East Kinchela (Swan Pool) Remediation Feasibility Study

WRL TR 2021/21, November 2021

By T A Tucker and D S Rayner

UNSW Water Research Laboratory

UNSW SYDNEY

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Executive summary

Swan Pool overview

The East Kinchela (Swan Pool) floodplain forms part of the larger Macleay River floodplain located on the NSW mid-north coast. The floodplain flows into the Macleay River estuary via Kinchela Creek through a natural connection approximately 30 km upstream of the ocean entrance at South West Rocks. An artificial channel also connects the floodplain to Korogoro Creek to the east which flows into the ocean at Hat Head. Prior to the 19th century, the floodplain was a low-lying backswamp environment with extensive freshwater wetlands resulting from prolonged water retention across the floodplain.

Development of the Swan Pool floodplain began in the late 19th century. To increase agricultural productivity it was determined that drainage infrastructure was required to lower the water table and enable the establishment of agriculture across previous wetland areas. By the 20th century six new surface water connections between Swan Pool and the Macleay River/Korogoro Creek estuaries had been created. Deep drains and floodgate structures resulted in the efficient drainage of the floodplain and improved agricultural productivity at the expense of wetland ecosystem values.

The drainage infrastructure also resulted in severe impacts to the water quality across the floodplain and to the downstream estuaries. As water levels across Swan Pool receded, acid sulfate soils underlying the floodplain were exposed to the atmospheric oxygen and reacted to create sulfuric acid and other metal by-products. Drainage of acid sulfate soils leads to the continuous production and export of acid to the downstream estuaries causing significant environmental impacts. The drying out of the floodplain also resulted in the proliferation of water intolerant vegetation (such as pasture grasses) across the floodplain. Prolonged inundation of standing water following flooding leads to the die off of water intolerant vegetation that decays and removes oxygen from the water column. Known as blackwater due to its colour, this low oxygen water is then efficiently transported to the estuary causing significant environmental impacts such as large-scale fish kill events.

A number of strategies have been developed over the past two decades seeking to address the issues associated with poor water quality generated at Swan Pool. These have resulted in repeated attempts to modify the Swan Pool floodplain to rehabilitate wetland habitats and improve water quality. These attempts have been largely unsuccessful due to lack of ongoing support and limited by existing drainage and present-day agricultural land uses within the Swan Pool floodplain hydrological unit (i.e. hydrologically connected areas). Of the 24 recommendations, actions and strategies identified for the remediation of Swan Pool, only one of these has been successfully implemented and only a further seven were attempted with partial success (Figure ES.1). It is clear that the implementation of current strategies in place for the remediation of Swan Pool have largely been unsuccessful and poor water quality discharging from floodplain continues to be an ongoing issue.

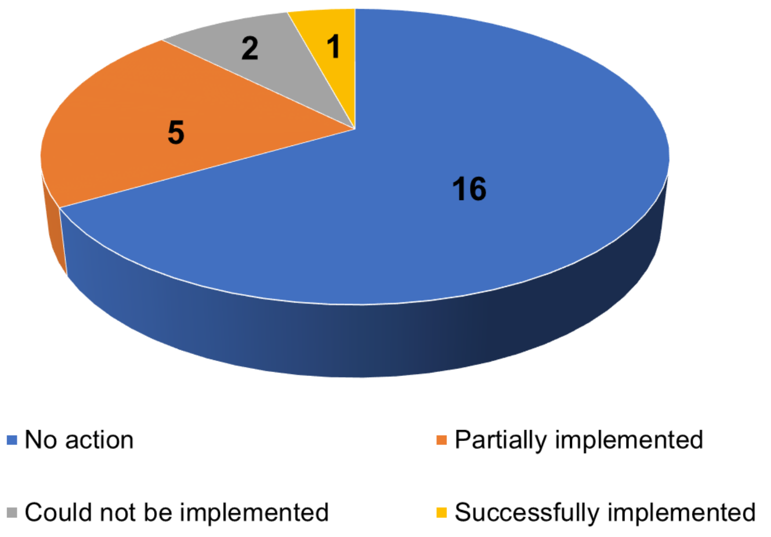

Figure ES.1: Success of existing recommendations, actions, and strategies for the remediation of Swan Pool

Presently, the environmental and agricultural values of the Swan Pool floodplain are mutually exclusive. Actions to improve wetland habitat and water quality are to the detriment of agricultural productivity. Recognition of this fact has led to a review of the remediation efforts at Swan Pool to determine their ongoing feasibility.

Study description

The aim of this study is to assess the feasibility of remediating Swan Pool to improve water quality into the future. To achieve this an extensive analysis has been completed to review existing information available for the site, including the development of a conceptual understanding of Swan Pool for historic, current and future conditions using GIS techniques (Figure ES.2). Using this conceptual understanding, a desktop investigation was completed to identify potential strategies for the remediation of Swan Pool. These informed recommendations for what is required to achieve large scale remediation of the Swan Pool floodplain.

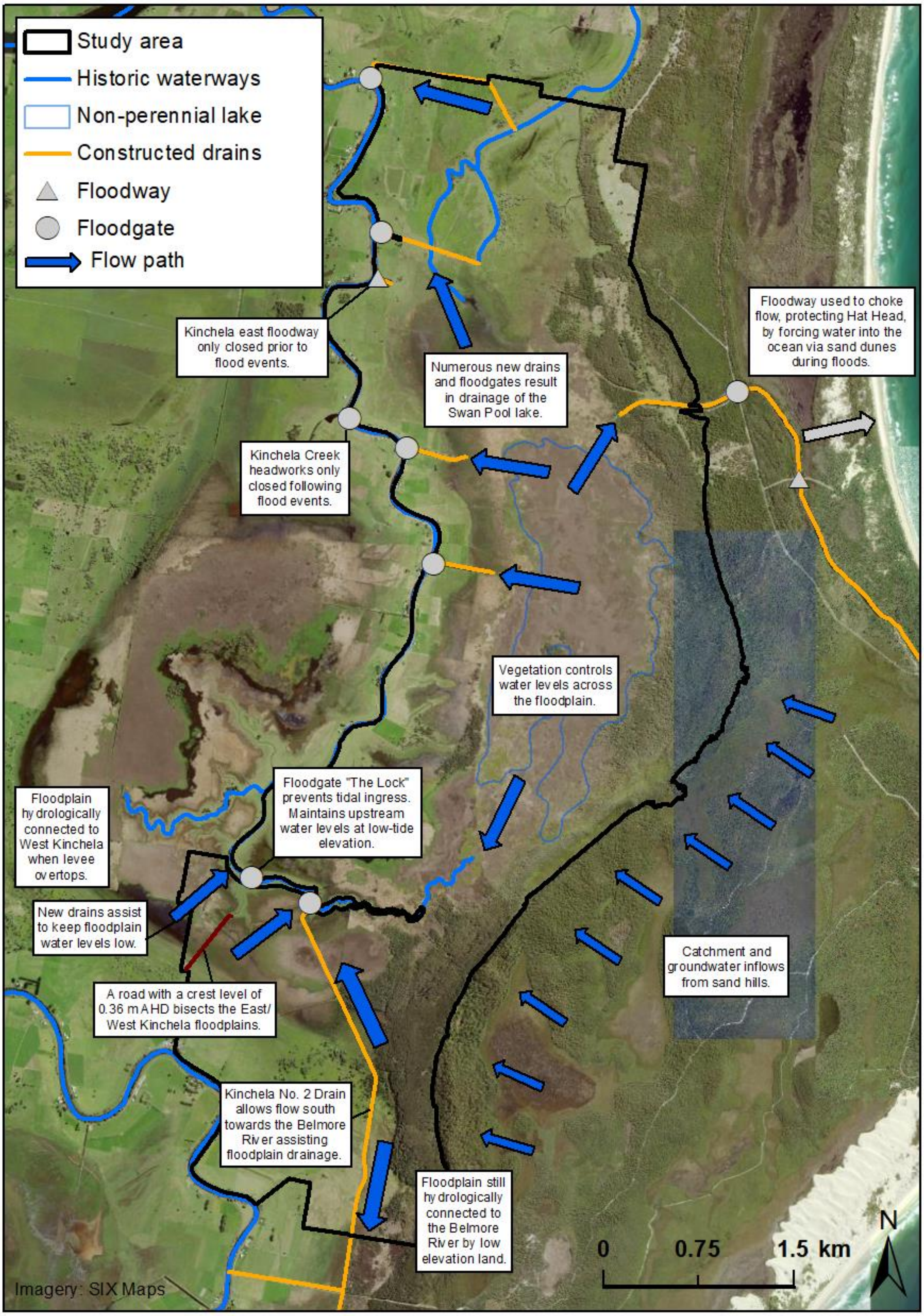

Figure ES.2 Current conceptual understanding of Swan Pool hydrology

Floodplain management strategies

Five management strategies were investigated for the remediation of Swan Pool, including:

- Implement existing recommendations
- Additional floodplain drainage modifications
- Full freshwater restoration of the natural floodplain hydrology
- Adapt for sea level rise (freshwater wetland)
- Adapt for sea level rise (estuarine wetland)

Investigation of these management strategies identified that the greatest improvement in water quality at Swan Pool could be achieved through the restoration of the historic floodplain hydrology to create and expand wetland habitat. Actions that promote increased (historical) water levels and retention times across the entire Swan Pool hydrological unit, resulting in improved wetland habitats and restoration of the natural floodplain hydrology, would provide the greatest improvements to ecosystem health and water quality. Conversely, remediation on a 'paddock scale' provides minor improvements to water quality and wetland habitats and generally requires a higher level of maintenance.

Large-scale remediation actions to restore the natural floodplain hydrology will be unsuccessful at Swan Pool without changing the existing land use of private land that is situated within the connected hydrological backswamp unit. To date, the greatest barrier for remediation of Swan Pool has been current floodplain land use, which requires continued drainage of the backswamp. While a large proportion of the floodplain is now managed for environmental values within Hat Head National Park, the remainder is utilised for agricultural practices such as grazing. Unfortunately, management of Swan Pool for both environmental values (including the creation of wetland habitat that improves water quality) and current agricultural practices is not possible due to the connectivity of the floodplain. Actions that would increase the value of wetland habitat would result in increased water levels across the floodplain, which in turn would reduce agricultural productivity. Similarly, drainage of the floodplain, which assists with agricultural productivity, has resulted in the reduction of environmental values and creation of poor water quality that discharges from the floodplain and impacts the downstream estuaries.

Since achieving large-scale improvements in water quality and wetland habitats requires consideration of the hydrological unit at Swam Pool as a whole, changing land use in low-lying connected areas is the single most important outcome that needs to be achieved before remediation on a floodplain-wide scale can be implemented. Evolving policy, and the acknowledgment by the corporate sector of the importance of the conservation, biodiversity and carbon sequestration values provided by wetland habitats has financially incentivised restoration of wetlands on land in private ownership. There is now potential for additional new pathways for restored land use change that can enable private land to be managed in an economically viable way. Pursuing these pathways may allow for progress in remediation of Swan Pool to occur. Properties where a change in land use is required to implement large-scale remediation at Swan Pool have been outlined in Figure ES.3.

To assist in progressing the remediation of Swan Pool, an assessment of the strategies was completed. This identified the potential benefits, risks, constraints, and unknowns of creating wetland habitat to improve water quality (Table ES.1).

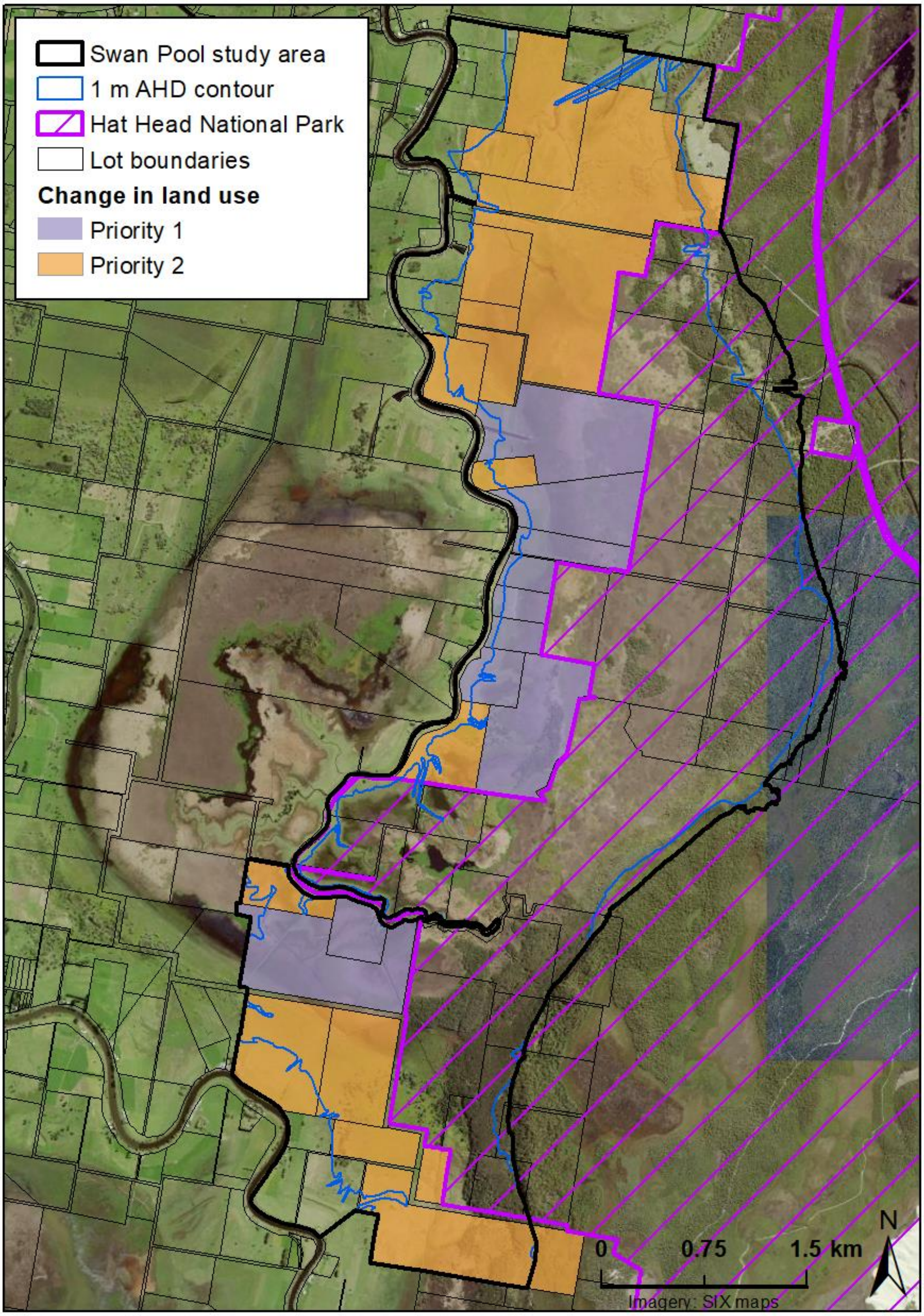

Figure ES.3: Freehold land where a change in land use is required to facilitate large scale remediation at Swan Pool

Table ES.1: Benefits, risks, constraints and unknowns identified for the remediation of wetlands at Swan Pool to improve water quality

Benefits	Risks
Improved water quality	Vegetation die off
Ecosystem services	Methane emissions
Carbon sequestration (teal and blue carbon)	Acid storage and generation
Wetland migration	Change in ecology
Removal of habitat barriers	Economic risk
Constraints	**Unknowns**
Funding	Future sea level rise extent
Jurisdiction	Future rainfall climate
Ownership of remediation	Private landowner support
Flooding	Salinity in Kinchela Creek

Recommendations

Investigations into the feasibility of remediation of Swan Pool identified that strategies implemented across the entire connected Swan Pool hydrological unit would provide the most significant benefits and water quality improvements. However, present day agricultural land use of low-lying areas limits the applicability of floodplain-wide remediation strategies The following staged approach is recommended to further progress remediation efforts at Swan Pool (Figure ES.4):

1. Address administrative and planning requirements
    a) Identify ownership of remediation outcomes
    b) Establish a funding framework
    c) Establish a pathway to change land use
    d) Determine private landowners willingness to change land uses
    e) Determine the framework for management of wetland habitat
    f) Complete required additional studies or administrative prerequisites
2. Data collection, assessment of preferred strategy, and detailed design
3. Land-use change
4. Implementation of remediation strategy
5. Monitoring and adaptive management

Extensive community consultation will be required in the first stage to ascertain a clear path forward and guide the future stages for the remediation. Engagement with relevant NSW State Government agencies should also be sought throughout all stages to ensure a unified approach to remediation efforts.

Figure ES.4: Staged approach to remediating Swan Pool

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1 Introduction

1.1 Study overview

The East Kinchela floodplain, also referred to as Swan Pool, forms part of the larger Macleay River floodplain and is located approximately 30 km upstream of the Macleay River's entrance to the ocean at South West Rocks on the NSW mid-north coast (Figure 1.1). Prior to the 1900s, extensive freshwater wetlands existed across the floodplain backswamps. Kinchela Creek, which flows north to the Macleay River, was the only connection between the floodplain and the estuary. During this time there would have been extended water retention times across the floodplain which promoted freshwater wetland habitat.

Towards the end of the 19th century, construction of floodplain drainage works were identified as a method to improve agricultural productivity of low lying backswamp areas. Construction of deep drainage channels and large one-way floodgate structures resulted in significant changes to the hydrology at Swan Pool. Five new connections between Swan Pool and Kinchela Creek, and a large connection between Swan Pool and Korogoro Creek (which flows into the ocean at Hat Head) were created via the construction of drainage channels (Figure 1.2). The increased connectivity between Swan Pool and the downstream estuaries altered the hydrology of the floodplain creating drier conditions that were beneficial for agricultural activities such as grazing. The drier conditions also resulted in the reduction of freshwater wetland habitat and the generation of poor quality water, which was then discharged to the downstream estuary (Tulau and Naylor, 1999; Tulau, 2011).

Floodplain drainage of Swan Pool resulted in the generation of poor quality water in two ways:

1. Oxidisation of acid sulfate soils
2. Prolonged inundation of water intolerant vegetation

Acid sulfate soils underly the Swan Pool floodplain and are innocuous as long as they remain below the water table. Floodplain drainage has resulted in drier conditions which have lowered the water table and exposed acid sulfate soils to the oxygen in the air. When this occurs, the acid sulfate soils react with the atmospheric oxygen to create sulfuric acid that can then be transported to the downstream estuaries and result in a range of environmental impacts.

Drier conditions have also resulted in the proliferation of water intolerant vegetation across the floodplain. When this vegetation is inundated for extended periods, it decomposes and consumes the oxygen in the water on the floodplain. Efficient drainage channels then export this water, which has been stripped of oxygen (known as blackwater due to its colour) to the estuary, also impacting downstream environments.

Since their construction, drainage works at Swan Pool have been identified as the major cause of poor water quality discharging from the floodplain to the downstream estuaries (Tulau and Naylor, 1999; Telfer and Birch, 2009b; Tulau, 2011;GeoLINK, 2012). Tucker et al. (2021) identified that the Kinchela Creek floodplain posed the highest risk to water quality in the Macleay River estuary as a source of low-oxygen blackwater.

Strategies for remediating the wetland habitat and improve the water quality discharging from the floodplain were developed in the early 2000s by Smith (2002). Subsequent estuary management programs for the Macleay River and Korogoro Creek have also identified strategies for remediating Swan Pool (Telfer and Birch, 2009b; GeoLINK, 2012). Despite these efforts, there has been limited progress towards the remediation of Swan Pool to improve water quality. A number of on-ground works designed to improve water quality have been removed and local opposition to remediation strategies that may result in a wetter floodplain is strong. In the Macleay River Coastal Management Program (CMP) Scoping Study, Rollason (2020a) identified three reasons for lack of progress in implementing remediation actions:

- The need for a Macleay River wide prioritisation for remediation
- Lack of clarity regarding jurisdiction across the floodplain
- Lack of private landowner support

This study focuses on identifying and assessing the feasibility of potential remediation strategies for reducing the impact that poor water quality generated on the Swan Pool floodplain has on the downstream estuaries. Existing and new strategies have been investigated, particularly in the context of climate change with the knowledge that sea level rise will impact floodplain hydrology. The feasibility of these strategies has also been reviewed to provide recommendations for how remediation of the Swan Pool floodplain can progress into the future.

A feasibility assessment of potential remediation strategies forms the first stage of a remediation process for the Swan Pool site. This included a literature review and data analysis to support future projects that seek to remediate Swan Pool. A conceptual model of the floodplain hydrology has also been developed. It is anticipated that this information, along with the feasibility assessment, can be used to inform future stages of the Swan Pool remediation process.

1.2 About this report

This report was commissioned by NSW North Coast Local Lands Services (LLS) and has been funded through the Saltwater Recreational Fishing Trust's Flagship Fish Habitat Action Program and the Marine Estate Management Strategy (MEMS). An Inter-agency Steering Committee oversees the study and includes representatives from LLS, Kempsey Shire Council, NSW Department of Primary Industries – Fisheries (DPI - Fisheries), NSW Department of Planning, Industry and Environment (DPIE), Energy, Environment and Science (EES), NSW National Parks and Wildlife Services (NPWS), and NSW Environment Protection Authority (EPA).

