5,000	None	None	Moderate	Low
Short-term	Drain reshaping	B_9, B_2, B_7, B_6, B_4, B_8	None	$520,000	None	None	None	Moderate	Low
Short-term	Floodgate management	B_7, B_6, B_4	None	$50,000	$5,000	None	Moderate	Moderate	Minimal
Long-term	Wet pasture/freshwater wetland	B_5, B_2, B_6, B_11, B_8	$4,000,000**	$600,000	$5,000	$430,000**	None	High	High
Long-term	Wetland remediation	B_9, B_7, B_10	$ 1,125,000	$450,000	$5,000	$ 120,000	High	High	High

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

** Assuming land in all target areas is acquired and agricultural land use ceases.

8.4 Moto subcatchment

Acid priority rank:	**2**
Blackwater priority rank:	**2**
Infrastructure	
Approximate waterway length (km)	139
# Privately owned end of system structures	21
# 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)	MANN019, MANN021, MANN023, MANN026, MANN027, MANN028, MANN031, MANN032, MANN060, MANN096
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-0.6 to 0.6
Approximate AASS elevation (m AHD)	0.8
Approximate PASS elevation (m AHD)	-0.4
Median blackwater elevation (m AHD)	0.6
Present day low water level (m AHD)	-0.1
Near future low water level (m AHD)	0
Far future low level (m AHD)	0.5
Proximity to sensitive receivers	
Oyster leases (km)	2.7
Saltmarsh (km)	Within subcatchment
Seagrass (km)	2.2
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	3,327
Classified as conservation and minimal use (ha (%))	289 (9%)
Classified as grazing (ha (%))	2281 (69%)
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 (%))	29 (1%)
Classified as marsh/wetland (ha (%))	654 (20%)
Other (ha (%))	75 (2%)
Land values	
Estimated total primary production value ($/year)	$1,100,000
Average land value above 0.6 m AHD ($/ha)	$5,400
Average land value below 0.6 m AHD ($/ha)	No property data available

8.4.1 Site description

The Moto subcatchment features a large backswamp and associated floodplain located in the northern-central part of the Manning River estuary. The Moto subcatchment is estimated to be the largest ASS-affected region in the Manning River estuary and covers an area of approximately 3,300 ha below 5 m AHD. The south-eastern portion of the Moto floodplain is currently managed by the Moto Drainage Union and is drained independently of the mid and northern sections of the floodplain. As shown in Figure 8-8, all of the floodplain infrastructure is privately owned.

A significant portion of the Moto floodplain is situated below 1 m AHD (Figure 8-9). The floodplain drains through an extensive, inter-connected drainage network and discharges acidified water into Ghinni Ghinni Creek and the Lansdowne River. Several sensitive receivers are located downstream of the Moto subcatchment, including key fisheries habitat, priority oyster leases and seagrass, that are impacted by acid discharges from Ghinni Ghinni Creek and the Lansdowne River. The Moto subcatchment was also identified as being within an ASS priority area in Tulau (1999). Issues associated with blackwater events have also been identified in the Moto subcatchment (Greater Taree City Council, 2009b) after summer floods.

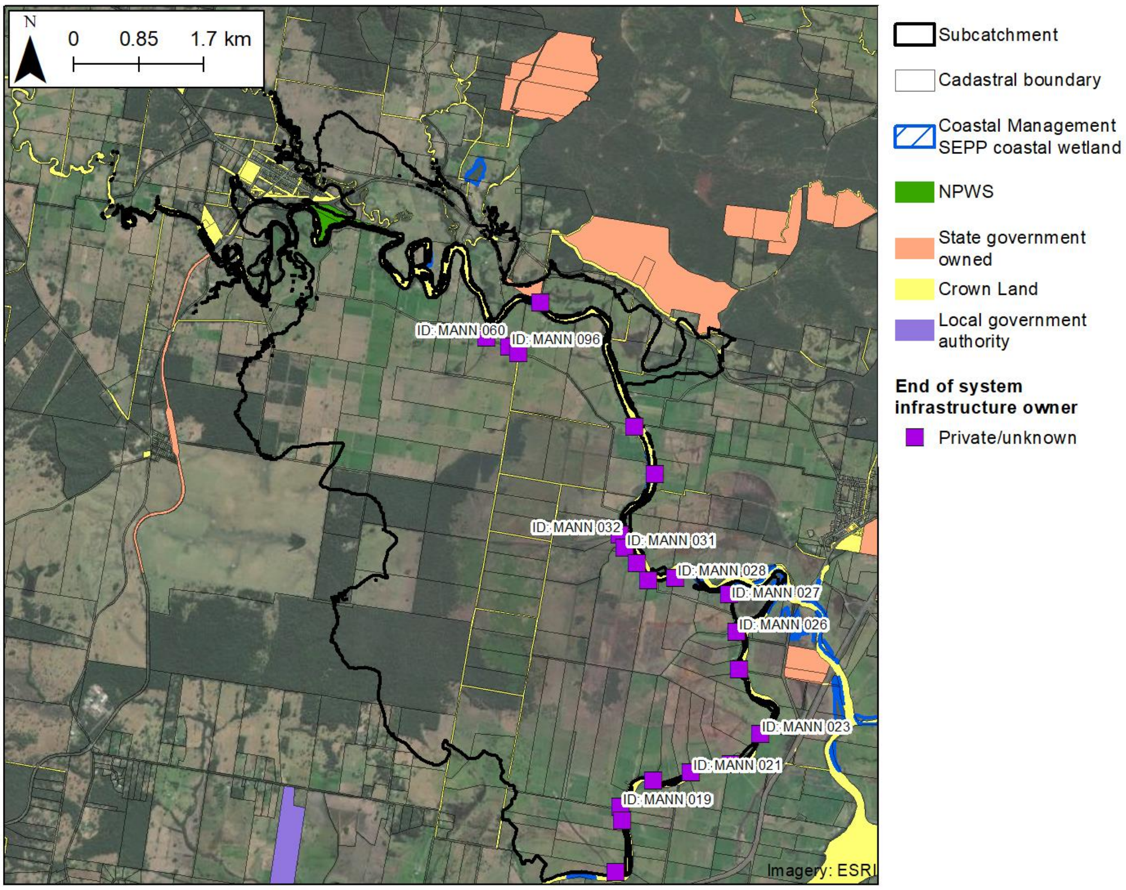

Figure 8-8: Moto subcatchment land and drainage infrastructure tenure

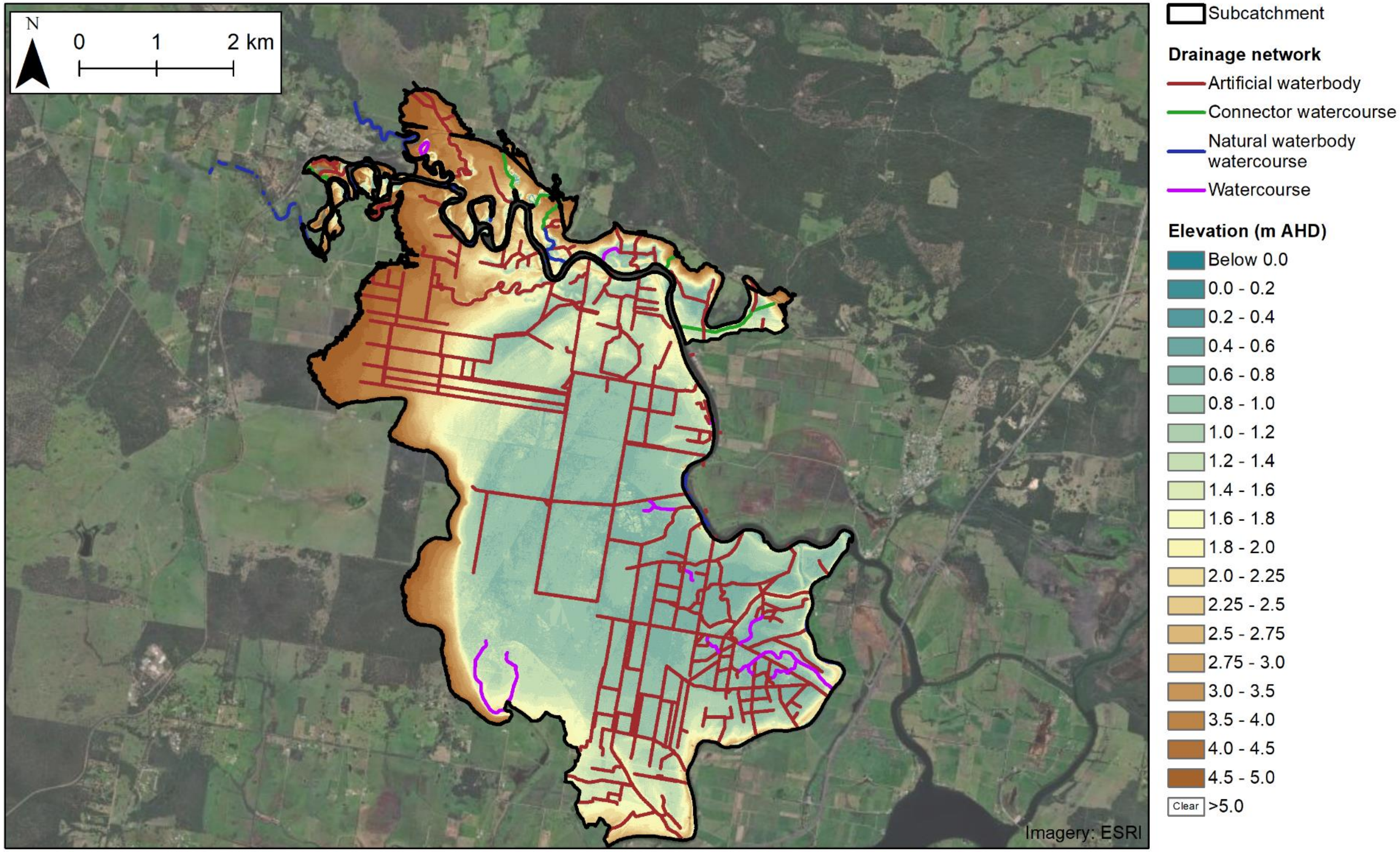

Figure 8-9: Moto subcatchment elevation and drainage network

8.4.2 History of Remediation

A timeline of remediation works within the Moto subcatchment is provided below with reference to Figure 8-10. The works included:

- 1999 – A scald revegetation project to remediate acid scald in areas of the Lower Lansdowne (north Moto) by the former NSW Agriculture.
- 2001 – Preparation of the 'Remediation Concept Plan for the Lower Lansdowne – Moto – Ghinni Ghinni Creek ASS Hot Spot' by the former Department of Land and Water Conservation as part of the NSW ASS Hot Spot Program (Currie and Atkinson, 2001). The Concept Plan was followed by a detailed Rehabilitation Plan, but it is unconfirmed if any on-ground works were completed as a result of the NSW ASS Hot Spot Program.
- January 2008 – Moto ASS Drainage Management Plan completed by the Moto Drainage Board. The Management Plan included recommendations for drainage and floodgate modification works in Moto Areas 16 (M16) and 10 (M10), as well as two (2) constructed breaches in the levee between north and south Moto to "*allow greater removal of surface water from south Moto through north Moto to the Lansdowne River*" (Greater Taree City Council, 2008d). The drainage modification works targeted three (3) drains: two (2) drains in Moto Area 16 (M16) and one (1) drain in Moto Area 10 (M10) – that included drain reshaping to raise the drain invert level to 0.1 m AHD, and installation of a water control structure with invert of 0.2 m AHD.
- February 2008 – An ASS Drainage Management Plan was prepared by MidCoast Council for remedial works on a portion of the Roche property on the Moto floodplain (M1). Funding of $60,000 was provided by MidCoast Council in partnership with the Hunter-Central Rivers Catchment Management Authority (Project Id: HCR 05-1/236). The project focused on expanding an existing low-lying wet pasture area (approximately 140 ha) on the southern-side of Moto Area 1 to "*reduce the severity of acid discharges from this portion of the property*" (Greater Taree City Council, 2008a). The on-ground works within the nominated wet pasture area included:
  - Infilling unused drains;
  - Constructing a weir to manage water levels; and
  - Constructing/reshaping levees to isolate the wet pasture area from adjacent productive agricultural land. Note that liming was used to treat any disturbed ASS.
- August 2009 – Addendum to the Moto ASS Drainage Management Plan by MidCoast Council for additional drainage modification works in Moto Areas 16 (M16) and 10 (M10) to "*improve the drainage capacity of the swale drains to maximise surface water removal while maintaining the in-drain structures as designed in the original management plan*" (Greater Taree City Council, 2009b).
- 2017/2018 - MidCoast Council installed two (2) floodgated weirs (i.e. floodgates with an elevated invert to prevent over drainage) new structures upstream of historical floodgates at floodgate ID MANN032 and MANN031. The invert of the two new structures was surveyed to be at approximately +0.2 m AHD by Rayner and Harrison (2020), and is shown in Figure 8-11.

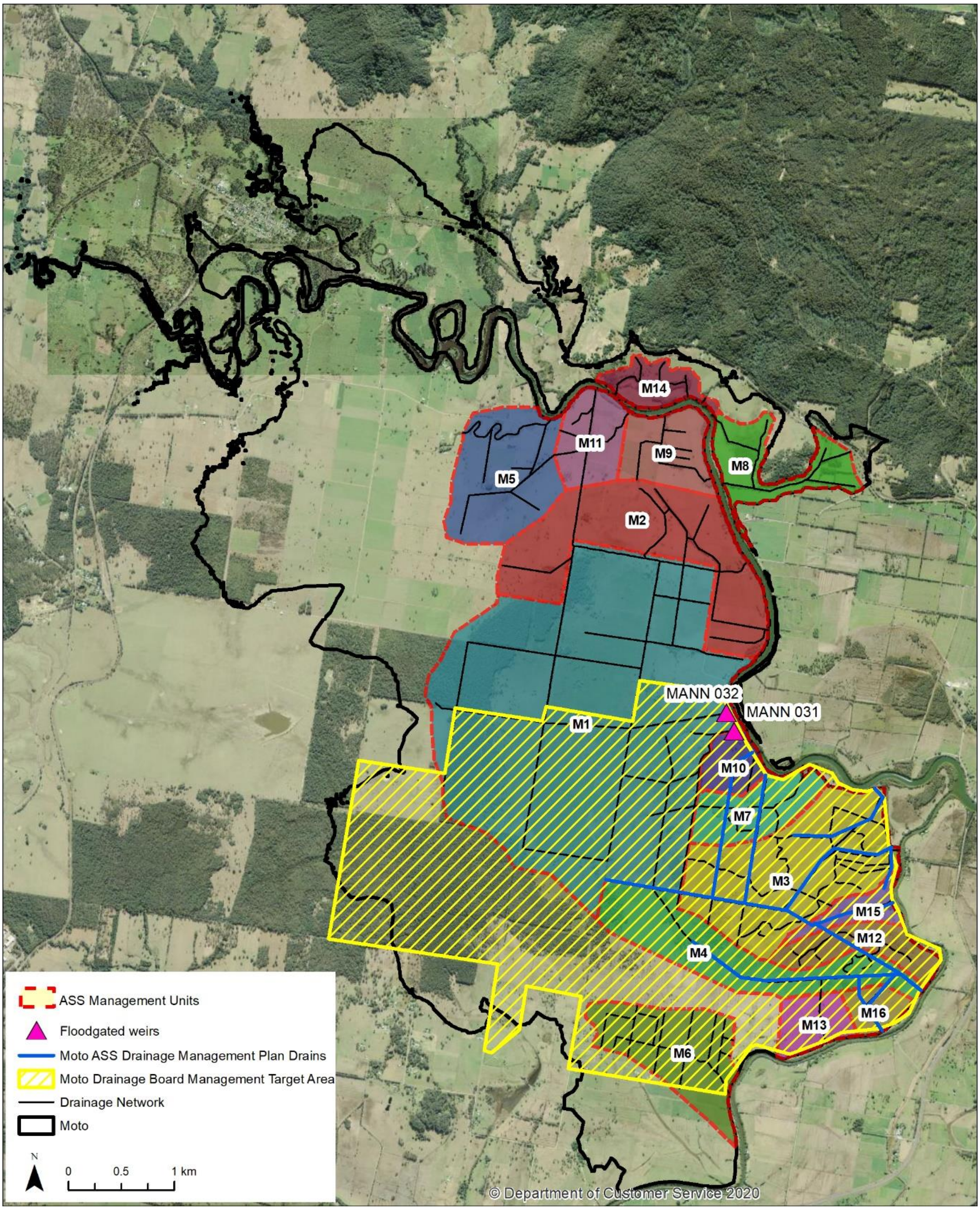

Figure 8-10: Management areas of the Moto subcatchment including Moto ASS Drainage Management Plan target area and new floodgated weirs

Figure 8-11: Floodgated weir at MANN031, invert 0.2 m AHD

8.4.3 Prioritisation of management areas in the Moto subcatchment

Management areas of the Moto floodplain were further prioritised to provide better information on the sources of acid. The highest impacted areas on Moto are also the lowest lying areas of the swamp, consequently these areas have the highest soil acidity values and have an observed AASS layer near to the surface (<0.5 m) in these areas.

The Moto subcatchment also ranked second in the blackwater prioritisation. While blackwater has generally not been identified as a key issue on the Manning River floodplain, the analysis suggests that areas below +1.4 m AHD (and particularly those areas below +0.6 m AHD) in the Moto subcatchment may contribute to blackwater generation after flood events. In the lowest areas of this subcatchment, remediation should also consider reducing the blackwater generation potential through encouraging water tolerant vegetation.

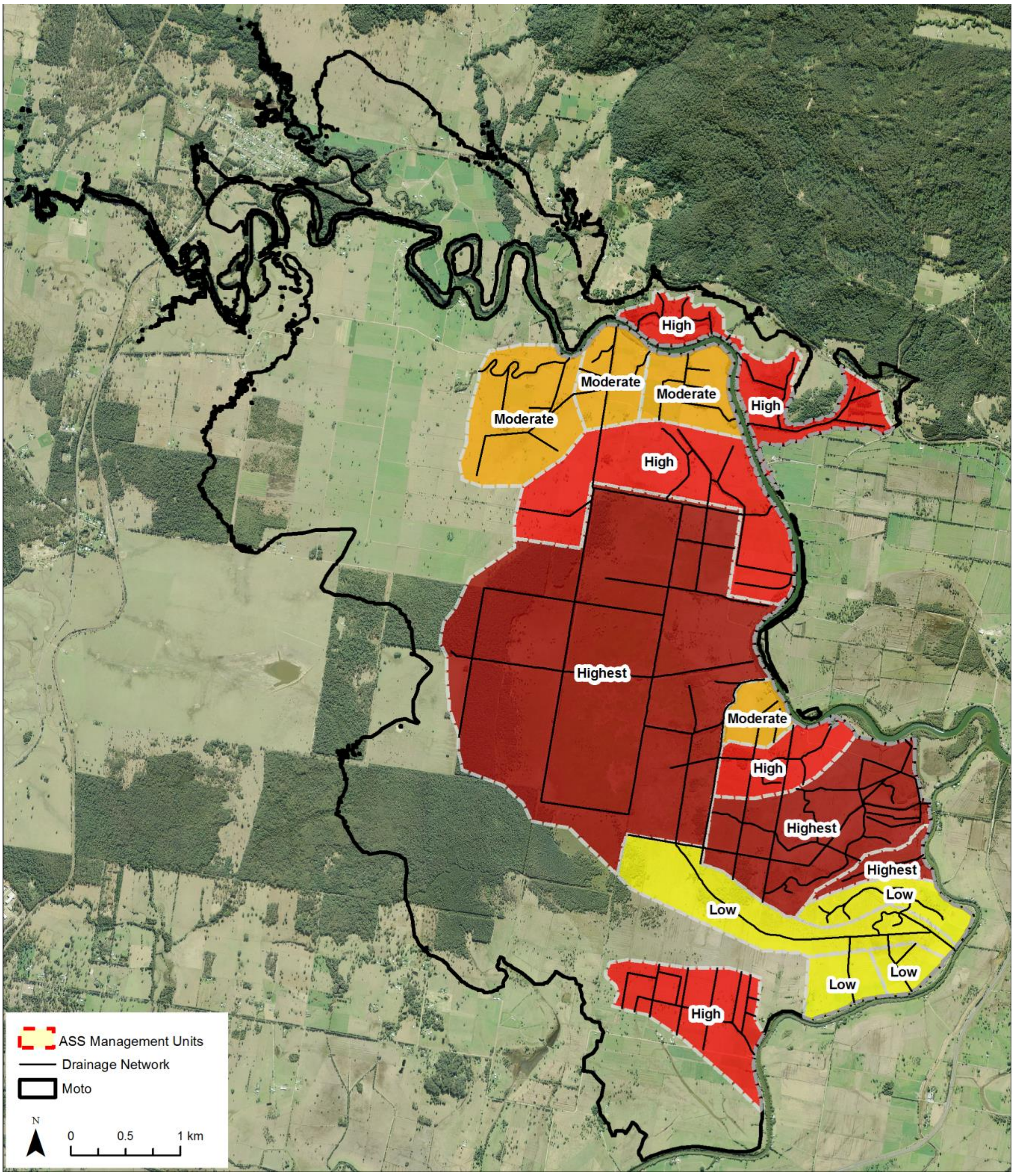

Figure 8-12: Reanalysis of ASS prioritisation of management areas in the Moto subcatchment (Glamore et al., 2016a)

8.4.4 Floodplain drainage – sea level rise vulnerability

The sea level rise vulnerability of the Moto floodplain is summarised in Figure 8-13. In present day conditions, the floodplain is largely not considered vulnerable. Under the near future sea level rise scenario, a small area is classified as low risk for reduced drainage, and the impacts on drainage may be manageable. However, under the far future scenario, the majority of the lower floodplain (<1.3 m AHD) is at risk for reduced drainage, and a substantial portion of the subcatchment is also below predicted median water levels.

Under the far future scenario, nine (9) of the floodgates (with survey information) are classified as ‘moderately vulnerable’ and a further two (2) are classified as ‘most vulnerable’. Figure 8-14 shows the elevation of the primary floodgates in the Moto subcatchment compared to key floodplain elevations. This shows that primary floodgate MANN027 (4 x 0.6 m circular culverts) is particularly vulnerable to the impacts to sea level rise. Productivity of agricultural land uses in the low areas of this subcatchment may be impacted by reduced drainage.

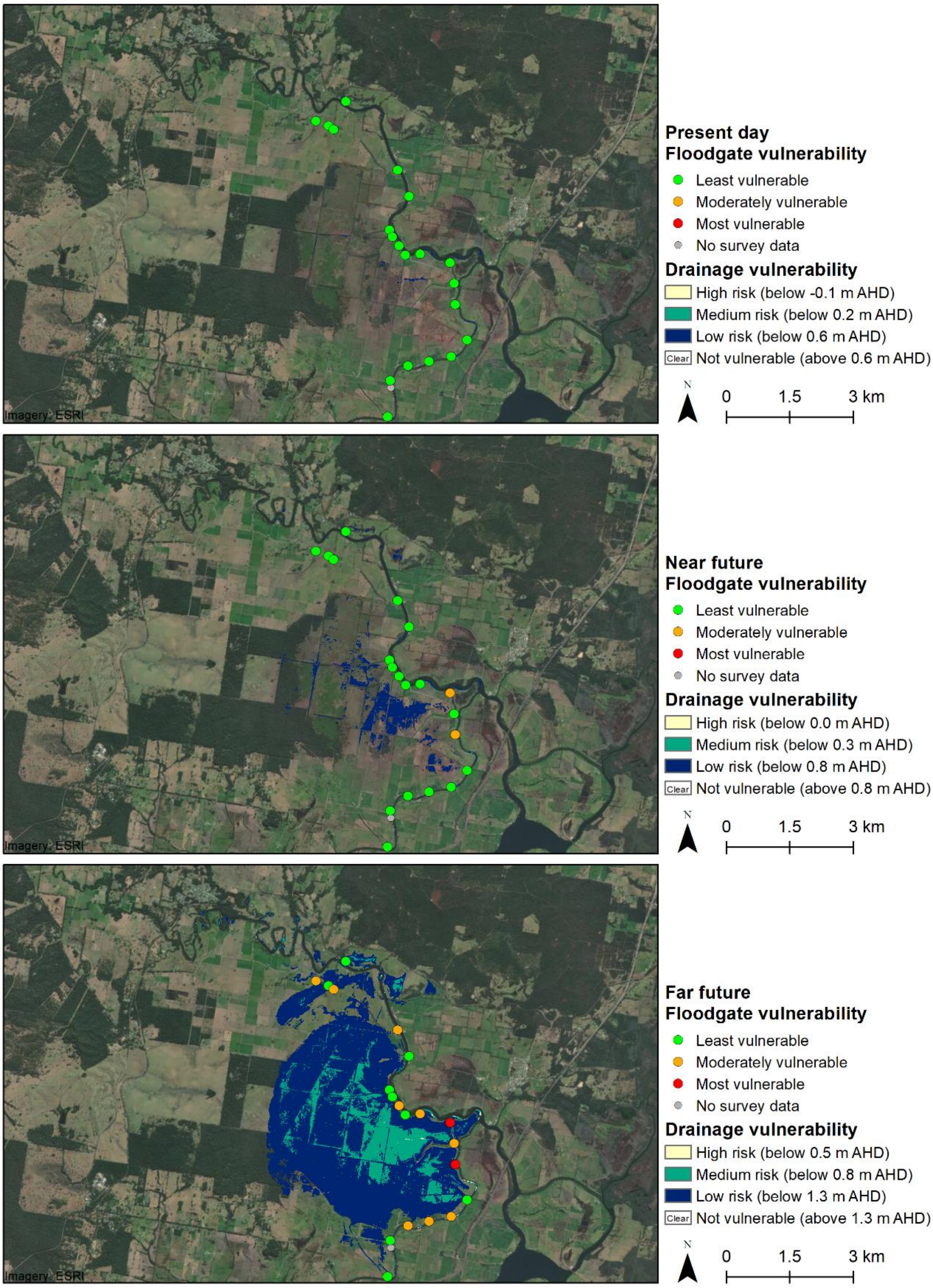

Figure 8-13: Sea level rise drainage vulnerability – Moto subcatchment

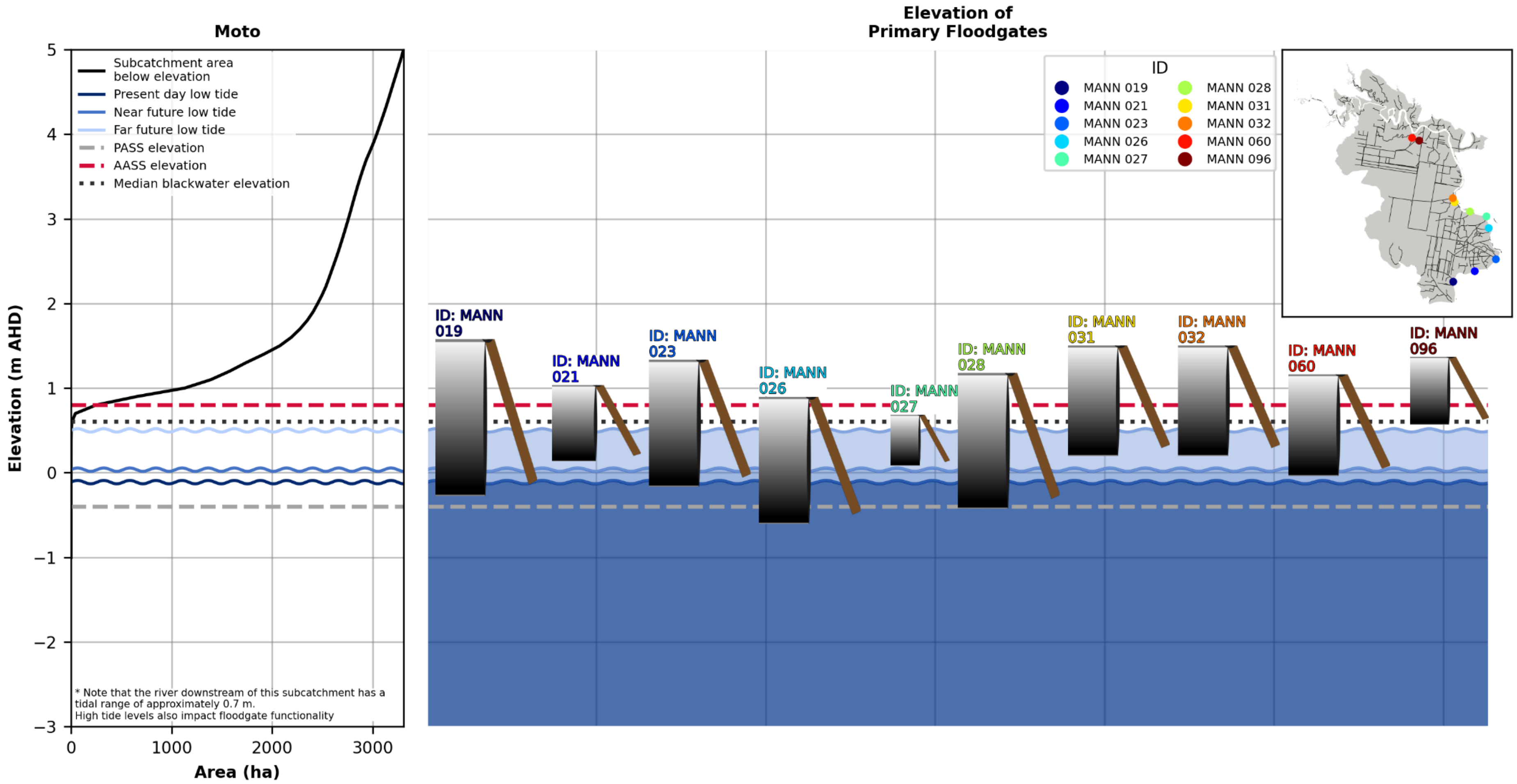

Figure 8-14: Key floodplain elevations – Moto subcatchment

8.4.5 Management options

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

- Short-term: Floodgate management and modification and drain reshaping; and
- Long-term: Wetland remediation of the low-lying areas of the subcatchment and wet pasture management in higher areas.

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

Short-term management options

Portions of the Moto subcatchment have previously been targeted for remediation as part of the Moto ASS Drainage Management Plan (refer to Section 8.4.2). Previous on-ground works have focused on partial remediation of Moto management areas M1, M3, M4, M7, M10, M15, and M16 in the southern portion of the Moto floodplain. The on-ground works in these areas involved wet pasture creation, infilling/reshaping main drains, and modification of structures on main drains to raise inverts. Where applicable, other areas of the Moto floodplain should be targeted to support the outcomes of the Moto Drainage Management Plan (Greater Taree City Council, 2009b) by further floodgate management/modification and filing/reshaping drains. This may include the installation of wider culvert/floodgates at a higher AHD level to allow surface water runoff, such as the ones installed at MANN032 and MANN031 (shown in Figure 8-11). These structures maintain surface water drainage during rain events, while preventing excessive groundwater drawdown to minimise acid drainage. Expanded wet pasture management is encouraged across all low-lying, poorly drained areas of the floodplain which will reduce the risk of blackwater events after summer floods, which is a known problem in the Moto area (Greater Taree City Council, 2009b).

Moto Management Areas M6, M8, and M14 are delineated from the main Moto swamp and are considered to be separate drainage units. These areas would benefit from a combination of floodgate management and drain infilling/reshaping to raise the local groundwater table and reduce the acid drainage from the surrounding floodplain to drains. Note that infilling/reshaping would also require fencing to avoid stock access across drains. These areas contain extensive acid stores and AASS within approximately 200 mm from the surface. As such, ASS soil sampling and analysis should be completed prior to detailed design of on-ground works.

Long-term management options

The Moto subcatchment features some of the lowest-lying topography on the entire Manning River floodplain. This area is likely to be increasingly affected by reduced drainage as sea level rise continues to occur. Without additional infrastructure the agricultural productivity of the Moto swamp is likely to become increasingly reduced and options for full remediation of poorly drained land to wet pastures (freshwater), or wetland (brackish/saline) should be investigated. This could be targeted in areas below +1.3 m AHD (the far future projected 95th percentile water level) and would be effective for addressing both acid and blackwater drainage. Remediation is likely to include:

- Remediation 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.

Indicative costs and qualitative benefits associated with the management options in the Moto subcatchment is provided in Table 8-4.

Table 8-4: Summary of management options for Moto subcatchment

Timeframe	Strategy	Targeted area(s)	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	Floodgate management	All	None	$150,000	$20,000	None	Moderate	Moderate	None
Short-term	Drain reshaping	M8, M14, M9, M11, M5	None	$500,000	None	None	None	Moderate	Minimal
Long-term	Wetland remediation of low-lying areas	M1, M3, M15, M8, M7, M2, M14, M6, M10, M4, M12, M16, M13	$9,500,000	$1,250,000	Minimal	$830,000	High	High	High
Long-term	Wet pasture management	M9, M11, M5	None	$280,000	$5,000	None	None	High	High

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

8.5 Ghinni Ghinni subcatchment

Acid priority rank:	**3**
Blackwater priority rank:	**1**
Infrastructure	
Approximate waterway length (km)	109
# Privately owned end of system structures	14
# Publicly owned end of system structures	0
# End of system structures within coastal wetlands	1
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (ID)	MANN014, MANN017, MANN062, MANN090, MANN117, WRL_MAN_03
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-0.7 to 0.1
Approximate AASS elevation (m AHD)	0.9
Approximate PASS elevation (m AHD)	-0.2
Median blackwater elevation (m AHD)	0.7
Present day low water level (m AHD)	-0.1
Near future low water level (m AHD)	0
Far future low level (m AHD)	0.5
Proximity to sensitive receivers	
Oyster leases (km)	4.2
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)	2,439
Classified as conservation and minimal use (ha (%))	55 (2%)
Classified as grazing (ha (%))	2117 (87%)
Classified as forestry (ha (%))	0 (0%)
Classified as horticulture (ha (%))	0 (0%)
Classified as other cropping (ha (%))	20 (1%)
Classified as urban/industrial/services (ha (%))	119 (5%)
Classified as marsh/wetland (ha (%))	37 (2%)
Other (ha (%))	91 (4%)
Land values	
Estimated total primary production value ($/year)	$1,000,000
Average land value above 0.7 m AHD ($/ha)	$6,700
Average land value below 0.7 m AHD ($/ha)	No property data available

8.5.1 Site description

The Ghinni Ghinni subcatchment is a backswamp area located in the central part of the Manning River floodplain, shown in Figure 8-15. The Ghinni Ghinni subcatchment is an extensive ASS-affected area of the Manning River estuary, covering an area of approximately 2,400 ha (below 5 m AHD) that is predominantly used for grazing (approximately 87% of the subcatchment area).

A large portion of the floodplain is situated below 1 m AHD, and there is an extensive artificial drainage system (Figure 8-16). Dickensons Creek and its natural levee banks divides the northern and southern parts of Ghinni Ghinni floodplain into two (2) separate hydrological units below approximately 2 to 4 m AHD. The majority of the floodplain drains through an extensive, inter-connected drainage network that discharges into Dickensons Creek, which then discharges into the Manning River estuary via Ghinni Ghinni Creek. The Ghinni Ghinni subcatchment was also identified as being within an ASS priority area in Tulau (1999). Issues associated with blackwater events have also been identified in the Ghinni Ghinni subcatchment (Greater Taree City Council, 2009a).

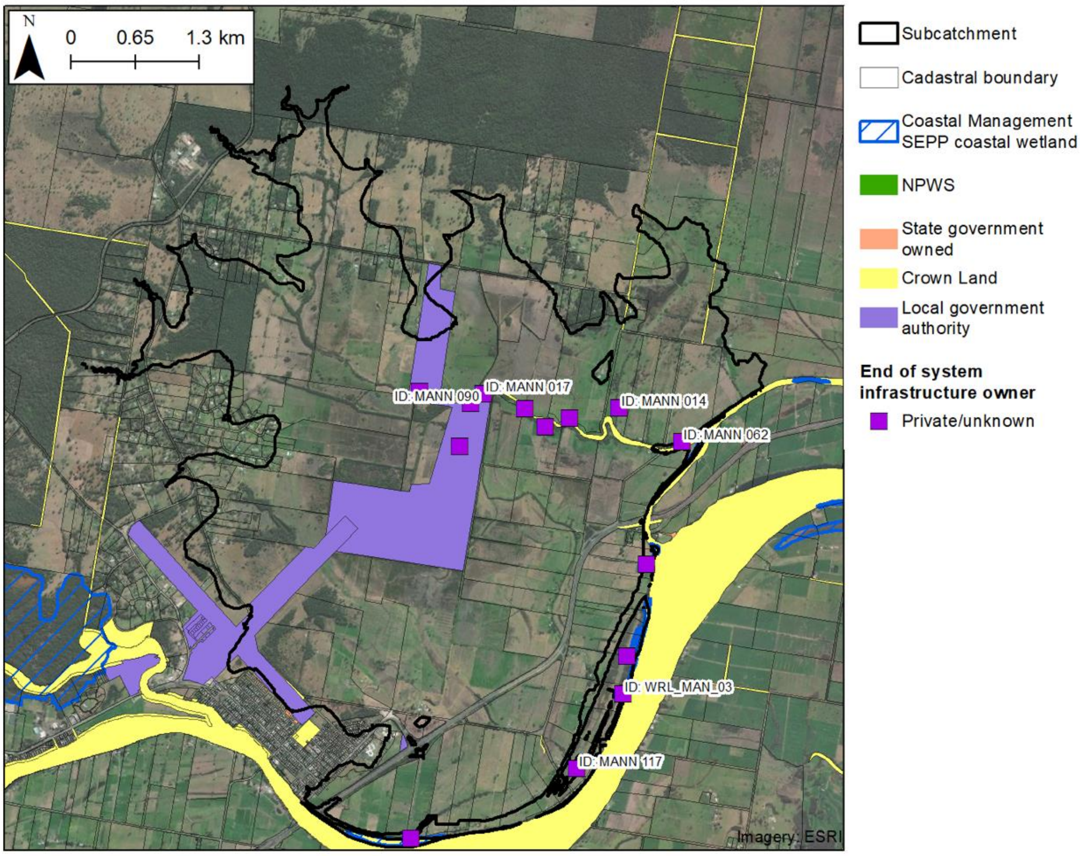

Figure 8-15: Ghinni Ghinni subcatchment land and end of system infrastructure tenure

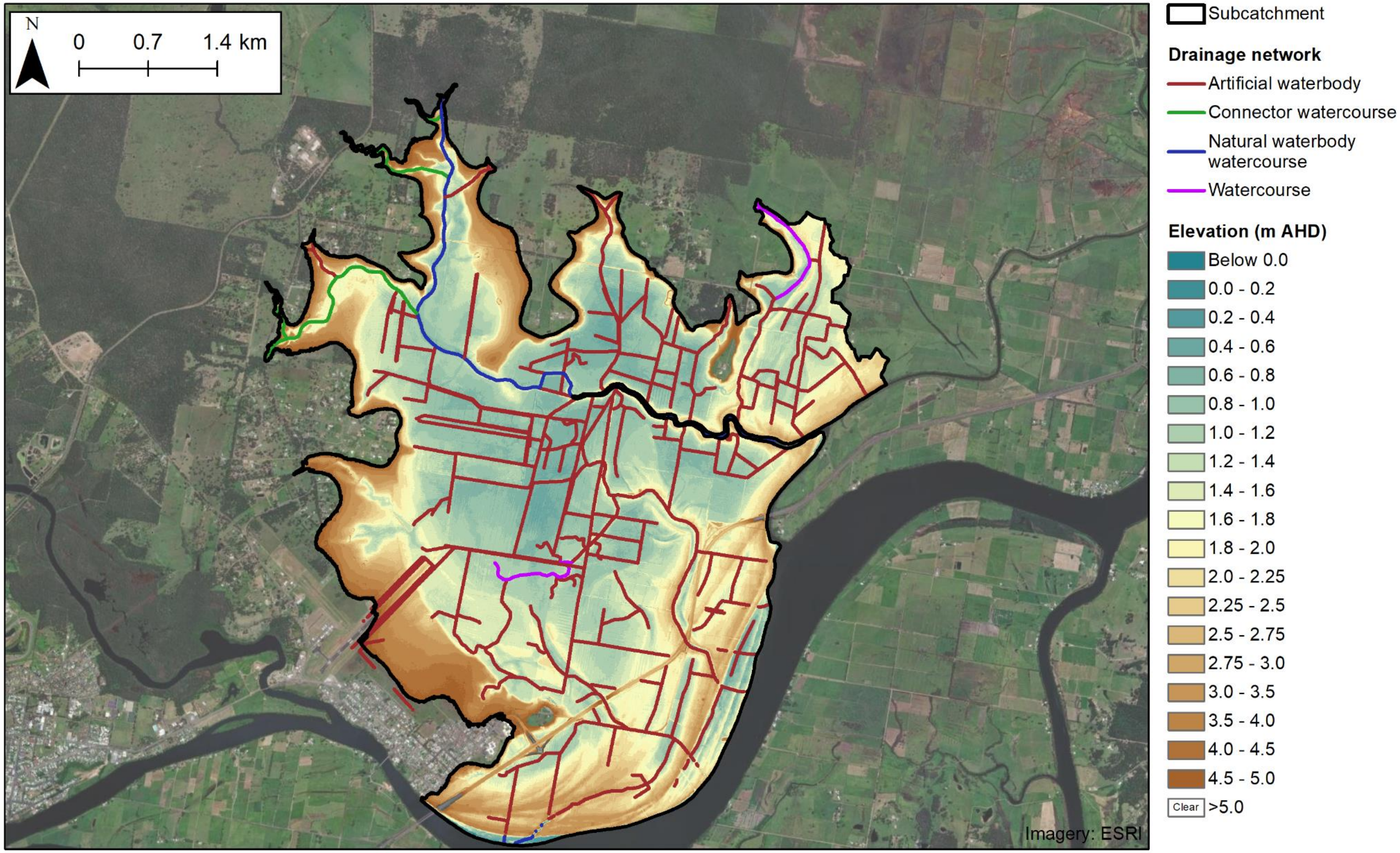

Figure 8-16: Ghinni Ghinni subcatchment elevation and drainage network

8.5.2 History of remediation

A timeline of remediation works within the Ghinni Ghinni subcatchment is provided below with reference to Figure 8-17. Previous remediation works include:

- May 2009 – Replacement of existing floodgate structures on two (2) major drainage networks along the left-bank of Dickensons Creek. The project replaced existing floodgate structures with new concrete culverts at an invert of +0.3 m AHD. Two (2) new floodgates on each drain were also installed to "*provide additional surface water removal capacity compared to the [previous] system…to reduce ponded water on the floodplain and subsequently deoxygenated black-water discharge events*" (Greater Taree City Council, 2009a). Funding of $30,000 was provided by MidCoast Council in partnership with the Hunter-Central Rivers Catchment Management Authority.

