Tweed River Floodplain Prioritisation Study

WRL TR 2020/04, June 2023

By T A Tucker, D S Rayner, A J Harrison, G Lumiatti,
P F Rahman, D M Gilbert and W C Glamore

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Executive summary

ES.1 Preamble

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

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

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

This report specifically provides an evidence-based assessment of 14 floodplain subcatchment drainage areas across the Tweed River floodplain. To determine how water quality from the Tweed River floodplain can be improved, subcatchments have been prioritised based on the risk they pose to the marine estate through the generation of poor water quality from ASS and blackwater runoff. Following the priority risk assessment, management options for short and long-term planning horizons have been suggested outlining potential strategies for each subcatchment to improve water quality outcomes. Importantly, this study identifies localised and site specific management responses targeted to sources of poor water quality considering key environmental, social, economic, cultural, and regulatory criteria. The outcomes from the study will provide an overview of floodplain processes, collate valuable datasets, provide potential management responses to address sources of poor water quality, and facilitate the streamlined implementation of actions to improve the health of the marine estate into the future.

ES.2 Background

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

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

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

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

ES.3 Study approach

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

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

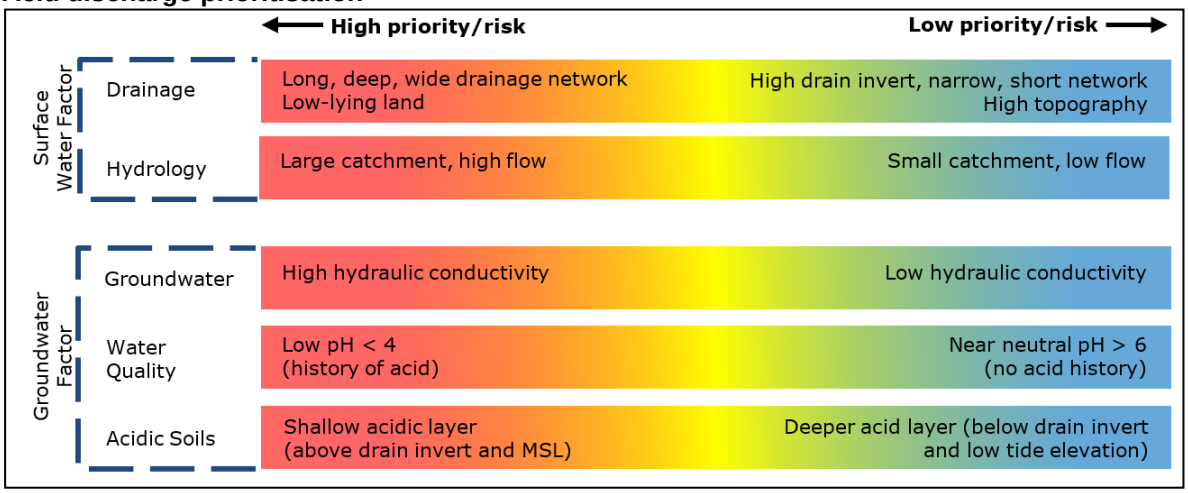
This approach enables the identification of high-priority subcatchments within coastal floodplain systems that can be targeted to improve water quality and guide floodplain management. The outcomes of the subcatchment prioritisation, development of management options and supporting information, provide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

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

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

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

Acid discharge prioritisation



Blackwater runoff prioritisation

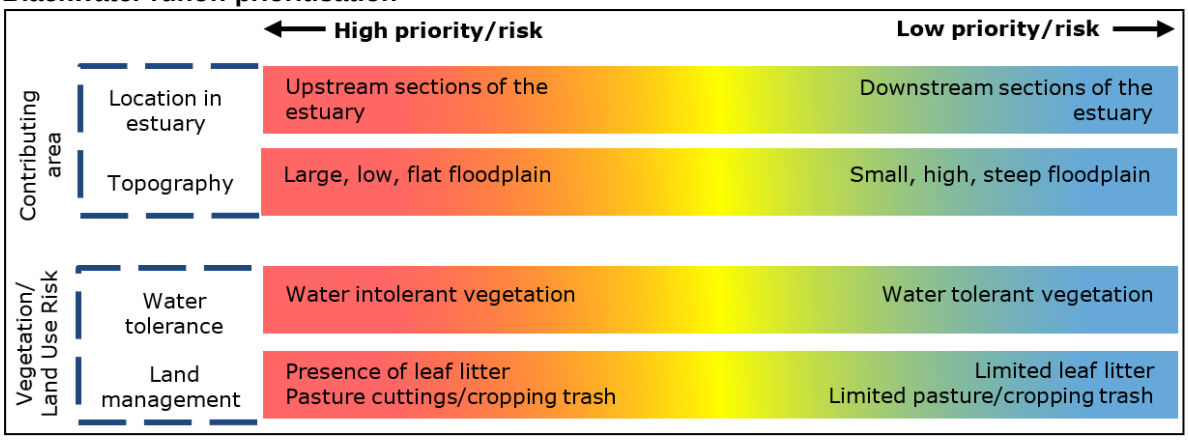


Figure ES-1: Factors influencing acid sulfate soil discharge and blackwater runoff from NSW coastal floodplain subcatchments

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

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

The management options suggested as part of this study are high level and intended to guide the overall strategy that should be considered by floodplain managers when addressing sources of diffuse poor

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

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

ES.4 Tweed River floodplain subcatchment prioritisation results

The multi-criteria prioritisation methodology was applied to rank subcatchment drainage areas of the Tweed 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 14 floodplain subcatchments outlined in Figure ES-2. Data considered during this analysis included:

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

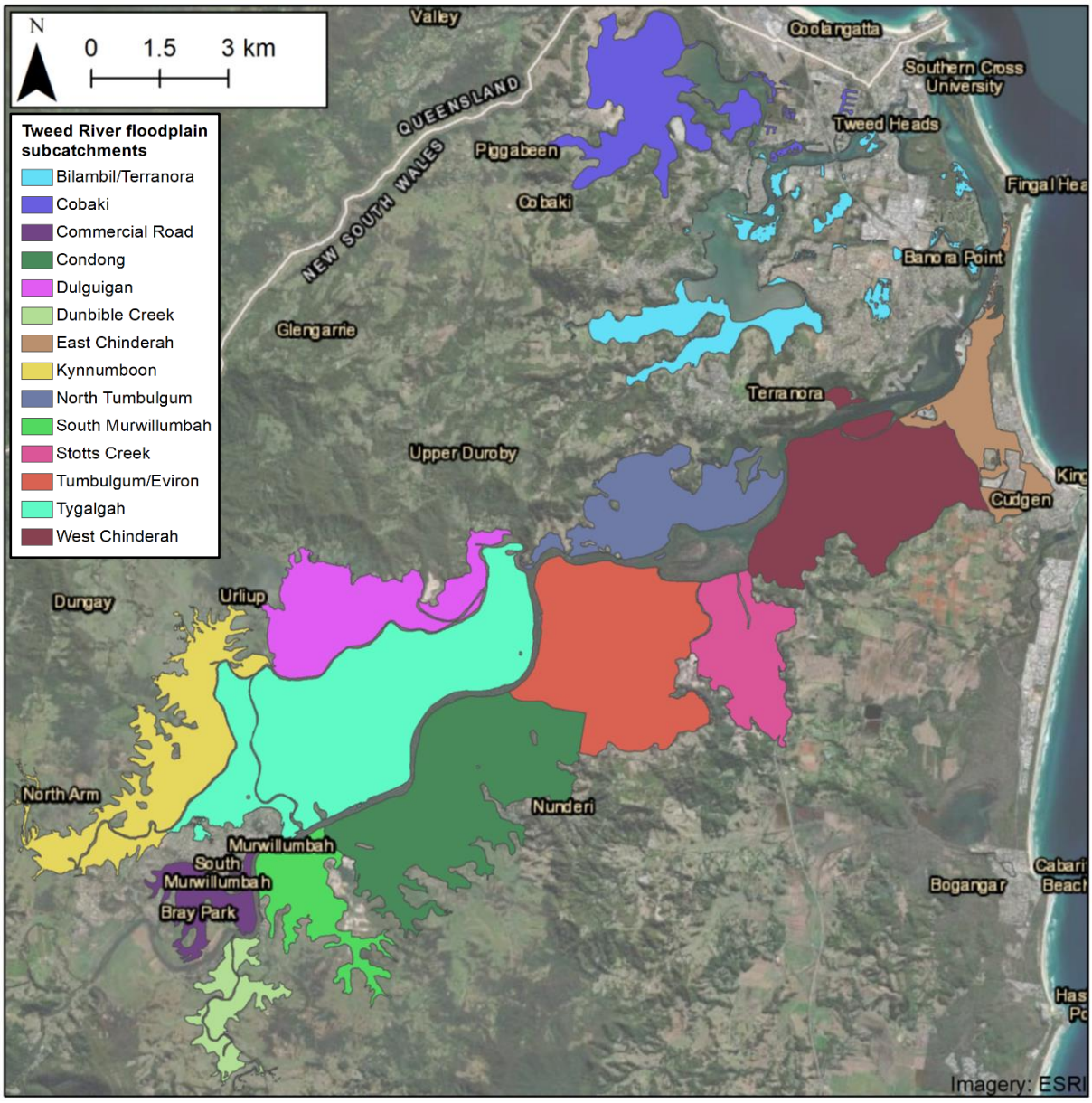


Figure ES-2: Tweed River floodplain subcatchments

The acid prioritisation assessment considers the volume of acid stored within a floodplain and the potential for it to be transported to the estuary to objectively rank subcatchment areas from the highest to lowest with respect to the risk of acid drainage to the estuary. Within the Tweed River floodplain, the highest two priority subcatchments were identified as Condong and South Murwillumbah (Table ES-1 and Figure ES-3). These subcatchments each individually contribute approximately 25% of the total acid risk for the Tweed River Estuary. High risk acid subcatchments were identified in the mid to upper reaches of the estuary, indicating that acid discharges from the floodplain have the potential to impact all areas of the Tweed River estuary. All four of the highest priority subcatchments are located in the upper estuary (Condong and South Murwillumbah on the Tweed River and Dulguigan and Kynnumboon on the Rous River) highlighting this section of the estuary as most at risk of acidification.

Table ES-1: Tweed River floodplain subcatchment priority ranking

Subcatchment	Acid rank	Blackwater rank
Condong	1	3
South Murwillumbah	2	9
Dulguigan	3	6
Kynnumboon	4	8
Stotts Creek	5	4
Tumbulgum/Eviron	6	1
Tygalgah	7	2
West Chinderah	8	7
North Tumbulgum	9	5
Cobaki	10	10
Bilambil/Terranora	11	11
East Chinderah	12	12
Commercial Road	13	14
Dunbible Creek	14	13

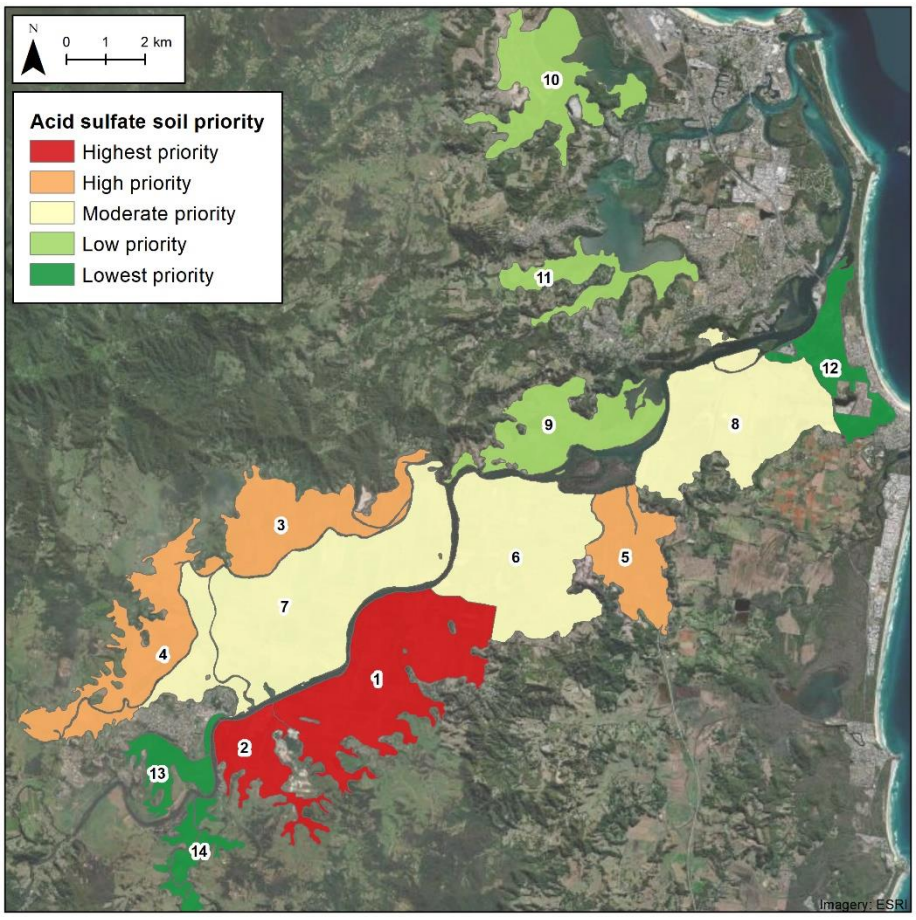


Figure ES-3: Tweed River floodplain subcatchment rankings of the acid prioritisation assessment

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

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

This data was used to objectively rank subcatchments from highest to lowest based on the risk they pose to the marine estate in terms of discharging low oxygen blackwater to the estuary (Table ES-1 and Figure ES-4). The assessment identified the highest priority subcatchment is Tumbulgum/Eviron which represented approximately 20% of the total blackwater generation risk in the Tweed River estuary. Since the blackwater prioritisation approach is based upon subcatchment area, and therefore subcatchment delineation, it is worth noting that if the adjacent Condong, Tumbulgum/Eviron and Stotts Creek subcatchments were combined they would collectively account for approximately 40% of the total blackwater generation risk.

It should be noted that blackwater runoff is less of an issue on the Tweed River floodplain compared to other large coastal floodplains in NSW (e.g. Richmond River, Clarence River and Macleay River). This is because the Tweed River estuary, in comparison to other large coastal floodplains in NSW (e.g. Richmond River, Clarence River and Macleay River), is relatively short in length, and does not feature the large backswamp topography and upland catchments of other coastal floodplains. Furthermore, while ASS and blackwater risks have been individually ranked, this does not mean that the impacts of blackwater are necessarily comparable to the impacts of ASS on the Tweed River floodplain.

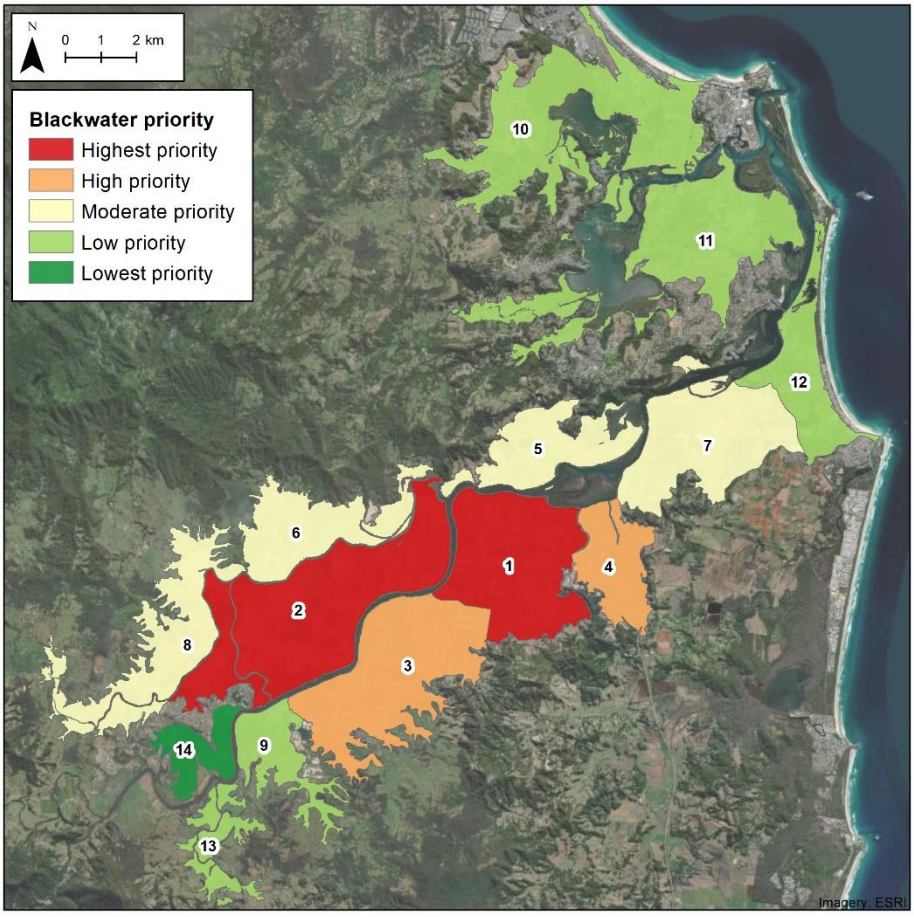


Figure ES-4: Tweed River floodplain subcatchment rankings of the blackwater prioritisation assessment

ES.5 Sea level rise and floodplain drainage vulnerability

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

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

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

Detailed numerical modelling of the Tweed 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.

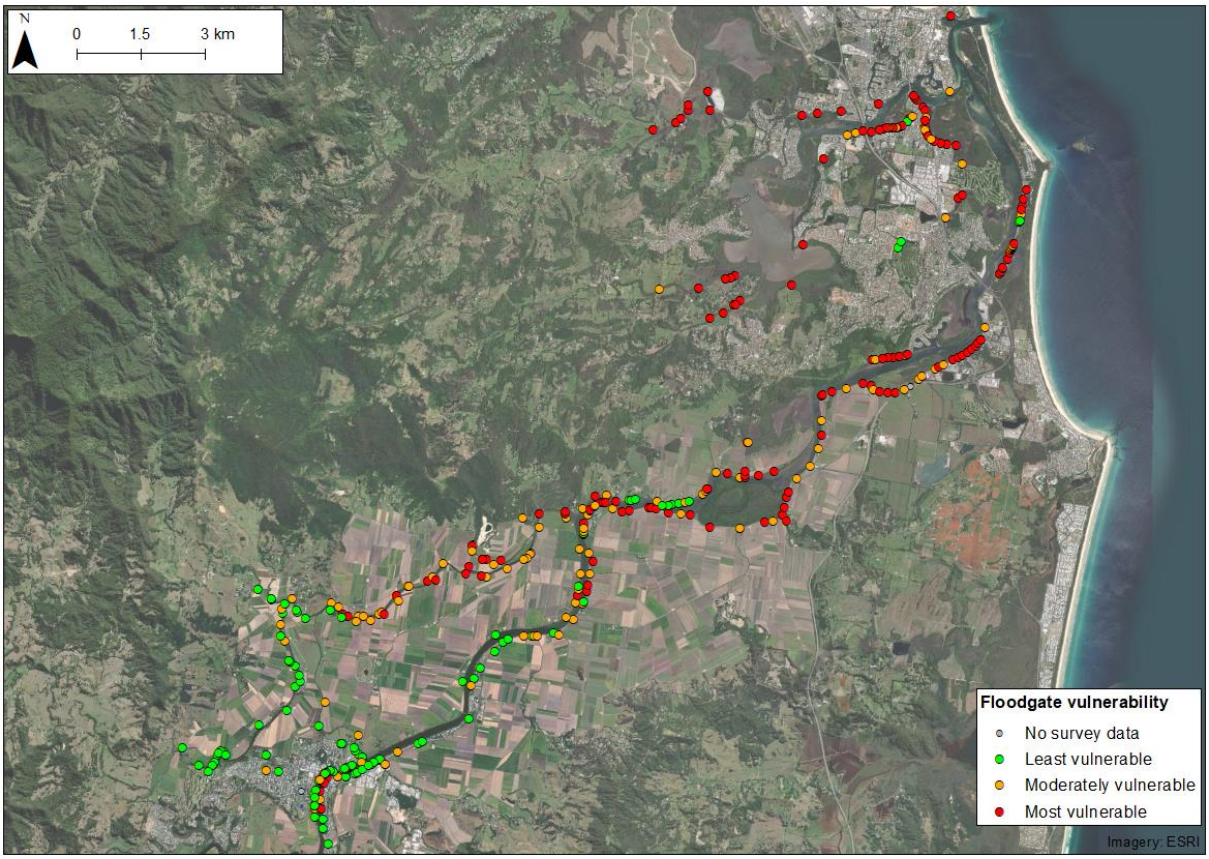


Figure ES-5: Tweed River estuary floodgate vulnerability with sea level rise (far future ~2100)

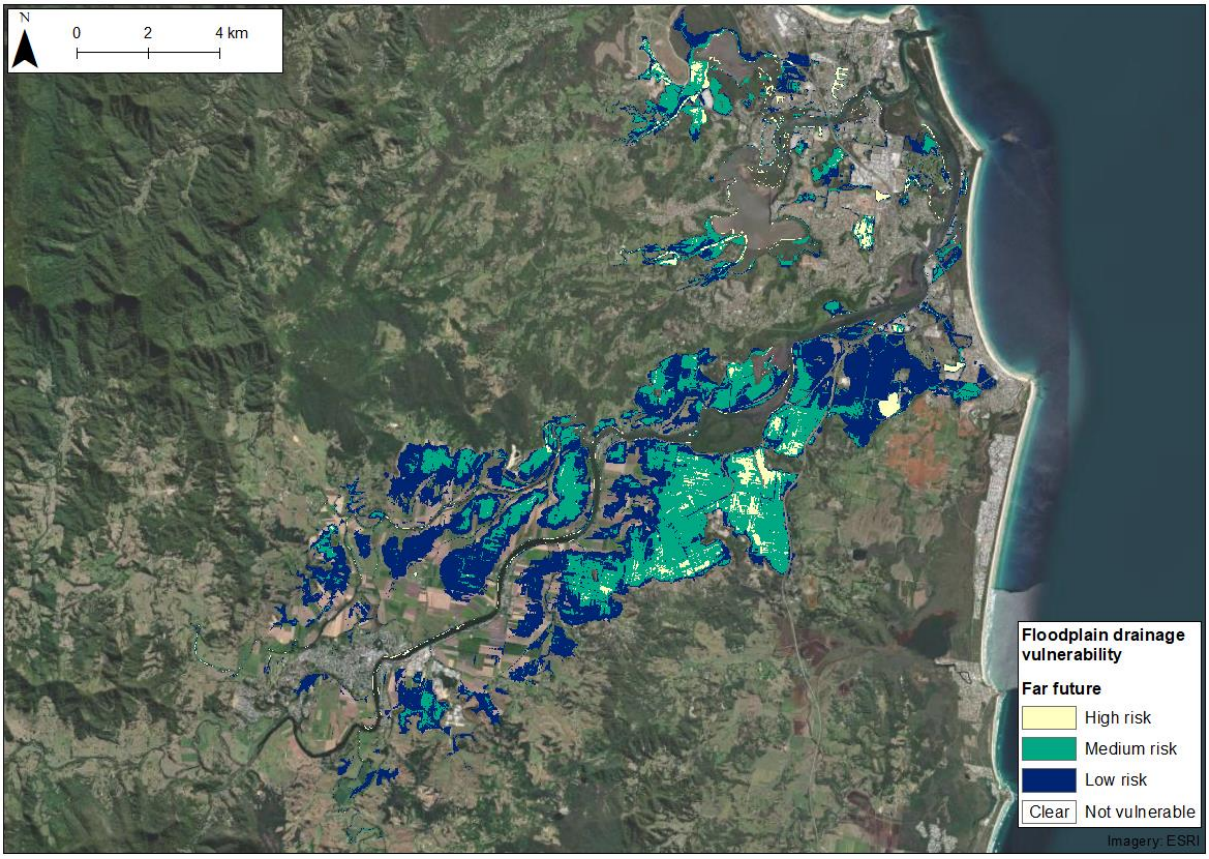


Figure ES-6: Tweed River floodplain vulnerability with sea level rise (far future ~2100)

ES.6 Management options for the top three priority subcatchments

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

- Condong;
- South Murwillumbah; and
- Dulguigan.

It is estimated that these three (3) floodplain subcatchments account for almost 70% of the overall acid generation risk in the Tweed River floodplain. Addressing water quality issues from these three (3) subcatchment would result in significant improvements in the overall health of the marine estate. Note, there is limited evidence of blackwater runoff events being a significant contributor to poor estuarine water quality on the Tweed River floodplain, particularly when compared to the impacts of acid sulfate soils. This is because the Tweed River estuary, in comparison to other large coastal floodplains in NSW (e.g. Richmond River, Clarence River and Macleay River), is relatively short in length, and does not feature the large backswamp topography and upland catchments of other coastal floodplains. Subsequently, greater improvements in water quality will be achieved by targeting the remediation of acid sulfate soils on the Tweed River floodplain.

Note, 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.

Condong subcatchment

The Condong subcatchment was ranked first for acid generation, and individually accounts for approximately 25% of the acid risk to the Tweed River estuary. Short-term management options for the Condong subcatchment should focus on identifying strategies to raise the water table across the floodplain to reduce the exposure of acid sulfate soils to air and the subsequent generation of acid. Potential options to achieve this include:

- Water retention structures such as weirs or drop boards in drains to retain runoff from the catchment and subsequently raise the water level;
- Installing and optimising existing floodgate structures to allow controlled in-drain tidal flushing upstream and into the drainage network to neutralise acidic water generated within the subcatchment.

Long-term management options for the Condong subcatchment should focus on reversing the changes to the floodplain that have occurred from drainage and subsequently reduce the export of acid from the floodplain. Key actions that could be implemented as part of this strategy include:

- Decentralising major drainage to enable different areas to be managed as individual hydrological units;
- Reshaping drains to be shallower and wider, thereby reducing acid export while not impacting drainage efficiency; and
- Identifying key areas to transition to wetland habitat.

South Murwillumbah subcatchment

The South Murwillumbah subcatchment was ranked second for acid generation, and individually accounts for approximately 25% of the acid risk to the Tweed River estuary. Remediation works have been completed by Tweed Shire Council and landholders in the upper subcatchment resulting in localised improvements in water quality, however, there are still further opportunities to improve water quality being discharged from the broader subcatchment.

Short-term strategies for the South Murwillumbah subcatchment should focus on optimising existing management practices across the subcatchment for water quality benefits. Investigations could be completed to:

- Determine if existing modifications to the floodgates, allowing tidal flow upstream and within the drainage network, can be further optimised to increase the benefits associated with flushing of the drainage network and naturalisation of acid;
- Review benefits of pumping of water from behind floodgates and associated affects on acid sulfate soils.
- Ongoing remediation of acid scalds including limiting stock access and revegetation, to reduce the impact of acidic first flush runoff following rainfall events to downstream waterways.

The long-term management options for the South Murwillumbah subcatchment should focus on restoring the natural hydrology to the floodplain. This could be completed by:

- Identifying existing drains which could be infilled or reshaped so that they are not intersecting acid sulfate soils; and
- Identifying low-lying areas which could be transitioned to wetland habitat.

Creating wetland habitat would involve retaining water on the floodplain resulting in reduced creation and export of acid.

Dulguigan subcatchment

The Dulguigan subcatchment was ranked third for acid generation, and individually accounts for approximately 15% of the acid risk to the Tweed River estuary. There are existing Coastal Management SEPP coastal wetlands within the Dulguigan subcatchment. It is important that future management options and strategies add value to this critical ecosystem.

Short-term management options for the Dulguigan subcatchment include optimising existing strategies to improve water quality and reduce the drainage of acid sulfate soils. This could be achieved by implementing the following objectives:

- Identify new, or refurbishing and optimising existing floodgates, to allow in-drain tidal flushing; and
- Reshaping key drains to reduce their intersection with acid sulfate soil layers.

Optimising tidal flushing improves water quality by ensuring water is continually being replenished within the drainage network and also by neutralisation of acid. Reshaping drains reduces the export of acid from the floodplain in the first instance.

Potential long-term management options for the Dulguigan subcatchment include:

- Restoring the natural floodplain hydrology. This option could be implemented with the goal of enhancing the existing Coastal Management SEPP coastal wetland habitat within the subcatchment. Actions to achieve this strategy include strategic infilling of drains and identifying key sections of floodplain for creation of wetland habitat. Both of these actions would reduce the export of acid from the floodplain.

ES.7 Outcomes and conclusions

Outcomes from the Coastal Floodplain Prioritisation Study for the Tweed 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.

Tweed Shire Council, with the support of local landholders, has already completed substantial on-ground works to reduce acid drainage in the estuary. Notably, a large number of major floodplain end-of-system infrastructure has been modified to allow some controlled flushing (e.g. sluice gates, auto-tidal gates and winches) and improved connectivity with the estuary. Numerous landholders have co-operated with paddock scale interventions, such as weirs or drain reshaping, with mixed success in terms of water quality improvements and maintenance/improvement of agricultural productivity. These remediation efforts should be encouraged and commended. However, addressing water quality issue on a large scale in the Tweed River will require 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 automatically 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 tupically 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 35 g/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 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 Tweed 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 Tweed 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 ASS 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 NSW Marine Estate Management Strategy (MEMS). The ten-year Strategy was developed by the NSW Marine Estate Management Authority (MEMA) to coordinate the management of the marine estate. The study was commissioned by NSW Department of Primary Industries - Fisheries under the MEMS Stage 1 and delivered by the Water Research Laboratory (WRL) of the School of Civil and Environmental Engineering at UNSW Sydney.

1.2 Connection to other reports

The prioritisation of the Tweed 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:

- Tweed River floodplain (this report);
- Richmond River floodplain (WRL TR2020/05);
- Clarence River floodplain (WRL TR2020/06);
- Macleay River floodplain (WRL TR2020/07);
- Hastings River floodplain (WRL TR2020/08);
- Manning River floodplain (WRL TR2020/09); and
- Shoalhaven River floodplain (WRL TR2020/10).

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

1.3 Coastal floodplain prioritisation method

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

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

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

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

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

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

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

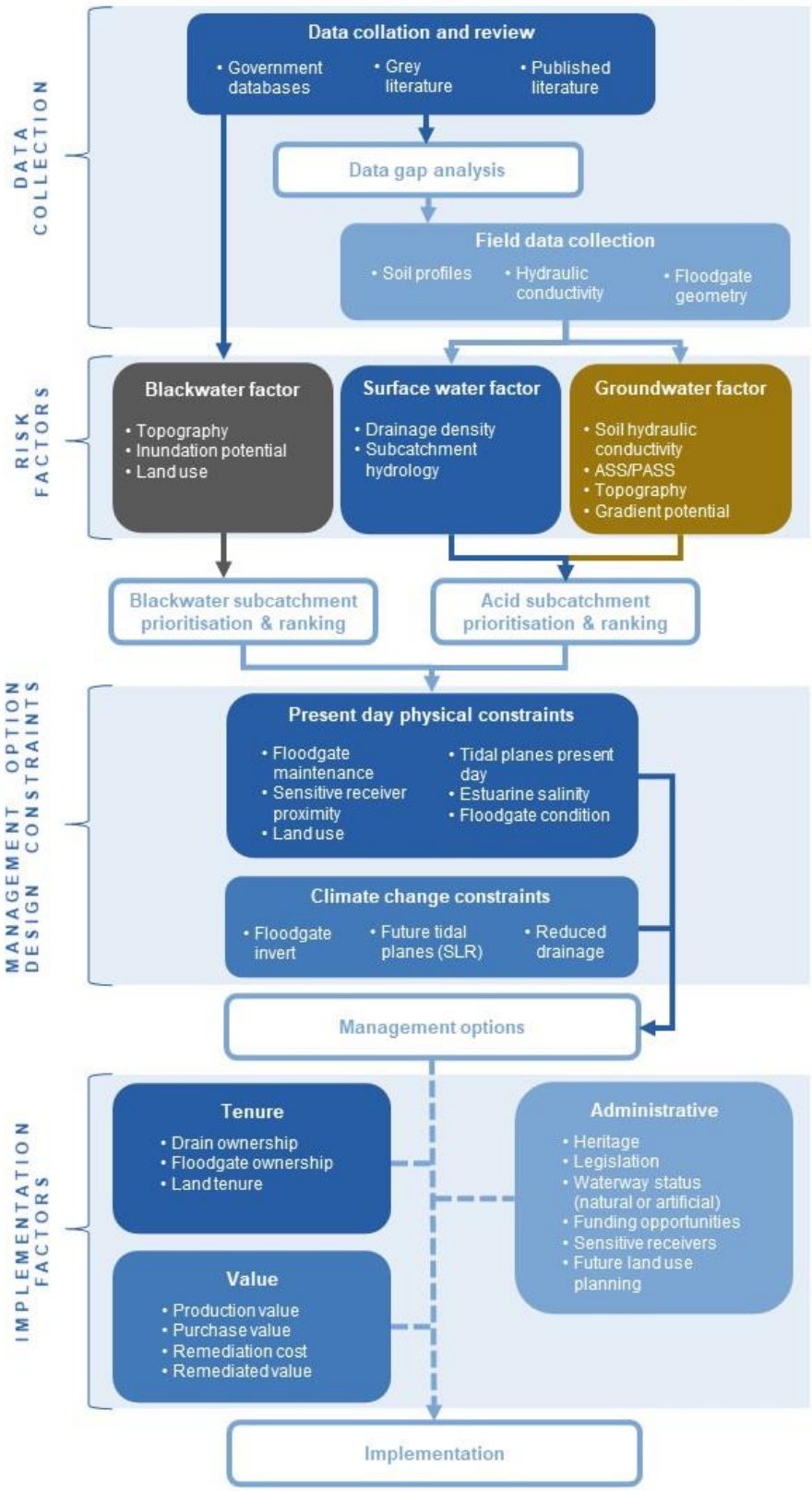


Figure 1-1: Study approach overview

1.4 Tweed River floodplain prioritisation

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

There is overall limited evidence of blackwater runoff events being a significant contributor to poor estuarine water quality on the Tweed River floodplain, particularly when compared to the impacts of acid sulfate soils. Subsequently, while the prioritisation methodology has been applied to the Tweed River floodplain for both ASS and blackwater in a consistent approach to other NSW coastal floodplains (Rayner et al., 2023), this does not mean that the impacts of blackwater are necessarily comparable to the impacts of ASS on the Tweed River floodplain. Blackwater runoff is less of an issue on the Tweed River floodplain compared to other large coastal floodplains in NSW (e.g. Richmond River, Clarence River and Macleay River), as the estuary is comparatively short in length, and does not feature the large backswamp topography and large upland catchments of other coastal floodplains. The large estuary wide deoxygenation events observed in other NSW estuaries from blackwater runoff (e.g. 2001 and 2008 Richmond River blackwater events) have not been observed to date in the Tweed River estuary. However, deoxygenation of standing floodwaters due to the die off and decay of organic matter does have the potential to result in blackwater runoff from subcatchments in the Tweed River floodplain (Seccull et al., 2019).

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

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

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

1.5 About this report

This report comprises the following sections:

- **Chapter 2** presents the drainage subcatchments considered in the Tweed River floodplain;
- **Chapter 3** provides background information describing the floodplain drainage and presence of ASS and blackwater in the Tweed River floodplain;
- **Chapter 4** provides an overview of the ASS and blackwater prioritisation methods;
- **Chapter 5** presents the outcomes of the ASS prioritisation in the Tweed River floodplain;
- **Chapter 6** presents the outcomes of the blackwater prioritisation in the Tweed River floodplain;
- **Chapter 7** provides information on the impact of sea level rise on floodplain drainage;
- **Chapter 8** outlines the management options developed for each subcatchment; and
- **Chapter 9** provides a summary and recommendations.

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

- **Appendix A** Floodplain 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** Cross-section;
- **Appendix H** Water quality;
- **Appendix I** Numerical modelling;
- **Appendix J** Sensitive receivers;
- **Appendix K** Heritage;
- **Appendix L** Soil profile data sheets.

2 Subcatchment delineation

2.1 Preamble

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

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

The primary data used for subcatchment delineation was topographical and waterway data which allows for the determination of hydrological flow paths. Using this data allows each subcatchment to be delineated as a single hydrological unit (as far as reasonably practical). This was deemed the most important factor in the delineation process as it then allows each subcatchment to be managed as a discretised unit. This typically allows for modifications to occur in one subcatchment without impacting or altering the hydrological conditions to an adjacent subcatchment. This section outlines the subcatchments developed for the Tweed River floodplain, which are used throughout this study.

2.2 Subcatchments of the Tweed River floodplain

The subcatchments in the Tweed River floodplain have been defined based on the floodplain geological and hydrological features. Generally, coastal planning has separated the Tweed River estuary into five zones (Seccull et al., 2019):

- Lower estuary from Tweed Heads to Chinderah;
- Transition zone from Chinderah to Terranora;
- Middle estuary from Terranora to Condong;
- Upper estuary from Condong to the Bray Park Weir; and
- The Rous estuary (including the Rous River).

Wherever possible, these zones have been utilised to guide the delineation of subcatchments and also to inform the management options for floodplain subcatchments that align with the Coastal Management Program (Seccull et al., 2019). The subcatchments in the Tweed River floodplain are shown in Figure 2-1.

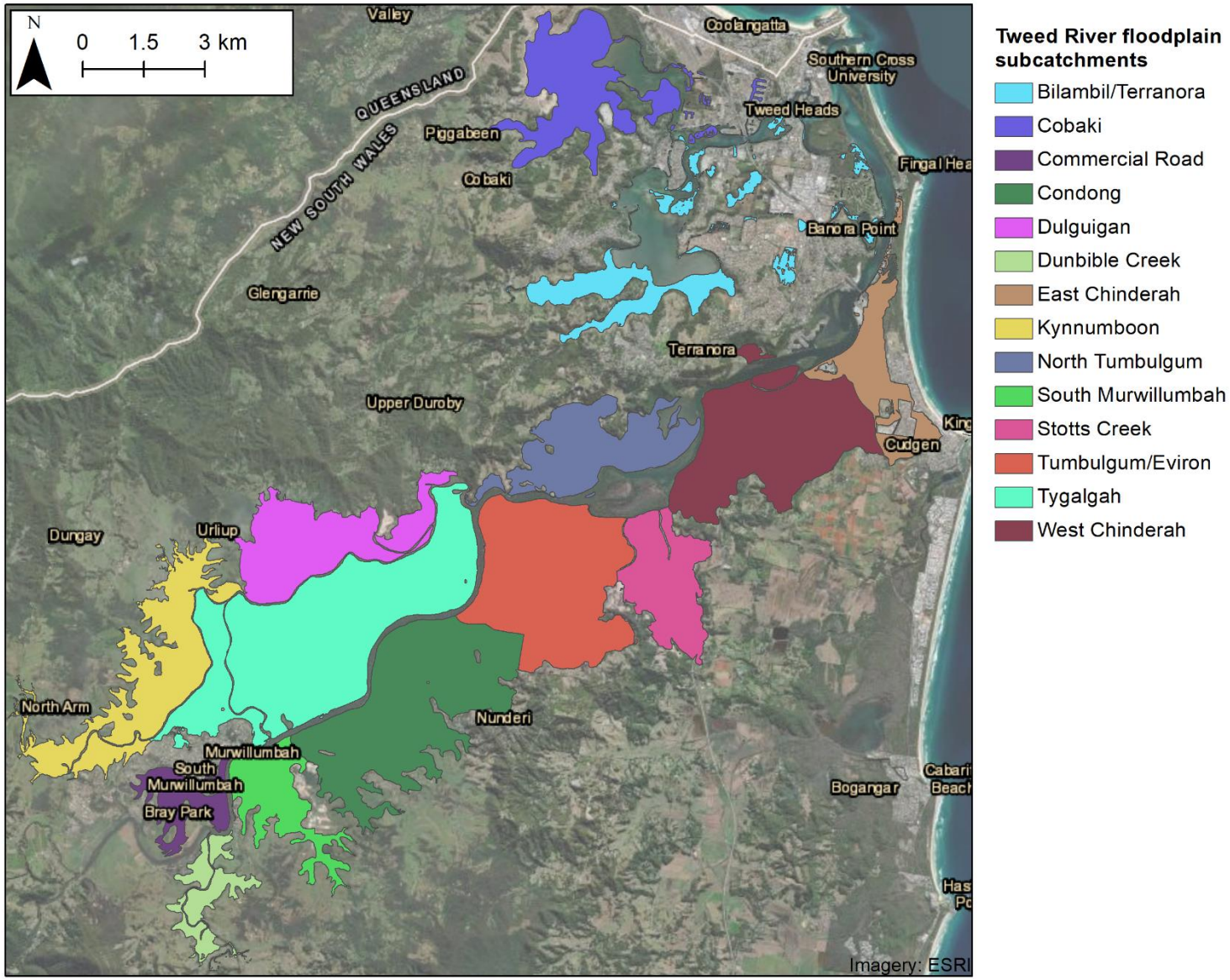


Figure 2-1: Subcatchments of the Tweed River floodplain

3 Background

3.1 Preamble

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

3.2 Local government

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

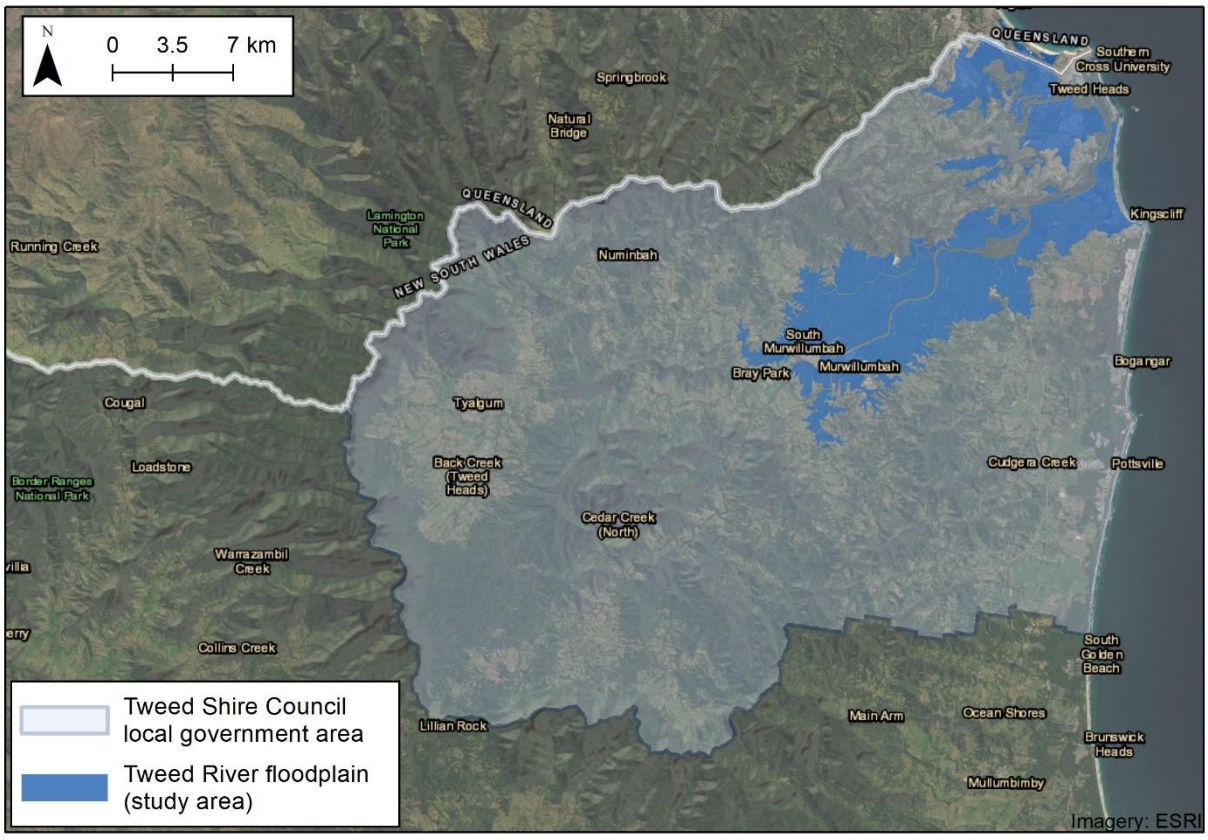


Figure 3-1: Tweed Shire Council local government area including the Tweed River floodplain

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

3.3 Floodplain history

The Tweed River floodplain (below 5 m AHD) covers an area of approximately 17,000 hectares. The Rous River is a major tributary of the Tweed River, joining in the middle estuary (Seccull et al., 2019). Other important tributaries include Cobaki Creek and Terranora Creek which join together before meeting the Tweed River near the ocean entrance at Tweed Heads (Figure 3-2). These major tributary streams connect the main river to numerous low elevation backswamps, with substantial areas below 1 m AHD, as shown in Figure 3-3.

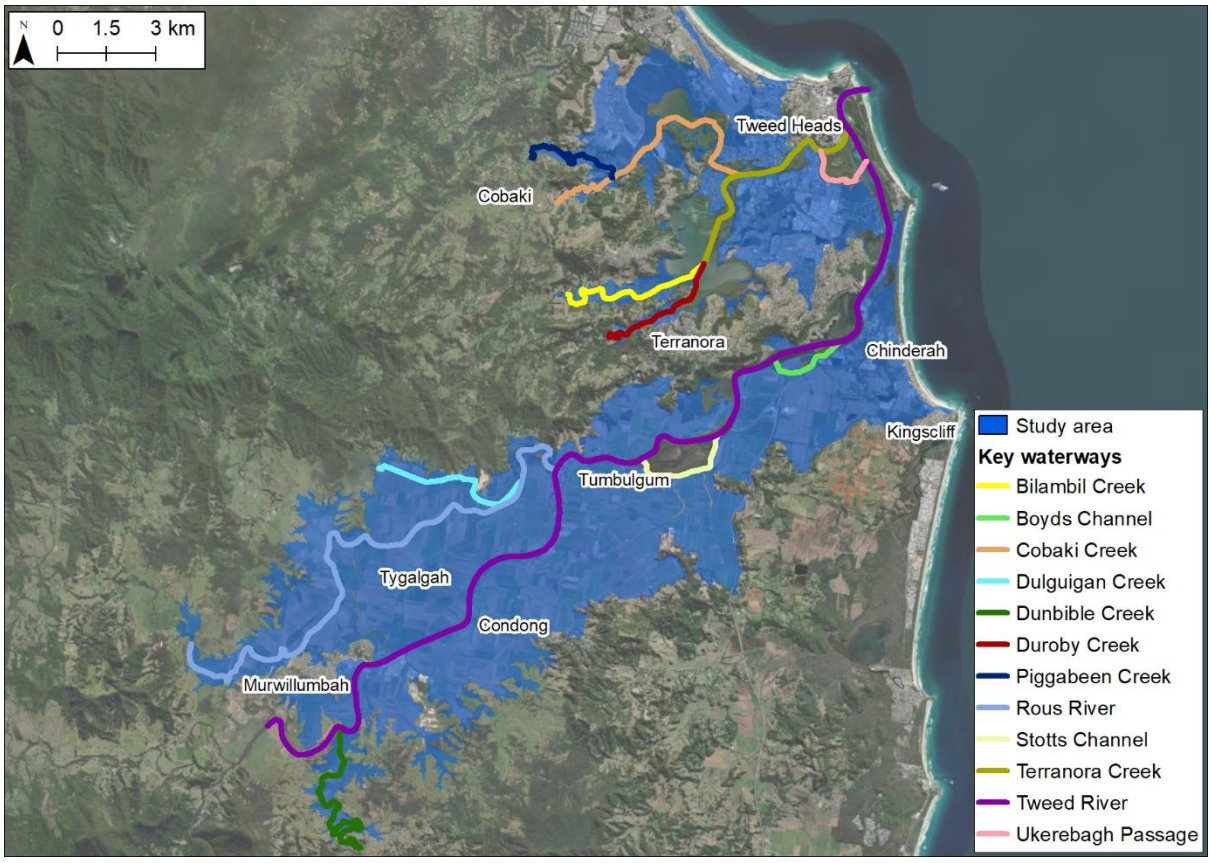


Figure 3-2: Key waterways within the Tweed River estuary

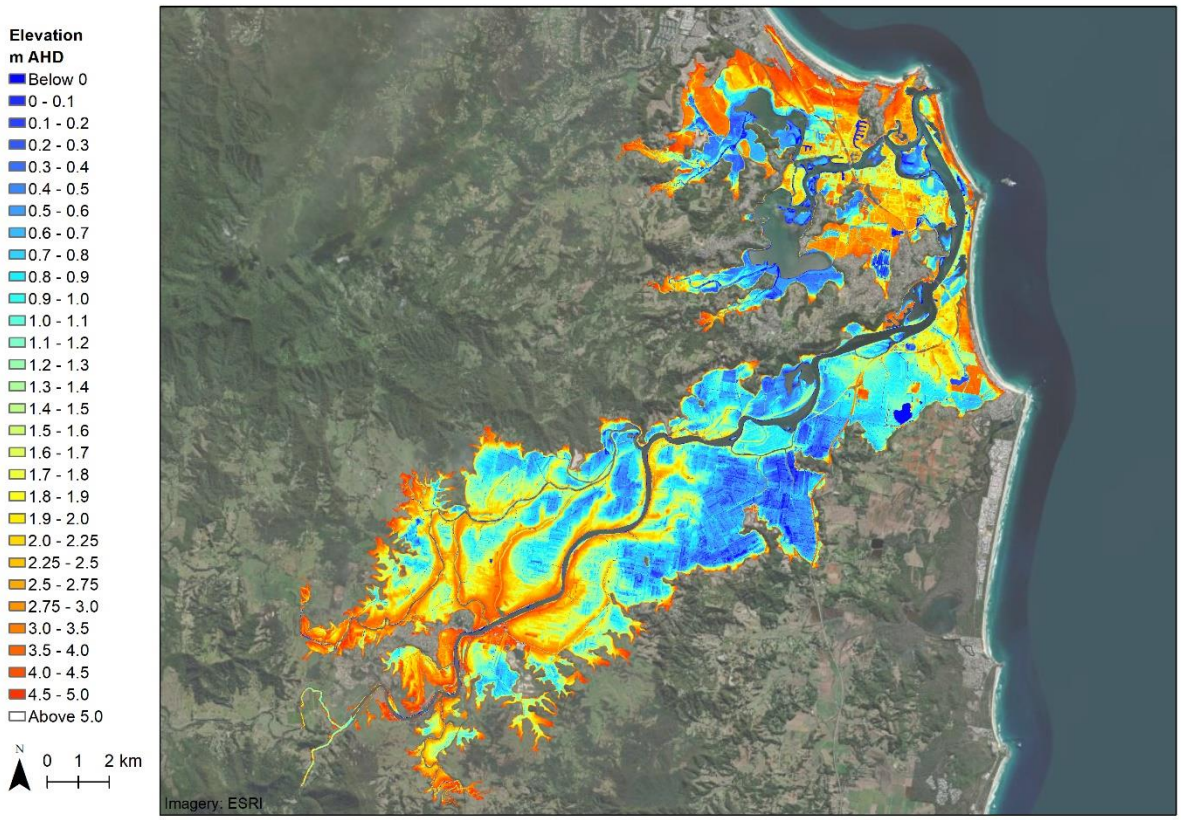


Figure 3-3: Digital elevation map of the Tweed River floodplain topography

On the Tweed River floodplain, modification of the natural drainage system through construction of drains began in the 1860s for the purpose of creating dry land for agriculture (Tulau, 1999). In the late 19th century and throughout the 20th and 21st centuries, further modifications were made to floodplain drainage to increase the extent of land available for agriculture and also to protect the low-lying floodplain from flooding. A timeline of key events and drainage works on the Tweed River floodplain includes (Tulau, 2011):

- 1823 – Explorer John Oxley discovers the Tweed River;
- 1840s – Logging of cedar began in the Terranora area;
- 1866 – Tweed River floodplain was opened for agricultural practices;
- 1860s to 1900s – Drainage was constructed in the Stotts Creek and Tumbulgum areas to dry out land for agriculture (Figure 3-4);
- 1907 – Drainage of the Terranora area;
- 1905 to 1923 – Further drainage works constructed in South Murwillumbah (Blacks Drain), Chinderah, Cudgen, Tumbulgum, Eviron and Commercial Road areas under the Water and Drainage Management Act 1902;
- 1945 to 1956 – Tweed River had 11 major flooding events;
- 1948 – Tweed River Flood Mitigation Committee was established;
- 1958 – Tweed River flood mitigation scheme began with works to be carried out by Tweed Shire Council;
- 1964 – Floodgates installed in the Condong area;
- 1965 to 1966 – Floodgates installed in the Condong and Tygalgah areas;
- 1967 – Floodgates installed in the Tygalgah area;
- 1968 – Floodgates installed in the Stotts Creek, North Tumbulgum and Chinderah areas;

- 1969 – Floodgates installed in the South Tweed Heads, Stotts Creek, Condong, Chinderah and North Tumbulgum areas;
- 1970 – Floodgates installed at Dulguigan and Murwillumbah;
- 1971 – Floodgates installed in the Tumbulgum, Eviron, Dulguigan, Condong, Kynnumboon, Chinderah, Murwillumbah, South Tweed Heads and Tygalgah areas.
- 1975 – Drainage completed in the Dulguigan, Chinderah, Kynnumboon, South Murwillumbah and Commercial Road areas.
- 1977 – Drainage Completed in the Murwillumbah, Kynnumboon, Duranbah, Dulguigan and Tumbulgum areas;
- 1977 – At the end of the flood mitigation scheme 475 kms of drains and 248 floodgate structures had been constructed on the Tweed River floodplain;
- 1987 – A major fish kill event was observed from Murwillumbah to Stotts Island on the Tweed River following a large rainfall event and was found to be a result of acidic runoff from ASS.

A schematic of floodplain evolution indicating the influence of extensive drainage works and the conceptual progression from past to present hydrologic conditions is presented in Figure 3-5.

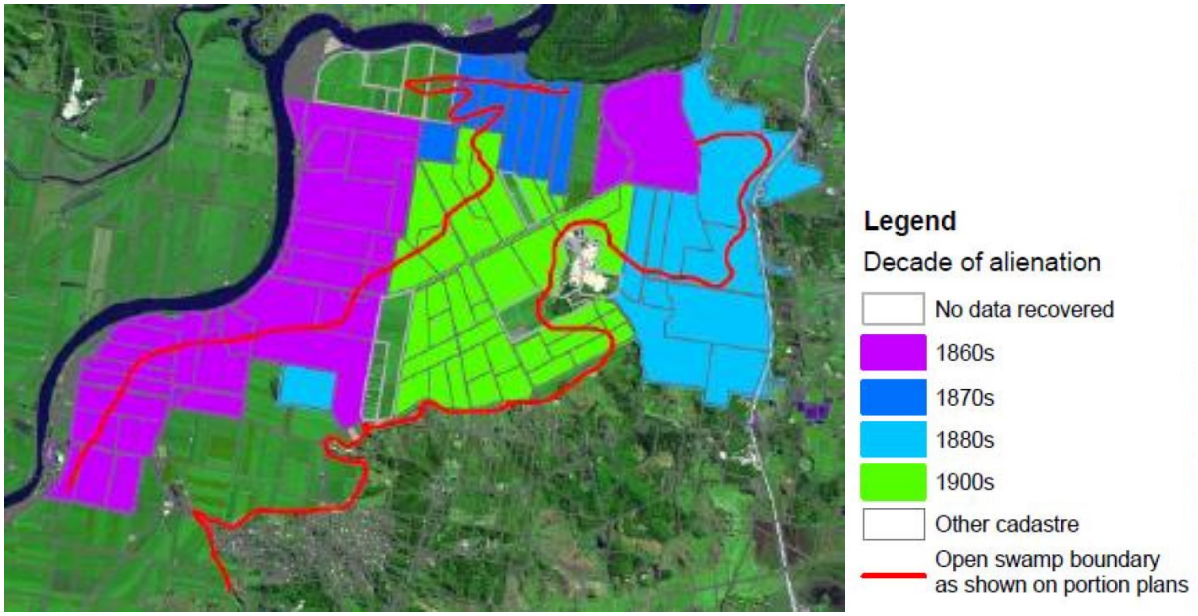


Figure 3-4: Drainage timeline of the Stotts Creek, Tumbulgum and Eviron floodplains in the 19th century (Tulau, 2011)

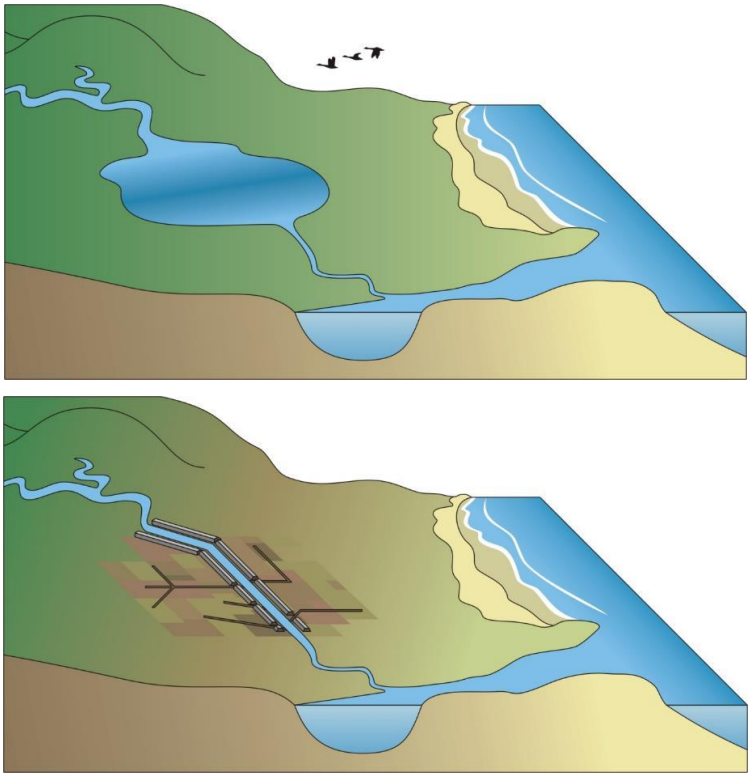


Figure 3-5: Schematic of floodplain evolution following European settlement

3.4 Land use and tenure

Although land use on the Tweed River floodplain is varied, the primary agricultural use of the floodplain is sugar cane, with substantial areas also used for grazing. Land uses in the Tweed River floodplain for areas below 5 m AHD are shown in Figure 3-6 (refer to Section 9 of Methods report (Rayner et al., 2023) for more detail). While the latest data available has been used for this study, it is recognised that floodplain land uses are constantly evolving and that some industries, such as macadamia farming (mapped under “Horticulture”), have likely grown since the time of the mapping.

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

- Tweed Estuary Nature Reserve, within Terranora Creek;
- Cobaki Nature Reserve, on the south bank of the Cobaki Broadwater;
- Ukerebagh Nature Reserve, at the confluence of Terranora Creek and the Tweed River; and
- Dodds Island Nature Reserve.

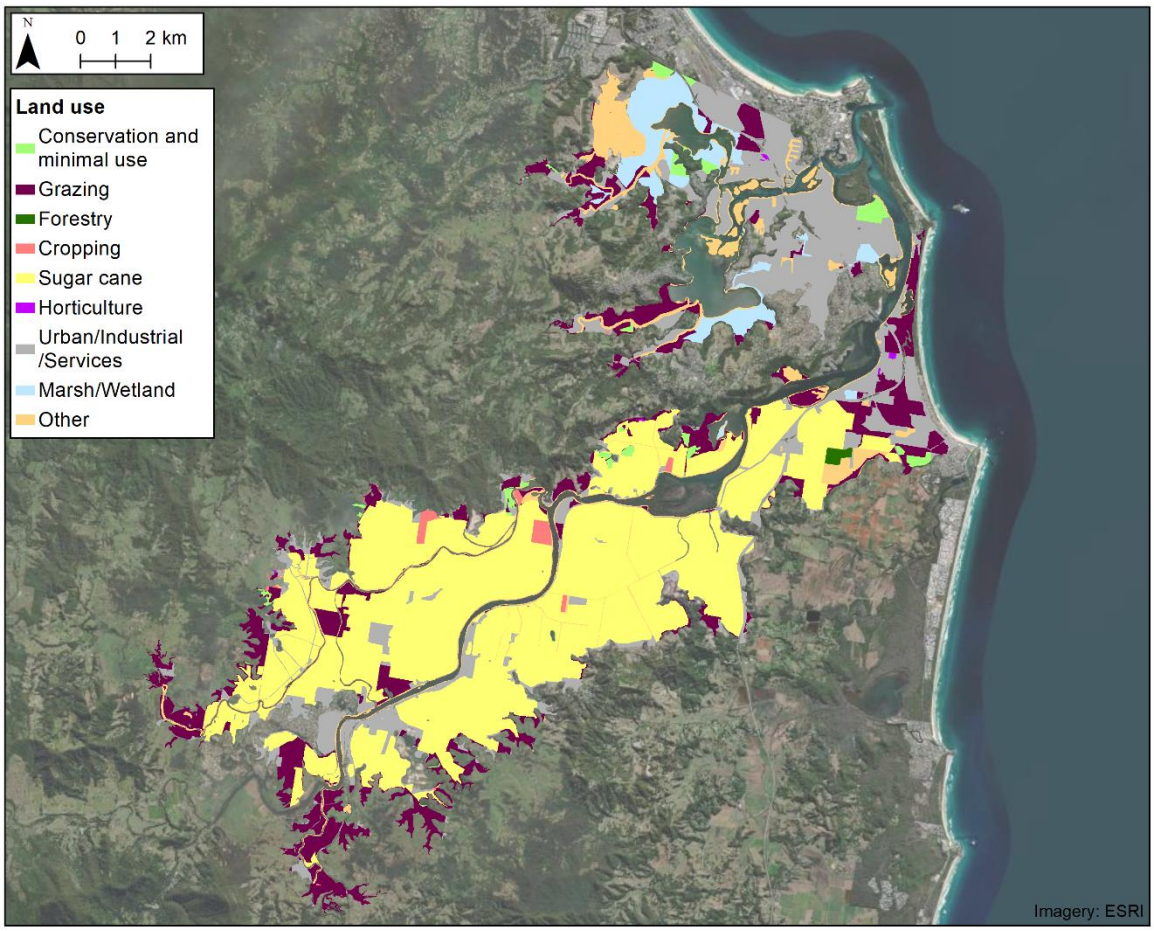


Figure 3-6: Land use in Tweed River floodplain, 2013 (DPIE, 2013)

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 Tweed 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 Tweed Region

The acid pollution hazard in NSW was originally mapped on the Acid Sulfate Soil Risk Maps prepared by Naylor et al. (1998). These maps highlight that the Tweed River floodplain contains approximately 9500 hectares of high-risk ASS below an elevation of 5 m AHD, as shown in Figure 3-7.

The extent and severity of ASS on the Tweed River floodplain has been confirmed by numerous investigations. The following subcatchments have previously been identified by various studies as ASS priority areas:

- Condong (Seccull et al., 2019);
- Dulguigan (Tulau, 1999; Seccull et al., 2019; PWD, 1991);
- South Murwillumbah (Seccull et al., 2019);
- Stotts Creek (Tulau, 1999; PWD, 1991);
- Tumbulgum/Eviron (Tulau, 1999; Seccull et al., 2019); and
- Commercial Road (Seccull et al., 2019).

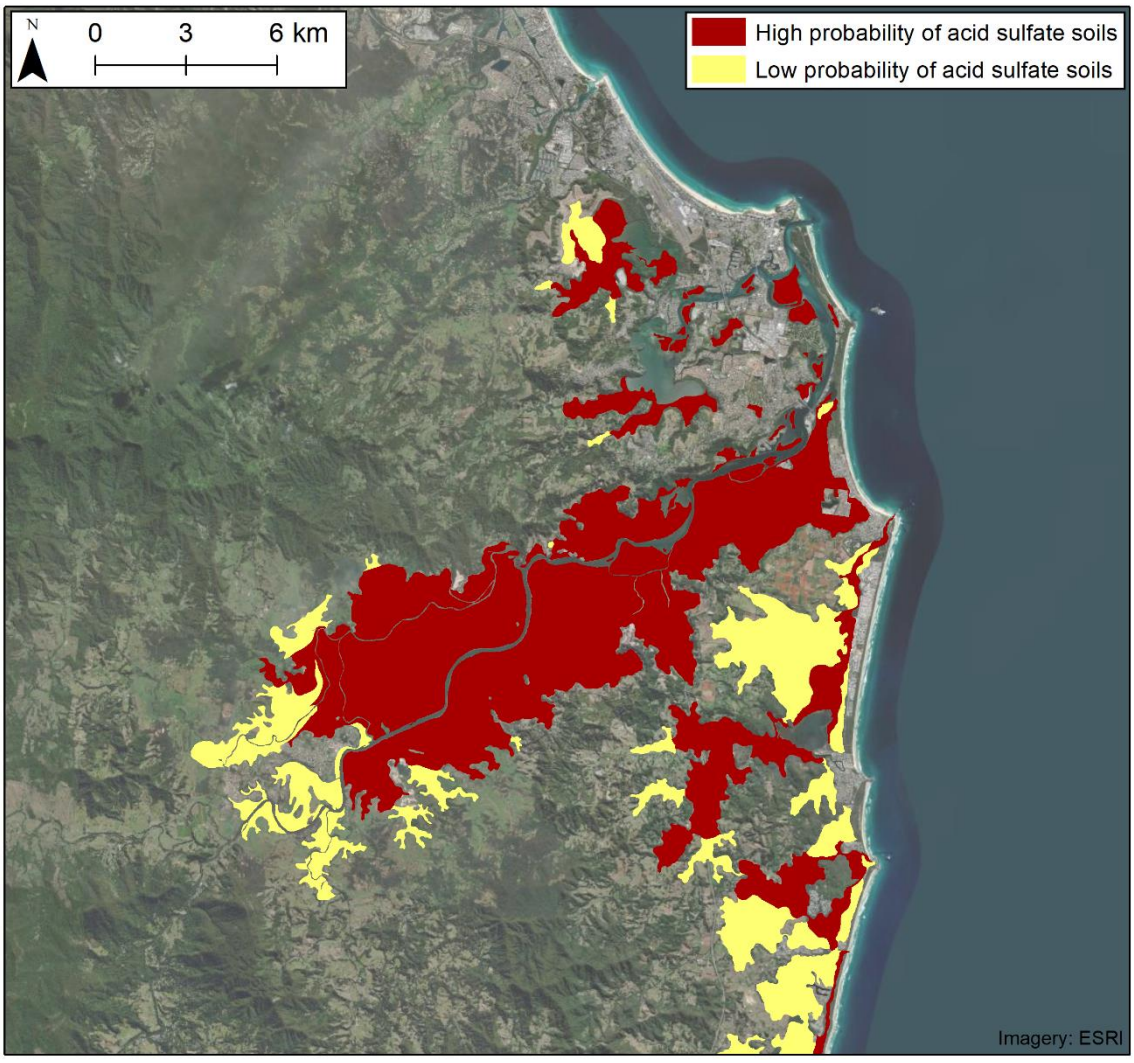


Figure 3-7: NSW Government ASS risk map of the Tweed River floodplain (Naylor et al., 1998)

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

The minimum pH at each available location is shown in Figure 3-8. Low pH (<5) in the soil profiles is common throughout the Tweed River floodplain. The lowest pH values were observed in the South Murwillumbah and Dulguigan subcatchments.

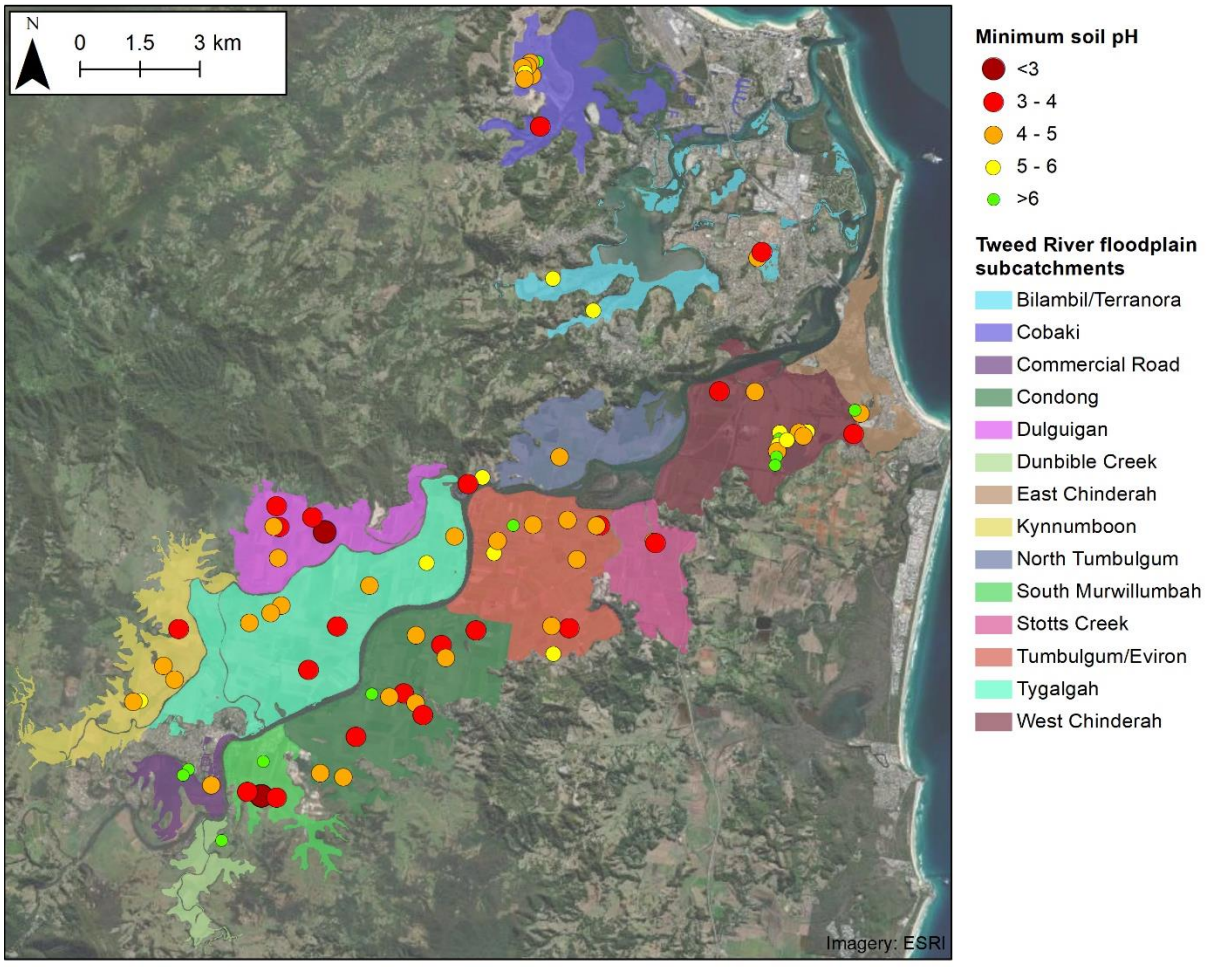


Figure 3-8: Minimum soil pH throughout the Tweed River floodplain

3.5.2 Acid discharge events in the Tweed Region

This section provides a brief overview of acid discharges that have been identified in the Tweed River. These events have been extensively recorded through numerous studies and monitoring programs since 1987, when a large rainfall event triggered an acid discharge event that resulted in major fish kills throughout the Tweed River estuary (Tulau, 2011). A list of water quality studies completed in the Tweed River floodplain can be found in Appendix H.