Following this introduction (Section 1), this report has the following sections:

- **Section 2: Conceptual understanding** – Review of the past, current and future floodplain hydrology using GIS modelling
- **Section 3: Floodplain management strategy** – Investigation of management strategies available for remediating water quality at Swan Pool and their feasibility
- **Section 4: Remediation strategy assessment** – Identification of the benefits, risks, constraints and unknowns for remediation of Swan Pool
- **Section 5: Recommendations:** A list of recommendations provided for the next steps required to remediate Swan Pool
- **Section 6: References**
- **Appendix A: Literature review** – A literature review for historic and ongoing management of water quality at Swan Pool

- **Appendix B: Data review** – A comprehensive review of existing data available for the Swan Pool floodplain
- **Appendix C: Review of current Swan Pool management strategies** – Identification and appraisal of the success of current management strategies for Swan Pool

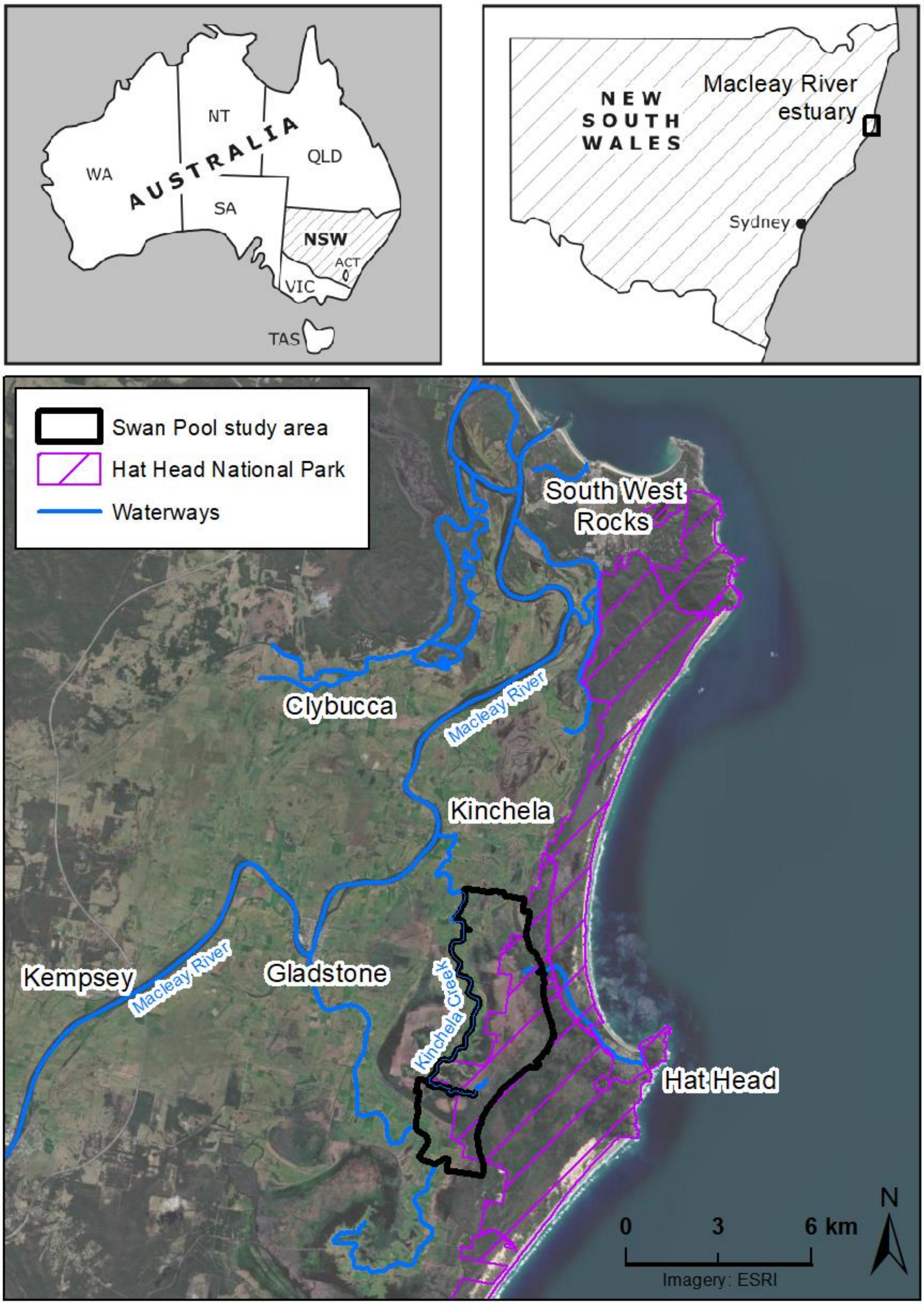


Figure 1.1: Study location

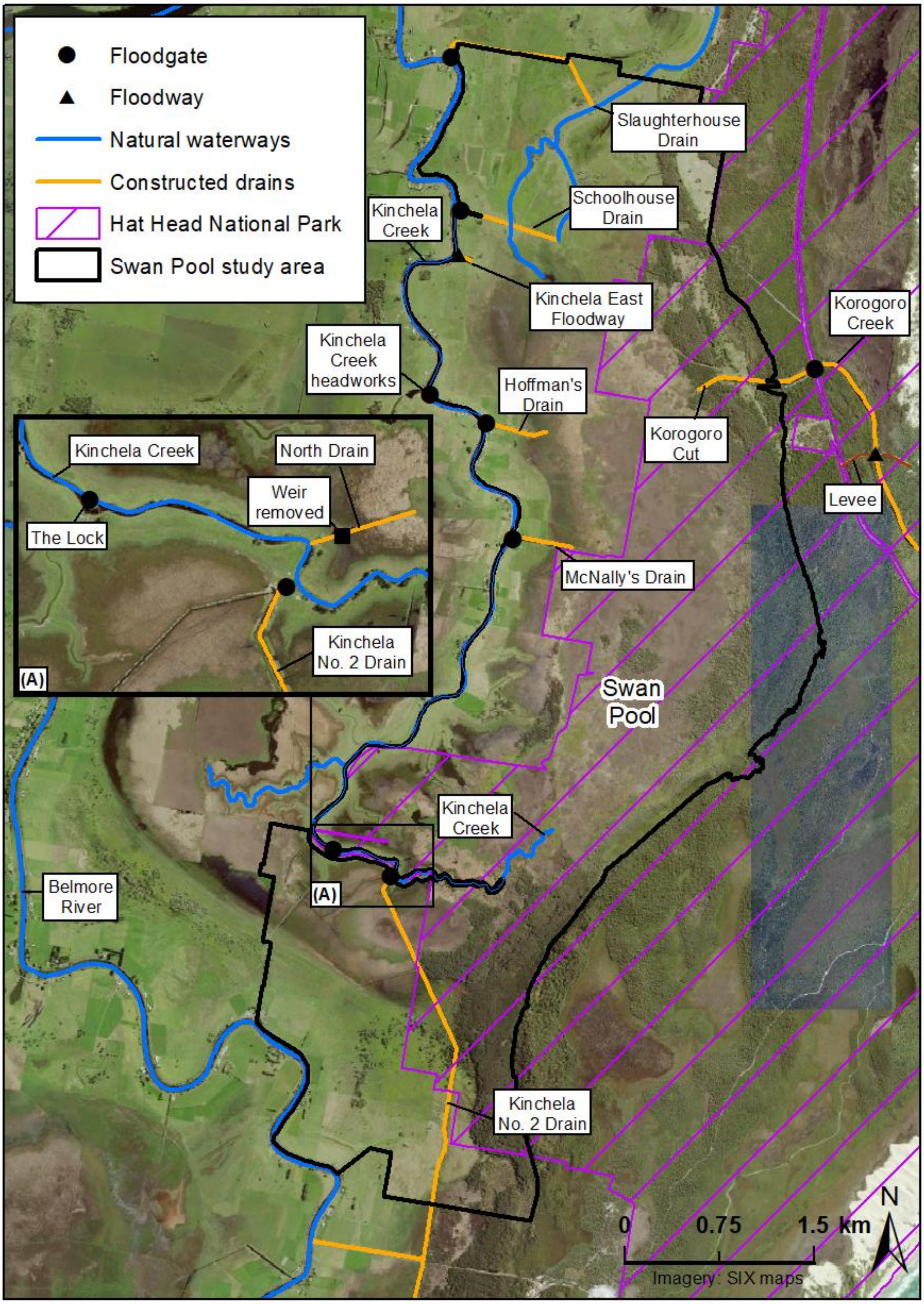


Figure 1.2: Key floodplain features at Swan Pool

2 Conceptual understanding

2.1 Preamble

A conceptual understanding of the study site was developed through a geographic information system (GIS) model. The GIS model utilised existing geospatial information, such as LiDAR survey data, alongside data identified in the literature review (Appendix A) and data review (Appendix B) to determine the historic, current, and future potential hydrology of the study site. The following section details the conceptual understanding developed for each of these time periods. A discussion on how the floodplain hydrology influences water quality and wetland habitat is also provided.

2.2 Historic hydrology

Prior to the 19th Century, a large open waterbody existed across the Swan Pool floodplain (Smith, 2002; Tulau, 2013). During this time extensive freshwater wetlands were abundant. Freshwater inflows would have occurred due to direct rainfall and drainage from the sand dunes to the east in Hat Head National Park, as well as inundation during larger catchment-wide flood events. The floodplain would have behaved as one large hydrological unit filling up as a basin from catchment and groundwater inflows. There would have been long retention times across the floodplain as dense vegetation slowed the movement of water (Figure 2.1). The floodplain was connected to the estuary to the north, through a series of disconnected channels, and to the south, via Kinchela Creek. During this time, water levels across the floodplain would have remained sufficiently high to ensure that acid sulfate soils were not exposed to air or oxidised. The Swan Pool floodplain would have been hydrologically connected to the floodplain on the west of Kinchela Creek and to the floodplain surrounding the Belmore River to the south.

Figure 2.1: Historical photo of dense reeds in Belmore Swamp south of Swan Pool (Kempsey Shire Council via Tulau, 2013)

During flood times, the Swan Pool floodplain would have acted as a storage basin filling up with water following catchment flood events. Only during the largest of floods would waters have overtopped the sand hills to the east of the floodplain (PWD, 1961). Quaternary geology mapping also identifies a historic connection between the floodplain and Korogoro Creek (Appendix A). Following flood events, a slow and gradual drainage of floodwaters back to the estuary would have occurred. Due to the long water retention times within the Swan Pool floodplain, the risk of blackwater would have been significantly reduced as the breakdown of vegetation, following inundation events, would have had time to complete, enabling water to regain oxygen before entering the estuary. Further, when blackwater did enter the estuary, it would have discharged at a relatively slow flow rate, which would have enabled mixing and reduced the potential for blackwater runoff to overwhelm the receiving waters' assimilation capacity.

The floodplain would have been connected to the estuary at the head of Kinchela Creek resulting in wet periods having a different hydrology compared to dry periods. During wetter periods with increased rainfall, freshwater catchment inflows would have limited any tidal ingress. During drier drought times, saline tidal water would have flowed onto the floodplain from Kinchela Creek. This intrusion would have been limited to only the southern portions of the floodplain.

Figure 2.3 provides an outline of the historic floodplain hydrology.

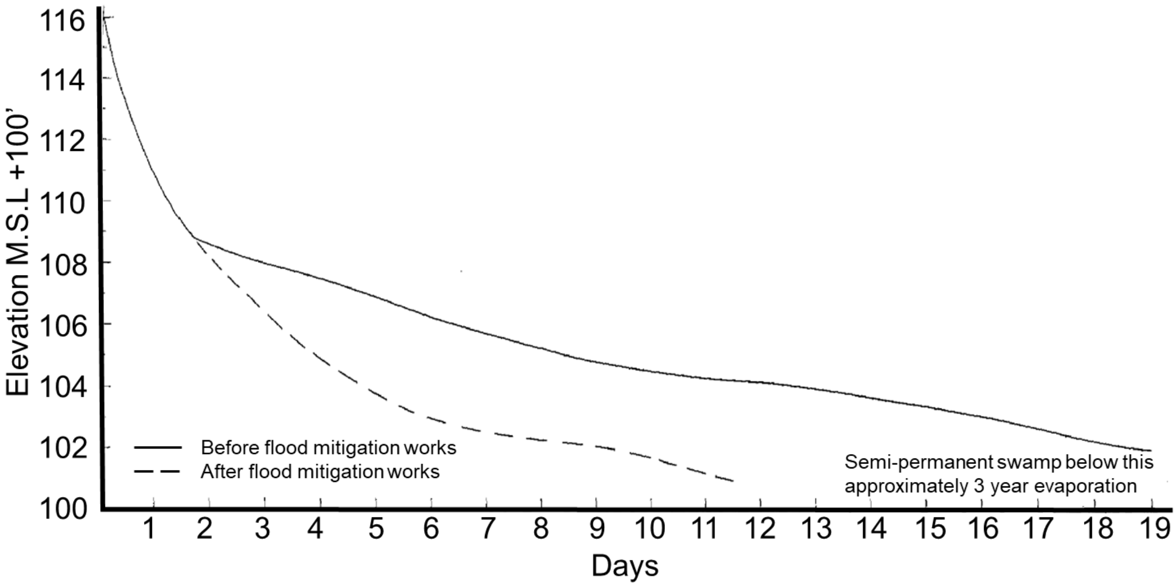


Figure 2.2: Drainage time for Kinchela Creek floodplain before (solid) and after (dashed) flood mitigation works (McDonald, 1967)

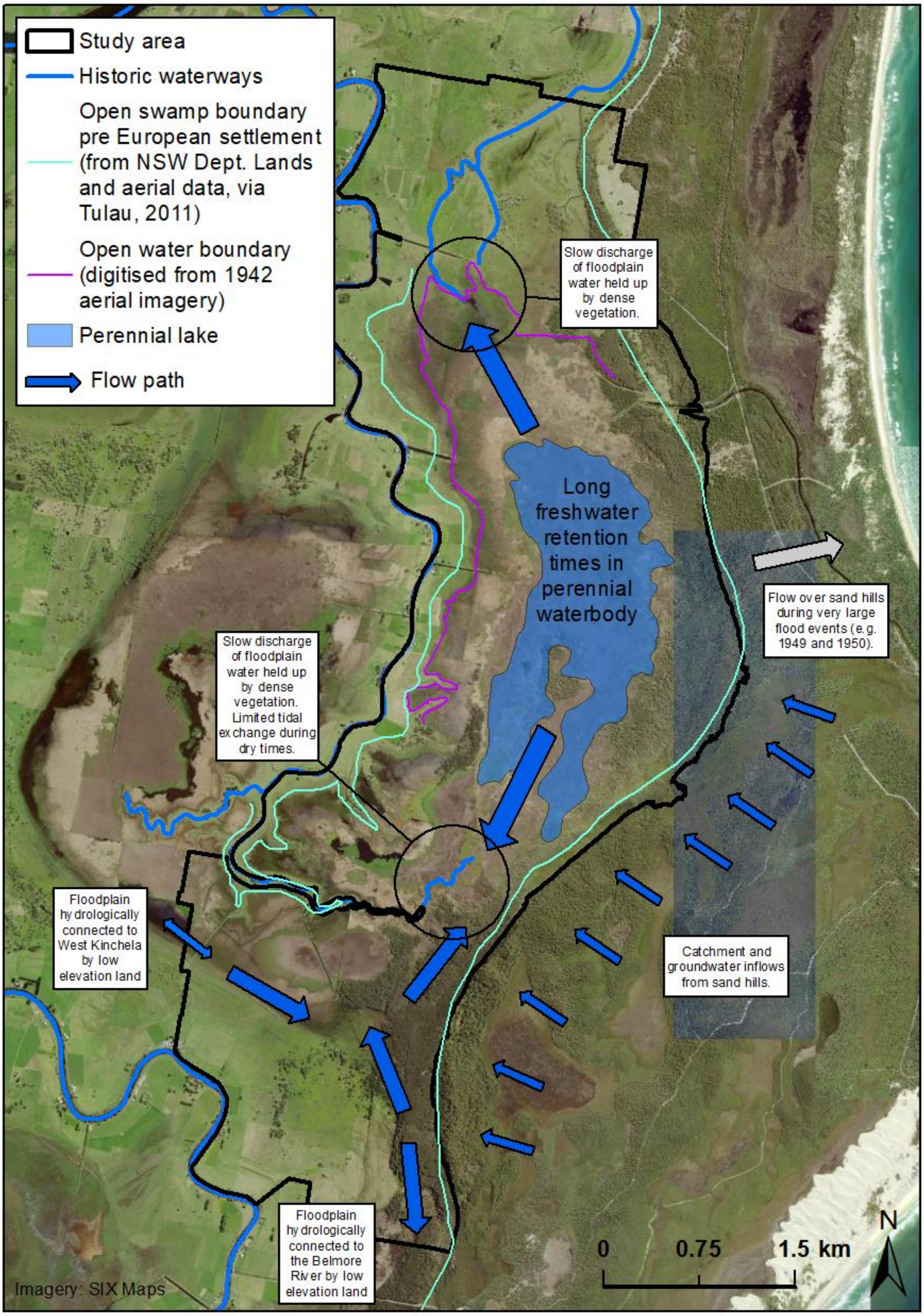


Figure 2.3: Historical Swan Pool floodplain hydrology

2.3 Present day hydrology

Construction of drainage infrastructure throughout the 20th Century resulted in significant changes in the hydrology of the Swan Pool floodplain. During this time, six additional connections between the floodplain and the estuary/ocean were created:

1. Slaughterhouse drain
2. Schoolhouse drain
3. Hoffman's drain
4. Kinchela east floodway
5. McNally's drain
6. Korogoro creek

With the exception of Kinchela east floodway, each of these drains had one-way floodgates constructed at the discharge location to limit upstream flows from the estuary while providing floodplain drainage. A floodgate was also constructed on upper Kinchela Creek (known as "The Lock"). Together these floodgates acted to maintain long-term floodplain water levels at low-tide elevations. This resulted in the drainage of the large open waterbody that formerly existed across the floodplain. This drainage also resulted in acid sulfate soils being exposed to atmospheric oxygen, creating sulfuric acid that is then exported to the estuary. A review of water levels completed by Tulau (2013) found that the growth of dense vegetation is now the main control for water levels across the floodplain.

To the south, changes to the floodplain have altered how Swan Pool connects to West Kinchela and the Belmore River floodplain. A low elevation road (at +0.36 m AHD) now disconnects Swan Pool and West Kinchela by acting as a weir, as shown in Figure 2.4. Overland flow only connects these two floodplains when inundation is sufficient to overtop the road. A number of small farm drains connecting directly to Kinchela Creek now drain the land in this area on each side of the road. The Belmore River floodplain is now connected to Swan Pool via Kinchela No. 2 Drain. Overland flow can still occur as it did previously through this area, however, Kinchela No. 2 Drain provides additional drainage and connectivity of the floodplain backswamps at this location.

Drainage and flood management infrastructure constructed across the Swan Pool floodplain has altered the hydrology during and following flood events. Operation of structures, such as the Kinchela east floodway, was designed to protect the floodplain from flood events that do not overtop the Kinchela Creek levee banks (Chong, 2019). Works on Korogoro Creek also help to reduce the flood impacts on the town of Hat Head (KSC, 2014). Following flood events, the infrastructure was designed to drain water from the floodplain as quickly as possible to reduce impacts to the floodplain. While the floodplain infrastructure has reduced drainage times across the floodplain (Figure 2.2), it has also exacerbated the export of low oxygen blackwater to the estuary that results from vegetation die-off and decay following prolonged inundation (Tucker et al., 2021).

Drainage of the Swan Pool floodplain has resulted in limited improvements for agriculture at the expense of wetland values (Tulau, 2011; Tulau, 2013). Smith (2002) reports that the agricultural productivity on the margins of the backswamp increased due to larger areas becoming available for dryland pasture.
Despite having a drier environment, as a result of increased drainage reducing water retention across the floodplain, Swan Pool still acts as a large basin with a hydrologically connected floodplain. Figure 2.4 provides an overview of the current floodplain hydrology.

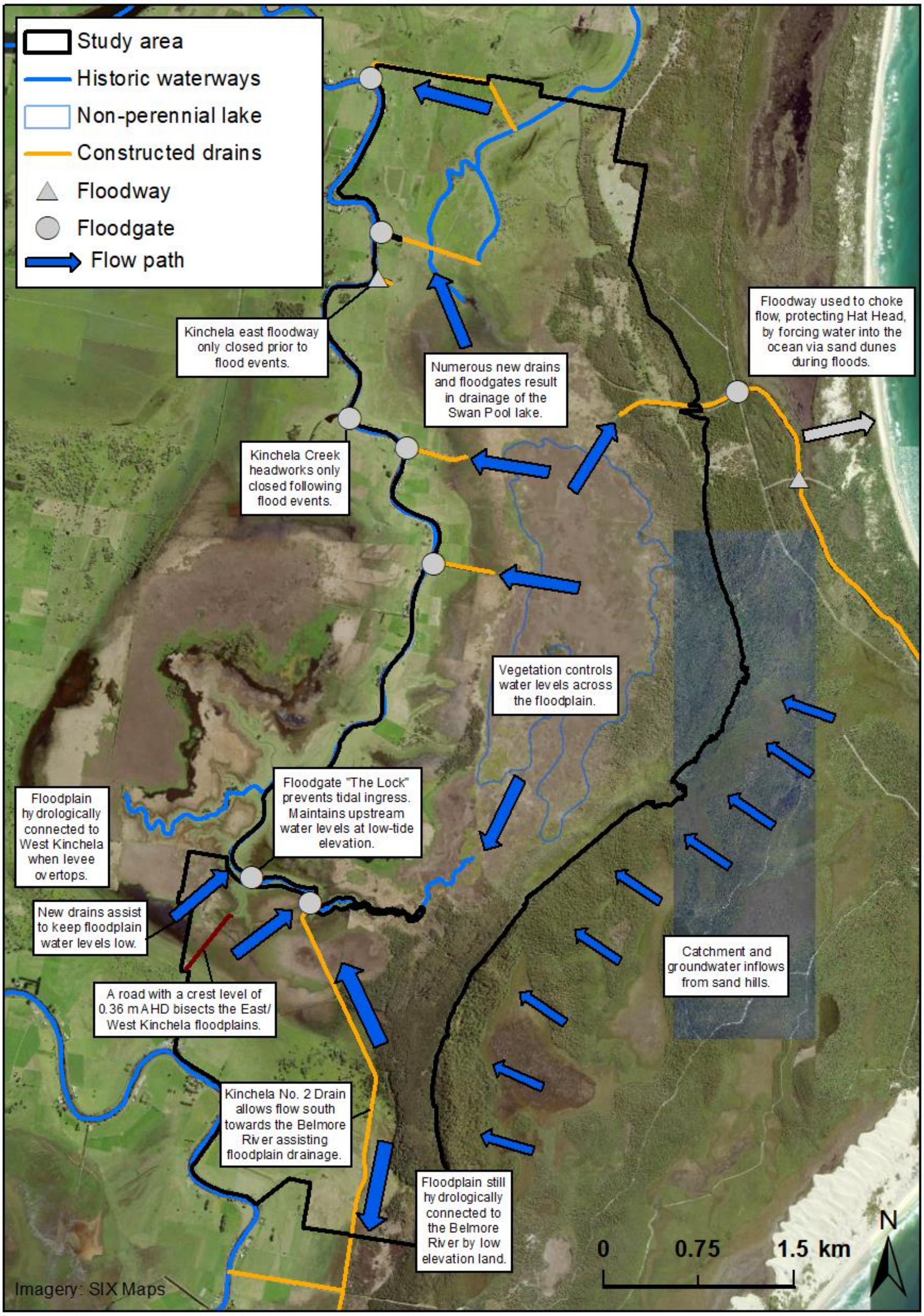
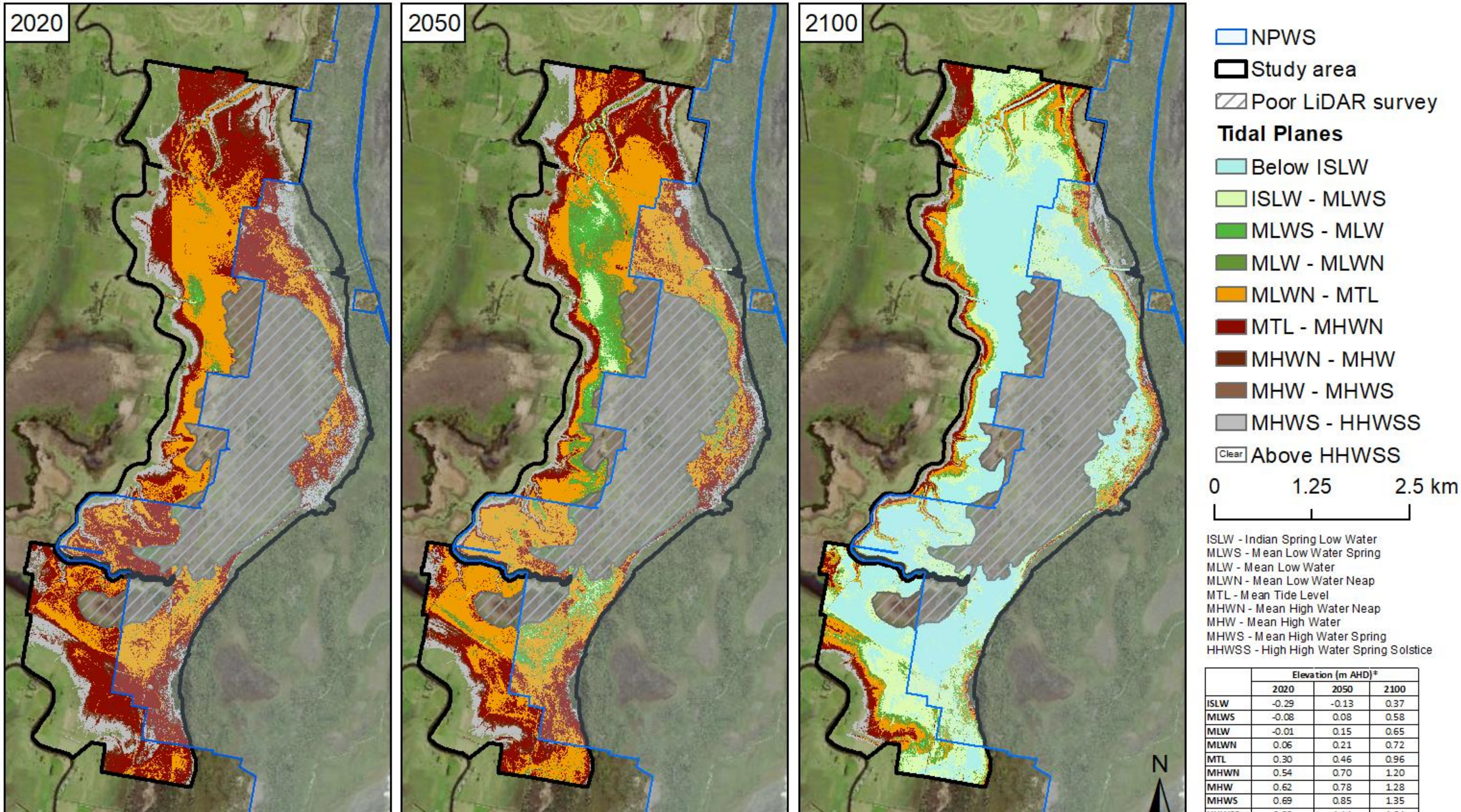


Figure 2.4: Present day Swan Pool floodplain hydrology

2.4 Future hydrology

In the future, Swan Pool will become increasingly influenced by the tide due to sea level rise (Figure 2.5). The floodplain will continue to act as a singular hydrological unit. Elevated estuarine water levels will result in reduced drainage across the entire floodplain due to an increased low-tide elevation (see Tucker et al., 2021). At the same time the potential for tidal ingress across the floodplain will increase. Preliminary investigations indicated that the tide elevation would not increase above the levee banks downstream of The Lock. This means that tidal ingress across the floodplain would be controlled through management of existing structures, such as The Lock, on Kinchela Creek, however the long-term floodplain water levels and residence time will be determined by tide levels in the wider Macleay River estuary.