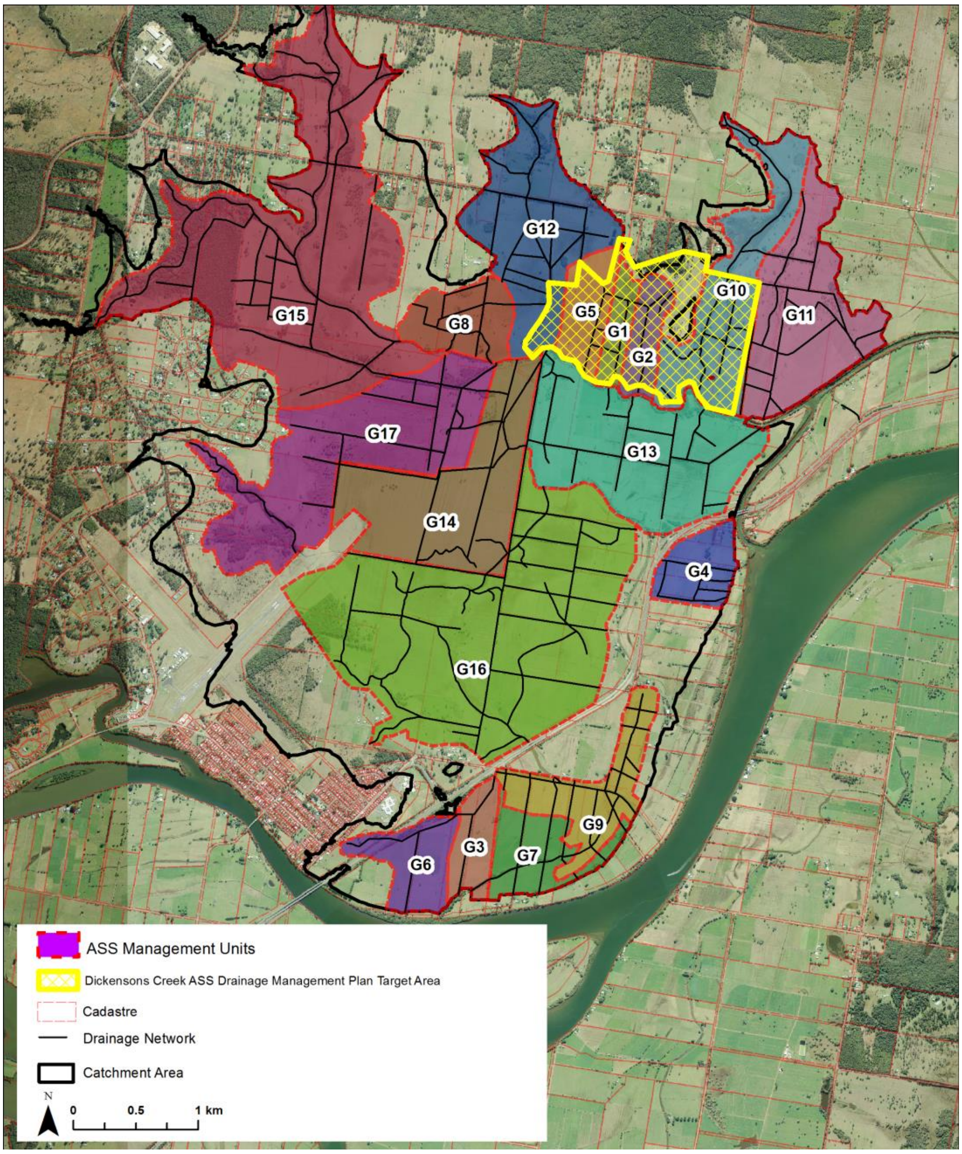

Figure 8-17: Management areas of the Ghinni Ghinni subcatchment including previous remediation target areas

8.5.3 Prioritisation of management areas in Ghinni Ghinni subcatchment

At Ghinni Ghinni, the reanalysis assessment identified the highest priority areas for remediation in the northern portion of the floodplain, or the upstream end of Dickensons Creek. These areas have some of the highest soil acidity found across the entire floodplain (pH<4.0) and also the highest potential stored acidity. The floodplain areas are also heavily drained with the deep (>0.5 m) drains controlled by floodgate structures discharging into Dickensons Creek. Note that a survey of these structures was not completed as part of this study. On the Ghinni Ghinni floodplain, the three (3) highest priority areas account for greater than 50% of the acid risk to the Ghinni Ghinni subcatchment.

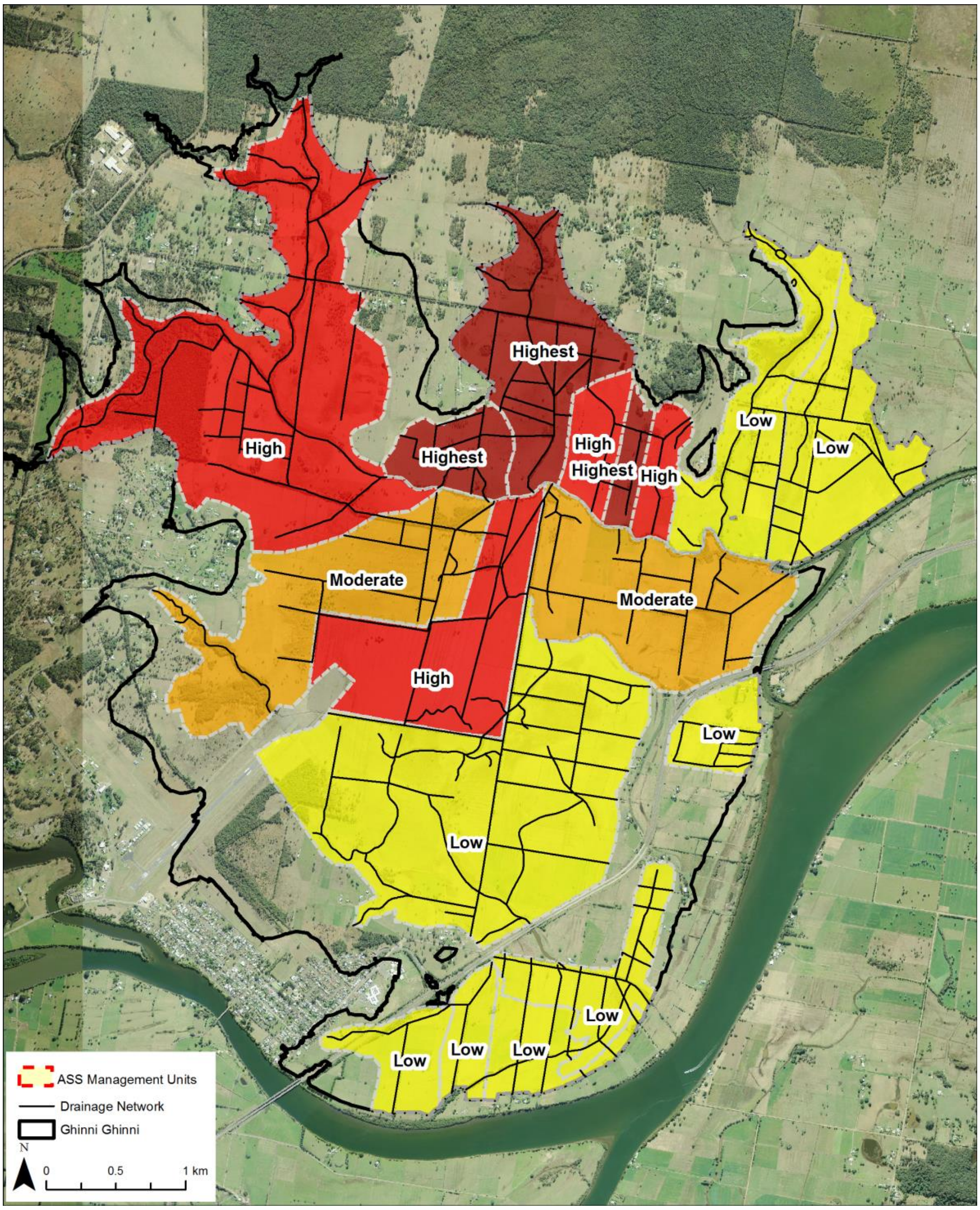

Figure 8-18: Reanalysis of ASS prioritisation of management areas in the Ghinni Ghinni subcatchment (Glamore et al., 2016a)

The Ghinni Ghinni subcatchment also ranked first in the blackwater prioritisation. While blackwater has generally not been identified as a key issue on the Manning River floodplain, the analysis suggests that areas below +1.7 m AHD (and particularly those areas below +0.7 m AHD) in the Ghinni Ghinni subcatchment may contribute to blackwater generation after flood events. In the lowest areas of this subcatchment, changes to land management should also consider reducing the blackwater generation potential through encouraging water tolerant vegetation.

8.5.4 Floodplain drainage – sea level rise vulnerability

The vulnerability of the Ghinni Ghinni floodplain is summarised in Figure 8-20. While the majority of the floodplain is not vulnerable to reduced drainage under present day and near future scenarios, Figure 8-20 indicates that reduced drainage as a result of sea level rise may be an increasing issue in this subcatchment in the near to far future. The most vulnerable areas will be below +1.3 m AHD. Under present day conditions, three (3) floodgates are classified as 'moderately vulnerable' to sea level rise, including primary floodgate MANN014. Risk increases into the near and far future, with most floodgates classified as moderately or most vulnerable to sea level rise in the far future.

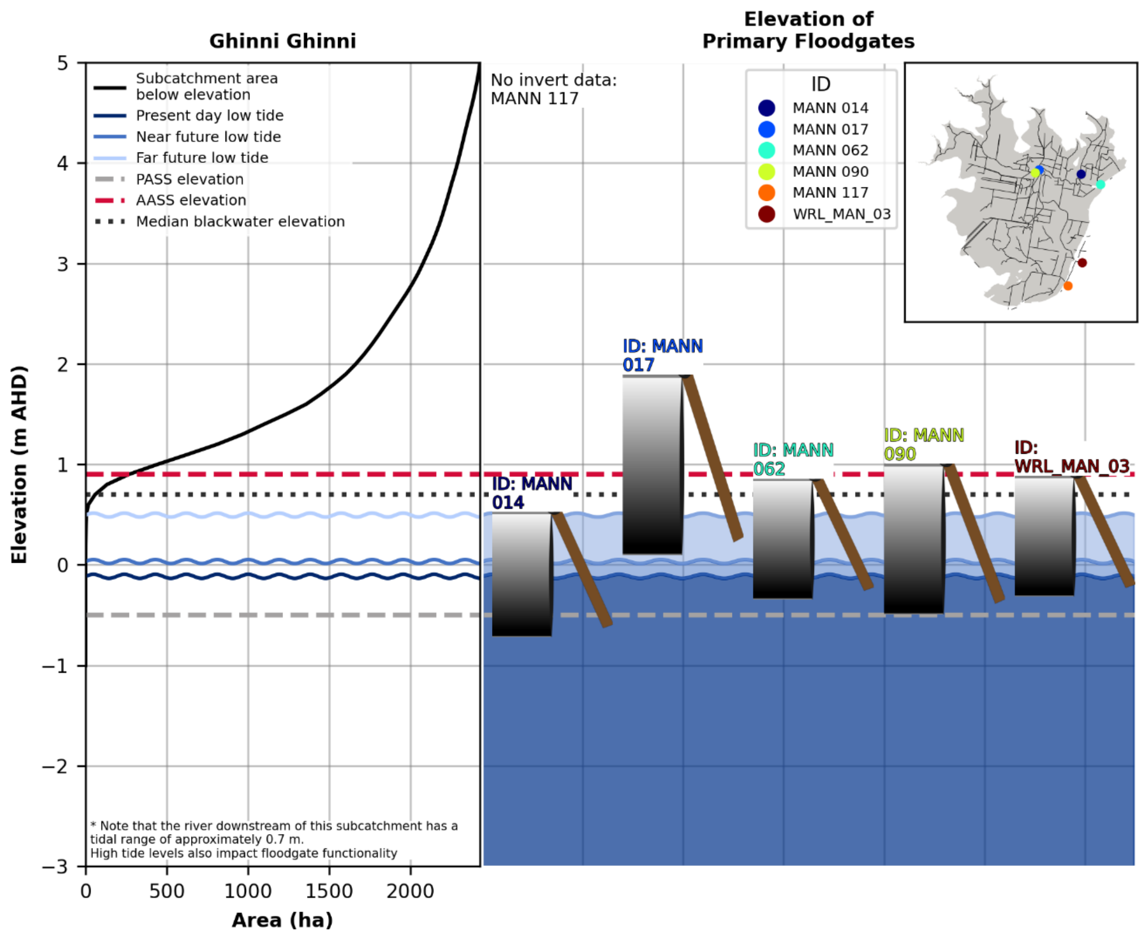

Figure 8-19: Key floodplain elevations – Ghinni Ghinni subcatchment

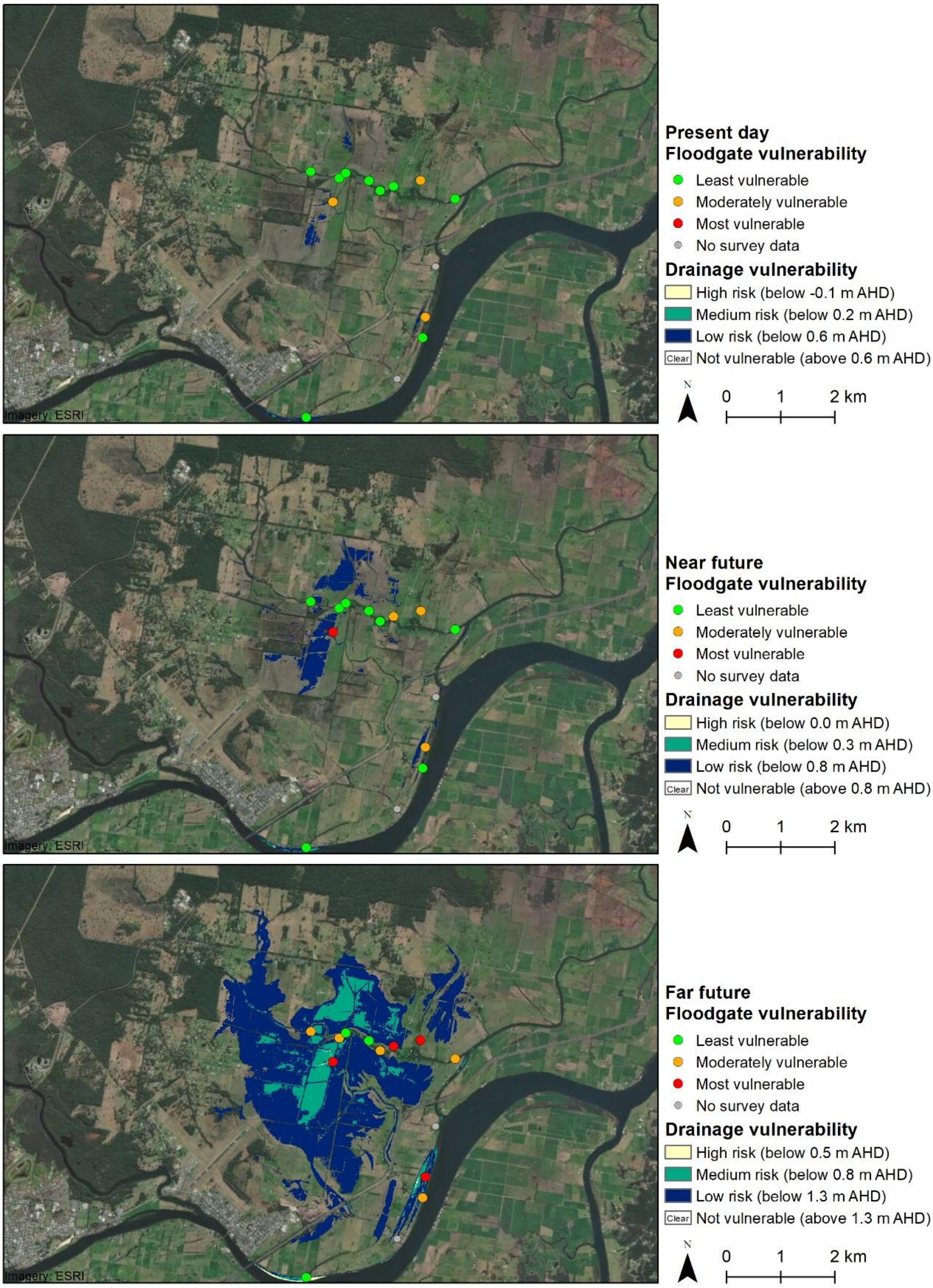

Figure 8-20: Sea level rise drainage vulnerability – Ghinni Ghinni subcatchment

8.5.5 Management options

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

- Short-term: Floodgate management and drain reshaping; and
- Long-term: Full remediation of low-lying areas to wetlands and wet pasture management in higher areas.

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

Short-term management options

A small portion of the Ghinni Ghinni subcatchment (approximately 150 ha) was previously targeted for remediation as part of the MidCoast Council ASS Drainage Management Plan (details are provided in Section 8.5.2). Previous on-ground works have focused on floodgate management in Ghinni Ghinni Management Areas G1, G5, and G12 in the northern portion of the Ghinni Ghinni floodplain. The on-ground works in these areas involved installation of new water control structures (i.e. culverts and associated floodgates) on the main drains located in Ghinni Management Areas G5 and G12 to raise the invert of the drainage points to +0.3 m AHD.

Note that based on the findings from this study, the AASS layer was estimated to be within approximately 400 mm from the surface (or located at an elevation of approximately +0.5 m AHD). While raising the invert of the drainage points to +0.3 m AHD on the main drains located in Ghinni Ghinni Management Areas G5 and G12 would help to raise the average local groundwater table, the structure inverts are still situated below the acidic soil layer, and acid discharge from these drains is still possible. It is therefore recommended that event-based investigation of water quality is undertaken following high rainfall events to monitor potential acid discharges from these sites.

Where applicable, other areas of the Ghinni Ghinni floodplain should be targeted to support the outcomes of the previous ASS Drainage Management Plan (Greater Taree City Council, 2009a) by further floodgate management in the northern and central areas of the floodplain that discharges to Dickensons Creek. Unused paddock drains connected to deep (>0.5 m) drains should be infilled/reshaped, and wet pasture management areas are encouraged across low-lying, poorly drained land. Floodgate modifications, or installation of drop board weirs in the upstream section of Dickensons Creek, along with drain infilling/reshaping across the floodplain, could be used to manage dry and wet weather acid discharges from the high priority sites (which account for approximately 85% of the acid discharge risk from the Ghinni Ghinni subcatchment). Further detailed survey, investigation, analysis, and design would be required before the implementation of any on-ground works.

Long-term management options

The Ghinni Ghinni subcatchment features some of the lowest-lying topography on the entire Manning River floodplain. This area, particularly portions of Ghinni Ghinni Management Areas G8, G12 and G14, is likely to be increasingly affected by reduced drainage as sea level rise continues to occur. Without additional infrastructure the agricultural productivity of the Ghinni Ghinni floodplain is likely to become increasingly reduced. Options for remediation to wet pastures (freshwater), or wetland (brackish/saline) should be investigated, which would be effective at reducing both acid and blackwater drainage from this subcatchment. MidCoast Council are encouraged to continue to engage with the community and landholders in the Ghinni Ghinni region about ongoing ASS legacy issues, and the advantages/benefits of progressing future land management practices towards wet pasture management and wetland remediation across the entire floodplain. 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.

Indicative costs and qualitative benefits associated with the management options in the Ghinni Ghinni subcatchment is provided in Table 8-5.

Table 8-5: Summary of management options for Ghinni Ghinni subcatchment

Timeframe	Strategy	Targeted area(s)	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing)	Indicative cost (lost productivity)	Effectiveness at improving: Wetland habitat and fish passage	Effectiveness at improving: Impacts of ASS	Effectiveness at improving: Impacts of blackwater
Short-term	Floodgate management	G8, G12, G15, G3, G14, G5, G11, G10, G7, G3, G9, G4	None	$150,000	$20,000	None	Moderate	Moderate	Minimal
Short-term	Drain reshaping	G8, G1, G12, G2, G17	None	$500,000	None	None	None	Moderate	Low
Short-term	Groundwater manipulation	G13, G16, G6	None	$110,000	$5,000	None	None	Moderate	Moderate
Long-term	Remediation of low-lying areas to wetlands	G8, G1, G12, G15, G2, G14, G5, G17	$6,000,000	$800,000	Minimal	$420,000	High	High	High
Long-term	Wet pasture management	G13, G16, G6	None	$500,000	$5,000	None	None	High	High

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

8.6 Bukkan Bukkan Creek subcatchment

Acid priority rank:	**4**
Blackwater priority rank:	**5**
Infrastructure	
Approximate waterway length (km)	47
# Privately owned end of system structures	7
# 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)	MANN040, MANN065
Elevations	
Invert of primary floodplain infrastructure (m AHD)	0.0 to 0.6
Approximate AASS elevation (m AHD)	0.4
Approximate PASS elevation (m AHD)	0
Median blackwater elevation (m AHD)	0.6
Present day low water level (m AHD)	-0.1
Near future low water level (m AHD)	0
Far future low level (m AHD)	0.5
Proximity to sensitive receivers	
Oyster leases (km	Within subcatchment
Saltmarsh (km)	Within subcatchment
Seagrass (km)	Within subcatchment
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	1,392
Classified as conservation and minimal use (ha (%))	0 (0%)
Classified as grazing (ha (%))	1342 (96%)
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 (%))	8 (1%)
Classified as marsh/wetland (ha (%))	12 (1%)
Other (ha (%))	31 (2%)
Land values	
Estimated total primary production value ($/year)	$630,000
Average land value above 0.6 m AHD ($/ha)	$17,800
Average land value below 0.6 m AHD ($/ha)	No property data available

8.6.1 Site description

The Bukkan Bukkan Creek subcatchment is on the northern side of Oxley Island (Figure 8-21). Drainage management in this subcatchment is either privately managed or managed by the North Oxley Island Drainage Union (Tulau, 1999). The vast majority (approximately 96% of the total subcatchment area) is used for grazing. The lowest part of the subcatchment is in the north-east of the island, which is serviced by a series of artificial drains (shown in Figure 8-22).

The Bukkan Bukkan subcatchment was identified as an ASS priority area in Tulau (1999) (referred to as North Oxley Island). Soil profiles within this subcatchment indicate that highly acidic soils are present, including profiles where a minimum pH of 3 was observed. Issues associated with blackwater events have also been identified in the Bukkan Bukkan Creek subcatchment (Greater Taree City Council, 2008e).

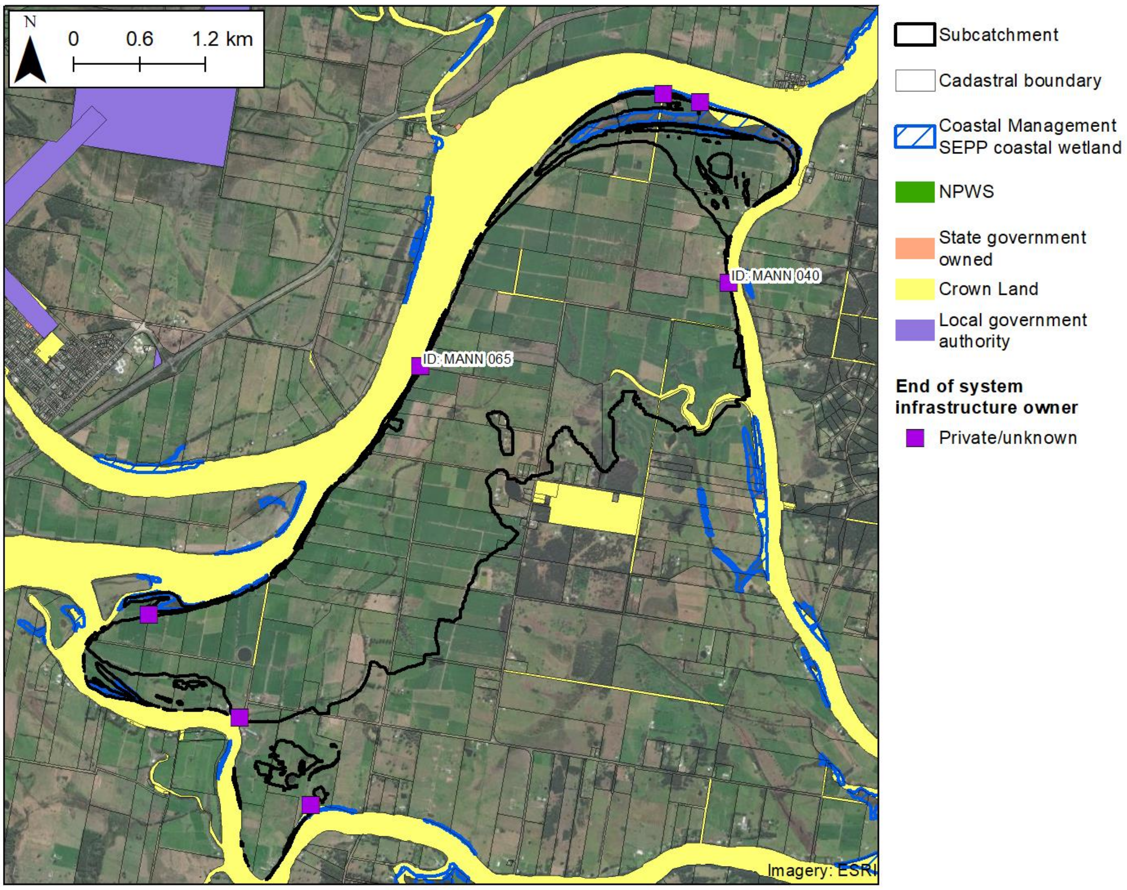

Figure 8-21: Bukkan Bukkan Creek subcatchment land and end of system infrastructure tenure

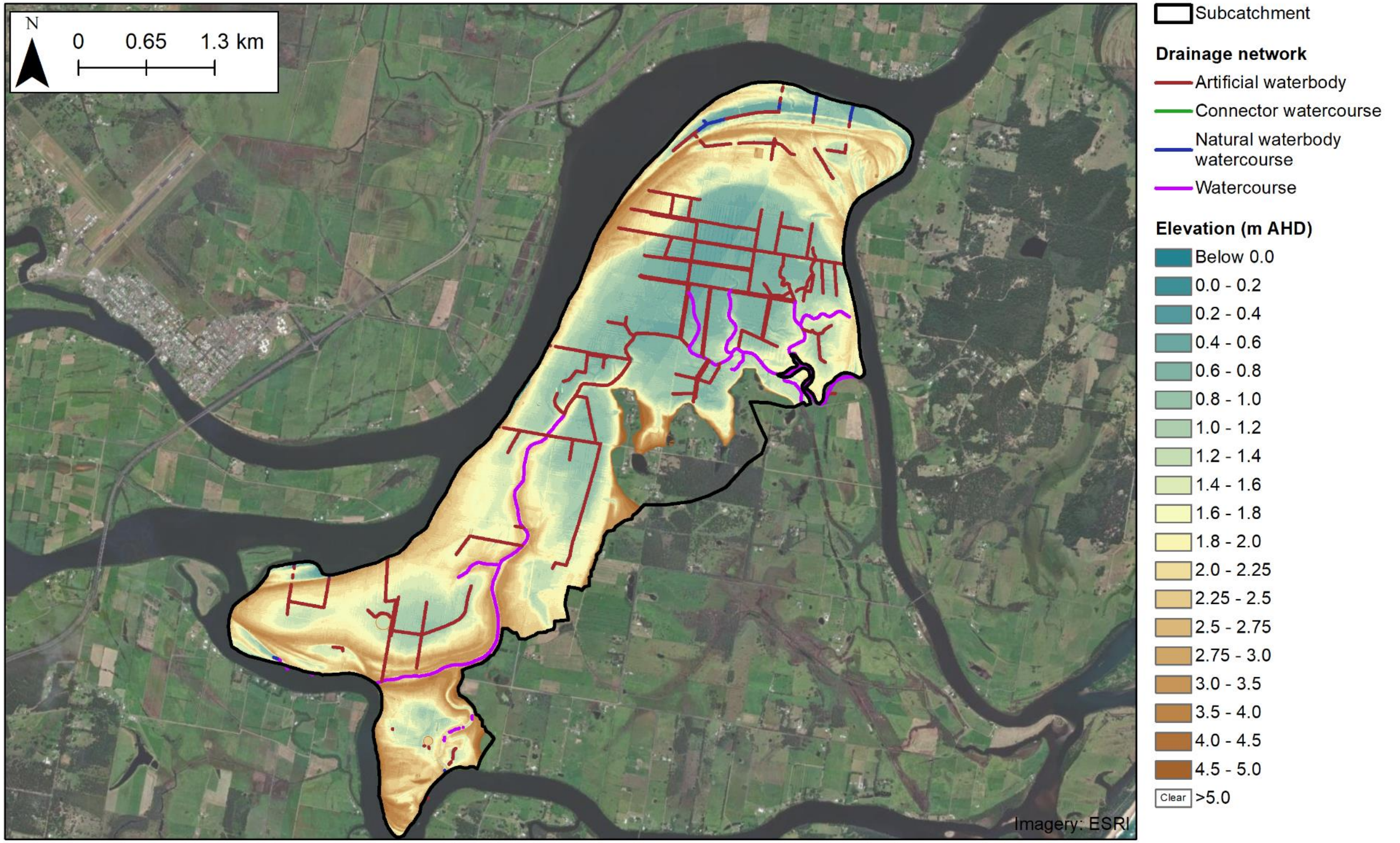

Figure 8-22: Bukkan Bukkan Creek subcatchment elevation and drainage network

8.6.2 History of remediation

A timeline of known remediation works within the Bukkan Bukkan Creek (North Oxley Island) subcatchment is provided below with reference to Figure 8-23. Previous remediation works include:

- February 2008 – An ASS Drainage Management Plan was prepared by MidCoast Council for remedial works on a portion of the Neal property on North Oxley Island. Funding of $10,000 was provided by MidCoast Council in partnership with the Hunter-Central Rivers Catchment Management Authority (Project Id: HCR 05-1/136). The project focused on improving surface water drainage across two (2) separate portions of the property (approximately 40 ha in total) to "*reduce potential for interception of acidic groundwater, while exporting fresh surface water as soon as possible to minimise potential formation of blackwater*" (Greater Taree City Council, 2008e). The on-ground works included reshaping shallow (<200 mm deep) surface paddock drains at 20 m intervals and treatment of surface soil with lime.

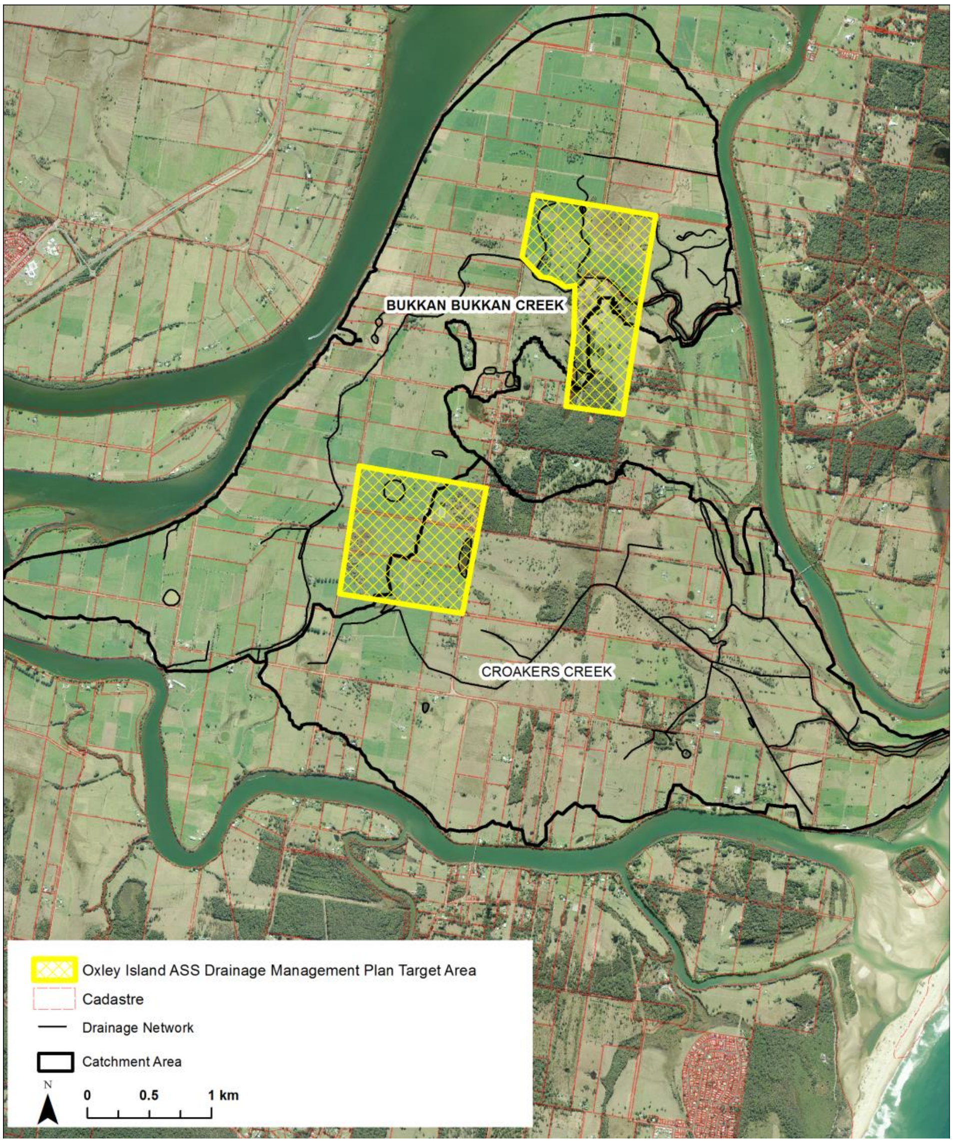

Figure 8-23: Previous ASS Management Target Areas on Oxley Island

8.6.3 Floodplain drainage – sea level rise vulnerability

The vulnerability of the Bukkan Bukkan Creek subcatchment to sea level rise is summarised in Figure 8-25. The low, northern area of the subcatchment is most vulnerable to reduced drainage as a result of sea level rise, with a substantial area projected to be at medium risk of reduced drainage under the far future sea level rise scenario. These areas may be increasingly subject to prolonged inundation after rainfall due to higher water levels in the main river channel in the near to far future. Reduced drainage may impact the productivity of grazing in the lowest areas of the subcatchment, particularly in areas below 0.8 m AHD.

The elevation of the two (2) primary floodgates is shown in Figure 8-24, relative to key floodplain elevations. Neither of these floodgates are considered highly vulnerable to reduced drainage, however two (2) secondary floodgates are classified as 'most vulnerable' under far future sea level rise scenarios.