Acid discharges have been recorded in the Tweed River estuary as early as 1907 when a fish kill event was observed between Murwillumbah and Condong (ASSAY, 2010). Originally thought to be caused by chemicals from the sugar mill, water samples collected during this event were found to contain by-products of ASS oxidisation (ASSAY, 2010). In 1924 another fish kill occurred following a rainfall event, this time originating from the Stotts Creek area (ASSAY, 2010). During this event water was found to contain sulfuric acid and aluminium, both of which are indicators of ASS (ASSAY, 2010). PWD (1991) noted further fish kill events in 1956, 1969 and 1978 when the cause was believed to be ASS.

In 1987, a particularly severe acid runoff event occurred (again following a large rainfall event) that resulted in a mass fish kill within the Tweed River estuary that extended from Murwillumbah to Stotts Creek and included sections of the Rous River (Tulau, 2011; PWD, 1991). It was discovered that the source of this fish kill was again ASS. This 1987 event resulted in extensive research being conducted across the Tweed River estuary to identify the source of the acidic water. Investigations completed in 1987 found significantly low pH water in areas to the north of Tygalgah, Dulguigan, South Murwillumbah and Stotts Creek (PWD, 1991).

Across NSW, the impacts that drainage of ASS had on water quality of estuaries became a focus of research (Tulau, 2011). On the Tweed River floodplain, as the prevalence of ASS was being discovered, investigations began to identify acid sources to commence remediation works. Blacks Drain within the South Murwillumbah subcatchment was identified as a source of acid on numerous occasions (PWD, 1991; Tulau, 2011), and a monitoring network was established by Collins et al. (2009) which discovered pH levels less than 3 being discharged from the upper catchment. At Stotts Creek, a number of investigations found consistently low pH water being discharged from the subcatchment (Wilson, 1995; Willett et al., 1993; White et al., 1993; Lin et al., 1998).

In recent years, water quality monitoring has been commissioned by Tweed Shire Council on an ongoing basis across the Tweed River estuary. The most recent analyses completed for monitoring results have identified the mid-to-upper Tweed River estuary and the Rous River estuary as areas severely impacted by acidic runoff (Pratt et al., 2017). This has led Seccull et al. (2019) to recommend Commercial Road, Condong and South Murwillumbah be added to the ASS hot spots list (along with Dulguigan and Tumbulgum/Eviron) within the Tweed River floodplain.

3.5.3 Acid sulfate soil management on sugar cane farms

While many agricultural industries have had to address the impacts of ASS and acid drainage, the sugar cane industry has been particularly active in creating formal, industry wide guidelines for ASS management. The sugar cane industry operates throughout the Northern Rivers of NSW, including on the Tweed River floodplain. Approximately 50% of sugar cane land in NSW is within areas with known occurrences of ASS (Sunshine Sugar, 2020). The 1987 mass fish kill event led to widespread criticism of the sugar cane industry related to the management of ASS (Tulau, 2011). Over the following decade, the industry took proactive steps to improve management of their soils and drainage to reduce impacts in downstream waterways (Beattie et al., 2001; Sunshine Sugar, 2020; White et al., 2006). This included research, cooperation with government agencies, and the engagement of individual famers.

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

- Soil profiling of individual cane farms to confirm the presence and depth of ASS;
- Development of drainage management plans for each cane farm in NSW, including information on:
    - Depth of ASS;
    - Location and dimension of drains and how to minimises acid discharge;
    - Liming rates required when excavation is necessary; and
    - How to manage farm drainage.
- Cooperation and participation in government programs to actively manage floodgates to improve water quality and allow tidal flushing;
- Laser levelling of farms to reduce the number of drains required to provide adequate surface water drainage and minimise acidic groundwater discharges; and
- Regular auditing and reporting.

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

3.6 Blackwater

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

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

Although blackwater events can be a natural part of lowland river ecosystems (Hladyz et al., 2011) and part of the floodplain carbon cycle (Wong et al., 2010b), the occurrence of blackwater events leads to low dissolved oxygen in estuarine waterways and can be fatal to fish and crustacean communities (Hladyz et al., 2011). Anthropogenic alterations to the floodplain hydrology and vegetation, mainly due to the construction of the drains and other flood mitigation works, have resulted in an increase in the frequency and magnitude of blackwater events (Eyre et al., 2006; Johnston et al., 2003b; Wong et al., 2010a). The construction of one-way floodgates also maintains upstream surface water levels at low tide levels (during average conditions) (Glamore, 2003), and enables non-water tolerant vegetation, such as pasture grasses, to establish at lower elevations where they could historically not survive (Southern Cross GeoScience, 2019). Despite extensive drainage and floodgate infrastructure, these low-lying areas remain prone to inundation during flood events, and are subject to prolonged inundation

due to the relatively flat gradient between backswamp areas and river water levels. Extended inundation of non-water tolerant vegetation leads to plant die off and decay, consuming oxygen from the water column, leading to the formation of low oxygen blackwater. When flood levels in the river recede, low oxygen blackwater drains into the estuary, often further consuming oxygen from the river water (Eyre et al., 2006). Where the blackwater discharges are sufficiently large to overwhelm the receiving water system, this can result in mass fish kill events.

3.6.1 Blackwater runoff in the Tweed River estuary

In the context of coastal floodplains there are a number of drivers that are capable of causing low dissolved oxygen and blackwater within an estuary. Within the Tweed River estuary, investigations that have measured low dissolved oxygen events have identified the main causes to be excess nutrient loading and chemical oxygen demand (SPCC, 1985; MHL, 1997; Pratt, 2017; Holloway et al., 2010). There is little evidence to suggest that blackwater runoff in the Tweed River estuary, caused by the deoxygenation of water resulting from the breakdown of organic matter when the floodplain is inundated, is an ongoing issue. Details of water quality events recorded in the Tweed River estuary, including low dissolved oxygen, are available in Appendix H. Further details outlining the generation of blackwater are available in Section 5 of the Methods report (Rayner et al., 2023)

Floodplain hydrological characteristics play an important role in the generation and transport of blackwater within an estuary. Key floodplain characteristics include:

- Upstream catchment;
- Land elevation;
- Time taken for water to drain from the floodplain;
- Drainage pathways from the floodplain to the estuary; and
- Layout of major waterways within the estuary.

Within the Tweed River estuary, the floodplain's hydrological characteristics are such that it is not prone to the generation of blackwater caused by the prolonged inundation of the floodplain. Note, this does not mean that blackwater cannot be an issue within the Tweed River estuary. Seccull et al. (2019) identified ponding on the floodplain forming blackwater following flood events as a key threat to water quality within the Tweed River estuary.

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 Tweed 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. Furthermore, while both mechanisms might produce poor water quality within the estuary, an abundance of data suggests that poor water quality resulting from ASS poses a significantly higher risk to the Tweed River estuary when compared to poor water quality resulting from blackwater.

3.7 Coastal management in the Tweed River estuary

This section provides a summary of how coastal management addresses acid drainage and blackwater runoff within the Tweed River estuary. The Tweed Shire Council is currently in the final stages of the development of the Tweed River estuary Coastal Management Program (CMP) (Seccull et al., 2019).

In addition to this, Holloway et al. (2010) have created a Coastal Zone Management Plan (CZMP) specific for the Cobaki Broadwater and Terranora Broadwater, which are tributaries of the Tweed River estuary. Together, the Tweed River estuary CMP and the Cobaki Broadwater and Terranora Broadwater CZMP outline the long-term strategy for the management of the estuary.

In addition to the coastal management programs, MEMS has completed a threat and risk assessment (TARA) for the NSW marine estate which includes the Tweed River estuary. This aims to identify and prioritise threats to the environmental, social, cultural and economic benefits derived from the NSW marine estate (Fletcher and Fisk, 2017).

3.7.1 Tweed River estuary CMP (Seccull et al., 2019)

Seccull et al. (2019) identified two key threats to the Tweed River estuary related to ASS and blackwater:

1. Habitat loss and barriers to habitat connectivity; and
2. Degraded estuarine water quality.

For each threat, Seccull et al. (2019) identified the individual contributions to the threat and developed actions required to reduce the threat alongside a ranking of each action. These rankings are based on the assessed risk of each threat and include low, medium, high, and fundamental.

To reduce habitat loss and increase connectivity to habitat Seccull et al. (2019) recommended restoring natural drainage and tidal exchange to the floodplain. Within the context of ASS, this action involves auditing floodgates to assess opportunities to improve connectivity while taking the risk of ASS into account. While this action was identified as a low priority, the remediation of floodplain wetlands as a way to mitigate the impacts of ASS was identified as a medium priority action.

ASS runoff has been identified as a major contributor to the threat of degraded water quality within the middle to upper Tweed River estuary. Actions identified by Seccull et al. (2019) to reduce this threat include:

- Work with the sugar industry to reduce acid runoff from the Tumbulgum/Eviron, Condong, South Murwillumbah and Commercial Road areas (high priority) and continually improve self-regulation of ASS (medium priority);
- Complete event based sampling of pH to identify ASS hot spots (medium priority);
- Utilise pH loggers to monitor ASS remediation (medium priority);
- Identify locations where ASS oxidation can be prevented through manipulation of the water table (medium priority); and
- Ensure appropriate management of consent and exemptions within high risk ASS affected land (low priority).

Blackwater was also found to be one of the key contributors to the threat of degraded estuarine water quality within the CMP. It was found that poor drainage and inundation of water intolerant vegetation increased the risk of poor water quality for the estuary, particularly following floods (Seccull et al., 2019). Despite this finding, no actions were recommended that specifically address reducing the risk of blackwater.

3.7.2 Cobaki Broadwater and Terranora Broadwater CZMP (Holloway et al., 2010)

Holloway et al. (2010) identified a number of management issues that relate to the impacts of ASS on poor water quality for the Cobaki Broadwater and Terranora Broadwater, including:

- Major urban development;
- Impacts on fauna (specifically oysters); and
- Climate change.

Blackwater has not been identified as an issue for the Cobaki Broadwater and Terranora Broadwater by Holloway et al. (2010), although reduced dissolved oxygen due to nutrient loading has been identified as an issue.

To address the threats posed by the management issues, a number of actions have been developed with the goal of protecting and remediating natural ecosystems (Holloway et al., 2010). These actions address issues that would assist in reducing the impacts of ASS and blackwater, including:

- Extensive remediation across the Cobaki Broadwater and Terranora Broadwater;
- Develop management options to help landholders remediate drains;
- Investigate locations identified as poor water quality sources;
- Investigate modifying culverts to allow tidal exchange; and
- Identify risks associated with climate change.

3.7.3 Summary of coastal management programs

The CMP for the Tweed River estuary and the CZMP for the Cobaki Broadwater and Terranora Broadwater highlight that addressing poor water quality resulting from acid, and to a lesser degree blackwater discharge, is a priority (Holloway et al., 2010; Seccull et al., 2019). Specific on-ground remediation works completed by Tweed Shire Council and DPIE as part of the coastal management program in the Tweed River floodplain are discussed in the history of remediation of individual subcatchments in Section 8. The prioritisation and associated management options developed in this study may be used to guide the implementation of the management strategies from the CMP for the Tweed River estuary and the CZMP for the Cobaki Broadwater and Terranora Broadwater. This includes identification of additional floodplain infrastructure that may be optimised by modification or active management and identifying subcatchments where improved farm management practices may be particularly effective at reducing acid or blackwater discharges.

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

A state-wide threat and risk assessment (TARA) was completed in 2017 to identify and prioritise threats to the environmental, social, cultural and economic benefits derived from the NSW Marine Estate (Fletcher and Fisk, 2017). This assessment found that diffuse agricultural runoff is the single highest priority threat to the environmental assets within estuaries in NSW and also presents 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 ASS and blackwater drainage associated with clearing riparian vegetation and artificial drainage as a high environmental risk to estuaries throughout the state.

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

4 Overview of prioritisation methods

4.1 Preamble

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

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

Both prioritisation methods have been designed to compare and rank subcatchments within an individual coastal floodplain. Therefore, the factors and subcatchment rankings in the Tweed 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.

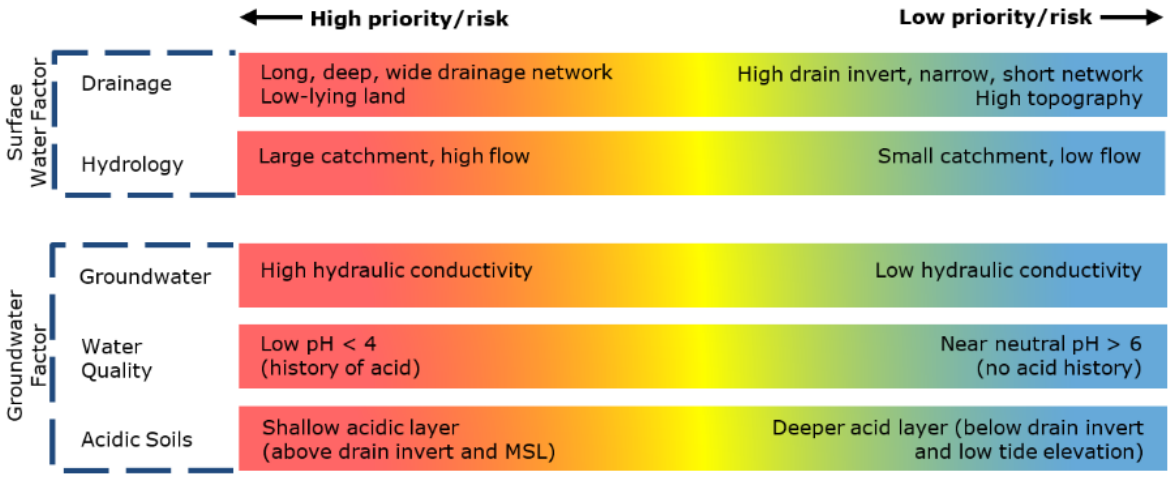


Figure 4-1: Factors influencing ASS discharge in coastal NSW that have been incorporated within the assessment method (adapted from Johnston et al. 2003a)

4.2.1 Surface water factor

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

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

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

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

4.2.2 Groundwater factor

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

The groundwater factor uses locally acquired sediment profile data and hydraulic conductivity measurements within each subcatchment. Where existing data was insufficient, additional data was collected specifically for this project, including 33 soil profiles and 22 soil hydraulic conductivity measurements on the Tweed River floodplain. Details of the calculation of the groundwater factor can be found in Section 4.4 in the Methods report (Rayner et al., 2023).

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

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

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

4.3 Blackwater prioritisation

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

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

(i) a contributing area of the catchment that results in blackwater production; and

(ii) the oxygen consumption risk associated with different land use and vegetation types.

These factors incorporate the key physical attributes that drive production of blackwater on coastal floodplains, discussed in detail in Section 6 of the Methods report (Rayner et al., 2023). Unlike the ASS prioritisation, the blackwater prioritisation has been undertaken with existing, catchment, or state-wide 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 Tweed River floodplain during a blackwater event).

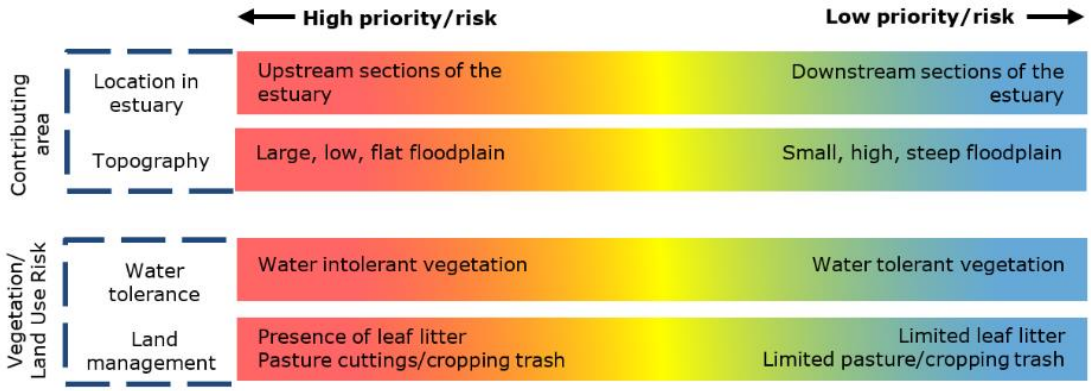


Figure 4-2: Factors influencing blackwater discharge within a coastal floodplain in NSW

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 Tweed River estuary and floodplain. While 25 water level thresholds are used in this analysis, a median elevation has been adopted throughout this report to provide an indicative elevation for blackwater contribution in each floodplain subcatchment.

4.3.2 Land use/vegetation risk factor

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

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

Areas that have been mapped as macrophytes by DPI Fisheries (2019) or as open water bodies have been excluded from contributing to blackwater risk. The land use risk factor has been combined with the contributing area factor to calculate the final blackwater risk ranking for each subcatchment. This ranking identifies areas that pose the greatest risk of blackwater generation. It is worth noting that this ranking does not consider 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 Tweed River floodplain. The summary rankings and acid prioritisation factors for each of the subcatchments are provided in Section 5.2. The final rankings in the ASS priority assessment are a function of a surface water drainage factor and a groundwater factor calculated for each subcatchment, as discussed in Section 4.2 and Appendices A - D. The highest priority subcatchments have the highest combination of the surface water and groundwater factors, thereby presenting the highest risk of acid drainage.

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

5.2 ASS Prioritisation of the Tweed River floodplain

A summary of the catchment wide ASS prioritisation is provided in Table 5-1 and presented in Figure 5-1 to Figure 5-3. The top two (2) priority subcatchments identified were Condong and South Murwillumbah, which are both located in the Tweed River upper estuary. The Dulguigan and Kynnumboon subcatchments on the Rous River were also ranked highly showing that a large proportion of the risk is sourced from the upper Tweed River estuary. Poor water quality from these areas has the potential to flow through and impact the entire estuary.

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

Subcatchment	Groundwater factor	Surface water factor	Final acid factor	Rank
Condong	306	953	291,186	1
South Murwillumbah	572	481	274,768	2
Dulguigan	311	538	167,614	3
Kynnumboon	102	1,349	137,934	4
Stotts Creek	173	375	64,909	5
Tumbulgum/Eviron	80	606	48,205	6
Tygalgah	74	458	34,103	7
West Chinderah	52	523	27,200	8
North Tumbulgum	43	455	19,380	9
Cobaki	34	283	9,650	10
Bilambil/Terranora	29	190	5,516	11
East Chinderah	12	82	991	12
Commercial Road	3	174	515	13
Dunbible Creek	4	120	448	14

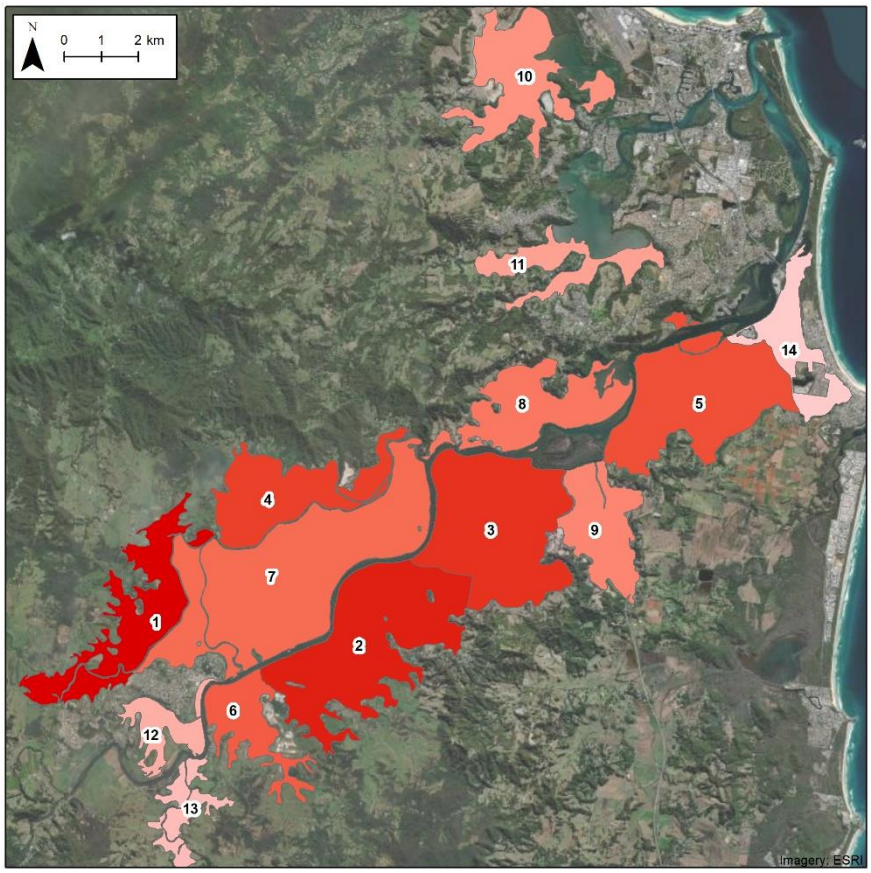


Figure 5-1: Surface water factor ranking for the Tweed River floodplain

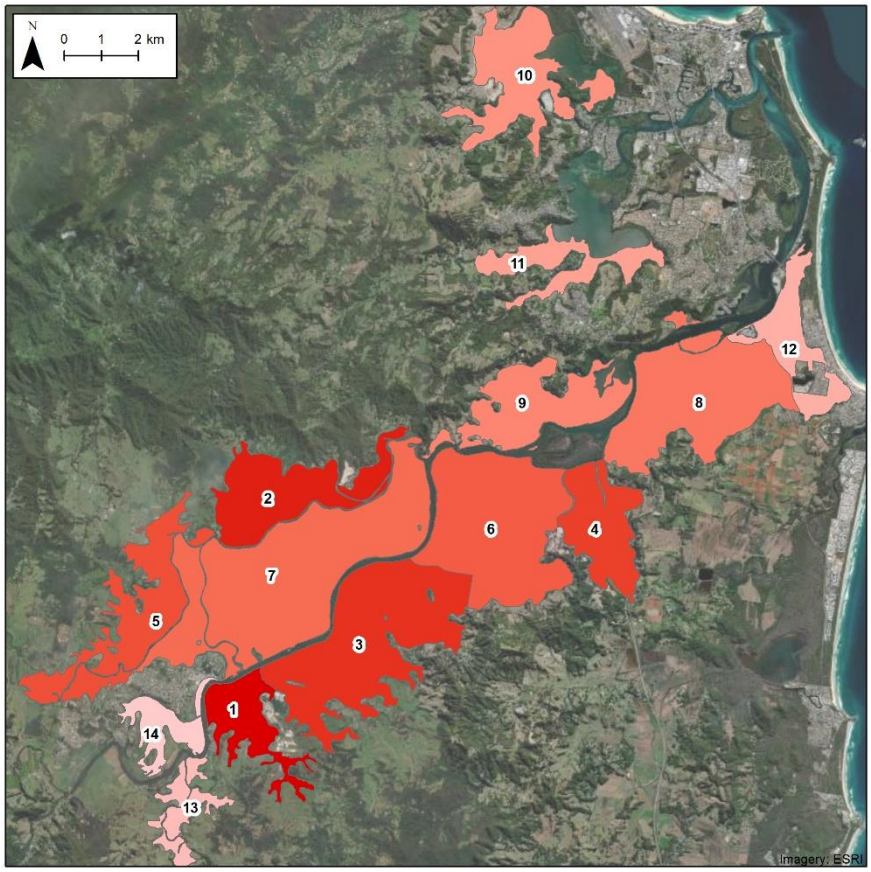


Figure 5-2: Groundwater factor ranking for the Tweed River floodplain

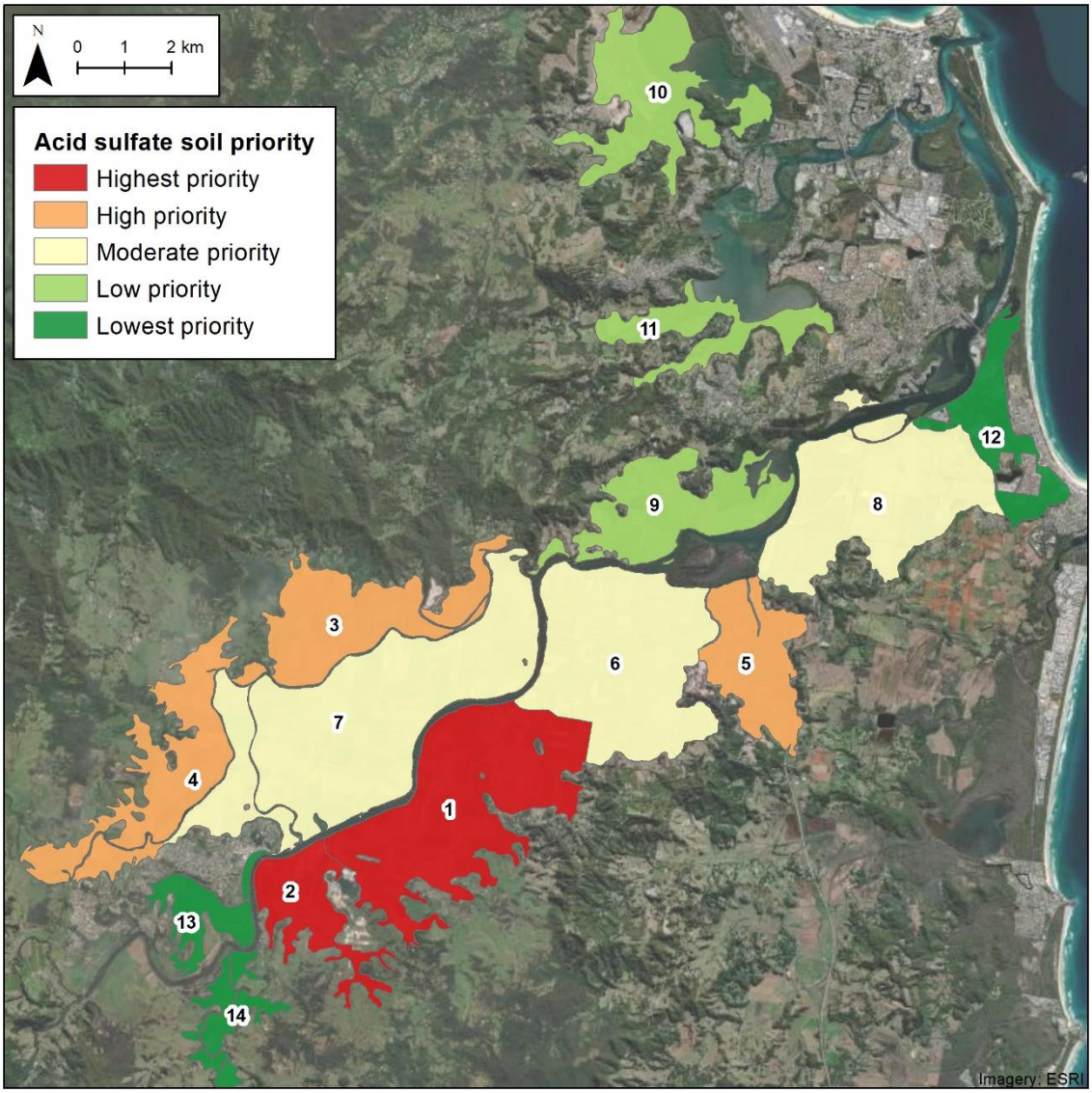


Figure 5-3: Final ranking of ASS prioritisation for the Tweed River floodplain

6 Blackwater prioritisation assessment outcomes

6.1 Preamble

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

A summary of blackwater prioritisation is provided in Table 6-1 and presented in Figure 6-1 and Figure 6-2. The top two (2) priority subcatchments were identified as Tumbulgum/Eviron and Tygalgah, both located in the mid-estuary. It should be noted that for Stotts Creek subcatchment (ranked 4), the median contributing area is large in comparison to other subcatchments. Despite this, due to its size and location within the Tweed River floodplain, the risk of blackwater from the Stotts Creek subcatchment is less than other subcatchments when considering the combination of water level thresholds (Section 4.3.1). However, the combined blackwater generation potential from connected backswamp areas within the southern floodplain subcatchments (i.e. Stotts Creek, Tumbulgum/Eviron, and Condong) represents the greatest blackwater risk from a combined inundation area.

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

Subcatchment	Median blackwater elevation (m AHD)	Final blackwater factor	Rank
Tumbulgum/Eviron	0.8	12.2	1
Tygalgah	1.0	12.1	2
Condong	0.8	7.5	3
Stotts Creek	0.7	6.9	4
North Tumbulgum	0.7	5.9	5
Dulguigan	1.0	5.8	6
West Chinderah	0.5	5.6	7
Kynnumboon	1.4	5.4	8
South Murwillumbah	0.7	1.6	9
Cobaki	0.4	1.2	10
Bilambil/Terranora	0.4	1.1	11
East Chinderah	0.4	0.9	12
Dunbible Creek	0.7	0.8	13
Commercial Road	0.7	0.4	14

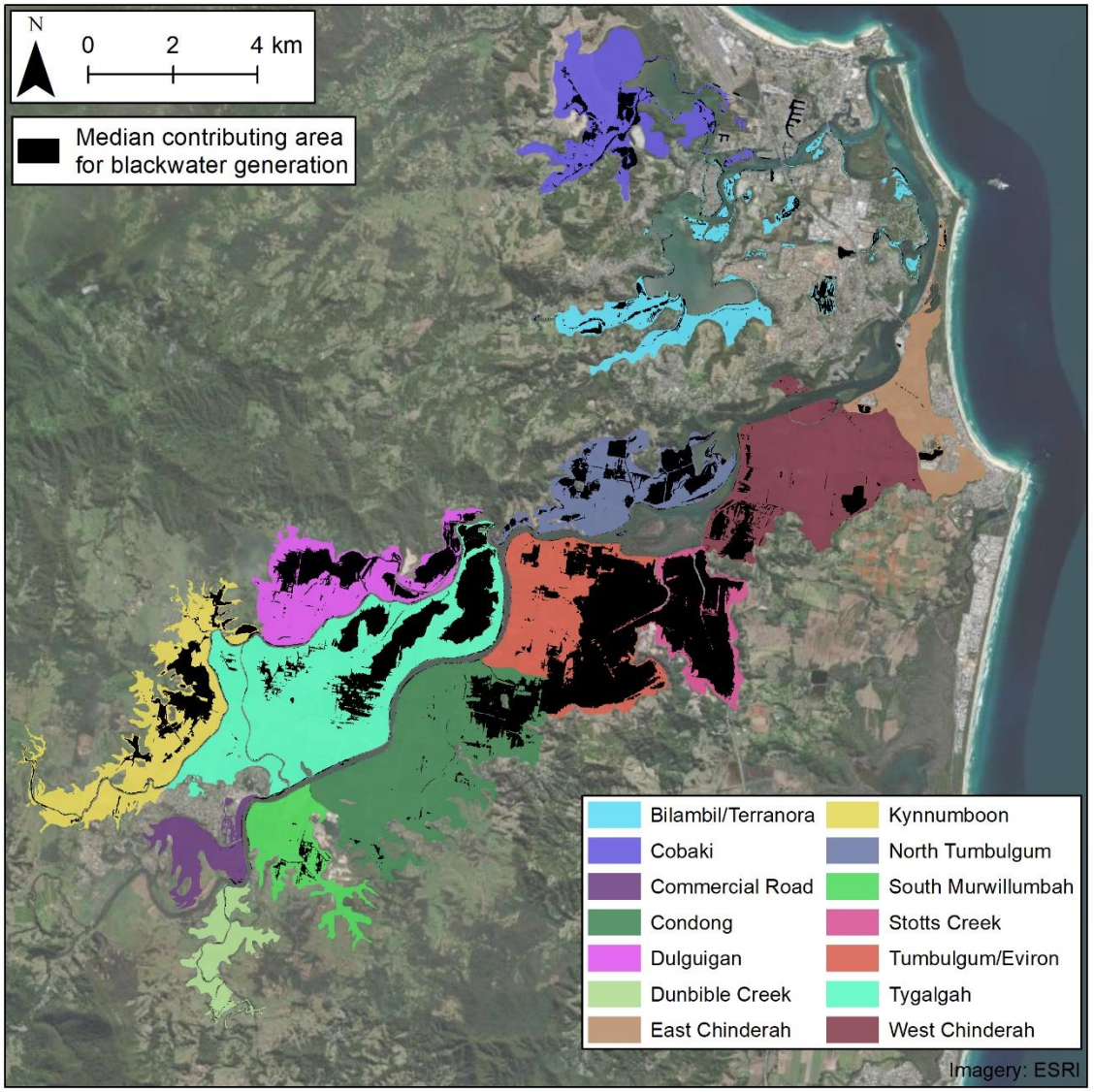


Figure 6-1: Median contributing area for blackwater generation across the Tweed River floodplain

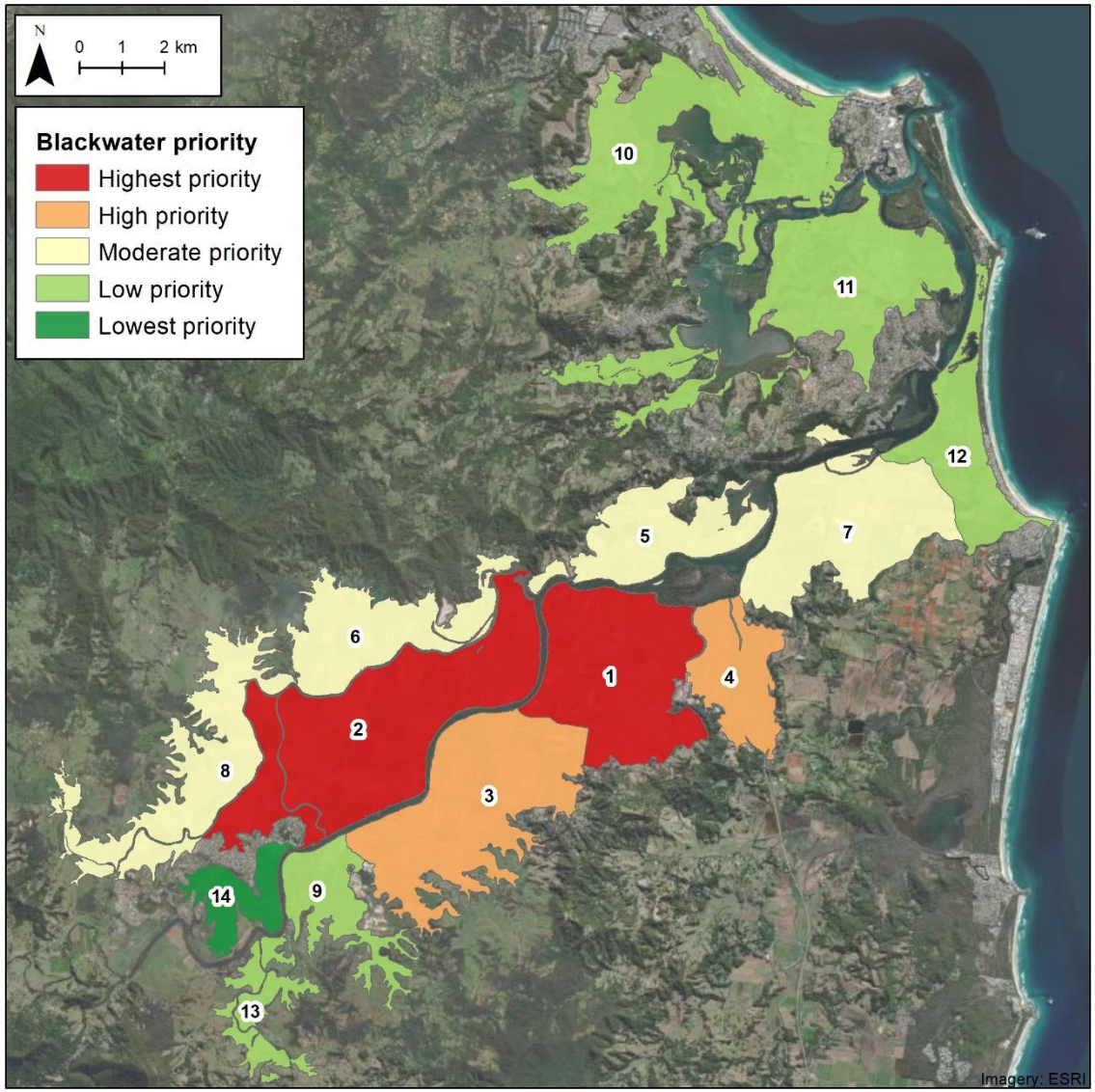


Figure 6-2: Final ranking of the blackwater prioritisation in the Tweed River floodplain

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

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

7.2 Changes to water levels in estuaries

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

Numerical models enable the behaviour and response of estuaries to sea level rise to be investigated. Section 11 of the Methods report (Rayner et al., 2023) discusses the different types of numerical models and their merit for use in dynamic estuarine systems. For this study, a hydrodynamic numerical model was constructed of the Tweed River estuary, and calibrated to present day tidal levels throughout the estuary. The tidal levels at the ocean 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 Tweed 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 Tweed River estuary. Further details on the model development and calibration can be found in Appendix I.

7.2.1 Tweed 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 Tweed River estuary. The model domain, shown in Figure 7-1, extends across the tidal regions including the Tweed River, Rous River and Terranora Creek. The numerical model was constructed using a combination of one dimensional (1-D) and two dimensional (2-D) elements. 1-D elements were used in areas where flow occurs perpendicular to the cross section and 2-D elements were used to represent the lower estuary where complex free surface flows occur (i.e. where the flow can occur in both the x-y plane).



Figure 7-1: Tweed River estuary hydrodynamic model extent

The model was developed to ensure coverage of the areas of interest (i.e. major floodgate infrastructure) in the lower estuary and extends up to the tidal limit at Bray Park Weir on the Tweed River and Boat Harbour on the Rous River. The hydrodynamic model comprised of three (3) main inputs:

1. **Channel bathymetry and geometry** are based on the numerical modelling undertaken by BMT (2019) for the Tweed Estuary Tidal Inundation Assessment and Mapping Study;
2. **Downstream tidal water levels** are applied at the downstream ocean boundary. This was based on the observed records from the NSW DPIE Manly Hydraulics Laboratory (MHL) water level station at Tweed Entrance South (Station # 201472); 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. Oxley River at Eungella (Station # 201001);
    b. Tweed River at Uki (Station # 201900);
    c. Rous River at Boat Harbour (Station # 201005).

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 Tweed River estuary (which is dominated by the downstream tidal dynamics). As such, the resulting hydrodynamic model is calibrated for everyday tides, but is not suitable to replicate catchment wide flood events. This is considered to be appropriate because the hydrodynamic model has been used in this study as a tool to assess the vulnerability of end of drainage system infrastructure, and floodplains subject to day-to-day drainage, rather than large-scale catchment flood events. Further information on the hydrodynamic model setup is provided within Appendix I.

The hydrodynamic model of the Tweed River estuary was calibrated to measured water level monitoring stations along the main river channel for a year of average rainfall (2017). Details of the model calibration are provided in Appendix I. The calibrated model was then used to simulate a representative 'wet' year (i.e. more rain than average across the catchment) and a representative 'dry' year (i.e. less rain than average across the catchment) based on analysis of rainfall records in Northern NSW. For this project, 2013 and 2019 were selected as the wet and dry years, respectively based on long term rainfall monitoring by the Bureau of Meteorology. The model results from these simulations were then used to verify the tidal water level patterns throughout the estuary.

7.2.2 Historic and future sea level rise

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

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

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

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 12-member 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 Tweed River estuary.

Table 7-1: Adopted Mean Sea Level (MSL) relative to present-day (2020)

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

7.3 Water level statistics

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

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

- **5th percentile water level** (water levels are below this level 5% of the time, or around 1 hour a day) – this represents a low tide water level at a given location. Areas below the 5th percentile water level are typically permanently inundated and difficult to drain without additional mechanical assistance (i.e. pumping);
- **50th percentile water level** (water levels are above/below this level 50% of the time) – this is a median water level. Areas below the 50th percentile water level can be difficult to drain efficiently, although the use of one-way floodgates has allowed agricultural development on low-lying land; and
- **95th percentile water level** (water levels are below this level 95% of the time, or around 23 hours a day) – this represents a high tide water level at a given location. While these areas

are commonly used for agriculture, areas below the 95th percentile water level may be impacted by reduced drainage, particularly after flood events.

7.4 Floodgate vulnerability

Tidal floodgates are used extensively throughout the Tweed River estuary to mitigate backwater flooding from the river, prohibit tidal water from inundating low areas of the floodplain, and to encourage regular tidal drainage to the low tide level for areas upstream of the floodgate. The vulnerability of a floodgate 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 to 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 tidal floodgate at the end of the drainage system, where the drainage system discharges into the estuary and where infrastructure survey data was available.

Figure 7-3 to Figure 7-6 present floodgate vulnerability maps for the Tweed River estuary for the scenarios tested. Detailed mapping for each floodplain subcatchment is provided in Section 8. Note, 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. Ongoing maintenance of floodgates will be required into the future and may result in upgrades to infrastructure (TSC, 2011).

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, 154 out of 363 (42%) surveyed floodgates are considered "Most Vulnerable", compared to just 18 (5%) in present day conditions. As shown in Figure 7-5 and Figure 7-6, the lower estuary has a higher portion of floodgate infrastructure that is identified as moderate-to-high vulnerability than the upper estuary.

Table 7-3: Vulnerability classification of Tweed River floodplain floodgates

	Historic (HS)	Present day (PD)	Near future (NF)	Far future (FF)
Least Vulnerable	259	245	198	101
Moderately Vulnerable	91	101	133	113
Most Vulnerable	11	15	30	147

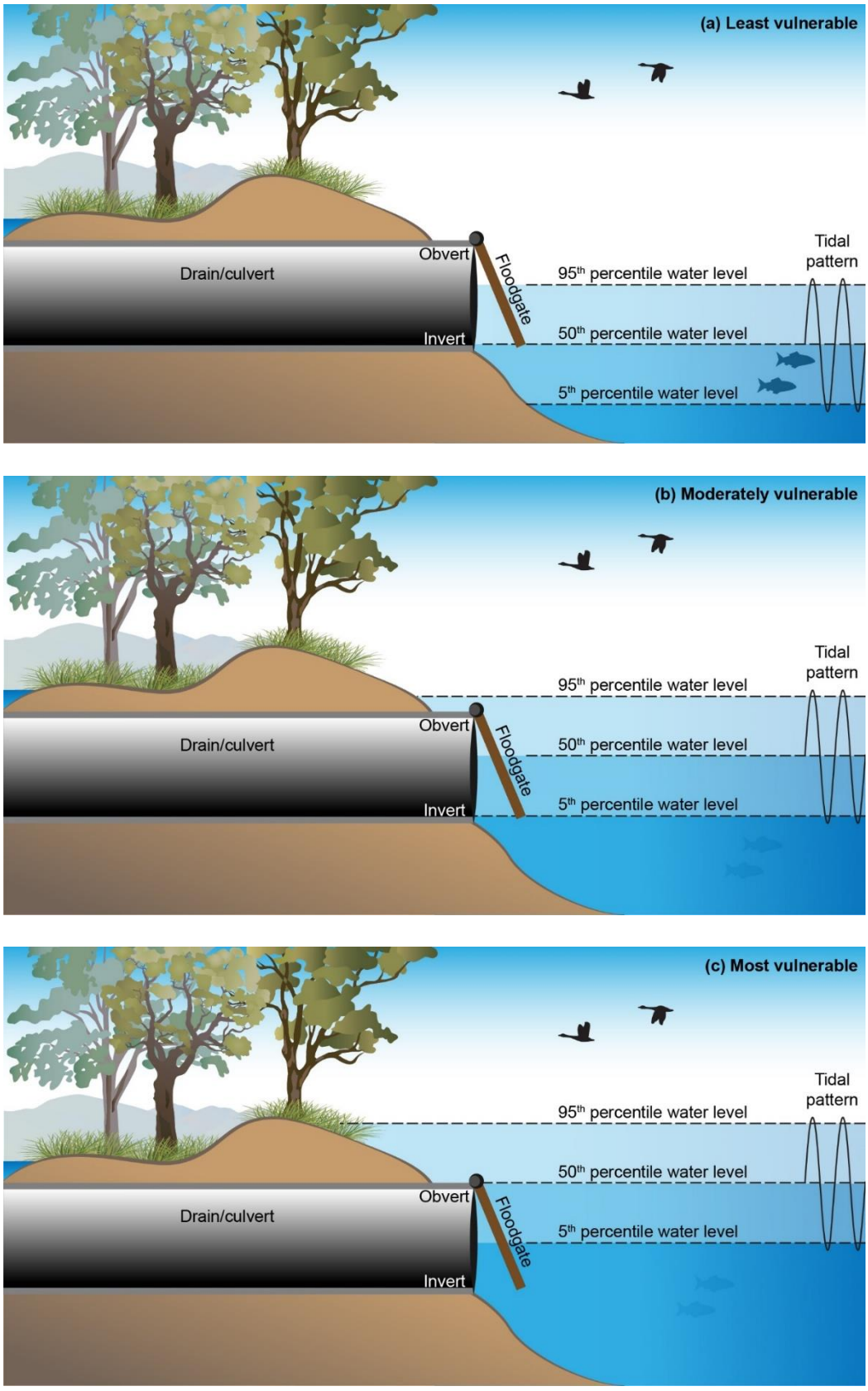


Figure 7-2: Floodgate vulnerability assessment

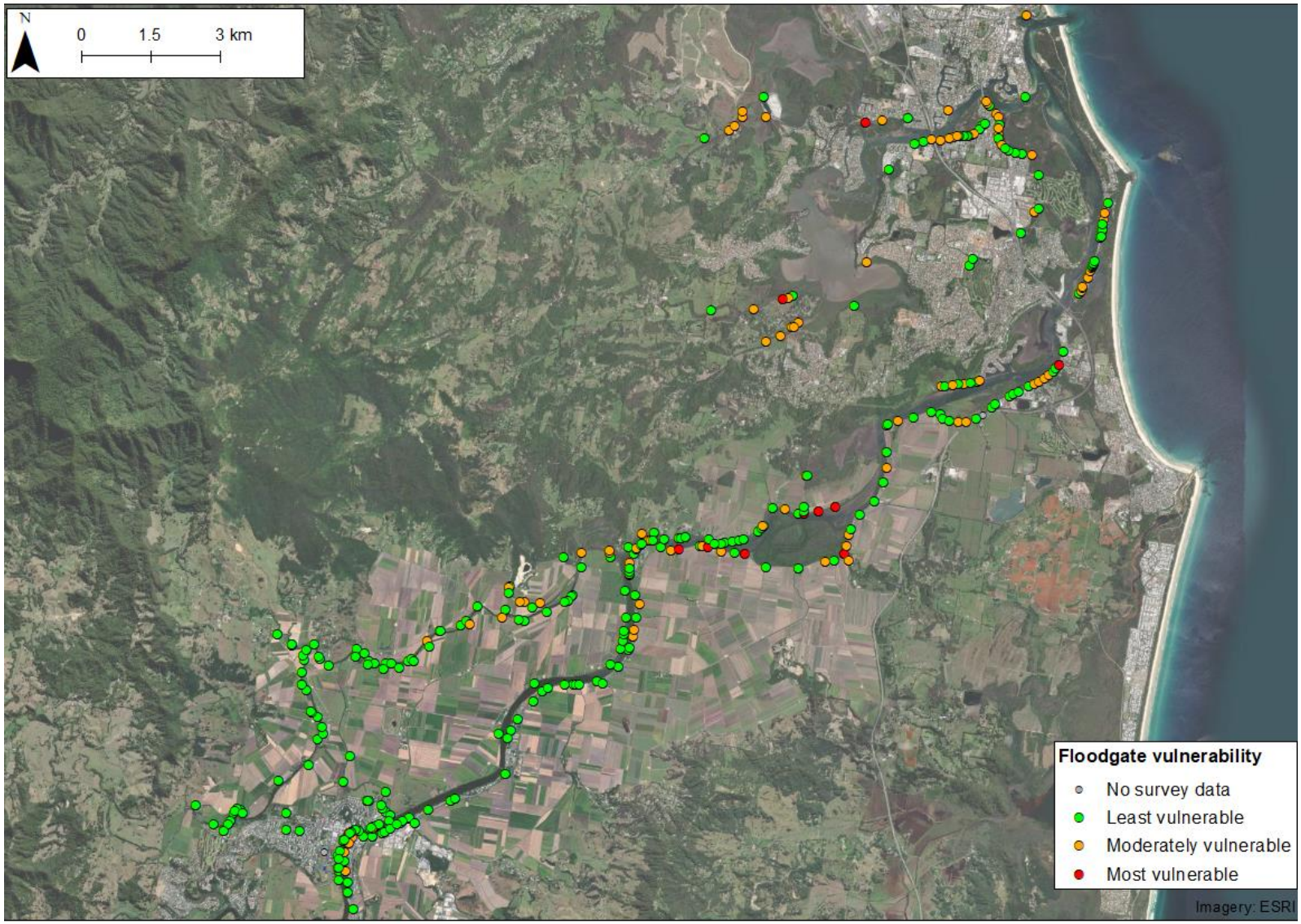


Figure 7-3: Historic (~1960s) floodgate vulnerability – Tweed River estuary

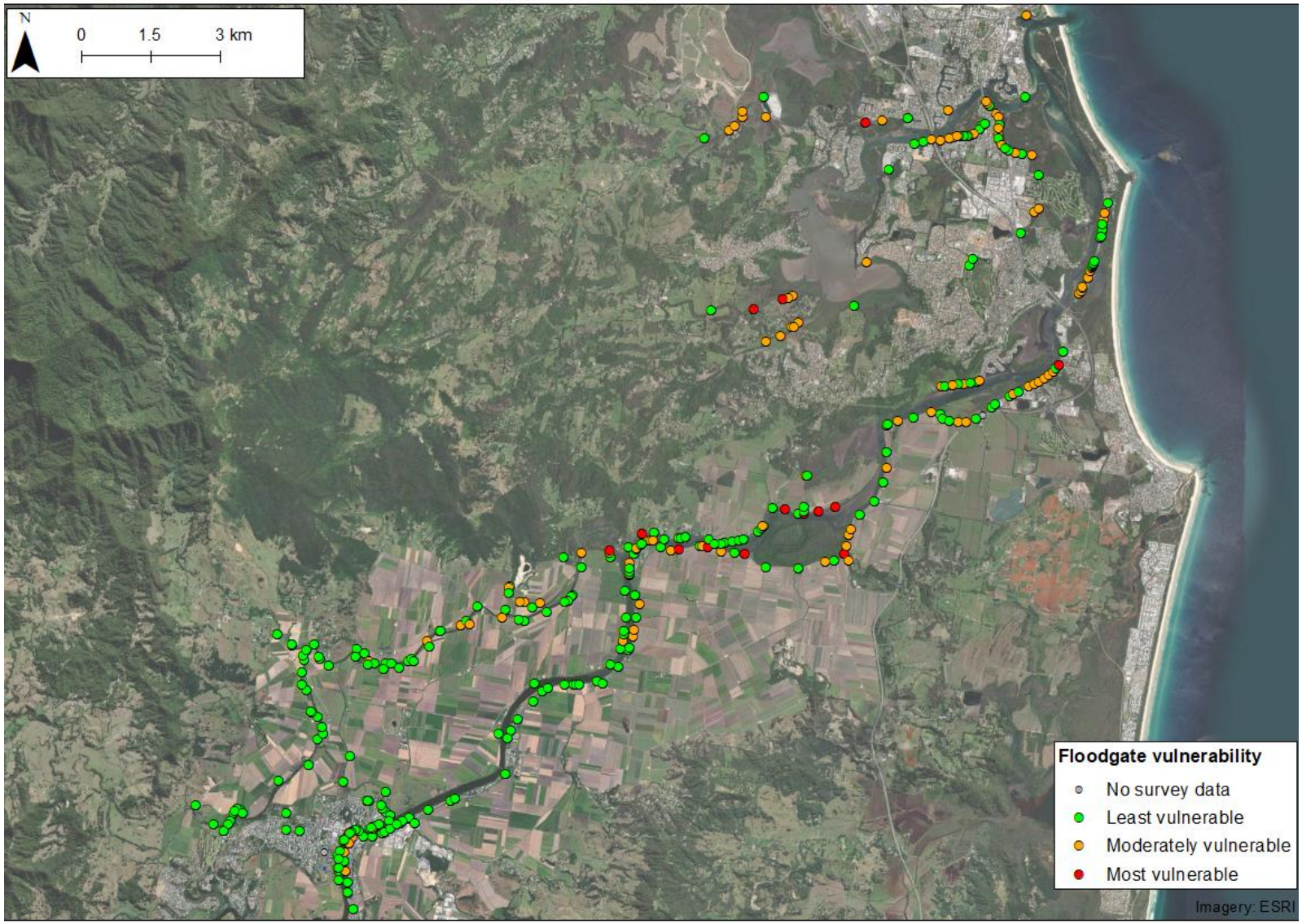


Figure 7-4: Present day floodgate vulnerability – Tweed River estuary

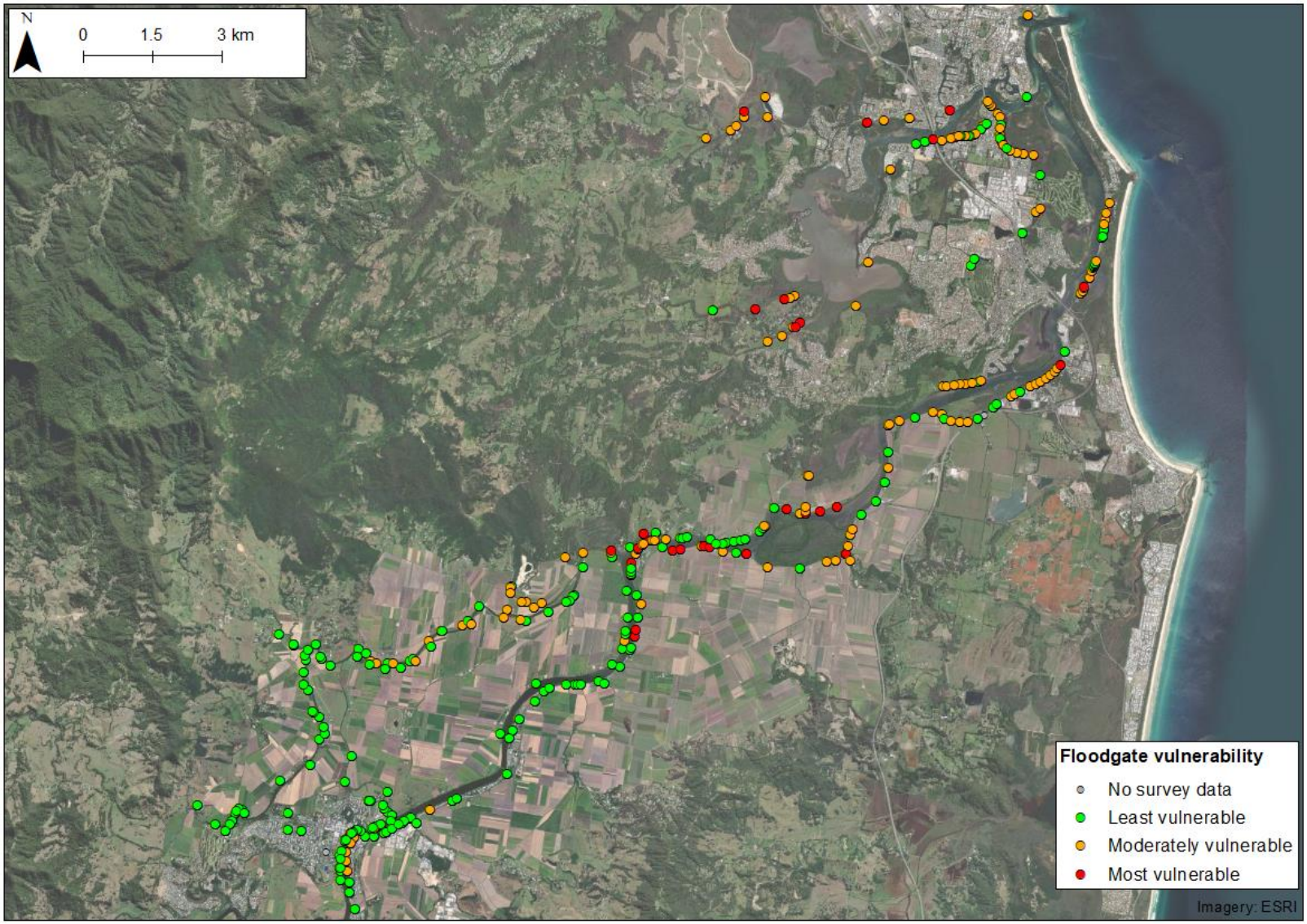


Figure 7-5: Near future (~2050) floodgate vulnerability – Tweed River estuary

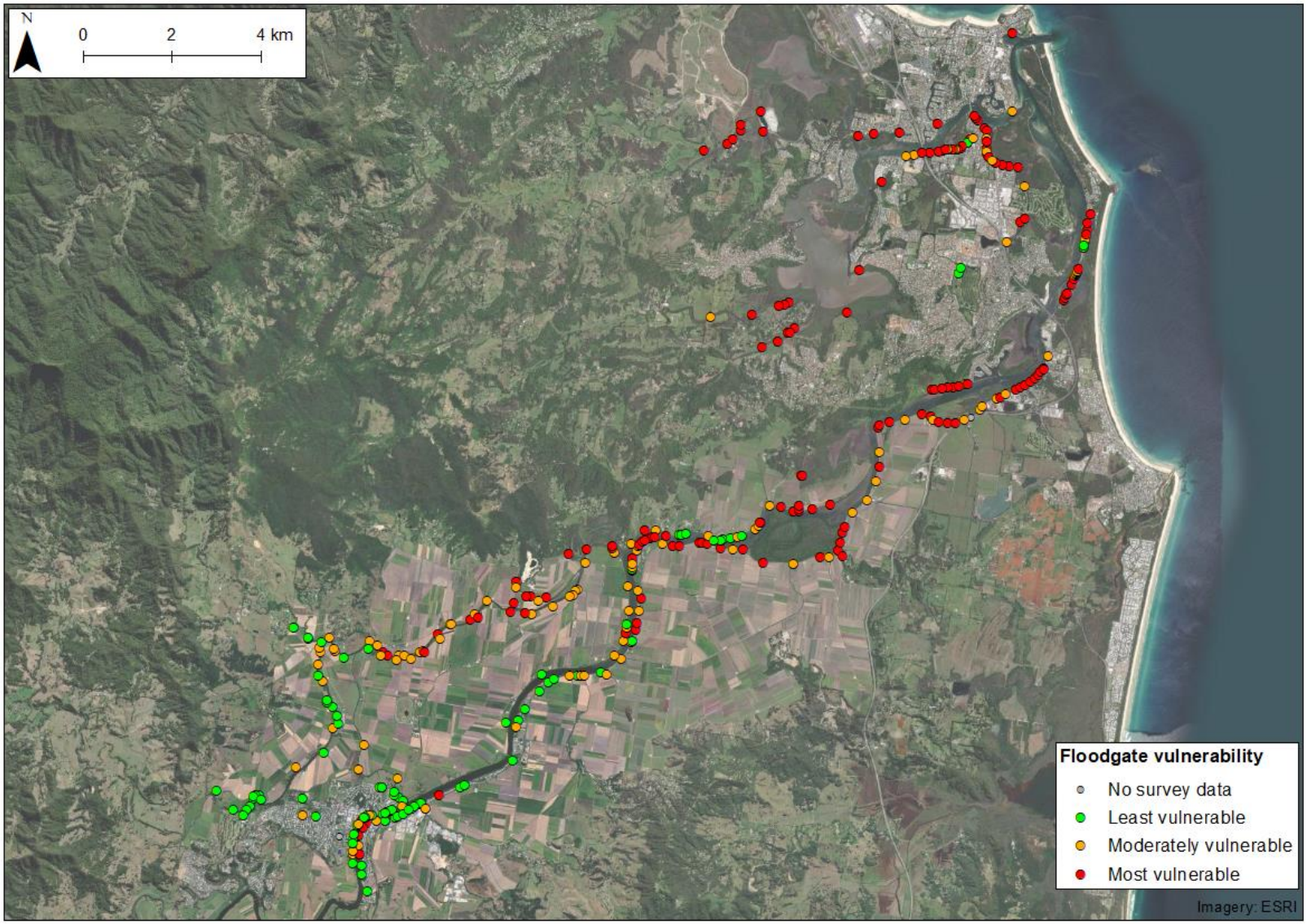


Figure 7-6: Far future (~2100) floodgate vulnerability – Tweed River estuary

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 on 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 Tweed 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.

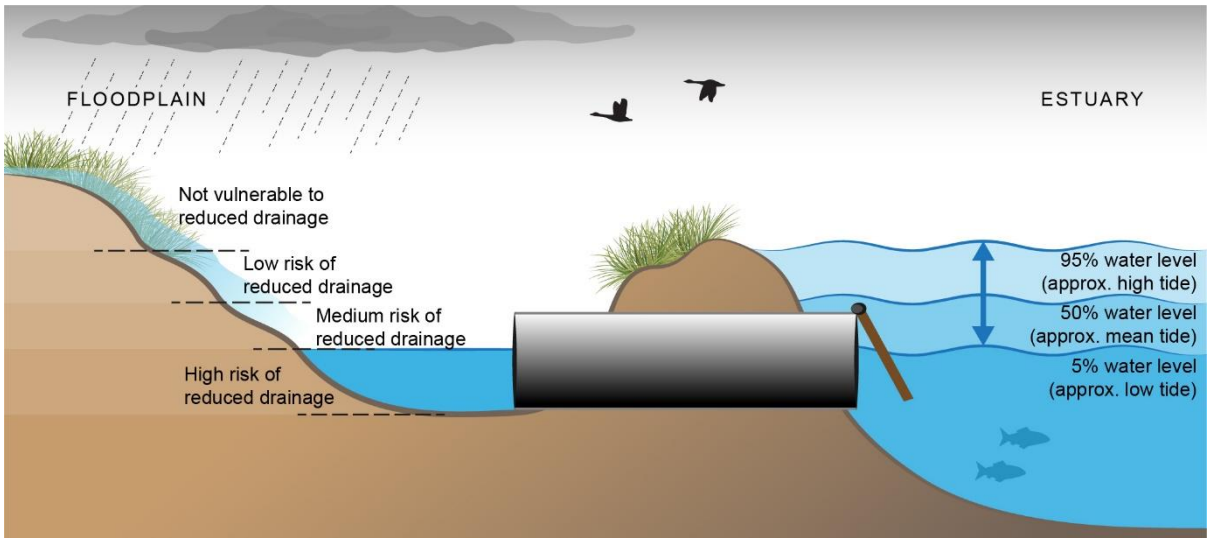


Figure 7-7:Floodplain drainage vulnerability

The total floodplain areas below the water level percentiles for the historic (HS), present day (PD), near future (NF) and far future (FF) sea level rise scenarios for the Tweed River are summarised in Table 7-5. While the area below the 5th percentile water level more than doubles between present day and the near future, this increases to more than 30 times in the far future to over 383 ha. The total floodplain area below the 95th percentile water level almost triples when the present day water levels are compared to the far future water levels.