Flooding in the Macleay River estuary will also be impacted due to sea level rise and an increase in the intensity of extreme rainfall events (i.e. more rainfall over a shorter duration) (Heimhuber et al., 2019). Chong (2019) modelled how changes in sea level rise and increased storm intensity would impact the Swan Pool floodplain for future climate scenarios. They found that for a 1% annual exceedance probability (AEP) event, the impacts of climate change would result in increases to flooding levels on the Swan Pool floodplain of between +0.3 m to +0.5 m for the 2050 scenario and +0.75 m to +1.0 m for the 2100 scenario. In the future, inundation of the floodplain due to flooding is also likely to occur more frequently resulting in overall wetter conditions.



	Elevation (m AHD)*		
	2020	2050	2100
ISLW	-0.29	-0.13	0.37
MLWS	-0.08	0.08	0.58
MLW	-0.01	0.15	0.65
MLWN	0.06	0.21	0.72
MTL	0.30	0.46	0.96
MHWN	0.54	0.70	1.20
MHW	0.62	0.78	1.28
MHWS	0.69	0.85	1.35
HHWSS	0.98	1.14	1.64

*Based on Allsop and Kadluczka (2004) and Tucker et al. (2021)

Figure 2.5: Future impact of tide on the Swan Pool floodplain

2.5 Water quality and remediation concepts

2.5.1 Existing water quality at Swan Pool

Drainage works at Swan Pool have resulted in poor quality water discharging from the floodplain (Tulau, 2011). Prior to floodplain drainage, extensive freshwater wetland habitat existed across Swan Pool. The construction of drainage infrastructure has resulted in the export of acidic runoff from acid sulfate soils, and low-oxygen blackwater caused by prolonged floodplain inundation.

The Swan Pool floodplain is underlain by acid sulfate soils. While these are relatively innocuous when the soils are in anaerobic (no oxygen) conditions below the water table, the drainage of the floodplain has resulted in the lowering of the water table and exposed acid sulfate soils to atmospheric oxygen (Figure 2.6). Upon exposure to oxygen, acid sulfate soils react and create sulfuric acid that can then be transported to the estuary, impacting downstream environments. Soil profile data (see Appendix B) indicates that acid sulfate soils are more prevalent across the low-lying backswamp areas compared to the higher elevated levee banks adjacent to Kinchela Creek. Despite the presence of acid sulfate soils, available water quality data did not indicate significant impacts of acid on Korogoro Creek. This could be due to high salinity levels within Korogoro Creek buffering acidic runoff from acid sulfate soils (see Appendix B). Telfer and Birch (2009a) noted acidic runoff is an issue that impacted Korogoro Creek, however, this observation was based upon unpublished water quality data. Similarly, there is no published water quality data available that identified the scale of acidic impacts to Kinchela Creek. Despite this, impacts have been noted by Tulau and Naylor (1999), and Hurrell et al. (2009) who each cite unpublished data. Additional data collection is required to understand the true impact of acid sulfate soils discharging from Swan Pool.

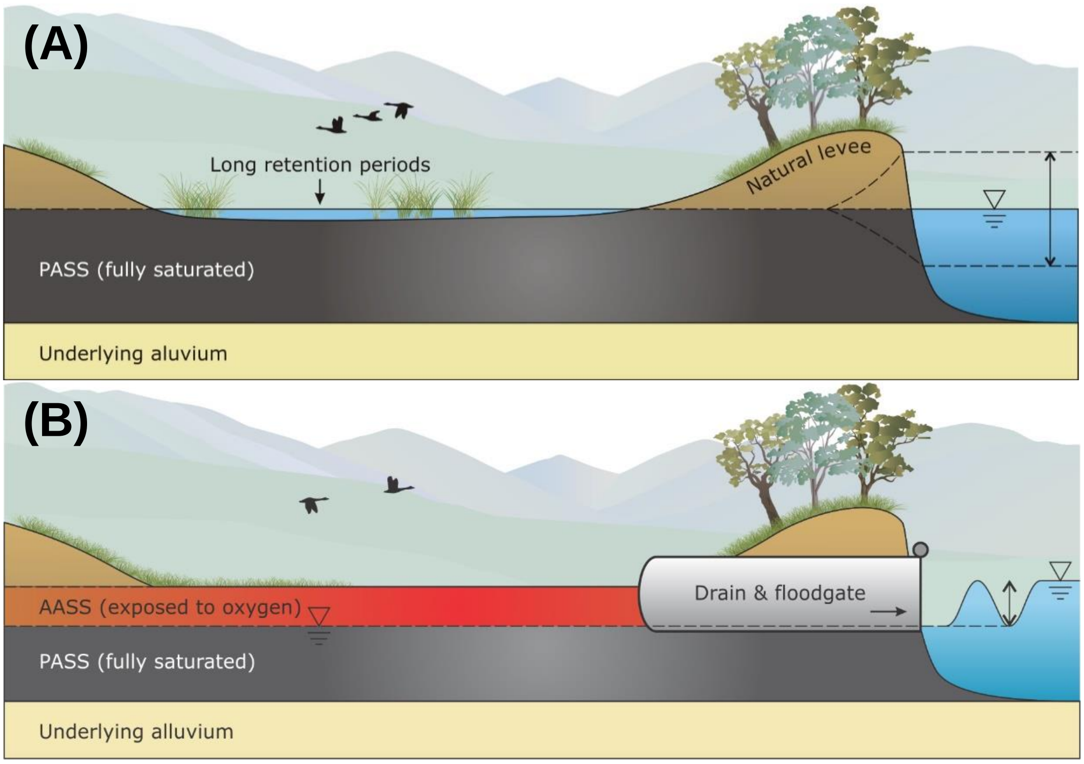


Figure 2.6: Potential acid sulfate soils (PASS) underlying natural wetland (A) and actual acid sulfate soils (AASS) that have become exposed to atmospheric oxygen in air due to floodplain drainage (B)

Low oxygen blackwater is generated when non-water tolerant vegetation is inundated for prolonged periods of time, leading to die-off and decay of organic material which consumes dissolved oxygen from the standing water column. The term blackwater comes from the colour of the water that is typically discharged from the floodplain prolonged inundation which commonly occurs following moderate-to-large flood events. The drainage of Swan Pool has enabled the establishment of non-water tolerant vegetation, such as pasture grasses, in low-lying historical wetland areas that are subject to prolonged inundation. Low oxygen blackwater is a natural phenomenon which is exacerbated in both magnitude and frequency by floodplain development and drainage. Furthermore, prior to drainage works, when blackwater was generated, its export from the floodplain would have slowly flowed to the estuary over a prolonged period via a naturally restricted connection. In some areas significantly disconnected from the estuary, the breakdown of organic material (carbon cycle) would have had time to complete, allowing water to regain oxygen before discharging to the estuary. Presently, efficient drainage channels enable blackwater generated on the floodplain to be efficiently transported to the estuary in significant volumes which overwhelms the assimilation capacity of the receiving water (Figure 2.7).

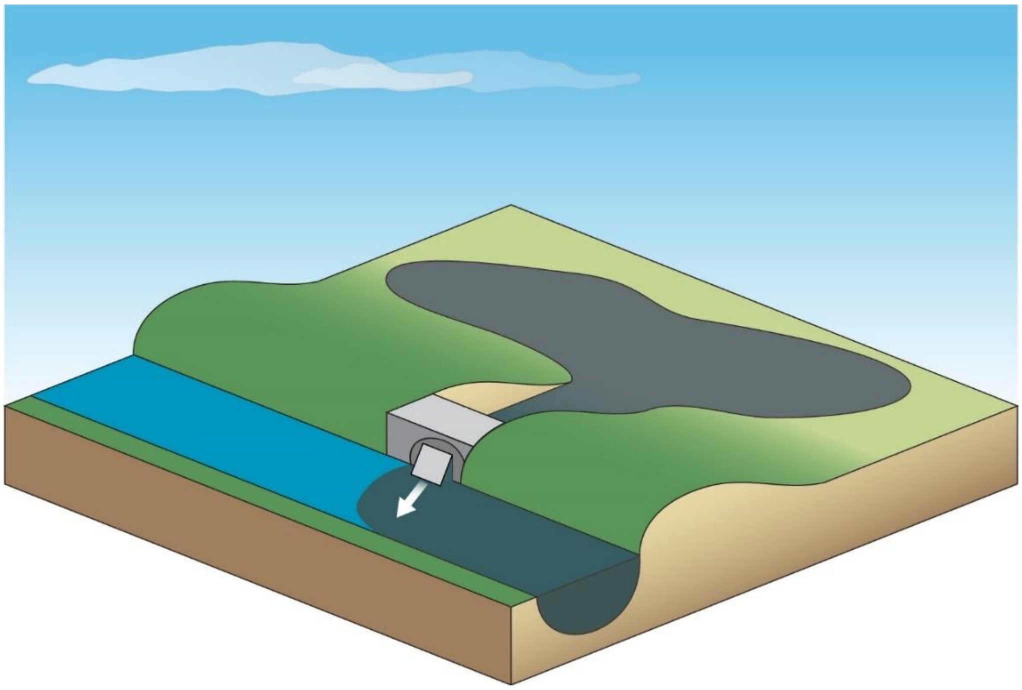


Figure 2.7: Efficient drainage of blackwater from a floodplain overwhelming the downstream receiving waters

Discharged blackwater typically contains a high biological oxygen demand (BOD) which further consumes dissolved oxygen from downstream waterways during mixing. Blackwater has significant impacts on the environment and many aquatic species cannot survive in water that does not contain oxygen. Mass fish kill events have regularly occurred on the Macleay River due to blackwater events caused by floodplain drainage (NSW DPI, 2020). Tucker et al. (2021) identified that the Kinchela Creek floodplain poses the largest risk to the entire Macleay River estuary in terms of poor water quality caused by the discharge of low-oxygen blackwater. Several other large backswamp systems on the Macleay floodplain (e.g. Belmore, Collombatti-Clybucca) also generate significant volumes of blackwater, which would typically all discharge blackwater under the same conditions.

In addition to water quality impacts associated with acid and blackwater runoff, mono-sulfidic black ooze (MBO) is often associated with the drainage of acid sulfate soils (Tulau, 2013). MBOs are often formed in the bottom of drains that intersect acid sulfate soils where high levels of sulphide and dissolved iron occur in anaerobic (no oxygen) conditions (Sullivan et al., 2018). Evidence of MBOs at Swan Pool is not recorded in literature, however, its likely occurrence is noted by Tulau (2013) and GeoLINK (2012). When mobilised MBOs undergo a chemical reaction that produces acid and further reduces oxygen content from the water column.

2.5.2 Freshwater wetland rehabilitation

Freshwater wetland habitats at Swan Pool could be rehabilitated through techniques that encourage the long-term retention of water on the floodplain, such as:

- Construction of weirs
- Shallowing and widening of constructed drains
- Infilling of constructed drains
- Increasing culvert inverts or use of drop boards
- Restoration of natural levee banks along Kinchela Creek

These actions act to increase surface and ground water levels and promote longer retention times. This improves water quality associated with acid and blackwater by limiting groundwater drawdown, promoting water tolerant vegetation and increasing water retention time.

Success of a freshwater wetland strategy at reducing the impact of acid sulfate soils would depend on the scale of the existing impact and the long-term rainfall climate at the site. Increased water levels across the floodplain would mean that the potential for acid sulfate soils to further oxidise would be limited. Some investigations have also shown that rewetting of acid sulfate soils can also neutralise soil pH (Johnston et al., 2014). Despite this, investigations have also shown that there tends to be a high concentration of iron across the acid sulfate soil affected floodplains which persists following re-wetting and can contribute to longer term water acidity (Johnston et al., 2014). Further, drought cycles can result in acid creation as the floodplain dries out (Karimian et al., 2017). While a perennial waterbody was historically located at Swan Pool prior to drainage works, indicating the site may not dry out, further investigations are required to determine how the site would be impacted by a changing climate into the future.

Rehabilitated freshwater wetlands and restoration of historical hydrology can significantly reduce the impact of blackwater on the estuary. Increased inundation times across low-lying floodplain areas can promote the establishment of water tolerant vegetation which is less susceptible than pasture grasses to die-off following prolonged inundation (although die-off can still occur). Where long retention times occur (over two months), the vegetation breakdown process has time to complete, and water regain oxygen, before entering the estuary (SCG, 2019). Importantly, the most significant improvements to water quality will occur due to the slow discharge of water to the estuary which replicates the historical natural floodplain hydrology.

2.5.3 Establishment of estuarine wetlands

In the long-term, there will be a greater potential for estuarine influence across Swan Pool due to increased tidal levels and increased salinity due to sea level rise (see Section 2.4). This provides the opportunity whereby establishment of estuarine wetlands across the floodplain could be considered to mitigate the impacts of acid and blackwater drainage, and allow for increased biodiversity and climate change adaptation. Works that would allow the creation of estuarine wetlands include:

- Modification of floodgates to allow the upstream tidal flows
- Removal of floodgates
- Removal of tidal barriers (such as weirs)

In terms of improving water quality, estuarine wetlands provide many of the same benefits as freshwater wetlands. Increased water levels reduce the production and export of acid, and a wetter floodplain promotes the growth of water tolerant vegetation. There are also a number of ways that estuarine wetlands provide additional water quality benefits:

- Tidal water can buffer and neutralise acid generated from acid sulfate soils
- Regular tidal flushing
- Establishment of water tolerant vegetation

As estuarine wetlands are directly connected to the estuary and receive daily tidal flows, there is less influence of rainfall (and drought) variability on wetland viability. Conversely, freshwater wetlands rely on either direct catchment rainfall, groundwater inflows and intermittent flooding to sustain the freshwater ecosystem. These freshwater sources are inherently more variable than daily tidal flushing, and subject to greater uncertainty under climate change than that of sea level rise.

3 Floodplain management strategies

3.1 Preamble

The Swan Pool floodplain is one of the largest contributors to poor water quality in the Macleay River estuary (Tucker et al., 2021). To address this issue, the following report section investigates potential remediation strategies available for management of the floodplain to address poor water quality issues. Throughout this investigation it was identified from a high level that the restoration of the natural floodplain hydrology (i.e. creation of wetland habitat) would be the single most effective approach for improving water quality discharging from the floodplain. It should also be highlighted that the present day land use within the Swan Pool hydrological unit will need to change before substantial improvements in water quality can be achieved. This will be a recuring theme for each of the strategies and is discussed further in Section 3.8.

3.2 Strategy overview

For actions that remediate poor water quality at Swan Pool to be successful the overarching strategy will need to:

- Target processes that result in the generation and export of acid and blackwater
- Treat the system as a single hydrological unit under a whole-of-system approach
- Implement actions that have longevity and consider future changes to the floodplain such as sea level rise

Five potential strategies for the remediation of Swan Pool have been identified as summarised in Table 3.1. The implementation and feasibility for each of these strategies has been investigated to determine the most practical path for remediation of the Swan Pool floodplain to improve water quality.

Table 3.1: Overview of floodplain management strategies

Strategy	Description	Indicative timeframe	Spatial scale
1	Implement existing recommendations	Immediate	Paddock
2	Additional floodplain drainage modifications	Immediate	Paddock
3	Full freshwater restoration of natural hydrology	Immediate	Hydrological unit
4	Adapt for sea level rise (freshwater)	Near future (~2050)	Hydrological unit
5	Adapt for sea level rise (estuarine)	Far future (~2100)	Hydrological unit

Remediation strategies have been investigated for a range of timeframes, on a range of spatial scales, with varying benefits and risks. Initially, remediation actions that have previously been investigated were assessed to determine their ongoing feasibility (Strategy 1). These actions are generally applicable at a paddock scale and lacking a whole-of-system approach. Secondly, a review was completed to identify if any paddock scale remediation actions that have not previously been recommended are feasible (Strategy 2). Thirdly, the scale of remediation efforts shifts from paddock scale to a catchment wide scale. The feasibility of remediating the entire Swan Pool floodplain to freshwater wetland, restoring its natural hydrology, and treating it as a single system has been investigated (Strategy 3).

The first three management strategies all look at implementation of remediation actions with the present day floodplain hydrology. Into the future, however, sea level rise will change the floodplain hydrology. Subsequently, Strategy 4 and Strategy 5 target remediation under sea level rise, considering remediation on a floodplain wide scale. Strategy 4 can be considered an extension of Strategy 3 and allows for adaptive management of the floodplain into the future to mitigate the impacts of sea level rise while maintaining a freshwater wetland. Strategy 5 investigates how sea level rise may enable the establishment of estuarine wetland habitat.

Each management strategy identified that due to the hydrology at Swan Pool, the existing floodplain land use will not be tenable into the future if environmental objectives to improve water quality are prioritised. Current agricultural practises and remediation of the natural floodplain hydrology are not compatible. Subsequently, a discussion has been provided regarding how a change in floodplain land use which would enable the remediation of Swan Pool might take place.

3.3 Strategy 1 – Implement existing recommendations

3.3.1 Strategy

Poor water quality discharging from Swan Pool has been an ongoing issue spanning multiple decades (see Appendix A). Throughout this time a number of investigations have identified remediation actions that could be explored to improve the water quality exported from the site. Responsibility for the implementation of these remediation actions has been allocated to a number of individual entities, which has resulted in remediation actions implemented to date having varying success despite their technical merit.

This strategy focuses on the immediate implementation of remediation actions that have already been recommended for the Swan Pool floodplain to improve water quality. The following section will review the existing strategy, assess the current technical merit of its implementation, and then identify its future feasibility.

3.3.2 Review of current strategy

Twenty-four (24) different recommendations, actions and strategies for the remediation of Swan Pool have been outlined in the following studies:

- Swan Pool drainage management project (Smith, 2002)
- Macleay River coastal zone management plan (GeoLINK, 2012)
- Korogoro Creek estuary management plan (Telfer and Birch, 2009b)

Of these studies, Smith (2002) provides the most detailed and site specific recommendations which aimed to promote wetland values without impacting agricultural productivity. GeoLINK (2012) and Telfer and Birch (2009b) developed actions and strategies as part of the coastal management program for the Macleay River and Korogoro Creek estuaries. These sought to address a number of management issues across the estuaries, however, at Swan Pool they specifically focused on improving poor water quality, floodplain drainage management, and habitat degradation. The actions and strategies provided by GeoLINK (2012) and Telfer and Birch (2009b) included the implementation of the Smith (2002) recommendations.

A review into the success of implementation of these recommendations, actions and strategies is provided in Appendix C. In summary, the following were successfully implemented (at least partly) at Swan Pool:

- Land acquisition (limited to properties on the south of the floodplain) (see Appendix A)
- Floodgate management plans have been created for the Kinchela Creek floodgates, The Lock and Kinchela No. 2 Drain (Note, the latter two are now outdated and a further four that were recommended have never been created.) (KSC, 2015a; KSC, 2006; KSC, 2007)
- Management of Hat Head National Park includes control of weeds such as *Salvinia molesta* (NPWS, 1998), however, it is unclear if any management takes place on private land and no studies have been identified verifying the success of weed management
- Land zoning in the Kempsey Local Environmental Plan (LEP) 2013 has been amended so that some areas of important habitat within Swan Pool are now classified as E2 (environmental conservation) (see Appendix B). Unfortunately, this zoning is now dated and does not include all low-lying floodplain that is hydrologically linked across the Swan Pool floodplain or all Coastal Management SEPP coastal wetlands across the floodplain.

It is clear that the implementation of current strategies in place for the remediation of Swan Pool have largely been unsuccessful and poor water quality discharging from floodplain continues to be an ongoing issue. In total, 24 recommendations, actions and strategies were provided for remediation of Swan Pool. Only one of these has been completely implemented, albeit now dated (i.e. updated LEP land zoning). A further seven were attempted with varying success (Figure 3.1).

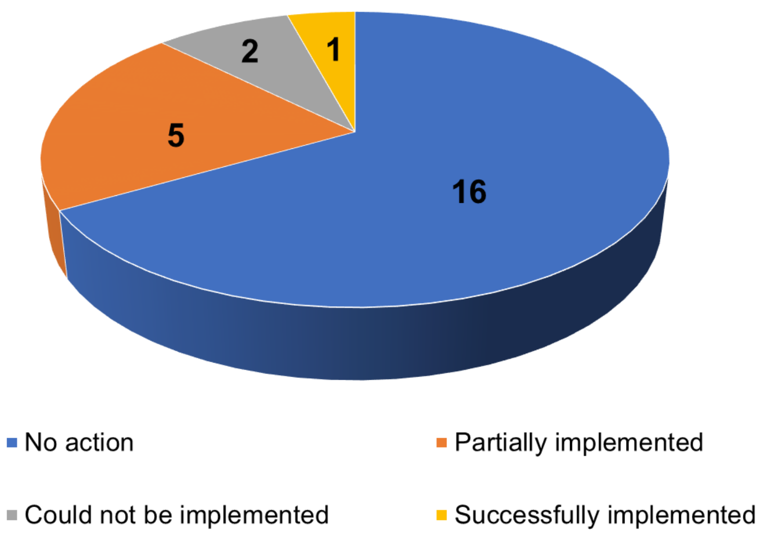


Figure 3.1: Success of recommendations/actions/strategies for remediation of Swan Pool (see Appendix C)

3.3.3 Technical appraisal of current strategy

Review of the current remediation strategy for Swan Pool indicates that social and governance aspects of implementation have been the primary impediment for remediation. While there has been limited success in the implementation of the current remediation strategy, this does not mean that the technical aspects of the remediation strategy are lacking. Subsequently, a review of the on-ground works components of the existing remediation strategy that result to changes in floodplain hydrology and promotion of wetland values has been completed based on the established conceptual understanding of Swan Pool (Section 2).