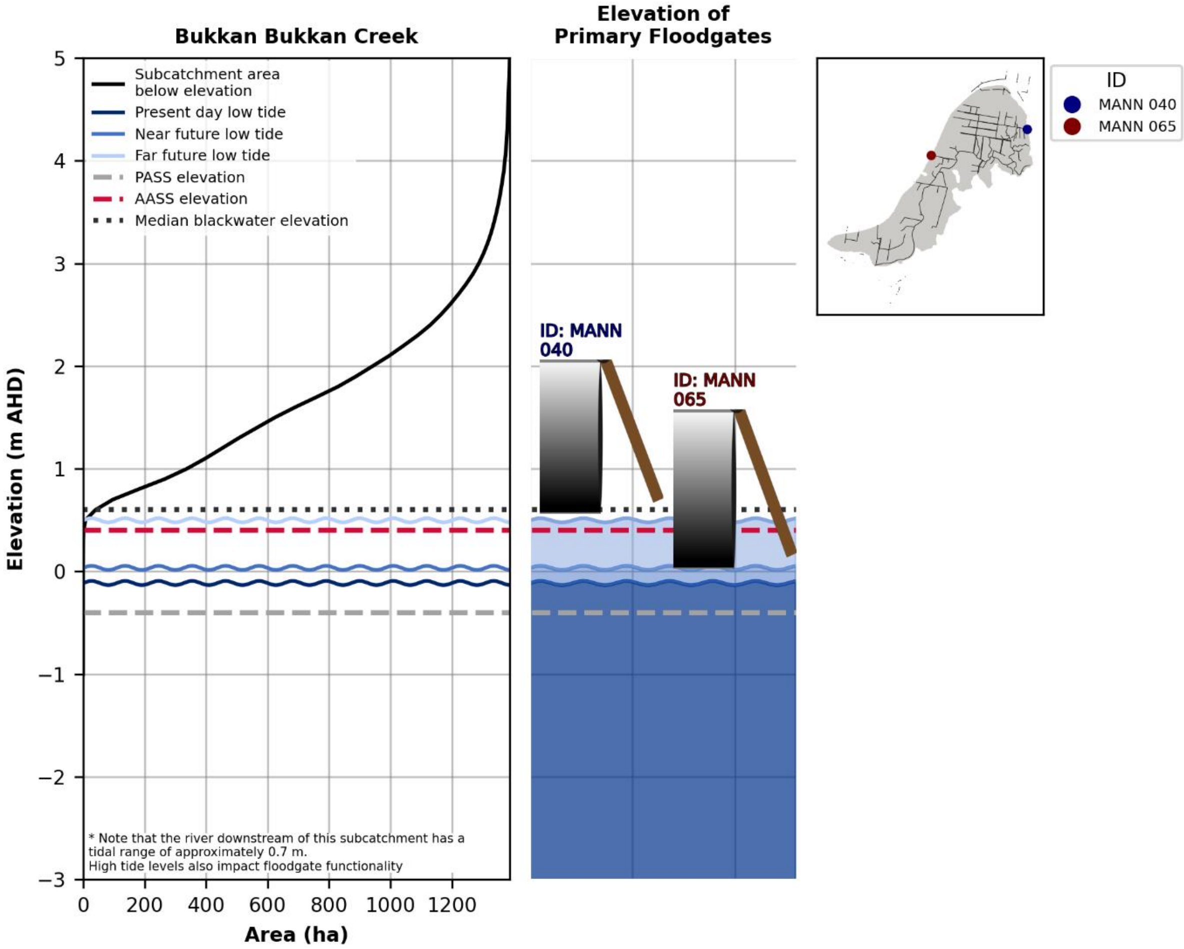

Figure 8-24: Key floodplain elevations– Bukkan Bukkan subcatchment

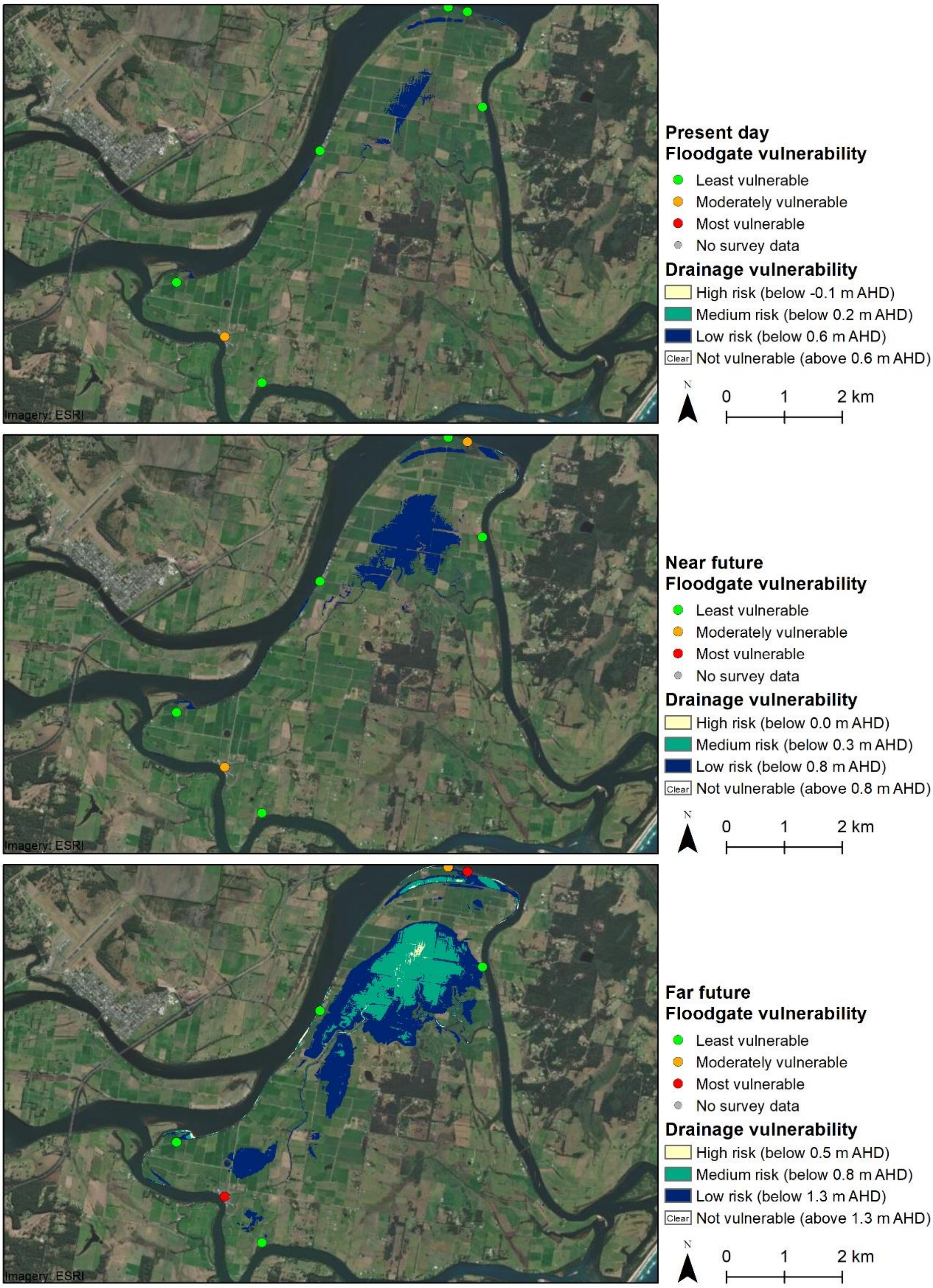

Figure 8-25: Sea level rise drainage vulnerability – Bukkan Bukkan Creek subcatchment

8.6.4 Management options

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

- Short-term: Groundwater manipulation through the use of weirs; and
- Long-term: Localised conversion of low-lying areas to tidal wetlands.

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

Short-term management options

The Bukkan Bukkan Creek subcatchment on the northern portion of Oxley Island has a higher priority ranking than the Croakers Creek subcatchment on the southern portion of Oxley Island due to significantly higher soil acidity and groundwater seepage removal rates. The Bukkan Bukkan Creek subcatchment also has an extensive low-lying floodplain that can be tidally inundated due to higher astronomical tides and leaky floodgates. The floodplain is extensively drained by deeply constructed, and inter-connected drainage lines that provide effective drawdown of the local groundwater table and release of acid stores into natural waterways.

While floodgate management is a preferable option to neutralise in-drain acidity, it is unlikely to be a feasible option in the short-term due to the low elevation topography of the landscape, and the potential impact of increased salinity levels across inundated pasture areas. As such, groundwater manipulation via weir installations is recommended. Unused drains should be infilled/reshaped where possible and wet pasture management encouraged where applicable.

Long-term management options

The Bukkan Bukkan Creek subcatchment features some of the lowest-lying topography (<0.2 m AHD) on the entire Manning River floodplain. This area is likely to be increasingly affected by reduced drainage as sea level rise continues to occur. Without additional infrastructure the agricultural productivity on low-lying, swamp areas is likely to become increasingly reduced, and options for full remediation of poorly drained land to wet pastures (freshwater), or wetland (saline) should be investigated. In particular, the close proximity of the site to the Manning River entrance makes North Oxley Island an ideal site for tidal wetland remediation. This would reduce acid drainage, promote acid neutralisation and encourage water tolerant vegetation (and subsequently reduced risk of blackwater drainage). It is expected that land management practices will transition to utilise higher surrounding land as sea level rise impacts the site. Any changes to land use will need to consider the social, cultural and economic impacts on local landholders.

Indicative costs and qualitative benefits associated with the management options in the Bukkan Bukkan Creek subcatchment is provided in Table 8-6.

Table 8-6: Summary of management options for the Bukkan Bukkan 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	Groundwater manipulation	None	$80,000	$5,000	None	None	Moderate	Low
Long-term	Remediation of low-lying areas to wetlands	$ 8,900,000	$450,000	Minimal	$ 240,000	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 Coopernook subcatchment

Acid priority rank:	**5**
Blackwater priority rank:	**6**
<u>Infrastructure</u>	
Approximate waterway length (km)	35
# Privately owned end of system structures	8
# 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):	MANN003, MANN005, MANN006, MANN007, MANN009
<u>Elevations</u>	
Invert of primary floodplain infrastructure (m AHD)	-0.6 to -0.3
Approximate AASS elevation (m AHD)	0.4
Approximate PASS elevation (m AHD)	-0.7
Median blackwater elevation (m AHD)	0.6
Present day low water level (m AHD)	-0.1
Near future low water level (m AHD)	0
Far future low level (m AHD)	0.5
<u>Proximity to sensitive receivers</u>	
Oyster leases (km)	2.4
Saltmarsh (km)	Within subcatchment
Seagrass (km)	3.3
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
<u>Land use</u>	
Total floodplain area (ha)	636
Classified as conservation and minimal use (ha (%))	2 (0%)
Classified as grazing (ha (%))	608 (96%)
Classified as forestry (ha (%))	0 (0%)
Classified as horticulture (ha (%))	0 (0%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	16 (3%)
Classified as marsh/wetland (ha (%))	2 (0%)
Other (ha (%))	8 (1%)
<u>Land values</u>	
Estimated total primary production value ($/year)	$290,000
Average land value above 0.6 m AHD ($/ha)	$8,100
Average land value below 0.6 m AHD ($/ha)	No property data available

8.7.1 Site description

The Coopernook subcatchment is located on the eastern side of the Lansdowne River. The subcatchment is largely privately owned and managed (shown in Figure 8-26) and is predominantly used for grazing (which occurs over 96% of the subcatchment area). The Coopernook subcatchment includes some of the lowest topography in the Manning River floodplain (with substantial areas below 0.8 m AHD) and has an extensive artificial drainage network, as shown in Figure 8-27.

The Coopernook subcatchment is one of the smaller subcatchments considered in the Manning River floodplain, covering an area of 636 ha. Soil profile data indicates extensive presence of ASS, with all seven (7) profiles available having a minimum pH below 4.5. The Coopernook subcatchment is within the Lower Lansdowne-Moto-Ghinni Ghinni Creek ASS Priority area identified by Tulau (1999).

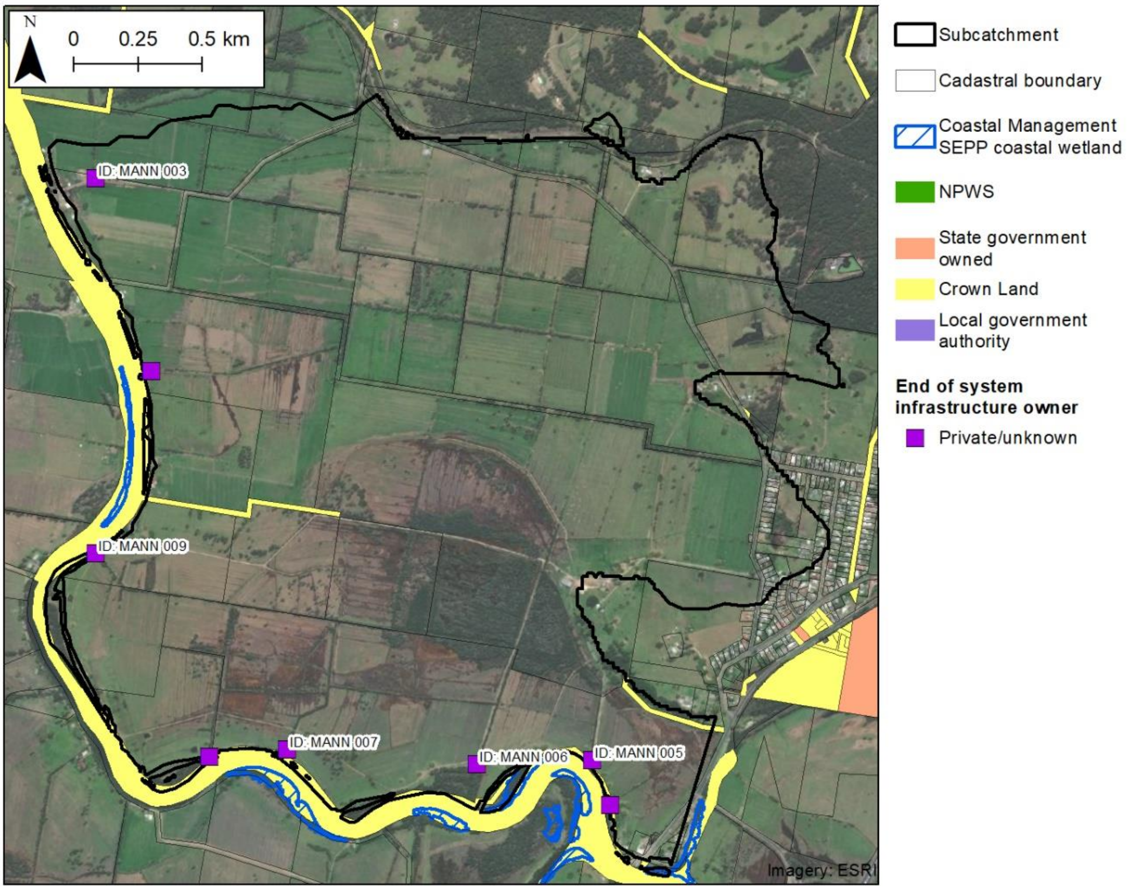

Figure 8-26: Coopernook subcatchment land and end of system infrastructure tenure

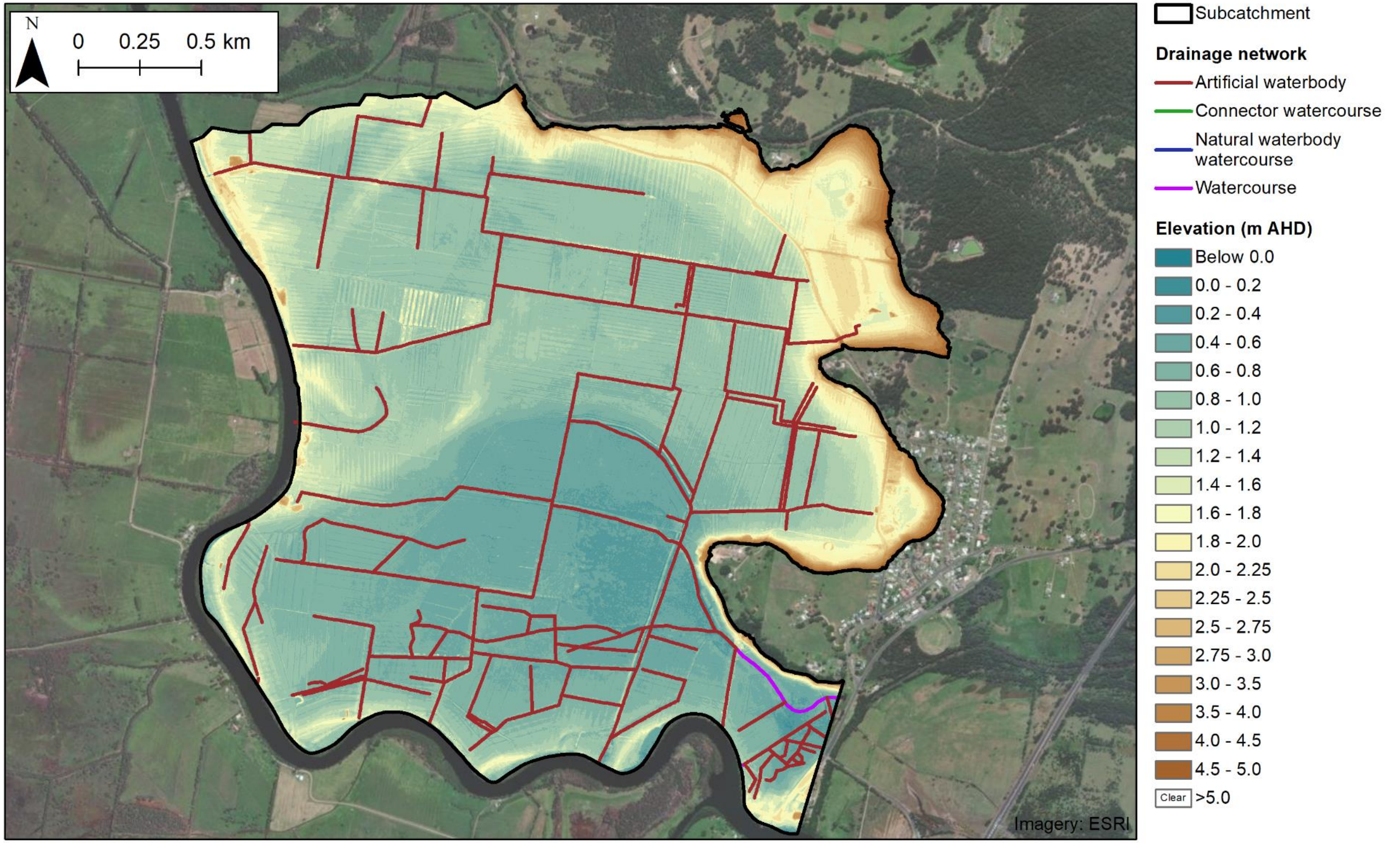

Figure 8-27: Coopernook subcatchment elevation detail and drainage network

8.7.2 History of remediation

A timeline of remediation works within the Coopernook subcatchment is provided below. Previous remediation works include:

- 2001 – Preparation of the 'Remediation Concept Plan for the Lower Lansdowne – Moto – Ghinni Ghinni Creek ASS Hot Spot' by the former Department of Land and Water Conservation as part of the NSW ASS Hot Spot Program. The Concept Plan was followed by a detailed Rehabilitation Plan, but it is unconfirmed if any on-ground works were completed as a result of the NSW ASS Hot Spot Program.
- 2020 – MidCoast Council is currently seeking funding for further investigations in the Coopernook subcatchment for broadscale wetland remediation.

8.7.3 Floodplain drainage – sea level rise vulnerability

The Coopernook subcatchment includes some of the lowest land on the Manning River floodplain. The vulnerability of the subcatchment to sea level rise is summarised in Figure 8-28. Even under present day conditions, a substantial area is at low risk of reduced drainage. This area increases in the near to far future. Under the far future sea level rise scenario, there are areas on the floodplain that are below the 5th percentile water levels and will likely be subject to prolonged inundation. The vast majority of the subcatchment is projected to be at risk of reduced drainage under the far future sea level rise scenario.

Figure 8-28 also shows the vulnerability of the floodgates in the Coopernook subcatchment. While no floodgates are considered vulnerable under present day conditions, MANN08 is classified as 'most vulnerable' under far future sea level rise scenarios. Six (6) other floodgates are classified as 'moderately vulnerable', including all primary floodgates. The productivity of the agricultural land uses in this subcatchment may be affected by reduced drainage as a result of sea level rise in the near to far future.

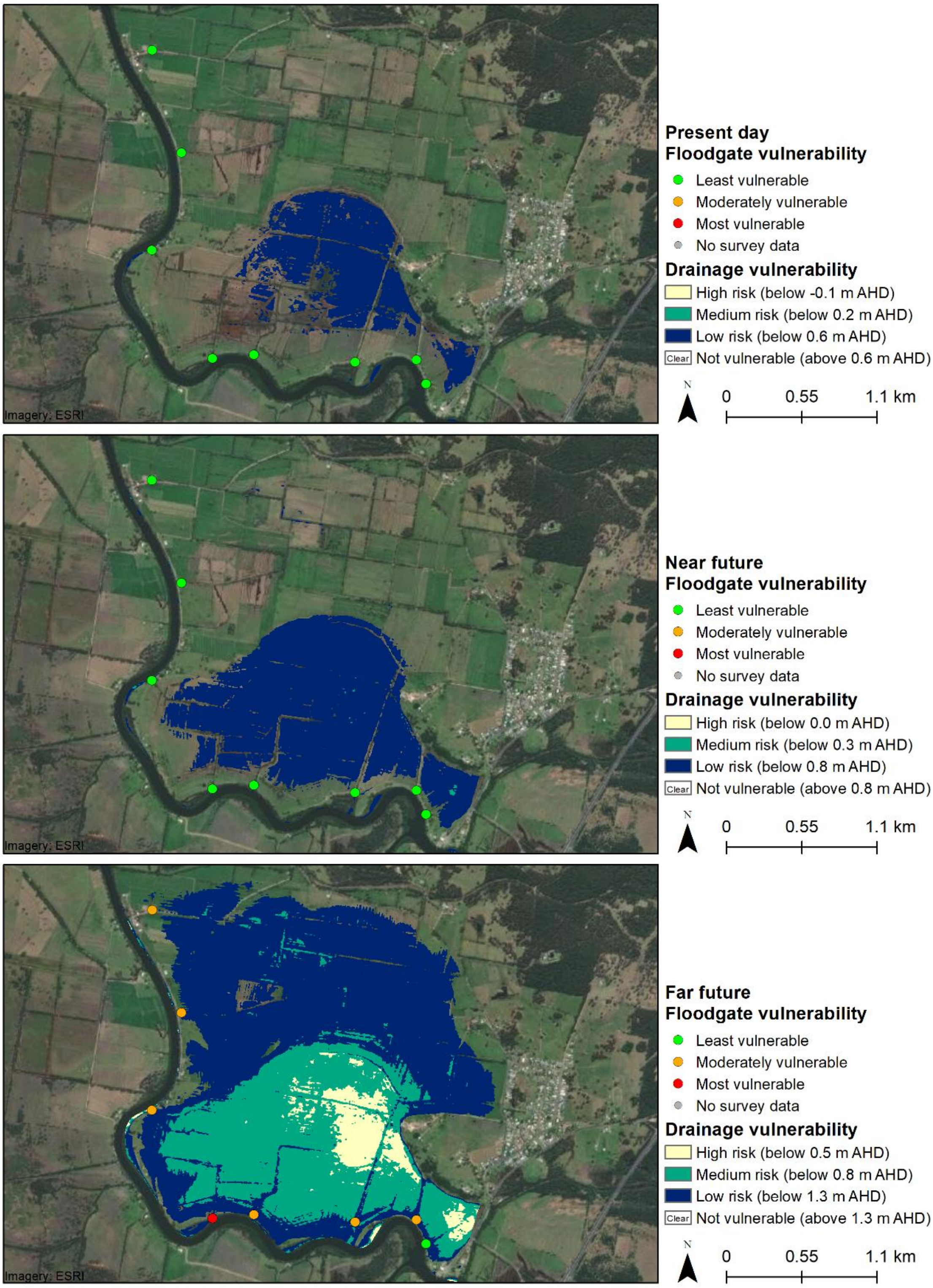

Figure 8-28: Sea level rise drainage vulnerability – Coopernook subcatchment

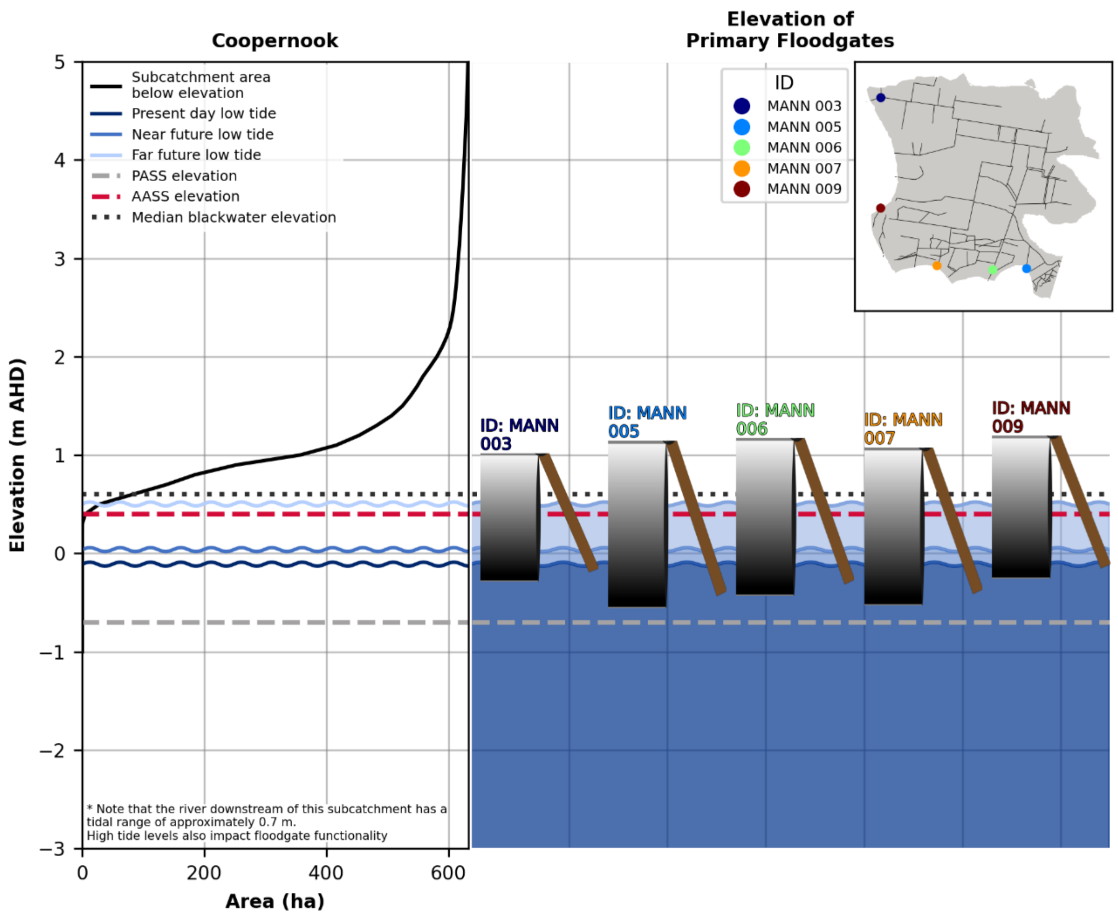

Figure 8-29: Key floodplain elevations – Coopernook subcatchment

8.7.4 Management options

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

- Short-term: Groundwater manipulation, with consideration of tidal wetland creation in the short-term; and
- Long-term: Full remediation of wetlands.

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

The Coopernook Swamp comprises of some of the lowest natural surface elevations (approximately 0.0 m AHD in some areas) across the Manning River floodplain. The site is marked by poor condition vegetation and extensive acid scalding, owing to its high soil acidity near the ground surface. The Coopernook Swamp has deep (>0.5 m) drains exporting acid and secondary by-products directly into the Lower Lansdowne River, and subsequently impacting downstream sensitive receivers.

The most effective management strategy for this site would be to revert the low-lying areas to a natural tidal wetland. This would provide immediate onsite neutralisation of acid and reduce future discharges of both acid and blackwater. In addition, it is encouraged that unused drains are infilled/reshaped, and floodgates removed, to maximise the benefit of reflooding the landscape. Alternative approaches may involve groundwater manipulation and encouraging wet pasture land management practices.

Long-term management options

The Coopernook subcatchment features some of the lowest-lying topography on the entire Manning River floodplain. This area is likely to be increasingly affected by reduced drainage with large areas remaining inundated by 2050 due to increases in low tide levels. Without additional infrastructure the agricultural productivity of the swamp is likely to become increasingly reduced and options for full remediation of poorly drained land to wet pastures (freshwater), or wetland (saline) should be investigated as a priority to minimise both acid and blackwater discharges.

Indicative costs and qualitative benefits associated with the management options in the Coopernook subcatchment are provided in Table 8-7.

Table 8-7: Summary of management options for Coopernook 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	Groundwater manipulation	None	$80,000	$5,000	None	None	Moderate	Moderate
Long-term	Remediation of wetlands	$ 4,000,000	$450,000	Minimal	$ 230,000	High	High	High

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

8.8 Cattai Creek subcatchment

Acid priority rank:	**6**
Blackwater priority rank:	**7**
Infrastructure	
Approximate waterway length (km)	38
# Privately owned end of system structures	9
# 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)	MANN053
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-0.5
Approximate AASS elevation (m AHD)	0.9
Approximate PASS elevation (m AHD)	0.7
Median blackwater elevation (m AHD)	0.5
Present day low water level (m AHD)	-0.1
Near future low water level (m AHD)	0
Far future low level (m AHD)	0.5
Proximity to sensitive receivers	
Oyster leases (km)	Within subcatchment
Saltmarsh (km)	Within subcatchment
Seagrass (km)	Within subcatchment
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	1,999
Classified as conservation and minimal use (ha (%))	789 (39%)
Classified as grazing (ha (%))	949 (47%)
Classified as forestry (ha (%))	0 (0%)
Classified as horticulture (ha (%))	0 (0%)
Classified as other cropping (ha (%))	1 (0%)
Classified as urban/industrial/services (ha (%))	31 (2%)
Classified as marsh/wetland (ha (%))	128 (6%)
Other (ha (%))	101 (5%)
Land values	
Estimated total primary production value ($/year)	$450,000
Average land value above 0.5 m AHD ($/ha)	$7,300
Average land value below 0.5 m AHD ($/ha)	No property data available

8.8.1 Site description

The Cattai Creek subcatchment is located between the Big Swamp subcatchment to the north-east and Mambo Island subcatchment to the south-west and is shown in Figure 8-30. Almost 40% of the subcatchment is classified as "conservation and minimal use" and the majority of the remaining area is used for grazing. The eastern side of the subcatchment is within the Crowdy Bay National Park.

The lowest areas of the subcatchment is near Cattai Creek and is below 1 m AHD, but is largely naturally drained (shown in Figure 8-31) and not actively used for agriculture. The most significant artificial drainage is on the western side of the subcatchment.

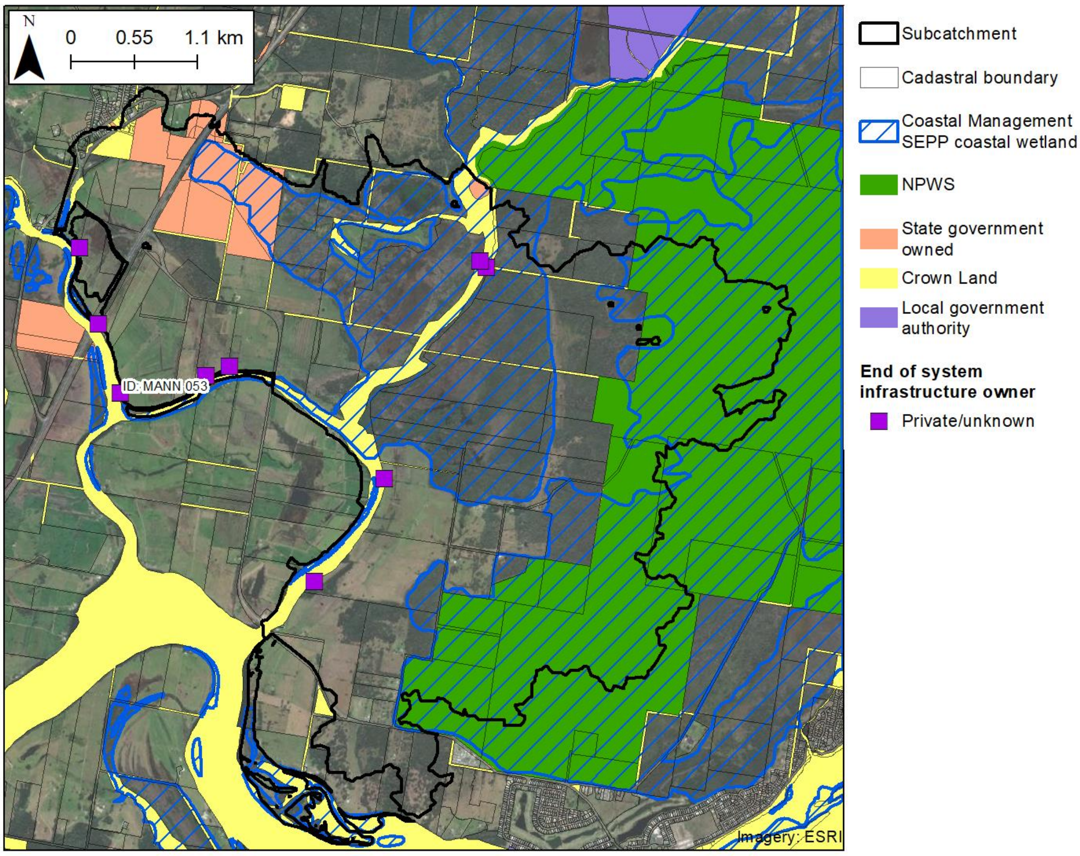

Figure 8-30: Cattai Creek subcatchment land and end of system infrastructure tenure

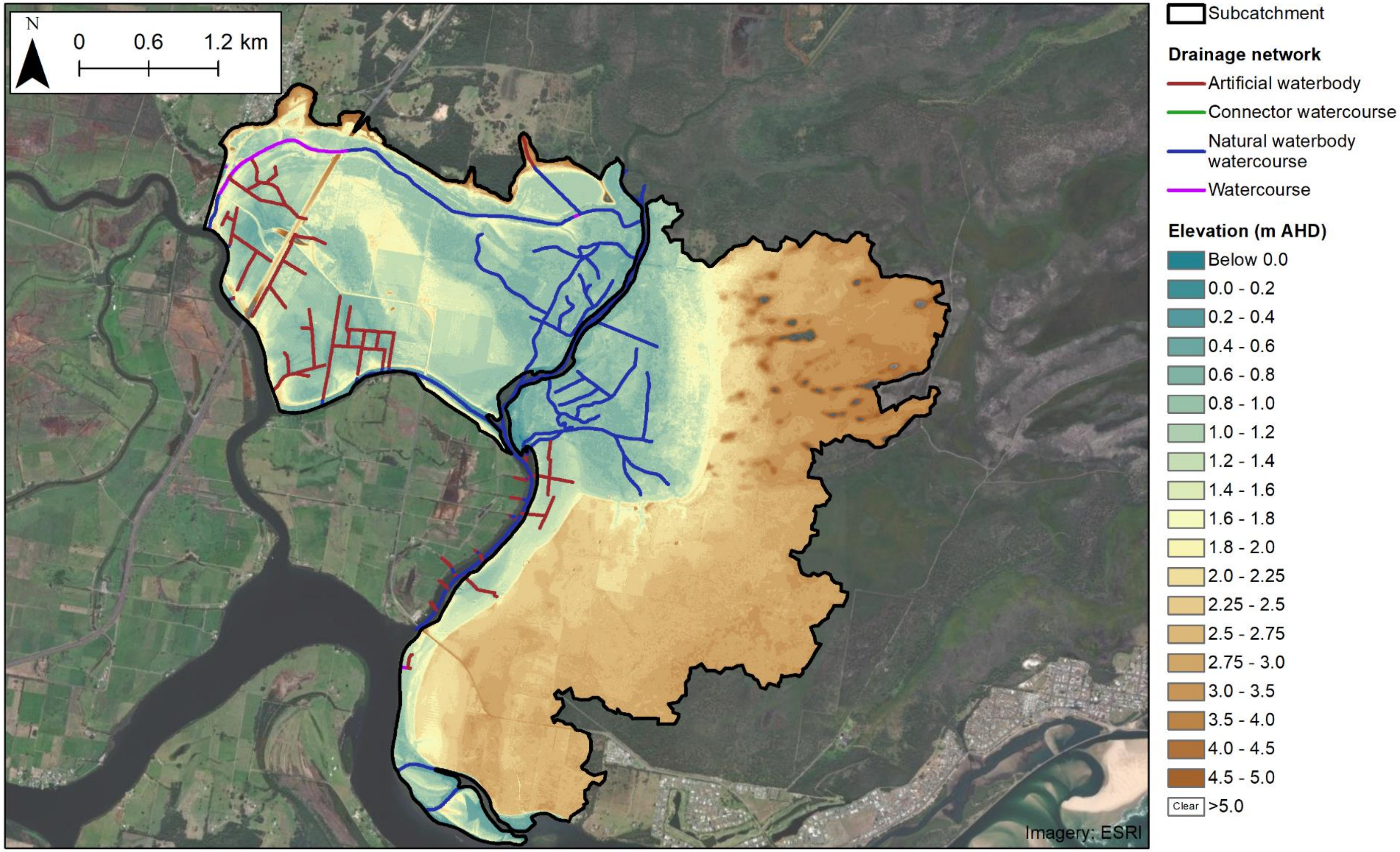

Figure 8-31: Cattai Creek subcatchment elevation and drainage network

8.8.2 History of remediation

A timeline of remediation works within the Cattai Creek subcatchment is provided below with reference to Figure 8-32. The works included:

- February 2008 – An ASS Drainage Management Plan was prepared by MidCoast Council for remedial works on the lower left-bank of Cattai Creek. Funding of $6,000 was provided by the Hunter-Central Rivers Catchment Management Authority (Project Id: HCR 05-1/136) for MidCoast Council to construct sill structures (made of sand/cement bags) at the outlets of eight (8) deep floodplain drains to raise drain inverts to +0.4 m AHD. The objective of the on-ground works was to "*maximise the retention of acid groundwater, while minimising ponded water on the floodplain for extended periods of time*" (Greater Taree City Council, 2008b). The program included periodic monitoring to assess the efficiency and structural integrity of the structures over time. The drainage management area was approximately 400 ha, including approximately 250 ha of high-risk ASS.

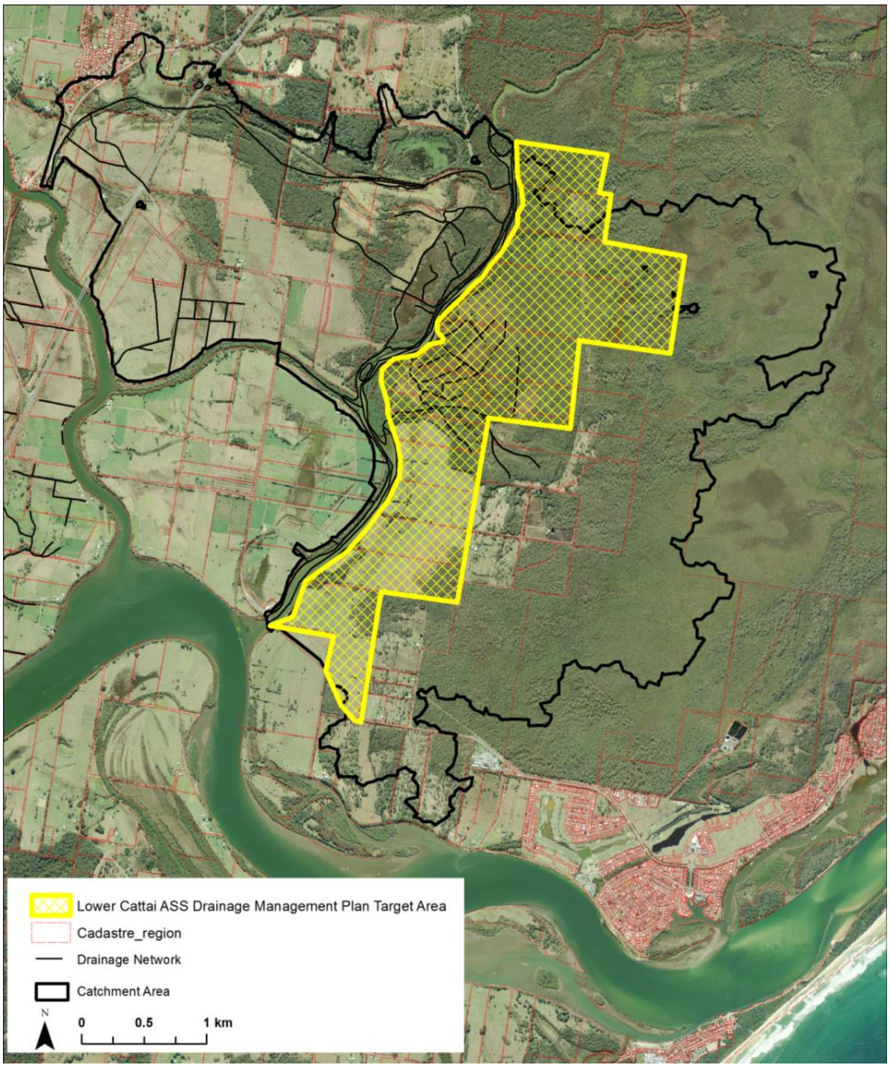

Figure 8-32: Previous ASS Management Target Area along Cattai Creek

8.8.3 Floodplain drainage – sea level rise vulnerability

The vulnerability of the Cattai Creek subcatchment to sea level rise is summarised in Figure 8-34. The low areas to the Cattai Creek subcatchment will be subject to reduced drainage in the near to far future. While a substantial portion of the subcatchment is classified as "conservation or minimal use" (41% of the total area), the area that is actively used for grazing may be impacted by sea level rise. This may be particularly an issue on the west of the subcatchment where three (3) floodgates (MANN053, MANN054 and MANN025) have been classified as "Most vulnerable" under the far future sea level rise scenario. This includes the primary floodgate MANN053, shown in Figure 8-33, which will be submerged in most tides under the far future scenario. All surveyed floodgates were modelled to be moderately or most vulnerable in the far future scenario.

