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Lower Manning River
Drainage Remediation Action Plan

WRL Technical Report 2016/01

August 2016

By W C Glamore, J E Ruprecht, and D S Rayner

Water Research Laboratory
University of New South Wales
School of Civil and Environmental Engineering

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Project Details

Report Title	Lower Manning River Drainage Remediation Action Plan
Report Author(s)	W C Glamore, J E Ruprecht and D S Rayner
Report No.	2016/01
Report Status	Final
Date of Issue	August 2016
WRL Project No.	2014061.01
Project Manager	W C Glamore
Client Name	MidCoast Council
Client Address	36 Arkwright Crescent Taree NSW 2430
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Client Reference	

Document Status

Version	Reviewed By	Approved By	Date Issued
Draft	W C Glamore	G P Smith	26 April 2016
Final	W C Glamore	G P Smith	09 August 2016

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Acknowledgements

This project is funded by MidCoast Council (formerly Greater Taree City Council) as part of Council's Environmental Levy, with funding assistance provided through the NSW Estuary Management Program and the Hunter Local Land Services. The Water Research Laboratory (WRL) of the School of Civil and Environmental Engineering at UNSW Australia wishes to acknowledge the contribution of Mr Bob McDonell (MidCoast Council) and Mr Errol Ruprecht (local oyster farmer) for their assistance with the field data collection program. Data not publicly available for this study was provided by MidCoast Council, NSW Food Authority, and the NSW Office of Environment and Heritage (OEH).

Executive Summary

Key Summary Points:

- Acid sulfate soils (ASS) are commonly known as the world's worst soils, associated with estuarine wide acidification, fish kills and poor water quality;
- The Manning River floodplain has extensive ASS deposits;
- Over the past two (2) centuries the construction of flood mitigation infrastructure on the Manning River has separated the floodplain from the estuary and lowered the groundwater table of the floodplain soils;
- The prolonged drying of the floodplain has allowed oxygen to penetrate into the ASS sediments creating acidified soils and groundwater;
- The flood mitigation drains and floodgates efficiently mobilise the groundwater and quickly transport the poor quality water into the Manning River estuary;
- Following rainfall events, extensive floodplain areas can be impacted by the acidic runoff and high concentrations of heavy metals;
- The waterway acidification can severely degrade whole estuarine ecosystems and impact primary producers (including the oyster industry) in the lower Manning River estuary;
- On-ground remediation has been shown to ameliorate many of the acidic effects, however the estuary-wide problem requires targeted actions and a strategic use of resources;
- For this study, all 15 floodplain sub-catchments of the Manning River estuary were assessed to prioritise where future resources are best targeted;
- A Multi-Criteria Priority Assessment methodology (developed by Glamore et al. 2014) was applied to systematically link the floodplain characteristics with the estuary for the first time;
- Action Plans were then developed to remediate each of the drainage sub-catchments including immediate (~10 years) and long-term plans;
- The three (3) highest ranking floodplain sub-catchments were shown to contribute 80% of the acid sulfate soil risk to the broader catchment. For these sites, fine scale drain-by-drain Action Plans were developed;
- The influence of climate change, and particularly sea level rise, were assessed for the highest priority sub-catchments; and
- Detailed consultation with local landholders and engineering design are required to ensure the Action Plans are successfully implemented on-ground.

Acid sulfate soils are considered one of the worst soils in the world. These soils were formed in estuarine floodplains 3,000 to 6,000 years ago when the ocean levels were higher and present day floodplains were tidal backswamps. When wet these soils are harmless, however when exposed to atmospheric oxygen the soils can acidify creating high concentrations of sulfuric acid and heavy metals. Acidic water impacts fish, oysters and other aquatic flora and fauna, as well as man-made structures such as, culverts and bridges. The Manning River floodplain has been categorised as having extensive high-risk acid sulfate soils.

Drainage of the Manning River floodplain has been ongoing since 1824. Significant floodplain drainage works throughout the 20th century were primarily undertaken for flood mitigation, as well as to promote dry land agricultural production, and to prevent saline intrusion onto the backswamp areas of the floodplain. The existing drainage system and infrastructure has largely been in place since the 1970s (Figure E.1). Research into the impacts and effects of acid sulfate soils in the Manning River estuary commenced in the late 1990s. While initial research focused on limiting acid production, recent studies have investigated remediation strategies for acidic groundwater and adjacent flood mitigation drains. In 1999, the NSW Department of Land and

Water Conservation (DLWC) identified twenty-six ASS hotspots in NSW, four (4) of which were located in the Manning area, including Cattai Creek-Pipeclay Canal (Big Swamp), Lower Lansdowne-Moto-Ghinni Ghinni Creek, North Oxley Island, and Dickensons Creek. In fact, the Cattai Creek-Pipeclay Canal area was generally recognised as one of the very worst areas for ASS pollution on the entire NSW coast.

Research has shown that it is very difficult to limit further acid production once the soil is acidified. Since the majority of the floodplain soils are already acidic, most remediation strategies focus on (i) containing the acid within the soil; (ii) neutralising the acidic water onsite before it is discharged into the estuary; or (iii) encouraging low oxygen/anaerobic conditions onsite. On-ground project examples at Big Swamp and elsewhere in NSW have effectively reduced acid drainage, and most projects include a combination of remediation strategies.

For this study an evidence-based prioritisation methodology was applied to rank the flood mitigation drains and larger drainage sub-catchments of the Manning River floodplain (Figure E.2). The method used field data for floodplain drainage, catchment characteristics, acid concentrations, soil parameters, asset condition, sensitive receivers and drainage capacity to objectively rank 15 large drainage sub-catchments identified (Figure E.3). The three (3) highest priority affected floodplain areas, namely Moto, Ghinni Ghinni, and Big Swamp, were estimated to contribute over 80% of the total acid being discharged into the estuary.

Action Plans were developed for each of the 15 drainage sub-catchments. These plans outline the recommended on-ground works required to reduce or eliminate acid drainage from each site. The action plans recommend one (1) option or a combination of remediation options, including immediate on-ground recommendations (5-10 years) and longer term (>10 year) plans for each site. Approximate costs for each remediation strategy are also provided. This strategic approach to floodplain planning ensures the ASS drainage sites that have the greatest potential for adverse impact are prioritised and future investments provide the best value-for-money and environmental outcomes.

The impact of climate change, particularly sea level rise (SLR), was examined to address potential issues arising over the next 35-70 years. For each drainage sub-catchment the impact of rising sea levels as predicted for 2050 and 2100 were assessed. This analysis showed the effect of changed tidal levels on backswamp connectivity, levee overtopping, infrastructure elevations and reduced drainage. While the forecasted increases in high tides are a concern in some regions, due to the foreseeable impact on agricultural productivity, the greater issue for land management is elevated low tides, which will reduce drainage from low-lying backswamps. Moto, Ghinni Ghinni, Big Swamp, Coopernook, and North Oxley Island, are areas of particular concern highlighted in the report.

The results from this study, including the Action Plans, require detailed stakeholder consultation and training prior to implementation on-ground. Several of the recommended strategies are different to existing land practices, however detailed engineering plans or changes to land tenure could result in win-win outcomes. Training for landholders in acid sulfate soil management and remediation techniques would be beneficial and may assist in developing improved long-term outcomes across the Manning River estuary.

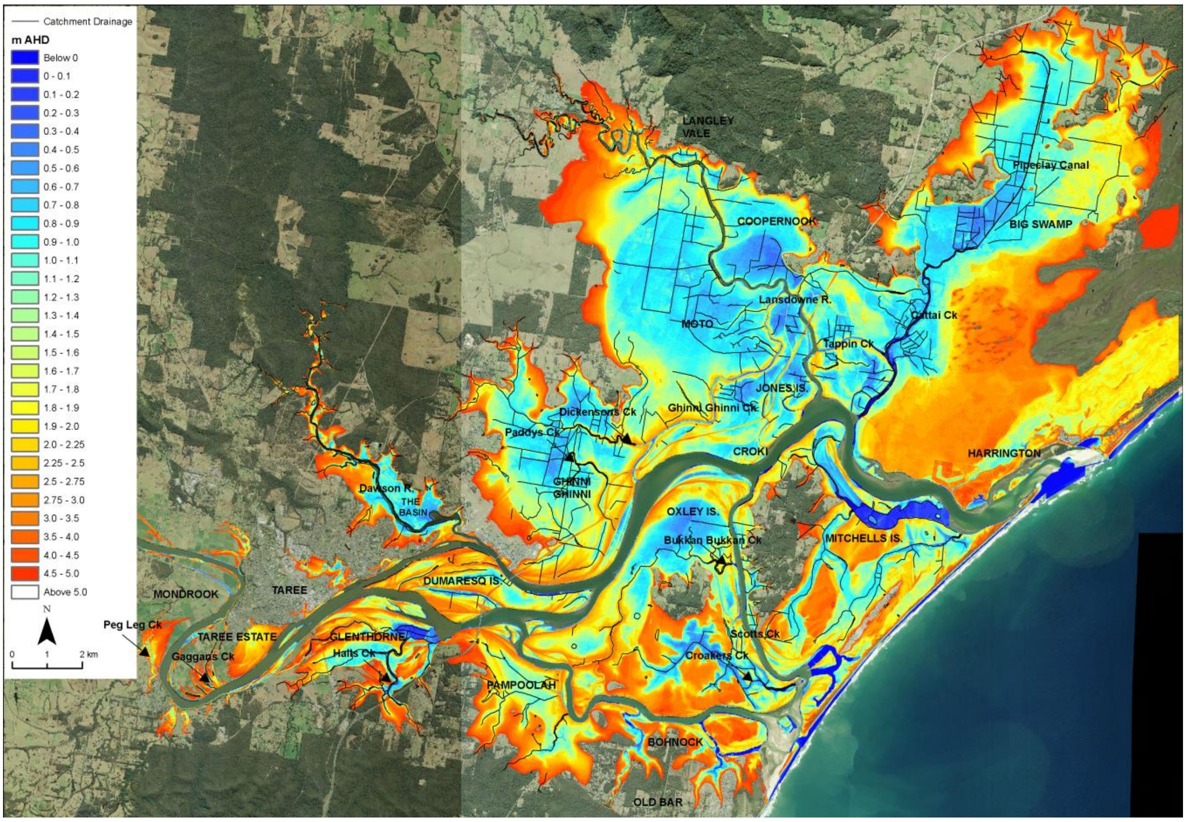


Figure E.1: Topography Based on LiDAR and Extent of Floodplain Drainage

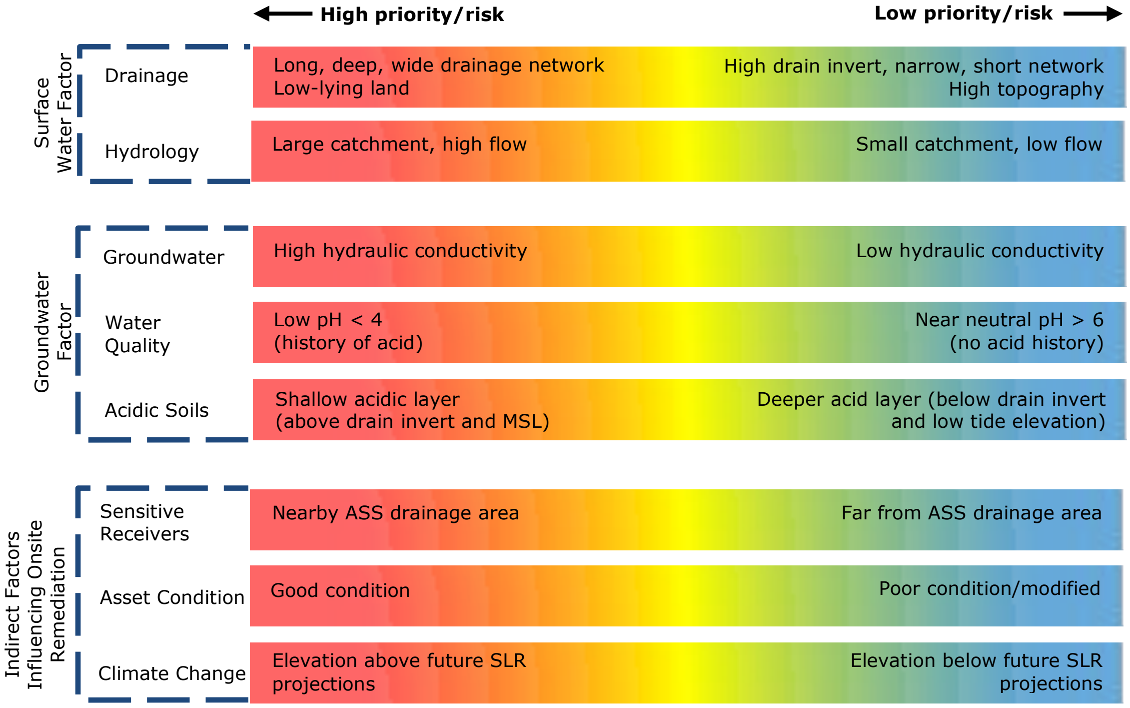
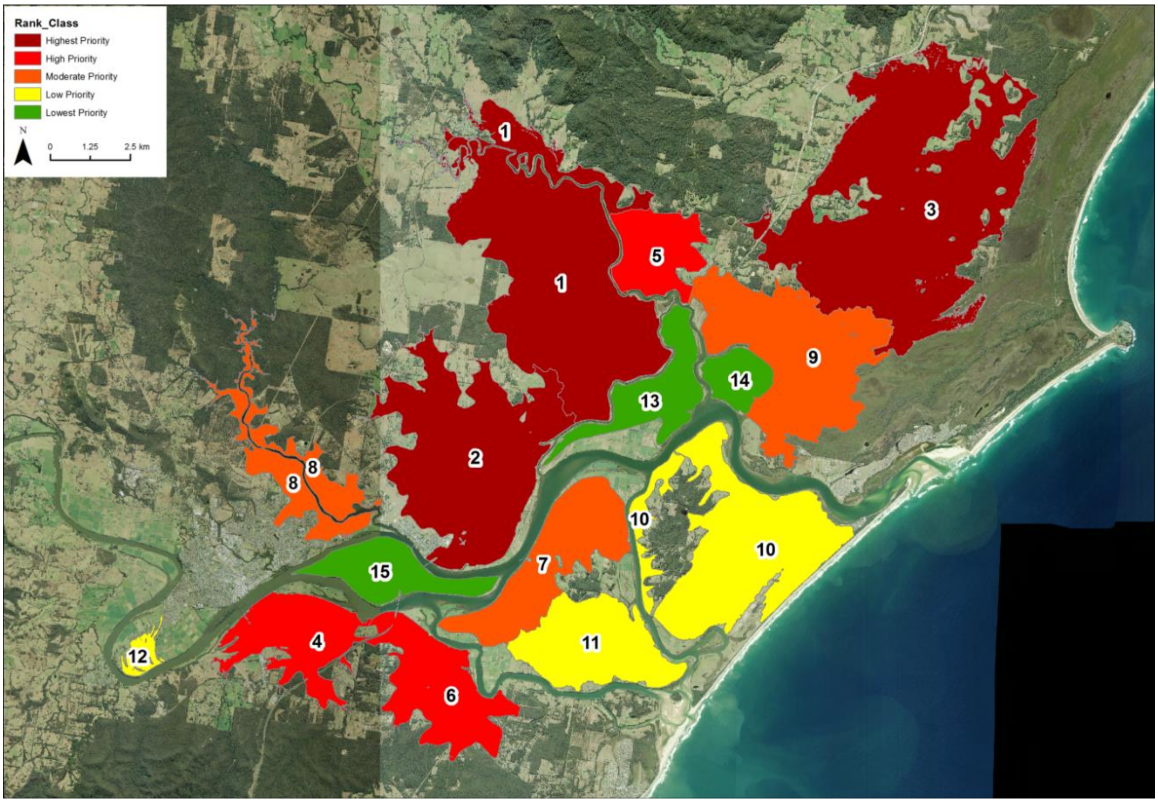


Figure E.2: Factors Influencing the Risk of Environmental Impacts from ASS Discharge from an ASS-Affected Floodplain in Coastal NSW (adapted from Johnston et al. 2003)



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1. Introduction

The Water Research Laboratory (WRL) of the School of Civil and Environmental Engineering at UNSW Australia was commissioned by MidCoast Council (formerly Greater Taree City Council), with additional funding support from the NSW Office of Environment and Heritage (OEH) Estuary Management Program and the Hunter Local Land Services (LLS), to prioritise acid sulfate soil (ASS) affected drainage areas of the Manning River floodplain (Figure 1.1) for remediation and rehabilitation. Despite the successes of recent rehabilitation efforts by MidCoast Council in former wetland areas of the floodplain, particularly in the Cattai Creek-Pipeclay Canal region, large areas within the Manning River estuary remain severely impacted by ASS. This study aims to provide MidCoast Council and LLS with an evidence-based list of high-priority ASS areas, along with on-ground Action Plans, to address the land and water impacts of ASS across the entire Manning River estuary.

The study methodology was developed to identify and assess high-priority ASS areas for remediation and rehabilitation on coastal floodplains in NSW. This approach has previously been benchmarked in the Shoalhaven River estuary (Glamore and Rayner 2014). Briefly, the methodology used for this study, as per Glamore and Rayner (2014), includes:

- Collation and review of existing data, previous on-ground works, floodplain asset condition and ASS research across the floodplain;
- Review of key ecological features and sensitive receivers in the Manning River estuary;
- Determining distinct sub-catchment areas to identify potential high impact remediation sites;
- Assessment of floodplain hydrology, drainage characteristics and soil acidity within each sub-catchment;
- Identification of knowledge gaps and datasets that limit the current understanding of ASS impacts across the estuary;
- Targeted field investigations to gather data on key knowledge gaps;
- Prioritised sub-catchment areas based on the benchmarked algorithm;
- Assessment of the implications of sea level rise on floodplain drainage; and
- Development of on-ground Action Plans for each sub-catchment.

This strategic approach to floodplain planning ensures the ASS drainage sites that have the greatest potential for adverse impact are prioritised and future investments provide the best value-for-money and environmental outcomes.

1.1 About this Report

The terms hydrology, remediation and rehabilitation are used regularly throughout this report. The term ‘hydrology’ is used in the broader sense relating to the interaction of surface water, groundwater and the contributing climate, as well as catchment characteristics which drive the water cycle. The term ‘remediation’ means to remedy a symptom of damage, and is often used in the context of reducing pollution from degraded ASS areas. Whereas, the term ‘rehabilitation’ is used to describe the process of returning degraded wetlands to something approaching their former state after some process (e.g. over drainage) has resulted in damage.

The report is composed of the following sections:

- **Chapter 2** provides background information to this study, including an overview of the history of drainage and ASS in the Manning River estuary;
- **Chapter 3** provides an overview of the priority assessment methodology;

- **Chapter 4** provides an overview of the application of the priority assessment methodology to the Manning River estuary;
- **Chapter 5** summarises the priority assessment outcomes for the Manning River estuary;
- **Chapter 6** summarises various short-term and long-term remediation strategies;
- **Chapter 7** provides the short-term and long-term on-ground Action Plans for each sub-catchment of the Manning River estuary;
- **Chapter 8** addresses the implications of sea level rise on floodplain drainage; and
- **Chapter 9** provides a summary and recommendations for moving forward.

This report has been structured to highlight the key findings of the study. Significant tasks that do not form the core of the priority assessment outcomes have been documented as appendices, rather than in the main body of the report. Specifically, readers unfamiliar with the background theory of ASS are directed to **Appendix A**. A detailed overview of the prioritisation methodology is provided in **Appendix B**.

All data values and sources used to determine the priority areas and Action Plans have been included where possible. Detailed datasets and analyses of the environmental factors that were used in the priority assessment are provided as additional appendices to the report, including:

- **Appendix C** summary of floodplain drainage;
- **Appendix D** summary of catchment hydrology;
- **Appendix E** summary of groundwater hydraulic conductivity;
- **Appendix F** summary of ASS distribution;
- **Appendix G** summary of water quality;
- **Appendix H** summary of sensitive environmental receivers; and
- **Appendix I** summary of floodplain drainage assets.

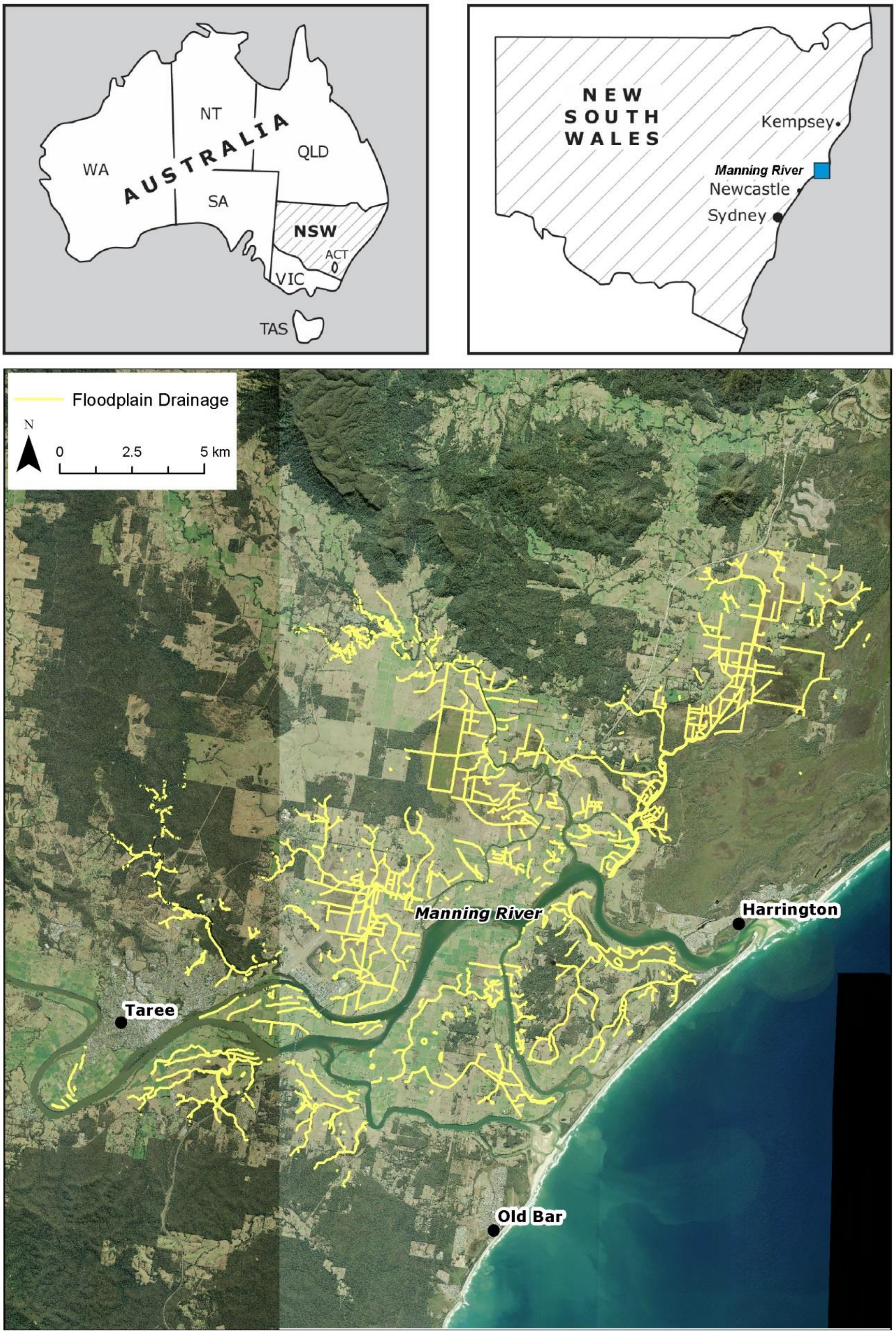


Figure 1.1: The Study Area

2. Background Information

2.1 Preamble

This section provides background information describing the history of drainage and the distribution of ASS across the Manning River floodplain. Further detailed information on the formation, mobilisation and impacts of ASS in the coastal estuaries of NSW is provided in Appendix A. Note that unless otherwise stated much of information provided here on the Manning River floodplain is sourced from Tulau (2011).

2.2 Acid Sulfate Soils in the Manning River Estuary

2.2.1 Floodplain History

The Manning River floodplain covers an area of approximately 450 km^2, approximately 5% of the Greater Taree catchment area. The most noticeable feature of the Manning River region is the proliferation of connecting channels that trace across the floodplain, dividing it into a number of low islands and backswamp areas. Large areas of the floodplain were once predominantly open swampland, with the wettest areas dominated by reeds or open water. Open swamps comprised large areas, including not only lands that would today be regarded as drained wetland, but extending to somewhat higher elevations as well, including areas that are now productive agricultural landscapes. The lowest point of the floodplain is found at Coopernook Swamp, an eastern section of the Moto basin at Coopernook, and is around 0.0 m Australian Height Datum (AHD), as shown in Figure 2.1. However, most backswamp areas of the floodplain are located well above mean high tide (>0.5 m AHD at the Harrington entrance), including most of the former Big Swamp area upstream of Cattai Creek. Note that AHD is approximately equal to mean sea level (MSL).

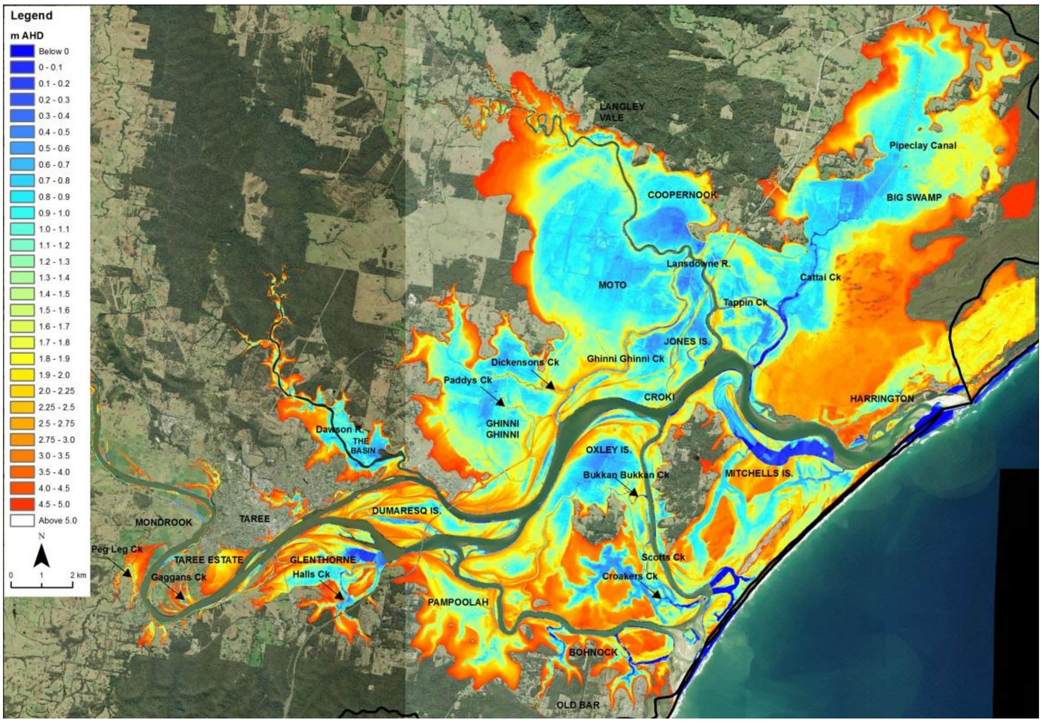


Figure 2.1: Digital Elevation Map of the Manning River Floodplain

The drainage history of the Manning River floodplain began in the early-19th century and has been continually modified until the present day. Significant floodplain drainage works throughout the 20th century were primarily undertaken for flood mitigation, as well as to promote dry land agricultural production and to prevent saline intrusion onto the backswamp areas of the floodplain. For more information on the past and present cadastral portions of the Manning River floodplain see Appendix C. A timeline of key events and drainage works on the Manning River floodplain (as per Tulau 2011) includes:

- 1824 – Moto swamp became the first backswamp drained, farmed and settled on the north coast of NSW;
- 1852 – The first wave of small-holding settlers began to purchase land on the Manning floodplain, selecting the higher, well drained alluvial soil on the levees on which to grow maize;
- 1856 – Most of the prime agricultural land on the floodplain had been subdivided and the higher levees alienated, including on Oxley Island, leaving only small areas of brush-covered land and the wet backswamps for later settlers. Extensive drainage works commenced across the Ghinni Ghinni and Moto floodplain areas to open up the swamp land to dry land agricultural production;
- 1861 – The swampy central portions of Oxley and Mitchells Islands, and on the north side of the river, the Big Swamp, were the only large areas of the floodplain not yet drained;
- 1898 – Big Swamp Project prepared and was the first major drainage scheme in NSW carried out under the Public Works Act of 1888;
- 1904 – Big Swamp Drainage Scheme completed and was designed to pass upland catchment inflows from Pipeclay Creek (and local catchment inflows draining from the floodplain) directly to Cattai Creek. This relied on the construction of Pipeclay Canal (approximately 6.5 km long, 15 m wide and 1.2 m deep) through the Big Swamp floodplain, separating the catchment into two halves. In addition, Coopernook Swamp Drainage Scheme was completed;
- 1911 to 1970s – Limited literature is available about drainage works carried out in the Manning Region. However, following the floods of the 1950s, the response of successive Local and State governments facilitated the construction of extensive drainage systems by drainage unions and private landholders;
- 1950 to 1970s – Despite the often misleading use of terminology, the ‘flood mitigation’ schemes of the 1950s to 70s were overwhelmingly swamp drainage schemes, whereby additional deepening, straightening and drainage control (i.e. floodgates) was carried out in accordance with flood mitigation policy funding;
- 1960s – Sections of Dickensons Creek were straightened;
- Late 1970s – Marked the end of new, large-scale drainage works in NSW coastal floodplain backswamps. However, by this stage the Manning floodplain landscape had been transformed and backswamp wetlands were all but gone, apart from a few diminished and temporary remnants;
- 1997 – The last approved major excavation works of Pipeclay Canal (MidCoast Council, 2010); and
- 2010 – MidCoast Council had introduced clause 7.1 on Acid Sulfate Soils into the Greater Taree LEP which stated that consent would be required for drainage undertaken by drainage unions, flood mitigation works undertaken by councils and county councils, and drain ‘cleaning’ by farmers. This was generally consistent with other north coast council LEPs, except the Greater Taree LEP included an allowance for ploughing of land >0.7 m AHD.

A schematic of floodplain evolution indicating the influence of extensive drainage works and its conceptual progression from past to present hydrologic conditions is presented in Figure 2.2.

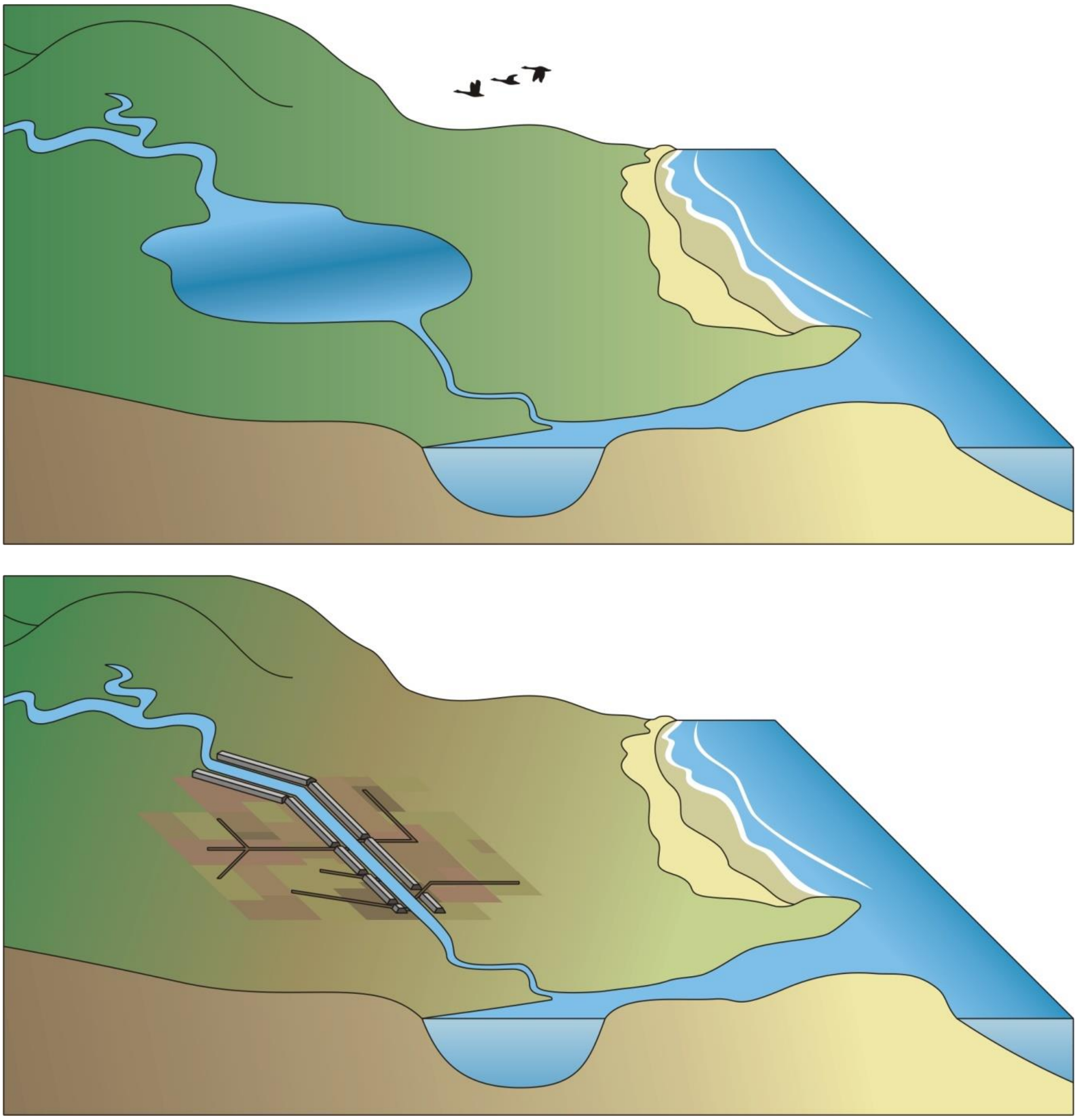


Figure 2.2: Schematic of Floodplain Evolution Following European Settlement

2.2.2 The ASS Legacy Issue

Early experiences with acid sulfate soils (ASS), formerly known as ‘cat clays’, date back to the drainage schemes of the 17th century in the Netherlands, and the late-19th century in Australia. In NSW the issue attracted official attention during the drainage trust years. By 1912, the issue of ASS was prevalent across the Big Swamp floodplain, where the water was “*clear and sparkling*”, “*stock would not touch it*”, and “*even eels and frogs died quickly if put into it*” – large tracts of land were “*absolutely bare*”. A local teacher, Mr L.V. Hill, asserted that “*the only logical explanation of the matter is that some poisonous matter has come up from the earth ... in dry times, a reddish dust appeared on the vegetation*”. Coralville resident Dorothy Mooney recalled that "*the water made the clothes yellow. They said there was a lot of alum in it and when we let it settle in a bucket there was a sediment in the bottom like rust*".

From the late 1800s to the 1960s, the dangers of excessively draining ASS gradually became understood in Australia amongst not only the scientific community, but also by land managers. However, in the post-war flood mitigation period, the advice from the NSW Department of Agriculture was consistent, it "*indicated that no harmful effects were expected to ensue from drainage*", even though by 1960, there were already signs of the extent of the problem in NSW.

In 1978, the general understanding regarding ASS had been publicly summarised by the State Pollution Control Commission (SPCC) Inquiry into flood mitigation works in NSW:

"*The floodplains of NSW contain anaerobic, waterlogged estuarine areas with sediments rich in sulphides. Construction of drainage channels may lower the water table in these areas, aerate the soils, [and] convert sulphides to acid ... Materials leached from soils by this process generally include iron, which can form brown precipitates ... Drained areas sometimes become devoid of vegetation as a result of acid conditions. The brown precipitates and [acid] slicks arising from these conditions may contribute to the discolouration of river water before and after a flood*".

By the 1990s, the ASS issue emerged as one (1) of the major environmental problems facing estuaries in coastal NSW. Over the next two (2) decades there was confirmation of the disastrous impacts of acid drainage flowing from drains and floodgates in high-risk ASS landscapes, including research reports identifying the extensive impacts on fish (Sammut 1998) and oyster industries (Dove 2003). In 1999, the NSW Department of Land and Water Conservation (DLWC) identified twenty-six ASS hotspots in NSW, four (4) of which were located in the Manning area, including Cattai Creek-Pipeclay Canal (Big Swamp), Lower Lansdowne-Moto-Ghinni Ghinni Creek, North Oxley Island, and Dickensons Creek. In fact, the Cattai Creek-Pipeclay Canal area was generally recognised as one (1) of the very worst areas for ASS pollution on the entire NSW coast (MidCoast Council 2010).

Ultimately, the legacy of artificial drainage on estuarine floodplains in NSW over the past century has accelerated oxidation of naturally occurring soil and sediment that contain iron sulfides, by unnaturally oxidising the ASS beneath many floodplain areas. The drains provide an efficient pathway for ASS-affected surface and groundwater to enter estuaries. Following high rainfall, extensive floodplain areas can be acidified, particularly after long dry spells. The subsequent acidification of waterways severely degrades whole estuarine ecosystems. For further information on ASS see Appendix A.

2.2.3 ASS Distribution in the Manning Region

The acid pollution hazard in NSW was originally mapped on the Acid Sulfate Soil Risk Maps prepared by Naylor et al. (1995). The study revealed that the Manning River floodplain contained an area of over 200 km^2 of high-risk ASS soil up to an elevation of approximately 5 m AHD as shown in Figure 2.3. The extent and severity of ASS on the Manning River floodplain has since been confirmed by several investigations, including Sonter (1999), Smith et al. (1999), Dove (2003), Johnston (2007), and Glamore et al. (2014).

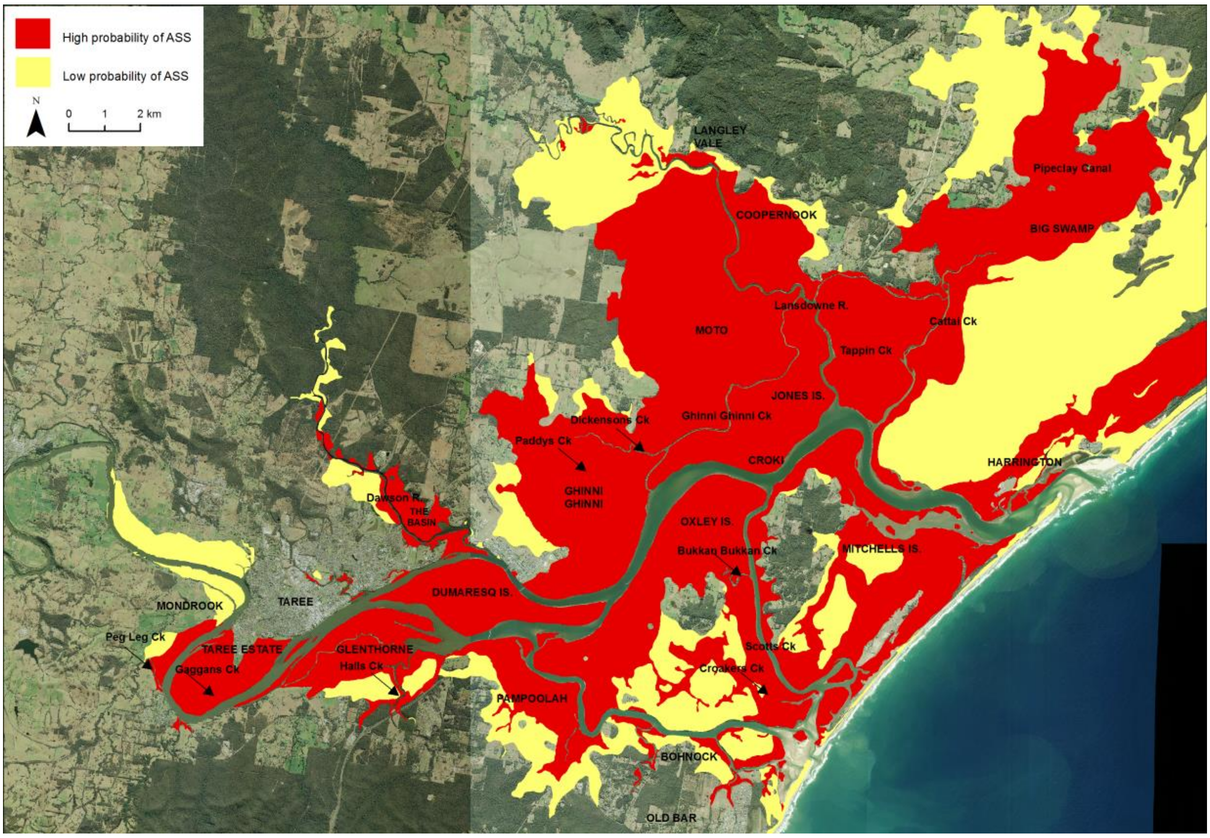


Figure 2.3: NSW Government ASS Risk Map of the Manning River Floodplain

Under most natural conditions, where the soil remains waterlogged, ASS remain innocuous. These soils are commonly referred to as potential acid sulfate soils (PASS). PASS have the 'potential' to produce acid if they dry out and form actual acid sulfate soils (AASS). When ASS are exposed to air – by drainage or excavation of the soil, when the water table is lowered artificially, or during droughts or prolonged dry weather – the soil reacts with oxygen in the air or water (through a process known as oxidation), and can produce large quantities of low-pH sulfuric acid (pH<4.5).

Available soil profile data was analysed to provide an indication of the distribution of AASS and PASS across the Manning River floodplain. This information was obtained from the NSW Office of Environment and Heritage eSPADE Database and recent field investigations completed by WRL. eSPADE provides access to soil profile and soil map information published by the NSW Office of Environment and Heritage, including map data, reports and images, primarily sourced from the NSW Soil and Land Information System (SALIS). This information is important to understand the existing and potential risk of stored acid within the soil on the floodplain. The approximate depths across the floodplain to the AASS and PASS layers is provided in Figure 2.4 and Figure 2.5, respectively. The low-lying areas of the floodplain are characterised by AASS near to the surface, between 0.0 m and -0.5 m, corresponding to existing high-risk ASS areas (Figure 2.3). Furthermore, the floodplain has a deeper PASS layer generally between -0.5 m and -2.0 m from the surface. The depth to actual and stored acid is fairly consistent across the floodplain, with some localised variations potentially due to topography and groundwater levels.

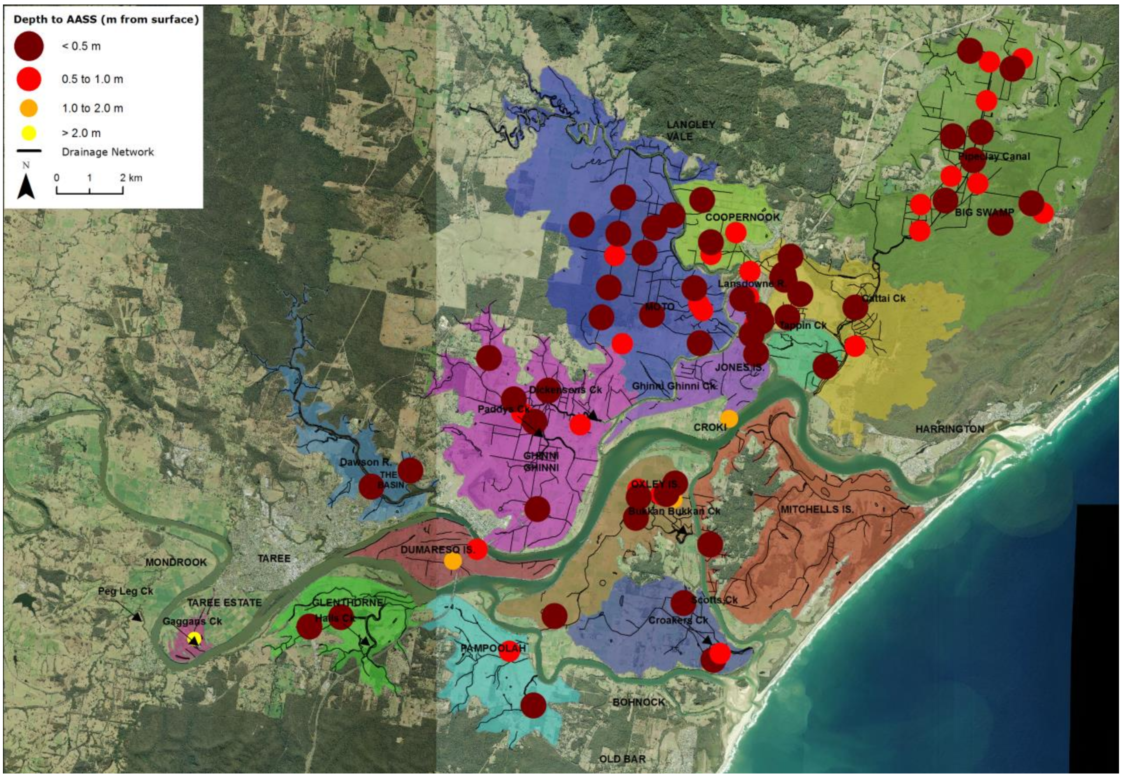


Figure 2.4: Approximate Depths to Actual Acid Sulfate Soil (AASS) Layer

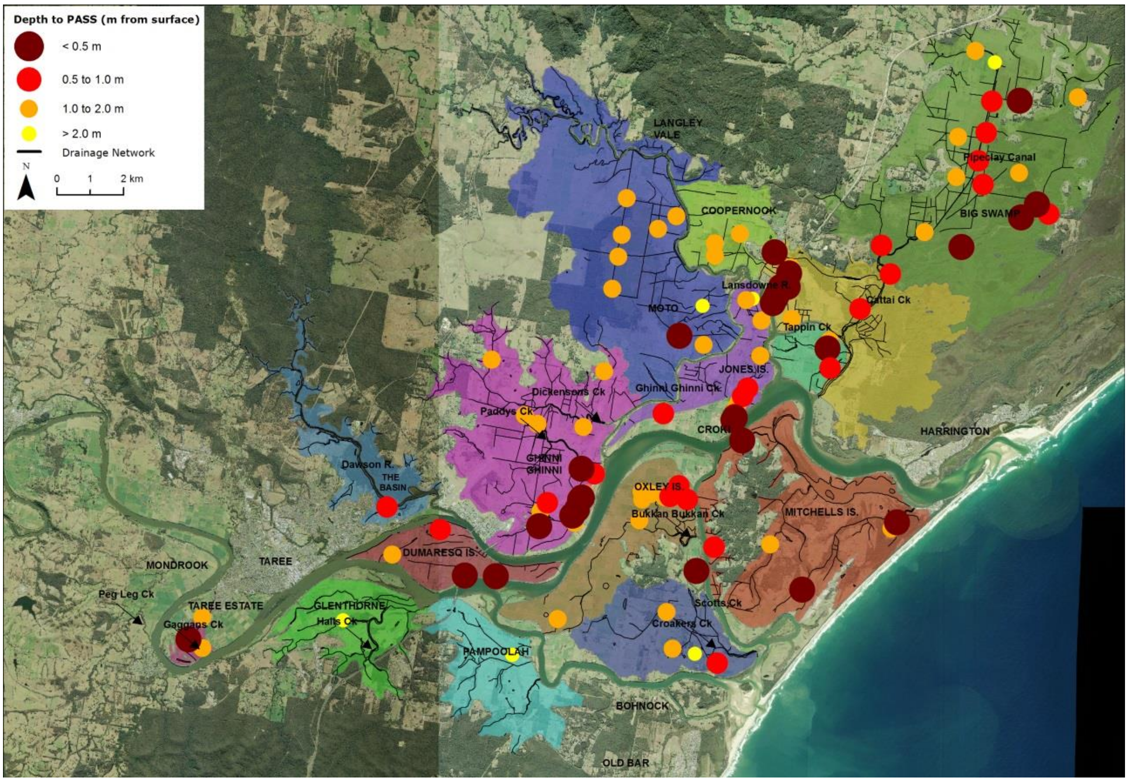


Figure 2.5: Approximate Depths to Potential Acid Sulfate Soil (PASS) Layer

3. Prioritisation Methodology Overview

The priority assessment undertaken for this study is a comprehensive, benchmarked methodology used to determine the risk of acid discharges from drained ASS-affected estuarine floodplains in coastal NSW. The method (developed by Glamore et al. 2014) can be applied to individual drainage channels within a paddock, or across larger sub-catchments of the floodplain, and is used to identify high-priority ASS drainage areas within these systems for remediation or rehabilitation. Identifying existing (or potential future) high-risk ASS drainage areas is fundamental to formulating objective, evidence-based, on-ground Action Plans for the drainage area, and to improve the eco-health of coastal estuaries.

The priority assessment is structured around three (3) major components: (i) a surface water drainage factor, (ii) a groundwater factor, and (iii) several other indirect factors that influence the recommended onsite ASS management strategies. Each component is formulated by environmental factors/processes that contribute to the risk of ASS oxidation and acid discharge on downstream sensitive receivers. The risk associated with each factor is determined by a desktop assessment of existing information and combined with a field assessment of onsite environmental conditions. These factors are then combined within a calibrated algorithm to rank each drainage area. A summary of the risk rating, as applied to each factor, is provided in Figure 3.1. These factors and the entire methodology are discussed further in Appendix B.

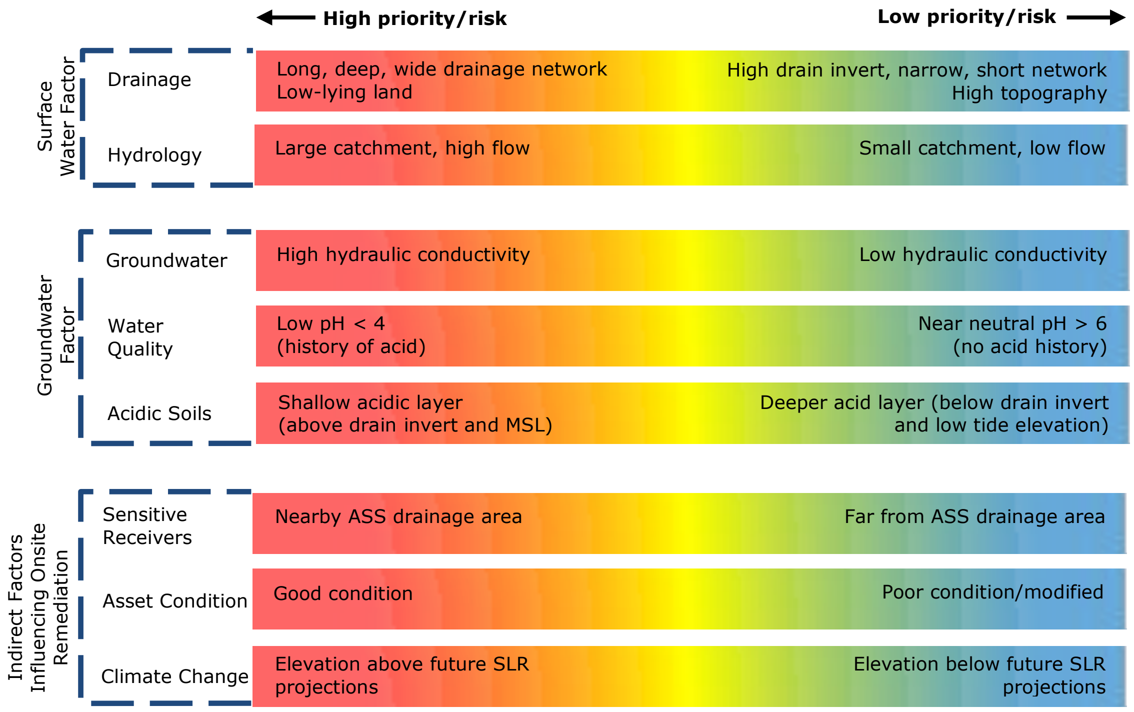


Figure 3.1: Factors Influencing the Risk of Environmental Impacts from ASS Discharge from an ASS-Affected Floodplain in Coastal NSW (adapted from Johnston et al. 2003)

4. Manning River Estuary Assessment

4.1 Preamble

This section discusses the application of the priority assessment to the Manning River estuary. Initially, the selection of distinct sub-catchment areas to identify potential high impact remediation sites is discussed in Section 4.2, followed by a brief description of the data gap analysis and 2015 field assessments in Sections 4.3. For this study, sufficient data was gathered to determine each factor incorporated into the priority assessment. Supporting data used in this study, as applied to each factor, is provided in Appendices C to I.

4.2 Sub-Catchment Delineation

The study area was divided into broad sub-catchments based on historical land management areas and cadastral subdivisions, high-resolution aerial imagery (nearmaps), LiDAR of the wider catchment and GIS mapping techniques. For the purpose of this study, sub-catchments were delineated based on the 5 m AHD contour. The 5 m AHD contour provided the same delineation of areas classified as having high and low risk ASS (as per Naylor et al. 1995). This information was combined to determine distinct management areas as provided in Figure 4.1. Note that partial areas of the floodplain previously identified for remediation, particularly in the Cattai Creek-Pipeclay Canal area, are included in the calculations of the priority assessment.

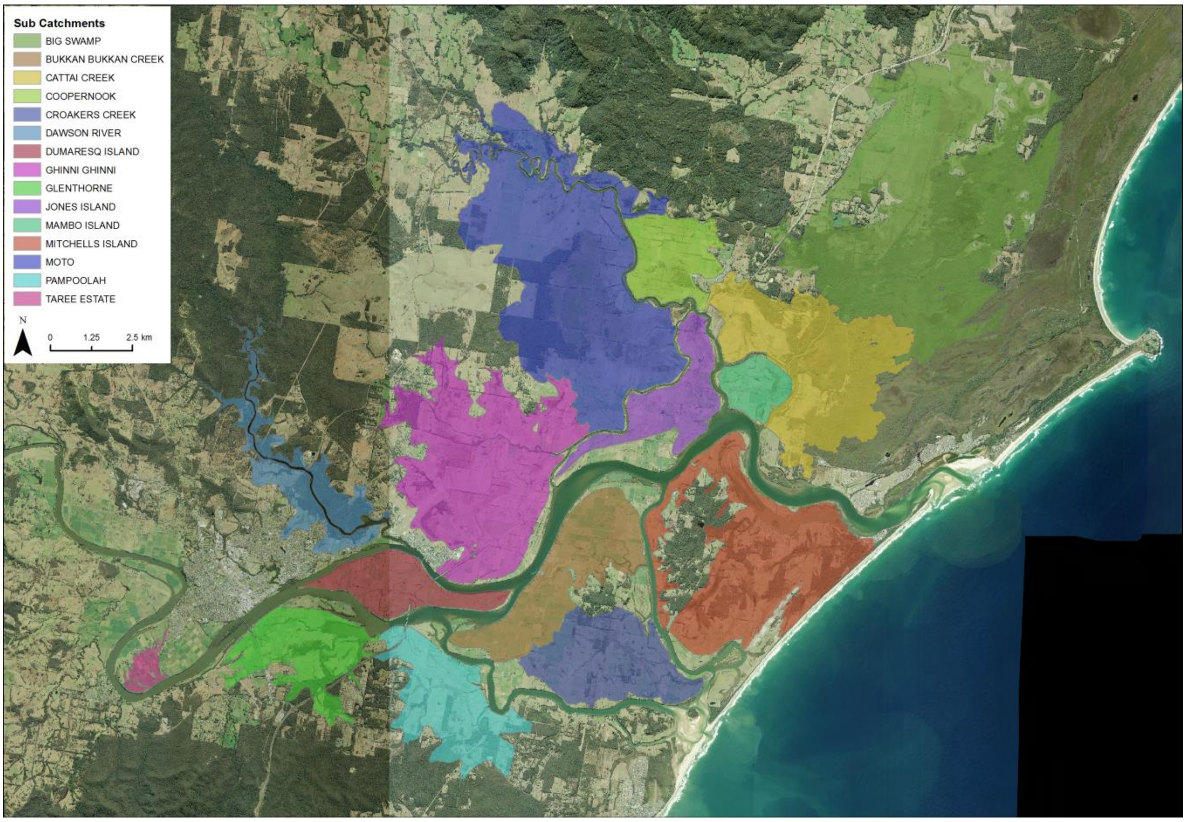


Figure 4.1: Priority Assessment Sub-Catchment Delineation of the Manning River Floodplain

4.3 Data Gap Analysis and Field Assessments

Following data collation and review of all available soil profile and hydraulic conductivity data for the Manning River floodplain, areas with limited AASS/PASS layer data, hydraulic conductivity measurements, or low data confidence, were identified (Figure 4.2). WRL staff completed 26 soil profiles and 18 hydraulic conductivity test pits over 10 days at the specified locations within the study area, to determine AASS and PASS depth and elevation, soil acidity and field hydraulic conductivity. A brief survey of floodgate structures was also completed during the final field investigation to obtain invert levels of structures in AHD (where possible). The field survey of floodgate structures was also used to validate the asset condition of the surveyed structures as a preliminary, independent assessment for comparison with existing data provided by MidCoast Council. Details of the field assessment dates and locations are provided in Table 4.1. A summary of the data and methods from the field investigations is presented in Appendix E, F, and I.

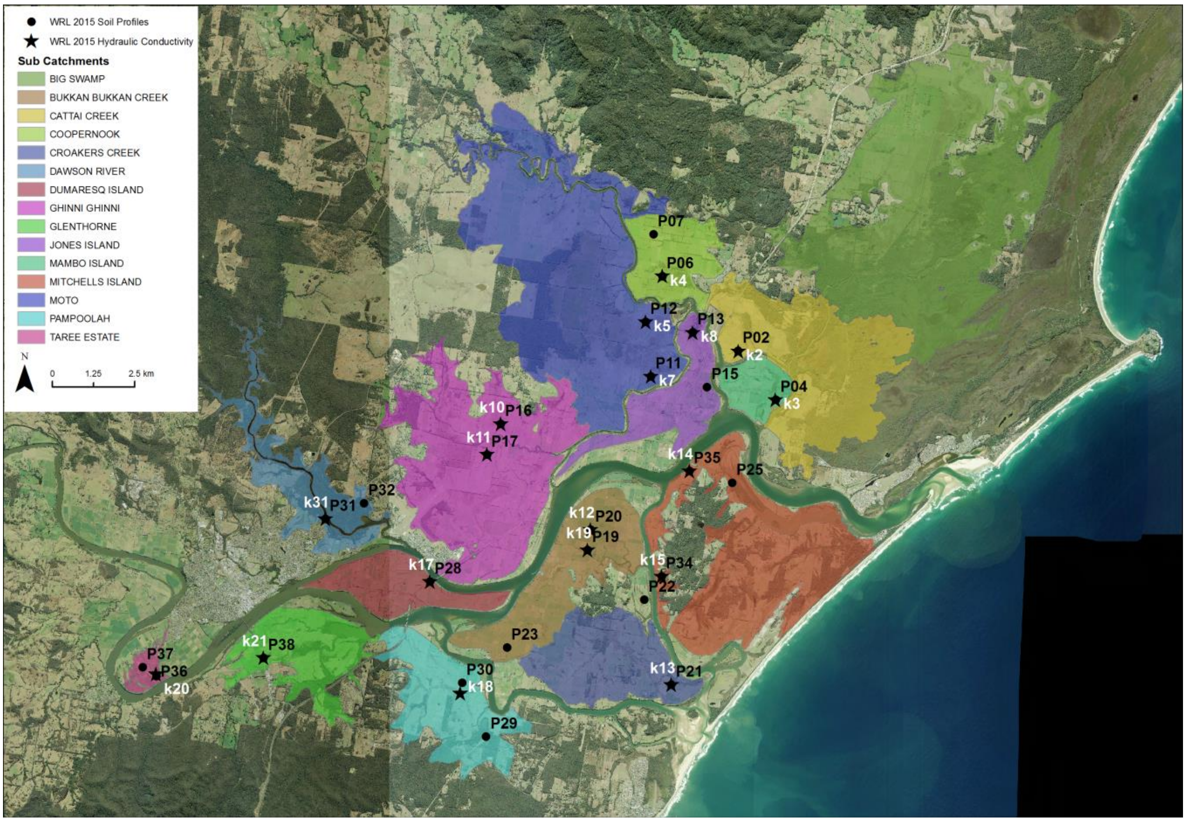


Figure 4.2: Data Gap Soil Profile and Hydraulic Conductivity Assessment Locations

Table 4.1: Field Assessment Details

Field Investigation	Date		Field Work Days	Tasks
	Start	End		
1	7/10/2015	8/10/2015	2	Soil profiles and hydraulic conductivity measurements on Mitchells Island and Oxley Island.
2	26/10/2015	28/10/2015	3	Soil profiles and hydraulic conductivity measurements on Oxley Island, Glenthorne, Pampoolah.
3	23/11/2015	27/11/2015	5	Soil profiles and hydraulic conductivity measurements on Dawson River, Taree Estate, Dumaresq Island, Ghinni Ghinni, Moto, Coopernook, Jones Island, Mambo Island and Cattai Creek. NB: A floodgate survey was completed on 26/11/2015 in the lower estuary.

5. Priority Assessment Outcomes

5.1 Preamble

This section summarises the results of the priority assessment on the Manning River floodplain and estuary. The overall results and rankings of the 15 sub-catchments assessed on the Manning River floodplain are discussed in Section 5.2. The top three (3) priority areas identified by the catchment-wide assessment were reanalysed and management units within these priority areas were ranked according to the ASS-risk of specific drains, structures, or land management sub-divisions. A summary of the highest priority areas is discussed in Section 5.3.

Note that the final rankings in the priority assessment are a function of a surface water drainage factor and a groundwater factor applied to each sub-catchment (see Appendix B to F). The 'highest priority' sites have the highest combined score of the surface water and groundwater factors, and thereby, attain the highest risk of land and water impacts from the disturbed ASS.

5.2 Catchment-Wide Priority Assessment Results and Rankings

A total of 15 sub-catchments were assessed to identify potential high impact remediation sites. A summary of the final results and rankings of the catchment-wide priority assessment of the Manning River estuary is provided in Table 5.1, and graphically in Figure 5.1 to Figure 5.3. Areas on the left-bank of the Manning River, including Moto, Ghinni Ghinni and Big Swamp, were identified as the worst ASS-affected areas on the floodplain, contributing 81% of the overall acid drainage risk. It follows that Ghinni Ghinni Creek, Dickensons Creek, the Lansdowne River, and the northern arm of the Manning River downstream of Dumaresq Island are the highest impacted surface water areas in the Manning River estuary. Acid drainage from these areas can directly impact key fisheries habitat and priority oyster leases in the lower Manning River estuary as discussed in Appendix H. Note that the left and right riverbanks are defined relative to an observer looking downstream.

Table 5.1: Final Results and Rankings of the Catchment-Wide Priority Assessment

Sub-Catchment	Surface Water Factor	Surface Water Ranking	Groundwater Factor	Groundwater Ranking	Priority Ranking
Moto	1117	2	297	3	1
Ghinni Ghinni	685	4	388	1	2
Big Swamp	1018	3	158	5	3
Glenthorne	617	5	207	4	4
Coopernook	48	13	352	2	5
Pampoolah	182	7	61	7	6
Bukkan Bukkan Creek	91	9	111	6	7
Dawson River	1294	1	4	12	8
Cattai Creek	179	8	11	9	9
Mitchells Island	297	6	6	10	10
Croakers Creek	83	10	5	11	11
Taree Estate	20	15	11	8	12
Jones Island	57	12	4	13	13
Mambo Island	33	14	3	14	14
Dumaresq Island	59	11	1	15	15

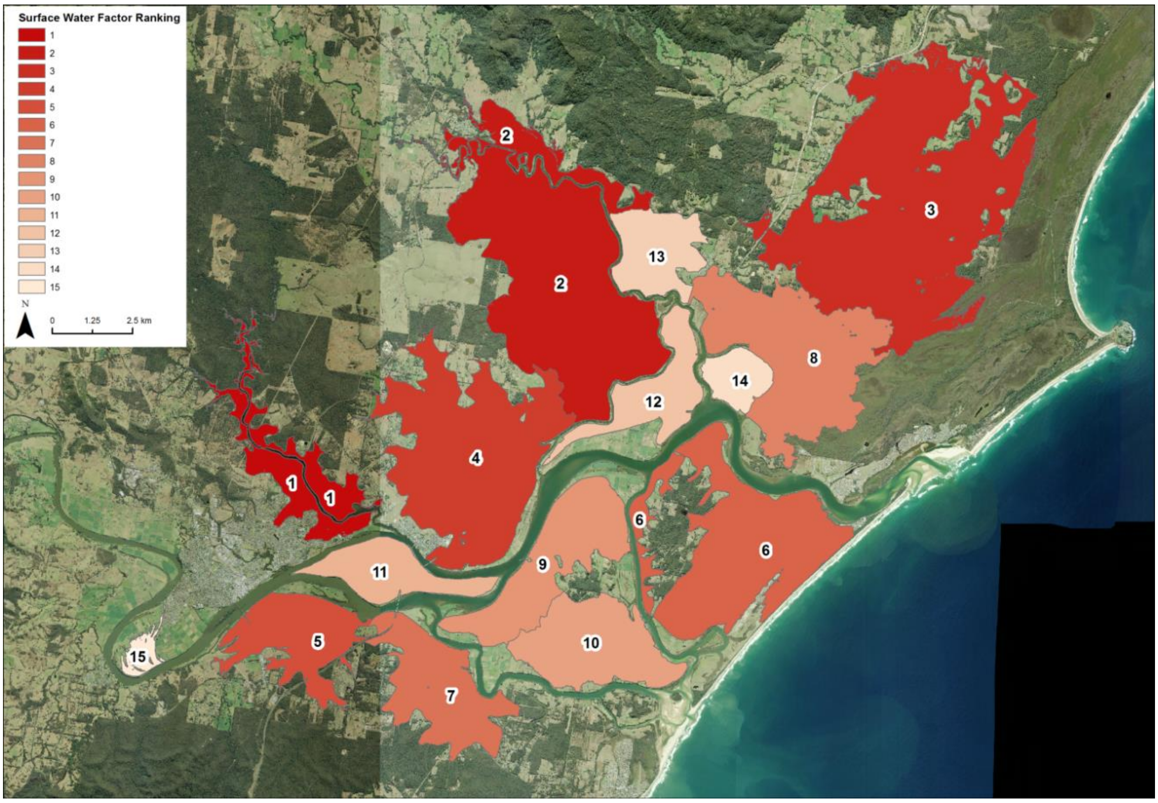


Figure 5.1: Surface Water Factor Ranking

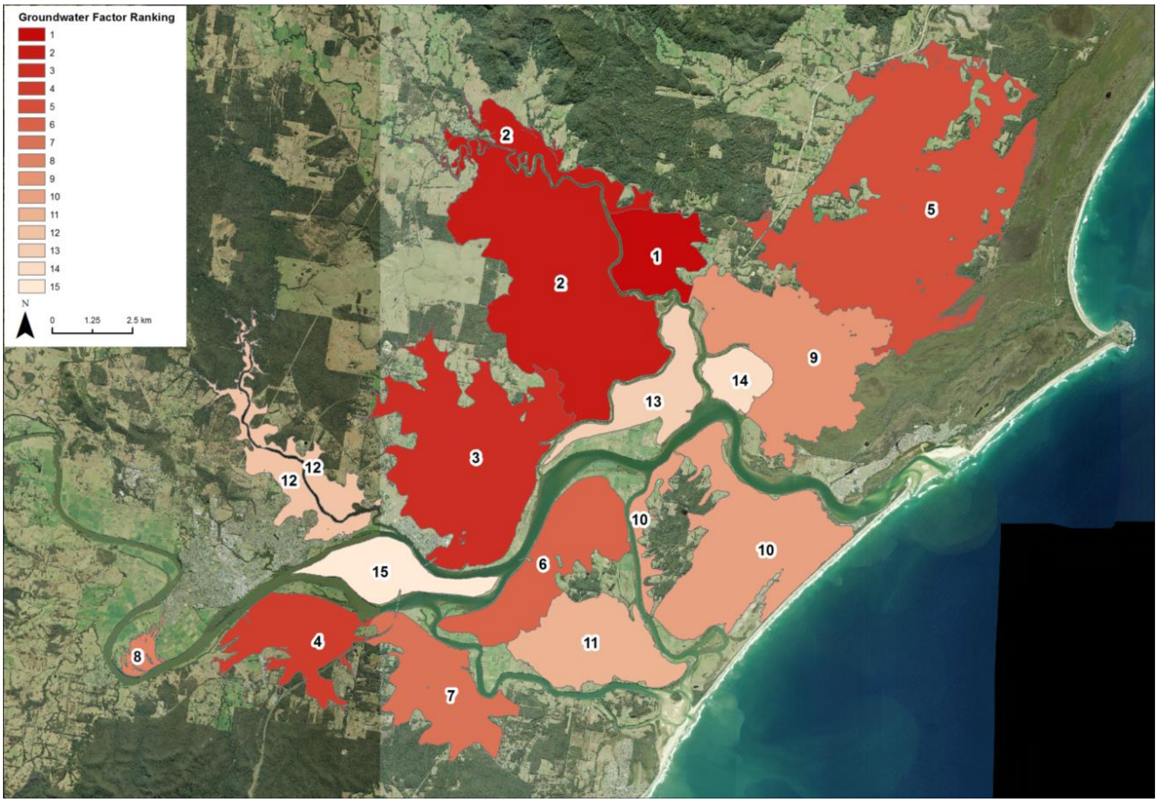


Figure 5.2: Groundwater Factor Ranking

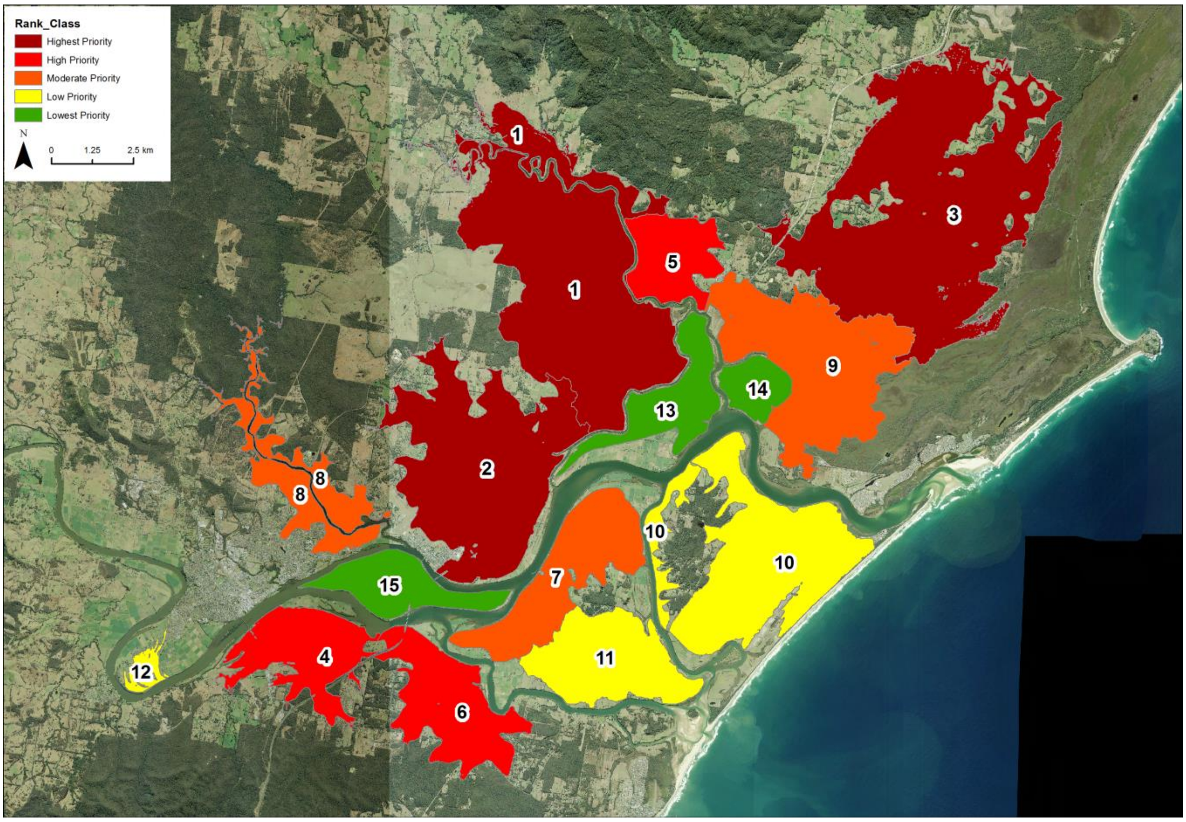


Figure 5.3: Final Rankings of Catchment-Wide Priority Assessment

5.3 Reanalysis of High Priority Areas

The three (3) highest priority areas identified by the catchment-wide assessment (Section 5.2) were reanalysed and management units within these priority areas were ranked according to the ASS-risk of specific drains, structures, or land management sub-divisions. These areas were:

1. Moto;
2. Ghinni Ghinni; and
3. Big Swamp.

5.3.1 Methodology

Catchment delineation of the drains, structures, or land management sub-divisions within the priority areas was based on high-resolution aerial photographs, LiDAR survey data, location of floodgate structures and main drains, potential flow paths, as well as on-site experience from recent field investigations. Floodplain areas for the reanalysis were estimated based on the 2 m AHD contour. The 2 m AHD contour was used to define the reanalysed drainage areas as it:

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

- Provides sufficient area to scope a range of options.

The floodplain drainage network layer provided by MidCoast Council and used in the catchment-wide assessment was subsequently updated for the reanalysis. The drainage network map of the three (3) highest priority areas was improved to represent the actual on-ground drainage density within the reanalysis drainage areas. The best available soil profile data, including soil acidity and depths to stored acid, were used to assign typical values to the reanalysis drainage areas. The majority of sites across each priority area had at least one (1) data point within the reanalysis drainage areas. If data was not available within each reanalysis drainage area, values were assigned to that drainage area based on an average of the nearest two (2) or three (3) data points from neighbouring sites (where possible). Note that for all cases catchment yield, hydraulic conductivity, and the lowest drainage elevation of each reanalysis drainage area were based on values used for the catchment-wide assessment of the priority areas.

5.3.2 Results and Rankings

A summary of the reanalysis results and rankings of the highest priority areas identified by the catchment-wide assessment are provided in Figure 5.4 to Figure 5.6. Note that these figures provide recommendations that highlight the ASS drainage sites with the greatest impact and target where future investments will provide the best value-for-money and environmental outcomes.

On the Moto floodplain, the reanalysis assessment has identified the highest priority areas for remediation in the central and lower portions of the floodplain. The highest impacted areas on Moto are also the lowest lying areas of the swamp, consequently these areas have the highest soil acidity values and have an observed AASS layer near to the surface (<0.5 m) in these areas. On the Moto floodplain, the three (3) highest priority areas account for approximately 40% of the acid risk to the broader catchment.