The following changes to the Swan Pool floodplain hydrology have previously been recommended or implemented (Smith, 2002; GeoLINK, 2012; Telfer and Birch, 2009b; Tucker et al., 2021):

- Modifications to floodgates (implemented then removed on The Lock, recommended otherwise)
- Modifications to drains (implemented for Slaughterhouse Drain only, recommended otherwise)
- Installation of weirs (implemented then removed)
- Wet pasture management (implemented)

These remediation strategies are shown in Figure 3.2.

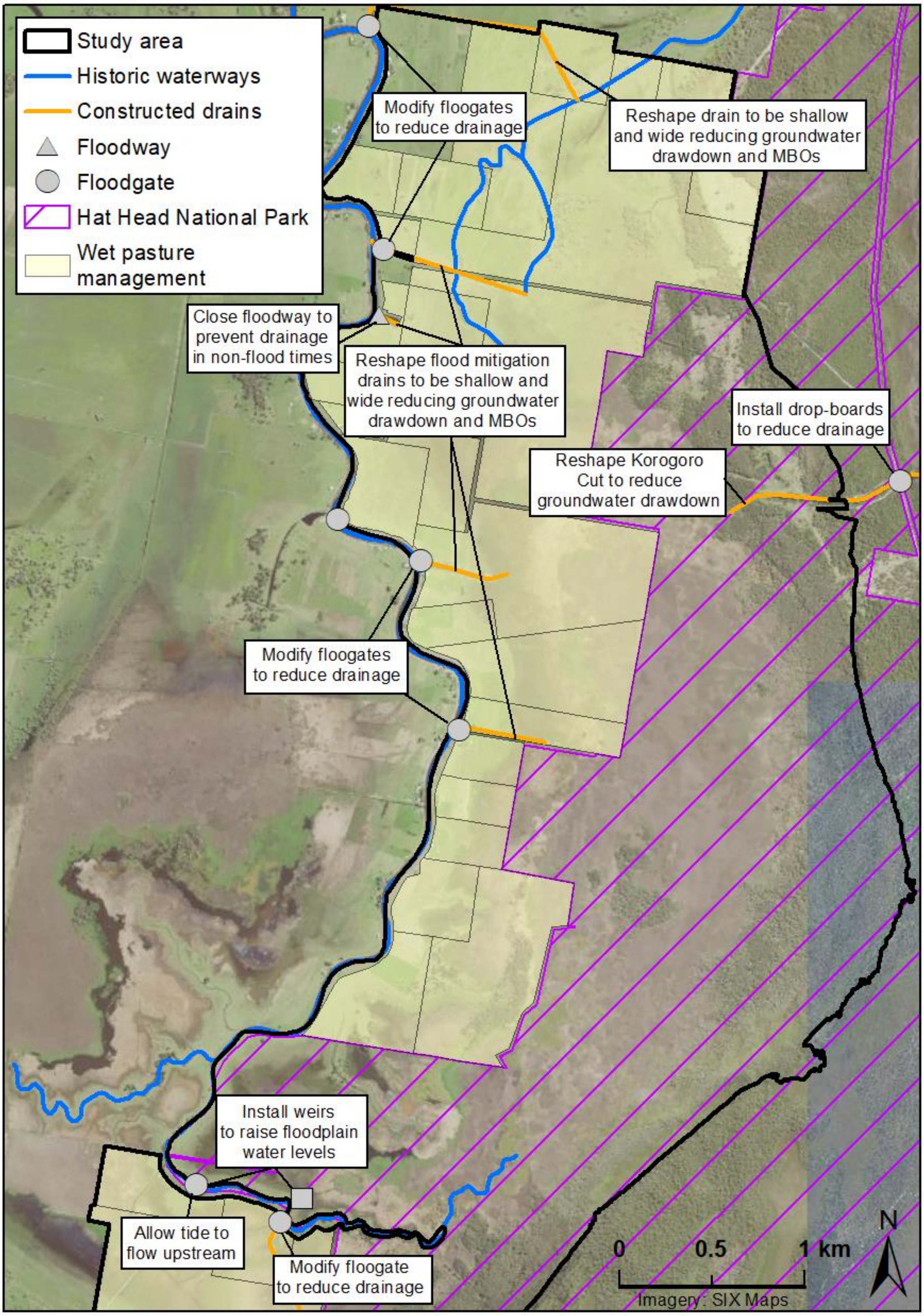


Figure 3.2: Current strategies for restoration of wetland habitat

The technical viability of these strategies has been reviewed with regard to achieving the remediation of wetland habitat at Swan Pool for improved water quality. The following recommendations are provided outlining whether the implementation of options under the current strategy would promote hydrological conditions that would be favourable for improved water quality associated with wetland habitat:

- **Weir installation should continue**. Review of water level data collected by Tulau (2013) indicated that weirs on The Lock and North Drain resulted in raised water levels across the floodplain which would promote freshwater wetland values.
- **Modifications to Korogoro Cut should be implemented**. Historically, connection of Swan Pool and Korogoro Creek would only occur for large floods (PWD, 1961). This was never a drainage pathway during day-to-day conditions so modifying the Cut to reduce groundwater drawdown would assist to restore the natural hydrology and prevent the drainage of the wetland to the west of the floodplain.
- **Reshaping flood mitigation drains should continue**. Deep drains facilitate the drawdown and drainage of groundwater. This results in a drier floodplain and increased export of acid to the estuary (from acid sulfate soils). By reshaping drains to be shallow and wide, groundwater drawdown can be reduced which allows for a wetter floodplain and reduced acid export. This strategy can be extended further by completely infilling of drains, restoring the natural wetland hydrology.
- **Modifying floodgates to reduce drainage should continue**. Floodgates act to ensure that water levels upstream are kept at the low tide level. Installing drop boards or raising the inverts of floodgates would reduce over drainage and promote freshwater wetland values across the floodplain. This strategy can be extended further by decommissioning floodgates and restoring the natural creek levees.
- **Allowing tidal flow upstream of The Lock should be implemented**. Historically the tide naturally flowed upstream of The Lock (Smith, 2002). Presently The Lock acts to keep the water level upstream at the low tide elevation. Allowing tide upstream would reduce drainage across Swan Pool and also open up the wetland for aquatic habitat. Note, particularly during dry times when the salinity within Kinchela Creek is higher, the habitat type may transition from estuarine wetlands close to The Lock, to freshwater habitats further upstream. This would mean that within Swan Pool there would be a mix of estuarine and freshwater wetland habitat.
- **Managing the Kinchela East floodway for wetland values should continue**. This would involve closing the floodway unless its operation is required during flood times. This would reduce drainage from the floodplain promoting freshwater wetland values.
- **Wet pasture management is not recommended for long-term management of Swan Pool**. Whilst minor improvements in water quality can be achieved from wet pasture management, ongoing active management requirements and water supply variability often results wet pasture practices being abandoned. Benefits are typically only realised on a paddock scale during small, frequent inundation events and have limited benefit to broadscale blackwater generation on a hydrological unit scale. Alternative strategies for management of private land that would encourage wetland habitat should be encouraged (see Section 3.8).

Overall, the current remediations strategies identified for Swan Pool have technical merit with regards to remediation of wetland habitat and improvement of water quality across the study area. It is clear, however, that the implementation of many of these options would result in a wetter floodplain which would impact the viability of current floodplain land uses.

3.3.4 Feasibility

Current remediation strategies, particularly those that seek to modify the broader floodplain hydrology, have so far been unsuccessful at Swan Pool. Rollason (2021a) identified that this is due to:

- The need for a Macleay River wide prioritisation for remediation
- Lack of clarity regarding jurisdiction across the floodplain
- Lack of private landowner support

Tucker et al. (2021) completed an extensive study of the Macleay River identifying the areas of floodplain that could be targeted to reduce poor water quality from diffuse agricultural runoff of acid (from acid sulfate soils) and blackwater (from prolonged floodplain inundation). The Kinchela floodplain was the highest priority target for reducing blackwater runoff and sixth for acid runoff. Tucker et al. (2021) clearly identified that remediation of the Swan Pool floodplain is a high priority for the health of the broader Macleay River estuary.

Management of the Swan Pool floodplain involves a significant number of stakeholders. A large proportion of the floodplain (over 1,000 ha) falls within Hat Head National Park which is managed by NSW National Parks and Wildlife Service (NPWS). Floodplain infrastructure across the floodplain is managed by Kempsey Shire Council (KSC). Other government departments and agencies, such as DPI – Fisheries and DPIE who have management responsibilities across the broader estuary, also have a vested interest in the site. Presently, a concerted effort to investigate remediation opportunities is being overseen by the Inter-agency Steering Committee.

Private landowner support at Swan Pool has been a historical barrier for site remediation. Due to the hydrological connectivity, actions that promote wetland values, such as water retention or allowing saline water past the floodgates, also reduce agricultural productivity. For example, retention of water on the Swan Pool floodplain has previously occurred through the construction of two weirs, one on the upstream side of The Lock and one on North Drain. Due to the lack of private landowner support these structures have now been removed. Review of water level data collected across the floodplain by Tulau (2013) indicated that drainage modifications at these locations have the ability to increase water levels across the Swan Pool floodplain between Kinchela Creek and Korogoro Cut. Increased water levels on this section of floodplain directly impact on agricultural productivity. Understandably, economic viability of private land is a key motive for a no-action scenario regarding the remediation of Swan Pool. Subsequently, it has been determined that the current strategy for remediation of wetland habitat is not feasible unless changes to the current floodplain land use occur.

Feasibility of the current remediation strategy also needs to consider the floodplain connectivity. To the south Swan Pool is hydraulically connected to the West Kinchela and Belmore River floodplains. Modifications to the floodplain that increase water retention or introduce tidal flows (as outlined in Section 3.3.3) are unlikely to impact West Kinchela due to a road that separates it from Swan Pool at an elevation of +0.36 m AHD. On the other hand, the same actions would likely result in increased flows through Kinchela No. 2 Drain and to the Belmore River which would affect drainage of the floodplain adjacent to Swan Pool. Further on-ground actions, such as a floodgate installed on Kinchela No. 2 Drain at the southern boundary of Hat Head National Park preventing water flowing south through the drain, would mitigate impacts to the Belmore River floodplain.

3.4 Strategy 2 – Additional floodplain drainage modifications

3.4.1 Strategy

Previous investigations have identified a range of recommendations to improve water quality at Swan Pool, as outlined in Strategy 1 (Smith, 2002; GeoLINK, 2012; Telfer and Birch, 2009b; Tucker et al., 2021). Strategy 2 focuses on identifying floodplain modifications that have not previously been identified and could be implemented to improve water quality discharging from the floodplain. Review of the floodplain hydrology has identified one area to the south of the floodplain within Hat Head National Park where additional remediation actions can be implemented without impacting the current floodplain land use.

Acquisition of land to the south of Swan Pool by NPWS has now allowed for localised remediation to occur within Hat Head National Park without impacting privately owned land. Figure 3.3 identifies a 1 km length of Kinchela No. 2 Drain within Hat Head National Park where modifications could be considered to improve water quality discharging from the floodplain. Actions that could be considered to improve water quality include:

- Construction of weirs
- Reshaping drains
- Infilling of drains

These actions would encourage water retention within Hat Head National Park promoting the natural floodplain hydrology, the creation of freshwater wetland habitat and the water quality benefits associated (Section 2.5.2).

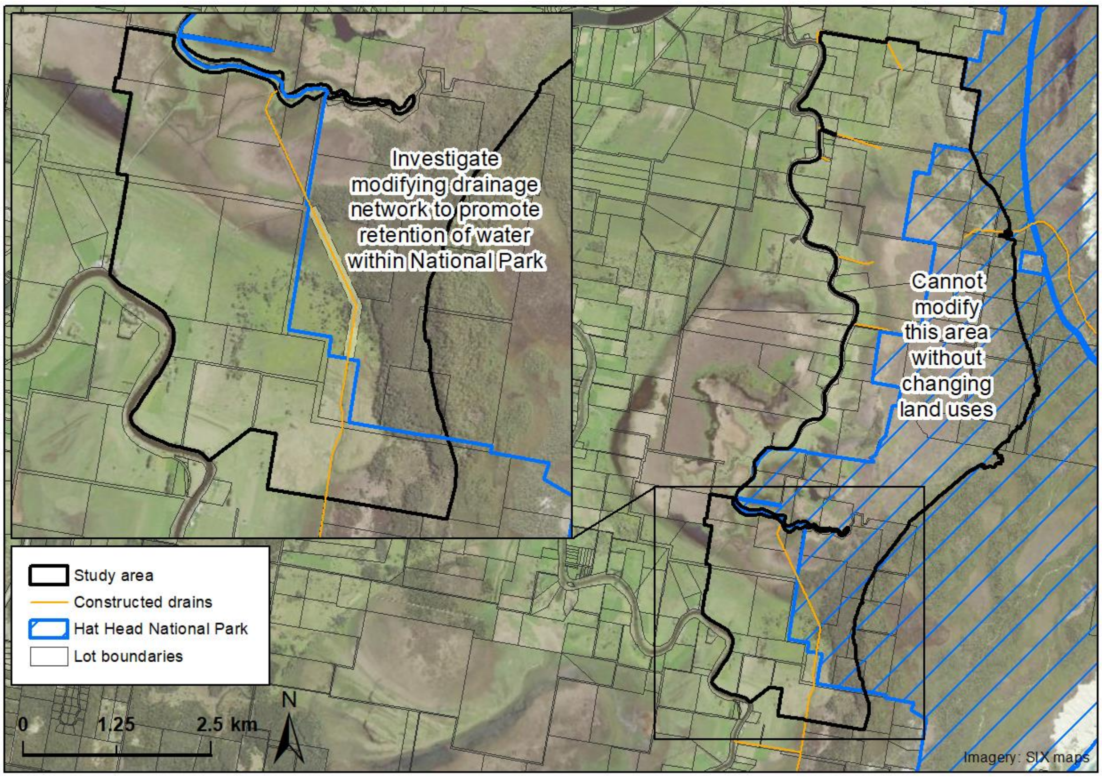


Figure 3.3: Promotion of water retention on the southern side of Swan Pool

3.4.2 Feasibility

Remediation of a smaller area within Swan Pool, as per Strategy 2, will not significantly improve the overall water quality discharging from the floodplain. Localised improvements in water quality will be negligible compared to the broader impact poor water quality generated from the remainder of the floodplain will have on the downstream estuaries. While Strategy 2 will achieve localised benefits to the environment, it will not result in the long-term remediation of the wider Swan Pool floodplain. Subsequently, implementation of Strategy 2 should only be considered a temporary solution with localised benefits and is only recommended as a step towards the larger goal of improving water quality discharging from the broader Swan Pool floodplain.

Implementation of this strategy would require additional data collection, site investigation and detailed design to determine the likely extent of changes to the existing local hydrology and ecology, and benefits to water quality. Ownership and any maintenance of any constructed infrastructure would require consideration within the Inter-agency Steering Committee, particularly NPWS.

3.5 Strategy 3 – Full freshwater restoration of the natural floodplain hydrology

3.5.1 Strategy

Large scale remediation efforts that treat the entire floodplain as one hydrological unit need to be completed to effectively improve water quality discharging from the Swan Pool floodplain. Strategy 3 focuses on the entire Swan Pool floodplain and the implementation of actions that would restore the natural floodplain hydrology and freshwater wetland habitat that existed prior to the floodplain being developed for agricultural purposes. By remediating the floodplain as a single hydrological unit, poor water quality associated with blackwater and acid discharge to the downstream estuaries can be effectively mitigated and provide long term benefits to the environment. Assessment of this strategy considers the floodplain in its current state if remediation were to occur today.

Actions that would restore the natural floodplain hydrology include (see also Figure 3.4):

- Infill artificial drains
- Decommission or remove floodgate structures
- Restore the natural creek levee banks
- Adjust the management strategy for the floodway

The Kinchela Creek floodplain, inclusive of Swan Pool, was identified by Tucker et al. (2021) as the highest risk site for low-oxygen blackwater generation on the Macleay River estuary. Restoring the natural floodplain hydrology would reduce the generation and export of blackwater to the estuary by retaining water on the floodplain creating freshwater wetland habitat. Retaining water on the floodplain results in (SCG, 2019):

- Increased growth of water tolerant vegetation reducing the likelihood and severity of blackwater
- Longer water retention times on the floodplain which allows the decomposition process of vegetation to complete and enables water to re-gain oxygen before flowing into the estuary

Additionally, by removing efficient connections between the floodplain and the downstream estuaries, when blackwater is generated, it slowly discharges from the floodplain at a rate that does not overwhelm the receiving waters assimilation capacity.

Some impacts of acid sulfate soils would also be reduced if water is retained on the floodplain. Increased water levels would prevent further oxidisation of acid sulfate soils and generation of sulfuric acid. In fact, increased saturation of soils under freshwater wetlands has been shown to neutralise soil acidity (Johnston et al., 2014). Infilling artificial drains would help to prevent the creation and mobilisation of MBOs. Note, the acidity and metal concentrations in surface water would likely persist in the long term and only decrease through dilution. There would also be an ongoing risk of further acid generation during drought periods.

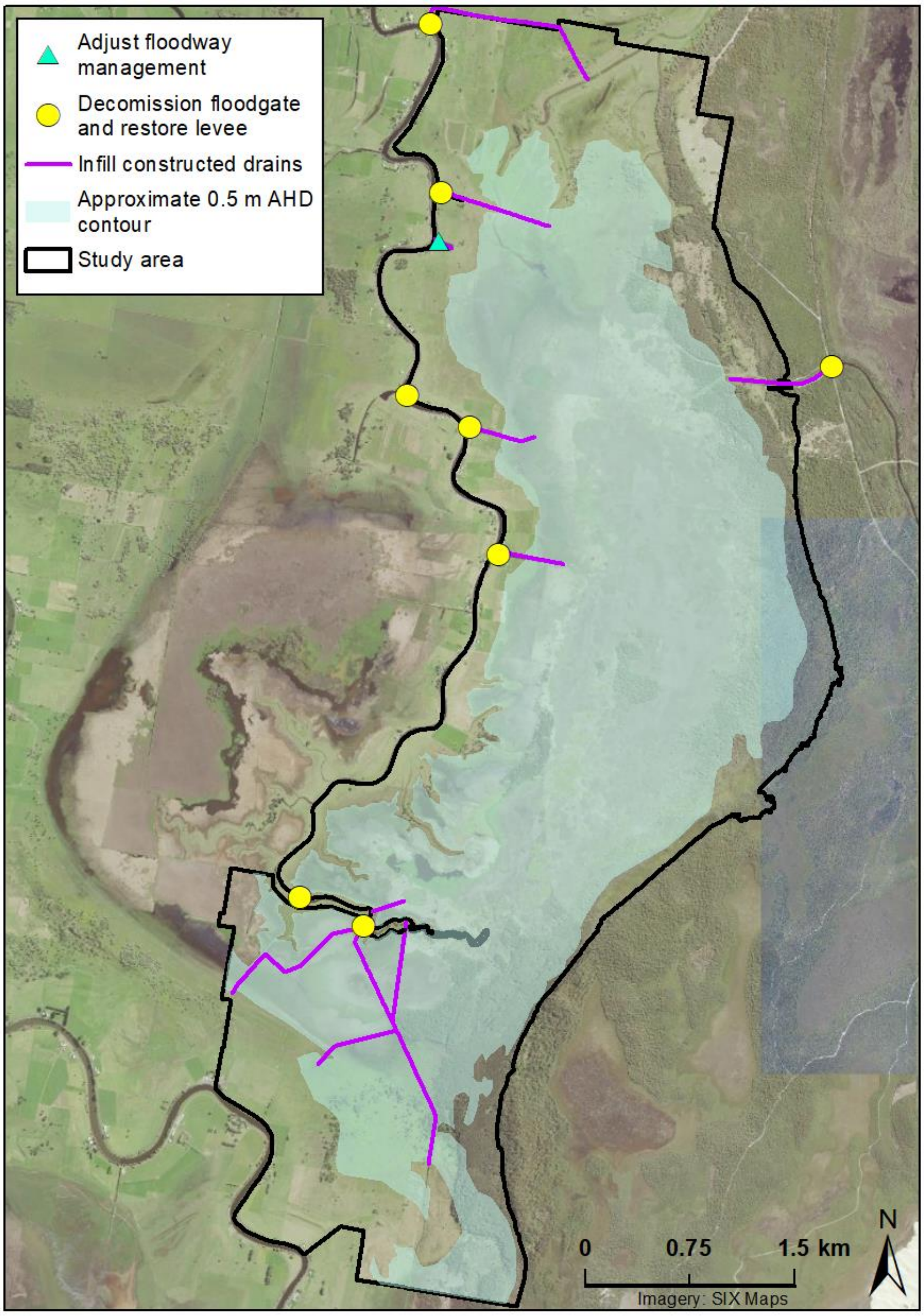


Figure 3.4: Restoration of the natural floodplain hydrology

3.5.2 Feasibility

A number of strategic changes would need to take place across the floodplain before this strategy would become feasible. Considerations that affect the feasibility of this strategy include:

- Impacts of flooding to the broader Macleay River
- Floodplain connectivity
- Susceptibility to droughts
- Land use

Modifying flood mitigation infrastructure would change flood behaviour across the broader Macleay River floodplain. Careful consideration, planning and modelling of how decommissioning and changing of flood mitigation strategies at Swan Pool would impact the wider estuary would be required.

The Swan Pool floodplain is highly connected to adjacent floodplains and as the wetland expands and contracts during wet and dry periods its extent is likely to reach up to 0.5 m AHD (see Figure 3.4) (Smith, 2002). To the north, relic channels allow flow towards Arakoon. To the south overland flow paths connect Swan Pool to West Kinchela and the Belmore River floodplain. Kinchela No. 2 Drain also provides additional connectivity to the Belmore River floodplain. By restoring the natural floodplain hydrology at Swan Pool there may be increased transport of water across these connections. Such an occurrence would unlikely be feasible as it would impact private landowners on these floodplains. Additional works to reduce this impact or a change in floodplain land use in these areas would be required before this strategy is feasible.

Restoring the natural floodplain hydrology and remediating freshwater wetland habitat will significantly improve the water quality associated with blackwater. In comparison, research indicates that freshwater wetlands are less likely to reduce the impact of acid sulfate soils (Johnston et al., 2014). While the retention of water will reduce the generation of acid and improve soil acidity, high metal concentrations and acidity in the surface water will likely persist. The floodplain is also very susceptible to droughts which would cause acid generation (Karimian et al., 2017). Additional research to understand the floodplain water balance cycle is required to quantify this. However, the impacts associated with acid sulfate soils on a remediated floodplain will not be any worse than the existing impacts. Therefore, since remediation of freshwater wetland and the natural floodplain hydrology will result in significant improvement to blackwater generation, it is a feasible strategy for improving water quality.