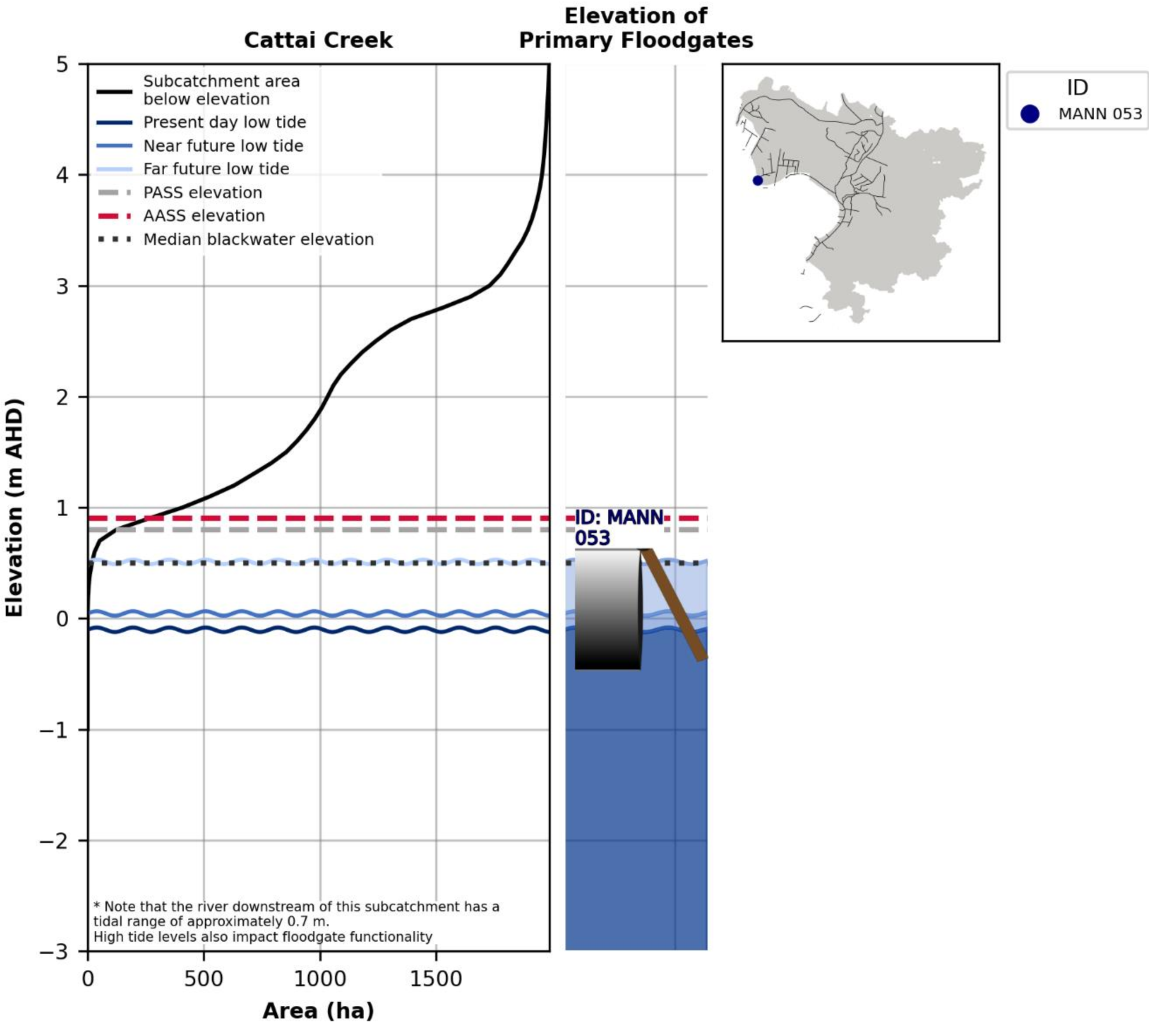

Figure 8-33: : Key floodplain elevations – Cattai Creek subcatchment

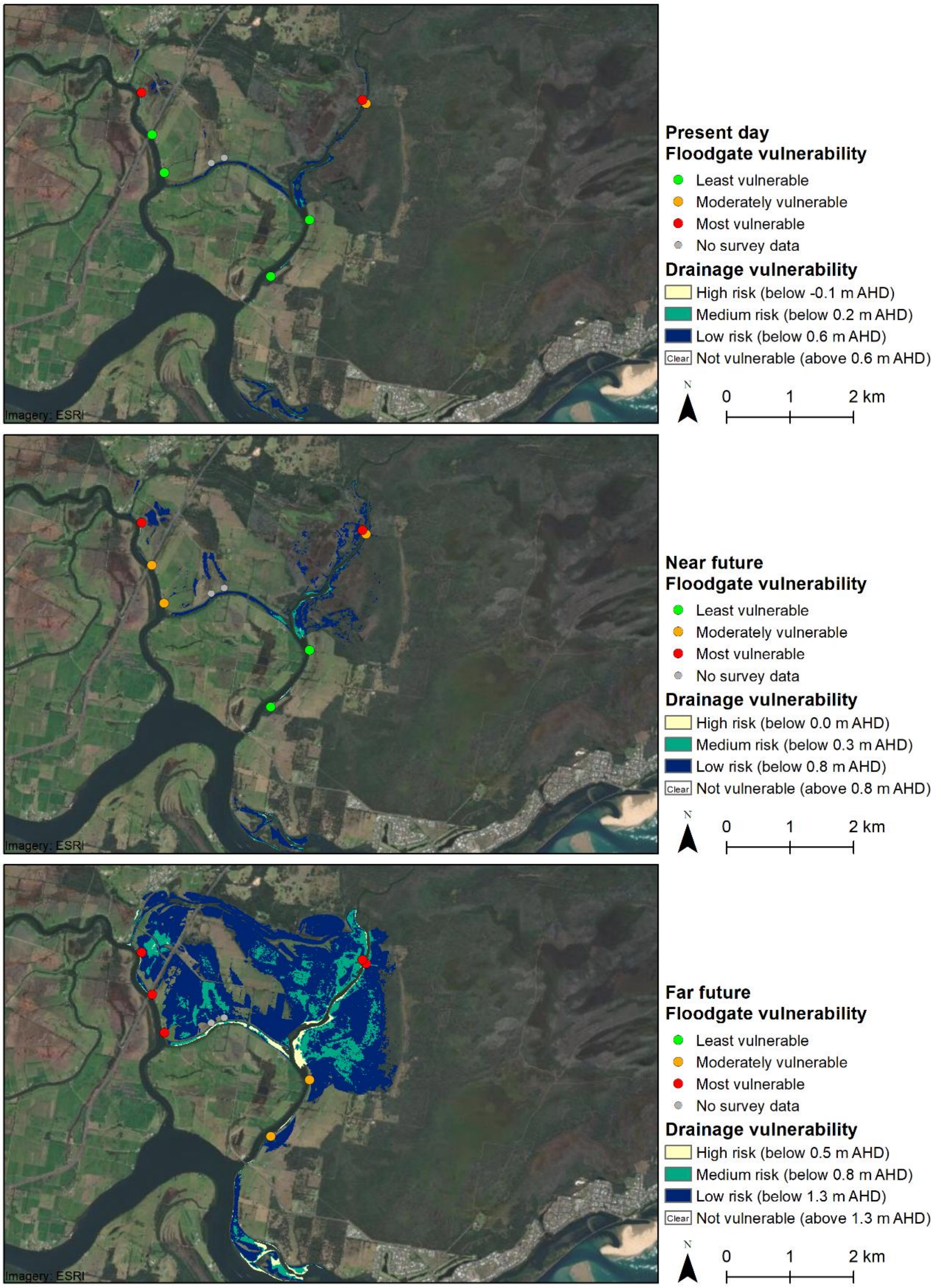

Figure 8-34: Sea level rise drainage vulnerability – Cattai Creek subcatchment

8.8.4 Management options

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

- Short-term: Drain reshaping, floodgate removal and maintenance of existing structures; and
- Long-term: Transition of low areas to wet pasture or wetland.

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
The on-ground works recommended for the Cattai Creek subcatchment align with previous works completed by MidCoast Council to raise drain invert levels at the discharge points to Cattai Creek. It is recommended that further investigation is undertaken by Council to assess effectiveness and structural integrity of the sills installed on eight (8) main drains along the left-bank of Cattai Creek. Maintenance should be carried out on the sills if required. It is also recommended that MidCoast Council further improve the management of the site by removing unused floodgate structures and infill/reshape drains (where possible). This will also reduce any ongoing costs associated with maintenance of the existing sills.

Long-term management options
Modification of existing land use practices is likely due to prolonged inundation and reduced drainage capacity due to sea level rise. Transition of affected low-lying areas to wet pasture or wetlands is to be expected and encouraged through community consultation and education provided by MidCoast Council. 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.

Indicative costs and qualitative benefits associated with the management options in the Cattai Creek subcatchment is provided in Table 8-8.

Table 8-8: Summary of management options for Cattai 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 and maintenance	None	$90,000	$5,000	None	None	Moderate	Minimal
Long-term	Transition to wetlands	$ 1,100,000	$250,000	Minimal	$ 70,000	High	High	High

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

8.9 Glenthorne subcatchment

Acid priority rank:	**7**
Blackwater priority rank:	**9**
Infrastructure	
Approximate waterway length (km)	26
# 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
Approximate PASS elevation (m AHD)	0
Median blackwater elevation (m AHD)	0.7
Present day low water level (m AHD)	-0.1
Near future low water level (m AHD)	0
Far future low level (m AHD)	0.5
Proximity to sensitive receivers	
Oyster leases (km)	10.4
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)	787
Classified as conservation and minimal use (ha (%))	58 (7%)
Classified as grazing (ha (%))	607 (77%)
Classified as forestry (ha (%))	0 (0%)
Classified as horticulture (ha (%))	1 (0.1%)
Classified as other cropping (ha (%))	18 (2%)
Classified as urban/industrial/services (ha (%))	50 (6%)
Classified as marsh/wetland (ha (%))	32 (4%)
Other (ha (%))	21 (3%)
Land values	
Estimated total primary production value ($/year)	$350,000
Average land value above 0.7 m AHD ($/ha)	$17,000
Average land value below 0.7 m AHD ($/ha)	No property data available

8.9.1 Site description

The Glenthorne subcatchment is located across the Manning River from Taree and is shown in Figure 8-35. The majority of the subcatchment is used for grazing, accounting for 77% of the total area. The lowest areas of the subcatchment are situated near 1 m AHD, and are typically located adjacent to the natural creek lines, shown in Figure 8-36.

The Glenthorne subcatchment is not heavily drained by an artificial drainage network and does not have floodgates, which prevents excessive acid drainage. However, soil profiles in the area indicate that acidic soils do exist, with two (2) of the four (4) profiles in the subcatchment having a minimum pH below 4.5.

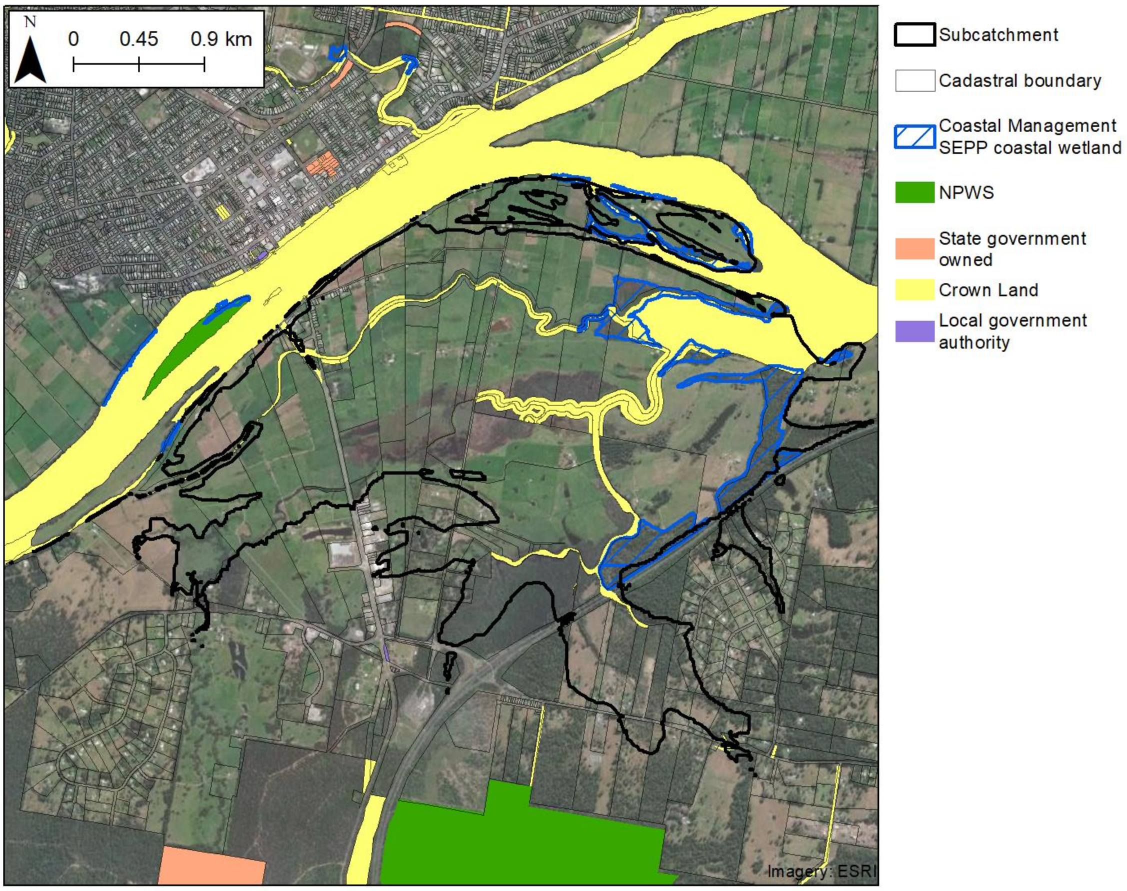

Figure 8-35: Glenthorne subcatchment - land and end of system infrastructure tenure

8.9.2 History of remediation

No known remediation to date.

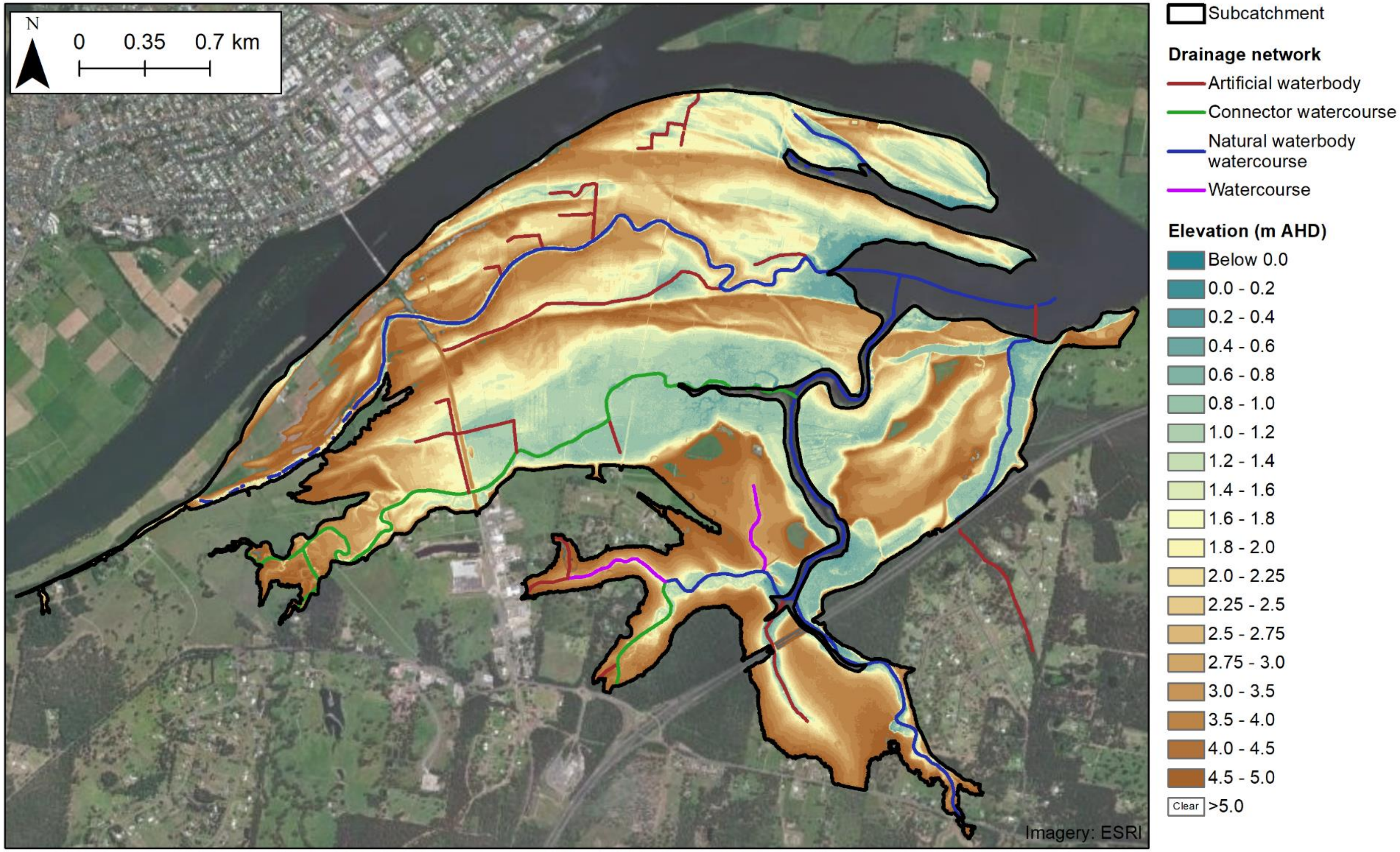

Figure 8-36: Glenthorne subcatchment elevation and drainage network

8.9.3 Floodplain drainage – sea level rise vulnerability

Figure 8-37 summarises the vulnerability of the Glenthorne subcatchment to sea level rise. The intertidal areas along creek lines may significantly increase as a result of increased tidal planes in the near to far future. This may impact land uses on the adjacent land which is presently used for grazing. No floodgates have been identified in this subcatchment, so the increased tidal range may result in direct inundation of land.

8.9.4 Management options

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

- Short-term: Groundwater manipulation through the use of weirs; and
- Long-term: Where reduced drainage impacts current land uses, investigate the opportunistic development of 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

While the Glenthorne subcatchment received a mid-priority ranking, soil data indicates that there is shallow acidity near the ground surface. Deep drains through the low-lying areas of the floodplain promote drawdown of the local groundwater table and interception of the acid store in the soil, resulting in potential acid discharges. Sensitive receivers, including key fisheries habitat and sea grasses lie immediately downstream of the drainage point of the floodplain and are impacted by acid discharges from the site.

No data of water control structures was available at the time of this study. However, in the absence of any infrastructure data, it is recommended that low-lying areas of the subcatchment impacted by ASS are managed by groundwater manipulation (i.e. weirs/sills) to maintain high local groundwater levels. Alternatively, in-drain neutralisation of acid stores could be utilised due to the proximity of the site to the Manning River entrances. However, further detailed design and survey would be required to assess the impact of tidal inundation on the floodplain. Note that drain reshaping to create shallow, wide swale drains is recommended where possible.

Long-term management options

Portions of this site are subject to future inundation due to sea level rise. Viable agriculture farming practices are encouraged on high land, while low-lying areas of the floodplain could revert to wet pasture or intertidal wetland habitats to minimise both acid and blackwater discharges. Ultimately, community and landholder engagement is essential in the Glenthorne region about ongoing ASS legacy issues, and the advantages/benefits of progressing future land management practices towards wet pasture management and wetland remediation across the entire floodplain.

Indicative costs and qualitative benefits associated with the management options in the Glenthorne subcatchment is provided in Table 8-9.

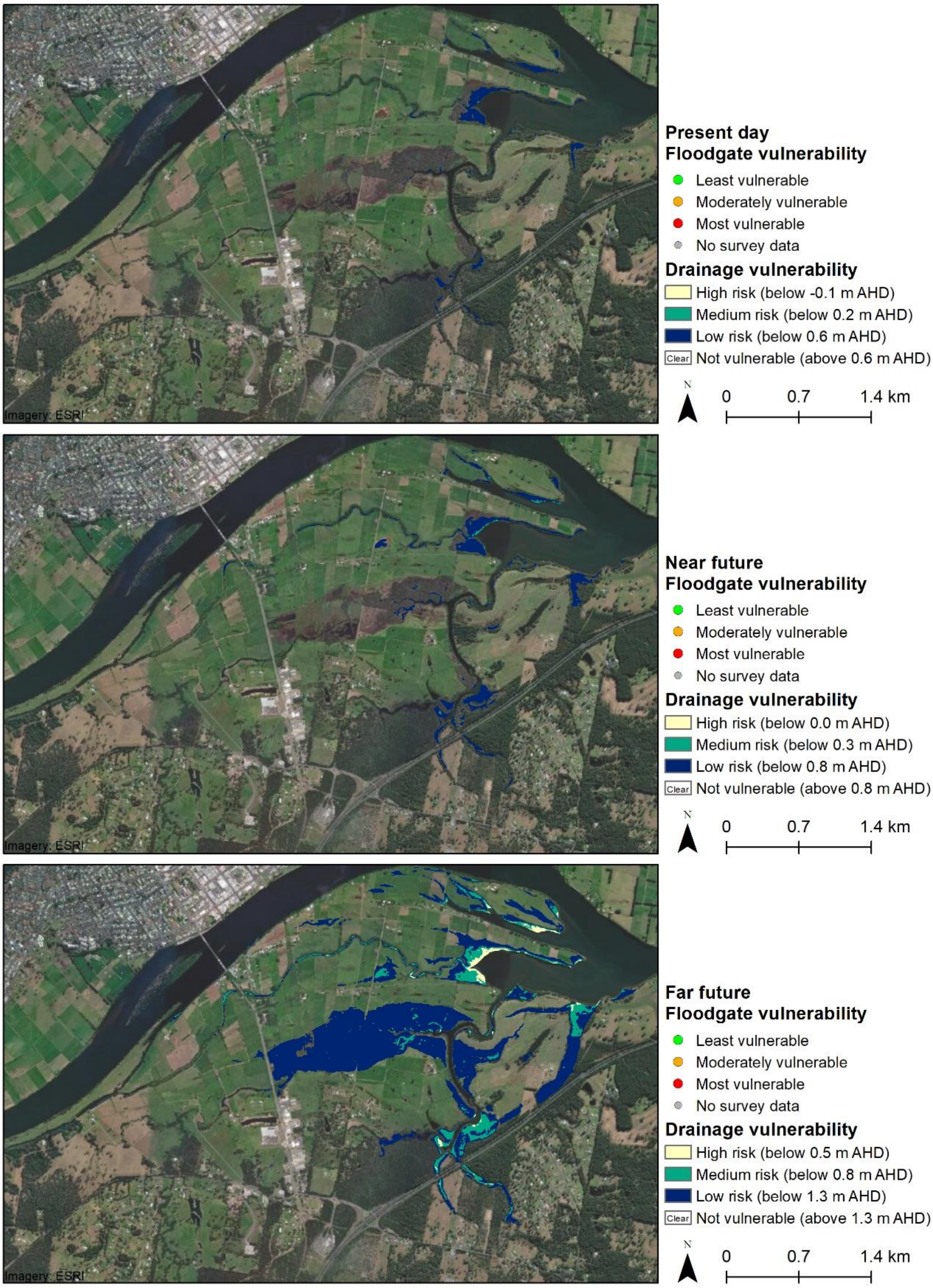

Figure 8-37: Sea level rise drainage vulnerability – Glenthorne subcatchment

Table 8-9: Summary of management options for Glenthorne

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	Groundwater manipulation	None	$80,000	$5,000	None	None	Moderate	Moderate
Long-term	Localised remediation of wetlands	$ 5,600,000	$150,000	Minimal	$ 160,000	High	High	High

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

8.10 Jones Island subcatchment

Acid priority rank:	**8**
Blackwater priority rank:	**4**
Infrastructure	
Approximate waterway length (km)	37
# Privately owned end of system structures	19
# 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):	MANN035, MANN069, MANN102, MANN107
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-0.5 to 0.0
Approximate AASS elevation (m AHD)	1
Approximate PASS elevation (m AHD)	-0.2
Median blackwater elevation (m AHD)	0.6
Present day low water level (m AHD)	-0.1
Near future low water level (m AHD)	0
Far future low level (m AHD)	0.5
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)	947
Classified as conservation and minimal use (ha (%))	0 (0%)
Classified as grazing (ha (%))	834 (88%)
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 (%))	53 (6%)
Classified as marsh/wetland (ha (%))	29 (3%)
Other (ha (%))	31 (3%)
Land values	
Estimated total primary production value ($/year)	$390,000
Average land value above 0.6 m AHD ($/ha)	$15,200
Average land value below 0.6 m AHD ($/ha)	$12,800

8.10.1 Site description

Jones Island is in the mid-upper Manning River estuary, downstream of Taree. As shown in Figure 8-38, the floodplain infrastructure on Jones Island is all privately owned. The majority of the Island is situated below +1.5 m AHD, and has an extensive artificial drainage network (Figure 8-39). The majority of the island is used for grazing (88%).

As this subcatchment is an island, there is limited catchment area to mobilise acid from ASS and the overall ASS priority ranking is relatively low (ranked 8th). However, soil profiles indicate a high degree of acidity within the subcatchment, with several profiles having a minimum pH between 3 - 4. Acidity in the drainage network may present a significant local risk in the Jones Island subcatchment. The Jones Island subcatchment ranked fourth in the blackwater prioritisation, mainly due to the low lying topography.

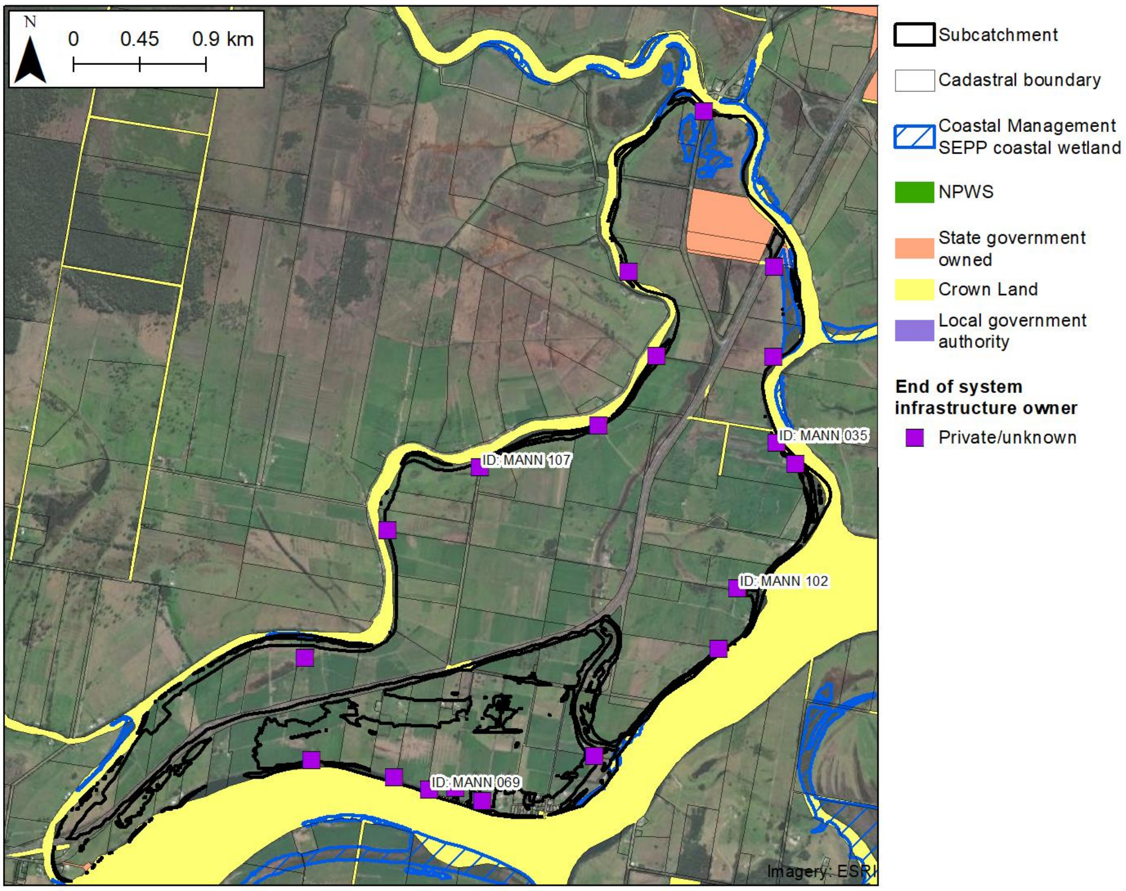

Figure 8-38: Jones Island subcatchment – land and end of system infrastructure tenure

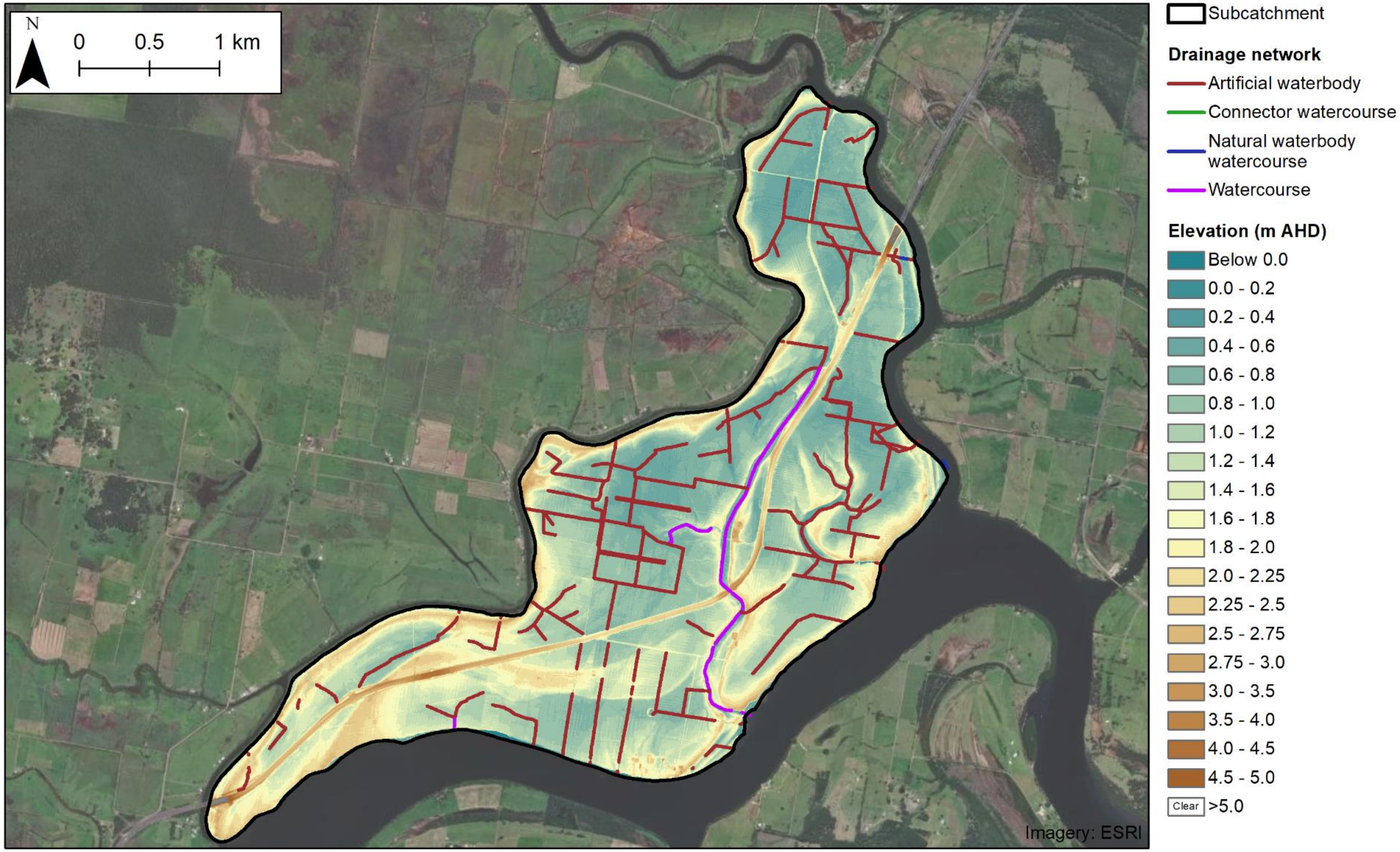

Figure 8-39: Jones Island elevation and drainage network

8.10.2 History of remediation

A timeline of known remediation works within the Jones Island subcatchment is provided below with reference to Figure 8-40. Previous remediation works include:

- January 2008 – An ASS Drainage Management Plan was prepared by MidCoast Council for remedial works on a portion of the Curtis property on Jones Island (Greater Taree City Council, 2008c). Funding of $9,000 was provided by MidCoast Council in partnership with the Hunter-Central Rivers Catchment Management Authority (Project Id: HCR 1/95). The project focused on decommissioning an unused drain, reshaping an existing drain to create a shallow swale drain, and upgrading two (2) separate culvert crossings. Approximately 30 ha was influenced by the modified drainage system.

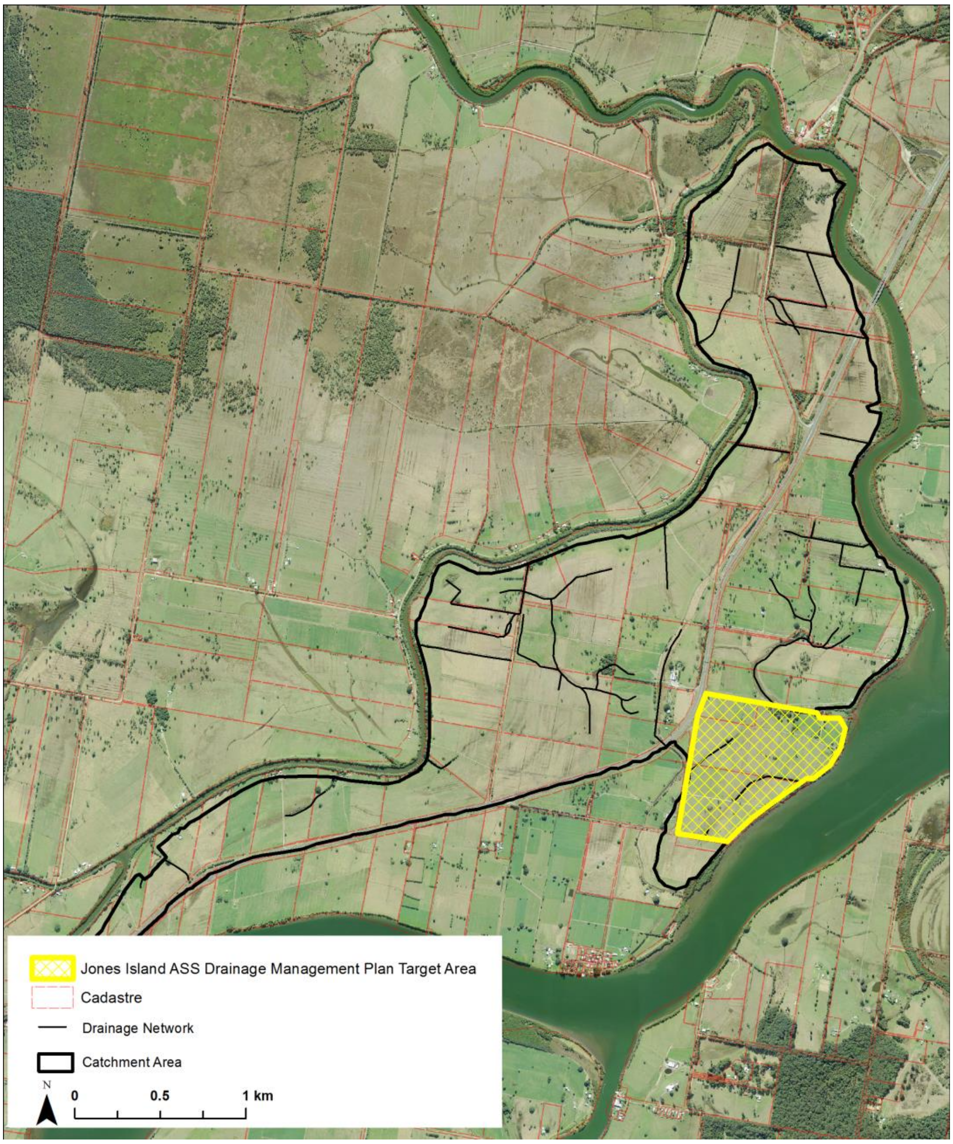

Figure 8-40: Previous ASS Management Target Areas on Jones Island

8.10.3 Floodplain drainage – sea level rise vulnerability

The sea level rise vulnerability of the Jones Island subcatchment is shown in Figure 8-42. There are small areas below the 95th percentile water level in the present day conditions, which increases under the near future sea level rise scenario. However, under the far future sea level rise scenario, a substantial portion of the Jones Island subcatchment is below the median (50th percentile) water level.

Similarly, the floodplain infrastructure in the Jones Island subcatchment is increasingly vulnerable as sea levels continue to rise in the near to far future. Under the far future sea level rise scenario, seven (7) of the 17 floodgates with survey information are classified as 'most vulnerable'. The productivity of the agricultural land uses (predominantly grazing) may be impacted by reduced drainage.