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

At Big Swamp, the reanalysis assessment identified the highest priority areas for remediation adjacent to existing MidCoast Council owned land and along the eastern-side Pipeclay Canal. These areas have a soil acidity below pH 4.5 and also correspond to the lowest lying areas of the site (generally <1.0 m AHD). On the Big Swamp floodplain, the two (2) highest priority areas account for approximately 60% of the acid risk to the broader catchment. Note that previously remediated sites in the Cattai Creek-Pipeclay Canal area, including upstream areas of the Cattai Wetlands, and publically acquired land on the south-west and eastern side of Pipeclay Canal at Big Swamp, were included in the reanalysis assessment. The results of the reanalysis assessment supports the ongoing management and rehabilitation objectives of the site, providing opportunities to expand existing wetland areas without impacting drainage across the site or adjacent land-holdings.

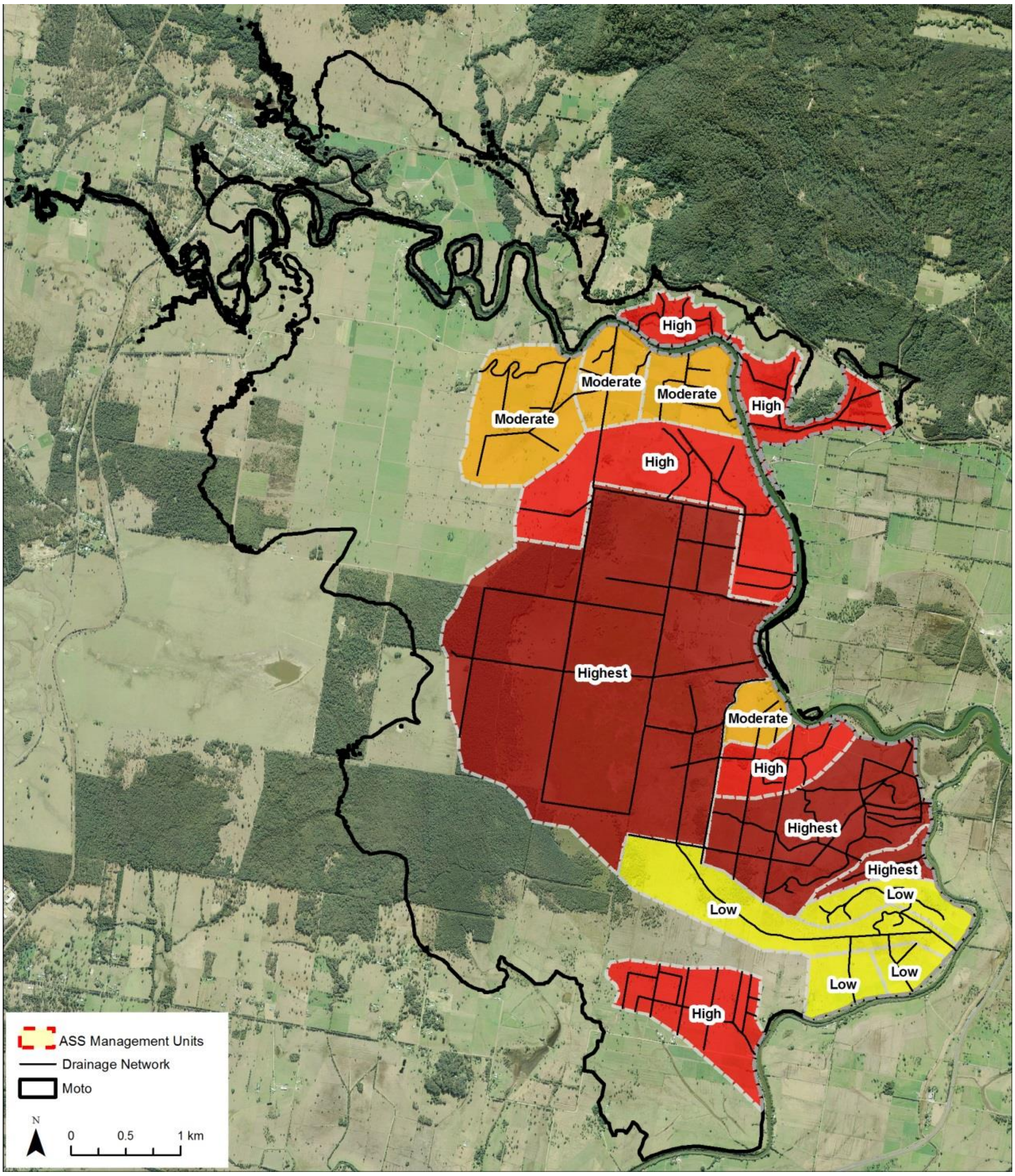


Figure 5.4: Ranking of Sub-Catchments in Priority Area 1 – Moto

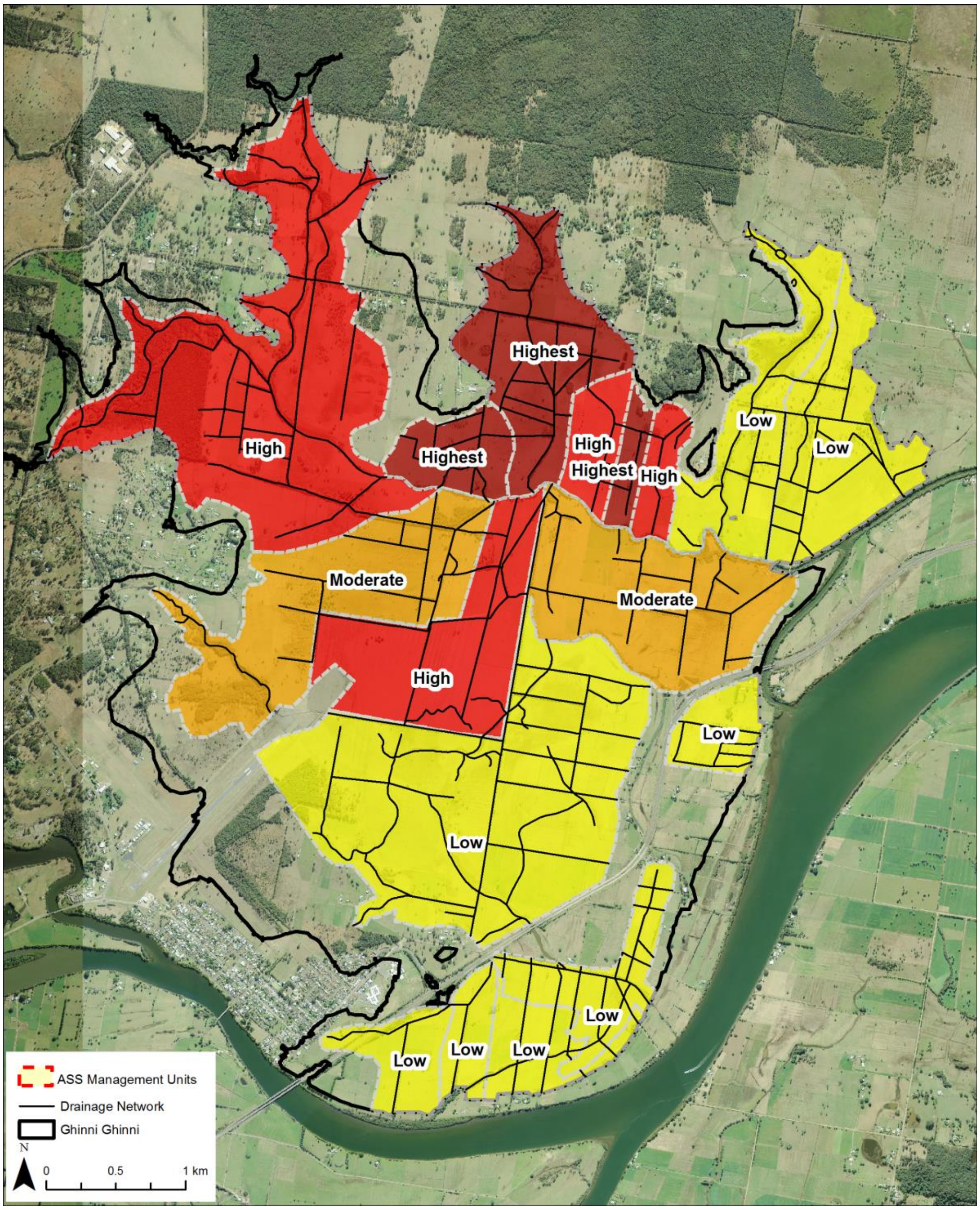


Figure 5.5: Ranking of Sub-Catchments in Priority Area 2 – Ghinni Ghinni

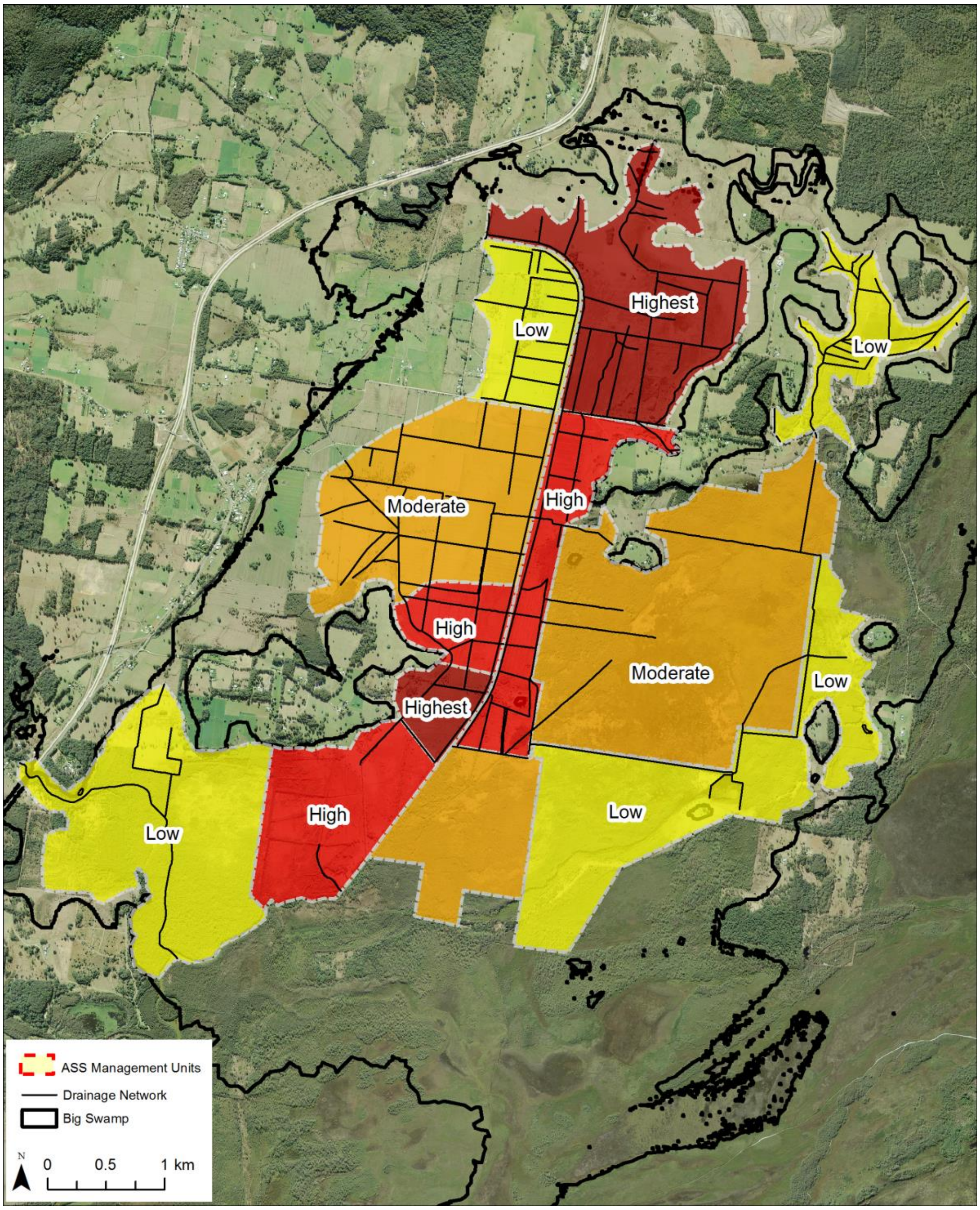


Figure 5.6: Ranking of Sub-Catchments in Priority Area 3 – Big Swamp

6. ASS Management Options

6.1 Preamble

A range of short-term (1 to 10 years) and long-term (>10 years) strategies exist for the remediation and rehabilitation of ASS-affected drains and floodplains. The applicability of each strategy is highly dependent on site specific factors such as, hydraulic conductivity, catchment topography, acid layer depth, drain condition, tidal amplitude, climate change, land use and landholder willingness. Some strategies include interim remediation options for limiting acid production and discharge, whereas other options aim to permanently stop acid production and export via rehabilitation of backswamps.

This chapter provides a brief description of short and long term remediation strategies for the management of high-priority ASS-affected areas. Further information regarding each management strategy and design considerations can be found in the Acid Sulfate Soils Remediation Guidelines for Coastal Floodplains in New South Wales (Tulau 2007).

6.2 Summary of Costs for Remediation Options

Table 6.1 provides a summary of the approximate costs (based on standard commercial rates) for the design, construction, implementation, and annual maintenance of various remediation options proposed.

Table 6.1: Approximate Costs for Various ASS Management Options

Management Option	Design Cost	Implementation	Maintenance (per annum)
Weir	$10,000	$10,000 to $30,000	$5,000 to 15,000
Floodgate modification	$10,000	$10,000 to $25,000 per gate	$5,000 to $10,000
Liming	$5,000	$15/m^3 acid soil (dependent on acid content)	None
Culvert relocation	$15,000	$60,000 to $100,000 per culvert	$8,000
Drain infilling	$15,000	Equipment establishment ($5,000) + unit rate ($10,000/500 m)	None
Drain reshaping	$15,000	Equipment establishment ($5,000) + unit rate ($20,000/500 m)	None
Permeable Reactive Barrier (PRB)	$40,000	$10,000/100 m to $100,000/100 m	$20,000
Wet pasture	$15,000	Potential: Structure relocation + Land acquisition + Drain infilling	None
Land raising	Design and potential flood impact assessment.	Equipment establishment + fill + daily rate	None
Full Rehabilitation	$15,000	Land acquisition (per ha) + Drain infilling + Drain reshaping + Infrastructure removal + Infrastructure relocation	None

6.3 Interim (Short-Term) Remediation Options

Interim remediation options aim to reduce the production and export of existing acidity and have a design life of approximately 10 years. Short-term acid management options can be characterised as:

- Low implementation cost;
- Low agricultural/landholder impact; and
- High ongoing maintenance cost.

A range of interim remediation options are detailed below.

6.3.1 Groundwater Manipulation

Installation of weirs in drainage channels has been shown to reduce the production of acid across ASS-affected floodplains (Blunden and Indraratna 2000). Weirs promote higher drain and groundwater elevations that reduce groundwater drawdown, thereby minimising the hydraulic gradient between groundwater and drainage channels.

Weirs are generally applicable in higher elevation locations on the floodplain, where increases in drain water levels do not result in inundated paddocks or decreased agricultural productivity. Lawrie and Eldridge (2002) noted that the impact of weirs on agricultural activity is minimal, while Blunden and Indraratna (2000) found weir installations to be a successful strategy for minimising acid export in the upper Broughton Creek floodplain, within the Shoalhaven River estuary. The optimal weir crest elevation is dependent on the elevation of the acidic soil layer. Ideally, the weir crest elevation is situated at, or above the elevation of the AASS layer. This minimises the potential for lateral flow of acidic water from the ground into the drain (Figure 6.1).

Weirs are often designed to reduce acid export whilst maintaining effective drainage during wet periods. Adjustable weirs (i.e. drop boards) are desirable to maintain agricultural productivity following flood periods, while raising the weir crest during dry periods reduces the groundwater hydraulic gradient and minimises acid export. Figure 6.1 depicts how a weir reduces acid generation and export.

Tulau (2007) listed a number of criteria that need to be considered for design and installation of weirs to be successful, including:

- Suitable to local conditions;
- Maintains the efficiency of the flood mitigation system;
- Controls different water levels;
- Uses low maintenance and durable materials;
- Complies with WH&S;
- Vandal resistant;
- Cost effective;
- Landholder willingness and approval; and
- Complies with current legislation.

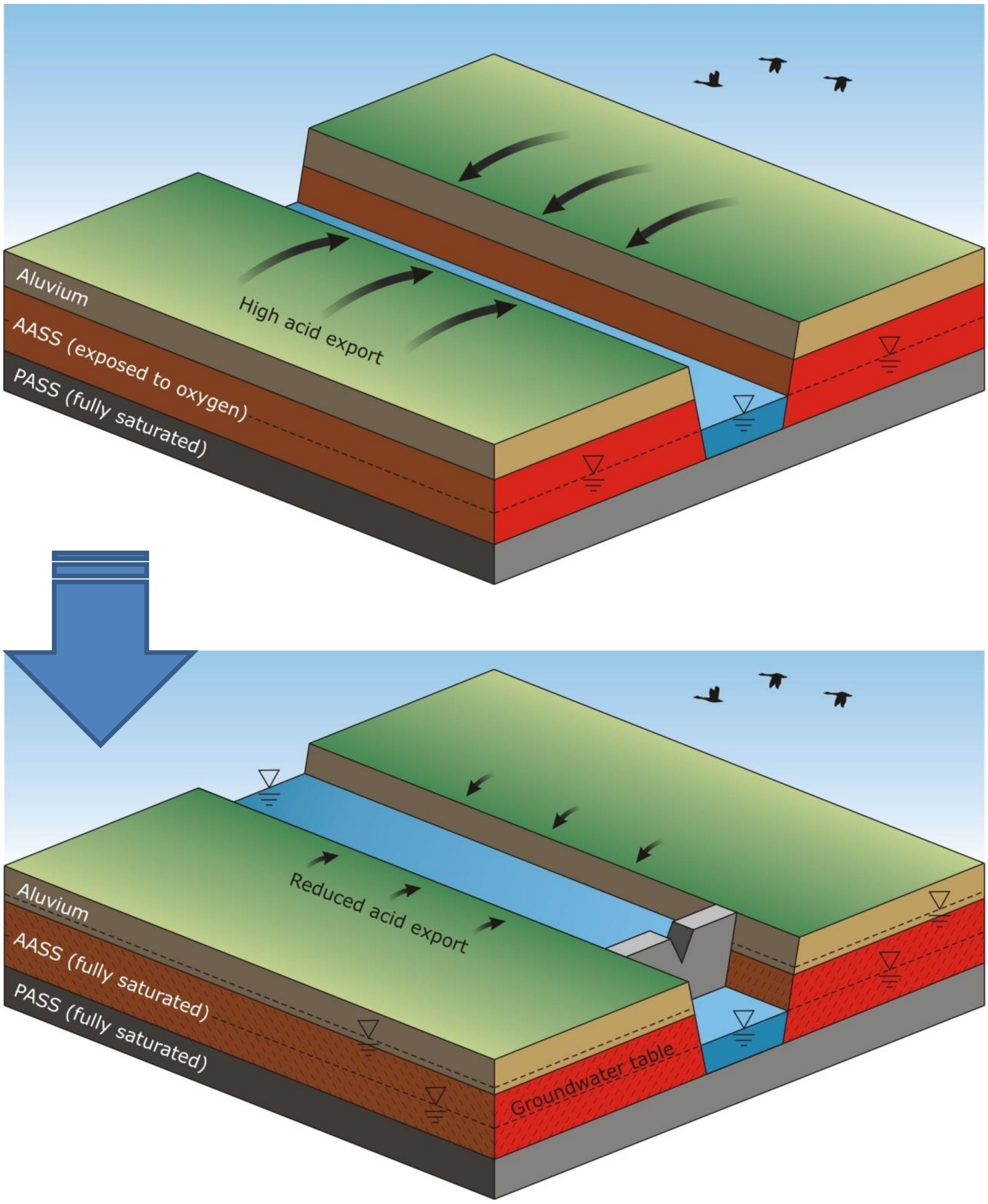


Figure 6.1: Weir Implementation Before (top) and After (bottom)

6.3.2 Tidal/Saline Manipulation

One-way floodgates prohibit tidal inundation, maximise pasture drainage, and maintain drain water levels at low tide elevations. When ASS are present, tidal floodgates increase acid discharge and restrict in-drain tidal buffering. Floodgate management and/or modification is widely practiced in NSW. Glamore (2003) showed in the Shoalhaven River Estuary that modified floodgates that permit two-way tidal flows significantly improved water quality, and generally reduced the downstream impacts of ASS discharges. Furthermore, specific benefits of floodgate modification include:

- Improved drain water quality through flushing and acid buffering;
- Reduced exotic drain vegetation; and
- Increased fish passage (NSW DPI 2007).

The extent of tidal restoration at a site is often dependent on the site topography, tidal elevations, available bicarbonate/carbonate from tidal water, and current land use practices. Typically, farmers use in-drain tidal flushing to control weed vegetation, while not impacting adjacent floodplain areas of agricultural production. Uninhibited tidal restoration is rarely undertaken, except when tidal amplitude is low, or where agricultural land use practices are abandoned, or where private land is publically acquired. The installation of auto-tidal gates permits tidal flushing up to a pre-determined elevation based on design. Maximum inundation elevations are usually dependent on the topography of the backswamp. Figure 6.2 depicts how a modified floodgate can restore tidal flushing to an ASS-affected drainage channel.

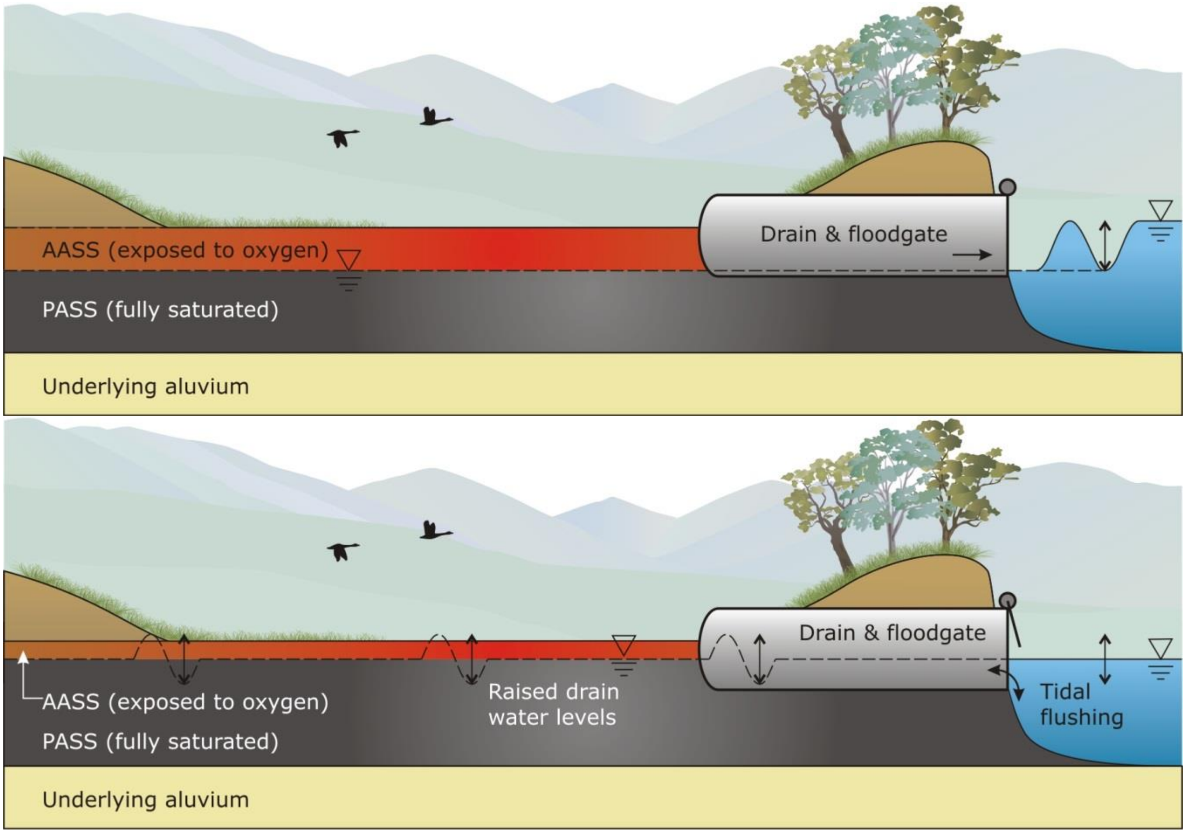


Figure 6.2: Before and After Floodgate Modification

6.3.3 Liming for Acid Neutralisation

When applied to ASS, lime reacts with the soil to neutralise its acidity. Lime is comprised of calcium hydroxide (CaOH) and is often applied directly to disturbed or exposed ASS as a dry powder. The liming approach is commonly undertaken when soil acidity levels are low or when ASS are excavated and small scale neutralisation is required. Lime is rarely applied directly to ASS as a broad-acre solution due to the large quantities required for neutralisation and the difficulty in mixing the lime with clayey soils.

The injection or application of lime to deep or shallow ASS-affected areas requires large quantities of lime mixed with water to form a slurry to facilitate pumping. Deeper lime injection requires the construction of a borehole network. Large scale application of lime on either the surface or sub-surface of acid affected soil is not a cost effective management strategy in the Manning region due to the acid content in the soil. Liming is often used in conjunction with other remediation strategies which require small scale earthworks such as, levee removal and drain reshaping.

6.3.4 Permeable Reactive Barriers (PRB)

Permeable Reactive Barriers (PRB) are a vertical barrier that allows the passing of groundwater. PRBs have been applied at various groundwater contamination sites due to the cost when compared to the cost of treating shallow aquifers (Regmi et al. 2009). PRBs can remove contaminants by (i) absorption and precipitation; (ii) chemical reaction; and (iii) biological processes (Tratnyek et al. 2003). The application of PRBs to groundwater contamination is usually applied to a point source contamination to remove the contamination in-situ or installed to protect important infrastructure from damage (e.g. building foundations).

PRBs can be applied to ASS-affected groundwater by installation beneath drain levee banks. Acidic groundwater flowing towards the drain passes through the PRB and is neutralised prior to being discharged into the drainage channel (Figure 6.3). The application of PRBs to buffer acidic groundwater was tested on the Broughton Creek floodplain in 2006 (Indraratna et al. 2006). Results from the field testing indicated that acid buffering by the PRB was effective. However, application of PRBs is not considered to be a cost-effective management strategy in the Manning region due to the widespread distribution of ASS. PRBs are more suited to smaller scale in-situ treatment of acidic groundwater or other sub-surface contamination.

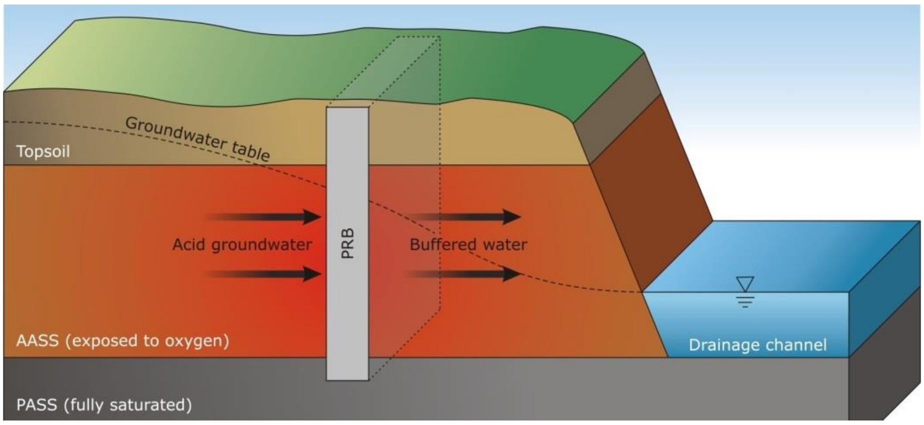


Figure 6.3: Permeable Reactive Barrier (PRB) Application to Neutralise Acidic Groundwater

6.4 Long-term Rehabilitation Options

Long-term management options aim to completely rehabilitate ASS-affected sites and prohibit future acid production. These strategies mainly target changes to current land use practices. Long-term management options are characterised by:

- Potential impact to agricultural/landholder;
- Minimal ongoing maintenance;
- Changed/improved land-use practices/management; and
- Higher capital cost.

Although longer-term management options may result in significant changes to land use practices, application of these management options have the potential to be implemented over a portion of an ASS-affected area to maintain agricultural activities. These areas can be targeted for long-term remediation, while lesser affected areas are managed on a short-term, reactive time-scale. This approach allows for agricultural productivity to continue, whilst addressing key areas of concern. A good example of this approach is shown by the rehabilitation of low-lying, high-priority areas at Big Swamp.

6.4.1 Wet Pasture

Wet pasture, or reflooding, involves retaining fresh surface water on pastures during dry periods by limiting drainage. Tulau (2007) asserted that this option aims to contain acid and other oxidation products within the soil and surface water by raising water levels in the drain (Figure 6.4). This is usually achieved by installation of structures in the drainage channel such as a weir, and/or modification of pasture drainage pathways by drain infilling or reshaping.

Johnston et al. (2003) showed that the acid discharge rate from a wet pasture managed system significantly reduces acid export where groundwater seepage is the main export pathway. This is mainly achieved by reducing the frequency and volume of groundwater flow. Subsequently, this option is particularly suitable to a site with high to extreme hydraulic conductivity.

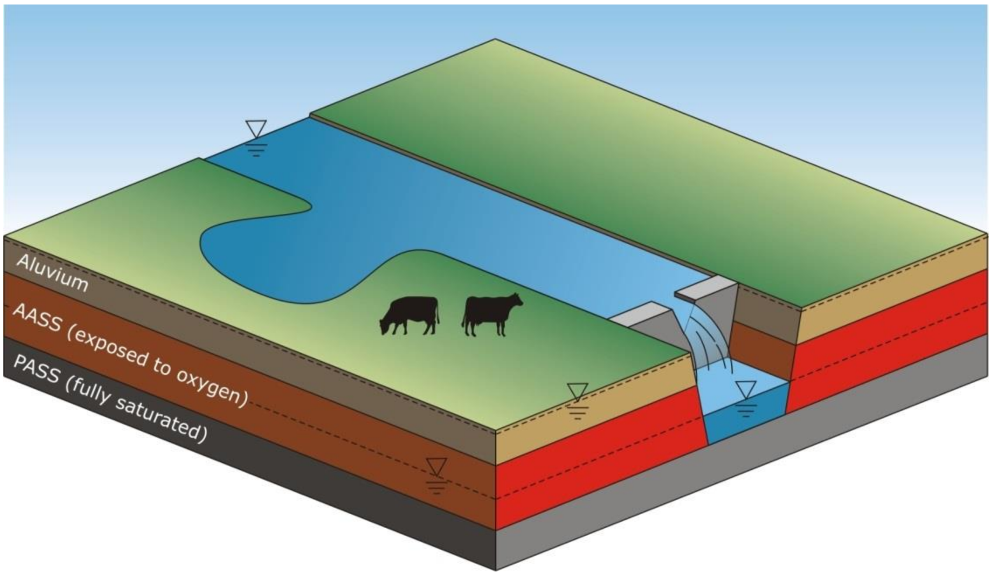


Figure 6.4: Wet Pasture Management

6.4.2 Drain Infilling and Reshaping

Infilling, shallowing and reshaping drains can be an effective means of reducing acid discharge and other negative impacts of over drainage, particularly in ASS-affected backswamps (Johnston et al. 2003). Raising drain invert levels, while maintaining the effective drain cross-sectional area, acts to reduce acid seepage and maintains drainage capacity of the existing system. These drains are commonly referred to as ‘swale drains’ and are depicted in Figure 6.5.

Narrow, deep drains are ideal candidates for drain reshaping, as the drain cross-sectional area required to provide efficient drainage can be maintained by conversion to a shallow, wide swale drain. Conversely, a wide, deep drain would require a significantly wider swale drain to be constructed to maintain the effective cross-sectional flow area. This strategy is applicable where the acid soil layer is sufficiently deep enough to enable an efficient drainage slope from the back swamp to the estuary without the drain invert disturbing the acid layer.

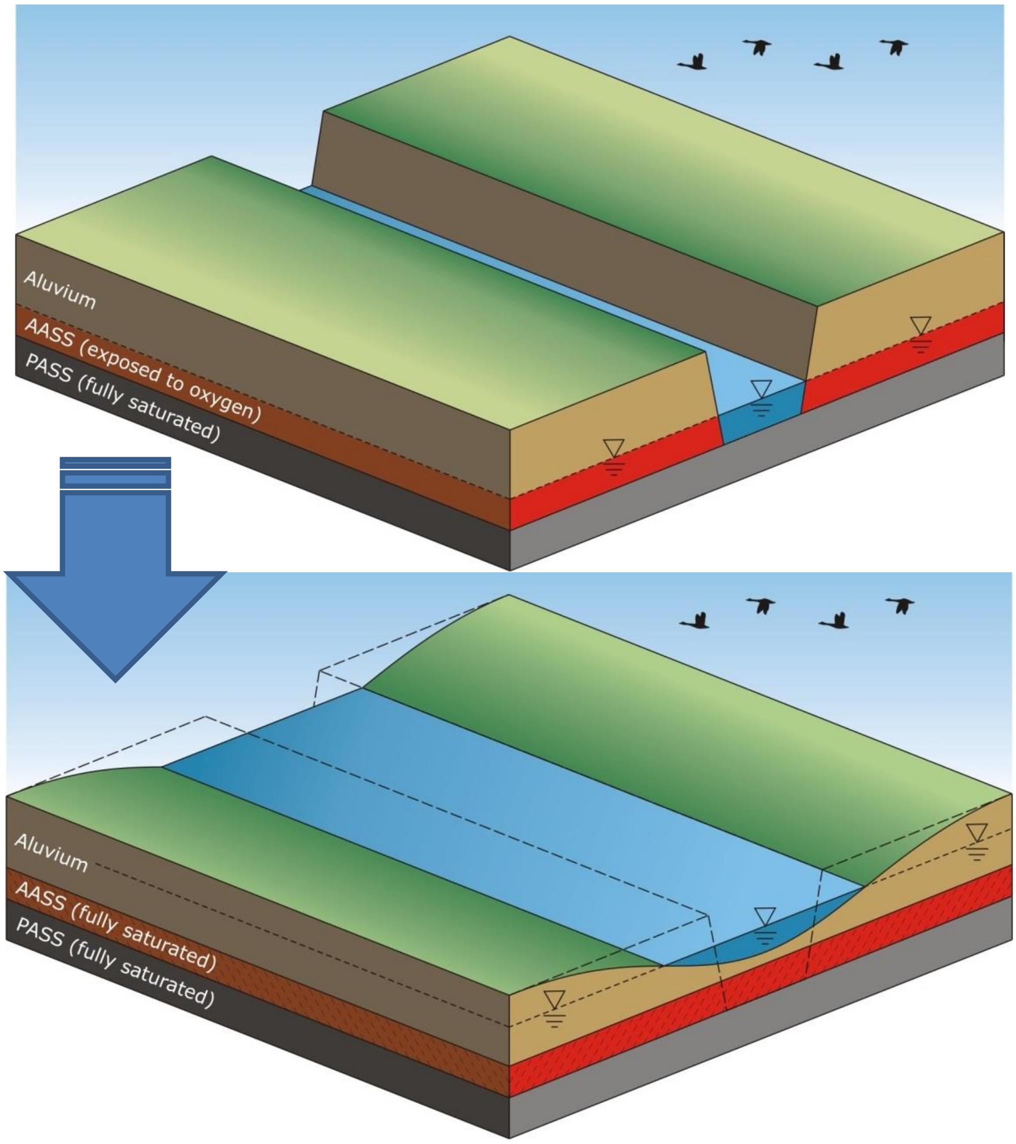


Figure 6.5: Before and After Swale Drain Construction

6.4.3 Land Raising

Raising of land by addition of fill (or reshaping) enables acid remediation strategies to be applied without affecting agricultural practices. Depending on the site, land raising would require significant volumes of soil to be transported and levelled across the pastures. This could be implemented where saline tidal inundation is likely to be detrimental to the upper soil profile and existing agricultural practices (Figure 6.6).

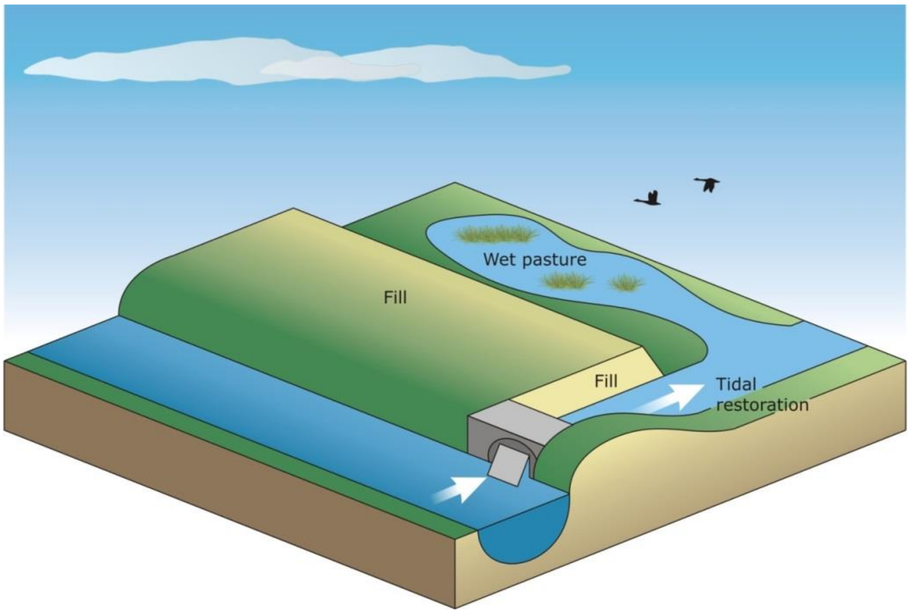


Figure 6.6: Schematic of Partial Land Raising

6.4.4 Full Rehabilitation

The floodplains of the north coast rivers once included extensive areas of largely freshwater backswamps. The wettest sites were formerly dominated by grasslands, sedgelands, reedlands, or open water. The open character and extent of backswamp vegetation has been confirmed by historical land survey records for a number of sites, including on the Manning at Moto, Ghinni Ghinni, and Big Swamp. Full rehabilitation of former backswamp areas to a resemblance of their former condition could effectively limit acid export and provide habitat for primary production. In a similar manner to land raising and wet pasture management options, rehabilitation of a site to create saltmarsh or tidal/freshwater wetlands could be undertaken over an entire ASS-affected drainage area, or on a portion of the floodplain. This strategy has been effectively applied at other acid affected sites in NSW, such as Tomago wetlands near Newcastle (Rayner and Glamore 2010) and Big Swamp (Glamore et al. 2014).

Wetland or saltmarsh creation would require flow restrictions, such as, levees and floodgates to be removed or relocated, as well as drains to be infilled or reshaped as depicted in Figure 6.7. Where partial rehabilitation is optioned, structures may be relocated to maintain existing agricultural land use conditions for other areas of the floodplain. Where full rehabilitation is considered, regular tidal inundation would provide immediate natural buffering of ASS-affected areas and maintain high groundwater levels. This management option has the greatest immediate environmental benefit by increasing water quality, eliminating acid discharge, and providing aquatic habitat and fish passage. This option requires the largest change to existing land management.

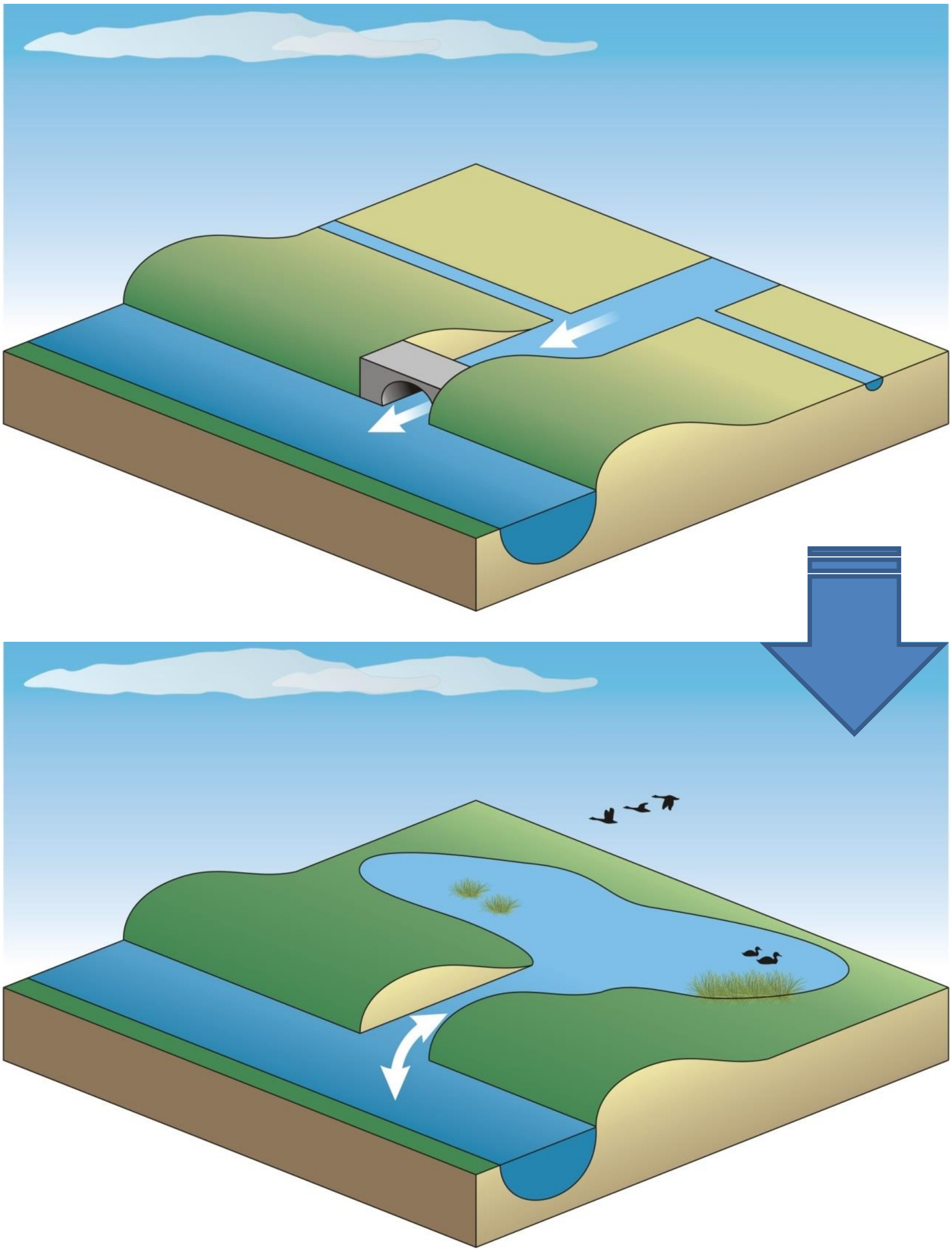


Figure 6.7: Full Rehabilitation to Natural, Unrestricted Wetland

7. Sub-Catchment ASS Remediation Action Plans

7.1 Preamble

This section presents the proposed short and long-term remediation Action Plans for 15 sub-catchments across the Manning River floodplain. Action Plans are presented in order of priority ranking from highest to lowest risk of ASS drainage. The Action Plans provide a preliminary outline of recommended remediation strategies to reduce the impact of ASS drainage on the Manning River estuary. For each drainage sub-catchment the cost estimate for design, implementation and ongoing maintenance of short and long-term Action Plans is provided throughout the discussion. These costs are based on 2016 prices and should be considered an estimate only. The cost estimates for each potential remediation option outlined in Table 6.1 was applied to each sub-catchment depending on the combination of remediation options recommended.

Further investigation will be required to determine precise engineering specifications prior to implementing any remedial works. Site investigations should adequately consider the potential impact of any remedial works on existing native wetland vegetation and naturally acidic landscapes. ASS soil sampling and analysis should be completed following detailed design of on-ground remediation works. All excavation should be undertaken with machinery utilising laser levelling equipment above AASS layer elevations to minimise potential disturbance. Any disturbed ASS should be treated with lime as per the ASS Remediation Guidelines. Monitoring of the remediation works using photo points or water quality sampling following high rainfall events should be undertaken (where practicable).

7.2 High Priority Area 1: Moto

7.2.1 Site Description

The Moto ASS Priority Area is a large backswamp and associated floodplain located in the northern-central part of the Manning River estuary. The Moto ASS Priority Area is the largest ASS-affected region in the Manning River estuary and covers an area of approximately 3,500 ha below 5 m AHD. Most of the Moto floodplain is situated below 1 m AHD (Figure 7.1). The floodplain drains through an extensive, inter-connected drainage network and discharges acidic surface waters into Ghinni Ghinni Creek and the Lansdowne River. The south-eastern portion of the Moto floodplain is currently managed by the Moto Drainage Union and is drained independently of the mid and northern sections of the floodplain. Several sensitive receivers are located downstream of the Moto ASS Priority Area, including key fisheries habitat, priority oyster leases and seagrass, that are impacted by acid discharges from Ghinni Ghinni Creek and the Lansdowne River.

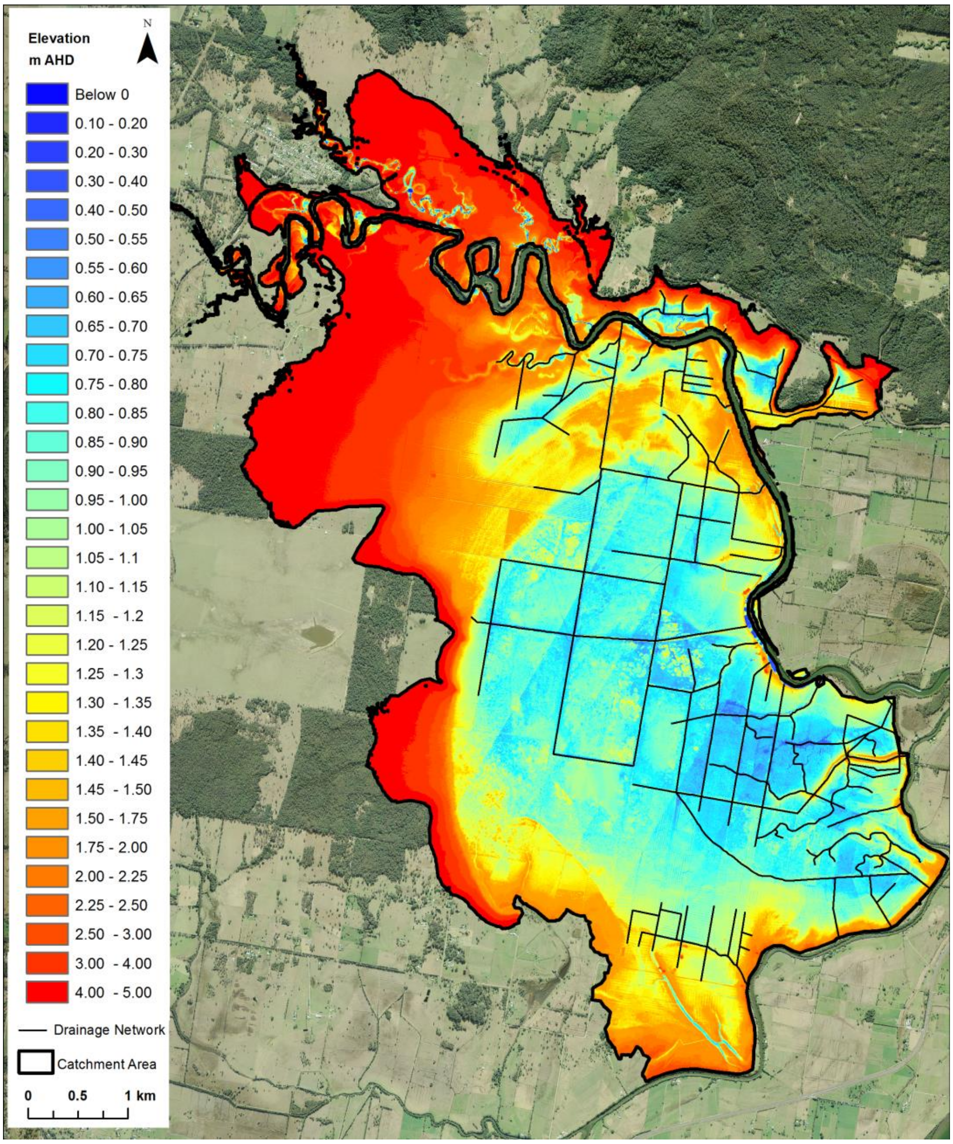


Figure 7.1: Sub-Catchment Boundary, Elevation Detail, Drainage Network – Moto

7.2.2 History of Remediation

A timeline of remediation works within the Moto Priority Area is provided below with reference to Figure 7.2. The works included:

- 1999 – A scald revegetation project to remediate acid scald in areas of the Lower Lansdowne (north Moto) by the former NSW Agriculture.
- 2001 – Preparation of the 'Remediation Concept Plan for the Lower Lansdowne – Moto – Ghinni Ghinni Creek ASS Hot Spot' by the former Department of Land and Water Conservation as part of the NSW ASS Hot Spot Program (Currie and Atkinson 2001). The Concept Plan was followed by a detailed Rehabilitation Plan, but it is unconfirmed if any on-ground works were completed as a result of the NSW ASS Hot Spot Program.
- January 2008 – Moto ASS Drainage Management Plan completed by the Moto Drainage Board. The Management Plan included recommendations for drainage and floodgate modification works in Moto Areas 16 (M16) and 10 (M10), as well as two (2) constructed breaches in the levee between north and south Moto to "*allow greater removal of surface water from south Moto through north Moto to the Lansdowne River*" (MidCoast Council 2008b). The drainage modification works targeted three (3) drains: two (2) drains in Moto Area 16 (M16) and one (1) drain in Moto Area 10 (M10) – that included drain reshaping to raise the drain invert level to 0.1 m AHD, and installation of a water control structure with invert of 0.2 m AHD.
- February 2008 – An ASS Drainage Management Plan was prepared by MidCoast Council for remedial works on a portion of the Roche property on the Moto floodplain (Moto Area 1 (M1) on Figure 7.2). Funding of $60,000 was provided by MidCoast Council in partnership with the Hunter-Central Rivers Catchment Management Authority (Project Id: HCR 05-1/236). The project focused on expanding an existing low-lying wet pasture area (approximately 140 ha) on the southern-side of Moto Area 1 to "*reduce the severity of acid discharges from this portion of the property*" (MidCoast Council 2008c). The on-ground works within the nominated wet pasture area included:
    1. Infilling unused drains;
    2. Constructing a weir to manage water levels; and
    3. Constructing/reshaping levees to isolate the wet pasture area from adjacent productive agricultural land. Note that liming was used to treat any disturbed ASS.
- August 2009 – Addendum to the Moto ASS Drainage Management Plan by MidCoast Council for additional drainage modification works in Moto Areas 16 (M16) and 10 (M10) to "*improve the drainage capacity of the swale drains to maximise surface water removal while maintaining the in-drain structures as designed in the original management plan*" (MidCoast Council 2009b).

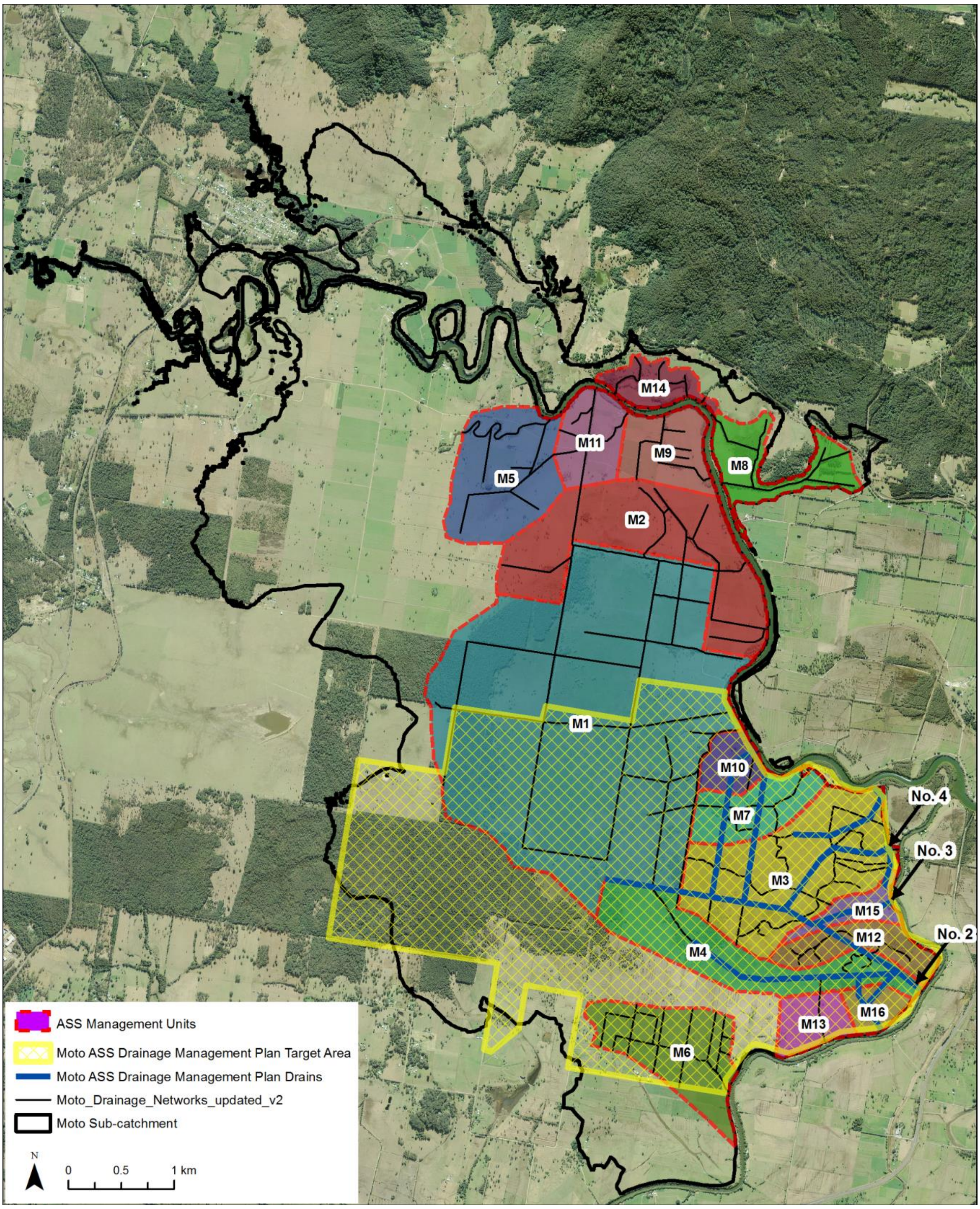


Figure 7.2: Sub-Catchments of the Moto Floodplain Including Moto ASS Drainage Management Plan Target Area

7.2.3 Remediation Action Plan

The Action Plan for the Moto ASS Priority Area includes preliminary recommendations for on-ground works within 16 drainage units of the sub-catchment. The 16 drainage units of the sub-catchment are presented in order of ranking from highest to lowest risk of ASS drainage as shown in Figure 7.3. A summary of the properties of the 16 drainage units is provided in Table 7.1. Preliminary recommendations and indicative costs of on-ground works for each drainage unit are then provided in Table 7.2.

A summary of the immediate and long-term management recommendations include:

Immediate Remediation Strategy

Portions of the Moto ASS Priority Area have previously been targeted for remediation as part of the Moto ASS Drainage Management Plan (refer to Section 7.2.2). Previous on-ground works have focused on partial remediation of Moto Priority Areas M1, M3, M4, M7, M10, M15, and M16 in the southern portion of the Moto floodplain. The on-ground works in these areas involved wet pasture creation, infilling/reshaping main drains, and modification of structures on main drains to raise inverts. Where applicable, other areas of the Moto floodplain should be targeted to support the outcomes of the 2008 Moto Drainage Management Plan by further floodgate management/modification and filing/reshaping drains. This may include the installation of much wider culvert/floodgates at a higher AHD level to allow surface water runoff and prevent black water events after summer floods, which is a known problem in the Moto area. Furthermore, expanded wet pasture management is encouraged across all low-lying, boggy areas of the floodplain.

Moto Priority Areas M2, M8, and M14 are delineated from the main Moto swamp and are considered to be separate drainage units. These areas would benefit from a combination of floodgate management and drain infilling/reshaping to raise the local groundwater table and reduce the acid drainage from the surrounding floodplain to drains. Note that infilling/reshaping would also require fencing to avoid stock getting stuck trying to cross infilled drains. These areas contain extensive acid stores and AASS within approximately 200 mm from the surface. As such, ASS soil sampling and analysis should be completed following detailed design of on-ground remediation works.

Long-term Remediation Strategy

The Moto ASS Priority Area features some of the lowest-lying topography on the entire Manning River floodplain. This area is likely to be increasingly affected by reduced drainage, with large areas remaining inundated by 2050 due to increases in low tide levels. Without additional infrastructure the agricultural productivity of the Moto swamp is likely to become increasingly reduced and options for full rehabilitation of poorly drained land to wet pastures (freshwater), or wetland (saline) should be investigated.

Indicative Cost: $15,000 for design plus costs for environmental offset. Environmental offset may include land acquisition, drain infilling, drain reshaping and/or infrastructure removal.

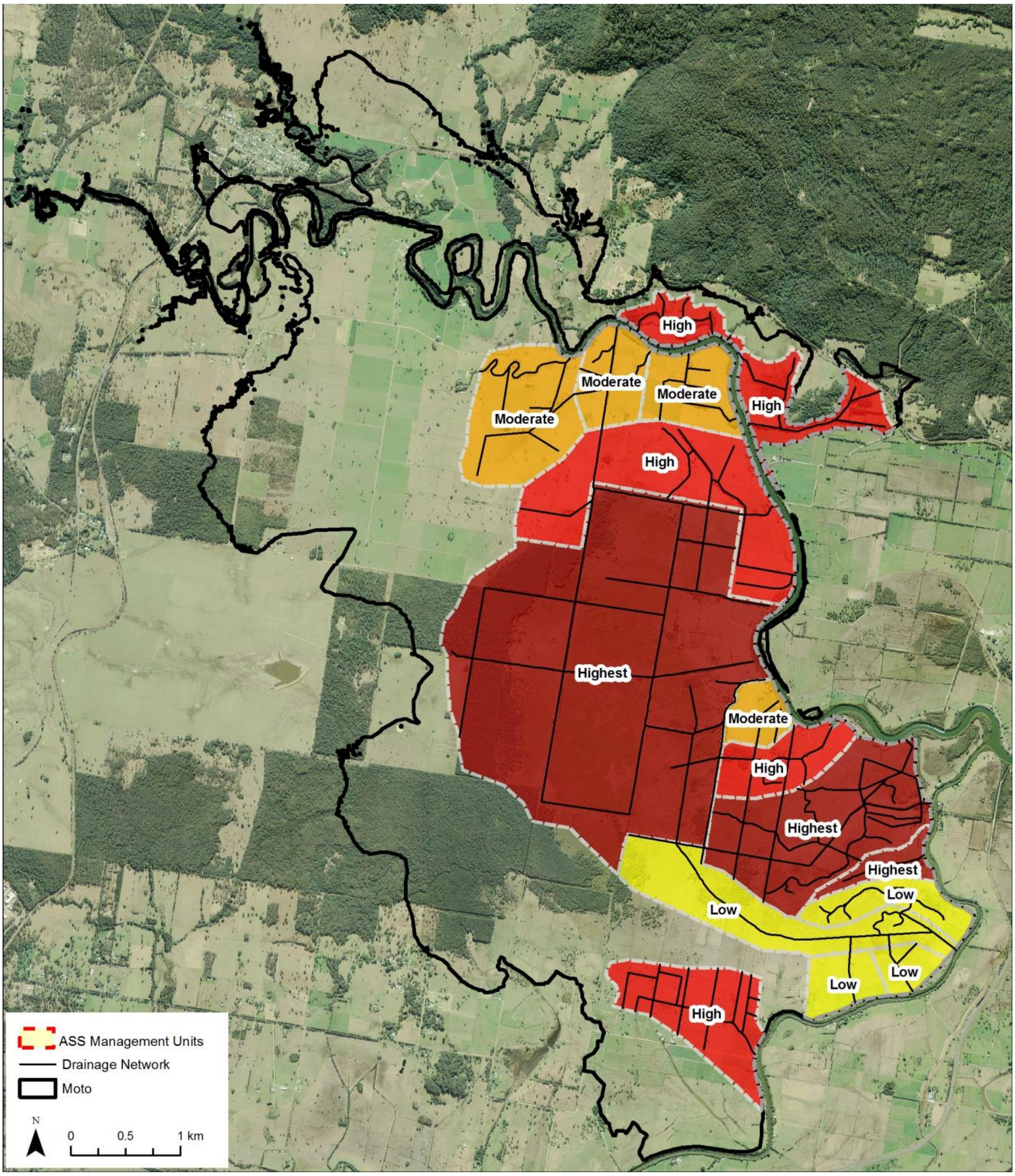


Figure 7.3: Ranking of Sub-Catchments in Priority Area 1 – Moto

Table 7.1: Sub-Catchment Site Details for Moto

Priority Management Areas	Priority Rank	Approximate Depth to AASS (m)	Approximate Depth to PASS (m)	Approximate Elevation of AASS (m AHD)	Approximate Elevation of PASS (m AHD)	Median pH	Drainage Area (ha)	Drain Details			
								Nominal Length (m)	Nominal Width (m)	MidCoast Council Floodgate Structure ID	Invert (m AHD)
M1	Highest	0.3	1.4	0.7	-0.4	3.6	708	21,480	4	568,574	-0.86
M3	Highest	0.5	2.4	0.4	-1.4	4.0	190	12,542	5	584,589	-
M15	Highest	0.6	2.4	0.4	-1.4	3.8	24	787	5	592	-
M8	High	0.2	1.5	0.5	-0.8	4.1	61	3,185	4	555	-
M7	High	0.3	1.8	0.7	-0.8	4.1	57	2,931	5	581	-
M2	High	0.1	1.5	1.1	-0.5	4.0	187	5,605	4	563	-
M14	High	0.2	1.5	1.5	-0.8	4.3	32	1,495	8	552	-
M6	High	0.3	1.5	0.7	-0.6	4.3	97	5,572	3	612,614	-
M9	Moderate	0.1	1.5	1.1	-0.5	4.3	56	2,328	10	554	-
M11	Moderate	0.2	1.4	0.9	-0.5	4.3	50	2,156	10	557,558	-
M10	Moderate	0.3	1.8	0.7	-0.8	4.1	29	794	6	575	-0.53
M5	Moderate	0.2	2.0	1.1	-1.0	4.4	114	4,237	5	556	-
M4	Low	0.3	1.5	0.7	-0.6	5.1	122	5,099	3	600	-
M12	Low	0.4	1.5	0.7	-0.6	5.1	46	1,797	5	-	-
M16	Low	0.4	1.5	0.5	-0.6	5.2	21	737	3	601	-
M13	Low	0.4	1.5	0.5	-0.6	5.2	33	468	3	605	-

Table 7.2: Sub-Catchment Remediation Action Plans for Moto

Priority Management Areas	Priority Rank	Short Term Management Option	Short Term Design Cost	Short Term Implementation Cost	Short Term Annual Maintenance Cost	Short-Term Indicative Cost	Long Term Management Option	Long-Term Indicative Cost
M1	Highest	A + C	$10,000	$30,000 + $5,000	$5,000	<$50,000	F	$15,000 + environmental offset*
M3	Highest	A + C	$10,000	$30,000 + $5,000	$5,000	<$50,000	F	$15,000 + environmental offset*
M15	Highest	A + C	$10,000	$15,000 + $5,000	$5,000	<$50,000	F	$15,000 + environmental offset*
M8	High	A + B	$10,000 + $15,000	$15,000 + $120,000	$5,000	>$150,000	E	$15,000 + environmental offset*
M7	High	A + C	$10,000	$15,000 + $5,000	$5,000	<$50,000	F	$15,000 + environmental offset*
M2	High	A + C	$10,000	$15,000 + $5,000	$5,000	<$50,000	F	$15,000 + environmental offset*
M14	High	A + B	$10,000 + $15,000	$15,000 + $60,000	$5,000	<$120,000	F	$15,000 + environmental offset*
M6	High	A	$10,000	$30,000	$5,000	<$50,000	E	$15,000 + environmental offset*
M9	Moderate	A + B	$10,000 + $15,000	$15,000 + $100,000	$5,000	<$150,000	D	$15,000 + environmental offset*
M11	Moderate	A + B	$10,000 + $15,000	$30,000 + $80,000	$5,000	<$150,000	D	$15,000 + environmental offset*
M10	Moderate	A + C	$10,000	$15,000 + $5,000	$5,000	<$50,000	F	$15,000 + environmental offset*
M5	Moderate	A + B	$10,000 + $15,000	$15,000 + $180,000	$5,000	>$200,000	D	$15,000 + environmental offset*
M4	Low	A + C	$10,000	$15,000 + $5,000	$5,000	<$50,000	E	$15,000 + environmental offset*
M12	Low	C	-	-	-	<$5,000	E	$15,000 + environmental offset*
M16	Low	A + C	$10,000	$15,000 + $5,000	$5,000	<$50,000	E	$15,000 + environmental offset*
M13	Low	A + C	$10,000	$15,000 + $5,000	$5,000	<$50,000	E	$15,000 + environmental offset*

Management Options Key:

A = Floodgate Management
B = Drain Reshaping
C = Community Engagement and Training
D = Wet Pasture
E = Partial Rehabilitation
F = Full Rehabilitation
G = Groundwater Manipulation
H = Drop Board Weir
I = Preliminary Investigation
J = Partial Land Raising
K = Acquisition
L = Adaptive Land Management

* Environmental Offset may include detailed design, land acquisition, drain infilling, drain reshaping, fencing and/or infrastructure removal/modification.

7.3 High Priority Area 2: Ghinni Ghinni (Dickensons Creek)

7.3.1 Site Description

The Ghinni Ghinni ASS Priority Area is a backswamp area located in the central part of the Manning River floodplain. The Ghinni Ghinni ASS Priority Area is an extensive ASS-affected region in the Manning River estuary, covering an area of approximately 2,500 ha below 5 m AHD. A large portion of the floodplain is situated below 1 m AHD (Figure 7.4). Dickensons Creek and its levee divides the northern and southern parts of Ghinni Ghinni floodplain into two (2) separate hydrological units below approximately 2 to 4 m AHD. The majority of the floodplain drains through an extensive, inter-connected drainage network that discharges acidic surface waters into Dickensons Creek. Dickensons Creek discharges into the Manning River estuary via Ghinni Ghinni Creek. Paddys Creek drains a portion of the southern floodplain and discharges directly into the Manning River. Several sensitive receivers are located downstream of the Moto ASS Priority Area, including key fisheries habitat, priority oyster leases and seagrass, that are impacted by acid discharges from Ghinni Ghinni Creek and the Lansdowne River.

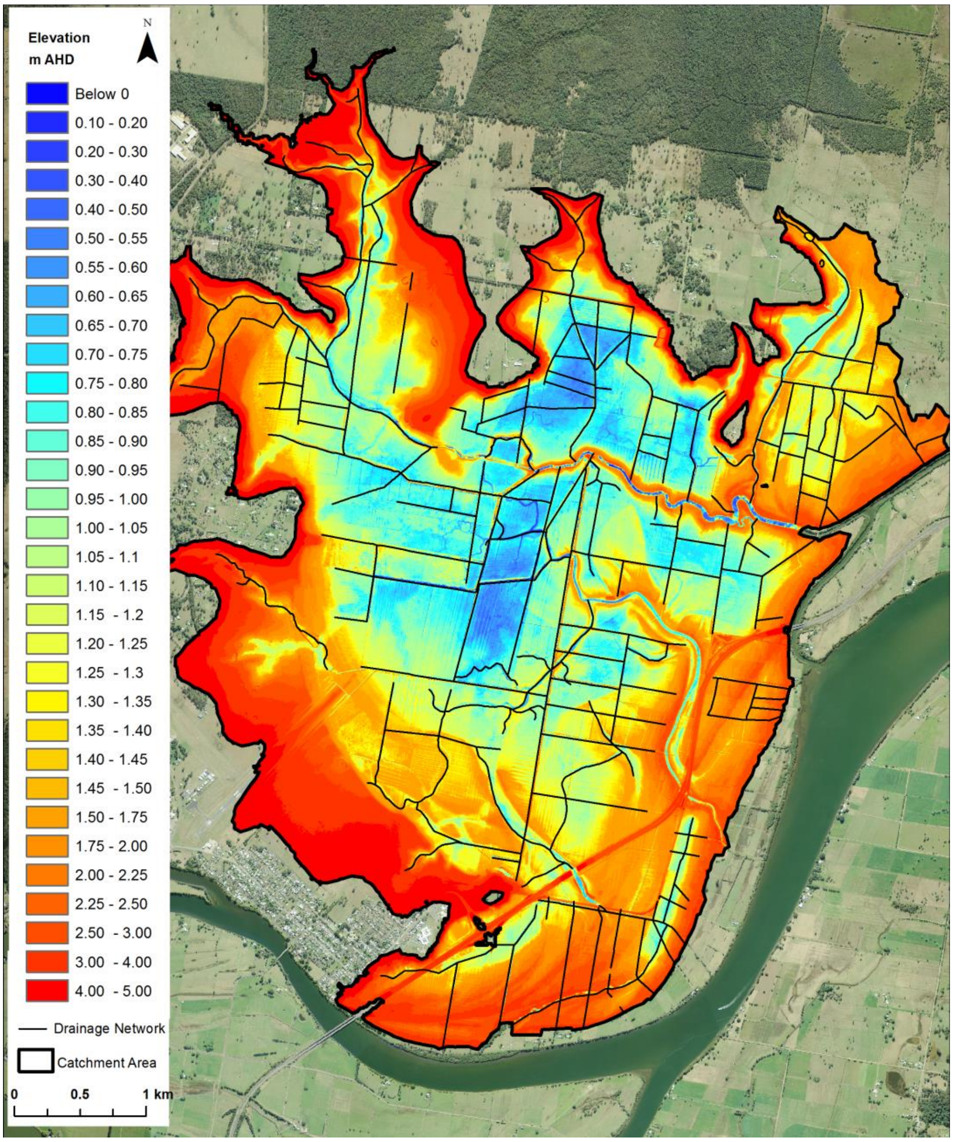


Figure 7.4: Sub-Catchment Boundary, Elevation Detail, Drainage Network – Ghinni Ghinni

7.3.2 *History of Remediation*

A timeline of remediation works within the Ghinni Ghinni Priority Area is provided below with reference to Figure 7.5. The works included:

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

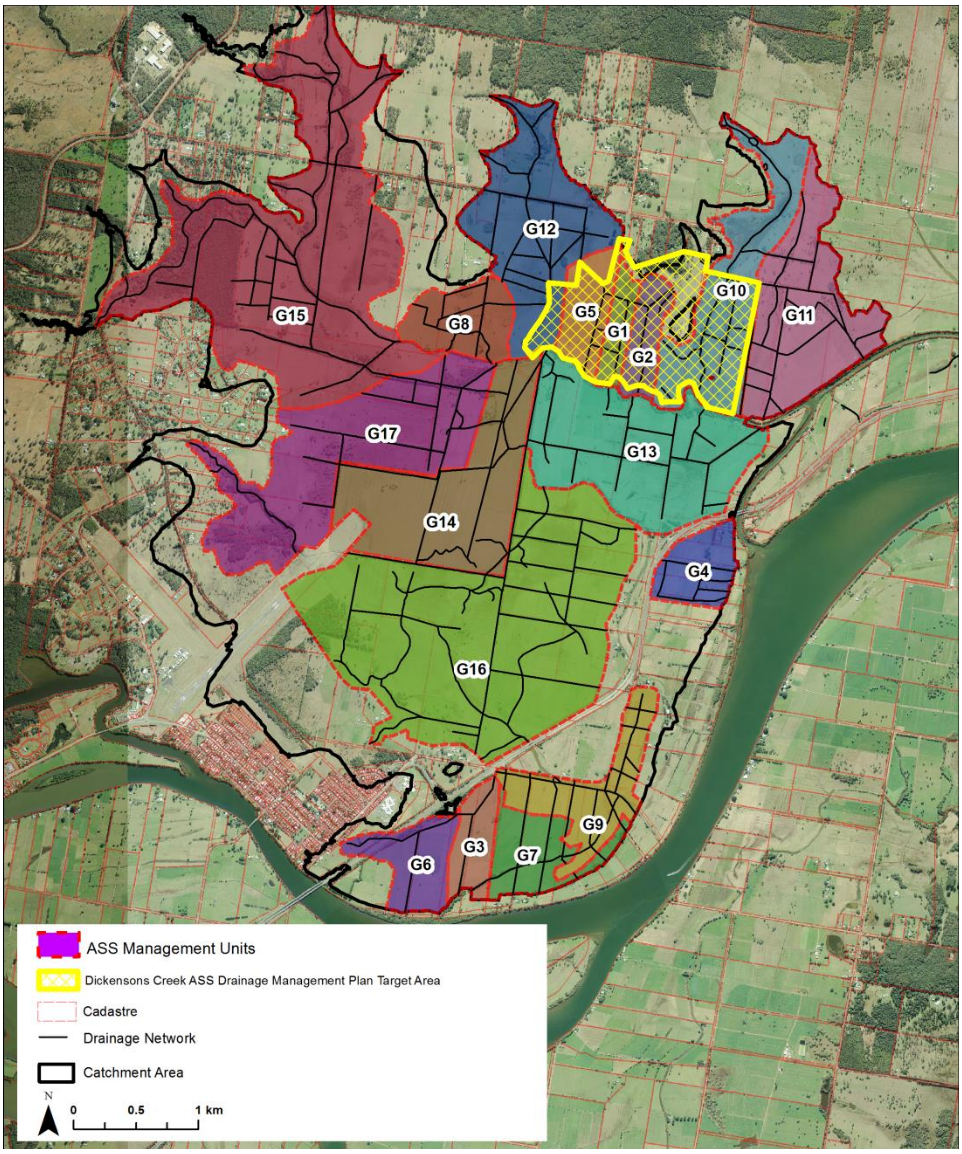


Figure 7.5: Sub-Catchments of the Ghinni Ghinni Floodplain Including Previous Remediation Target Area

7.3.3 Remediation Action Plan

The Action Plan for the Ghinni Ghinni ASS Priority Area includes preliminary recommendations for on-ground works within 17 drainage units of the sub-catchment. The 17 drainage units of the sub-catchment are presented in order of ranking from highest to lowest risk of ASS drainage as shown in Figure 7.6. A summary of the properties of the 17 drainage units is provided in Table 7.3. Preliminary recommendations and indicative costs of on-ground works for each drainage unit are then provided in Table 7.4.

A summary of the immediate and long-term management recommendations includes:

Immediate Remediation Strategy

A small portion of the Ghinni Ghinni ASS Priority Area (approximately 150 ha) was previously targeted for remediation as part of the MidCoast Council ASS Drainage Management Plan (details are provided in Section 7.3.2). Previous on-ground works have focused on floodgate management in Ghinni Ghinni Priority Areas G1, G5, and G12 in the northern portion of the Ghinni Ghinni floodplain. The on-ground works in these areas involved installation of new water control structures (i.e. culverts and associated floodgates) on the main drains located in Ghinni Priority Areas G5 and G12 to raise the invert of the drainage points to 0.3 m AHD.