Restoring the natural floodplain hydrology will require a change in land use. Current agricultural practices that occur across the floodplain are unlikely to remain tenable as the floodplain becomes wetter. Until a change in land use occurs this strategy will not be feasible.

3.6 Strategy 4 - Adapt for sea level rise (freshwater)

3.6.1 Strategy

Sea level rise will provide an opportunity for adaptation measures including the creation of extensive freshwater wetlands across the Swan Pool floodplain. Where Strategy 3 focuses on the wetland extent that is possible under current hydrological conditions, this strategy (Strategy 4) focuses on how the extent of freshwater wetland habitat can be increased into the future. As floodplain drainage becomes reduced due to sea level rise, it is likely the current floodplain land uses will become increasingly unsustainable and create the opportunity for remediation of wetland habitat across larger areas of the floodplain. This would provide water quality benefits associated with freshwater wetland habitat (Section 2.5.2).

Measures that could be implemented alongside sea level rise to promote freshwater wetland habitat include:

- Installing weirs to retain water on the floodplain
- Reducing drainage from the floodplain by modifying floodgates and drains
- Managing vegetation to promote freshwater wetland species

Note, in the future sea level rise may allow higher levels of salinity to travel up Kinchela Creek. To ensure a freshwater wetland is maintained, barriers such as weirs between the tidal water and freshwater wetland would be required.

Figure 3.5 and Figure 3.6 show the area and extent of freshwater wetland which could be created as floodplain drainage reduces. Note, the approximate mean tide level is used as an indicator for freshwater wetland extent. While floodgates act to drain the upstream water level to low tide during day-to-day drainage conditions, vegetation will hold the water level up across the floodplain (Tulau (2013) found water levels on the floodplain were up to 0.3 m higher than in major drainage channels due to vegetation effects). Note, predictions for the far future (2100) sea level rise scenario indicate that reduced drainage will result in increased connectivity of Swan Pool with the adjacent floodplains to the north and south.

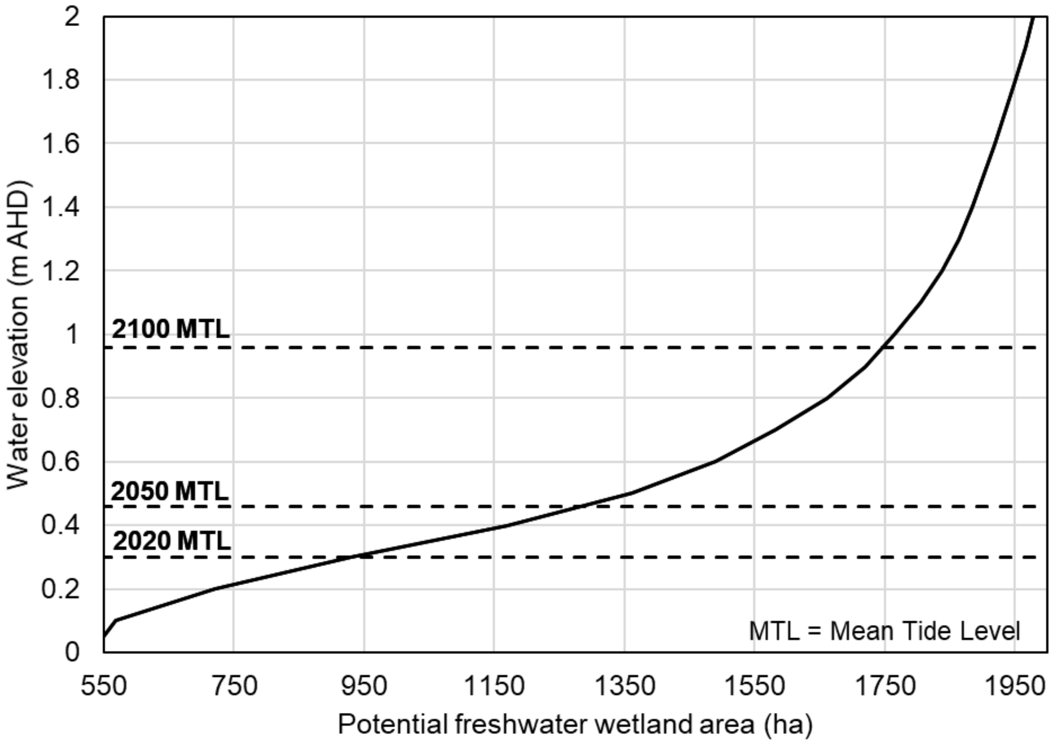
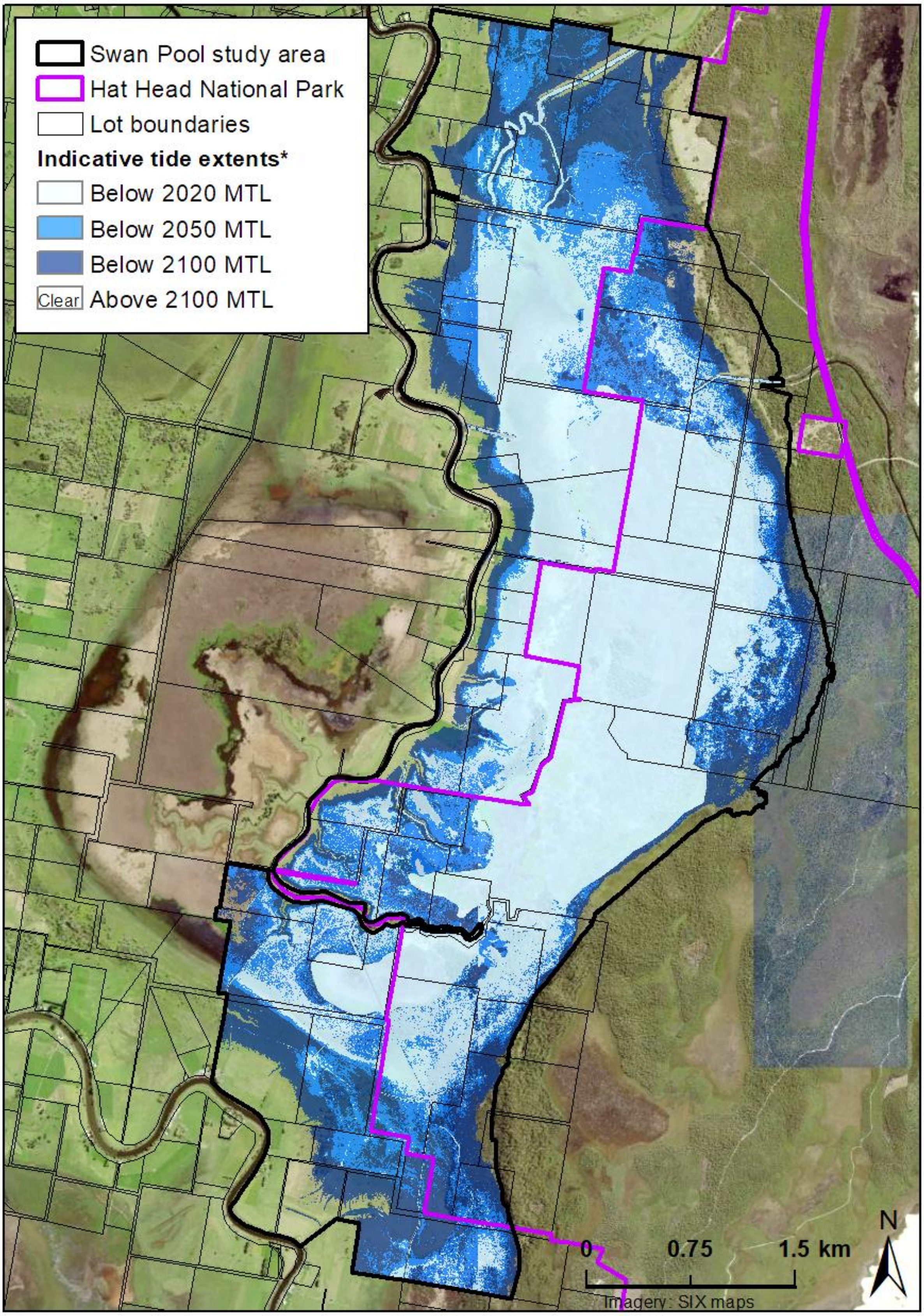


Figure 3.5: Potential freshwater wetland area across Swan Pool under sea level rise



*MTL = Mean Tide Level, where: 2020 MTL = 0.30 m AHD; 2050 MTL = 0.46 m AHD; 2100 MTL = 0.96 m AHD, see Figure 2.5.

Figure 3.6: Potential freshwater wetland extent for various water levels across Swan Pool

3.6.2 Feasibility

Increases in the low-tide elevation due to sea level rise will naturally result in reduced drainage across the Swan Pool floodplain which will impact present day agriculture (Tucker et al., 2021). Due to the nature of the hydrology at Swan Pool, the entire floodplain will be affected by reduced drainage. This is because there is a high level of connectivity across the floodplain with changes in water levels at one side of the floodplain impacting the opposite side (see Section 2). There is now an opportunity whereby transitioning the floodplain from its current land use (agriculture) to conservation will allow for remediation of the entire Swan Pool area as freshwater wetland habitat. This will allow for water quality benefits associated with freshwater wetland habitat to be fully realised. If no changes to the current land use occur, the water quality benefits provided by creating freshwater wetland habitat will be reduced and limited to within Hat Head National Park. If no changes to the current land use occur it is likely poor water quality discharging from the floodplain will persist. The feasibility and success of this strategy relies on changing the floodplain land use.

Note, considerations that affect the feasibility of Strategy 3 also apply to this strategy (see Section 3.5.2).

3.7 Strategy 5 - Adapt for sea level rise (estuarine)

3.7.1 Strategy

As the sea level rises, water levels in the Macleay River estuary and Kinchela Creek will increase. The volume and concentration of saline water that has potential to travel to the Swan Pool floodplain will also increase (Khojasteh et al., 2021). This will provide an opportunity to create estuarine wetland habitat with the associated water quality benefits across the Swan Pool floodplain. Estuarine wetlands provide some certainty around the type and persistence of the habitat created. The daily tidal ingress provides a reliable source of water making the wetland permanent, and independent of a reliance on rainfall.

Prior to floodplain drainage works, Swan Pool was linked to the Macleay River estuary at the upstream extent of Kinchela Creek (Smith, 2002). Particularly during drought times, the tide would have flowed into Kinchela Creek and onto sections of the Swan Pool floodplain. A transition between estuarine and freshwater wetland habitat would have occurred with its extent fluctuating based on the rainfall climate (Figure 3.7 - A). Restoration of this type of connection could be implemented by permanently opening or removing the Kinchela Creek floodgates and by implementing various modifications to The Lock, such as:

- Installing automatic tide gates
- Installing sluice gates
- Winching open The Lock floodgates
- Removing The Lock structure

These modifications would seek to restore the natural wetland habitat that occurred across Swan Pool prior to floodplain drainage works. Alternatively, sea level rise would allow for extensive inundation of the Swan Pool floodplain with saline tidal water to create an estuarine wetland. Since flood mitigation drains and infrastructure have been installed, there are now six additional connections between Swan Pool and the Macleay River and Korogoro Creek estuaries. Removing floodgate infrastructure that holds back the tide could result in the creation of extensive estuarine wetland across the Swan Pool floodplain as saline water inundates the floodplain. Whereas prior to floodplain drainage estuarine wetlands would have only existed in the vicinity of the upstream extent of Kinchela Creek, this option would result in the majority of the floodplain becoming an estuarine wetland (Figure 3.7 - B).

3.7.2 Feasibility

Hydrologically, creating estuarine wetlands at Swan Pool will become increasingly feasible as sea level rise occurs and the potential of the estuary to deliver tidal water to the floodplain increases. This will be at the expense of current private land use practices that occur across the floodplain. In addition to causing increased inundation across the Swan Pool floodplain, creating estuarine wetlands will also result in saline tidal water across the floodplain which will prevent current agricultural practices that require freshwater conditions. Subsequently, unless a change in land use occurs this strategy will not be feasible.

Restoring the natural floodplain hydrology and allowing an estuarine connection through Kinchela Creek only (Figure 3.7 - A) would be the preferred method for remediation of Swan Pool within this strategy. Under this option an estuarine wetland would be established in the southern areas of the Swan Pool floodplain and transition to a freshwater wetland in the northern sections of the floodplain. This option would preserve the values associated with the existing freshwater wetland habitat while improvements to water quality associated with blackwater and acid would still be realised. NPWS (1998) identified that "Swan Pool and the other wetlands that remain are of critical importance for the conservation of wetland plant and animal communities."

There is currently limited data regarding salinity levels within Kinchela Creek which establishes uncertainty in determining how estuarine habitat may establish across Swan Pool in the future if Strategy 5 is adopted (see Section 4.5.4). Additional investigations are required to determine the long-term salinity levels within Kinchela Creek and whether they are high enough to allow the establishment of estuarine wetlands across the floodplain. Additional data collection and investigation of estuarine salinity dynamics under sea level rise may be required.

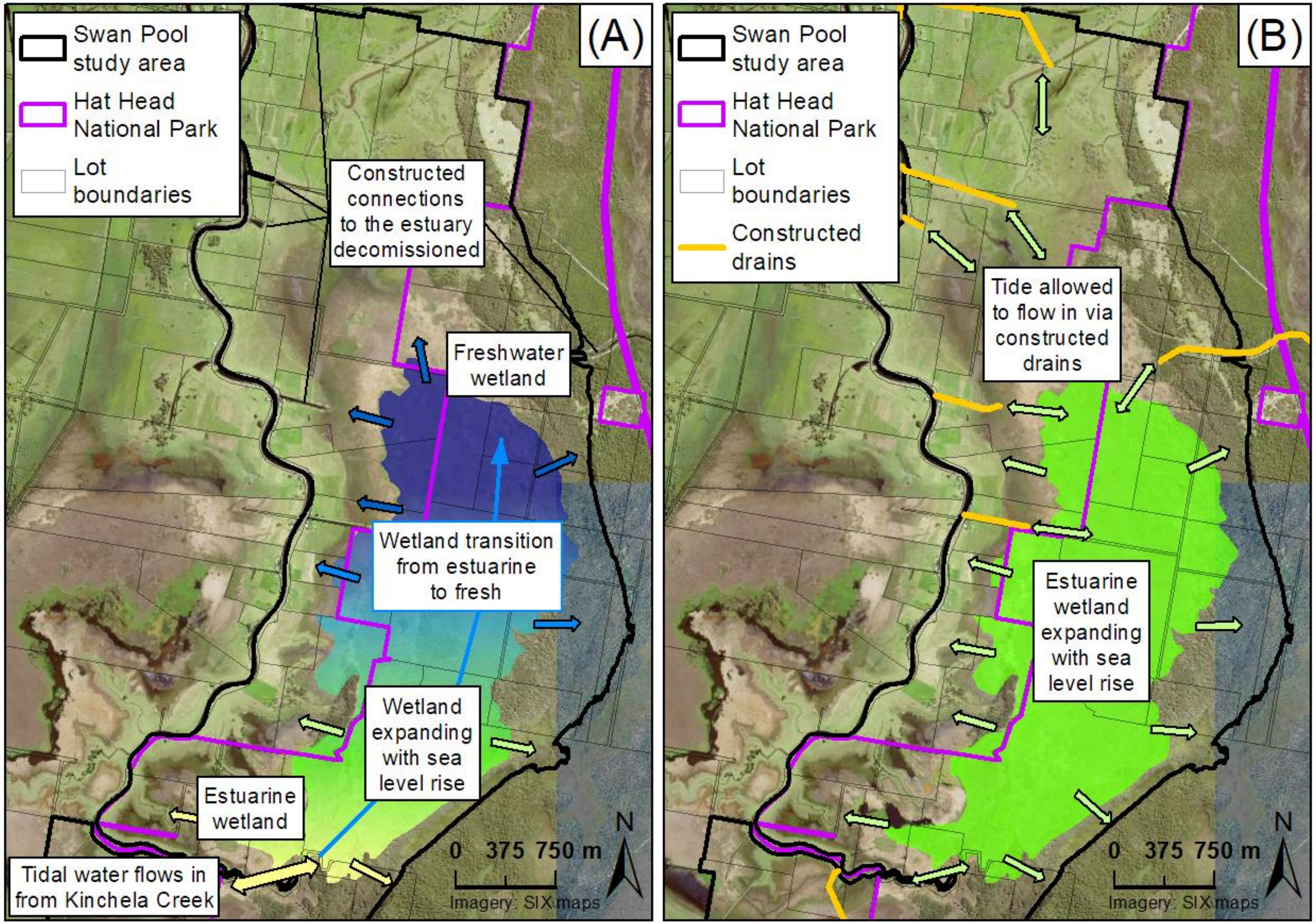


Figure 3.7:Remediation of Swan Pool to natural hydrology (A) or extensive (B) estuarine wetland

3.8 Changing floodplain land use

3.8.1 Change pathways

As identified in Strategies 1 to 5, large scale remediation actions are unlikely to succeed at Swan Pool without changing the existing land use of private land with the connected hydrological unit area. To date, the greatest barrier for remediation of Swan Pool has been current floodplain land use, which requires continued drainage of the backswamp. While a large proportion of the floodplain is now managed for environmental values within Hat Head National Park, the remainder is utilised for agriculture such as grazing. Unfortunately, management of Swan Pool for both environmental values (including the creation of wetland habitat that improves water quality) and current agricultural practices is not possible due to the connectivity of the floodplain (see Section 2). Actions that would increase the value of wetland habitat would result in increased water levels across the floodplain which in turn reduce agricultural productivity. Similarly, drainage of the floodplain which assists with agricultural productivity has resulted in the reduction of environmental values and creation of poor water quality which discharges from the floodplain and impacts the downstream estuaries.

Presently, despite 58% of the land below 0.5 m AHD upstream of The Lock being within Hat Head National Park, the system is managed for agricultural benefit. This is to the detriment of the wetland habitat potential of the floodplain and water quality impacts to the wider estuary. In order to rehabilitate wetland habitat and improve the water quality that is exported from the floodplain, the land use needs to change to environmental protection.

Previous attempts to change the land use across Swan Pool have focused on the purchase of freehold land owned by private landowners. There has been little progress in this regard since it was first recommended by Smith (2002). Land zoning for some low-lying areas of the floodplain was changed in 2013 to environmental conservation (see Appendix B), however, unless the land is sold there is no tangible change to land management practices.

While the purchase of land by the government and merging with Hat Head National Park would achieve a change in land use, there are also a number of other mechanisms that could be pursued to achieve the same outcome. Increasingly, the value of land for biodiversity, conservation and carbon sequestration is being realised. Using such a mechanism may allow for progress with the remediation of Swan Pool with the land remaining in private ownership. There are a number of pathways that may allow for the economic viability of privately owned land to occur simultaneously with a change in land use, albeit without the sale of land being required. Examples of pathways that could be further investigated, include:

- Biodiversity Stewardship Agreement under the NSW biodiversity offset scheme
- Biodiversity Conservation Trust conservation management program
- Biodiversity Conservation Trust management partners program
- Australian Government Clean Energy Regulator emissions reduction fund
- Australian Government Clean Energy Regulator climate solutions fund

Privately owned properties where a change in land use is required to ensure remediation at Swan Pool has been identified in Figure 3.8. Properties identified are based on the hydrological connectivity of the floodplain (and therefore based on available LiDAR survey data) and in many cases the land use would only need to change in the low-lying areas of these properties. As sea level rise occurs, the extent of land that will be required to change land use to meet environmental outcomes (change to wetland habitat that improves water quality) will need to increase. This has been reflected in the prioritisation of properties where a change in land use is required. Note, it is likely that the agricultural productivity of land above 1 m AHD will remain tenable into the longer term.

Smith (2002) identified that land under 0.5 m AHD will be impacted if wetland values are established across the floodplain. The sea level rise assessment indicates that in the long term this will not be the case and that land up to 1.0 m AHD will likely be affected. In this case, the connectivity across the Swan Pool floodplain will also occur between the floodplains to the north (towards Arakoon) and south (to West Kinchela and Belmore River) outside of the study area. This will require a broader strategy for the management of floodplains and wetlands across the Macleay River estuary.

3.8.2 Further considerations

Changing the floodplain land use is entirely dependent upon the support of private landowners on the Swan Pool floodplain. Without their support, actions to change the land use at Swan Pool are only likely to occur when sea level rise causes reduced drainage and existing agriculture to be unsustainable.

Progress is also dependent upon the available alternate pathways that allow a change in floodplain land use without the need to acquire land. It is likely that unless alternative pathways are economically viable compared to the current land use on the floodplain they will not succeed. The success of alternative pathways to change floodplain land use may also be dependent upon support from government entities such as the Biodiversity Conservation Trust or the Clean Energy Regulator.

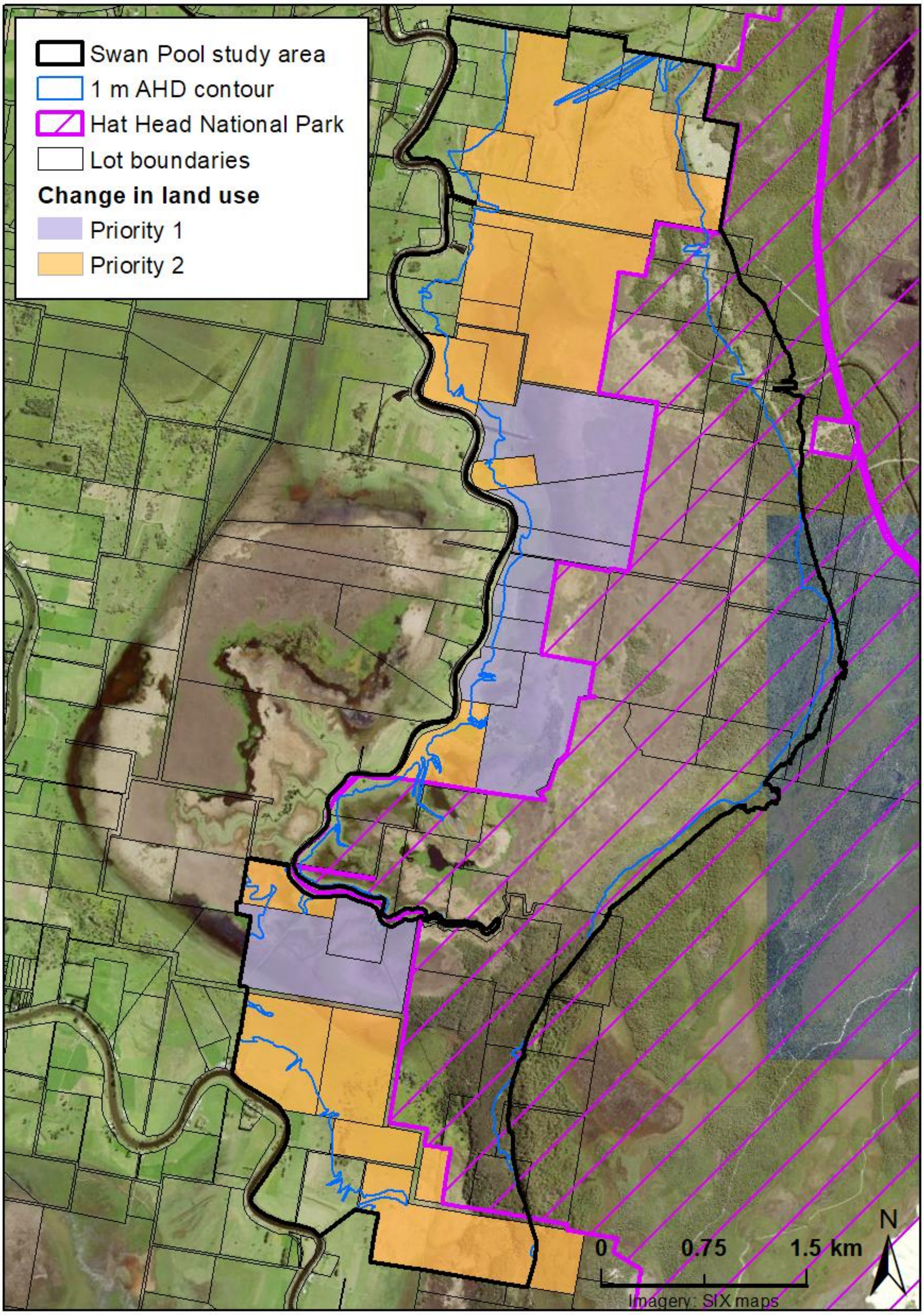


Figure 3.8: Identification of privately owned properties that require a land use change to facilitate large-scale remediation of Swan Pool

4 Remediation strategy assessment

4.1 Preamble

Remediation of wetland habitat across Swan Pool to improve water quality discharging from the floodplain contains a number of benefits, risks, constraints, and unknowns. The following section identifies and discusses each of these (Table 4.1).