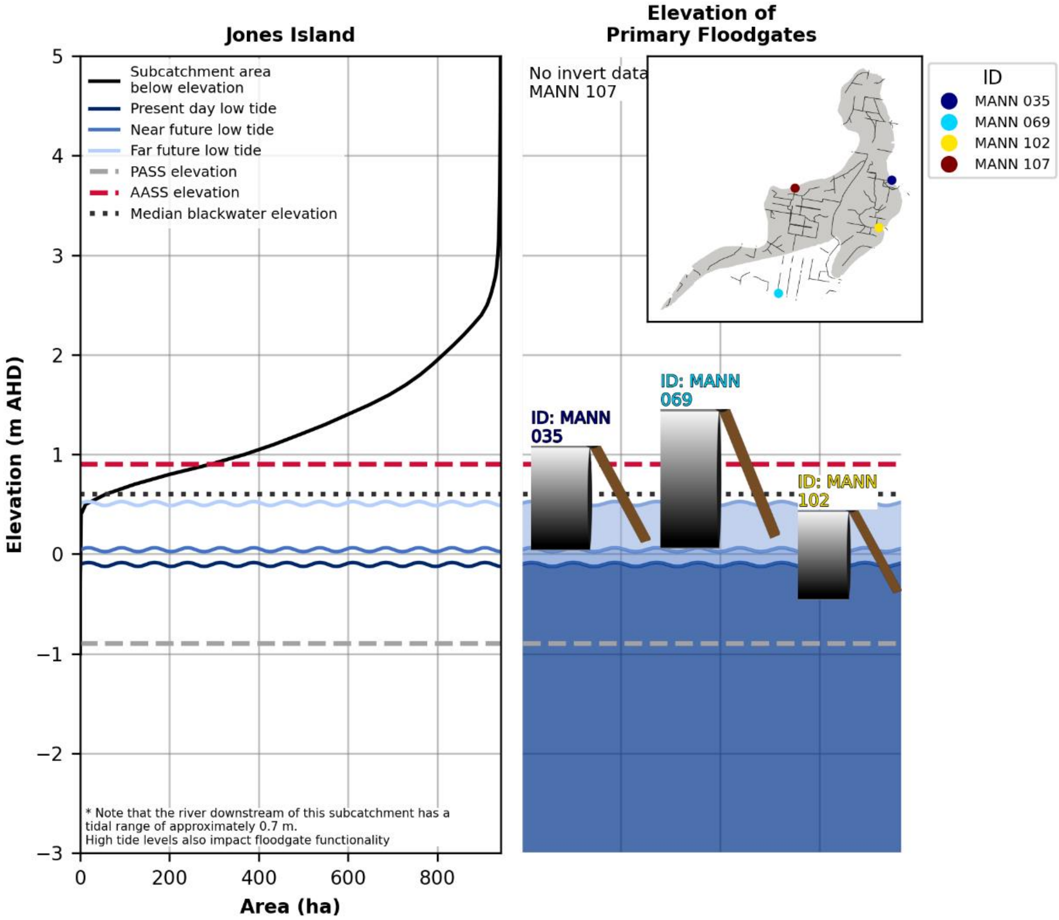

Figure 8-41: Key floodplain elevations – Jones Island subcatchment

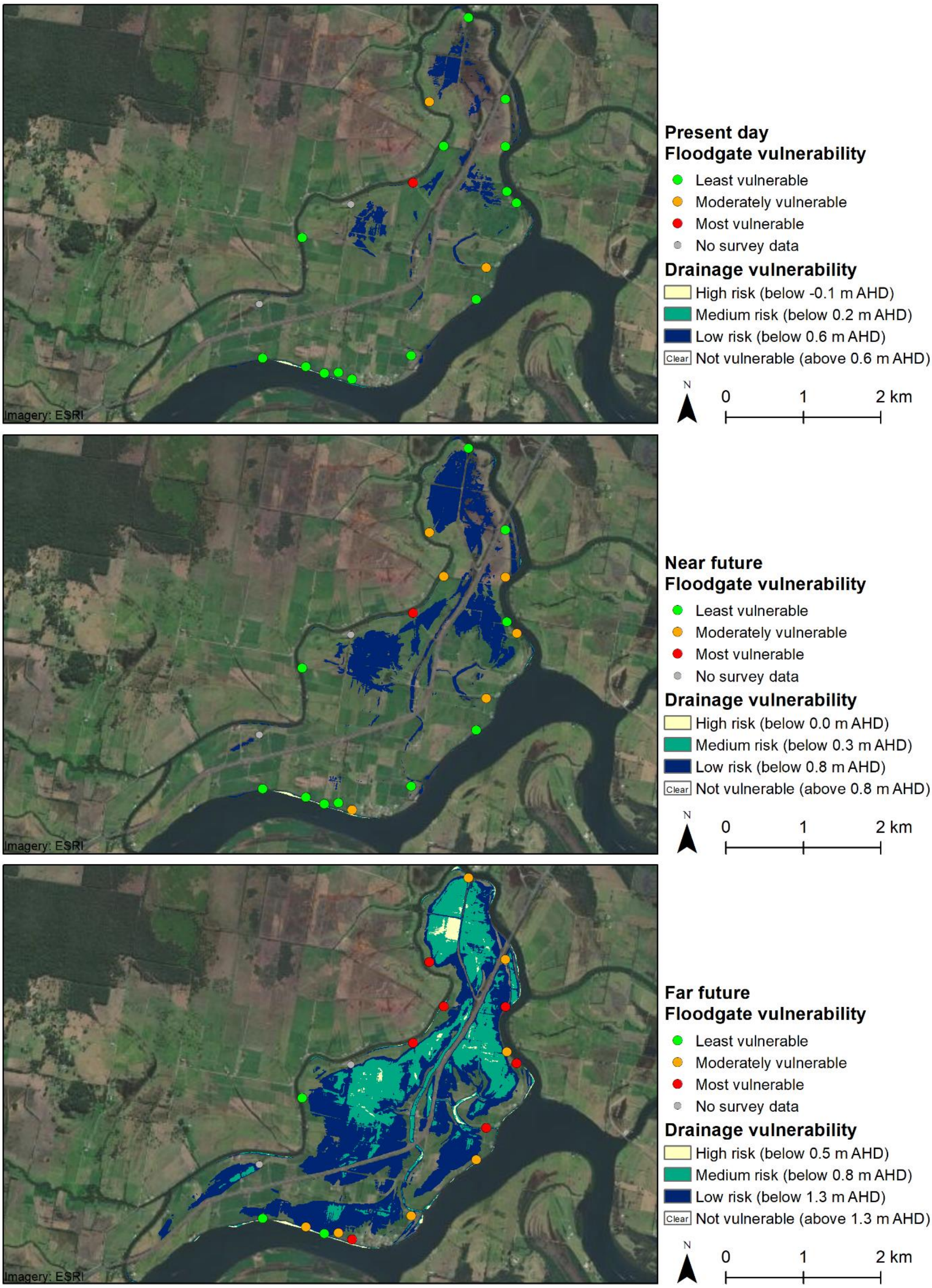

Figure 8-42: Sea level rise drainage vulnerability – Jones Island subcatchment

8.10.4 Management options

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

- Short-term: Floodgate management and drain infilling; and
- Long-term: Where reduced drainage due to sea level rise impacts current land uses, investigate the opportunistic rehabilitation 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
Portions of the Jones Island subcatchment have previously been targeted for remediation as part of the MidCoast Council ASS Drainage Management Plan (refer to Section 8.10.2). Previous on-ground works have focused on decommissioning unused drains and reshaping existing drains to create a shallow swale drain. Where applicable, other areas of the Jones Island should be targeted to achieve the same outcomes as the 2008 ASS Drainage Management Plan. This could be achieved by further floodgate management and filing/reshaping drains across the island to reduce acid mobilisation, while also encouraging expanded wet pasture management areas across low-lying, boggy land to address both blackwater and acid discharges.

Long-term management options
Jones Island features some of the lowest-lying topography on the entire Manning River floodplain. This area is likely to be increasingly affected by reduced drainage as sea level rise continues to occur. Without additional infrastructure the agricultural productivity of the Jones Island is likely to become increasingly reduced and options for full remediation of poorly drained land to wet pastures (freshwater), or wetland (saline) should be investigated. This would be effective at managing both acid and blackwater generated from the lowest parts of the subcatchment. 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.

Indicative costs and qualitative benefits associated with the management options in the Jones Island subcatchment is provided in Table 8-10.

Table 8-10: Summary of management options for Jones Island

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	Floodgate management	None	$95,000	$15,000	None	Moderate	Moderate	Minimal
Short-term	Drain infilling	None	$220,000	None	None	None	Moderate	Low
Long-term	Localised remediation of wetlands	$ 3,300,000	$450,000	Minimal	$ 100,000	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 Mitchells Island subcatchment

Acid priority rank:	**9**
Blackwater priority rank:	**15**
Infrastructure	
Approximate waterway length (km)	56
# Privately owned end of system structures	10
# Publicly owned end of system structures	1
# End of system structures within coastal wetlands	1
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (ID)	MANN082
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-0.1
Approximate AASS elevation (m AHD)	1.2
Approximate PASS elevation (m AHD)	0.9
Median blackwater elevation (m AHD)	0.5
Present day low water level (m AHD)	-0.1
Near future low water level (m AHD)	0
Far future low level (m AHD)	0.5
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)	2,203
Classified as conservation and minimal use (ha (%))	173 (8%)
Classified as grazing (ha (%))	1697 (77%)
Classified as forestry (ha (%))	0 (0%)
Classified as horticulture (ha (%))	2 (0.1%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	100 (5%)
Classified as marsh/wetland (ha (%))	139 (6%)
Other (ha (%))	93 (4%)
Land values	
Estimated total primary production value ($/year)	$850,000
Average land value above 0.5 m AHD ($/ha)	$17,000
Average land value below 0.5 m AHD ($/ha)	No property data available

8.11.1 Site description

Mitchells Island is in the lower Manning River estuary, with the eastern edge of the subcatchment on the Old Bar/Manning Point beaches and includes the waterbody referred to as Pelican Bay in the north east of the subcatchment. The majority of the subcatchment is used for grazing. As shown in Figure 8-43, one of the few floodgates managed by MidCoast Council in the Manning River floodplain is on Mitchells Island (ID MANN082).

Mitchells Island includes low areas (below 1.5 m AHD), particularly around the natural waterways shown in Figure 8-44. Most of the available soil profiles in the Mitchells Island subcatchment have minimum pH above 5, although localised areas of higher acidity may be an issue. The subcatchment is ranked low (15th) in the blackwater prioritisation due to generally higher topography and proximity to the river entrances.

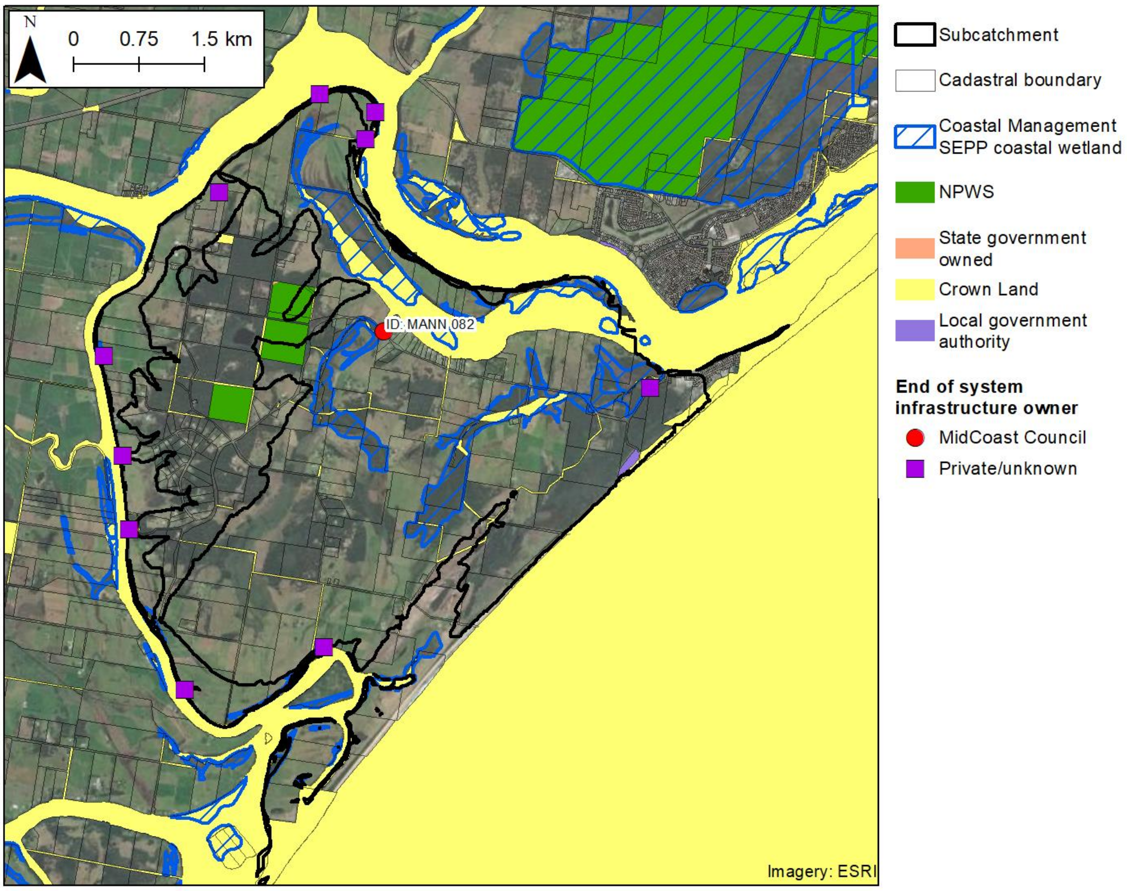

Figure 8-43: Mitchells Island subcatchment - land and end of system infrastructure tenure

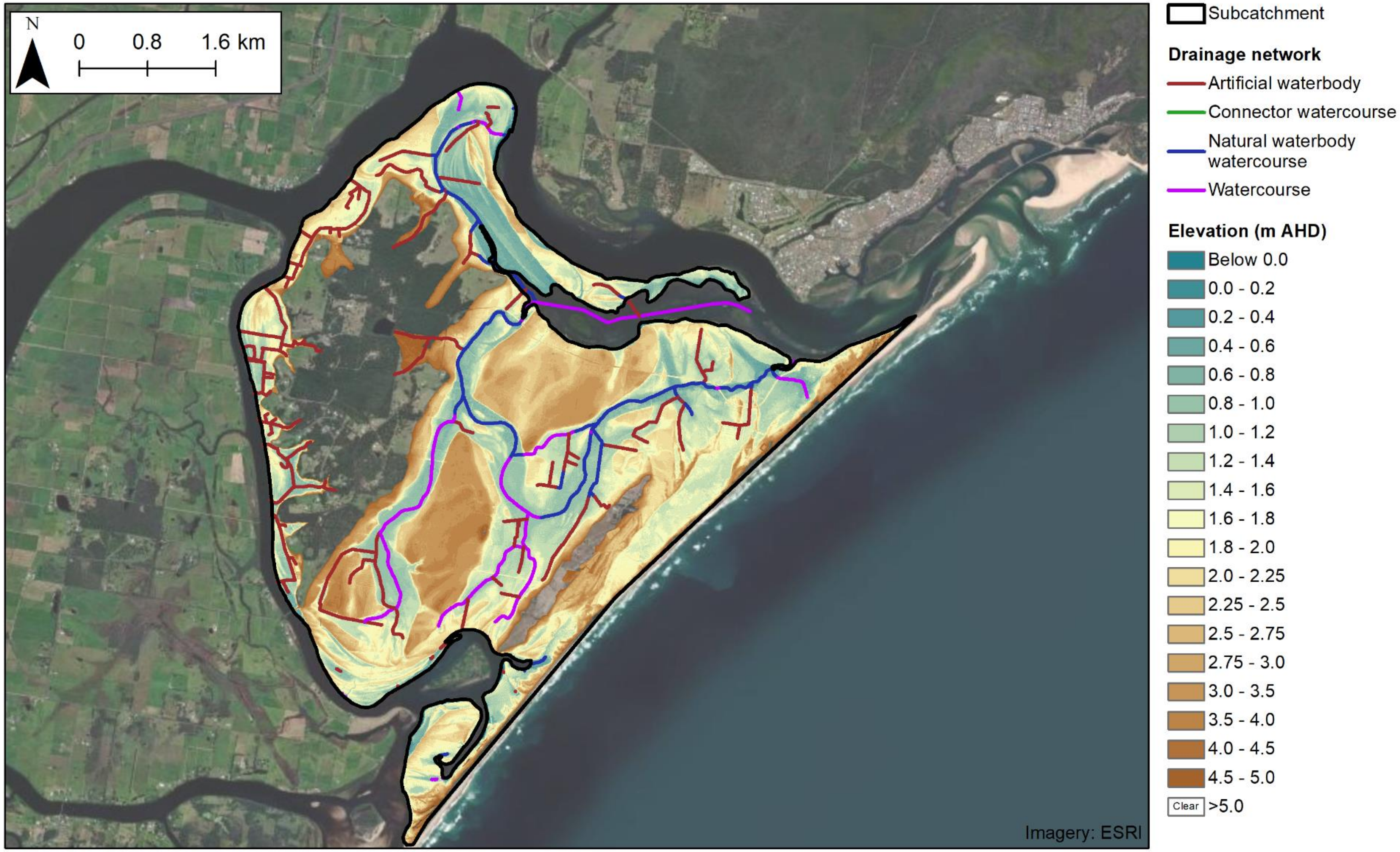

Figure 8-44: Mitchells Island subcatchment elevation and drainage network

8.11.2 History of remediation

Rayner et al. (2020) recently completed an assessment of three (3) sites (shown in Figure 8-45) on Mitchells Island to support Hunter Local Land Service and MidCoast Council to improve outcomes relating to water quality, wetland conservation and assisting graziers with pasture production. Their recommendations primarily suggest improving tidal connectivity through floodgate removal, stock exclusion and support of wetland vegetation, summarised in Figure 8-45. No on ground works have been completed to data.

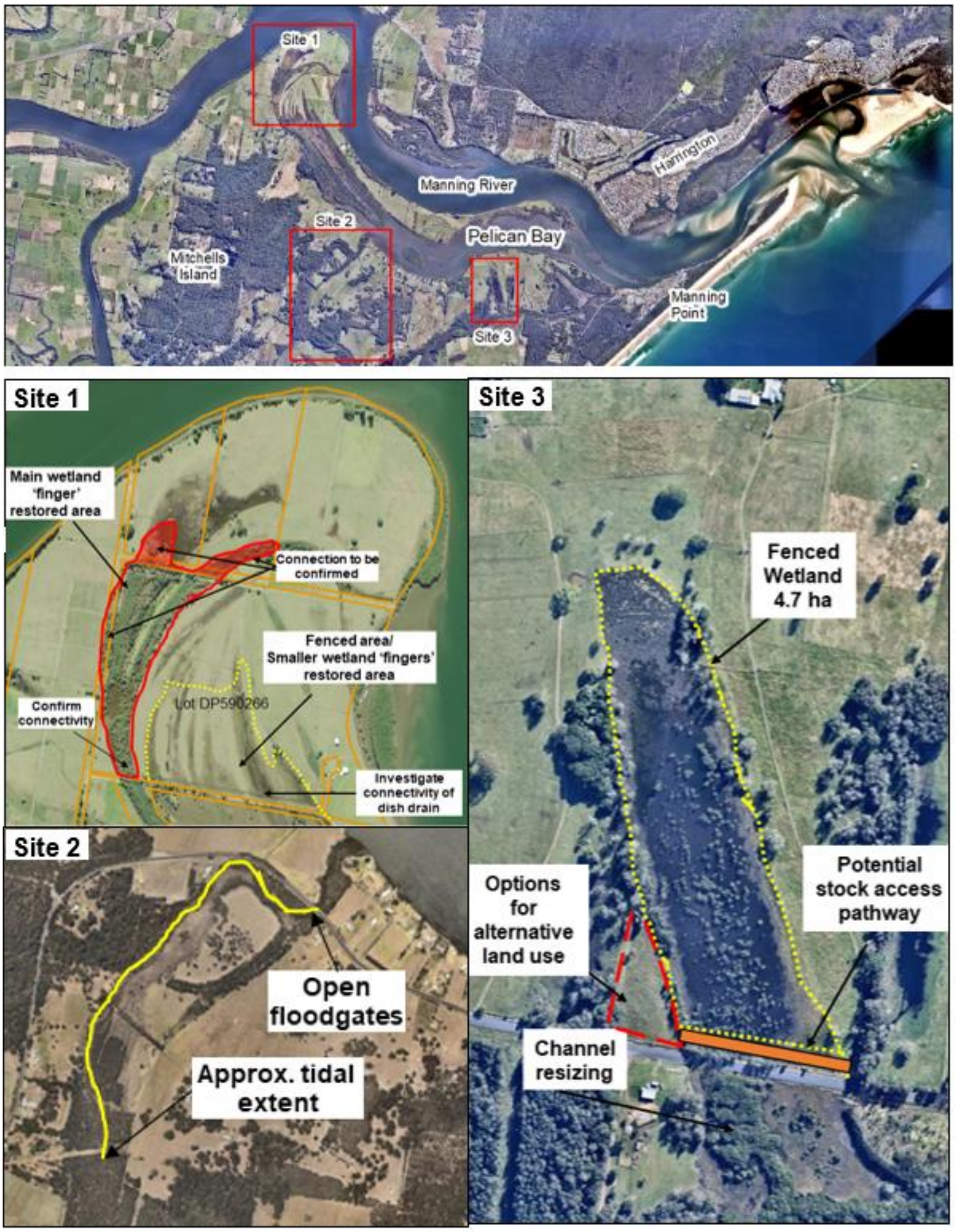

Figure 8-45: Potential management options on Mitchells Island from Rayner et al. (2020)

8.11.3 Floodplain drainage – sea level rise vulnerability

Figure 8-47 summarises the sea level rise vulnerability of the Mitchells Island subcatchment. The intertidal areas of Pelican Bay are likely to increase as tidal planes increase and sea levels continue to rise. The low areas along the banks for Milers Creek and Sheather Creek may also be impacted by reduced drainage as a result of sea level rise.

The floodplain infrastructure will also be increasingly impacted by sea level rise in the near to far future. In present day conditions one (1) of the floodgates is classified as 'most vulnerable' (MANN072). However, under the far future sea level rise scenario six (6) of the 11 floodgates with survey information are classified as 'most vulnerable'. The primary floodgate in the Mitchells Island subcatchment (MANN082, shown in Figure 8-46) is classified as 'moderately vulnerable' under the far future sea level rise scenario. Reduced capacity of floodplain infrastructure to remove floodwaters may result in prolonged inundation as sea levels continue to rise.

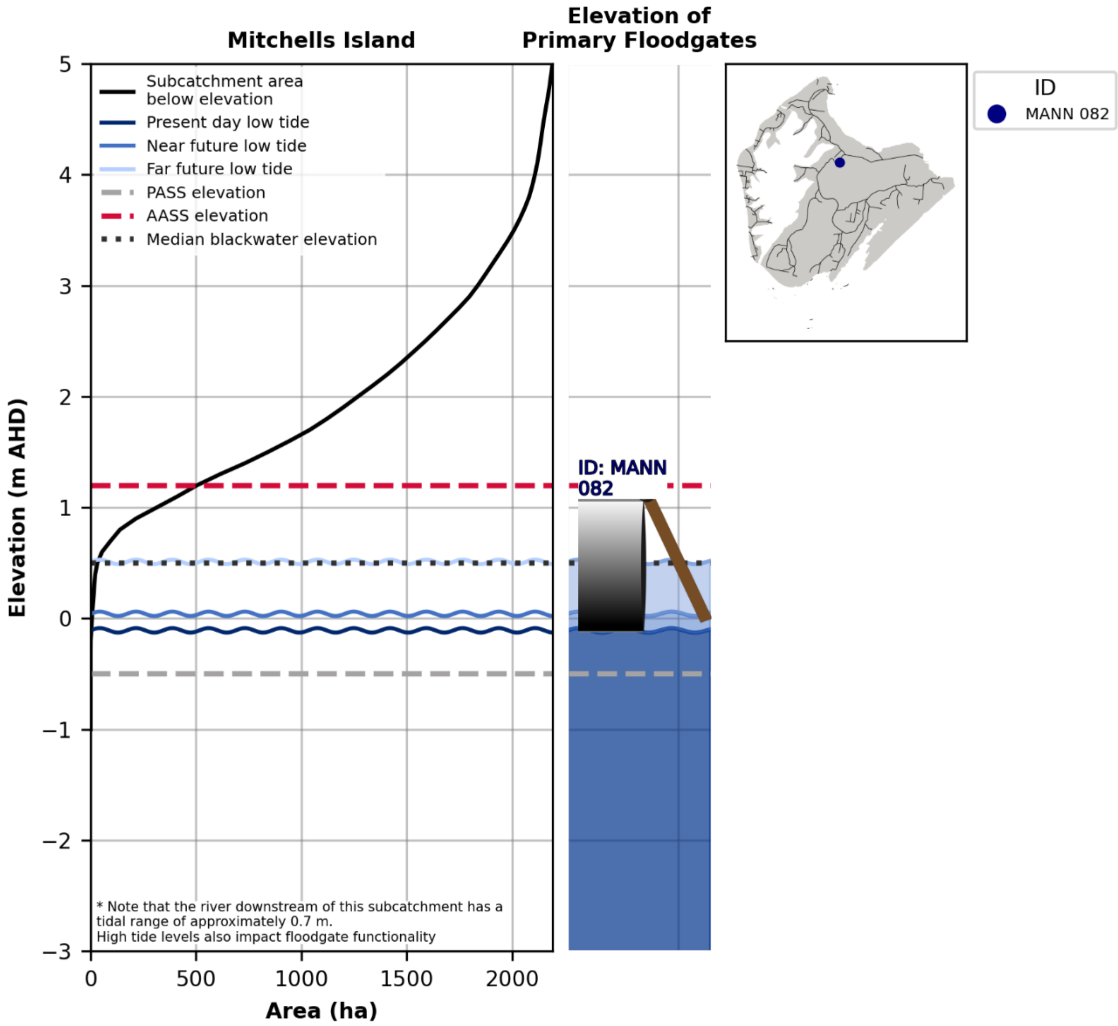

Figure 8-46: Key floodplain elevations – Mitchells Island subcatchment

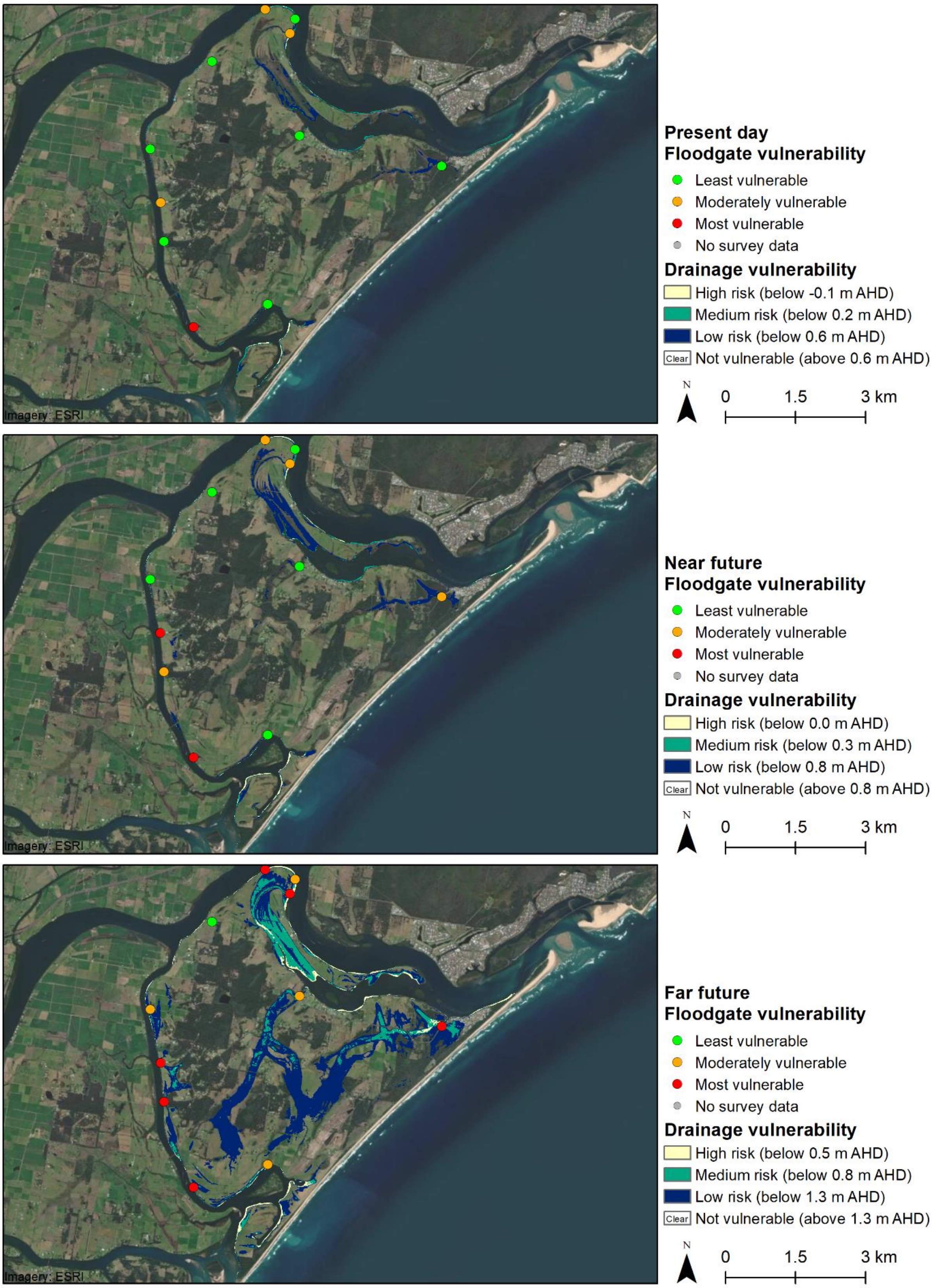

Figure 8-47: Sea level rise drainage vulnerability – Mitchells Island subcatchment

8.11.4 Management options

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

- Short-term: Floodgate management to improve tidal flushing; and
- Long-term: Wet pasture management and localised wetland remediation.

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

On a catchment-wide basis, Mitchells Island ranks low compared to other floodplain areas for both acid and blackwater. Existing data for Mitchells Island shows limited presence of acid stores and its location in the lower estuary reduces the potential for blackwater generation. However, floodgate management is recommended to encourage in-drain neutralisation of potential localised acid stores, improve day to day water quality, rehabilitate wetland habitats, and for fish passage. Any unused drains are recommended to be infilled/reshaped to reduce groundwater drawdown.

Long-term management options

A natural increase in water levels and extended periods of inundation are likely across low-lying areas of Mitchells Island. A long-term shift in land practices and reversion to wet pasture management, a natural saltmarsh or natural wetland is recommended where possible.

Indicative costs and qualitative benefits associated with the management options in the Mitchells Island subcatchment is provided in Table 8-11.

Table 8-11: Summary of management options for Mitchells Island

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	Floodgate management	None	$95,000	$15,000	None	Moderate	Moderate	Minimal
Long-term	Wet pasture	Limited	$180,000	$5,000	Limited	None	High	High

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

8.12 Pampoolah subcatchment

Acid priority rank:	**10**
Blackwater priority rank:	**13**
<u>Infrastructure</u>	
Approximate waterway length (km)	18
# Privately owned end of system structures	1
# 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)	UNK03
<u>Elevations</u>	
Invert of primary floodplain infrastructure (m AHD)	0.1
Approximate AASS elevation (m AHD)	0.4
Approximate PASS elevation (m AHD)	0.3
Median blackwater elevation (m AHD)	0.6
Present day low water level (m AHD)	-0.1
Near future low water level (m AHD)	0
Far future low level (m AHD)	0.5
<u>Proximity to sensitive receivers</u>	
Oyster leases (km)	Within subcatchment
Saltmarsh (km)	Within subcatchment
Seagrass (km)	Within subcatchment
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
<u>Land use</u>	
Total floodplain area (ha)	1,088
Classified as conservation and minimal use (ha (%))	55 (5%)
Classified as grazing (ha (%))	862 (79%)
Classified as forestry (ha (%))	54 (5%)
Classified as horticulture (ha (%))	1 (0.1%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	47 (4%)
Classified as marsh/wetland (ha (%))	24 (2%)
Other (ha (%))	46 (4%)
<u>Land values</u>	
Estimated total primary production value ($/year)	$430,000
Average land value above 0.6 m AHD ($/ha)	$17,900
Average land value below 0.6 m AHD ($/ha)	No property data available

8.12.1 Site description

The Pampoolah subcatchment is located adjacent to the Manning Rivers South Channel, approximately 8 km from the Farquhar Inlet at Old Bar. As shown in Figure 8-48, there is only two privately owned floodgates in the north of the subcatchment, and the major artificial drainage network is also in the north. The topography of the Pampoolah subcatchment is above present day tidal levels (high tide approximately 0.6 m AHD), with the majority of the area above 1 m AHD (Figure 8-49).

Soil profiles in the Pampoolah subcatchment typically show minimum pH between 4.3 and 5. Investigations of the drainage network by Ruprecht et al. (2020b) showed that the majority of the drains were relatively shallow, with only localised areas with an invert below 0 m AHD.

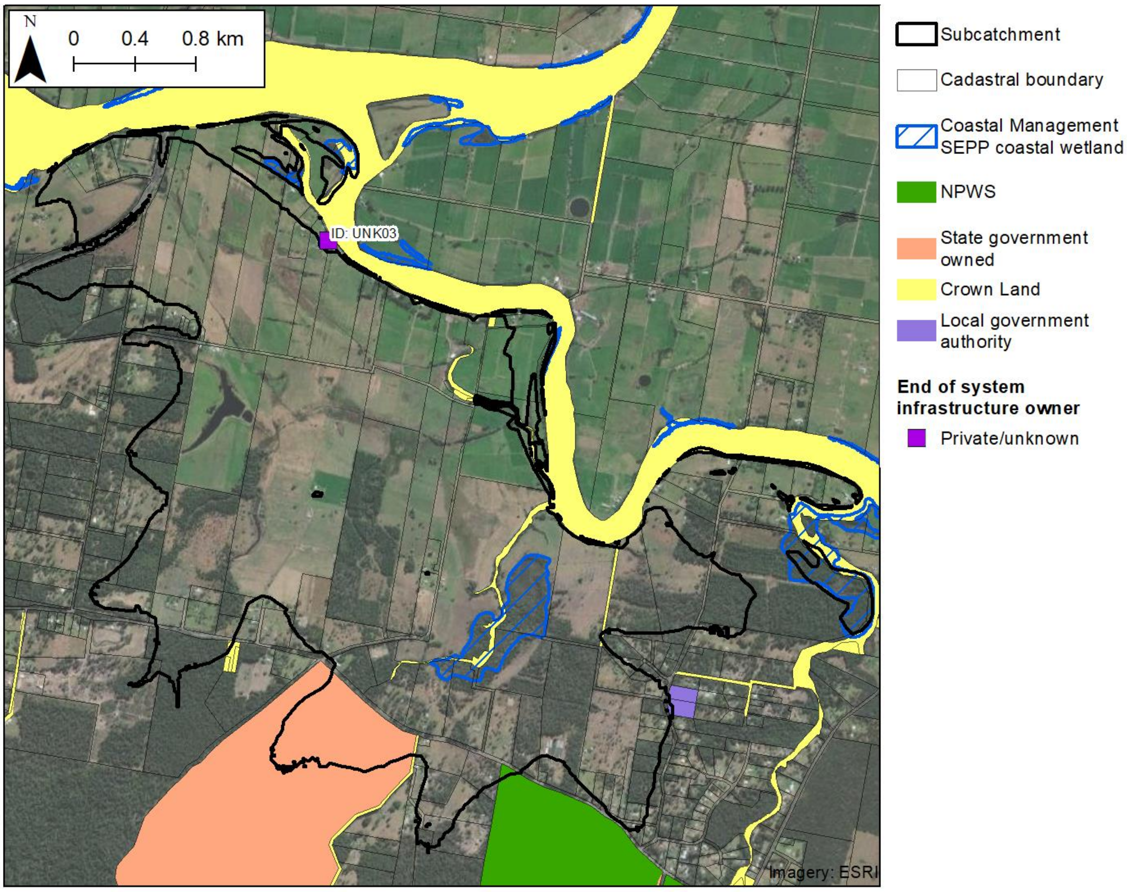

Figure 8-48: Pampoolah subcatchment - land and end of system infrastructure tenure

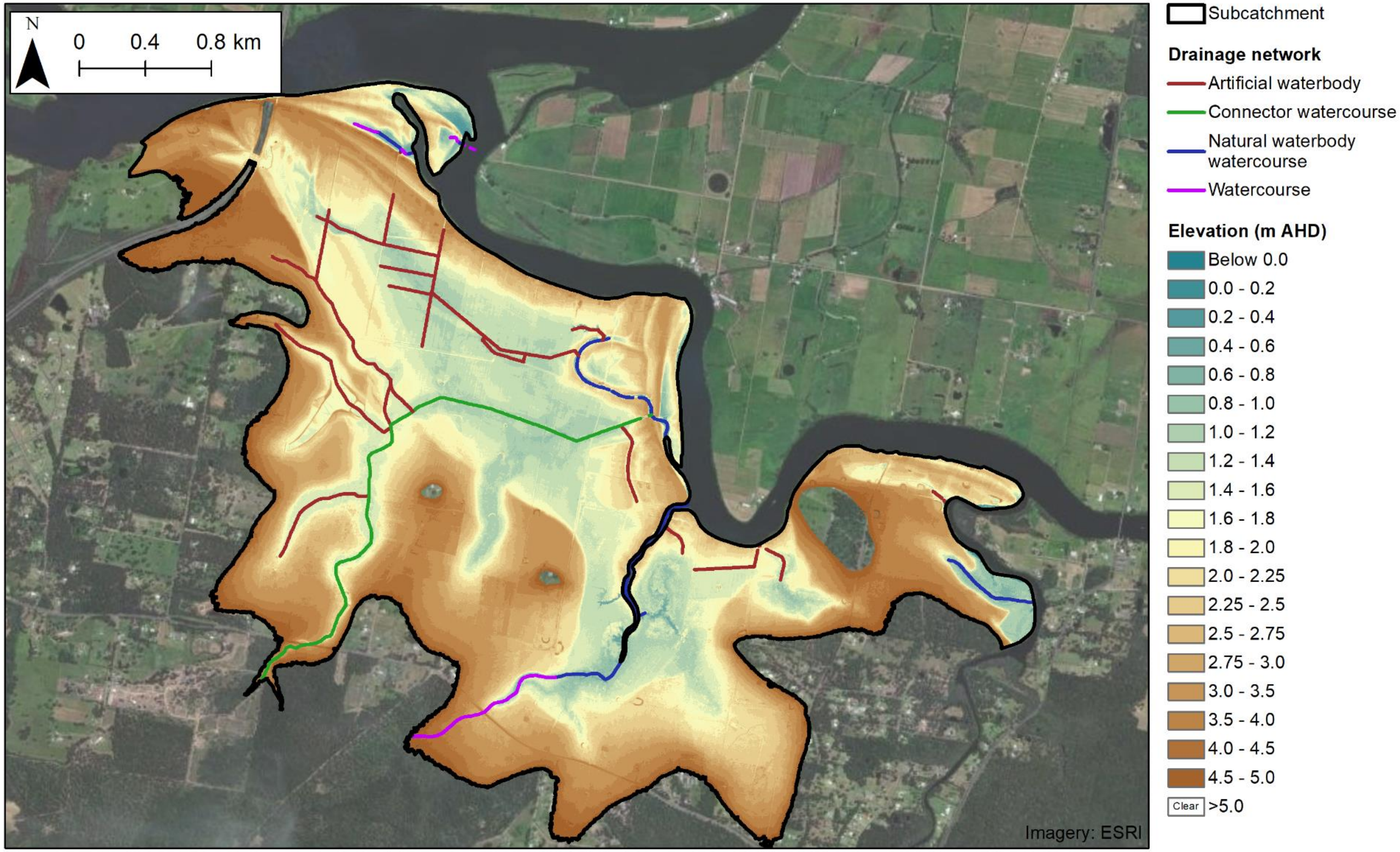

Figure 8-49: Pampoolah elevation and drainage network

8.12.2 History of remediation

In 2019/2020, WRL completed a study to provide strategies for on-ground remediation to address a combination of floodplain and riverbank erosion issues at Pampoolah (Ruprecht et al., 2020b). The recommendations on the floodplain were targeted at reducing the impact of ASS in the area, without impacting present day land uses. At this stage, no on-ground works have been completed as a result of these recommendations. The recommendations of this study have been incorporated in to the management options for the Pampoolah subcatchment in Section 8.12.4.

8.12.3 Floodplain drainage – sea level rise vulnerability

The sea level rise vulnerability of the Pampoolah subcatchment is shown in Figure 8-51. Due to the higher topography on the Pampoolah subcatchment, it is unlikely to be seriously impacted by reduced drainage as a result of sea level rise in the near future. However, as sea levels continue to rise, the lowest sections of the subcatchment are projected to be at risk of reduced drainage under the far future sea level rise scenario. This may impact productivity of grazing in the lowest areas of the floodplain. The main floodgate (UNK03, shown in Figure 8-50) was classified as "Moderately vulnerable" under the far future sea level rise modelling.