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

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

Long-term Remediation Strategy

The Ghinni Ghinni ASS Priority Area features some of the lowest-lying topography on the entire Manning River floodplain. This area, particularly portions of Ghinni Ghinni Priority Areas G8, G12 and G14, is likely to be increasingly affected by reduced drainage with large areas remaining inundated by 2050 due to increases in low tide levels. Without additional infrastructure the agricultural productivity of the Ghinni Ghinni floodplain is likely to become increasingly reduced and options for full rehabilitation of poorly drained land to wet pastures (freshwater), or wetland (saline) should be investigated. MidCoast Council are encouraged to continue to engage with the community and landholders in the Ghinni Ghinni region about ongoing ASS legacy issues, and the advantages/benefits of progressing future land management practices towards wet pasture management and wetland rehabilitation across entire floodplain.

Indicative Cost: $15,000 for design plus costs for environmental offset. Environmental offset may include land acquisition, drain infilling, drain reshaping and/or infrastructure removal.

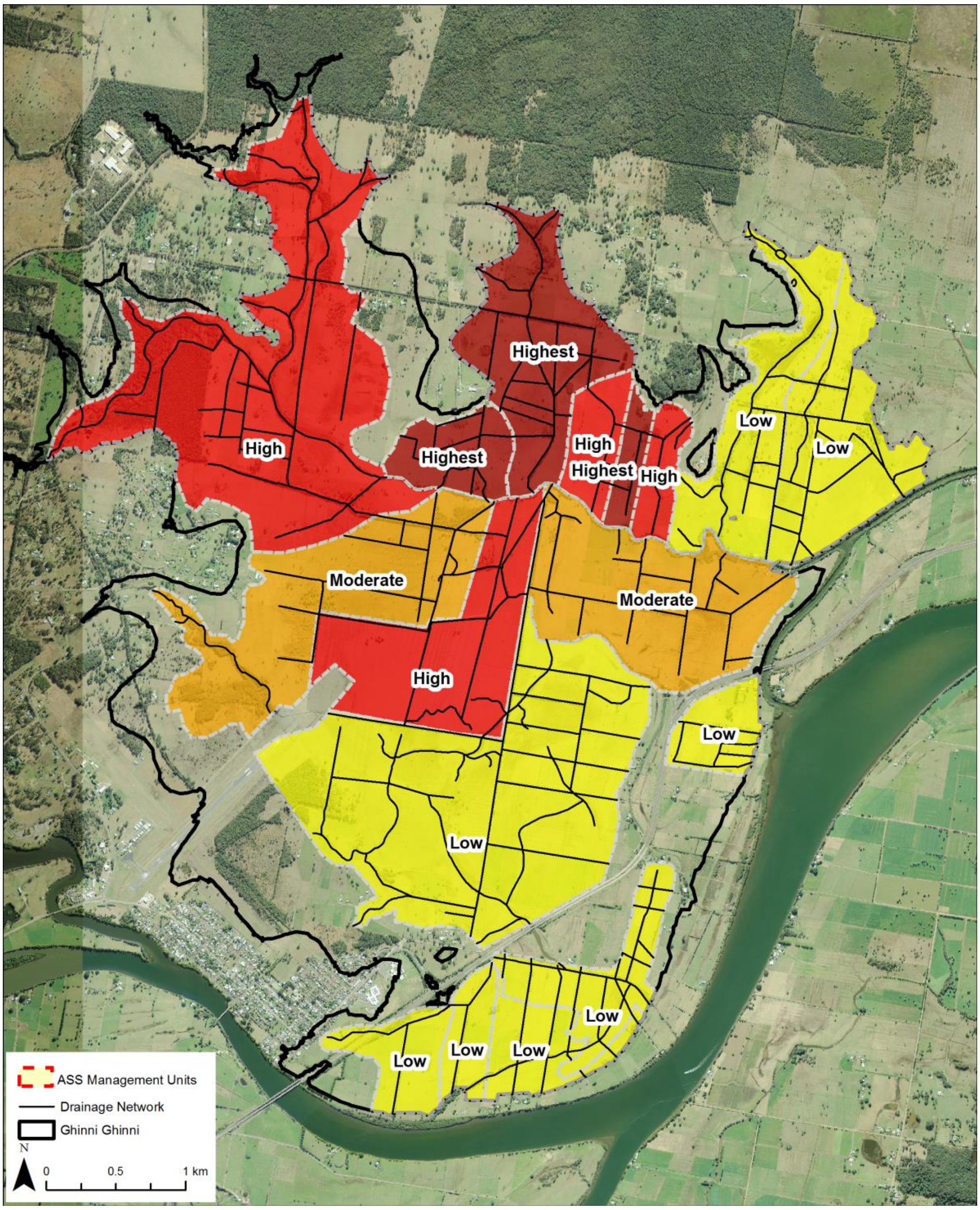


Figure 7.6: Ranking of Sub-Catchments in Priority Area 2 – Ghinni Ghinni

Table 7.3: Sub-Catchment Site Details for Ghinni Ghinni

Priority Management Areas	Priority Rank	Approximate Depth to AASS (m)	Approximate Depth to PASS (m)	Approximate Elevation of AASS (m AHD)	Approximate Elevation of PASS (m AHD)	Median pH	Drainage Area (ha)	Drain Details			
								Nominal Length (m)	Nominal Width (m)	MidCoast Council Floodgate Structure ID	Invert (m AHD)
G8	Highest	0.3	1.7	0.7	-0.7	3.5	45	3,029	5	622	-
G1	Highest	0.3	1.3	0.5	-0.3	3.7	19	1,092	4	-	-
G12	Highest	0.3	1.5	0.4	-0.7	3.7	130	8,470	10	623	-
G15	High	0.4	1.5	0.5	-0.7	3.8	360	18,692	10	622	-
G2	High	0.4	1.3	0.4	-0.3	3.7	26	1,292	7	629	-
G14	High	0.6	1.5	0.3	-0.7	3.7	139	6,800	8	625,631,635,640	-0.34
G5	High	0.3	1.3	0.4	-0.3	3.7	34	1,250	9	628	-
G17	Moderate	0.6	1.5	0.3	-0.7	3.7	182	7,530	8	-	-
G13	Moderate	0.5	1.4	0.4	-0.4	4.0	165	7,884	5	632	-
G11	Low	0.5	1.3	0.4	-0.3	4.5	119	7,167	8	634	-
G10	Low	0.5	1.3	0.4	-0.3	4.5	108	6,395	8	626	-
G16	Low	0.4	1.7	0.6	-0.8	5.6	368	20,890	9	115	-
G7	Low	0.4	1.8	0.6	0.3	6.0	44	2,569	9	659	-
G3	Low	0.4	1.8	0.6	0.3	6.0	28	1,291	10	659	-
G6	Low	0.4	1.8	0.6	0.3	6.0	41	1,640	5	-	-
G9	Low	0.4	1.8	0.6	0.3	6.5	63	5,678	5	656	-
G4	Low	0.5	1.8	0.5	0.3	6.9	34	2,247	3	649,650	-

Table 7.4: Sub-Catchment Remediation Action Plans for Ghinni Ghinni

Priority Management Areas	Priority Rank	Short Term Management Option	Short Term Design Cost	Short Term Implementation Cost	Short Term Annual Maintenance Cost	Short-Term Indicative Cost	Long Term Management Option	Long-Term Indicative Cost
G8	Highest	A + B	$10,000 + $15,000	$15,000 + $120,000	$5,000	<$150,000	L + F	$20,000 + environmental offset*
G1	Highest	B	$15,000	$40,000	-	>$50,000	L + J + F	$20,000 + design/flood assessment + environmental offset*
G12	Highest	A + B	$10,000 + $15,000	$15,000 + $320,000	$5,000	>$300,000	L + F	$20,000 + environmental offset*
G15	High	A	$10,000	$15,000	$5,000	<$50,000	H + E	$50,000 + environmental offset*
G2	High	A + B	$10,000 + $15,000	$15,000 + $40,000	$5,000	<$100,000	L + J + F	$20,000 + design/flood assessment + environmental offset*
G14	High	A + C	$10,000	$30,000 + $5,000	$5,000	<$50,000	F	$15,000 + environmental offset*
G5	High	A	$10,000	$15,000	$5,000	<$50,000	L + J + F	$20,000 + design/flood assessment + environmental offset*
G17	Moderate	B	$15,000	$40,000	-	>$50,000	L + J + F	$20,000 + design/flood assessment + environmental offset*
G13	Moderate	C + G	$10,000	$30,000	$5,000	<$50,000	D	$15,000 + environmental offset*
G11	Low	A	$10,000	$15,000	$5,000	<$50,000	B	$15,000 + $320,000
G10	Low	A	$10,000	$15,000	$5,000	<$50,000	E	$15,000 + environmental offset*
G16	Low	G	$10,000	$30,000	$5,000	<$50,000	D	$15,000 + environmental offset*
G7	Low	A	$10,000	$15,000	$5,000	<$50,000	-	-
G3	Low	A	$10,000	$15,000	$5,000	<$50,000	-	-
G6	Low	G	$10,000	$30,000	$5,000	<$50,000	-	-
G9	Low	A	$10,000	$15,000	$5,000	<$50,000	-	-
G4	Low	A	$10,000	$30,000	$5,000	<$50,000	-	-

Management Options Key:

A = Floodgate Management
B = Drain Reshaping
C = Community Engagement and Training
D = Wet Pasture
E = Partial Rehabilitation
F = Full Rehabilitation
G = Groundwater Manipulation
H = Drop Board Weir
I = Preliminary Investigation
J = Partial Land Raising
K = Acquisition
L = Adaptive Land Management

* Environmental Offset may include detailed design, land acquisition, drain infilling, drain reshaping, fencing, and/or infrastructure removal/modification.

7.4 High Priority Area 3: Big Swamp

7.4.1 Site Description

The Big Swamp ASS Priority Area is a large backswamp and associated floodplain located in the northern-eastern part of the Manning River floodplain. Pipeclay Canal flows into Cattai Creek, a north bank tributary of the Manning River, and is located 15 km upstream of the northern entrance of the Manning River. Draining into Pipeclay Canal, the Big Swamp floodplain includes approximately 4,400 hectares below 5 m AHD and is located immediately north of Cattai Wetlands. Several sensitive receivers are located downstream of the Big Swamp ASS Priority Area, including key fisheries habitat, priority oyster leases and seagrass, that are impacted by acid discharges from the Cattai Creek-Pipeclay Canal region.

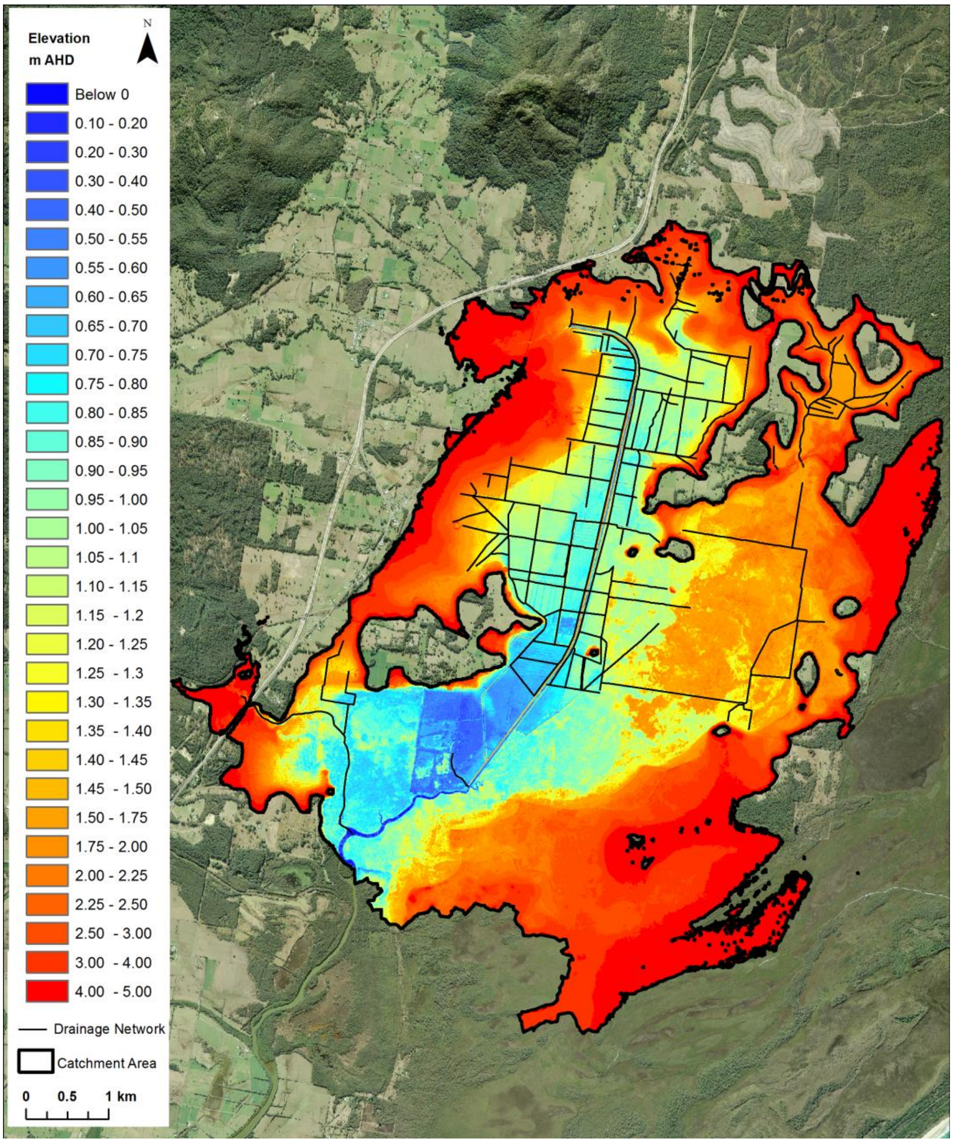


Figure 7.7: Sub-Catchment Boundary, Elevation Detail, Drainage Network – Big Swamp

7.4.2 History of Remediation

A timeline of remediation works within the Big Swamp Priority Area (including a portion of Cattai Wetlands) is provided below with reference to Figure 7.8. The works included:

- 2003 – Public acquisition of approximately 500 ha of land along the right-bank of Cattai Creek to restore an area of Manning River floodplain known as Cattai Wetlands. The Plan of Management recommended decommissioning a non-functional floodgate, as well as drain and levee structures. The objective of the project was to acquire the portions of the floodplain with wetland habitat values, develop and dispose the surplus higher land as hobby farms, and retain the wetland areas (approximately 400 ha).
- 2014 – Following a comprehensive hydrological study conducted by WRL, MidCoast Council acquired land and implemented the on-ground works program recommended by WRL as part of a $2 million Federal Government grant in 2011 to reduce acid runoff into the Manning River estuary. On-ground outcomes included:
  - Public acquisition of 700 ha of private land;
  - Conversion of agricultural land into an 80-ha tidal wetland by infilling/reshaping several main drains, construction of low profile levees (crest height approximately 1 m AHD), decommissioning several floodgates and associated infrastructure; and
  - Elevation of ground water levels above the acidic soil layer over the remaining 620 ha of drained floodplain.
- 2016 – MidCoast Council has recently received further funding of $350,000 through the NSW Estuary Management Program to purchase and rehabilitate an additional 250 hectares of degraded farmland across the Big Swamp floodplain. MidCoast Council will also provide an additional $350,000 towards the project through an Environmental Levy. The total cost of Stage 2 of the project is $700,000.

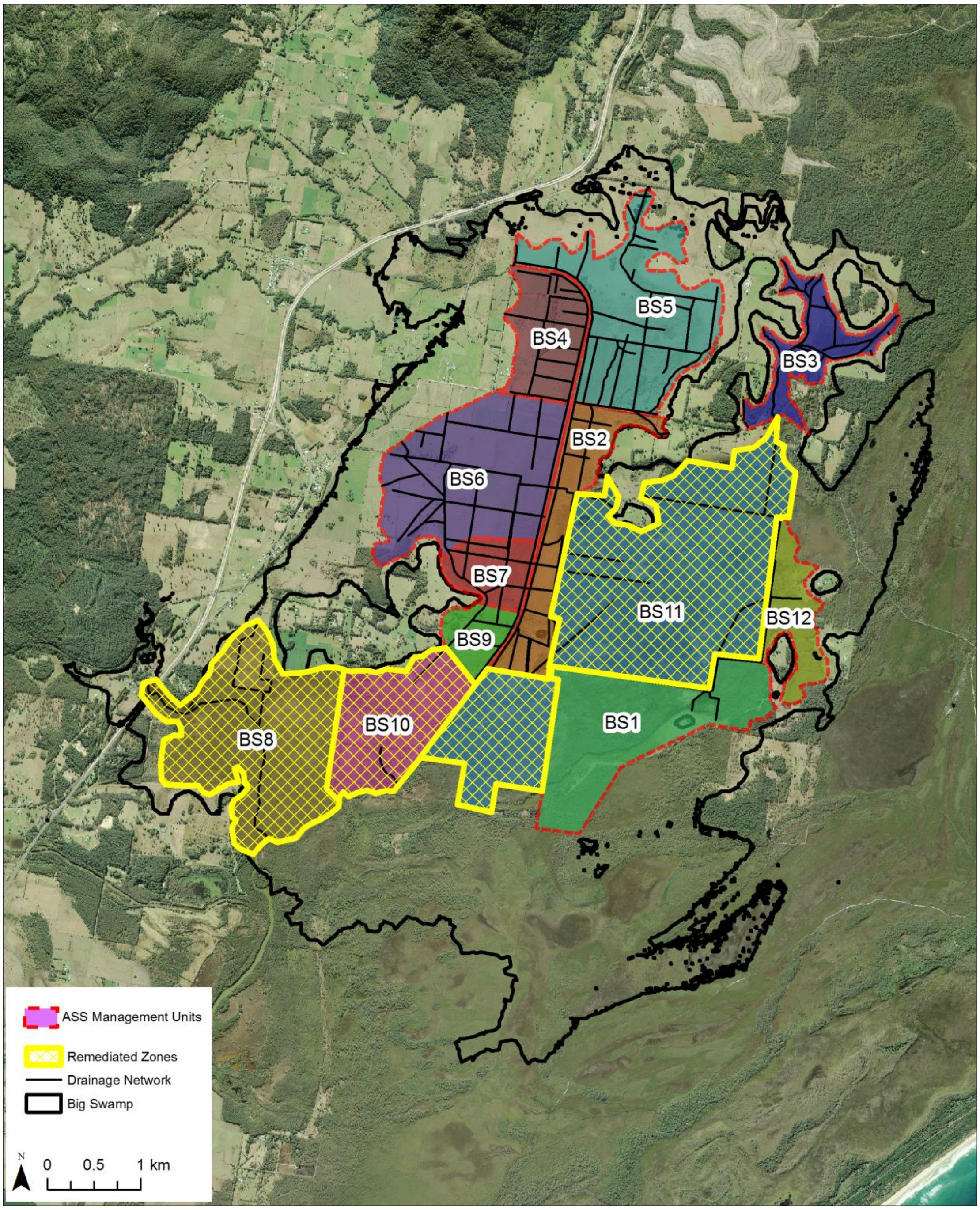


Figure 7.8: Sub-Catchments of the Big Swamp Floodplain Including Previous Remediation Target Area

7.4.3 Remediation Action Plan

The Action Plan for the Big Swamp ASS Priority Area includes preliminary recommendations for on-ground works within 12 drainage units of the sub-catchment. The 12 drainage units of the sub-catchment are presented in order of ranking from highest to lowest risk of ASS drainage as shown in Figure 7.9. A summary of the properties of the 12 drainage units is provided in Table 7.5. Preliminary recommendations and indicative costs of on-ground works for each drainage unit are then provided in Table 7.6.

A summary of the immediate and long-term management recommendations includes:

Immediate Remediation Strategy

A significant portion of the Big Swamp ASS Priority Area (approximately 700 ha) was previously targeted for remediation as part of the MidCoast Council ASS Drainage Management Plan (details are provided in Section 7.4.2). Previous on-ground works have focused on full rehabilitation in Big Swamp Priority Areas BS8 and BS10, and groundwater manipulation/wet pasture management within Big Swamp Priority Area BS11. The on-ground works in these areas involved decommissioning several large deep (>0.5 m) drains, removing floodgates, and notching levees. The works were completed with an objective of maintaining the flood mitigation capacity of adjacent landholders via the construction of new wide shallow drains (with an equivalent hydraulic capacity to the original drain), and neutralising the existing acid store by promoting shallow tidal inundation (and buffering). Furthermore, installation of new perimeter fences were implemented to restrict cattle access to remediated areas, allowing land regeneration.

Where applicable, other areas of the Big Swamp floodplain should be targeted for remediation to support the outcomes of the previous ASS Drainage Management Plan of the region by further land acquisition, groundwater manipulation, and tidal wetland or wet pasture (freshwater) creation. In particular, it is recommended that MidCoast Council acquire Big Swamp Priority Areas BS2 and BS9 to expand the existing rehabilitation sites using these strategies. However, acquisition of Big Swamp Priority Areas BS2 and BS9 would require further detailed design to assess flooding impacts on adjacent private land. In addition to drain infilling/reshaping, it is also recommended that low-level concrete causeways are used (where necessary) to raise local groundwater levels, while maintaining access along the existing levees flanking Pipeclay Canal.

Following on from previous remediation efforts at Big Swamp, the next highest priority drainage unit nominated for the region is Big Swamp Priority Area BS5, situated in north-eastern portion of the floodplain. Big Swamp Priority Area BS5is extensively drained and has one (1) of the highest stores of soil acidity across the landscape. Since the land topography is generally above 1.0 m AHD, in-drain tidal buffering through floodgate modification or groundwater manipulation are encouraged. Low-lying areas of the landscape could also be remediated by encouraging wet pasture management via installation of drop board weirs on main drains. It is also recommended that unused drains are infilled and reshaped to create shallow, wide swale drains as used in other areas of the site. Swale drains can be effectively designed to maintain existing surface water removal capacity. Further detailed surveys and design would be required before the implementation of any on-ground works.

Long-term Remediation Strategy

The Big Swamp ASS Priority Area features some of the lowest-lying topography on the entire Manning River floodplain. Low-lying portions of the floodplain, particularly along the western side of Pipeclay Canal (Big Swamp Priority Areas BS6, BS7, and BS9), are likely to be increasingly affected by reduced drainage with large areas remaining inundated by 2050 due to increases in low tide levels. Without additional infrastructure the agricultural productivity of the Big Swamp backswamp is likely to become increasingly reduced and options for full rehabilitation of poorly drained land to wet pastures (freshwater), or wetland (saline) should be investigated, since the rehabilitation process is already underway in Big Swamp Priority Areas BS8 and BS10.

Indicative Cost: $15,000 for design plus costs for environmental offset. Environmental offset may include land acquisition, drain infilling, drain reshaping and/or infrastructure removal.

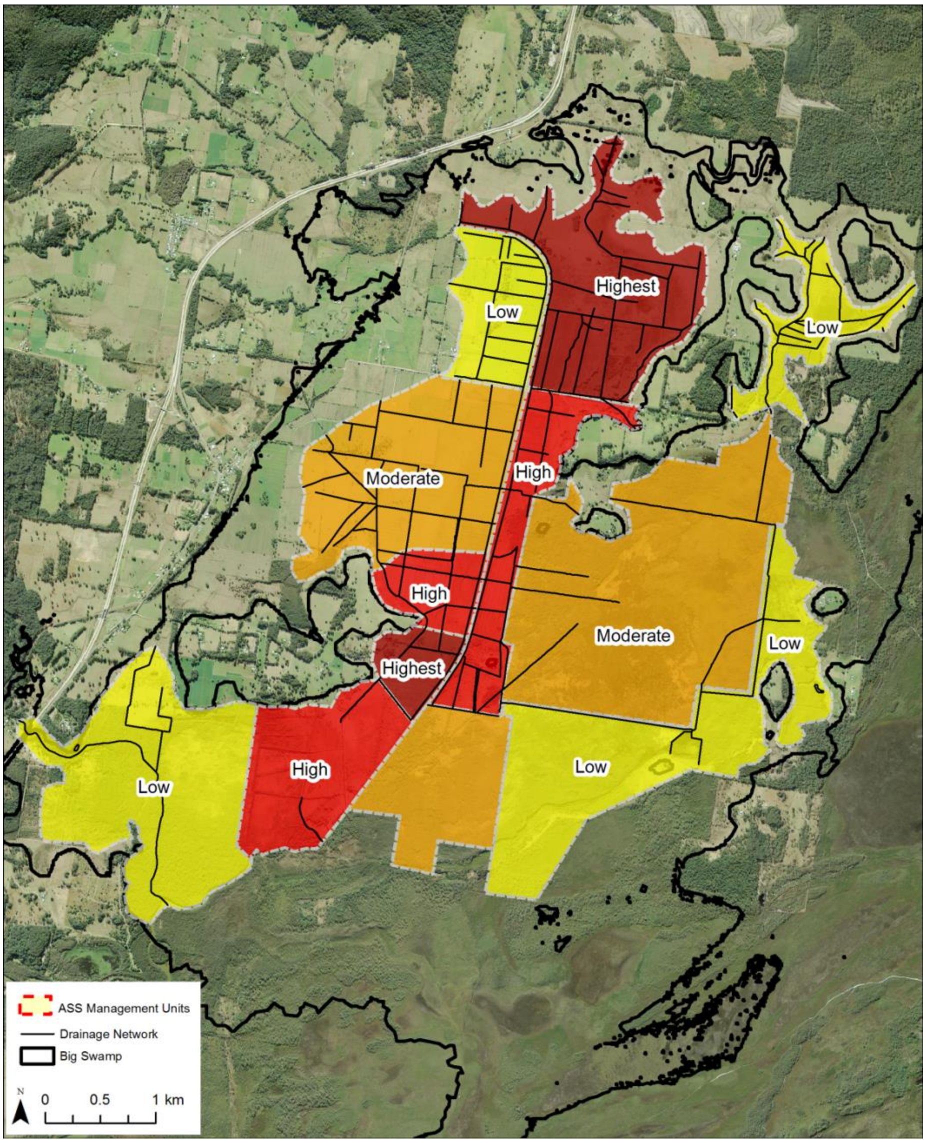


Figure 7.9: Ranking of Sub-Catchments in Priority Area 3 – Big Swamp

Table 7.5: Sub-Catchment Site Details for Big Swamp

Priority Management Areas	Priority Rank	Approximate Depth to AASS (m)	Approximate Depth to PASS (m)	Approximate Elevation of AASS (m AHD)	Approximate Elevation of PASS (m AHD)	Median pH	Drainage Area (ha)	Drain Details			
								Nominal Length (m)	Nominal Width (m)	MidCoast Council Floodgate Structure ID	Invert (m AHD)
BS5	Highest	0.5	1.2	0.4	-0.2	4.0	254	15,591	5	546	-0.39
BS9	Highest	0.4	1.2	0.4	-0.2	4.3	45	2,642	5	559	-0.47
BS2	High	0.4	0.9	0.6	0.1	4.8	129	10,719	4	549	-0.20
BS10	High	0.5	1.1	0.4	-0.1	3.9	156	1,475	40	-	-
BS7	High	0.4	1.2	0.5	-0.3	4.9	59	4,617	10	553	-0.20
BS6	Moderate	0.4	1.2	0.6	-0.3	4.8	266	13,882	7	550,551	-0.79
BS11	Moderate	0.2	0.7	0.8	0.2	4.2	610	6,807	10	-	-
BS4	Low	0.6	1.7	0.4	-0.8	5.3	103	6,979	5	544,545,543	-0.20
BS3	Low	0.5	1.2	0.9	2.2	5.5	88	7,308	5	-	-
BS12	Low	0.1	0.5	1.4	1.1	5.5	74	2,219	6	-	-
BS1	Low	0.1	0.5	1.1	1.1	5.3	231	3,313	8	-	-
BS8	Low	0.6	0.7	0.4	0.3	6.3	302	5,159	10	-	-

Table 7.6: Sub-Catchment Remediation Action Plans for Big Swamp

Priority Management Areas	Priority Rank	Short Term Management Option	Short Term Design Cost	Short Term Implementation Cost	Short Term Annual Maintenance Cost	Short-Term Indicative Cost	Long Term Management Option	Long-Term Indicative Cost
BS5	Highest	G	$10,000	$30,000	$5,000	<$50,000	D	$15,000 + environmental offset*
BS9	Highest	K + B	$15,000 + $15,000	$2,000/ha + $100,000	-	>$200,000	D + F	<$20,000
BS2	High	K + B	$15,000 + $15,000	$2,000/ha + $400,000	-	>$600,000	D	<$20,000
BS10	High	-	-	-	-	-	F	-
BS7	High	A + B	$10,000 + $15,000	$15,000 + $150,000	$5,000	>$150,000	D + F	$15,000 + environmental offset*
BS6	Moderate	A + B	$10,000 + $15,000	$30,000 + $500,000	$5,000	>$500,000	D	$15,000 + environmental offset*
BS11	Moderate	-	-	-	-	-	D	$15,000 + environmental offset*
BS4	Low	A + B	$10,000 + $15,000	$45,000 + $250,000	$5,000	>$300,000	L	$5,000 to $10,000 per year
BS3	Low	I	$10,000 to $30,000	-	-	<$10,000	L	$5,000 to $10,000 per year
BS12	Low	I	$10,000 to $30,000	-	-	<$10,000	L	$5,000 to $10,000 per year
BS1	Low	I	$10,000 to $30,000	-	-	<$10,000	L	$5,000 to $10,000 per year
BS8	Low	B	$15,000	$20,000/500m	$5,000	<$30,000	D	$15,000 + environmental offset*

Management Options Key:

A = Floodgate Management
B = Drain Reshaping
C = Community Engagement and Training
D = Wet Pasture
E = Partial Rehabilitation
F = Full Rehabilitation
G = Groundwater Manipulation
H = Drop Board Weir
I = Preliminary Investigation
J = Partial Land Raising
K = Acquisition
L = Adaptive Land Management

* Environmental Offset may include detailed design, land acquisition, drain infilling, drain reshaping, fencing, and/or infrastructure removal/modification.

7.5 Priority Area 4: Glenthorne

7.5.1 Site Description

Priority Rank:	4
Approximate Floodplain Area (ha):	860
Approximate Drainage Length (km):	39
# Floodgate Structures (MidCoast Council ID):	No Data
Structure Invert Level (m AHD):	No Data
Median pH	4.2
Approximate Depth to AASS (m):	0.3
Approximate Depth to PASS (m):	0.8
Approximate Elevation of AASS (m AHD):	0.8
Approximate Elevation of PASS (m AHD):	0.7

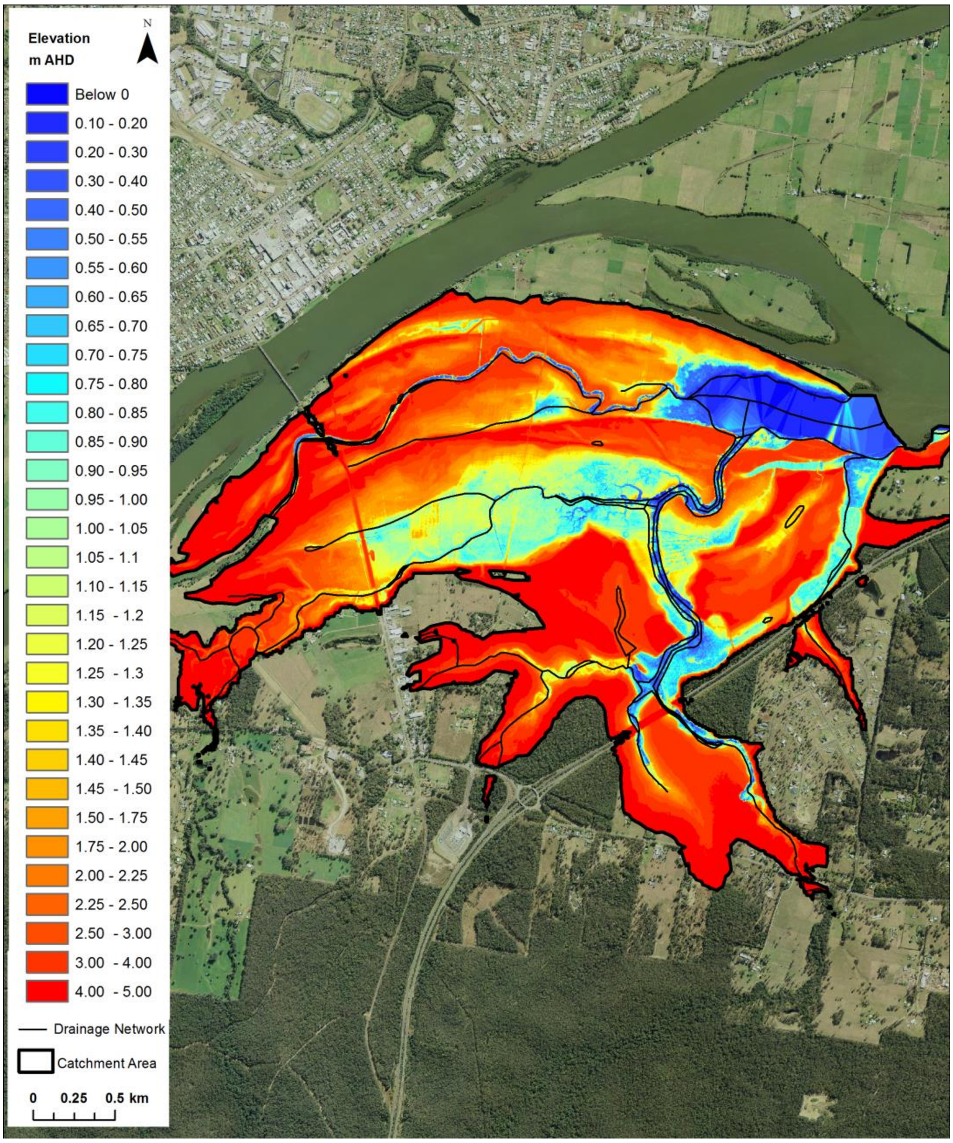


Figure 7.10: Sub-Catchment Boundary, Elevation Detail, Drainage Network – Glenthorne

7.5.2 History of Remediation

No known attempt at remediation to date.

7.5.3 Remediation Action Plan

A summary of the immediate and long-term management recommendations includes:

Immediate Remediation Strategy

The Glenthorne sub-catchment received a high-priority ranking due to the existing acid store near the ground surface, combined with high catchment inflows and extremely high groundwater flows. Deep drains through the low-lying areas of the floodplain promote drawdown of the local groundwater table and interception of the acid store in the soil, resulting in potential acid discharges. Sensitive receivers, including key fisheries habitat and sea grasses lie immediately downstream of the drainage point of the floodplain and are impacted by acid discharges from the site.

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

Indicative Cost: <$100,000. The cost includes $10,000 to $25,000 for design of weir(s)/structure and drain modifications, plus at least $30,000 for on-ground works, depending on the extent of drainage modification works. Annual maintenance of weir would be approximately $5,000.

Long-term Remediation Strategy

Portions of this site are subject to future inundation due to SLR predictions for the Manning River estuary. However, the floodplain topography at this site is favourable to encourage changes to existing land management practices. Viable agriculture farming practices are encouraged on high land, while low-lying areas of the floodplain could revert to wet pasture or tidal wetland. Ultimately, MidCoast Council is encouraged to engage with the community and landholders in the Glenthorne region about ongoing ASS legacy issues, and the advantages/benefits of progressing future land management practices towards wet pasture management and wetland rehabilitation across entire floodplain.

Indicative Cost: $15,000 for design plus costs for environmental offset. Environmental offset may include land acquisition, drain infilling, drain reshaping and/or infrastructure removal.

7.6 Priority Area 5: Coopernook

7.6.1 Site Description

Priority Rank:	5
Approximate Floodplain Area (ha):	630
Approximate Drainage Length (km):	10
# Floodgate Structures (MidCoast Council ID):	10 (583,579,580,577,578,573,566,565,561,560)
Structure Invert Levels (m AHD):	-0.557,0.1,0.187
Median pH	3.87
Approximate Depth to AASS (m):	0.3
Approximate Depth to PASS (m):	1.1
Approximate Elevation of AASS (m AHD):	0.5
Approximate Elevation of PASS (m AHD):	0.3

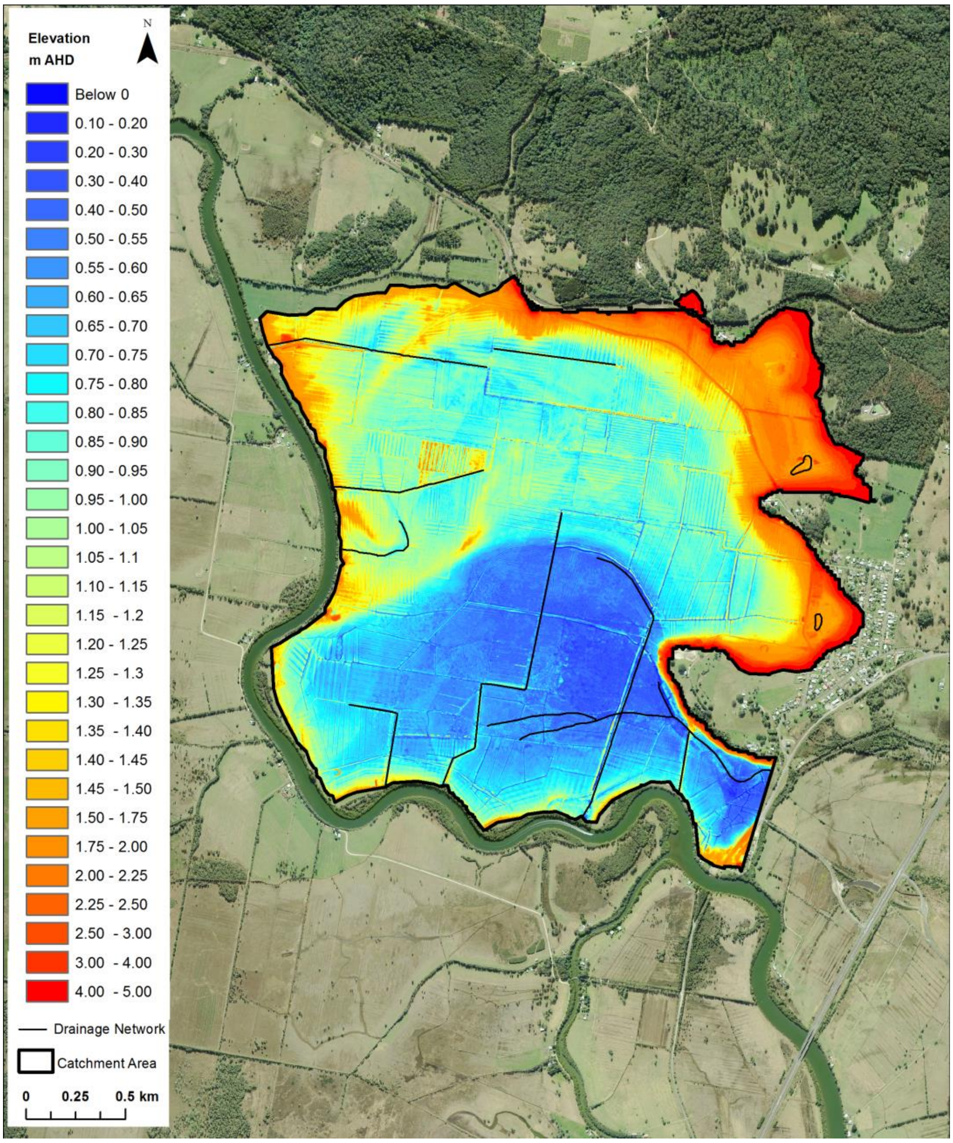


Figure 7.11: Sub-Catchment Boundary, Elevation Detail, Drainage Network – Coopernook

7.6.2 History of Remediation

A timeline of remediation works within the Coopernook Priority Area is provided below. The works included:

- 2001 – Preparation of the 'Remediation Concept Plan for the Lower Lansdowne – Moto – Ghinni Ghinni Creek ASS Hot Spot' by the former Department of Land and Water Conservation as part of the NSW ASS Hot Spot Program. The Concept Plan was followed by a detailed Rehabilitation Plan, but it is unconfirmed if any on-ground works were completed as a result of the NSW ASS Hot Spot Program.

7.6.3 Remediation Action Plan

A summary of the immediate and long-term management recommendations includes:

Immediate Remediation Strategy

The Coopernook Swamp has been identified as one (1) of the highest priority areas for remediation in the Manning River estuary. The swamp comprises some of the lowest natural surface elevations (approximately 0.0 m AHD in some areas) across the whole Manning River floodplain. The site is marked by poor quality vegetation and extensive acid scalding, owing to its high soil acidity near to the ground surface. The Coopernook Swamp has deep (>0.5 m) drains exporting acid and secondary by-products directly into the Lower Lansdowne River, and subsequently impacting downstream sensitive receivers.

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

Indicative cost: >$100,000. Detailed design of the appropriate on-ground works would cost between $10,000 to $20,000. If land acquisition is possible, it is estimated to cost approximately $2,000/ha. On-ground works, including land/drain infilling/reshaping would cost approximately $10,000 to $20,000/500 m of drain modified. Detailed post-restoration monitoring of the site is strongly encouraged and would cost approximately $10,000 per year.

Long-term Remediation Strategy

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

Indicative Cost: $15,000 for design plus costs for environmental offset. Environmental offset may include land acquisition, drain infilling, drain reshaping and/or infrastructure removal.

7.7 Priority Area 6: Pampoolah

7.7.1 Site Description

Priority Rank:	6
Approximate Floodplain Area (ha):	1,015
Approximate Drainage Length (km):	23
# Floodgate Structures (MidCoast Council ID):	No Data
Structure Invert Levels (m AHD):	No Data
Median pH	4.68
Approximate Depth to AASS (m):	0.3
Approximate Depth to PASS (m):	1.5
Approximate Elevation of AASS (m AHD):	0.2
Approximate Elevation of PASS (m AHD):	-1.0

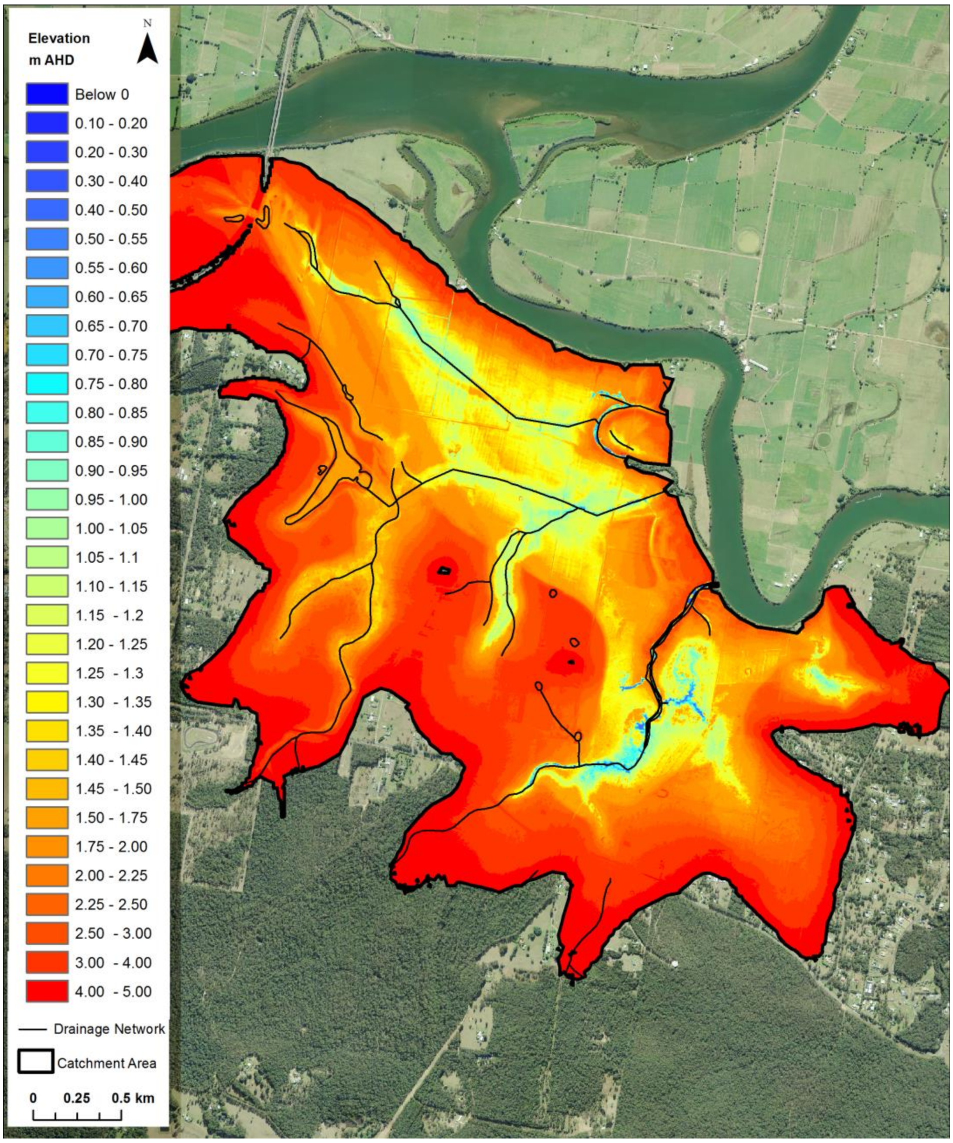


Figure 7.12: Sub-Catchment Boundary, Elevation Detail, Drainage Network – Pampoolah

7.7.2 History of Remediation

No known attempt at remediation to date.

7.7.3 Remediation Action Plan

A summary of the immediate and long-term management recommendations includes:

Immediate Remediation Strategy

The Pampoolah sub-catchment has a high priority ranking due to the observed extensive acid store across the floodplain, combined with a large catchment area and high groundwater seepage rates. Several constructed main drains effectively drawdown local groundwater levels and promote acid discharges directly into the south channel of the Manning River. Acid discharges from the site can impact downstream sensitive receivers, including priority oyster leases and seagrasses.

Since the site drains slightly higher elevated land, groundwater manipulation is recommended and wet pasture management is encouraged (where applicable). It is also recommended that unused drains across the floodplain are infilled or reshaped to raise local groundwater levels and prevent acid discharges.

Indicative Cost: <$100,000. The cost includes $10,000 to $25,000 for design of weir(s) and drain modifications plus at least $30,000 for on-ground works, depending on the extent of drainage modification works. Annual maintenance of weir would be approximately $5,000.

Long-term Remediation Strategy

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

Indicative Cost: $15,000 for design plus costs for environmental offset. Environmental offset may include land acquisition, drain infilling, drain reshaping and/or infrastructure removal.

7.8 Priority Area 7: Bukkan Bukkan Creek (North Oxley Island)

7.8.1 Site Description

Priority Rank:	7
Approximate Floodplain Area (ha):	1,100
Approximate Drainage Length (km):	21
# Floodgate Structures (MidCoast Council ID):	5 (653,655,670,671,676)
Structure Invert Levels (m AHD):	-0.561
Median pH	4.34
Approximate Depth to AASS (m):	0.4
Approximate Depth to PASS (m):	1.1
Approximate Elevation of AASS (m AHD):	0.6
Approximate Elevation of PASS (m AHD):	0.1

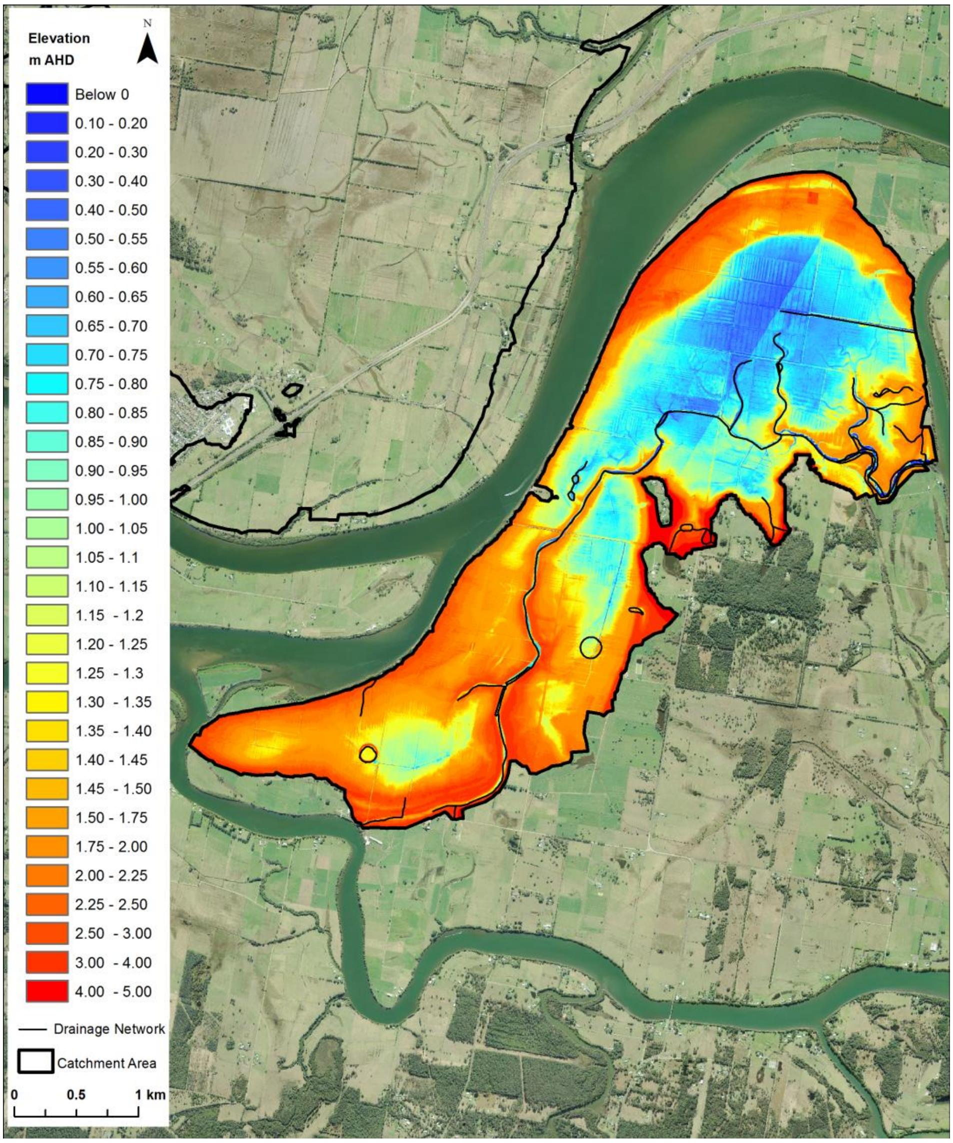


Figure 7.13: Sub-Catchment Boundary, Elevation Detail, Drainage Network – Bukkan Bukkan Creek

7.8.2 *History of Remediation*

A timeline of known remediation works within the Bukkan Bukkan Creek (North Oxley Island) Priority Area is provided below with reference to Figure 7.18. The works included:

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

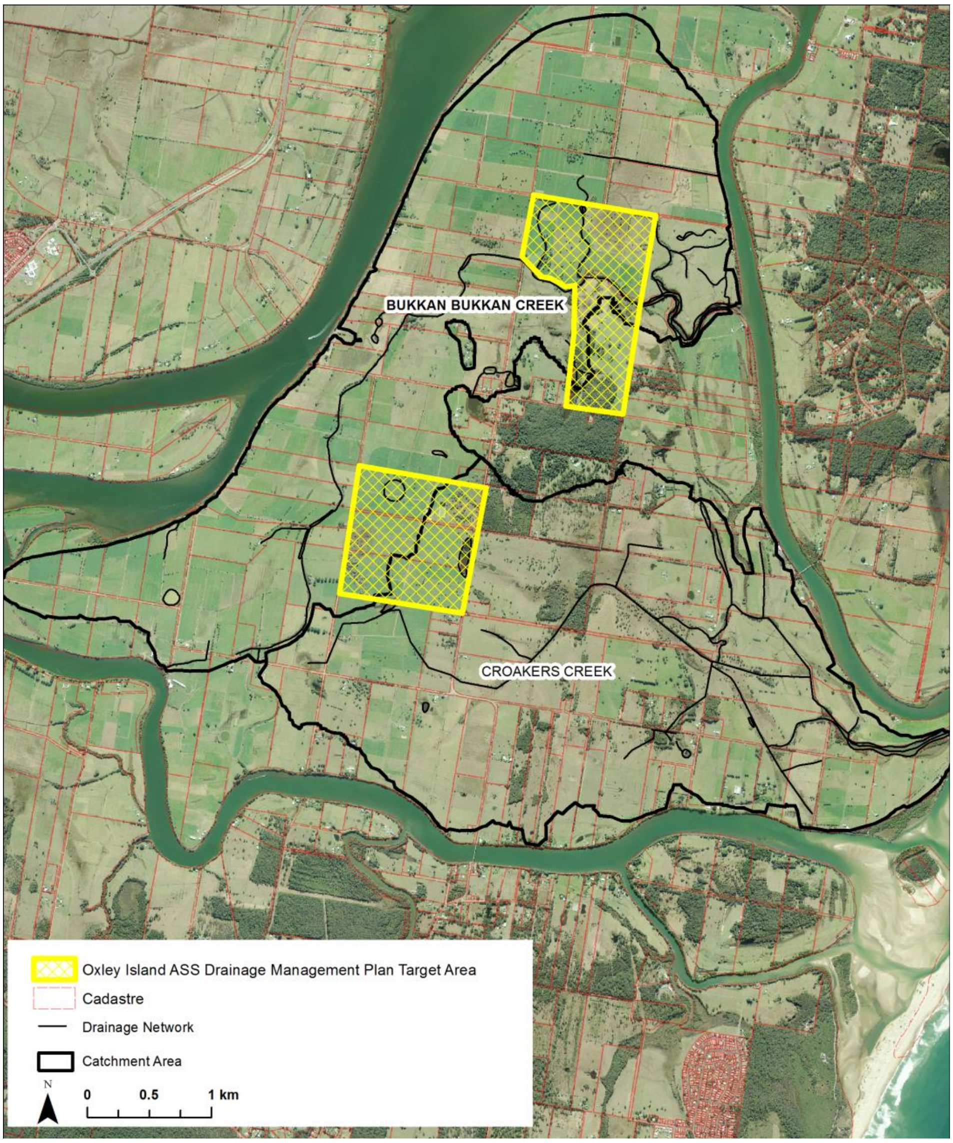


Figure 7.14: Previous ASS Management Target Areas on Oxley Island

7.8.3 Remediation Action Plan

A summary of the immediate and long-term management recommendations includes:

Immediate Remediation Strategy

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

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

Indicative Cost: <$100,000. The cost includes $10,000 to $25,000 for design of weir(s) and drain modifications plus at least $30,000 for on-ground works, depending on the extent of drainage modification works. Annual maintenance of weir would be approximately $5,000.

Long-term Remediation Strategy

The Bukkan Bukkan Creek Priority Area features some of the lowest-lying topography (<0.2 m AHD) on the entire Manning River floodplain. This area is likely to be increasingly affected by reduced drainage with large areas remaining inundated by 2050 due to increases in low tide levels. Without additional infrastructure the agricultural productivity on low-lying, swamp areas is likely to become increasingly reduced, and options for full rehabilitation of poorly drained land to wet pastures (freshwater), or wetland (saline) should be investigated. In particular, the close proximity of the site to the Manning River entrances makes North Oxley Island an ideal site for tidal wetland rehabilitation. It is expected that land management practices will transition to utilise higher surrounding land as SLR impacts the site.

Indicative Cost: $15,000 for design plus costs for environmental offset. Environmental offset may include land acquisition, drain infilling, drain reshaping and/or infrastructure removal.

7.9 Priority Area 8: Dawson River

7.9.1 Site Description

Priority Rank:	8
Approximate Floodplain Area (ha):	785
Approximate Drainage Length (km):	30
# Floodgate Structures (MidCoast Council ID):	N/A
Structure Invert Levels (m AHD):	N/A
Median pH	5.28
Approximate Depth to AASS (m):	0.3
Approximate Depth to PASS (m):	0.8
Approximate Elevation of AASS (m AHD):	0.7
Approximate Elevation of PASS (m AHD):	0.7

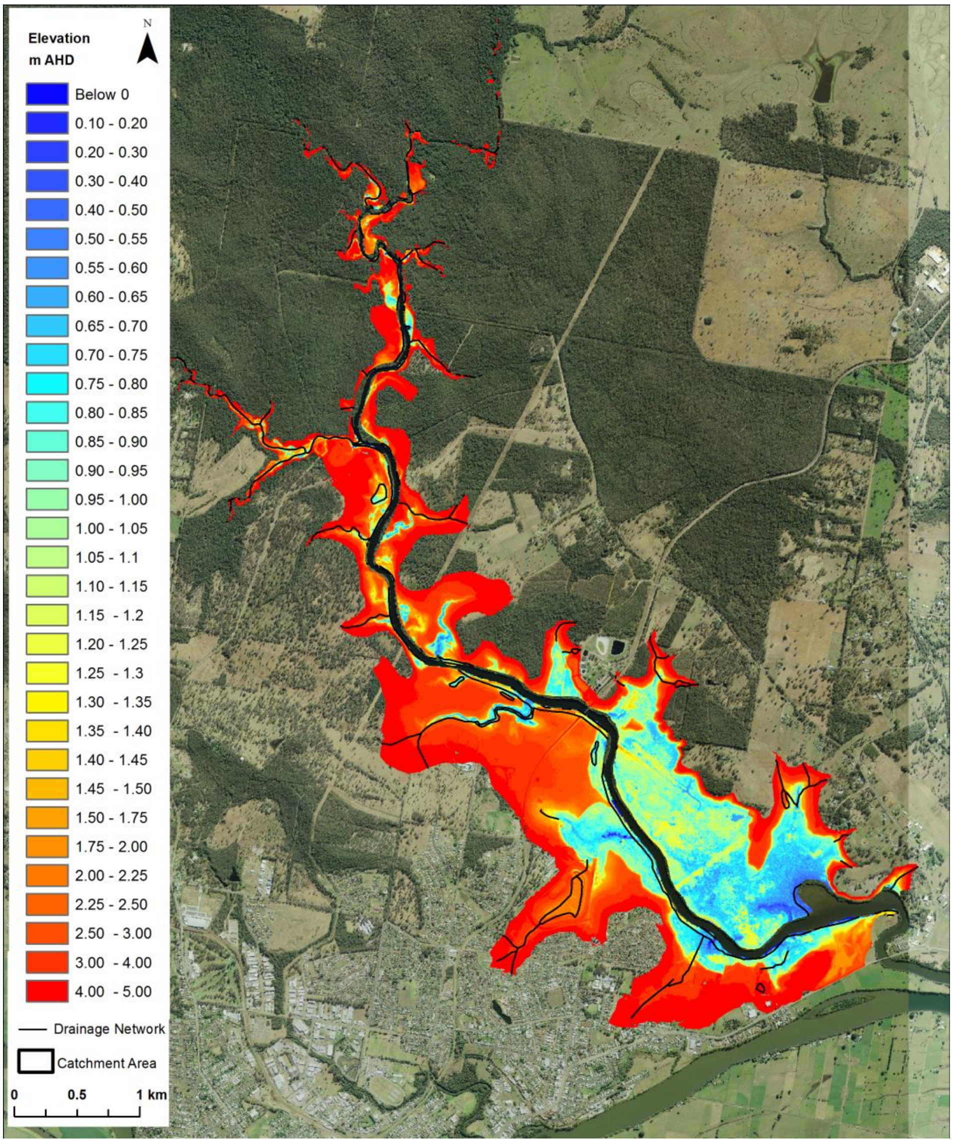


Figure 7.15: Sub-Catchment Boundary, Elevation Detail, Drainage Network – Dawson River

7.9.2 History of Remediation

No known attempt at remediation to date.

7.9.3 Remediation Action Plan

A summary of the immediate and long-term management recommendations includes:

Immediate Remediation Strategy

No immediate action recommended.

Long-term Remediation Strategy

Existing data does not indicate the presence of acid within the Dawson River Priority Area. A portion of the sub-catchment, known as 'The Basin', is low-lying, but remains in a natural, vegetated state, with limited artificial surface drainage. It is anticipated that low-lying portions of the site will be subjected to frequent inundation in the future due to climate change impacts. No remediation strategy is recommended for the Dawson River Priority Area.

7.10 Priority Area 9: Cattai Creek

7.10.1 Site Description

Priority Rank:	9
Approximate Floodplain Area (ha):	1,890
Approximate Drainage Length (km):	43
# Floodgate Structures (MidCoast Council ID):	10 (587,588,602,616, 595, 596,597,591,586,114)
Structure Invert Levels (m AHD):	-0.75
Median pH	5.7
Approximate Depth to AASS (m):	0.4
Approximate Depth to PASS (m):	1.1
Approximate Elevation of AASS (m AHD):	0.6
Approximate Elevation of PASS (m AHD):	0.2

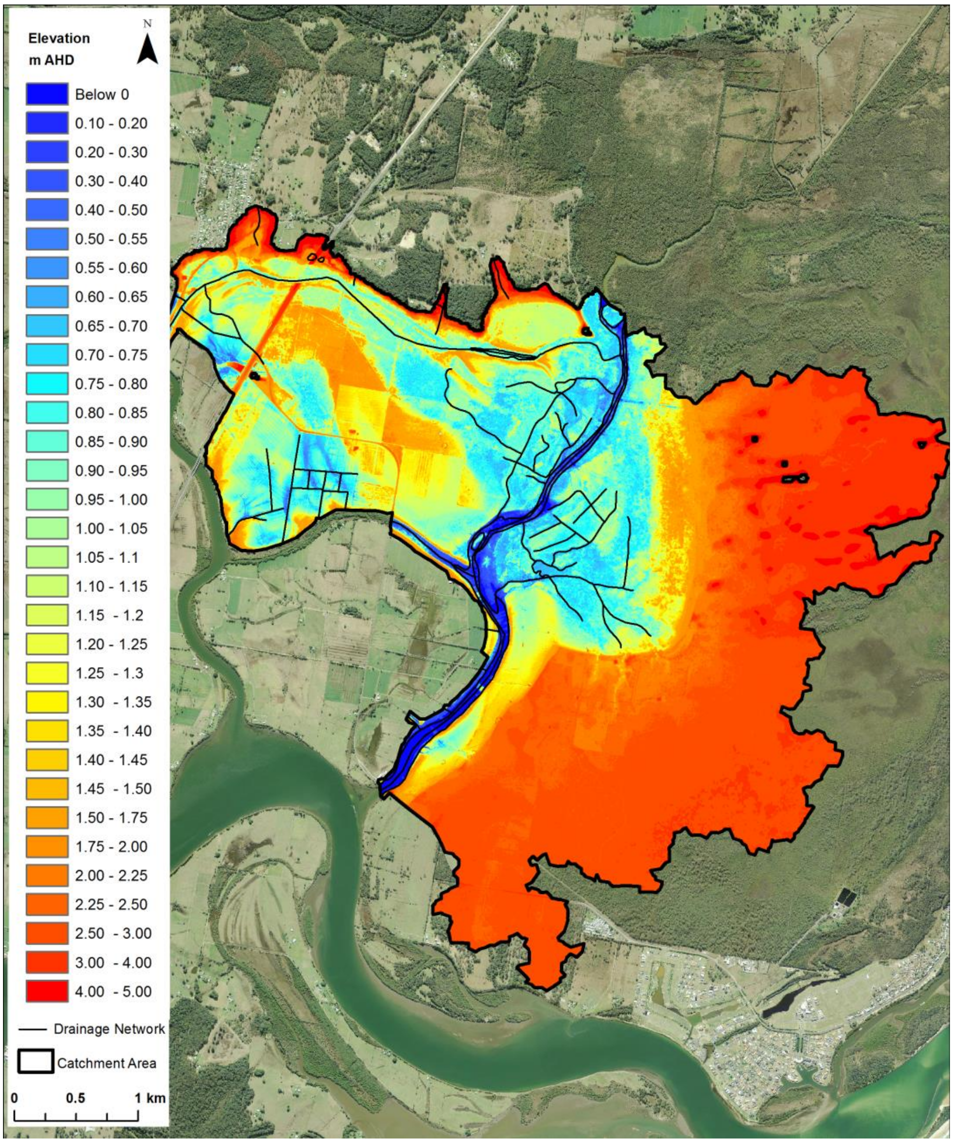


Figure 7.16: Sub-Catchment Boundary, Elevation Detail, Drainage Network – Cattai Creek

7.10.2 History of Remediation

A timeline of remediation works within the Cattai Creek Priority Area is provided below with reference to Figure 7.17. The works included:

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

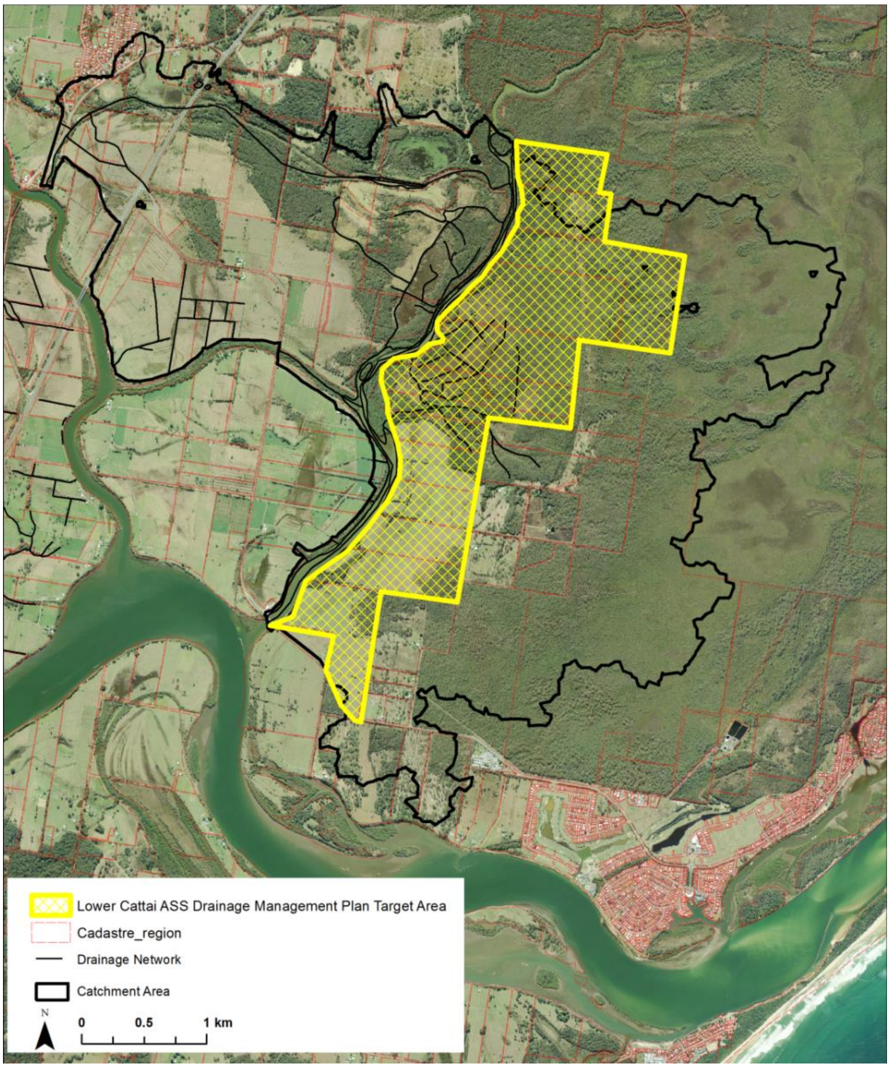


Figure 7.17: Previous ASS Management Target Area Along Cattai Creek

7.10.3 Remediation Action Plan

A summary of the immediate and long-term management recommendations includes:

Immediate Remediation Strategy

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

Indicative Cost: <$100,000. $5,000 for preliminary investigation and maintenance of existing sills, plus an extra $20,000 to $50,0000 for decommissioning unused infrastructure. Costs of drain reshaping will vary depending on the extent of drain modifications, however, reshaping of 3 km of drainage lines would cost approximately $20,000 to $50,000 for design and on-ground works.

Long-term Remediation Strategy

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

Indicative Cost: $15,000 for design plus costs for environmental offset. Environmental offset may include land acquisition, drain infilling, drain reshaping and/or infrastructure removal.

7.11 Priority Area 10: Mitchells Island

7.11.1 Site Description

Priority Rank:	10
Approximate Floodplain Area (ha):	2,070
Approximate Drainage Length (km):	60
# Floodgate Structures (MidCoast Council ID):	13 (633,627,620,644,643,646,654,657,662,668,673,674,651)
Structure Invert Levels (m AHD):	0.199, -0.196
Median pH	6.0
Approximate Depth to AASS (m):	0.3
Approximate Depth to PASS (m):	0.9
Approximate Elevation of AASS (m AHD):	0.6
Approximate Elevation of PASS (m AHD):	0.4

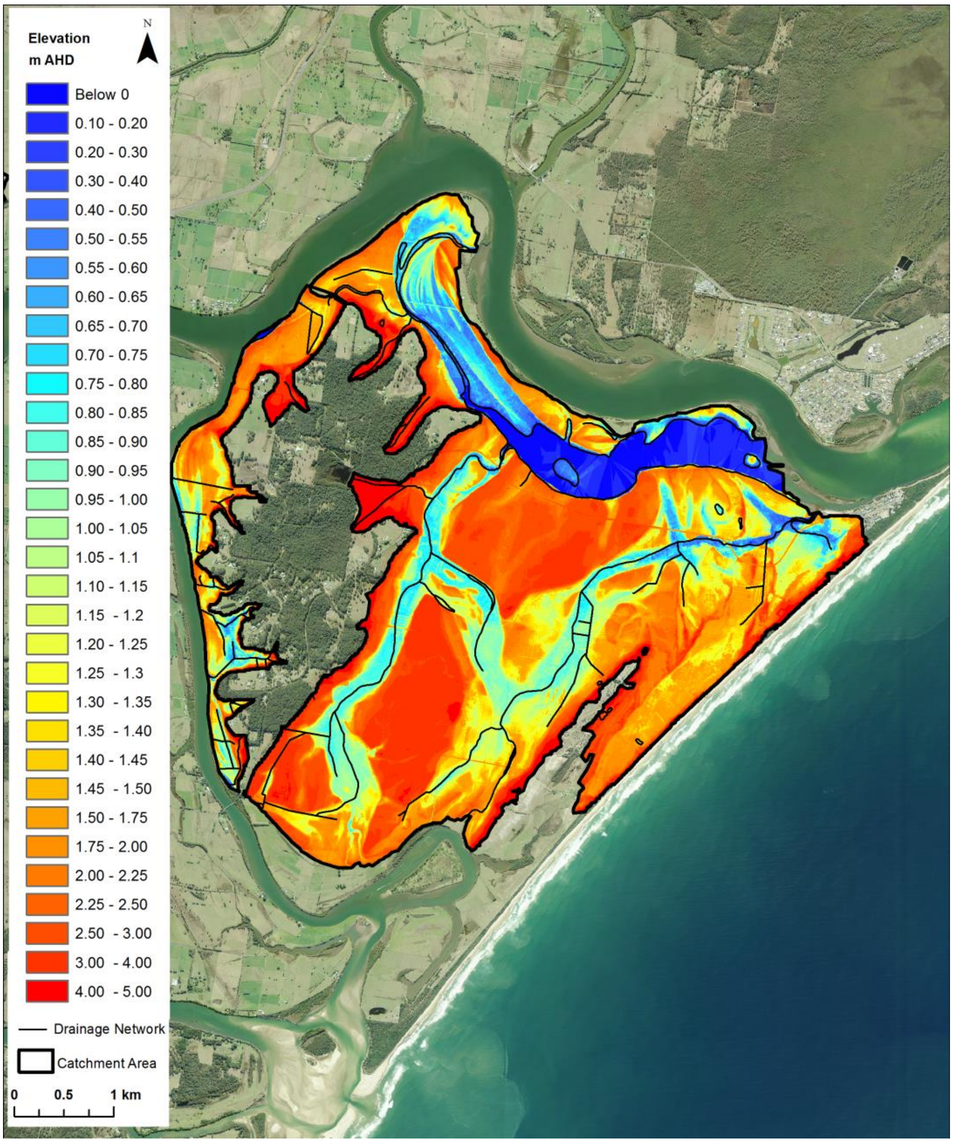


Figure 7.18: Sub-Catchment Boundary, Elevation Detail, Drainage Network – Mitchells Island

7.11.2 History of Remediation

No known attempt at remediation to date.

7.11.3 Remediation Action Plan

A summary of the immediate and long-term management recommendations includes:

Immediate Remediation Strategy

On a catchment-wide basis, Mitchells Island ranks low compared to other floodplain areas. Existing data for Mitchells Island does not indicate the presence of acid stores. However, floodgate management is recommended to encourage in-drain neutralisation of potential localised acid stores and for fish passage. Any unused drains are recommended to be infilled/reshaped to reduce groundwater drawdown.

Indicative Cost: $10,000 for design of modified floodgates plus $20,000 to $50,000 for implementation. Annual maintenance is between $5,000 to $10,000 per year.

Long-term Remediation Strategy

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

Indicative Cost: $15,000 for design plus costs for environmental offset. Environmental offset may include land acquisition, drain infilling, drain reshaping and/or infrastructure removal.