Table 4.1: Benefits, risks, constraints and unknowns

Benefits	**Risks**
Improved water quality (see also Section 2.5)	Vegetation die off
Ecosystem services	Methane emissions
Carbon sequestration (teal and blue carbon)	Acid storage and generation
Wetland migration	Change in ecology
Removal of habitat barriers	Economic risk
Constraints	**Unknowns**
Funding	Future sea level rise extent
Jurisdiction	Future rainfall climate
Ownership of remediation	Private landowner support
Flooding	Salinity in Kinchela Creek

4.2 Benefits

4.2.1 Improved water quality

Restoring the natural floodplain hydrology and creating wetland habitat would result in the reduction of poor water quality associated with acid and blackwater being exported from the floodplain to the downstream estuaries. The benefits of wetlands for water quality have previously been discussed in Section 2.5.

4.2.2 Ecosystem services

In addition to improving water quality, wetland habitat provides numerous ecosystem services (sometimes referred to as co-benefits), including (Mitsch and Gosselink, 2015):

- Provisioning services – products derived from ecosystems (e.g. food, water and other raw materials)
- Regulating and maintaining services – Benefits derived from the regulating capacity of ecosystem processes (e.g. carbon storage, flood mitigation, biodiversity, etc.)

- Cultural services – Non-material benefits from ecosystems (e.g. recreation, tourism, cultural heritage, etc.)

A literature review completed by Harrison et al. (2021) identified that the ecosystem services provided by freshwater wetland habitat can be valued at $20,667/ha/year. Similarly, they valued estuarine wetland habitat at $27,147/ha/year for mangrove habitat and $21,806/ha/year for saltmarsh habitat. A site specific assessment for Big Swamp on the NSW mid-north coast found that the benefits of remediation of estuarine wetland habitat outweighed the costs in the long term by 7 to 1 (Harrison et al., 2019).

As sea level rise occurs the area available for wetland habitat across Swan Pool will increase (Section 3.6). This can be translated to an increase in the value of ecosystem services provided by wetland habitat. Figure 4.1 and Figure 4.2 show the increase in value of ecosystem services for freshwater wetland and mangrove habitat as the water level across the wetland increases, respectively. Note, there is also an optimum elevation to maximise mangrove habitat values as water would become too deep for mangroves to grow.

Figure 4.1 and Figure 4.2 provide indicative first-pass estimates of wetland value based on a number of high level assumptions, such as:

- Existing LiDAR data is correct (which we know overestimates ground elevation – see Appendix B3)
- Wetland habitat would occur across the entire area
- Water levels across the floodplain
- There is no tidal attenuation
- Mangroves will only grow in areas where the water depth is less than 0.5 m (note: assumption based on approximation of survey data outlined by Sadat-Noori et al., (2021))
- Salinity levels will be high enough to allow estuarine habitat to grow across the floodplain

A site specific economic analysis paired with dynamic hydrodynamic modelling would be required to reduce uncertainty.

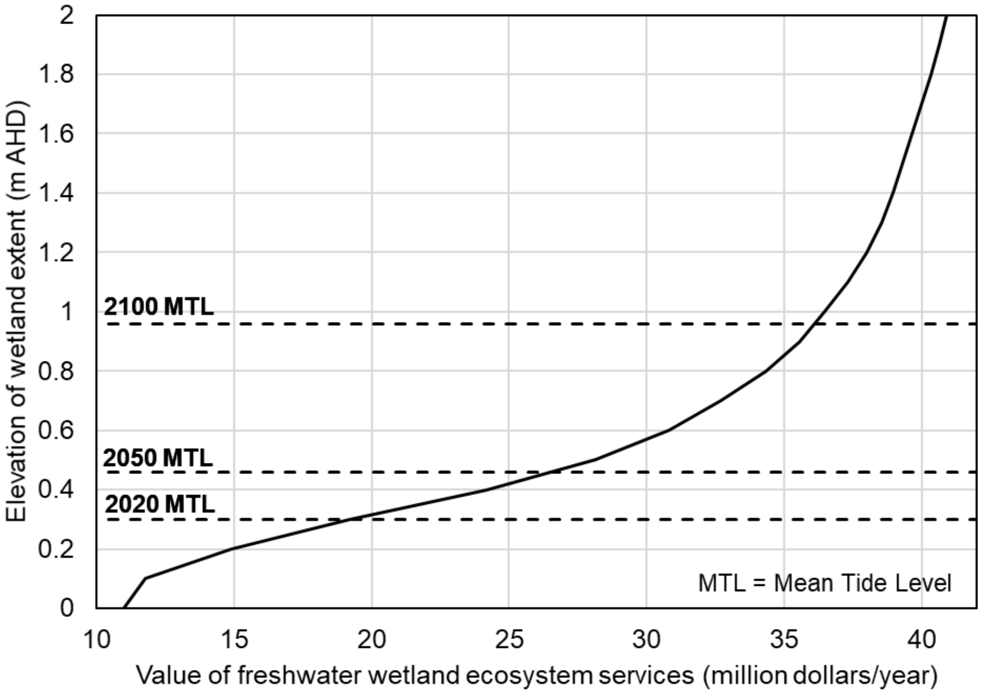


Figure 4.1: Indicative estimate of the yearly value for freshwater wetland ecosystem services at Swan Pool for different wetland elevation extents (based on Harrison et al., 2021)

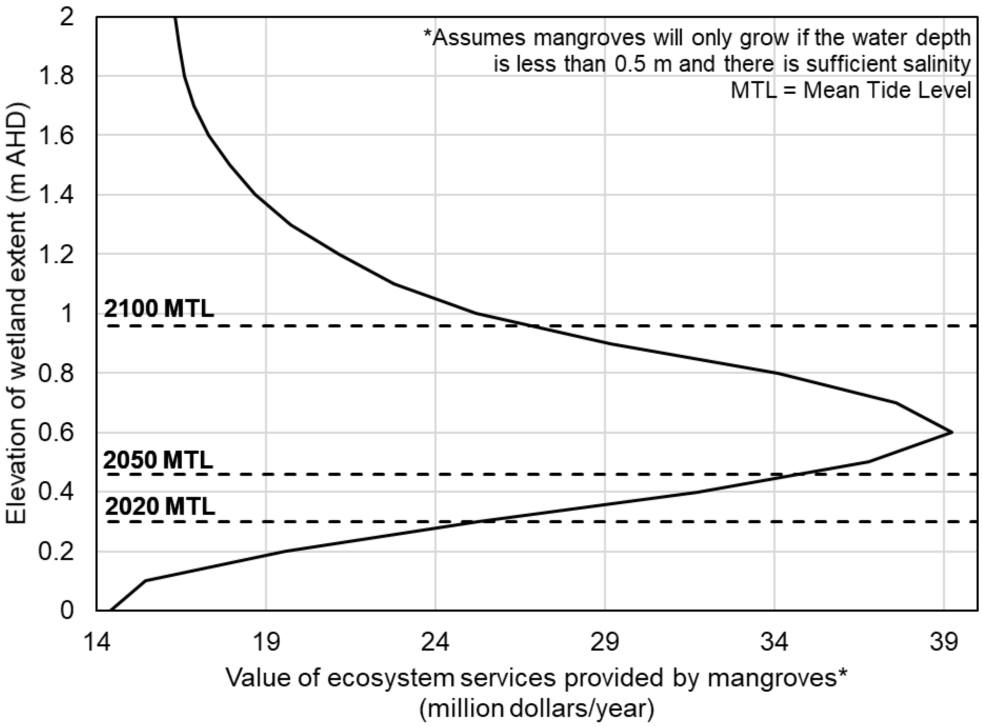


Figure 4.2: Indicative first-pass estimate of the yearly value for ecosystem services provided by mangroves at Swan Pool for different water elevation extents (based on Harrison et al., 2021)

4.2.3 Carbon sequestration (teal carbon)

One of the benefits of creating freshwater wetland habitat is carbon sequestration. Carbon stored within freshwater wetlands is referred to as “teal carbon”, as opposed to “blue carbon” which is the carbon stored within saline and intertidal ecosystems (Nahlik and Fennessy, 2016). Teal carbon can be found in vegetation as well as the soil underlying freshwater wetlands (Limpert et al., 2021). As vegetation undergoes photosynthesis, it captures carbon dioxide (CO_2). When freshwater vegetation dies, the carbon it has captured is stored in the soil structure as anoxic (i.e. zero oxygen) conditions that occur in wetlands prevent the release of carbon as would otherwise naturally occur (Pearse et al., 2017). Over time, this enables carbon to build up within freshwater wetland ecosystems.

Teal carbon can be considered a regulating ecosystem service. In their investigation, Harrison et al. (2021) identified that carbon storage alone in freshwater wetlands has a value of $84/ha/year. Note, compared to the value of blue carbon this does not consider carbon that is already stored within wetlands. Another factor that would also affect the price of teal carbon is the social value it provides, which is not considered in the valuation presented here. Despite this, the value of carbon sequestration is important when considering the roll estuaries will play in addressing the challenges of climate change. Currently there is not a defined method for the assessing sequestration of teal carbon for emission reduction offsets.

4.2.4 Carbon sequestration (blue carbon)

Benefits of carbon sequestration are also realised in estuarine wetland habitat. Blue carbon refers to the carbon which is stored in estuarine wetland habitats, such as mangroves, saltmarsh and seagrass (Macreadie et al., 2017). Blue carbon habitat sequesters carbon through two mechanisms in a similar manner to freshwater wetlands. First, as vegetation grows, it captures and stores carbon. Secondly, as vegetation dies, anoxic conditions trap the carbon it has stored in the soil preventing its release to the atmosphere (Lovelock et al., 2014). Carbon sequestration rates depend upon individual plant species (Serrano et al., 2019).

By comparison, the benefits of creating blue carbon are much higher than teal carbon. Harrison et al. (2021) identified that the climate regulating ecosystem service provided by blue carbon alone is worth $17,280/ha/year for mangrove habitat and $5,040/ha/year for saltmarsh habitat. This is based on values determined by Serrano et al. (2019) for established habitats and accounts for the value associated with avoided carbon emissions, stored carbon, and ongoing carbon sequestration. Comparatively, Carnell et al. (2019) valued the carbon sequestration of mangrove habitats without considering avoided emissions and stored carbon at $88/ha/year. Presently, the Australian Government Clean Energy Regulator is developing a method for remediation of blue carbon habitat which will allow carbon storage projects under the emissions reduction fund (CER, 2021). The draft method has been released and is currently in the technical expert review and public consultation phase.

4.2.5 Wetland migration

As sea level rise occurs, many existing wetland habitats will be lost due to barriers preventing their horizontal and vertical migration (Sadat-Noori et al., 2021). In the future Swan Pool could be a strategic location within the wider Macleay River estuary where intertidal wetland habitats can migrate, offsetting loss of wetland at other locations in the estuary. Due to the hydrological conditions at Swan Pool (Section 2), provided land use is changed, the site would be suitable for establishment of intertidal wetlands. Note however, further investigations are required to determine if salinity levels would be high enough within Kinchela Creek to establish intertidal wetland habitat (see Section 4.5.4).

4.2.6 Removal of habitat barriers

Floodgates and weirs reduce the habitat available for aquatic life. The removal of these barriers, as is proposed in Strategy 4, will significantly increase the area of habitat available.

4.3 Risks

4.3.1 Vegetation die off

During the initial stages of works to remediate wetland habitat there will be a level of vegetation that dies off and has potential to cause blackwater. This could occur for freshwater wetland creation as previously dry areas become inundated, or for estuarine wetland creation as vegetation changes to species that are tolerant to saline water. If hydrology is altered significantly there will be an initial period of change, with long term improvements in blackwater outweighing the initial impact.

4.3.2 Methane emissions

Freshwater wetland habitat is known to be a large emitter of methane which is a greenhouse gas that contributes to global warming. Mitsch et al, (2013) showed that while this is the case, most freshwater wetlands reduce the impacts of climate change due to the levels of carbon sequestration outweighing the methane emitted.

4.3.3 Acid storage and generation

Acid generated by the oxidisation of acid sulfate soils that has already occurred across Swan Pool will still exist into the future even with freshwater wetland restoration. Johnston et al. (2014) showed that improvements in pH may occur within the soil structure, however, high iron levels would be likely to persist in surface water and cause acidity. Furthermore, the site is likely to be susceptible to drought (Karimian et al., 2017) which, once the site dries out, may cause further oxidisation of acid sulfate soils. Further investigations are required to identify the water balance across the floodplain to determine how severely droughts may impact a restored site.

4.3.4 Change in ecology

The remediation to full estuarine wetland habitat may result in a change in the ecology across the floodplain. The impacts of this would need to be investigated before this strategy is pursued further. For this reason, the recommended estuarine remediation option is to restore tidal flows through the upstream extent of Kinchela Creek so that the historical connectivity of the system is restored.

4.3.5 Economic risk

Remediation of wetland habitat has the potential to pose an economic risk to private landowners on the floodplain if they wish to continue using the floodplain for its current land use (e.g. grazing). Increased inundation is likely to impact on the growth of pasture grasses. Impacts on pasture growth will likely result in a loss of agricultural productivity.

It is recommended that a change in floodplain land use occur prior to any remediation works or compensation to impacted landholders, to ensure there is no economic impact due to the loss of agricultural productivity.

4.4 Constraints

4.4.1 Funding

Works required to remediate Swan Pool will incur various costs. Examples of these costs include:

- Land use change
- Acquisition of land
- Detailed design of floodplain modifications
- Environmental assessment and management plans
- Modifications to floodplain infrastructure
- Consultation with private landowners
- Long-term management of the floodplain (e.g. weed and pest control)

4.4.2 Jurisdiction

Rollason et al. (2020a) identified that there was a lack of clarity regarding jurisdiction of floodplain management which has hampered remediation efforts. This is because the floodplain does not fall within the jurisdiction of one single entity. It is recommended that the government working group continue to provide leadership in forwarding the progress of remediation at Swan Pool with joint responsibility for floodplain management as relevant for each stakeholders purview.

4.4.3 Ownership of remediation

Current remediation efforts have been ad-hoc and lacked a whole-of-system approach that considers the entire Swan Pool floodplain. It is recommended that ownership of remediation be allocated so that there is clear accountability for improving water quality at Swan Pool. Without a clear ownership of remediation, it is unlikely that a whole-of-system approach will be successful.

4.4.4 Flooding

Any changes to the floodplain should be considered with respect to flooding. Changes, particularly to flood mitigation infrastructure, may have a number of consequences and detailed modelling should be completed to ensure any changes do not increase the risk or severity of flood events.

4.5 Unknowns

4.5.1 Future sea level rise extent

While it is known that sea level rise will occur, the extent of this in the long term becomes less certain. Predictions of sea level rise used in this study were based upon modelling for the Macleay River estuary outlined by Tucker et al. (2021) who used the sea level values defined by Glamore et al. (2016) for NSW (+0.16 m for the 2050 scenario and +0.67 m for the 2100 scenario, referenced to the 2020 sea level elevation). These values are based upon the representative concentration pathway (RCP) specified by the Intergovernmental Panel on Climate Change (IPCC) for the highest emission scenario (referred to as RCP 8.5) (IPCC, 2014). Research into climate change is still ongoing, and recently the IPCC has provided updated guidance (IPCC, 2021). RCPs have now been replaced with shared socioeconomic pathways (SSPs) which take into consideration a larger range of factors that may contribute to sea level rise. For the purpose of this investigation RCPs and SSPs can be considered comparable, however, it is worth noting that predictions for sea level rise will most likely improve into the future. As the world moves to mitigate the impacts of climate change these will also be included within climate models and allow for more accurate predictions of sea level rise.

IPCC (2021) have noted with high confidence that between 1901 and 2018 there has been an increase in mean sea level of 0.20 m. They also noted that for SSP-8.5 there is likely to be between 0.63 and 1.02 m of sea level rise by 2100.

4.5.2 Future rainfall climate

Climate change has resulted in changes to rainfall patterns which will impact the hydrology at Swan Pool. Changes in rainfall patterns will mean that the historic wetting and drying of the floodplain may be altered and, in the future, the same patterns may not persist. Heimhuber et al. (2019) noted that climate change will result in:

- Minimal changes to long-term rainfall averages
- An increase in the intensity of extreme rainfall events (i.e. more rainfall over a shorter duration)
- An increase in the number of dry days

Further investigations are required to determine how these changes will impact Swan Pool. Additional investigations that look at modelling the water balance of the site using climate change scenarios would assist in determining possible changes to the wetting and drying of the floodplain.

4.5.3 Private landowner support

The willingness of private landowners to sell their properties, change land use on their properties, or take up alternative pathways (e.g. compensation, offset programs) is still unknown. The willingness of private landholders to change existing land use has significant implications for the feasibility of large scale change at Swan Pool.

4.5.4 Salinity in Kinchela Creek

Review of existing salinity data highlights that there is currently a data gap regarding salinity within Kinchela Creek. A number of investigations have made observations regarding salinity, however, these have been short-term only:

- Smith (2002) identified that tidal water was able to flow up Kinchela Creek and onto the Swan Pool floodplain, however no salinity data was provided
- Allsop and Kadluczka (2004) measured salinity levels over one day, finding water in the upstream extent of Kinchela Creek was relatively fresh (<1 ppt)
- Ad-hoc measurements collected by Tucker et al. (2021) found that salinity at Hoffman's Drain was approximately 10 ppt during drought conditions
- Mapping of estuarine macrophytes (such as mangroves) does not indicate any growth within Kinchela Creek as would be expected in estuarine conditions (Creese et al., 2009)

These observations do not provide sufficient information to develop an understanding of how salinity in Kinchela Creek behaves now or into the future.

5 Recommendations

5.1 Preamble

Assessment of remediation strategies identified that it is feasible to improve water quality that is discharging from the Swan Pool floodplain to the downstream estuaries (Section 2.5). The preferred method for remediation was identified as rehabilitating the natural floodplain hydrology and creating wetland habitat. While remediation of wetland habitat is technically achievable, the current floodplain land use remains a significant barrier to remediation and achieving broadscale change.

The following section outlines recommendations for progressing remediation of Swan Pool. Note, a number of recommendations have been provided throughout this report, however, this section specifically provides recommendation for the next steps required to progress remediation. These steps are shown in Figure 5.1.

Figure 5.1: Recommendations for a staged approach for the remediation of Swan Pool

5.2 Recommendation 1 – Administration and planning

A number of administrative and planning objectives will need to be achieved to progress remediation at Swan Pool. These include:

- Identifying ownership of remediation outcomes
- Establishing a funding framework
- Establish a pathway to change land use
- Determining if there is willingness from private landowners to change land uses
- Determine the framework for management of wetland habitat
- Complete required additional studies or administrative prerequisites

For remediation of Swan Pool to progress there has to be clear responsibility identified for who will lead remediation actions. This entity will oversee the overarching remediation strategy and liaise between the multiple stakeholders at Swan Pool to ensure that remediation progresses.

A clear funding stream needs to be established for the remediation of Swan Pool. Remediation efforts will require capital and maintenance expenditure. It may be required that economic analysis (such as a cost benefit analysis (CBA)) is required to secure funding.

A pathway that will allow for land use change to occur and be economically viable needs to be established. Pathways should consider options such as biodiversity, carbon sequestration, or conservation offsets. Alternatively, if land acquisition is to occur the long-term tenure needs to be considered.

Private landowners need to be consulted to determine if there is a pathway forward to change the land use at Swan Pool. Unless a change in land use occurs, remediation of Swan Pool will not be possible. Consultation with landowners should discuss all options including acquisition or environmental offset of their property.

Once a pathway for establishing a change in land use is developed, the framework for how land will be managed needs to be considered. Management of wetland habitat may be best implemented by one single entity, such as NPWS, despite having multiple landowners.

Changing land use at Swan Pool and restoration of the natural hydrology will require a number of additional investigations or management actions to be completed. Examples of additional considerations that may be required include; environmental assessments, flood impact assessments, amendments to the Local Environmental Plan (LEP), and economic justification. Note, a timeline for when these management considerations are addressed should be developed. Some actions, such as a flood study, may be better conducted following design of on-ground remediation actions.

5.3 Recommendation 2 – Data collection, assessment of preferred strategy, and detailed design

Further investigations to develop a detailed understanding of the Swan Pool floodplain hydrology require additional and improved data. As a priority topography, water level and salinity data should be collected. Existing LiDAR survey data inadequately represents areas of the floodplain where there is dense vegetation or surface water. Other surveys that provide topography data do not cover the full extent of the floodplain. There is limited water level and salinity data across the floodplain to accurately characterise present day hydrology dynamics and inform future hydrology in detail. The review of existing data (see Appendix B) also identified a number of other data gaps which would provide valuable information for remediation of the site. Subsequently, data collection should focus on collecting:

- Accurate topographic (LiDAR)/bathymetry data for low-lying areas of the Swan Pool floodplain
- Long-term water level timeseries data across the Swan Pool floodplain and receiving waters
- Long-term water quality data for Kinchela Creek (including pH and salinity data)
- Cross-section data for flood mitigation drains and Kinchela Creek upstream of The Lock
- Invert elevation for Kinchela No. 2 Drain
- Discharge at drainage points across the Swan Pool floodplain
- Groundwater inflow data
- Updated vegetation/habitat data

Additional data collection would be able to inform the detailed assessment of a preferred management strategy. As part of this process detailed numerical modelling of the site may need to be completed. Modelling would inform the long-term management of the site identifying the feasibility of strategies such as the creation of estuarine wetland habitat. Other factors such as the implication of changes to the flood mitigation scheme would need to be considered as part of these works. Investigations could be completed to determine the balance between freshwater and estuarine systems that would provide the highest value to the downstream estuaries. This step should be completed in consultation with the relevant stakeholders.

Once a detailed assessment determining the preferred remediation strategy for Swan Pool has been completed, the exact nature of on-ground works required to remediate Swan Pool can be identified. The goal of the detailed design process should identify the on-ground works that are required to facilitate remediation of the site.

5.4 Recommendation 3 – Land use change

Changing the land use at Swan Pool is the single most important objective that needs to be achieved before large-scale remediation of the site can occur. Unless the land use changes, on-ground works that restore the natural floodplain hydrology and create wetland habitat will not be possible.