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

Vulnerability status	Level criteria	Area (hectares)			
		Historic (HS) ~1960	Present day (PD) 2020	Near future (NF) ~2050	Far future (FF) ~2150
Low	50th percentile water level < Land elevation < 95th percentile water level	1,696	2,002	2,895	4,023
Moderate	5th percentile water level < Land elevation < 50th percentile water level	93	121	308	2,438
High	Land elevation < 5th percentile water level	9	13	36	383

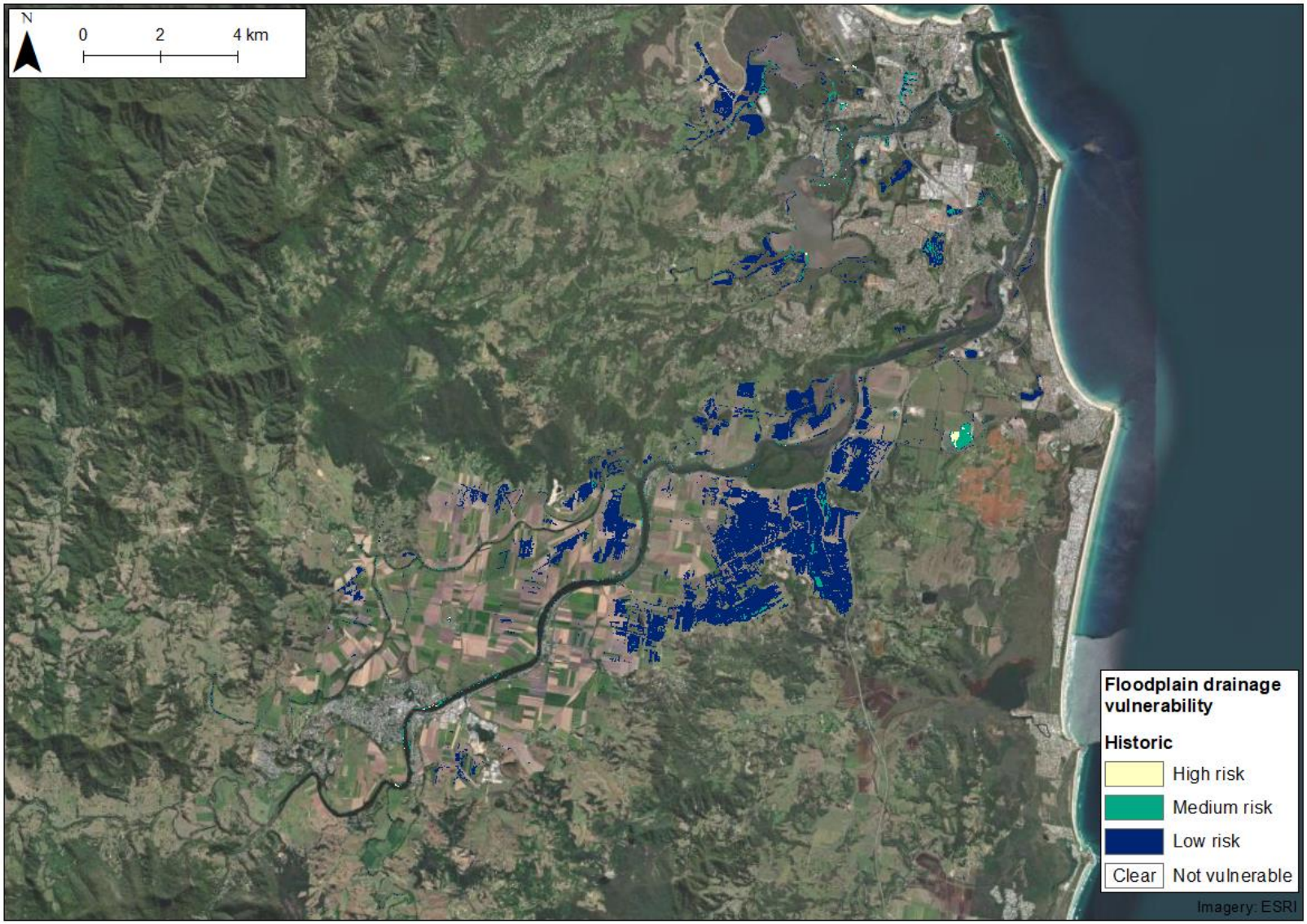


Figure 7-8: Historic (~1960s) floodplain vulnerability – Tweed River estuary

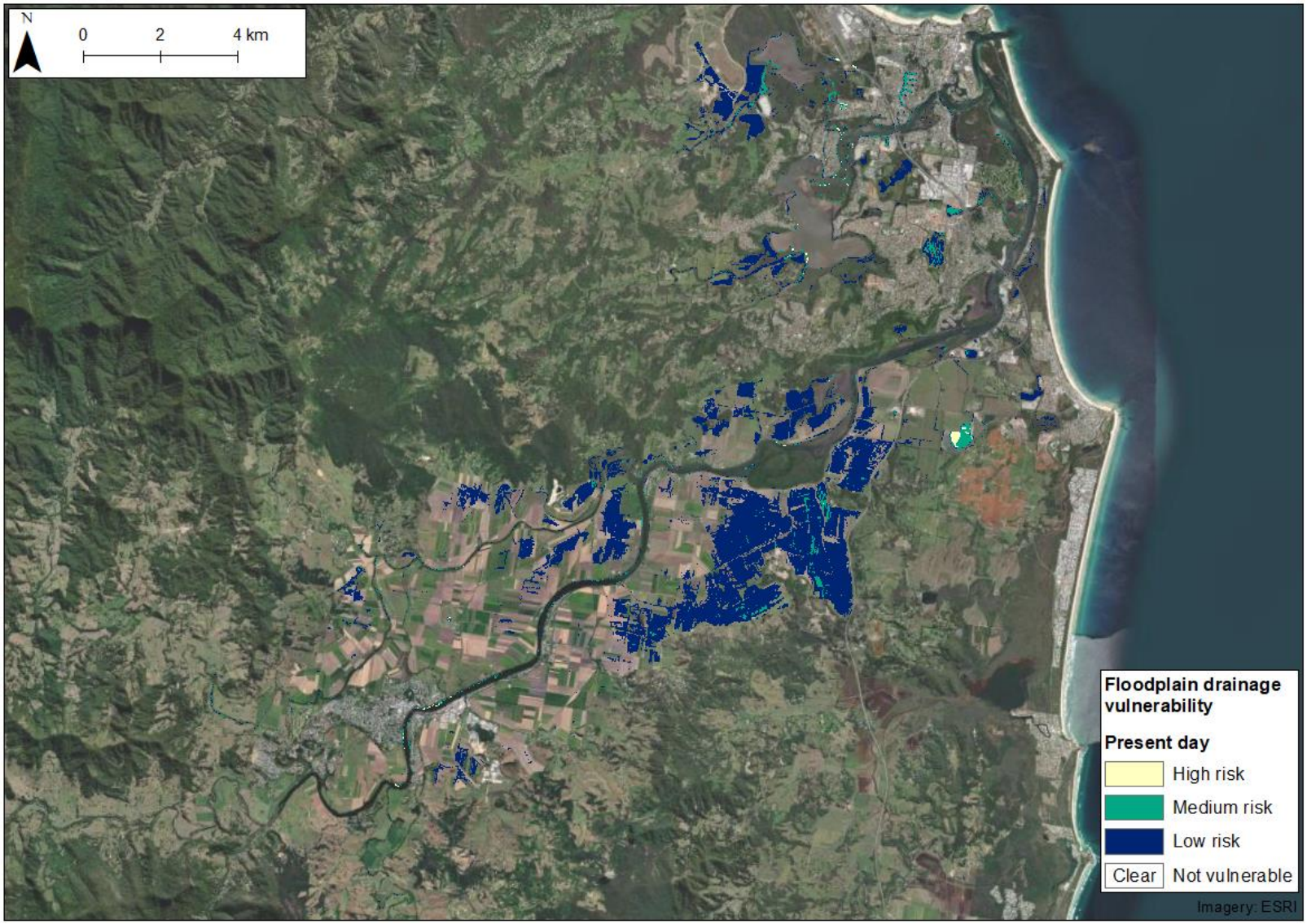


Figure 7-9: Present day floodplain vulnerability – Tweed River estuary

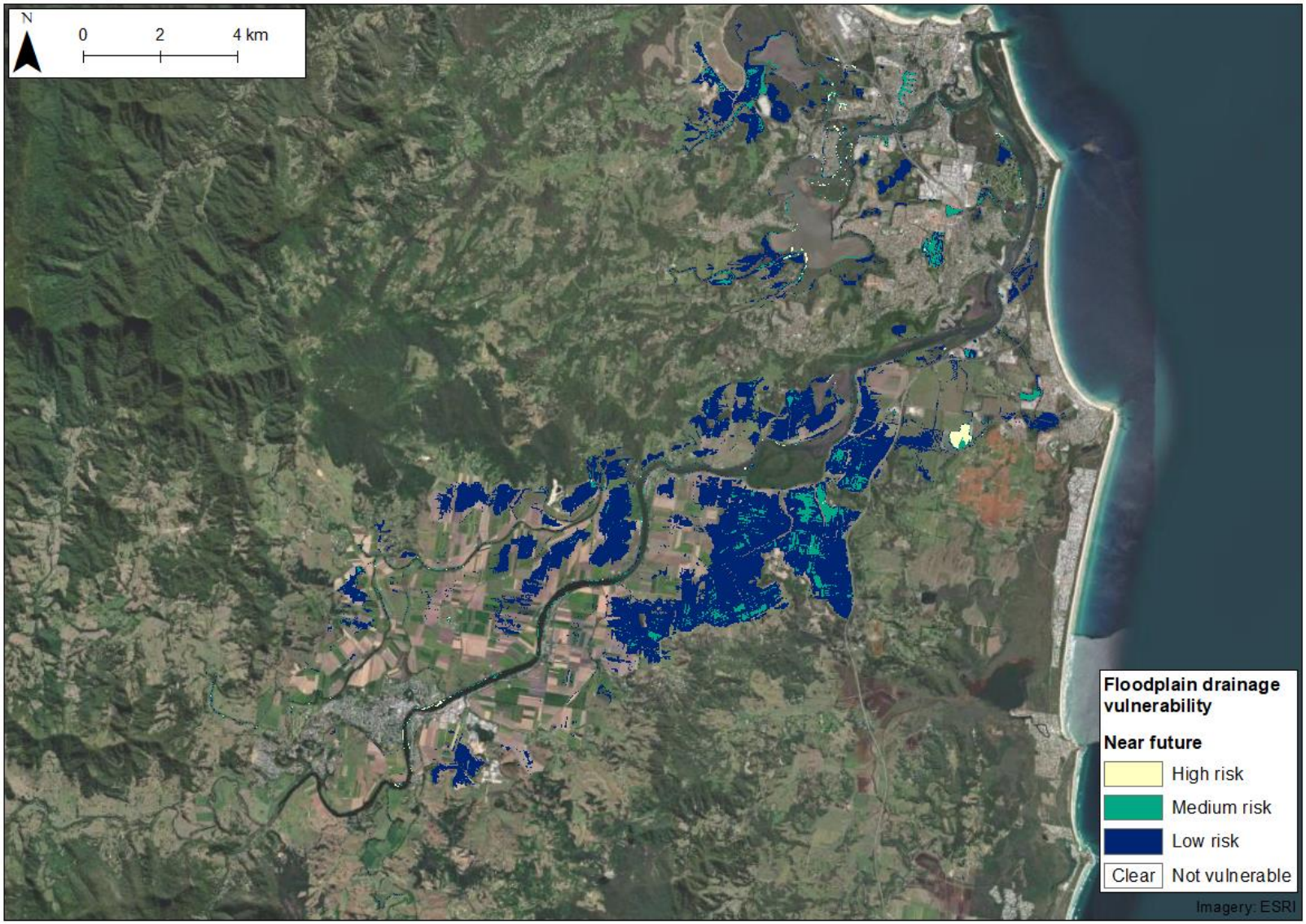


Figure 7-10: Near future (~2050) floodplain vulnerability – Tweed River estuary

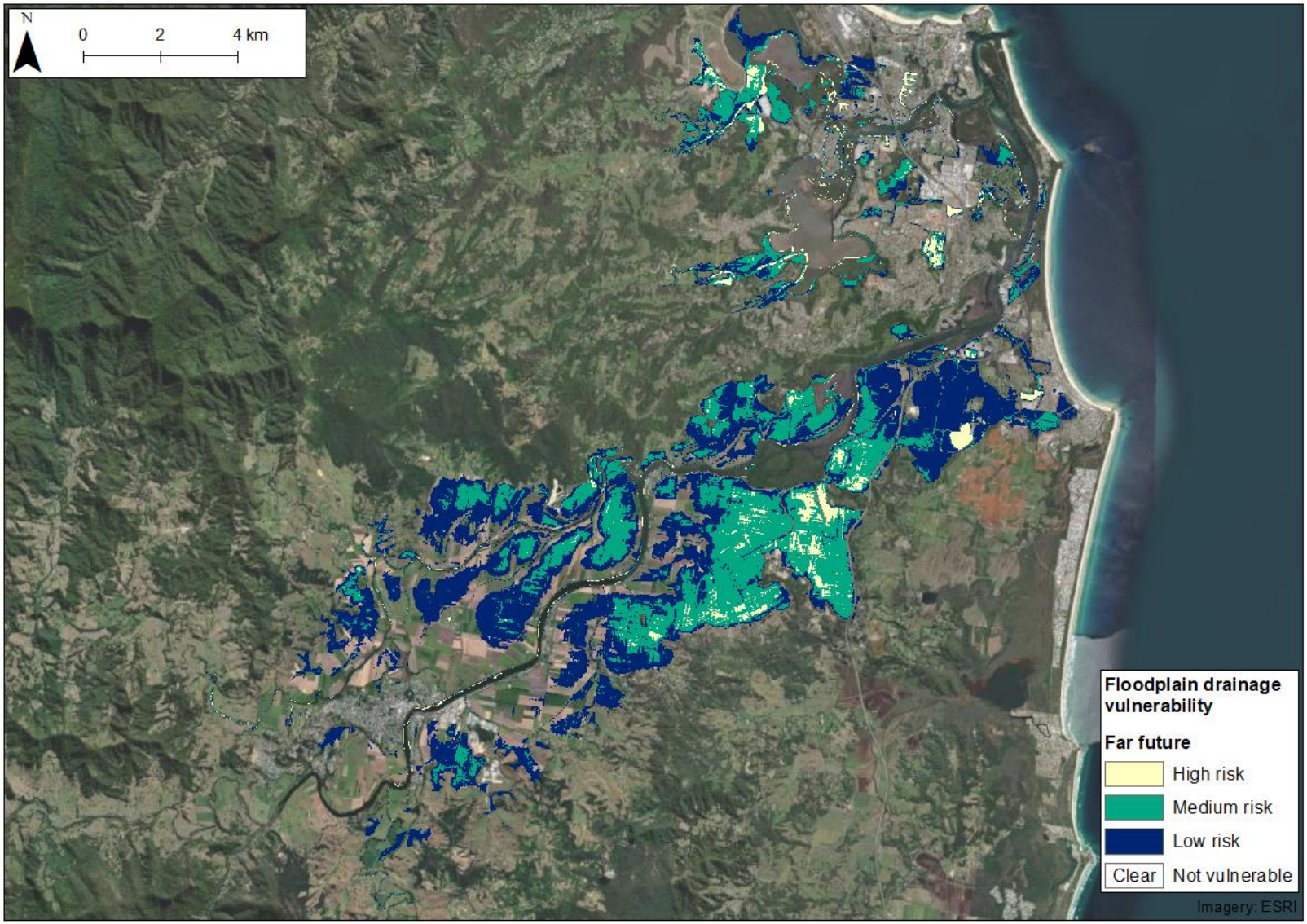


Figure 7-11: Far future (~2100) floodplain vulnerability – Tweed River estuary

8 Subcatchment management options

8.1 Preamble

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

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

8.2 Explanation of key information

8.2.1 Summary table

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

8.2.2 Floodgates and tenure

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

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

Table 8-1: Subcatchment data summary table

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 water ways 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) for significant infrastructure
<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)	5th percentile water level from present day estuary model
Near future low water level (m AHD)	5th percentile water level from near future estuary model
Far future low water level (m AHD)	5th percentile water level from far future estuary model
<u>Proximity to sensitive receivers</u>	
Oyster leases (km)	
Saltmarsh (km)	Distance (along the river channel) to sensitive receivers from any discharge point (may be within catchment)
Seagrass (km)	
Mangroves (km)	
Coastal Management SEPP coastal wetlands (km)	
<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 (%))	Area (percentage of floodplain) classified for various land uses below 5 m AHD
Classified as sugar cane (ha (%))	
Classified as horticulture (ha (%))	
Classified as other cropping (ha (%))	
Classified as urban/industrial/services (ha (%))	
Classified as marsh/wetland (ha (%))	
Other (ha (%))	
<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 above/below the median blackwater elevation (X m AHD), based on NSW Valuer General data Rural properties only included, below 5m AHD
Average land value below X m AHD ($/ha)	

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. White et al., 2014; Glamore et al., 2016b). 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;
- **Floodplain vulnerability:** represented as downstream water level statistics (5th, 50th and 95th percentile) translated directly onto upstream floodplain topography. Note that this simplified 'bathtub' 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

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

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

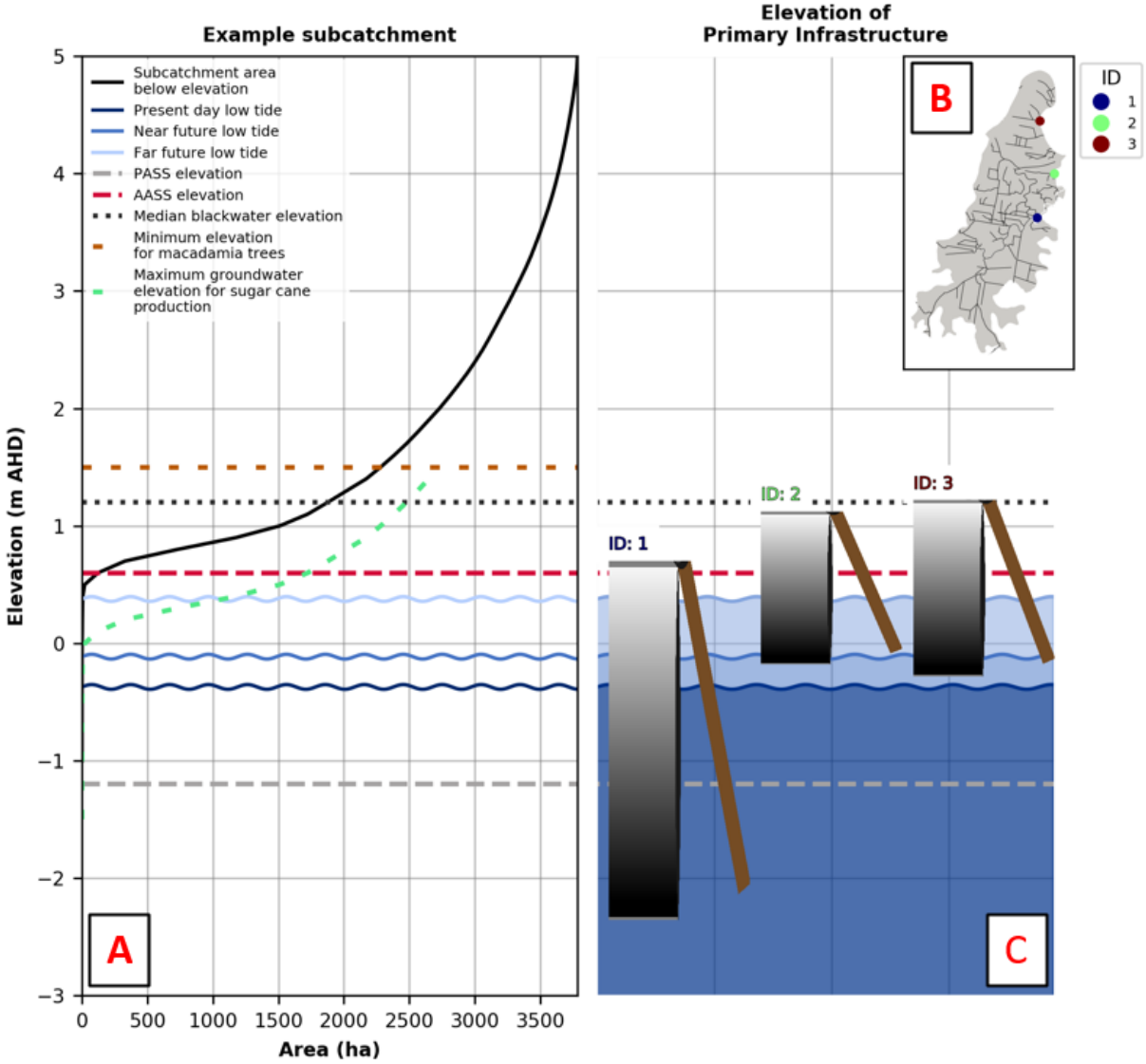


Figure 8-1: Reduced drainage vulnerability summary figure example

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

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

    - The minimum recommended ground elevation for developing and managing macadamia trees (+1.5 m AHD), based on the recommendation of Bright (2020); and
    - The maximum groundwater elevation for sugar cane production (approximately 0.5 m below the ground elevation), based on the findings of Rudd and Chardon (1977). Frequent water logging resulting in higher water tables can reduce sugar cane crop yield.
- **Panel B** shows the location of the primary floodplain floodgates within the subcatchment; and
- **Panel C** which shows the elevation (invert and obvert) of each primary floodgate in the relevant subcatchment, relative to the present day, near future and far future low tide conditions. Each of these are labelled with the floodgate ID. These floodgates are only designed to show elevation of the floodgate, and do not reflect other information such as the number of culverts, the shape of the culvert or the height of the headwall.

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

8.2.4 Costs and benefits of changes in land management

Changes to land management and remediation of coastal floodplains can have substantial environmental benefits including improved water quality, however there are also costs associated with capital works and changing land use. The cost of on-ground works, including factors such as compensation for changes in land use, and how to acquire funding are often key limiters to whether environmental remediation is pursued. To provide land managers with an order of magnitude cost estimate associated with the proposed management options, a first-pass estimate of costs 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 regard to the effectiveness of reducing the impacts of ASS and blackwater while improving wetland habitat and connectivity. This is based on the type of remediation, experience and engineering judgement.

In addition to reducing the impacts of ASS and blackwater, 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).

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

- A cost-benefit analysis of a large scale remediation 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 floodplain on the Richmond River 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 (a tributary of the Hastings River) was estimated to have a benefit-cost ratio of 1.1:1 to 3:1 (Aaso, 2000) (using a pessimistic and optimistic scenario), before considering any non-market ecosystem service benefits from remediation works.

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

8.2.5 Waterway classification

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

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

8.2.6 Subcatchment management areas

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

- Condong subcatchment (ASS and blackwater);
- South Murwillumbah subcatchment (ASS only);
- Dulguigan subcatchment (ASS only);
- Kynnumboon subcatchment (ASS only);
- Tumbulgum/Eviron subcatchment (blackwater only); and
- Tygalgah subcatchment (blackwater only).

8.3 Condong subcatchment

Acid priority rank:	**1**
Blackwater priority rank:	**3**
Infrastructure	
Approximate waterway length (km)	55
# Privately owned end of system structures	0
# Publicly owned end of system structures	17
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (floodgate ID)	17L, 27, 30, 31, 32
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-0.6 to -0.2
Average AASS elevation (m AHD)	0.8
Average PASS elevation (m AHD)	-0.3
Median blackwater elevation (m AHD)	0.8
Present day low water level (m AHD)	-0.3
Near future low water level (m AHD)	-0.2
Far future low water level (m AHD)	0.3
Proximity to sensitive receivers	
Oyster leases (km)	25.4
Saltmarsh (km)	8.9
Seagrass (km)	12.2
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	3.2
Land use	
Total floodplain area (ha)	1,446
Classified as conservation and minimal use (ha (%))	3 (0.2%)
Classified as grazing (ha (%))	99 (7%)
Classified as forestry (ha (%))	0 (0%)
Classified as sugar cane (ha (%))	1,192 (81%)
Classified as horticulture (ha (%))	1 (0.1%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	148 (10%)
Classified as marsh/wetland (ha (%))	0 (0%)
Other (ha (%))	23 (2%)
Land values	
Estimated total primary production value ($/year)	$1,700,000
Average land value above 0.8 m AHD ($/ha)	$13,400
Average land value below 0.8 m AHD ($/ha)	$13,000

8.3.1 Site description and brief history of drainage

The Condong subcatchment is located on the right bank of the mid-to-upper Tweed River estuary. The subcatchment floodplain is characterised by three major drainage pathways: Condong Creek, Johnsons Creek and Disneys Creek. Condong Creek is a major trunk drain that services the southern section of the floodplain where it discharges to the Tweed River through Structure 17L, the largest structure within the Condong subcatchment. Structure 17L also provides drainage for the South Murwillumbah subcatchment, which is adjacent to the Condong subcatchment (to the south). Condong Creek connects to Johnsons Creek on its northern end which then flows north through the subcatchment before connecting to the Tweed River via Structures 30 and 31. Disneys Creek drains the low-lying north eastern section of the floodplain through Structure 32. Note, the north eastern section of the Condong subcatchment is hydrologically connected with the Tumbulgum/Eviron subcatchment through a series of smaller farm scale drains.

Drainage of the Condong subcatchment began in the early 19th century, however, it was not until the 1960s and 1970s when construction of the Tweed River flood mitigation scheme resulted in significant drainage works being completed (Tulau, 2011). Throughout the 1960s a large number of floodgates were installed on the existing drainage network in the Condong subcatchment (Tulau, 2011). Further works were completed in the 1970s that included both drainage channels and floodgate structures, including the Condong Creek headworks (Structure 17L) (Tulau, 2011).

There are few records of investigations completed to assess the impacts of floodplain drainage within the Condong subcatchment on water quality. Tulau (1999) found anecdotal evidence that there was poor water quality within Condong Creek and subsequent investigations found a small drop in pH levels (to pH 5.7) following a large runoff event. Long term monitoring within the Tweed River has not indicated prolonged impacts of acid to this section of the estuary (Ferguson, 2012; Pratt, 2017). Point measurements observed at specific locations across the subcatchment have resulted in a mixture of measurements with some low pH levels (pH < 5) (Pratt et al., 2017; PWD, 1991) and neutral pH levels (pH ≈ 7) (SPCC, 1985) measured.

The dominant land use within the Condong subcatchment is sugar cane which is widespread across the floodplain. The higher elevation land on the bank of the Tweed River within this subcatchment is utilised for residential and industrial land uses, which make up 10% of the floodplain area. Note within this area is located the Condong Sugar Mill. Tenure information for the Condong subcatchment is shown in Figure 8-2. Information on drainage and floodplain elevation is shown in Figure 8-3.

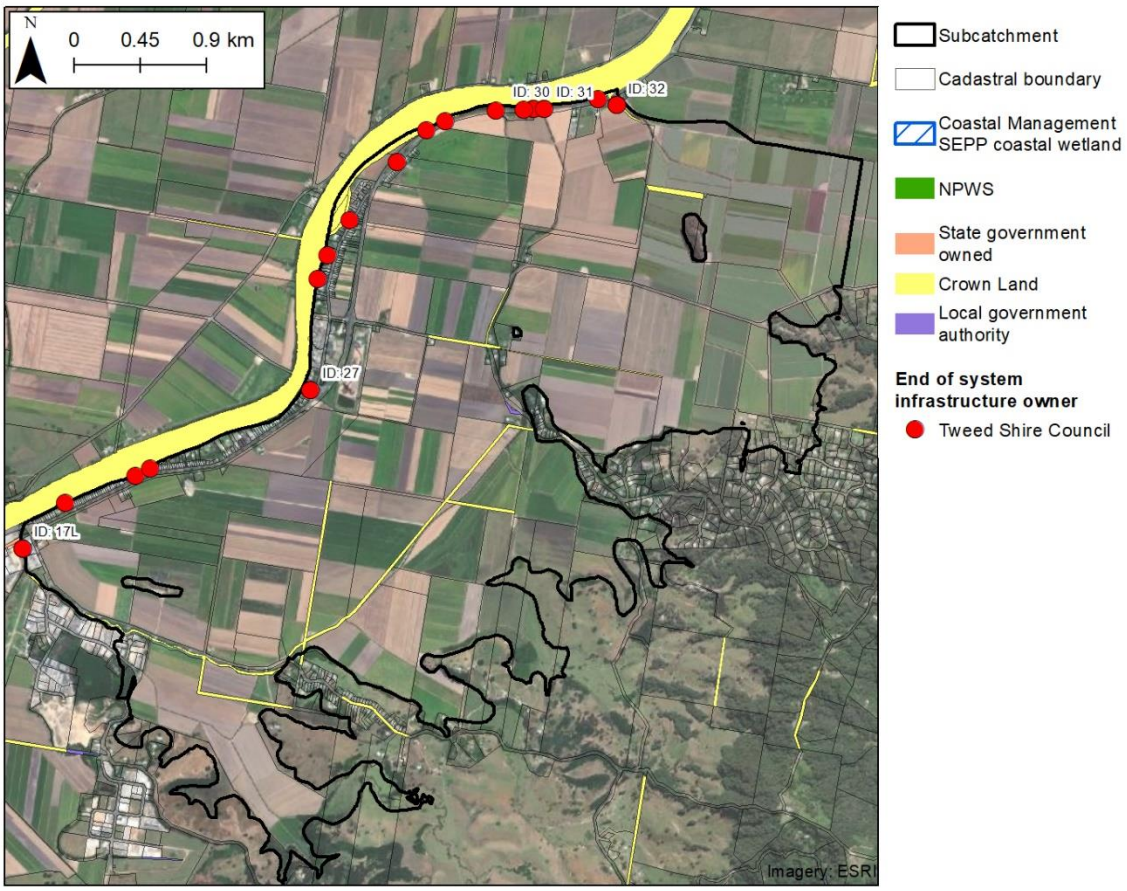


Figure 8-2: Condong subcatchment - land and end of system infrastructure tenure

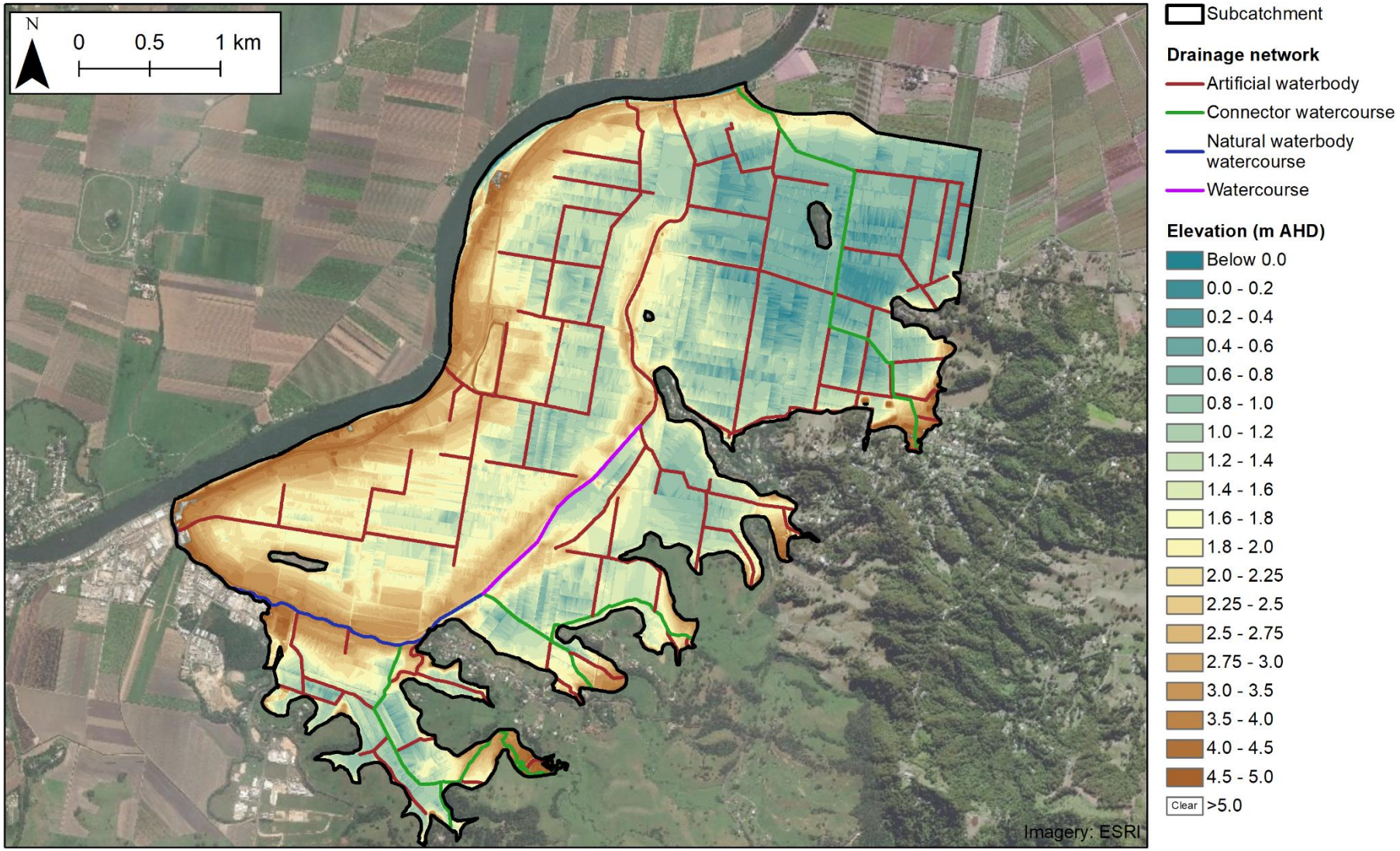


Figure 8-3: Condong subcatchment elevation and drainage network

8.3.2 History of remediation

Previous remediation efforts within the Condong subcatchment include modification of floodgates to enable controlled tidal flushing, installation of a water retention structure, and spraying of a limestone slurry to neutralise acid. Three primary end of system floodgates have been modified to allow controlled tidal flushing within the drainage network. These structures are located on Condong Creek (Structure 17L), Johnsons Creek (Structure 31) and a union drain within management area C1 (Structure 27) (Figure 8-4). During field investigations evidence of remediation attempts to the south of the floodplain were observed where a weir/sluice gate structure has been installed. A drainage management plan has been created for the downstream section of Condong Creek which, while focusing on improving drainage efficiency, provided recommendations for the remediation of the creeks banks for improved environmental value and to reduce the risk of erosion (AWC, 2018). Locations of existing floodplain remediation efforts are shown in Figure 8-4.

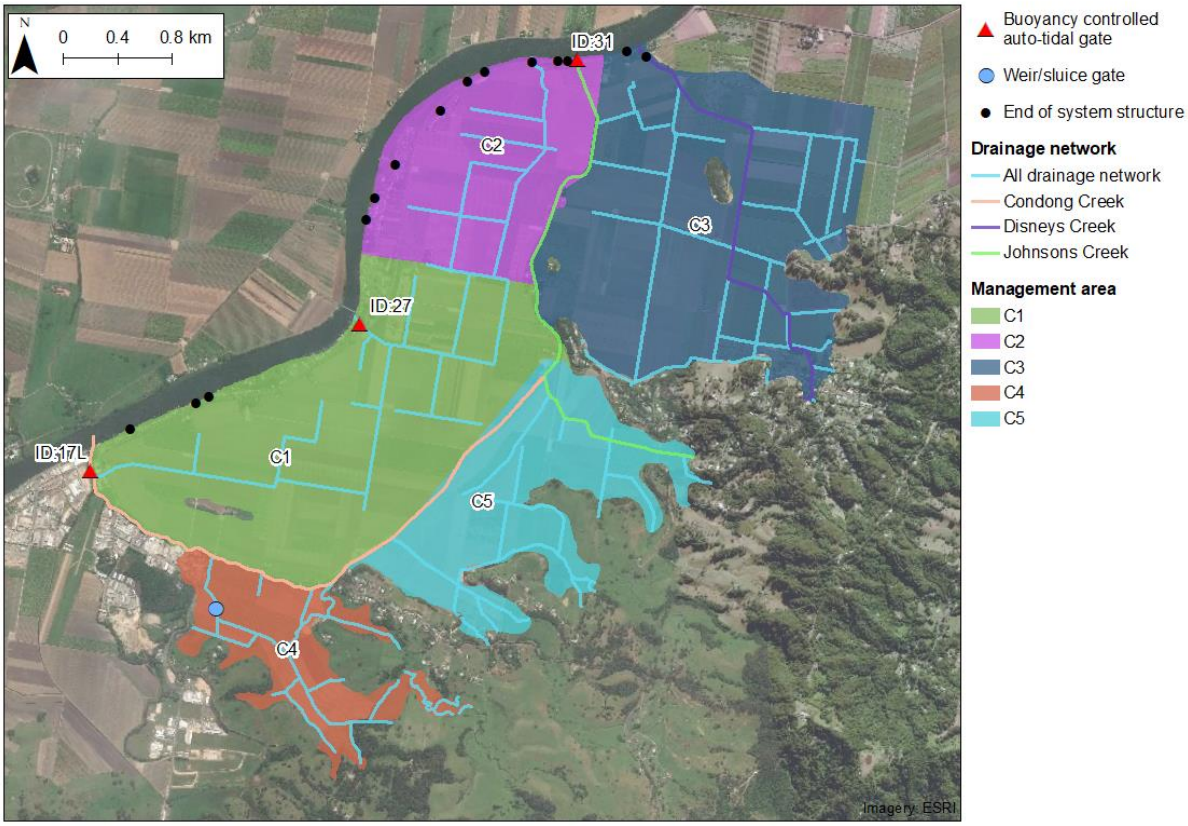


Figure 8-4: The Condong subcatchment including previous remediation actions

On Condong Creek, Structure 17L previously had a winch installed on one of its floodgate flaps. The floodgate was winched open in 1998 and within two years there was a visible reduction in weed infestation upstream of the floodgates (Walsh et al., 2002; Lofthouse and Capeland, 1998). Images provided by Tweed Shire Council showed that the winch was still functioning in March 2005, however inspection of aerial images indicated this has now been removed and instead a buoyancy controlled auto-tidal gate has been installed. There has been observations of mangroves on the upstream side of the floodgates indicating tidal exchange (AWC, 2018).

A buoyancy controlled auto-tidal gate has also been installed on one of the floodgates flaps of Structure 31 on Johnsons Creek (Figure 8-5) and Structure 27 on a union drain (Industry and Investment NSW, 2009). Field inspections of Structure 31 indicated that the buoyancy controlled auto-tidal gate is functioning well and continuing to allow controlled tidal flushing and fish passage upstream of the floodgates.



Figure 8-5: Buoyancy controlled auto-tidal gate on Structure 31

On the floodplain in the south of the Condong subcatchment, during field investigations a weir/sluice gate structure was observed. This device retains water to an elevation of -0.02 m AHD when open (as in Figure 8-6) and +0.59 m AHD when closed. Upstream of the structure, the bed of the drain has been infilled to approximately 0 m AHD.



Figure 8-6: A weir/sluice gate structure located on the south of the Condong subcatchment floodplain

In 2002, Green (2005) trialled active management of acidic water through spraying of a limestone slurry across a pond within the Condong subcatchment. The study found that it was an effective short-term tool that could be used to quickly raise pH levels for small areas, particularly following large rainfall events.

Sugar cane farms in the Tweed River floodplain operate in compliance with "The NSW sugar industry best practice guidelines for acid sulfate soils" (Sunshine Sugar, 2020). The drainage management plan for one farm in the Condong subcatchment outlined the following actions to remediate ASS (Sunshine Sugar, 2000):

- Laser levelling completed to reduce the drainage density required to allow surface water drainage;
- Spoil from cleaning drains or laser levelling of areas with ASS within 0.5 m of the surface should be treated with lime; and
- No further drains are to be constructed without an assessment of acid hazard.

While details of specific drainage management on other cane farms in the Condong subcatchment were not obtained, cane farms typically have similar plans to minimise ASS impacts, including:

- Laser levelling of farms to reduce the drainage density required to allow surface water drainage;
- Constructing new drainage works that are designed to minimise the interaction with ASS; and
- Completing extensive liming.

8.3.3 Prioritisation of management areas in the Condong subcatchment

The Condong subcatchment ranked first in the acid prioritisation, and third in the blackwater prioritisation. The subcatchment has been further delineated into five (5) smaller management areas (referred to as C1 to C5, shown in Figure 8-7) to provide additional information on the sources of acid and blackwater. The areas have been delineated based on land tenure, data availability, elevation, changes in soil acidity and drainage units.

The management areas have been prioritised for acid generation using the method described in Section 4.2. The results of the acid prioritisation for the management areas of the Condong subcatchment are shown in Figure 8-7 and Table 8-3. The largest source of acid risk was found in management area C1 which has an acid factor double that of C5 and C3, the second and third ranked management areas respectively.

Figure 8-8 shows the management areas for the Condong subcatchment below the median elevation for blackwater generation (+0.8 m AHD). As elevation is a primary driver of the production of blackwater, the areas below this level statistically contribute the most to potential blackwater generation (although this can be managed through changing vegetation, land use, and hydrology). The majority of blackwater risk in the Condong subcatchment originates from management area C3, with the remaining management areas only contributing arbitrarily to the overall subcatchments blackwater risk.

Based on the findings from the management area prioritisation shown in Figure 8-7 and Figure 8-8, it is suggested that remediation in the Condong subcatchment focus on management areas C1, C3 and C5.

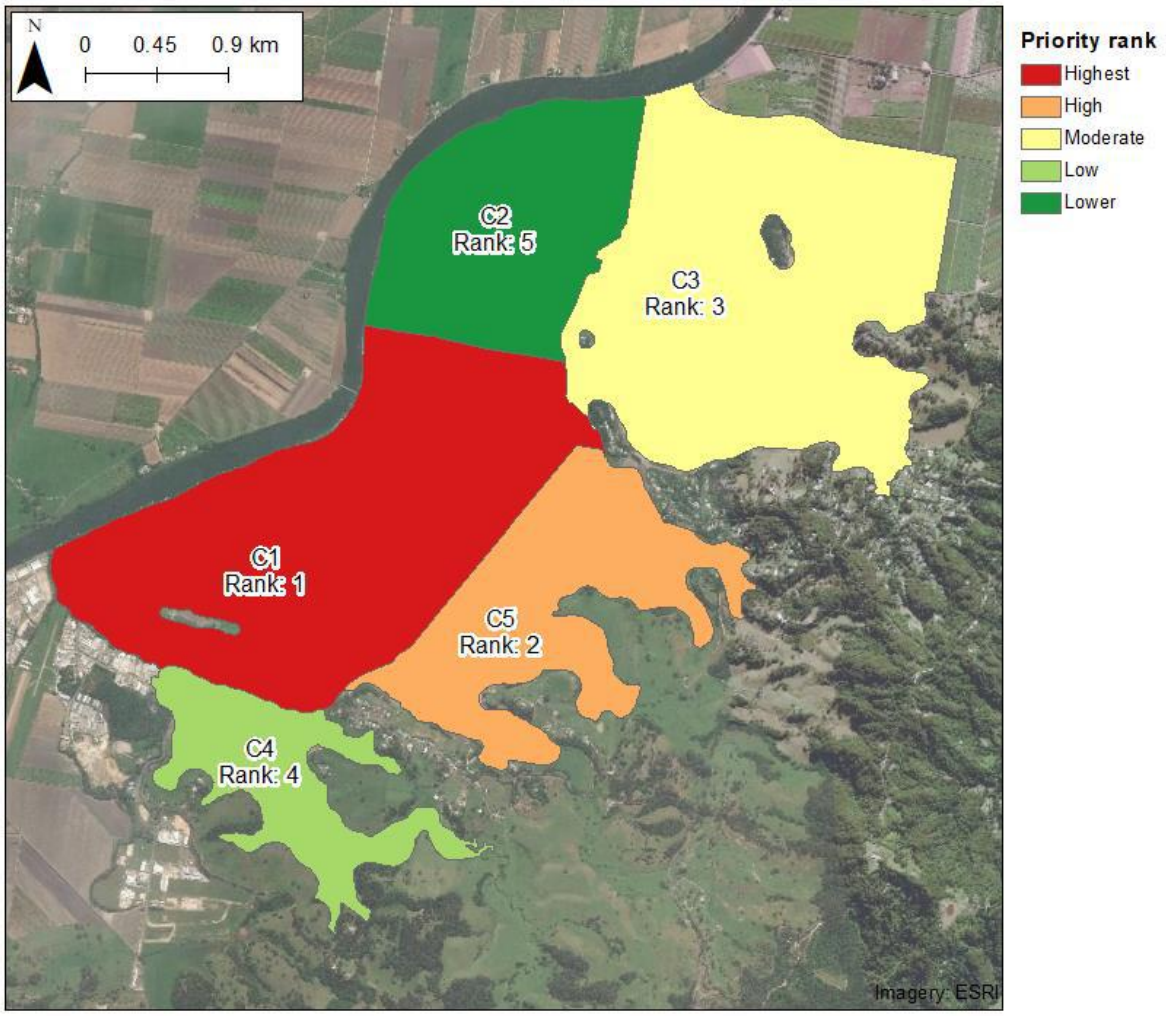


Figure 8-7: The Condong subcatchment management areas for acid prioritisation

Table 8-3: Management area acid prioritisation of the Condong subcatchment

Management area	Groundwater factor	Surface water factor	Final acid factor	Final rank
C1	459	764	351,118	1
C5	219	631	138,400	2
C3	220	452	99,201	3
C4	43	822	35,458	4
C2	71	361	25,533	5

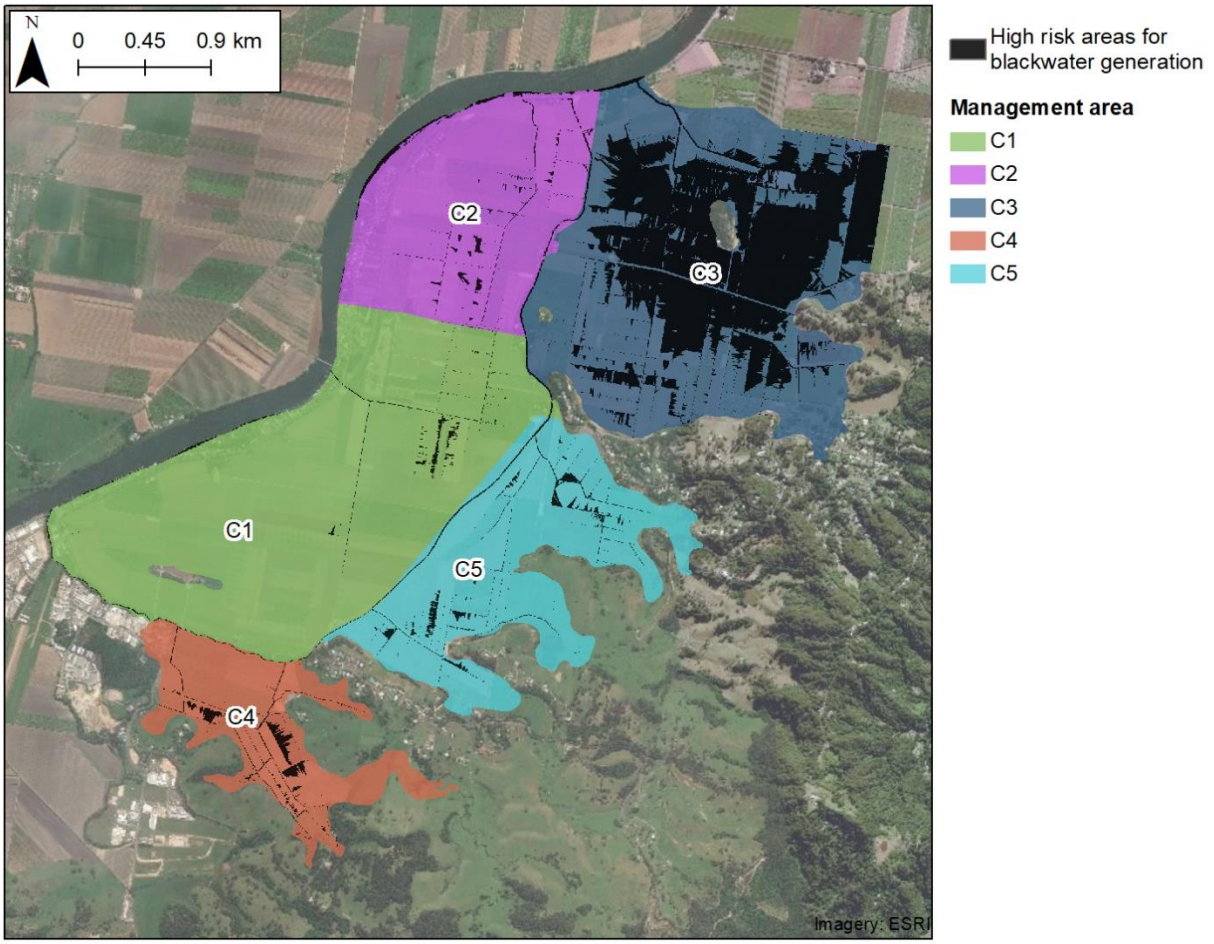


Figure 8-8: Blackwater contribution in each management area for the Condong subcatchment (median blackwater level +0.8 m AHD)

8.3.4 Floodplain drainage - sea level rise vulnerability

The sea level rise vulnerability assessment of the Condong subcatchment is summarised in Figure 8-9. The vulnerability assessment of floodgates within the subcatchment found that all floodgates are classed as least vulnerable present day water levels. As shown in Figure 8-10, the top of the primary floodgates in the subcatchment remain well above far future low tide water levels. However, drainage from a number of floodgates (Structures 17M, 17L, 27C, 29, 30, 31 and 32, see Appendix F) will become reduced as receiving water levels in the estuary increase in the far future, making these structures moderately vulnerable.

Low-lying areas of the floodplain may also become vulnerable to sea level rise, with analysis indicating that some low-lying areas within management areas C3 have already begun to be impacted by reduced drainage. This will likely be contained to management area C3 under near future sea level rise, however, modelling of the far future sea level rise scenario indicated that all management areas will be affected by reduced drainage to some degree. Within the Condong subcatchment, large areas of management area C3 will have a moderate risk of reduced drainage in the far future.

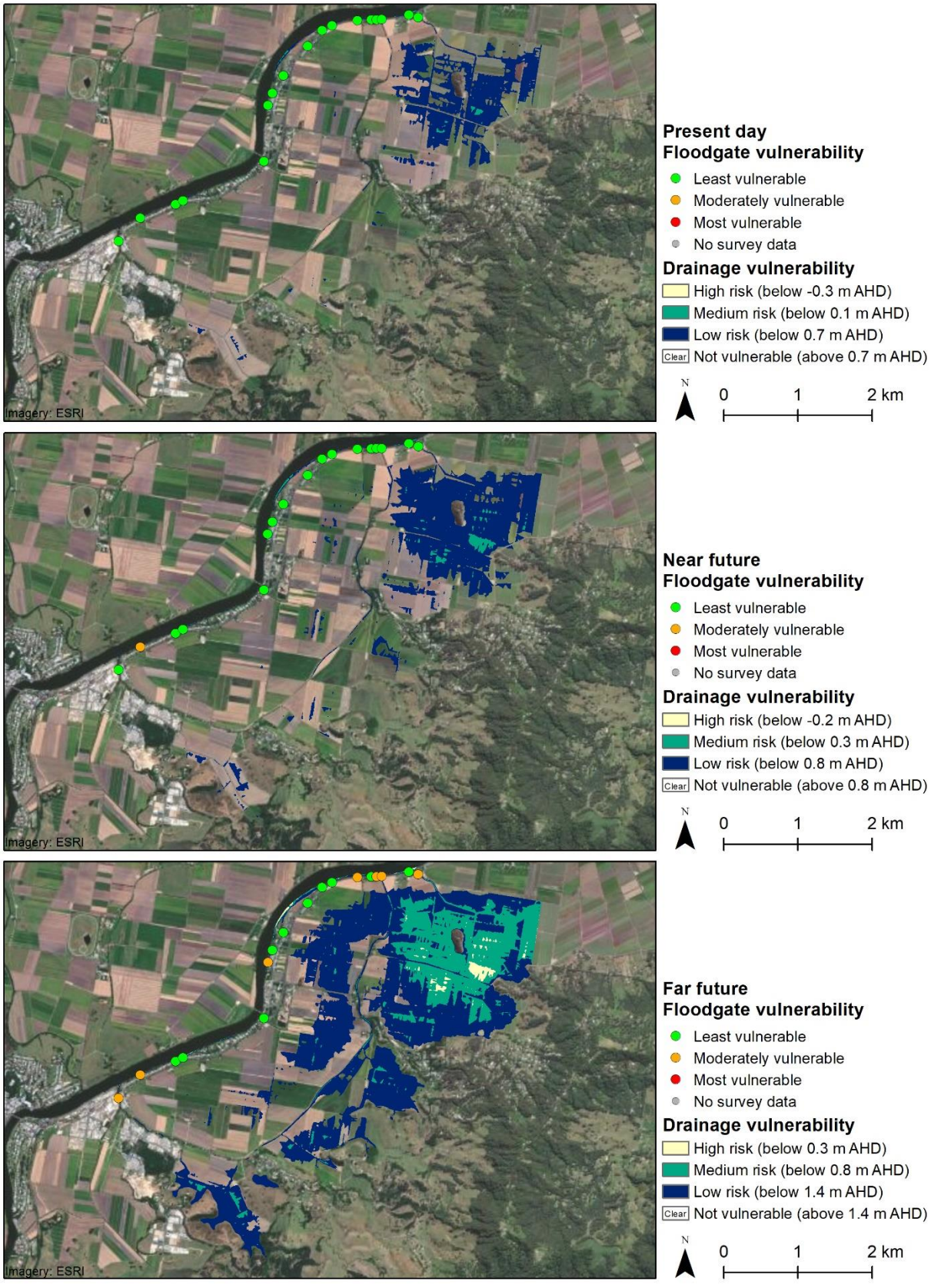


Figure 8-9: Sea level rise drainage vulnerability for the Condong subcatchment

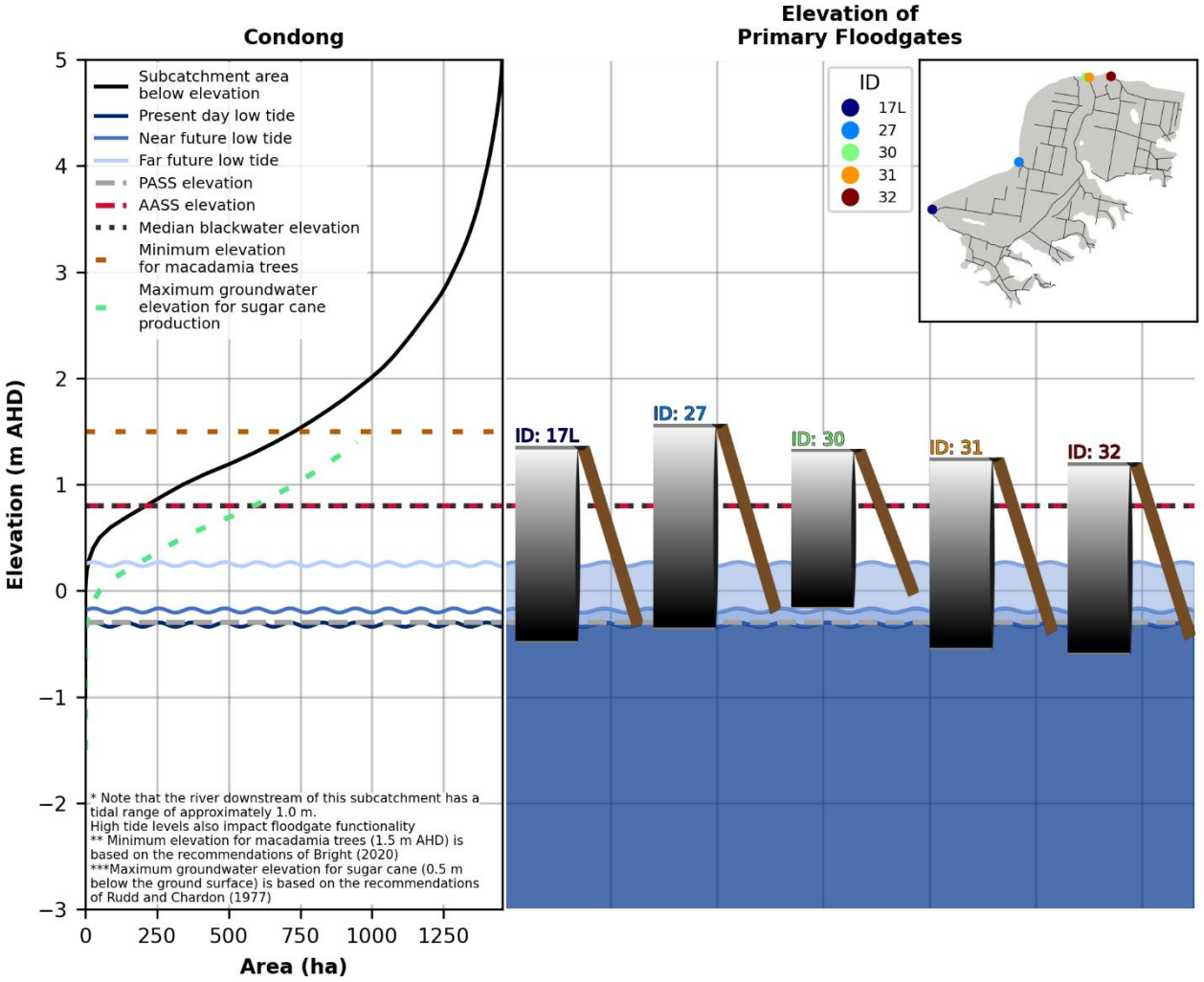


Figure 8-10: Key floodplain elevations- Condong subcatchment

8.3.5 Management options

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

- Short-term: Optimise tidal flushing through structures, drain reshaping, and installation of water retention structures.
- Long-term: Relocation of floodgates, optimise tidal flushing through structures, drain reshaping, and localised transition of low-lying areas to 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
Existing remediation works to introduce tidal flushing to floodplain drainage channels has benefits for water quality and aquatic connectivity. These modifications could be reviewed and optimised to assess if additional benefit and improved flushing could be achieved without impacting present day land uses. Key floodgates in management area C1 include Structure 17L and Structure 27. Note that modifications to Structure 17L may also have implications for the South Murwillumbah subcatchment which would need to be considered. Similar assessments could be completed to determine if sections of drains within management area C1 could be shallowed and widened without this impacting existing land uses.

Structure 29 (see Figure 8-11) in management area C2 could be modified to allow controlled tidal flushing upstream of the floodgates. Modification of the floodgate to include a buoyancy controlled auto-tidal gate or sluice gate would allow for improvements of water quality within the drain through flushing as well as buffering of acidic discharges during dry periods. Groundwater hydraulic conductivity should be considered when assessing tidal flushing to ensure daily tidal flows do not increase hydraulic pumping of acidic groundwater. Soil hydraulic conductivity was observed to moderate in the Condong subcatchment.

Options for management area C3 are limited in the short term due to the low elevation of the land. Strategies such as tidal flushing or weirs have the potential to impact present day drainage and land use/productivity, however additional site-specific investigation (e.g. drainage survey, assessment of connectivity, landholder engagement, etc.) may be required to confirm the extent of potential management options. Strategic raising of the invert levels of drains within the management area would assist in reducing acid export.

There are a number of existing remediation structures in management area C4 that are assisting to reduce the export of acid sulfate soils (see Figure 8-11). The current levels and design of these structures could be assessed and optimised to reduce the export of acidified water.

Drop board or weir structures could be considered within management area C5 to raise the water table within drains and reduce acid export. These structures could be constructed on Johnsons Creek, upstream of Condong Creek, and on the drain that connects to Condong Creek to the south of management area C5 so that the water table is raised but remains in-drain so that present day land uses are not affected (see Figure 8-11).

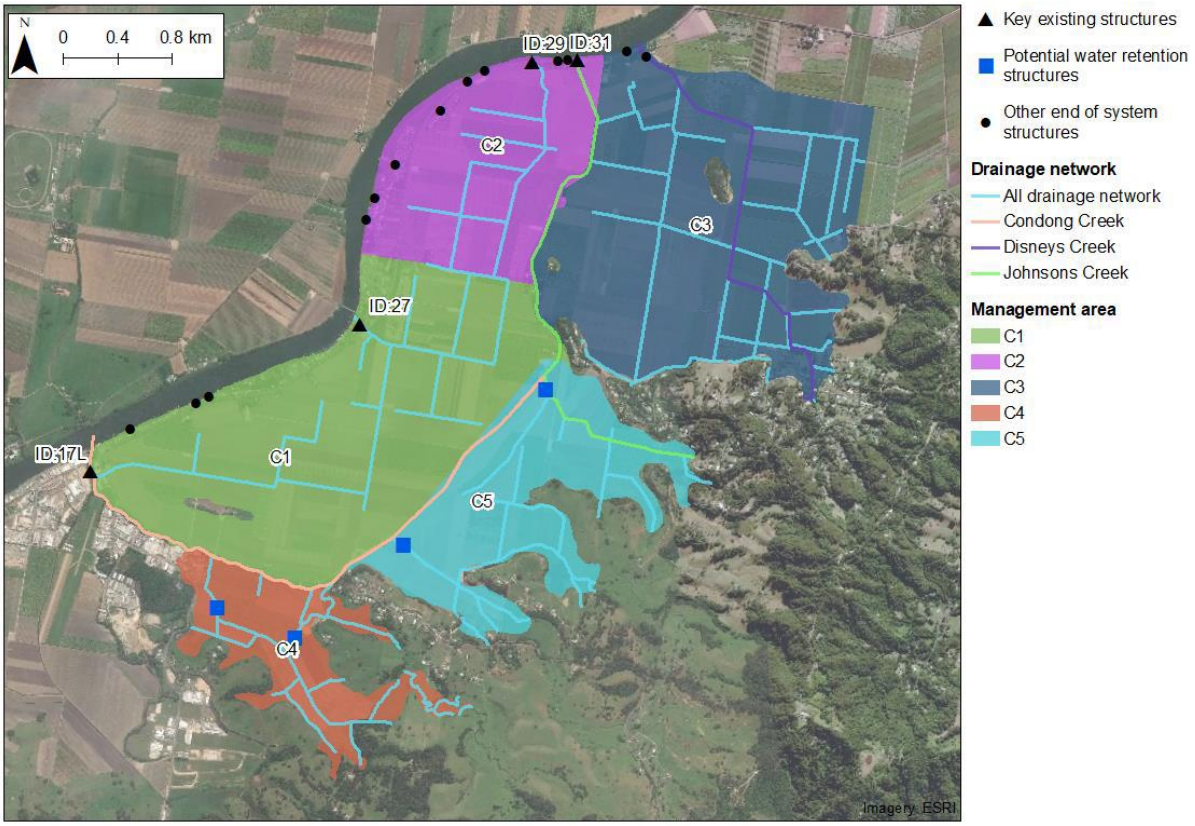


Figure 8-11: Short-term management options for the Condong subcatchment

Long-term management options

In the long term, decentralising major drainage would enable improved management of different drainage areas within management areas C1 and C2 to reduce acidic discharge and remediate wetland habitats. Structure 27 could be hinged open to allow tidal flushing and new structures installed upstream to allow separate management of floodplain areas C1 and C2. Low-lying areas in the north east of management area C1 could be managed in the same manner as management area C2 (see Figure 8-12). The southern area of management area C1 is generally higher in elevation and could therefore support tidal flushing within the drainage network for benefits to water quality. Drains could also be shallowed and widened, raising their invert level above acidic soil layer elevations reducing the risk of acid export while retaining their drainage capacity. A summary of these options is shown in Figure 8-12.

Within management area C2, and low areas of management area C1 (see Figure 8-12), drains could be reshaped to raise their invert elevation to reduce groundwater drawdown and acid discharge. Where land use allows, the density of drainage could also be reduced.

The existing land use within management area C3 is likely to be threatened in the long-term due to sea level rise. Where sustaining existing land uses are no longer feasible, transition to estuarine wetlands should be considered. Note, this is likely to be limited to the south of management area C3 so that changes do not impact the Tumblegum/Eviron subcatchment which is hydrologically linked to management area C3 on its north eastern boundary. This strategy will require extensive consultation and consideration of the social, cultural and economic impacts on local landholders.

Low-lying floodplain in management areas C4 and C5 may also be impacted by reduced drainage due to sea level rise. In areas where present day land uses become unviable, low-lying areas could be transitioned to a freshwater wetland ecosystem.

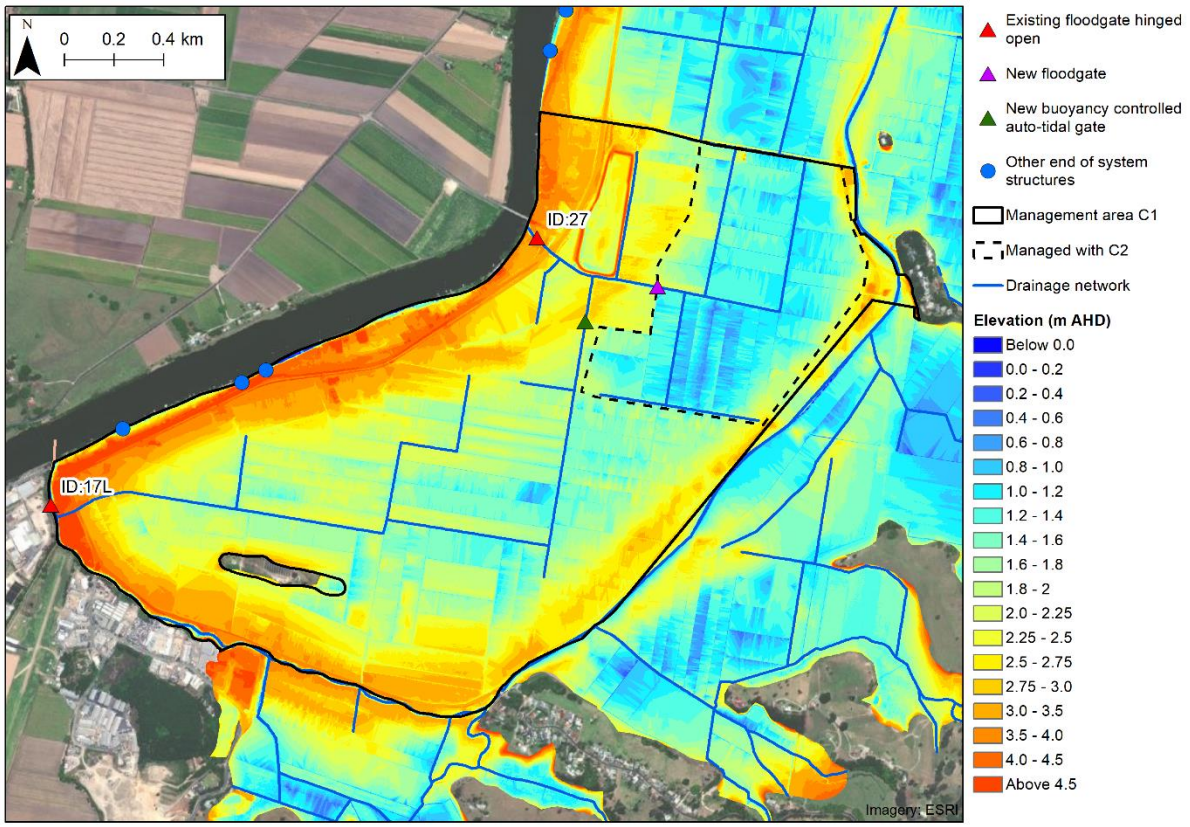


Figure 8-12: Long-term management options for management area C1

Table 8-4: Summary of management options for the Condong subcatchment

Timeframe	Strategy	Target management area(s)	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing per year)	Indicative cost (lost productivity per year)	Effectiveness at improving:		
							Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Optimise tidal flushing	C1, C2	None	$50,000	$10,000	None	Moderate	Moderate	Negligible
Short-term	Install water retention structures	C1, C4, C5	None	$100,000	$20,000	Minimal	None	Moderate	Low
Short to long-term	Drain reshaping	C1, C2, C3	None	$750,000	None	Minimal	None	Moderate	Low
Long-term	Relocate floodgates	C1	None	$200,000	$20,000	None	Moderate	Moderate	None
Long-term	Restoration of wetlands	C3, C4, C5	$3,000,000	$350,000	Minimal	$450,000	None	High	High

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

8.4 South Murwillumbah subcatchment

Acid priority rank:	**2**
Blackwater priority rank:	**9**
Infrastructure	
Approximate waterway length (km)	15
# Privately owned end of system structures	0
# Publicly owned end of system structures	21
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (floodgate ID)	10, 17L
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-0.5 to -0.1
Average AASS elevation (m AHD)	0.8
Average PASS elevation (m AHD)	-0.3
Median blackwater elevation (m AHD)	0.7
Present day low water level (m AHD)	-0.3
Near future low water level (m AHD)	-0.2
Far future low water level (m AHD)	0.2
Proximity to sensitive receivers	
Oyster leases (km)	32.3
Saltmarsh (km)	15.5
Seagrass (km)	19.2
Mangroves (km)	0.3
Coastal Management SEPP coastal wetlands (km)	2.2
Land use	
Total floodplain area (ha)	439
Classified as conservation and minimal use (ha (%))	1 (0.2%)
Classified as grazing (ha (%))	103 (23%)
Classified as forestry (ha (%))	0 (0%)
Classified as sugar cane (ha (%))	213 (48%)
Classified as horticulture (ha (%))	0 (0%)
Classified as other cropping (ha (%))	1 (0.2%)
Classified as urban/industrial/services (ha (%))	115 (26%)
Classified as marsh/wetland (ha (%))	0 (0%)
Other (ha (%))	6 (1%)
Land values	
Estimated total primary production value ($/year)	$300,000
Average land value above 0.7 m AHD ($/ha)	$9,800
Average land value below 0.7 m AHD ($/ha)	No property data available

8.4.1 Site description and brief history of drainage

The South Murwillumbah subcatchment is located on the right bank of the upper Tweed River estuary. The main drainage pathway through the subcatchment is via Blacks Drain which runs from the south east to the north of the subcatchment where it connects to Condong Creek, which discharges to the Tweed River through a large set of eight floodgates that were constructed in the 1970s (Structure 17L) (Tulau, 2011). Note that Structure 17L also drains a large area of the Condong subcatchment which is adjacent to the South Murwillumbah subcatchment to the north. During periods of higher flow, water can also discharge from the subcatchment through Structure 10 which has a higher invert of -0.06 m AHD compared to -0.49 m AHD for Structure 17L. During the data collection completed for this study, it was observed that downstream of Structure 10 there was a build-up of sediment which may inhibit connectivity of the waterway to the Tweed River (Figure 8-13).



Figure 8-13: The downstream side of Structure 10

There are a large number of smaller floodgate structures that provide drainage to urban areas on the bank of the Tweed River to the north of the subcatchment. Land use across the remainder of the subcatchment includes sugar cane on the lower floodplain closer to the river and grazing on higher areas of the floodplain to the south east. Murwillumbah Airport is located on the north east side of the subcatchment.

Drainage of the floodplain is an ongoing issue that will become more severe into the future due to sea level rise. To overcome this issue a number of pumps have been installed across the floodplain to allow drainage of water below the low tide level. A number of investigations have also been completed to address floodplain drainage:

- AWC (2018) created a drainage management plan for the downstream section of Condong Creek which included recommendations to increase flow capacity with the aim of improving drainage of agricultural land; and

- Tetley and Steele (2019) investigated how modifications to the lower sections of Blacks Drain and Condong Creek would reduce flooding, finding that modifications provided little to negligible benefit.

There have been a number of studies that have investigated acid sulfate soils and their impacts within the South Murwillumbah subcatchment (Kinsela, 2007; Kinsela et al., 2007; Collins et al., 2009; Collins et al., 2012; Collins and Stroud, 2014; Jones, 2010; Tweed Shire Council, 2010). These studies mainly focused on areas surrounding Blacks Drain and include implementation of remediation works in the upstream grazing areas.

Tenure information for the South Murwillumbah subcatchment is shown in Figure 8-14. Information on drainage and floodplain elevation is shown in Figure 8-15.