7.12 Priority Area 11: Croakers Creek (South Oxley Island)

7.12.1 Site Description

Priority Rank:	11
Approximate Floodplain Area (ha):	1,040
Approximate Drainage Length (km):	20
# Floodgate Structures (MidCoast Council ID):	2 (677,680)
Structure Invert Levels (m AHD):	-0.423, 0.062
Median pH	5.25
Approximate Depth to AASS (m):	0.4
Approximate Depth to PASS (m):	1.1
Approximate Elevation of AASS (m AHD):	0.6
Approximate Elevation of PASS (m AHD):	0.2

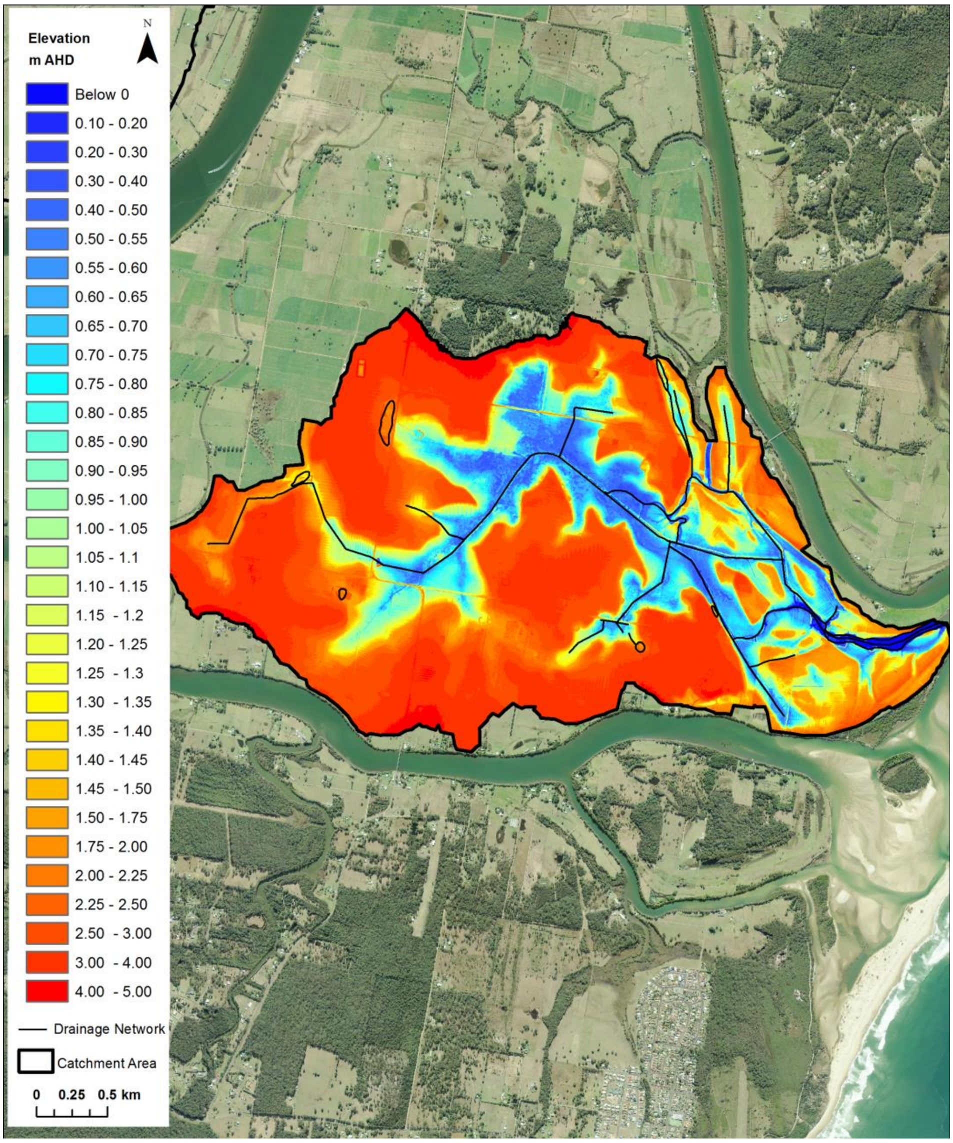


Figure 7.19: Sub-Catchment Boundary, Elevation Detail, Drainage Network – Croakers Creek

7.12.2 History of Remediation

A timeline of known remediation works within the Croakers Creek (South Oxley Island) Priority Area is provided below with reference to Figure 7.20. The works included:

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

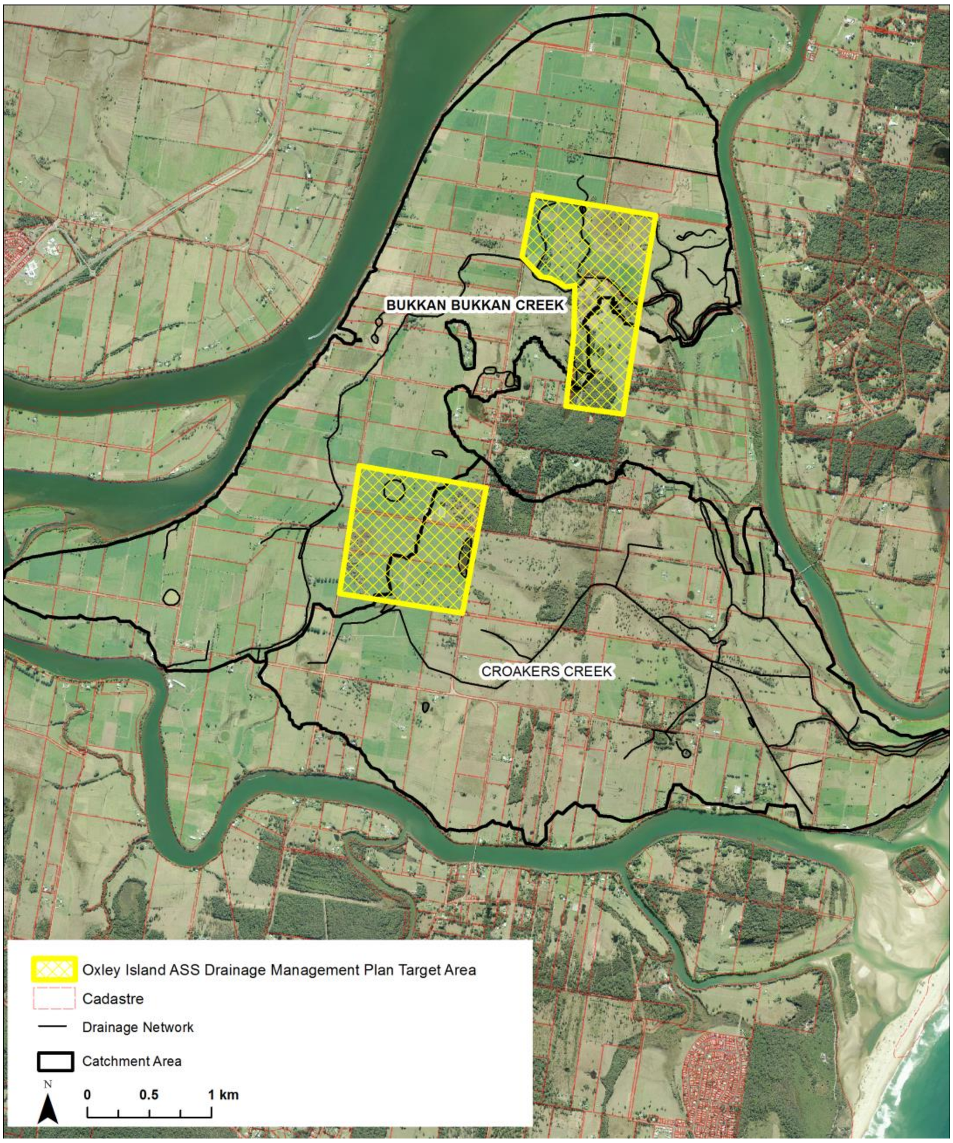


Figure 7.20: Previous ASS Management Target Areas on Oxley Island

7.12.3 Remediation Action Plan

A summary of the immediate and long-term management recommendations includes:

Immediate Remediation Strategy

While the Croakers Creek sub-catchment has been identified as a priority area, existing data suggests that soil acidity is lower on the southern portion of Oxley Island when compared to North Oxley Island. Furthermore, the hydraulic conductivity across Oxley Island is highly variable and the pit tested during the field investigation may not be representative of the hydraulic conductivity of the remainder of the Croakers Creek floodplain. As such, further ASS assessment is required if any significant works are proposed that may disturb stores of acid on the floodplain.

The most effective remediation strategy for this site would involve floodgate management to restore fish passage, infilling/reshaping drains, as well as groundwater manipulation. Wet pasture management is also encouraged.

Indicative Cost: <$100,000. The cost includes $10,000 to $25,000 for design of weir and drain modifications plus at least $30,000 for on-ground works, depending on the extent of drainage modification works. Annual maintenance of weir would be approximately $5,000.

Long-term Remediation Strategy

Low-lying areas of the Croakers Creek floodplain are at a higher risk of being impacted by future SLR projections. Increases in low tide elevations by 2050 will result in prolonged periods of inundation. This may result in a change to land management practices. Without extensive on-ground works, this site is likely to revert to a wetland (saline or otherwise) or wet pasture system.

Indicative Cost: $15,000 for design plus costs for environmental offset. Environmental offset may include land acquisition, drain infilling, drain reshaping and/or infrastructure removal.

7.13 Priority Area 12: Taree Estate

7.13.1 Site Description

Priority Rank:	12
Approximate Floodplain Area (ha):	115
Approximate Drainage Length (km):	4.5
# Floodgate Structures (MidCoast Council ID):	No Data
Structure Invert Levels (m AHD):	No Data
Median pH	5.86
Approximate Depth to AASS (m):	0.4
Approximate Depth to PASS (m):	1.0
Approximate Elevation of AASS (m AHD):	0.7
Approximate Elevation of PASS (m AHD):	0.4

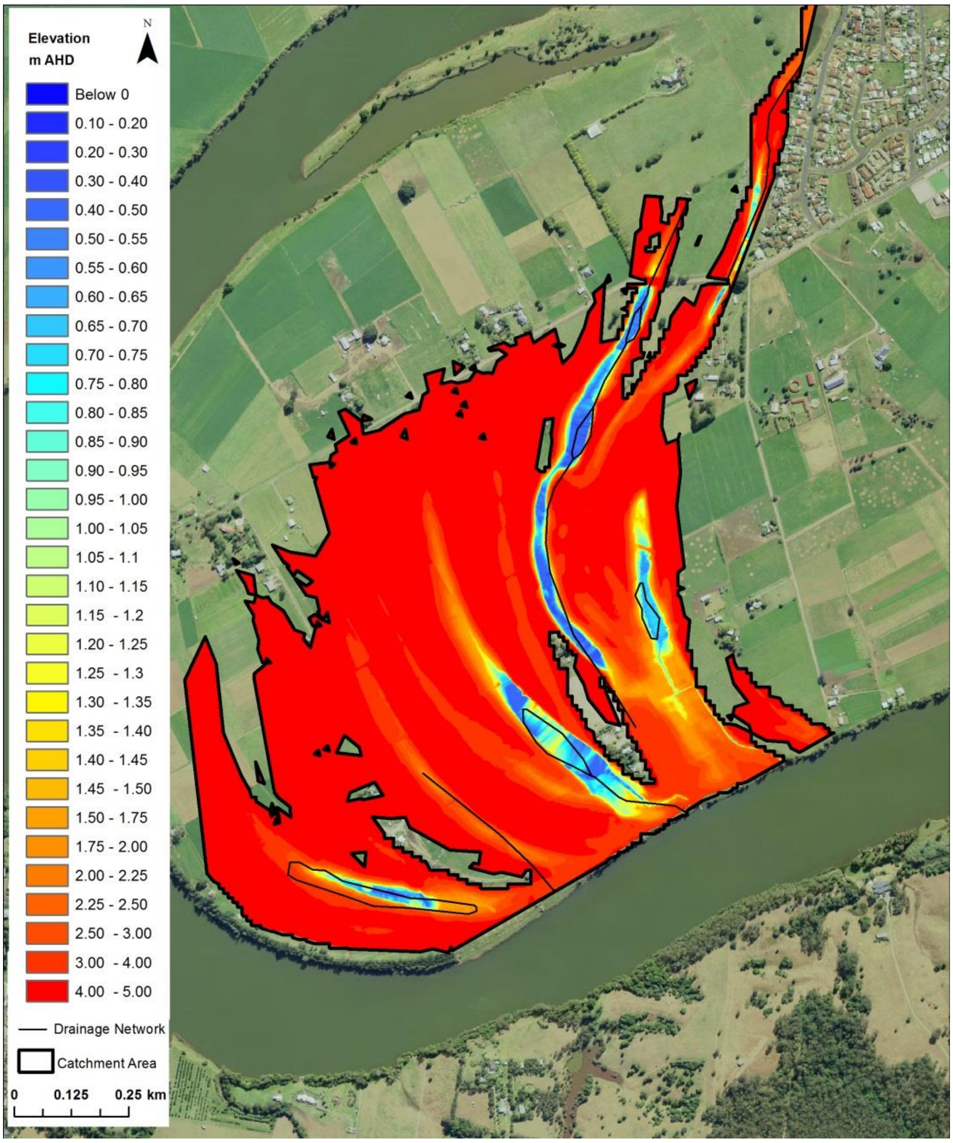


Figure 7.21: Sub-Catchment Boundary, Elevation Detail, Drainage Network – Taree Estate

7.13.2 History of Remediation

No known attempt at remediation to date.

7.13.3 Remediation Action Plan

A summary of the immediate and long-term management recommendations includes:

Immediate Remediation Strategy

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

Indicative Cost: <$30,000. The cost includes approximately $10,000 for drain design plus $10,000 to $20,000 for on-ground works, depending on the extent of drainage modification works.

Long-term Remediation Strategy

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

Indicative Cost: $5,000 to $10,000 per year for maintenance.

7.14 Priority Area 13: Jones Island

7.14.1 Site Description

Priority Rank:	13
Approximate Floodplain Area (ha):	650
Approximate Drainage Length (km):	15
# Floodgate Structures (MidCoast Council ID):	15 (637,630,621,618,610,607,593,590,585,594,598,604,609,615,624)
Structure Invert Levels (m AHD):	No Data
Median pH	5.53
Approximate Depth to AASS (m):	0.3
Approximate Depth to PASS (m):	0.9
Approximate Elevation of AASS (m AHD):	0.6
Approximate Elevation of PASS (m AHD):	0.4

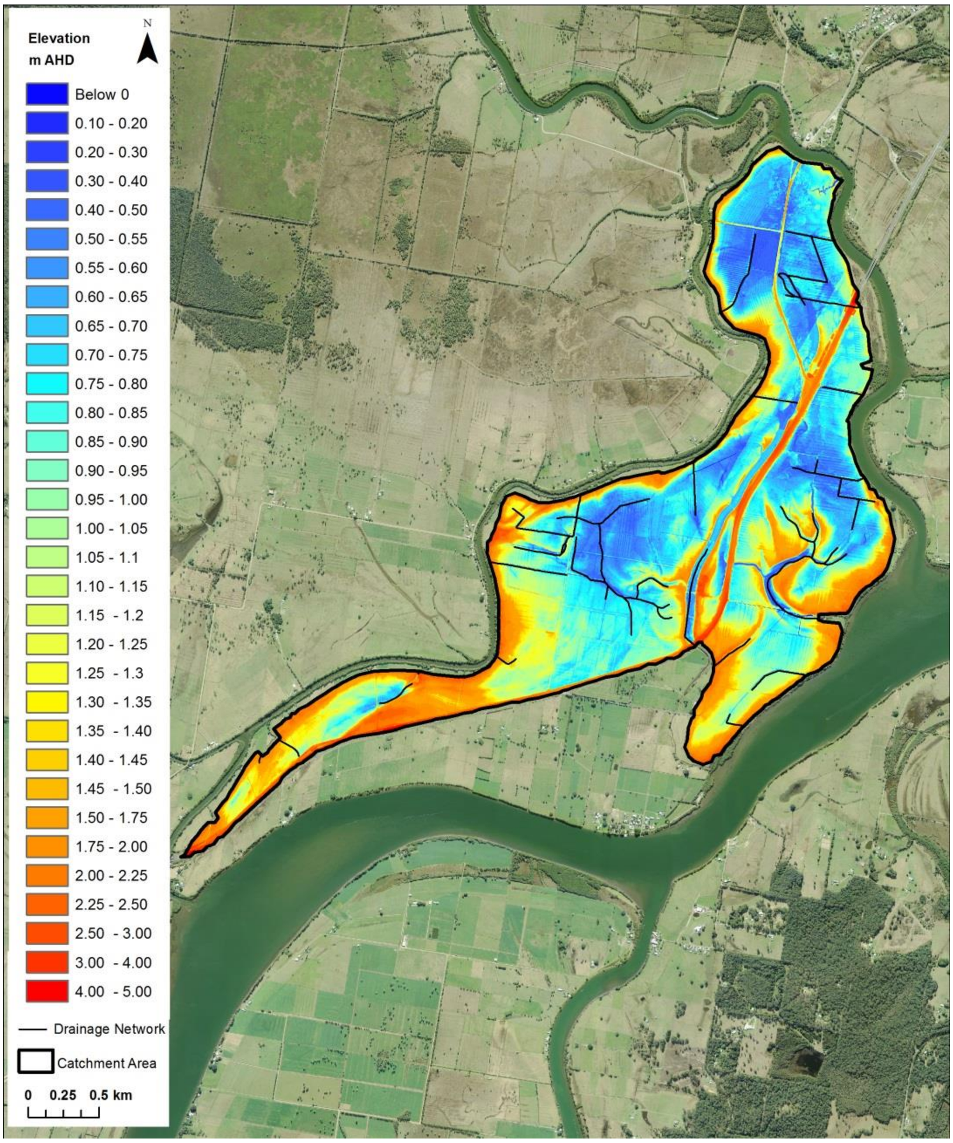


Figure 7.22: Sub-Catchment Boundary, Elevation Detail, Drainage Network – Jones Island

7.14.2 History of Remediation

A timeline of known remediation works within the Jones Island Priority Area is provided below with reference to Figure 7.23. The works included:

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

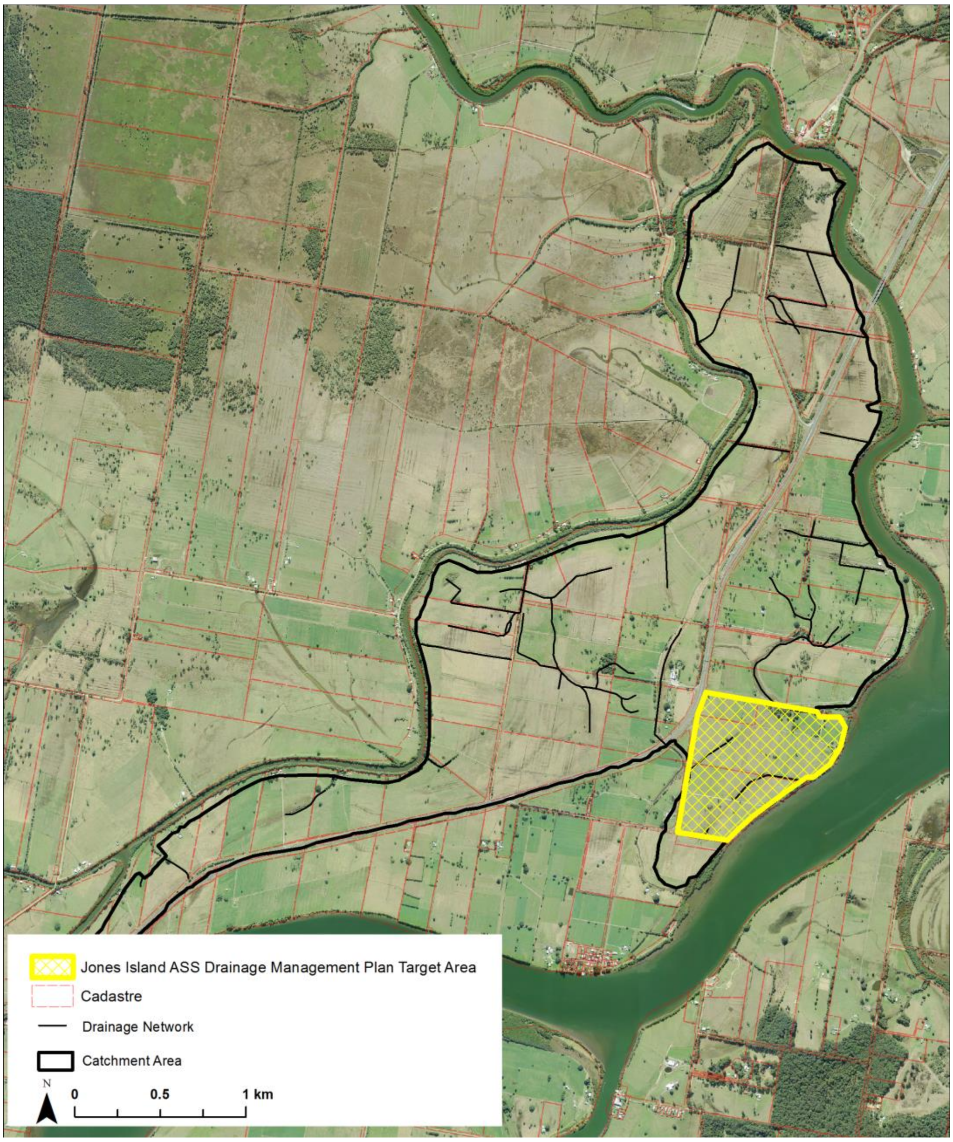


Figure 7.23: Previous ASS Management Target Areas on Jones Island

7.14.3 Remediation Action Plan

A summary of the immediate and long-term management recommendations includes:

Immediate Remediation Strategy

Portions of the Jones Island ASS Priority Area have previously been targeted for remediation as part of the MidCoast Council ASS Drainage Management Plan (refer to Section 7.14.2). Previous on-ground works have focused on decommissioning unused drains and reshaping existing drains to create a shallow swale drain. Where applicable, other areas of the Jones Island should be targeted to achieve the same outcomes as the 2008 ASS Drainage Management Plan. This could be achieved by further floodgate management and filing/reshaping drains across the island, while also encouraging expanded wet pasture management areas across low-lying, boggy land.

Indicative Cost: $10,000 for design of modified floodgates plus $20,000 to $50,000 for implementation. Annual maintenance is between $5,000 to $10,000 per year. Drain design and reshaping is estimated to cost $20,000 per 500 m of drain length modified.

Long-term Remediation Strategy

Jones Island features some of the lowest-lying topography on the entire Manning River floodplain. This area is likely to be increasingly affected by reduced drainage with large areas remaining inundated by 2050 due to increases in low tide levels. Without additional infrastructure the agricultural productivity of the Jones Island is likely to become increasingly reduced and options for full rehabilitation of poorly drained land to wet pastures (freshwater), or wetland (saline) should be investigated.

Indicative Cost: $15,000 for design plus costs for environmental offset. Environmental offset may include land acquisition, drain infilling, drain reshaping and/or infrastructure removal.

7.15 Priority Area 14: Mambo Island

7.15.1 Site Description

Priority Rank:	14
Approximate Floodplain Area (ha):	300
Approximate Drainage Length (km):	8.5
# Floodgate Structures (MidCoast Council ID):	5 (606,617,613,611,603)
Structure Invert Levels (m AHD):	0.037,0.51
Median pH	5.67
Approximate Depth to AASS (m):	0.3
Approximate Depth to PASS (m):	0.9
Approximate Elevation of AASS (m AHD):	0.6
Approximate Elevation of PASS (m AHD):	0.4

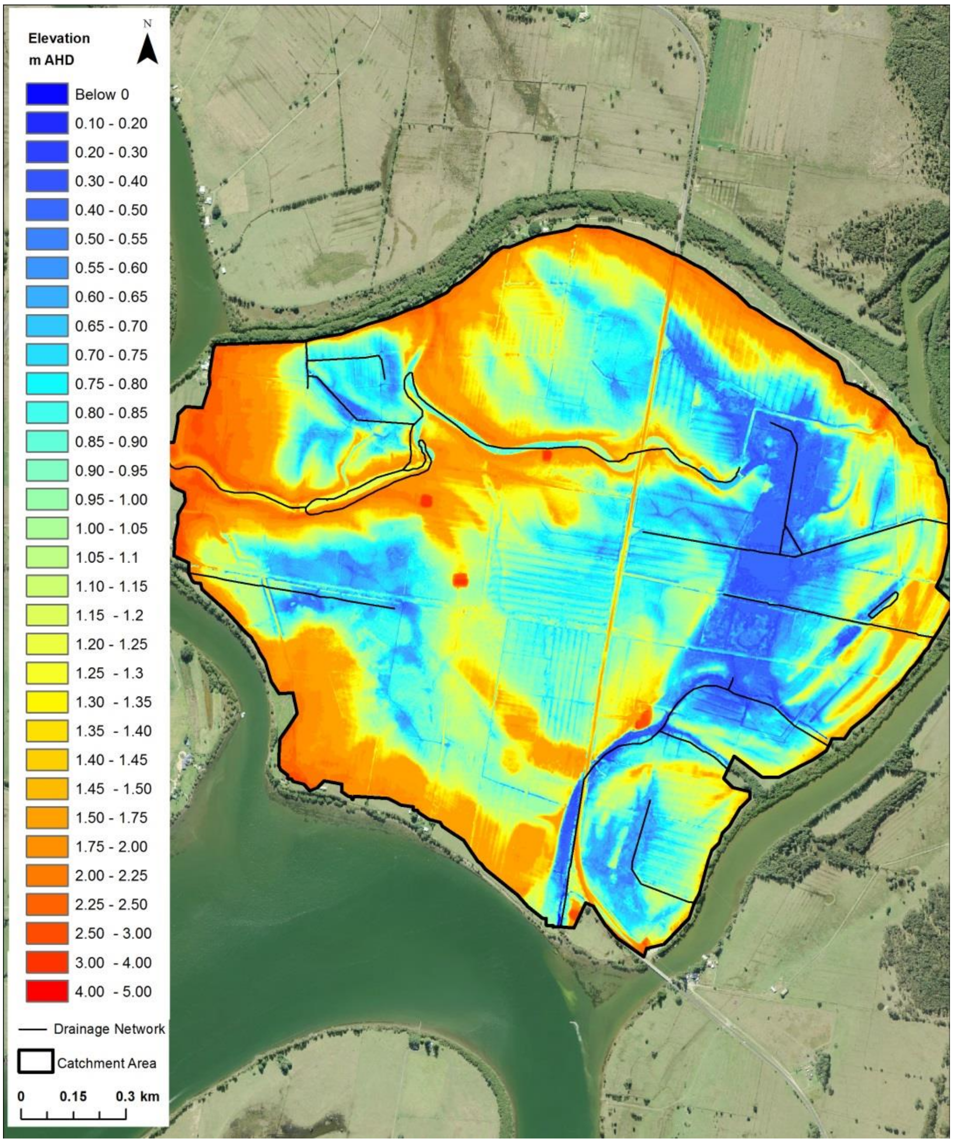


Figure 7.24: Sub-Catchment Boundary, Elevation Detail, Drainage Network – Mambo Island

7.15.2 History of Remediation

No known attempt at remediation to date.

7.15.3 Remediation Action Plan

A summary of the immediate and long-term management recommendations includes:

Immediate Remediation Strategy

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

Indicative Cost: $10,000 for design of modified floodgates plus $20,000 to $50,000 for implementation. Annual maintenance is between $5,000 to $10,000 per year. Drain design and reshaping is estimated to cost $20,000 per 500 m of drain length modified.

Long-term Remediation Strategy

This area is likely to be increasingly affected by reduced drainage with large areas remaining inundated by 2050 due to increases in low tide levels. Without additional infrastructure the agricultural productivity of Mambo Island is likely to become increasingly reduced and options for full rehabilitation of poorly drained land to wet pastures (freshwater), or wetland (saline) should be investigated.

Indicative Cost: $15,000 for design plus costs for environmental offset. Environmental offset may include land acquisition, drain infilling, drain reshaping and/or infrastructure removal.

7.16 Priority Area 15: Dumaresq Island

7.16.1 Site Description

Priority Rank:	15
Approximate Floodplain Area (ha):	600
Approximate Drainage Length (km):	15
# Floodgate Structures (MidCoast Council ID):	6 (661,667,666,663,664,660,658)
Structure Invert Levels (m AHD):	No Data
Median pH	6.25
Approximate Depth to AASS (m):	0.4
Approximate Depth to PASS (m):	1.1
Approximate Elevation of AASS (m AHD):	0.6
Approximate Elevation of PASS (m AHD):	0.1

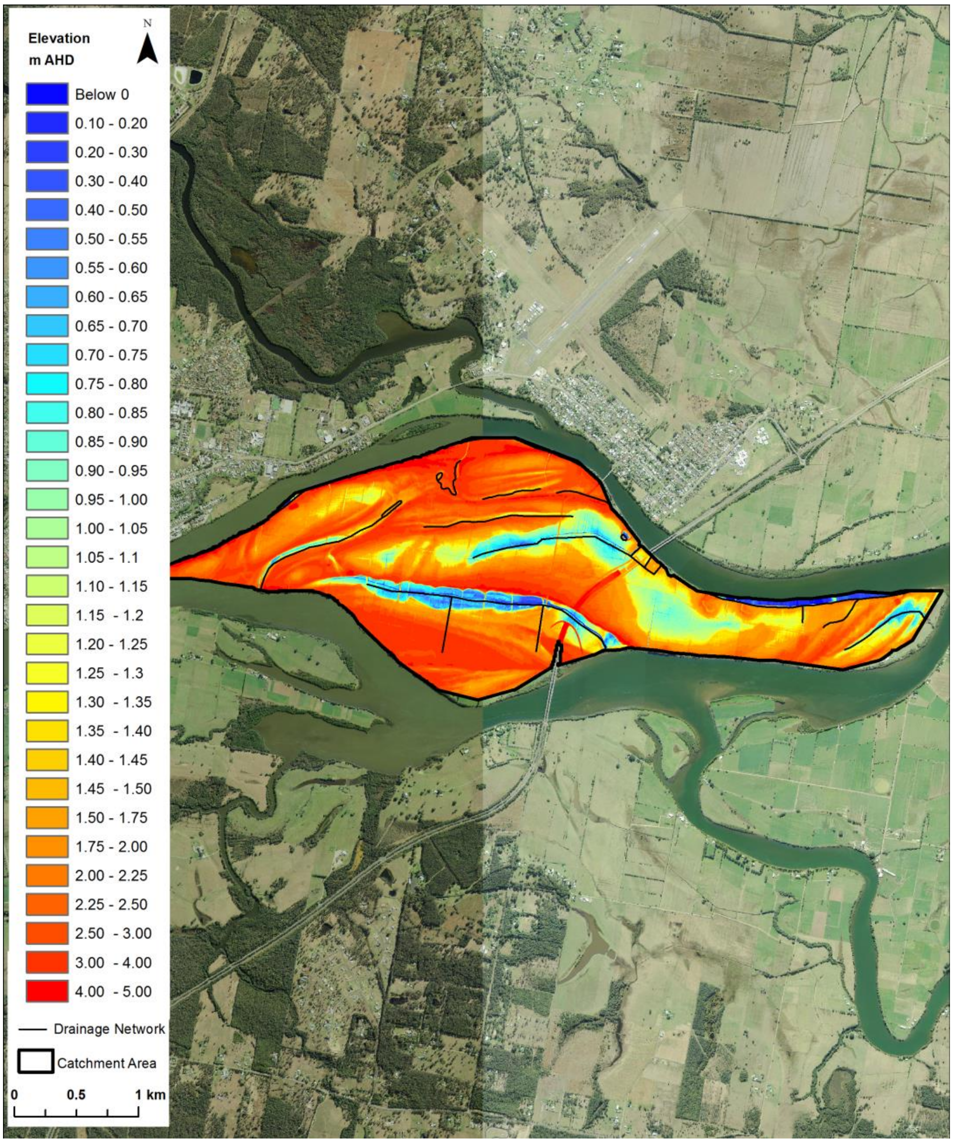


Figure 7.25: Sub-Catchment Boundary, Elevation Detail, Drainage Network – Dumaresq Island

7.16.2 History of Remediation

No known attempt at remediation to date.

7.16.3 Remediation Action Plan

A summary of the immediate and long-term management recommendations includes:

Immediate Remediation Strategy

Review of existing field data did not indicate a significant source of acid across Dumaresq Island. However, since the site drains slightly higher elevated land, groundwater manipulation and wet pasture management is encouraged (where applicable). It is also recommended that unused drains across the floodplain are infilled or reshaped to raise local groundwater levels and prevent potential acid discharges.

Indicative Cost: <$50,000. The cost includes $10,000 to $25,000 for design of weir(s) and drain modifications plus at least $30,000 for on-ground works, depending on the extent of drainage modification works. Annual maintenance of weir would be approximately $5,000.

Long-term Remediation Strategy

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

Indicative Cost: $15,000 for design plus costs for environmental offset. Environmental offset may include land acquisition, drain infilling, drain reshaping and/or infrastructure removal.

8. Climate Change Implications

8.1 Preamble

In 2009, the NSW Government outlined policy to include defined sea level rise (SLR) benchmarks into coastal planning and assessment. Adopted benchmarks were +0.4 m SLR by 2050 and +0.9 m SLR by 2100. In 2013, the Intergovernmental Panel on Climate Change (IPCC) released revised predictions of sea level rise. Since the release of the IPCC's fifth report, the NSW Government has revised planning policy, announcing that predetermined state-wide SLR projections in policy would no longer apply. Councils now have the flexibility to determine SLR projections to suit local conditions. For the purposes of this investigation, the 2009 state-wide 2050 and 2100 sea level rise planning levels have been used (Table 8.1).

Table 8.1: Sea Level Rise Prediction Values Utilised

Year	Sea Level Rise (m)
Present Day	+ 0.0 m
2050	+ 0.4 m
2100	+ 0.9 m

The Manning River floodplain is generally below 2 m AHD with some areas below 0 m AHD. Subsequently the estuary and floodplain is highly susceptible to SLR. Existing levees and infrastructure are likely to be threatened by rising sea levels and result in the inundation of low-elevation backswamp areas. Rising sea levels will also raise low tide elevations, reducing drainage across the Manning River floodplain. In this section the implications to floodplain drainage and inundation are investigated. Topographic data (from ground-truthed LiDAR) is used to determine regions impacted by predicted rising sea levels as shown in Figure 2.1. This information is then used to inform the on-ground action plans for the high-priority ASS-risk drainage areas, including Moto, Big Swamp, and Ghinni Ghinni.

The sea level rise predictions will occur in addition to normal tidal variations experienced in the Manning River estuary. Manly Hydraulics Laboratory (MHL 2012) analysed tidal harmonics at five (5) locations in the lower Manning River estuary for the period 1990 to 2010 (Figure 8.1). The average tidal planes for the record period were used for this investigation (Table 8.2). Tidal planes applied at Croki were considered to be representative of the tidal planes within the high-priority ASS-risk drainage areas, including Moto, Big Swamp, and Ghinni Ghinni. The mean high water (MHW) elevation (not the highest astronomical tide (HAT)) was used as the benchmark for climate change assessments. The MHW elevation regularly occurs, in comparison to HAT tidal levels which occur once every 18.6 year lunar cycle.

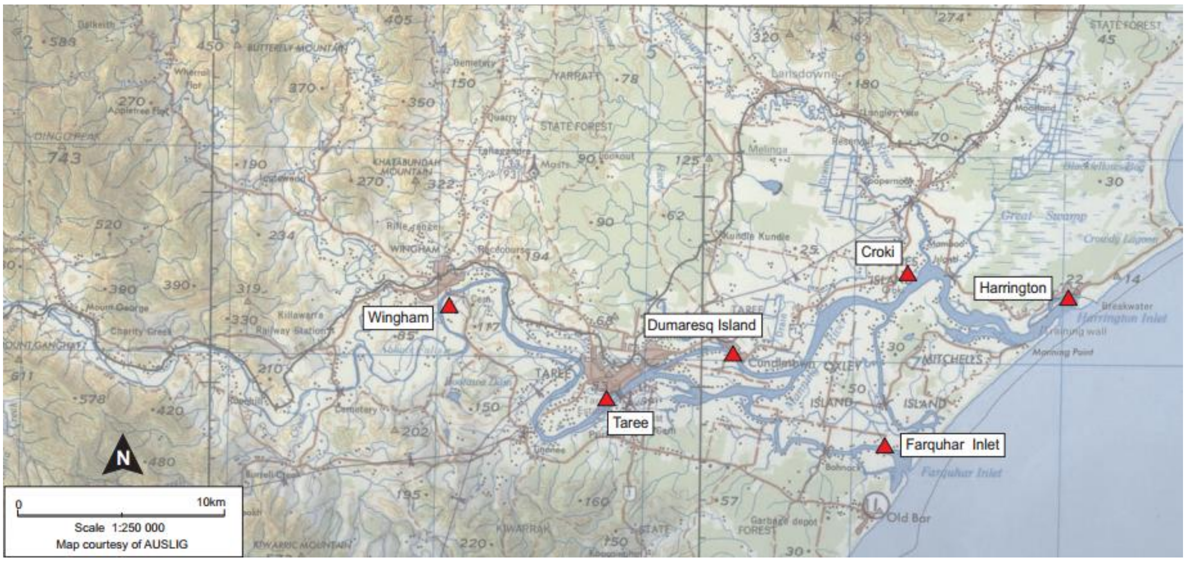


Figure 8.1: Tidal Plane Locations (Source: MHL 2012)

Table 8.2: Manning River Tidal Planes (m AHD) (MHL 2012)

Tidal Plane*	Harrington	Farquhar Inlet	Croki	Dumaresq Island	Taree
H.H.W.S.S.	0.855	0.646	0.638	0.648	0.725
M.H.W.S.	0.528	0.379	0.378	0.409	0.444
M.H.W.	0.437	0.338	0.339	0.362	0.397
M.H.W.N.	0.346	0.298	0.302	0.315	0.351
M.S.L.	0.082	0.133	0.146	0.172	0.155
M.L.W.N.	-0.182	-0.031	-0.009	0.029	-0.041
M.L.W.	-0.273	-0.072	-0.047	-0.018	-0.087
M.L.W.S.	-0.364	-0.112	-0.085	-0.065	-0.134
I.S.L.W.	-0.598	-0.303	-0.271	-0.236	-0.335

*Expanded tidal plane acronyms are as follows:

H.H.W.S.S – High High Water Spring Solstice
M.H.W.S – Mean High Water Springs
M.H.W – Mean High Water
M.H.W.N – Mean High Water Neaps
M.S.L – Mean Sea Level
M.L.W.N – Mean Low Water Neaps
M.L.W – Mean Low Water
M.L.W.S – Mean Low Water Springs
I.S.L.W – Indian Spring Low Water

8.2 Impacts of Climate Change

Predicted climate change over the coming century will result in changes to the existing hydrology and hydrodynamics of the Manning River estuary. Changes in evaporation and rainfall across the Manning River catchment, both increases and decreases, are likely to influence catchment hydrology, flooding and land management. Climate change projections are presented in Table 8.3 for the near future (2030) and far future (2070), compared to the baseline climate (1990–2009). The projections are based on simulations from a suite of twelve climate models run to provide detailed future climate information for NSW and the ACT (AdaptNSW 2014).

Table 8.3: Summary of Predicted Temperature and Rainfall Changes in the North Coast Region to 2070 (AdaptNSW 2014)

Forecast Period	Season	Minimum Temperatures	Maximum Temperatures	Precipitation
Near Future (2030)	Summer	0.7°C warmer	0.7°C warmer	-17% to +14%
	Autumn			-9% to +37%
	Winter			-40% to +30%
	Spring			-18% to +25%
Far Future (2070)	Summer	2.0°C warmer	1.9°C warmer	-10% to +39%
	Autumn			-8% to +39%
	Winter			-35% to +38%
	Spring			-18% to +49%

A detailed assessment of the above changes on biota, saline dynamics, catchment hydrology and flooding was not assessed in detail as a part of this study. The NSW Government summarised the overall impacts of climate change on the North Coast region (AdaptNSW 2014):

- *Based on long-term (1910–2011) observations, temperatures have been increasing in the North Coast Region since about 1970, with higher temperatures experienced in recent decades.*
- *The North Coast Region is projected to continue to warm in the near future (2020–2039) and far future (2060–2079), compared to recent years (1990–2009).*
- *The warming is projected to be on average about 0.7°C in the near future, increasing to about 2°C in the far future. The number of high temperature days is projected to increase, while a reduction is anticipated in instances of potential frost risk. The warming trend projected for the region is large compared to the natural variability in temperature and is of a similar order to the rate of warming projected for other regions of NSW.*
- *The North Coast currently experiences considerable rainfall variability across seasons and from year-to-year and this variability is also reflected in the projection.*
- *Sea level is extremely likely to keep rising.*
- *Sea level rise is likely to affect agricultural soils in low-lying areas. Coastal dune erosion is likely to increase significantly. Soil erosion is likely to increase on steeper slopes in the upper catchments, potentially causing sedimentation on the floodplains.*
- *Sea level rise, coupled with increased flooding, is virtually certain to pose a risk to property and infrastructure. Developments near estuary entrances and beaches and on coastal floodplains are most vulnerable.*
- *Sea level rise is very likely to alter estuarine and coastal lowland ecosystems. Seasonal drying is likely to degrade freshwater wetlands and higher temperatures are likely to cause cool-adapted ecosystems to change or contract. Altered fire regimes have the potential to cause major ecological change.*

Future sea level rise will result in changes to the present day tidal elevations provided in Table 8.2. Tidal dynamics in the estuary are variable with changes in tidal amplitude throughout the river. This trend will result in higher high tide levels, and elevated low tide levels. The overall impact to floodplain hydrology includes:

- Increased frequency of tidal/saline inundation;
- Elevated groundwater levels;
- Increased soil salinity in exposed low-lying areas adjacent to the open estuary due to elevated groundwater levels;

- Reduced drainage due to elevated low tides levels;
- Extended inundation of backswamp areas following flooding; and
- Reduced severity of acid discharge events.

A schematic of how sea level rise will impact floodplain drainage by raising low tide levels is presented in Figure 8.2.

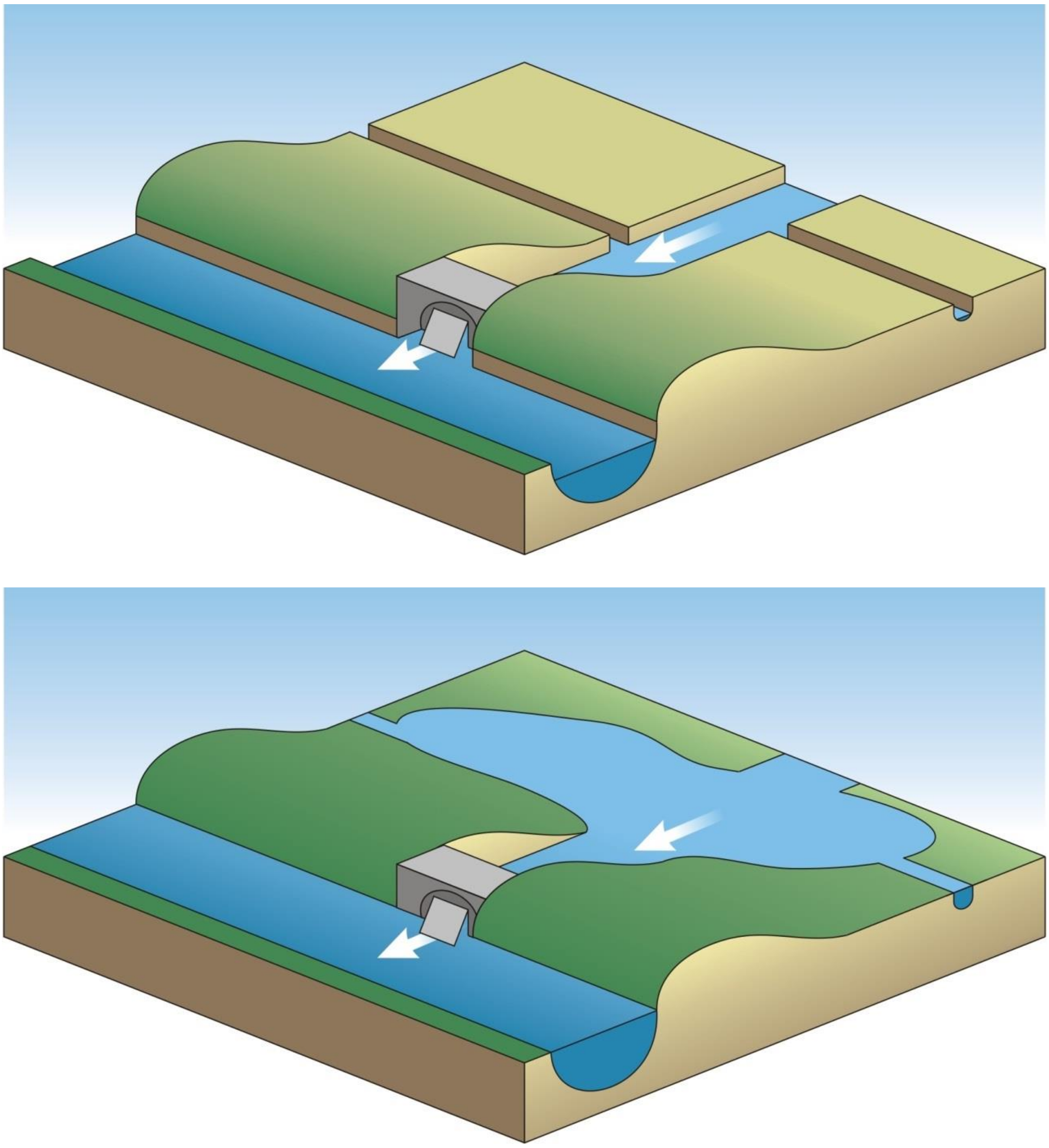


Figure 8.2: Impact of Sea Level Rise on Potential Drainage

Low-lying areas of the Manning River floodplain are likely to have significantly reduced drainage due to sea level rise. Increases in low tide elevation reduces drainage times and hydraulic gradients between draining floodwaters and the estuary. Although all areas of the estuary will experience reduced drainage, very low-lying areas will be subjected to periods of extended inundation by 2050. This impact will be most pronounced in the high-priority areas of the floodplain, including Moto, Big Swamp and Ghinni Ghinni (Figure 8.3). The degree of impact on these areas of the floodplains is detailed below.

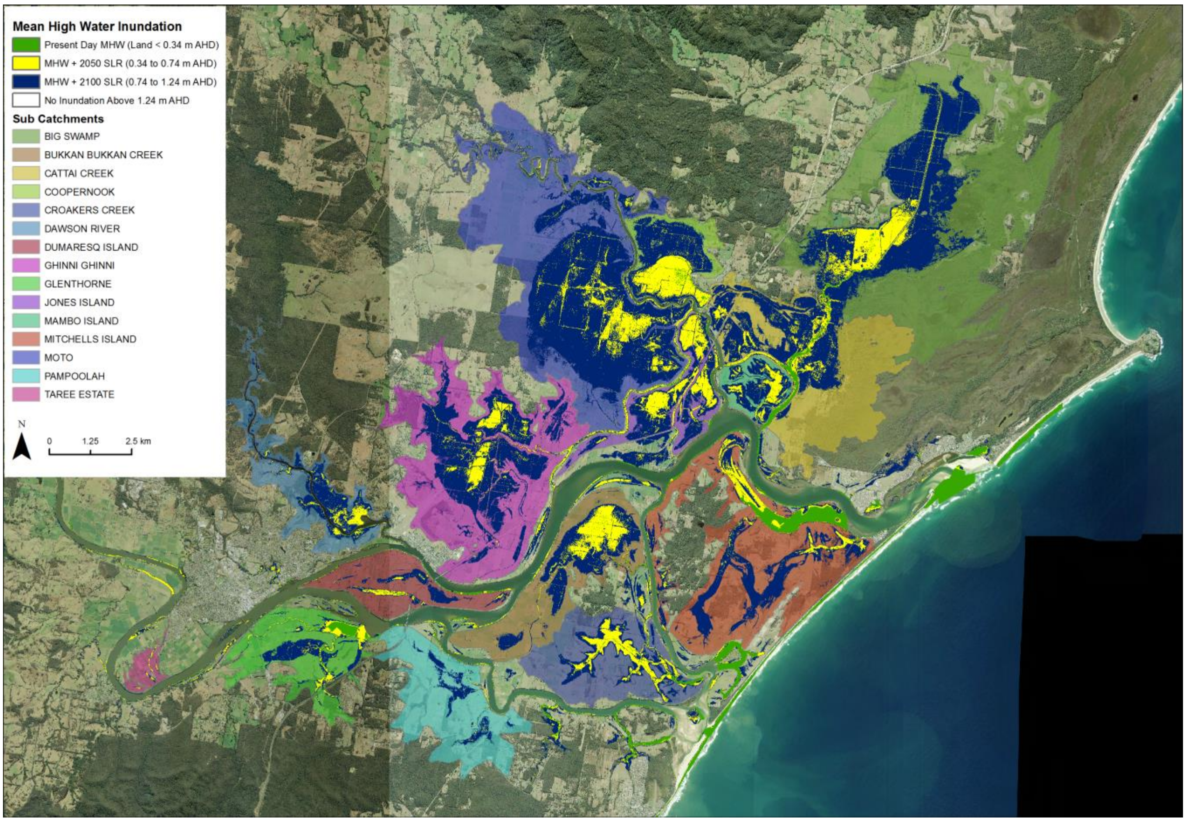


Figure 8.3: Climate Change Impacts Showing Changes to MHW Inundation

8.3 Climate Change Impact on Long-Term Management of Drainage Areas

When developing a long-term management strategy for drainage areas across the Manning River floodplain, the impact of climate change should be considered. Short-term (<10 years) drainage remediation strategies are aimed at maintaining existing agricultural productivity, whilst mitigating acid drainage impacts. Longer term management strategies target sustainable land-use practices which include low maintenance solutions to acid drainage. Sites that are susceptible to reduced backswamp drainage, overtopping of levee banks and/or structure headwalls, and increasing soil salinity in the near future due to sea level rise should have long-term remediation strategies implemented at an earlier stage, than sites with a low susceptibility to SLR. Furthermore, any short-term infrastructure invested in such sites should be designed to consider the transition towards a long-term strategy.

8.4 Susceptibility to Sea Level Rise

The impact of SLR on each sub-catchment of the Manning River estuary cannot be assessed without considering adjacent areas where connectivity at high water is likely to occur. Detailed ‘bath tub’ modelling of topographic data was undertaken to determine areas of connectivity during high water events. The elevation used to determine connected areas was the appropriate mean high water elevation for 2100 (M.H.W plus 2100 sea level rise of +0.9 m). Although this is not the highest possible tide level, this elevation will result in regular (monthly) inundation of the floodplain. The present day highest of high tides (H.H.W.S.S) for the lower Manning River estuary is approximately 0.65 m AHD. Table 8.4 outlines the elevations used for assessing the vulnerability of the Lower Manning River floodplain to SLR. Inundation mapping and stage-volume relationships for the top three (3), highest priority sub-catchment management areas of the Manning River estuary are presented in Figure 8.4 to Figure 8.6.

Table 8.4: Sea Level Rise and Future Tidal Planes

Benchmark	Elevation (m AHD)
Present Day M.H.W	0.34
M.H.W + 2050 SLR	0.74
M.H.W + 2100 SLR	1.24

The results of the inundation mapping showed areas that are susceptible to regular inundation for 0.4 m SLR (predicted by 2050) with existing infrastructure and/or significantly reduced drainage include:

- Moto Floodplain:
    - Priority Areas M1, M2, M3, M4, M7, M8, M10, M12, and M14.
- Ghinni Ghinni Floodplain:
    - Priority Areas G2, G5, G8, G12, G14, G15, and G17.
- Big Swamp Floodplain:
    - Priority Areas BS2, BS7, BS8, BS9, and BS10.

The results of the inundation mapping showed areas that are susceptible to regular inundation for 0.9 m SLR (predicted by 2100) with existing infrastructure and/or significantly reduced drainage include:

- Moto Floodplain:
    - All Priority Areas.
- Ghinni Ghinni Floodplain:
    - All Priority Areas, except G4 and G7.
- Big Swamp Floodplain:
    - All Priority Areas, except BS3 and BS12.

The SLR inundation assessment has shown that the floodplains of Moto, Ghinni Ghinni, and Big Swamp are highly susceptible to climate change. Changes in rainfall, evaporation, temperature, and sea levels are also likely to have a dramatic impact on existing land use practices across the whole Manning River estuary, where floodplain topography is in the zone of influence. Particularly, increases in sea levels over the next 50 to 100 years will affect low-lying backswamp areas. Likely sea level rise impacts on backswamp hydrology include:

- Reduced drainage due to elevated low tide levels;
- Elevated groundwater levels due to elevated low tide levels;
- Prolonged periods of inundation following flood events due to elevated low tide levels;
- Changes in groundwater salinity in areas immediately adjacent to the open estuary; and
- Overtopping of levees and floodgate structures during high tide.

Low-lying backswamp areas on the Manning River floodplain will be the first areas to be affected by reduced drainage. Increases in low tide elevations will reduce the time of drainage and increase drain water levels over the next 50 to 100 years. This will result in prolonged periods of pasture inundation following wet weather events, and elevated groundwater levels. Conversely, saline inundation due to the overtopping of levees and structures during spring tides is unlikely to cause significant salinity changes in floodplain soil over the same time period. Furthermore, the effects of overtopping due to high tides can be mitigated by the raising of levee banks and flood mitigation structures. In comparison, maintaining present day drainage of low-lying pastures over the next 50 to 100 years will be significantly more challenging. The long-term action plan for low-lying backswamp areas that are highly susceptible to reduced drainage should target the transition of land use practices to include wet pasture management, and/or reversion of highly susceptible land to a natural wetland system (i.e. full rehabilitation), sooner rather than later.

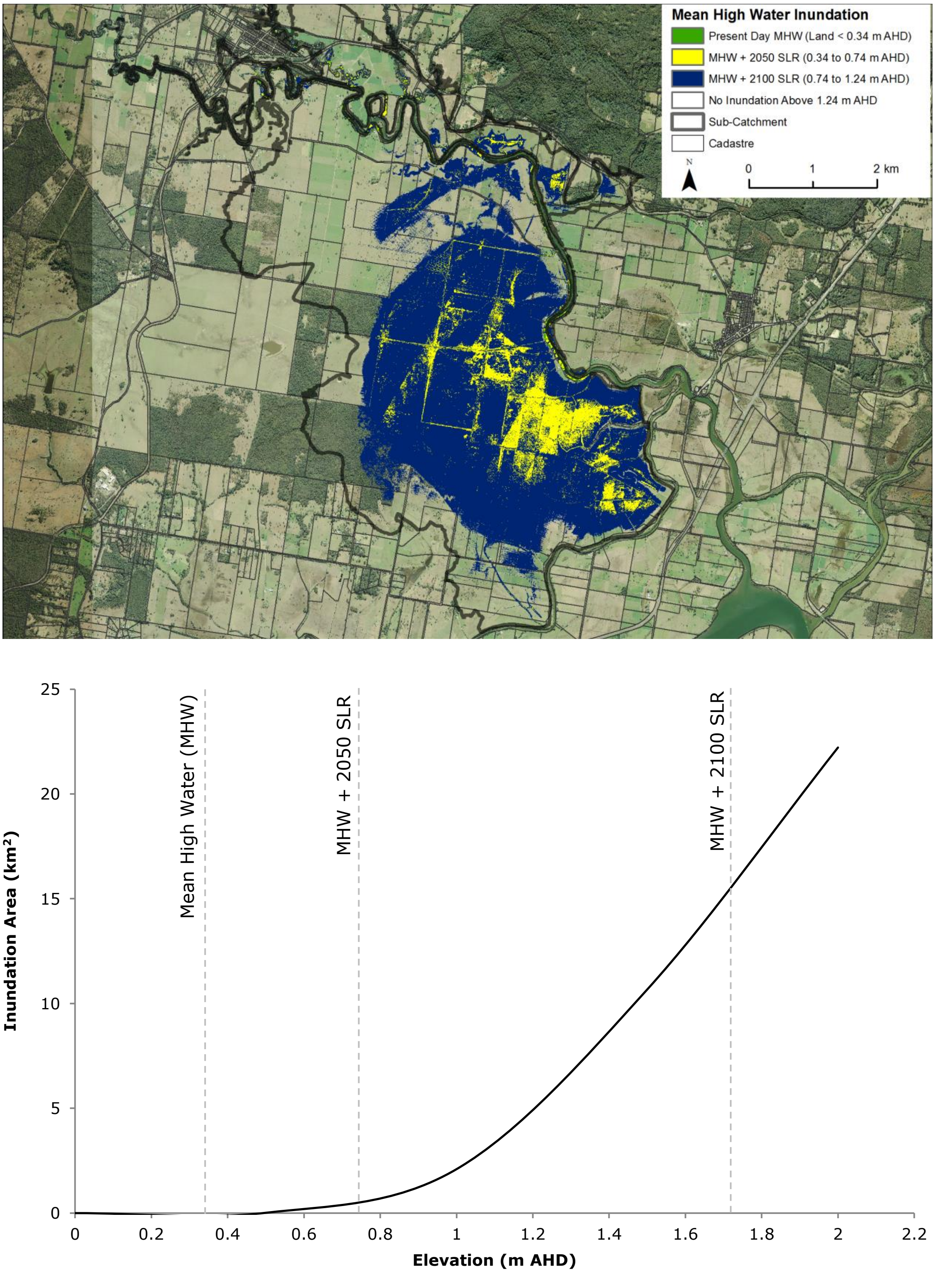


Figure 8.4: Potential Inundation of Moto due to Climate Change (top) and Stage-Volume Relationship for Moto (bottom)

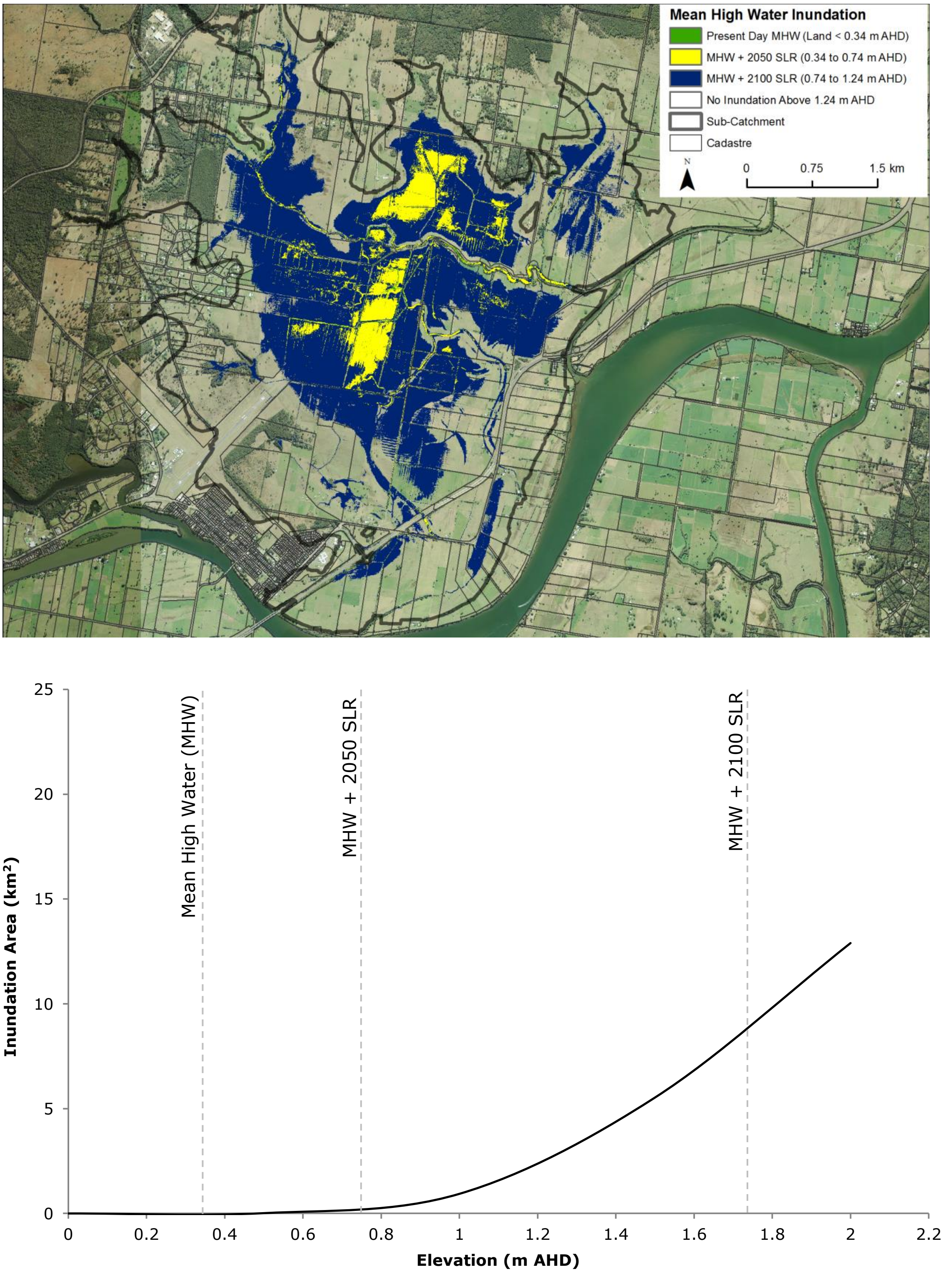
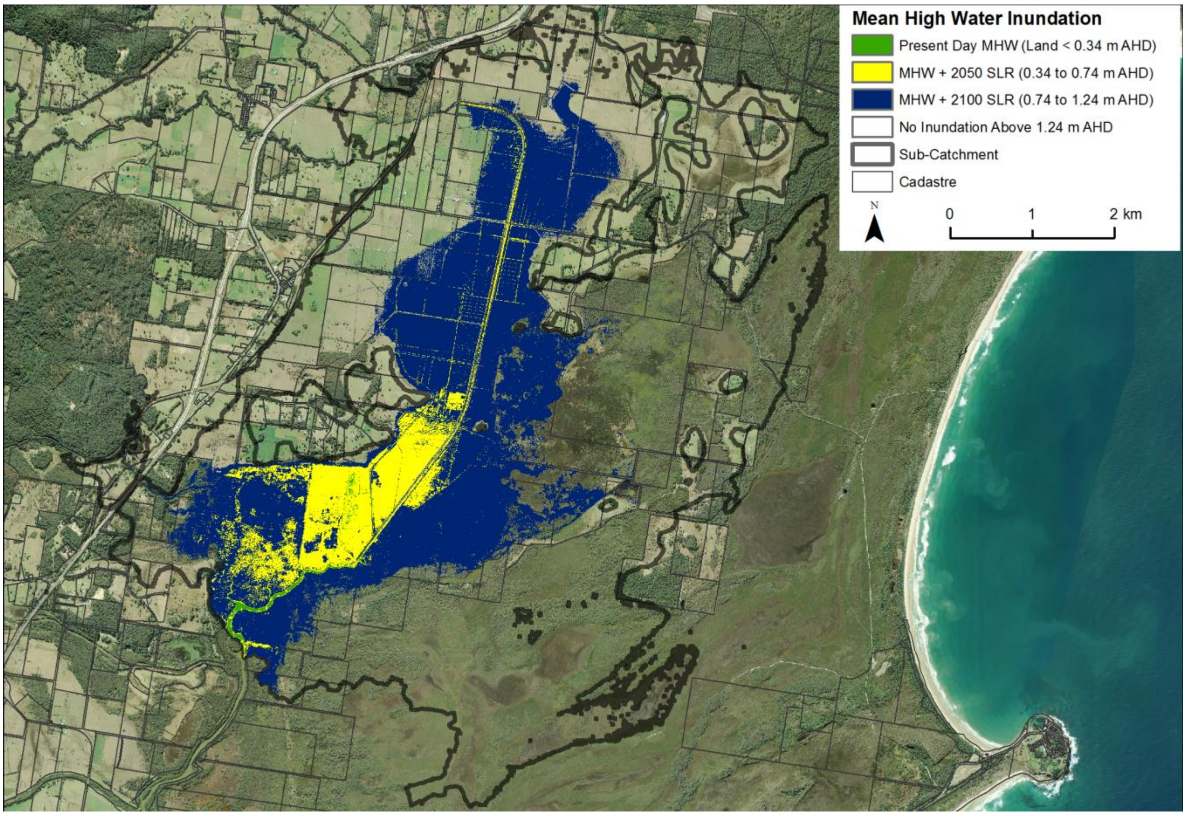


Figure 8.5: Potential Inundation of Ghinni Ghinni due to Climate Change (top) and Stage-Volume Relationship for Ghinni Ghinni (bottom)



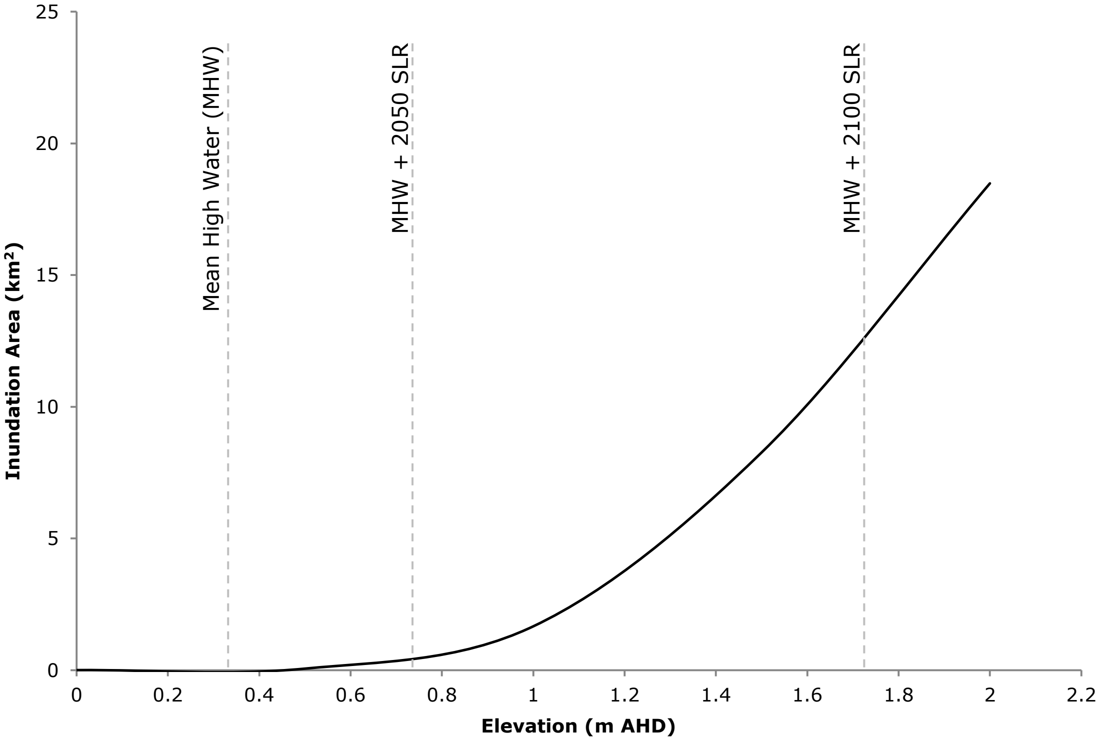


Figure 8.6: Potential Inundation of Big Swamp due to Climate Change (top) and Stage-Volume Relationship for Big Swamp (bottom)

9. Outcomes and Recommendations

This study aimed to identify and prioritise the remediation of drainage channels on the Manning River floodplain. Acid risk from each drainage channel and associated catchment was evaluated using a multi-criteria risk assessment. A range of environmental factors/processes contributing to acid risk were identified and the data associated with each factor collated and reviewed. Factors/drainage characteristics used to determine the acid risk of each drainage area were:

- Drainage;
- Catchment hydrology;
- Groundwater movement;
- Water quality; and
- Acid sulfate soil distribution.

These factors were used to rank the 15 sub-catchment drainage areas on the Manning River floodplain. Short and long-term remediation action plans were designed for each drainage area. Remediation plans were based on drainage characteristics and designed to incorporate:

- Asset condition;
- Landholder support;
- Climate change; and
- Sensitive receivers/habitat.

The Moto, Ghinni Ghinni, Big Swamp, and Coopernook backswamp floodplains were found to have significantly greater acid risk compared to the other floodplain across the Manning River estuary. The higher acid risk of the top five (5) highest priority floodplains was due to a number of factors, including shallow AASS, high soil hydraulic conductivity, low groundwater and soil pH, and a dense network of floodplain drainage channels. Conversely, the other lower priority floodplains across the Manning River estuary were characterised by deeper AASS layers, higher groundwater pH, lower catchment yield, and a reduced drainage density. Furthermore, the large Moto, Ghinni Ghinni, Big Swamp, and Coopernook backswamp floodplains have the potential for acid discharges in the Lansdowne River, Ghinni Ghinni Creek, and Cattai Creek to join to form a large acidic plume following high rainfall events. Smaller, more isolated sub-catchments across the Manning region do not discharge into a single water body (like Cattai Creek), but drain into a large area of the Lower Manning River estuary, providing higher potential dilution and buffering of acidic discharges.

The Action Plans presented in this report focus on short and long-term remediation of ASS-affected drainage areas and improvement of estuarine ecology. The areas of Moto, Ghinni Ghinni, Big Swamp, and Coopernook were identified as high priority areas. Further investigation is required at each drainage area to design detailed engineering specifications for on-ground remediation works. Co-currently, further landholder engagement and training is recommended to ensure landholder support for drain remediation and wetland rehabilitation. These actions should be implemented at the same time or prior to the application of any remediation Action Plans.

9.1 Summary

A detailed evidence-based prioritisation list of flood mitigation drains across the Manning River estuary has been developed. The outcomes from the study should be used to determine where and how future restoration and/or environmental funding should be allocated. The results from the study indicate that large portions of the floodplain are severely impacted by ASS discharges and that a range of techniques are available to remediate historical land practices.

The study provides, for the first time, an objective and catchment-wide assessment of acid impacts across the Manning River floodplain. The 15 sub-catchment drainage systems were prioritised based on their documented acid impact to the landscape and adjacent surface waters. For each drainage system a data summary table has been developed and immediate and long-term Action Plans created. Successfully implementing the plans will be reliant on collaborative efforts between the MidCoast Council and willing landholders. Previous efforts indicate that any on-ground works will need to be supported by long-term maintenance programs.

The forecasted impact of sea level rise was shown to be of particular importance to many of the drainage systems. While tidal overtopping of levees and structure headwalls may occur by 2100, elevated low tide levels due to climate change are likely to have a greater impact on backswamp drainage (and thus agricultural productivity). While this may reduce acid drainage, a coordinated approach will likely provide better agricultural and environmental outcomes.

9.2 Recommendations

Stakeholder consultation and training. Stakeholder engagement and training is crucial to the successful management of floodplain drainage across the Manning region. A consultation and training program should be designed and implemented which presents the science, various management options and their impacts on both the environment and agriculture.

Implementation of Action Plans via detailed design of on-ground works. MidCoast Council is encouraged to focus environmental funding on targeted on-ground works to remediate high priority ASS-risk areas of the floodplain based on the recommendations provided in this report.

Development of a Manning River estuary floodplain database. A significant quantity of high quality data was collated and reviewed as a part of this study. This information should be stored in an easily accessible and centralised database to aid future floodplain management decisions. New additional data should then be added as it becomes available.

Ongoing monitoring of water quality and further collection of data. Existing data collection on the Manning River estuary should be maintained, particularly:

- Ongoing water quality data collection at Big Swamp; and
- Water levels and gauging stations currently monitored by NSW DPI, Manly Hydraulics Laboratory, and NSW Office of Water.

Additional monitoring should also be undertaken:

- Continuous upstream water level, pH and salinity monitoring of Dickensons Creek, Ghinni Ghinni Creek, Cattai Creek-Pipeclay Canal, and the Lansdowne River, with increased focus on acid related constituents and post-flood event monitoring across the Lower Manning River estuary;
- Expansion of the existing soil profile database; and
- Additional hydraulic conductivity data measurements across high priority areas.

Confirmation of acid threat to Lower Manning River estuary. WRL recommends that the acid threat be quantified by targeting a large wet weather event to capture acid discharged from the floodplain drainage network, particularly in Dickensons Creek, Ghinni Ghinni Creek, Cattai Creek-Pipeclay Canal, and the Lansdowne River. This monitoring program should feature high resolution, intensive monitoring of all drains and the estuary for a one to four week period following a flood event.

Economic assessment of management options by undertaking a Management Cost-Benefit Analysis. An economic assessment may provide recommendations regarding the cost/benefit of the different management options, particularly voluntary acquisition of land compared to on-ground remediation works.

10. References

AdaptNSW (2014), North Coast Climate Change Snapshot. NSW Government, Office of Environment and Heritage.

ANZECC (2004)*, Australian Water Quality Guidelines for Fresh and Marine Waters*, Australian and New Zealand Environment and Conservation Council.

ARR (2001), Book 8 of *Australian Rainfall and Runoff*.

Asao T (2000), 'Towards sustainable landuse within acid sulfate soil landscapes: A case study on the Maria River', New South Wales, Lund University, Sweden.

Blunden, BG and Indraratna, B (2000), 'Evaluation of Surface of Groundwater Management Strategies for Drained Sulfidic Soils using Numerical Simulation Models', *Australian Journal of Soil Research*, 38, 569-90.

Boughton, W (2004), 'The Australian Water Balance Model', *Environmental Modelling and Software*, 19, 943-956.

Boughton, W and Chiew, F (2007), 'Estimating Runoff in Ungauged Catchments from Rainfall, PET and the AWBM Model', *Environmental Modelling & Software*, 22, 476-487.

Chow, VT (1959), *Open Channel Hydraulics*, New York, NY, McGraw-Hill Book Co.

Currie, BA and Atkinson, G (2001), Lower Lansdowne-Moto-Ghinni Ghinni Creek Acid Sulfate Soil Hotspot Remediation Concept Plan, Greater Taree City Council.

Dent, D (1986), *Acid Sulfate Soils: a baseline for research and development*, IRRI Publication No. 39, Wageningen, The Netherlands.

Dent, D and Pons, L (1993), 'Acid and muddy thoughts', In *Proceedings National Conference on Acid Sulfate Soils*, (Ed. R. Bush), 24-25 June 1993 Coolangatta, NSW, 1-19.

Department of Environment and Climate Change (DECC) (2008), *What are the effects of acid sulfate soils?*, NSW Government.

Department of Natural Resources and Mines (NRM) (2011), *What are acid sulfate soils?*, QLD Government.

Department of Resources and Environment (DERM) (2009), What are acid sulfate soils?, QLD Government.

Digby, MJ, Land and Water Resources Research and Development Corporation (Australia), and National River Health Program (Australia), Urban Sub-Program (1999), A physical classification of Australian estuaries, Land and Water Resources Research and Development Corporation, Canberra.

Dove, MC (2003), Effects of estuarine acidification on survival and growth of the Sydney rock oyster Saccostrea glomerata, PhD Thesis, Geography Program, Faculty of Built Environment, UNSW, 2003.

El-Mowelhi, NM and van Schilfgaarde, JV (1982), Computation of Soil Hydrological Constants from Field Drainage Experiments in Some Soils of Egypt, ASAE. 25 (4): 0984-0986. (doi: 10.13031/2013.33651).

Ferguson, A and Eyre, BD (1996), 'Floodplain Hydrology and the Transport of Acid Sulfate Soil Products', in *Proceedings of 2nd National Conference on Acid Sulfate Soils,* Coffs Harbour, 5-6 September 1996, (Eds. R J Smith and H J Smith), 120-127.

Glamore, W and Indraratna, B (2001), 'The impact of floodgate modifications on water quality in acid sulfate soil terrains', in *15th Australasian Coastal and Ocean Engineering Conference Proceedings*, 25-28th September, Gold Coast, Australia.

Glamore, WC (2003), 'Evaluation and Analysis of Acid Sulfate Soil Impacts via Tidal Restoration', PhD Thesis, Faculty of Engineering, University of Wollongong.

Glamore, W and Rayner, D (2014), Lower Shoalhaven River Drainage Remediation Action Plan, Water Research Laboratory, WRL Technical Report No. 2012/25.

Glamore, WC, Ruprecht, JE, Rayner, DS and Smith, GP (2014), Big Swamp Rehabilitation Project: Hydrological Study, Water Research Laboratory, WRL Technical Report No. 2012/23.

Golab, AN and Peterson, MA (2009), 'Selection of permeable reactive barrier materials for Treating Acidic Groundwater in Acid Sulfate Soil Terrains Based on Laboratory Column Tests', *Environmental Earth Sciences*, 59, 241-254.

Hirst, P, Slavich, P, Johnston, S and Walsh, S (2009), Assessment of Hydraulic Conductivity in Coastal Floodplain Acid Sulfate Soils on the North Coast of NSW, NSW Dept. of Industry and Investment.