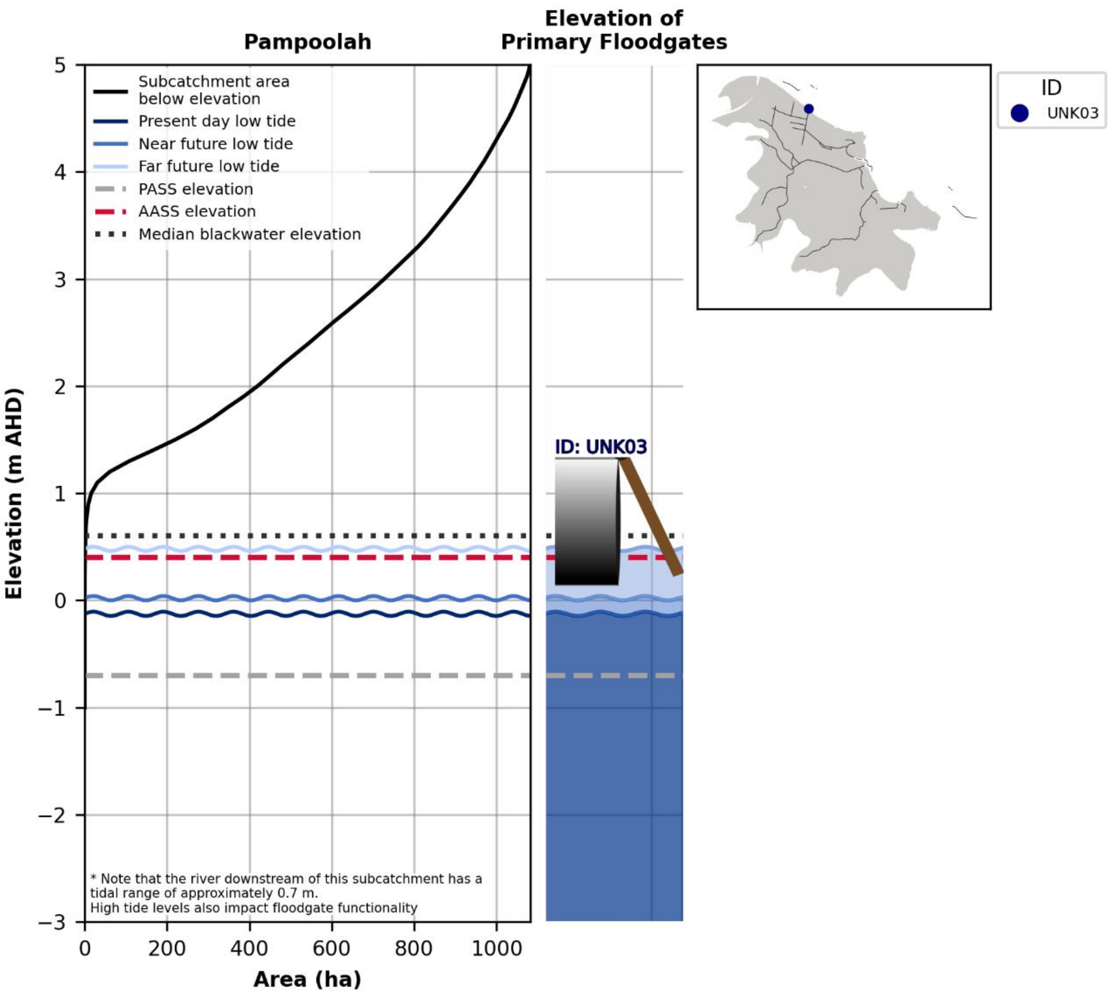

Figure 8-50: Key floodplain elevations – Pampoolah subcatchment

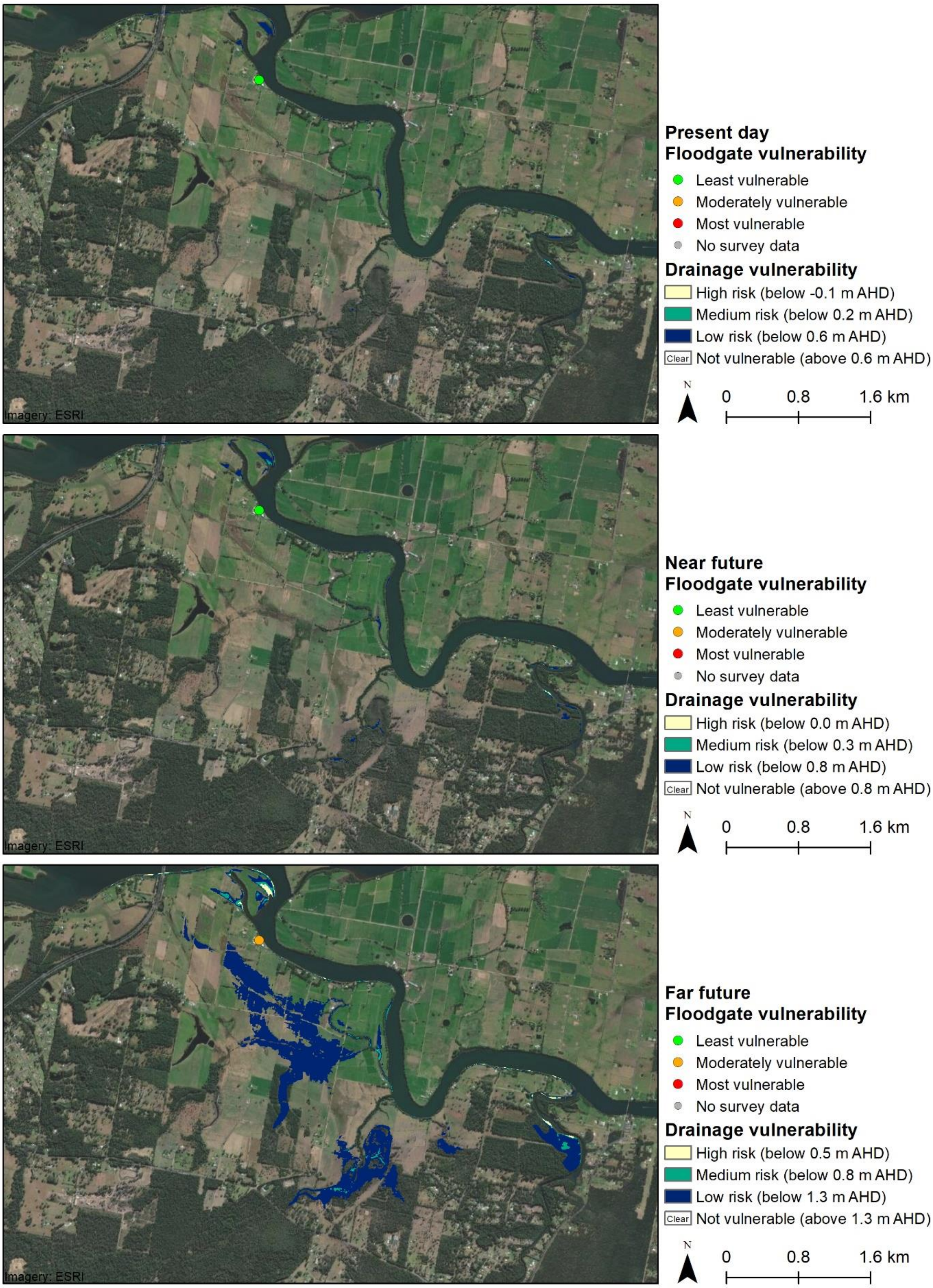

Figure 8-51: Sea level rise drainage vulnerability – Pampoolah subcatchment

8.12.4 Management options

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

- Short-term: Infilling and reshaping drains and partial infilling of dams as per Ruprecht et al. (2020b);
- Long-term: Where present day land uses are impacted by reduced drainage with sea level rise, consider conversion to estuarine wetlands through floodgate removal and tidal inundation.

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

Ruprecht et al. (2020b) completed detailed on-ground investigations on the Pampoolah floodplain and developed a series of recommendations to minimise acid drainage from the subcatchment while still maintaining existing land uses. The field investigations showed that the existing drainage network is generally relatively shallow and will not be exacerbating issues associated with ASS. The short-term recommendations from this study included:

- Partial infilling of a dam to reduce interaction with acidic layers;
- Maintenance of culverts to maintain surface water drainage;
- Protection of existing coastal saltmarsh, including in areas that are not currently mapped as Coastal Management SEPP coastal wetlands; and
- Consider reshaping drainage network to increase invert levels.

In the short term, the recommendations from Ruprecht et al. (2020b) should be reviewed and implemented on the Pampoolah floodplain to manage ASS discharges.

Long-term management options

Modification of existing land use practices is likely due to prolonged inundation and reduced drainage capacity due to sea level rise. Transition of affected low-lying areas to wet pasture or wetlands is to be expected. This will reduce both acid and blackwater discharges originating from this subcatchment, although changes in land use practises will require consideration on the social and economic impact on local landholders.

Indicative costs and qualitative benefits associated with the management options in the Pampoolah subcatchment is provided in Table 8-12.

Table 8-12: Summary of management options for Pampoolah

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	Reshaping/infilling drains	None	$260,000	None	None	None	Moderate	Low
Long-term	Localised wetland remediation	$1,500,000	$240,000	Minimal	$40,000	High	High	High

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

8.13 Croakers Creek subcatchment

Acid priority rank:	**11**
Blackwater priority rank:	**8**
Infrastructure	
Approximate waterway length (km)	25
# Privately owned end of system structures	3
# Publicly owned end of system structures	0
# End of system structures within coastal wetlands	1
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (ID)	MANN043, MANN044
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-0.4 to 0.1
Approximate AASS elevation (m AHD)	0.5
Approximate PASS elevation (m AHD)	-0.1
Median blackwater elevation (m AHD)	0.5
Present day low water level (m AHD)	-0.1
Near future low water level (m AHD)	0
Far future low level (m AHD)	0.5
Proximity to sensitive receivers	
Oyster leases (km)	Within subcatchment
Saltmarsh (km)	Within subcatchment
Seagrass (km)	Within subcatchment
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	1,240
Classified as conservation and minimal use (ha (%))	1 (0%)
Classified as grazing (ha (%))	1204 (97%)
Classified as forestry (ha (%))	0 (0%)
Classified as horticulture (ha (%))	1 (0%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	8 (1%)
Classified as marsh/wetland (ha (%))	10 (1%)
Other (ha (%))	17 (1%)
Land values	
Estimated total primary production value ($/year)	$580,000
Average land value above 0.5 m AHD ($/ha)	$17,000
Average land value below 0.5 m AHD ($/ha)	No property data available

8.13.1 Site description

The Croakers Creek subcatchment, shown in Figure 8-52, is located on the southern side of Oxley Island between the Manning River South Arm and Scotts Creek. Almost all of the subcatchment area is actively used for grazing, including the lowest areas (elevation <1 m AHD) adjacent to the major drainage system (Figure 8-52).

While soil profiles in the Croakers Creek subcatchment indicate the presence of ASS (minimum pH observed is around 4), the subcatchment has less stored acidity than the adjacent subcatchment on Oxley Island (Bukkan Bukkan Creek).

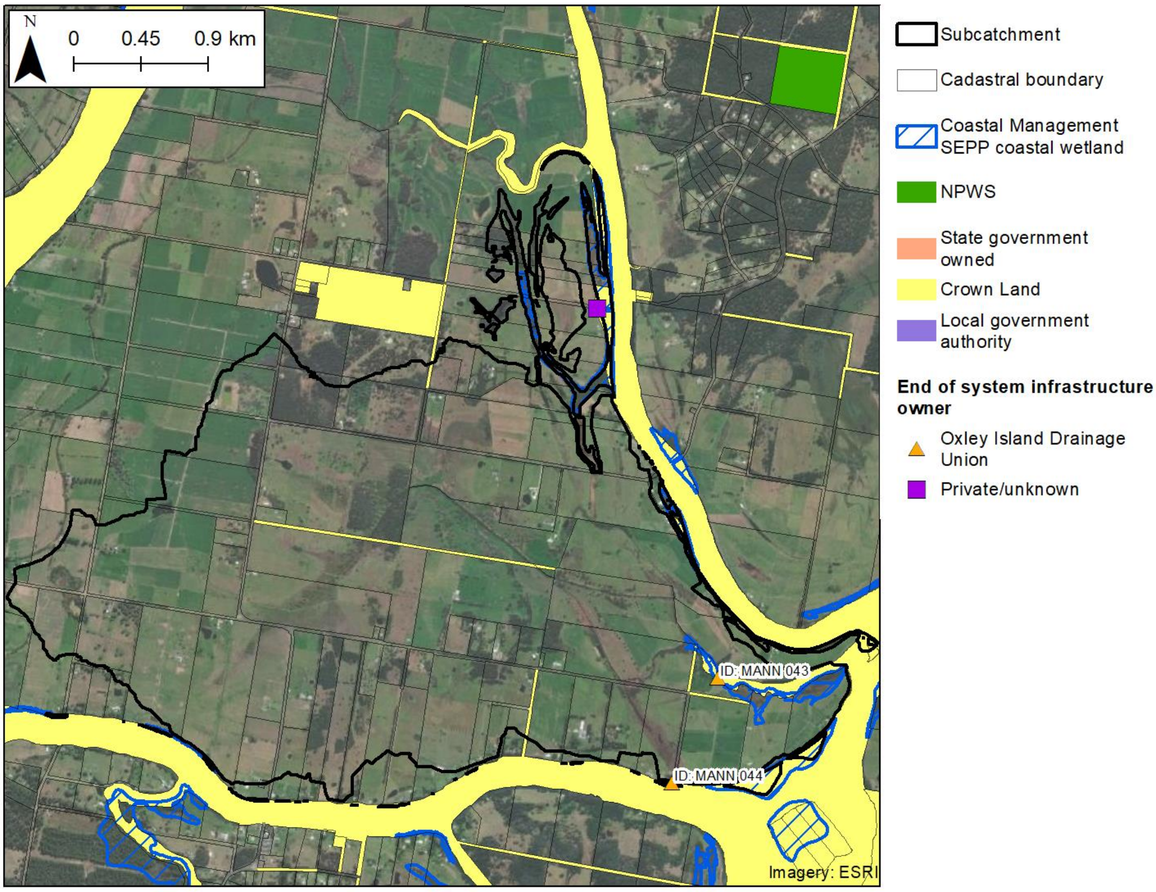

Figure 8-52: Croakers Creek subcatchment - land and end of system infrastructure tenure

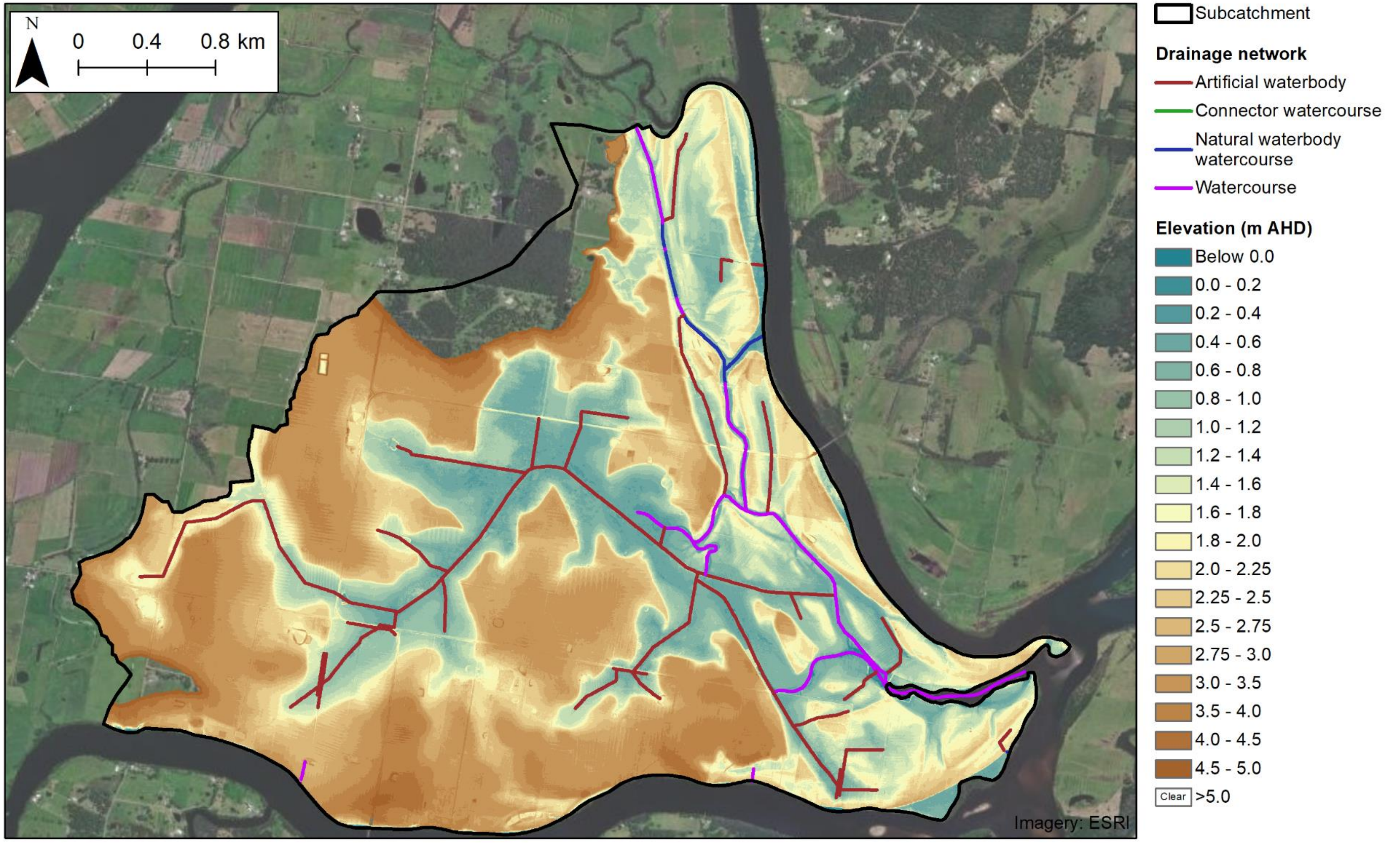

Figure 8-53: Croakers Creek subcatchment elevation and drainage network

8.13.2 History of remediation

A timeline of known remediation works within the Croakers Creek (South Oxley Island) subcatchment is provided below with reference to Figure 8-54. Previous remediation works include:

- February 2008 – An ASS Drainage Management Plan was prepared by MidCoast Council for remedial works on a portion of the Neal property on South Oxley Island. Funding of $10,000 was provided by MidCoast Council in partnership with the Hunter-Central Rivers Catchment Management Authority (Project Id: HCR 05-1/136). The project focused on improving surface water drainage across two (2) separate portions of the property (approximately 40 ha in total) to "*reduce potential for interception of acidic groundwater, while exporting fresh surface water as soon as possible to minimise potential formation of blackwater*" (Greater Taree City Council, 2008c). The on-ground works included reshaping shallow (<200 mm deep) surface paddock drains at 20 m intervals and treatment of surface soil with lime.

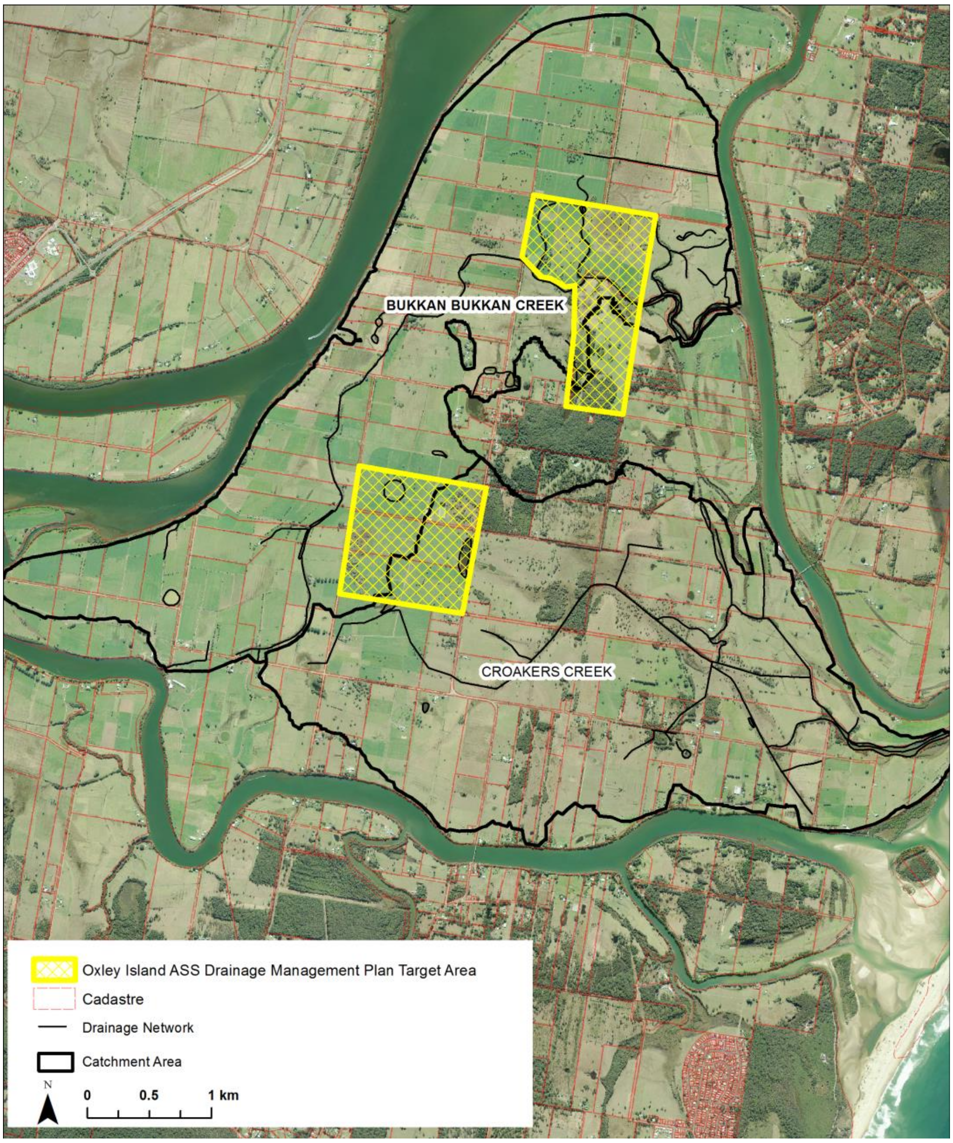

Figure 8-54: Previous ASS Management Target Areas on Oxley Island

8.13.3 Floodplain drainage – sea level rise vulnerability

The floodplain vulnerability to sea level rise for the Croakers Creek subcatchment is shown in Figure 8-56. The low areas along the banks of Croakers Creek are likely to be increasingly impacted by reduced drainage as a result of sea level rise in the near to far future.

Of the two (2) primary floodgates in the subcatchment (shown in Figure 8-55), MANN043 is considerably lower, and was classified as 'moderately vulnerable' under the far future sea level rise scenario. The second primary floodgate (MANN044) was not considered vulnerable under any of the sea level rise modelling.

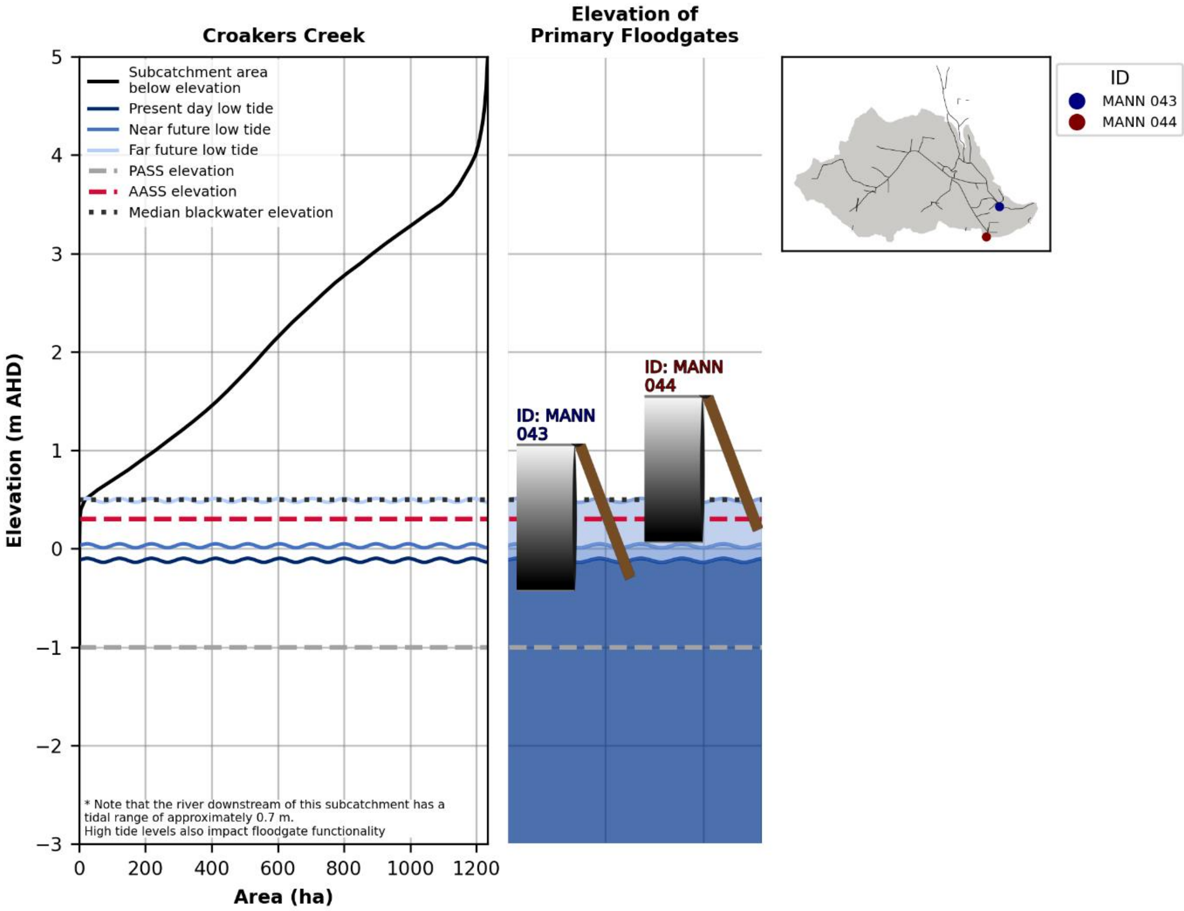

Figure 8-55: Key floodplain elevations – Croakers Creek subcatchment

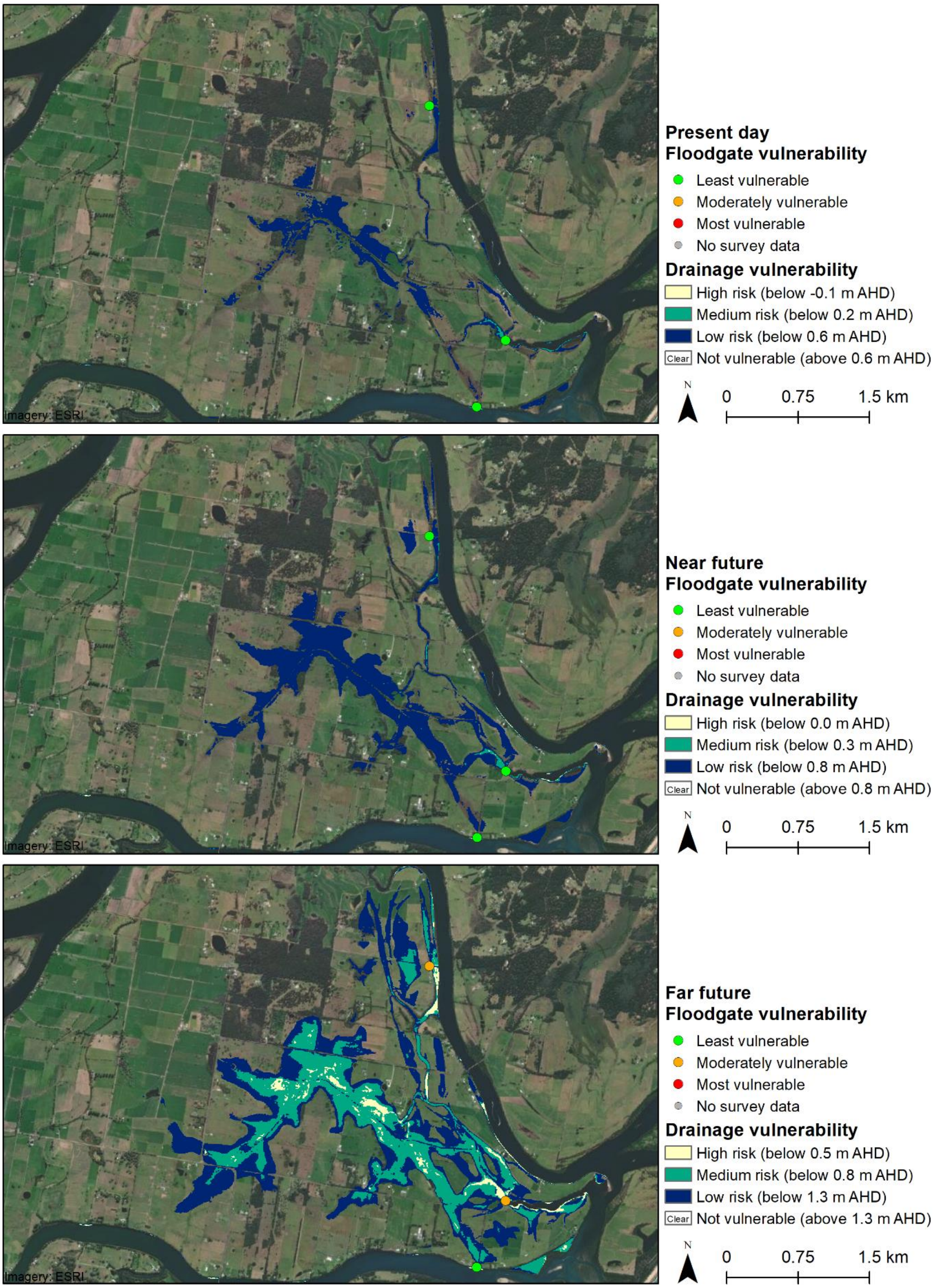

Figure 8-56: Sea level rise drainage vulnerability – Croakers Creek subcatchment

8.13.4 Management options

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

- Immediate: Wet pasture management and groundwater manipulation, and floodgate management; and
- Long-term: Where reduced drainage impacts current land uses, investigate the opportunistic rehabilitation 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

Existing data suggests that soil acidity is lower on the southern portion of Oxley Island in the Croakers Creek subcatchment when compared to Bukkan Bukkan Creek to the north. The hydraulic conductivity across Oxley Island is highly variable and testing by Glamore et al. (2016a) may not be representative of the hydraulic conductivity of the remainder of the Croakers Creek floodplain. As such, further assessment of ASS is required if any significant works are proposed that may disturb acid soil layers on the floodplain.

The most effective land management for this subcatchment would involve floodgate management to restore fish passage, infilling/reshaping drains, as well as groundwater manipulation. Wet pasture management is also encouraged to reduce blackwater generation from this subcatchment.

Long-term management options

Low-lying areas of the Croakers Creek floodplain are at a higher risk of being impacted by future sea level rise projections. Increases in low tide elevations in the near to far future may result in prolonged periods of inundation. This may result in a change to land management practices, which will require extensive consultation of local landholders and consideration of the social and economic impacts of such changes. Without extensive on-ground works, this site is likely to revert to a wetland (saline or otherwise) or wet pasture system, which would result in reductions in both acid and blackwater generation from the Croakers Creek subcatchment.

Indicative costs and qualitative benefits associated with the management options in the Croakers Creek subcatchment is provided in Table 8-13.

Table 8-13: Summary of management options for Croakers 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	Floodgate management	None	$35,000	$5,000	None	Moderate	Moderate	Minimal
Short-term	Groundwater manipulation	None	$35,000	$5,000	None	None	Moderate	Moderate
Long-term	Localised remediation of wetlands	$ 2,700,000	$340,000	Minimal	$ 75,000	High	High	High

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

8.14 Mambo Island subcatchment

Acid priority rank:	**12**
Blackwater priority rank:	**12**
<u>Infrastructure</u>	
Approximate waterway length (km)	14
# Privately owned end of system structures	6
# 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)	MANN049, WRL_MAN_02
<u>Elevations</u>	
Invert of primary floodplain infrastructure (m AHD)	-0.5 to 0.0
Approximate AASS elevation (m AHD)	0.4
Approximate PASS elevation (m AHD)	0
Median blackwater elevation (m AHD)	0.5
Present day low water level (m AHD)	-0.1
Near future low water level (m AHD)	0
Far future low level (m AHD)	0.5
<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)	334
Classified as conservation and minimal use (ha (%))	0 (0%)
Classified as grazing (ha (%))	295 (88%)
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 (%))	7 (2%)
Classified as marsh/wetland (ha (%))	20 (6%)
Other (ha (%))	12 (4%)
<u>Land values</u>	
Estimated total primary production value ($/year)	$140,000
Average land value above 0.5 m AHD ($/ha)	$16,400
Average land value below 0.5 m AHD ($/ha)	No property data available

8.14.1 Site description

Mambo Island is located downstream of Cattai Creek at the confluence of the Lansdowne River and the Manning River. The island is privately owned and managed, as shown in Figure 8-57 and predominantly used for grazing. The topography, shown in Figure 8-58 is very flat and low, with the majority of the subcatchment below 1.5 m AHD. A number of sensitive receivers exist within the subcatchment, or immediately downstream, including Coastal Management SEPP coastal wetlands, saltmarsh, mangroves and oyster leases.

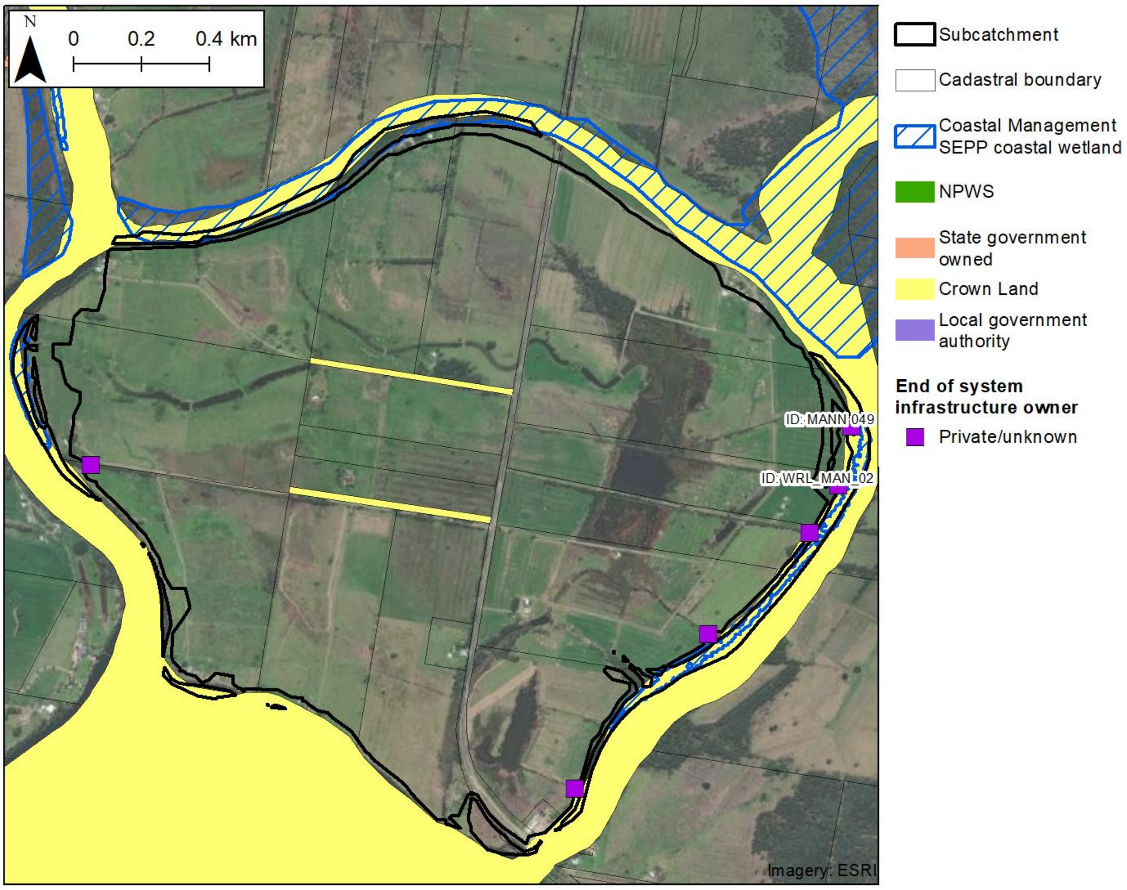

Figure 8-57: Mambo Island subcatchment - land and end of system infrastructure tenure

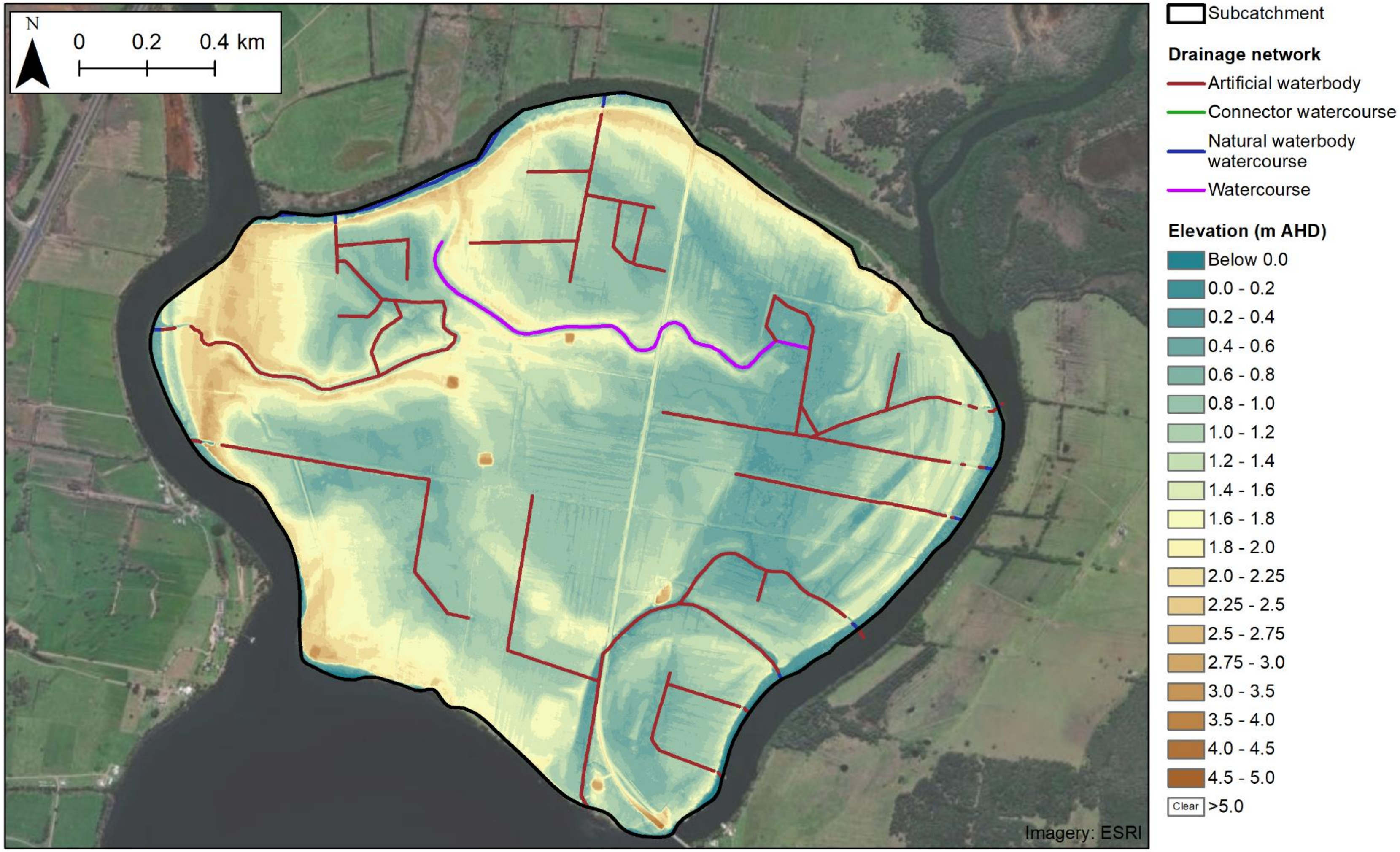

Figure 8-58: Mambo Island subcatchment elevation and drainage network

8.14.2 History of remediation

No known attempt at remediation.

8.14.3 Floodplain drainage – sea level rise vulnerability

Due to the low topography of the Mambo Island subcatchment, it may be particularly impacted by reduced drainage as a result of sea level rise, as shown in Figure 8-60. There are sections of the eastern side of the subcatchment that are already at risk of reduced drainage. However, under the far future sea level rise scenario, the majority of the Island is at risk of reduced drainage and a substantial area is classified as medium risk for reduced drainage. Of the two (2) primary floodgates (shown in Figure 8-59), MANN049 is classified as ‘moderately vulnerable’ under the far future sea level rise scenario. One secondary floodgate, MANN 052, is classified as ‘most vulnerable’ under the far future sea level rise scenario. This may result in prolonged inundation over some parts of the subcatchment, which may impact the viability of present day land uses.