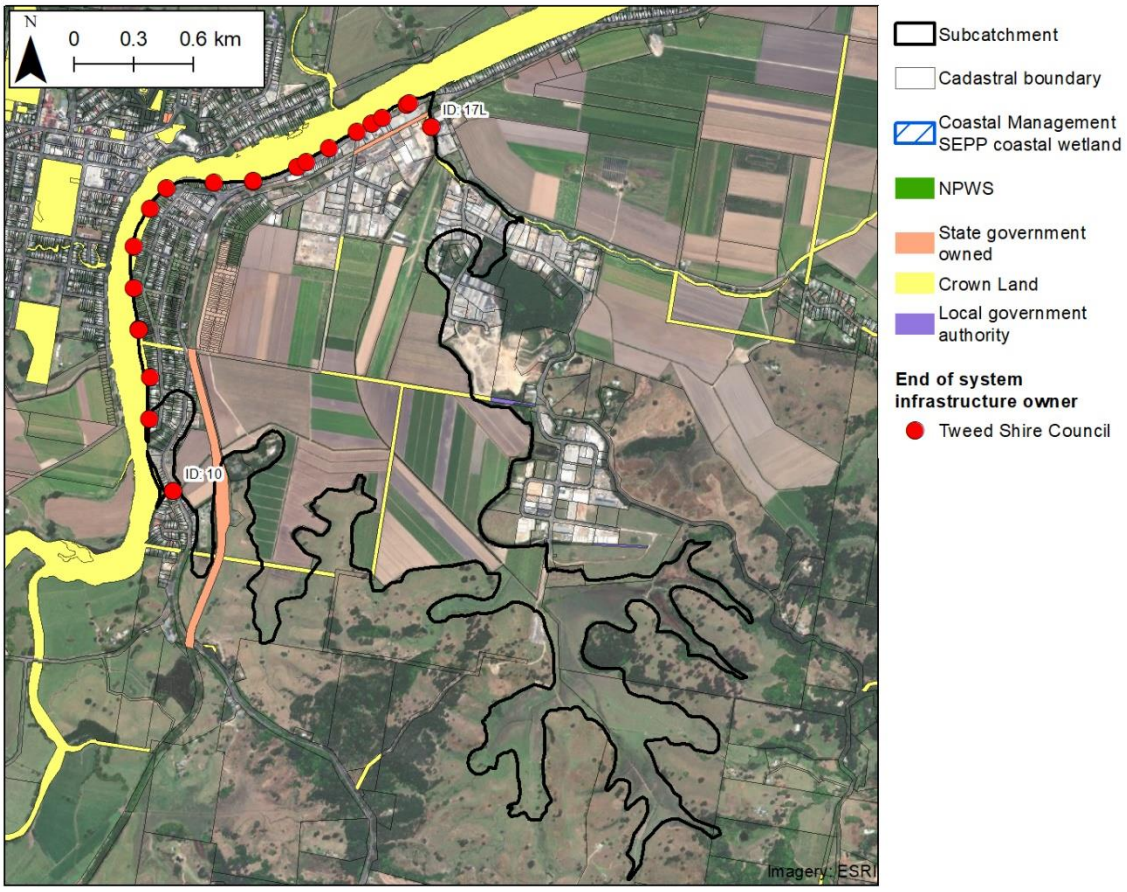


Figure 8-14: South Murwillumbah subcatchment – land and end of system infrastructure tenure

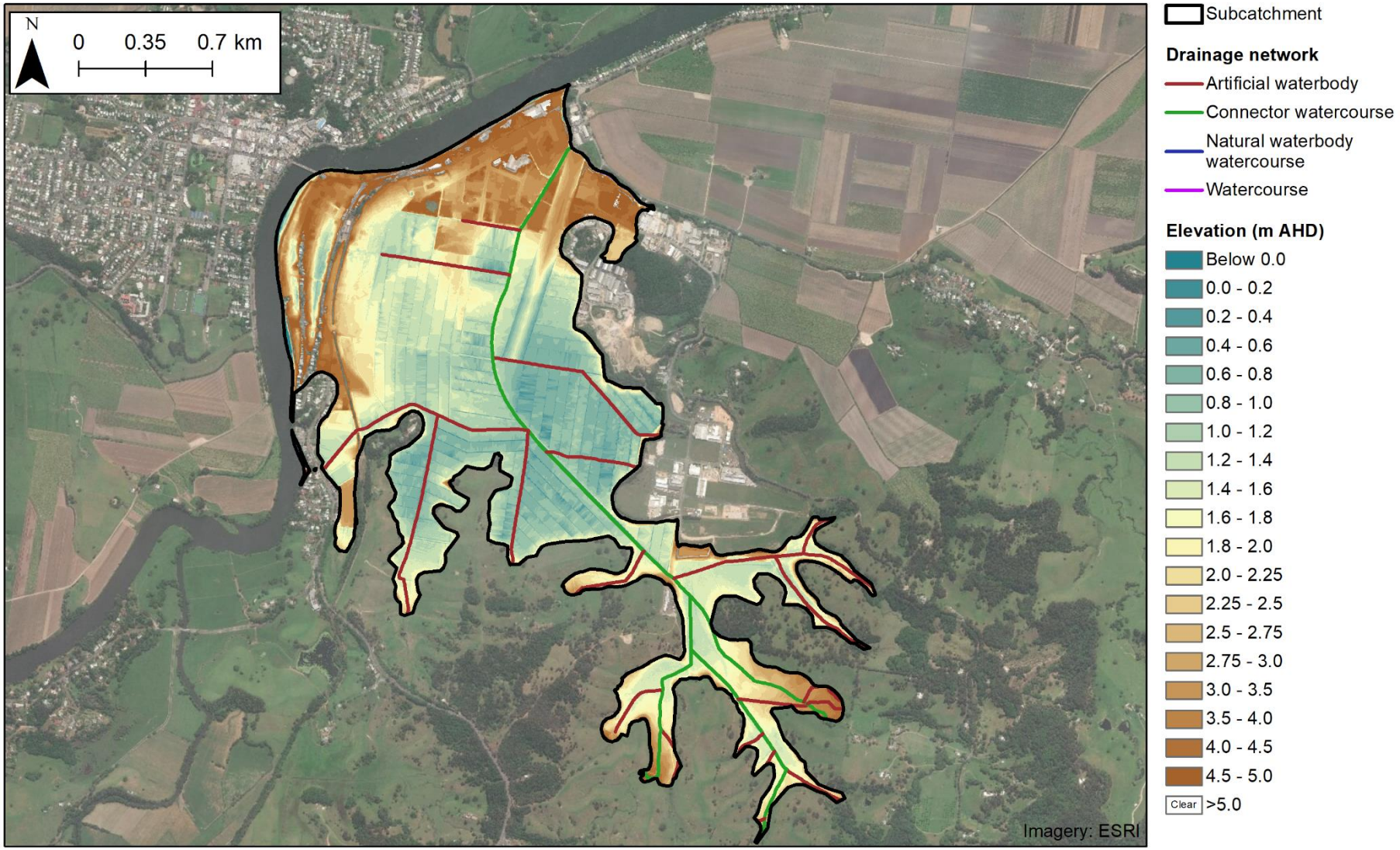


Figure 8-15: South Murwillumbah subcatchment elevation and drainage network

8.4.2 History of remediation

There have been a number of remediation actions implemented within the South Murwillumbah subcatchment, including:

- Modification of Structure 17L on Condong Creek to allow controlled tidal flushing;
- Modification of Structure 10 to enable it to be winched open;
- A number of land based remediation actions on higher grazing land to the south east of the South Murwillumbah subcatchment; and
- Investigations completed by AWC (2018) recommending remediation of the banks of the downstream sections of Condong Creek and the channel connecting to Blacks Drain to improve environmental value and to reduce the risk of erosion.

On Condong Creek, Structure 17L previously had a winch installed on one of its floodgate flaps. The floodgate was winched open in 1998 and within two years there was a visible reduction in weed infestation upstream of the floodgates (Walsh et al., 2002; Lofthouse and Capeland, 1998). Images provided by Tweed Shire Council showed that the winch was still functioning in March 2005, however inspection of aerial images indicated this has now been removed and instead a buoyancy controlled auto-tidal gate installed. There has been observations of mangroves on the upstream side of the floodgates indicating tidal exchange (AWC, 2018).

One of the floodgate flaps on Structure 10 has been modified so that it can be winched open which would allow controlled tidal flushing of the drainage system. During the data collection campaign, inspection of the structure indicated that there was sediment build up in front of the floodgates that would prevent any controlled tidal flushing during low to mid-tides (Figure 8-13). Prior to recent refurbishments, this structure was fitted with a buoyancy controlled auto-tidal gate (Industry and Investment NSW, 2009), indicating that tidal exchange can occur with the drainage network.

Between 2005 and 2008, Collins et al. (2009) completed investigations to determine potential remediation works that could be completed for Blacks Drain. Recommendations provided by the study included:

- Continued controlled tidal flushing in Condong Creek and lower Blacks Drain;
- Installing a weir control on the upper section of Blacks Drain; and
- Infilling upper sections of Blacks Drain to create a shallower and wider drain.

During 2010, Tweed Shire Council implemented these recommendations in addition to topdressing scalded paddocks with lime (to buffer acidic soils), introducing water tolerant pasture (i.e. implementing wet pasture management), and excluding stock from waterways (to prevent bank erosion) (Tweed Shire Council, 2010). Revegetation of the drainage channel was also completed on lower sections of the drainage network.

Investigations completed in 2011 found early signs that the remediation actions were working to reduce acidic discharge within the South Murwillumbah subcatchment (Collins et al., 2012). Further investigations completed in 2014 found that topdressing of one acid scald had only provided short-term benefit and otherwise confirmed that remediation efforts implemented by Tweed Shire Council in 2010 had been successful (Collins and Stroud, 2014). Figure 8-16 and Figure 8-17 provide details of the remediation actions that have been completed for the South Murwillumbah subcatchment.

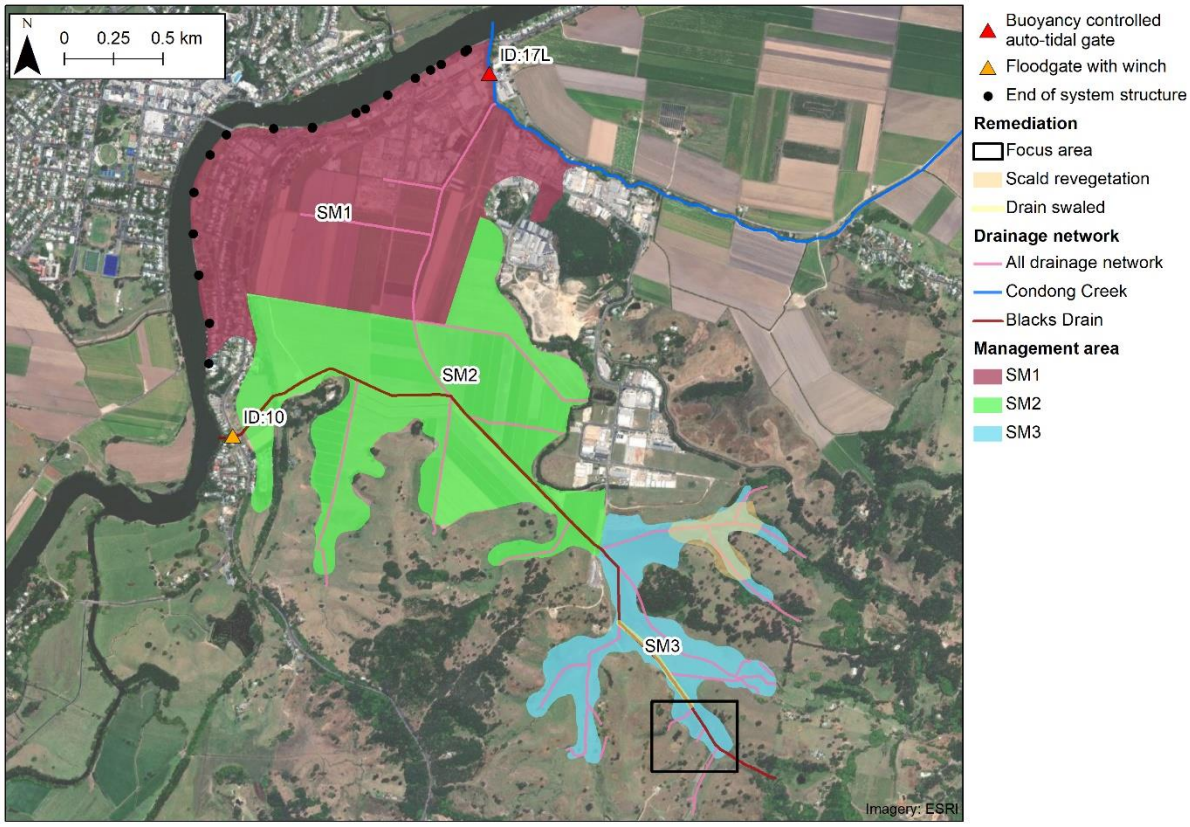


Figure 8-16: The South Murwillumbah subcatchment including previous remediation actions. See focus area in Figure 8-17



Figure 8-17: Before (8/26/2009) and after (4/11/2010) remediation completed on upstream sections of the South Murwillumbah subcatchment including drain infilling, weir installation and planting of water tolerant pasture (source: Google Earth) (see location in Figure 8-16)

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

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

8.4.3 Prioritisation of management areas in the South Murwillumbah subcatchment

The South Murwillumbah subcatchment ranked second in the acid prioritisation, and ninth in the blackwater prioritisation. The subcatchment has been further delineated into three (3) smaller management areas (referred to as SW1 to SW3, shown in Figure 8-7) to provide additional information on potential sources of acid. The areas have been delineated based on land tenure, data availability, elevation, changes in soil acidity and drainage units. Note, blackwater has been considered on the subcatchment scale.

The management areas have been prioritised for acid generation using the method described in Section 4.2. The results of the acid prioritisation for the management areas of the South Murwillumbah subcatchment are shown in Table 8-5. Note there was no available soil profile data to determine a groundwater factor for management area SW3. Despite this, investigations completed by Collins et al. (2009) found water with a low pH (<4) continually discharging from this management area and highlighted it as the primary source of acid for the subcatchment. Furthermore, Collins and Stroud (2014) noted at least two acid scalds within the management area. This information has been used to help develop management options, however, it is recommended that further investigations be completed to quantify the acid risk with respect to the other management areas. Additionally, a rank has been assigned to management area SM3 based upon this information. Additional investigation would be required to confirm management area priority ranking.

Based on available literature and the findings from the management area prioritisation shown in Table 8-5 and Figure 8-18, it is suggested that remediation in the South Murwillumbah subcatchment focus on management areas SM2 and SM3. Management strategies should target acid sulfate soils, as the risk of blackwater runoff from the South Murwillumbah subcatchment is limited.

Table 8-5: Management area acid prioritisation of the South Murwillumbah subcatchment

Management area	Groundwater factor	Surface water factor	Final acid factor	Final rank*
SM3	Insufficient data	285	Insufficient data	1
SM2	783	160	124,998	2
SM1	0.4	451	164	3

* Rank based upon acid prioritisation and review of existing data.

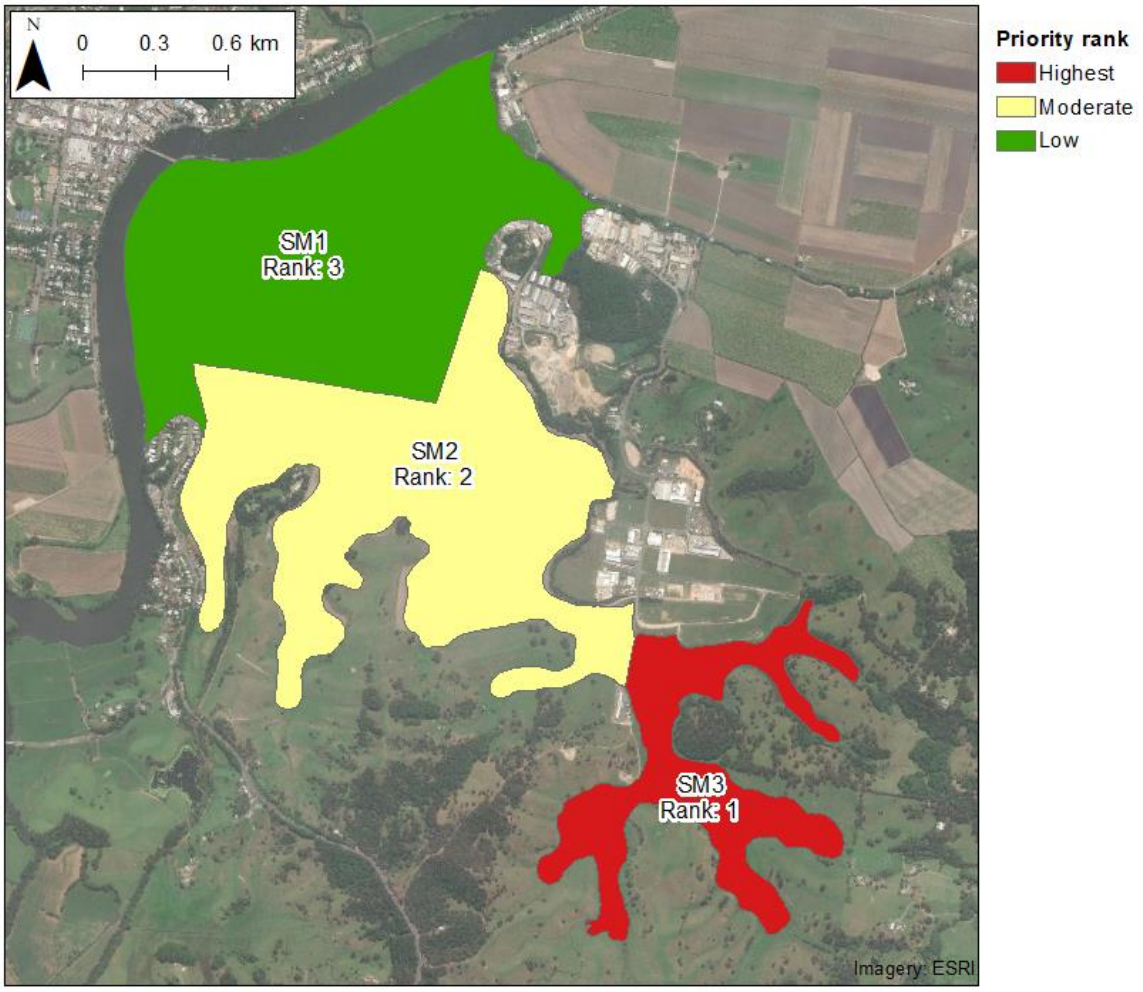


Figure 8-18: The South Murwillumbah subcatchment management area priority

8.4.4 Floodplain drainage – sea level rise vulnerability

The sea level rise vulnerability assessment of the South Murwillumbah subcatchment is summarised in Figure 8-19. Analysis found that drainage of the lowest lying areas in management area SM2 is potentially impacted by present day water levels. Reduced drainage under natural gradients is confirmed by the presence of pumping infrastructure for additional dewatering of the subcatchment floodplain. In the near future sea level rise scenarios, the majority of management area SM2 will be impacted by reduced drainage. Modelling indicated that by the far future, all areas within the South Murwillumbah subcatchment may be impacted by sea level rise.

Presently, a number of smaller floodgates on the bank of the Tweed River servicing urban areas of South Murwillumbah are moderately vulnerable to sea level rise. These smaller floodgates are the most susceptible to sea level rise, with the obvert of some structures being situated below the approximate mean tide water level (i.e. most vulnerable) in the far future. The primary floodgates, shown in Figure 8-20, are significantly larger and higher, although floodgate 17L is still classified as “Moderately vulnerable” under far future sea level rise scenarios. Note, this analysis of sea level rise vulnerability does not consider increased risk related to flood events, which may also impact the South Murwillumbah subcatchment.

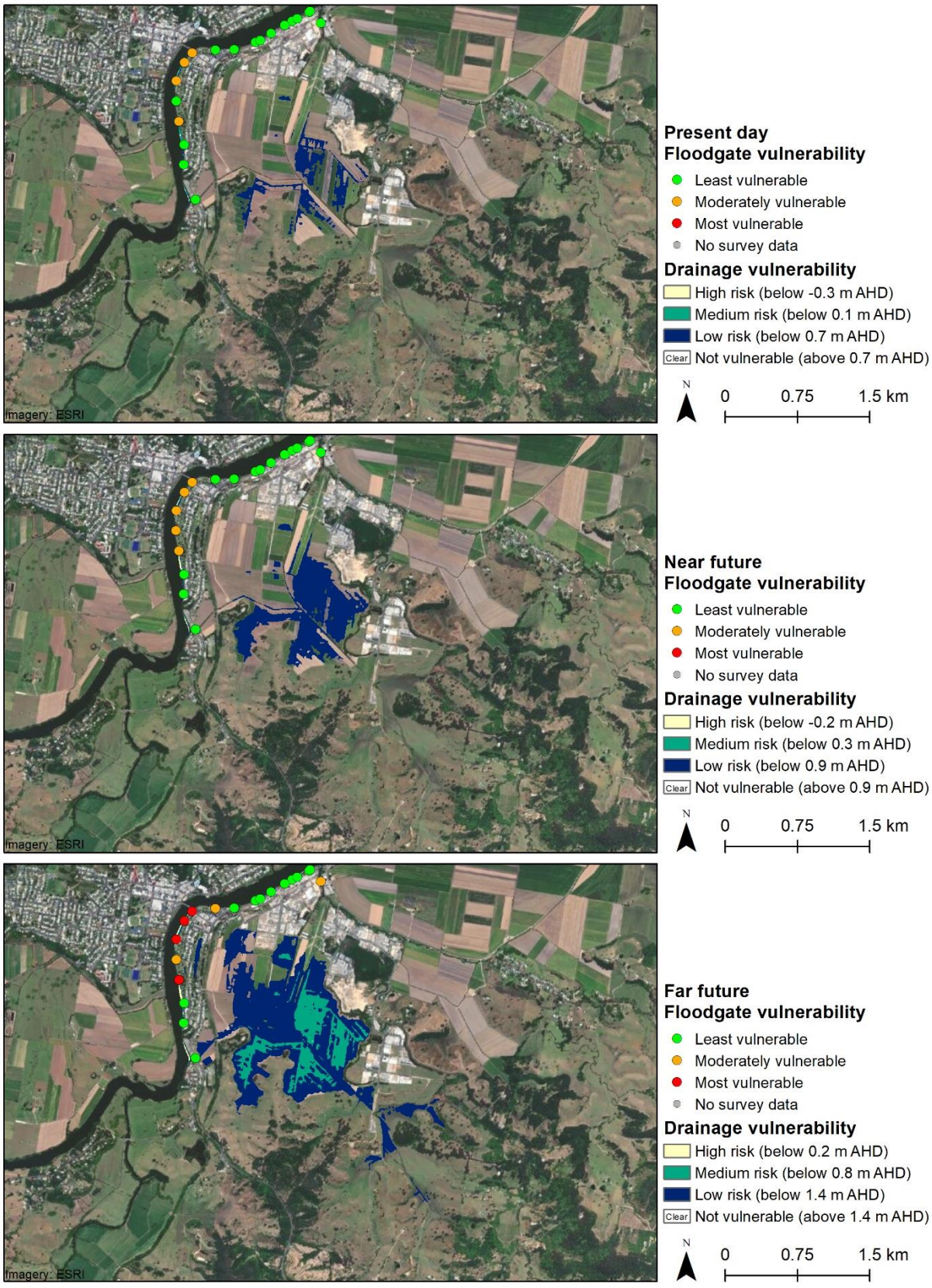


Figure 8-19: Sea level rise drainage vulnerability for the South Murwillumbah subcatchment

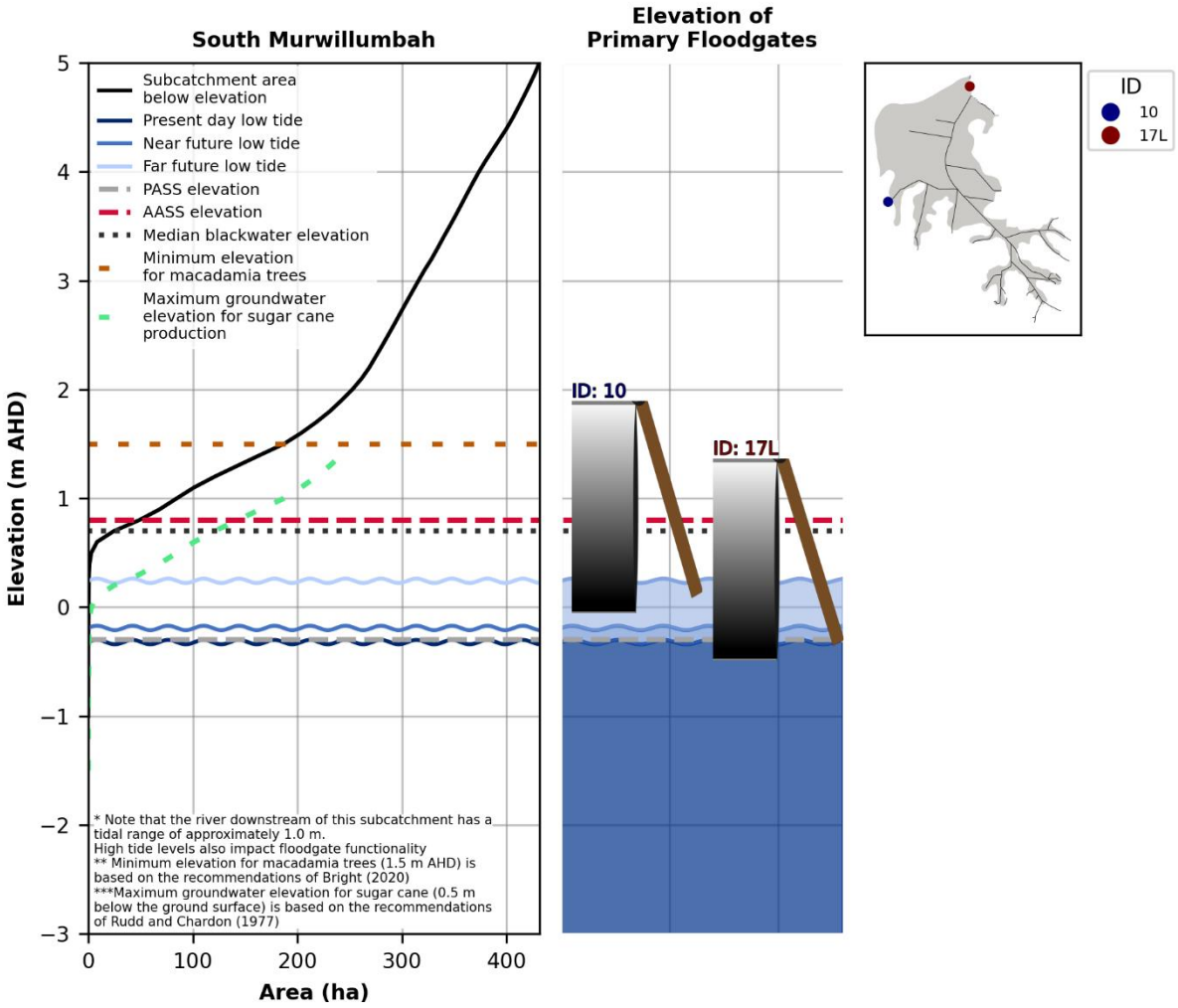


Figure 8-20: Key floodplain elevations – South Murwillumbah subcatchment

8.4.5 Management options

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

- Short-term: Optimise tidal flushing through structures, review pumping, and revegetation of acid scalds.
- Long-term: Drain reshaping, installing weirs, wet pasture management, and localised transition of low-lying areas to freshwater 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

Management options that have been previously implemented within the South Murwillumbah subcatchment have benefits for water quality and aquatic connectivity. Investigations could be undertaken to assess the effectiveness of tidal flushing modifications to Structure 17L and determine if

further improvements in water quality and aquatic connectivity could be achieved. This assessment would determine if it is feasible to further optimise tidal flushing within the drainage network, which may provide additional water quality benefits to management areas SM1 and SM2. Note modifications to Structure 17L would also have implications for the adjacent Condong subcatchment which would need to be considered. Groundwater hydraulic conductivity should be considered when assessing tidal flushing to ensure daily tidal flows do not increase hydraulic pumping of acidic groundwater. Soil hydraulic conductivity was observed to be moderate in the South Murwillumbah subcatchment.

In the short term, pumping of water from behind floodgate structures in management area SM2 should be reviewed. Pumping has the potential to increase groundwater drawdown and discharge, which in turn could increase the export of acid to the estuary.

Research has shown that remediation efforts undertaken within management area SM3 have been successful in reducing the discharge of acidic water from the floodplain (Collins and Stroud, 2014). Revegetation of low-lying areas with water tolerant vegetation, including acid scalds identified by Collins and Stroud (2014), would further reduce acidification and deoxygenation of waterways. Additional investigations could be completed to quantify the depth and elevation of the acidic layer within management area SM3 to guide further management option development.

Long-term management options

Long-term management options for the South Murwillumbah subcatchment should target reduction of acid discharge, and transition of poorly drained backswamp areas to wetland environments. Reduction of drainage density should be considered, where practical on a farm scale level, within management area SM1. Larger drains should be widened and shallowed, reducing the risk of acid export while maintaining the existing drainage capacity. Any modifications would need to be assessed to ensure they do not have any implications for flood drainage.

Sections of Blacks Drain (within management area SM2) could be potentially reshaped and converted to a floodway (with appropriate investigations), which would raise the drain invert level and reduce acid discharge. The lowest lying areas of management area SM2 will be subject to reduced drainage due to sea level rise, which may impact current land use. In these areas, development of freshwater wetlands should be encouraged if current land uses no longer remain viable. Infilling of secondary drains and construction of weirs on smaller drains will assist with this retention of water in wetland areas. Blacks Drain (between SM3 and the main drain junction) could be reshaped to reduce intersection with acid sulfate soils (which have an average elevation of +0.6 m AHD). 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.

In management area SM3, reshaping of drains could continue and include restoration of natural flow paths. Installing weirs could promote an increased water table, reducing further oxidation of acid sulfate soils. This strategy could be implemented alongside wet pasture management.

A summary of the recommended management options for the South Murwillumbah subcatchment including indicative costs is provided in Table 8-6.

Table 8-6: Summary of management options for the South Murwillumbah subcatchment

Timeframe	Strategy	Target management area(s)	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing per year)	Indicative cost (lost productivity per year)	Effectiveness at improving:		
							Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Optimise tidal flushing	SM1, SM2	None	$20,000	$2,000	None	Moderate	Moderate	Negligible
Short-term	Review pumping	Entire subcatchment	None	None	None	Minimal	None	Moderate	Negligible
Short-term	Acid scald revegetation	Sm3	None	$20,000	None	None	None	Moderate	Negligible
Long-term	Drain reshaping	Entire subcatchment	None	$400,000	None	Minimal	None	Moderate	Low
Long-term	Install weirs	SM3	None	$100,000	$20,000	Minimal	None	Moderate	Moderate
Long-term	Wet pasture management	SM3	None	$20,000	None	Minimal	None	Moderate	Moderate
Long-term	Restoration of wetlands	SM2	$1,300,000	$150,000	$15,000	$200,000	None	High	High

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

8.5 Dulguigan subcatchment

Acid priority rank:	**3**
Blackwater priority rank:	**6**
Infrastructure	
Approximate waterway length (km)	29
# Privately owned end of system structures	4
# Publicly owned end of system structures	18
# End of system structures within coastal wetlands	1
# Publicly owned end of system structures within coastal wetlands	1
Primary floodplain infrastructure (floodgate ID)	170, 188, 191, WRL_TW_15
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-0.9 to -0.2
Average AASS elevation (m AHD)	0.7
Average PASS elevation (m AHD)	-0.5
Median blackwater elevation (m AHD)	1.0
Present day low water level (m AHD)	-0.3
Near future low water level (m AHD)	-0.2
Far future low water level (m AHD)	0.3
Proximity to sensitive receivers	
Oyster leases (km)	25.5
Saltmarsh (km)	8.3
Seagrass (km)	12.4
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	767
Classified as conservation and minimal use (ha (%))	19 (3%)
Classified as grazing (ha (%))	66 (9%)
Classified as forestry (ha (%))	0 (0%)
Classified as sugar cane (ha (%))	588 (77%)
Classified as horticulture (ha (%))	2 (0.2%)
Classified as other cropping (ha (%))	28 (4%)
Classified as urban/industrial/services (ha (%))	46 (6%)
Classified as marsh/wetland (ha (%))	0 (0%)
Other (ha (%))	19 (2%)
Land values	
Estimated total primary production value ($/year)	$900,000
Average land value above 1.0 m AHD ($/ha)	$13,900
Average land value below 1.0 m AHD ($/ha)	$12,600

8.5.1 Site description and brief history of drainage

The Dulguigan subcatchment is located on the left bank of the Rous River, a tributary of the Tweed River estuary. The Dulguigan subcatchment was named as an acid sulfate soil hot spot by Tulau (1999). Dulguigan Creek runs from west to east and is the main drainage pathway within the subcatchment. End of system headworks (Structure 191) have been constructed on Dulguigan Creek approximately two km upstream from the Rous River at Dulguigan Road. In addition to this, a drain has been constructed which runs from north to south connecting Dulguigan Creek approximately 1.5 km upstream from the headworks along a more direct route to the Rous River through Structure 188. The western area of the floodplain drains to the south of the floodplain through Structure 170 to the Rous River.

Early records show that interest in constructing drainage works within the Dulguigan subcatchment began as early as the 1910s (Tulau, 2011). In the 1930s, the survey of the backswamp was completed, however, major drainage works did not occur until the 1970s (Tulau, 2011). In 1970 the headworks structure was installed on Dulguigan Creek. In the subsequent years a number of drains were constructed throughout the subcatchment as part of the Tweed River flood mitigating scheme (Tulau, 2011).

As the effects of acid export from acid sulfate soils was observed in the Tweed River estuary, early investigations identified the Dulguigan subcatchment as a key location of acid discharge (PWD, 1991). Further investigations found that at a local quarry, pyrite in quartz being mined would oxidise and generate acidic runoff inflow into Dulguigan Creek (PWD, 1991) following rainfall events. After implementation of remediation actions at the quarry it was discovered that acidic water within the Dulguigan subcatchment was also originating from the floodplain (PWD, 1991). Long term water quality monitoring in the Rous River has shown persistently low pH levels at the Dulguigan subcatchment (Ferguson, 2012; Pratt, 2017).

The major land use in the Dulguigan subcatchment is sugar cane. On the east of the floodplain there are some areas used for grazing, however, large sections of this area are mapped as Coastal Management SEPP coastal wetlands. Aerial imagery shows that since 2012, approximately 27 ha of land marked as other cropping land use appears to have been developed into a racetrack. It is unclear if cropping still occurs on land around the racetrack. Tenure information for the Dulguigan subcatchment is shown in Figure 8-21. Information on drainage and floodplain elevation is shown in Figure 8-22.

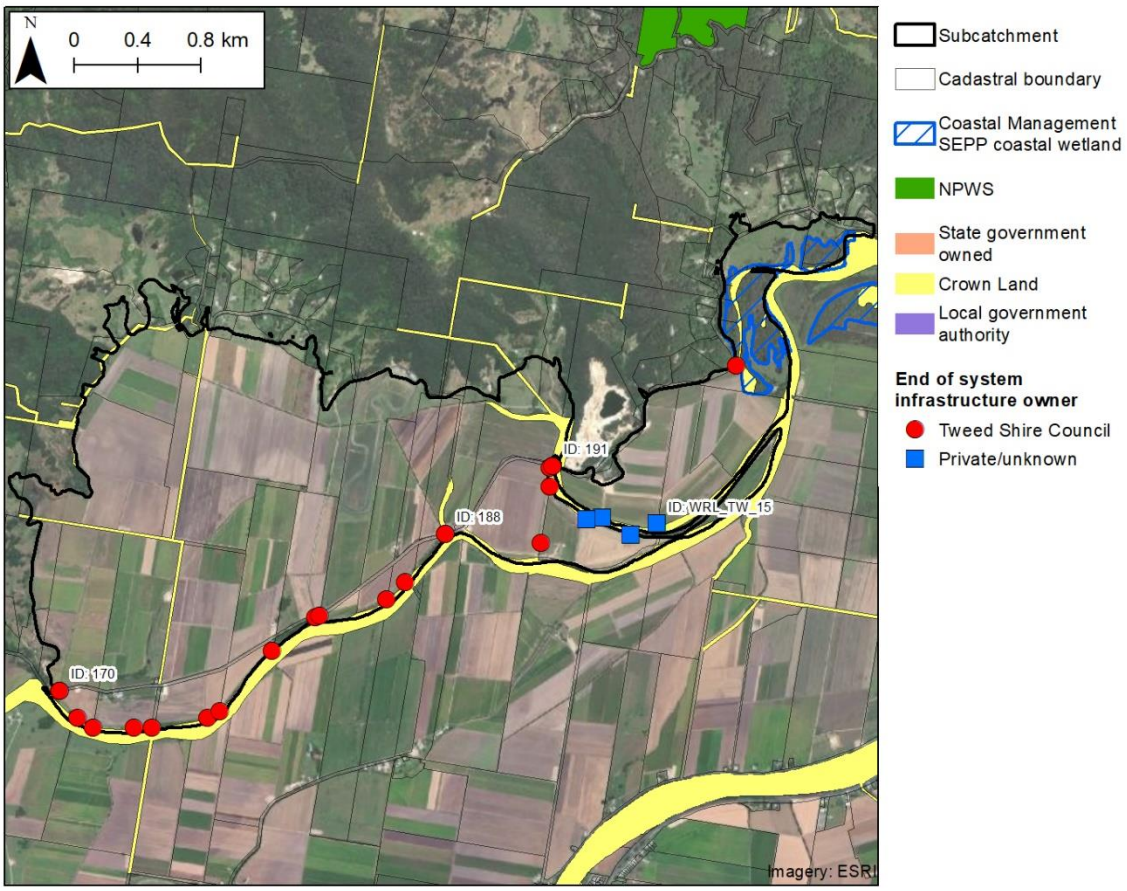


Figure 8-21: Dulguigan subcatchment – land and end of system infrastructure tenure

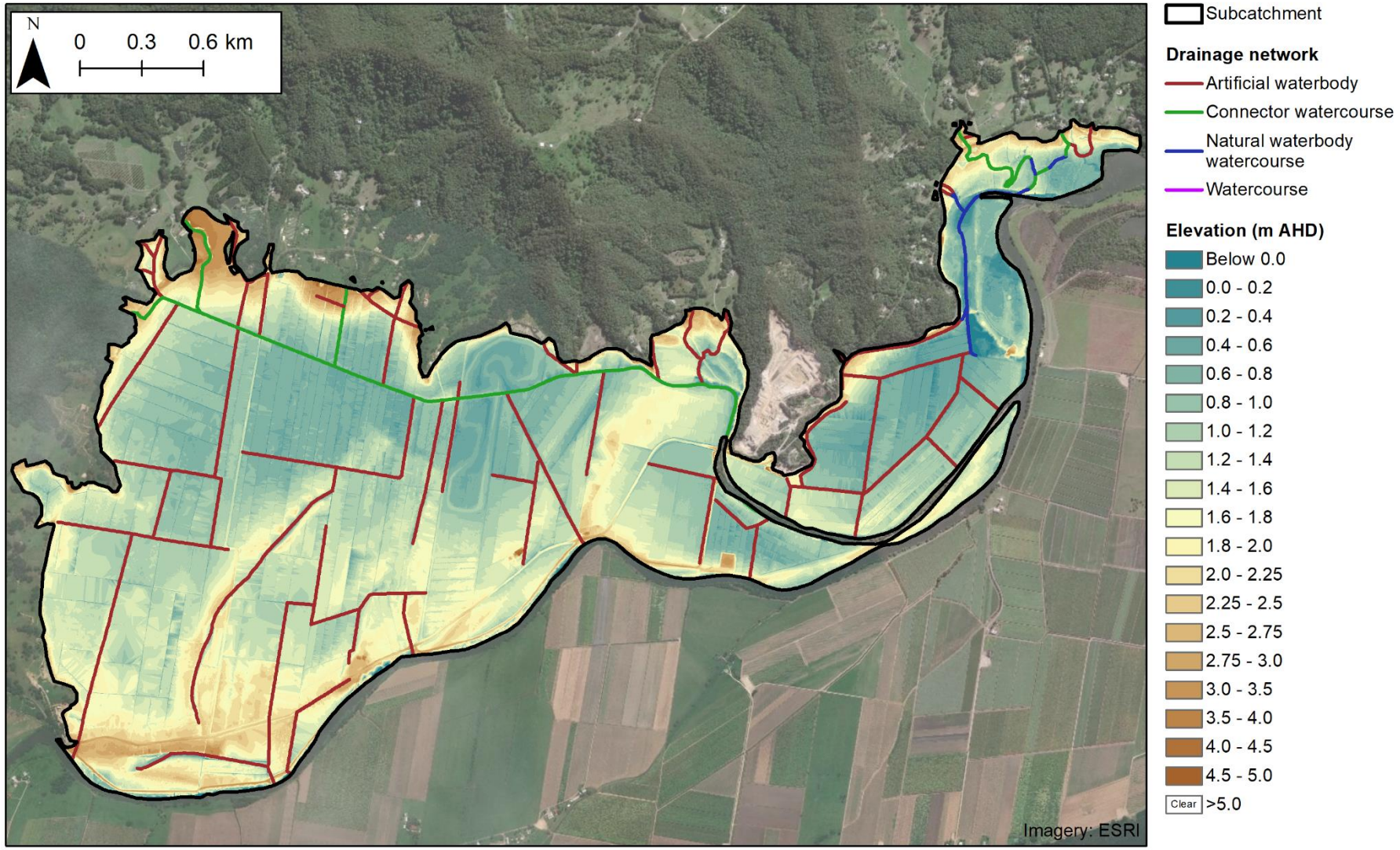


Figure 8-22: Dulguigan subcatchment elevation and drainage network

8.5.2 History of remediation

Within the Dulguigan subcatchment, previous remediation efforts have focused on modifying drainage infrastructure to allow controlled tidal flushing of the drainage network. In 1998, three winches were installed on the Dulguigan Creek headworks (Structure 191) to facilitate tidal flushing (Figure 8-23) (Lofthouse and Capeland, 1998). Initially, operation of these winches was manual with the floodgate being opened during dry times and closed when the water level threatened to inundate upstream land during wet periods and high tides (Tulau, 1999). Inspection of floodgate structures for this study found that there was only one functioning winch remaining on Structure 191 and at the time of the inspection the floodgate remained closed. Photos provided by Tweed Shire Council indicated that there has only been one floodgate winch since as early as 2007. There are no records available to determine when the two other winches were removed.



Figure 8-23: Three winches installed in 1998 on Structure 191 across Dulguigan Creek (note there is now only one winch on this structure) (Tulau, 2011)

Structure 188 and Structure 170 have also been modified to enable managed flushing with winches installed on one floodgate on each structure. During field investigations, the floodgates on Structure 188 remained shut while one floodgate flap on Structure 170 was winched slightly open to allow controlled tidal flushing. Figure 8-24 shows the location remediation actions with respect to the drainage network.

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

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

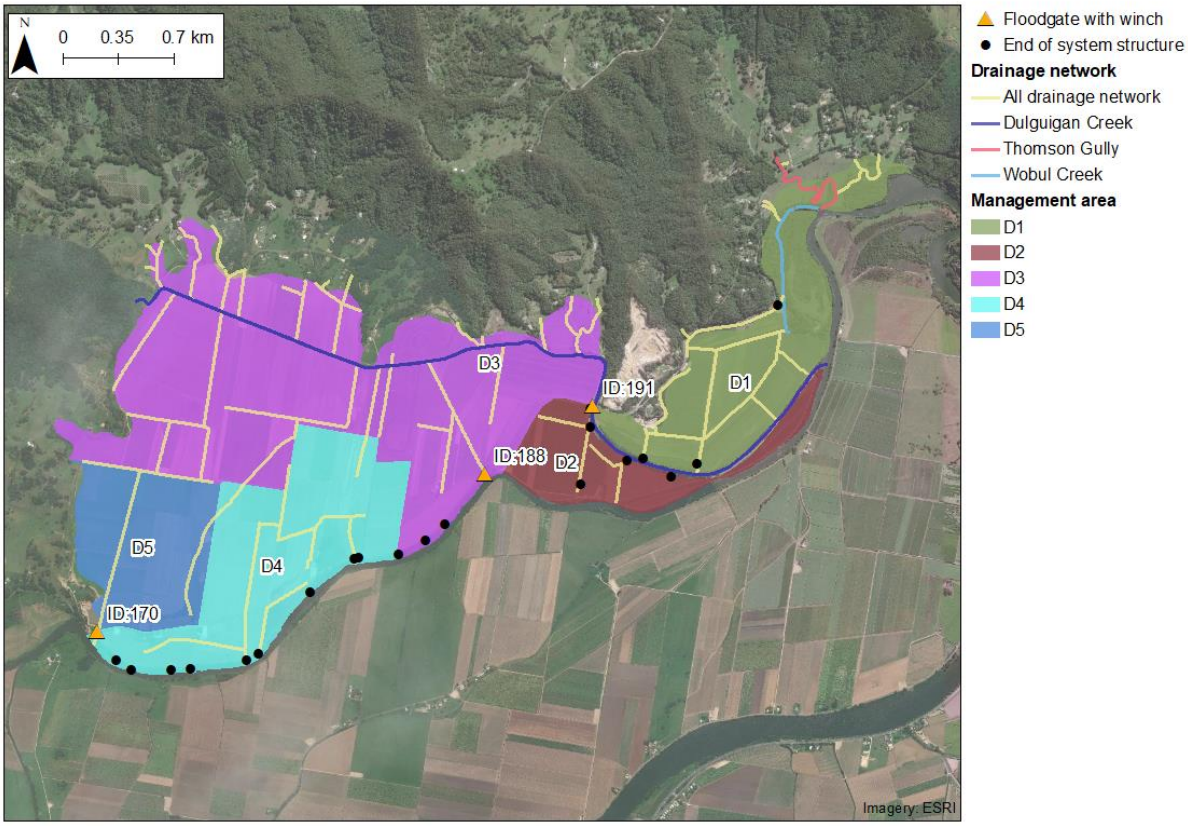


Figure 8-24: The Dulguigan subcatchment including previous remediation actions

8.5.3 Prioritisation of management areas in the Dulguigan subcatchment

The Dulguigan subcatchment ranked third in the acid prioritisation, and sixth in the blackwater prioritisation. The subcatchment has been further delineated into five (5) smaller management areas (referred to as D1 to D5, shown in Figure 8-7) to provide additional information on the sources of acid. The areas have been delineated based on land tenure, data availability, elevation, changes in soil acidity and drainage units. Note, blackwater has been considered on the subcatchment scale.

The management areas have been prioritised for acid generation using the method described in Section 4.2 and are detailed in Table 8-7. Limited soil profile data was available for some areas of the Dulguigan subcatchment. Subsequently only D3 and D4 could be compared on a management area basis in terms of acid risk, with management areas D1, D2 and D5 being compared qualitatively based upon drainage and hydrology. A rank has been assigned to these management areas based upon this qualitative assessment. Additional investigation would be required to confirm the management area priority ranking.

Based on the findings from the management area prioritisation and analysis of drainage and hydrology data shown in Figure 8-25, it is suggested that remediation in the Dulguigan subcatchment should target management areas D1, D2 and D3.

Table 8-7: Management area acid prioritisation of the Dulguigan subcatchment

Management area	Groundwater factor	Surface water factor	Final acid factor	Final rank
D3	335	485	162,806	1
D2	Insufficient data	771	Insufficient data	2*
D1	Insufficient data	533	Insufficient data	3*
D5	Insufficient data	500	Insufficient data	4*
D4	6	764	4,540	5*

* Rank based upon qualitative assessment.

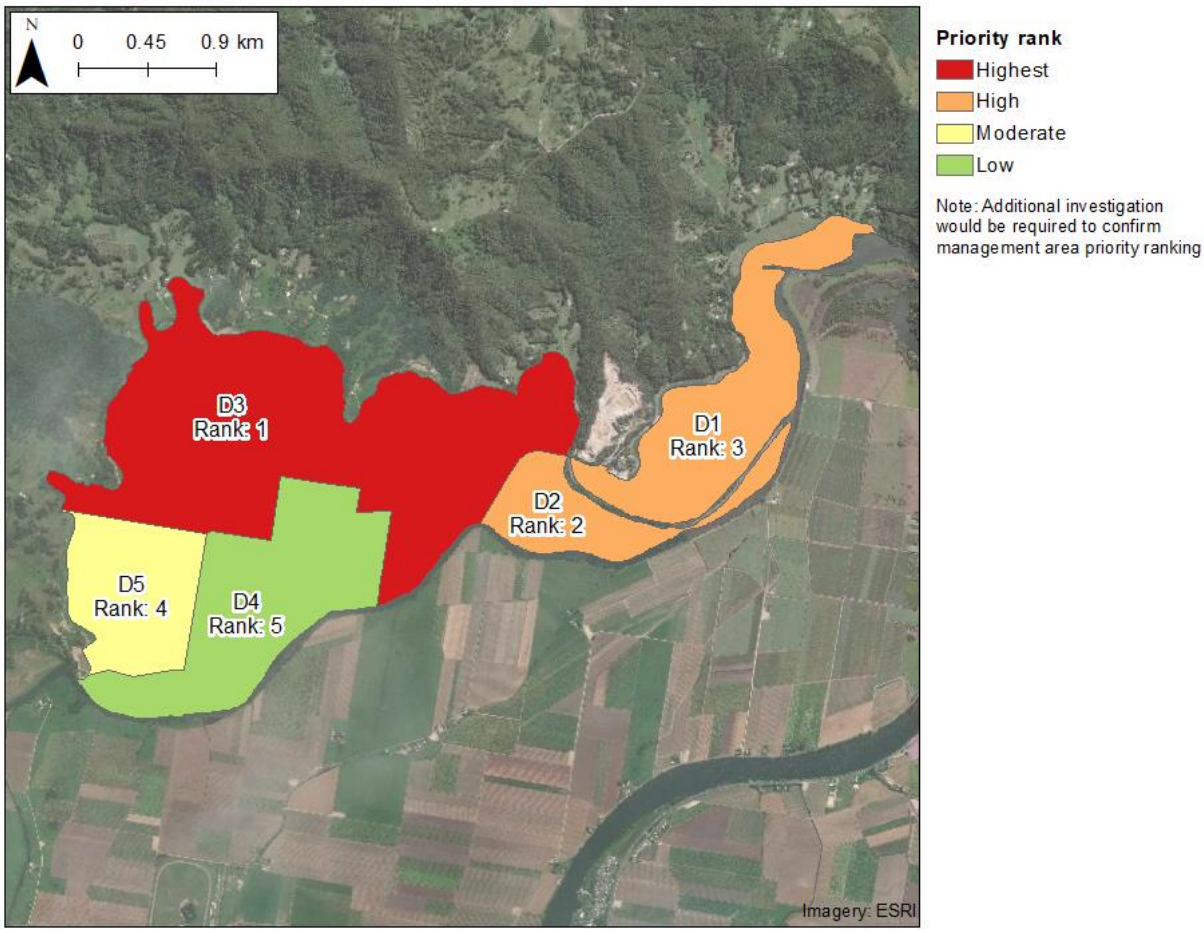


Figure 8-25: The Dulguigan subcatchment management area priority

8.5.4 Floodplain drainage - sea level rise vulnerability

The sea level rise vulnerability assessment of the Dulguigan subcatchment is summarised in Figure 8-26. Modelling of different sea level rise scenarios indicated that drainage of management areas D1, D2 and D3 were potentially impacted by present day estuarine water levels. This is most significant in management area D1, which has the lowest lying land in the Dulguigan subcatchment. Into the future, drainage will become increasingly impacted by sea level rise, with large areas of the floodplain within the D1 and D3 management areas predicted to be at medium risk of reduced drainage in the far future.

Floodgates in the Dulguigan subcatchment will be affected by sea level rise to varying degrees, including the primary floodgates shown in Figure 8-27. Currently, a major floodgate servicing the D1 management area (ID: WRL_TW_15) is most vulnerable. This floodgate is also moderately vulnerable in the near future modelling due to its obvert level being below the approximate high tide water level (i.e. moderately vulnerable). Far future modelling indicated that all floodplain infrastructure servicing the Dulguigan subcatchment will become at least moderately vulnerable.

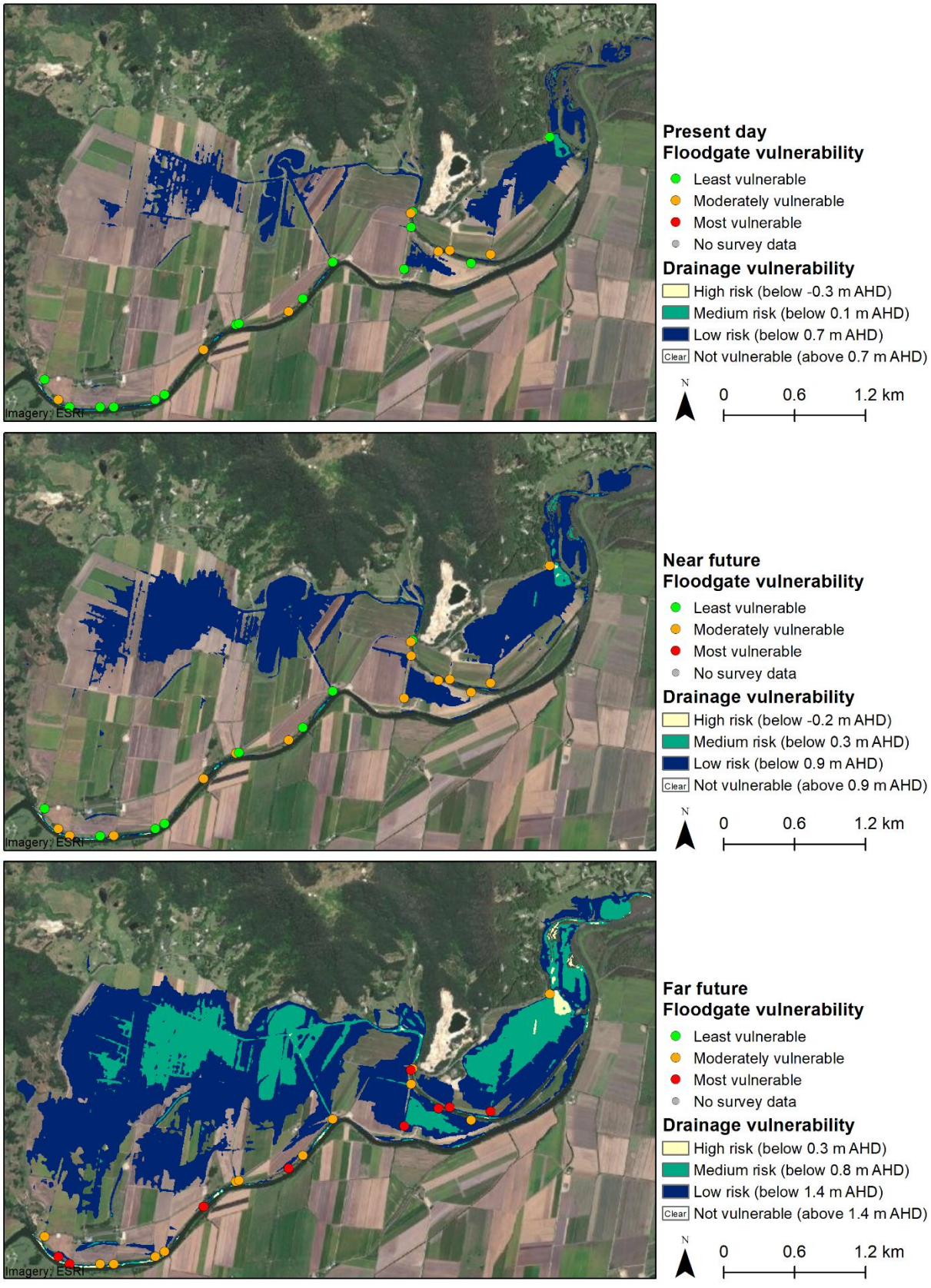


Figure 8-26: Sea level rise drainage vulnerability for the Dulguigan subcatchment

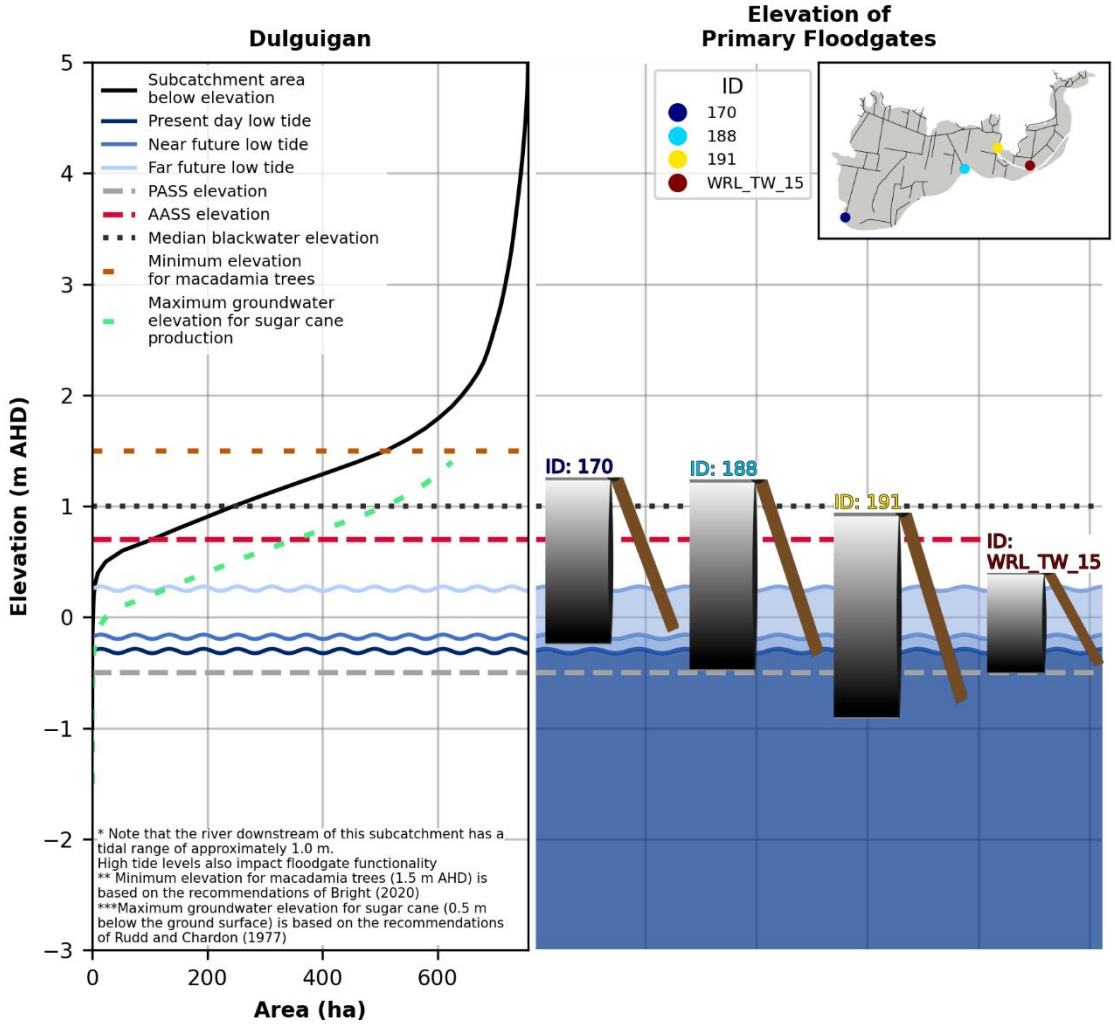


Figure 8-27: Key floodplain elevations – Dulguigan subcatchment

8.5.5 Management options

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

- Short-term: Optimise tidal flushing through structures, drain reshaping, introducing water tolerant vegetation, and protection of existing wetlands.
- Long-term: Drain reshaping, restoring natural flow paths, installing weirs, wet pasture management, and transition of low-lying areas to 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
Coastal Management SEPP coastal wetlands are situated within management area D1. Ongoing protection of this area should continue to maximise environmental benefits for the Tweed River estuary.

Floodgate Structure 192 and a private structure (WRL_TW_15) to the south of management area D1 (see Figure 8-28) could be modified to allow controlled in-drain tidal flushing. This would improve water quality within the drainage network and have the potential to buffer any acidic discharges during low flow periods while providing aquatic connectivity. However, buffering of acid would likely be limited during moderate to high flow periods. Pratt (2017) found salinity levels in the Rous River to be lower than similar estuarine areas in the upper Tweed River estuary, with salinity generally below 5 - 10 ppt during low inflow (i.e. dry) periods. A similar strategy could be adopted for key floodgates within management area D2.

A number of floodgates within the Dulguigan subcatchment have existing modifications that would allow controlled in-drain tidal flushing of the drainage network. This includes Structures 170, 188 and 191 which service management areas D3 and D5. Continued active management of these floodgates to improve tidal flushing would benefit these management areas.

The constructed drain between Dulguigan Creek and Rous River upstream of Structure 188 could be shallowed and widened (within management area D3). This would ensure that drainage capacity is sustained while limiting the exposure of acid sulfate soils.

Depending upon the current land use surrounding the existing racetrack area in management area D3, water tolerant vegetation could be planted to replace non-water tolerant species to reduce the blackwater risk. This could be assisted by infilling of unrequired drains or installing drop board or weir structures to retain a higher water table.

The floodgate on Structure 183 could be modified to allow controlled tidal flushing of the upstream waterways. Due to the relatively higher elevation of land within management area D4, permanent opening of the floodgate on Structure 183 with a winch or similar device could be investigated. This would allow the floodgate to be managed so that it is opened during dry times and closed during wet events and predicted extreme high tides.

Short-term management strategies for the Dulguigan subcatchment are summarised in Figure 8-28.

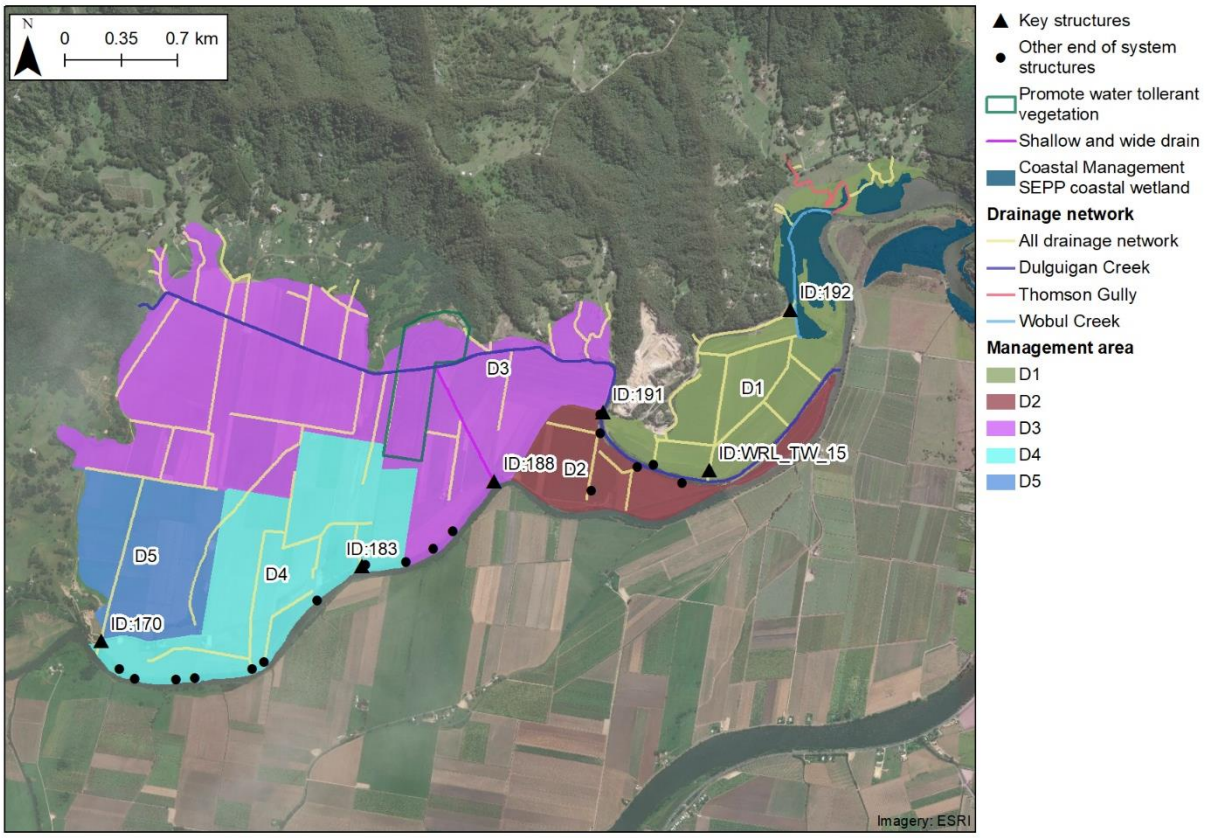


Figure 8-28: Short-term management options for the Dulguigan subcatchment

Long-term management options

Modelling of future sea level rise scenarios indicated that both management areas D1 and D2 will be significantly impacted by reduced drainage, which could potentially impact current land uses. Full restoration of these areas to estuarine wetland could be considered into the future. Coastal Management SEPP coastal wetlands, which already exist in management area D1, could be allowed to expand to include low lying floodplain areas.

Management area D3 is also likely to be impacted by reduced drainage in the far future. In low lying areas development of wetlands could be considered, which could be promoted via the installation of weirs, and drain infilling/reshaping. For higher areas that are also prone to reduced drainage, wet pasture management could be considered. The drain running north to south connecting Dulguigan Creek through Structure 188 to the Rous River could be infilled, restoring the natural flow path of the subcatchment through Dulguigan Creek. The floodgate on Structure 191 could also be removed increasing flushing within the drainage network and improve aquatic habitats.

Management areas D4 and D5 contain higher elevation land that will continue to be productive under far future planning horizons. Land management practices such as laser levelling to reduce drainage density, and use of acid sulfate soil management plans should continue to ensure the export of acid from this area is minimised.

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

Table 8-8: Summary of management options for the Dulguigan subcatchment

Timeframe	Strategy	Target management area(s)	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing per year)	Indicative cost (lost productivity per year)	Effectiveness at improving:		
							Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Optimise tidal flushing	D1, D3, D4, D5	None	$85,000	$30,000	None	Moderate	Moderate	Negligible
Short-term	Wet pasture management	D3	None	$20,000	None	Minimal	None	Moderate	Moderate
Short-term	Drain reshaping	D3	None	$70,000	None	Minimal	None	Moderate	Low
Long-term	Dain infilling	D3	None	$50,000	None	None	None	Moderate	Low
Long-term	Restoration of wetlands	D1, D2	$4,000,000	$600,000	Minimal	$450,000	Very high	High	High

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

8.6 Kynnumboon subcatchment

Acid priority rank:	**4**
Blackwater priority rank:	**8**
Infrastructure	
Approximate waterway length (km)	35
# Privately owned end of system structures	4
# Publicly owned end of system structures	25
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (floodgate ID)	145, 148, 150, 162
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-0.5 to 0.0
Average AASS elevation (m AHD)	1.0
Average PASS elevation (m AHD)	-0.2
Median blackwater elevation (m AHD)	1.4
Present day low water level (m AHD)	-0.3
Near future low water level (m AHD)	-0.2
Far future low water level (m AHD)	0.2
Proximity to sensitive receivers	
Oyster leases (km)	32.1
Saltmarsh (km)	14.8
Seagrass (km)	18.9
Mangroves (km)	2.0
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	1,003
Classified as conservation and minimal use (ha (%))	7 (1%)
Classified as grazing (ha (%))	282 (28%)
Classified as forestry (ha (%))	0 (0%)
Classified as sugar cane (ha (%))	545 (54%)
Classified as horticulture (ha (%))	2 (0.2%)
Classified as other cropping (ha (%))	2 (0.2%)
Classified as urban/industrial/services (ha (%))	124 (12%)
Classified as marsh/wetland (ha (%))	0 (0%)
Other (ha (%))	40 (4%)
Land values	
Estimated total primary production value ($/year)	$900,000
Average land value above 1.4 m AHD ($/ha)	$15,100
Average land value below 1.4 m AHD ($/ha)	$18,200

8.6.1 Site description and brief history of drainage

The Kynnumboon subcatchment is the furthest upstream within the Rous River tributary of the Tweed River estuary. Dungay Creek, Pipeclay Creek and Graham Creek flow into the Rous River within the downstream section of the floodplain providing a flow path for water draining from the upper catchment. Across the floodplain the predominant drainage is supplied by constructed drains which flow directly into the Rous River.

Drainage infrastructure in the Kynnumboon subcatchment was constructed as part of the Tweed River flood mitigation scheme with works being completed between 1971 and 1977 (Tulau, 2011). Works completed as part of the scheme included drains and headworks structures flowing into the Rous River. The effect of draining the floodplain was observed as early as 1987 when PWD (1991) completed extensive testing of pH across the Tweed River estuary following a large fish kill event and observed low pH levels (pH<4) in the Kynnumboon subcatchment.

Land use across the Kynnumboon subcatchment includes sugar cane (54%), which exists on lower elevation areas of the floodplain, and grazing (28%) on higher areas. Murwillumbah Golf Course is located on the southern side of the Rous River to the south of the subcatchment. It is also at approximately this location where the Murwillumbah Wastewater Treatment Plant discharges into the Rous River. Tenure information for the Kynnumboon subcatchment is shown in Figure 8-29. Information on drainage and floodplain elevation is shown in Figure 8-30.