Indraratna, B, Sullivan, J and Nethery, A (1995), 'Effect of Groundwater Table on the Formation of Acid Sulfate Soils', *Mine Water and the Environment*, 14(6), 71-84.

Indraratna, B and Blunden, B (1998), 'Remediation of Acid Sulfate Soils by Management of Groundwater Table', In *Proceedings of GREEN 2: Contaminated and Derelict Land*, ed. R. W. Sarsby, Kraków, Poland, 324-333.

Indraratna, B, Tularam, GA and Blunden, B (2001), 'Reducing the Impact of Acid Sulfate Soils at a Site in Shoalhaven Floodplain of New South Wales, Australia', *Quarterly Journal of Engineering Geology and Hydrogeology*, 34, 333-346.

Indraratna, B, Golab, AN, Glamore, W and Blunden, B (2006), 'Acid Sulfate Soil Remediation Techniques on the Shoalhaven River Floodplain, Australia', *Journal of Engineering Geology and Hydrogeology*, 38, 129-142.

Indraratna, B, Golab, AN and Banasiak, LJ (2006), 'Installation of a lime injection barrier for the remediation of acid sulfate soil problems', *Journal of Engineering Geology and Hydrogeology*, 39, 391-402.

Johnston, S, and Slavich, P, (2003), Hydraulic Conductivity – A simple field test for shallow and coastal acid sulfate soils, NSW Agriculture: Wollongbar, pp.1-9.

Johnston, S, Kroon, F, Slavich, P, Cibilic, A and Bruce, A (2003), 'Restoring the balance: Guidelines for managing floodgates and drainage systems on coastal floodplains', NSW Agriculture, Wollongbar, Australia.

Johnston, S, Slavich, P, and Hirst, P (2004), 'The acid flux dynamics of two artificial drains in acid sulfate soil backswamps on the Clarence River floodplain, Australia', *Australian Journal of Soil Research*, 42, 623-637.

Johnston S. (2007), Cattai Creek – Preliminary Acid Sulfate Soil Assessment.

Kiker, GA, Bridges, TS, Varghese, A, Seager, TP and Linkov, I (2005), 'Application of multi-criteria decision analysis in environmental decision making', *Journal of Integrated Environmental Assessment and Management*, 1(2), 95-108.

Lawrie RA and Eldridge SM (2002), *Soil Study of the acid sulfate soil hotspot areas along Broughton Creek*, Nowra, NSW (unpublished report to Shoalhaven City Council, Nowra).

Lin, C and Melville, MD (1993), 'Control of Soil Acidification by Fluvial Sedimentation in an Estuarine Floodplain, Eastern Australia', *Journal of Sedimentary Geology*, 85, 271-284.

MidCoast Council (formerly Greater Taree City Council) (2008a), Acid Sulfate Soil Drainage Management Plan – Jones Island (Curtis Property), January 2008.

MidCoast Council (formerly Greater Taree City Council) (2008b), Acid Sulfate Soil Drainage Management Plan – Moto Drainage Board (Ghinni Ghinni Creek/Lansdowne River), January 2008.

MidCoast Council (formerly Greater Taree City Council) (2008c), Acid Sulfate Soil Drainage Management Plan – Lansdowne River (Roche Property), February 2008.

MidCoast Council (formerly Greater Taree City Council) (2008d), Acid Sulfate Soil Drainage Management Plan – Lower Cattai Creek Drainage Management Plan, February 2008.

MidCoast Council (formerly Greater Taree City Council) (2008e), Acid Sulfate Soil Drainage Management Plan – Oxley Island Surface Drainage Laser Levelling Project (Neal Property), February 2008.

MidCoast Council (formerly Greater Taree City Council) (2009a), Acid Sulfate Soil Drainage Management Plan – Dickensons Creek (former Mills Property), May 2009.

MidCoast Council (formerly Greater Taree City Council) (2009b), Acid Sulfate Soil Drainage Management Plan – Moto Drainage Board Addendum, August 2009.

MidCoast Council (formerly Greater Taree City Council) (2010), The Big Swamp Feasibility Study.

Nash, C and Rubio-Zuazo, AM (2012), 'Monitoring the Canaries of Our Catchments', *21st NSW Coastal Conference*, Australia.

Naylor, S, Chapman, G, Atkinson, G, Murphey, C, Tulau, M, Flewin, T, Milford, H and Moran, D (1995), *Guidelines for the use of acid sulfate soil risk maps*, Soil Conservation Service, Sydney.

NSW Department of Primary Industries (2007), 'The Assessment and Management of Floodgates on the NSW South Coast', Report to the National Heritage Trust, NSW Department of Primary Industries, Sydney.

NSW Food Authority (2016), <http://www.foodauthority.nsw.gov.au/industry/shellfish>.

NSW Public Works Manly Hydraulics Laboratory (MHL), (2012), OEH Tidal Planes Analysis: 1990 – 2010 Harmonic Analysis, Report MHL2053.

Office of Environment and Heritage NSW, (2016), <http://www.environment.nsw.gov.au/eSpadeWebapp/>

Oosterbaan, R.J. and Nijland, H.J. (1994), Determining the Saturated Hydraulic Conductivity. Chapter 12, In: Ritzema, H.P., Ed., Drainage Principles and Applications, International Institute for Land Reclamation and Improvement (ILRI), Wageningen, 1125.

Partington, DJ, Maier, HR, Dandy, GC, Simmons, CT and Werner, AD (2008), 'A Review of Modelling Surface Water - Groundwater Interaction in and Around Deep Drains with Weirs', *Proceeding of Down Under Water Conference*, Adelaide, 2519-2528.

Pilgrim, DH and McDermott, GE (1981), Design Floods for Small Rural Catchments in Eastern New South Wales, First National Local Government Engineering Conference, Institution of Engineers, Australia, pp.138-142.

Raaijmakers, R, Kywkow, J and van der Veen, A (2008), 'Flood risk perceptions and spatial multi-criteria analysis: an exploratory research for hazard mitigation', *Journal of Natural Hazards*, 46(3), 307-322.

Rashed, T and Weeks, J (2003), 'Assessing vulnerability to earthquake hazards through spatial multicriteria analysis of urban areas', *International Journal of Geographical Information Science*, 17(6), 547-576

Rayment, GE and Higginson, FR (1992), *Australian laboratory handbook of soil and water chemical methods*, Inkata Press Pty Ltd, Melbourne.

Rayner, DS (2010), 'Understanding the Transport and Buffering Dynamics of Acid Plumes Within Estuaries', Water Research Laboratory, WRL Research Report 238.

Rayner, DS (2012), 'Tidal Inundation and Wetland Restoration of Tomago Wetland: Hydrodynamic Modelling', Water Research Laboratory, WRL Technical Report 2010/30.

Rayner, DS, Glamore, WC, Ruprecht, JE (2015), Predicting the buffering of acid plumes within estuaries, Estuarine and Coastal Shelf Science, Volume 164, Pages 56-64.

Regmi, G, Indraratna, B, Nghiem, LD and Banasiak, L (2001), 'Evaluating Waste Concrete for the Treatment of Acid Sulfate Soil Groundwater from Coastal Floodplains', *Desalination and Water Treatment*, 32, 126-132.

Regmi, G, Indraratna, B and Nghiem, LD (2009), 'Long-term performance of a Permeable Reactive Barrier in acid sulfate soil terrain', *Journal of Water, Air, & Soil Pollution*, 9, 409-421.

Regmi, G, Indraratna, B and Golab, A (2012), ‘Permeable reactive barrier (PRB) technology for the remediation of acidic groundwater from acid sulfate soil floodplain in south east New South Wales’, *Australian Geomechanics Journal*, 47(1), 73-78

Rosicky, MA, Sullivan, LA, Slavich, PG and Hughes, M (2004), ‘Factors Contributing to the Acid Sulfate Soil Scalding Process in the Coastal Floodplains of New South Wales, Australia’, *Australian Journal of Soil Research*, 42, 587-594.

Rosicky, MA, Slavich, PG, Sullivan, LA and Hughes, M (2006), ‘Surface and Sub-surface Salinity in and Around Acid Sulfate Soil Scalds in the coastal Floodplains of New South Wales, Australia’, *Australian Journal of Soil Research*, 44, 17-25.

Roy, P (1984), ‘New South Wales estuaries: their origin and evolution’, *Coastal Geomorphology in Australia*, Ed. Thom, Academic Press Australia, Sydney.

Russell, DJ and Helmke, SA (2002), ‘Impacts of acid leachate on water quality and fisheries resources of a coastal creek in northern Australia’, *Marine and Freshwater Research*, 51(1), 19-33.

Ruprecht, J, (2014), On-ground Remediation Works at Big Swamp, Manning River Estuary, NSW, prepared for NSW Department of Primary Industries, Fisheries, Milestone Report, Fish Habitat Program.

Sammut, J, and Melville, M (1994), ‘Impacts of poor water quality on fish’, In *Proceedings of Geomorphology and river health in New South Wales*, (Editors Brierley, G. J. and Nagel, F.) October 7th, Macquarie University.

Sammut, J, White, I and Melville, MD (1996), Acidification of an estuarine tributary in eastern Australia due to drainage of acid sulfate soils, *Marine & Freshwater Research*, 47, 669-684.

Sammut, J (1998), Associations between Acid Sulfate Soils, Estuarine Acidification, and Gill and Skin Lesions in Estuarine and Freshwater Fish, Ph.D. Dissertation, The University of New South Wales, Sydney.

Sammut, J (2000), An Introduction to Acid Sulfate Soils, National Library of Australia: 1-28.

Smith, R, Sammut, J, and Dove, M (1999), Impacts of Acid Water Drainage on the Manning Oyster Industry.

Sonter, L (1999), Spatial Characteristics of Acid Sulfate Soil – Induced Estuarine Acidification within Cattai Creek.

State Pollution Control Commission (SPCC), (1987), Water Quality in the Manning River, Northern Rivers Study No. 7.

Stone, Y, Ahern, C and Blunden, B (1998), *NSW Acid Sulfate Soil Manual*, NSW Government, Sydney.

Tratnyek, PG, Scherer, MM, Johnson, TL and Matheson, LJ (2003), ‘Permeable reactive barriers of iron and other zero-valent metals’, *Journal of Environmental Science and Pollution Control Series*, 371-422.

Tulau, MJ (1999), *Acid Sulfate Soil Priority Management Areas in the Lower Manning Floodplain*, NSW Department of Land and Water Conservation, Sydney.

Tulau, MJ (2001), *Agricultural drainage in acid sulfate soil backswamps in New South Wales, Australia - technical, regulatory and policy responses*, Dept. of Natural Resources, Kempsey, NSW.

Tulau, MJ (2007), *Acid Sulfate Soils Remediation Guidelines for Coastal Floodplains in New South Wales*, Department of Environment and Climate Change. DECC Report No. 2007/321.

Tulau, M.J. (2011), Lands of the richest character: agricultural drainage of backswamp wetlands on the North Coast of New South Wales, Australia: development, conservation and policy change: an environmental history., PhD thesis, Southern Cross University, Lismore, NSW.

Toniato, T (1998), 'Laboratory testing of pyrite oxidation in column tests'. Undergraduate Honours Thesis, University of Wollongong, NSW.

Umitsu, M, Buman, M, Kawase, K and Woodroffe, C (2001), 'Holocene Palaeoecology and Formation of the Shoalhaven River Deltaic-Estuarine Plains, Southeast Australia', *The Holocene*, 11, 407-418.

van Holst, AF and Westerveld, CJW (1973), 'Corrosion of concrete foundations in potential acid sulfate soils and subsoils in The Netherland'. In *H. Dost (ed.) Acid Sulfate Soils. Proc. Int. Symp. on Acid Sulfate Soils*, Wageningen, The Netherlands. 13-20 Aug. 1972. Pub. 18 - Vol. II. Int. Inst. For Land Reclamation and Improvement, Wageningen, The Netherlands' p. 373-382.

Vadrevu, KP, Eaturu, A and Badarinath, KVS (2010), 'Fire risk evaluation using multicriteria analysis—a case study', *Journal of Environmental Monitoring and Assessment*, 166(1-4), 223-239.

Webb McKeown and Associates (1997), Manning River Estuary Process Study.

White, I and Melville, M (1993), *Treatment and Containment of Acid Sulfate Soils. Technical Report 53*, Centre for Environmental Mechanics, CSIRO, Canberra.

White, I, Melville, MD, Wilson, BP and Sammut, J (1997), 'Reducing acidic discharges from coastal wetlands in eastern Australia', *Wetlands Ecology and Management*, 5, 55-72.

Williams, RJ and Watford, FA (1997), 'Identification of structures restricting tidal flow in New South Wales, Australia', *Wetlands Ecology*, 5, 87-97.

Willet, I and Walker, P (1982), 'Soil morphology and distribution of iron and sulfur fractions in a coastal plain toposequence', *Australian Journal of Soil Research,* 20, 283-294.

Willett, I, Crockford, R, and Milnes, A (1992), 'Transformation of iron, manganise and aluminium during oxidation of a sulfidic material from an acid sulfate soil', in *Biomineralisation Processes of Iron and Manganese - Modern and Ancient Environments* (Eds. Skinner, H. and Fitzpatrick, R.) pp 287-301, Germany, Catena Verlag.

Wilson, B (1995), 'Soil and hydrological relations to drainage from sugarcane on acid sulfate soils', Unpublished PhD thesis, University of New South Wales, Sydney.

Winberg, PC and Heath, T (2010), *Ecological Impacts of Floodgates on Estuarine Tributary Fish Assemblages*, Report to the Southern Rivers Catchment Management Authority.

Appendix A – Acid Sulfate Soil Theory

A.1 Preamble

Early experiences with acid sulfate soils (ASS), formerly known as 'cat clays', date back to the 17th century in the Netherlands, and the late-19th century in Australia; but it was not until the early 1970s that acidic clays on coastal floodplains were causing problems worldwide. Since then the various manifestations and impacts of ASS has been extensively researched and consequently well known, both overseas and in Australia, for a very long time. This section provides an introduction to the pertinent aspects of ASS theory, including its formation, mobilisation, and the various land and water impacts.

A.2 What are Acid Sulfate Soils?

Acid sulfate soil is the common name given to soils and sediments containing iron sulfides, the most common being pyrite (FeS_2) (DERM 2009). ASS are chemically inert whilst in reducing (anaerobic) conditions, including when situated below the water table, and are known as potential acid sulfate soils (PASS). When PASS are exposed to atmospheric oxygen due to climatic, hydrological, or geological changes, oxidation occurs. The oxidised layer produces sulfuric acid and is termed an actual acid sulfate soil (AASS).

A.2.1 Formation

ASS are predominantly located within 5 metres of the surface and are found extensively on Australia's coastline (DERM 2009). Pyrite is formed in reducing environments where there is a supply of easily obtained decomposed organic matter, sulfate, iron and reducing bacteria (Figure A.1). The deposition of these sands and muds occurs in low-lying coastal zones characterised by low energy environments, such as estuaries and coastal lakes. ASS that are of concern on Australia's coastal floodplains were formed during the last 10,000 years (i.e. the Holocene epoch).

DERM (2009) stipulates that the formation of pyrite requires:

- A supply of sulfur (usually from seawater);
- anaerobic (oxygen free) conditions;
- A supply of energy for bacteria (usually decomposing organic matter);
- A system to remove reaction products (e.g. tidal flushing of the system);
- A source of iron (most often from terrestrial sediments); and
- Temperatures greater than 10ºC.

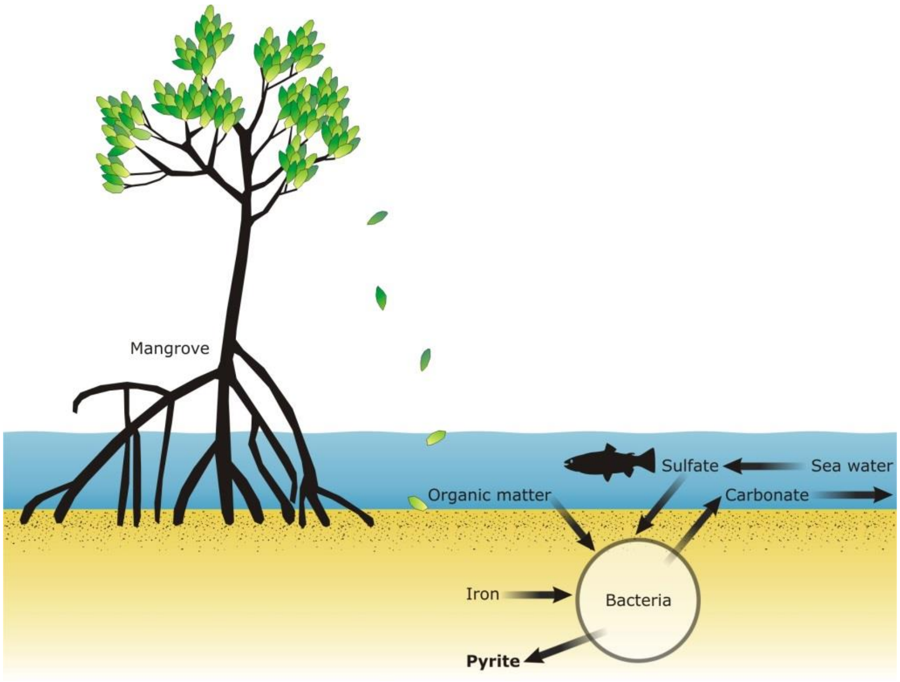


Figure A.1: Pyrite Formation (NRM 2011)

A.2.2 Acidification

The pH scale (Figure A.2) is used to grade acidity and is a measure of the hydrogen ion (H^+) concentration. The pH scale is logarithmic, ranging from 0 (strongly acidic) to 14 (strongly alkaline). Due to the logarithmic scale, a soil with a pH of 4 is 10 times more acidic than a soil with a pH of 5, and 1,000 times more acidic than a soil with a pH of 7 (NRM 2011).

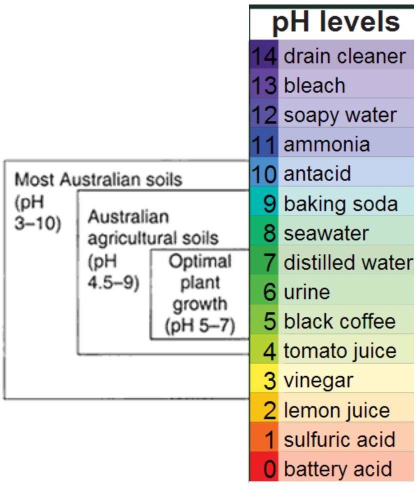
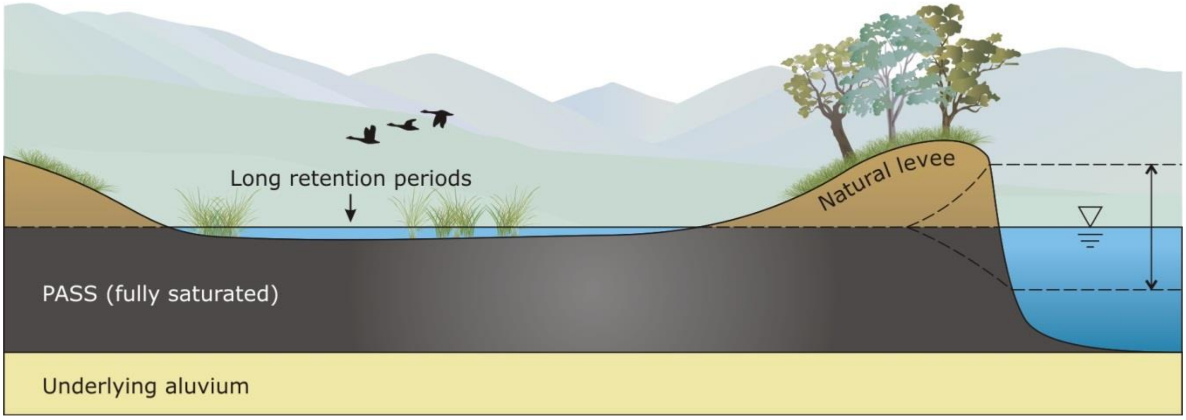


Figure A.2: pH Scale (Source: NRM 2011)

PASS are oxidised to form AASS by clearing of coastal land for agriculture, resulting in extensive drainage and a lower groundwater table, introducing gaseous oxygen to the soil matrix. When pyrite is exposed to atmospheric oxygen, the iron sulfides react to form sulfuric acid and numerous iron cations (e.g. Fe^{2+} and Fe^{3+}). The acid generated can break down the fine clay particles in the soil profile, causing the release of metals including aluminium (Al^{2+}). Generated acid is often mobilised from the soil matrix by rainfall raising the groundwater table, resulting in runoff into the drainage network or other receiving waters (Figure A.3). Depending on the pyrite content of the soil, acidity levels can fall below a pH of 4.5. At a pH of 4.5, iron and aluminium concentrations become soluble and can greatly exceed environmentally acceptable levels.

The soil structure of coastal floodplains is typically comprised of five (5) distinct zones of varying thickness. On the surface, an organic peat layer exists comprised largely of roots and decomposing matter. This layer transforms into an alluvial/clay zone. An AASS layer commonly exists below this and can be identified by the presence of orange/yellow mottling caused by the oxidation of pyrite. This soil layer often overlies a PASS layer characterised by dark grey, saturated estuarine mud. The PASS layer often has a pH near neutral, as pyritic material in the soil is unoxidised. The PASS layer is underlain by non-acidic sub-soil.

Undisturbed Environment



Drained Paddock

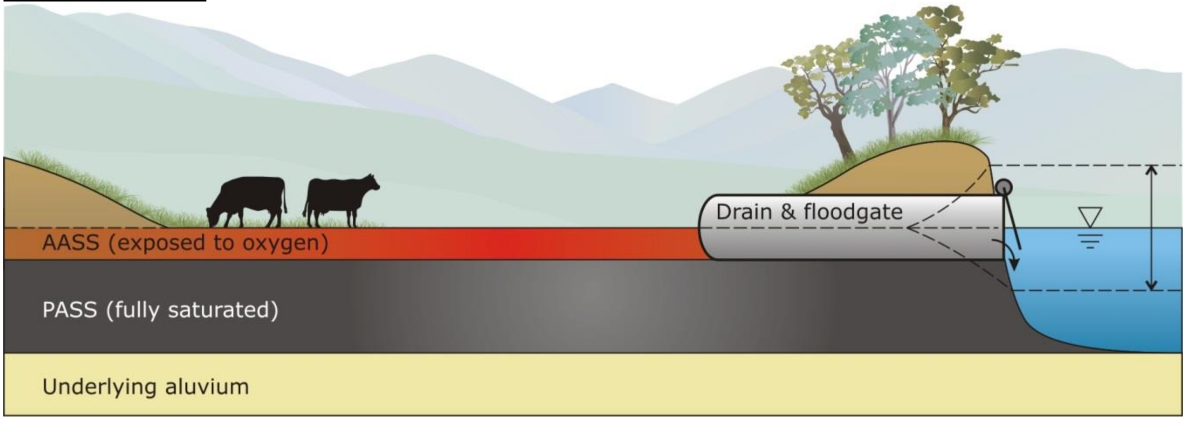


Figure A.3: Soil Acidification by Lowering of Groundwater Levels

A.3 Groundwater Drainage

The construction of deep drainage channels on floodplains acts to drain the low-lying backswamp and wetland areas, to allow for agricultural production. However, on coastal floodplains, drainage channels also allow tidal water to potentially inundate pasture and groundwater. As such, one-way floodgates are commonly installed to reduce tidal inundation of backswamp areas. The tidal floodgates restrict saline intrusion, and may provide livestock with a source of drinking water (Figure A.4).

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. Floodgates and drainage structures are usually designed to maintain drain levels at the low tide mark to drain backswamp areas and reduce pasture water logging (Glamore 2003). Since the pyritic layer is normally at the mid to high tide level, by maintaining drain water elevations lower than the pyritic layer, such as the low tide elevation, one-way floodgates increase the hydraulic gradient between the drain water and the surrounding acidic groundwater (Glamore 2003).

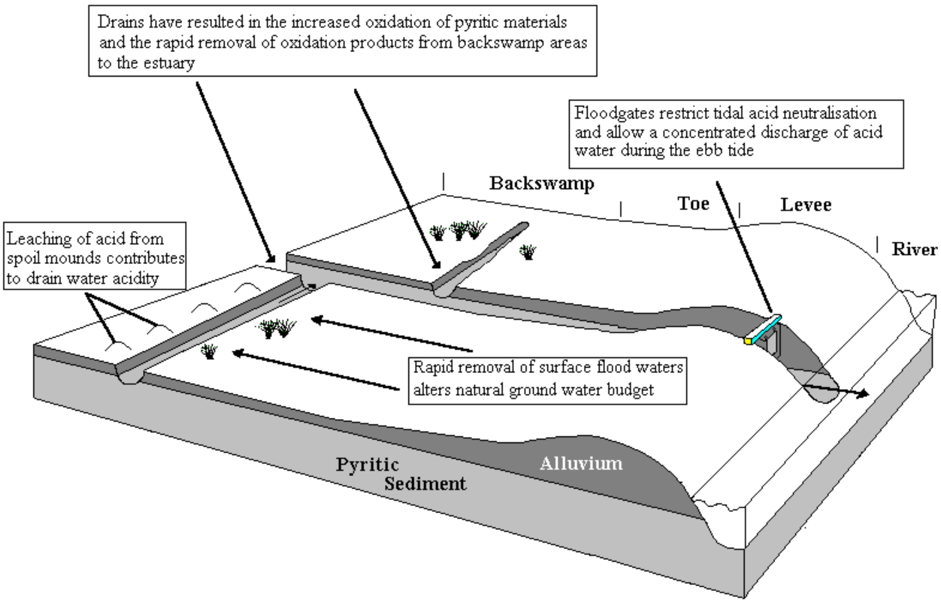


Figure A.4: Schematic of a Backswamp Drainage and Floodgate Network (Naylor et al. 1993)

The difference in hydraulic gradient caused by the tidal floodgates promotes the transport of oxygen into sulfidic subsoil material and the leaching of acid by-products into the drain (Blunden and Indraratna 2000). This is particularly evident following large rainfall events when receiving water levels drop, groundwater levels remain elevated, and floodgates effectively drain surface waters from the floodplain causing low drain water levels (Glamore and Indraratna 2001).

The depth of a drain (or drain invert) in relation to the acidic layer influences the potential risk of acid discharge. A deeply incised drain with a low invert constructed in a shallow AASS layer has a high risk, or potential, for acidic discharge. Conversely, a shallow drain constructed in the same shallow AASS layer floodplain would have a lower risk of acid discharge.

The ease at which groundwater flows through the soil and into a drain also influences the risk of acid discharge. Soil with a low potential groundwater flow rate, or low hydraulic conductivity, will export less acid compared to a soil with a high groundwater flow rate. This effectively relates back to the porosity of the soil. Generally, gravel is more porous than sand, which is more porous than clay. The higher the porosity, the greater potential for rapid acid discharge into a drain.

A.4 Acid Discharge

In a similar manner to geographical/geomorphological descriptions of estuaries internationally, Australian estuaries have recently been classified by Digby et al. (1999). Digby et al. (1999) describes an Australian estuary classification regime based on climate and hydrology. In Australia, most estuaries (approximately 70%) fall within the wet and dry tropical/subtropical category. The Manning River estuary is an example of this type of estuary (Digby et al. 1999). These estuarine systems are dominated by episodic short-lived large freshwater inputs during summer, and very little or no flow during winter. Under high flows, salt water may be flushed out of these estuaries completely. Many of these estuaries have a high tidal range, so following a flushing event, a salt-wedge intrudes along the estuary bottom, and the estuary progresses from a highly stratified salt-wedge estuary to a partially mixed estuary, to a vertically homogeneous estuary.

An understanding of estuarine systems in NSW under various climatic conditions has important implications for the cause and effect of acid discharges from coastal floodplains. While the water in drains on ASS-affected coastal floodplains can be highly acidic on a day-to-day basis, large plumes of acidic discharge are not typically recorded within estuaries during dry conditions. Conversely, large quantities of acid are often discharged following significant rainfall events. This typically occurs in the 5 to 14 days following the peak of a flood event. During other periods, the risk of widespread acidic contamination to the estuary is reduced.

Figure A.5 depicts a period of strong tidal flushing, limited acid flux (concentration x discharge) and thereby, high tidal buffering. The acid buffering capacity of an estuary is directly proportional to the volume of buffering agents within the system (Rayner et al. 2015). In areas with limited upstream inflows of buffering agents, the primary buffering agents are sourced from the diffusion of marine constituents. During dry climatic conditions (little or no flow), bicarbonate-rich seawater diffuses upstream from the tidal ocean boundary creating a salinity gradient throughout the estuary creating low acid risk conditions.

Figure A.6 depicts a period during or immediately following a flood event, whereby coastal floodplains are inundated with fresh floodwaters. As the floodwaters recede, large volumes of freshwater drain from the floodplain into the estuary. This process, in conjunction with large freshwater flows in the main river channel, reduces estuarine salinity. During these periods, acid is quickly flushed from the estuary and/or is highly diluted.

Figure A.7 depicts a period after floodwaters have receded and tidal levels slowly re-establish. During this period, floodplain pastures are saturated and groundwater levels remain elevated, resulting in a steep gradient between drain water levels and the surrounding groundwater. This process mobilises acid from the soil towards drainage channels and receiving waters (Figure A.8). As the natural buffering capacity of the estuary has been removed by the fresh floodwaters, acidic plumes comprised of low pH water and high soluble metal concentration remain in the open estuary.

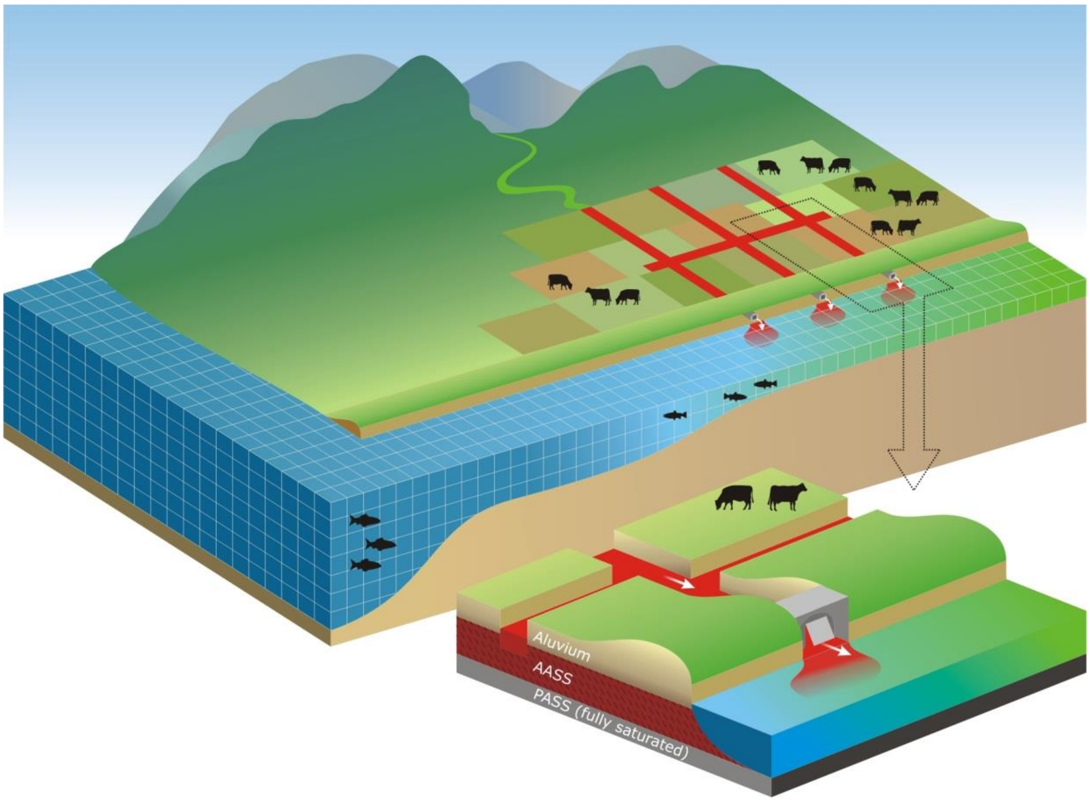


Figure A.5: Period of Tidal Buffering and Low Acid Risk

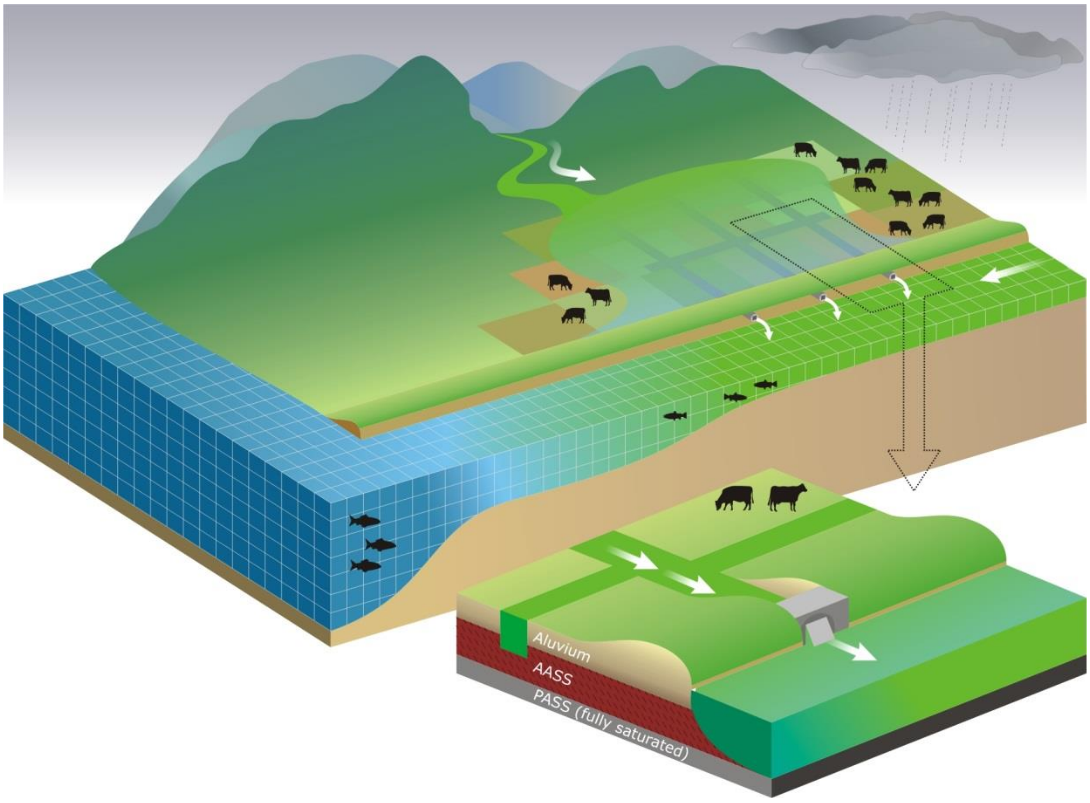


Figure A.6: Flow Dilution Period as a Result of a Large Rainfall Event

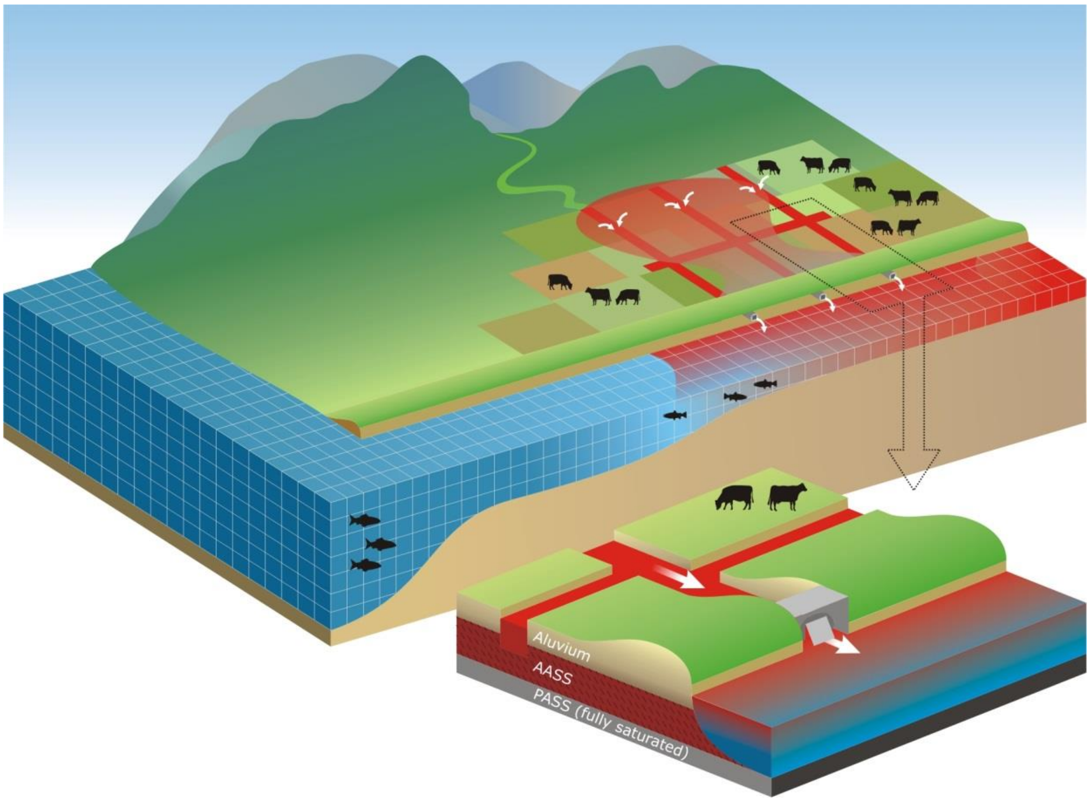


Figure A.7: Period of Acid Impact Following Rainfall Event

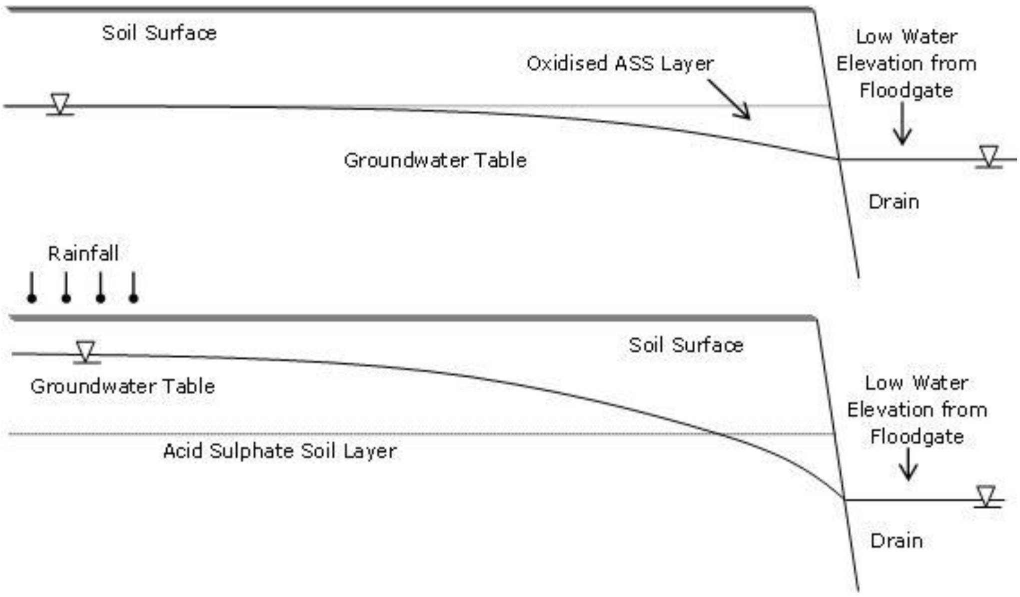


Figure A.8: Influence of One-way Floodgates on Groundwater Elevation under Normal (top) and Flood (bottom) Conditions (Glamore 2003)

A.5 Environmental Impacts

Pyrite oxidation causes adverse environmental, ecological, and economic effects worldwide. Soil acidification can lead to a deficiency in essential plant nutrients and plant base minerals such as calcium, magnesium, and potassium, while at the same time, toxic metals such as aluminium, iron, and other heavy metals increase. Furthermore, the release of acidic plumes, containing aluminium and iron flocs, is well known to cause widespread environmental pollution in tidal estuaries resulting in large scale fish kills (Sammut et al. 1995, 1996; Winberg and Heath 2010), and negatively impacts oyster health (Dove 2003).

In 2008, the NSW Office of Environment and Heritage (formerly the NSW Department of Environment and Climate Change (DECC)) identified numerous environmental impacts of acid discharge including:

- Habitat degradation;
- Fish kills;
- Outbreaks of fish disease;
- Reduced resources for aquatic food;
- Reduced ability of fish to migrate;
- Reduced recruitment of fish;
- Changes to communities of water plants;
- Weed invasion by acid-tolerant plants;
- Subsidence and structural corrosion of engineering structures; and
- Indirect degradation of water quality.

Asao (2000) notes further chronic impacts, such as:

- Loss of spawning sites and recruitment failure in both estuarine and fresh-water species;
- Habitat degradation and fragmentation from acid plumes, thermochemical, stratification of waters and the smothering of benthos from iron oxy-hydroxide flocculation;
- Altered population demographics within species;
- Simplified estuarine biodiversity with invasions of acid-tolerant exotics and loss of native species; and
- Reduction in dissolved nutrients and organic matter entering the estuarine food web.

Key Points For Acid Sulfate Soils

- Pyrite (acid sulfate soil) is a natural soil, which when left undisturbed, does not produce acid;
- Acid is naturally buffered by bicarbonate (present in seawater);
- Drainage of soil containing pyrite results in oxidation and acid formation with a pH below 4;
- Deep drainage channels constructed in acid sulfate soils increase acid export;
- A by-product of acid production is high concentrations of iron and aluminium;
- One-way floodgates maintain low drain water levels which results in a large gradient between the drain and surrounding groundwater, leaching acidic water into the drain;
- Acid drainage is greatest following flood events; and
- Acid plumes with high metal content are highly toxic to aquatic flora and fauna.

Appendix B – Detailed Prioritisation Methodology

B.1 Preamble

The priority assessment is structured around three (3) major components: (i) a surface water drainage factor, (ii) a groundwater factor, and (iii) several other indirect factors that influence the recommended onsite ASS management strategies. Each component is formulated by a range of environmental factors/processes that determine the risk of acid production from an ASS-affected floodplain drainage area. These factors are combined within a benchmarked algorithm to rank each drainage area in terms of acidic discharge risk. This section provides detailed information the data required to determine each factor used in the priority assessment.

B.2 Surface Water Drainage Factor

A surface water drainage factor is calculated for each sub-catchment or drainage unit within the study area. The surface water factor is comprised of:

- A drainage density factor = total drainage length / floodplain drainage area; and
- Inflow factor = catchment runoff coefficient x catchment size factor.

The surface water factor is determined by multiplying the drainage density factor by the inflow factor. The combination of these factors provides an indication of how 'well' a catchment is drained (drainage density), and accounts for the potential runoff from the drainage catchment following a rainfall event (catchment yield).

B.2.1 Floodplain Drainage

The drainage capacity of a floodplain drainage network influences the potential for the release of acid from the floodplain. Drain dimensions (length, width and depth) are critical factors with respect to ASS oxidation and mobilisation. For example, a long, wide drain, that is deeply incised into the acidic soil layers (AASS and PASS), poses a greater potential environmental risk, than a short, narrow drain with a high invert. That is, the larger the drainage network across a floodplain, the greater potential for ASS oxidation and mobilisation.

In the prioritisation methodology, 'drainage density' refers to the size of the drainage network relative to the floodplain area which is being drained. A sub-catchment with a high drainage density would have a higher drainage capacity, when compared to a sub-catchment with a low drainage density. It follows that a high drainage density is associated with a high priority risk rating. The drainage density is expressed in a measurement of metres of drain per square kilometre of floodplain area (below 5 m AHD). Calculation of the drainage density effectively removes catchment size as a contributing factor to the ASS risk. The drainage factor ranking is provided in Table C.1. Drain dimensions and conditions are provided Appendix C.

B.2.2 Catchment Hydrology

The combination of a runoff coefficient and a normalised catchment size factor is used to provide an estimation of the relative water yield of each sub-catchment of the floodplain. The inflow factor accounts for the potential runoff from each sub-catchment following a rainfall event, and is determined by multiplying the runoff coefficient by the catchment size factor. A full description of the sub-catchment hydrology assessment and predicted inflow factors for each sub-catchment of the Manning River floodplain is provided in Appendix D.

Alternatively, surface water runoff from each sub-catchment may be estimated using standard catchment modelling software such as the Australian Water Balance Model v2002 (AWBM) (Boughton 2004). Daily flows can be analysed to produce percentile exceedance statistics for each drainage unit to enable a normalised ranking to be calculated. The 98th percentile exceedance flows should be used to rank each drainage unit. More information on this modelling approach as applied to the prioritisation methodology can be found in Glamore and Rayner (2014).

B.3 Groundwater Factor

The groundwater factor provides a measure of the ASS oxidation and mobilisation potential of a drainage area. This factor includes:

- Hydraulic conductivity (K_{sat});
- Measured acidity (pH) of the soil, groundwater, and adjacent drain water, expressed as hydrogen protons (H^+) in units of μmol/L; and
- Potential acid gradient, or thickness of the acid zone contributing to the risk of acid discharge, between the AASS layer and the lowest drain water level (i.e. mean low water (MLW) or invert of the structure/floodgate).

The product of these factors ensures that high acid potential drainage areas receive a higher risk, and associated priority ranking, than areas with limited evidence of ASS oxidation and mobilisation. The most critical element of the groundwater factor was found to be the elevation of the AASS layer with respect to the expected low water level in the drainage network. An acidic layer that is deeper than the expected low water level will produce a negative potential acid groundwater gradient and subsequently remove the risk associated with the drainage area.

B.3.1 Groundwater

The potential for water to flow through the soil matrix is known as the hydraulic conductivity (K_{sat}). A high hydraulic conductivity implies a greater potential groundwater flow rate. In high-risk ASS-affected floodplains, a high soil hydraulic conductivity increases the potential for acid to be released from the soil into drainage network and the estuary. Areas with a high hydraulic conductivity are subsequently assigned a high priority ranking as shown in Table B.1. The hydraulic conductivity of soils can be determined by standard field and laboratory techniques. A common approach is to use the field method presented in Johnston and Slavich (2003). Information and data regarding hydraulic conductivity for each sub-catchment of the Manning River floodplain is detailed in Appendix E.

Table B.1: Approximate K_{sat} Ranges and Associated Risk Rating (after Johnston and Slavich 2003)

Hydraulic Conductivity Range (m/day)	Category	Risk Rating
~0	Extremely Low (Dry)	1
<1.5	Low	2
1.5 – 15	Moderate	3
15 – 100	High	4
>100	Extremely High	5

B.3.3 Acidic Soils

The extent of ASS across a coastal floodplain is a key component of the priority assessment and contributes the acidity component of the groundwater factor. Soil profile data is used to determine soil acidity and the thickness of the acid zone contributing to the risk associated with acid discharges. Soil acidity is the most accurate way to determine the potential risk associated with acid discharges of a drainage area, because it is independent of external environmental factors (i.e. dilution via rainfall, bacterial oxidation causing a drop in pH etc.) that may artificially manipulate the acidity of drain water and receiving waters. Note that since pH is a logarithmic measure of hydrogen protons (H^+), pH values are converted to H^+ concentrations (in μmol/L) before being used in the priority assessment to calculate the groundwater factor.

The depth to the AASS and PASS soil layers is used to identify acid sources and the potential acid production of a drainage area. Relating the depth of the AASS layer to the lowest drainage point of a drain (or sub-catchment) enables high-risk drainage areas to be identified, and the thickness of the acid zone contributing to the potential environmental risk to be calculated. Mapping and presentation of soil acidity data and thickness of the acid zone is provided in Appendix F.

B.3.2 Water Quality

In the absence of accurate soil profile acidity data, wet weather water quality information can be used in the priority assessment to calculate the acidity component of the groundwater factor. While field measurements of drain water quality (i.e. acidity) during dry periods can provide an indication of the potential risk associated with discharges from a future acid event, the measurement of actual acid flux during and after a wet weather event is preferred. Field measurements of post-flood discharges and water quality enables the total acid flux from a drain to be determined, as well as the contribution of each drain in the drainage network to the overall risk to estuarine water quality. Water quality data for each sub-catchment of the Manning River floodplain is provided in Appendix G.

B.4 Prioritisation Rating

The priority assessment is fundamentally based on environmental factors that contribute to acid flux (discharge x acid concentration) from a drained, ASS-affected floodplain area. As such, the combination of the surface water drainage factor and the groundwater factor provides the prioritisation rating of each drainage unit within the study area. The prioritisation rating is then used to rank each drainage unit to identify areas with the highest risk of ASS oxidation and mobilisation.

B.5 Formulation of Remediation Action Plan(s)

Several indirect factors that influence the recommended onsite remediation strategies, but do not contribute to the prioritisation rating were also considered in the priority assessment. The factors address issues associated with the design and implementation of short and long-term remediation action plans for the study area. The factors described in this section, include:

- Sensitive receivers;
- Asset condition;
- Climate change; and
- Landholder willingness.

B.5.1 Sensitive Receivers

The proximity of each drainage area to sensitive environmental receivers is an important factor to consider when assessing the benefits of remediation. NSW estuaries have significant environmental and economic values that are impacted by poor water quality and acidic discharges. Some sensitive receivers, such as commercial oyster leases and seagrasses, are located adjacent to the discharge point of high-risk ASS drainage areas, and are subsequently highly susceptible to poor water quality.

Common stationary sensitive receivers may include:

- Oyster leases;
- Macrophytes;
- Endangered Ecological Communities (EEC); and
- Riverbank stabilisation projects.

These sensitive receivers should be mapped and the proximity to each ASS drainage area be determined.

Potential aquatic habitat contained within, or downstream of, each drainage area should also be considered as part of proposed remediation strategies of high-risk ASS drains. Winberg and Heath (2010) identified that floodgates eliminate natural fish and invertebrate life from tributary habitats, and reduce overall primary production in the lower estuary. Tributaries function as key fishery nursery habitat and contribute to the overall population of fisheries in estuaries (NSW DPI 2007; Winberg and Heath 2010). Mapping of sensitive receivers and drain proximity is detailed in Appendix H.

B.5.2 Asset Condition

When assessing floodgate structures, condition reporting is undertaken on the ability of the floodgate to restrict tidal intrusion and to maintain efficient drainage. That is, a new floodgate that effectively restricts tidal intrusion into a flood mitigation drain would be reported in 'good' condition. If a floodgate has been previously modified for an auto-tidal gate, the condition of the auto-tidal gate would be reported as 'modified'. Asset condition can be summarised under the following categories:

- Good;
- Fair;
- Poor;
- Very Poor/Missing; or
- Modified.

Asset condition survey for all drains and structures is detailed in Appendix I.

B.5.3 Climate Change

Climate change in coastal estuaries is likely to affect land use and flood mitigation management over the next 10 to 50 years. Sea level rise predictions indicate a 0.4 m rise in average water levels by 2050 (AdaptNSW 2014). As long-term tidal levels increase, individual drainage areas become connected at higher elevations. Although increased high tide elevations are likely to impact the floodplain in the long-term, the major short-term impact will be reduced drainage. This is particularly relevant to low-lying areas where prolonged periods of inundation following wet weather events are expected by 2050. Subsequently, climate change should be assessed on management areas where the interconnectivity of future sea levels is predicted.

The elevation of existing infrastructure (levees, headwalls, and floodgates) must be incorporated into the climate change assessment. Typically headwalls of existing structures are the lowest point on levee banks across the floodplain and are the first point of overtopping in many drainage areas. Areas identified as being highly susceptible to sea level rise were given a higher priority for implementation of a long-term remediation strategy. Drainage areas that are likely to be unaffected by climate change in the short to mid-term (10 to 20 years) are logical candidates for implementation of interim remediation strategies. The impact of climate change is applied in the priority assessment by characterising climate change susceptibility as:

- High = Significantly reduced drainage;
- Medium = Saline inundation/overtopping and/or reduced drainage; and
- Low = General reduced drainage.

Interconnected drainage areas are assessed for sea level rise in Section 8 of the main body of the report.

B.5.4 Landholder Willingness

Landholder willingness is a major component of the priority assessment process. Although interim (short-term) remediation strategies are aimed at minimal disturbance to the landholder and existing agricultural practices, long-term remediation strategies aim to improve existing land-use practices for a portion, or all of a drainage area. A willing landholder greatly influences the potential remediation strategy that is achievable, particularly in the long-term.

Existing land productivity also influences potential future land management strategies. Some areas have high soil salinity from previous natural tidal inundation resulting in poor agricultural yields. Other agricultural areas are extremely low-lying (below 0 m AHD), and have a history of poor drainage and extended inundation. These areas are candidates for changing land-use practices, whereby poor quality land is utilised for wet pasture management, or transformed to a natural wetland, or saltmarsh system. Future risk to climate change and sea level rise may also influence landholder willingness to vary existing land use management strategies.

A survey of landholder knowledge regarding ASS and willingness to adopt various remediation strategies is recommended. Statistical analysis of survey results can be undertaken to determine if further education is required to inform landholders about ASS remediation strategies and the potential impact it may have on existing land use practices. Note that this assessment was outside the scope of this project to develop remediation action plans for sub-catchments of the Manning River floodplain, but a landholder survey is recommended at a future stage of the project, and before the remediation action plans are implemented.

Appendix C – Floodplain Drainage

C.1 Preamble

This section provides details of the settlement, topography and drainage network of the Manning River floodplain. LiDAR survey data of the wider catchment was used to create a Digital Elevation Model (DEM) of the study region. For the purpose of this study, the catchment area below 5 m AHD was used to determine the floodplain area. The 5 m AHD contour provided the same delineation of areas classified as having high and low risk ASS (Naylor et al. 1995). This information was used to determine catchment boundaries, flow paths and the drainage density factor used in the priority assessment.

C.2 LiDAR

WRL received LiDAR survey data from MidCoast Council of the Greater Taree area to AHD at a 1 m horizontal resolution. GIS techniques were used to produce a DEM below 5 m AHD of the study region at a 1 m horizontal resolution as shown in Figure C.1.

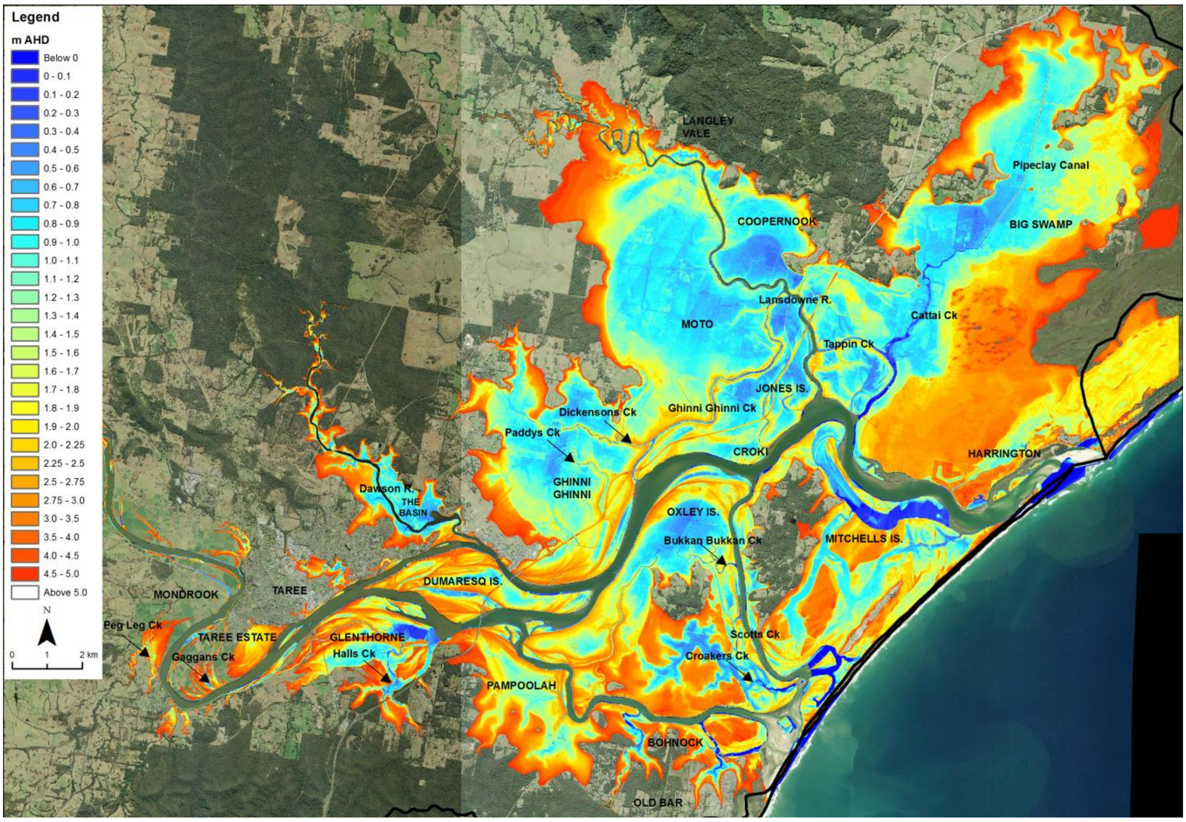


Figure C.1: Digital Elevation Map of the Manning River Floodplain

C.3 Cadastre

The number, size, shape and location of cadastral portions in relation to floodplain backswamps, and the consistency of cadastral boundaries with physical boundaries meaningful to management, are key ingredients in both the process of environmental degradation of backswamps, and in providing opportunities and constraints to remediation options.

C.3.1 *Historical Maps*

Historical maps of Oxley Island (Figure C.2) and Big Swamp (Figure C.3) provide insight into the sequence and patterns of European settlement on the Manning River floodplain.

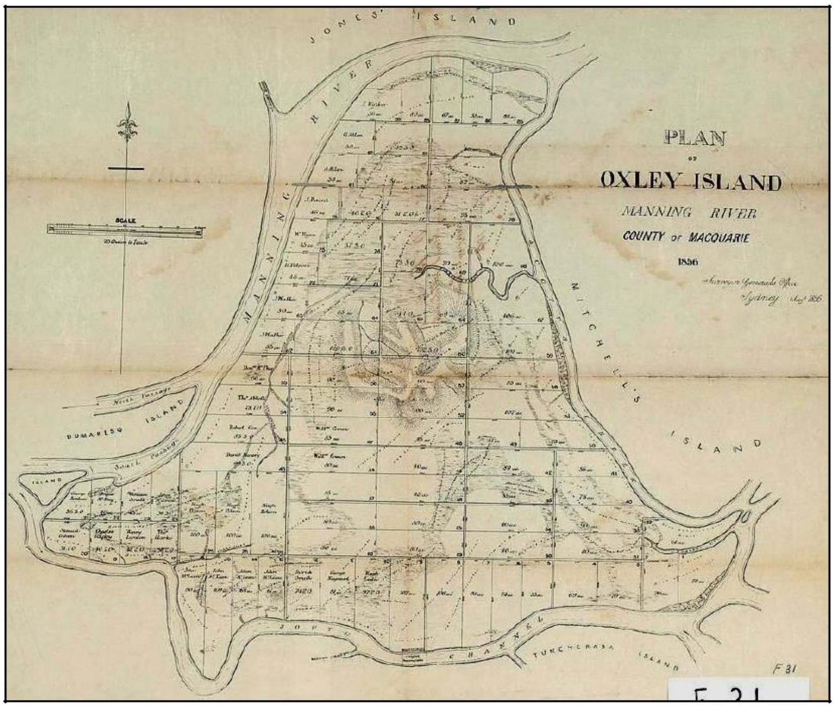


Figure C.2: Plan of Oxley Island, Manning River, 1856 (Source: Tulau 2011)

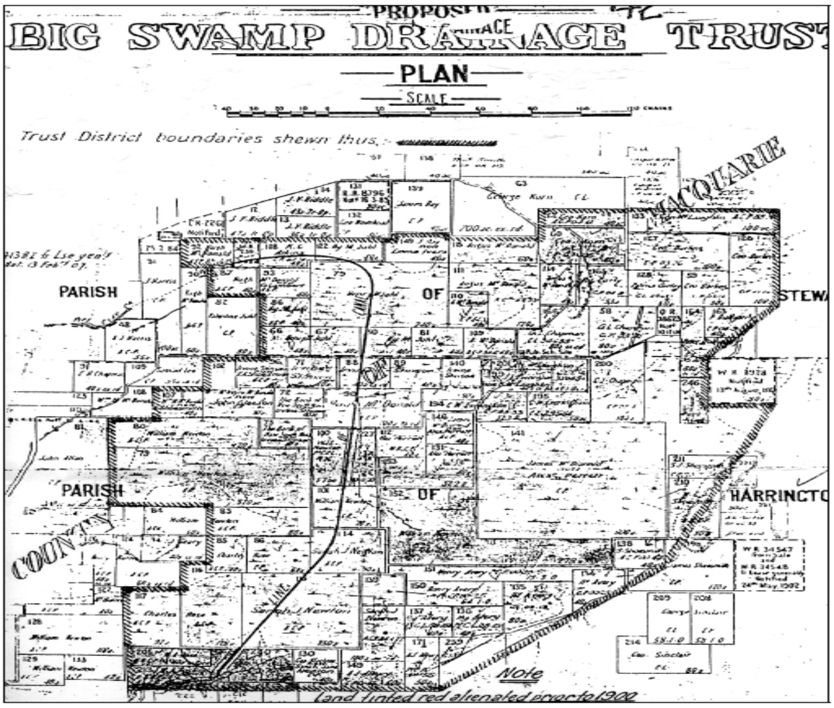


Figure C.3: Big Swamp Drainage Trust District, Manning River, 1902 (Source: Tulau 2011)

C.3.2 Modern Day

WRL received a current cadastral map from MidCoast Council of the Greater Taree area as provided in Figure C.4. The current subdivisions of the floodplain shown in Figure C.4 are consistent with the historical partitioning of Oxley Island and the Big Swamp district. The cadastre was also used to provide information on land holder properties for access permission during the field investigations completed during this study.

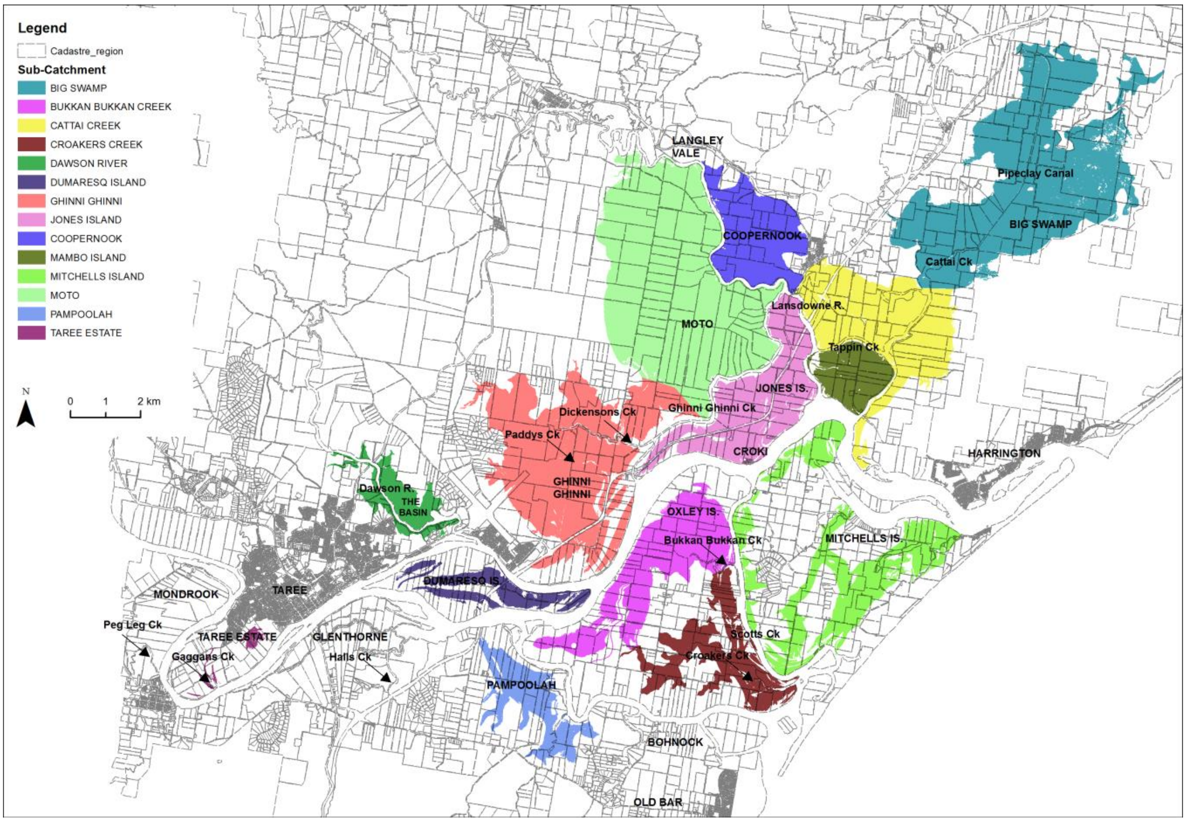


Figure C.4: Current Manning District Cadastre (Source: MidCoast Council)

C.4 Floodplain Drainage Network

In addition to the LiDAR survey data provided for the wider catchment, MidCoast Council also provided a map of the floodplain drainage network of the lower Manning River estuary. This information was used to determine the boundary lines of each sub-catchment of the Manning River floodplain, as shown in Figure C.5. The floodplain drainage network map was also used to calculate the total drainage length of each sub-catchment, as required for the drainage density factor in the priority assessment.

Figure C.5: Floodplain Drainage Network (Source: MidCoast Council)

C.5 Drainage Density Factor

The drainage density factor of each sub-catchment is determined by the total drainage length of the floodplain relative to the floodplain area. When assessing the length of drains that contribute to the drainage of an ASS-affected landscape, all drains were included in the priority assessment to provide a total drain length of each sub-catchment, because all drains have the potential to impact ASS oxidation and mobilisation. The drainage length factor of each sub-catchment used in the priority assessment is presented in Figure C.6. The floodplain area of each sub-catchment below 5 m AHD was normalised against the sub-catchment with the largest floodplain area (i.e. floodplain area factor = 1.0), to produce a floodplain area factor of each sub-catchment, as provided in Figure C.7. A summary of the floodplain drainage analysis is provided in Table C.1, and the drainage density factor of each sub-catchment of the Manning River floodplain is presented in Figure C.8.

Table C.1: Floodplain Drainage Analysis

Sub-catchment	Total Drain Length (m)	Drainage Length Factor	Floodplain Area (m^2)	Floodplain Area Factor	Drainage Density	Drainage Density Factor
Moto	95,685	0.92	35,611,100	0.81	2,687	0.60
Ghinni Ghinni	89,587	0.86	24,527,600	0.56	3,653	0.81
Big Swamp	104,031	1.00	43,951,200	1.00	2,367	0.52
Glenthorne	38,845	0.37	8,615,840	0.20	4,509	1.00
Coopernook	9,937	0.10	6,288,670	0.14	1,580	0.35
Pampoolah	22,979	0.22	10,157,800	0.23	2,262	0.50
Bukkan Bukkan Creek	21,412	0.21	11,019,200	0.25	1,943	0.43
Dawson River	28,860	0.28	7,838,410	0.18	3,682	0.82
Cattai Creek	42,788	0.41	18,926,300	0.43	2,261	0.50
Mitchells Island	58,907	0.57	20,671,190	0.47	2,850	0.63
Croakers Creek	20,358	0.20	10,406,100	0.24	1,956	0.43
Taree Estate	4,375	0.04	1,146,060	0.03	3,817	0.85
Jones Island	14,607	0.14	6,492,460	0.15	2,250	0.50
Mambo Island	8,505	0.08	3,015,950	0.07	2,820	0.63
Dumaresq Island	15,226	0.15	5,982,610	0.14	2,545	0.56

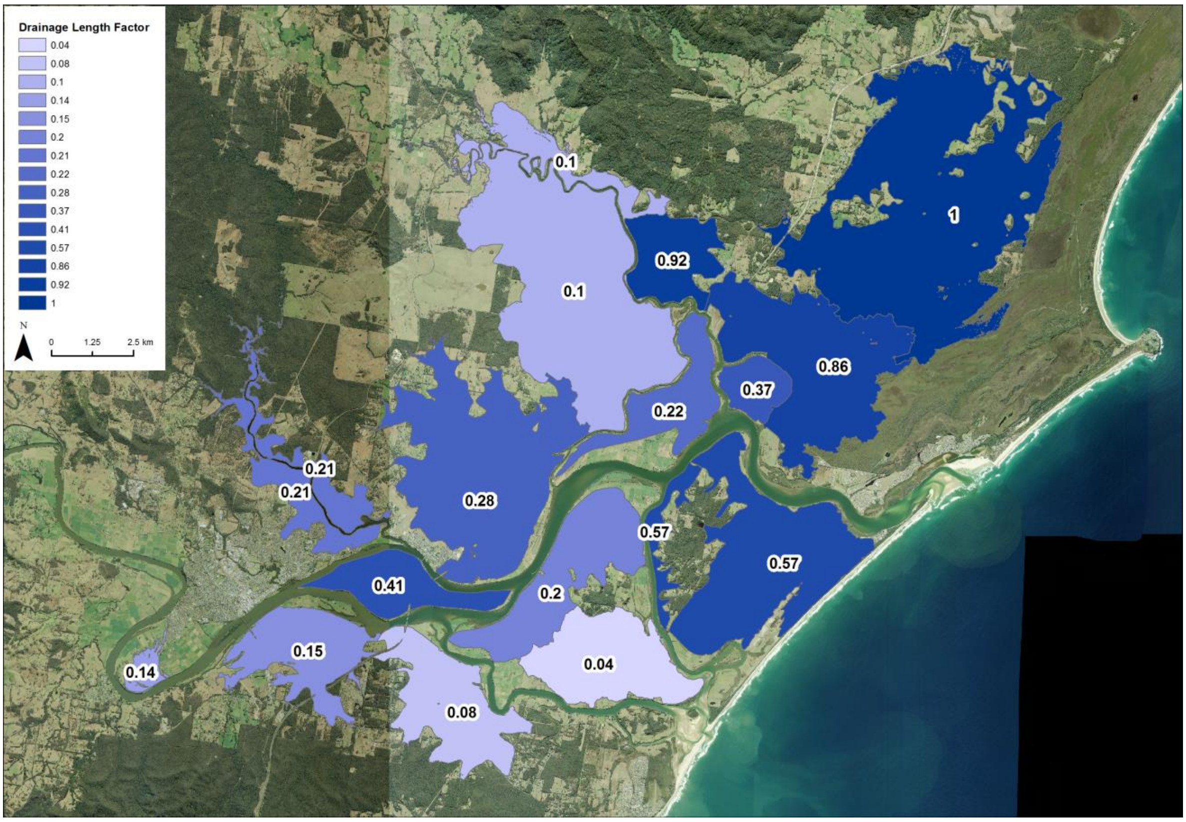


Figure C.6: Floodplain Drainage Length Factor

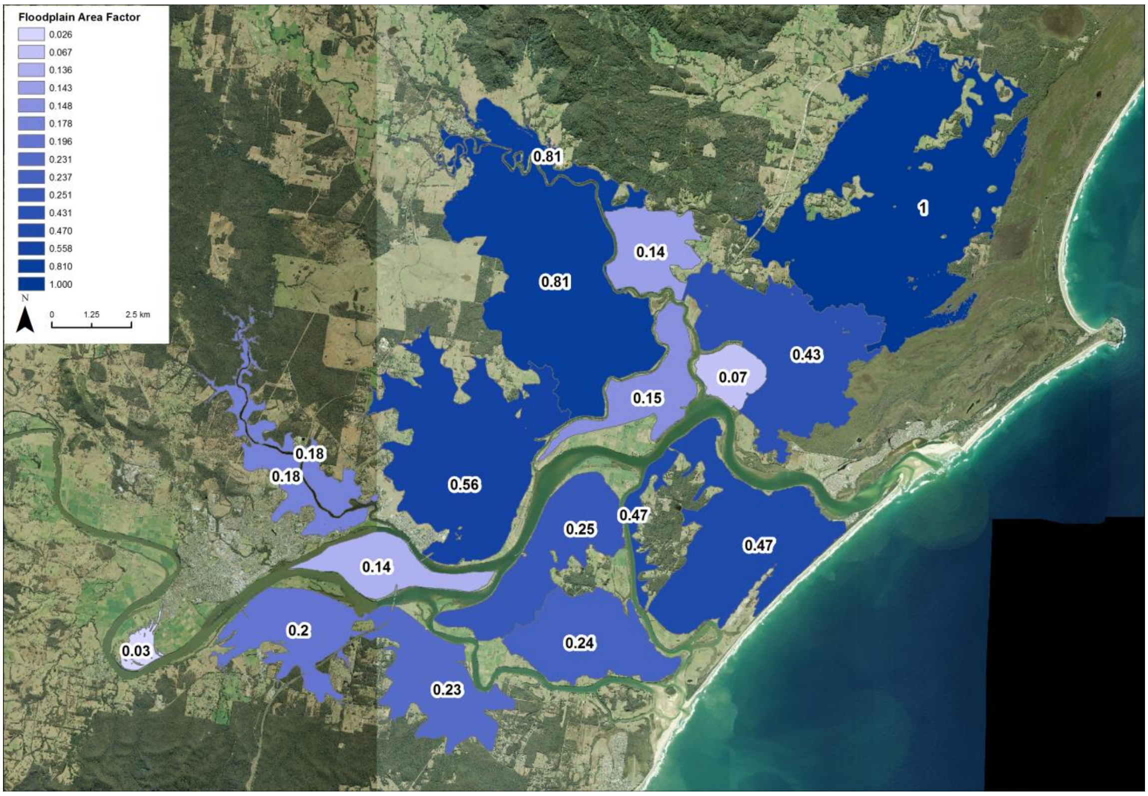


Figure C.7: Floodplain Area Factor

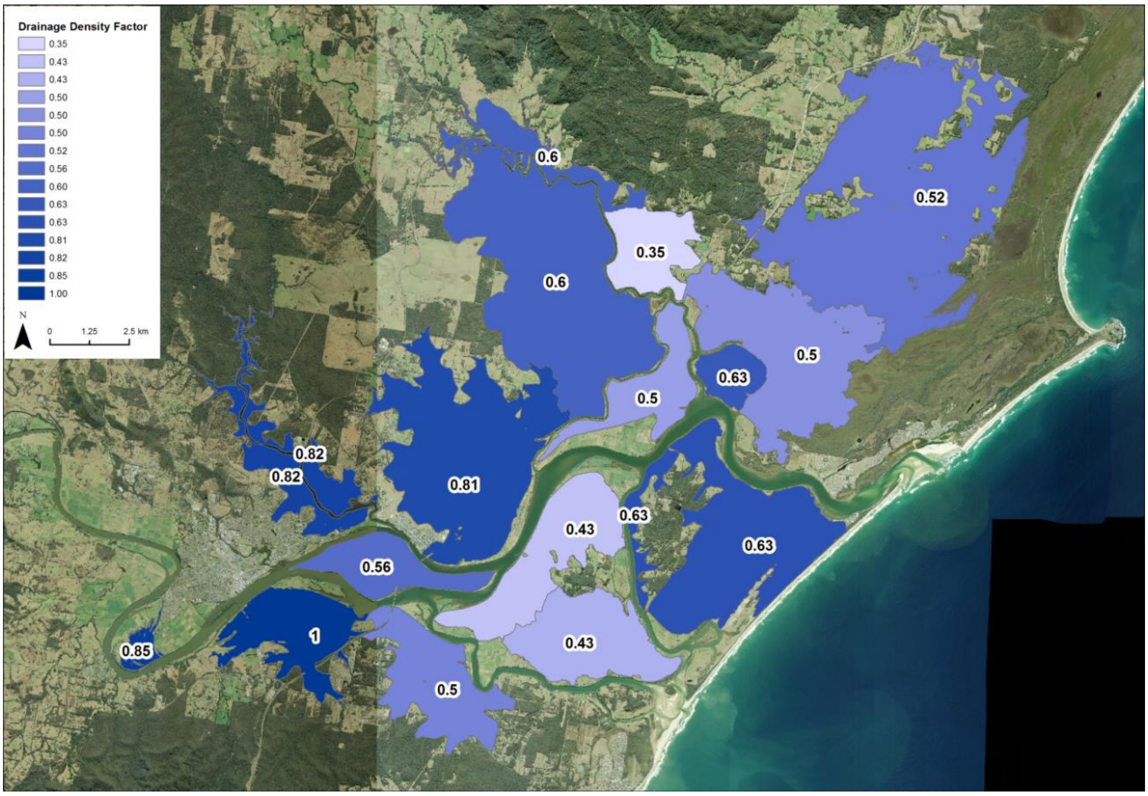


Figure C.8: Floodplain Drainage Density Factor

Appendix D – Catchment Hydrology

D.1 Preamble

This section details the catchment hydrology component of the priority assessment. Due to the lack of available streamflow data required to calibrate a rainfall-runoff model of each sub-catchment of the Manning River floodplain, a catchment yield analysis was used to provide an estimated runoff contribution from each sub-catchment. The catchment yield analysis included the calculation of a runoff coefficient (Section D.2) and a catchment size factor (Section D.3), to determine an inflow factor (Section D.4) used in the priority assessment.