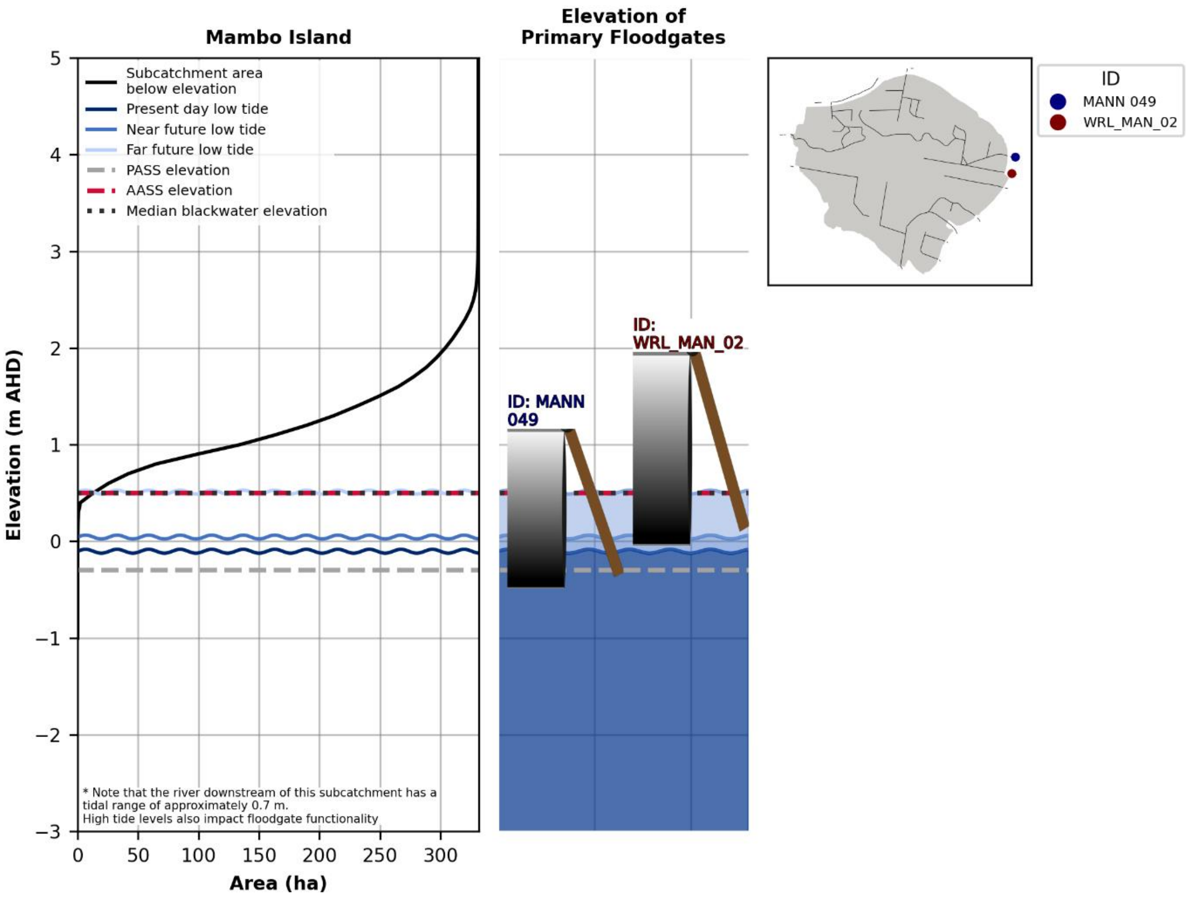

Figure 8-59: Key floodplain elevations – Mambo Island subcatchment

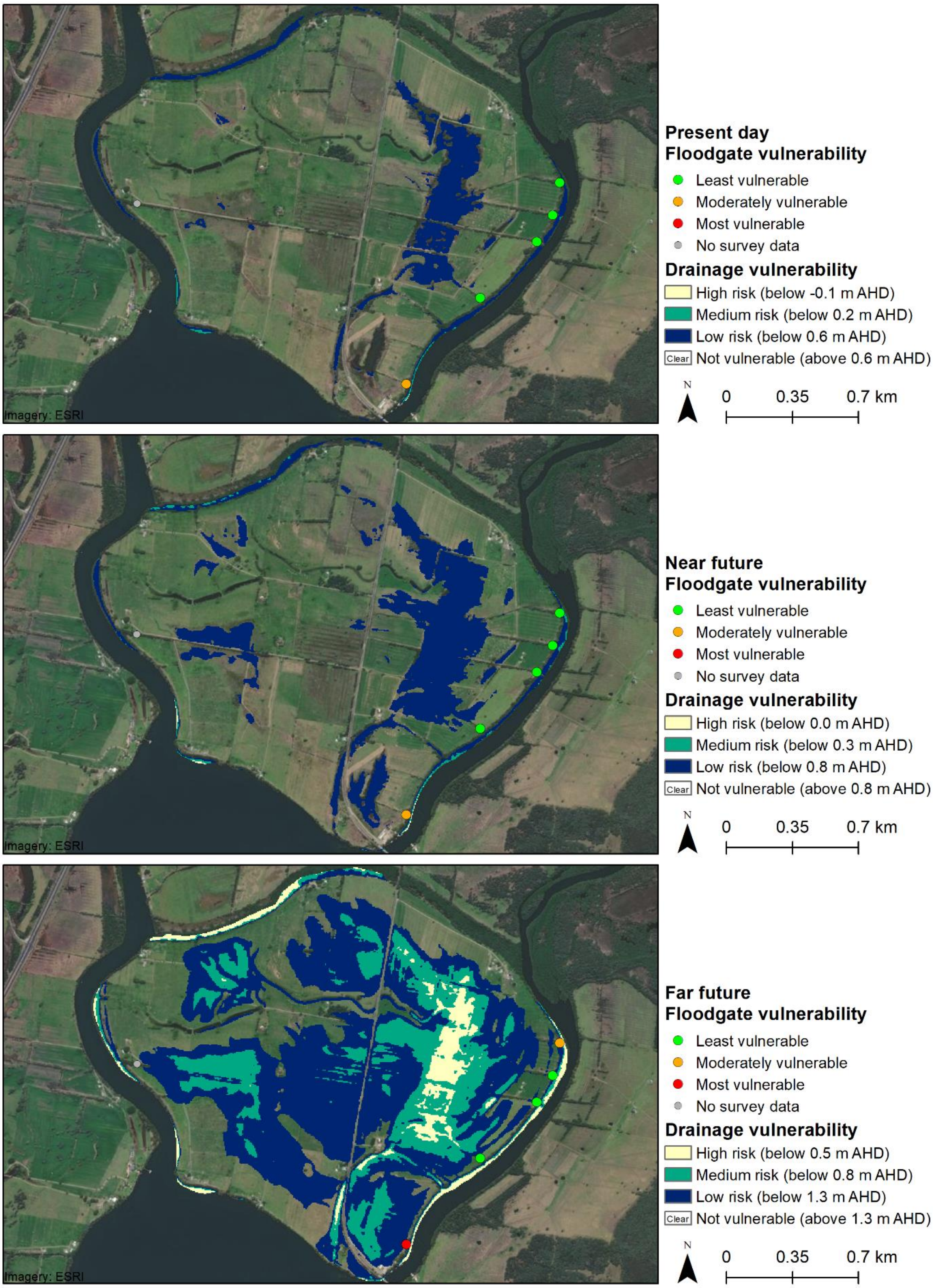

Figure 8-60: Sea level rise drainage vulnerability – Mambo Island subcatchment

8.14.4 Management options

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

- Short-term: Consider reshaping drains; and
- Long-term: Localised rehabilitation of wetlands in lowest areas through drain infilling and water retention.

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

While Mambo Island has one of the lower priority rankings for ASS-risk and blackwater, the island features some of the lowest-lying topography on the entire Manning River floodplain. The site also contains a substantial source of acid in areas that are deeply drained, with a minimum pH of 4 recorded in one (1) of the available soil profiles. For areas that are deeply drained below the AASS layer, it is recommended that unused drains are decommissioned, floodgates are removed or modified, and the drains are infilled/reshaped to create a shallow, wide swale drain. Low lying areas should also be managed by encouraging wet pasture (where applicable) to reduce the risk of blackwater generation and minimise further acidification.

Long-term management options

This area is likely to be increasingly affected by reduced drainage as sea levels continue to rise. Without additional infrastructure the agricultural productivity of Mambo Island is likely to become increasingly reduced and options for full remediation of poorly drained land to wet pastures (freshwater), or wetland (saline) should be investigated.

Indicative costs and qualitative benefits associated with the management options in the Mambo Island subcatchment is provided in Table 8-14.

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

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	Improve tidal flushing	None	$35,000	$5,000	None	Moderate	Moderate	Negligible
Long-term	Freshwater wetland remediation	$1,500,000	$100,000	Minimal	$80,000	None	High	High

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

8.15 Dawsons River subcatchment

Acid priority rank:	**13**
Blackwater priority rank:	**10**
<u>Infrastructure</u>	
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
<u>Elevations</u>	
Invert of primary floodplain infrastructure (m AHD)	N/A
Approximate AASS elevation (m AHD)	N/A
Approximate PASS elevation (m AHD)	0.8
Median blackwater elevation (m AHD)	0.7
Present day low water level (m AHD)	-0.1
Near future low water level (m AHD)	0
Far future low level (m AHD)	0.5
<u>Proximity to sensitive receivers</u>	
Oyster leases (km)	8.4
Saltmarsh (km)	0.8
Seagrass (km)	Within subcatchment
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
<u>Land use</u>	
Total floodplain area (ha)	703
Classified as conservation and minimal use (ha (%))	199 (28%)
Classified as grazing (ha (%))	161 (23%)
Classified as forestry (ha (%))	8 (1%)
Classified as horticulture (ha (%))	0 (0%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	173 (25%)
Classified as marsh/wetland (ha (%))	96 (14%)
Other (ha (%))	67 (9%)
<u>Land values</u>	
Estimated total primary production value ($/year)	$80,000
Average land value above 0.7 m AHD ($/ha)	$4,000
Average land value below 0.7 m AHD ($/ha)	No property data available

8.15.1 Site description

The Dawsons River subcatchment is immediately east of Taree, shown in Figure 8-61. Approximately one third of the subcatchment is classified as minimal use and conservation, while grazing occurs over another third of the catchment. No floodgates have been identified in the Dawsons River subcatchment.

Figure 8-62Figure 8-61 shows that there are some low (<1 m AHD) areas in the Dawsons River subcatchment, however the majority of these areas are mapped as Coastal Wetland and are not actively used or drained. Most of the grazing occurs in higher areas of the subcatchment and there is limited major artificial drainage.

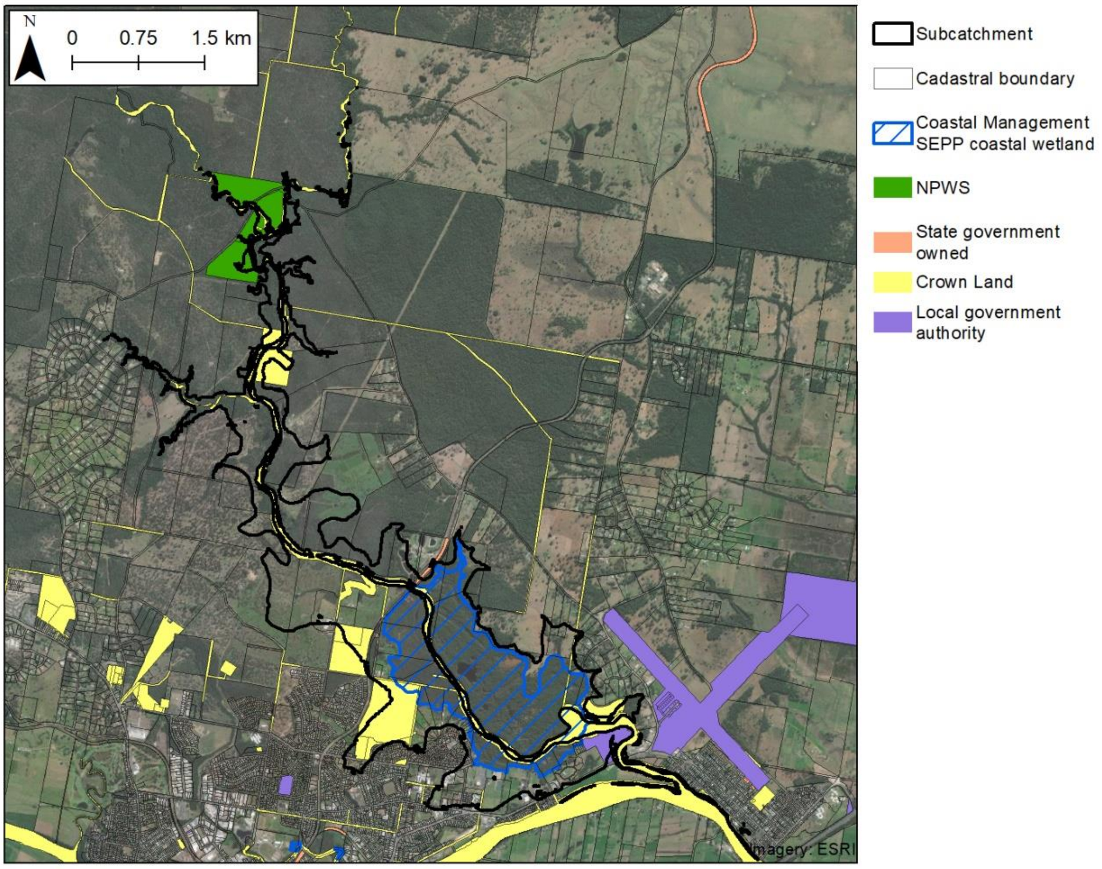

Figure 8-61: Dawsons River subcatchment - land and end of system infrastructure tenure

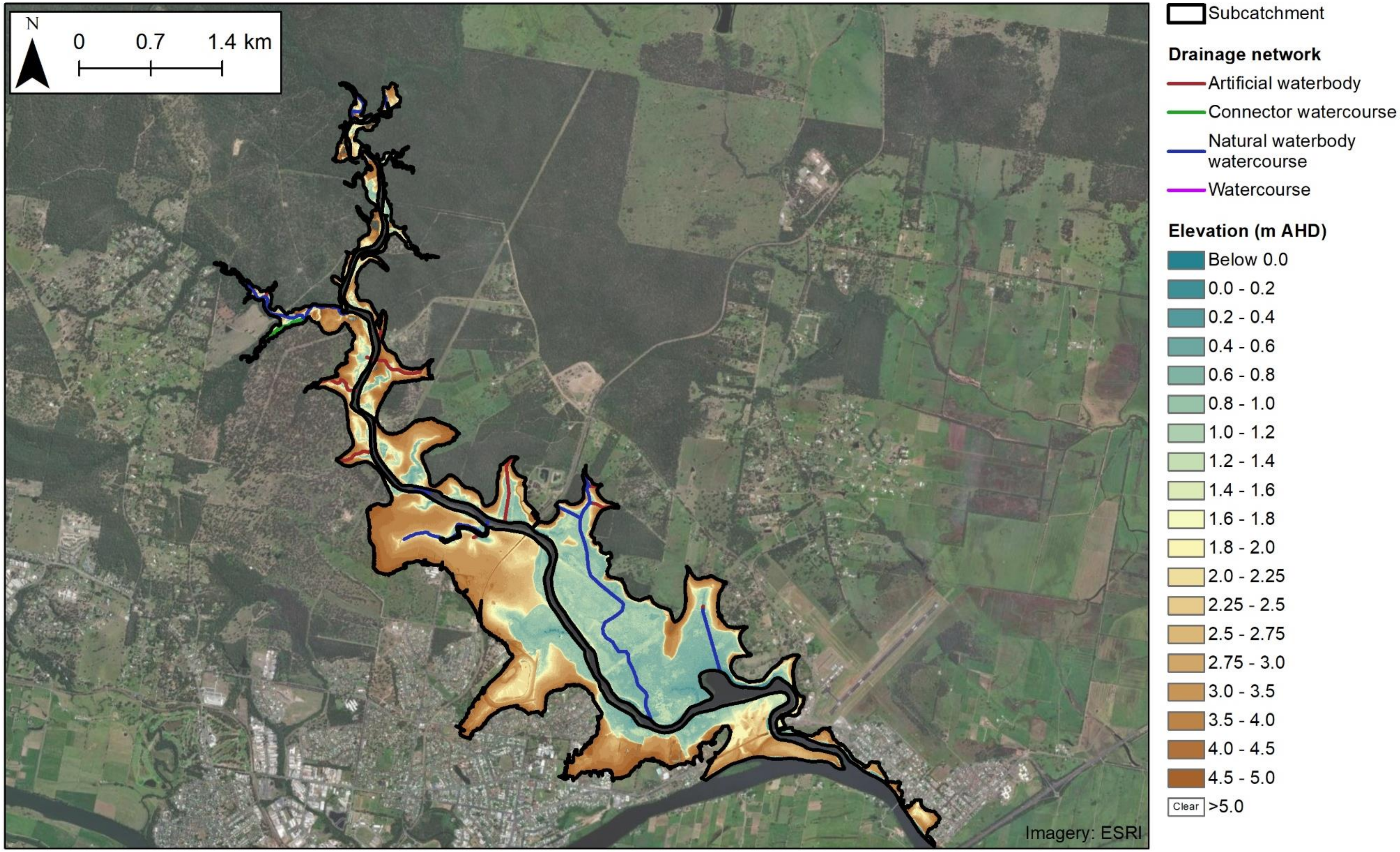

Figure 8-62: Dawsons River subcatchment elevation and drainage network

8.15.2 History of remediation

No known attempt at remediation.

8.15.3 Floodplain drainage – sea level rise vulnerability

Figure 8-63 summarises the floodplain vulnerability of the Dawsons River subcatchment. While there is a small area that is at risk of reduced drainage under the near and far future sea level rise scenarios, this area is already classified as wetland area. Due to the elevation of the actively used areas in this subcatchment, it is unlikely to be particularly impacted by reduced drainage as a result of sea level rise.

8.15.4 Management options

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

- Short-term: Due to low acid and blackwater generation potential, no short-term action is recommended; and
- Long-term: Continued protection and management of Coastal Management SEPP coastal wetlands.

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

Short-term management options
No short-term action recommended.

Long-term management options
Existing data does not indicate the presence of acid within the Dawson River subcatchment. A portion of the subcatchment known as ‘The Basin’, is low-lying, but remains in a natural, vegetated state, with limited artificial surface drainage. This area is mapped Coastal Management SEPP coastal wetlands. It is anticipated that low-lying portions of the site will be subjected to frequent inundation in the future due to climate change impacts. While no change in land management is recommended for the Dawson River subcatchment, these coastal wetlands should be protected and managed into the future.

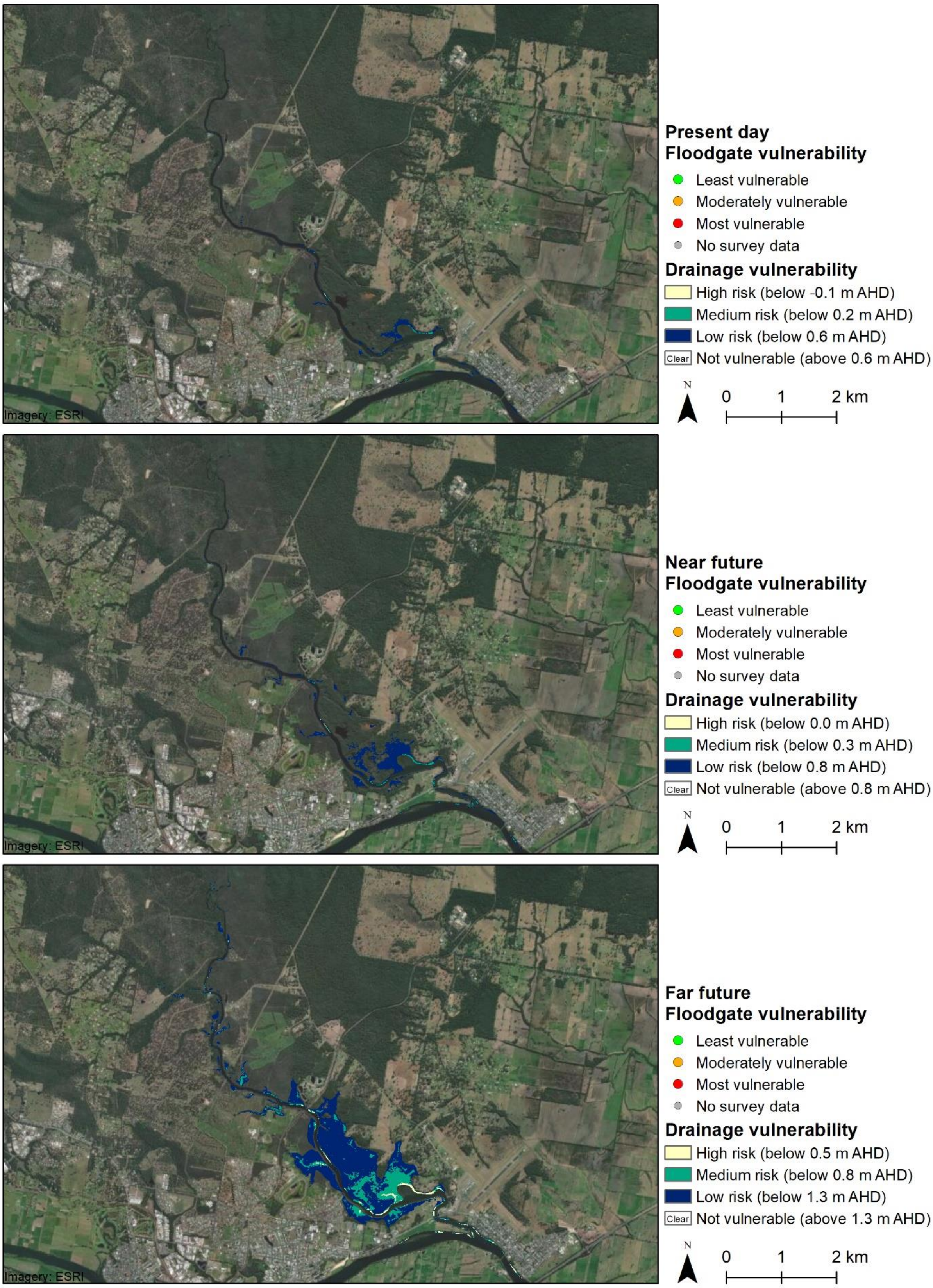

Figure 8-63: Sea level rise drainage vulnerability – Dawsons River subcatchment

8.16 Dumaresq Island subcatchment

Acid priority rank:	**14**
Blackwater priority rank:	**11**
Infrastructure	
Approximate waterway length (km)	18
# Privately owned end of system structures	5
# 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)	MANN066, MANN113
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-0.6 to -0.1
Approximate AASS elevation (m AHD)	-0.4
Approximate PASS elevation (m AHD)	N/A
Median blackwater elevation (m AHD)	0.7
Present day low water level (m AHD)	-0.1
Near future low water level (m AHD)	0
Far future low level (m AHD)	0.5
Proximity to sensitive receivers	
Oyster leases (km)	5.9
Saltmarsh (km)	0.5
Seagrass (km)	Within subcatchment
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	612
Classified as conservation and minimal use (ha (%))	0 (0%)
Classified as grazing (ha (%))	551 (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 (%))	22 (4%)
Classified as marsh/wetland (ha (%))	12 (2%)
Other (ha (%))	27 (4%)
Land values	
Estimated total primary production value ($/year)	$260,000
Average land value above 0.7 m AHD ($/ha)	$26,400
Average land value below 0.7 m AHD ($/ha)	No property data available

8.16.1 Site description

The Dumaresq Island subcatchment in located in the mid-upper Manning River estuary and is shown in Figure 8-64. Like most of the Manning River floodplain, the predominant land use is grazing, occurring over 90% of the subcatchment. Figure 8-65 shows that the island has low areas adjacent to major waterways with elevations around 1 m AHD.

Four (4) out of the five (5) profiles in the Dumaresq Island subcatchment have relatively little acidity, with all pH values at or above 5. However, one profile (P21) had a minimum pH of 4.1 observed at an elevation of approximately +0.1 m AHD, indicating localised pockets of acidity may exist throughout the island.

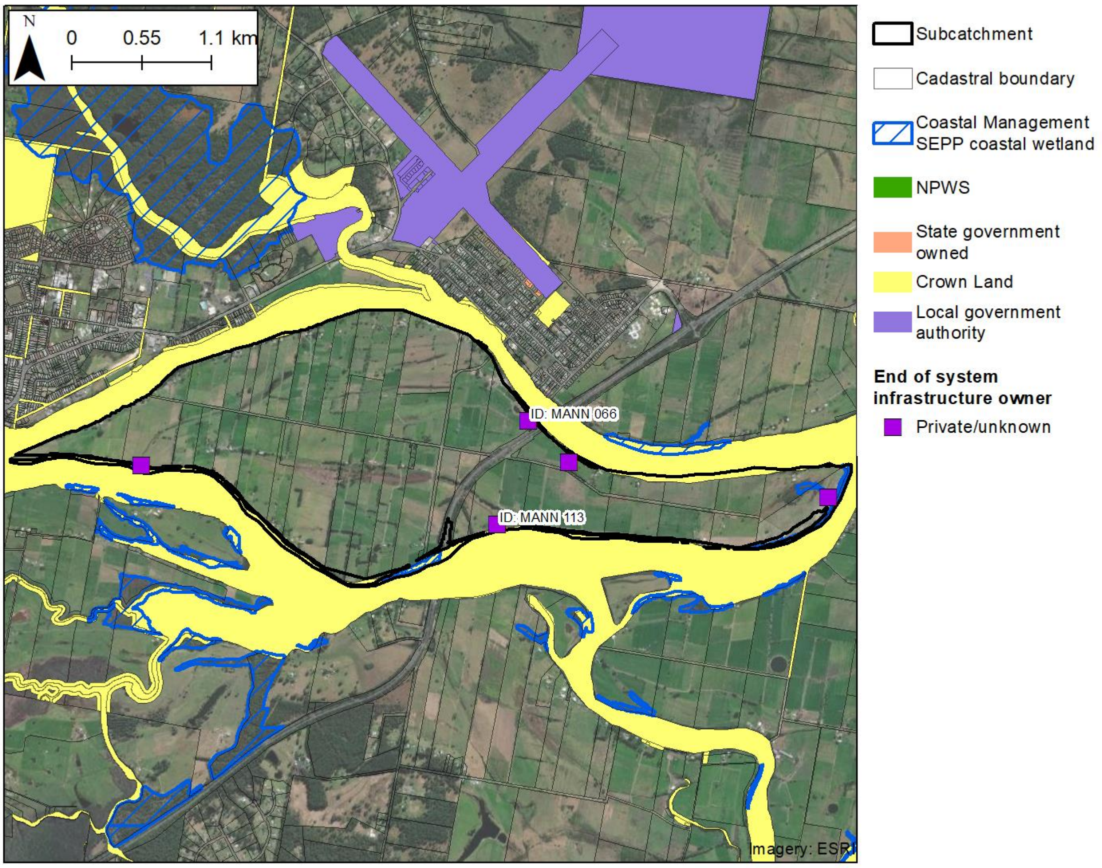

Figure 8-64: Dumaresq Island subcatchment - land and end of system infrastructure tenure

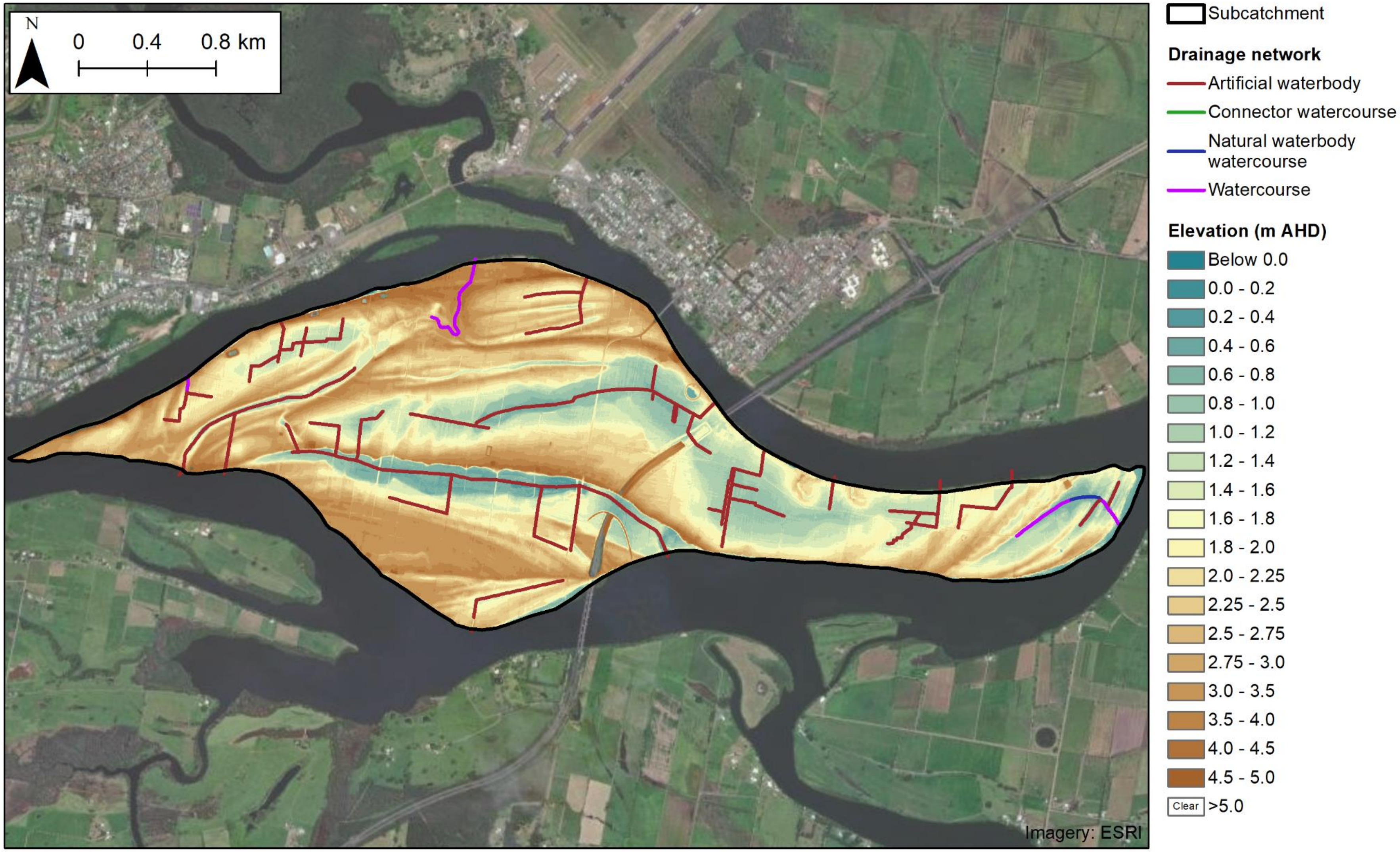

Figure 8-65: Dumaresq subcatchment elevation and drainage network

8.16.2 History of remediation

No known attempt at remediation to date.

8.16.3 Floodplain drainage – sea level rise vulnerability

The vulnerability of the Dumaresq Island to sea level rise is shown in Figure 8-67. Under present day conditions and the near future sea level rise scenario, there is limited area at risk of reduced drainage. However, under the far future sea level rise scenario, the low areas adjacent to main drainage lines are projected to be at risk of reduced drainage. Reduced drainage may impact present day land uses in the localised low area.

One (1) of the floodgates on this subcatchment is classified as 'moderately vulnerable' in present day conditions (primary floodgate MAN066). This same floodgate is classified as 'most vulnerable' under the far future sea level rise scenario. As shown in Figure 8-66, this floodgate will be below the far future low tide water level and will be unable to freely drain during most tides. Reduced drainage capacity of this floodgate may impact drainage of the upstream area.

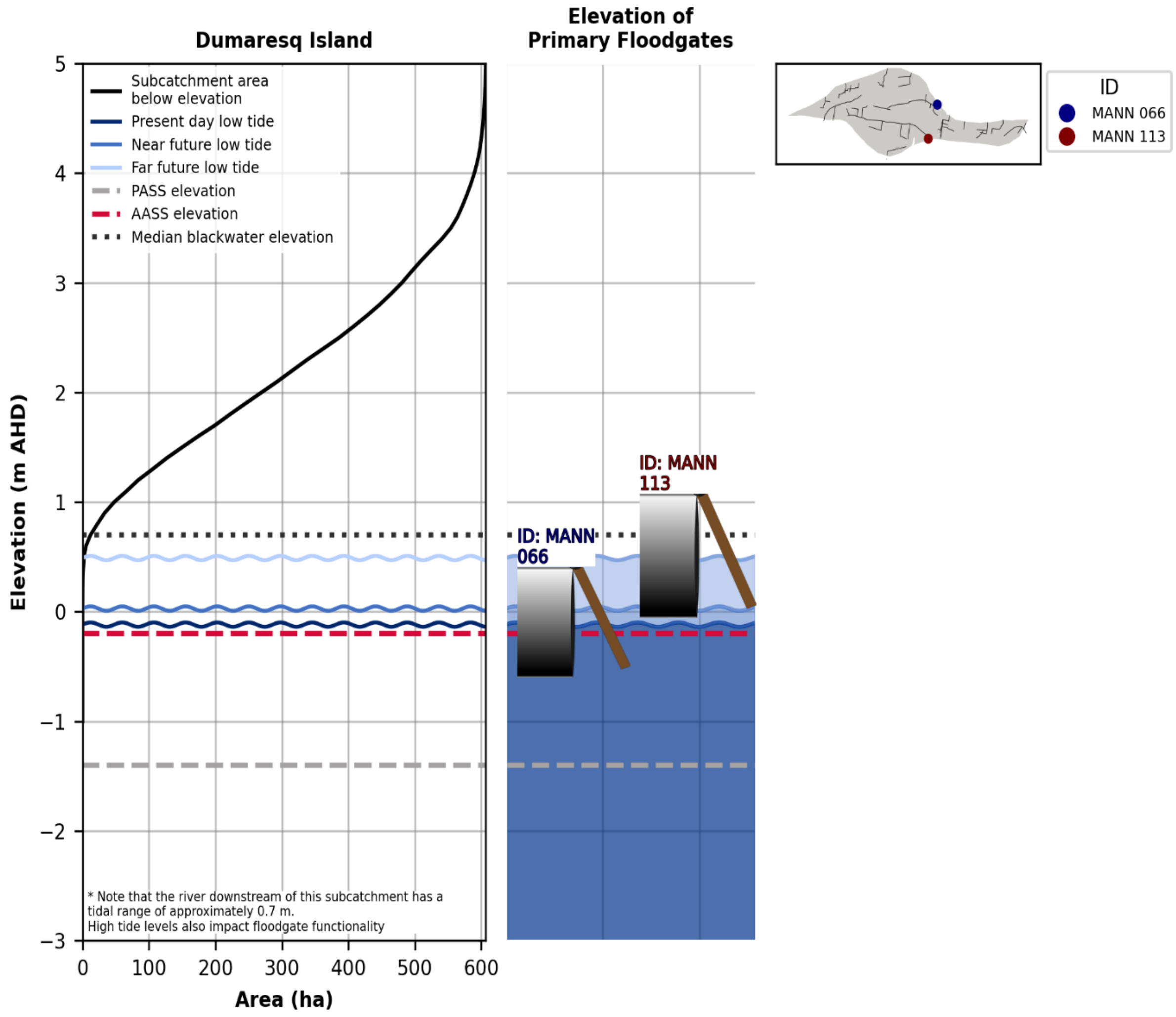

Figure 8-66: Key floodplain elevations - Dumaresq Island subcatchment

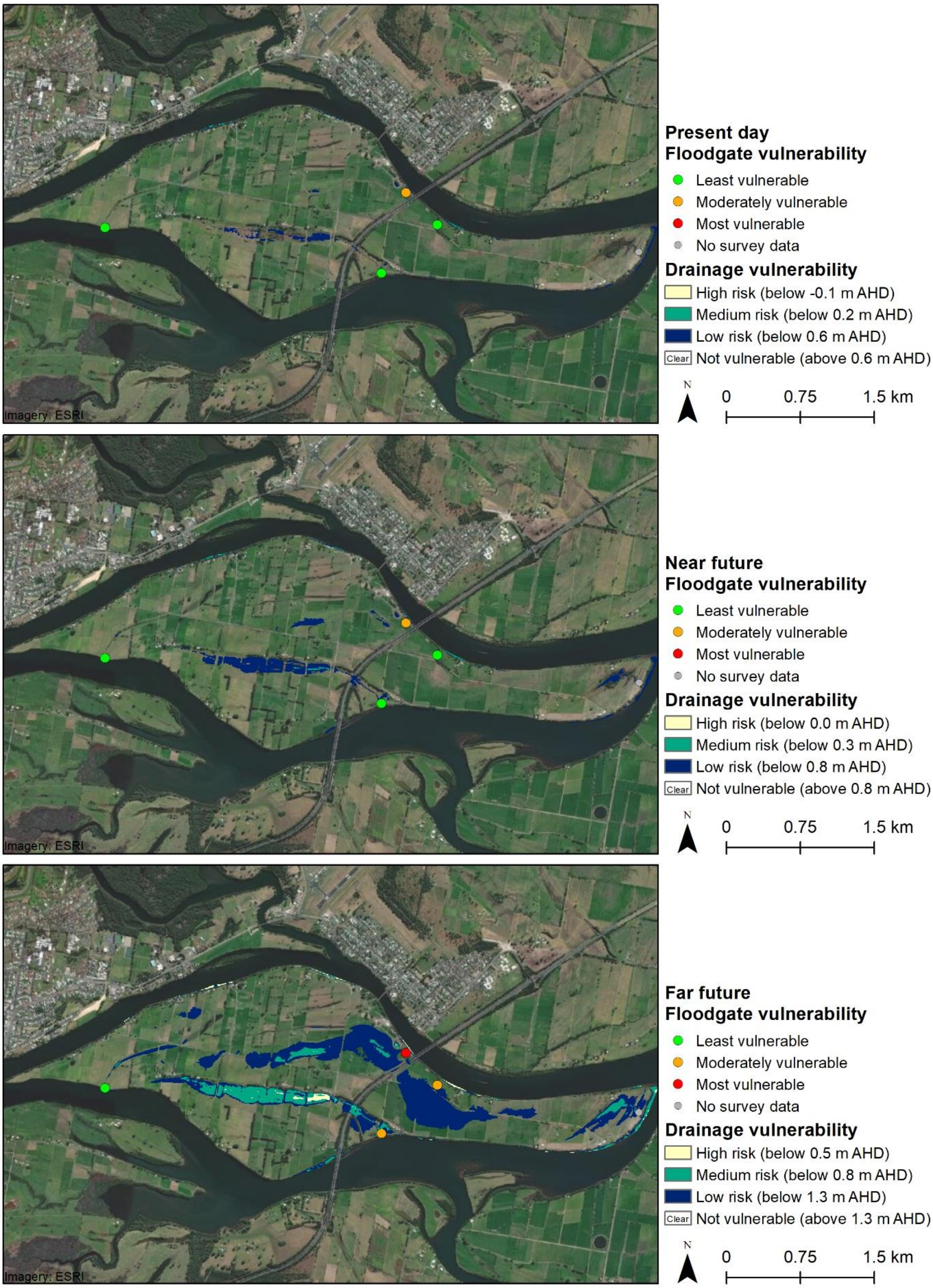

Figure 8-67: Sea level rise drainage vulnerability – Dumaresq Island subcatchment

8.16.4 Management options

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

- Short-term: Groundwater manipulation and wet pasture management; and
- Long-term: Localised remediation of wetlands through floodgate removal and drain infilling.

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

Review of existing field data did not indicate a significant source of acid across Dumaresq Island, and the island ranked relatively low for blackwater generation potential. However, since the subcatchment is mostly higher than 1 m AHD, groundwater manipulation and wet pasture management is encouraged to reduce the risk of over drainage and blackwater generation (where applicable). It is also recommended that unused drains across the floodplain are infilled or reshaped to raise local groundwater levels and prevent potential acid discharges. Drainage modification should be considered on an individual drain basis.

Long-term management options

Modification of existing land use practices is likely due to prolonged inundation and reduced drainage capacity due to sea level rise. Transition of affected low-lying areas to wet pasture or wetlands is to be expected.

Indicative costs and qualitative benefits associated with the management options in the Dumaresq Island subcatchment is provided in Table 8-15.