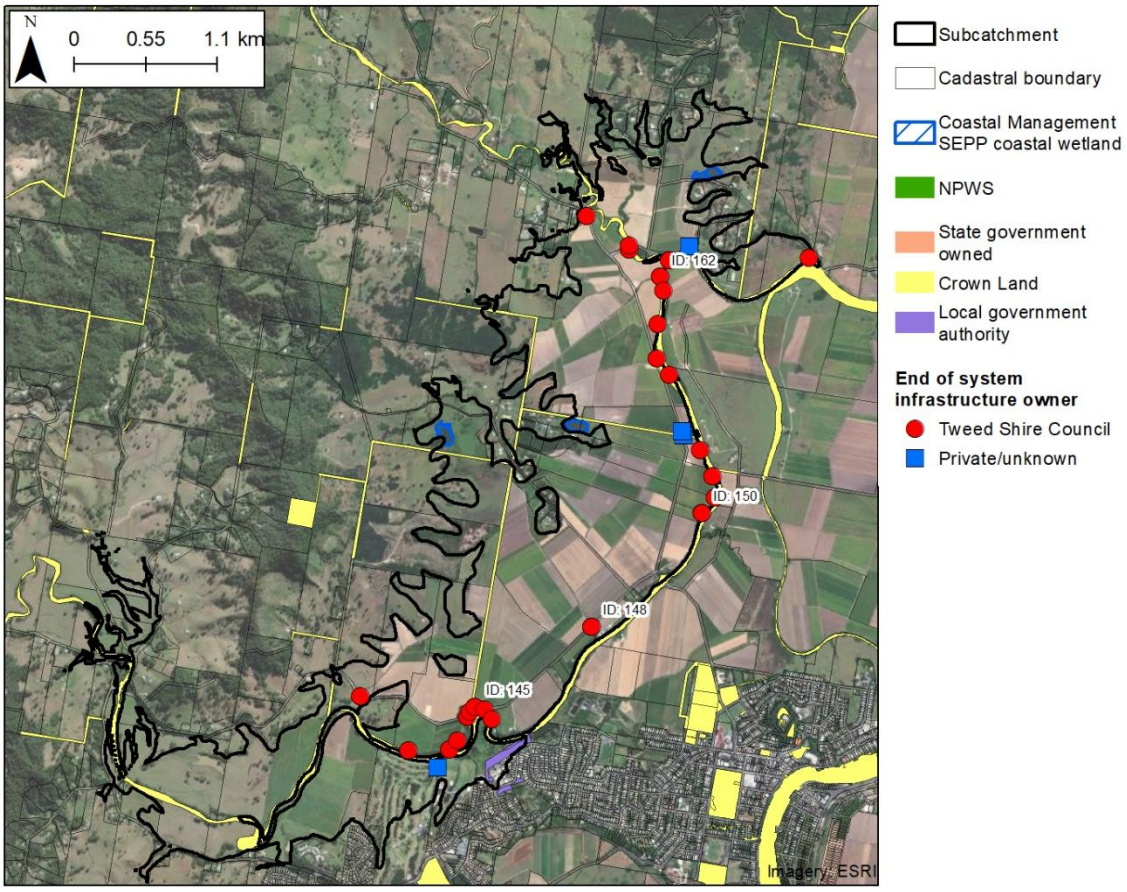


Figure 8-29: Kynnumboon subcatchment - land and end of system infrastructure tenure

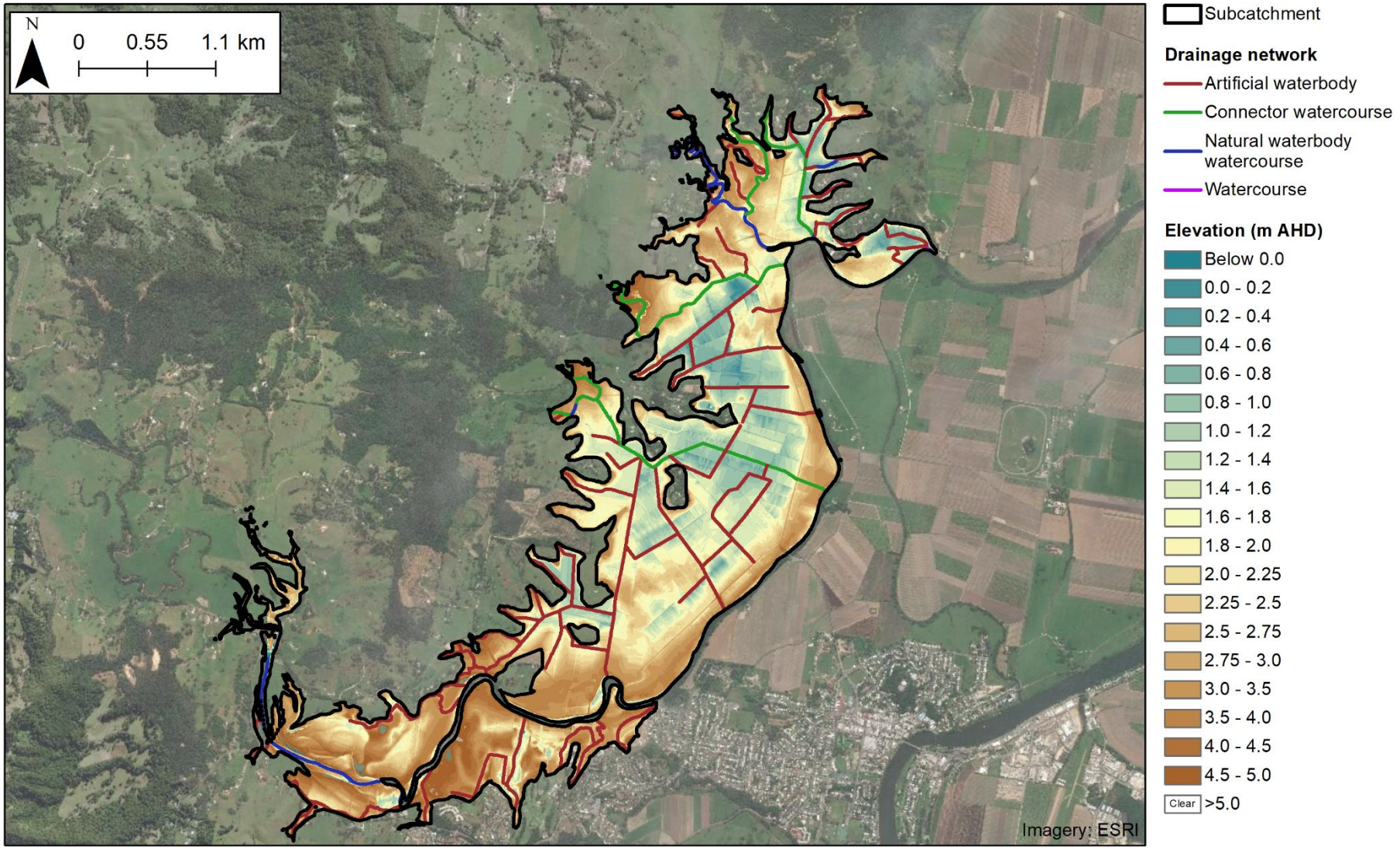


Figure 8-30: Kynnumboon subcatchment elevation and drainage network

8.6.2 History of remediation

Within the Kynnumboon subcatchment, modification of floodgate structures has enabled controlled tidal flushing within the drainage network. Between 2006 and 2009, Industry and Investment NSW (2009) modified the floodgates on Structure 140 and Structure 150 (highlighted in Figure 8-32) to have buoyancy controlled auto-tidal gates that opened waterways for fish passage. During field investigations the buoyancy controlled auto-tidal gate on Structure 140 was observed to be in good condition (Figure 8-31).

In addition to the buoyancy controlled auto-tidal gates, winches have been installed on Structure 145 (closed during site inspection) and Structure 148. Photos provided by Tweed Shire Council in 2007 show that one of the floodgate flaps on Structure 148 is in an open position.

An historic floodgate is located on a drain that connects to Graham Creek approximately 300 m upstream of its confluence with Rous River. This indicates that historically a structure located on Graham Creek (Structure 162) may have been able to be opened, however, there is no evidence of any winch structures or similar on this structure to allow such opening.

Tweed Shire Council currently has an ongoing program to infill paddock scale drains across the Tweed River floodplain (TSC, 2020). To date, over 40 km of drains have been infilled, including drains within the Kynnumboon subcatchment.

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

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



Figure 8-31: Buoyancy controlled auto-tidal gate on Structure 140

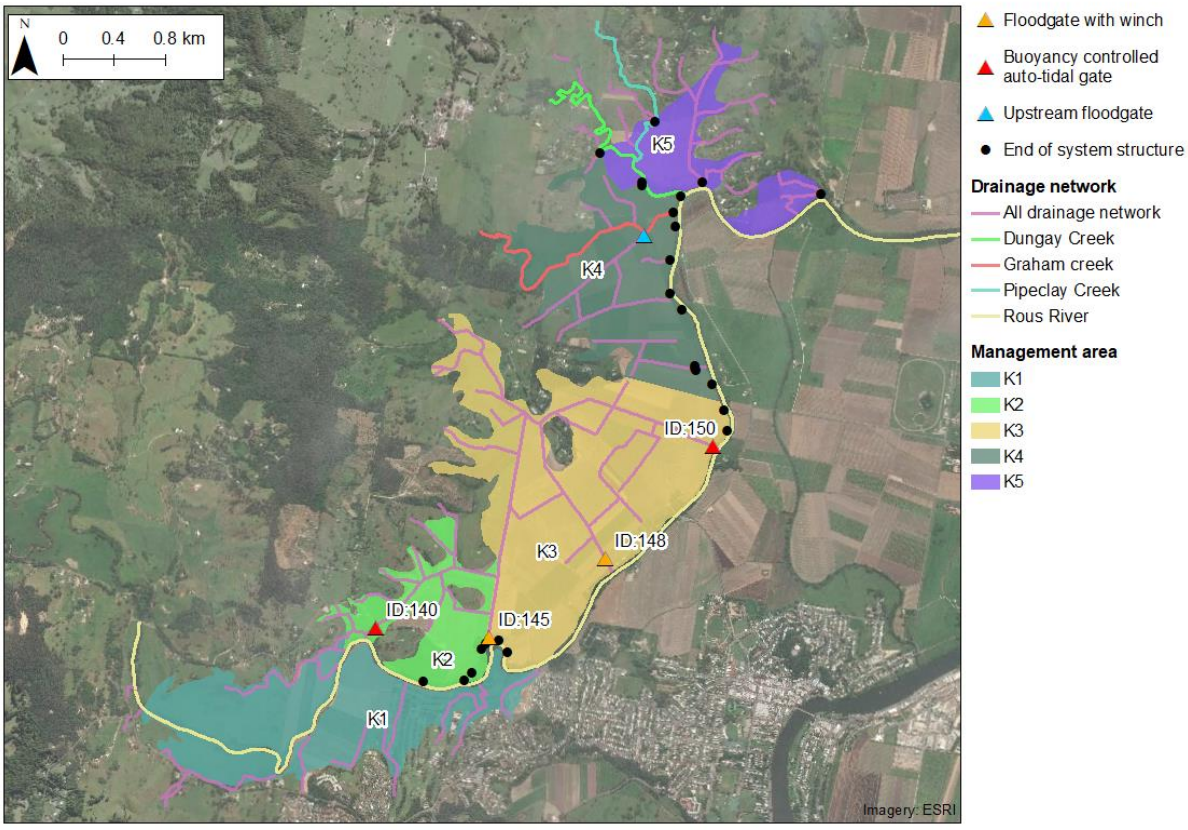


Figure 8-32: The Kynnumboon subcatchment including previous remediation actions

8.6.3 Prioritisation of management areas in the Kynnumboon subcatchment

The Kynnumboon subcatchment ranked fourth in the acid prioritisation, and eighth in the blackwater prioritisation. The subcatchment has been further delineated into five (5) smaller management areas (referred to as K1 to K5, shown in Figure 8-7) to provide additional information on the sources of acid. The areas have been delineated based on land tenure, data availability, elevation, changes in soil acidity and drainage units. Blackwater has been considered on the subcatchment scale.

The management areas have been prioritised for acid generation using the method described in Section 4.2, and the prioritisation results are detailed in Table 8-9. Limited soil profile data was available within the Kynnumboon subcatchments resulting in insufficient data to calculate the groundwater factor during the management area prioritisation. Subsequently, management areas K1, K2 and K5 have been assessed qualitatively based upon drainage and hydrology. A rank has been assigned to these management areas based upon this qualitative assessment. Additional investigation would be required to confirm the management area priority ranking.

Based on the findings from the management area prioritisation and an assessment of the drainage and hydrology shown in Figure 8-33 in the Kynnumboon subcatchment, remediation should focus on management areas K3, K4 and K5.

Table 8-9: Management area acid prioritisation of the Kynnumboon subcatchment

Management area	Groundwater factor	Surface water factor	Final acid factor	Final rank
K4	157	410	64,558	1
K3	69	267	18,462	2
K5	Insufficient data	1,872	Insufficient data	3*
K2	Insufficient data	643	Insufficient data	4*
K1	Insufficient data	251	Insufficient data	5*

* Rank based upon qualitative assessment.

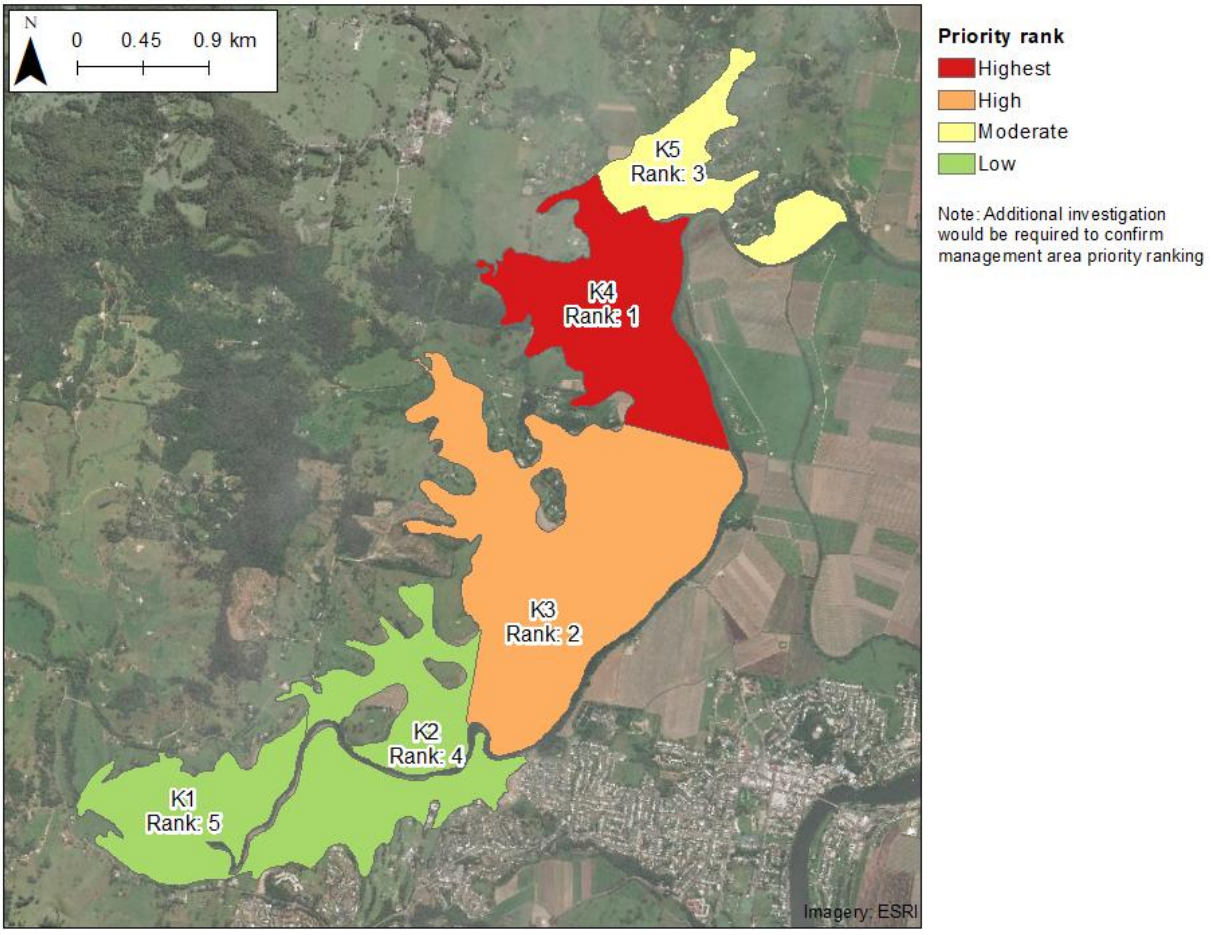


Figure 8-33: The Kynnumboon subcatchment management area priority

8.6.4 Floodplain drainage – sea level rise vulnerability

The sea level rise vulnerability assessment of the Kynnumboon subcatchment is summarised in Figure 8-34. Modelling shows that the most vulnerable areas of the floodplain are located on sections of the subcatchment further downstream, with management areas K4 and K5 being potentially impacted by reduced drainage under present day conditions. In the near future and far future sea level rise scenarios, this reduction in drainage potential will increase and extend to management area K3. The lowest locations on the floodplain, management areas K4 and K5, will have a medium risk of reduced drainage in the far future sea level rise scenario.

Floodgate structures in the Kynnumboon subcatchment will be affected by future sea level rise, with five (5) structures becoming moderately vulnerable in the far future, including major floodgate Structure 162 (shown in Figure 8-35).

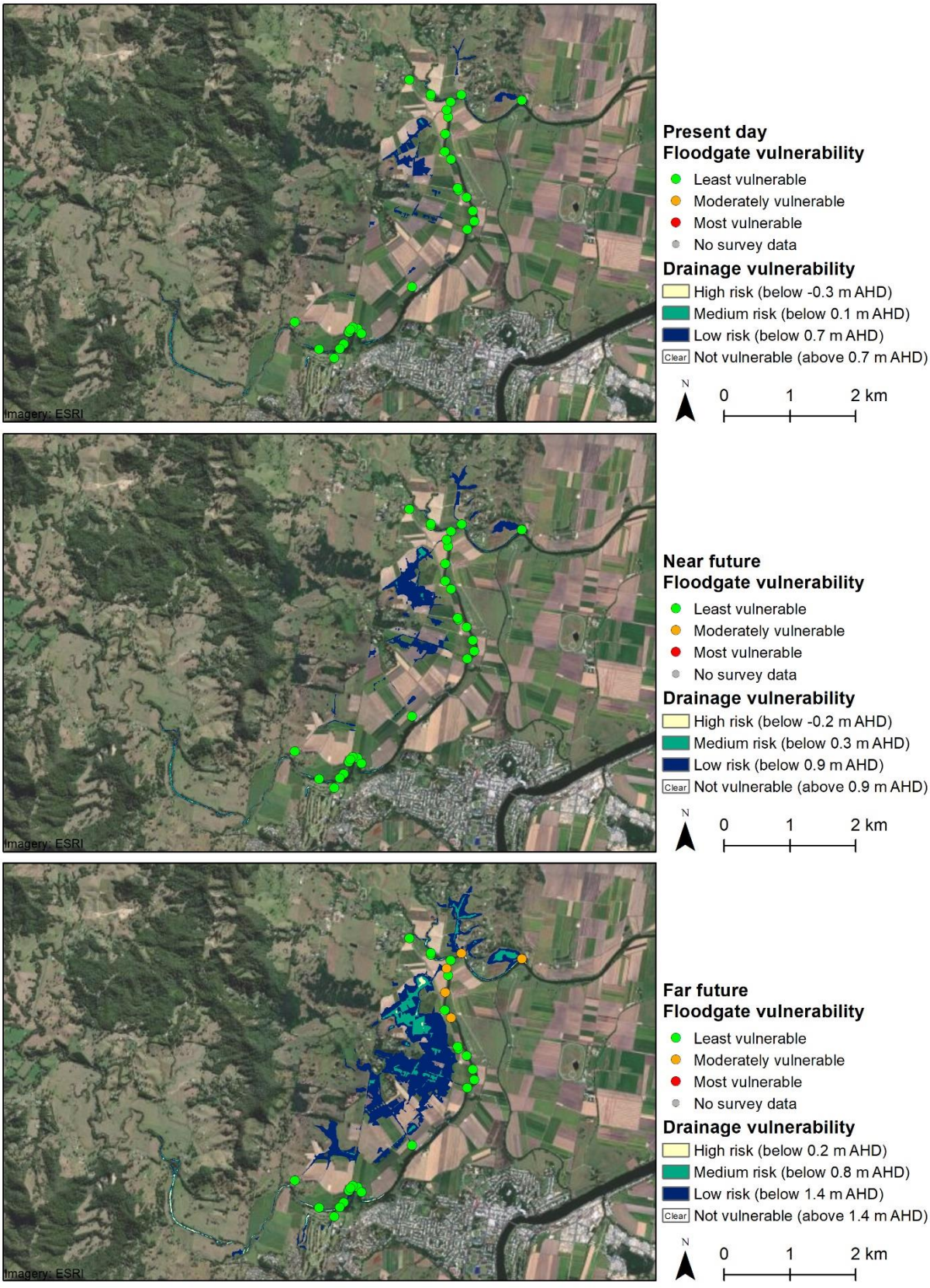


Figure 8-34: Sea level rise drainage vulnerability for the Kynnumboon subcatchment

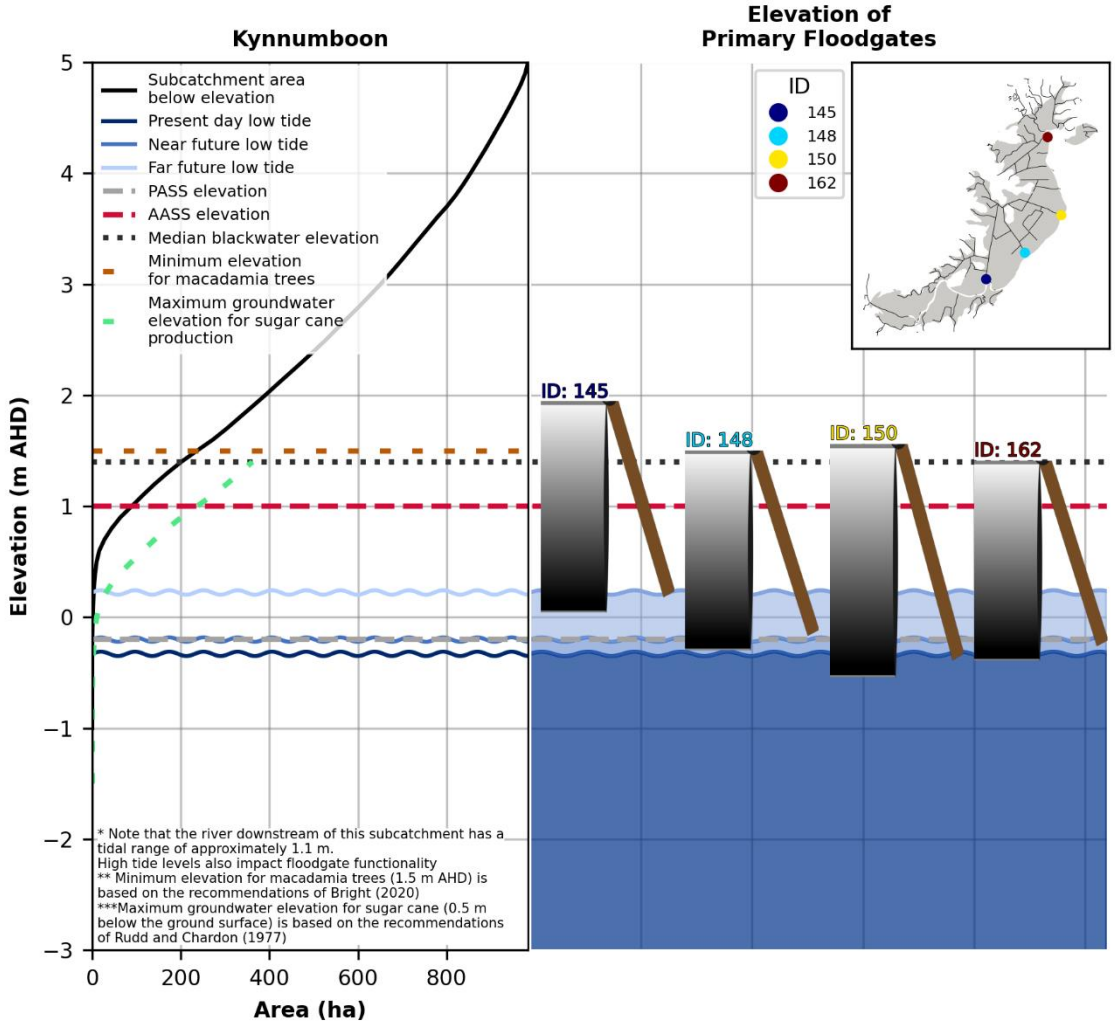


Figure 8-35: Key floodplain elevations - Kynnumboon subcatchment

8.6.5 Management options

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

- Short-term: Optimise tidal flushing through structures, and restoring natural flow paths.
- Long-term: Drain modifications, restoring natural flow paths, installing weirs, wet pasture management, and transition of low-lying areas to 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 current strategy of allowing controlled tidal flushing of the drainage network is the most effective available as it improves water quality through flushing and provides an increased habitat for aquatic life. Structures 140, 145, 148 and 150 have all been modified and are providing benefits to management areas K1, K2 and K3 (Figure 8-36). Maintenance and management of these structures should continue to achieve a balance of both agricultural and environmental outcomes.

Modification of structures to allow controlled tidal flushing within management areas K4 and K5 could be implemented to achieve similar outcomes. Structures 159, 162, 168 and 169 could be investigated for modification. Tidal flushing could be controlled to be in-drain only within these systems so as not to impact agricultural land but also provide maximum environmental benefit. It should be noted that salinity in the upper Rous River estuary is dependent on inflows, with the Pratt (2017) review of water quality finding that salinity levels are brackish during low inflow periods, and salinity is flushed from the upper Rous River during moderate to high inflow events. Subsequently, tidal flushing may have some benefits for buffering acid discharges during dry periods only. Site specific assessment and design would be required to confirm the possible extent of tidal flushing.

Alternatively, Structure 162 within management area K4 could be modified so that the floodgates can be winched open. At the same time an existing floodgate located further upstream could be serviced to ensure it is functioning well. By winching open Structure 162, tidal flows could be reintroduced to Graham Creek while the refurbished floodgate would protect low-lying agricultural land from inundation.

Long-term management options
Management of area K1 is unlikely to be impacted into the future due to the higher elevation of this land. There is limited knowledge of acid sulfate soils in this area so further investigations could be completed to assess its risk. Where there are areas with lower elevation, wet pasture management could be considered to minimise the risk of blackwater.

Within management area K2, the drain running north to south connecting to the Rous River at Structure 145 could be infilled and natural flow paths within this management area could be restored (Figure 8-36). Weirs could be installed on higher areas to raise the water table. Wet pasture management practices could be implemented in low-lying areas or where weirs are constructed to raise the water table.

The drainage density within management area K3 could be reduced in the long term, and wherever practical, drains could be reshaped wider and shallower. Some very low-lying areas are likely to be impacted by reduced drainage due to sea level rise resulting in impacts to current land. At these locations consideration should be given for the restoration of wetlands.

Far future modelling indicates that drainage within management area K4 may be impacted by sea level rise. If current land uses become unsustainable due to the impacts of sea level rise, low-lying land within management area K4 could be strategically restored to a wetland by infilling of drains and reinstating the natural hydrology.

Wet pasture management could be utilised in low-lying areas within management area K5. In addition, the structure that passes under Colefax Court could be modified to retain water upstream, promoting freshwater ponding, which would also allow the area to be managed as wet pasture (Figure 8-36).

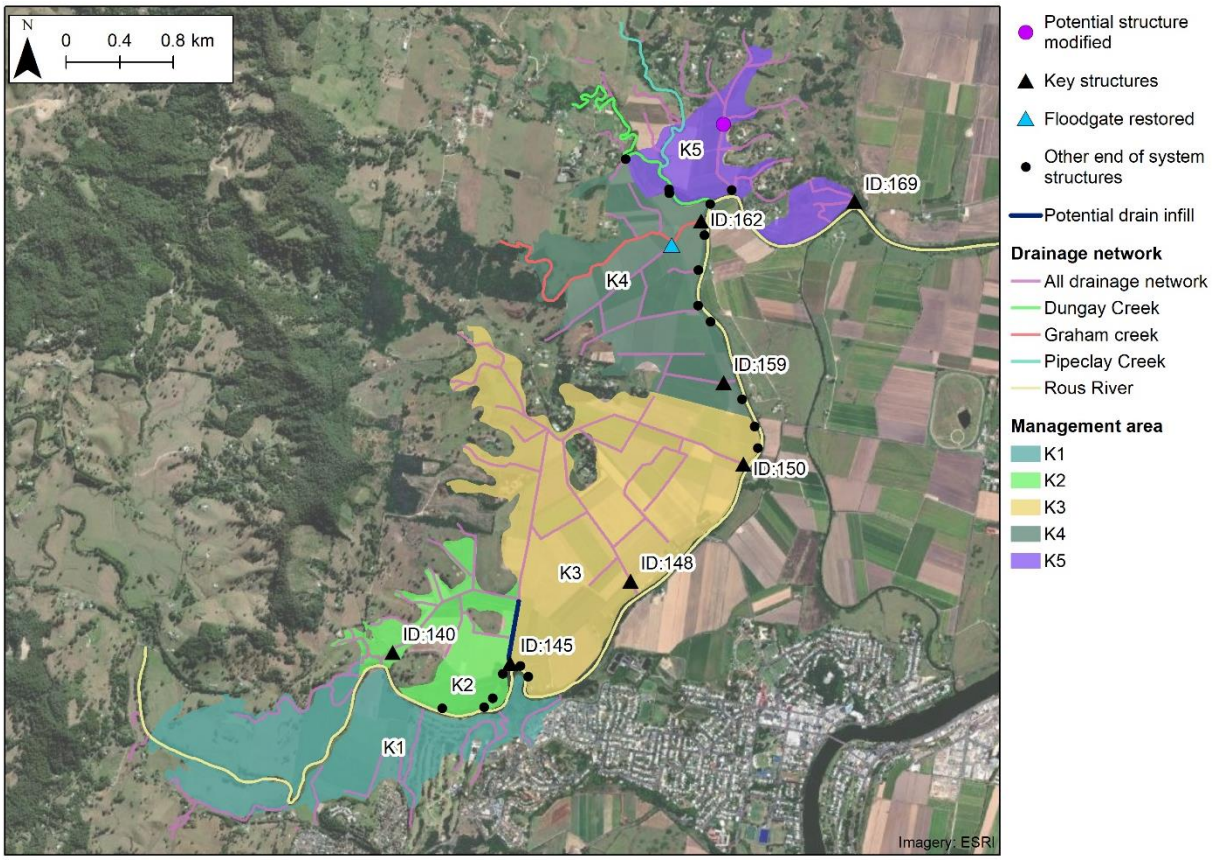


Figure 8-36: Long-term management options for the Kynnumboon subcatchment

A summary of the recommended management options for the Kynnumboon subcatchment including indicative costs is provided in Table 8-10.

Table 8-10: Summary of management options for the Kynnumboon subcatchment

Timeframe	Strategy	Target management area(s)	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing per year)	Indicative cost (lost productivity per year)	Effectiveness at improving:		
							Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Optimise tidal flushing	Entire subcatchment	None	$120,000	$40,000	None	Moderate	Moderate	Negligible
Short-term	Restore natural flow path	K4	None	$60,000	$20,000	None	High	Moderate	Negligible
Long-term	Wet pasture management	K1	None	$20,000	None	Minimal	None	Moderate	Moderate
Long-term	Dain reshaping/infilling	K2, K3	None	$375,000	None	Minimal	None	Moderate	Low
Long-term	Restoration of wetlands	K3, K4	$2,750,000	$500,000	Minimal	$215,000	Very High	High	High

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

8.7 Stotts Creek subcatchment

Acid priority rank:	**5**
Blackwater priority rank:	**4**
Infrastructure	
Approximate waterway length (km)	27
# Privately owned end of system structures	0
# Publicly owned end of system structures	5
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (floodgate ID)	78, 80
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-1.0 to -0.7
Average AASS elevation (m AHD)	N/A
Average PASS elevation (m AHD)	N/A
Median blackwater elevation (m AHD)	0.7
Present day low water level (m AHD)	-0.3
Near future low water level (m AHD)	-0.2
Far future low water level (m AHD)	0.3
Proximity to sensitive receivers	
Oyster leases (km)	19.6
Saltmarsh (km)	3.1
Seagrass (km)	6.5
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	0.1
Land use	
Total floodplain area (ha)	544
Classified as conservation and minimal use (ha (%))	0 (0%)
Classified as grazing (ha (%))	29 (5%)
Classified as forestry (ha (%))	0 (0%)
Classified as sugar cane (ha (%))	457 (84%)
Classified as horticulture (ha (%))	0 (0%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	55 (10%)
Classified as marsh/wetland (ha (%))	0 (0%)
Other (ha (%))	3 (1%)
Land values	
Estimated total primary production value ($/year)	$700,000
Average land value above 0.7 m AHD ($/ha)	$22,900
Average land value below 0.7 m AHD ($/ha)	$10,200

8.7.1 Site description and brief history of drainage

The Stotts Creek subcatchment is located on the right bank of the Tweed River estuary and is hydrologically connected to the estuary via three floodgates which discharge to Stotts Channel. The two major drainage pathways to Stotts Channel are via Leddays Creek and Stotts Creek which both have buoyancy controlled auto-tidal gates installed on them. Leddays Creek also drains the Tumbulgum/Eviron subcatchment to the west of the Stotts Creek subcatchment.

The Stotts Creek subcatchment is very low lying with the majority of the floodplain below +0.5 m AHD and some areas situated below 0 m AHD (Lin et al., 1995). Since the 1970s the major land use for the area has been sugar cane which continues today (Tulau, 1999). Drainage of the floodplain began as early as the 1930s and has undergone various modifications such that today there is in extensive drainage network across the former backswamp (Tulau, 1999). Stotts Creek was identified as an acid sulfate soils hotspot by Tulau (1999). Some literature highlights Stotts Creek as a source of fish kills (Willett et al., 1993; Thackway and Hosking, 2019), however, this appears to be due to issues associated with acid as opposed to blackwater, for the latter, there is little information available for the subcatchment.

Acid sulfate soils drainage has been an ongoing issue within the Stotts Creek subcatchment and as a result the area has been extensively studied (Willett et al., 1993; White et al., 1993; Lin et al., 1995; Wilson, 1995; Yang, 1997; Lin et al., 1998; Wilson et al., 1999; Ward et al., 2002; Smith et al., 2003; Waite et al., 2003; Kinsela and Melville, 2004; Macdonald et al., 2004; Smith and Melville, 2004; Green, 2005; Macdonald et al., 2002; Smith, 2005; Kinsela, 2007; Thackway and Hosking, 2019). Note that within the literature, Stotts Creek subcatchment is often referred to as “McLeods Creek” or “Macleods Creek”.

Tenure information for the Stotts Creek subcatchment is shown in Figure 8-37. Information on drainage and floodplain elevation is shown in Figure 8-38.

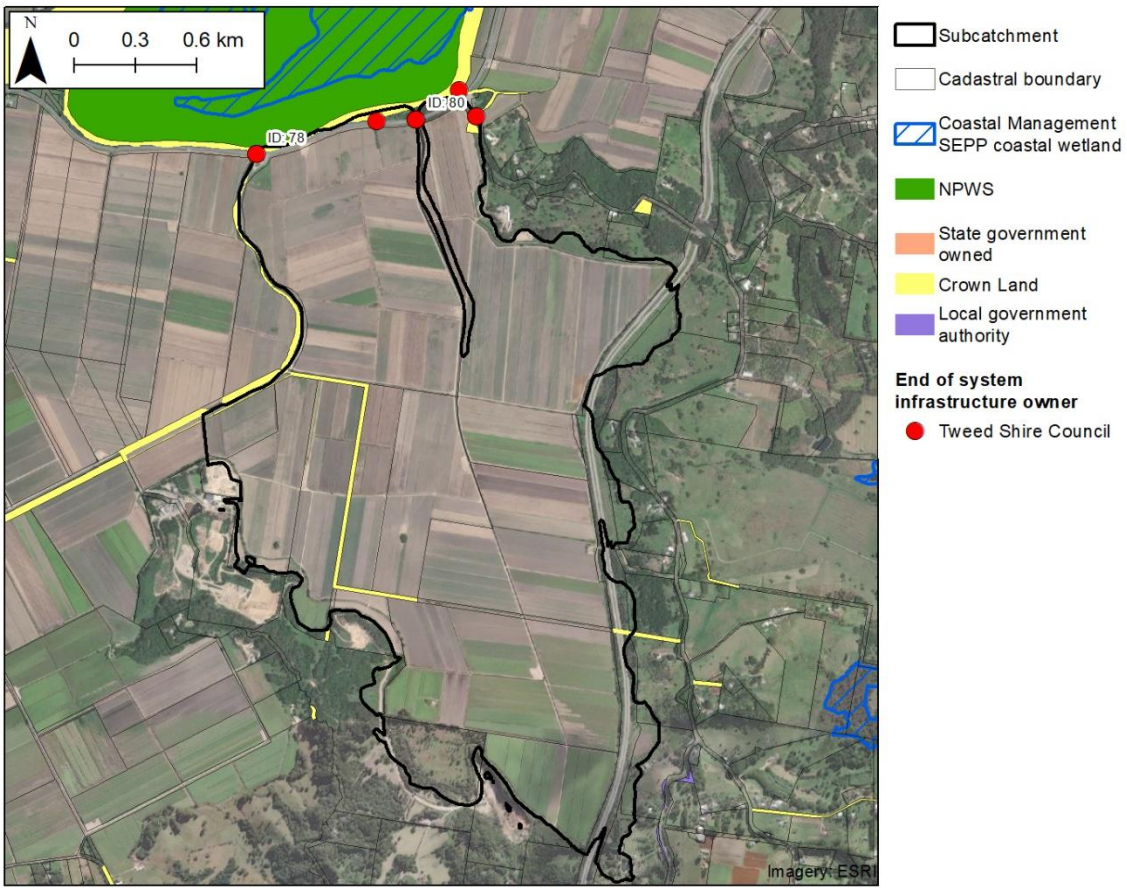


Figure 8-37: Stotts Creek subcatchment - land and end of system infrastructure tenure

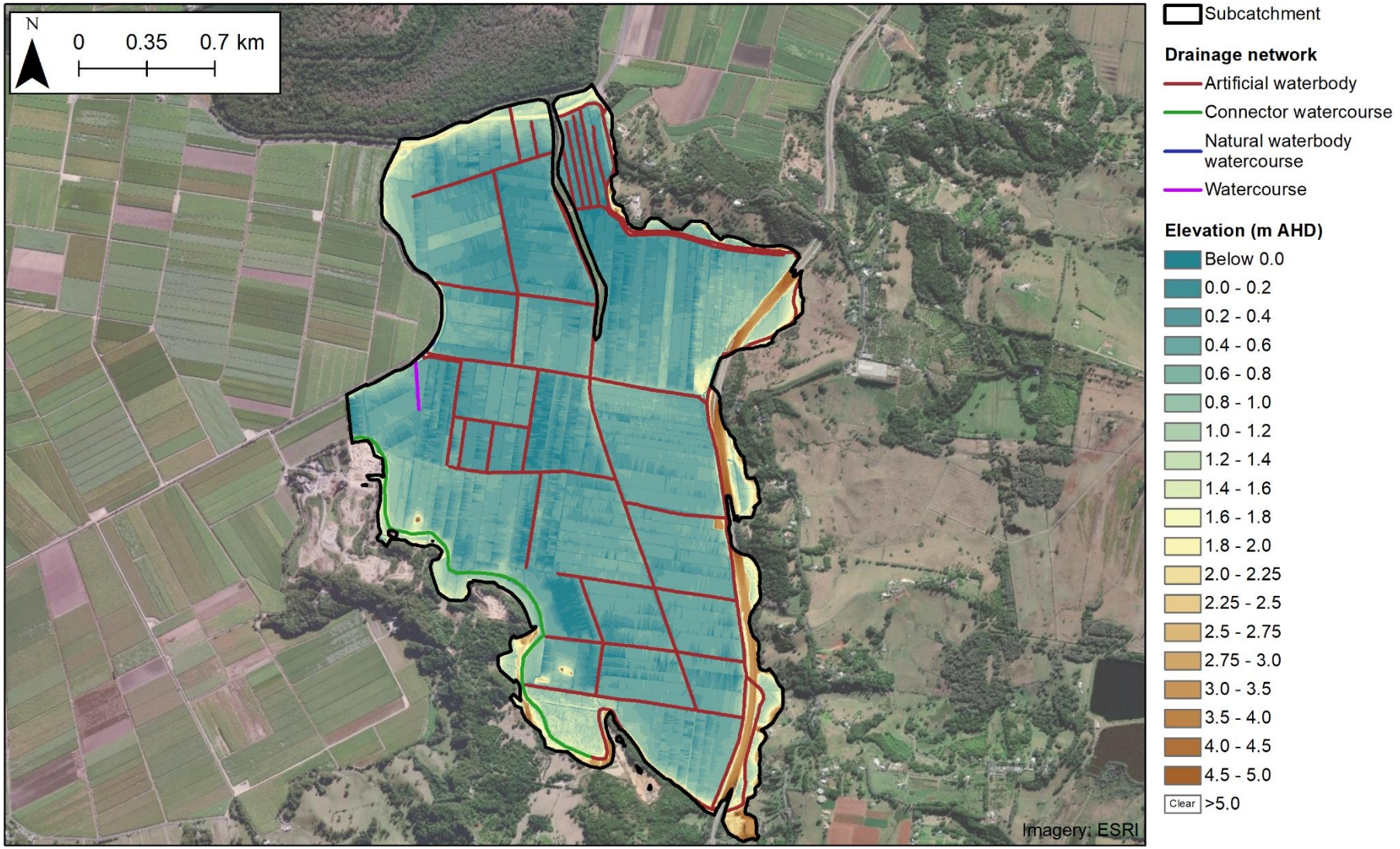


Figure 8-38: Stotts Creek subcatchment elevation and drainage network

8.7.2 History of remediation

The Stotts Creek subcatchment has a long history of remediation attempts related to managing the issues associated with acid sulfate soils. Tulau (1999) noted that management practices such as laser levelling (to reduce drainage density), planting in mounds, modifying the drainage network and liming the drain banks have been implemented as strategies to reduce acid export from the system. According to Tulau (1999), by 1999 the total length of drainage channels within the Stotts Creek subcatchment had been halved to reduce acid export. Other remediation attempts include tidal flushing via floodgate modification (to raise the water table and buffer acid) and smaller scale research projects which used the Stotts Creek subcatchment to test and verify management strategies, such as the use of open limestone channels.

In 2005, Green (2005) tested the ability of an open limestone channel and pond to buffer acidic runoff from within the Stotts Creek subcatchment. Water was pumped into a channel where it passed over progressive channel sections containing limestone to buffer acid. There was a pond located on the downstream end of the channel which allowed sedimentation of suspended solids. A schematic of the channel is shown in Figure 8-39 with the location of the channel shown in Figure 8-40. The 120 m long channel was constructed from September to December 2001. Green (2005) observed that the open limestone channel was effective in reducing the acidity in water, however, it was noted that as the system ages it would become less efficient.

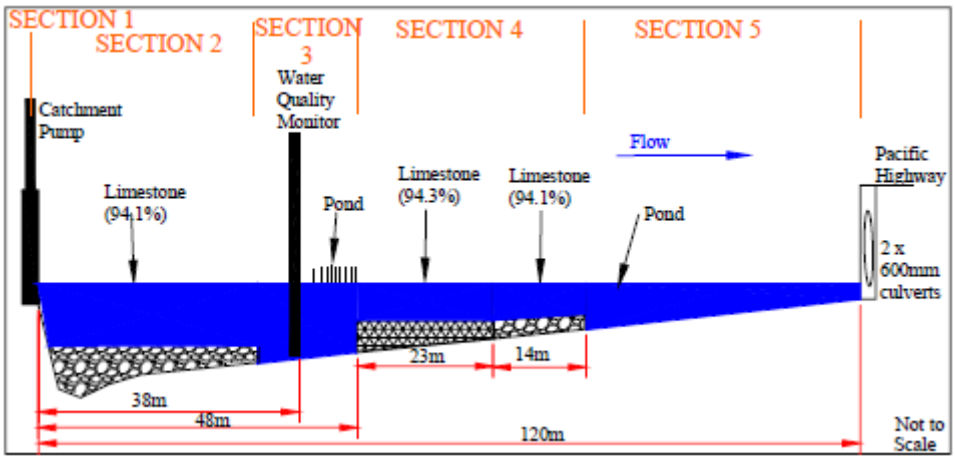


Figure 8-39: Open limestone channel installed within Stotts Creek subcatchment (from Green, 2005)

In addition to the open limestone channel experiment, Green (2005) tested a closed tank reactor. This device pumps acidic water into a closed system which neutralises acid using limestone and removes precipitates during the process (see Figure 8-41). The experiment was found to successfully treat acidic water. It was noted by Green (2005) that, similar to the open limestone channel, as the device ages it would become less efficient. The closed tank reactor, which was only able to treat smaller quantities of water, was deemed not suitable for large scale implementation within the Stotts Creek subcatchment and the device was suggested to be better suited to supporting other treatment options.

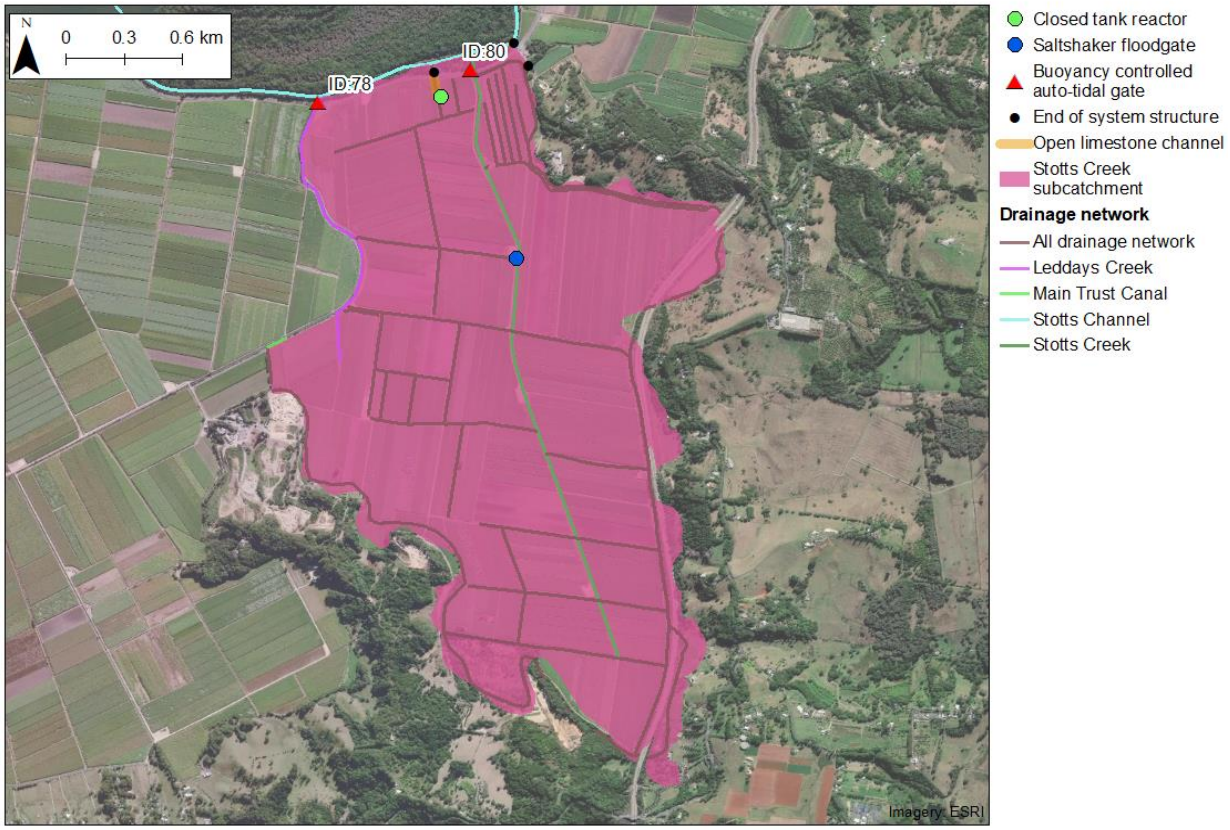


Figure 8-40: The Stotts Creek subcatchment including previous remediation actions

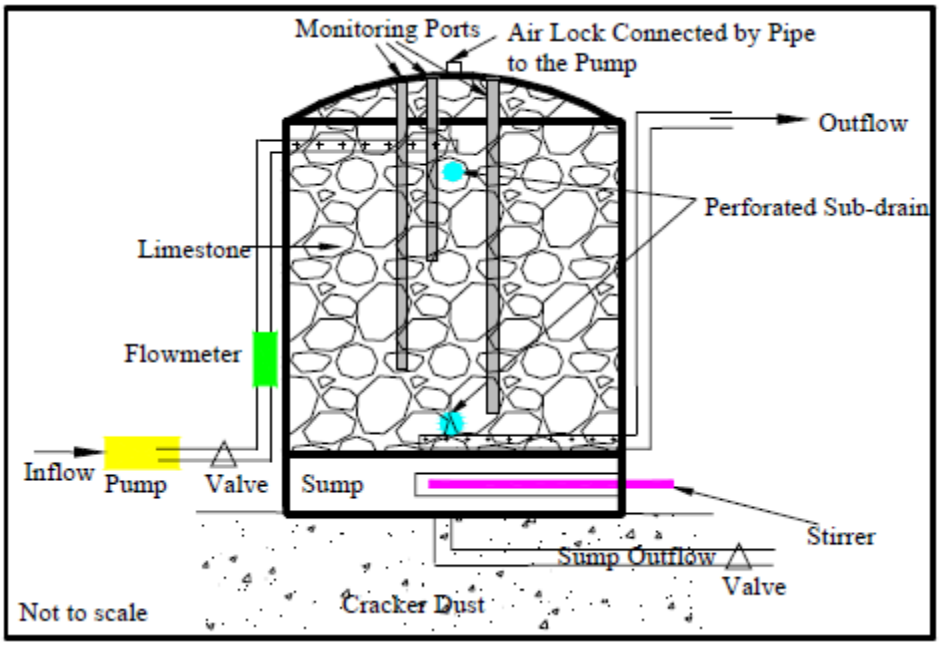


Figure 8-41: Schematic for a closed tank reactor installed within Stotts Creek subcatchment (from Green, 2005)

Smith and Melville (2004) investigated remediation efforts that had been undertaken within the Stotts Creek subcatchment. It was observed that Structure 80 was frequently opened to allow tidal flushing within Stotts Creek. Green (2005) noted that there was an existing auto-tidal floodgate located on Stotts

Creek. To prevent inundation of low-lying floodplain upstream of Structure 80, floodgates were constructed on smaller tributary drains. On one drain, a saltshaker floodgate was installed to facilitate further controlled tidal flow upstream (Macdonald et al., 2002). This device allowed a controlled volume of water upstream of the floodgate raising the water table and preventing the drain drying out.

Currently, buoyancy controlled auto-tidal gates have been installed on Structures 78 and 80 (see Figure 8-42 and Figure 8-43) (Industry and Investment NSW, 2009). During field investigations, inspection of these devices showed that they were good condition.



Figure 8-42: Structure 80 with one buoyancy controlled auto-tidal gate



Figure 8-43: The buoyancy controlled auto-tidal gate on Structure 78

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

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

8.7.3 Floodplain drainage – sea level rise vulnerability

The sea level rise vulnerability assessment of the Stotts Creek subcatchment is summarised in Figure 8-44. Modelling shows that drainage within the Stotts Creek subcatchment is potentially inhibited by current estuarine water levels, with the majority of the subcatchment situated below the present day 95th percentile water level. Lin et al. (1995) suggested that while the floodplain is naturally low lying (generally below +0.5 m AHD), burning of natural peat material and drying out of estuarine clays have resulted in subsidence in the subcatchment. To maintain agricultural productivity, pumps have been used to dewater the floodplain to below low-tide levels (Tulau, 1999). Modelling of sea level rise scenarios indicates that this issue will be exacerbated into the future with large areas of the subcatchments floodplain situated below the approximate far future low tide water level (i.e. at high risk of reduced drainage).

Comparison of the primary floodgates (Structure 80 and 78, shown in Figure 8-45) obvert levels to sea level rise, indicates that both structures may be vulnerable to sea level rise. Far future sea level rise modelling results indicate that these floodgates will become moderately vulnerable as high tide levels increase above their obverts. Three (3) secondary floodgates (Structures 79, 81, 82, see Appendix F) will be most vulnerable to sea level rise in the far future as their obverts are below the predicted future 50th percentile water level.

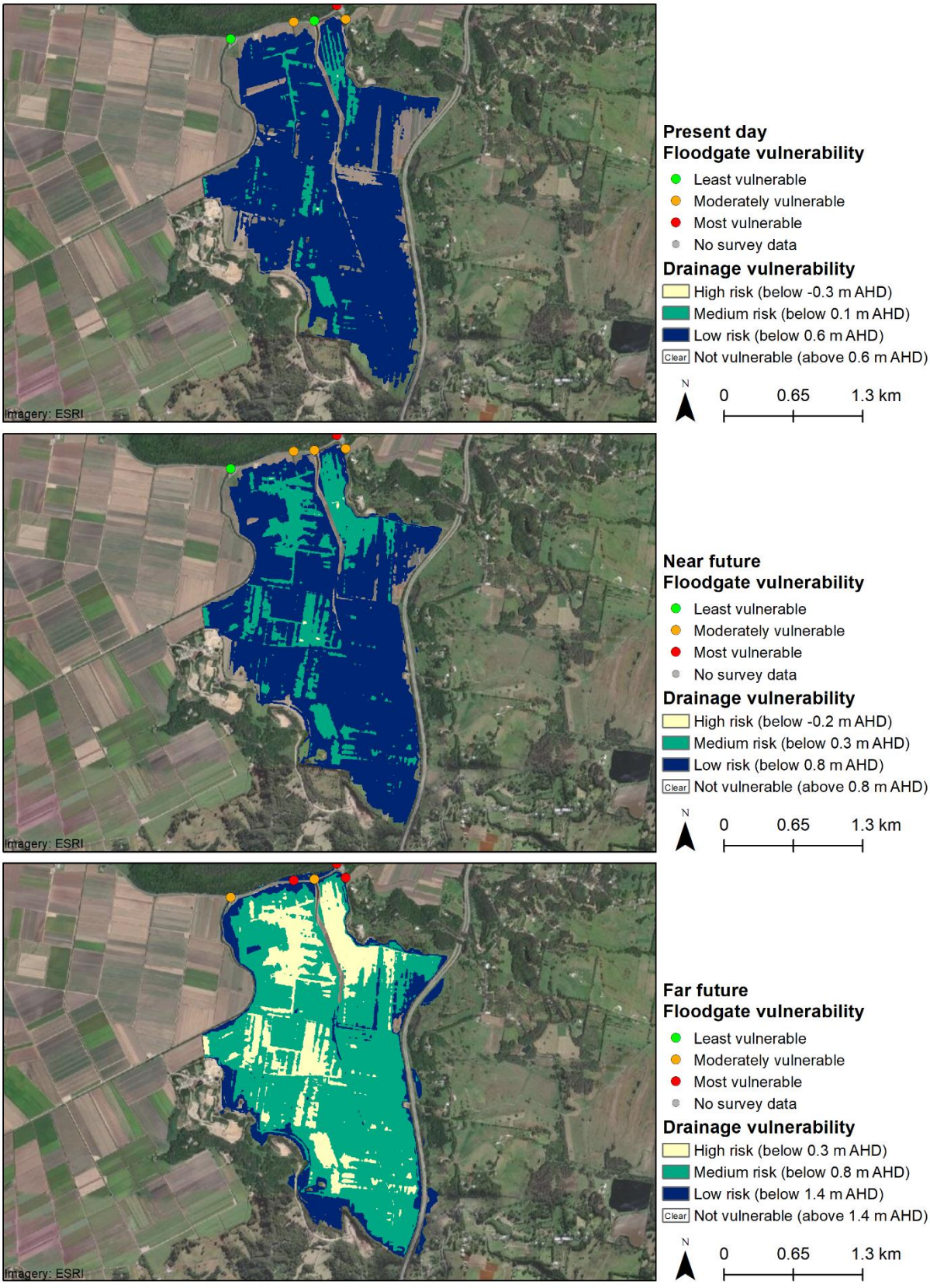


Figure 8-44: Sea level rise drainage vulnerability for the Stotts Creek subcatchment

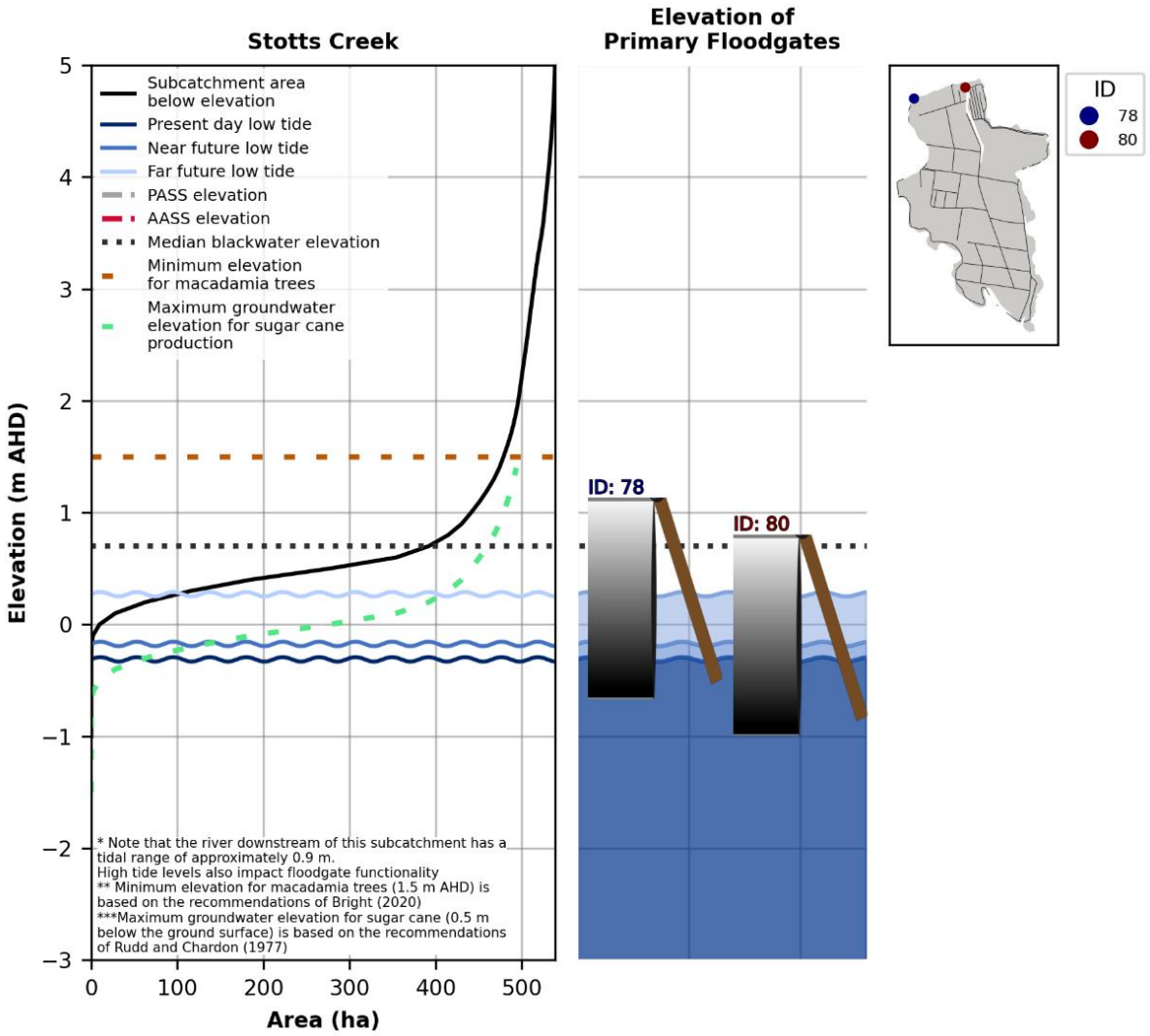


Figure 8-45: Key floodplain elevations - Stotts Creek subcatchment

8.7.4 Management options

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

- Short-term: Optimise tidal flushing through structures, review pumping and raise the invert of drains.
- Long-term: Transition of low-lying areas to estuarine 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
Presently, Structures 78 and 80 have been modified with buoyancy controlled auto-tidal gates which allow tidal flushing upstream of the floodgates at a controlled level. Investigations could be completed to determine if these structures can be further adjusted to optimised tidal flushing and acid buffering. Pratt (2017) found salinity in the main estuary at Stotts Creek to be high (15 to 25 ppt) during low inflow periods, and fresh to brackish during high inflows. Note, where practical, further modification of upstream floodgates could also be considered.

In the short term, pumping of water from behind floodgate structures should be reviewed. Pumping has the potential to increase groundwater drawdown which could increase the oxidation of acid sulfate soils and the subsequent export of acid to the estuary.

Where possible, drains could be shallowed to raise their invert levels. This strategy would need to be investigated to ensure any modifications would not impact on existing land use.

Long-term management options
Modelling indicates that sea level rise will impact future drainage of the Stotts Creek subcatchment. Detailed investigations would allow opportunistic development of estuarine wetlands within low-lying areas of the subcatchment as sea level rise impacts future land productivity. In the far future scenario, removal of the floodgates within the Stotts Creek subcatchment would further assist this.

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

Table 8-11: Summary of management options for the Stotts Creek subcatchment

Timeframe	Strategy	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing per year)	Indicative cost (lost productivity per year)	Effectiveness at improving:		
						Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Optimise tidal flushing	None	$70,000	$20,000	None	Moderate	Moderate	Negligible
Short-term	Cease pumping	None	None	None	Minimal	None	Moderate	Negligible
Short-term	Drain reshaping/infilling	None	$800,000	None	Minimal	None	Moderate	Low
Long-term	Restoration of wetlands	$4,000,000	$550,000	Minimal	$550,000	Very high	High	High

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

8.8 Tumbulgum/Eviron subcatchment

Acid priority rank:	**6**
Blackwater priority rank:	**1**
Infrastructure	
Approximate waterway length (km)	55
# Privately owned end of system structures	0
# Publicly owned end of system structures	33
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (floodgate ID)	33, 38, 68, 75, 78
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-1.1 to -0.5
Average AASS elevation (m AHD)	0.3
Average PASS elevation (m AHD)	-0.4
Median blackwater elevation (m AHD)	0.8
Present day low water level (m AHD)	-0.3
Near future low water level (m AHD)	-0.2
Far future low water level (m AHD)	0.3
Proximity to sensitive receivers	
Oyster leases (km)	20.7
Saltmarsh (km)	4.2
Seagrass (km)	7.5
Mangroves (km)	0
Coastal Management SEPP coastal wetlands (km)	0.1
Land use	
Total floodplain area (ha)	1,306
Classified as conservation and minimal use (ha (%))	0 (0%)
Classified as grazing (ha (%))	19 (1%)
Classified as forestry (ha (%))	0 (0%)
Classified as sugar cane (ha (%))	1,172 (90%)
Classified as horticulture (ha (%))	5 (0.4%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	77 (6%)
Classified as marsh/wetland (ha (%))	0 (0%)
Other (ha (%))	32 (2%)
Land values	
Estimated total primary production value ($/year)	$1,700,000
Average land value above 0.8 m AHD ($/ha)	$12,200
Average land value below 0.8 m AHD ($/ha)	$10,200

8.8.1 Site description and brief history of drainage

The Tumbulgum/Eviron subcatchment is located on the right bank of the Tweed River in the mid-estuary. The major drainage pathway for the subcatchment is by Bartlets Creek and Leddays Creek which are connected in the centre of the subcatchment by Main Trust Canal. Note that Leddays Creek also connects to the Stotts Creek subcatchment to the east, and the Tumbulgum/Eviron subcatchment is hydrologically connected to the Condong subcatchment in the south west by a system of secondary floodplains drains.

The topography of the subcatchment features a very low-lying backswamp (situated at 0 m AHD) and higher elevation land adjacent to the Tweed River. The backswamp area, formerly known as the Eviron swamp/Duranbah swamp, was originally drained in 1902 when Main Trust Canal was constructed and was one of the first areas drained in the Tweed River floodplain (Tulau, 2011). Intensive draining had occurred over the previous century and as a result the backswamp has been completely turned into farmland. This included extensive drainage in the 1970s to allow for sugar cane farming, which is now the major land use for the subcatchment (Tulau, 1999). The town of Tumbulgum is situated on the north western side of the subcatchment and SEPP coastal wetlands are located directly to the east and west of the northern subcatchment border. Tenure information for the Tumbulgum/Eviron subcatchment is shown in Figure 8-46. Information on drainage and floodplain elevation is shown in Figure 8-47.

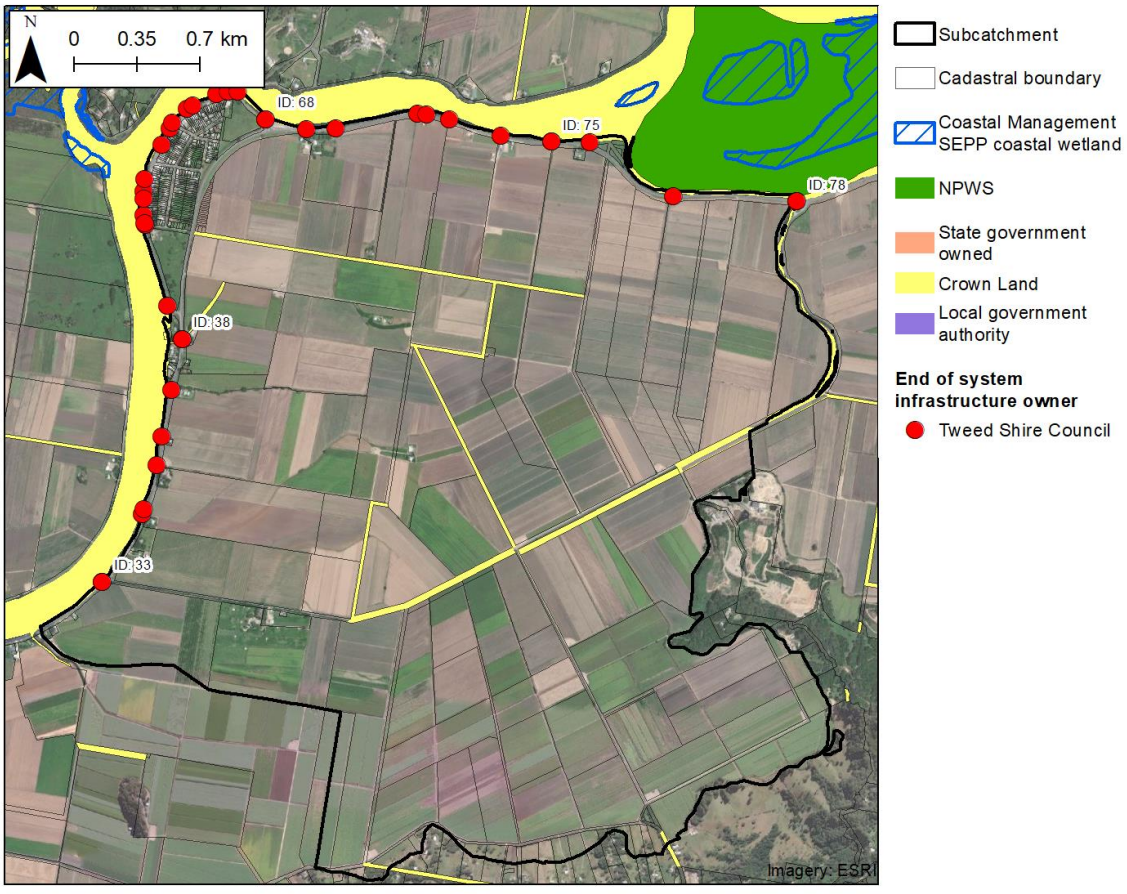


Figure 8-46: Tumbulgum/Eviron subcatchment - land and end of system infrastructure tenure

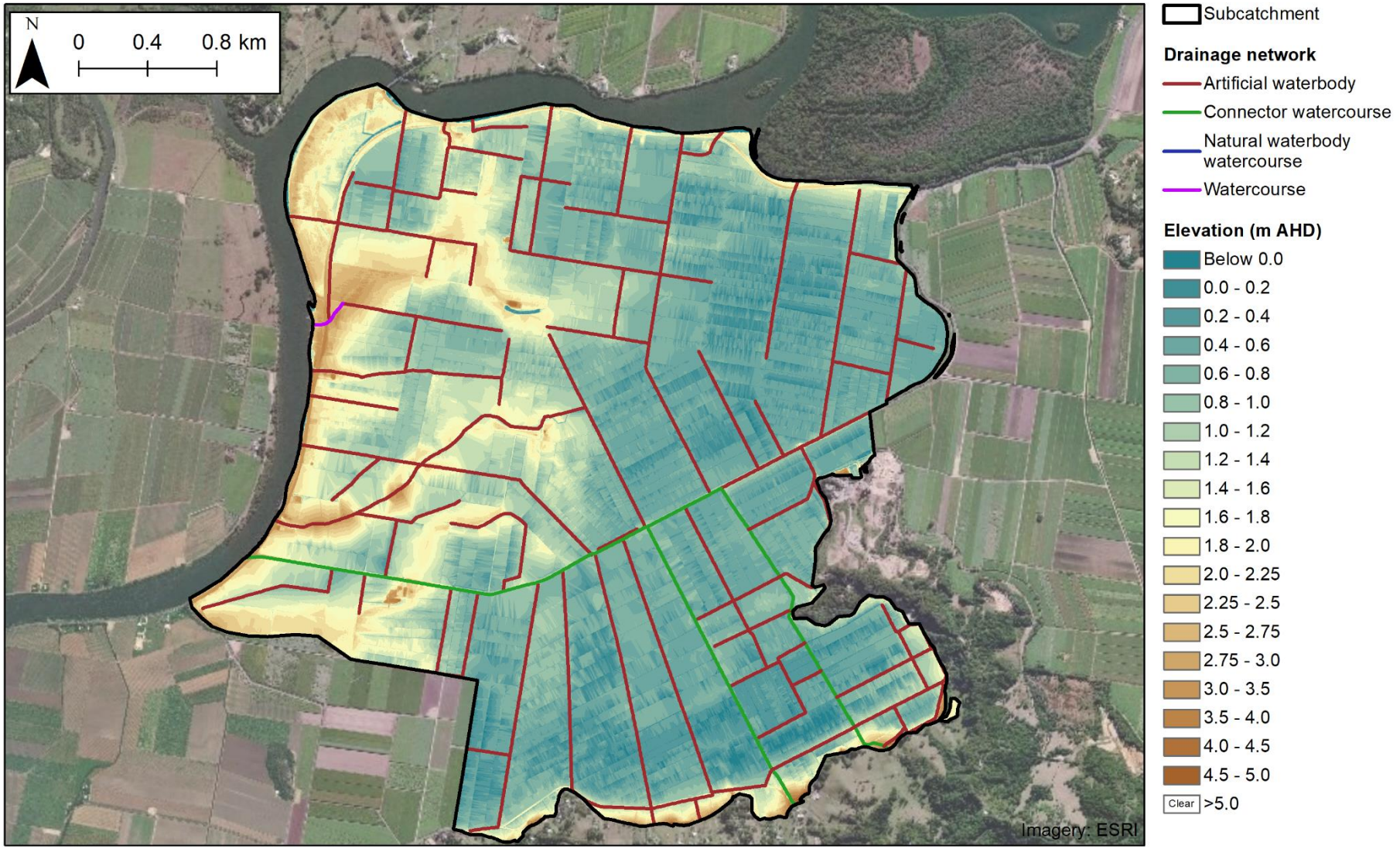


Figure 8-47: Tumbulgum/Eviron subcatchment elevation and drainage network

8.8.2 History of remediation

Buoyancy controlled auto-tidal gates have been installed on Bartlets Creek (Structure 33) and Leddays Creek (Structure 78) to allow controlled tidal flushing within the upstream drainage network. During field investigations these floodgates were observed to be in good condition (Figure 8-48). Location of the buoyancy controlled auto-tidal gates are shown in Figure 8-49.