D.2 Runoff Coefficient

The predicted runoff volume from incident rainfall on the catchment identified in Figure D.1 was calculated using the principles of the rational method as described in Book 8 of Australian Rainfall and Runoff (ARR 2001). Daily rainfall data used for the assessment was obtained from the Bureau of Meteorology (BOM) rainfall gauge at Taree Airport (BOM station ID 60141). The runoff volume (m^3) from the catchment was calculated using the following formula, assuming the catchment was 100% impervious (i.e. C = 1.0):

$$V_c = CiA$$

where

C = runoff coefficient (dimensionless)
i = rainfall depth (mm) equal to rainfall intensity (mm/hr) x storm duration (hrs)
A = area of catchment (m^2).

Runoff coefficients provide a relationship between rainfall-runoff volumes and allow for varying amounts of pervious and impervious surfaces across a catchment. It follows that if the predicted runoff volume from incident rainfall is known, and is compared to observed streamflow data in the Lansdowne River (Figure D.1), then the volume difference would be equivalent to the runoff coefficient. The NSW Office of Water (NOW) gauges the Lansdowne River at Lansdowne (NOW station ID 208015). An annual time-series of streamflow data for 2015 from the Lansdowne River gauge was compared to the predicted runoff volume from the contributing catchment for rainfall recorded in the same year, and was used to calculate the runoff coefficient of the catchment. Figure D.2 shows the time-series of predicted and observed runoff at the NOW streamflow gauge on the Lansdowne River. This method yielded an estimated runoff coefficient of 0.43. The estimated runoff coefficient value was consistent with the design value for the same location predicted by Pilgrim and McDermott (1981). Note that for this study, it was assumed that land-use type, vegetation, and the proportion of pervious and impervious surfaces, was the same for each sub-catchment of the Manning River floodplain.

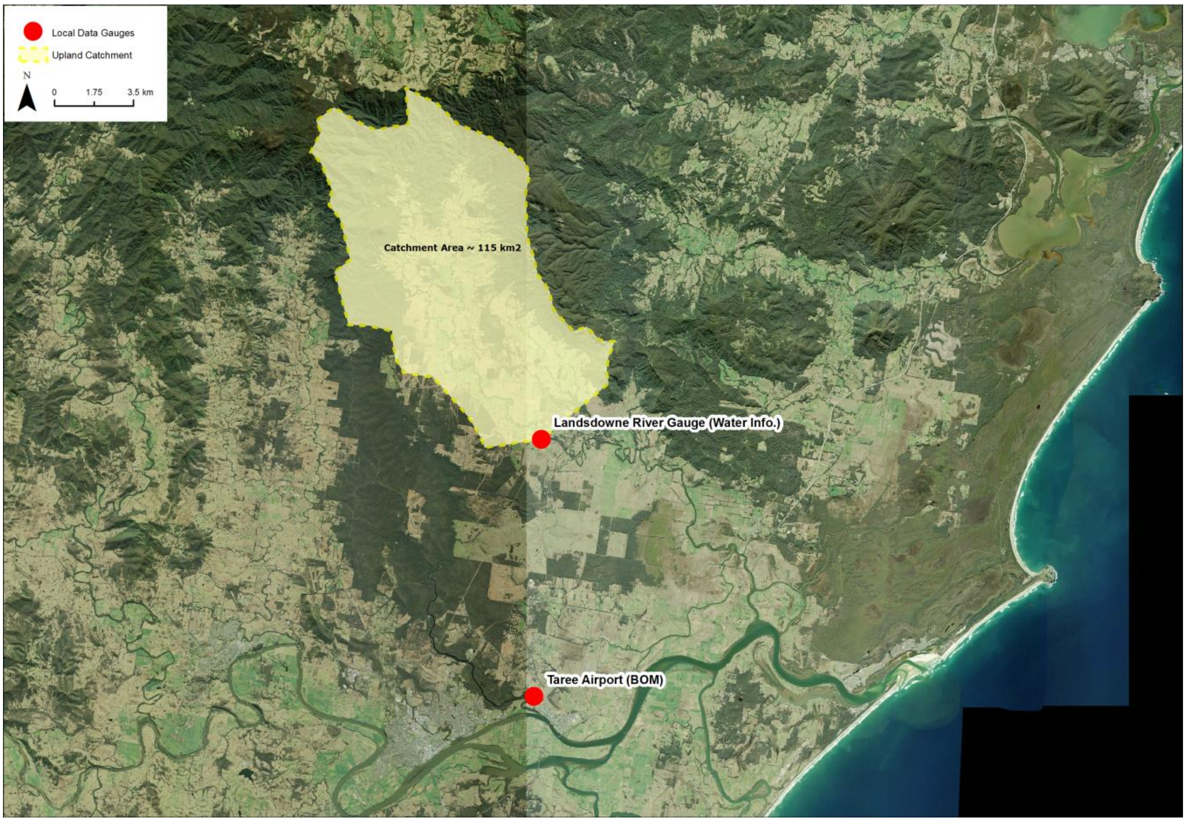


Figure D.1: Runoff Coefficient Estimation

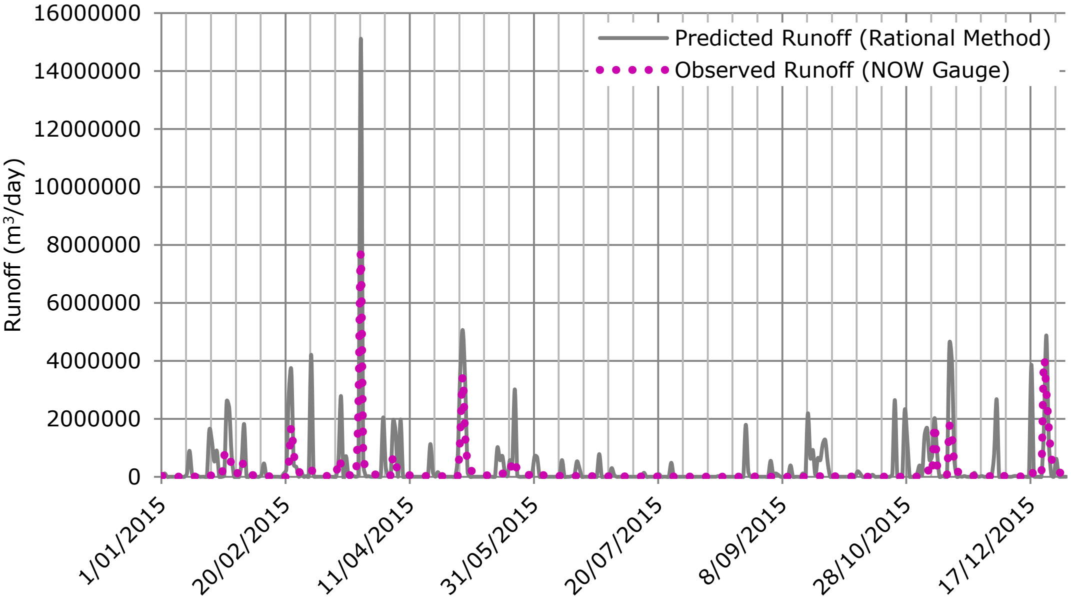


Figure D.2: Predicted and Observed Runoff for the Catchment Area Upstream of the NOW Gauging Location (208015)

D.3 Catchment Size Factor

The sub-catchments of a coastal floodplain are typically comprised of both steep, upland catchments, and flat, low-lying floodplain catchments. Delineation of catchment type is important when assessing hydrology as steep and flat catchments respond differently during rainfall events, and subsequently, produce different runoff hydrographs (i.e. streamflow over time). A steep catchment will produce a greater peak discharge, over a shorter hydrograph period, compared to a flat catchment which typically has a lower peak discharge. A flatter catchment, however, will continue to drain for a longer period of time.

Furthermore, the size of the sub-catchment also influences the hydrological response of the site during a rainfall event. When comparing drainage areas of similar acidity, a large catchment will have a greater potential to discharge more acid than a small catchment. That is, a drainage unit with high-risk ASS and a large catchment area has a greater potential to produce high acid flux post-flood. Subsequently, accurate estimates of sub-catchment areas and the potential discharge from those areas is critical in assessing drainage units that are of a high-risk for acid drainage.

For the purpose of this study, catchment areas above 5 m AHD were classified as 'steep' and catchments below 5 m AHD were classified as 'flat'. The total area of each sub-catchment was estimated by the contribution of the floodplain area and upland area components as provided in Figure D.3. The total areas of each sub-catchment were then normalised against the sub-catchment with the largest total area (i.e. catchment size factor = 1.0). The catchment size factors for each sub-catchment of the Manning River floodplain are provided in Figure D.3.

D.4 Inflow Factor

The combination of a runoff coefficient and a normalised catchment size factor was used to provide an estimation of the relative water yield of each sub-catchment of the Manning River floodplain. The inflow factor accounts for the potential for acidic discharge from each sub-catchment following a rainfall event, and was determined by multiplying the runoff coefficient by the catchment size factor. A summary of the catchment hydrology analysis is provided in Table D.1, and the inflow factor of each sub-catchment of the Manning River floodplain is presented in Figure D.4.

Table D.1: Catchment Hydrology Analysis

Sub-catchment	Runoff Coefficient	Upland Catchment Area (m^2)	Upland Area Factor	Total Catchment Area[1] (m^2)	Catchment Size Factor	Inflow Factor
Moto	0.43	70,898,900	0.8626	106,510,000	0.9670	0.42
Ghinni Ghinni	0.43	23,527,600	0.2862	48,055,200	0.4363	0.19
Big Swamp	0.43	66,195,800	0.8053	110,147,000	1.0000	0.43
Glenthorne	0.43	26,432,760	0.3216	35,048,600	0.3182	0.14
Coopernook	0.43	1,415,430	0.0172	7,704,100	0.0699	0.03
Pampoolah	0.43	10,428,900	0.1269	20,586,700	0.1869	0.08
Bukkan Bukkan Creek	0.43	919,500	0.0112	11,938,700	0.1084	0.05
Dawson River	0.43	82,196,294	1.0000	90,034,704	0.8174	0.35
Cattai Creek	0.43	1,308,440	0.0159	20,234,740	0.1837	0.08
Mitchells Island	0.43	6,019,450	0.0732	26,690,640	0.2423	0.10
Croakers Creek	0.43	406,400	0.0049	10,812,500	0.0982	0.04
Taree Estate	0.43	189,740	0.0023	1,335,800	0.0121	0.01
Jones Island	0.43	0	-	6,492,460	0.0589	0.03
Mambo Island	0.43	0	-	3,015,950	0.0274	0.01
Dumaresq Island	0.43	0	-	5,982,610	0.0543	0.02

[1] Note that total catchment area is calculated as the sum of the floodplain area (refer to Table D.1) and upland area.

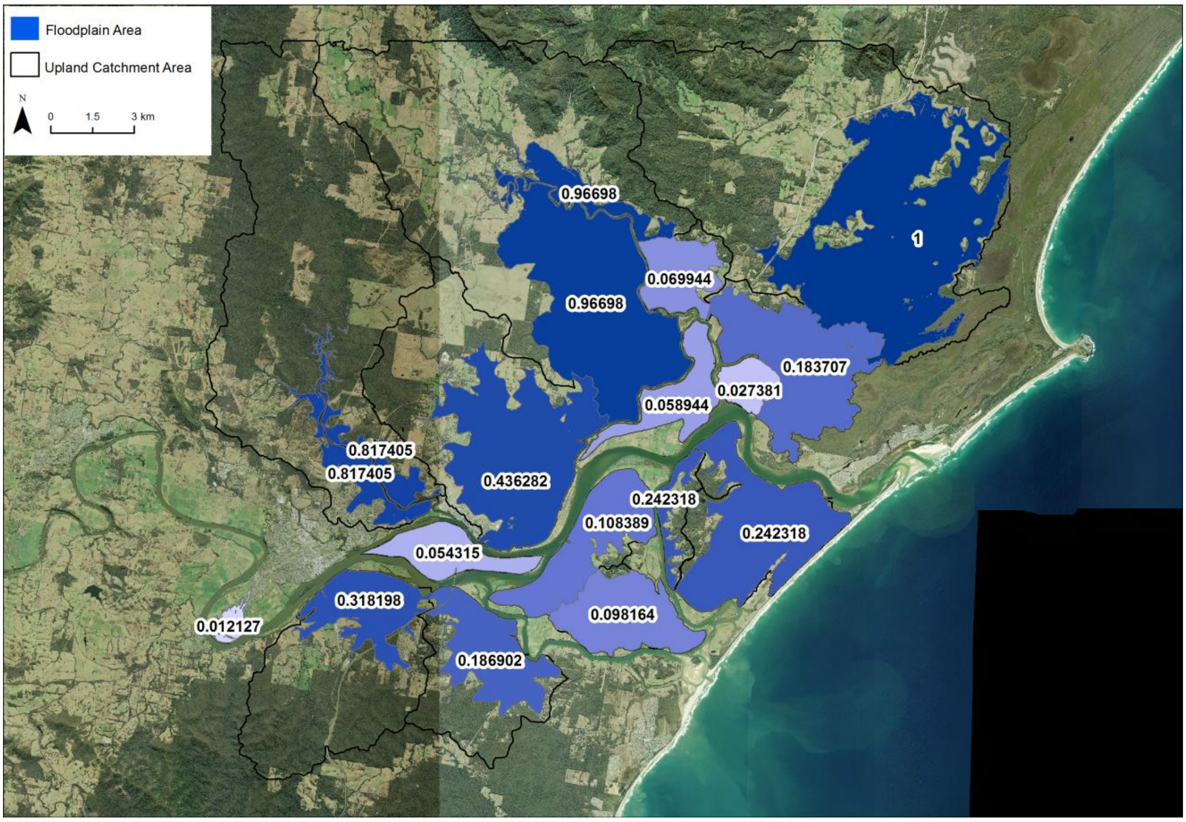


Figure D.3: Catchment Size Factor for Each Sub-Catchment of the Manning River Floodplain

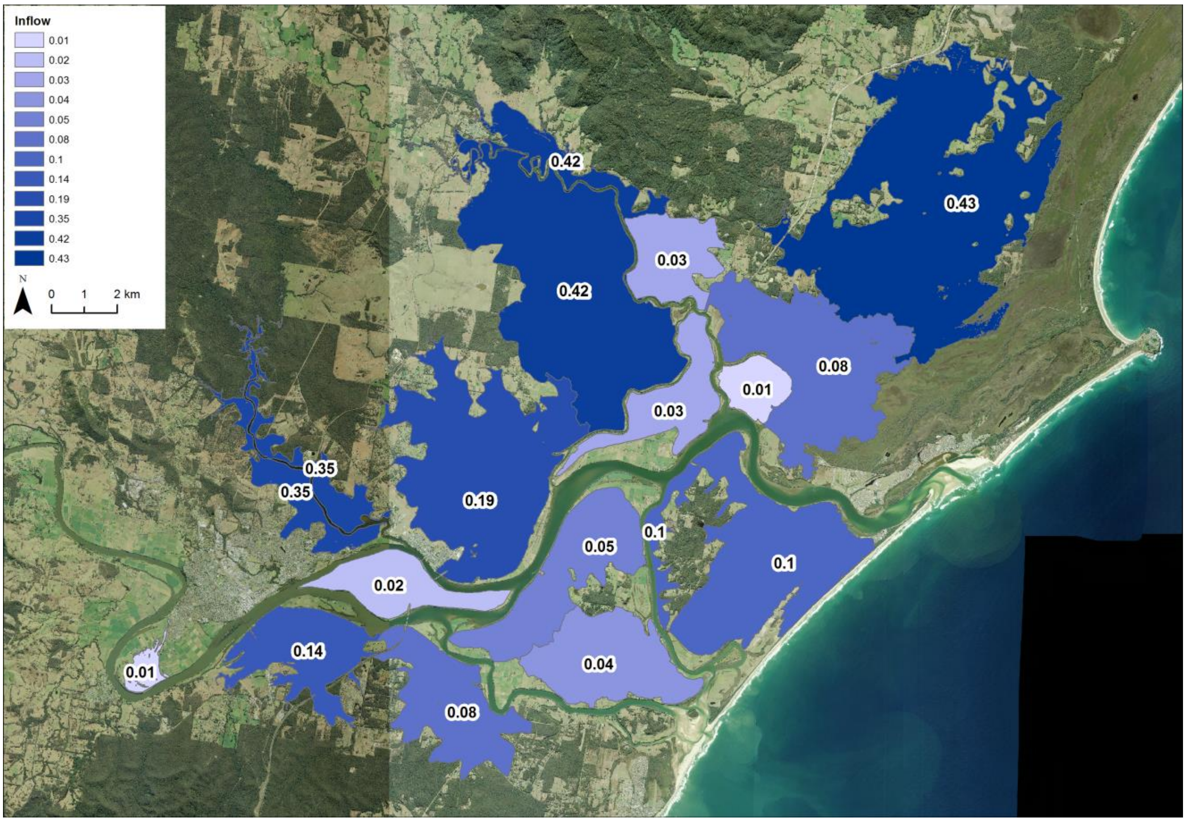


Figure D.4: Sub-Catchment Inflow Factors

Appendix E – Groundwater Hydraulic Conductivity

E.1 Preamble

Following background information on the definition of the hydraulic conductivity of soil, this section provides a summary of the hydraulic conductivity data available for the Manning River floodplain. Data compilation and review identified sources of existing hydraulic conductivity data and knowledge gaps within the study area (Section E.2). Field investigations were then targeted to fill the identified data gaps. A summary of the hydraulic conductivity data collected during the field investigations and the risk applied to each sub-catchment of the study area is provided in Section E.3.

The hydraulic conductivity of soil is defined as the constant of proportionality in Darcy's Law, which describes the flow of a fluid (usually water) through a porous medium. The law was formulated by Henry Darcy based on the results of experiments on the flow of water through beds of sand, and is expressed as:

$$V = K\left(\frac{dh}{dx}\right)$$

where,

V = apparent velocity of the groundwater (m/d)
K = hydraulic conductivity (m/d)
h = hydraulic head (m)
x = distance in the direction of groundwater flow (m).

In Darcy's equation, dh/dx represents the hydraulic gradient (s), which is the difference of h over a small difference of x. Hence, the hydraulic conductivity can be expressed as K = V/s, and can thus be regarded as the apparent velocity (m/d) of the groundwater when the hydraulic gradient equals unity (s = 1) (Oosterbaan and Nijland 1994).

The K-value of a soil profile can be highly variable from place to place, and will also vary at different depths (spatial variability). Not only can different soil layers have different hydraulic conductivities, but even within a soil layer, the hydraulic conductivity can vary. In coastal floodplains, coarser soil particles (e.g. sand and gravel) are deposited as levees near riverbanks, whereas finer particles (e.g. silt and clay) are deposited in backswamps further away from the river. In particular, finer, consolidated sediments are usually characterised by low hydraulic conductivities, whereas coarser sediments are characterised by high hydraulic conductivities. Furthermore, when floodplain soils are drained they become on the average drier than before, which affects their biological conditions, or leads to the decay of organic material, and excessive leaching during wet periods when groundwater levels are elevated. In fact, clay soils can often show an increased K-value when drained (El-Mowelhi and van Schilfgaarde 1982) because of increased biological activity, originating from an improved soil structure.

Unconfined aquifers (e.g. coastal floodplains) of shallow to intermediate depth (e.g. up to 10 m depth) are associated with the presence of a free water table, so the groundwater can flow in any direction, however the flow of groundwater to subsurface drains is mainly horizontal. A schematic of an unconfined aquifer of shallow to intermediate depth is provided in Figure F.1. The K-value of a saturated soil (K_{sat}) represents its average hydraulic conductivity, which depends mainly on the size, shape, and distribution of the pore spaces in the soil profile.

Measurement of K_{sat} by the open pit method outlined in Johnston and Slavich (2003), can produce varying results depending on the presence of macropores in the pit. The presence of macropores can increase measured K_{sat} rates from extreme low (<0.0001 m/day) to high (>15 m/day). Subsequently, hydraulic conductivity measurements across ASS-affected floodplains can be highly variable, and should be taken as estimates of the flow connectivity between shallow groundwater and subsurface drains, and the potential risk for ASS discharges.

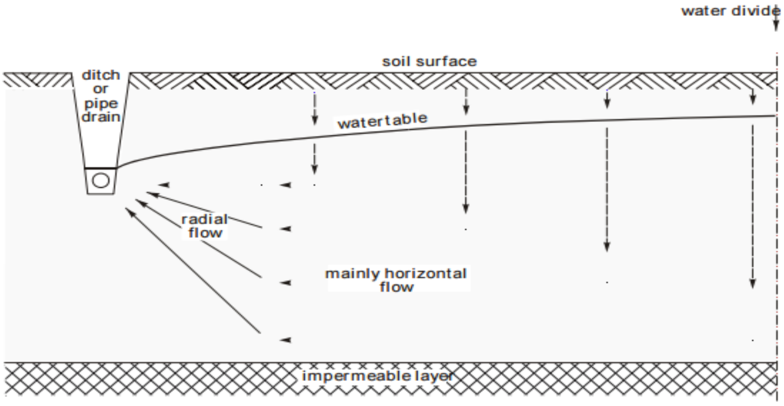


Figure E.1: Groundwater Flow to Subsurface Drains in Unconfined Aquifers of Intermediate Depth

E.2 Existing Hydraulic Conductivity Data

Prior to this study, field measurements of insitu saturated hydraulic conductivity across the sub-catchments of the Manning River floodplain were limited. Whilst widespread soil profile investigations had been undertaken, limited resources were allocated to investigate insitu saturated hydraulic conductivity. Existing data showed a large variability in K_{sat} across the floodplain, with a range between <0.0001 m/day (i.e. extremely low) to >100 m/day (i.e. extremely high). Reviewed sources of insitu saturated hydraulic conductivity data included:

- Johnston (2007);
- Hirst et al. (2009); and
- Glamore et al (2014).

The insitu hydraulic conductivity data from these sources is provided in Tables E.1 to E.3. The locations of the measurements are provided in Figure E.2. Note that the K-values presented are considered estimates of the average saturated hydraulic conductivity of the soil profile at the measurement locations. The categories for each measurement listed in Tables E.1 to E.3 are inferred from the field assessment guidelines outlined in Johnston and Slavich (2003), and are presented for comparison with insitu hydraulic conductivity measurements collected during the field assessment component of this study (Section E.3).

Table E.1: Summary of Insitu Hydraulic Conductivity Data Collected by Johnston (2007)

ID	Catchment	Easting (m)	Northing (m)	Estimated K_{sat} (m/day)	Category	pH
P1	Big Swamp	468214.8	6479921	2.1	Moderate	3.14
P2	Big Swamp	468116.4	6479913	6.9	Moderate	3.15
P3	Big Swamp	468078.3	6479771	18	High	3.46
P4	Big Swamp	469474.2	6480872	29	High	-

Table E.2: Summary of Insitu Hydraulic Conductivity Data Collected by Hirst et al. (2009)

ID	Catchment	Easting (m)	Northing (m)	Estimated K_{sat} (m/day)	Category
Templeman-1	Moto	461526.41	6477588.9	3.2	Moderate
Templeman-2	Moto	461400.92	6477411.1	14.7	Moderate
Templeman-3	Moto	461335.95	6477492.2	8.6	Moderate
Roche-1	Moto	459934.6	6478536.1	0.8	Low
Roche-2	Moto	459543.67	6478481	6.26	Moderate
Roche-3	Moto	459222.02	6478453.9	11.28	Moderate
Roche-4	Moto	459350.53	6478264.1	11.12	Moderate
Roche-5	Moto	459885.04	6478303.1	21.8	High
Roche-6	Moto	459939.49	6478495.5	0.8	Low
Roche-7	Moto	459934.57	6478545.3	9.31	Moderate
Roche-8	Moto	459940.85	6478550.9	29.03	High
Roche-9	Moto	459955.11	6478536.2	8.87	Moderate
Cattai-1	Cattai Creek	465959.39	6477643.4	1.07	Low
Cattai-2	Cattai Creek	465938.92	6477632.2	3.36	Moderate
Cattai-3	Cattai Creek	465483.35	6477571.6	1.88	Moderate
Cattai-4	Cattai Creek	465164.21	6477276.8	1.5	Low
Cattai-5	Cattai Creek	465320.82	6477131.4	<0.0001	Extremely Low
Cattai-1a	Cattai Creek	466234.00	6477980.00	10.86	Moderate

Table E.3: Summary of Insitu Hydraulic Conductivity Data Collected by Glamore et al. (2014)

ID	Catchment	Easting (m)	Northing (m)	Estimated K_{sat} (m/day)	Category	pH
1	Big Swamp	469062	6480970	60	High	-
2	Big Swamp	469243	6481231	20	High	-
3	Big Swamp	469435	6482521	15	High	-
4	Big Swamp	467979	6479503	35	High	4.0
5	Big Swamp	469668	6484688	>100	Extremely High	4.8
6	Big Swamp	469797	6483516	60	High	3.4
7	Big Swamp	470084	6483083	30	High	3.4
8	Big Swamp	469483	6481467	90	High	3.8
9	Big Swamp	468888	6480137	70	High	4.4
10	Big Swamp	469172	6480564	15	High	4.3
11	Big Swamp	470570	6483794	8	Moderate	3.7

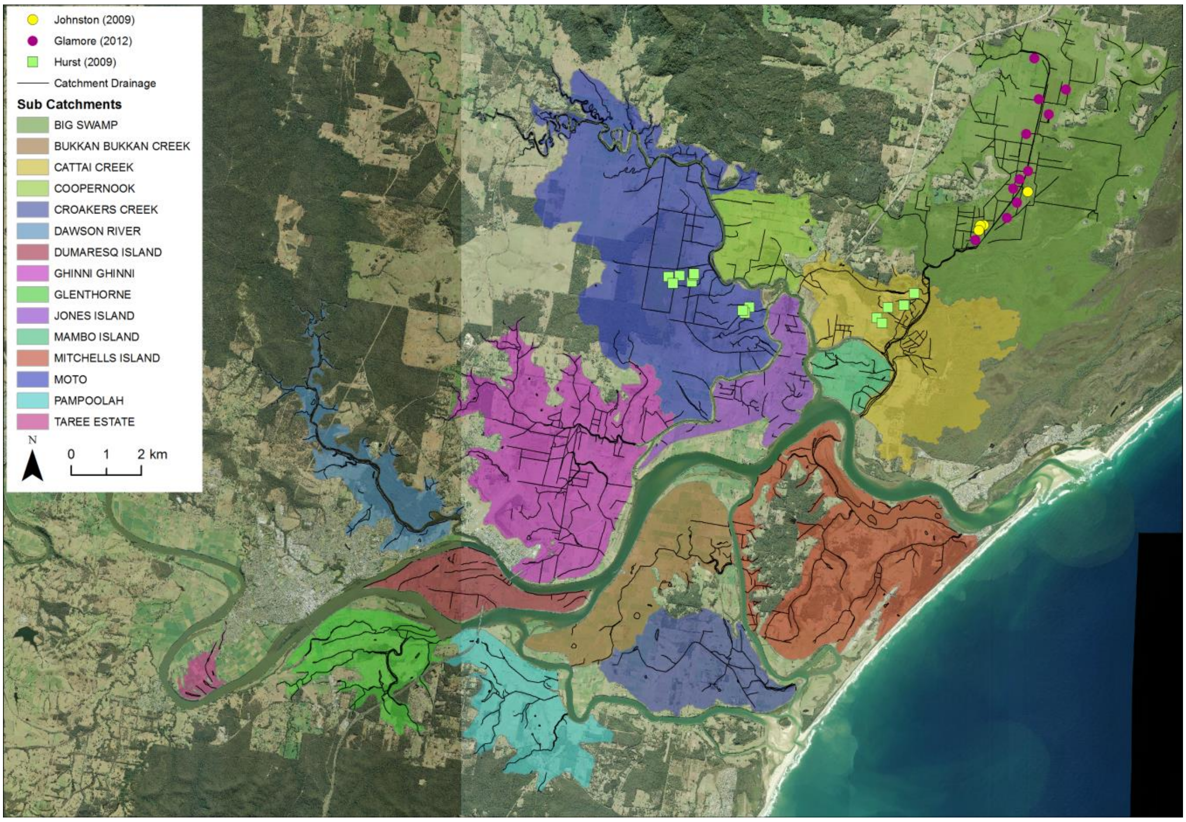


Figure E.2: Previously Published Insitu Saturated Hydraulic Conductivity Measurement Sites

E.3 Data Gaps and Field Investigation

The data compilation and review revealed that the Big Swamp sub-catchment had the best spatial coverage of existing hydraulic conductivity data across the Manning River floodplain. Due to the paucity of hydraulic conductivity data in the other sub-catchments of the Manning River floodplain, field investigations were required to collect insitu hydraulic conductivity data to undertake the priority assessment. Sites were selected at locations within the sub-catchments of the Manning River floodplain to achieve the greatest coverage of data within the project constraints.

WRL completed several field investigations to measure the insitu saturated hydraulic conductivity at selected locations in the sub-catchments of the Manning River floodplain, using the Johnston and Slavich (2003) open pit methodology. Location and results of the field measurements are provided in Figure E.3 and Table E.4. An overall summary of the risk associated with the hydraulic conductivity for each drainage area is provided in Table E.5 and Figure E.4.

Note that the spatial coverage of hydraulic conductivity data across certain sub-catchments of the Manning River floodplain is still generally poor, and since hydraulic conductivity measurements across ASS-affected floodplains can be highly variable, further hydraulic conductivity investigations may be required for preparation of detailed drain remediation plans.

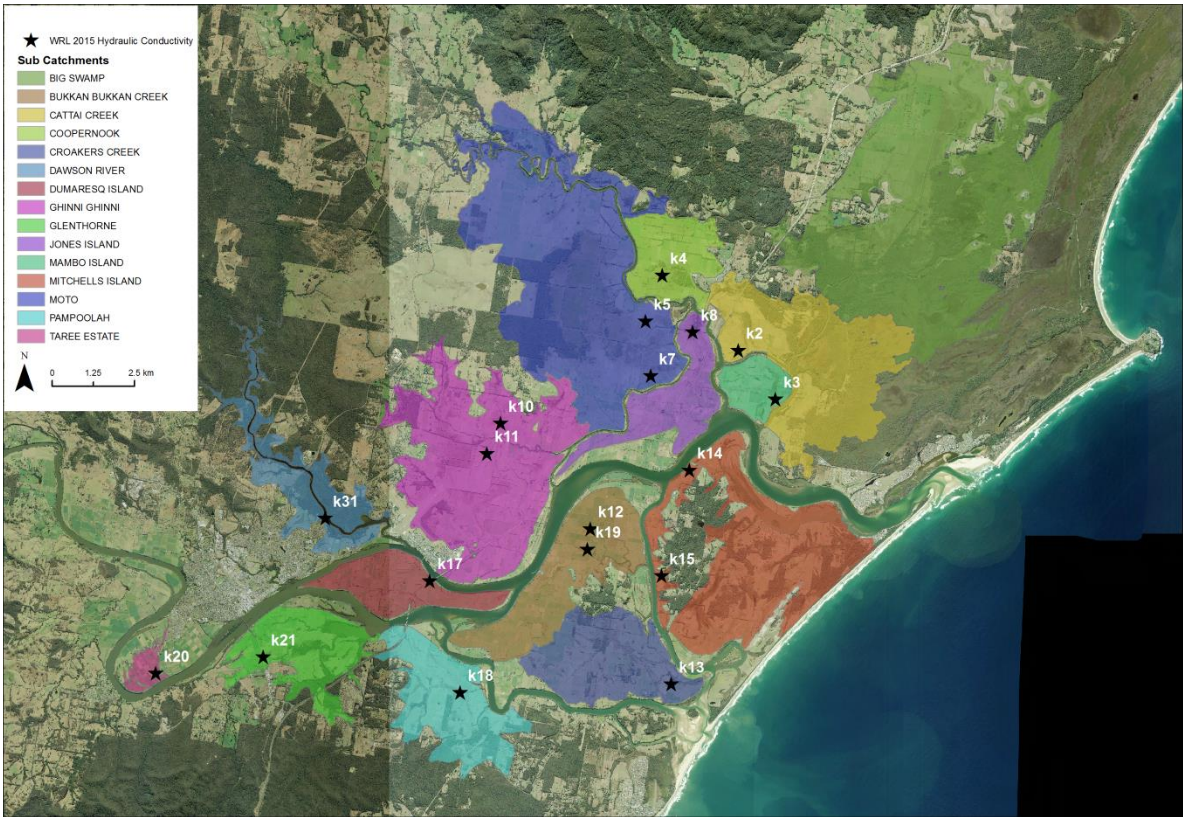


Figure E.3: 2015 Field Assessment Locations of Hydraulic Conductivity

Table E.4: Summary of 2015 Insitu Hydraulic Conductivity Data

Site	Sub-Catchment	Easting (m)	Northing (m)	$K_{sat(H)}$ Category	Rating	pH	EC (µS/cm)
k12	Bukkan Bukkan Creek	459426.21	6471360.54	Extremely High	5	3.74	9,890
k21	Glenthorne	449478.68	6467467.16	Extremely High	5	3.98	668
k15	Mitchells Island	461586.11	6469935.31	High	4	4.65	29,000
k19	Bukkan Bukkan Creek	459339.13	6470738.18	High	4	3.60	9,223
k18	Pampoolah	455470.16	6466387.83	High	4	4.22	11,900
k11	Ghinni Ghinni	456278.02	6473648.49	High	4	3.88	1,277
k7	Moto	461267.02	6476012.87	High	4	3.70	n.s.
k5	Moto	461105.33	6477666.16	High	4	3.95	9,312
k20	Taree Estate	446217.30	6466968.75	Moderate	3	n.s.	747
k10	Ghinni Ghinni	456692.25	6474571.13	Moderate	3	3.72	1,288
k2	Cattai Creek	463919.76	6476781.11	Moderate	3	5.95	13,020
k4	Coopernook	461607.79	6479065.87	Moderate	3	3.64	17,430
k3	Mambo Island	465048.76	6475303.75	Low	2	5.65	35,300
k8	Jones Island	462539.07	6477341.50	Extremely Low	1	4.62	18,820
k31	Dawson River	451360.42	6471680.67	Extremely Low	1	n.s.	n.s.
k17	Dumaresq Island	454543.28	6469780.96	Extremely Low	1	n.s.	n.s.
k13	Croakers Creek	461882.98	6466644.47	Extremely Low	1	n.s.	n.s.
k14	Mitchells Island	462431.61	6473144.52	Extremely Low	1	n.s.	n.s.

Table E.5: Summary of 2015 Insitu Hydraulic Conductivity Data

Sub-catchment	K_{sat} Category	Risk Rating	# Data Points Per Area	pH
Moto	High	4	14	3.70
Ghinni Ghinni	High	4	2	3.72
Big Swamp	High	4	15	3.96
Glenthorne	Extremely High	5	1	3.98
Coopernook	Moderate	3	1	3.64
Pampoolah	High	4	1	4.22
Bukkan Bukkan Creek	Extremely High	5	2	3.60
Dawson River	Extremely Low	1	1	-
Cattai Creek	Moderate	3	7	5.95
Mitchells Island	High	4	2	4.65
Croakers Creek	Extremely Low	1	1	-
Taree Estate	Moderate	3	1	-
Jones Island	Extremely Low	1	1	4.62
Mambo Island	Low	2	1	5.65
Dumaresq Island	Extremely Low	1	1	-

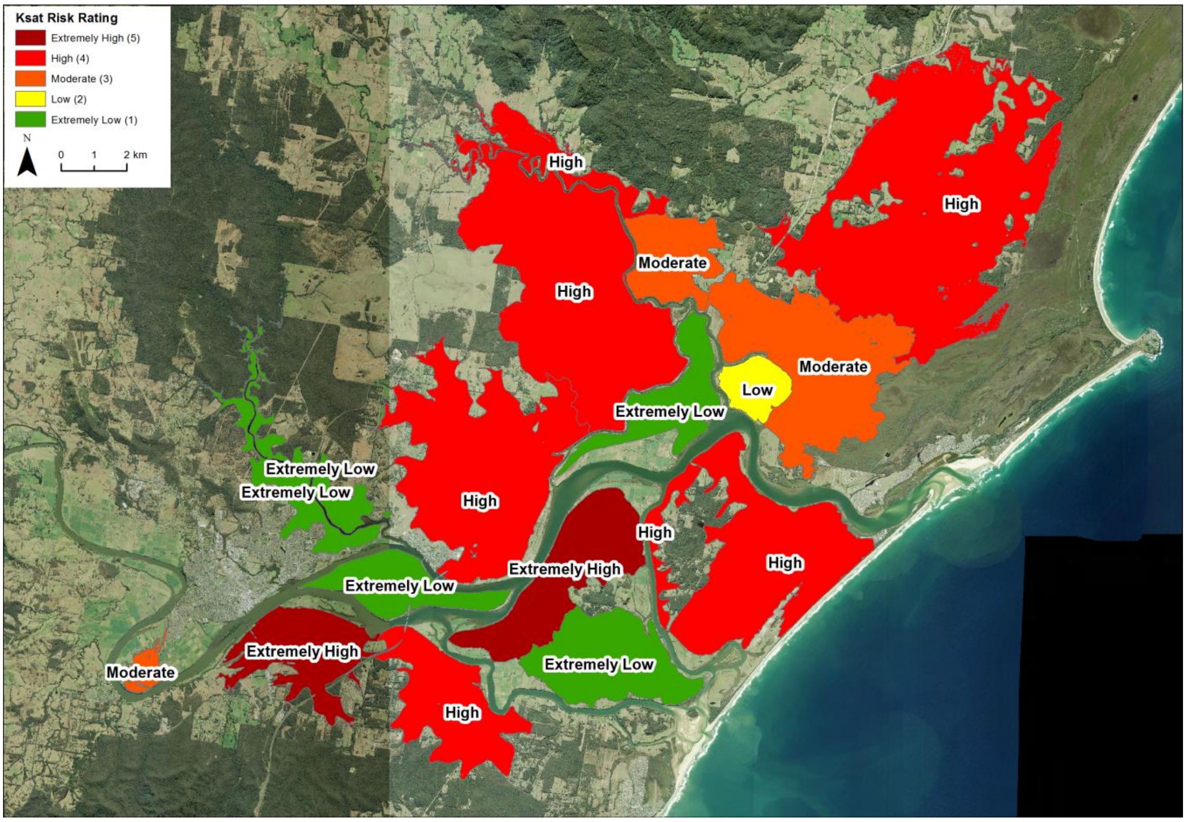


Figure E.4: Hydraulic Conductivity Sub-Catchment Risk Rating

Appendix F – Acid Sulfate Soil Distribution

F.1 Preamble

This section provides a summary of the soil profile data, including depths and elevations of AASS/PASS, available for the Manning River floodplain. Data compilation and review identified sources of existing soil profile data and knowledge gaps within the study area (Section F.2). Field investigations were then targeted to fill the identified data gaps. A summary of the soil profile data collected during the field investigations is provided in Section F.3. Results of the soil profile data analysis for application in the priority assessment is provided in Section F.4.

F.2 Existing Soil Profile Data

Soil profile data on the Manning River floodplain that was available prior to the completion of this study was sourced from:

- eSPADE Database (OEH 2016); and
- Ruprecht (2014).

eSPADE provides a substantial database of information collected by earth scientists and other technical experts. eSPADE contains descriptions of soils, landscapes and other geographic features, and is used by the NSW Government, other organisations, and individuals, to improve planning and decision-making for land management. eSPADE contained extensive soil profile data for the Greater Taree area. The soil profile data on the Manning River floodplain that was contained within eSPADE was collected through various investigations, including:

- Soil Landscapes of the Camden Haven, Wingham, and Bulahdelah 1:100 000 Sheet;
- Coopernook Bypass;
- Pacific Highway Upgrade;
- Taree Effluent Feasibility Study;
- Mid Coast Water Floodplain Survey; and
- North Oxley Island Drain Mapping.

eSPADE provided the best available information on the distribution of ASS in the study area. The information obtained from eSPADE was used to provide approximate AASS and PASS depths across the entire study area and identified data gaps. Analysis of the soil pH data for profiles within the study area was used to infer AASS and PASS layers. Note that a low pH (less than 5.5) often indicates oxidised soils, particularly in conjunction with the presence of yellow/orange mottling (jarosite). A near neutral pH (pH 7 to 8) below an acidic layer indicates a potential acidic layer, often in conjunction with a soil description of dark grey estuarine muds and clays. The location of all available eSPADE soil profiles within the study area is presented in Figure F.1, and a summary of the soil profile data, including depths and elevations of AASS/PASS, is provided in Table F.1.

WRL also completed a field investigation on 26 February 2014 to assess soil conditions at Big Swamp where the construction of a swale drain was proposed. The investigation resulted in soil profiles for nine (9) different sites (Figure F.2). Soil profiles were taken up to 1 m in depth from the surface using a standard gouge auger. Laboratory analysis of soil samples taken during the investigation showed all samples had a pH < 4.6. A summary of the depths to AASS are provided in Table F.2. Note that no shallow PASS layers were identified during the study.

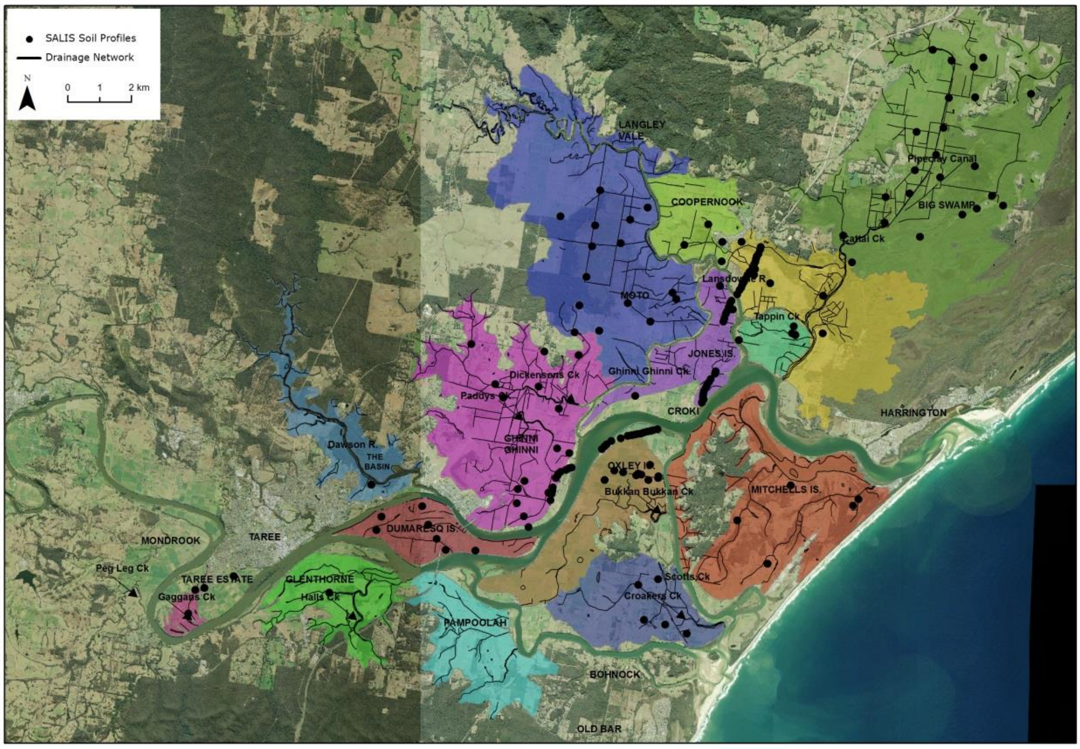


Figure F.1: Locations of eSPADE Soil Profiles in Each Sub-Catchment of the Study Area

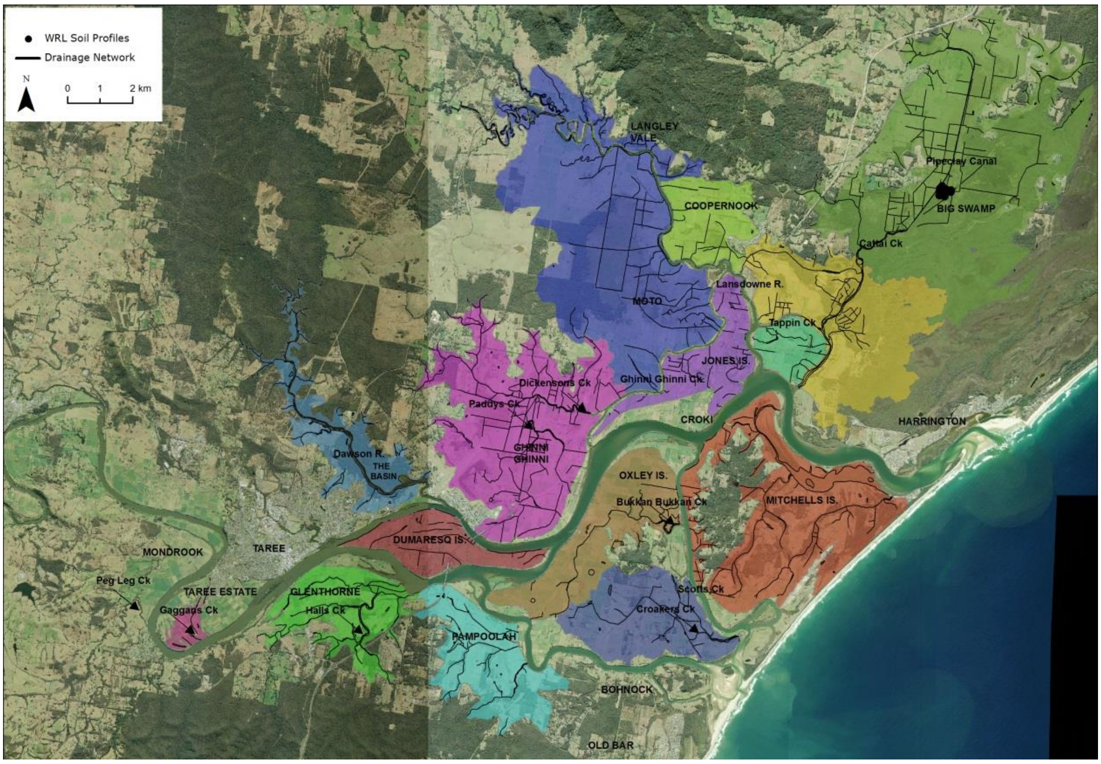


Figure F.2: Locations of HAG Soil Profiles in the Big Swamp Catchment

Table F.1: Summary of Approximate AASS and PASS Depth and Elevations (OEH 2016)

Profile ID	Easting (m)	Northing (m)	Sub-Catchment	Surface Elevation (m AHD)	Depth to AASS (m)	Depth to PASS (m)	Elevation of AASS (m AHD)	Elevation of PASS (m AHD)
24280	470754	6483339	Big Swamp	1.42	-	0.16	-	1.12
24281	469924	6483319	Big Swamp	0.86	0.52	1	0.44	-0.04
24282	469754	6482379	Big Swamp	1.03	0.18	0.73	0.78	0.23
24283	469654	6480819	Big Swamp	0.65	0.61	0.96	0.35	0
24284	468684	6480309	Big Swamp	0.66	0.5	-	0.46	-
24285	467904	6479389	Big Swamp	0.51	0.67	1.05	0.29	-0.09
24286	468854	6481039	Big Swamp	0.72	0.54	1.19	0.42	-0.23
24287	468904	6482249	Big Swamp	1.03	0.35	1.23	0.61	-0.27
24294	470004	6484489	Big Swamp	0.66	0.75	2.3	0.21	-1.34
24295	471004	6484589	Big Swamp	1.3	0.56	-	0.4	-
24296	470704	6484289	Big Swamp	1.5	0.37	-	1.33	-
24297	467934	6480189	Big Swamp	0.59	0.52	-	0.44	-
24300	466604	6478989	Big Swamp	0.94	-	0.67	-	0.29
24307	470804	6479839	Big Swamp	1.53	-	0.49	-	1.45
24308	470344	6479639	Big Swamp	1.23	0.12	-	1.08	-
33384	469014	6478946	Big Swamp	2.23	-	0.37	-	1.33
33385	471624	6479929	Big Swamp	2.28	0.87	0.62	1.83	1.58
72245	472504	6483439	Big Swamp	2.46	-	1.2	-	2.16
16441	469418	6484829	Big Swamp	0.91	0.45	1.15	0.51	-0.19
16442	471275	6480232	Big Swamp	1.21	0.05	0.39	1.01	0.57
16491	470737	6481171	Big Swamp	1.54	-	1.12	-	-0.16
16492	469523	6481527	Big Swamp	1.12	0.14	0.74	0.82	0.22
24278	460154	6471489	Bukkan Bukkan creek	0.63	0.61	1.33	0.35	-0.37
24279	460254	6471459	Bukkan Bukkan creek	1.14	0.17	0.92	0.79	0.04
22646	460779	6471359	Bukkan Bukkan creek	0.95	-	0.86	-	0.1
22647	460786	6471409	Bukkan Bukkan creek	0.94	-	1.39	-	-0.43
22648	460467	6471290	Bukkan Bukkan creek	0.68	1.21	-	-0.25	-
22649	460520	6471773	Bukkan Bukkan creek	0.98	0.18	0.91	0.78	0.05
22650	460094	6471439	Bukkan Bukkan creek	0.61	0.68	1.35	0.28	-0.39
22651	459674	6471534	Bukkan Bukkan creek	0.51	-	1.55	-	-0.59
22652	459404	6471589	Bukkan Bukkan creek	0.71	0.85	1.25	0.11	-0.29
7934	464304	6477489	Cattai Creek	0.96	0.2	-	0.76	-
24299	465954	6475909	Cattai Creek	1.02	0.59	-	0.37	-
24301	466874	6478139	Cattai Creek	1.09	-	0.87	-	0.09
24302	465964	6477089	Cattai Creek	0.92	0.37	0.92	0.59	0.04
20523	463404	6478789	Cattai Creek	1.27	-	0.13	-	1.09
21571	463791	6477752	Cattai Creek	1.73	-	0.43	-	0.53

Profile ID	Easting (m)	Northing (m)	Sub-Catchment	Surface Elevation (m AHD)	Depth to AASS (m)	Depth to PASS (m)	Elevation of AASS (m AHD)	Elevation of PASS (m AHD)
21572	463594	6477751	Cattai Creek	0.83	-	0.48	-	0.48
21573	463340	6477271	Cattai Creek	1.27	-	0.79	-	0.17
21574	463344	6477269	Cattai Creek	1.21	-	0.45	-	0.51
21586	463390	6477347	Cattai Creek	1.05	-	-	-	-
21587	463430	6477427	Cattai Creek	1.18	-	0.13	-	0.83
21588	463477	6477525	Cattai Creek	1.1	-	0.21	-	0.75
21589	463528	6477629	Cattai Creek	0.95	-	0.26	-	0.7
21591	463753	6477993	Cattai Creek	1.47	0.11	-	1.07	-
21592	463794	6478076	Cattai Creek	1.3	0.16	-	0.8	-
21593	463838	6478159	Cattai Creek	1.41	-	0.15	-	1.11
21594	463854	6478252	Cattai Creek	2.87	-	1.61	-	2.57
21595	463881	6478331	Cattai Creek	3.16	-	1.6	-	2.56
21596	463929	6478400	Cattai Creek	3.44	2.18	-	3.14	-
21597	463983	6478540	Cattai Creek	3.47	-	-	-	-
21598	464007	6478626	Cattai Creek	1.24	0.13	-	1.09	-
21606	463827	6477925	Cattai Creek	0.98	0.28	-	0.68	-
7980	460329	6466889	Croakers Creek	2.7	-	1.04	-	2
7982	461004	6466739	Croakers Creek	3.71	-	2.25	-	3.21
7986	460779	6468164	Croakers Creek	2.2	0.16	-	0.8	-
16446	460154	6467989	Croakers Creek	0.48	-	1.98	-	-1.02
16512	461674	6466449	Croakers Creek	1.55	0.25	0.66	1.21	0.3
19017	451764	6471139	Dawson River	1.15	-	0.76	-	0.2
7984	453814	6469439	Dumaresq Island	3.07	1.81	-	2.77	-
22337	455029	6469064	Dumaresq Island	1.46	-	0.4	-	0.56
22338	454104	6469089	Dumaresq Island	1.11	-	0.09	-	0.87
22339	453354	6470464	Dumaresq Island	2.29	-	0.7	-	1.66
22344	451917	6469714	Dumaresq Island	3.28	-	1.68	-	2.64
24288	458154	6475939	Ghinni Ghinni	1.95	-	-	-	-
24303	455654	6474309	Ghinni Ghinni	0.99	0.3	-	0.66	-
24304	455904	6473889	Ghinni Ghinni	0.91	0.9	1.25	0.06	-0.29
24305	457024	6474239	Ghinni Ghinni	0.71	-	-	-	-
24306	457654	6473539	Ghinni Ghinni	0.92	0.54	1.4	0.42	-0.44
16444	458284	6475218	Ghinni Ghinni	0.96	-	1.27	-	-0.31
16448	456366	6471005	Ghinni Ghinni	1.02	0.37	1.79	0.59	-0.83
16508	454904	6475564	Ghinni Ghinni	1.17	0.44	1.69	0.52	-0.73
22336	456333	6470564	Ghinni Ghinni	1.78	-	0.45	-	1.41
22340	456554	6470152	Ghinni Ghinni	3.1	-	-	-	-
22341	457979	6472139	Ghinni Ghinni	2.34	-	0.65	-	1.61
22342	457604	6472289	Ghinni Ghinni	1.71	-	0.47	-	1.43

Profile ID	Easting (m)	Northing (m)	Sub-Catchment	Surface Elevation (m AHD)	Depth to AASS (m)	Depth to PASS (m)	Elevation of AASS (m AHD)	Elevation of PASS (m AHD)
22343	457329	6470889	Ghinni Ghinni	1.26	-	0.16	-	0.8
22347	456579	6471264	Ghinni Ghinni	1.25	-	0.66	-	0.3
24911	457395	6470658	Ghinni Ghinni	2.86	-	1.8	-	2.76
24913	457435	6470855	Ghinni Ghinni	2.58	-	1.62	-	2.58
24914	457451	6470953	Ghinni Ghinni	2.58	-	1.12	-	2.08
24915	457467	6471061	Ghinni Ghinni	2.37	-	0.41	-	1.37
24918	457558	6471358	Ghinni Ghinni	2.39	-	0.43	-	1.39
24919	457609	6471429	Ghinni Ghinni	1.75	-	0.31	-	0.65
24920	457646	6471492	Ghinni Ghinni	2.74	-	0.58	-	1.54
24921	457708	6471543	Ghinni Ghinni	2.57	-	1.21	-	2.17
19014	450434	6467744	Glenthorne	0.96	0.28	2.05	0.68	-1.09
7983	460054	6473939	Jones Island	1.82	-	0.66	-	1.62
16443	462731	6477397	Jones Island	0.66	0.6	2.05	0.36	-1.09
21576	462832	6476275	Jones Island	1.75	0.49	-	1.45	-
21577	462866	6476377	Jones Island	1.97	0.61	-	1.57	-
21578	462907	6476517	Jones Island	2.13	0.92	-	1.88	-
21579	462945	6476606	Jones Island	2.04	0.78	-	1.74	-
21580	463001	6476735	Jones Island	2.37	-	1.16	-	2.12
21581	463049	6476856	Jones Island	1.07	0.24	-	0.72	-
21582	463086	6476932	Jones Island	1.77	-	-	-	-
21583	463127	6476659	Jones Island	1.01	0.15	-	0.81	-
24970	462202	6473995	Jones Island	1	-	1.46	-	-0.5
24971	462218	6474082	Jones Island	1.18	-	1.28	-	-0.32
24972	462273	6474186	Jones Island	1.28	-	1.18	-	-0.22
24973	462312	6474273	Jones Island	1.14	-	1.32	-	-0.36
24974	462373	6474367	Jones Island	0.92	-	1.04	-	-0.08
24975	462435	6474463	Jones Island	0.81	-	0.65	-	0.31
24977	462571	6474634	Jones Island	0.69	-	-	-	-
24978	462592	6474708	Jones Island	0.38	-	0.58	-	0.38
24979	462206	6473825	Jones Island	1.9	-	0.44	-	1.4
24980	462158	6473724	Jones Island	2.36	1.3	0.8	2.26	1.76
24981	462164	6473755	Jones Island	2.1	-	0.14	-	1.1
24982	462189	6473909	Jones Island	0.97	-	0.99	-	-0.03
24314	462354	6479339	Coopernook	0.51	0.7	1.73	0.26	-0.77
24315	461604	6478689	Coopernook	0.59	0.6	1.52	0.36	-0.56
21575	462782	6478168	Coopernook	0.56	0.65	-	0.31	-
16495	464988	6475903	Mambo Island	0.86	-	0.37	-	0.59
16496	465099	6475849	Mambo Island	0.41	-	1.55	-	-0.59
70311	465044	6476129	Mambo Island	0.69	-	1.27	-	-0.31

Profile ID	Easting (m)	Northing (m)	Sub-Catchment	Surface Elevation (m AHD)	Depth to AASS (m)	Depth to PASS (m)	Elevation of AASS (m AHD)	Elevation of PASS (m AHD)
16452	467079	6470686	Mitchells Island	1.5	-	0.24	-	1.2
16454	464223	6468659	Mitchells Island	1.14	-	0.04	-	0.92
16510	463269	6470019	Mitchells Island	1.2	-	1.46	-	-0.5
16511	464954	6471124	Mitchells Island	2.18	-	-	-	-
20533	466904	6470489	Mitchells Island	2.13	-	1.17	-	2.13
24289	458304	6476789	Moto	1.12	0.01	-	0.97	-
24290	461354	6476989	Moto	0.6	0.56	-	0.4	-
24291	459604	6478739	Moto	1.03	0.31	-	0.65	-
24292	459904	6479489	Moto	0.89	0.25	1.57	0.71	-0.61
24293	458954	6480409	Moto	1.26	0.1	1.2	1.06	-0.24
24309	458804	6479309	Moto	0.8	0.24	1.66	0.72	-0.7
24310	458704	6478649	Moto	0.79	0.62	1.13	0.34	-0.17
24311	458524	6477689	Moto	0.95	0.31	1.11	0.65	-0.15
24312	457704	6479589	Moto	1.43	0.22	-	1.18	-
24313	459824	6476859	Moto	0.82	0.3	-	0.66	-
16445	458929	6475988	Moto	1.66	0.52	-	0.44	-
16461	460452	6479869	Moto	1.26	0.12	1.8	1.08	-0.84
16462	461235	6477183	Moto	0.66	0.53	2.4	0.43	-1.44
70310	460540	6476279	Moto	1.03	-	0.23	-	0.73
73169	446218	6467829	Taree Estate	0.52	-	1.14	-	-0.18
73377	446004	6467089	Taree Estate	5.65	4.54	4.29	5.5	5.25

Table F.2: Summary of Approximate AASS Depth and Elevations (Ruprecht 2014)

Profile ID	Easting (m)	Northing (m)	Sub-Catchment	Surface Elevation (m AHD)	AASS Depth (m)	AASS Elevation (m AHD)
530	469056	6480563	Big Swamp	0.40	0.28	0.12
531	469112	6480639	Big Swamp	0.42	0.28	0.14
532	469231	6480547	Big Swamp	0.65	0.27	0.38
533	469392	6480519	Big Swamp	0.57	0.27	0.30
534	469383	6480460	Big Swamp	0.63	0.18	0.45
535	469216	6480458	Big Swamp	0.70	0.28	0.42
536	469186	6480322	Big Swamp	0.75	0.20	0.55
537	469043	6480489	Big Swamp	0.61	0.25	0.36
538	469030	6480353	Big Swamp	0.61	0.23	0.38

F.3 Data Gaps and Field Investigation

Following data collation and review of all available soil profile data on the Manning River floodplain, areas with limited AASS/PASS layer data, or low data confidence, were identified as provided in Figure F.3. WRL staff completed 26 soil profiles over 10-days at the specified locations within the study area to determine AASS and PASS depth and elevation, and soil acidity. A summary of the soil profile AASS/PASS layer data obtained from the field investigation is provided in Table F.3. Detailed data logs of each soil profile is provided in Figures F.5 to F.30.

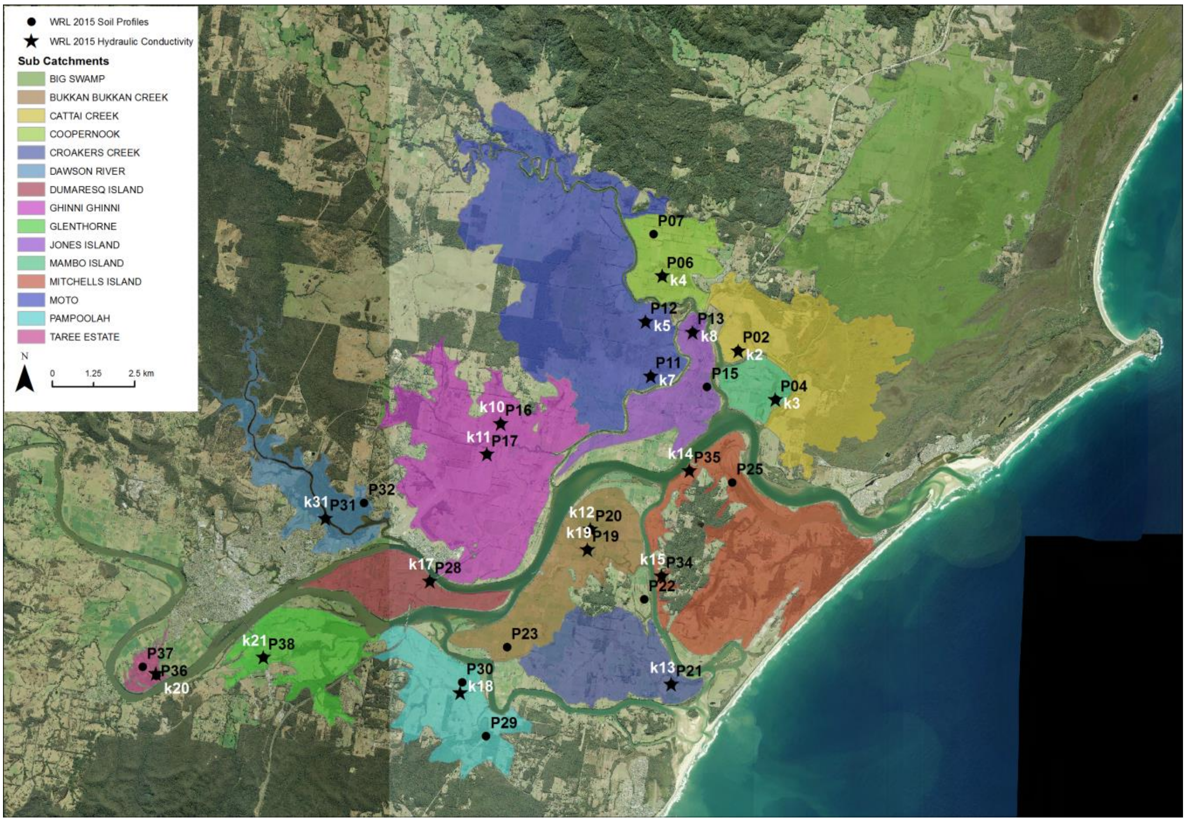


Figure F.3: Data Gap Soil Profile Locations

Table F.3: Summary of Approximate AASS and PASS Depth and Elevation

ID	Sub-Catchment	Depth to AASS (m)	Depth to PASS (m)	Elevation of AASS (m AHD)	Elevation of PASS (m AHD)
P02	Dawson River	0.20	1.20	0.42	-0.58
P04	Mitchells Island	0.10	0.70	0.55	-0.05
P06	Taree Estate	0.10	1.10	0.17	-0.83
P07	Glenthorne	0.20	-	0.55	-
P11	Pampoolah	0.45	1.50	0.43	-0.62
P12	Taree Estate	0.20	-	0.09	-
P13	Dawson River	0.10	1.50	0.24	-1.16
P15	Mitchells Island	0.40	1.30	-0.05	-0.95
P16	Pampoolah	0.30	-	0.40	-
P17	Dumaresq Island	0.20	1.70	0.47	-1.03
P19	Coopernook	0.30	1.60	0.15	-1.15
P20	Coopernook	0.20	1.65	0.09	-1.37
P21	Jones Island	0.60	-	0.17	-
P22	Moto	-	0.30	-	0.48
P23	Moto	0.50	1.60	0.47	-0.63
P25	Mitchells Island	-	-	-	-
P28	Croakers Creek	1.00	-	-0.03	-
P29	Ghinni Ghinni	0.20	-	0.77	-
P30	Bukkan Bukkan	0.70	2.10	0.55	-0.85
P31	Croakers Creek	0.10	-	0.82	-
P32	Bukkan Bukkan Creek	0.40	-	0.76	-
P34	Mambo Island	0.10	0.80	0.54	-0.16
P35	Cattai Creek	-	0.30	-	1.03
P36	Jones Island	-	1.10	-	2.17
P37	Ghinni Ghinni	-	0.10	-	2.02
P38	Bukkan Bukkan Creek	0.30	-	0.77	-

F.3.1 Methodology

Soil profiles were collected using a Dormer stainless steel, spiral-tipped, general purpose hand auger and a stainless steel gouge auger, attached to a Dingo Post Hole Digger, as shown in Figure F.4. Soil samples from the unsaturated zone were extracted in approximately 250 mm sections using the general purpose hand auger and laid in open PVC piping for logging and sample collection. Soil samples from the saturated zone were extracted using a gouge auger to ensure reliable sample retrieval. All soil profiles were logged in-situ and samples collected from each distinct soil horizon. Borehole depths ranged between 1.3 m to 3.5 m below ground surface. Soil horizons across all profiles ranged between three (3) and eight (8) distinct layers. Borehole locations and ground surface elevations were measured using a Trimble R10 RTK-GPS and offset using the NSW CorsNET network to an accuracy of ± 2 mm vertically and horizontally.

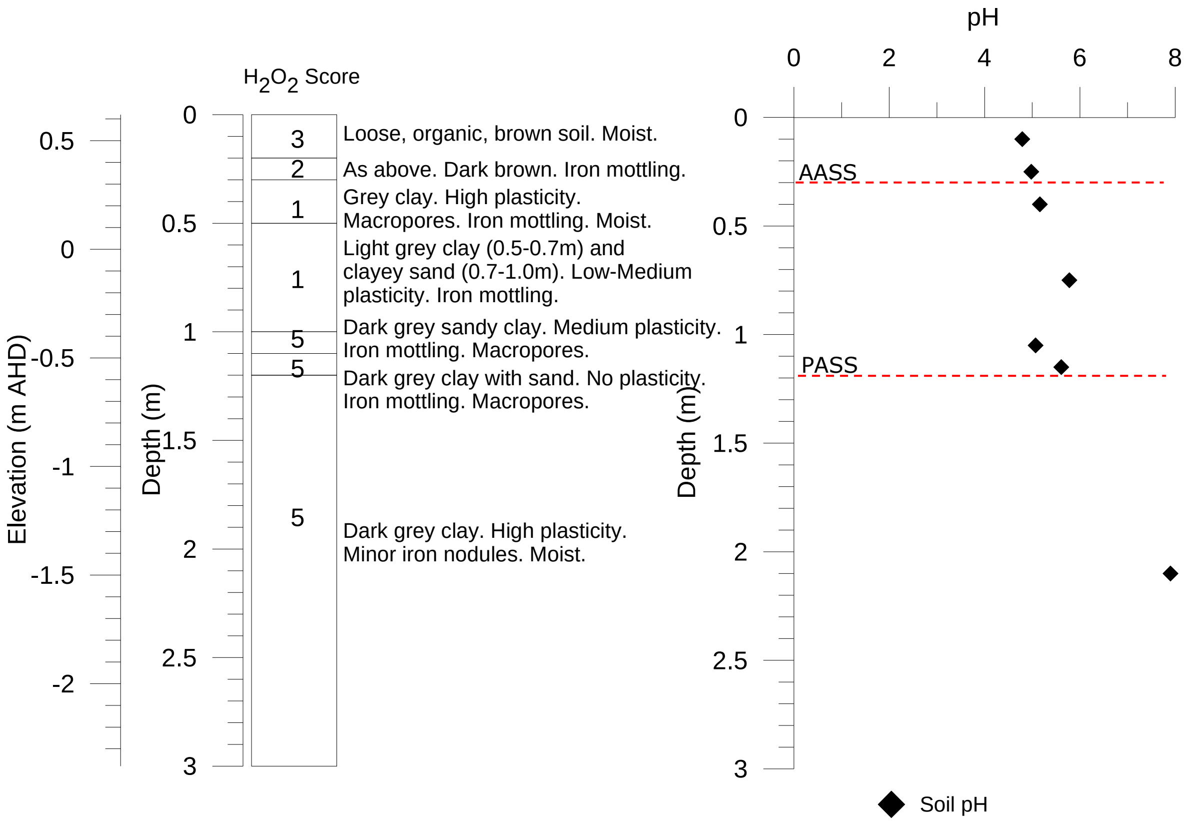
Samples were immediately bagged and cooled following collection and refrigerated during storage. Soil samples were analysed at the WRL soil analysis laboratory following completion of the field investigation. Soil pH and electrical conductivity (EC) was assessed using the methodology (4A1) outlined in Rayment and Higginson (1992). This is the standard method for determination of soil pH and EC that utilises a 1:5 soil to water ratio.

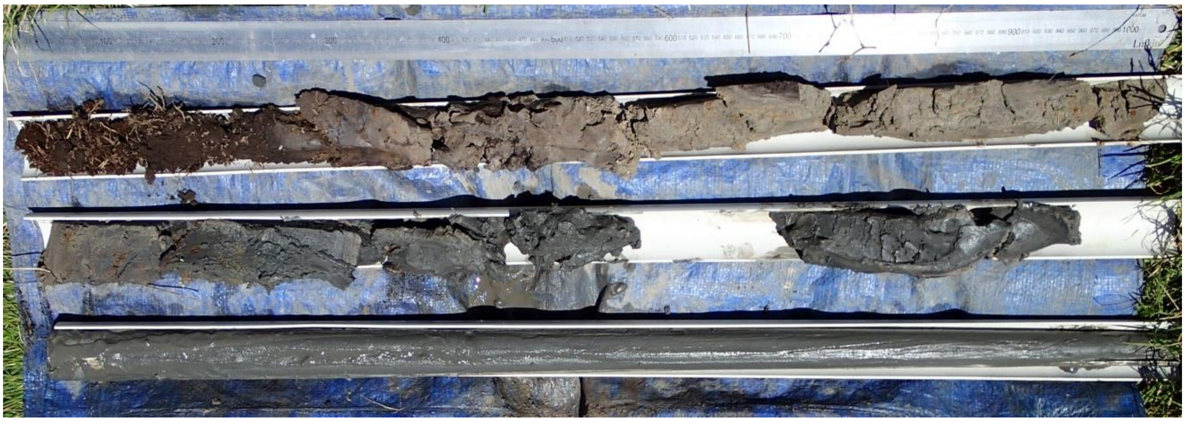
The presence of ASS was tested insitu using the methodology (4E1) outlined in Rayment and Higginson (1992). This methodology is also known as the pH_{FOX} test. Soil samples were placed in a plastic Falcon 50 mL test tube and covered with 30% hydrogen peroxide (H_2O_2). The hydrogen peroxide was pH adjusted to between 4.5 - 5.5 using 0.1M sodium hydroxide (NaOH) prior to testing. Following reaction of any potential acid sulfate soils, the sample was allowed to settle and the pH of the supernatant was tested. Calibration of pH and EC meters was undertake prior to testing of soil samples. The pH of the hydrogen peroxide was tested prior to addition to each set of soil profile samples.

The strength of the oxidation reaction is generally rated on a zero (0) to five (5) scale, with zero (0) reaction indicating absent acidity (no bubbling) and five (5) indicating high levels of acidity (violent bubbling). All soil horizons analysed during the field investigation showed a reaction greater than one (1). Extreme oxidation reactions (5) were observed at 65% of the boreholes analysed (P2, P4, P6, P7, P11, P12, P13, P15, P16, P17, P23, P36, P38), while moderate reactions (1 to 4) were at observed at all other sites, except for P19, P20, P21, P22, P25, and P34, because these sites were not tested. Strong reactions predominantly occurred in soils extracted from the saturated zone and were characterised by dark grey estuarine muds. These samples are typical of PASS and generally have a high pre-oxidation soil pH, indicating un-oxidised (anaerobic) soils. The highly reactive horizons were generally overlaid by a horizon of oxidised pyrite, indicated by the presence of yellow jarosite mottling. Referencing of the horizons to AHD and typical tidal levels that control groundwater drainage indicated that the jarosite layer occurred near MSL with the PASS layer occurring below expected the low tide elevations.