Once a pathway to change the land use at Swan Pool has been identified, the actions that would facilitate the change in land use should take place.

5.5 Recommendation 4 – Implementation

Implementation of on-ground works to remediate the natural hydrology of the Swan Pool floodplain and create wetland habitat should be completed in a strategic manner to ensure that there are minimal environmental impacts. Works that may be required have been discussed throughout this report.

5.6 Recommendation 5 – Monitoring and adaptive management

A long-term monitoring program for Swan Pool would allow improvements in water quality to be demonstrably validated. Monitoring data would allow for informed adaptive management of the site into the future. It would identify where further improvements in the management of the site may be possible or required. Adaptive management should be considered as a cyclic process that continually seeks to improve the environmental values of the Swan Pool floodplain into the future (Figure 5.2).

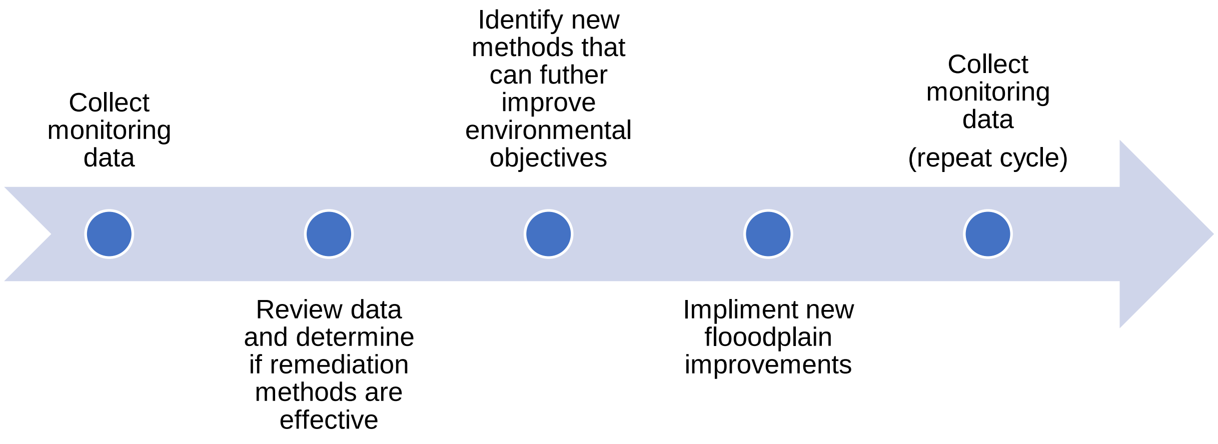


Figure 5.2: Adaptive management cycle

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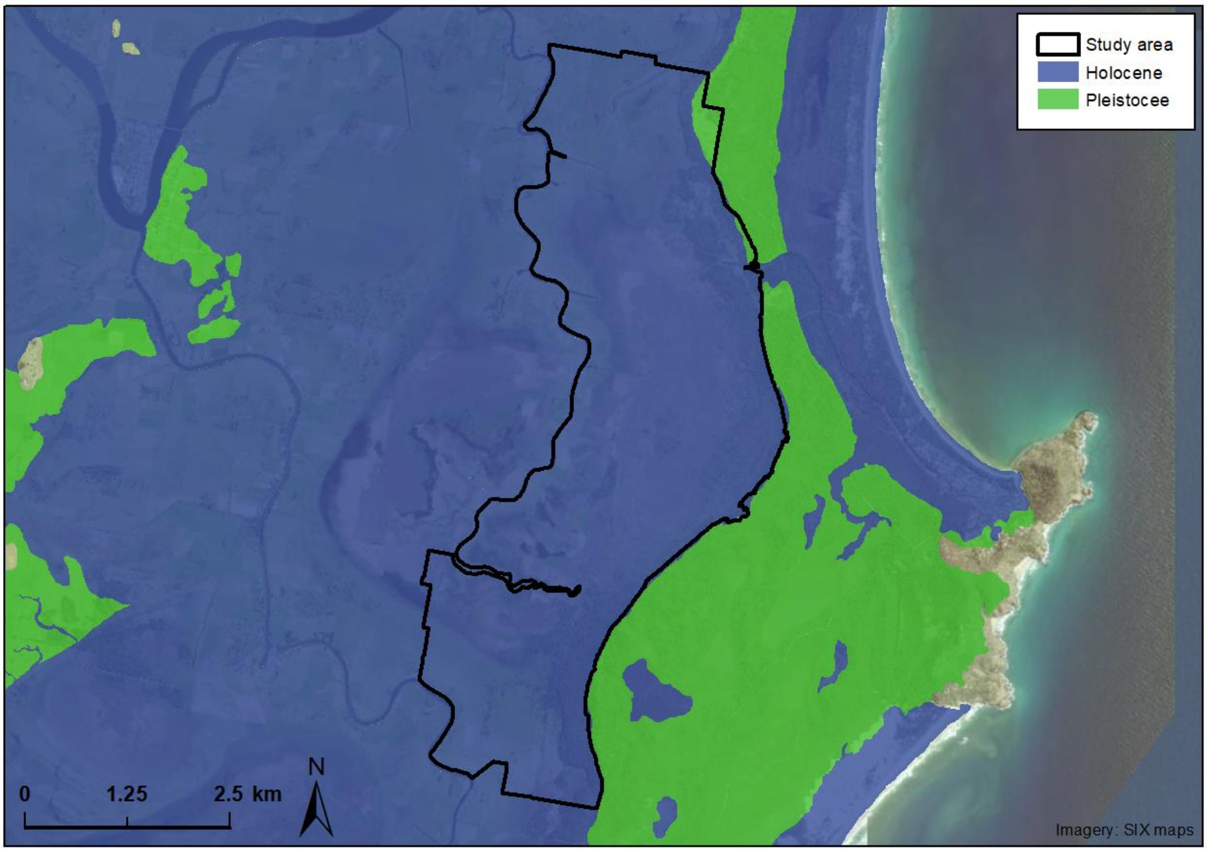
Appendix A Literature review

A1 Floodplain drainage history

The Macleay River estuary is classified as an open and trained, mature, wave dominated, barrier estuary (Roy et al., 2001). The estuary was formed throughout the Holocene (the last 10,000 years) when ocean water levels were one to two meters above their present level. During this period, a coastal barrier between Hat Head and South West Rocks, which was formed during the Pleistocene (1.8 to 0.01 million years ago), created a low-energy lagoon across what is now the Macleay floodplain (Figure A.1). This allowed for the formation of a deltaic plain where estuarine muds were deposited in the low-energy conditions over time. As the ocean water levels dropped to their current level, the estuary transitioned towards a system dominated by fluvial and riverine processes with the main channel (the Macleay River) bypassing the deltaic plain mud basins (Telfer, 2005). Kinchela Creek is an example of a former delta where estuarine muds were deposited as the Macleay River estuary matured.



A.1: Swan Pool quaternary geology (Troedson and Hashimoto, 2008)

Prior to the 1800s the area located on the eastern side of Kinchela Creek (Swan Pool) comprised a large wetland complex ranging from saline water to freshwater (Smith, 2002). Saline water from the estuary used to flow into the south-west of the wetland at the southern upstream extent of Kinchela Creek during dry times. Rainfall across the floodplain and groundwater inflows from the sand dunes to the east of Swan Pool were the main source of freshwater. The area obtained its name, “Swan Pool,” from a large open water body that historically persisted across the floodplain (Smith, 2002).

The Swan Pool area was first utilised for agriculture in the 1860s, however, this was generally limited to the levee banks of Kinchela Creek (Tulau, 2011) (Figure A.2). Large scale development of the floodplain did not occur until the 1880s when the first floodplain drainage works were observed with attempts to construct drainage channels on both the northern and southern sides of Swan Pool by private landowners (Telfer, 2005; Tulau, 2011). Construction of these drains foreshadowed extensive drainage works across the floodplain which would permanently change the hydrology of Swan Pool.

Despite existing drainage works, large extents of land in the Swan Pool area was situated below the low tide level and drainage of the land was poor. This resulted in the formation of the Swan Pool Drainage Union in 1925. The objective of the drainage union was to improve floodplain drainage (Tulau, 2011). It was not long before “The Lock,” a one-way floodgate structure, was constructed on Kinchela Creek in 1931 to control in-drain water levels and prevent saline water from travelling further upstream (Smith, 2002; KSC, 2007). By 1945, despite opposition from the NSW Public Works Department, three major channels had also been constructed to drain Swan Pool, including (Tulau, 2011):

- Slaughterhouse Drain
- Schoolhouse Drain
- McNally’s Drain

A2 Flood mitigation scheme

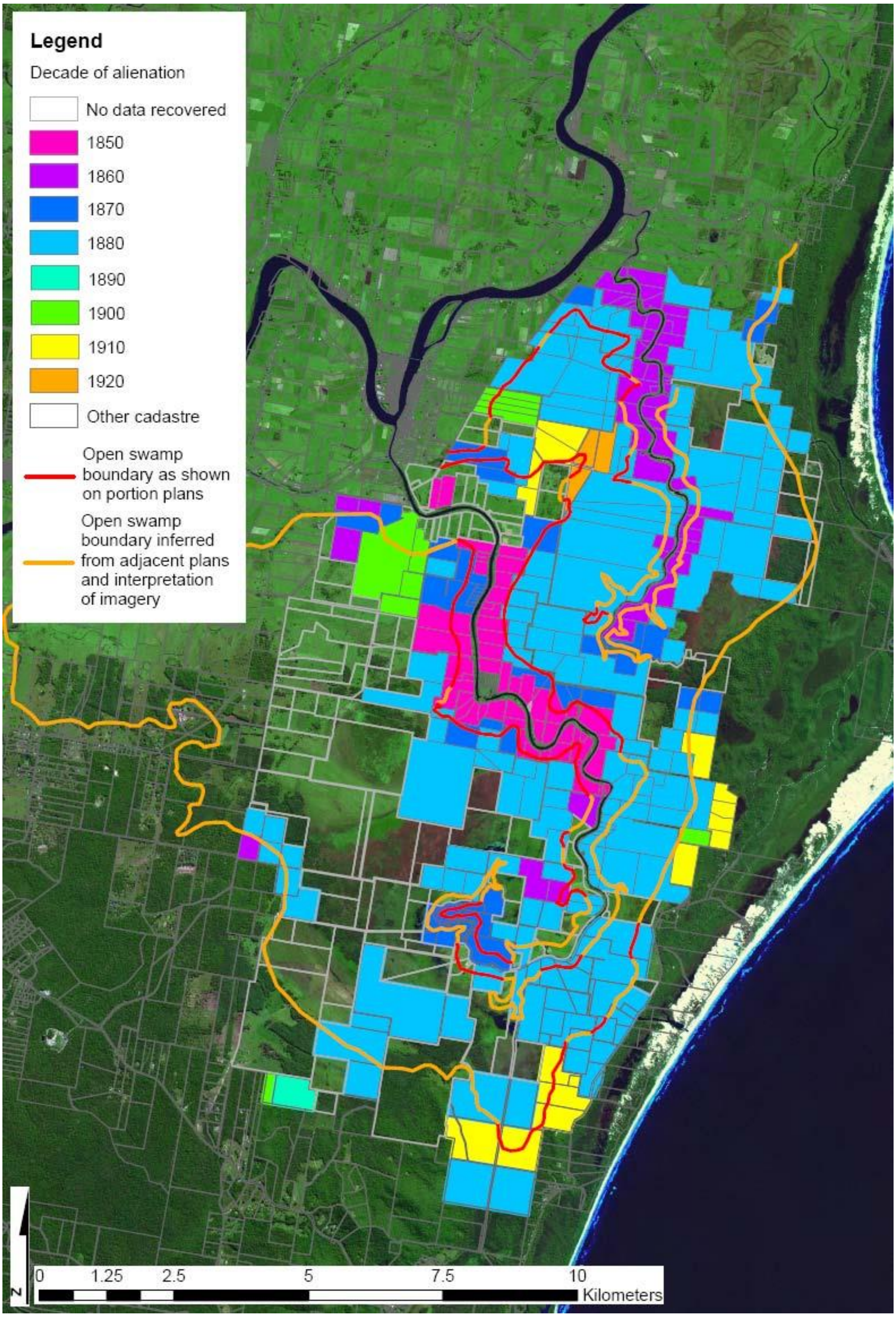
The period between the 1890s and 1940s can be generally characterised by its dry conditions in comparison to the following decades up until the 1970s when the Macleay River experienced 19 large flood events (Tulau, 2011). As a result of two particularly large floods in 1949 and 1950, the Macleay Valley Flood Mitigation Committee (MVFMC) was established and planning of extensive flood mitigation works commenced (Walker, 1962). Construction of flood mitigation works in the Swan Pool area included (Telfer, 2005; Tulau, 2011):

- Kinchela No. 2 Drain (1961)
- Reilly’s Drain and headworks (pre 1962)
- Schoolhouse Drain and headworks (pre 1962)
- Slaughterhouse Drain and headworks (pre 1962)
- Hoffman’s Drain and headworks (pre 1962)
- McNally’s Drain and headworks (pre 1962)
- Korogoro Cut and headworks (1968)
- Kinchela Creek headworks (1968)
- Kinchela Creek west fabridam floodway (1968)
- Kinchela Creek east fabridam floodway (1968)
- Kinchela Creek west floodway steel gate replacement (1980)
- Kinchela Creek east floodway steel gate replacement (1980)

The function of flood mitigation works was designed to be dependent upon the scale of flooding that would impact the Macleay River and could function in one of two ways (McDonald, 1967):

1. For events where the peak river discharge is less than 1,700 m^3/s (60% AEP), the flood mitigation scheme aimed to confine the peak flood elevation within the main river channel banks and reduce the time the floodplain was inundated by providing efficient drainage from the floodplain.

2. For events with a peak discharge greater than 1,700 m^3/s but below 2,500 m^3/s (45% AEP), the flood mitigation scheme aimed to confine the peak flood elevation to within the main river channel banks or across the Belmore and Kinchela floodplains in addition to providing efficient drainage from the floodplain.



A.2: Alienation of the Kinchela Creek floodplain (Tulau, 2011)

At Swan Pool the operation of the Kinchela Creek headworks and Korogoro Cut allow for improved post flood drainage and reduced nuisance flooding (PWD, 1994). McDonald (1967) estimated that construction of the flood mitigation works meant that the time it takes for the Swan Pool area to drain following a flood event was reduced by up to nine days. During large flood events, operation of the Kinchela east floodway means that Swan Pool is used as a flood retention basin to protect other areas of the Macleay River floodplain (Walker, 1962).

Following completion of the flood mitigation scheme, local landowners at Swan Pool suggested that the works had actually increased flood frequency, depth and duration on their properties and proposed constructing a channel to connect the Kinchela east floodway directly to Korogoro Cut as a way to improve drainage (WMA, 1994a). This resulted in a number of investigations to determine the feasibility of this option (WMA, 1994a; WMA, 1994b; WMA, 1995; WMA, 1996). Findings of these studies determined that creating a new channel would reduce the impacts of flooding, however, there were a number of other options such as raising levees that could also be implemented for a similar outcome. Subsequently, in 1999, the levees on Kinchela Creek were raised to a level of 3.05 m AHD to provide additional flood protection for Swan Pool (Telfer, 2005; KSC, 2015b).

Original designs for the operation of the Kinchela east floodway were to open the sluice gate once a flood is predicted to exceed a predetermined elevation to minimise flooding elsewhere in the Macleay River (Walker, 1962). This operation strategy has since changed and the Kinchela east floodway is now closed prior to any flooding and only opened to prevent the levees on Kinchela Creek from overtopping (Chong, 2019; KSC, 2021a). During everyday conditions the Kinchela east floodway and Kinchela Creek headworks are opened to allow tidal passage upstream (KSC, 2021a).

A3 Estuary management

Coastal management in NSW is important for establishing the long-term management strategy of estuaries. Swan Pool directly impacts two estuaries, each of which have their own coastal management programs:

- Macleay River estuary
- Korogoro Creek estuary

The long-term management strategy for the Macleay River estuary is outlined by the Macleay River coastal zone management program (CZMP) (GeoLINK, 2012). Similarly, the Korogoro Creek estuary management plan (EMP) summarises the strategy for Korogoro Creek estuary (Telfer and Birch, 2009b). The following sections detail each of these coastal management strategies and their relevance to Swan Pool. Note, Kempsey Shire Council are currently in the process of developing an updated coastal management program (CMP) that will include a combined strategy for the Macleay River estuary and Korogoro Creek estuary (Rollason, 2020a; Rollason, 2020b).

A3.1 Macleay River estuary management

A number of studies have been completed to inform the development of the Macleay River CZMP (GeoLINK, 2012). Telfer (2005) completed a data compilation study for the Macleay River estuary. They highlighted how the wetlands on the Macleay River floodplain, particularly those adjacent to Kinchela Creek (i.e. Swan Pool), had drastically changed as a result of the flood mitigation works completed from the 1950s to 1970s. Due to this a number of monitoring programs, policies and management plans were created for the protection of wetland ecosystem values. Telfer (2005) also described the coastal processes involved in the development of the wetland complex at Swan Pool (see Section A1 for further details).

The work of Telfer (2005) was furthered during the development of the Macleay River estuary processes study which aimed to understand the human impact on estuarine processes (Hurrell et al., 2009). Hurrell et al. (2009) highlighted that flood mitigation works at Swan Pool had caused:

1. Oxidisation of acid sulfate soils, resulting in runoff containing low pH and high metal concentrations
2. Proliferation of water intolerant pastures across the floodplain which die during floods and produce deoxygenated water (i.e. ‘blackwater’)

This was observed to have broader impacts to the Macleay River estuary and its overall ecology.

Birch (2010) completed an estuary and floodplain ecology study for the Macleay River to provide further information to assist in the development of the CZMP. The study highlighted Swan Pool as part of one of the three major floodplain complexes on the Macleay River. It also highlighted how poor water quality originating from the floodplain was having an impact on estuarine ecology. The findings of this study resulted in a number of recommended management options relating to the Macleay River estuary and floodplain. Recommendations specifically relevant to Swan Pool included:

- Improve fish passage through the Kinchela Creek floodgates
- Improve management of Swan Pool for wetland ecological values

These studies were used to inform the development of an estuary management study (EMS) for the Macleay River estuary (GeoLINK, 2010). The EMS aimed to provide a set of management objectives which local government could use to strategically manage the Macleay River estuary in the long-term. General management objectives that were relevant for Swan Pool were associated with (GeoLINK, 2010):

- Floodplain wetlands management
- Acid sulfate soils
- Floodgates and drain management
- Water quality

The EMS provided the following clear and strategic actions for Swan Pool that would be required to address these objectives (GeoLINK, 2010):

- NSW National Parks and Wildlife Service (NPWS) to continue acquiring land up to the +0.5 m AHD contour
- Exclude stock (via fencing) from Hat Head National Park
- Reinstate the natural hydrology including open water habitat

- Reshape drains to reduce acidic runoff, raise the water table and promote water retention
- Reshape Korogoro Cut to reduce acidic runoff, raise the water table and reduce impacts on Korogoro Creek
- Incorporate Swan Pool management into the Hat Head National Park plan of management
- Continue to control weeds
- Assess current drainage infrastructure based on cost, effectiveness, landowner satisfaction, environmental values and productivity
- Compile a list of drainage infrastructure and prioritise its management for landowner and environmental outcomes with the objective of completing on-ground works
- Determine appropriate management objectives and required works for floodgates during non-flood and flood periods
- Provide landowners with the opportunity to visit successful wet pasture management sites
- Provide information for landowners to allow them to implement wet pasture management
- Utilise digital elevation model data for prioritising water management options
- Amend Local Environmental Planning (LEP) land zoning to protect important habitat
- Encourage biobanking

Following the development of the EMS the Macleay River CZMP was developed to prioritise and address the issues involved in management of the estuary (GeoLINK, 2012). The CZMP outlines 30 strategies ranging from high to low priority for the Macleay River estuary. Strategies that are directly relevant to Swan Pool include (GeoLINK, 2012):

- Improve water quality from floodplain wetlands (high priority)
- Coordinate and prioritise drainage projects (high priority)
- Active water management of floodgates (high priority)
- Conservation of floodplain wetlands (high priority)
- Develop a floodgate management regime for flood and non-flood events (medium priority)
- Protect and manage important habitat areas (medium priority)

Review of these management strategies completed by Rollason (2020a) found that they had been implemented to varying degrees with the exception of improving water quality from floodplain wetlands. The success of implementing this strategy was deemed inadequate due to:

- The need for a Macleay River wide prioritisation for remediation
- Lack of clarity regarding jurisdiction across the floodplain
- Lack of private landowner support

A3.2 Korogoro Creek estuary management

Prior to the development of the estuary management plan (EMP) for Korogoro Creek an estuary data compilation and processes study (Telfer, 2007) as well as an estuary management study (Telfer and Birch, 2009a) were completed. The objectives of the data compilation and estuary processes study was to identify existing data and data gaps for the estuary and to determine what processes drive the overall estuarine health (Telfer, 2007). During this study it was found that Swan Pool is a major contributor to poor water quality in Korogoro Creek through discharges of acidic water, low-oxygen water and nutrient rich water. It was noted that generally water only flows from Swan Pool to Korogoro Creek during flood events.

The Korogoro Creek estuary management study (EMS) was completed to identify management issues within the estuary and potential strategies for addressing them (Telfer and Birch, 2009a). During the study it was identified that a healthy and functioning wetland at Swan Pool was a key value of moderate importance to the estuary and subsequently two management objectives were created directly associated with Swan Pool (Telfer and Birch, 2009a):

- Reduce the impact of the flood mitigation scheme (i.e. the construction of Korogoro Cut and associated headworks)
- Reduce the impacts of poor water quality associated with acids sulfate soils at Swan Pool

These objectives were identified as medium and low priority, respectively. Following these objectives, three key estuary management issues were identified in relation to Swan Pool and ranked out of a total of 23 issues in terms of their importance for management of the overall estuary. These included:

- Damage to aquatic ecosystems due to flood mitigation works (rank 2)
- Low dissolved oxygen and high nutrients associated with discharges from Swan Pool (rank 10)
- The impact on poor water quality due to the management of Swan Pool (rank 14)

The Korogoro Creek estuary management plan (EMP) utilised the information provided by the EMS to specify a five year program of management for the Korogoro Creek estuary (Telfer and Birch, 2009b). The EMP largely provided the same recommendations as the EMS, including the following actions which directly impact Swan Pool:

- Undertake a dry time assessment of water quality impacts of the flood mitigation infrastructure
- Undertake an event based assessment of water quality impacts of the flood mitigation infrastructure
- Investigate the source of observed water quality in the upper estuary and if it originates from Swan Pool take appropriate actions
- Investigate potential changes to flood mitigation infrastructure to improve water quality
- Identify specific water quality issues within Swan Pool that impact Korogoro Creek
- Continue efforts to manage acid sulfate soils and overall wetland values
- Consider further acquisition of the Swan Pool area by NPWS

Review of these management strategies completed by Rollason (2020b) found that there had been little or no progress in their implementation since the development of the EMP.

A4 Acid sulfate soils

Telfer (2005) summarised the history of the Macleay floodplain and identified that scientists had discovered acid sulfate soils (then known as cat clays) within the floodplain sediments in the early 1960s and 1970s. Walker (1972) found that there were highly acidic soils underlying the floodplain adjacent to Kinchela Creek. Close to the creek levee bank it was found that acid sulfate soils were well below the water table, however, across the backswamp they were close to the surface. Despite these findings it was not until the 1990s that the issues associated with drainage of acid sulfate soils and the impacts of floodplain drainage began to be fully realised and investigated.