Figure 8-48: Buoyancy controlled auto-tidal gate on Structure 33 (left) and Structure 78 (right)

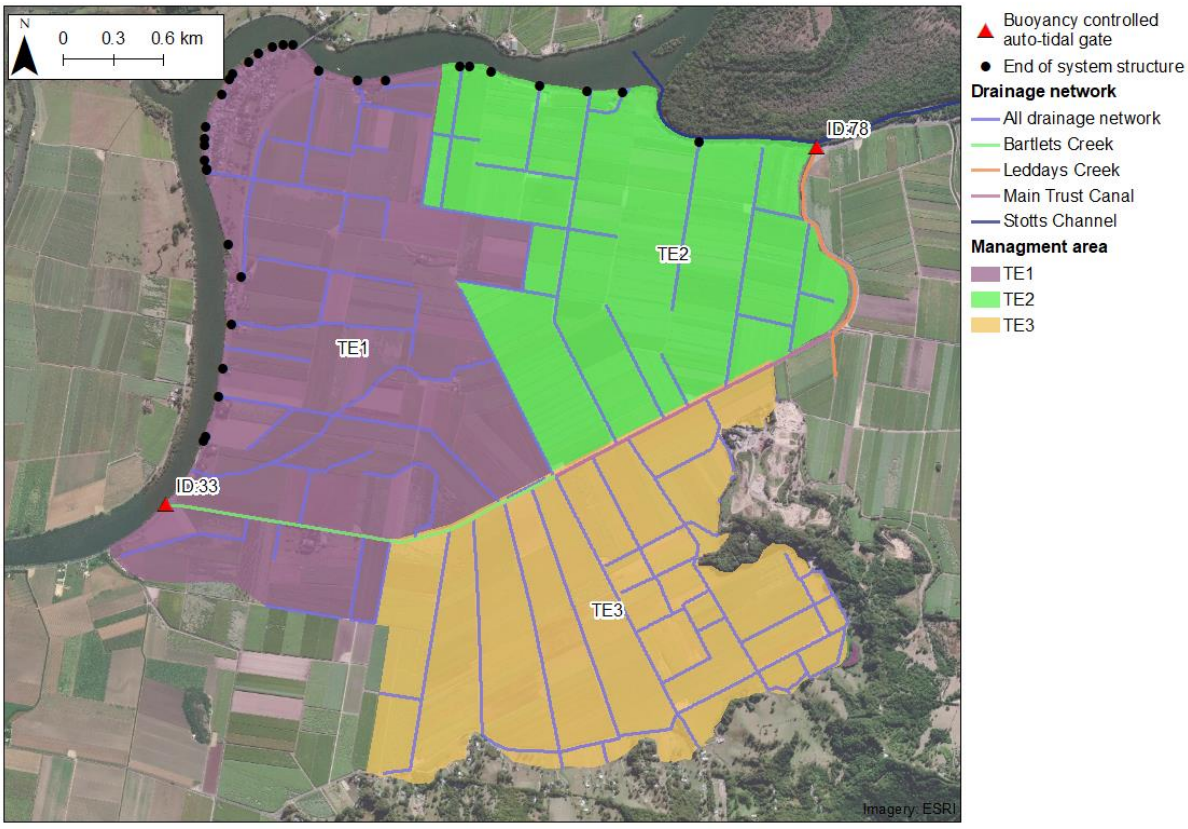


Figure 8-49: The Tumbulgum/Eviron subcatchment including previous remediation actions

In addition to buoyancy controlled auto-tidal gates, Tweed Shire Council currently has an ongoing program to infill field drains across the Tweed River floodplain (TSC, 2020). To date, over 40 km of drains have been infilled, including drains within the Tumbulgum/Eviron subcatchment.

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

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

8.8.3 Prioritisation of management areas in the Tumbulgum/Eviron subcatchment

The Tumbulgum/Eviron subcatchment ranked sixth in the acid prioritisation, and first in the blackwater prioritisation. The subcatchment has been further delineated into three (3) smaller management areas (referred to as TE1 to TE3, shown in Figure 8-50) to provide additional information on the sources of blackwater. The areas have been delineated based on land tenure, data availability, elevation and drainage units. Note, acid risk has been considered on the subcatchment scale.

Figure 8-50 shows the management areas for the Tumbulgum/Eviron subcatchment below the median elevation for blackwater generation (+0.8 m AHD). As elevation is a primary driver of the production of blackwater, the areas below this level typically contribute the most to the risk of large scale deoxygenation (although this can be managed through changing vegetation and land uses). The majority of blackwater risk in the Tumbulgum/Eviron subcatchment can be found in management areas TE2 and TE3 with the remaining management area only contributing arbitrarily to the overall subcatchments blackwater risk. Based on these findings it is suggested that remediation efforts should target management areas TE2 and TE3.

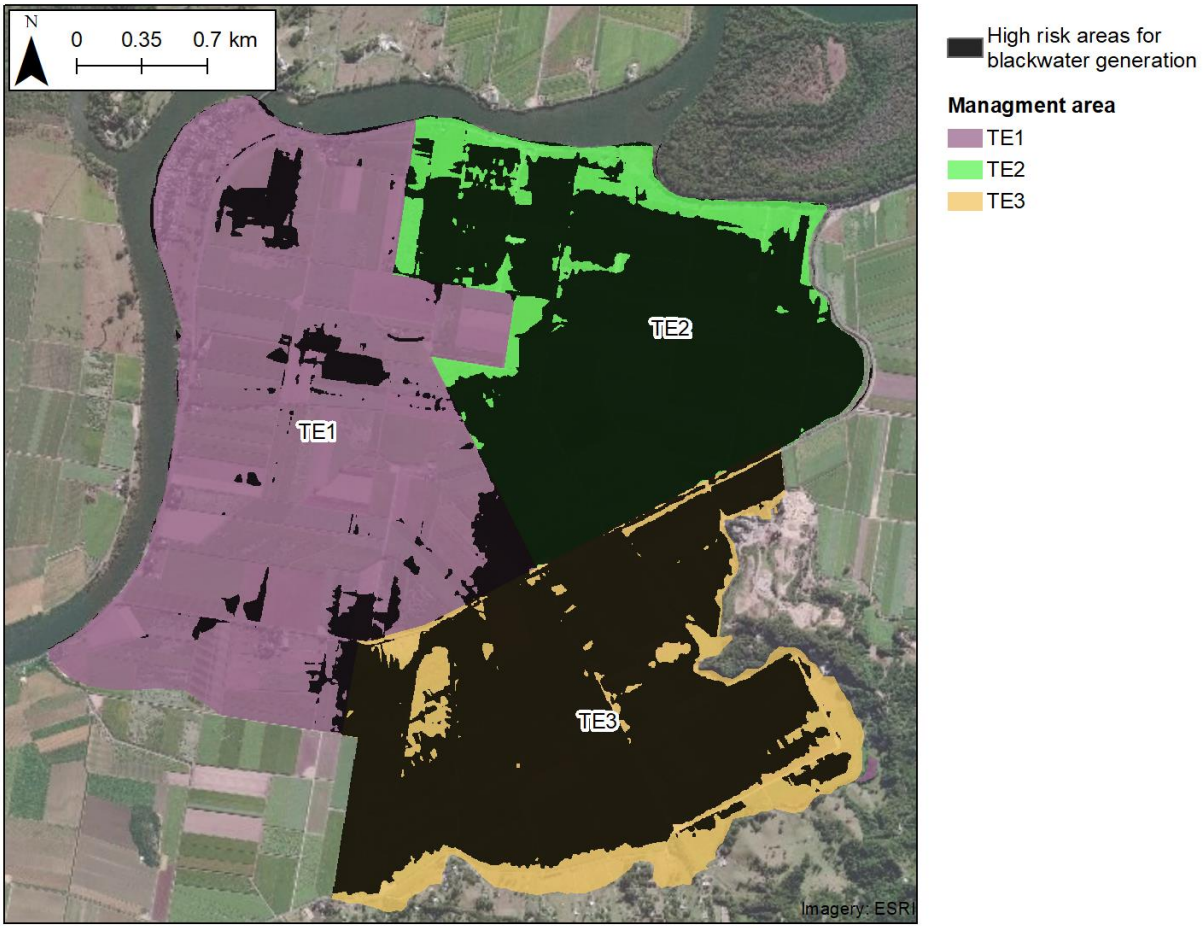


Figure 8-50: Blackwater contribution in each management area for the Tumbulgum/Eviron subcatchment (median blackwater level +0.8 m AHD)

8.8.4 Floodplain drainage - sea level rise vulnerability

The sea level rise vulnerability assessment of the Tumbulgum/Eviron subcatchment is summarised in Figure 8-51. Modelling for the present day scenario indicates that low-lying sections of management areas TE2 and TE3 area are already subject to reduced drainage, whereas the higher management area TE1 is relatively unaffected. In the near future and far future, only the highest areas within management area TE1 will be unaffected by reduced drainage. Indeed, in the far future scenario the majority of management areas TE2 and TE3 will have a medium risk of reduced drainage and the lowest lying areas will have a high risk of reduced drainage.

Floodgates within the Tumbulgum/Eviron subcatchment include a number of smaller structures which provide urban drainage for Tumbulgum and a number of larger floodgates which facilitate floodplain drainage, summarised in Figure 8-52. A range of these structures are already moderately to most vulnerable in present day conditions. Most structures will be classified as moderately or most vulnerable for far future sea level rise scenarios, including major Structure 38.

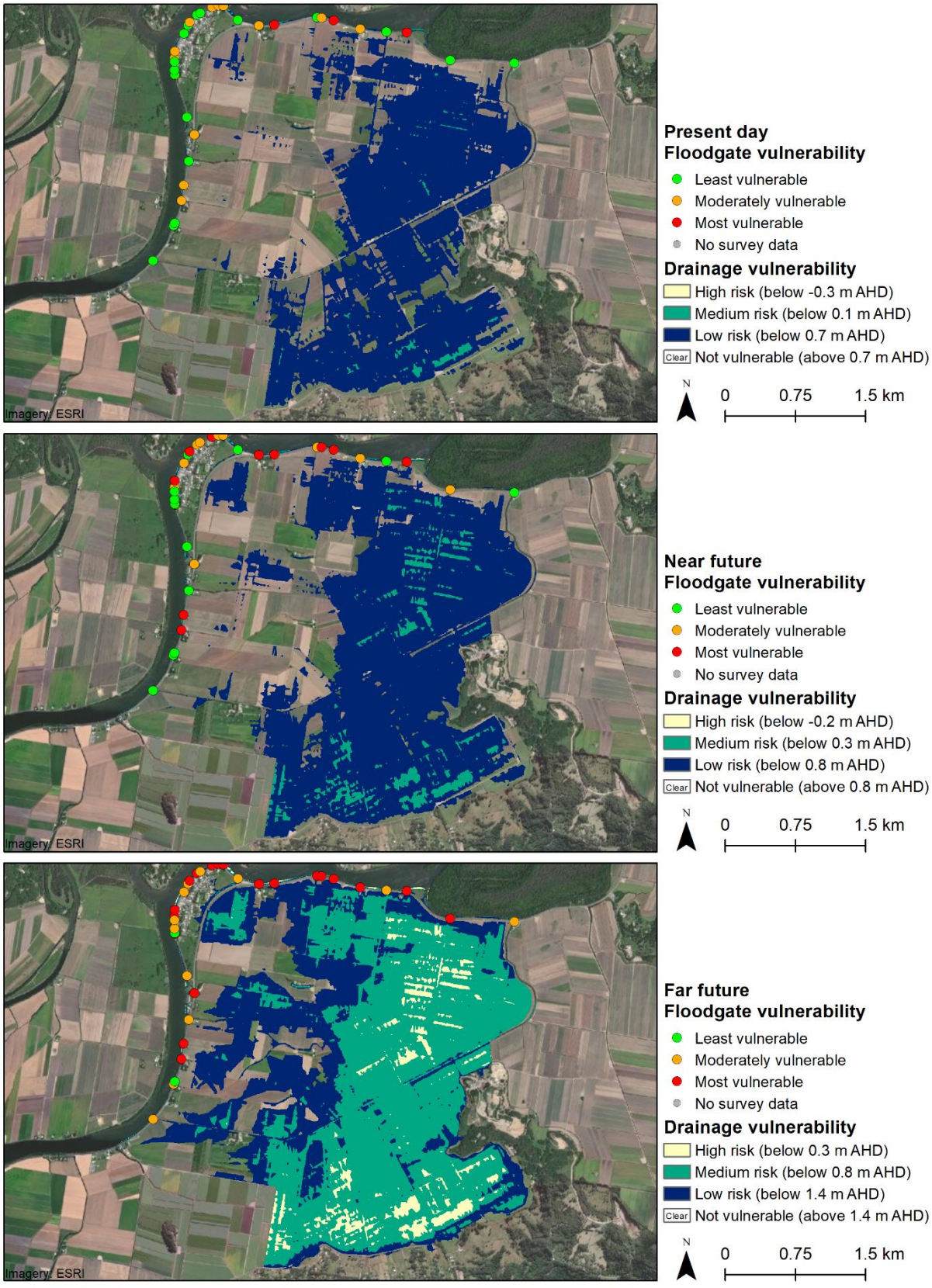


Figure 8-51: Sea level rise drainage vulnerability for the Tumbulgum/Eviron subcatchment

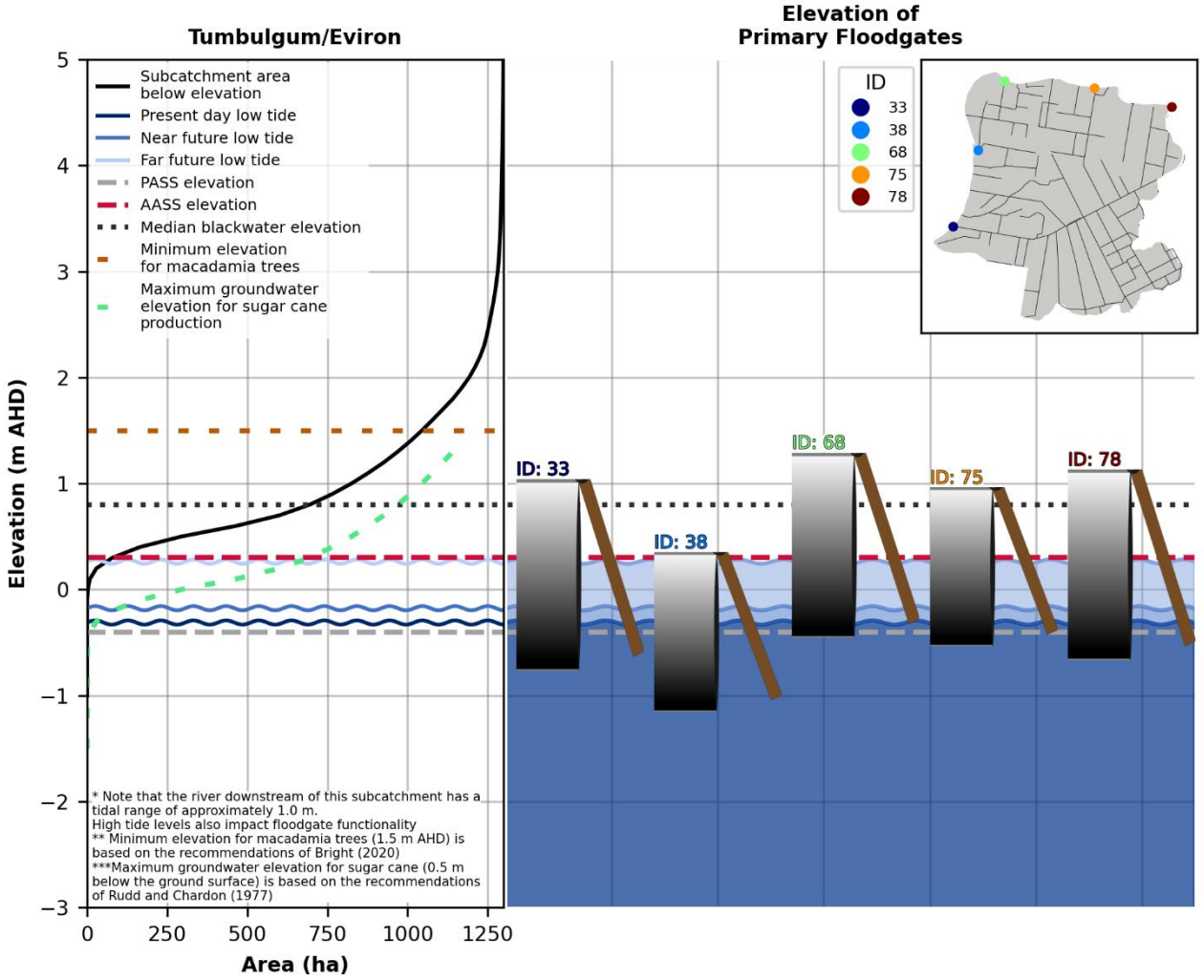


Figure 8-52: Key floodplain elevations - Tumbulgum/Eviron subcatchment

8.8.5 Management options

Potential management options for short-term and long-term planning horizons for the Tumbulgum/Eviron subcatchment include:

- Short-term: Optimise tidal flushing through existing modified floodgates, and expand tidal flushing to other floodgates.
- Long-term: Conversion of low-lying areas to estuarine wetlands, and continue optimised tidal flushing through structures.

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

Short-term options for the Tumbulgum/Eviron subcatchment are influenced by the low-lying elevation of the floodplain. Controlled in-drain tidal flushing within the Tumbulgum/Eviron subcatchment could be investigated to determine if existing auto-tidal gates on Structures 33 and 78 could be optimised to provide additional increase to the volume of flushing within the drainage network. This approach would provide water quality benefits to all management areas within the subcatchment. In addition to this, Structures 68 and 75 (see Figure 8-53) could also be modified to provide controlled tidal flushing within management areas TE1 and TE2. Salinity levels in this area of the Tweed River estuary are high during dry periods (Pratt, 2017).

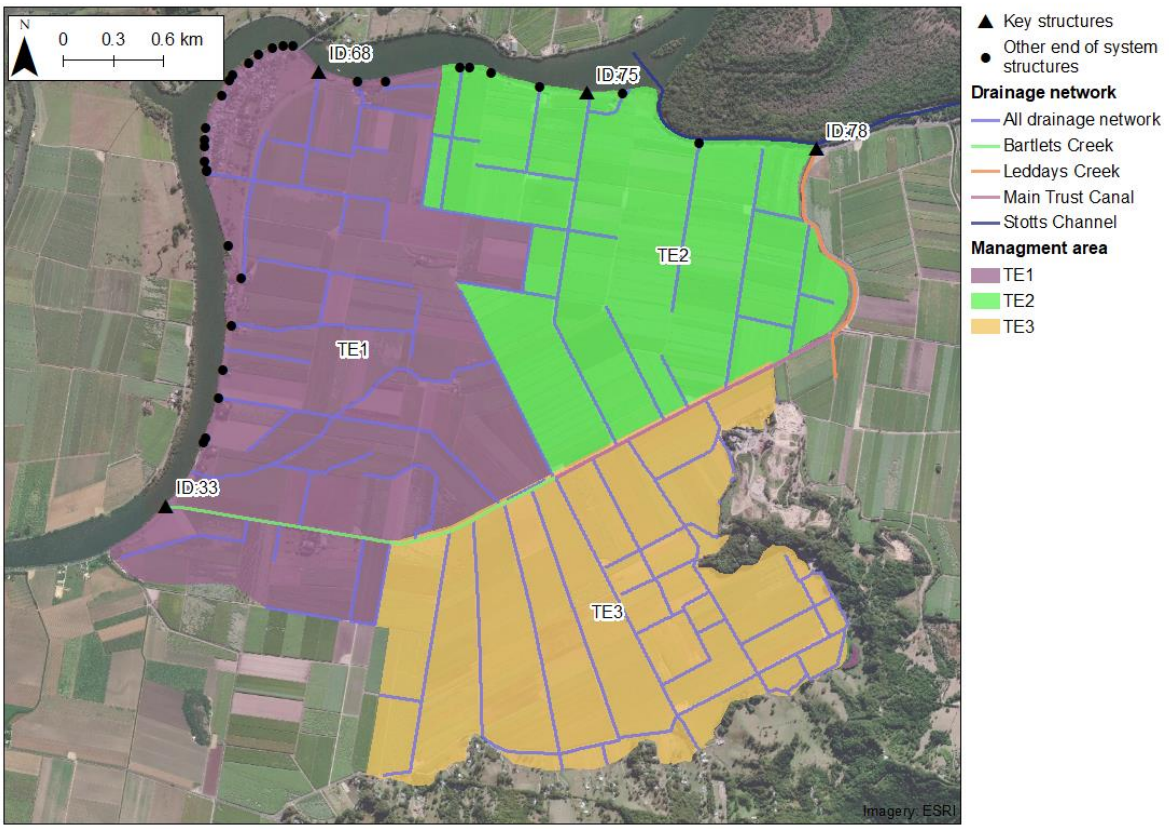


Figure 8-53: Short-term management options structure locations for the Tumbulgum/Eviron subcatchment

Where possible drainage density within the Tumbulgum/Eviron subcatchment should be reduced and/or reshaped to increase the drain invert level to reduce the risk of acid sulfate soil oxidation and export. This would be most effective within management areas TE2 and TE3, provided there is no impact to existing land uses. Existing land use and the present day drainage potential (influenced by the low-lying elevation of the floodplain) should be considered when assessing management options in this subcatchment.

Long-term management options

Sea level rise is predicted to impact drainage under near and far future sea level rise scenarios, particularly for low-lying areas (management areas TE2 and TE3). Where existing land uses no longer become viable, options for wetland habitats within Eviron Swamp/Duranbah Swamp should be investigated. Consideration would need to be given for how any changes would impact the surrounding subcatchments. 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.

Higher elevated land in management area TE1 is unlikely to be impacted by sea level rise (in comparison to TE2 and TE3) and agricultural productivity should be able to continue into the future. Continued management of floodgates to allow controlled tidal flushing will help reduce the risk of acid export from management area TE1.

A summary of the recommended management options for the Tumbulgum/Environ subcatchment including indicative costs is provided in Table 8-12.

Table 8-12: Summary of management options for the Tumbulgum/Eviron subcatchment

Timeframe	Strategy	Target management area(s)	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing per year)	Indicative cost (lost productivity per year)	Effectiveness at improving:		
							Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Optimise tidal flushing	Entire subcatchment	None	$60,000	$10,000	None	Moderate	Moderate	Negligible
Short-term	Drain reshaping/infilling	TE2, TE3	None	$850,000	None	Minimal	None	Moderate	Low
Long-term	Restoration of wetlands	TE2, TE3	$7,000,000	$1,000,000	Minimal	$950,000	Very high	High	High

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

8.9 Tygalgah subcatchment

Acid priority rank:	**7**
Blackwater priority rank:	**2**
Infrastructure	
Approximate waterway length (km)	49
# Privately owned end of system structures	0
# Publicly owned end of system structures	56
# End of system structures within coastal wetlands	2
# Publicly owned end of system structures within coastal wetlands	2
Primary floodplain infrastructure (floodgate ID)	28, 43, 155, 173, 194, 195, 199, 205
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-1.0 to -0.5
Average AASS elevation (m AHD)	0.5
Average PASS elevation (m AHD)	-0.5
Median blackwater elevation (m AHD)	1.0
Present day low water level (m AHD)	-0.3
Near future low water level (m AHD)	-0.2
Far future low water level (m AHD)	0.3
Proximity to sensitive receivers	
Oyster leases (km)	24.9
Saltmarsh (km)	7.7
Seagrass (km)	11.8
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	1,984
Classified as conservation and minimal use (ha (%))	0 (0%)
Classified as grazing (ha (%))	141 (7%)
Classified as forestry (ha (%))	0 (0%)
Classified as sugar cane (ha (%))	1,601 (81%)
Classified as horticulture (ha (%))	0 (0%)
Classified as other cropping (ha (%))	41 (2%)
Classified as urban/industrial/services (ha (%))	135 (7%)
Classified as marsh/wetland (ha (%))	0 (0%)
Other (ha (%))	66 (3%)
Land values	
Estimated total primary production value ($/year)	$2,400,000
Average land value above 1.0 m AHD ($/ha)	$13,400
Average land value below 1.0 m AHD ($/ha)	$12,100

8.9.1 Site description and brief history of drainage

The Tygalgah subcatchment is located on the left bank of the Tweed River, upstream of its confluence with the Rous River. The subcatchment is the largest on the Tweed River floodplain and includes an island which is bounded by the Tweed River, Rous River and Mayal Creek. The main flow paths drain the subcatchment towards the Rous River, however there are some floodgate structures that assist drainage to the Tweed River and Mayal Creek. During the Tweed River flood mitigation scheme, from 1955 to 1957 a large number of floodgates were installed to facilitate drainage across the Tygalgah subcatchment (Tulau, 2011).

Sugar cane dominates land use across the Tygalgah subcatchment accounting for 81% of land use. Other major land uses across the subcatchment include grazing and urban/industry/services. The Murwillumbah Wastewater Treatment Plant is located on the south western corner of the subcatchment where it discharges into the Rous River, and there is also a horse racing track located in the centre of the island. Coastal Management SEPP coastal wetlands are located on the northern area of the subcatchment at the confluence of the Rous River and the Tweed River. Tenure information for the Tygalgah subcatchment is shown in Figure 8-54. Information on drainage and floodplain elevation is shown in Figure 8-55.

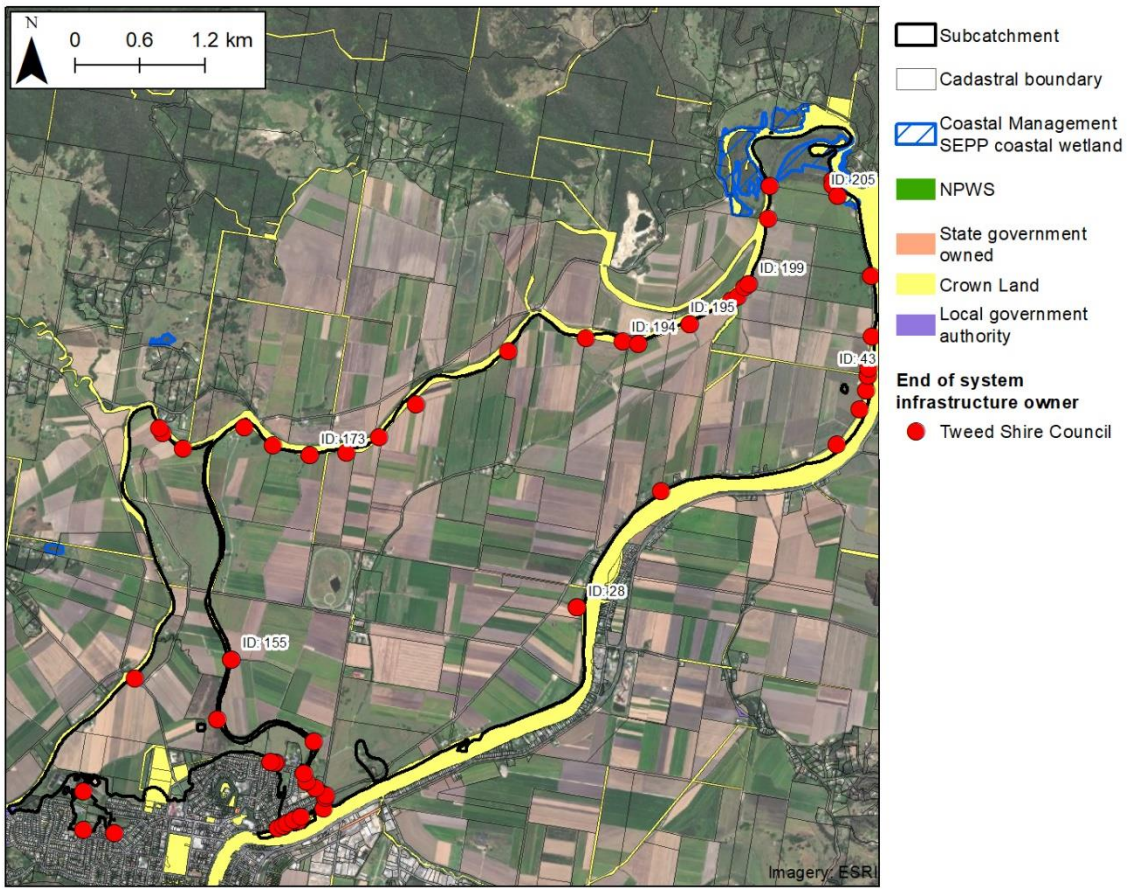


Figure 8-54: Tygalgah subcatchment - land and end of system infrastructure tenure

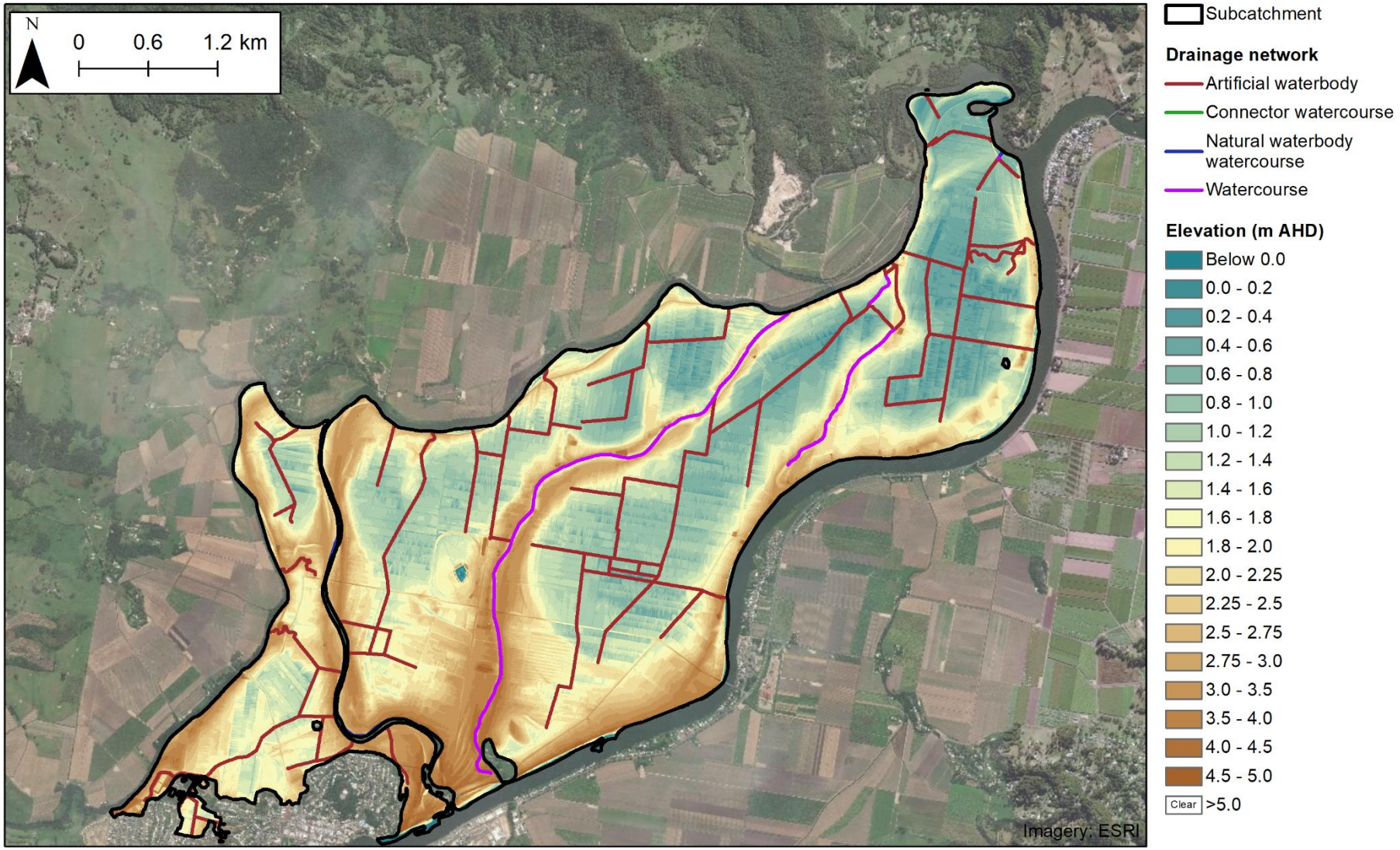


Figure 8-55: Tygalgah subcatchment elevation and drainage network

8.9.2 History of remediation

Nine (9) buoyancy controlled auto-tidal floodgates have been installed on floodgates within the Tygalgah subcatchment. These structures, originally constructed to allow fish passage (Industry and Investment NSW, 2009), improve the water quality within the drainage network by allowing regular flushing and in buffering of acidic discharges. Locations of modified floodgates are shown in Figure 8-56.

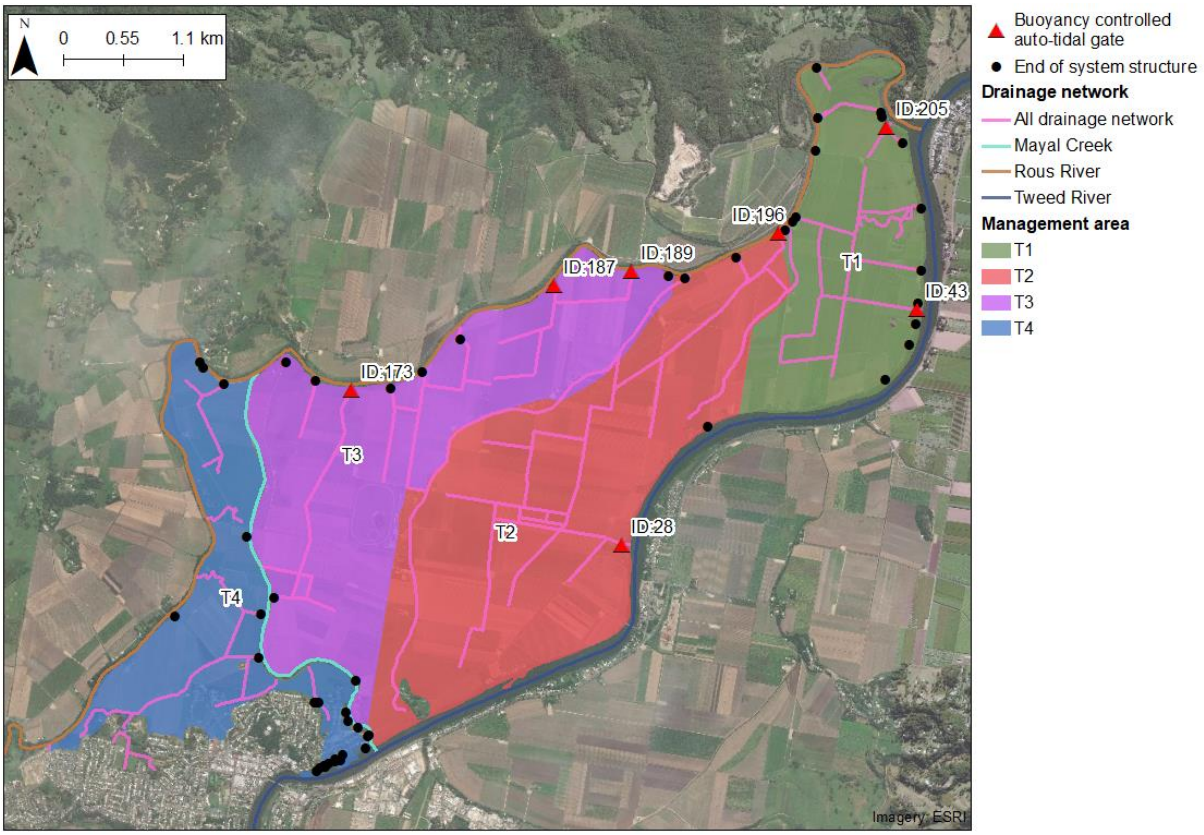


Figure 8-56: The Tygalgah subcatchment including previous remediation actions

Tweed Shire Council currently has an ongoing program to infill field drains across the Tweed River floodplain (TSC, 2020). To date, over 40 km of drains have been filled in, including drains within the Tygalgah subcatchment.

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

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

8.9.3 Prioritisation of management areas in the Tygalgah subcatchment

The Tygalgah subcatchment ranked seventh in the acid prioritisation, and second in the blackwater prioritisation. The subcatchment has been further delineated into four (4) smaller management areas (referred to as T1 to T4, shown in Figure 8-57) to provide additional information on potential sources of blackwater. The areas have been delineated based on land tenure, data availability, elevation and drainage units. Note, acid risk has been considered on the subcatchment scale.

Figure 8-57 shows the management areas for the Tygalgah subcatchment below the median elevation for blackwater generation (+1.0 m AHD). As elevation is a primary driver of the production of blackwater, the areas below this level typically contribute the most to the risk of large scale deoxygenation (although this can be managed through changing vegetation and land uses). The majority of blackwater risk in the Tygalgah subcatchment can be found in management areas T1, T2 and T3 with the remaining management area only contributing arbitrarily to the overall subcatchments blackwater risk. Based on these findings it is suggested that remediation focus on management areas T1 and T2.

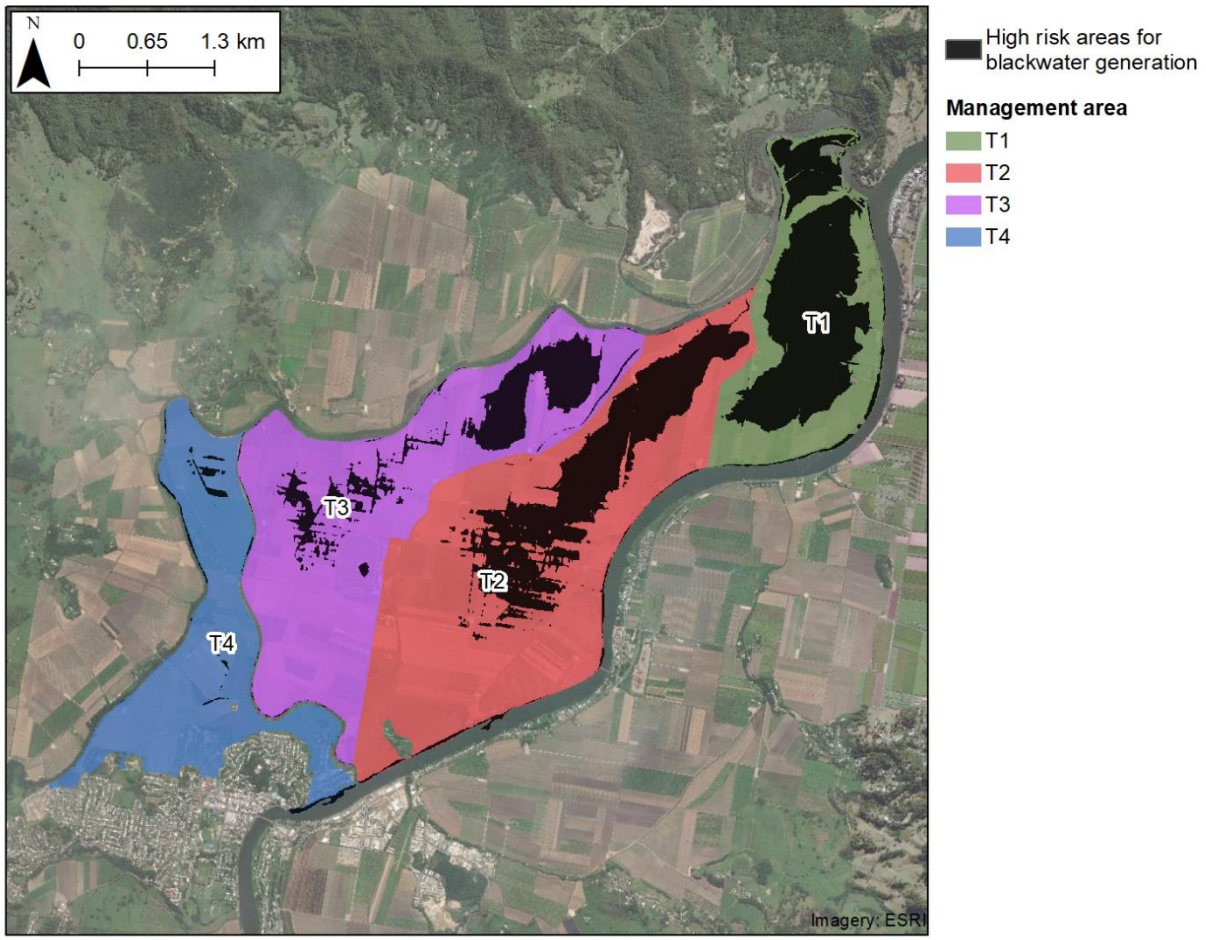


Figure 8-57: Blackwater contribution in each management area for the Tygalgah subcatchment (median blackwater level +1.0 m AHD)

8.9.4 Floodplain drainage - sea level rise vulnerability

The sea level rise vulnerability assessment of the Tygalgah subcatchment is summarised in Figure 8-58. Modelling indicates that drainage of management areas T1 and T2 is influenced by present day high tide levels. In the future, the subcatchment will become increasingly vulnerable to reduced drainage, affecting the low elevation land in the north of subcatchment. Large areas within management areas T1, T2 and T3 are situated below the approximate mean tide water level (i.e. at medium risk of reduced drainage) in the far future sea level rise scenario. Management area T1 will be the most severely impacted by sea level rise.

A number of floodgates within the Tygalgah subcatchment are identified as being moderately vulnerable to sea level rise (Figure 8-58), with the number of floodgates likely to be vulnerable increasing into the near and far future. The floodgates that are classified as the most vulnerable are generally smaller, secondary structures. Primary floodgates in this subcatchment are generally a similar size and the inverts are typically between 0.8 – 0.4 m AHD (shown in Figure 8-59). All primary floodgates except Structure 28 are moderately vulnerable to sea level rise in the far future.

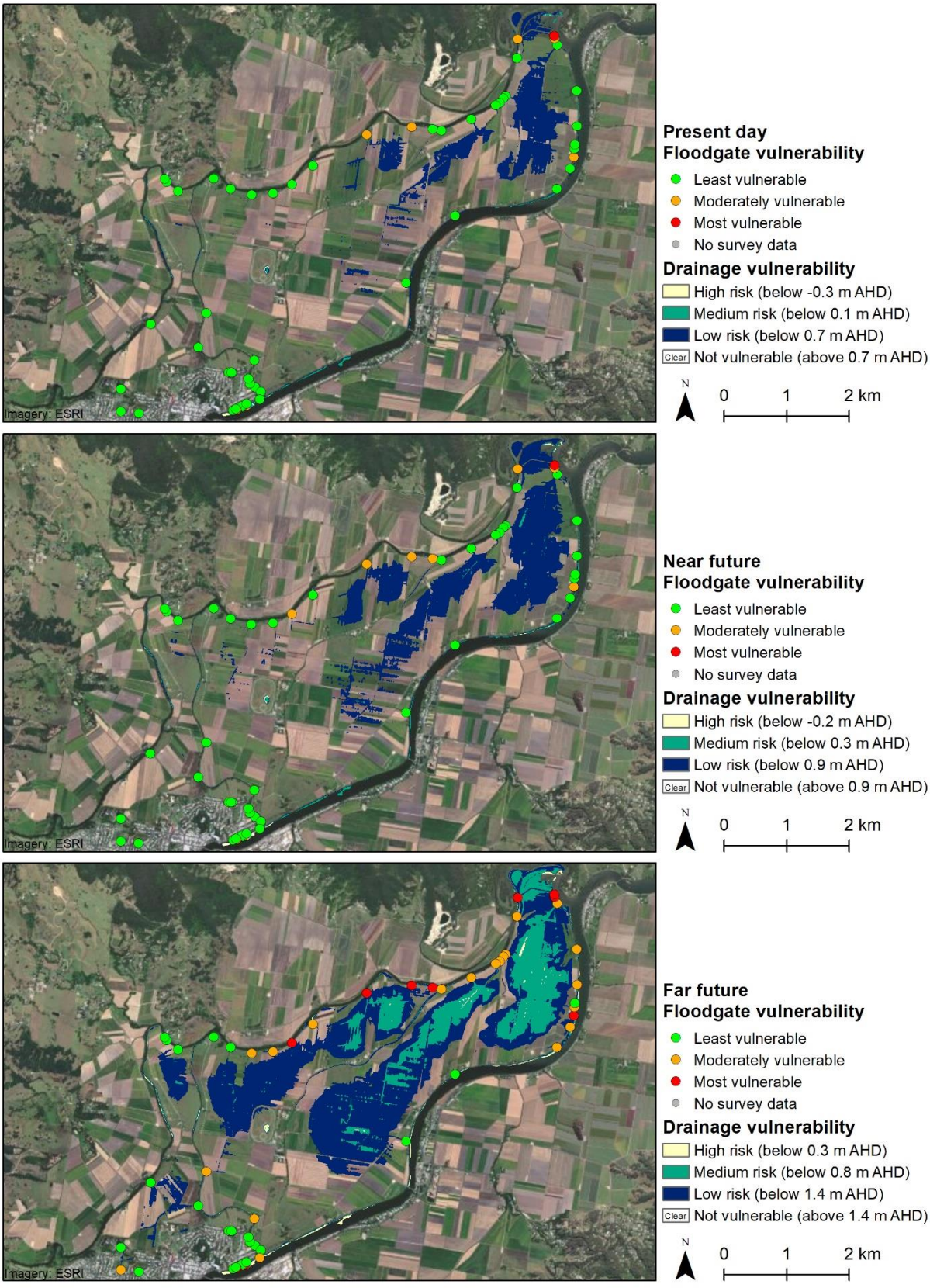


Figure 8-58: Sea level rise drainage vulnerability for the Tygalgah subcatchment

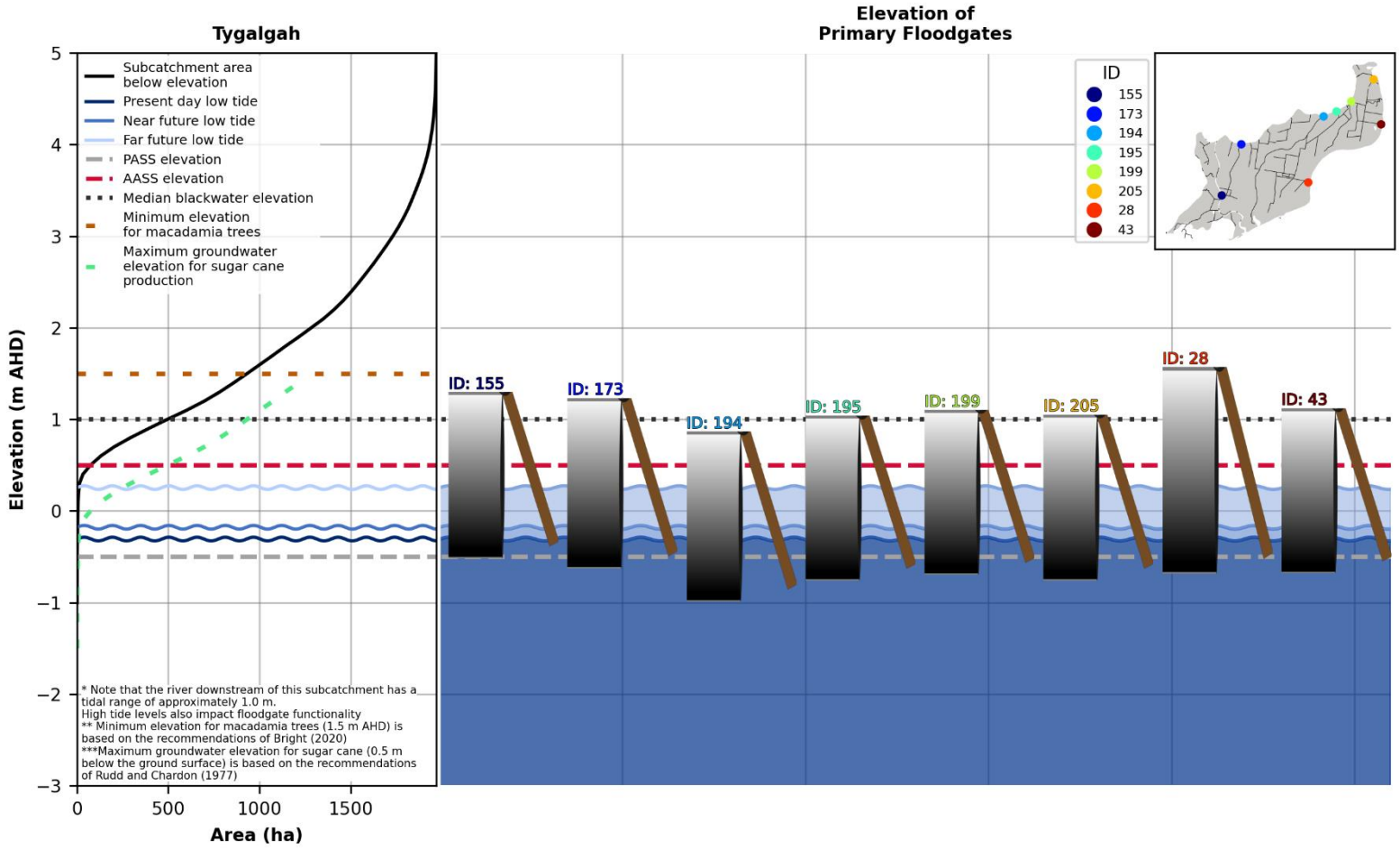


Figure 8-59: Key floodplain elevations - Tygalgah subcatchment

8.9.5 Management options

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

- Short-term: Optimise tidal flushing through structures, actively manage Coastal Management SEPP coastal wetlands, review pumping regimes, and modify/reshape drains.
- Long-term: Drain modifications, removal of floodgates, transition of low-lying areas to wetlands, and restoration of natural flow paths.

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
There are existing Coastal Management SEPP coastal wetlands in management area T1. Active protection of these high value ecosystems should be encouraged and continued. Controlled tidal flushing through Structures 43 and 205 should continue and be maintained. Pumping of water from within the drainage channels to lower the water table should be reviewed to limit soil oxidation and acid discharge.

Floodgate modifications to Structure 195 could be completed to allow additional controlled, in-drain tidal flushing within management area T2 for water quality benefits, noting that salinity in the Rous River is generally lower than the main Tweed River estuary (Pratt, 2017), which has implications for the effectiveness of controlled tidal flushing for buffering in-drain acidity. This would supplement existing modifications to Structures 28 and 196 which should continue to be maintained.

Drains located in management area T3 could be shallowed and widened to reduce their intersection with acid sulfate soils, where this strategy would not impact existing land uses. The existing management of buoyancy controlled auto-tidal gate should continue with the possibility of modification to Structure 155 (shown in Figure 8-60) to allow controlled in-drain tidal flushing for further water quality benefits, noting lower salinity levels in the Rous River during periods of moderate to high inflow (Pratt, 2017).

Modifications of floodgates to allow controlled in-drain tidal flushing in management area T4 should also be considered through either sluice gates or buoyancy controlled auto-tidal floodgates. Structures 153 and 168a are potentially suitable structures for modification.

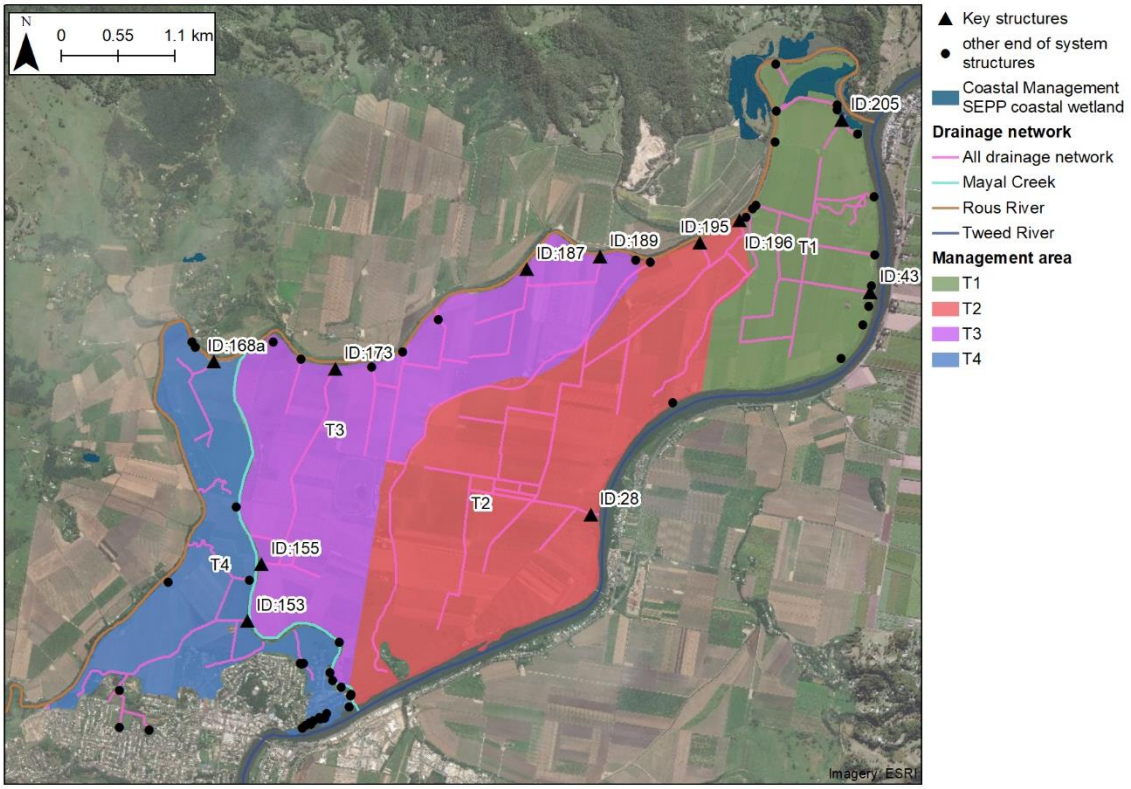


Figure 8-60: Short-term management options for the Tygalgah subcatchment

Long-term management options

Drainage in management area T1 will be impacted due to sea level rise. This will provide an opportunity to expand existing Coastal Management SEPP coastal wetlands within this management area to extend to low-lying areas when current land uses become unsustainable. Infilling of existing drainage and removal of floodgates would promote wetland creation in this area.

Management area T2 will also be impacted by reduced drainage in the long-term due to sea level rise, potentially impacting existing land uses. Where this occurs, low-lying areas could be rehabilitated to support wet pasture management or wetland environments. Natural flow paths could be restored, for example flow through the waterway that connects to Structure 196 could be encouraged. Structures 195 and 196 could be opened and the drain upstream of Structure 195 could be reshaped or infilled. This could occur alongside opportunistic reshaping/infilling of artificial drains and restoration of the natural flow paths.

The north eastern section of management area T3 will be impacted by reduced drainage into the future. This part of the floodplain could be disconnected from the higher area to the west and converted to a wetland. To the west of management area T3, drainage density could be reduced and larger drains could be shallowed and widened to reduce the risk of acid sulfate soil oxidation and acidic export.

Within management areas T4 drains could be made shallower and wider. Wherever possible drains could be infilled to reduce the drainage density and reduce acid export and blackwater runoff.

A summary of the recommended management options for the Tygalgah subcatchment including indicative costs is provided in Table 8-13.

Table 8-13: Summary of management options for the Tygalgah subcatchment

Timeframe	Strategy	Target management area(s)	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing per year)	Indicative cost (lost productivity per year)	Effectiveness at improving:		
							Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Optimise tidal flushing	Entire subcatchment	None	$120,000	$20,000	None	Moderate	Moderate	Negligible
Short-term	Cease pumping	Entire subcatchment	None	None	None	Minimal	None	Moderate	Negligible
Short to long-term	Drain reshaping/infilling	T2, T3	None	$300,000	None	Minimal	None	Moderate	Low
Long-term	Restoration of wetlands	T1, T2, T3	$3,600,000	$350,000	Minimal	$450,000	Very high	High	High

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

8.10 West Chinderah subcatchment

Acid priority rank:	**8**
Blackwater priority rank:	**7**
Infrastructure	
Approximate waterway length (km)	45
# Privately owned end of system structures	0
# Publicly owned end of system structures	30
# End of system structures within coastal wetlands	9
# Publicly owned end of system structures within coastal wetlands	9
Primary floodplain infrastructure (floodgate ID)	86, 87, 100, 103
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-1.3 to -0.3
Average AASS elevation (m AHD)	0.7
Average PASS elevation (m AHD)	-1.7
Median blackwater elevation (m AHD)	0.5
Present day low water level (m AHD)	-0.3
Near future low water level (m AHD)	-0.2
Far future low water level (m AHD)	0.3
Proximity to sensitive receivers	
Oyster leases (km)	14.0
Saltmarsh (km)	Within subcatchment
Seagrass (km)	0.5
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	1,191
Classified as conservation and minimal use (ha (%))	1 (0.1%)
Classified as grazing (ha (%))	151 (13%)
Classified as forestry (ha (%))	27 (2%)
Classified as sugar cane (ha (%))	706 (59%)
Classified as horticulture (ha (%))	2 (0.2%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	187 (16%)
Classified as marsh/wetland (ha (%))	0 (0%)
Other (ha (%))	116 (10%)
Land values	
Estimated total primary production value ($/year)	$1,100,000
Average land value above 0.5 m AHD ($/ha)	$36,400
Average land value below 0.5 m AHD ($/ha)	$10,200

8.10.1 Site description and brief history of drainage

The West Chinderah subcatchment is located on the right bank of the lower Tweed River estuary. Major drainage was constructed across the West Chinderah subcatchment during the 1960s and 1970s (Tulau, 2011). There are four main waterways that provide floodplain drainage. These include two channels that drain the eastern area of the floodplain to Boyds Channel through Structures 100 and 103, one drain that runs from east to west across the floodplain draining through Structure 87, and McLeods Creek which has been heavily modified and drains the south west of the floodplain into Stotts Channel.

Sugar cane is the predominate land use within the subcatchment, however there are a number of other land uses which make up one third of the floodplain land. These include a sand quarry, a lobster farm, a golf course, and Kingscliff Wastewater Treatment Plant. Between 1999 and 2002 the Pacific Highway was constructed and bisects the floodplain running from north to south through the floodplain.

On the northern side of the floodplain, Dodds Island and a small parcel on the northern side of the Tweed River are also included within the West Chinderah subcatchment. These areas are predominantly used for grazing, feature farm scale drainage, and contain sensitive receivers including Coastal Management SEPP coastal wetlands. Tenure information for the West Chinderah subcatchment is shown in Figure 8-61. Information on drainage and floodplain elevation is shown in Figure 8-62.

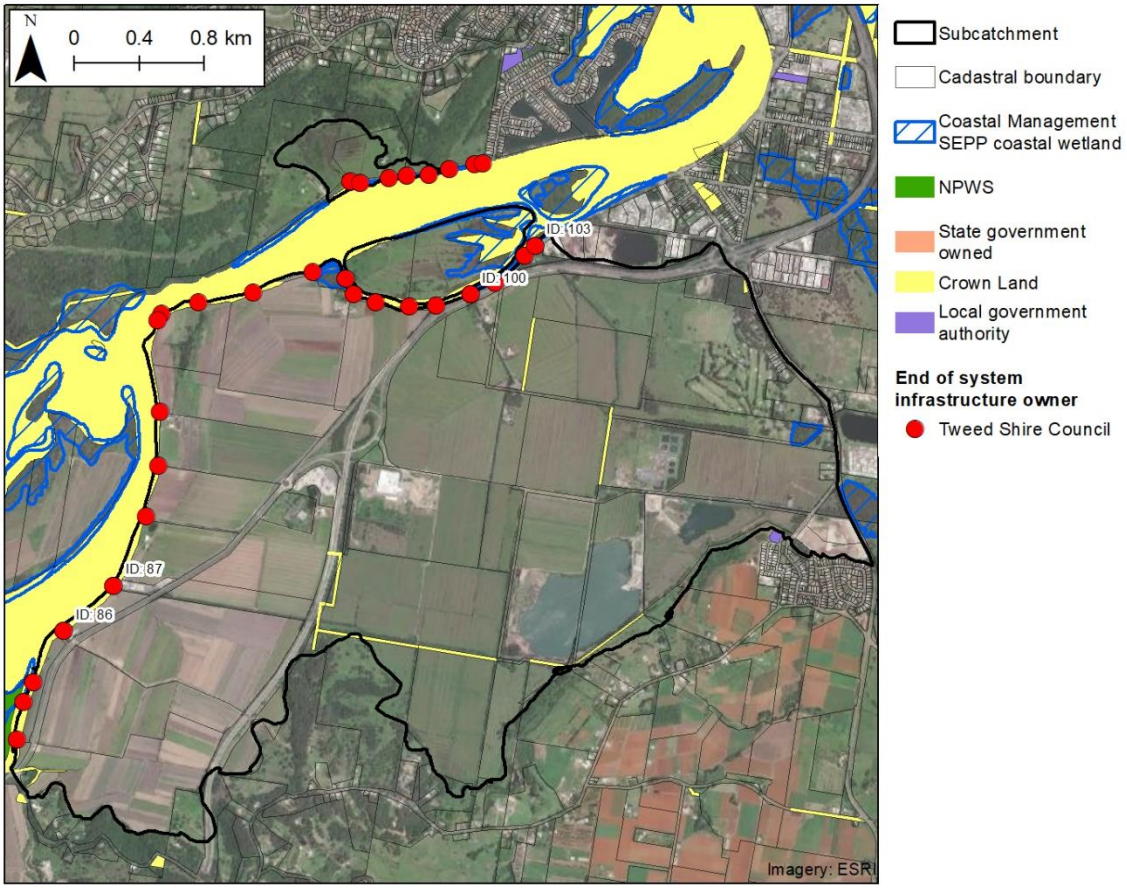


Figure 8-61: West Chinderah subcatchment - land and end of system infrastructure tenure

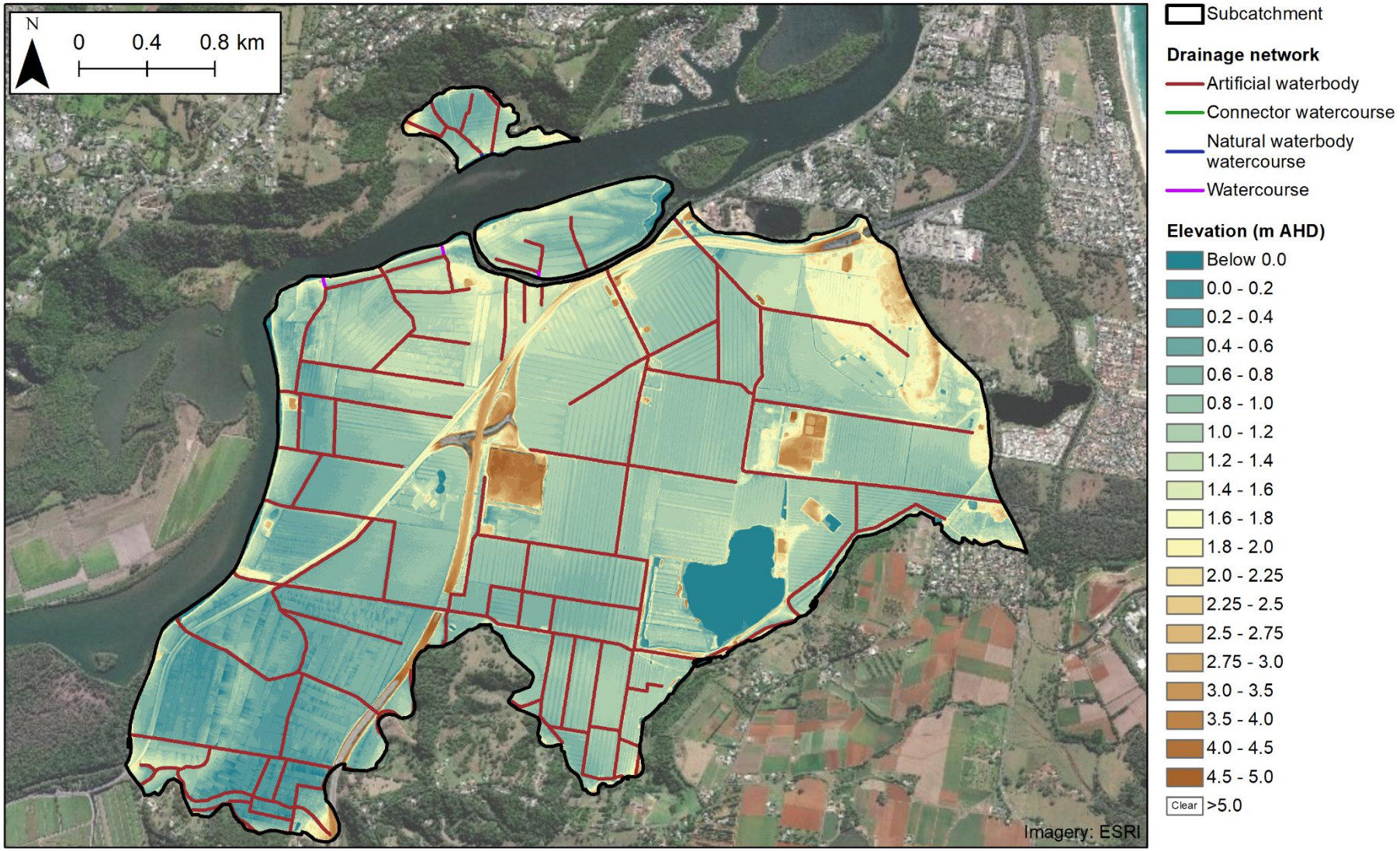


Figure 8-62: West Chinderah subcatchment elevation and drainage network

8.10.2 History of remediation

Remediation actions that have taken place within the West Chinderah subcatchment include modification of floodgate structures and the infilling of drains (Figure 8-63). In addition to these actions, during construction of the Pacific Highway from Yulgun to Chinderah (from 1999 to 2002), a detailed acid sulfate soil management plan was implemented considering the design features of the highway including (Hsi and Martin, 2005):

- Using driven piles to minimise excavation for foundations;
- Reducing excavation within acid sulfate soils;
- Installing wide and shallow drains that minimised drainage interaction with acid sulfate soils;
- Use of construction material that can withstand acidic exposure; and
- Extensive treatment of groundwater and soil displaced through construction.

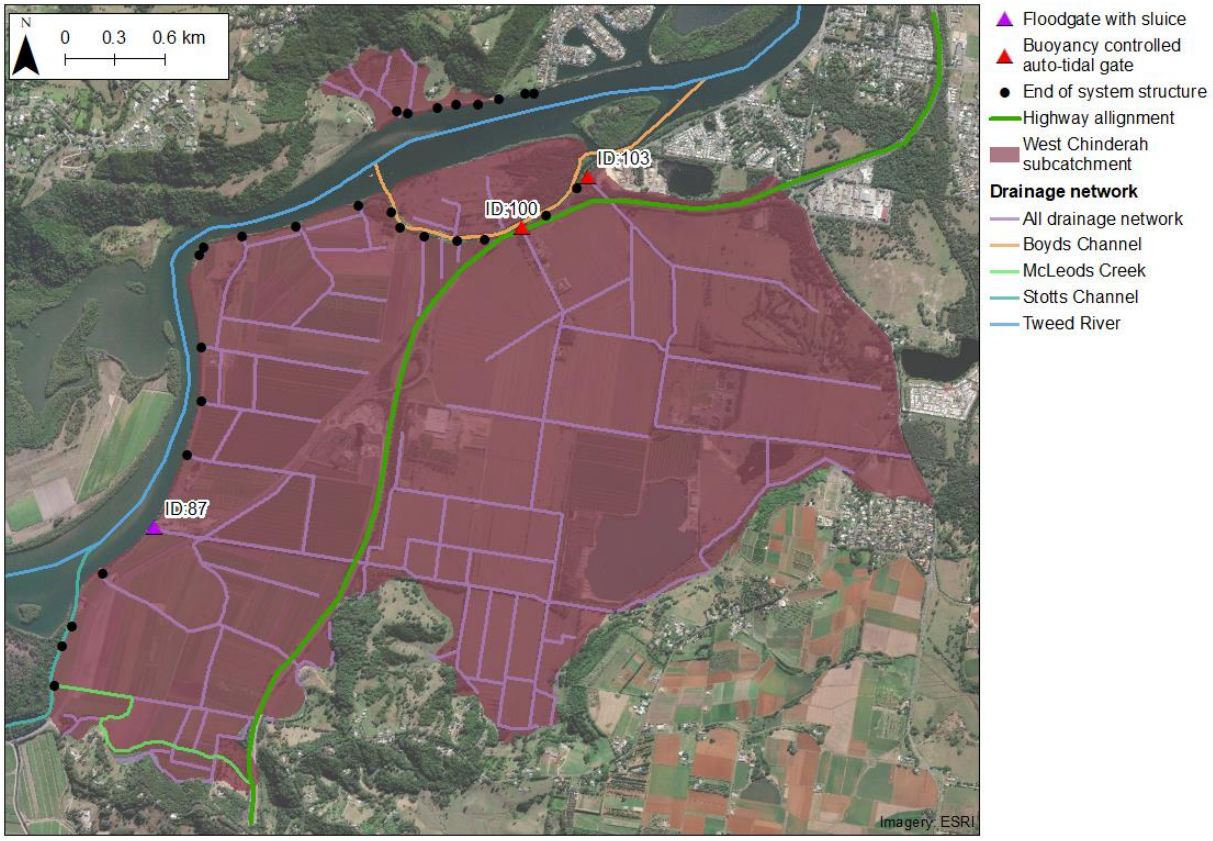


Figure 8-63: The West Chinderah subcatchment including previous remediation actions

Primary drainage Structures 87, 100 and 103 have all been modified with buoyancy controlled auto-tidal gates for the purpose of providing fish passage and improved water quality (Industry and Investment NSW, 2009). Field investigations completed for this project found that the buoyancy controlled auto-tidal gate previously installed on Structure 87 has been removed and replaced with a sluice gate (Figure 8-64).



Figure 8-64: Structure 87 with a sluice gate on one of its floodgate flaps

Tweed Shire Council currently has an ongoing program to infill field drains across the Tweed River floodplain (TSC, 2020). To date, over 40 km of drains have been filled in, including ones within the West Chinderah subcatchment. Infilling drains can be completed alongside laser levelling which allows paddocks to maintain drainage while increasing the area for productive farming.

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

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

8.10.3 Floodplain drainage - sea level rise vulnerability

The sea level rise vulnerability assessment of the West Chinderah subcatchment is summarised in Figure 8-65. In present day conditions, areas to the south west of the West Chinderah subcatchment are potentially affected by reduced drainage due to estuarine water levels. Some areas of land to the north of the Tweed River area also impacted. Drainage in these areas will become more severely impacted under near and far future sea level rise scenarios, with large areas of floodplain being situated below the approximate future mean water level (i.e. at medium risk of reduced drainage). Some areas, such as the area drained by McLeods Creek, are situated below the approximate future low tide water level (i.e. at high risk of reduced drainage), with limited potential for natural drainage. In the far future sea level rise scenario, the majority of the floodplain drainage will be impacted to some degree by sea level rise.