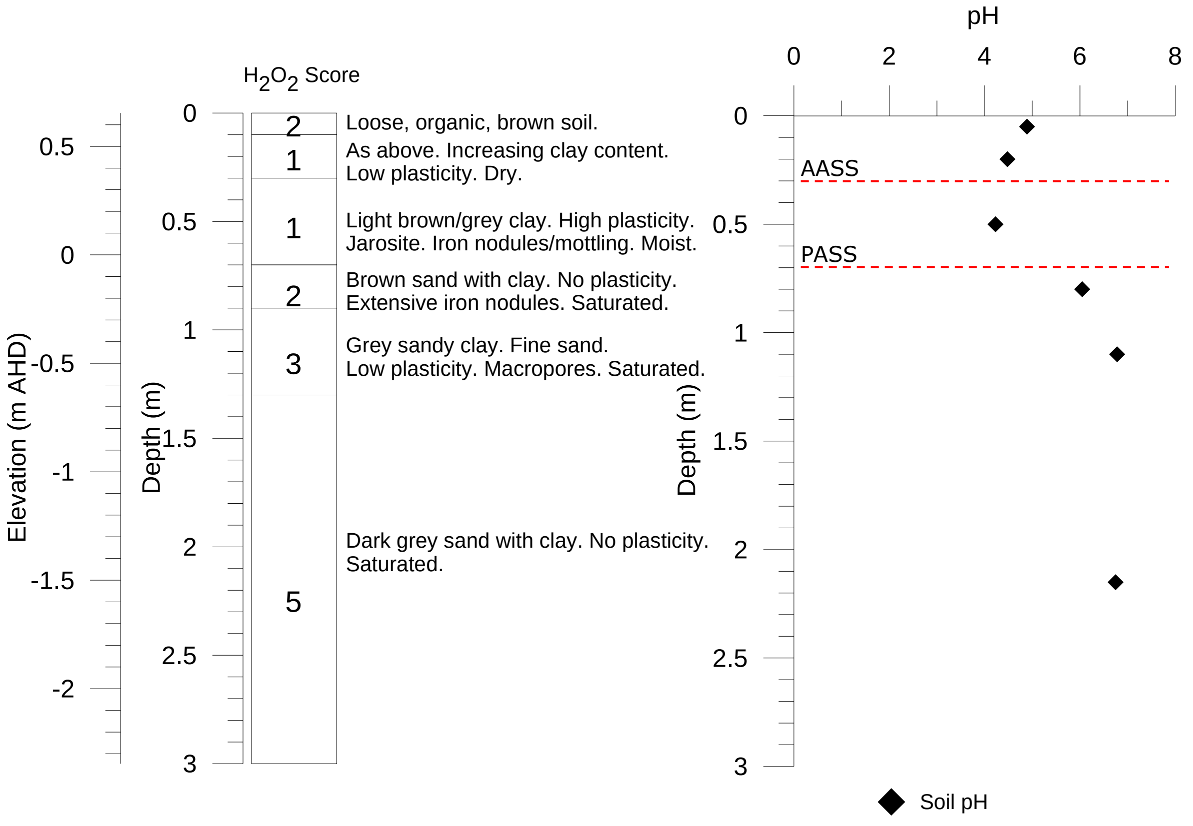
Figure F.4: Dingo Post Hole Digger Showing In-house Coupling used to Attach the Hand Auger

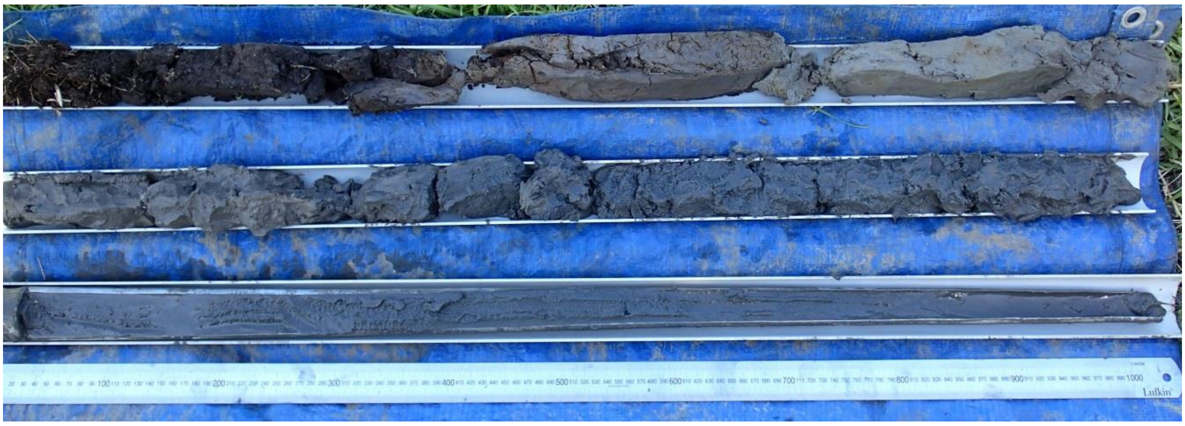
Location	P2
Date	25/11/2015
Easting (m)	463911.201
Northing (m)	6476789.175
Elevation (m AHD)	0.620



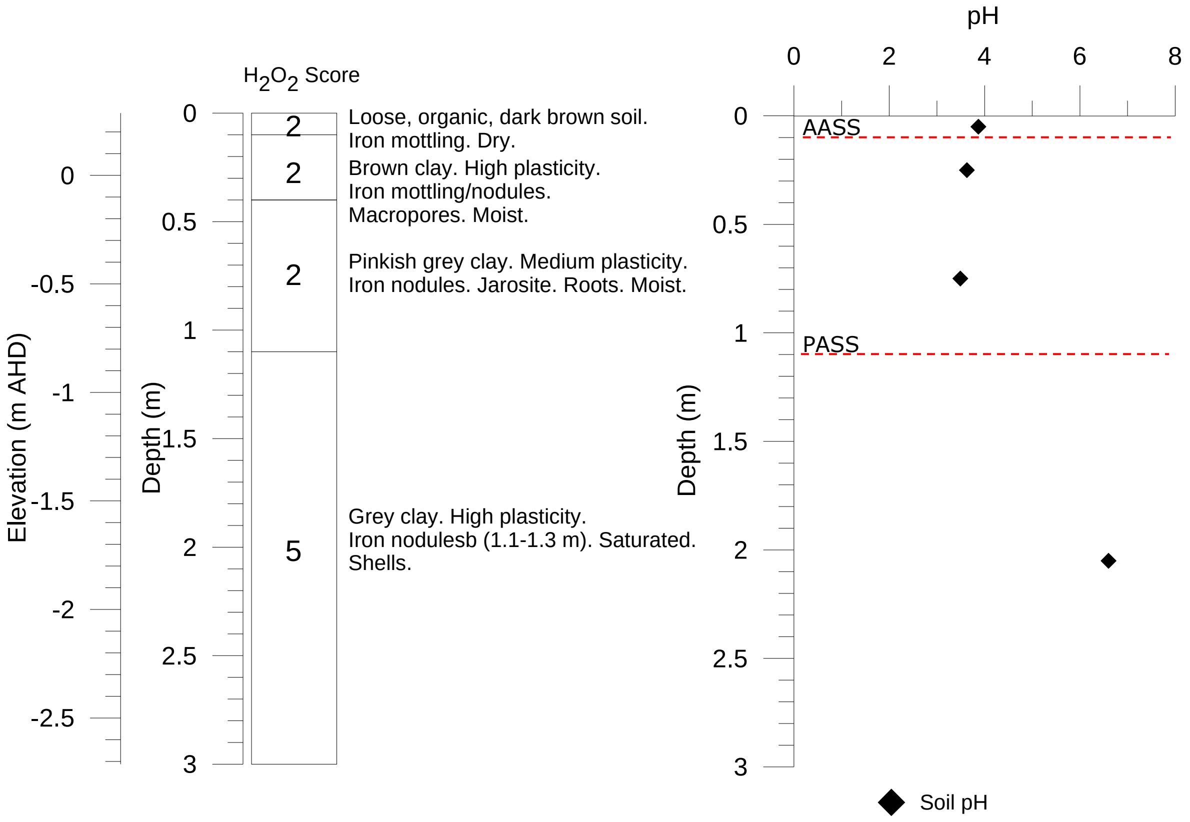


Location	P4
Date	25/11/2015
Easting (m)	465066.990
Northing (m)	6475308.717
Elevation (m AHD)	0.654

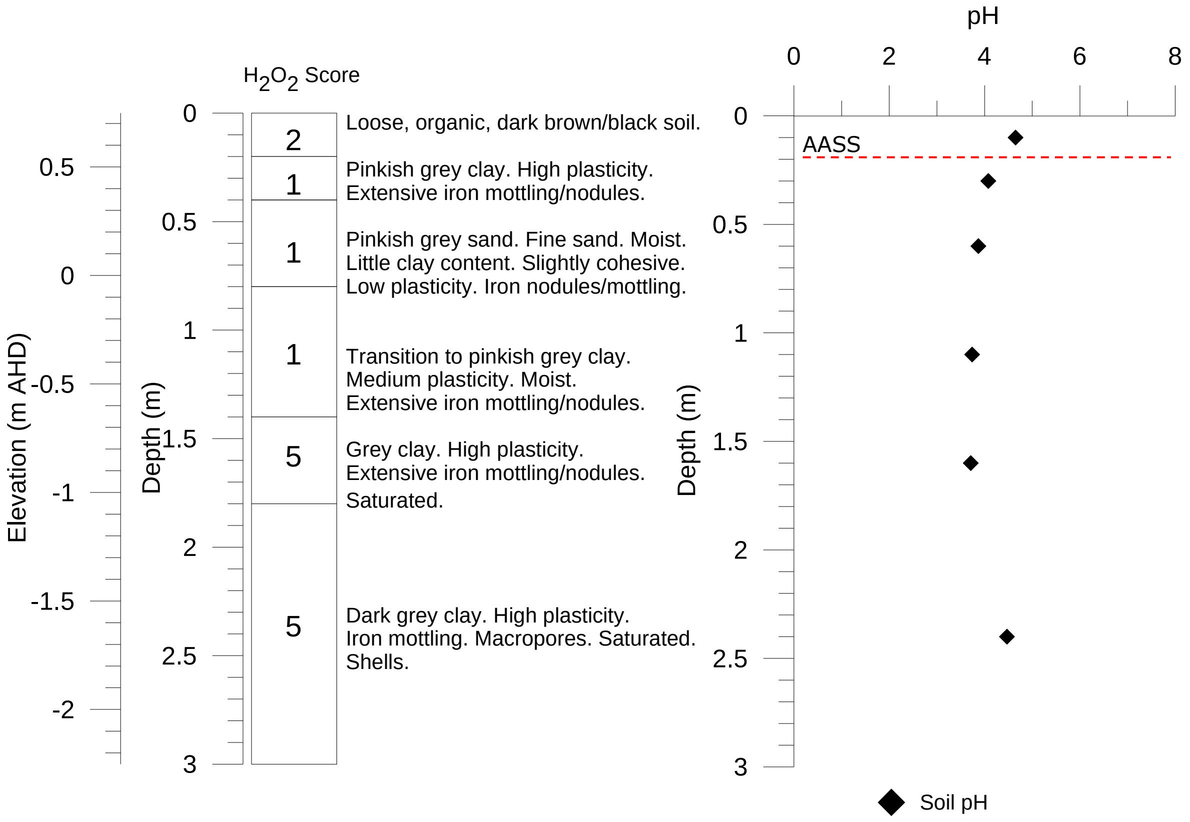


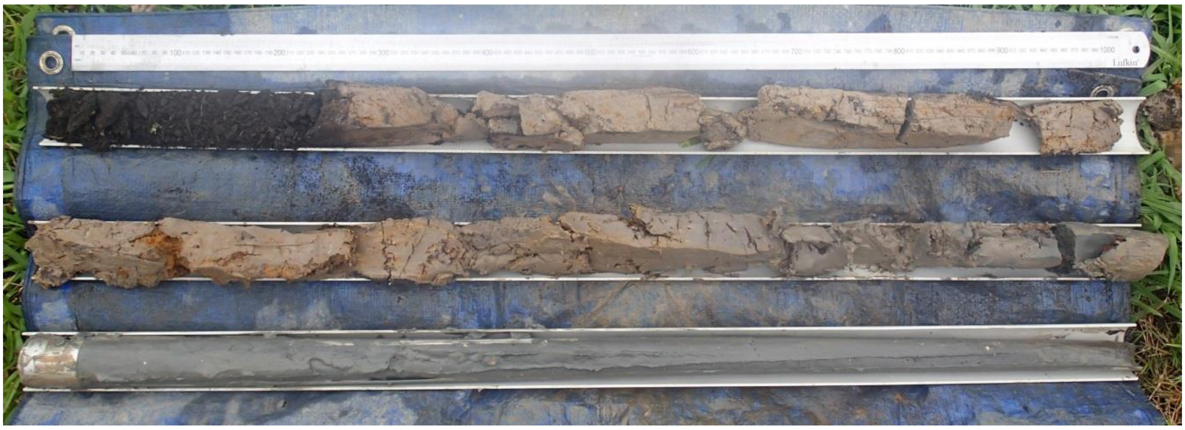


Location	P6
Date	27/11/2015
Easting (m)	461607.121
Northing (m)	6479057.872
Elevation (m AHD)	0.273

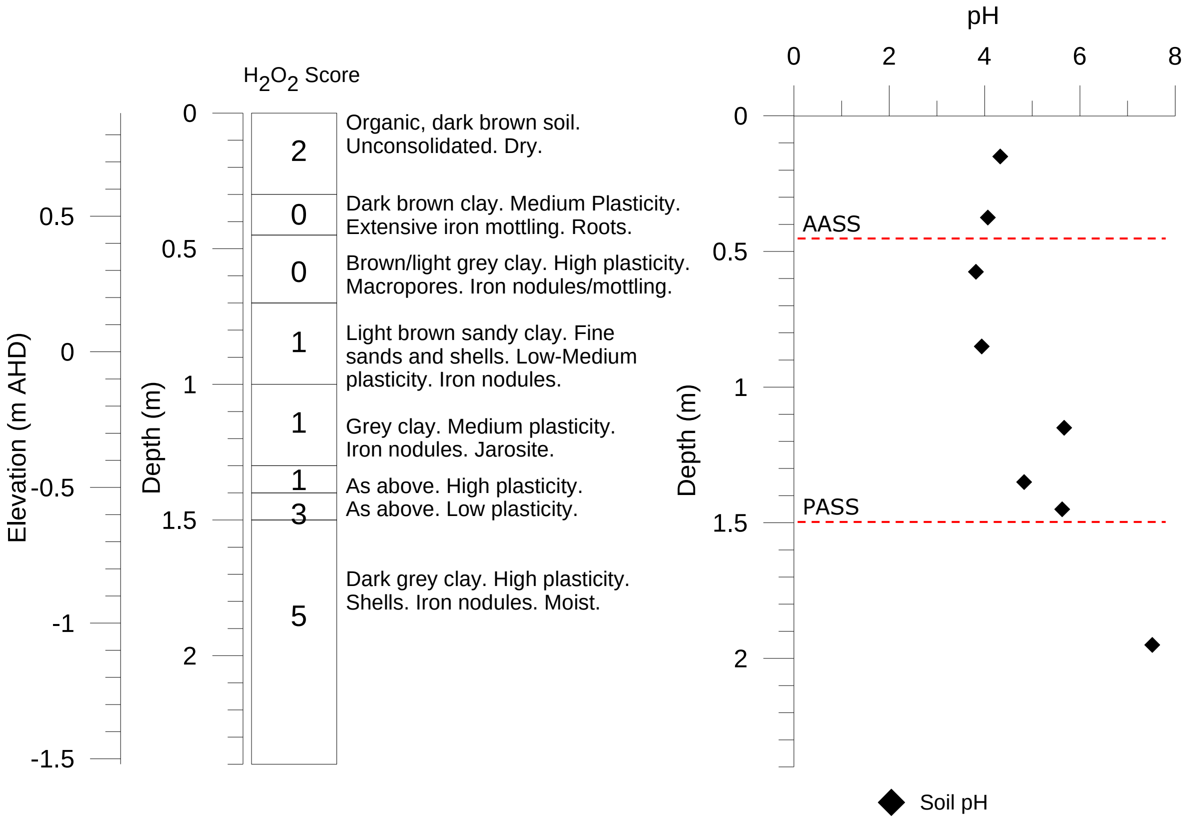


Location	P7
Date	27/11/2015
Easting (m)	461338.679
Northing (m)	6480330.789
Elevation (m AHD)	0.748

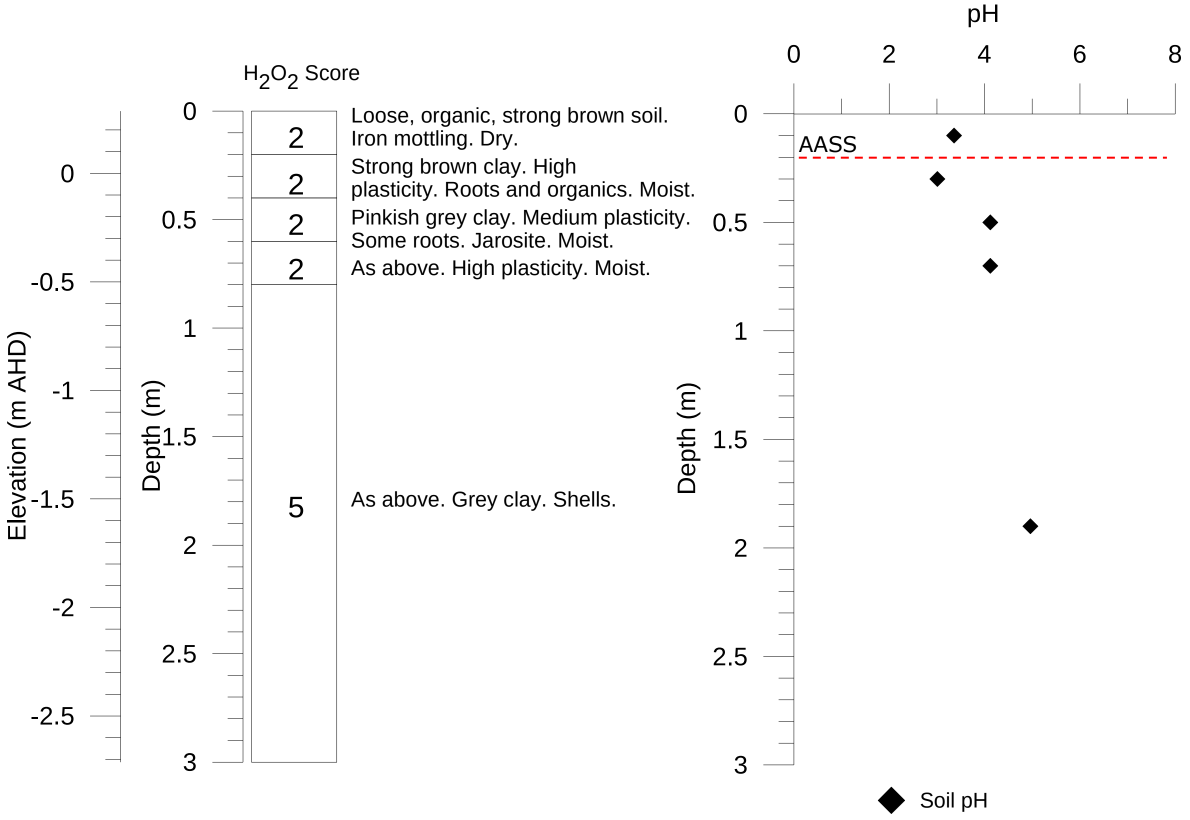


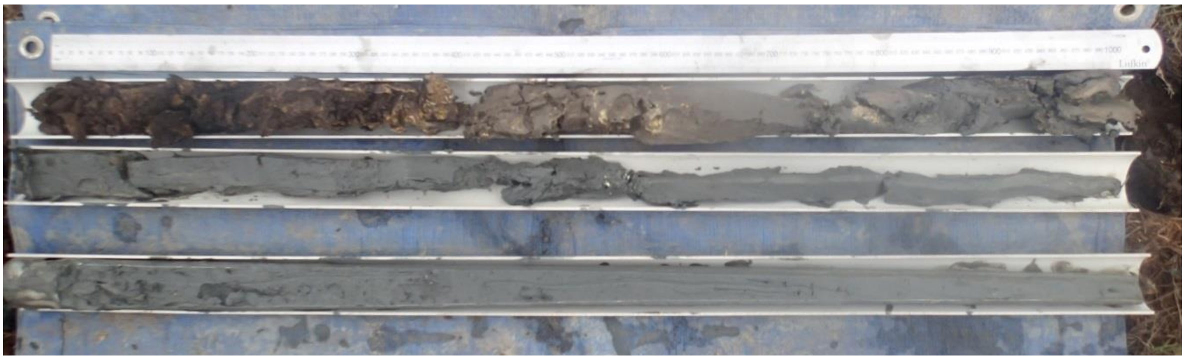


Location	P11
Date	24/11/2015
Easting (m)	461265.864
Northing (m)	6476010.979
Elevation (m AHD)	0.880

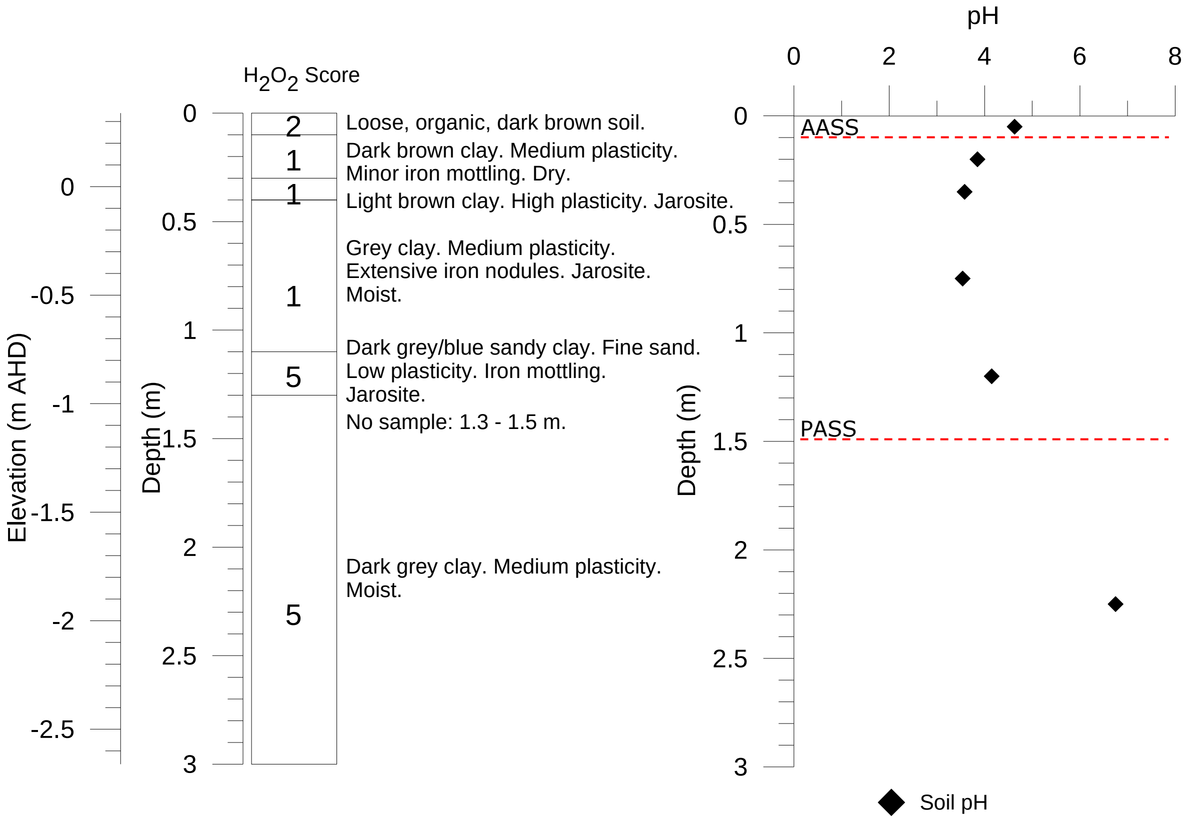


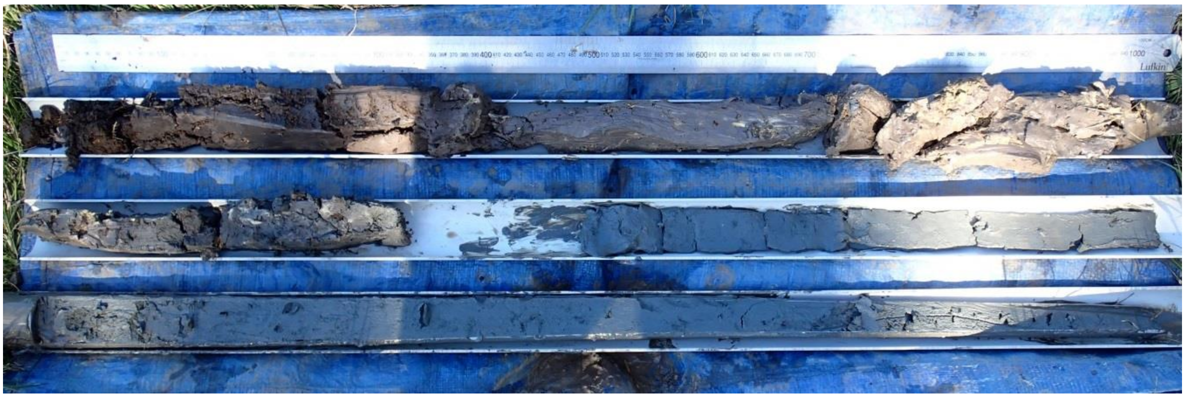
Location	P12
Date	27/11/2015
Easting (m)	461105.335
Northing (m)	6477668.653
Elevation (m AHD)	0.287



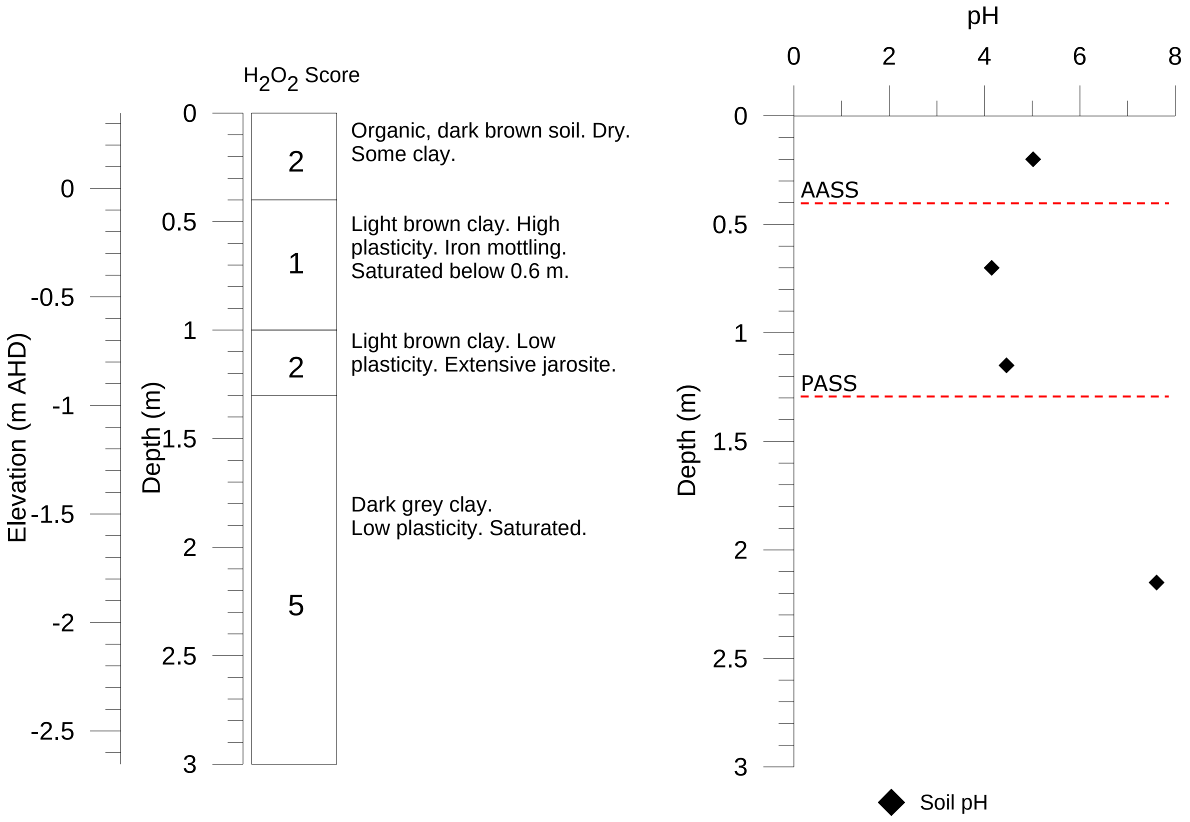


Location	P13
Date	25/11/2015
Easting (m)	462539.644
Northing (m)	6477352.801
Elevation (m AHD)	0.339

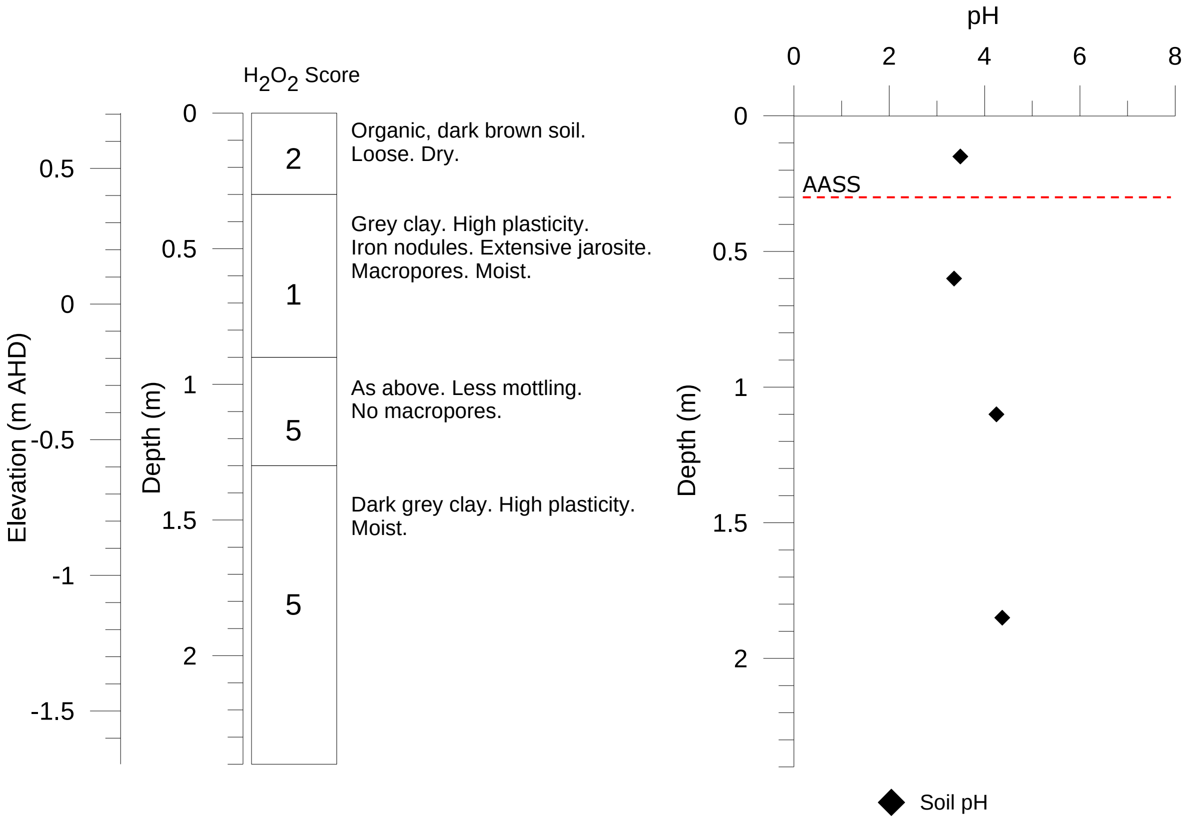




Location	P15
Date	25/11/2015
Easting (m)	462964.392
Northing (m)	6475684.073
Elevation (m AHD)	0.347

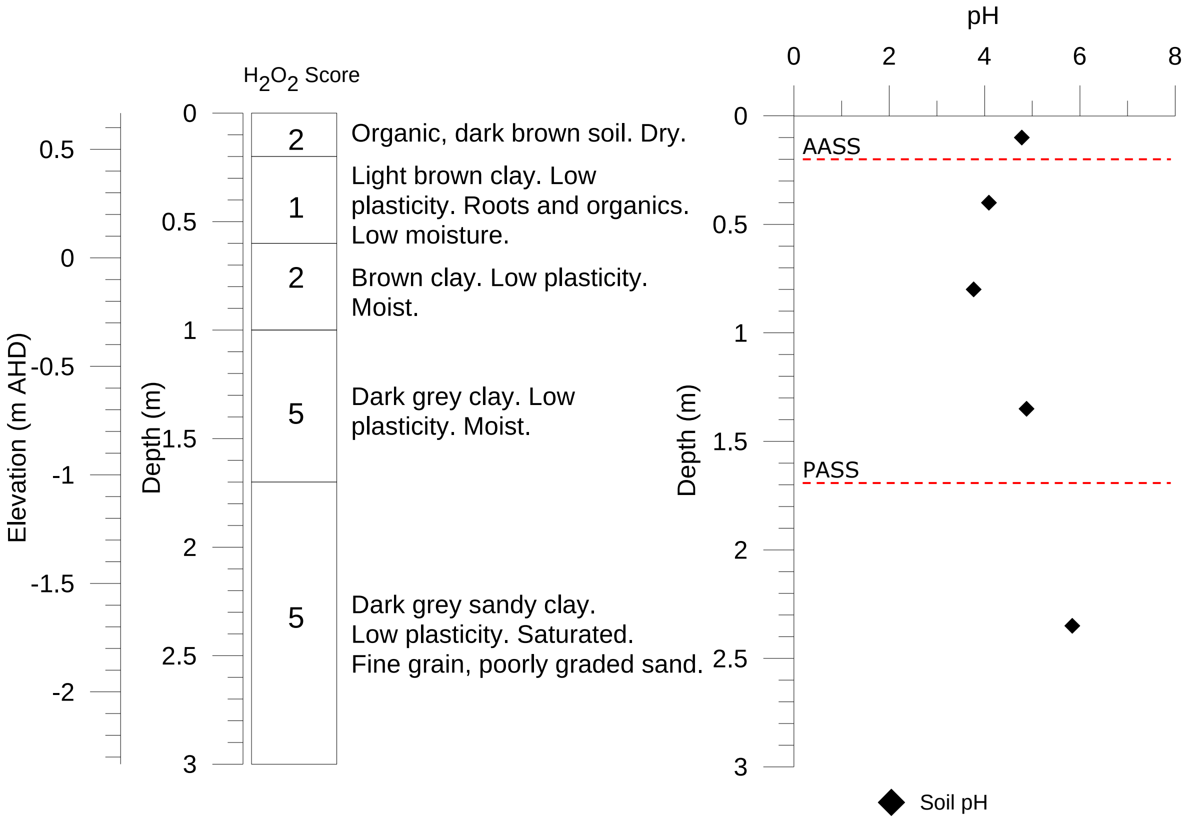


Location	P16
Date	24/11/2015
Easting (m)	456694.895
Northing (m)	6474575.794
Elevation (m AHD)	0.704

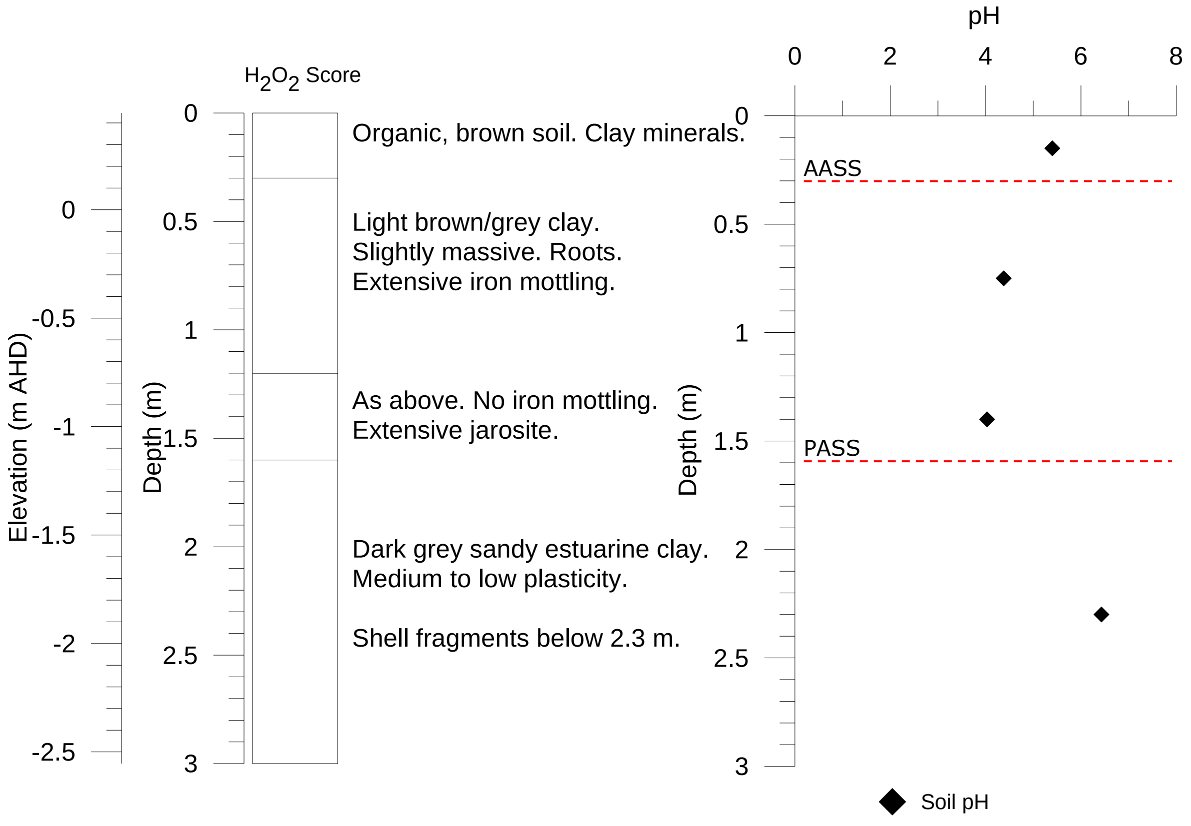


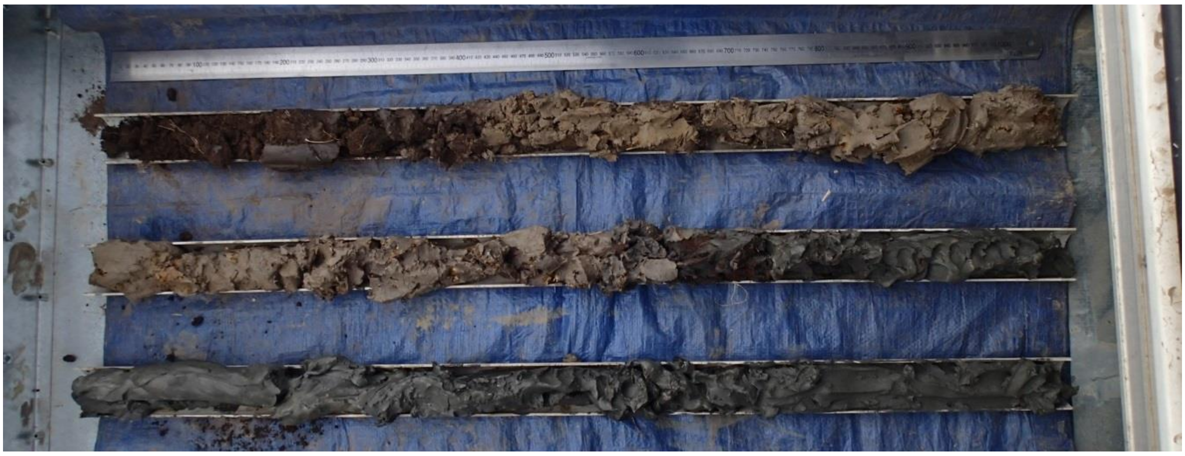
Water Research Laboratory

Location	P17
Date	24/11/2015
Easting (m)	456277.008
Northing (m)	6473639.496
Elevation (m AHD)	0.667

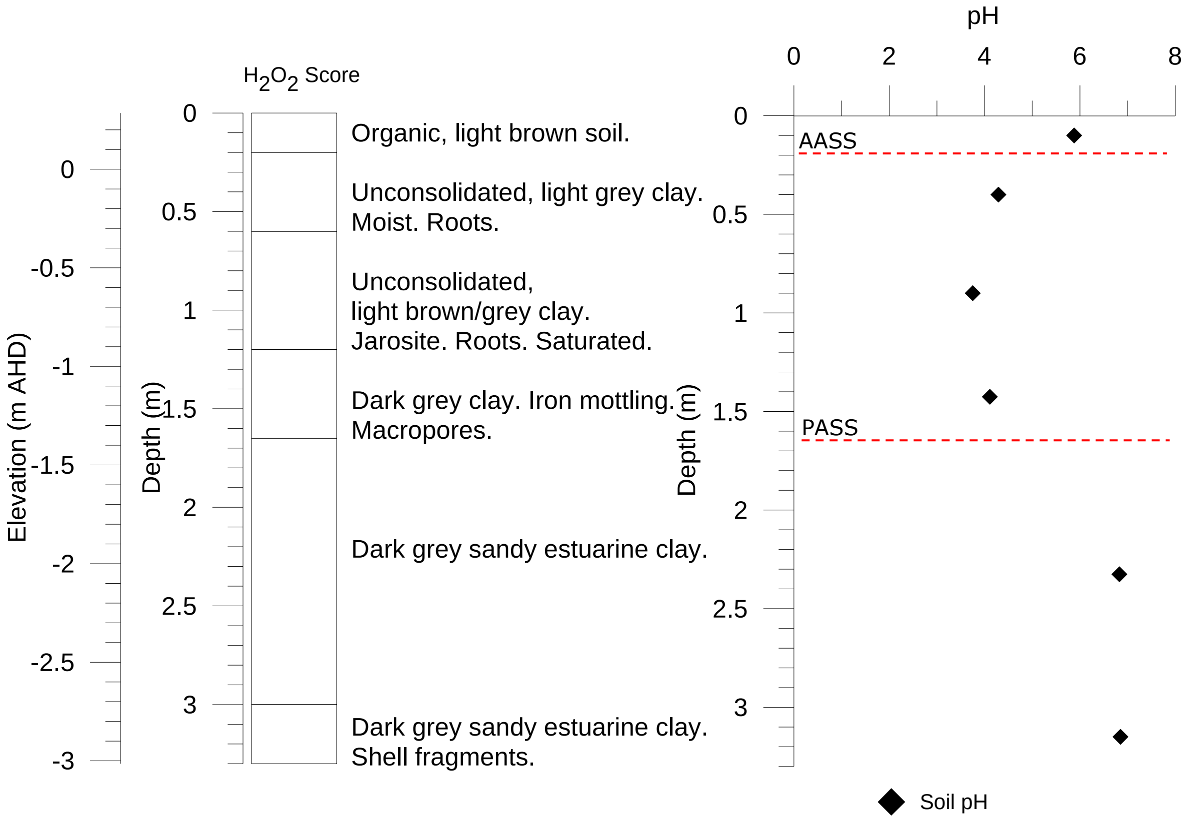


Location	P19
Date	8/10/2015
Easting (m)	459335.788
Northing (m)	6470738.757
Elevation (m AHD)	0.446

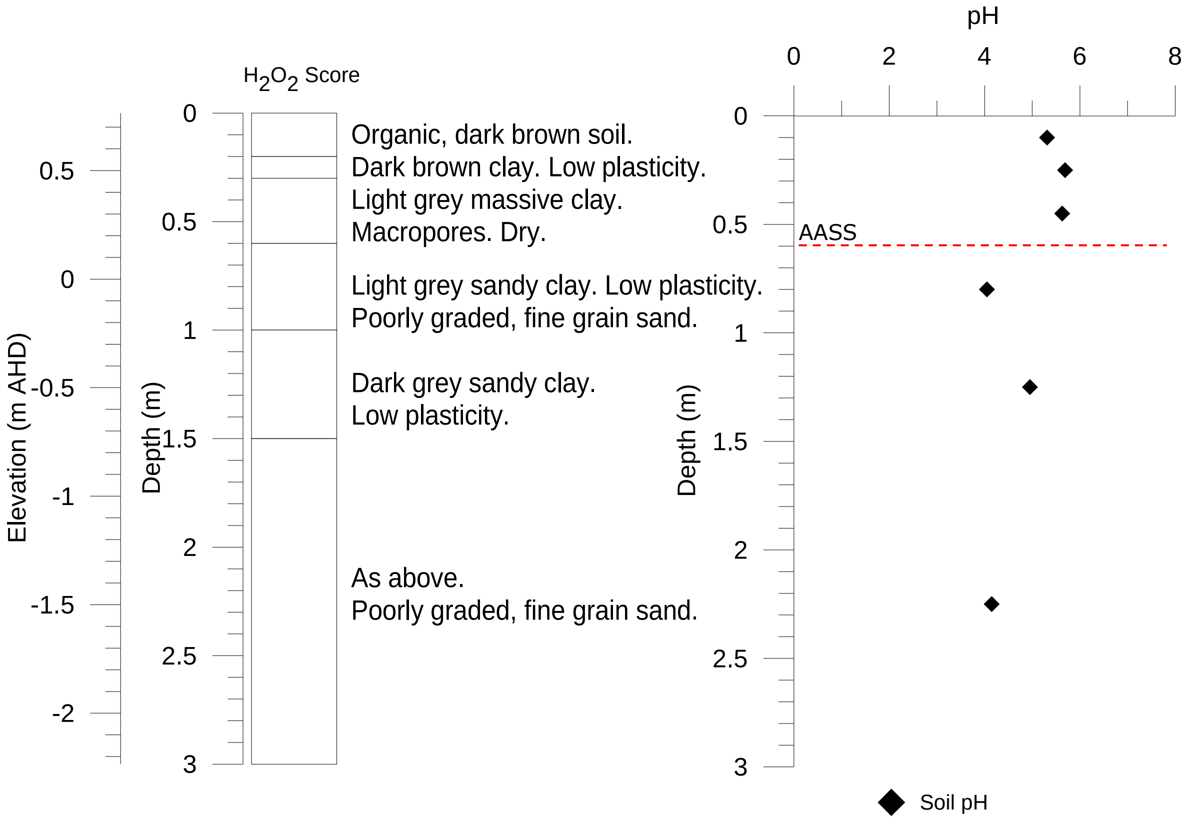




Location	P20
Date	8/10/2015
Easting (m)	459425.688
Northing (m)	6471356.431
Elevation (m AHD)	0.285



Location	P21
Date	26/10/2015
Easting (m)	461882.977
Northing (m)	6466644.467
Elevation (m AHD)	0.765

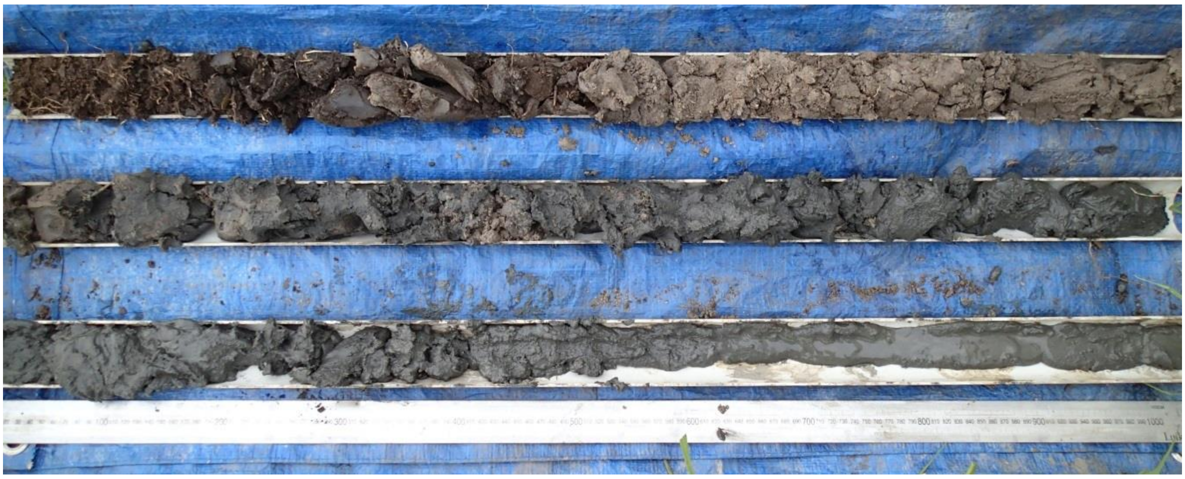


Organic, dark brown soil.
Dark brown clay. Low plasticity.
Light grey massive clay.
Macropores. Dry.

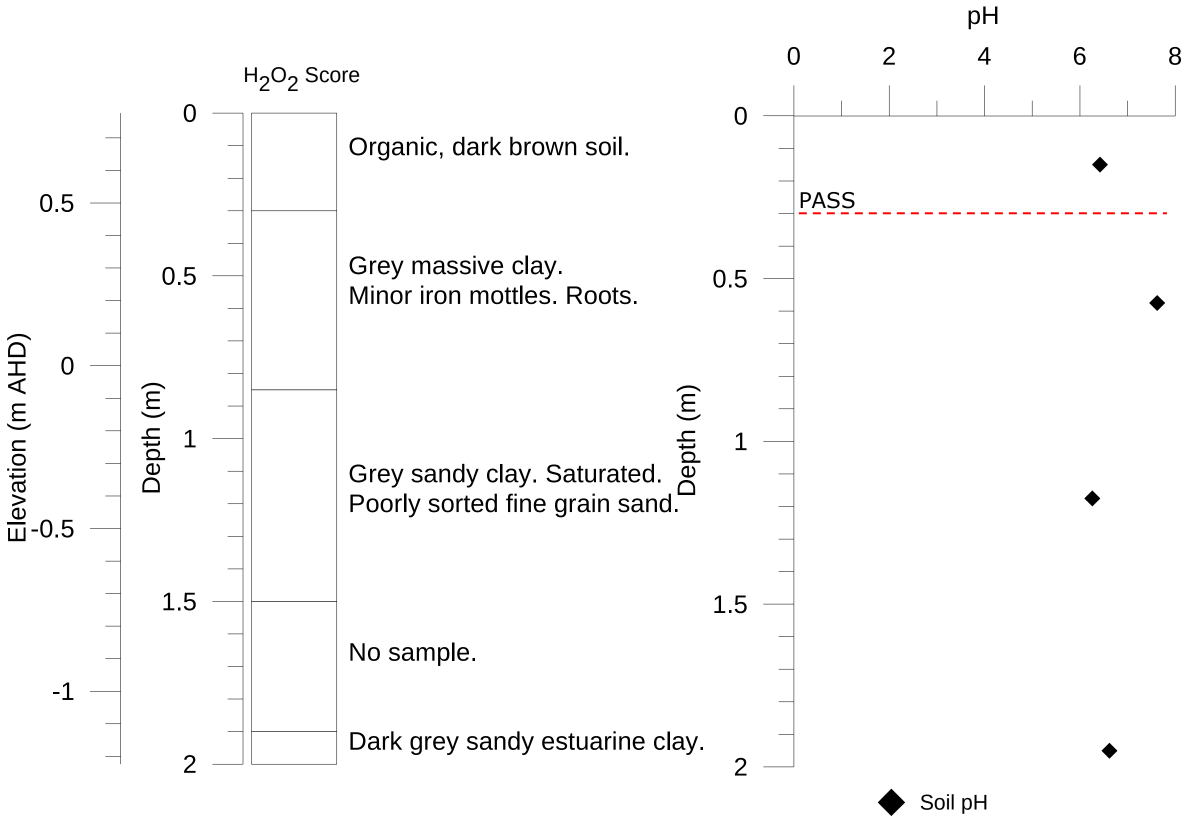
Light grey sandy clay. Low plasticity.
Poorly graded, fine grain sand.

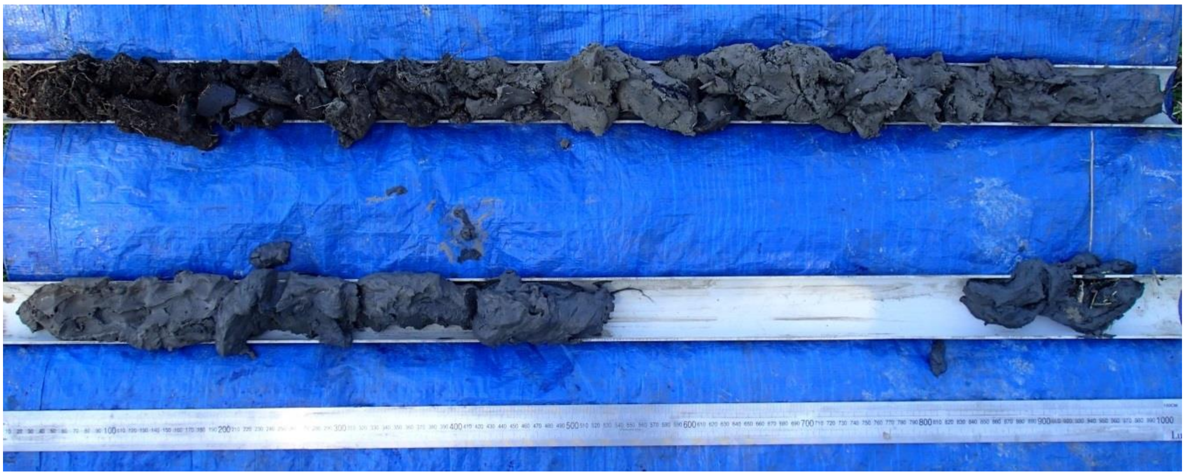
Dark grey sandy clay.
Low plasticity.

As above.
Poorly graded, fine grain sand.

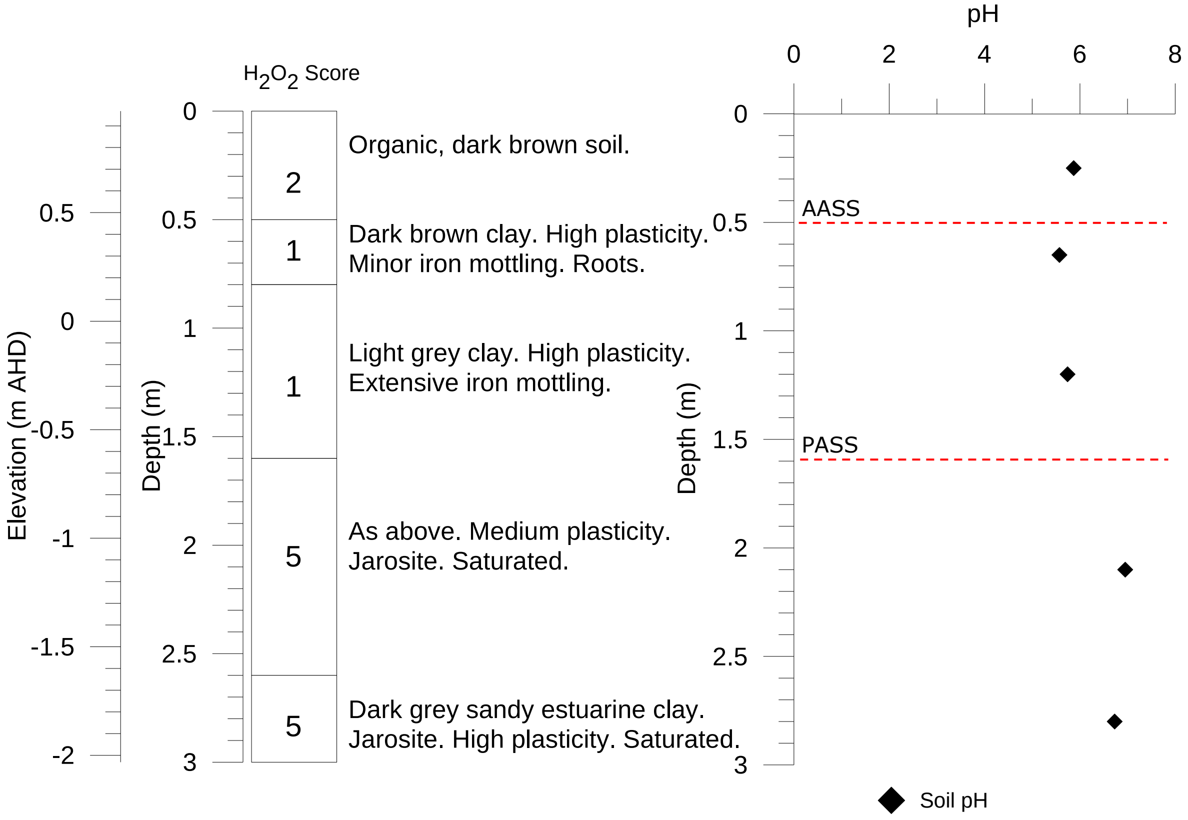


Location	P22
Date	26/10/2015
Easting (m)	461053.968
Northing (m)	6469225.942
Elevation (m AHD)	0.776





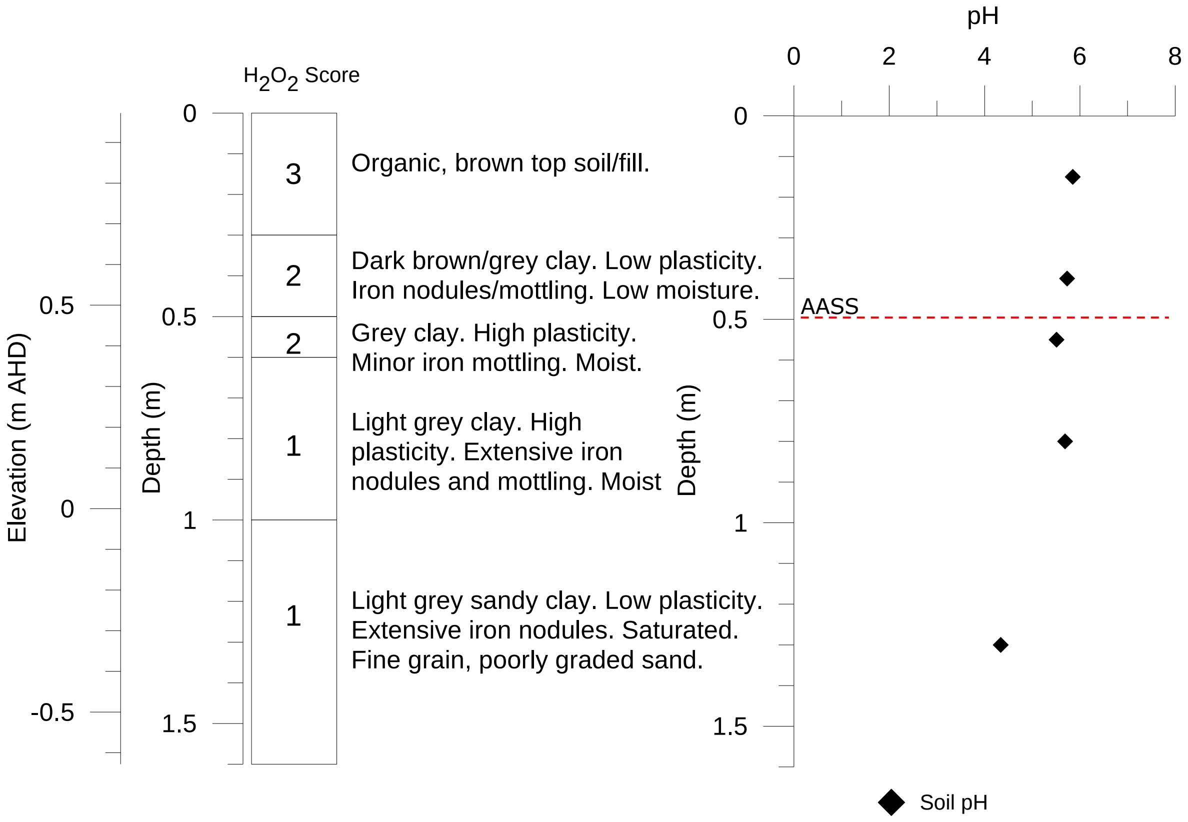
Location	P23
Date	26/10/2015
Easting (m)	456883.259
Northing (m)	6467774.408
Elevation (m AHD)	0.968



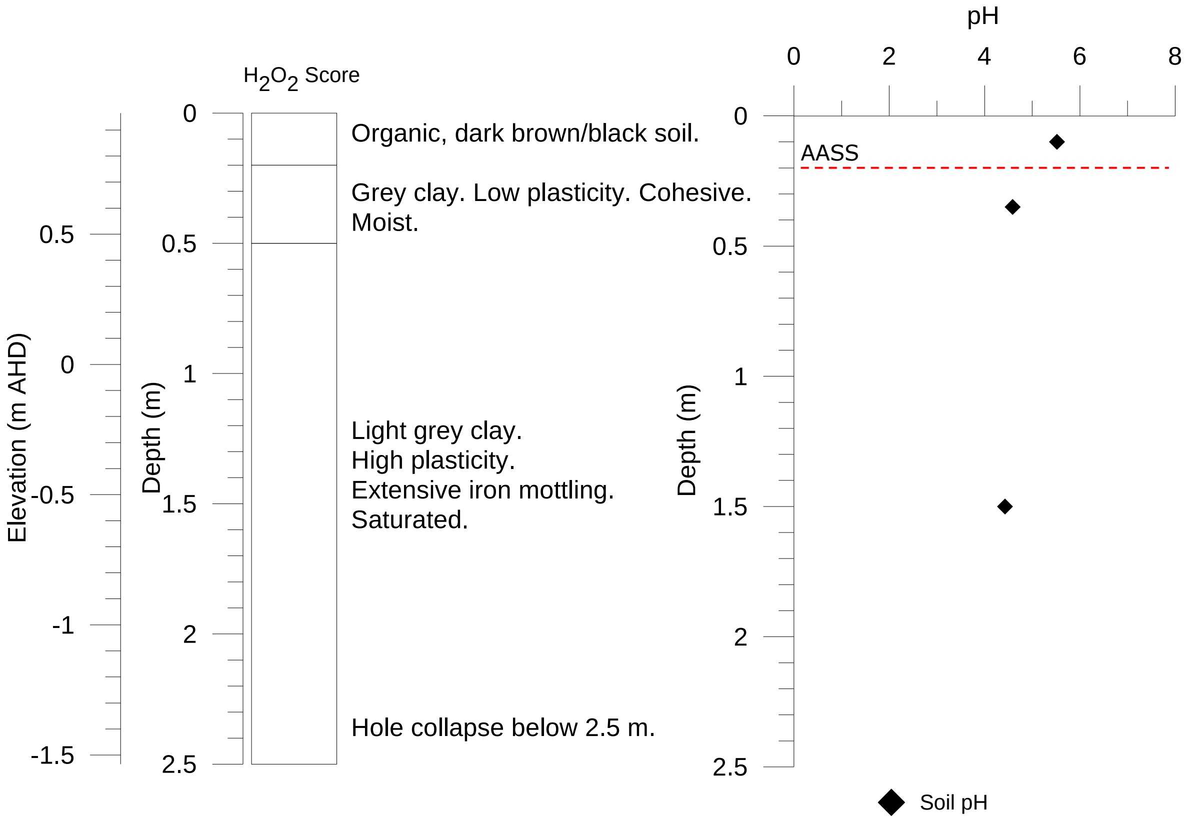
Location	P25
Date	7/10/2015
Easting (m)	463729.917
Northing (m)	6472776.868
Elevation (m AHD)	1.177

X
No Profile.

Location	P28
Date	23/11/2015
Easting (m)	454543.276
Northing (m)	6469780.956
Elevation (m AHD)	0.972



Location	P29
Date	27/10/2015
Easting (m)	456246.113
Northing (m)	6465071.795
Elevation (m AHD)	0.965



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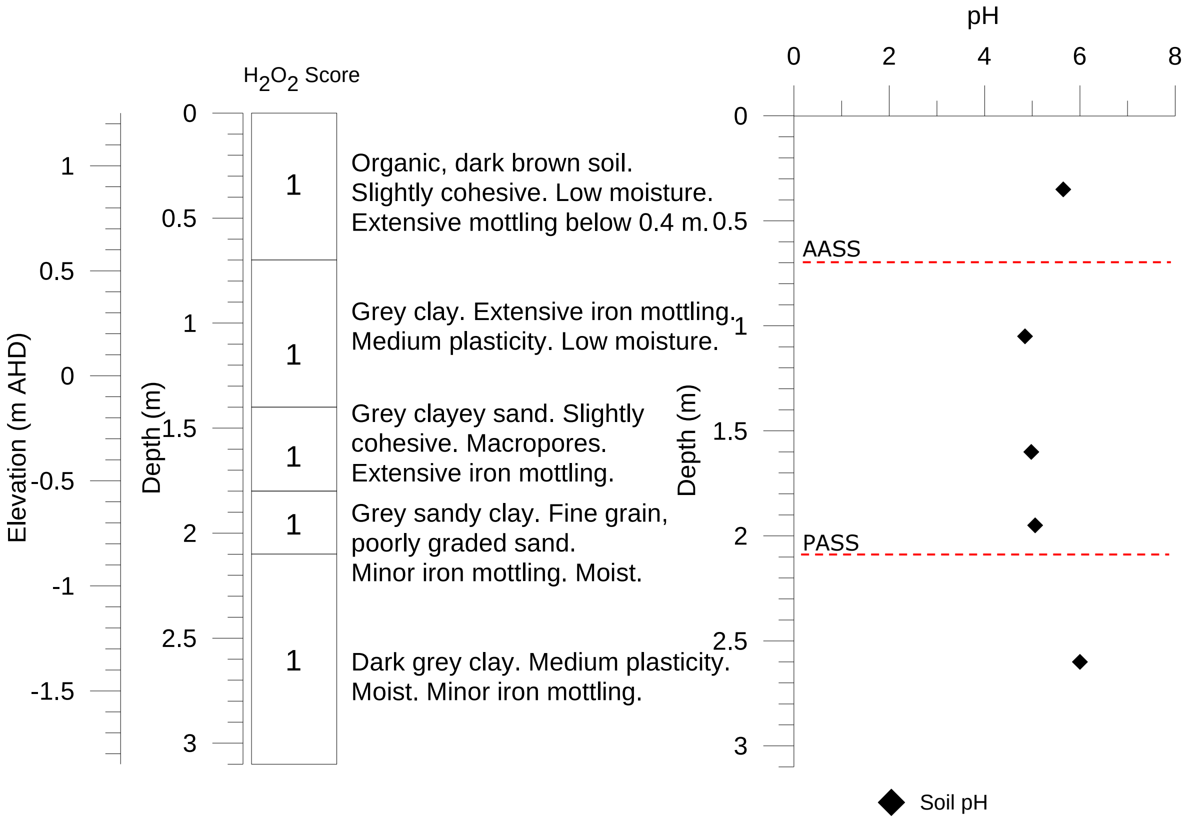
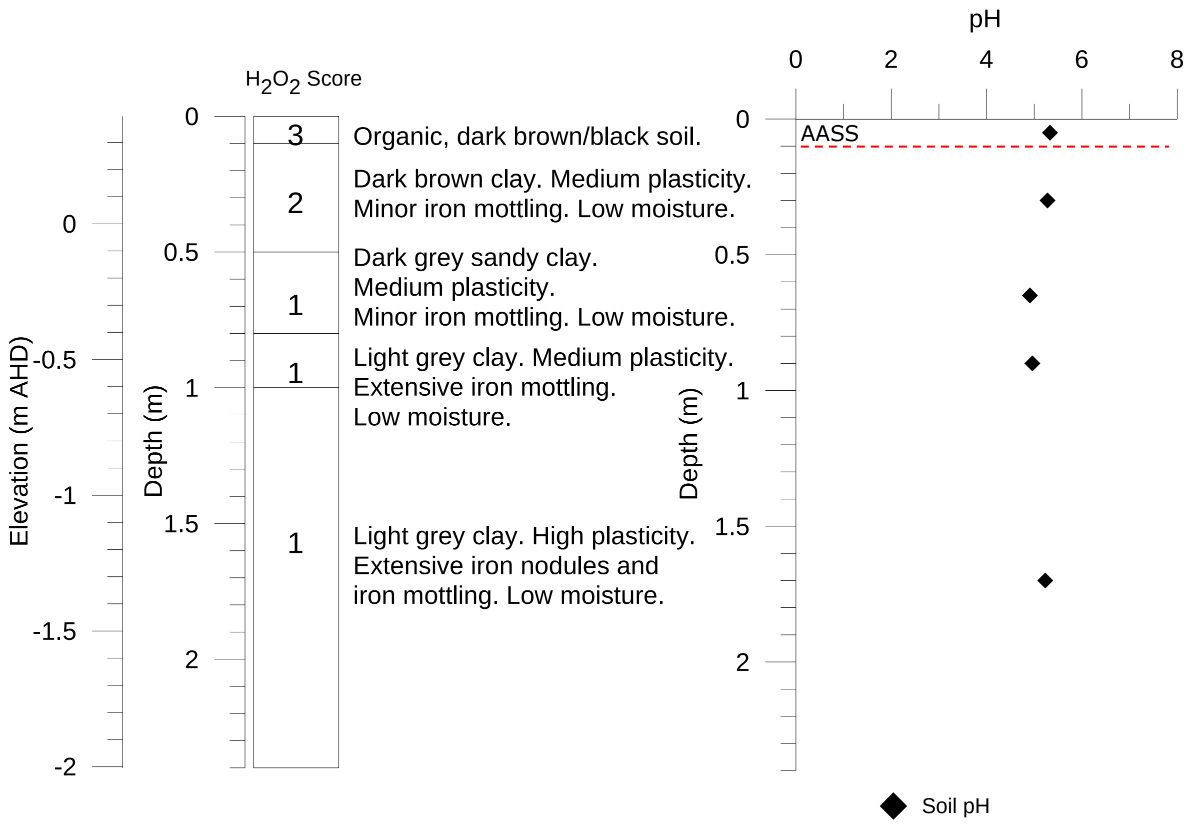
Date	28/10/2015
Easting (m)	455522.382
Northing (m)	6466707.131
Elevation (m AHD)	1.251



Location	P31
Date	23/11/2015
Easting (m)	451360.424
Northing (m)	6471680.667
Elevation (m AHD)	0.917



Organic, dark brown/black soil.

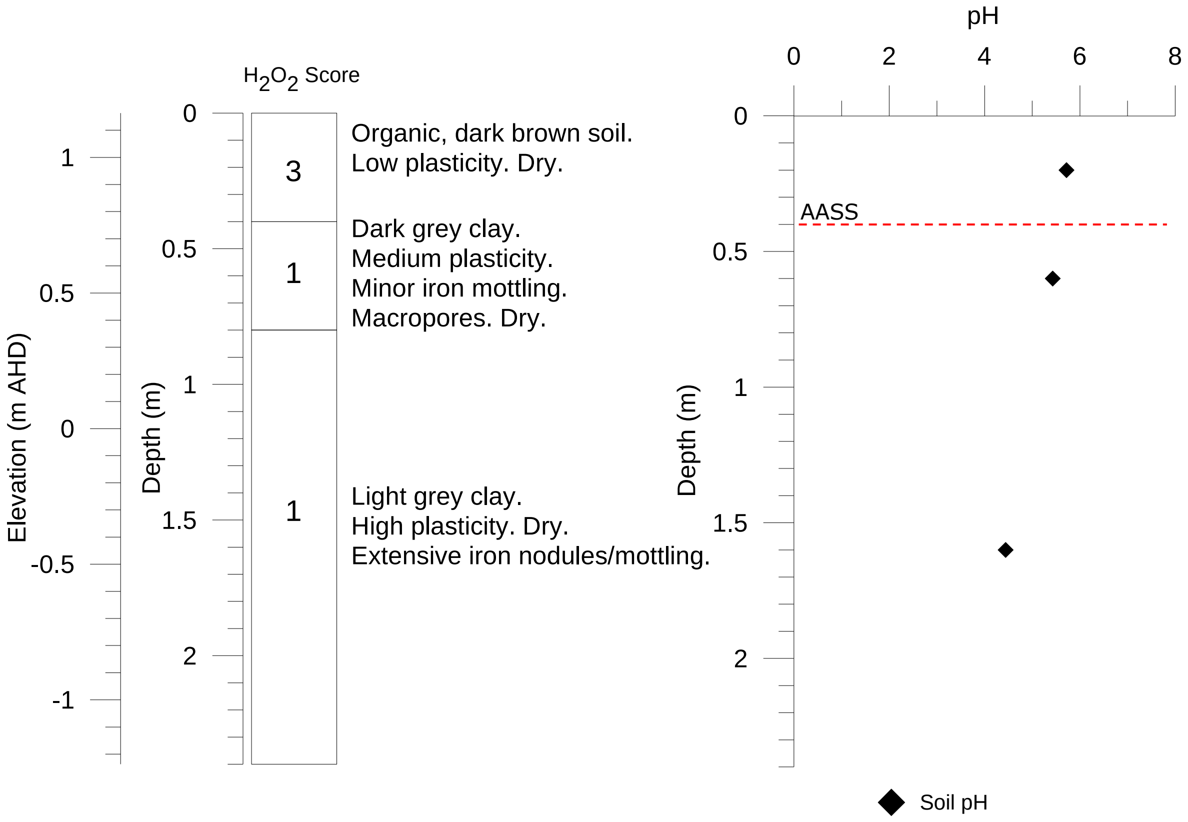
Dark brown clay. Medium plasticity. Minor iron mottling. Low moisture.

Dark grey sandy clay. Medium plasticity. Minor iron mottling. Low moisture.

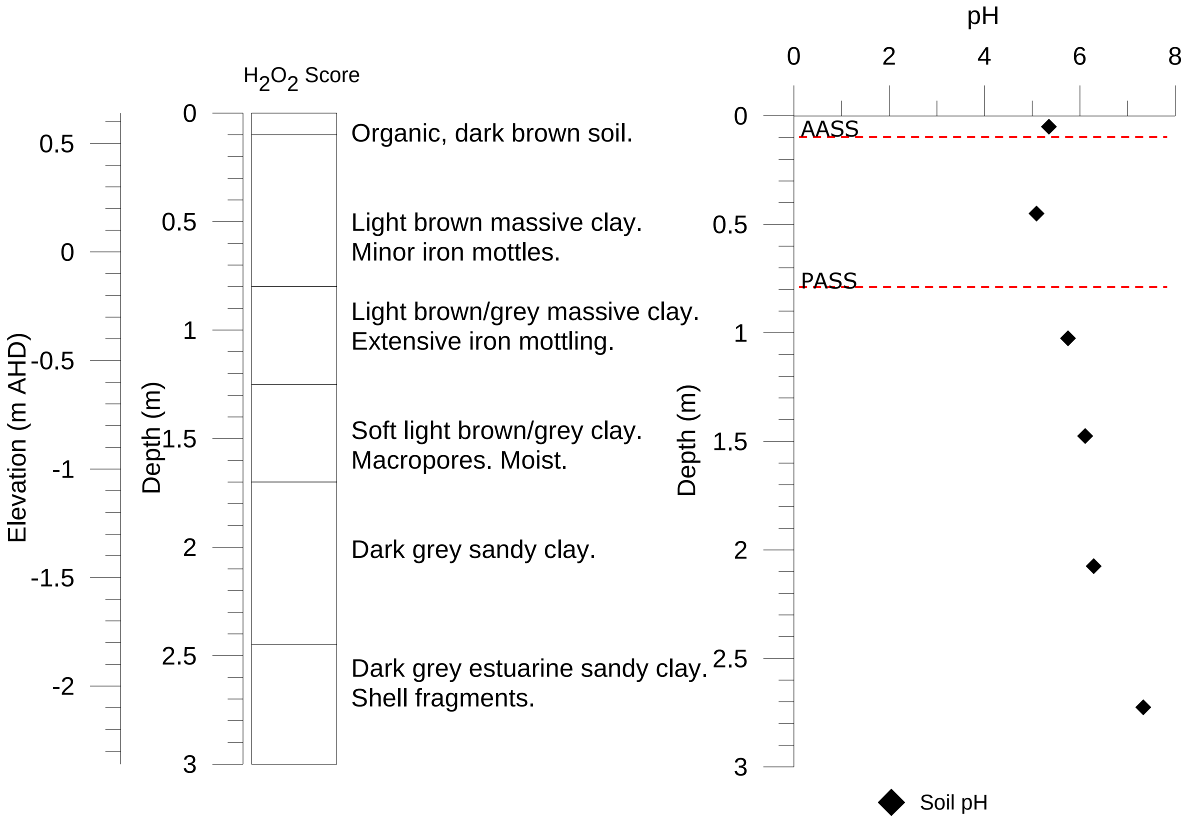
Light grey clay. Medium plasticity. Extensive iron mottling. Low moisture.