Table 8-15: Summary of management options for Dumaresq Island

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	Groundwater manipulation	None	$50,000	$5,000	None	None	Moderate	Moderate
Long-term	Localised wetland remediation	$870,000	$100,000	Minimal	$15,000	High	High	High

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

8.17 Taree Estate subcatchment

Acid priority rank:	**15**
Blackwater priority rank:	**14**
Infrastructure	
Approximate waterway length (km)	2
# Privately owned end of system structures	1
# 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)	N/A
Approximate PASS elevation (m AHD)	2.7
Median blackwater elevation (m AHD)	0.7
Present day low water level (m AHD)	-0.1
Near future low water level (m AHD)	0
Far future low level (m AHD)	0.5
Proximity to sensitive receivers	
Oyster leases (km)	17.0
Saltmarsh (km)	2.4
Seagrass (km)	Within subcatchment
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	207
Classified as conservation and minimal use (ha (%))	0 (0%)
Classified as grazing (ha (%))	149 (72%)
Classified as forestry (ha (%))	0 (0%)
Classified as horticulture (ha (%))	0 (0%)
Classified as other cropping (ha (%))	13 (6%)
Classified as urban/industrial/services (ha (%))	27 (13%)
Classified as marsh/wetland (ha (%))	8 (4%)
Other (ha (%))	11 (5%)
Land values	
Estimated total primary production value ($/year)	$110,000
Average land value above 0.7 m AHD ($/ha)	$26,200
Average land value below 0.7 m AHD ($/ha)	No property data available

8.17.1 Site description

The Taree Estate subcatchment is the furthest upstream subcatchment considered in this study, and is also the smallest subcatchment, covering an area of 207 ha below 5 m AHD. As shown in Figure 8-68, the majority of the subcatchment is privately owned and used for grazing. Figure 8-69 shows that the area is relatively high, with minimal floodplain below 1 m AHD. Soil profile data in this subcatchment does not show any highly acidic layers (minimum pH above 5.5 in every profile).

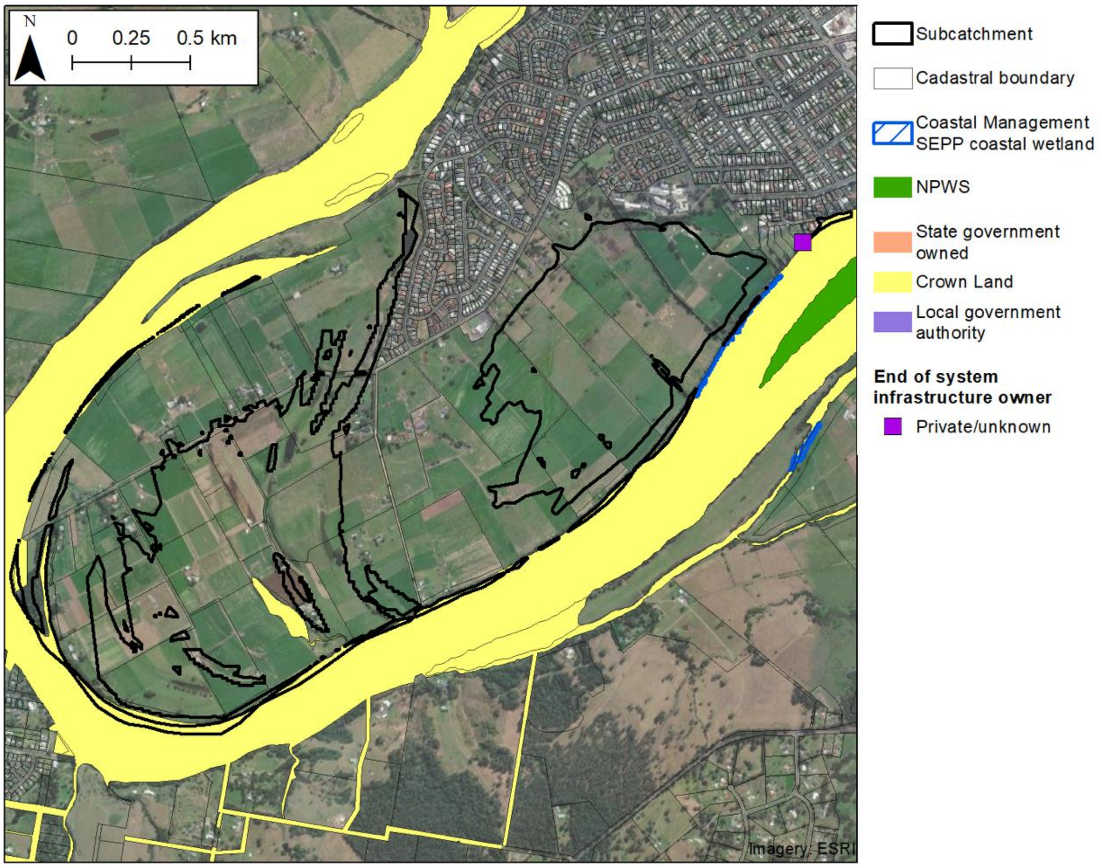

Figure 8-68: Taree Estate subcatchment - land and end of system infrastructure tenure

Figure 8-69: Taree Estate subcatchment elevation and drainage network

8.17.2 History of remediation

No known attempt at remediation to date.

8.17.3 Floodplain drainage – sea level rise vulnerability

Figure 8-70 summarises the sea level rise vulnerability of the Taree Estate subcatchment. The lowest areas in this subcatchment are already semi-permanent water bodies, which only dry in periods of extended drought. The remainder of the area is relatively high and unlikely to be impacted by reduced drainage as a result of sea level rise in the near to far future. Note that this assessment does not include the impact of increased flooding as a result of sea level rise, which may impact the Taree Estate subcatchment.

8.17.4 Management options

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

- Short-term: Reshaping deep drains where required; and
- Long-term: Localised remediation of brackish wetland through floodgate removal and drain infilling and providing incentives for landholders to improve the management of their properties.

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 Taree Estate floodplain is significantly impacted by flooding from the main river channel during times of high freshwater flows. Therefore, appropriate drainage is required to maintain existing land management practices. Due to the topographic features of the landscape, constructed drains follow natural drainage lines. Deep constructed drains could be reshaped to form shallow, wide swale drains that reduce potential acid drainage, while maintaining the surface water removal capacity of existing drains. It is estimated that there are less than 1 km of drains to reshape. However, soil profile data indicates a low risk of acid export and further investigation and detailed design of any on-ground works is required.

Long-term management options
Ongoing adaptive management and maintenance of drainage infrastructure and inundation will be required as drainage is reduced and high tide elevations increase. Changes in land management practices may also be required due to variations in hydrology. Wet pasture management should be encouraged where applicable in low-lying, boggy land to reduce the risk of blackwater generation.

Indicative costs and qualitative benefits associated with the management options in the Taree Estate subcatchment is provided in Table 8-16.

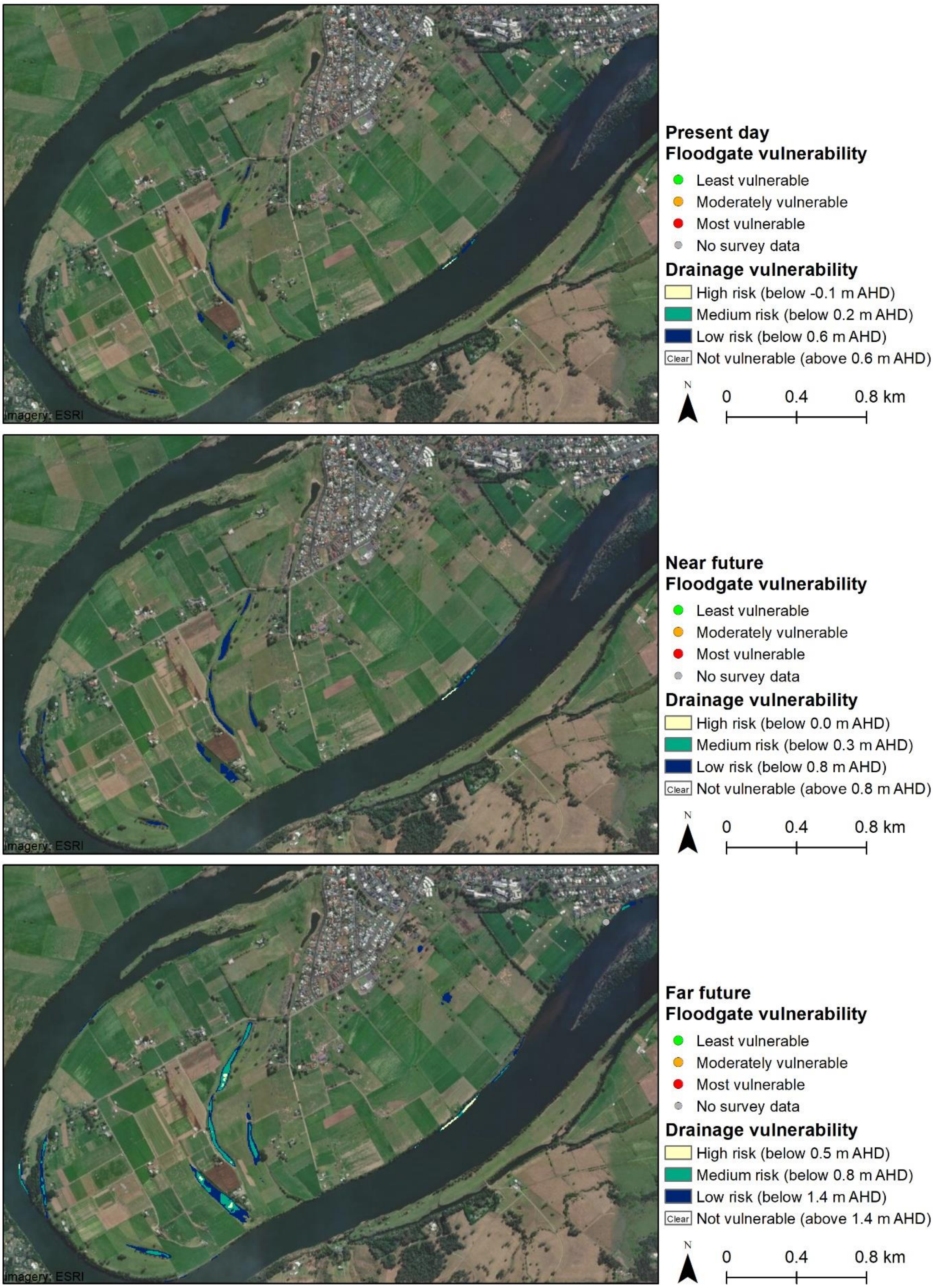

Figure 8-70: Sea level rise drainage vulnerability – Taree Estate subcatchment

Table 8-16: Summary of management options for Taree Estate

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	$30,000	None	None	None	Moderate	Low
Long-term	Wet pasture management	None	$50,000	$5,000	None	None	Moderate	Moderate

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

8.18 Old Bar subcatchment

Acid priority rank:	**N/A**
Blackwater priority rank:	**16**
Infrastructure	
Approximate waterway length (km)	7
# 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)	N/A
Approximate PASS elevation (m AHD)	N/A
Median blackwater elevation (m AHD)	0.5
Present day low water level (m AHD)	-0.1
Near future low water level (m AHD)	0
Far future low level (m AHD)	0.5
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)	514
Classified as conservation and minimal use (ha (%))	52 (10%)
Classified as grazing (ha (%))	334 (65%)
Classified as forestry (ha (%))	2 (0%)
Classified as horticulture (ha (%))	0 (0%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	45 (9%)
Classified as marsh/wetland (ha (%))	47 (9%)
Other (ha (%))	35 (7%)
Land values	
Estimated total primary production value ($/year)	$160,000
Average land value above 0.5 m AHD ($/ha)	$27,000
Average land value below 0.5 m AHD ($/ha)	No property data available

8.18.1 Site description

The Old Bar subcatchment is located adjacent to Farquhar Inlet in the lower Manning River South Channel and includes the area known as Cabbage Tree Island. As shown in Figure 8-71, no floodplain infrastructure has been identified in this subcatchment. The lowest areas are located adjacent to Oyster Creek in the south-east of the subcatchment, shown in Figure 8-72.

This subcatchment was not included in ASS prioritisation as there was insufficient soil profile data. While it is assumed to be a low risk for ASS based on topography and drainage, additional data should be collected to confirm the low risk classification.

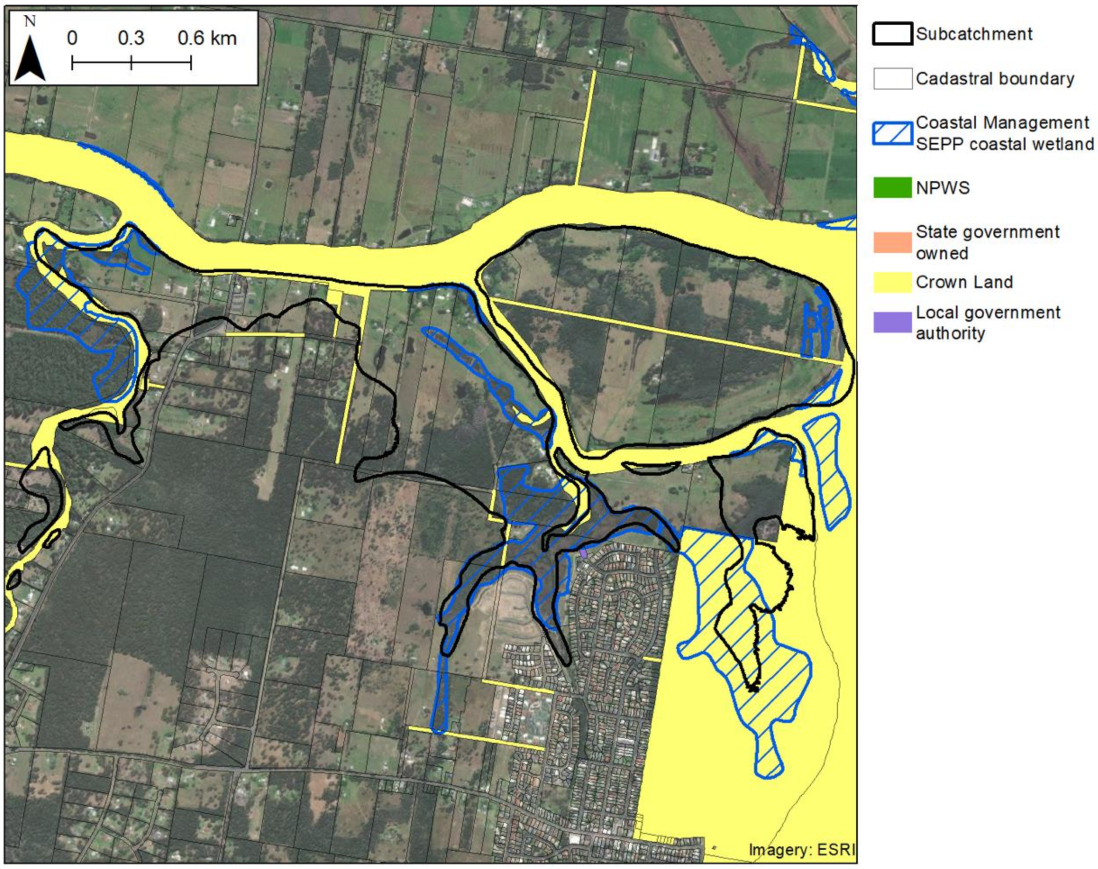

Figure 8-71: Old Bar subcatchment - land and end of system infrastructure tenure

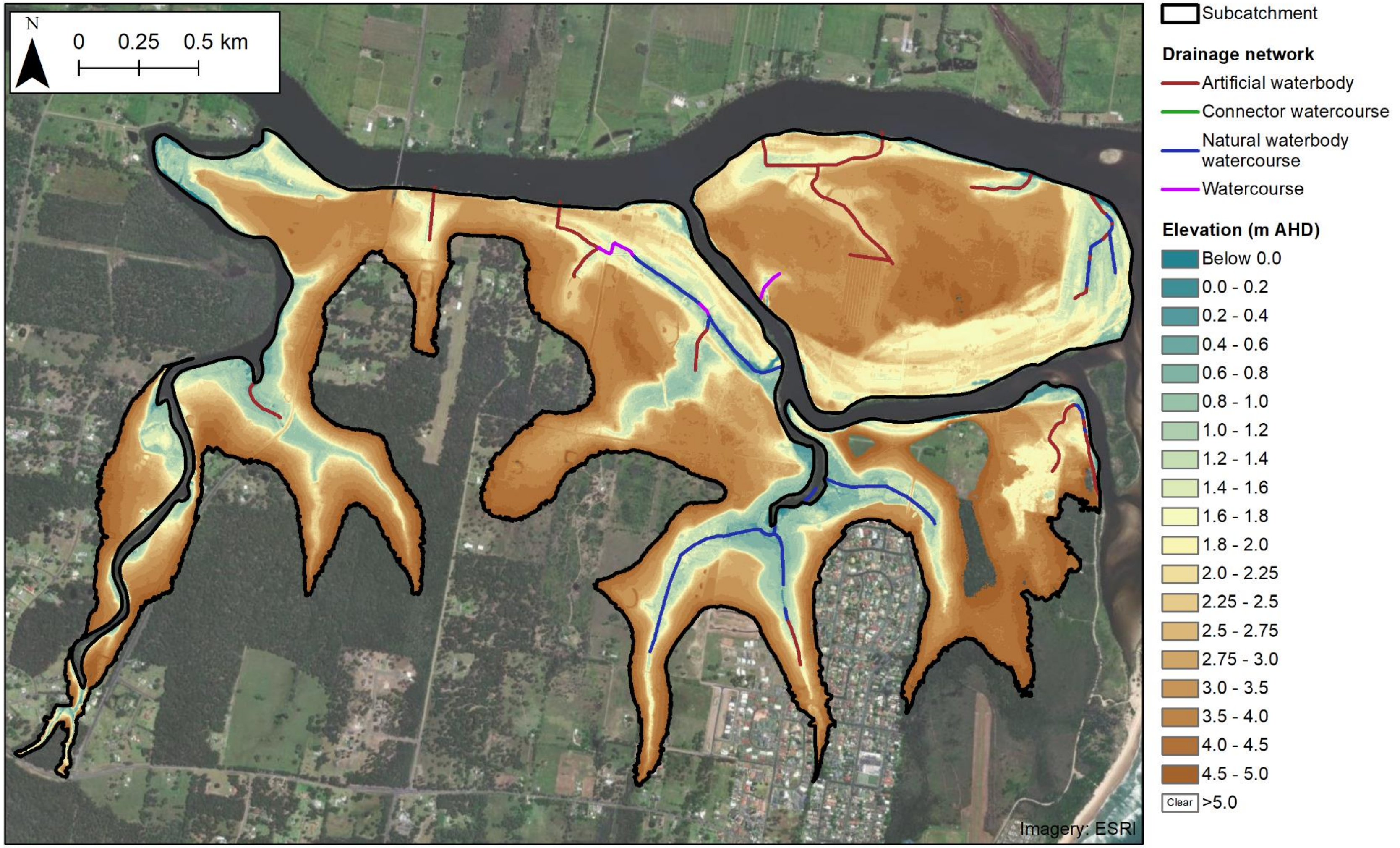

Figure 8-72: Old Bar subcatchment elevation and drainage network

8.18.2 History of remediation

No known attempt at remediation to date.

8.18.3 Floodplain drainage – sea level rise vulnerability

Figure 8-73 summarises the vulnerability of the Old Bar subcatchment to sea level rise. There are no floodgates in this subcatchment. However, the intertidal area along the creek lines may increase as tidal planes increase as a result of sea level rise. This may impact land uses in adjacent areas due to reduced drainage, increased inundation and increase salinity levels.

8.18.4 Management options

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

- Short-term: Due to low blackwater generation potential and assumed low acid generation, no short-term action is recommended; and
- Long-term: Continued protection and management 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
No short-term action recommended. Further investigations to confirm low risk acid sulfate soils is recommended.

Long-term management options
The low areas along the natural creek lines are the most susceptible to impacts of sea level rise. These areas are mapped as Coastal Management SEPP coastal wetlands. It is anticipated that low-lying portions of the site will be subjected to frequent inundation in the future due to sea level rise. While no changes in land management is recommended these coastal wetlands should be protected and managed into the future.

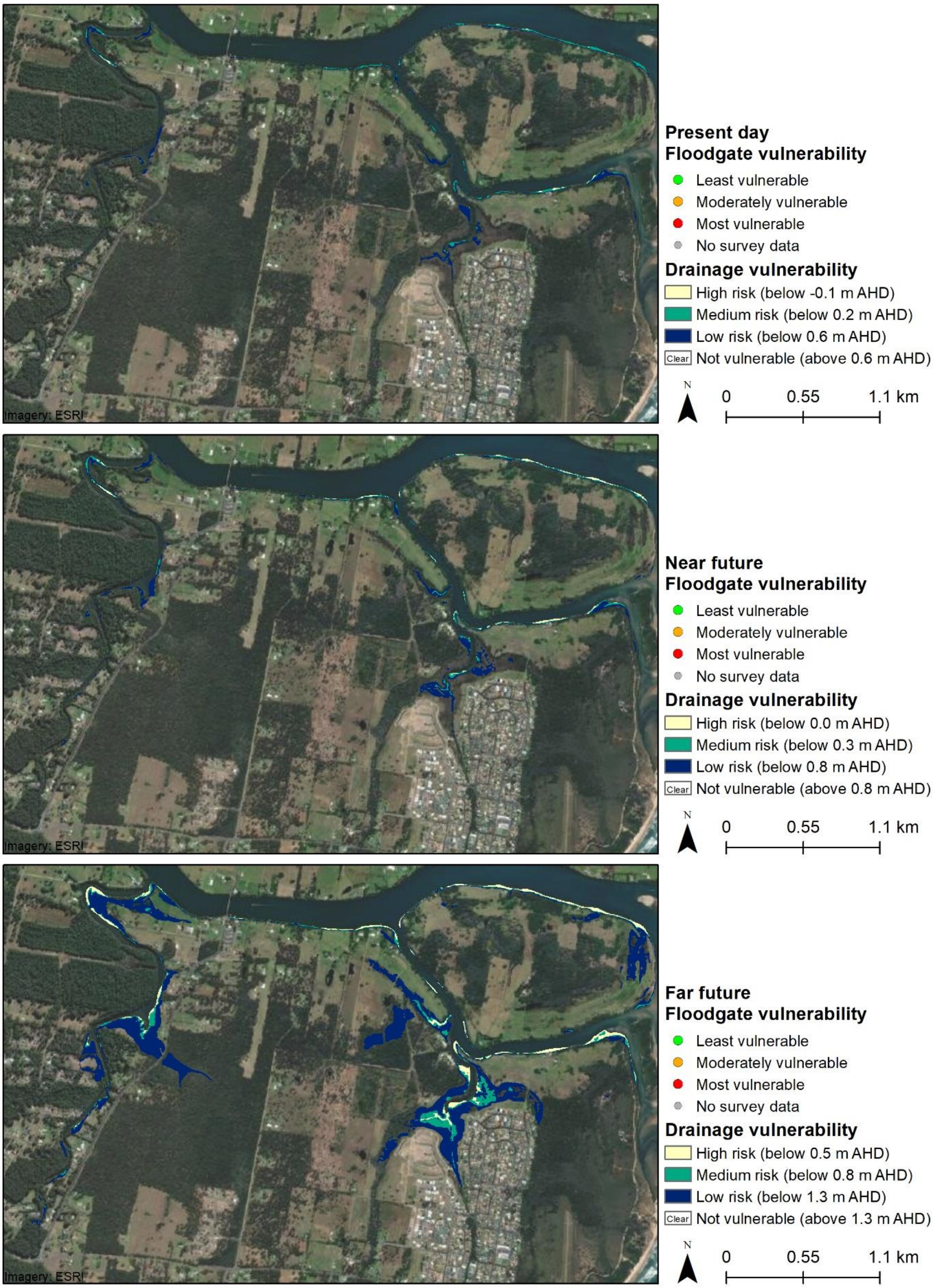

Figure 8-73: Sea level rise drainage vulnerability – Old Bar subcatchment

8.19 Harrington subcatchment

Acid priority rank:	**N/A**
Blackwater priority rank:	**17**
Infrastructure	
Approximate waterway length (km)	6
# 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)	N/A
Approximate PASS elevation (m AHD)	N/A
Median blackwater elevation (m AHD)	0.4
Present day low water level (m AHD)	-0.1
Near future low water level (m AHD)	0
Far future low level (m AHD)	0.5
Proximity to sensitive receivers	
Oyster leases (km)	Within subcatchment
Saltmarsh (km)	Within subcatchment
Seagrass (km)	Within subcatchment
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	1,861
Classified as conservation and minimal use (ha (%))	1344 (72%)
Classified as grazing (ha (%))	256 (14%)
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 (%))	240 (13%)
Classified as marsh/wetland (ha (%))	1 (0%)
Other (ha (%))	21 (1%)
Land values	
Estimated total primary production value ($/year)	$120,000
Average land value above 0.4 m AHD ($/ha)	$9,400
Average land value below 0.4 m AHD ($/ha)	No property data available

8.19.1 Site description

The Harrington subcatchment is located at the entrance of the Manning River. Approximately 10% of the subcatchment is the urban areas around the township of Harrington. As shown in Figure 8-74, a significant portion of the subcatchment is within the boundaries of Crowdy Bay National Park and has undergone minimal development. The topography of the Harrington subcatchment is higher than most of the Manning River floodplain, with few areas below 1 m AHD (Figure 8-75).

This subcatchment was not included in ASS prioritisation as there was insufficient soil profile data. While it is assumed to be a low risk for ASS based on topography and drainage, additional data should be collected to confirm the low risk classification.

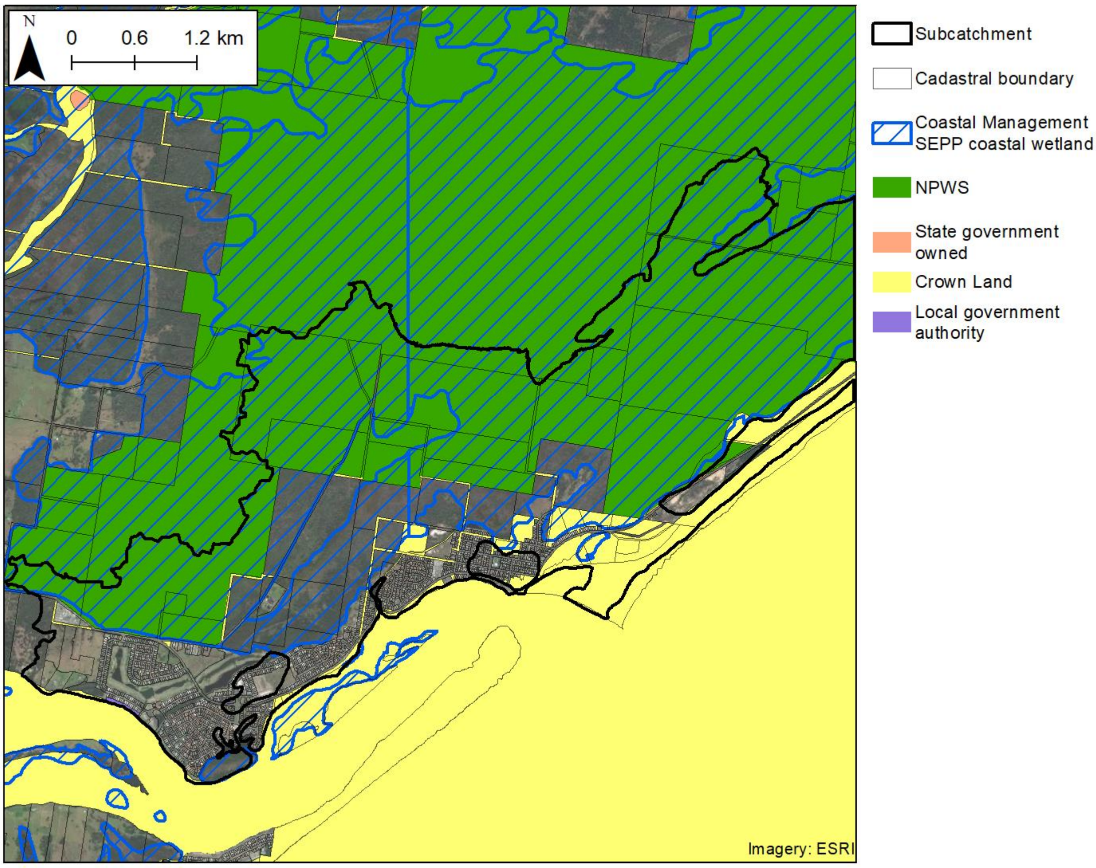

Figure 8-74: Harrington subcatchment - land and end of system infrastructure tenure

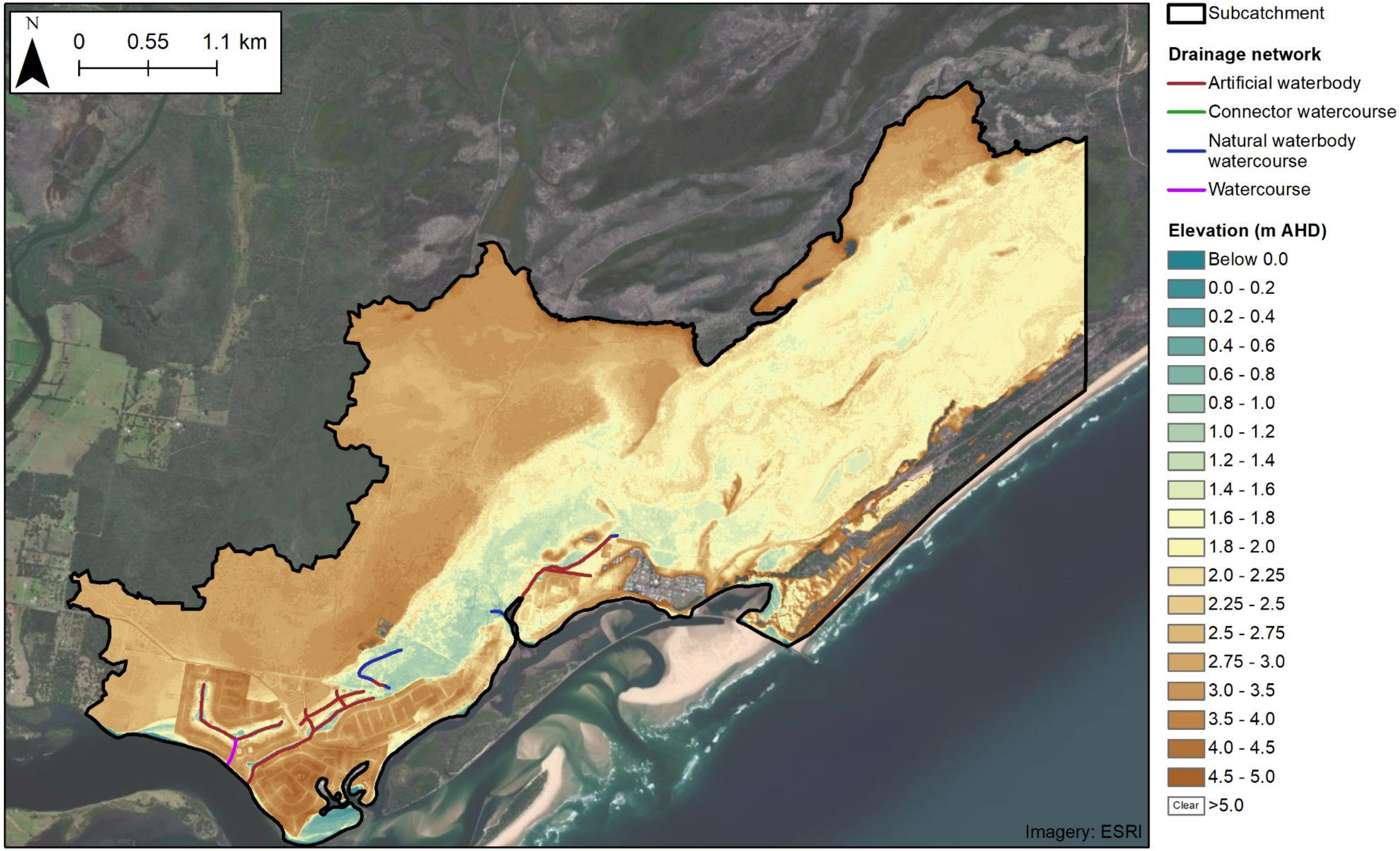

Figure 8-75: Harrington subcatchment elevation and drainage network

8.19.2 History of remediation

No known attempt at remediation to date.

8.19.3 Floodplain drainage – sea level rise vulnerability

The Harrington subcatchment is relatively high (mostly above +1.5 m AHD), based on the LiDAR survey data available (shown in Figure 8-76). No major floodgates were identified in the subcatchment. As a result, combined with minimal active agricultural use in the subcatchment, land uses in the Harrington subcatchment are unlikely to be impacted by reduced drainage. Note that this assessment considers surface water drainage, and any subsurface drainage of urban areas was not assessed.

8.19.4 Management options

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

- Short-term: Support the on-going management of the National Park; and
- Long-term: Ensure development and urban growth do not encroach on conservation 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
The vast majority of the Harrington subcatchment is within the Crowdy Bay National Park and has not been artificially drained. No change in land management is required to further address these issues, although on-going support for NPWS is recommended. Further investigations to confirm low risk acid sulfate soils is recommended.

Long-term management options
Long-term, urban growth and development pressure in the town of Harrington should be managed with development controls to prevent unnecessary drainage in this subcatchment. Otherwise, continued management of the National Park should continue to be supported.

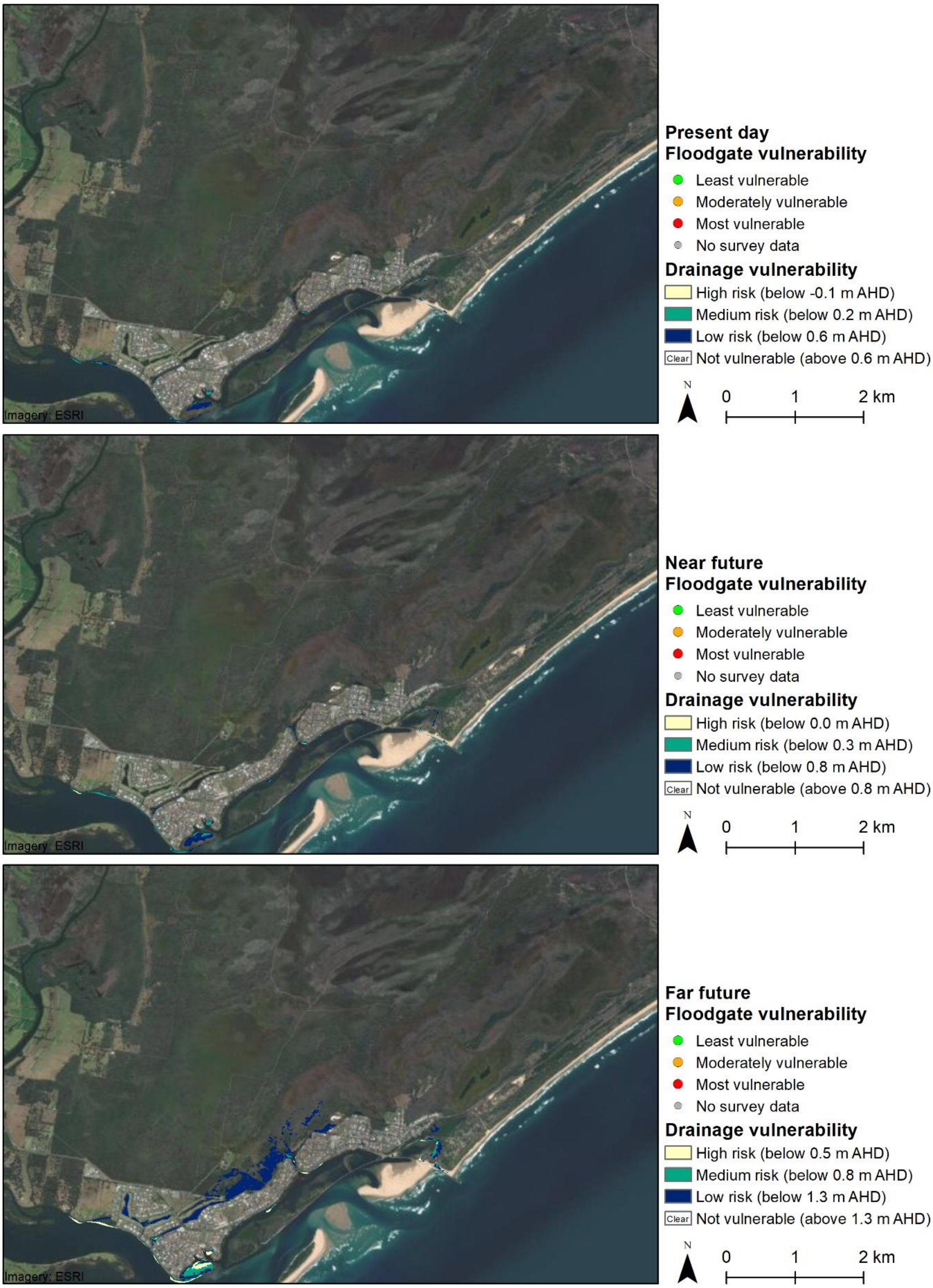

Figure 8-76: Sea level rise drainage vulnerability – Harrington subcatchment

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 17 subcatchments on the Manning 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 Manning Rivers coastal floodplain system to allow targeted floodplain management to improve water quality. The outcomes of the subcatchment prioritisation, management option development and supporting information, provide an objectively prioritised list of 17 floodplain subcatchments with a roadmap on how to achieve water quality improvements across the Manning 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 17 subcatchment drainage areas of the Manning 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 Manning River floodplain, the highest priority subcatchments (shown in Table 9-1) for acid drainage, namely Big Swamp (1), Moto (2) and Ghinni Ghinni (3), are estimated to contribute 90% of the total acid risk to the estuary. The Big Swamp subcatchment was estimated to individually be the source of 38% of acid risk to the estuary.

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.

The assessment identified the highest four (4) priority subcatchments collectively represent over 55% of the total blackwater generation risk in the Manning River estuary (Table 9-1). However, compared to other, larger coastal floodplains in NSW (e.g. Clarence River, Richmond River and Macleay River), prevalence of blackwater and low dissolved oxygen associated with prolonged inundation of floodplains is not as common in the Manning River floodplain. It should be noted that the blackwater prioritisation is separate from the ASS prioritisation. Subsequently, rankings of subcatchments in terms of blackwater risk are not comparable to rankings of subcatchments in terms of ASS risk. While both mechanisms might produce poor water quality within the estuary, it is likely that estuary wide poor water quality resulting from ASS poses a higher risk to the Manning River estuary when compared to poor water quality resulting from blackwater.

Table 9-1: Manning River floodplain subcatchment priority ranking

Subcatchment	Acid rank	Blackwater rank
Big Swamp	1	3
Moto	2	2
Ghinni Ghinni	3	1
Bukkan Bukkan Creek	4	5
Coopernook	5	6
Cattai Creek	6	7
Glenthorne	7	9
Jones Island	8	4
Mitchells Island	9	15
Pampoolah	10	13
Croakers Creek	11	8
Mambo Island	12	12
Dawson River	13	10
Dumaresq Island	14	11
Taree Estate	15	14
Harrington	N/A	17
Old Bar	N/A	16

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

Table 9-2: Drainage vulnerability under sea level rise

Vulnerability Status	Historic Scenario (HS)	Present Day (PD)	Near Future (NF)	Far Future (FF)
Floodgates (number of)				
Least vulnerable floodgates	88	87	73	27
Moderately vulnerable floodgates	15	13	25	45
Most vulnerable floodgates	1	4	6	32
Floodplain Area (hectares)				
Low vulnerability area	266	444	1,393	6,504
Moderate vulnerability area	15	18	32	1,822
High vulnerability area	2	3	10	182

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

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

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

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

9.3 Conclusions

Substantial efforts have been put into managing water quality in the Manning River estuary, through both Council driven efforts and the cooperation of local landholders. Notably, MidCoast Council proactively pursued large scale restoration in the Big Swamp floodplain. Numerous landholders have co-operated with paddock scale interventions, such as weirs or modified floodgates, with mixed success in terms of water quality improvements and maintenance/improvement of agricultural productivity. These remediation efforts should be encouraged and commended. However, the scale of on-going large event-based floodplain discharges of blackwater and acid, particularly from the three (3) highest priority subcatchments (Big Swamp, Moto, and Ghinni Ghinni) can only be substantially addressed through broadscale changes to land use and a restoration of natural floodplain hydrology. Broadscale management changes throughout the floodplain will need to consider, and have a plan to mitigate, potential social, cultural, and economic impacts to local landholders.

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

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