Figure 8-66 summarises the key floodplain elevations, including present day and future low tide levels, compared to the primary floodgates in this subcatchment. The number of floodgates across the subcatchment which are vulnerable to sea level rise will increase into the near and far future until all are classified as moderately or most vulnerable. All primary floodgates are moderately vulnerable to sea level rise in the far future.

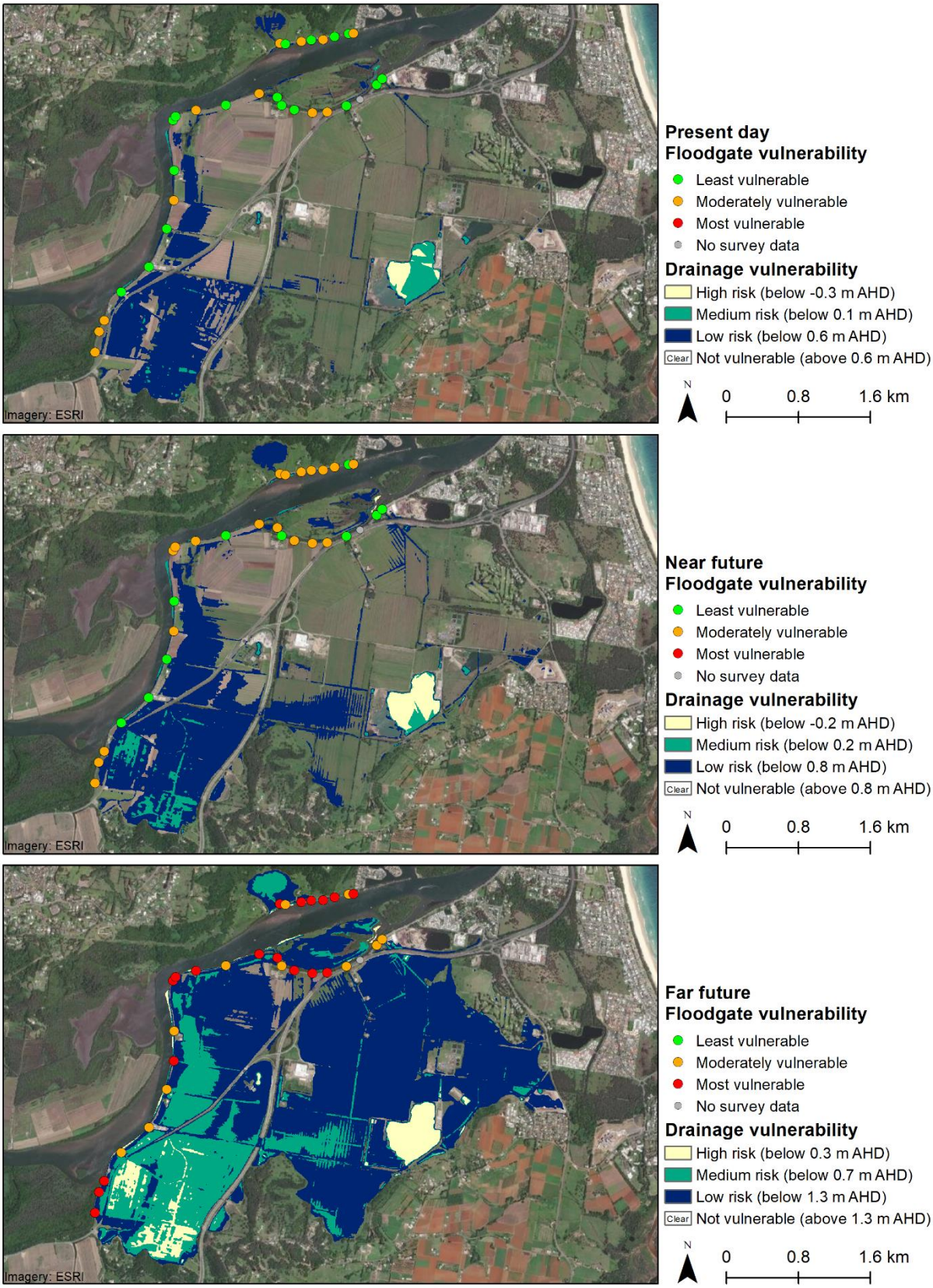


Figure 8-65: Sea level rise drainage vulnerability for the West Chinderah subcatchment

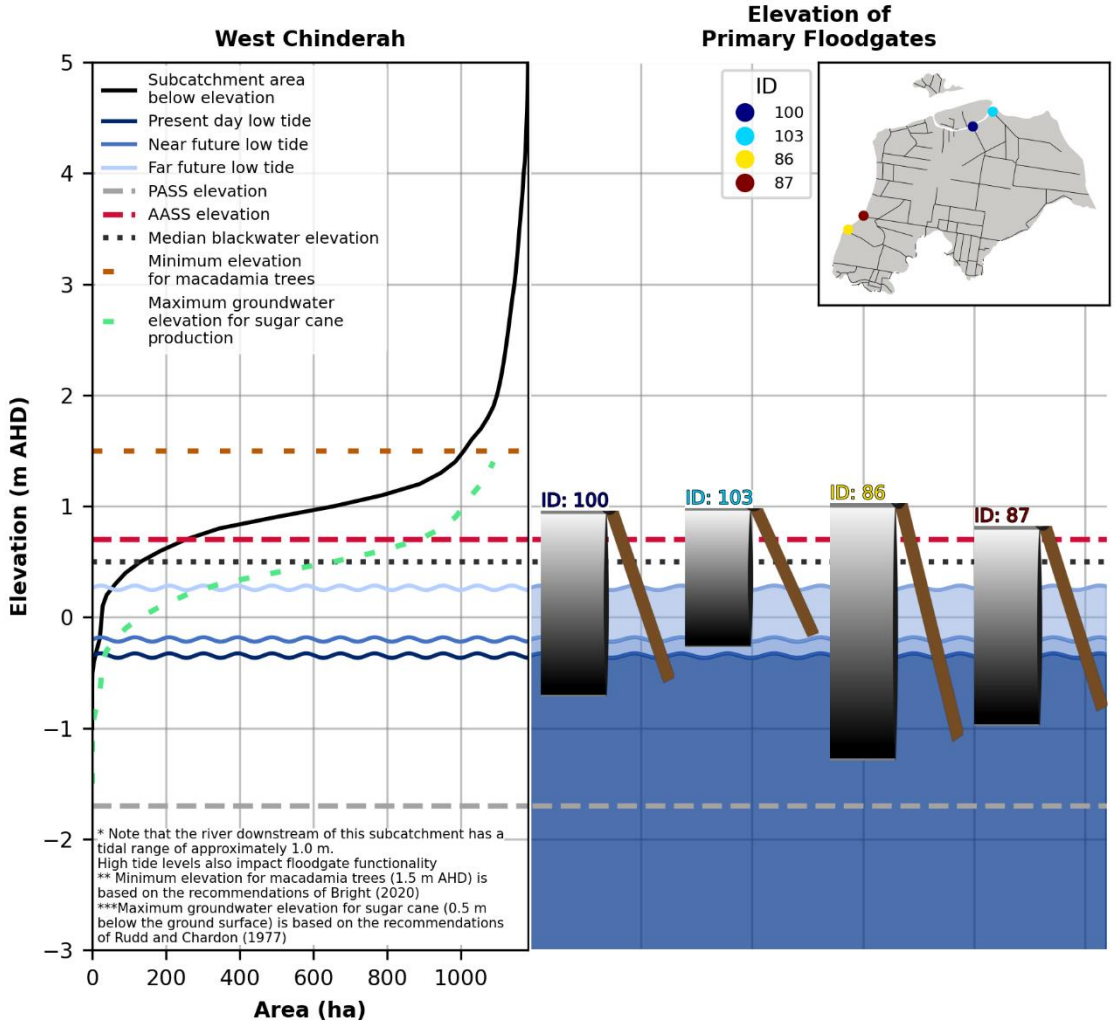


Figure 8-66: Key floodplain elevations - West Chinderah subcatchment

8.10.4 Management options

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

- Short-term: Optimise tidal flushing through structures, modification of the drainage network, actively protect existing Coastal Management SEPP coastal wetlands, installation of weirs, and encourage wet pasture management.
- Long-term: Conversion of low-lying areas to estuarine wetlands, expand existing Coastal Management SEPP coastal wetlands, promote wet pasture management by installing weirs, modify the drainage network and remove floodgates.

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
Short-term management options in the West Chinderah subcatchment are summarised in Figure 8-67. Within the West Chinderah subcatchment existing modified floodgates should continue to be maintained and managed for controlled tidal flushing. Structure 86 could also be modified to provide controlled in-drain tidal flushing for water quality benefits.

Existing Coastal Management SEPP coastal wetlands on Dodds Island, and to the north of the Tweed River, should be actively protected. Floodgates to the north of the Tweed River are currently in poor condition and could potentially be replaced with weir flow control structures. This approach would promote wet pasture management in upstream areas.

Across the floodplain, drain reshaping should be investigated to determine if floodplain drainage channels can be shallowed and widened to reduce interaction with acid sulfate soils whilst maintaining drainage capacity (where this has not already taken place). This would reduce acid export while maintaining existing drainage efficiencies.

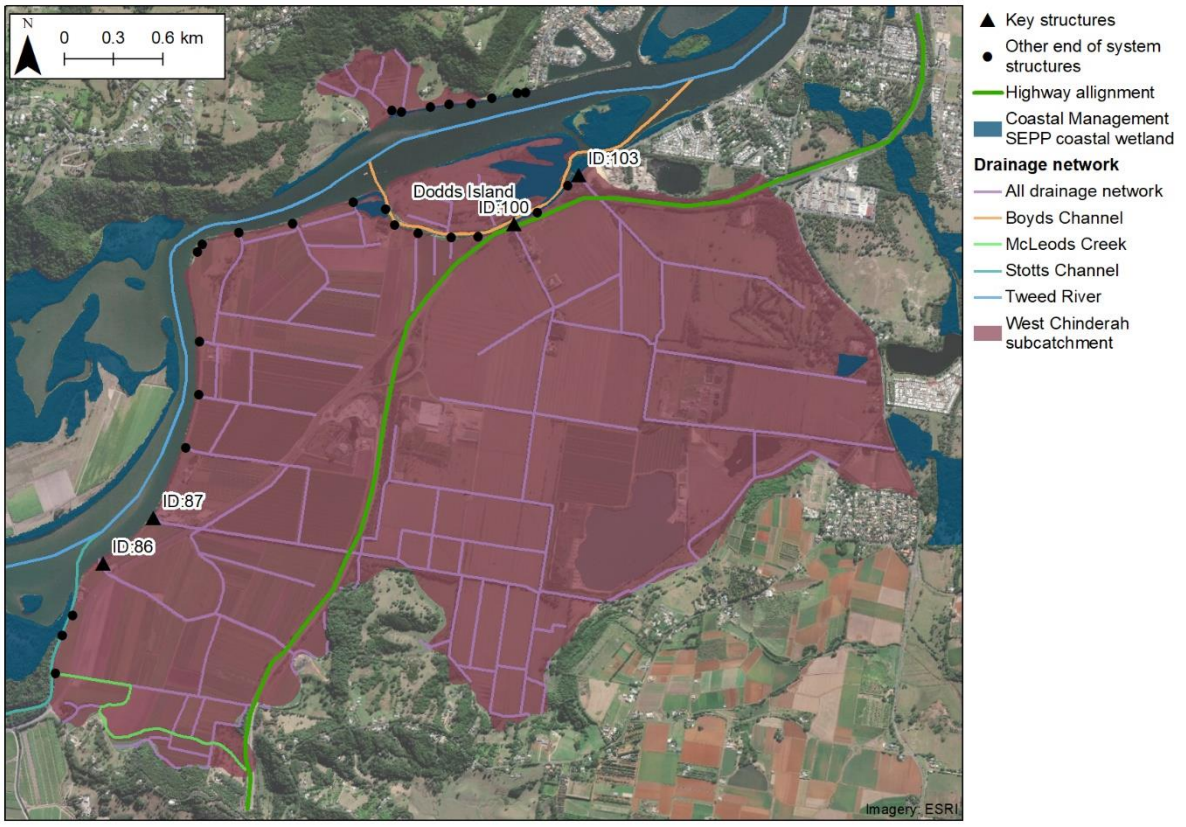


Figure 8-67: Short-term management options for the West Chinderah subcatchment

Long-term management options

Sea level rise will impact drainage across the floodplain and specifically in areas to the south west that drain via McLeods Creek. In this area, alternative land uses, such as conversion of low-lying land to wetland could be considered, as existing land use becomes impractical. Wetlands could also be encouraged on Dodds Island and low-lying areas to the north of the Tweed River expanding the existing Coastal Management SEPP coastal wetland area.

Weirs could be installed on the waterways within land currently used for grazing to the south of the floodplain to allow for wet pasture management while raising the water table of the surrounding area to reduce acid export. More broadly across the floodplain the drainage density could be reduced through infilling of drains, drains could be shallowed and widened, and floodgates could be removed to promote natural drainage pathways and reduce acid discharge.

A summary of the recommended management options for the West Chinderah subcatchment including indicative costs is provided in Table 8-14.

Table 8-14: Summary of management options for the West Chinderah subcatchment

Timeframe	Strategy	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing per year)	Indicative cost (lost productivity per year)	Effectiveness at improving:		
						Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Optimise tidal flushing	None	$60,000	$10,000	None	Moderate	Moderate	Negligible
Short-term	Wet pasture management	None	$20,000	None	Minimal	None	Moderate	Moderate
Short-term	Drain reshaping	None	None	$500,000	Minimal	None	Moderate	Low
Short to long-term	Weirs	None	$100,000	$20,000	Minimal	None	Moderate	Low
Long-term	Restoration of wetlands	$1,500,000	$250,000	Minimal	$250,000	Very high	High	High

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

8.11 North Tumbulgum subcatchment

Acid priority rank:	**9**
Blackwater priority rank:	**5**
Infrastructure	
Approximate waterway length (km)	31
# Privately owned end of system structures	4
# Publicly owned end of system structures	26
# End of system structures within coastal wetlands	3
# Publicly owned end of system structures within coastal wetlands	1
Primary floodplain infrastructure (floodgate ID)	53, 63, 67
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-0.8 to -0.7
Average AASS elevation (m AHD)	0.2
Average PASS elevation (m AHD)	-0.9
Median blackwater elevation (m AHD)	0.7
Present day low water level (m AHD)	-0.3
Near future low water level (m AHD)	-0.2
Far future low water level (m AHD)	0.3
Proximity to sensitive receivers	
Oyster leases (km)	17.2
Saltmarsh (km)	Within subcatchment
Seagrass (km)	4.0
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	680
Classified as conservation and minimal use (ha (%))	35 (5%)
Classified as grazing (ha (%))	117 (17%)
Classified as forestry (ha (%))	0 (0%)
Classified as sugar cane (ha (%))	453 (67%)
Classified as horticulture (ha (%))	9 (1%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	35 (5%)
Classified as marsh/wetland (ha (%))	3 (0.4%)
Other (ha (%))	29 (4%)
Land values	
Estimated total primary production value ($/year)	$800,000
Average land value above 0.7 m AHD ($/ha)	$14,700
Average land value below 0.7 m AHD ($/ha)	$14,500

8.11.1 Site description and brief history of drainage

The North Tumbulgum subcatchment is located on the left bank of the Tweed River within the middle to lower estuary. In the 1960s and 1970s drains were constructed in what was formerly known as the Terranora-Tumbulgum backswamp (Tulau, 2011). The floodplain has three (3) major drainage discharge points including Structures 53 and 63 which drain to the Tweed River, and Structure 67 which drains through the Tweed Broadwater, located on the eastern boundary of the subcatchment.

On the eastern side of the floodplain, Coastal Management SEPP coastal wetlands extend from within the Tweed Broadwater onto the low-lying floodplain. The major land use on the floodplain is sugar cane. Tenure information for the North Tumbulgum subcatchment is shown in Figure 8-68. Information on drainage and floodplain elevation is shown in Figure 8-69.

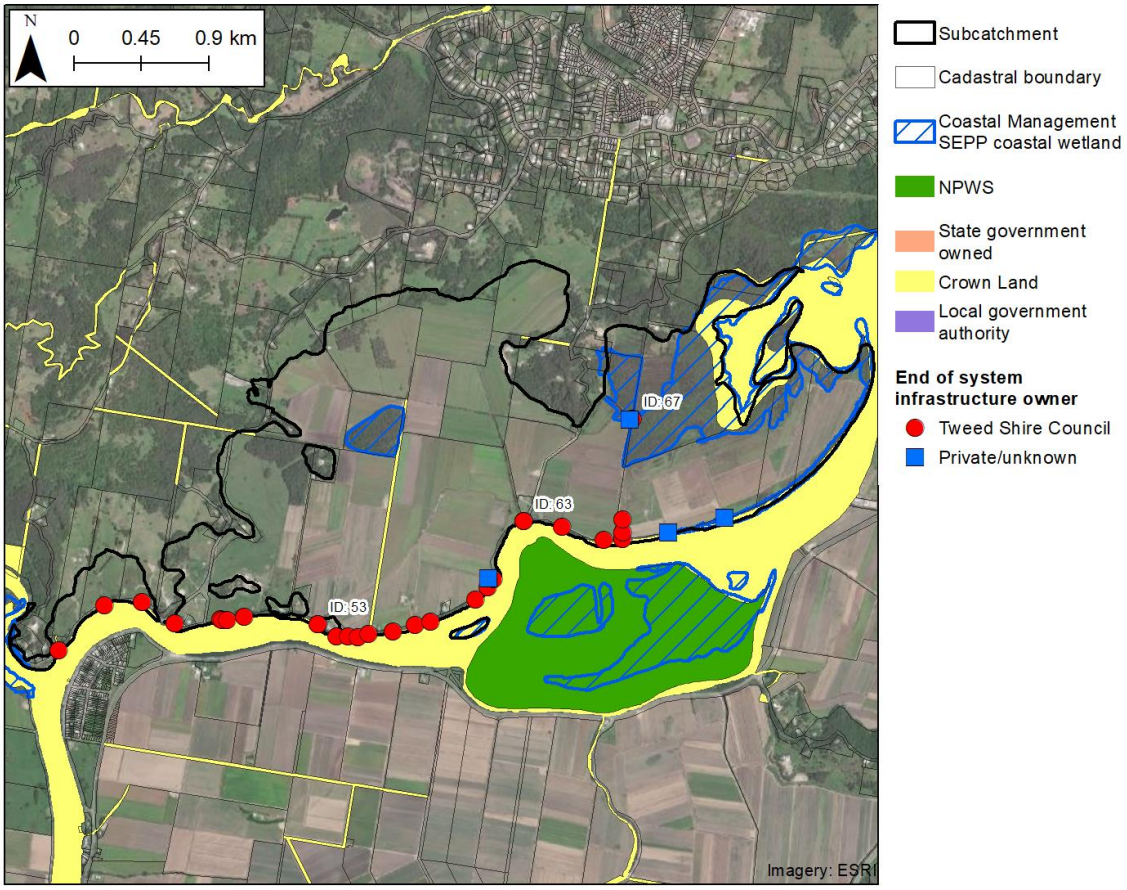


Figure 8-68: North Tumbulgum subcatchment - land and end of system infrastructure tenure

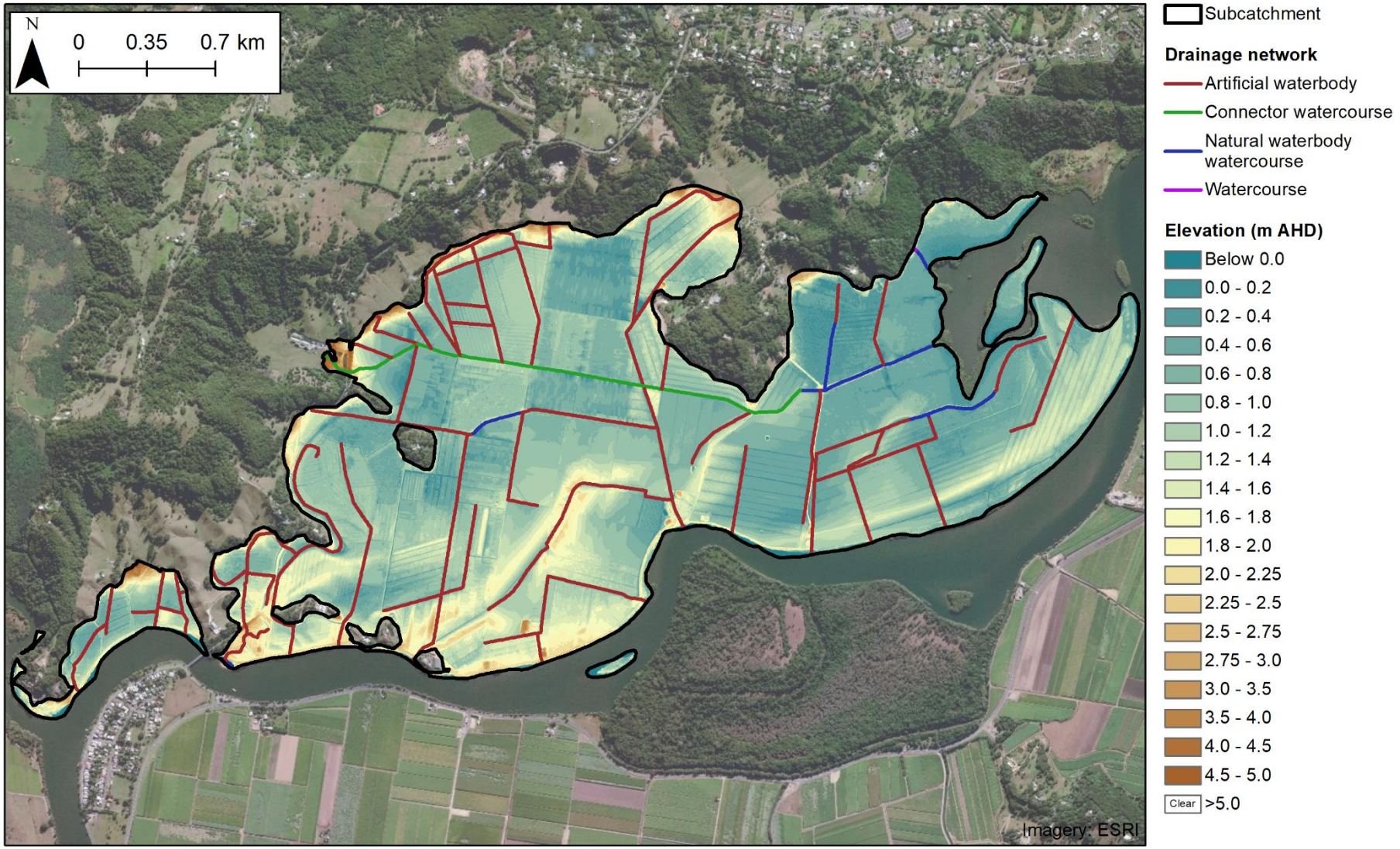


Figure 8-69: North Tumbulgum subcatchment elevation and drainage network

8.11.2 History of remediation

Remediation efforts within the North Tumbulgum subcatchment have targeted the modification of floodgate structures. Three (3) structures have been modified:

- The floodgate flaps have been completely removed on Structure 52 (see Figure 8-70);
- Structure 63 has winches installed to open its three floodgate flaps; and
- Structure 67 has winches installed to open its three floodgate flaps (see Figure 8-70).

Macdonald et al. (2004) observed that the North Tumbulgum subcatchment, which encompasses the former Terranora-Tumbulgum backswamp, is within the saline region of the Tweed River estuary, which is able to provide a buffer to acidic runoff from the subcatchment. Figure 8-71 shows the locations where floodgate structures have been modified.



Figure 8-70: Modified floodgates in the North Tumbulgum subcatchment (Structure 52 on the left and Structure 63 on the right)

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

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

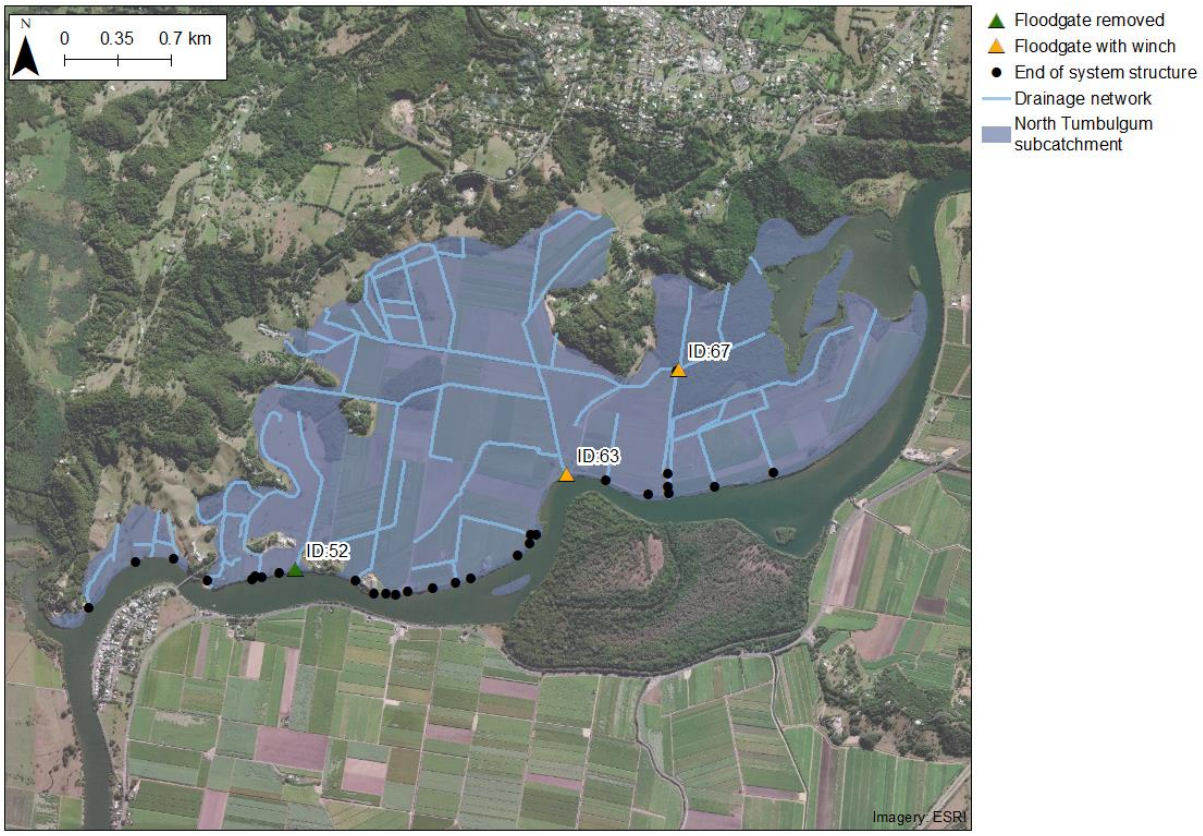


Figure 8-71: The North Tumbulgum subcatchment including previous remediation actions

8.11.3 Floodplain drainage - sea level rise vulnerability

The sea level rise vulnerability assessment of the North Tumbulgum subcatchment is summarised in Figure 8-72 and shows that low-lying areas on the east of the subcatchment are the most vulnerable. Floodplain elevation in this area is situated below the approximate present day high tide water level (+0.6 m AHD) and is presently at low risk to reduced drainage. Future scenario modelling shows that this area is below the approximate far future low tide water level (i.e. at high risk of reduced drainage). In addition, large areas of the floodplain will be below the approximate mean tide water level under the far future sea level rise scenario (i.e. at medium risk of reduced drainage).

Figure 8-73 summarises the elevation of primary floodgates in this subcatchment compared to key floodplain elevations. Structures 67, one of the primary structures providing drainage to the North Tumbulgum subcatchment, is identified as being moderately vulnerable in the near future and most vulnerable in the far future. The obvert of Structure 67 is situated below the approximate near future mean tide water level making it one of the most vulnerable on the floodplain. In the far future scenario, primary Structures 53 and 63 will also become moderately vulnerable. Twelve (12) secondary structures will also be most vulnerable to sea level rise in the far future.

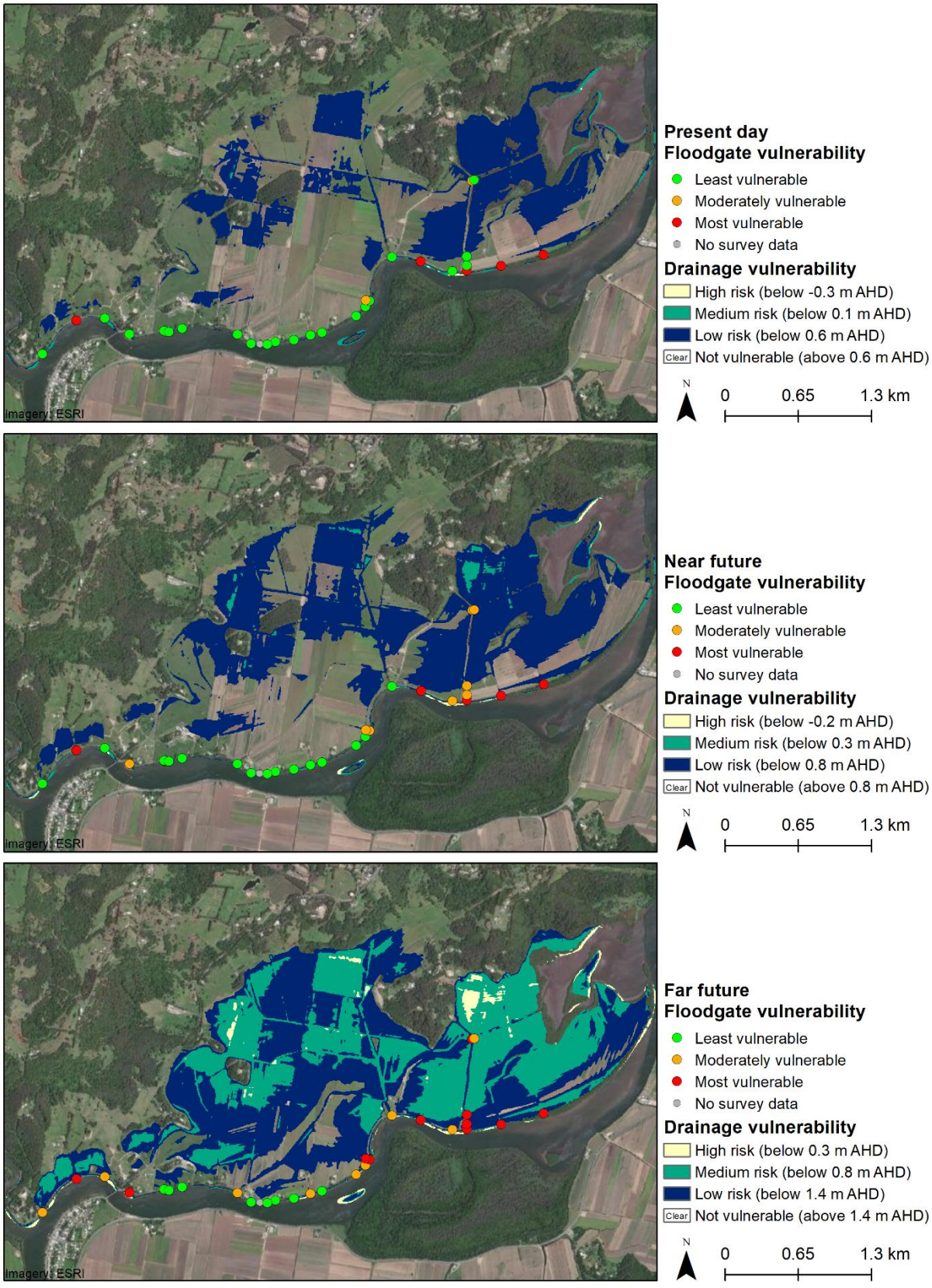


Figure 8-72: Sea level rise drainage vulnerability for the North Tumbulgum subcatchment

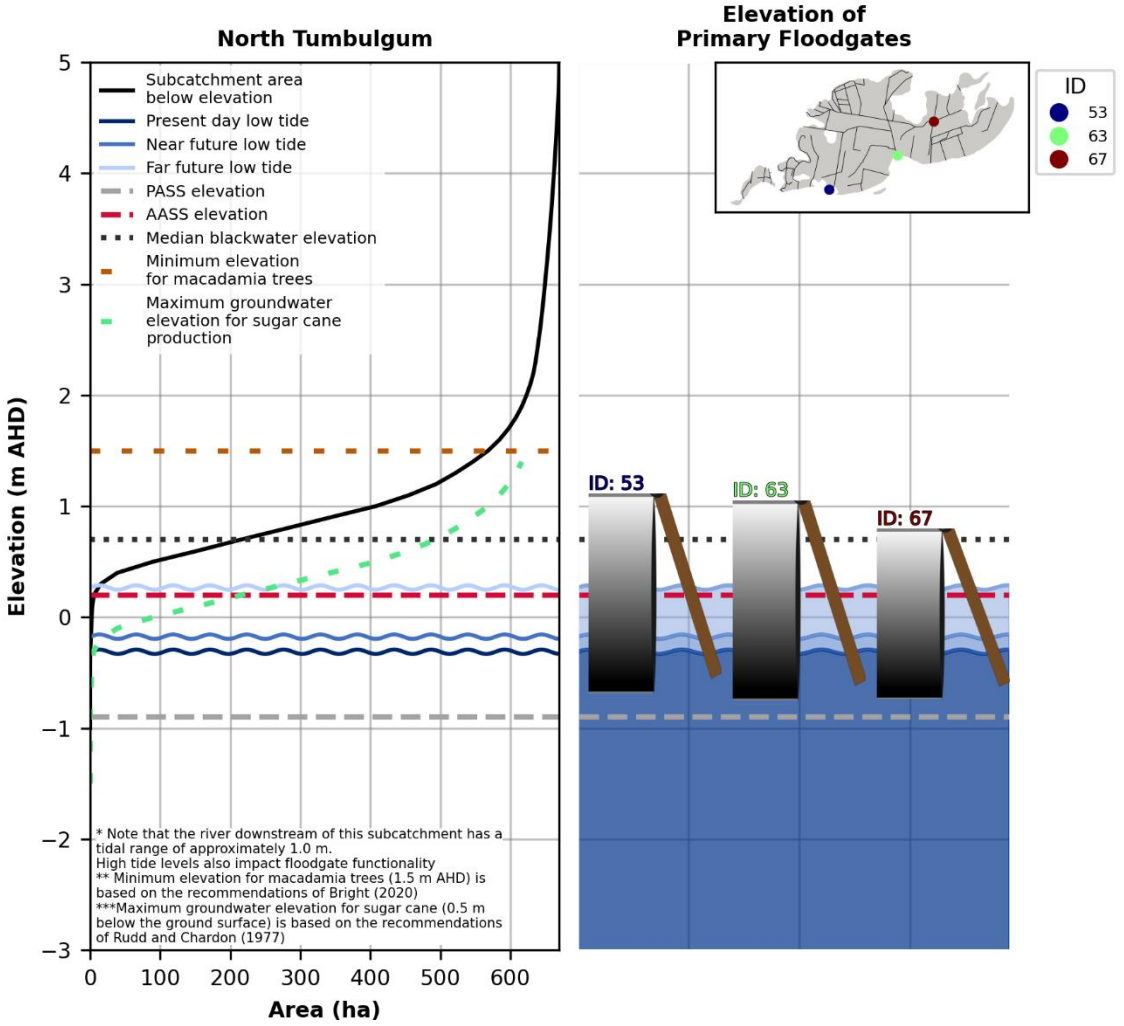


Figure 8-73: Key floodplain elevations - North Tumbulgum subcatchment

8.11.4 Management options

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

- Short-term: Optimise tidal flushing through structures.
- Long-term: Conversion of low-lying areas to wetlands, install weirs, modify the drainage network and promote wet pasture management.

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
Existing structures with winches could be actively managed to allow controlled in-drain tidal flushing upstream. Further, Structure 53 (see Figure 8-74) could also be modified to allow controlled tidal flushing upstream of the floodgates.

Long-term management options
Structure 67 could be removed and the drain it services could be infilled up to its confluence with the drain connecting to Structure 63 (Figure 8-74). This would allow for expansion of coastal wetland habitat on the eastern side of the North Tumbulgum Subcatchment which could be actively encouraged.

Into the future, existing land use may be impacted by reduced drainage due to sea level rise. The impacts of this could be mitigated by installing weirs to promote freshwater ponding and wet pasture management upstream. Existing farm scale drains could be infilled and larger drains made shallower and wider to reduce soil oxidation and acid discharge.

A Coastal Management SEPP coastal wetland is situated on the eastern side of the North Tumbulgum subcatchment surrounding low-lying farmland. This farmland area could be converted to estuarine wetland to supplement the existing habitat, which itself should be actively protected. This would involve a change in land use and on-ground works to infill drains and remove levees. Floodgate infrastructure is located upstream of this location, so any modifications are unlikely to impact the surrounding floodplain.

A summary of the recommended management options for the North Tumbulgum subcatchment including indicative costs is provided in Table 8-15.

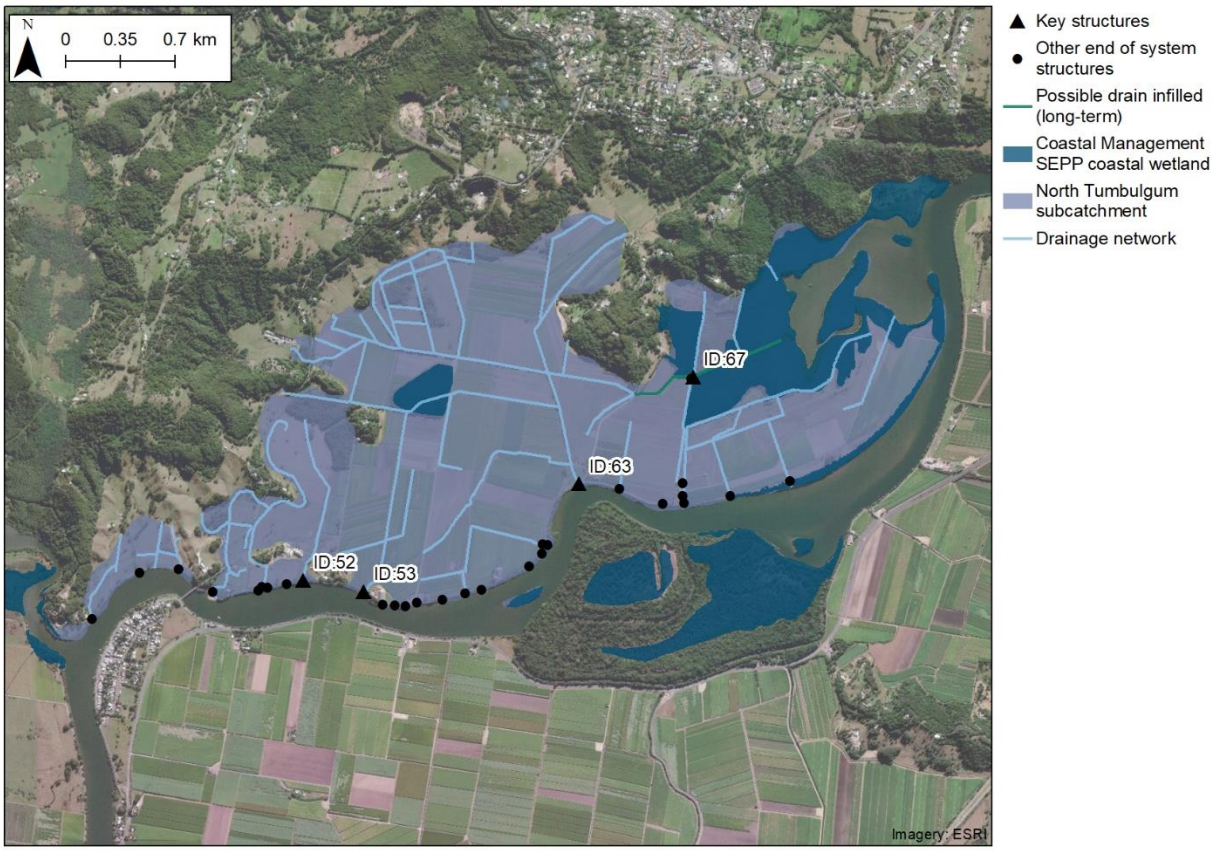


Figure 8-74: Short and long-term management options for the North Tumbulgum subcatchment

Table 8-15: Summary of management options for the North Tumbulgum subcatchment

Timeframe	Strategy	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing per year)	Indicative cost (lost productivity per year)	Effectiveness at improving:		
						Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Optimise tidal flushing	None	$30,000	$2,000	None	High	Moderate	Negligible
Long-term	Drain infilling	None	$80,000	None	Minimal	None	Moderate	Low
Long-term	Wet pasture management	None	$20,000	None	Minimal	None	Low	Moderate
Long-term	Restoration of wetlands	$2,200,000	$200,000	Minimal	$200,000	Very high	High	High

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

8.12 Cobaki subcatchment

Acid priority rank:	**10**
Blackwater priority rank:	**10**
Infrastructure	
Approximate waterway length (km)	20
# Privately owned end of system structures	5
# Publicly owned end of system structures	7
# End of system structures within coastal wetlands	2
# Publicly owned end of system structures within coastal wetlands	1
Primary floodplain infrastructure (floodgate ID)	N/A
Elevations	
Invert of primary floodplain infrastructure (m AHD)	N/A
Average AASS elevation (m AHD)	-0.4
Average PASS elevation (m AHD)	-0.8
Median blackwater elevation (m AHD)	0.4
Present day low water level (m AHD)	-0.3
Near future low water level (m AHD)	-0.2
Far future low water level (m AHD)	0.3
Proximity to sensitive receivers	
Oyster leases (km)	2.7
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)	1,470
Classified as conservation and minimal use (ha (%))	54 (4%)
Classified as grazing (ha (%))	244 (17%)
Classified as forestry (ha (%))	0 (0%)
Classified as sugar cane (ha (%))	0 (0%)
Classified as horticulture (ha (%))	3 (0.2%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	454 (31%)
Classified as marsh/wetland (ha (%))	386 (26%)
Other (ha (%))	330 (22%)
Land values	
Estimated total primary production value ($/year)	$100,000
Average land value above 0.4 m AHD ($/ha)	$121,500
Average land value below 0.4 m AHD ($/ha)	No property data available

8.12.1 Site description and brief history of drainage

The Cobaki subcatchment is located to the north west of the Tweed River floodplain and is a tributary on the left bank of the Tweed River. The main waterway for the Cobaki subcatchment is Cobaki Creek, which flows from the upstream catchment into Cobaki Broadwater and then to Terranora Creek. Upstream of Cobaki Broadwater, Piggabeen Creek flows into Cobaki Creek. There is limited artificial drainage within the subcatchment, however, the Cobaki Lakes development on the west of the floodplain is currently under construction and includes a number of large artificial channels.

Within the Cobaki subcatchment, marsh/wetland land use makes up 26% of the floodplain area and includes Coastal Management SEPP coastal wetland. Some grazing occurs on the low-lying floodplain surrounding Cobaki Creek and Piggabeen Creek. Tenure information for the Cobaki subcatchment is shown in Figure 8-75. Information on drainage and floodplain elevation is shown in Figure 8-76.

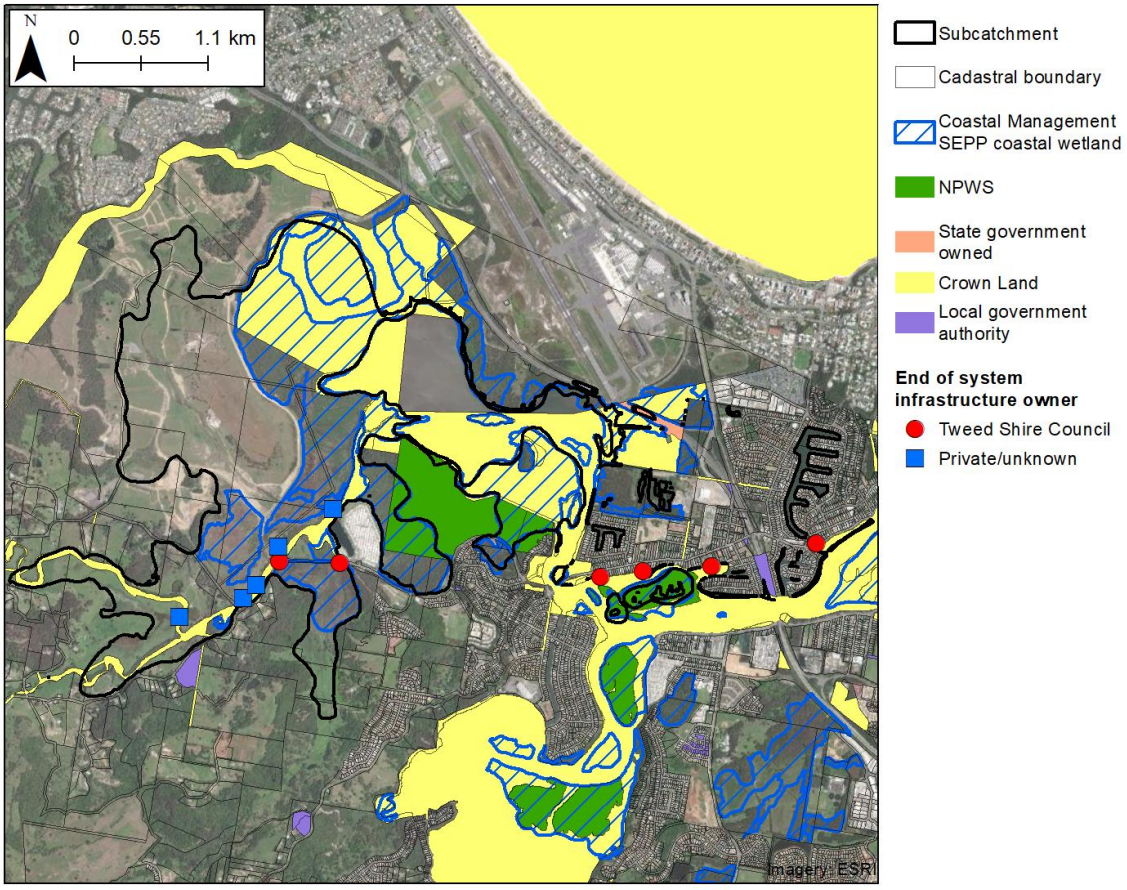


Figure 8-75: Cobaki subcatchment - land and end of system infrastructure tenure

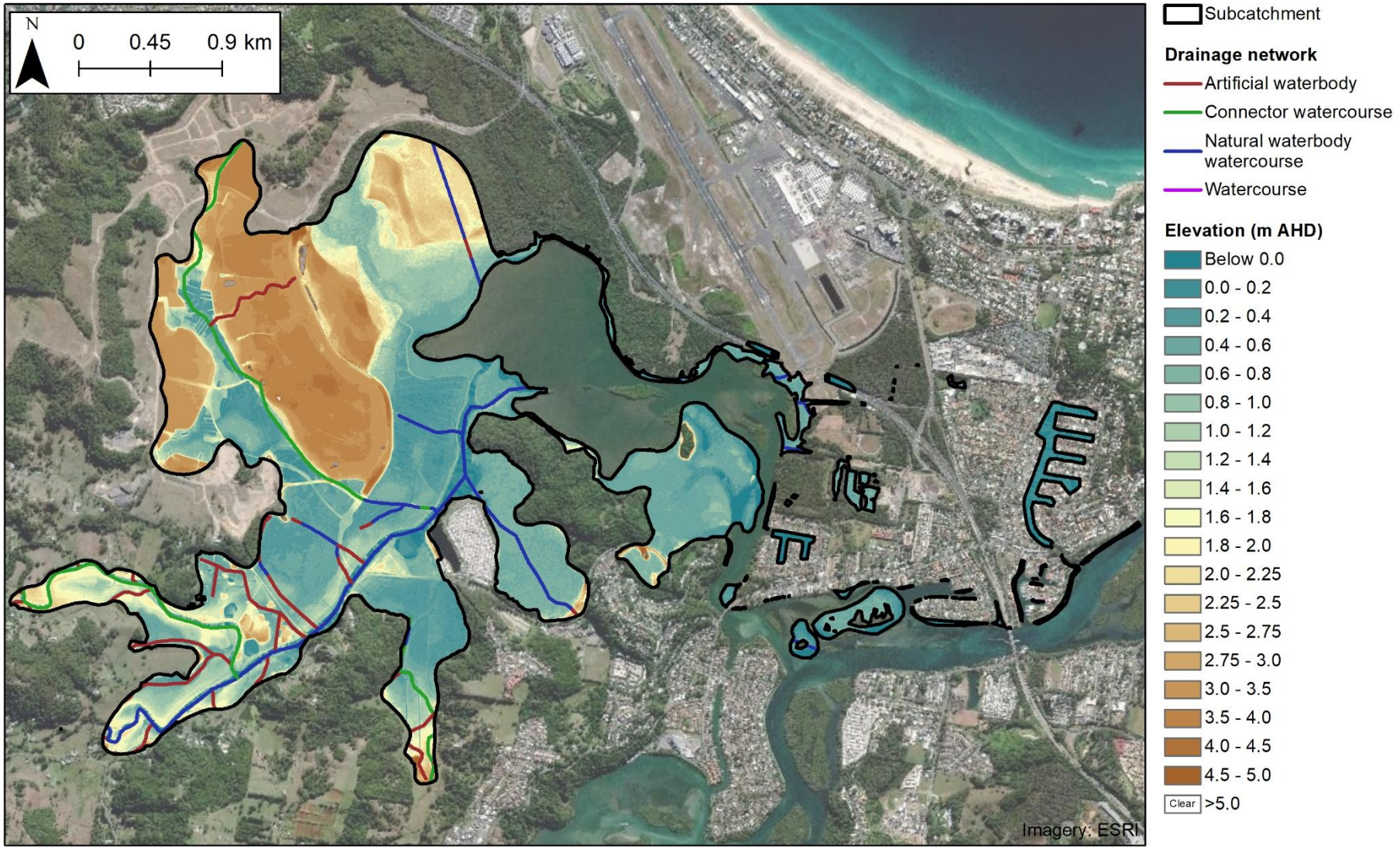


Figure 8-76: Cobaki subcatchment elevation and drainage network

8.12.2 History of remediation

Remediation within the Cobaki subcatchment has been limited to the treatment of acid sulfate soil excavated during construction of the Cobaki Lakes development with lime (Gilbert and Sutherland, 2009). There is no further evidence of any remediation attempts within the subcatchment. It was noted during field investigations that Structure 246 was in poor condition and had subsequently allowed tidal flow to leak upstream, which provides benefits to water quality. Major waterways and end of system infrastructure in the Cobaki subcatchment are shown in Figure 8-77.

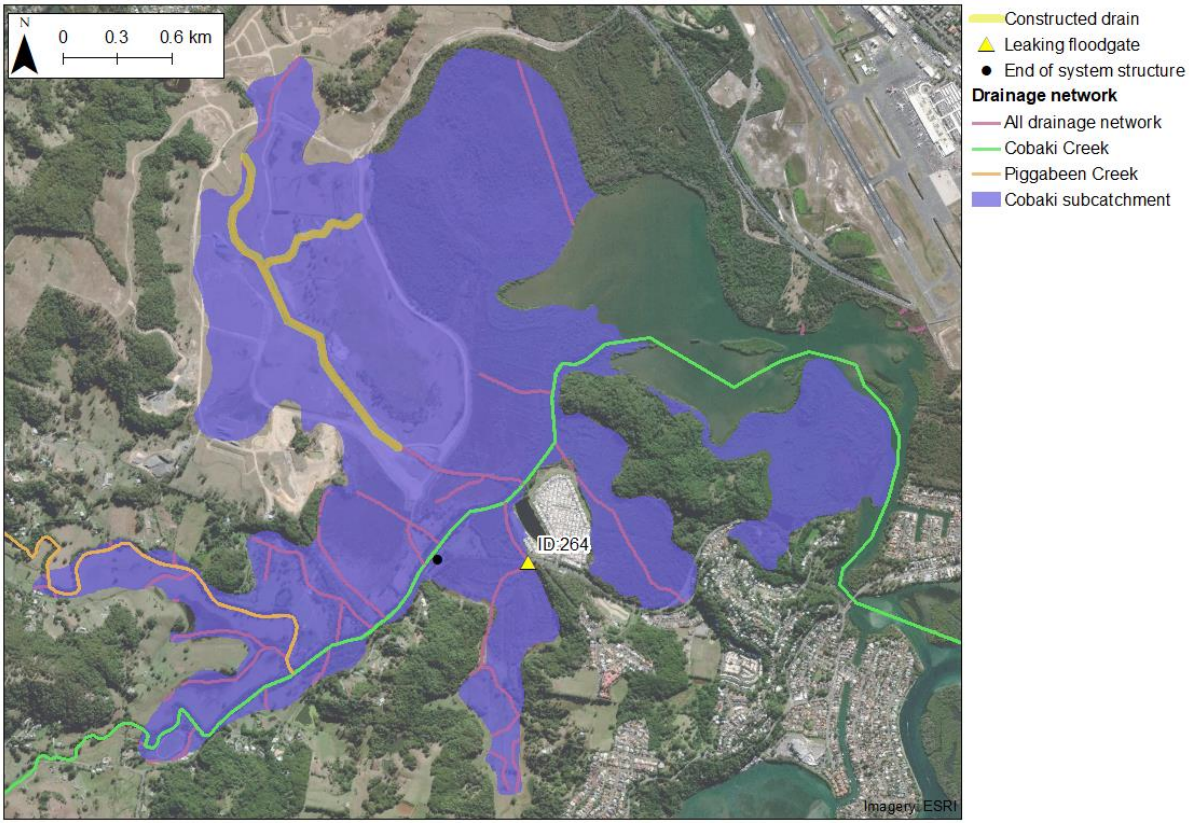


Figure 8-77: The Cobaki subcatchment including previous remediation actions

8.12.3 Floodplain drainage - sea level rise vulnerability

The sea level rise vulnerability assessment of the Cobaki subcatchment is summarised in Figure 8-78. Presently reduced drainage within the Cobaki subcatchment is limited to wetland areas with the exception of some areas within the Cobaki Lakes development that are below the approximate high tide water level (+0.6 m AHD) (i.e. at low risk of reduced drainage). The area of reduced drainage will expand in the near and far future sea level rise scenarios to encompass some low-lying farmland on the banks of Cobaki Creek.

Many of the structures within the Cobaki subcatchment are classified as moderately vulnerable under present day conditions. Under far future sea level rise scenario all the structure obverts will be below the approximate mean tide water level (i.e. they will be classified as most vulnerable).

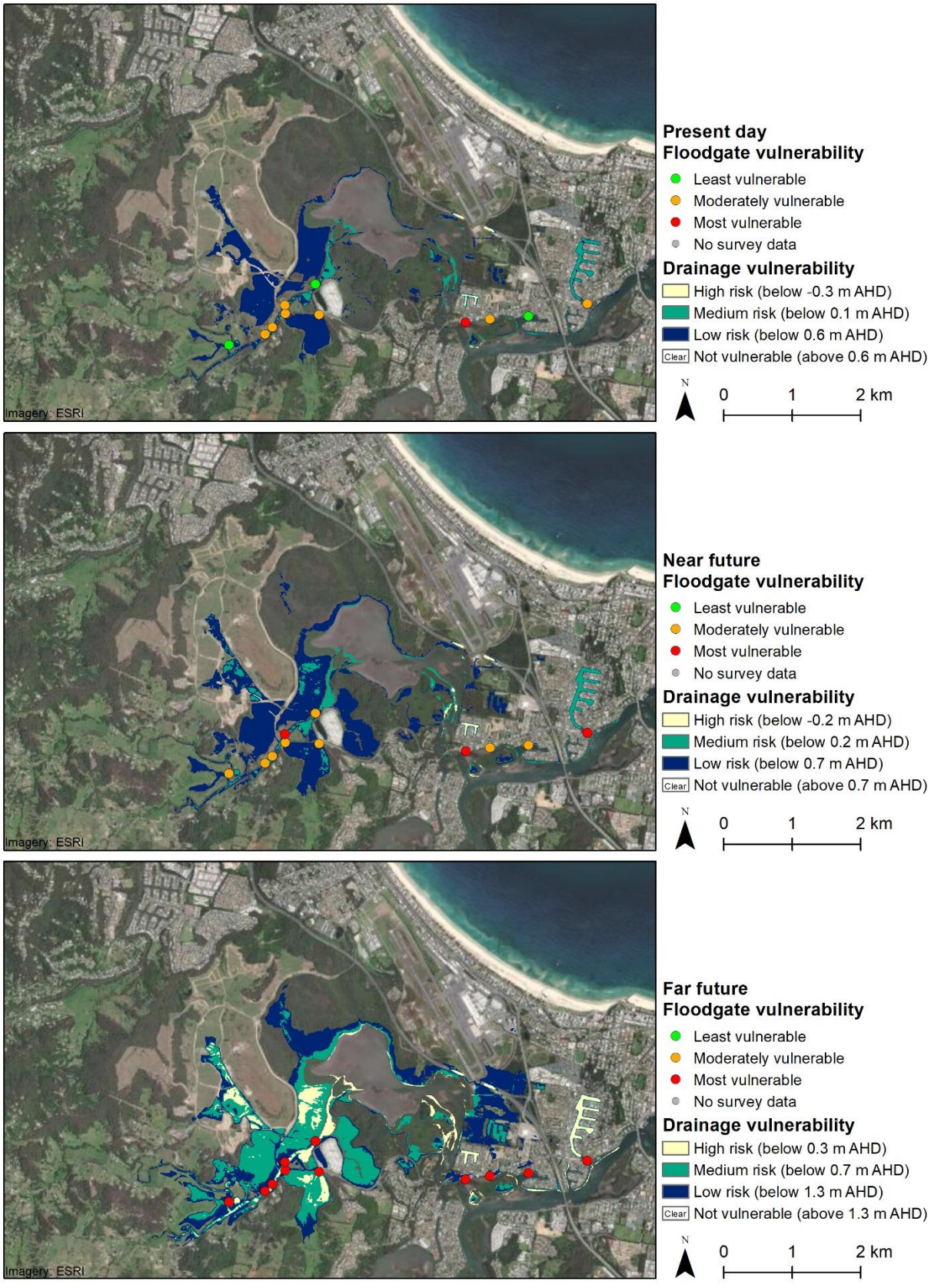


Figure 8-78: Sea level rise drainage vulnerability for the Cobaki subcatchment

8.12.4 Management options

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

- Short-term: Active protection of existing Coastal Management SEPP coastal wetlands and wet pasture management.
- Long-term: Active protection of existing Coastal Management SEPP coastal wetlands and transition of low-lying areas to estuarine 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 Cobaki subcatchment contains a large area of Coastal management SEPP coastal wetlands. These wetlands should be actively protected and enhanced where possible (such as within the Cobaki Lakes development, noting that earthworks within the development area may have resulted in changes to land surface elevations since the collection of LiDAR topography data).

Low-lying grazing land on the left bank of Cobaki Creek could be managed as wet pasture. Where required, installation of weir or drop boards structures could assist with maintaining an elevated water table.

Long-term management options
The Cobaki Subcatchment is marked for urban growth and includes developments such as Cobaki Lakes. Protection of existing sensitive receivers including Coastal Management SEPP coastal wetlands should be considered at all stages of the development process.

Future sea level rise will result in reduced drainage for low-lying grazing areas on the left bank of Cobaki Creek, particularly at its confluence with Piggabeen Creek. Investigations could be completed to determine if these areas could transition to estuarine wetland. As sea level rise threatens downstream habitats such as mangroves and saltmarsh this location could be an ideal area for habitat retreat.

A summary of the recommended management options for the Cobaki subcatchment including indicative costs is provided in Table 8-16.

Table 8-16: Summary of management options for the Cobaki subcatchment

Timeframe	Strategy	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing per year)	Indicative cost (lost productivity per year)	Effectiveness at improving:		
						Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Wet pasture management	None	$20,000	None	Minimal	None	Moderate	Moderate
Long-term	Restoration of wetlands	$3,600,000	$40,000	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.

8.13 Bilambil/Terranora subcatchment

Acid priority rank:	**11**
Blackwater priority rank:	**11**
Infrastructure	
Approximate waterway length (km)	15
# Privately owned end of system structures	12
# Publicly owned end of system structures	45
# End of system structures within coastal wetlands	4
# Publicly owned end of system structures within coastal wetlands	3
Primary floodplain infrastructure (floodgate ID)	N/A
Elevations	
Invert of primary floodplain infrastructure (m AHD)	N/A
Average AASS elevation (m AHD)	N/A
Average PASS elevation (m AHD)	-0.7
Median blackwater elevation (m AHD)	0.4
Present day low water level (m AHD)	-0.3
Near future low water level (m AHD)	-0.1
Far future low water level (m AHD)	0.3
Proximity to sensitive receivers	
Oyster leases (km)	0.7
Saltmarsh (km)	Within subcatchment
Seagrass (km)	0.8
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	1,445
Classified as conservation and minimal use (ha (%))	41 (3%)
Classified as grazing (ha (%))	199 (14%)
Classified as forestry (ha (%))	0 (0%)
Classified as sugar cane (ha (%))	0 (0%)
Classified as horticulture (ha (%))	1 (0.1%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	995 (69%)
Classified as marsh/wetland (ha (%))	81 (6%)
Other (ha (%))	128 (9%)
Land values	
Estimated total primary production value ($/year)	$100,000
Average land value above 0.4 m AHD ($/ha)	$68,600
Average land value below 0.4 m AHD ($/ha)	No property data available

8.13.1 Site description and brief history of drainage

The Bilambil/Terranora subcatchment is located upstream on the Terranora Creek tributary of the Tweed River. The subcatchment bounds Charles Bay and Trutes Bay of the Terranora Broadwater. Bilambil Creek and Duroby Creek are the two major flow paths through the subcatchment. Some small farm scale drains exist which flow into these creeks. A number of low-lying areas surrounding the Tweed Heads South urban area are also included within this subcatchment.

There is varied land use across the Bilambil/Terranora subcatchment, however, urban/industrial/services, which includes the Tweed Heads South suburb, makes up the largest proportion of area (69%). Grazing is mainly limited to the low-lying land on the banks of Bilambil Creek and Duroby Creek. Coastal Management SEPP coastal wetlands exist in the downstream sections of the floodplain. Tenure information for the Bilambil/Terranora subcatchment is shown in Figure 8-79. Information on drainage and floodplain elevation is shown in Figure 8-80.

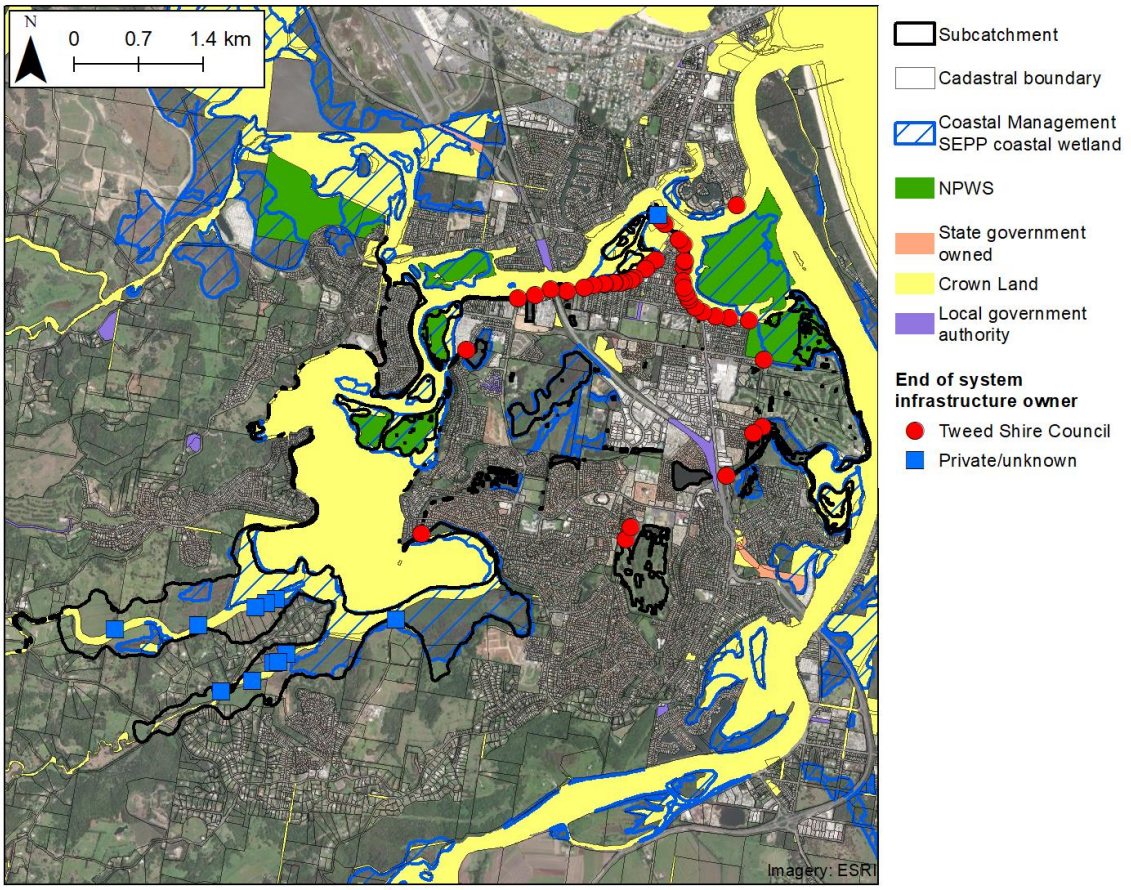


Figure 8-79: Bilambil/Terranora subcatchment - land and end of system infrastructure tenure

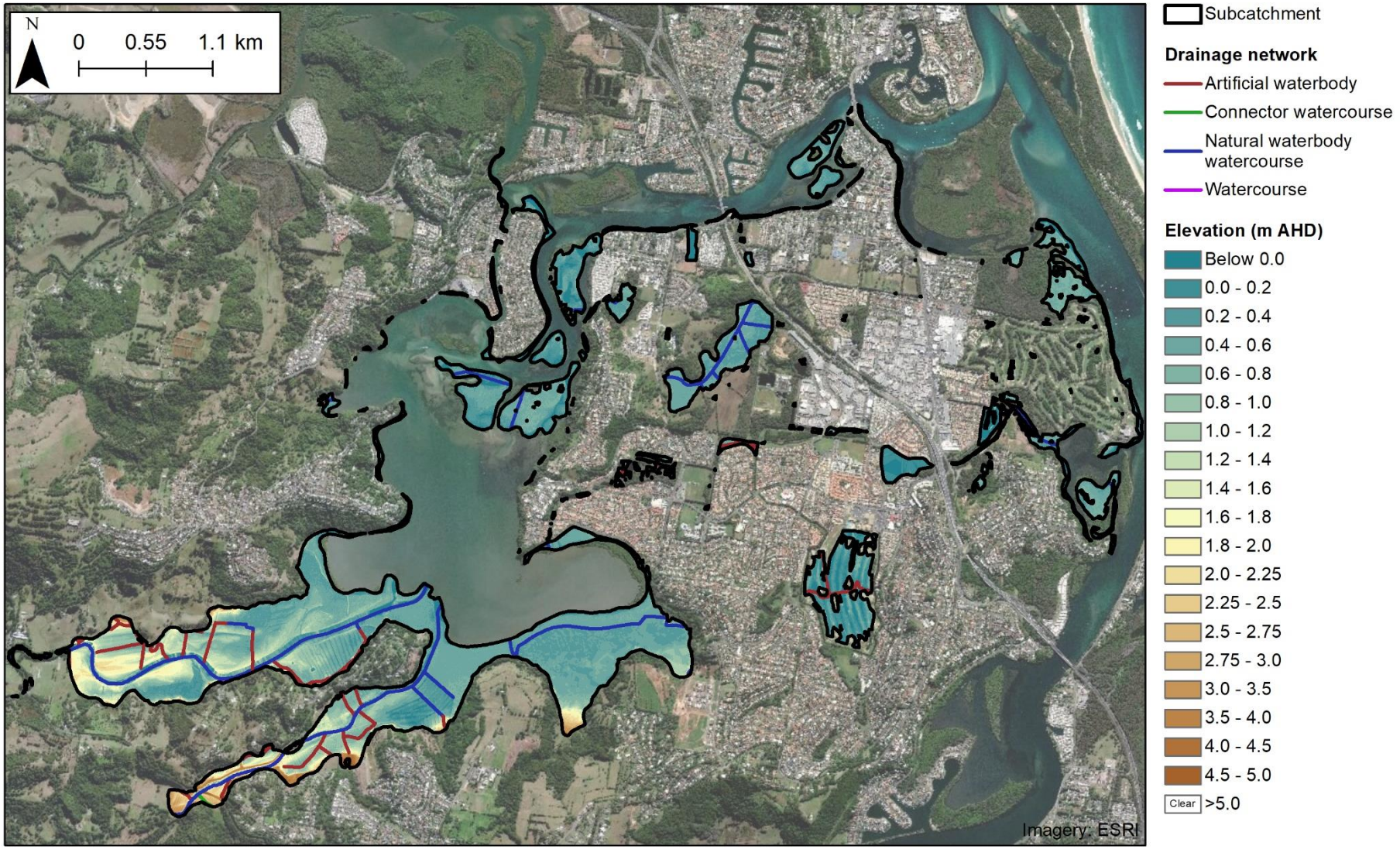


Figure 8-80: Bilambil/Terranora subcatchment elevation and drainage network

8.13.2 History of remediation

In the Bilambil/Terranora subcatchment, one floodgate has been modified to have a buoyancy controlled auto-tidal gate. The location of this structure is identified in Figure 8-81.



Figure 8-81: The Bilambil/Terranora subcatchment including previous remediation actions

8.13.3 Floodplain drainage - sea level rise vulnerability

The sea level rise vulnerability assessment of the Bilambil/Terranora subcatchment is summarised in Figure 8-82. Presently, reduced drainage is confined to floodplain areas that have been identified as Coastal Management SEPP coastal wetlands. Under future sea level rise scenarios reduced drainage will extend to low-lying floodplain areas used for other land uses such as grazing.