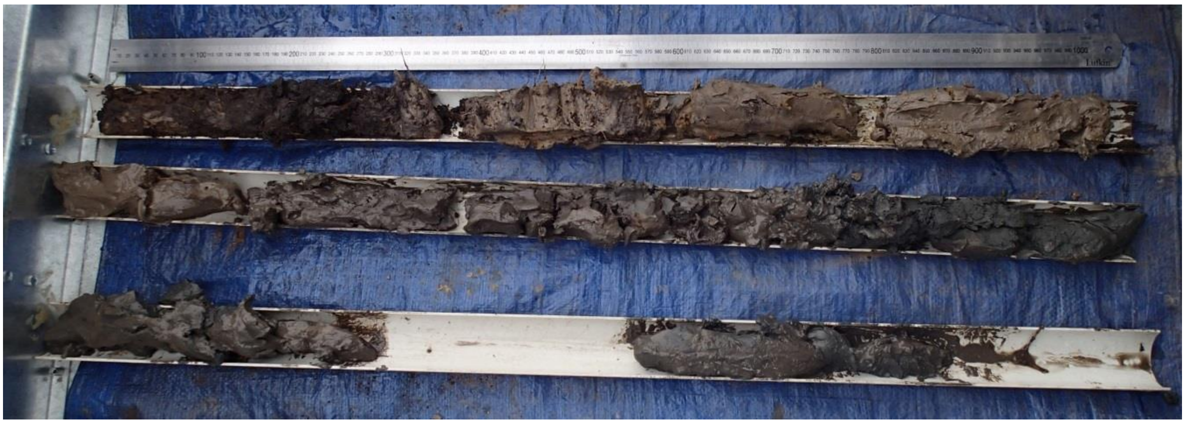
Light grey clay. High plasticity. Extensive iron nodules and iron mottling. Low moisture.

Location	P32
Date	23/11/2015
Easting (m)	452534.535
Northing (m)	6472161.680
Elevation (m AHD)	1.163

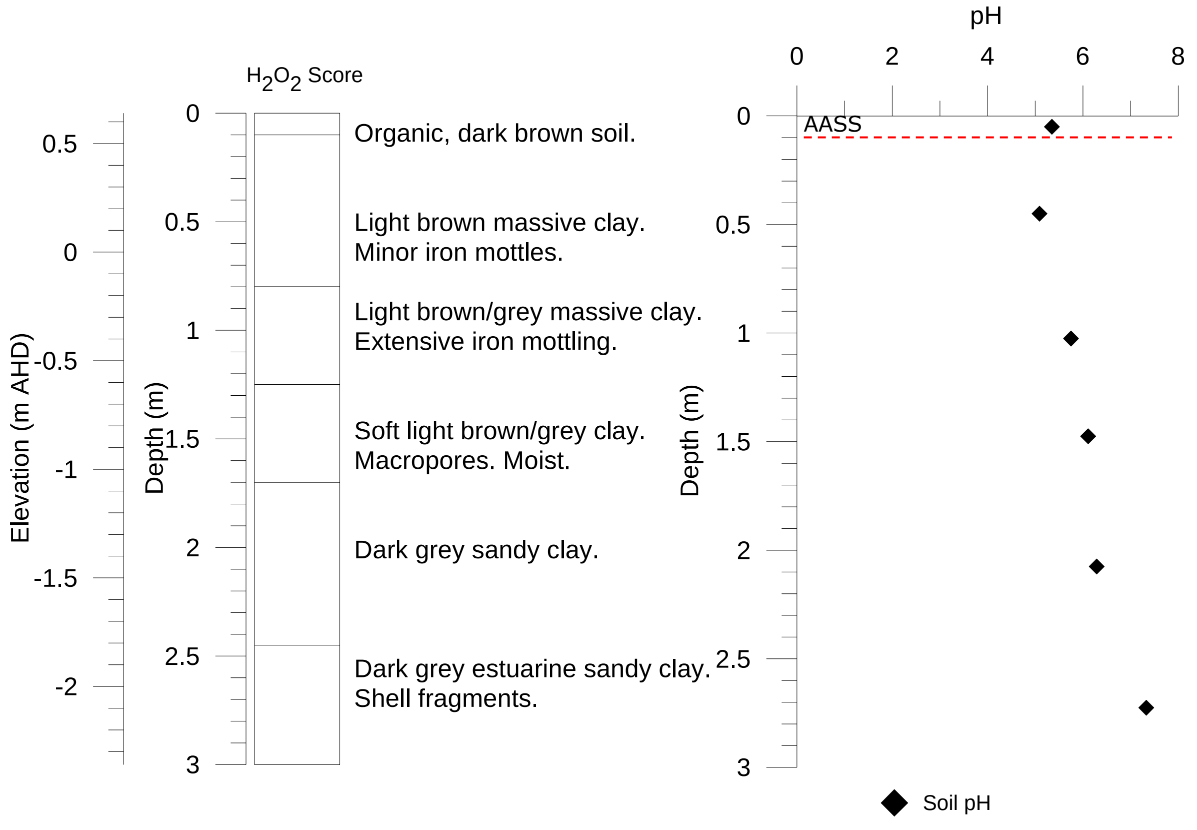


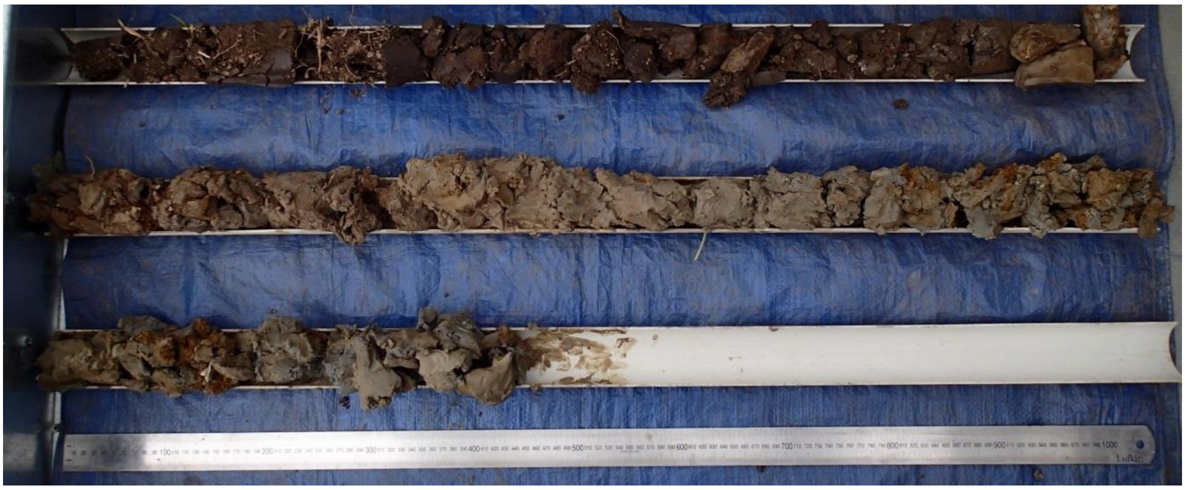
Location	P34
Date	8/10/2015
Easting (m)	461583.877
Northing (m)	6469935.147
Elevation (m AHD)	0.640



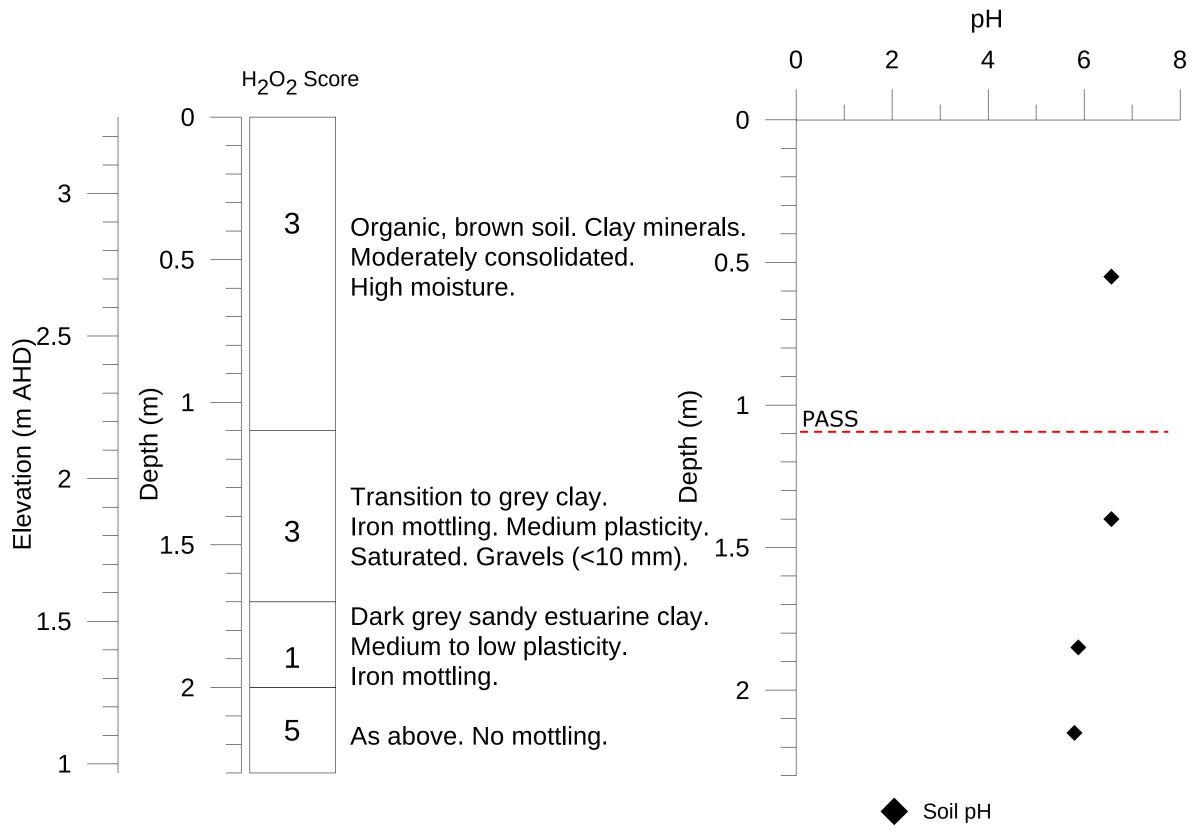


Location	P35
Date	7/10/2015
Easting (m)	462431.614
Northing (m)	6473144.516
Elevation (m AHD)	1.328

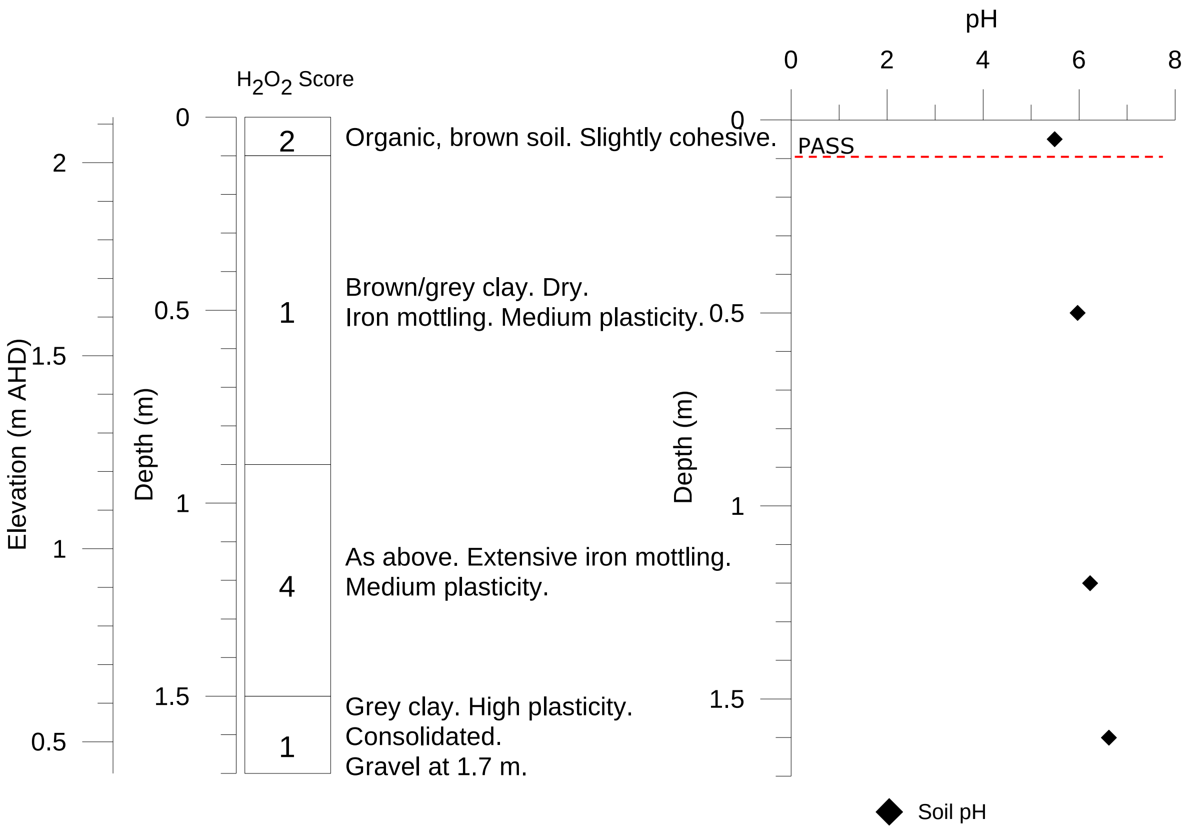


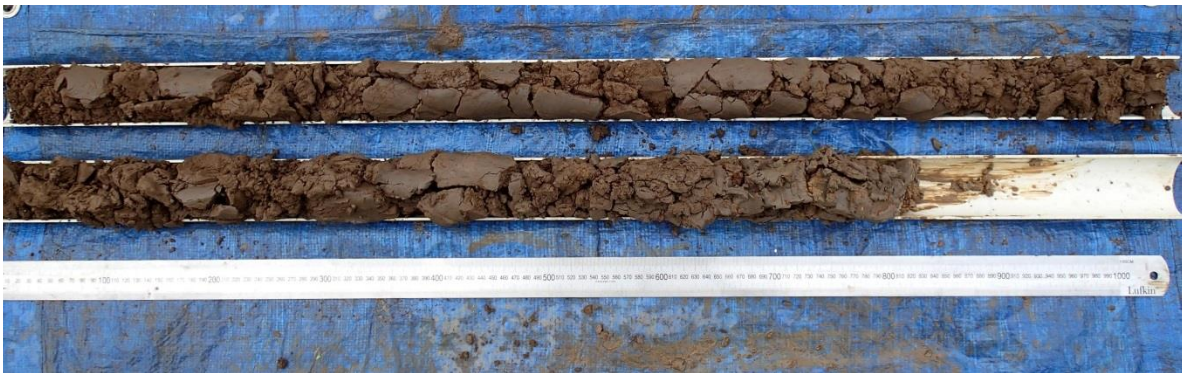


Location	P36
Date	27/10/2015
Easting (m)	446219.325
Northing (m)	6466901.117
Elevation (m AHD)	3.268

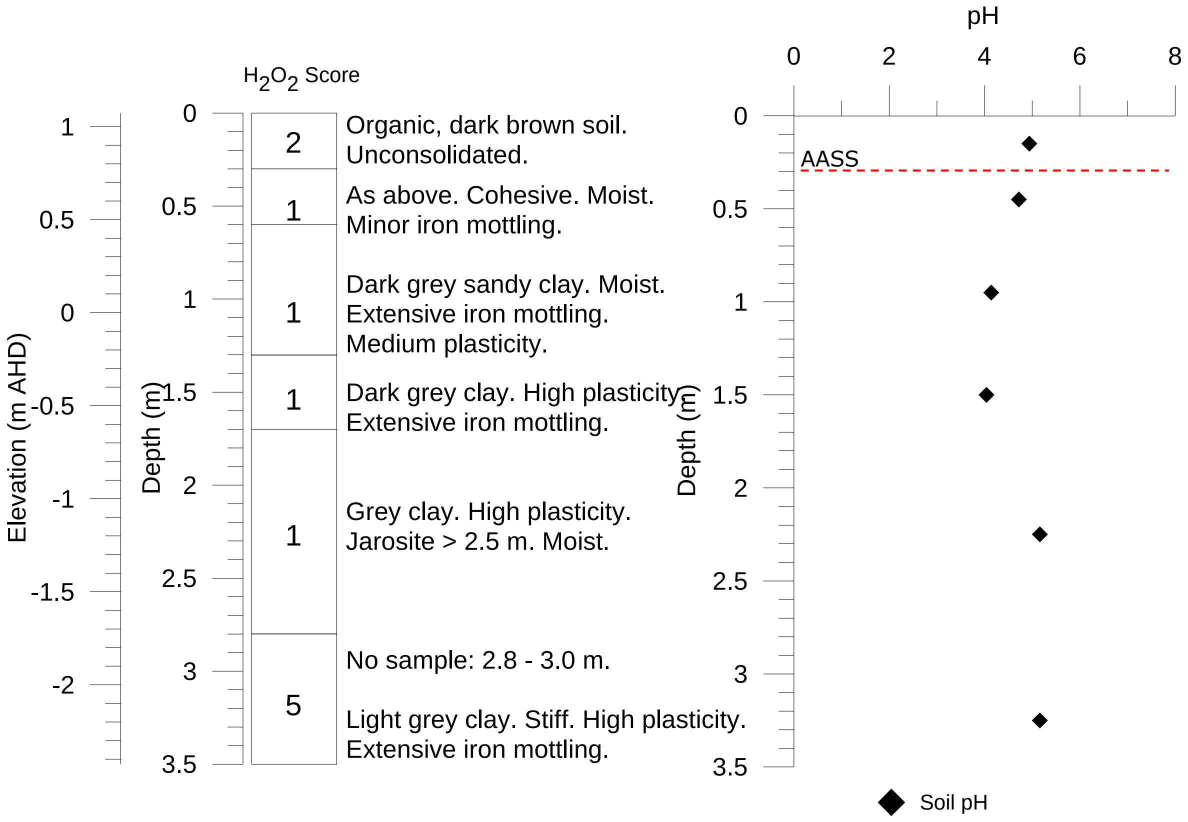


Location	P37
Date	27/10/2015
Easting (m)	445803.538
Northing (m)	6467170.610
Elevation (m AHD)	2.118





Location	P38
Date	28/10/2015
Easting (m)	449482.914
Northing (m)	6467452.841
Elevation (m AHD)	1.073



F.4 Summary of Soil Acidity

Two key elements used to determine the groundwater factor in the priority assessment are:

- Measured acidity (pH) of the soil expressed as hydrogen protons (H^+) in units of μmol/L; and
- Potential acid gradient, or thickness of the acid zone contributing to the potential risk of acid discharge.

These elements are determined using the following approach:

1. Collate and review all available soil profile data for each drainage sub-catchment;
2. Identify AASS layer based on soil acidity ($pH<5.5$) and characteristics (i.e. jarosite);
3. Identify lowest drainage elevation of drainage unit (i.e. floodgate/structure invert or MLW);
4. Determine median thickness of the ASS zone;
5. Determine the median acidity of the ASS zone based on available soil profile data; and
6. Convert the median acidity of each drainage unit to equivalent hydrogen protons (H^+).

Note that median values are used in the priority assessment since they are typically less affected by large deviations in the data and therefore, provide a more realistic representation of the data compared to average values. A summary of the data for the ASS zone contributing to the potential risk of acid discharge that was applied to each sub-catchment in the study area is provided in Table F.4. The distribution of acidity across the study area based on the median pH values of available soil profile data is provided in Figure F.31. Figure F.31 also provides the spatial coverage of acidity data within each sub-catchment of the study area. Figure F.32 provides the median acidity of each sub-catchment based on the median acidity values determined from the soil profile data. Figure F.33 provides the median thickness of the ASS zone for each sub-catchment.

Table F.4: Summary of Data for the ASS Zone Contributing to Potential Risk of Acid Discharge

Sub-Catchment	Median Thickness (m)	Median pH	[H+] μmol/L	Max pH	Min pH	Avg. pH
Moto	1.52	4.31	48.98	5.35	3.50	4.36
Ghinni Ghinni	0.58	3.97	108.39	4.50	3.36	3.95
Big Swamp	1.25	4.50	31.62	6.25	3.25	4.63
Glenthorne	0.65	4.20	63.83	4.25	4.14	4.20
Coopernook	0.87	3.87	134.90	4.30	3.50	3.85
Pampoolah	0.73	4.68	20.89	4.85	4.51	4.68
Bukkan Bukkan Creek	0.48	4.34	46.24	6.10	3.25	4.49
Dawson River	0.85	5.28	5.25	5.50	4.94	5.24
Cattai Creek	1.84	5.70	2.00	8.00	3.30	5.54
Mitchells Island	1.40	6.00	1.00	8.25	4.50	6.28
Croakers Creek	0.87	5.25	5.62	7.62	4.05	5.49
Taree Estate	2.73	5.86	1.37	6.23	5.50	5.86
Jones Island	1.21	5.53	2.99	7.00	3.40	5.29
Mambo Island	0.60	5.67	2.14	7.00	4.25	5.65
Dumaresq Island	1.90	6.25	0.56	6.50	5.00	6.02

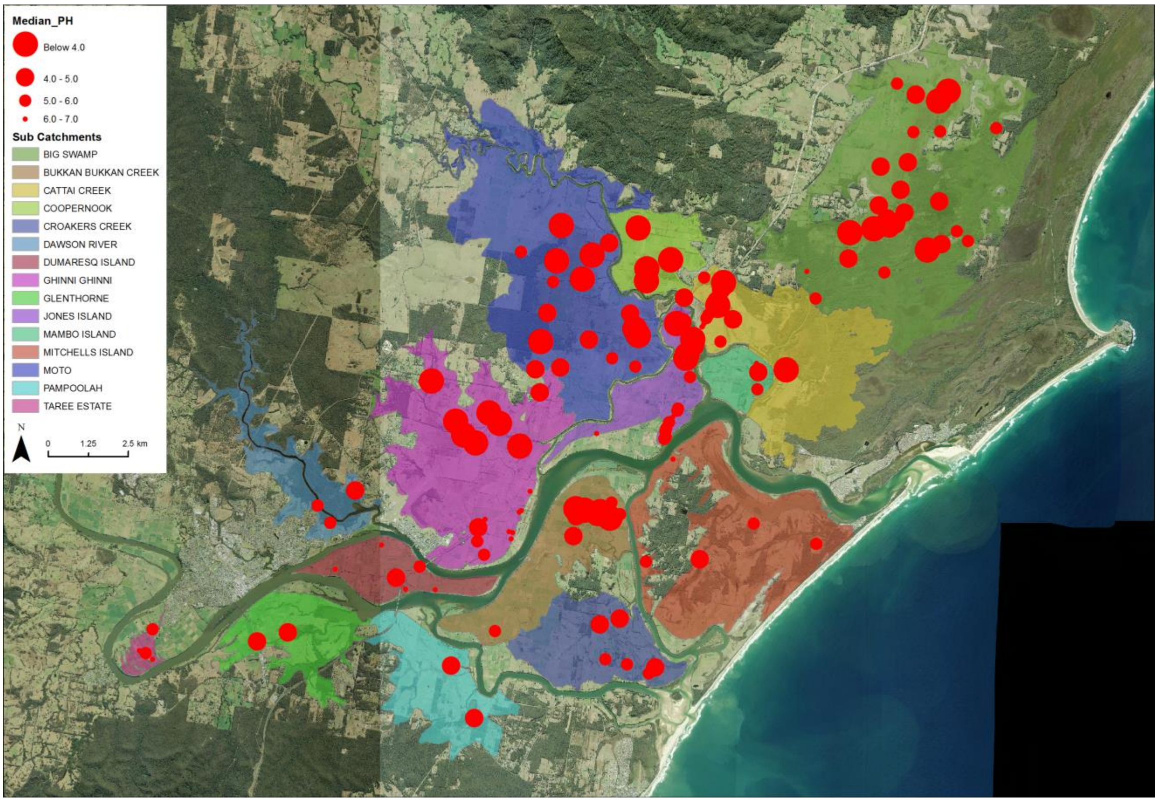


Figure F.31: Distribution of Acidity Across the Study Area Based on Median pH of ASS Zone

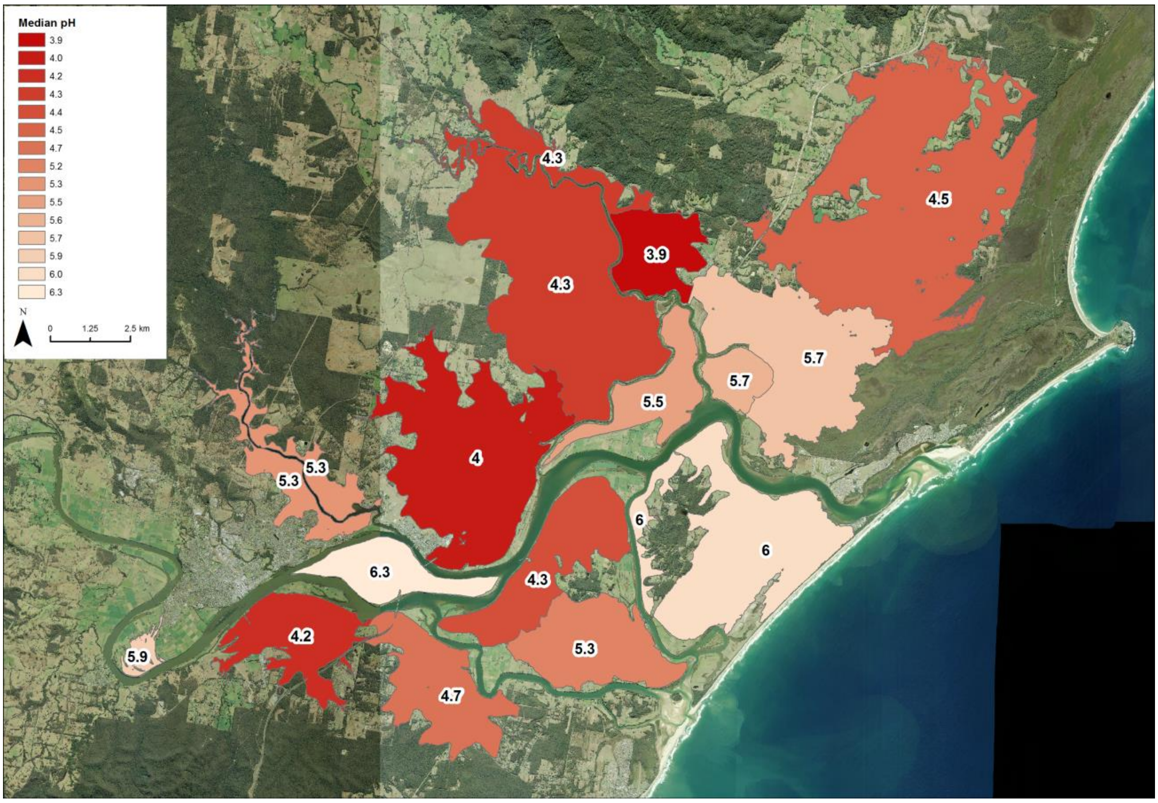


Figure F.32: Median pH of ASS Zone for Each Sub-Catchment

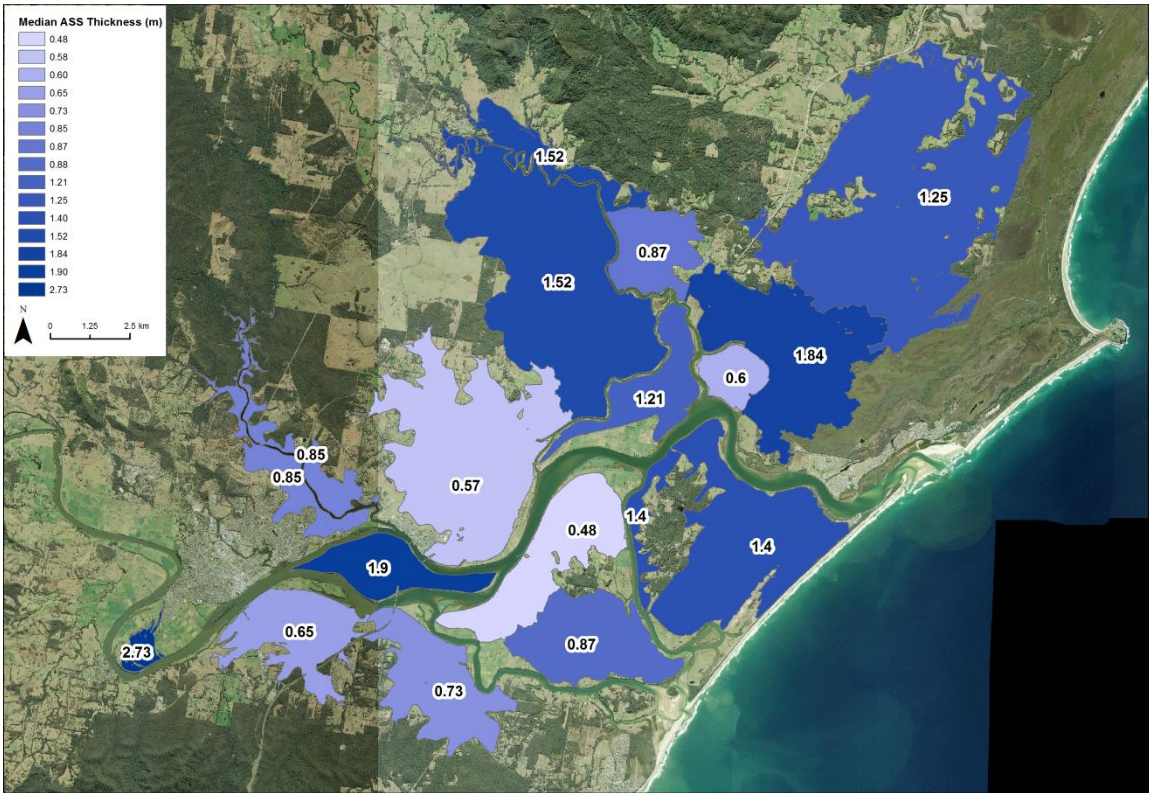


Figure F.33: Median Thickness of ASS Zone for Each Sub-Catchment

Appendix G – Water Quality

G.1 Preamble

Historically, the Manning River estuary and backswamp drainage areas have been extensively monitored. Water quality monitoring has typically focused on spot checks of dry weather pH and salinity, or a range of other water quality indicators as part of the NSW Food Authority Shellfish Quality Assurance Program following freshwater inflows from the catchment. More recently, extensive monitoring of the Cattai Creek-Pipeclay Canal area was undertaken as part of the Big Swamp Hydrologic Study (Glamore et al. 2014). This study included dry weather drain pH and wet weather sampling events of acid flux (concentration x discharge) from the Big Swamp floodplain. Overall, low pH water (pH < 4.0) was measured across the site in drains before the rain event and in Cattai Creek-Pipeclay Canal post-flood. Following Big Swamp Hydrologic Study and subsequent on-ground remediation works, MidCoast Council commissioned a 3-year continuous monitoring program of the Cattai Creek-Pipeclay Canal drainage area, the first of its kind in the Manning River estuary targeting acid drainage.

Other key water quality studies of the Manning River estuary, include:

- Sonter (1999);
- Smith et al. (1999);
- Dove (2003); and
- Johnston (2007).

However, the majority of water quality information measured during these investigations cannot be used to assign typical pH values to individual drains or drainage areas, and as such, the data from these studies has not been reproduced in this report. Nonetheless, the information provided in these studies is useful in understanding the extent of the ASS drainage issue across the Manning River estuary.

This section provides an overview of prominent water quality objectives for the Manning River estuary, as well as a summary of the water quality monitoring program at Big Swamp since its inception in early 2014. It also provides a summary of statistics on salinity in the lower estuary based on data provided by the NSW Food Authority.

G.2 Manning River Water Quality Objectives

Surface water quality objectives for the Manning River are based on recommendations from the ANZECC guidelines for marine and/or estuarine waters. Table G.1 outlines default trigger values for stressors applicable to south-east Australia for slightly disturbed ecosystems. Trigger values are used to assess the risk of adverse effects to sensitive receivers due to water quality parameters in various ecosystem types.

Table G.1 - ANZECC Guidelines for Estuaries and Wetlands in NSW (ANZECC 2004)

Ecosystem Type	DO (% saturation)		pH	
	Lower Limit	Upper Limit	Lower Limit	Upper Limit
Estuaries	80	110	7.0	8.5
Wetlands	No data	No data	No data	No data

G.3 Big Swamp Water Quality Monitoring Program

WRL commenced a monitoring program at Big Swamp in April 2014 following the recent Big Swamp hydrological study (Glamore et al. 2014) and subsequent on-ground remediation works to improve onsite ASS drainage issues. As part of the monitoring program, MidCoast Council initially purchased three (3) water quality monitoring units that measure pH, temperature, electrical conductivity (EC), dissolved oxygen (DO) and water levels. This equipment was installed in August 2014 and strategically placed in key areas of the remediation zones including the Eastern Swale Drain, Angelina Swamp and Angelina Mouth, as shown in Figure G.1. Additional water quality units were purchased in September 2014 and stationed at Cockatoo Island and Cattai Creek (Figure G.1) to improve and quantify understanding of the acid contribution from other areas of the site following the remediation works.

All monitoring stations record pH, electrical conductivity (EC), temperature, and pressure (i.e. water levels). Note that all water levels are reported relative to AHD. In addition, monitoring sites located at Angelina Mouth, Angelina Swamp, and the Eastern Swale Drain also record Dissolved Oxygen (DO), which is reported as a % saturation in the water column as per the ANZECC Guidelines (2004).

A summary of all records of water quality data at the monitoring locations, including the median, and 10th percentile and 90th percentile values, are provided in Table G.2. Note that by definition, a percentile indicates the value below which a given percentage of observations in a time series of observations fall. For example, the 10th percentile is the value below which 10 percent of the observations may be found.

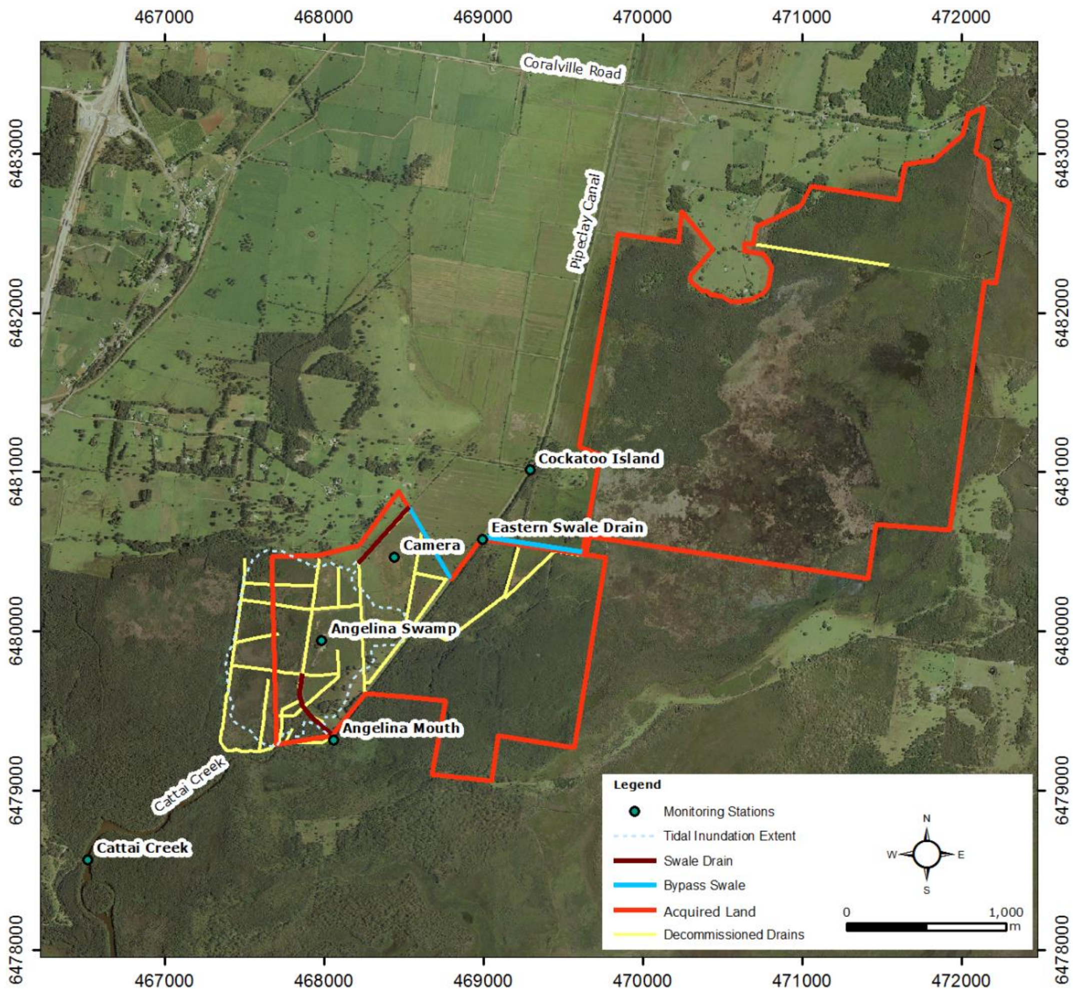


Figure G.1: Water Quality Monitoring Sites at Big Swamp

Table G.2 – Summary of Statistics for All Rounds of the Monitoring Program

Station	Statistic	Temperature	EC (µS/cm)	pH	DO (% Saturation)
Angelina Mouth	10th Percentile	14.70	1056	4.66	1.3
	Median	21.30	16355	6.34	52.4
	90th Percentile	26.85	42583	7.24	83.1
Angelina Swamp	10th Percentile	16.10	23866	4.03	0
	Median	20.92	32810	4.86	0.1
	90th Percentile	25.74	41924	6.00	0.6
Eastern Swale Drain	10th Percentile	13.77	458	3.55	1.1
	Median	20.63	1891	5.09	49.7
	90th Percentile	26.61	31534	6.69	78.8
Cattai Creek	10th Percentile	15.09	1829	5.82	No Data
	Median	23.72	30194	6.98	No Data
	90th Percentile	26.95	46078	8.20	No Data
Cockatoo Island	10th Percentile	13.26	266	4.59	No Data
	Median	20.65	1845	5.55	No Data
	90th Percentile	27.09	29555	7.07	No Data

G.4 Manning River Shellfish Quality Assurance Program

The Sydney rock oyster (Saccostrea glomerata) is produced in areas of the Manning River estuary that are at times impacted by acid discharges from ASS-affected floodplain drainage areas. Acidification of waterways severely degrades estuarine ecosystems – it can cause fish and oyster kills, fish disease, and impact oysters.

Oyster farmers on the Manning River hold a food safety licence which is regulated by the Food Standards Code in accordance with Australian Shellfish Quality Assurance Program (ASQAP). As part of ASQAP, the NSW Food Authority is responsible for implementing the Shellfish Quality Assurance Program on the Manning River. The program includes water quality sampling each year in search of poor water quality risks. A growing area can be closed for harvesting if there is any potential risk from known triggers such as high rainfall or algal blooms.

The water quality sampling sites on Manning River monitored by the NSW Food Authority are shown in Figure G.2. A summary of all records of water quality data at the monitoring locations, including the median, and 10th percentile and 90th percentile values, are provided in Table G.3. Note that the salinity of seawater is approximately 35.0 ppt (or 56,000 µS/cm). Also note that water pH is not regularly sampled at these locations by the NSW Food Authority.

Figure G.2: Manning River Shellfish Quality Assurance Program Sampling Sites (Source: NSW Food Authority 2016)

Table G.3 – Summary of Statistics from the Manning River Shellfish Quality Assurance Program Sampling Sites

Station	Period	Statistic	Salinity (ppt)
Pelican Point	2003 - Present	10th Percentile	18.58
		Median	23.50
		90th Percentile	30.04
Mangrove Island	2003 - Present	10th Percentile	13.90
		Median	21.00
		90th Percentile	27.90
Mitchells Island	2003 - Present	10th Percentile	15.26
		Median	20.05
		90th Percentile	27.20
Scotts Creek	2003 - Present	10th Percentile	14.36
		Median	20.80
		90th Percentile	27.24
South Channel	2005 - Present	10th Percentile	14.76
		Median	22.40
		90th Percentile	29.88

Appendix H – Sensitive Environmental Receivers

H.1 Preamble

Acid discharges from ASS-affected floodplains are well reported to cause stress to sensitive environmental receivers (Sammut et al. 1996; Glamore 2003; Rayner 2010; Winberg and Heath 2010). Furthermore, water control structures associated with ASS-affected drains, such as one-way floodgates, prohibit the passage of fisheries and limit the overall primary production of estuaries (Winberg and Heath 2010). Sensitive environmental receivers are widespread throughout the Manning River estuary. This section provides an overview of the proximity of sensitive environmental receivers to acidic drainage areas within the study area, and the information provided in this section was used to inform the prioritisation of each sub-catchment.

H.2 Sensitive Environmental Receivers of the Manning River Estuary

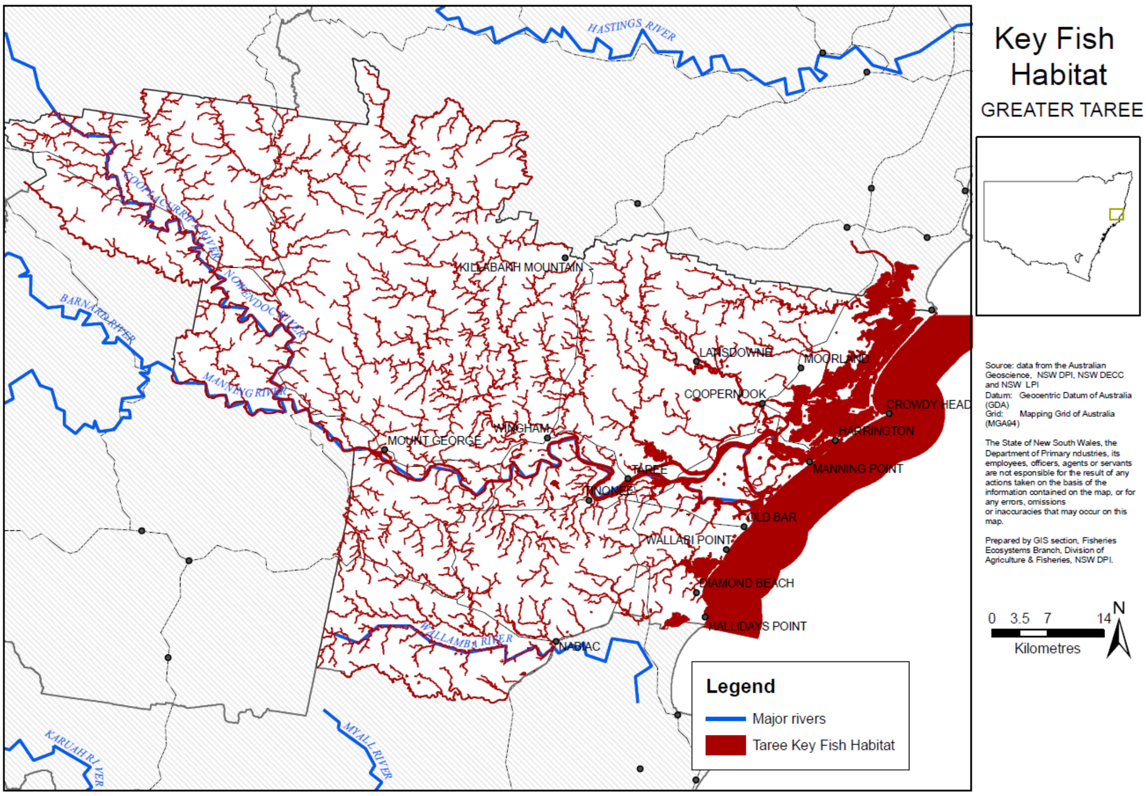
Several sensitive environmental receivers were identified during the course of this investigation. Both aquatic and terrestrial ecological communities and sensitive locations were identified and mapped as provided in Figures H.1 to H.4, including:

- Fisheries habitat;
- Oyster leases;
- Estuarine macrophytes; and
- SEPP14 wetlands.

The proximity of each sub-catchment in the study area to downstream stationary sensitive receivers was calculated as provided in Table H.1. Note that all waterways in the Greater Taree catchment are considered to be important for fisheries habitat.

Table H.1: Summary of Approximate Proximity (in Metres) of Sensitive Receivers to each Sub-Catchment within the Study Area

Sub-Catchment	Priority Oyster Leases	Seagrass	EEC Upstream of Structures
Moto	500	3,500	None
Ghinni Ghinni	5,000	2,500	None
Big Swamp	6,000	6,500	None
Glenthorne	7,500	1,000	None
Coopernook	2,500	5,500	None
Pampoolah	500	4,000	None
Bukkan Bukkan Creek	0	2,500	None
Dawson River	13,500	6,500	None
Cattai Creek	2,500	3,000	Saltmarsh
Mitchells Island	0	2,000	Saltmarsh
Croakers Creek	0	1,000	None
Taree Estate	13,000	2,000	None
Jones Island	0	500	Saltmarsh
Mambo Island	0	500	None
Dumaresq Island	8,000	2,500	None



Source: data from the Australian Geoscience, NSW DPI, NSW DECC and NSW LPI
Datum: Geocentric Datum of Australia (GDA)
Grid: Mapping Grid of Australia (MGA94)

The State of New South Wales, the Department of Primary ndustries, its employees, officers, agents or servants are not esponsible for the result of any actions taken on the basis of the information contained on the map, or for any errors, omissions or inaccuracies that may occur on this map.

Prepared by GIS section, Fisheries Ecosystems Branch, Division of Agriculture & Fisheries, NSW DPI.

Figure H.1: Key Fisheries Habitat (Source: NSW DPI Fisheries)

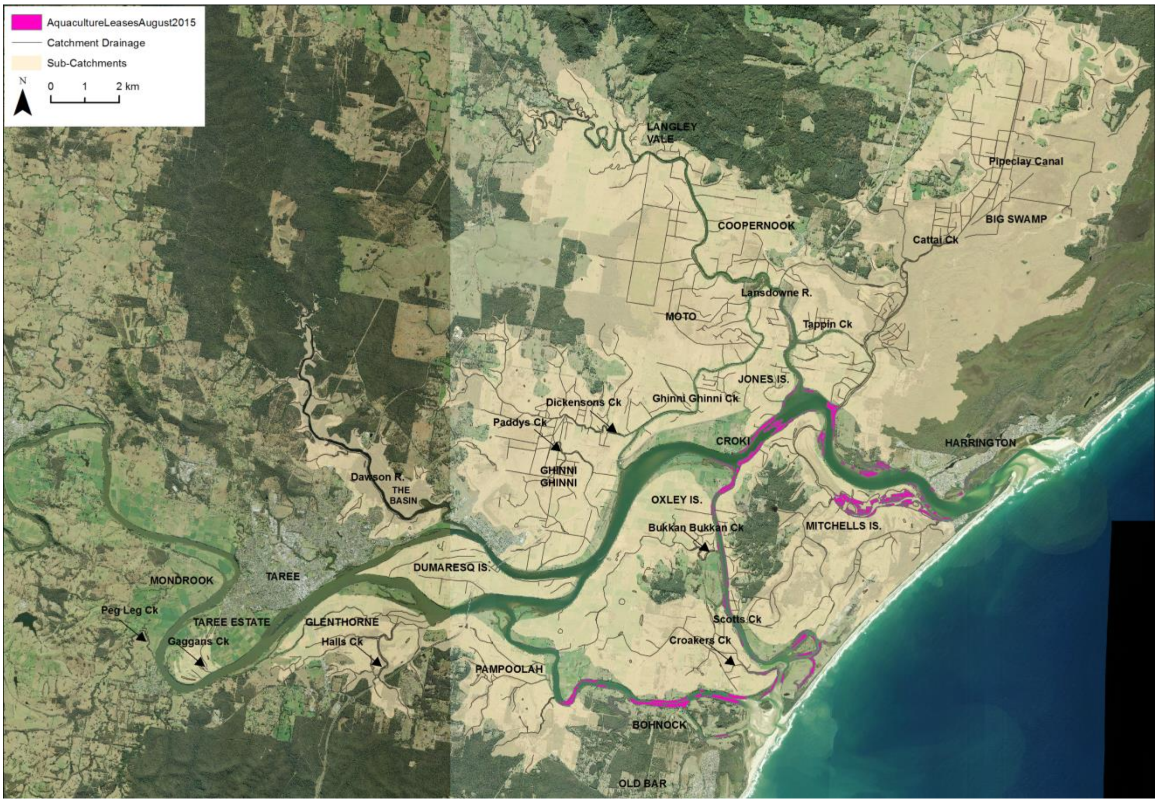


Figure H.2: Priority Oyster Leases (Source: NSW DPI Fisheries)

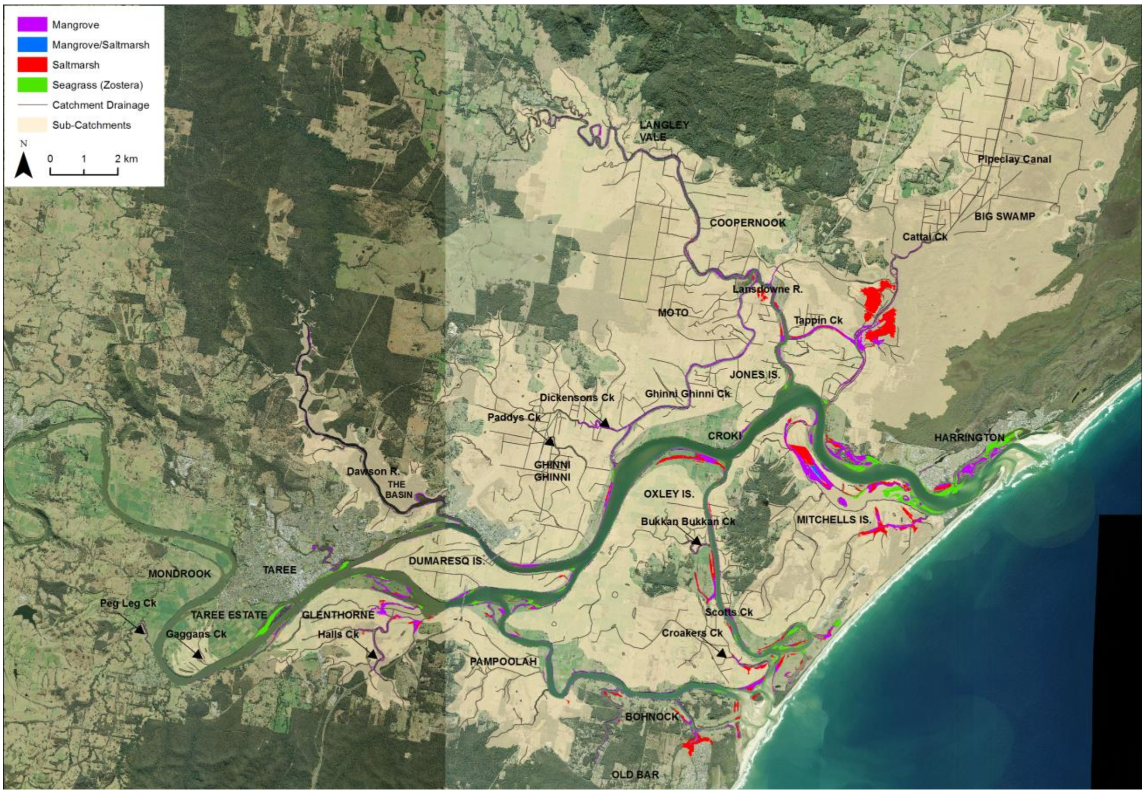


Figure H.3: Estuarine Macrophytes (Source: NSW DPI Fisheries)

Figure H.4: SEPP14 Wetlands (Source: MidCoast Council)[1]

[1] Note that the State Environmental Planning Policy No. 14 (SEPP14) for Coastal Wetlands was gazetted in 1985 to ensure that coastal wetlands are preserved and protected in the environmental and economic interests of the State.

Appendix I – Asset Condition

I.1 Preamble

A range of flood mitigation assets are distributed across the Manning River floodplain. The majority of the flood mitigation assets located within the study area are one-way floodgates that restrict tidal inundation of the floodplain. The network of floodgates and the associated drainage channel network across the Manning River floodplain was designed to prohibit saline intrusion during dry periods, and provide efficient drainage of floodwaters following wet periods. Maximising agricultural productivity of the floodplain and mitigating flood risk were the main goals of the flood mitigation works. This section provides a summary of the floodgates located within the study area.

I.2 Floodgate Data

A floodgate survey was last completed by the NSW Department of Primary Industries (Fisheries) in 2006 and revealed that there are approximately 140 floodgates located within the MidCoast Council LGA. The majority of the floodgates are located in Pipeclay Canal-Cattai Creek, Dickensons Creek, Ghinni Ghinni Creek, Scotts Creek, and the Lansdowne River. While some of the floodgates in the LGA are owned by MidCoast Council and the drainage unions of Moto and Oxley Island, the majority of the floodgates are owned by private land holders. The distribution of floodgates located within the study area is presented in Figure I.1 and a summary of the available floodgate data is provided in Table I.1.

Note that the survey completed by Fisheries in 2006 did include any invert levels of the drainage structures across the LGA. This information is critical to identifying and understanding the potential risk of acid discharge from the drainage area upstream of the floodgates. As such, WRL completed a field survey on 26 November 2015 of key floodgates in Scotts Creek, Cattai Creek, and the Lansdowne River. The field survey was undertaken to assess the floodgate condition and to obtain drain invert levels. Where possible, floodgate structures and culvert inverts were surveyed to AHD using Trimble RTK-GPS survey gear. A summary of the field survey completed by WRL is provided in Table I.2.

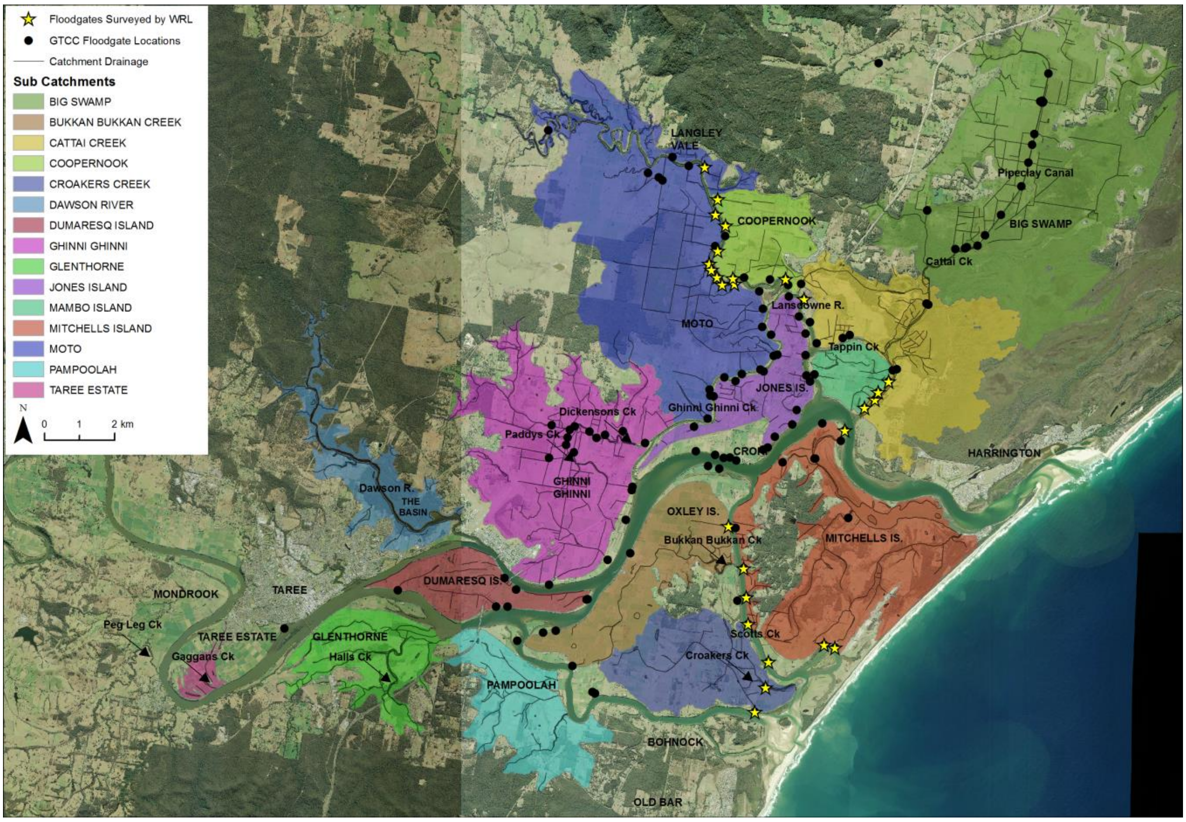


Figure I.1: Floodgates Located within the Study Area

Table I.1: Summary of Floodgate Data Provided by MidCoast Council

ID	Alias	Easting (m)	Northing (m)	Type	Remediation	Details	Condition
114	MANN140F	463006.0256	6478255.251	Floodgate	-	Steel concrete	
115	MANN141F	456522.4584	6473451.189	Floodgate	-	Concrete	
543	MANN120F	470073.1924	6484245.692	Floodgate	Floodgate management	Concrete and timber	Fair
544	MANN121F	469889.7636	6483474.929	Floodgate	Floodgate management	Concrete and timber	Fair
545	MANN122F	469836.3223	6483459.482	Floodgate	Floodgate management	Concrete and timber	Fair
546	MANN123F	469917.4036	6483444.535	Floodgate	Floodgate management	Concrete and timber	Fair
547	MANN124F	469886.6549	6483438.786	Floodgate	Floodgate management	Concrete and timber	Fair
548	MANN125F	469880.05	6483430.238	Floodgate	Floodgate management	Concrete and timber	Fair
549	MANN126F	469910.2627	6483426.218	Floodgate	Floodgate management	Concrete and timber	Poor
550	MANN127F	469669.8881	6482521.613	Floodgate	Floodgate management	Concrete and timber	Fair
551	MANN128F	469601.6868	6482214.825	Floodgate	Floodgate management	Concrete and timber	Poor
552	MANN059F	459342.3969	6481869.945	Floodgate	Remove	Concrete and fibro	Poor
553	MANN129F	469493.3611	6481715.277	Floodgate	Floodgate management	Concrete and timber	Poor
554	MANN058F	459799.5548	6481620.466	Floodgate	Remove	Timber and fibro	Poor
555	MANN057F	460262.6826	6481585.353	Floodgate	Maintenance	Concrete and fibro	Poor
556	MANN060F	458634.6314	6481411.239	Floodgate	Floodgate management	Concrete and fibro	Good
557	MANN096F	458942.7538	6481292.763	Floodgate	Floodgate management	Concrete and fibro	Fair

ID	Alias	Easting (m)	Northing (m)	Type	Remediation	Details	Condition
558	MANN095F	459053.4626	6481208.18	Floodgate	Floodgate management	Concrete and fibro	Fair
559	MANN130F	469293.0201	6481029.356	Floodgate	Floodgate management	Concrete and timber	Fair
560	MANN004F	460628.089	6480667.77	Floodgate	Floodgate management	Concrete and timber	Poor
561	MANN003F	460632.5582	6480661.461	Floodgate	Floodgate management	Timber	Poor
562	MANN119F	466605.1304	6480345.955	Floodgate	Floodgate management	Concrete and steel	Fair
563	MANN056F	460570.3103	6480234.268	Floodgate	Floodgate management	Concrete and fibro	Fair
564	MANN131F	468709.3875	6480215.692	Floodgate	Decommissioned	-	-
565	MANN001F	460848.6736	6479910.564	Floodgate	Floodgate management	Concrete and timber	Poor
566	MANN002F	460845.4494	6479612.935	Floodgate	Floodgate management	Concrete and fibro	Poor
567	MANN132F	468254.0354	6479634.37	Floodgate	Decommissioned	-	-
568	MANN033F	460551.3449	6479330.712	Floodgate	Floodgate management	Steel and fibro	Fair
569	MANN133F	468046.9081	6479344.319	Floodgate	Decommissioned	-	-
570	MANN134F	467742.8673	6479301.918	Floodgate	Floodgate management	Concrete and timber	Poor
571	MANN135F	467692.3368	6479270.394	Floodgate	Floodgate management	Concrete and timber	Poor
572	MANN136F	467417.4038	6479240.93	Floodgate	Floodgate management	Concrete and timber	Fair
573	MANN009F	460631.0657	6479196.679	Floodgate	Floodgate management	Concrete and timber	Poor
574	MANN032F	460382.1897	6478822.186	Floodgate	Floodgate management	Concrete and steel	Fair
575	MANN031F	460447.8596	6478652.85	Floodgate	Floodgate management	Concrete and timber	Poor
576	MANN030F	460609.8244	6478442.543	Floodgate	Floodgate management	Concrete and steel	Fair
577	MANN007F	461378.568	6478431.045	Floodgate	Floodgate management	Concrete and timber	Poor
578	MANN008F	461074.1479	6478403.291	Floodgate	Floodgate management	Concrete and timber	Poor
579	MANN005F	462568.9051	6478392.003	Floodgate	Floodgate management	Concrete and fibro	Poor
580	MANN006F	462119.4571	6478376.716	Floodgate	Floodgate management	Concrete and timber	Poor
581	MANN028F	461109.4566	6478250.582	Floodgate	Floodgate management	Concrete and steel	Fair
582	MANN029F	460760.4348	6478230.966	Floodgate	Floodgate management	Concrete and steel	Fair
583	MANN010F	462638.4341	6478216.789	Floodgate	Floodgate management	Concrete and fibro	Poor
584	MANN027F	461817.1232	6478040.635	Floodgate	Floodgate management	Concrete and steel	Poor
585	MANN098F	462660.1536	6477890.325	Floodgate	Floodgate management	Concrete and steel	Fair
586	MANN025F	463091.906	6477819.95	Floodgate	Floodgate management	Steel	Good
587	MANN051F	466589.6118	6477693.135	Floodgate	Floodgate management	Timber	Fair
588	MANN050F	466637.1491	6477653.174	Floodgate	Floodgate management	Steel	Fair
589	MANN026F	461921.1611	6477545.335	Floodgate	Floodgate management	Concrete and steel	Good
590	MANN055F	462951.9493	6477322.211	Floodgate	Floodgate management	Concrete and steel	Fair
591	MANN054F	463260.2532	6477155.385	Floodgate	Floodgate management	Concrete and steel	Fair
592	MANN024F	461897.8171	6477028.061	Floodgate	Floodgate management	Concrete and timber	Poor
593	MANN037F	463133.7702	6476832.491	Floodgate	Floodgate management	Concrete and steel	Fair
594	MANN097F	462151.2861	6476799.887	Floodgate	Floodgate management	Concrete and fibro	Fair
595	MANN100F	464398.9548	6476788.849	Floodgate	Floodgate management	Concrete and fiberglass	Fair
596	MANN099F	464193.8312	6476705.566	Floodgate	Floodgate management	Concrete and fiberglass	Fair
597	MANN053F	463452.3896	6476554.647	Floodgate	Floodgate management	Concrete and fibro	Fair

ID	Alias	Easting (m)	Northing (m)	Type	Remediation	Details	Condition
598	MANN103F	462333.3543	6476226.944	Floodgate	Floodgate management	Concrete and timber	Fair
599	MANN036F	463134.067	6476222.865	Floodgate	Floodgate management	Steel and fibro	Fair
600	MANN023F	462227.4942	6476198.29	Floodgate	Floodgate management	Concrete and steel	Fair
601	MANN022F	461845.5961	6475801.5	Floodgate	Floodgate management	Concrete and timber	Fair
602	MANN048F	465742.9367	6475811.918	Floodgate	Floodgate management	Concrete and fibro	Poor
603	MANN049F	465628.9462	6475780.835	Floodgate	Floodgate management	Concrete and fibro	Fair
604	MANN061F	461940.0935	6475754.97	Floodgate	Floodgate management	Concrete and fibro	Good
605	MANN021F	461320.7811	6475683.374	Floodgate	Floodgate management	Concrete and steel	Fair
606	MANN101F	463386.7609	6475668.777	Floodgate	Floodgate management	Concrete and fibro	Fair
607	MANN035F	463154.8878	6475640.463	Floodgate	Floodgate management	Concrete and fibro	Fair
608	MANN020F	460815.5005	6475579.816	Floodgate	Floodgate management	Concrete and fibro	Fair
609	MANN107F	461140.964	6475474.647	Floodgate	Floodgate management	Concrete	Poor
610	MANN034F	463263.8236	6475470.158	Floodgate	Floodgate management	Concrete and steel	Fair
611	MANN047F	465507.287	6475467.848	Floodgate	Floodgate management	Concrete and fibro	Fair
612	MANN019F	460398.3845	6475235.376	Floodgate	Floodgate management	Steel and fibro	Fair
613	MANN046F	465210.3294	6475160.371	Floodgate	Floodgate management	Concrete and steel	Poor
614	MANN018F	460412.4849	6475061.961	Floodgate	Floodgate management	Timber	Poor
615	MANN108F	460510.9403	6475044.385	Floodgate	Floodgate management	Concrete and timber	Fair
616	MANN045F	465116.7391	6474944.465	Floodgate	Floodgate management	Concrete and fibro	Poor
617	MANN052F	464815.2875	6474712.322	Floodgate	Maintenance	Brick	Poor
618	MANN102F	462886.098	6474650.115	Floodgate	Floodgate management	Concrete and fibro	Good
619	MANN094F	460346.0564	6474404.855	Floodgate	Floodgate management	Concrete and fibro	Fair
620	MANN080F	463615.8305	6474273.641	Floodgate	Floodgate management	Concrete	Poor
621	MANN012F	462759.6727	6474244.417	Floodgate	Floodgate management	Concrete and fibro	Poor
622	MANN089F	455885.8215	6474214.513	Floodgate	Floodgate management	Timber	Good
623	MANN017F	456541.5805	6474185.829	Floodgate	Floodgate management	Timber and fibro	Poor
624	MANN106F	459954.0737	6474181.31	Floodgate	Floodgate management	Concrete and timber	Fair
625	MANN090F	456401.7145	6474087.249	Floodgate	Floodgate management	Concrete and timber	Good
626	MANN014F	457921.0195	6474053.916	Floodgate	Floodgate management	Concrete and fibro	Fair
627	MANN081F	464254.5618	6474073.822	Floodgate	Floodgate management	Concrete and steel	Poor
628	MANN016F	456967.6927	6474036.11	Floodgate	Floodgate management	Concrete and fibreglass	Fair
629	MANN015F	457414.568	6473940.979	Floodgate	Floodgate management	Concrete and fibro	Fair
630	MANN013F	462257.0555	6473895.638	Floodgate	Maintenance	Concrete	Poor
631	MANN093F	456345.115	6473871.753	Floodgate	Floodgate management	Concrete	Poor
632	MANN063F	457169.5345	6473858.826	Floodgate	Floodgate management	Concrete and fibro	Fair
633	MANN079F	464145.2302	6473771.944	Floodgate	Maintenance	Concrete and steel	Poor
634	MANN062F	458554.8446	6473711.436	Floodgate	Floodgate management	Concrete and fibro	Fair
635	MANN092F	456299.6639	6473662.506	Floodgate	Maintenance	Concrete	Poor
636	MANN104F	462058.0338	6473588.201	Floodgate	Floodgate management	Concrete and timber	Good
637	MANN105F	461916.9887	6473516.186	Floodgate	Floodgate management	Concrete and timber	Fair
638	MANN067F	460001.6357	6473481.743	Floodgate	Floodgate management	Concrete and timber	Fair

ID	Alias	Easting (m)	Northing (m)	Type	Remediation	Details	Condition
639	MANN068F	460558.6095	6473372.175	Floodgate	Floodgate management	Concrete and fibro	Fair
640	MANN091F	455811.411	6473284.433	Floodgate	Floodgate management	Concrete and timber	Fair
641	MANN070F	460976.3852	6473300.06	Floodgate	Floodgate management	Concrete and fibro	Fair
642	MANN069F	460796.4361	6473288.062	Floodgate	Floodgate management	Concrete	Good
643	MANN078F	463393.8276	6473263.857	Floodgate	Maintenance	Concrete	Poor
644	MANN077F	463414.7308	6473263.707	Floodgate	Maintenance	Concrete	Poor
645	MANN071F	461155.3942	6473211.288	Floodgate	Floodgate management	Concrete and fibro	Fair
646	MANN076F	462476.5517	6473157.679	Floodgate	Floodgate management	Concrete and steel	Fair
647	MANN039F	460350.0226	6473059.119	Floodgate	Floodgate management	Concrete and fibreglass	Fair
648	MANN038F	460675.0243	6472981.564	Floodgate	Floodgate management	Concrete and fibro	Fair
649	MANN115F	458196.34	6472460.66	Floodgate	Floodgate management	Concrete and timber	Poor
650	MANN116F	458172.1302	6472368.229	Floodgate	Maintenance	Concrete	Poor
651	MANN082F	464354.6334	6471570.232	Floodgate	Floodgate management	Concrete and timber	Fair
652	MANN064F	458002.9915	6471522.131	Floodgate	Floodgate management	Concrete and fibro	Fair
653	MANN040F	460941.8763	6471334.12	Floodgate	Floodgate management	Concrete and fibreglass	Fair
654	MANN075F	461141.3186	6471284.55	Floodgate	Floodgate management	Concrete and timber	Fair
655	MANN065F	458130.8598	6470570.395	Floodgate	Floodgate management	Concrete and fibro	Fair
656	MANN117F	457484.3773	6470379.414	Floodgate	Floodgate management	Concrete and timber	Poor
657	MANN084F	461366.628	6470140.833	Floodgate	Floodgate management	Concrete and timber	Fair
658	MANN066F	454548.7248	6469860.81	Floodgate	Floodgate management	Concrete and fibro	Fair
659	MANN118F	455810.1576	6469668.469	Floodgate	Floodgate management	Concrete and steel	Fair
660	MANN111F	454869.0099	6469533.016	Floodgate	Remove	Concrete	Poor
661	MANN114F	451495.0578	6469504.302	Floodgate	Floodgate management	Concrete and steel	Fair
662	MANN073F	461440.2139	6469305.683	Floodgate	Floodgate management	Concrete and steel	Fair
663	MANN109F	456915.8016	6469253.853	Floodgate	Floodgate management	Concrete and timber	Poor
664	MANN110F	456878.9674	6469243.945	Floodgate	Floodgate management	Concrete and timber	Fair
665	MANN085F	461185.7554	6469212.722	Floodgate	Floodgate management	Concrete and steel	Fair
666	MANN112F	454630.334	6469046.685	Floodgate	Floodgate management	Concrete and fiberglass	Fair
667	MANN113F	454299.824	6469041.006	Floodgate	Floodgate management	Concrete and fiberglass	Good
668	MANN138F	461494.117	6468547.717	Floodgate	Remove	Concrete	Poor
669	MANN139F	448258.7866	6468422.912	Floodgate	Floodgate management	Concrete and timber	Poor
670	MANN088F	456007.4642	6468353.256	Floodgate	Floodgate management	Concrete and timber	Poor
671	MANN087F	455649.0091	6468298.178	Floodgate	Floodgate management	Concrete	Poor
672	MANN137F	454906.6604	6468066.375	Floodgate	Remove	Concrete	Poor
673	MANN083F	463661.4053	6467953.968	Floodgate	Floodgate management	Concrete and timber	Fair
674	MANN074F	463971.2758	6467879.253	Floodgate	Maintenance	Concrete	Poor
675	MANN072F	462076.0592	6467466.057	Floodgate	Floodgate management	Concrete and fibro	Fair
676	MANN086F	456482.8206	6467349.711	Floodgate	Floodgate management	Concrete and timber	Fair
677	MANN043F	461988.4801	6466738.375	Floodgate	Floodgate management	Concrete and fibro	Good

ID	Alias	Easting (m)	Northing (m)	Type	Remediation	Details	Condition
678	MANN042F	457047.9908	6466613.981	Floodgate	Floodgate management	Concrete and steel	Fair
679	MANN041F	457125.411	6466566.97	Floodgate	Floodgate management	Concrete and fibro	Fair
680	MANN044F	461687.0121	6466038.378	Floodgate	Floodgate management	Concrete and timber	Poor

Table I.2: Summary of Floodgates Assessed by WRL

ID	Easting (m)	Northing (m)	Invert (m AHD)	Headwall Elevation (m AHD)	Condition
680	461689.060	6466042.086	0.062	2.048	Good
677	461990.304	6466739.118	-0.423	1.888	Good
674	463968.816	6467873.561	0.199	1.622	None
673	463661.405	6467953.968	-	-	None
675	462076.059	6467466.057	-	-	Unknown
668	461494.117	6468547.717	-	-	Unknown
662	461440.214	6469305.683	-	-	Unknown
657	461372.331	6470137.101	-0.196	1.312	Good
653	460938.117	6471341.832	0.561	1.606	Good
627	464254.562	6474073.822	-	-	None
617	464819.619	6474718.44	0.037	1.537	Good
616	465116.739	6474944.465	-	-	Good
613	465210.329	6475160.371	-	-	Good
611	465507.477	6475466.517	0.51	1.71	Good
555	460262.683	6481585.353	-	-	None
560	460628.089	6480667.77	-	-	Good
563	460570.310	6480234.268	-	-	Good
565	460852.246	6479914.354	0.186	1.486	Fair
573	460631.066	6479196.679	-	-	Good
574	460380.612	6478823.602	-0.86	1.323	Good
575	460447.311	6478647.625	-0.528	1.485	Good
576	460609.824	6478442.543	-	-	Good
582	460760.435	6478230.966	-	-	Good
581	461109.457	6478250.582	-	-	Good
578	461066.728	6478406.524	-0.1	1.659	Good
579	462568.905	6478392.003	-0.557	1.348	Poor
586	463091.906	6477819.95	-0.75	0.154	Good