The majority of floodgates within the Bilambil/Terranora subcatchment are located around the Tweed Heads South urban area providing drainage for urban runoff. Currently some of these floodgates are identified as most vulnerable. In future sea level rise scenarios, the vulnerability of these structures will increase significantly, potentially affecting the Tweed Heads South area, particularly in the far future where the obvert of a majority of structures will be below the approximate mean tide water level (i.e. classifying them as most vulnerable). Note, this analysis of sea level rise vulnerability does not consider increased risk related to flood events, which may also impact the Bilambil/Terranora subcatchment.

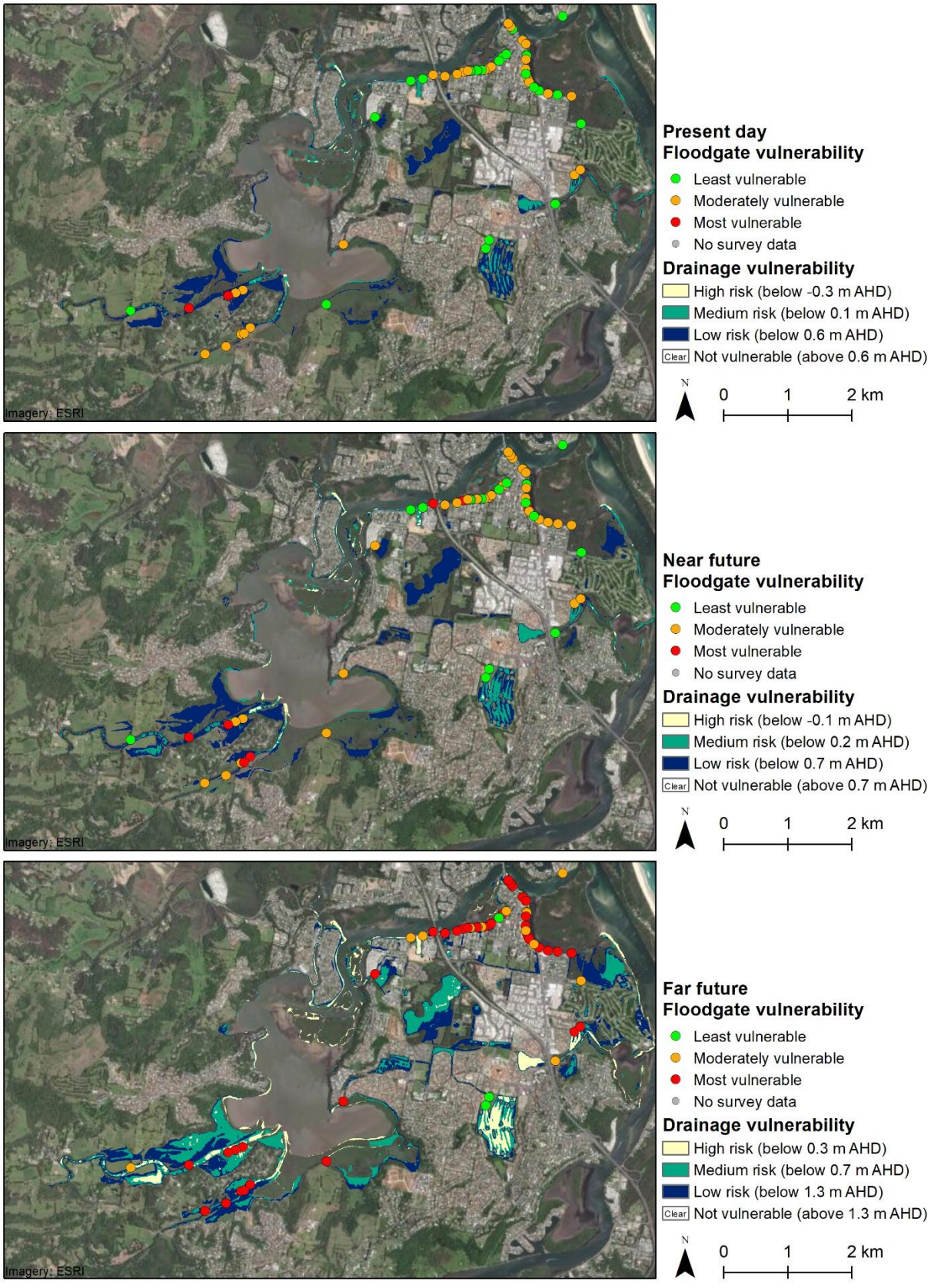


Figure 8-82: Sea level rise drainage vulnerability for the Bilambil/Terranora subcatchment

8.13.4 Management options

Potential management options for short-term and long-term planning horizons for the Bilambil/Terranora subcatchment include:

- Short-term: Wet pasture management.
- Long-term: Conversion of low-lying areas to estuarine wetlands and protect existing 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
Where possible encourage wet pasture management of low-lying grazing land. Installing weir or drop board structures in drainage channels could assist in raising the water table.

Long-term management options
Some areas within the Bilambil/Terranora subcatchment are marked for urban growth. Coastal Management SEPP coastal wetlands should be protected during this process.

Within Bilambil Creek and Duroby Creek, sea level rise will impact existing drainage. Low-lying areas should be opportunistically converted to estuarine wetlands when current land uses are no longer viable.

A summary of the recommended management options for the Bilambil/Terranora subcatchment including indicative costs is provided in Table 8-17.

Table 8-17: Summary of management options for the Bilambil/Terranora subcatchment

Timeframe	Strategy	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing per year)	Indicative cost (lost productivity per year)	Effectiveness at improving:		
						Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Wet pasture management	None	$20,000	None	Minimal	None	Moderate	Moderate
Long-term	Restoration of wetlands	$6,000,000	$50,000	Minimal	$30,000	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 East Chinderah subcatchment

Acid priority rank:	**12**
Blackwater priority rank:	**12**
Infrastructure	
Approximate waterway length (km)	7
# Privately owned end of system structures	3
# Publicly owned end of system structures	33
# End of system structures within coastal wetlands	3
# Publicly owned end of system structures within coastal wetlands	2
Primary floodplain infrastructure (floodgate ID)	110, WRL_TW_02 (Weir)
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-0.6 to -0.2
Average AASS elevation (m AHD)	N/A
Average PASS elevation (m AHD)	N/A
Median blackwater elevation (m AHD)	0.4
Present day low water level (m AHD)	-0.4
Near future low water level (m AHD)	-0.2
Far future low water level (m AHD)	0.3
Proximity to sensitive receivers	
Oyster leases (km)	10.8
Saltmarsh (km)	0.2
Seagrass (km)	Within subcatchment
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	634
Classified as conservation and minimal use (ha (%))	24 (4%)
Classified as grazing (ha (%))	271 (43%)
Classified as forestry (ha (%))	0 (0%)
Classified as sugar cane (ha (%))	0 (0%)
Classified as horticulture (ha (%))	5 (1%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	301 (48%)
Classified as marsh/wetland (ha (%))	8 (1%)
Other (ha (%))	26 (4%)
Land values	
Estimated total primary production value ($/year)	$100,000
Average land value above 0.4 m AHD ($/ha)	$108,000
Average land value below 0.4 m AHD ($/ha)	No property data available

8.14.1 Site description and brief history of drainage

The East Chinderah subcatchment is located on the right bank of the Tweed River within the lower estuary. There are two main drainage pathways which provide drainage of rural grazing land through an urban area on the riverbank into what is known as Chinderah Bay via Structures 104 and 110.

The major land uses for the East Chinderah subcatchment are urban/industrial/services (48%) and grazing (43%). The waterway that drains through Structure 110 has large areas of Coastal Management SEPP coastal wetlands along its banks. There is also a large area designated as Coastal Management SEPP coastal wetlands to the north of the subcatchment surrounding a waterbody known as Wommin Lake. Tenure information for the East Chinderah subcatchment is shown in Figure 8-83. Information on drainage and floodplain elevation is shown in Figure 8-84.

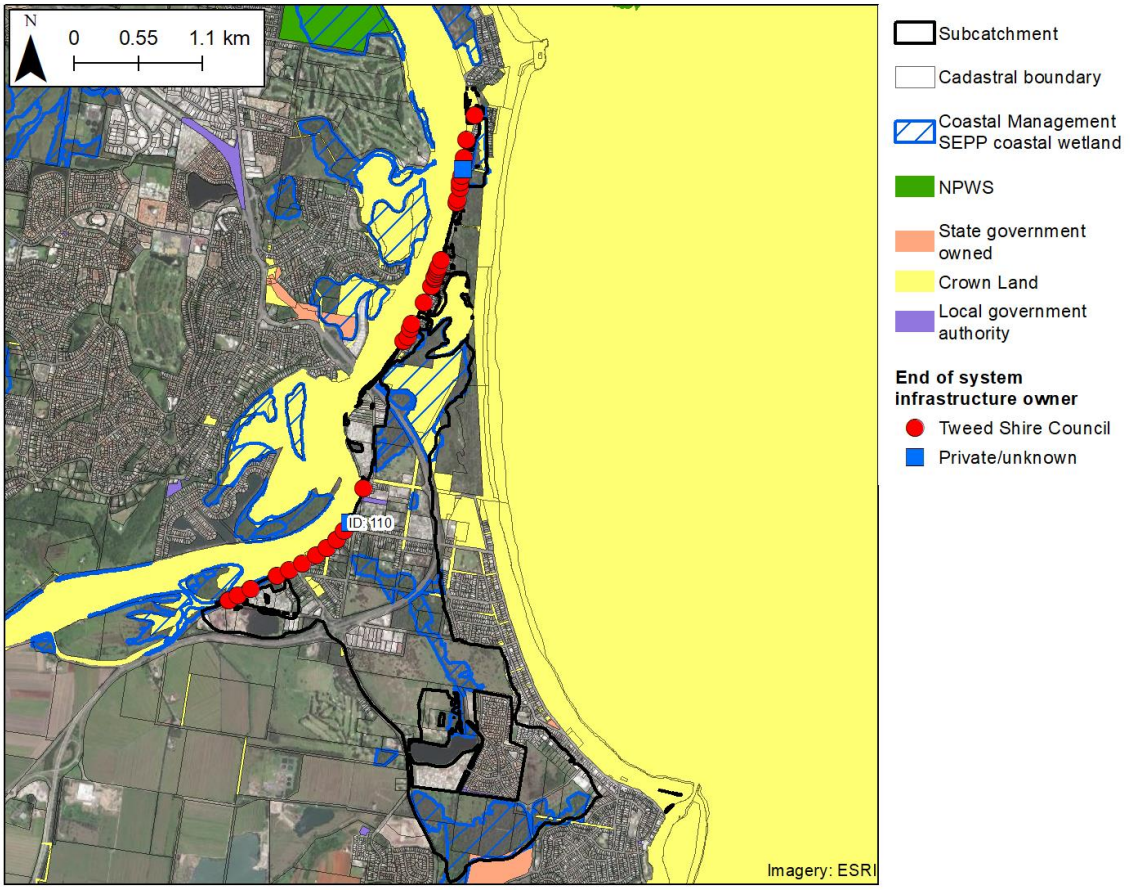


Figure 8-83: East Chinderah subcatchment - land and end of system infrastructure tenure

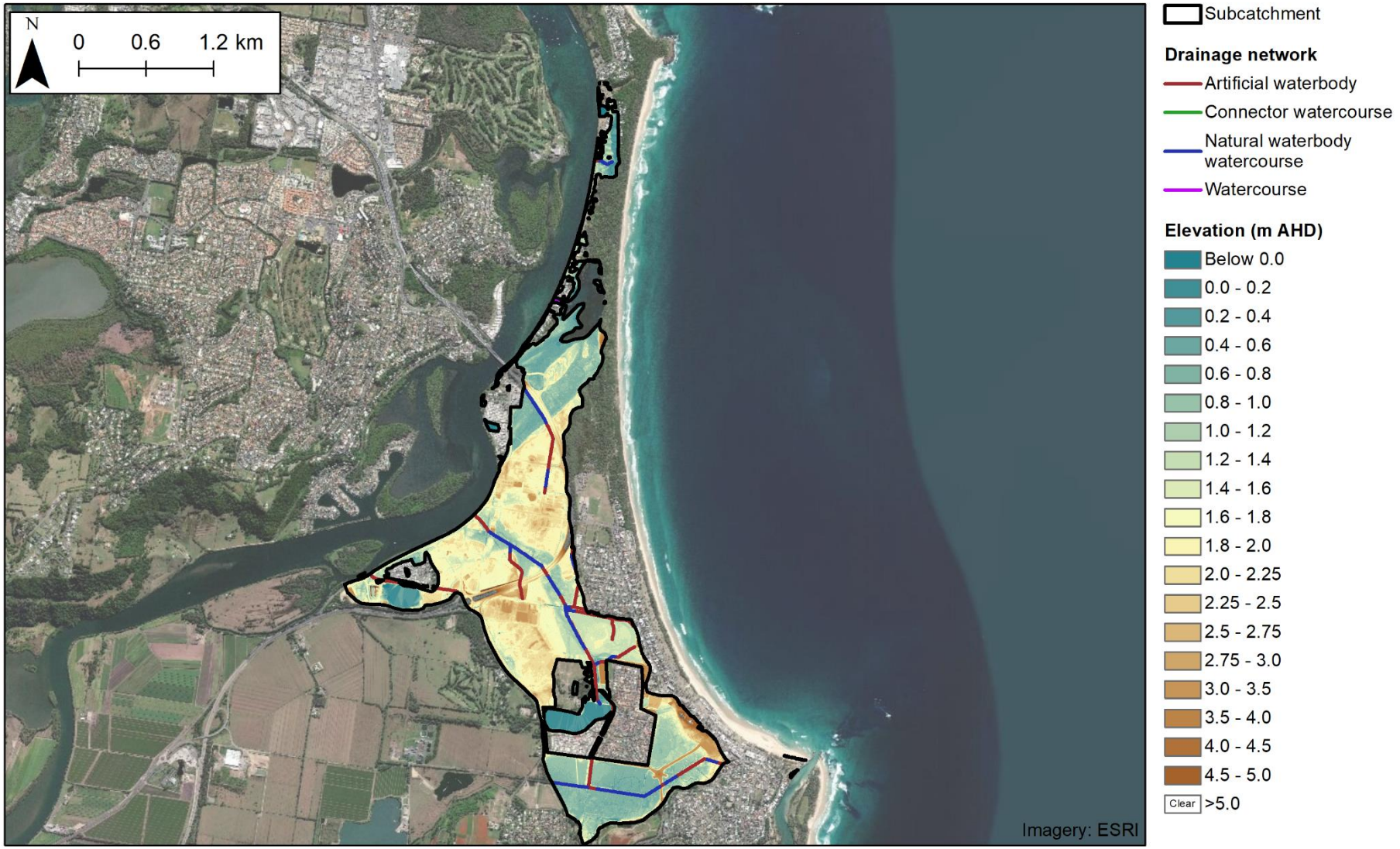


Figure 8-84: East Chinderah subcatchment elevation and drainage network

8.14.2 History of remediation

During field investigations completed in the East Chinderah subcatchment a number of remediation actions were observed (Figure 8-85). A winch has been installed on Structure 104 which is currently being actively managed to allow tidal flows upstream of the floodgate. Also, in 2016 during upgrades to the Fingal Road bridge, a rock weir was installed to protect important Coastal Management SEPP coastal wetlands located upstream within Wommin Lake. Figure 8-86 shows the location of these structures.



Figure 8-85: Floodgate on Structure 104 winched open (left) and rock weir installed near Fingal Road bridge to protect upstream tidal aquatic habitat (right) (Structure WRL_TW_02)

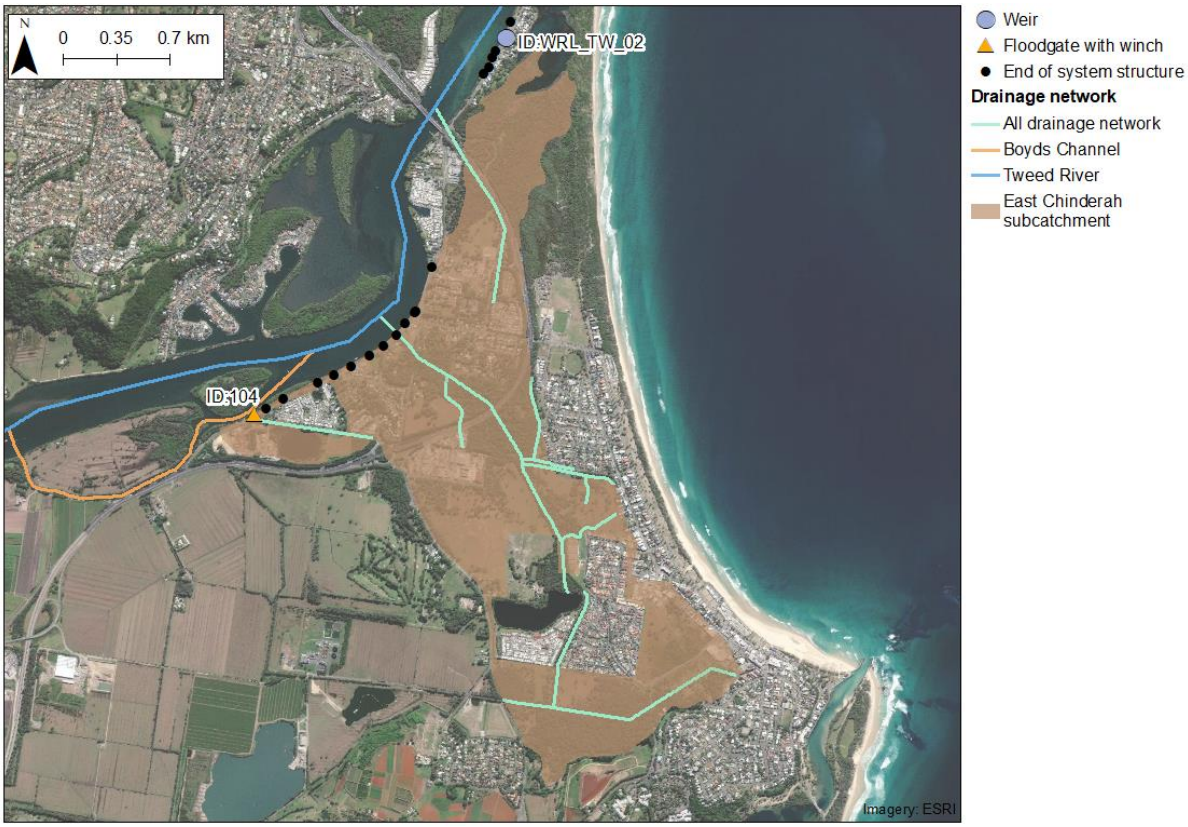


Figure 8-86: The East Chinderah subcatchment including previous remediation actions

8.14.3 Floodplain drainage - sea level rise vulnerability

The sea level rise vulnerability assessment of the East Chinderah subcatchment is summarised in Figure 8-87. The impact of sea level rise on floodplain drainage in the East Chinderah subcatchment is minimal and mainly limited to areas zoned as Coastal Management SEPP coastal wetlands.

With the exception of Structures 104 and 110, floodgates within the East Chinderah subcatchment service the drainage needs of the Chinderah urban area. A large number of these floodgates are most vulnerable and in the far future, their vulnerability will increase due to an obvert level situated below the approximate far future mean tide water level (i.e. they will become most vulnerable to sea level rise). This was also the case for Structure 110, the primary floodgate in this subcatchment, shown in Figure 8-88 which provides drainage to the agricultural area within the East Chinderah subcatchment. Structure 104 is identified to be most vulnerable in the far future scenario modelling.

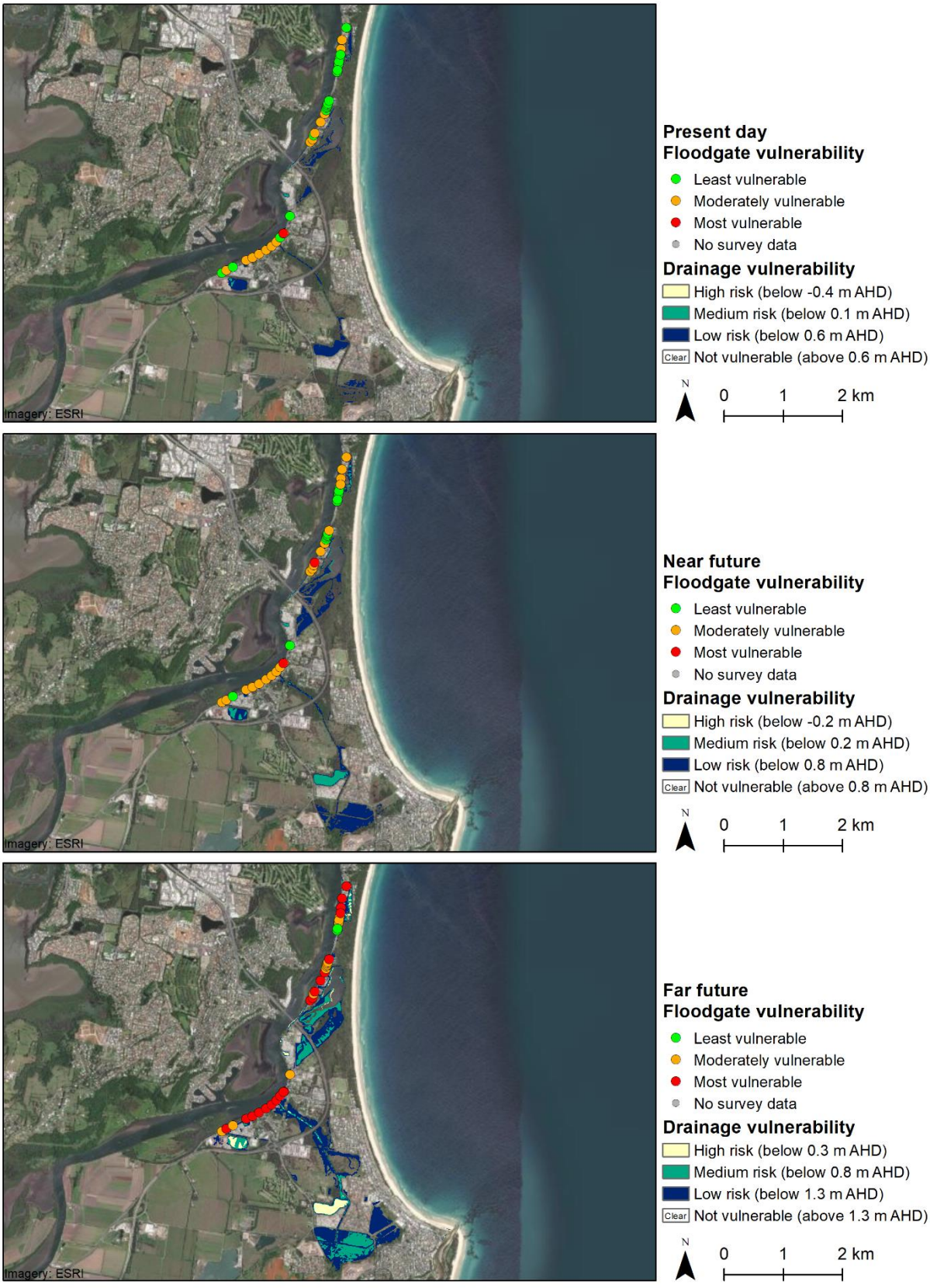


Figure 8-87: Sea level rise drainage vulnerability for the East Chinderah subcatchment

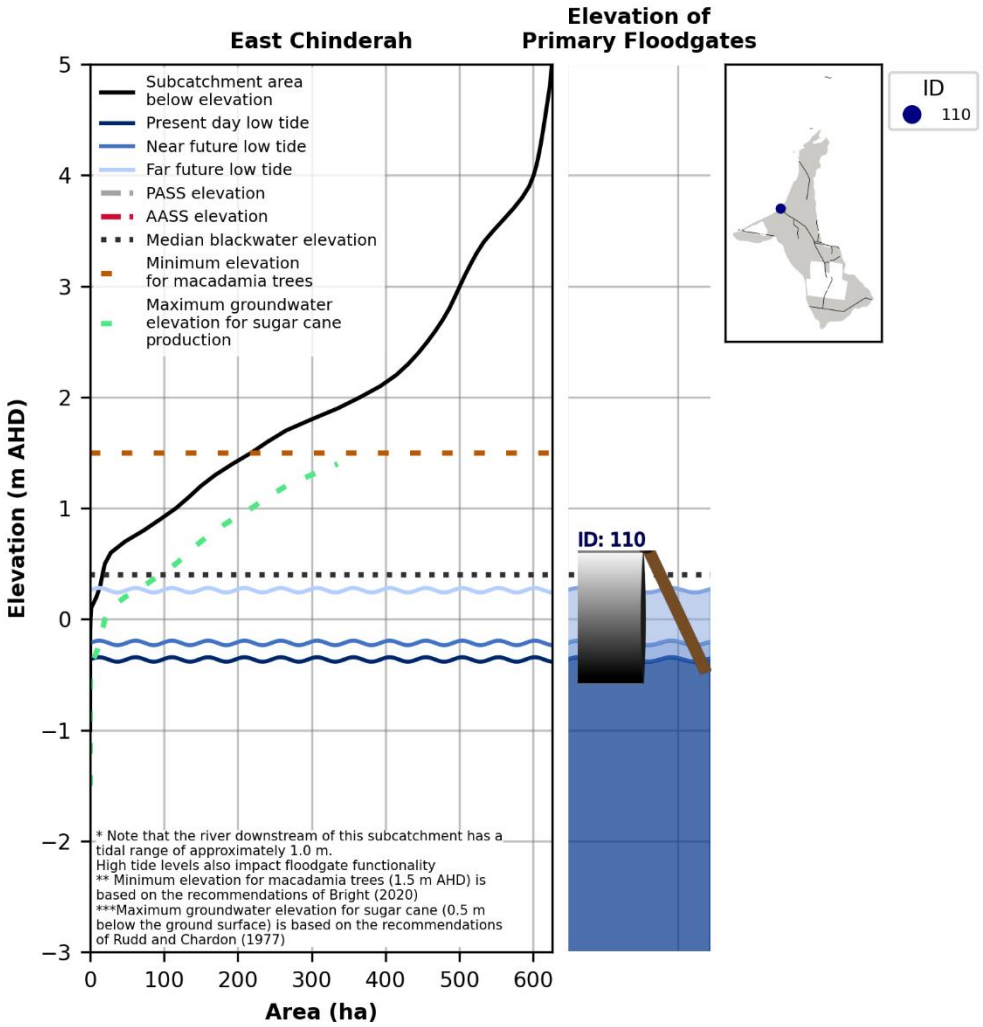


Figure 8-88: Key floodplain elevations - East Chinderah subcatchment

8.14.4 Management options

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

- Short-term: Optimise tidal flushing and actively protect existing Coastal Management SEPP coastal wetlands.
- Long-term: Actively protect existing Coastal Management SEPP coastal wetlands during urban growth.

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

During field investigations Structure 110 was observed to be leaking allowing tidal flow upstream. Management of this floodgate could be formalised to allow controlled tidal flushing upstream.

There are extensive Coastal Management SEPP coastal wetlands across the East Chinderah subcatchment. These should be actively protected and any changes to the subcatchment should be completed in a way that they do not impact the Coastal Management SEPP coastal wetlands.

Long-term management options

The East Chinderah subcatchment is marked as an area for urban growth in the long term. During this process Coastal Management SEPP coastal wetlands should be protected.

A summary of the recommended management options for the East Chinderah subcatchment including indicative costs is provided in Table 8-18.

Table 8-18: Summary of management options for the East Chinderah subcatchment

Timeframe	Strategy	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing per year)	Indicative cost (lost productivity per year)	Effectiveness at improving:		
						Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Optimise tidal flushing	None	$30,000	$2,000	None	High	Moderate	Negligible

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

8.15 Commercial Road subcatchment

Acid priority rank:	**13**
Blackwater priority rank:	**14**
Infrastructure	
Approximate waterway length (km)	11
# Privately owned end of system structures	0
# Publicly owned end of system structures	22
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (floodgate ID)	2, WRL_TW_16 (Weir)
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-0.1
Average AASS elevation (m AHD)	N/A
Average PASS elevation (m AHD)	0.1
Median blackwater elevation (m AHD)	0.7
Present day low water level (m AHD)	-0.3
Near future low water level (m AHD)	-0.2
Far future low water level (m AHD)	0.2
Proximity to sensitive receivers	
Oyster leases (km)	33.5
Saltmarsh (km)	16.6
Seagrass (km)	20.3
Mangroves (km)	1.5
Coastal Management SEPP coastal wetlands (km)	1.2
Land use	
Total floodplain area (ha)	315
Classified as conservation and minimal use (ha (%))	0 (0%)
Classified as grazing (ha (%))	95 (30%)
Classified as forestry (ha (%))	0 (0%)
Classified as sugar cane (ha (%))	121 (38%)
Classified as horticulture (ha (%))	0 (0%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	91 (29%)
Classified as marsh/wetland (ha (%))	0 (0%)
Other (ha (%))	7 (2%)
Land values	
Estimated total primary production value ($/year)	$200,000
Average land value above 0.7 m AHD ($/ha)	$12,500
Average land value below 0.7 m AHD ($/ha)	No property data available

8.15.1 Site description and brief history of drainage

The Commercial Road subcatchment is located on the left bank of the Tweed River at the upper limit of the estuary. The subcatchment is to the south of the township of Murwillumbah and surrounded by a system of natural and artificial levees designed to protect the town. There is one major drain that runs from west to east along the northern border of the subcatchment and has a large headworks that drains the subcatchment to the Tweed River through what is known as the Commercial Road levee. The major land uses within the subcatchment are a mixture of sugar cane (38%), grazing (30%) and urban/industrial/services (29%). Bray Park Water Treatment Plant is located on the western boundary of the subcatchment. Tenure information for the Commercial Road subcatchment is shown in Figure 8-89. Information on drainage and floodplain elevation is shown in Figure 8-90.

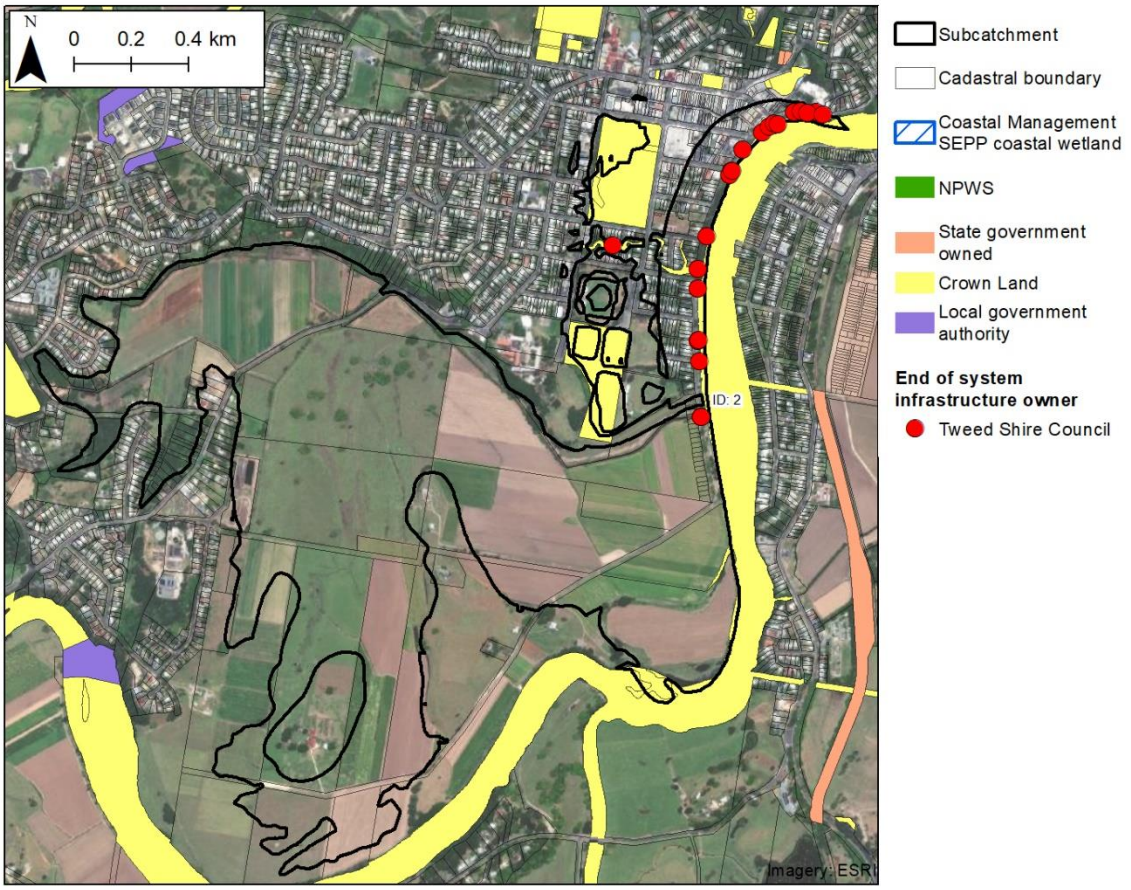


Figure 8-89: Commercial Road subcatchment - land and end of system infrastructure tenure

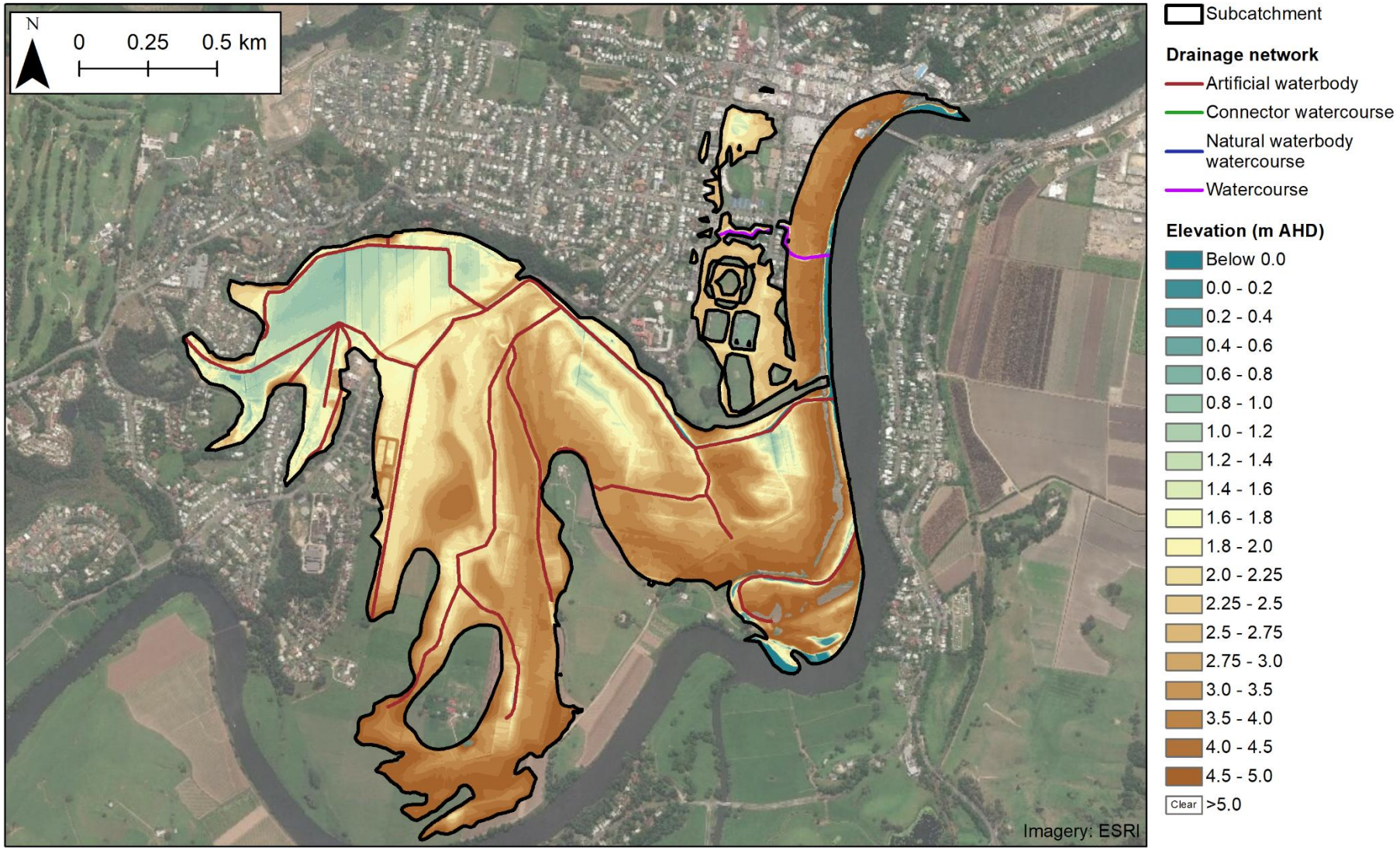


Figure 8-90: Commercial Road subcatchment elevation and drainage network

8.15.2 History of remediation

There is one major drainage channel that services the rural areas of the Commercial Road subcatchment. A buoyancy controlled auto-tidal floodgate has been installed on Structure 2 to promote fish passage and improve water quality (Figure 8-91). The location of this structure is shown in Figure 8-92.



Figure 8-91: Buoyancy controlled auto-tidal gate on Structure 2

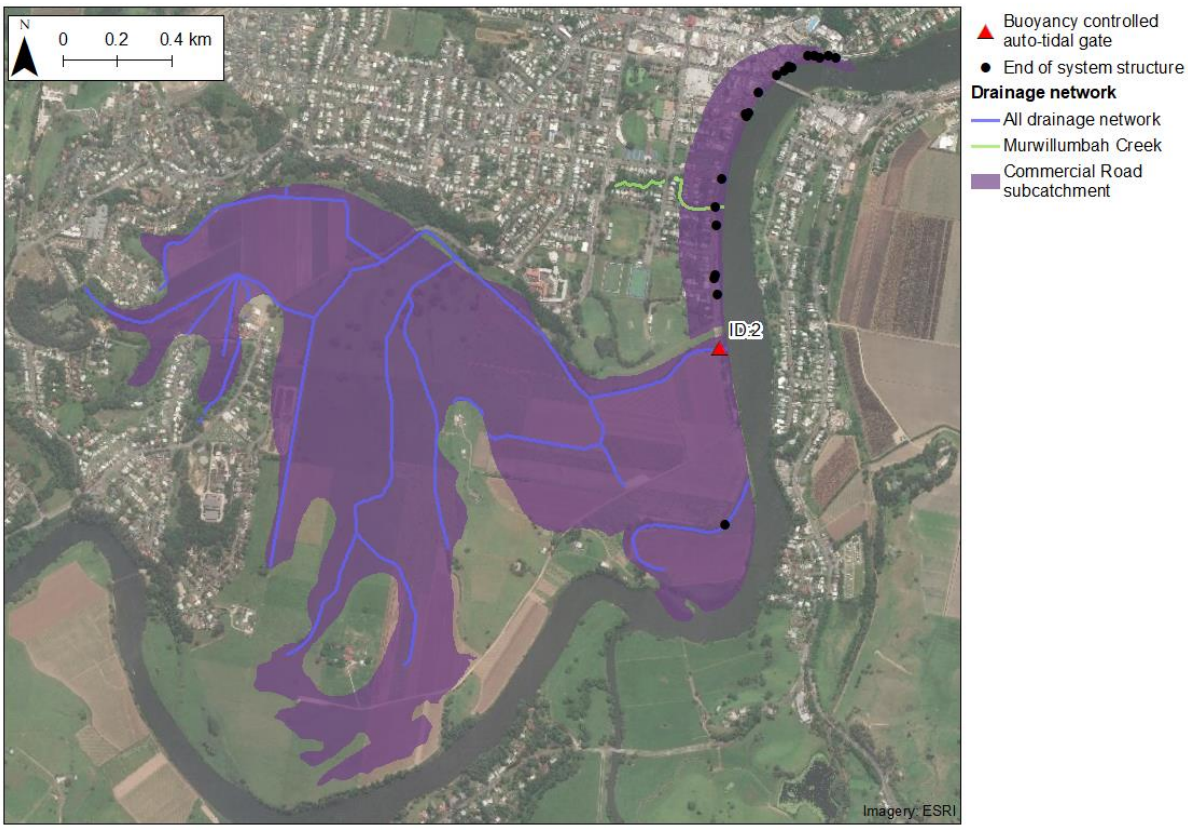


Figure 8-92: The Commercial Road subcatchment including previous remediation actions

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

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

8.15.3 Floodplain drainage - sea level rise vulnerability

The sea level rise vulnerability assessment of the Commercial Road subcatchment is summarised in Figure 8-93 and Figure 8-94. Modelling has shown that in the far future scenario only sections of the floodplain to the west of Kyogle Road will be impacted by reduced drainage. In addition to this, four (4) smaller floodgate structures which provide urban drainage to Murwillumbah will be become moderately vulnerable (Structures 1, 4, 8 and 502) and Structure 5A will be most vulnerable (see Appendix F).

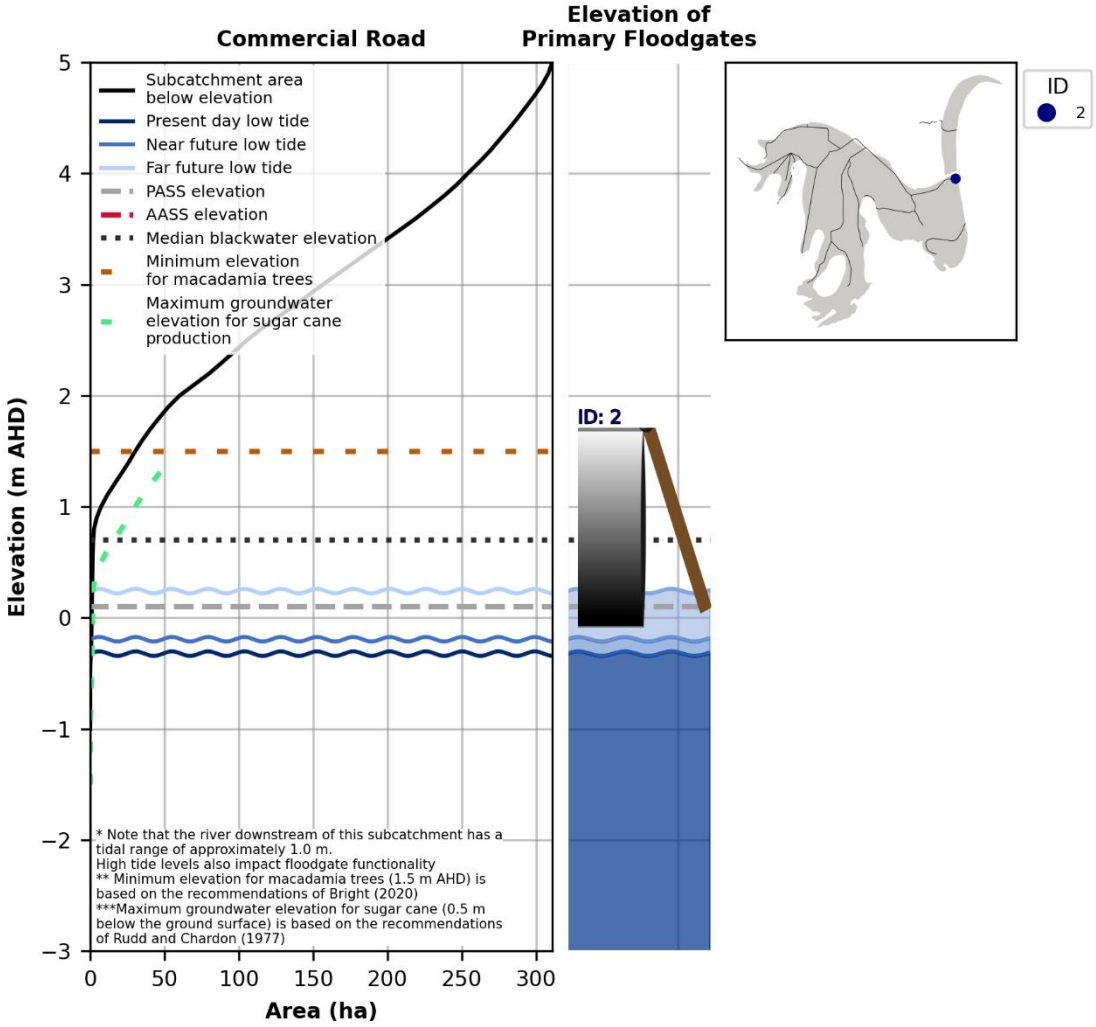


Figure 8-93: Key floodplain elevations – Commercial Road subcatchment

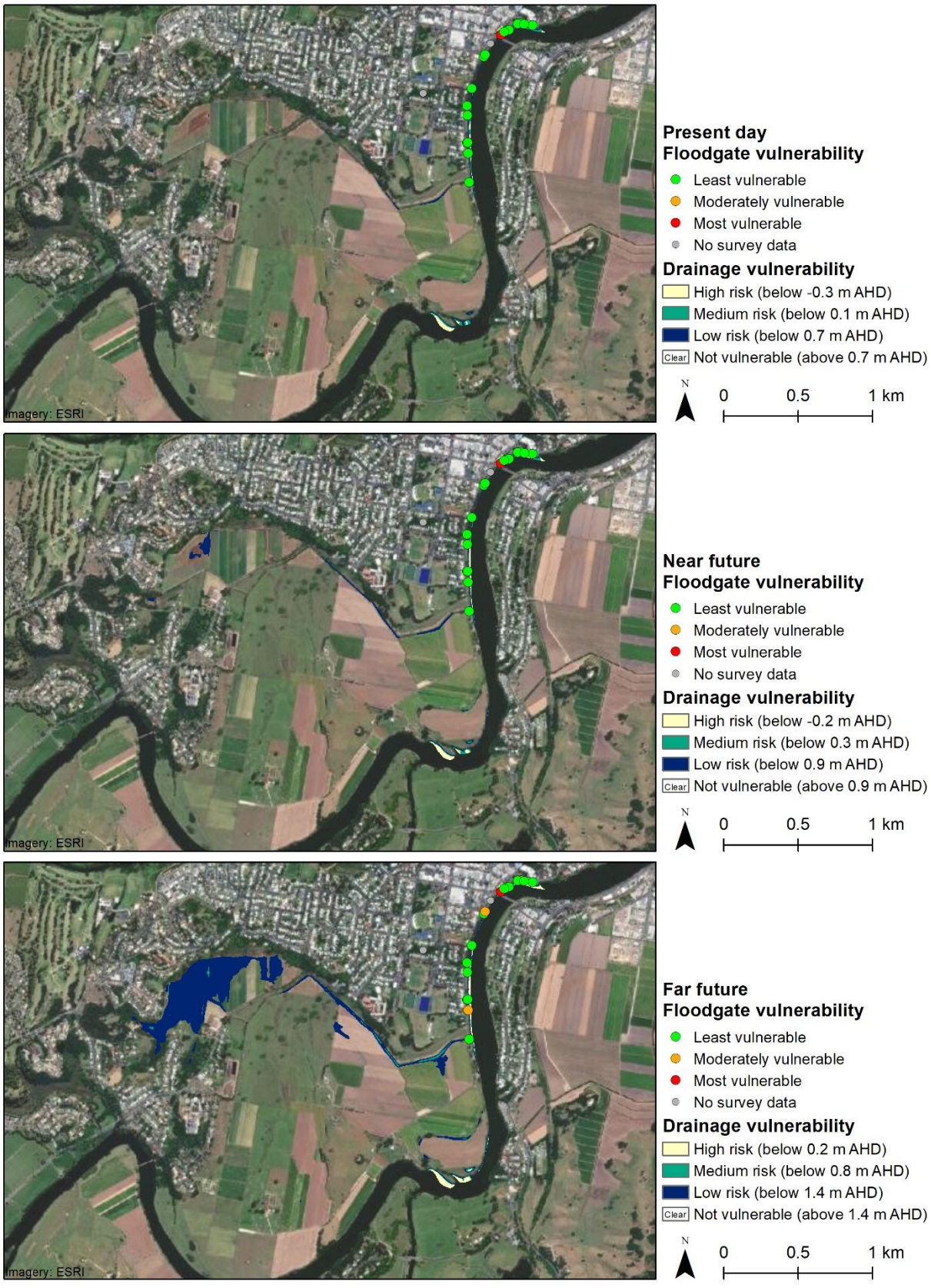


Figure 8-94: Sea level rise drainage vulnerability for the Commercial Road subcatchment

8.15.4 Management options

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

- Short-term: Optimise tidal flushing through structures.
- Long-term: Opportunistically manage low-lying areas for community/ecological values.

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 existing management of tidal flushing within the drainage network could be reviewed to determine if it is possible to provide additional flushing to the upstream drainage network. High elevation land could allow for the floodgates to be winched open or additional buoyancy controlled auto-tidal gates to be installed. Low lying area to the west of Kyogle Road could be protected by installing secondary upstream floodgates.

Water quality samples collected in the Commercial Road subcatchment indicated a drop in pH to 4.8 following a large runoff event in 2017 (Pratt et al., 2017). This has resulted in the Commercial Road subcatchment being identified as an acid sulfate soil priority remediation area in the Tweed River estuary Coastal Management Plan (Seccull et al., 2019). Soil profiles sampled during field investigations (see Appendix L) indicated that potential acid sulfate soils are present in the Commercial Road subcatchment, however, no oxidised actual acid sulfate soils were identified. Further, investigations should be completed to determine the source of acid within the Commercial Road subcatchment.

Long-term management options
In the far future, areas to the west of Kyogle Road will be impacted by reduced drainage. As sea level rise begins to impact existing land uses, this area could be opportunistically converted to a recreational area or restored to a wetland habitat. Modifications to the floodplain should include consultation with the local community and consider other issues such as flooding and mosquito management.

A summary of the recommended management options for the Commercial Road subcatchment including indicative costs is provided in Table 8-19.

Table 8-19: Summary of management options for the Commercial Road subcatchment

Timeframe	Strategy	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing per year)	Indicative cost (lost productivity per year)	Effectiveness at improving:		
						Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Optimise tidal flushing	None	$100,000	$10,000	None	High	Moderate	Negligible
Long-term	Restoration of wetlands	$400,000	$100,000	Minimal	$45,000	High	High	High

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

8.16 Dunbible Creek subcatchment

Acid priority rank:	**14**
Blackwater priority rank:	**13**
Infrastructure	
Approximate waterway length (km)	12
# 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 (floodgate ID)	N/A
Elevations	
Invert of primary floodplain infrastructure (m AHD)	N/A
Average AASS elevation (m AHD)	N/A
Average PASS elevation (m AHD)	N/A
Median blackwater elevation (m AHD)	0.7
Present day low water level (m AHD)	-0.3
Near future low water level (m AHD)	-0.2
Far future low water level (m AHD)	0.2
Proximity to sensitive receivers	
Oyster leases (km)	35.7
Saltmarsh (km)	18.9
Seagrass (km)	22.5
Mangroves (km)	3.7
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	313
Classified as conservation and minimal use (ha (%))	0 (0%)
Classified as grazing (ha (%))	262 (84%)
Classified as forestry (ha (%))	0 (0%)
Classified as sugar cane (ha (%))	6 (2%)
Classified as horticulture (ha (%))	1 (0.2%)
Classified as other cropping (ha (%))	0 (0%)
Classified as urban/industrial/services (ha (%))	27 (9%)
Classified as marsh/wetland (ha (%))	0 (0%)
Other (ha (%))	17 (6%)
Land values	
Estimated total primary production value ($/year)	$100,000
Average land value above 0.7 m AHD ($/ha)	$13,500
Average land value below 0.7 m AHD ($/ha)	No property data available

8.16.1 Site description and brief history of drainage

The Dunbible Creek subcatchment is located on the right bank of the upper Tweed River estuary. Dunbible Creek is the main waterway that flows from south to north through the subcatchment. There are a number of artificial channels that have been constructed to provide drainage to what is predominantly grazing land. There are no known tidal barriers on any of these waterways. Coastal Management SEPP coastal wetlands have been mapped on the northwestern side of the subcatchment. Tenure information for the Dunbible Creek subcatchment is shown in Figure 8-95. Information on drainage and floodplain elevation is shown in Figure 8-96.

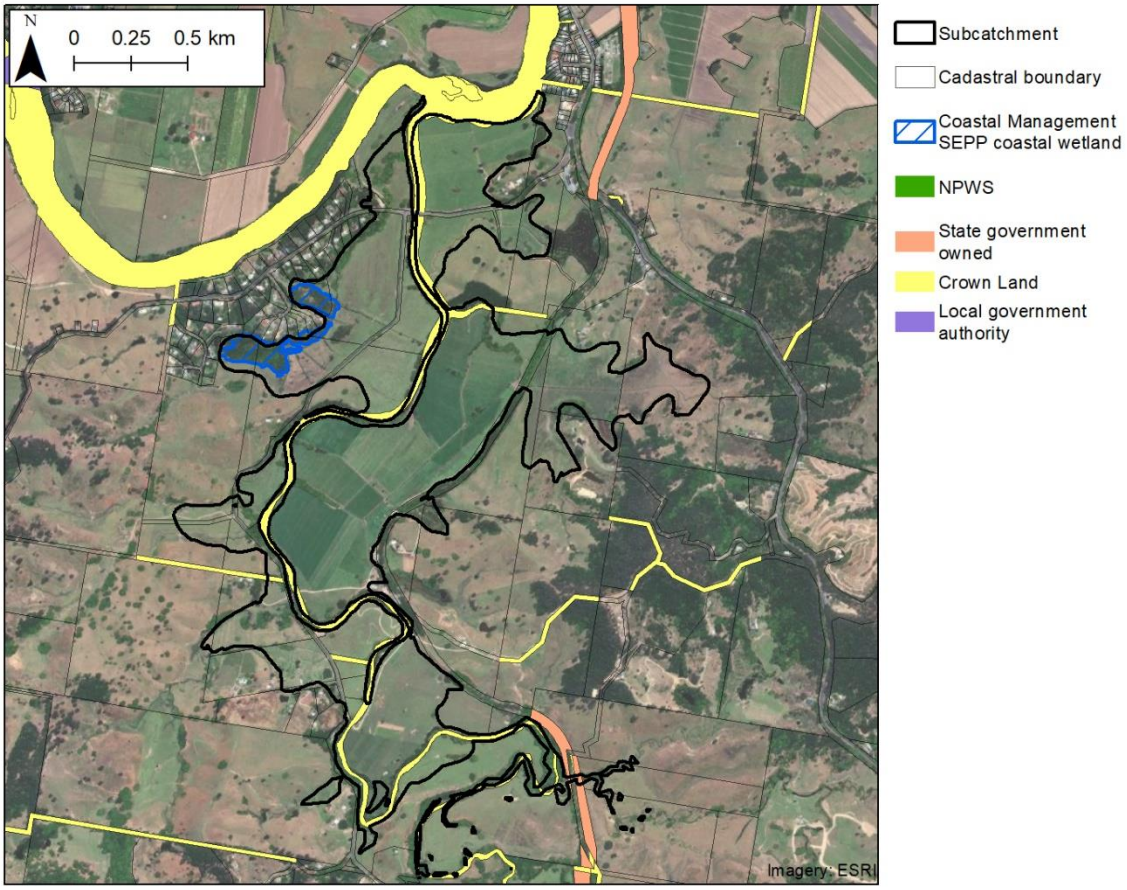


Figure 8-95: Dunbible Creek subcatchment - land and end of system infrastructure tenure

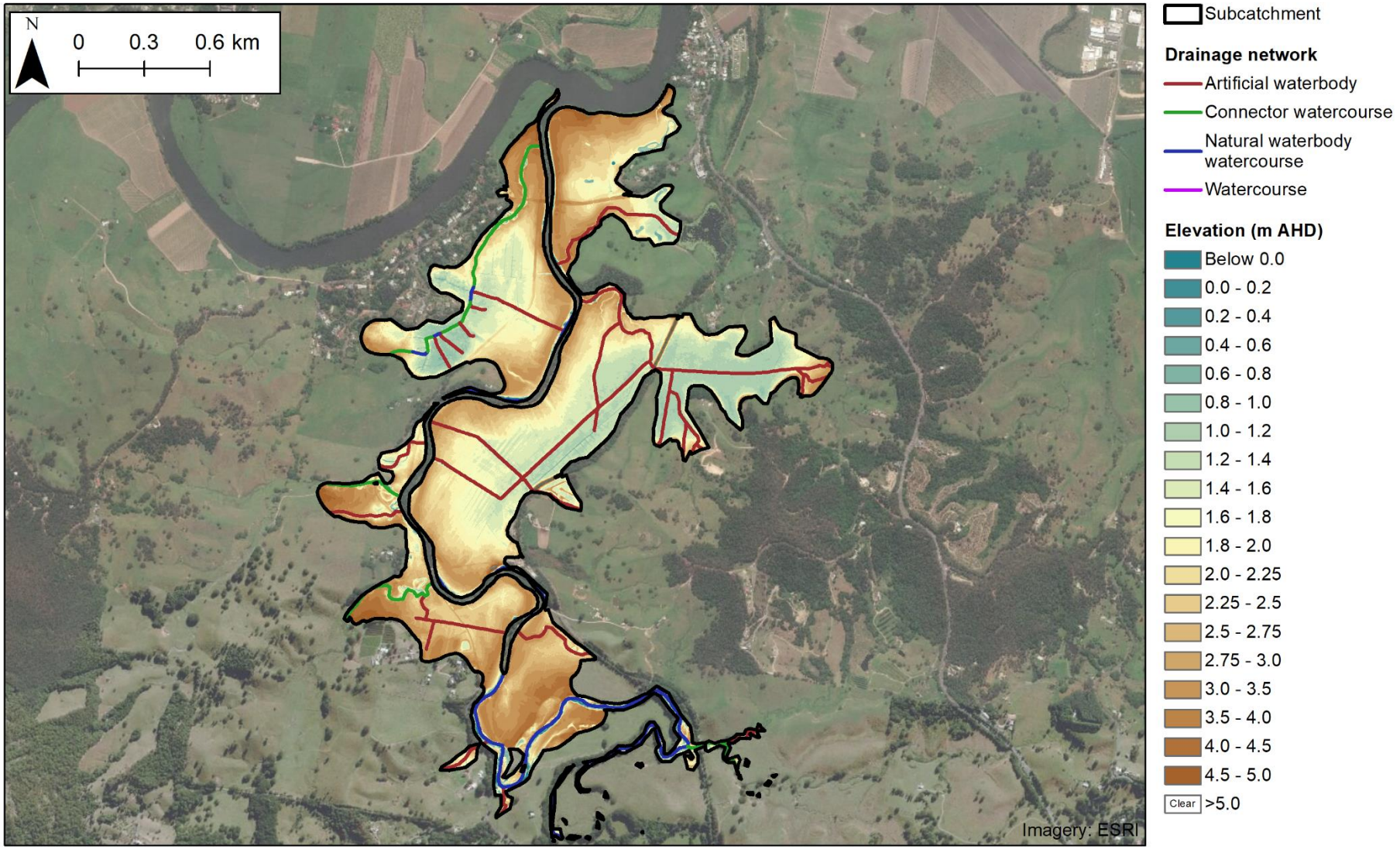


Figure 8-96: Dunbible Creek subcatchment elevation and drainage network

8.16.2 History of remediation

There are no known attempts of remediation within the Dunbible Creek subcatchment.

8.16.3 Floodplain drainage - sea level rise vulnerability

The sea level rise vulnerability assessment of the Dunbible Creek subcatchment is summarised in Figure 8-97. Low-lying areas across the floodplain will be impacted due to sea level rise in the far future modelling scenario. Areas that will be potentially impacted include those mapped as Coastal Management SEPP coastal wetlands and some grazing land to the east of the floodplain which have an elevation below the approximate far future high tide water level (+1.4 m AHD) (i.e. at low risk of reduced drainage). There are no known floodgates within the Dunbible Creek subcatchment.

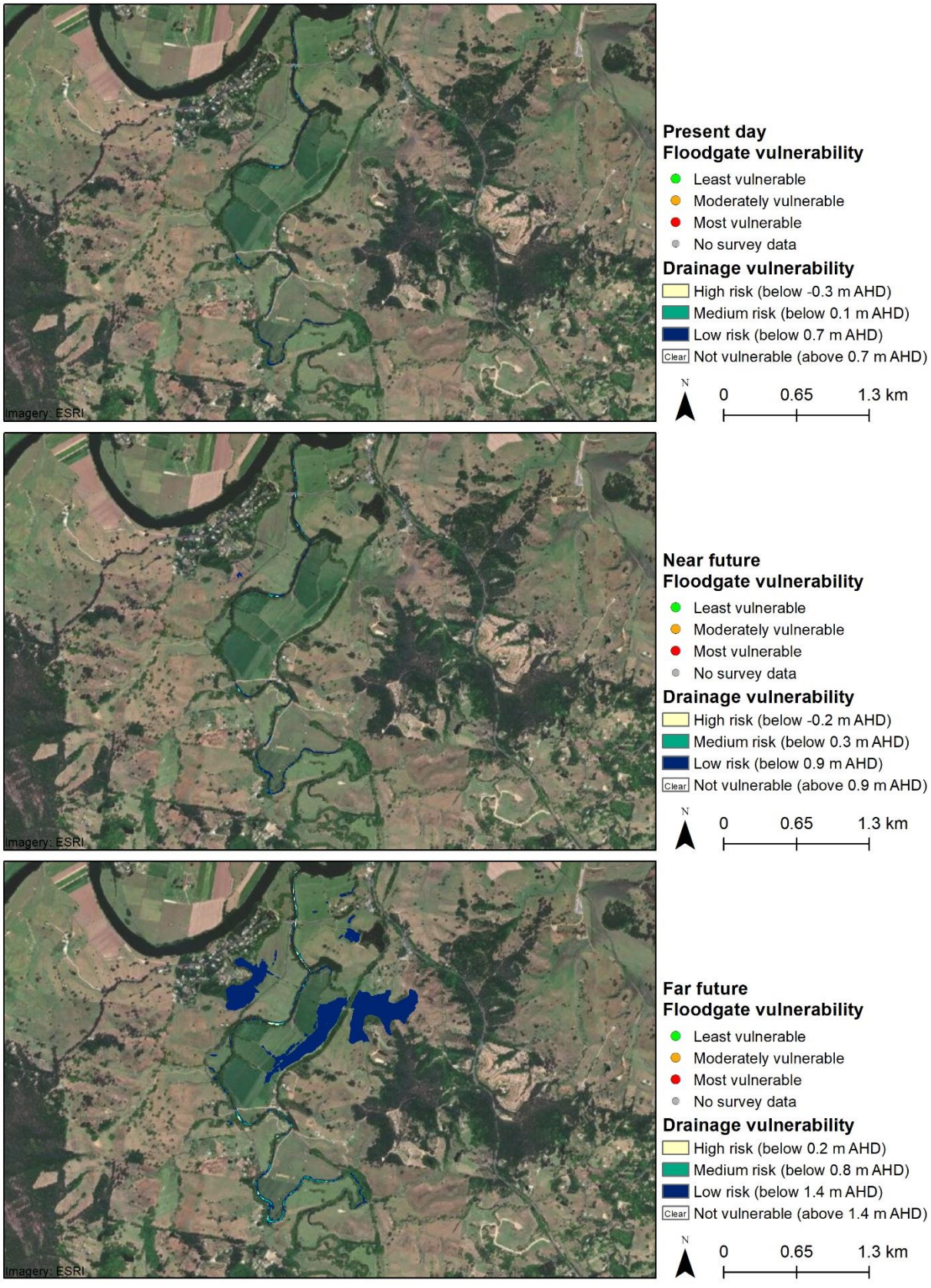


Figure 8-97: Sea level rise drainage vulnerability for the Dunbible Creek subcatchment

8.16.4 Management options

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

- Short-term: Active protection of existing Coastal Management SEPP coastal wetlands.
- Long-term: Conversion/transition of low-lying areas to freshwater wetlands or wet pasture.

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
Areas zoned as Coastal Management SEPP coastal wetlands should be actively protected.

Long-term management options
For areas that are impacted by reduced drainage in the far future investigations could be completed to convert the low-lying areas to freshwater wetlands. This would involve installing weirs and infilling drains. These areas could alternatively be managed as wet pasture.

Areas zoned as Coastal Management SEPP coastal wetlands should be actively protected and expanded where possible.

A summary of the recommended management options for the Dunbible Creek subcatchment including indicative costs is provided in Table 8-20.

Table 8-20: Summary of management options for the Dunbible Creek subcatchment

Timeframe	Strategy	Indicative cost (land acquisition)	Indicative cost (upfront)	Indicative cost (ongoing per year)	Indicative cost (lost productivity per year)	Effectiveness at improving:		
						Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Wet pasture management	None	$20,000	None	Minimal	None	Moderate	Moderate
Long-term	Restoration of wetlands	$400,000	$75,000	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.

9 Outcomes and recommendations

9.1 Preamble

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

- Application of a prioritisation methodology to rank 14 subcatchments on the Tweed River floodplain with regard to their contribution to acid and blackwater generation and the risk they pose to the health of the marine estate;
- Suggested management options for individual subcatchments outlining potential strategies for on-ground works to improve water quality; and
- Collation of catchment specific data relevant to the implementation of management options.

This approach has identified high-priority subcatchments within the Tweed Rivers coastal floodplain system to allow targeted floodplain management to improve water quality. The outcomes of the subcatchment prioritisation, management option development and supporting information, provide an objective prioritised list of 14 floodplain subcatchments with a roadmap on how to achieve water quality improvements across the Tweed River coastal floodplain. This can be used by floodplain managers to directly reduce the environmental threats posed to the marine estate by diffuse runoff associated with acid sulfate soil discharges and blackwater generation, and will allow for the subsequent social, cultural and economic benefits to be fully realised.

9.2 Summary

The multi-criteria prioritisation methodology was applied to rank the 14 subcatchment drainage areas of the Tweed River floodplain with respect to the risk they pose to the marine estate due to poor water quality associated with ASS and blackwater runoff. The prioritisation methodology utilised a data driven approach to objectively rank the subcatchments. It is strongly recommended that this data, as well as additional data collected into the future be collated into an estuary wide database that is readily accessible to land managers. Data considered during this analysis included:

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

The acid prioritisation assessment considers the volume of acid stored within a floodplain and the potential for it to be transported to the estuary, to objectively rank subcatchment areas from the highest to lowest with respect to the risk of acid drainage to the estuary. Within the Tweed River floodplain, the

two highest priority subcatchments were identified as Condong and South Murwillumbah (Table 9-1). These subcatchments each individually contribute approximately 25% of the total acid risk for the Tweed River estuary. High risk acid subcatchments were identified in the upper, middle, and lower reaches of the estuary, indicating that acid discharges from the floodplain have the potential to impact all areas of the Tweed River estuary. All four (4) of the highest priority subcatchments are located in the upper estuary (Condong and South Murwillumbah on the Tweed River and Dulguigan and Kynnumboon on the Rous River) highlighting this section of the estuary as most at risk of acidification.

Table 9-1: Tweed River floodplain subcatchment priority ranking

Subcatchment	Acid rank	Blackwater rank
Condong	1	3
South Murwillumbah	2	9
Dulguigan	3	6
Kynnumboon	4	8
Stotts Creek	5	4
Tumbulgum/Eviron	6	1
Tygalgah	7	2
West Chinderah	8	7
North Tumbulgum	9	5
Cobaki	10	10
Bilambil/Terranora	11	11
East Chinderah	12	12
Commercial Road	13	14
Dunbible Creek	14	13

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

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

This data was used to objectively rank subcatchments from highest to lowest based on the risk they pose to the marine estate in terms of discharging low oxygen blackwater to the estuary (Table 9-1). The assessment identified the highest priority subcatchment is Tumbulgum/Eviron which represented approximately 20% of the total blackwater generation risk in the Tweed River estuary. Since the blackwater prioritisation approach is based upon subcatchment area, and therefore subcatchment delineation, it is worth noting that if the Condong, Tumbulgum/Eviron and Stotts Creek subcatchments were combined they would collectively account for approximately 40% of the total blackwater generation risk.

It should be noted that blackwater runoff is less of an issue on the Tweed River floodplain compared to other large coastal floodplains in NSW (e.g. Richmond River, Clarence River and Macleay River). Furthermore, while ASS and blackwater risks have been individually ranked, this does not mean that the impacts of blackwater are necessarily comparable to the impacts of ASS on the Tweed River floodplain.

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

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

Management options have also considered the impacts that sea level rise will have on floodplain drainage. To complete this assessment, detailed numerical modelling of the Tweed 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 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: Tweed River drainage vulnerability under sea level rise

Vulnerability status	Historic scenario (HS)	Present day (PD)	Near future (NF)	Far future (FF)
Floodgates (number of)				
Least vulnerable floodgates	259	245	198	101
Moderately vulnerable floodgates	91	101	133	113
Most vulnerable floodgates	11	15	30	147
Floodplain area (hectares)				
Low vulnerability area	1,696	2,002	2,895	4,023
Moderate vulnerability area	93	121	308	2,438
High vulnerability area	9	13	36	383

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 Tweed 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:

4. 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;
5. Developed potential management options that describe the overall strategy for floodplain management to improve water quality; and
6. Identified and collated key datasets that will be valuable for the implementation of management options.

9.3 Conclusions

Tweed Shire Council, with the support of local landholders, has completed substantial on-ground works to reduce acid drainage in the estuary. Notably, a large number of major floodplain end-of-system infrastructure has been modified to allow some controlled flushing (e.g. sluice gates, auto-tidal gates and winches) and improved connectivity with the estuary. Numerous landholders have co-operated with paddock scale interventions, such as weirs or drain reshaping, with mixed success in terms of water quality improvements and maintenance/improvement of agricultural productivity. These remediation efforts should be encouraged and commended. However, to address water quality issue on a large scale in the Tweed River, broadscale changes to land use and a restoration of natural floodplain hydrology will be required. Broadscale management changes throughout the floodplain will need to consider, and have a plan to mitigate, potential social, cultural, and economic impacts to local landholders.

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

implementation of scientific knowledge and technical solutions is impeded by political, social, and economic barriers, which will need to be overcome if our estuaries are to thrive into the future.

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