Comprehensive mapping of acid sulfate soils was first completed in the Swan Pool area by Atkinson (1997a; 1997b) who identified that the area comprised acid sulfate soils at the ground surface and was at severe risk of being disturbed. Mapping of the location and risk of acid sulfate soils was completed using landform information from aerial imagery in addition to soil profile field data (Naylor et al., 1998) (see Appendix B).

In the following years, Tulau and Naylor (1999) identified Swan Pool (as part of the Kinchela area) as one of six acid sulfate soil priority areas on the Macleay River floodplain. They found that drainage had resulted in the oxidisation of acid sulfate soils and resulted in acidic runoff from the floodplain. Tulau and Naylor (1999) attributed poor water quality in Kinchela Creek to acid sulfate soils as monitoring in the location identified low pH and high levels of aluminium and iron, products of acid sulfate soil oxidation and drainage. Hurrell et al. (2009) also noted similar observations within Kinchela Creek.

In recent years, floodplain management has identified that poor water quality resulting from acid sulfate soils is an ongoing issue at Swan Pool and provided an ongoing strategy to address the issue (Telfer, 2009; GeoLINK, 2012) (see also Section A3). Further to this, Tucker et al. (2021) completed an extensive study of the Macleay River floodplain ranking low-lying floodplain areas with regard to the risk they pose to the water quality of the estuary. They identified that the Kinchela Creek area, inclusive of Swan Pool, posed the sixth largest risk to the estuary water quality (out of 11 areas) in terms of diffuse acidic runoff associated with acid sulfate soils.

A5 Blackwater

Low dissolved oxygen blackwater is caused through the prolonged inundation of water intolerant vegetation generally following flood events. When this occurs, vegetation dies off and consumes the oxygen within water as it breaks down. Once flood levels receded this low-oxygen water is then able to discharge into the estuary via efficient drainage channels causing significant environmental impacts (Figure A.3).

A.3: Low oxygen blackwater discharging from Swan Pool via Kinchela Creek and about to enter the Macleay River at Kinchela (February 2020)
(Source: Max Osborne, NSW Department of Primary Industries)

Blackwater generated following flood events has been attributed on numerous occasions to the floodplain of Kinchela Creek of which Swan Pool is a major contributor. Since 1995, at least six blackwater events have been recorded and attributed to blackwater caused by prolonged floodplain inundation in the Swan Pool area (NSW DPI, 2020). One event that occurred in 2001 resulted in 10,000's of fish mortality events and the disruption of the commercial fisheries industry for over six months (Kennelly and McVea, 2002). GeoLINK (2010) noted that blackwater from the Swan Pool area was an ongoing issue.

Tucker et al. (2021) recently completed a detailed study looking at the risk which different areas of low-lying floodplain in the Macleay River estuary pose to water quality due to blackwater events. Their data driven analysis found that the Kinchela floodplain, including Swan Pool, contributed the single largest risk to the estuary water quality due to blackwater.

A6 Water quality

A number of studies have been completed measuring water quality in the waterways in and around Swan Pool. Turner and Pells (2003; 2004) completed surface water samples in Korogoro Creek (in addition to groundwater samples) as part of an effluent monitoring program. This work was continued by Cunningham and Timms (2008) and Ruprecht and Timms (2011). Findings of the water quality monitoring did not report any traceable observations regarding poor water quality originating from Swan Pool.

Telfer (2007) identified a number of other sources of water quality data including long term monitoring of water quality by Kempsey Shire Council and tidal cycle monitoring by Manly Hydraulics Laboratory in Korogoro Creek. Telfer (2005) identified a number of programs that measured water quality in the Macleay River, however, none of these specifically addressed Swan Pool or water quality within Kinchela Creek.

As outlined in Section A4, Tulau and Naylor (1999) and Hurrell et al. (2009) both noted that poor water quality with low pH and high iron/aluminium concentrations have been observed in Kinchela Creek, thought to be caused by runoff from acid sulfate soils. Hurrell et al. (2009) also completed a water quality monitoring program throughout the broader Macleay River estuary. While not specifically addressing water quality from Swan Pool, they noted that in the future the impacts of climate change may result in impacts to temperature, dissolved oxygen levels, algal blooms, salinity, and nutrient loading.

A state of the catchments assessment was completed for all NSW estuaries in 2010 and included both the Macleay River and Korogoro Creek (Roper et al., 2011). This assessment reviewed the condition and pressures of individual estuaries based on a number of datasets including water quality. The analysis assessed the condition of the Macleay River and Korogoro Creek as good, while for the pressure rating the Macleay River was given a moderate score in comparison to Korogoro Creek's good score.

From 2015 to 2016 ecohealth monitoring of the Macleay River was completed (Ryder et al., 2016). As part of this project a report card was developed whereby different waterways were given a rating based upon a number of water quality indicators. Kinchela Creek was given an overall rating of F (very poor), the worst possible rating and below average for the wider Macleay catchment which scored a D+. The report recommended that discharges from the floodplain (i.e. Swan Pool) should be investigated as a source of low pH, low dissolved oxygen, high turbidity, and high nutrient loads.

The Swan Pool wetlands (in conjunction with those at Belmore Swamp) were assessed as part of the North Coast region state of the environment assessment completed in 2016 (NCRSERWG, 2016). During this project the coastal floodplain was assessed on the basis of pressures it is under and its overall condition. The assessment determine that Swan Pool was under high pressure and overall had a very poor condition.

A7 Remediation

In a study conducted by NSW National Parks and Wildlife Service (NPWS), Swan Pool ranked in the top two percent of wetlands on the Macleay floodplain in terms of value that would be received by either protecting the area and enhancing ecological value or simply protecting the area without any active effort to enhance the ecology (Pressey, 1987). Despite this, further investigations completed following the construction of floodplain drainage works in the Macleay, found that approximately 96% of all floodplain wetlands were directly impacted by drainage, with 99% of wetlands being actively grazed (Pressey, 1989). LMP (1980) found that the construction of one-way floodgates on Kinchela Creek had significantly altered the floodplains ecological value. Freshwater habitat available for waterbirds was only observed in a small section of the floodplain to the north of Swan Pool as the floodgates restricted tidal flows to the southern parts of the wetland resulting in the infestation of weeds.

In past decades, the impacts of floodplain drainage and subsequent degraded environment at Swan Pool has resulted in a number of concerted efforts to remediate the historical ecosystem values (Birch, 2010; GeoLINK, 2010; Tucker at al. 2021). Subsequently, a number of programs have been completed attempting to improve the environmental values at Swan Pool.

The first record of remediation efforts in the Kinchela area is recorded by Tulau and Naylor (1999) who noted that local landowners constructed sills to promote water retention on the floodplain. Similar works are mentioned by RJSA (1999) who identified that a landowner in the Kinchela area opposed construction of flood mitigation works and instead constructed sills. Note, it is likely these works were not located in Swan Pool but rather the floodplain to the west.

The first definitive records of works being completed at Swan Pool are reported by Henderson and Tulau (2000) who noted the construction of a drop board structure in Kinchela No. 2 drain for the purpose of containing acid sulfate soils through freshwater ponding (Figure A.4). In subsequent years a number of organisations focused on efforts to precure funding for new designs and modification of floodgates at both The Lock and Korogoro Creek (NSW Fisheries, 2002; Walsh et al., 2002; Kemsley, 2003). This resulted in modifications to The Lock in 2002 where plastic floodgates and lifting devices were installed (KSC, 2007). These modifications allowed tidal water from Kinchela Creek to flow upstream to Swan Pool creating 1.4 km of fish passage (Walsh and Copeland, 2004).

A.4: Drop boards on Kinchela No. 2 drain (Source: Ron Kemsely, Kempsey Shire Council)

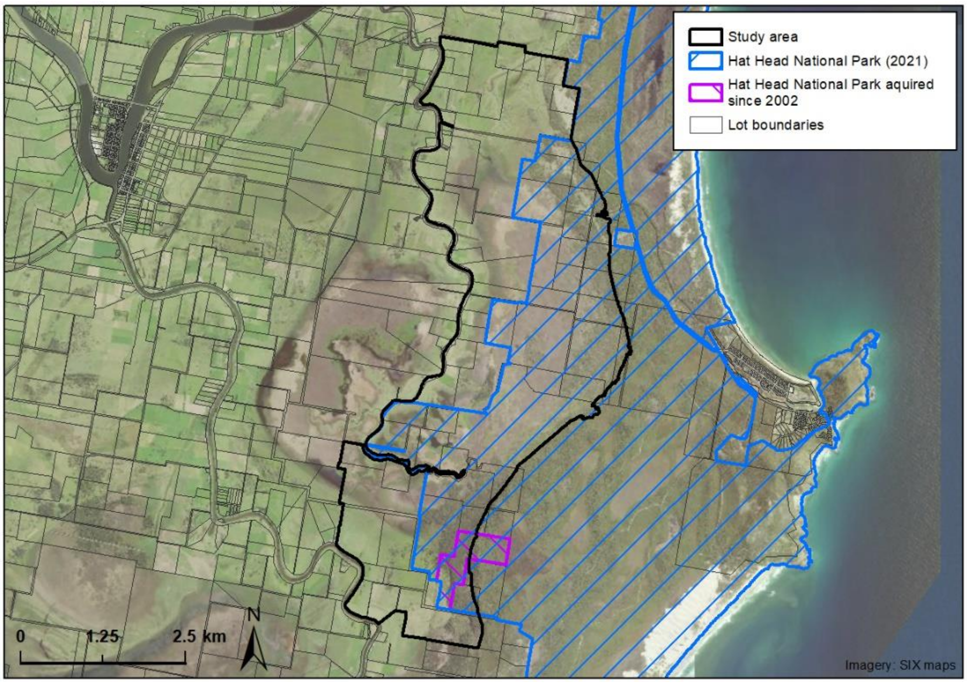
In 2002, Smith (2002) completed an extensive assessment of the drainage management of the Swan Pool area. The goal of the investigation was to identify if there were any possible improvements that could be completed to:

- Benefit private landowners
- Benefit wetland ecology
- Improve water quality of water leaving the site

Throughout the investigation, Smith (2002) found that agricultural and ecological values of the site were for the most part mutually exclusive. Despite this, Smith (2002) was able to identify seven strategies that could be implemented to improve the degraded wetland area at Swan Pool:

- Adopt a 5-10 year strategy to reinstate the natural hydrology of the area
- Ensure wetland values are included in maintenance and management strategies for floodgates
- Adopt best management practices for floodgate management to allow improved communication with stakeholders
- Explore options to incorporate private land below +0.5 m AHD into the Hat Head National Park
- Modify Korogoro Cut to reduce groundwater draw down
- Acquire existing wetland that remains freehold for incorporation to the Hat Head National Park
- Replace The Lock with a new structure on Kinchela Drain No. 2 to reinstate tidal flows in upstream Kinchela Creek

Following the project, private landowners were contacted and given the opportunity to express their interest in selling their properties to NPWS (Smith, 2002). GeoLINK (2010) reported that some land acquisitions have since been completed. Review of cadastre data indicates that this is limited to the south of the Swan Pool study area (Figure A.5). Other recommendations that have been implemented include modifications to The Lock to allow tidal flows upstream. These works, originally completed in 2002, were upgraded in 2007 with a buoyancy controlled auto-tidal gate and a weir at 0.00 m AHD on the upstream side of the floodgates (KSC, 2007) (Figure A.6). Survey of the weir by Tulau (2013) found that the weir crest was actually at an elevation between 0.05 and 0.06 m AHD. Other works completed in the area include modifications on Kinchela No. 2 Drain where a new culvert and floodgate was installed to prevent inundation of agricultural land when tidal flushing is allowed past The Lock (Figure A.8), and construction of a low level earthen weir at 0.0 m AHD approximately 1 km upstream of The Lock on North Drain to retain high water levels within Swan Pool (Figure A.9) (KSC, 2006; KSC, 2007; pers comms. Ron Kemsely).



A.5: NPWS land acquisitions for Hat Head National Park since 2002

A.6: Buoyancy controlled auto-tide gate on The Lock
(Source: Ron Kemsely, Kempsey Shire Council)

A.7: Wier constructed on the upstream side of The Lock
(Source: Ron Kemsely, Kempsey Shire Council)

A.8: Floodgate on Kinchela No. 2 Drain (Source: Ron Kemsely, Kempsey Shire Council)

A.9: North Drain weir (KSC, 2007)

Other recommendation outlined by Smith (2002) are yet to be implemented. For example, the existing Hat Head National Park plan of management does not specifically address management of the Swan Pool area (NPWS, 1998). Coastal management planning has recommended actions outlined by Smith (2002) be adopted, including for the Hat Head National Park plan of management to be updated and include Swan Pool (GeoLINK, 2012; Rollason, 2020a). A review of the plan of management is currently underway (NPWS, 2021; pers comms. S. Meehan).

In 2015, Kempsey Shire Council proposed to remove aquatic vegetation blocking Korogoro Cut. A review of the plans completed by Tulau (2015) found that the best way to manage the area would be to implement the recommendations of Smith (2002). Site inspections conducted on 10 June 2021 found that there is significant vegetation growth at the location where Korogoro Cut meets the Swan Pool floodplain (Figure A.10).

A.10: Growth of vegetation where Korogoro Cut meets Swan Pool observed on 10 June 2021

Other remediation works that have been completed include the development of an active management plan for the Kinchela headworks and active management of the Kinchela east floodway (KSC, 2015a; KSC, 2021a). GeoLINK (2010) noted that wet pasture management and stock exclusion was occurring adjacent to Schoolhouse Drain. Tucker et al. (2021) noted that Hoffman's Drain headworks had a lifting device installed, however, GeoLINK (2012) identified that it was not actively managed. It should also be noted that the McNally's Drain headworks and the Schoolhouse Drain headworks were originally constructed with slots that would enable drop boards to be installed (MRCC, 1960). It is understood that these are for maintenance purposes and Tucker et al. (2021) notes that there is no evidence of drop boards being used on these structures otherwise.

In some instances, remediation actions across the floodplain have been undone. A site inspection conducted on 10 June 2021 found that the upstream weir and buoyancy gate on The Lock had been removed and that the floodgate structure had been recently refurbished (Figure A.11). The earthen weir on North Drain was also found to be in significant disrepair, however, growth of vegetation across the drain was acting as a weir at -0.15 m AHD (Figure A.12).

In addition to reviewing existing remediation efforts at Swan Pool, Tucker et al. (2021) created short and long-term management options for the site. These recommendations generally aligned with the existing strategies outlined by Smith (2002) while considering other factors such as the impact of sea level rise. Recommended management options included (Tucker et al. 2021):

- Short-term: Optimising active management of floodplain structures, installing drop boards and weirs, promoting wet pasture management, and protecting existing wetlands
- Long-term: Investigating full restoration to an estuarine/freshwater wetland and encourage floodwater retention, particularly during summer months to reduce blackwater generation and runoff

A.11: The Lock as inspected on 10 June 2021. Images are of The Lock from the downstream side (A) and upstream side (B) as well as on top of The Lock looking upstream (C) and looking downstream (D)

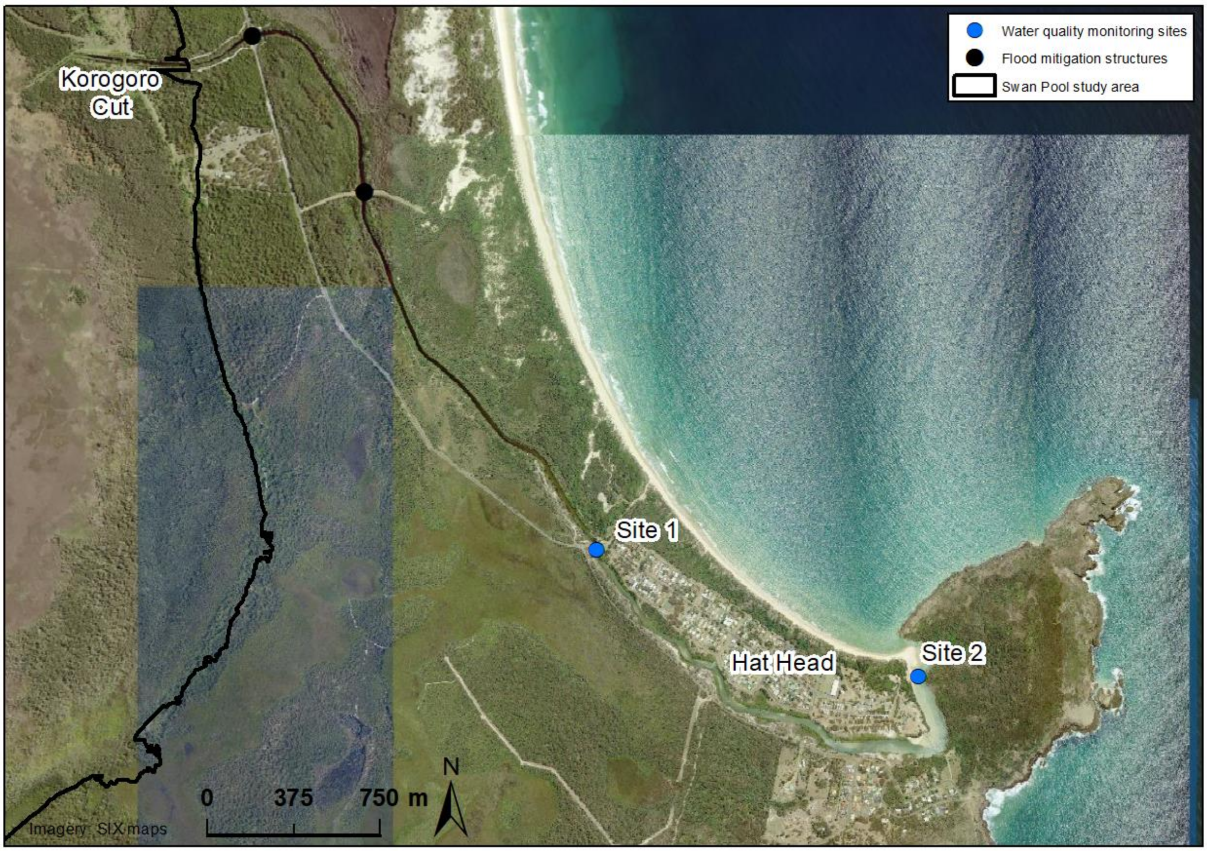
A.12: The remnants of North Drain weir as inspected on 10 June 2021

Appendix B Data review

B1 Water quality

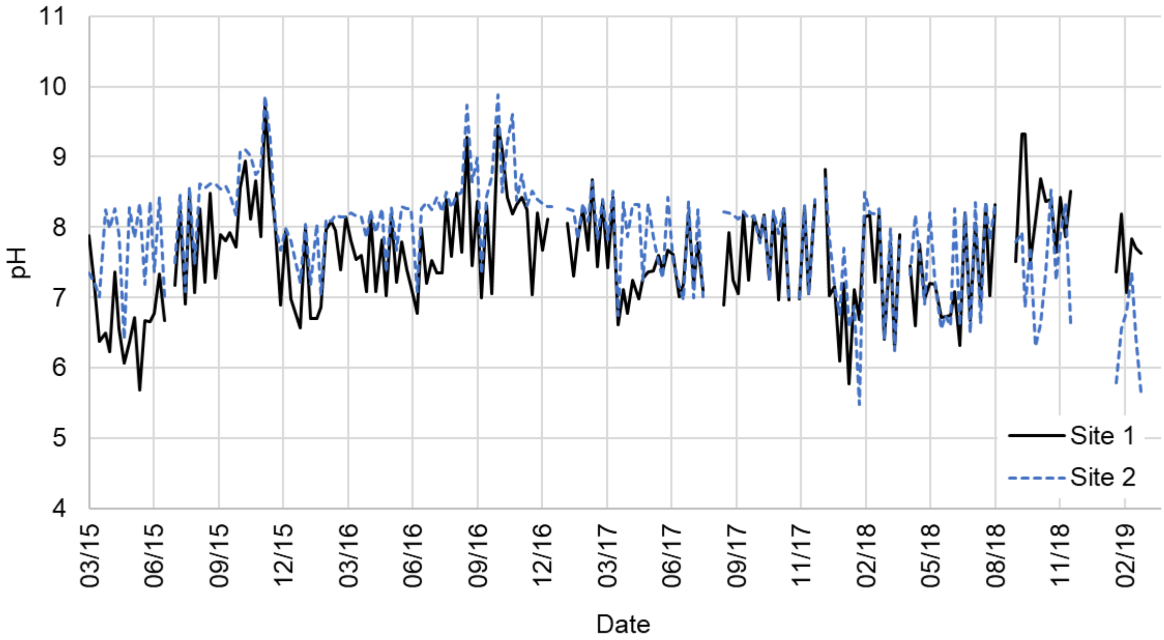
Kempsey Shire Council collected water quality data in Korogoro Creek between 2015 and 2019 at two sites (Figure B.1). Data collected included:

- Temperature
- pH
- Oxidation-reduction potential
- Conductivity
- Dissolved oxygen
- Total dissolved solids
- Enterococci

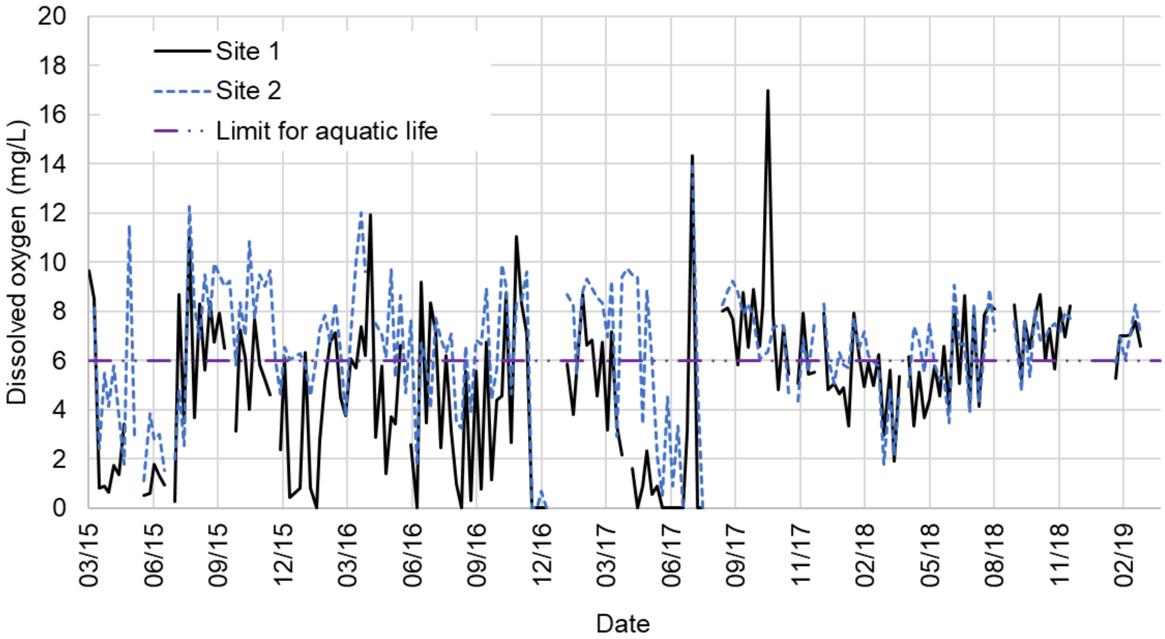


B.1: Location of Kempsey Shire Council water quality monitoring sites on Korogoro Creek

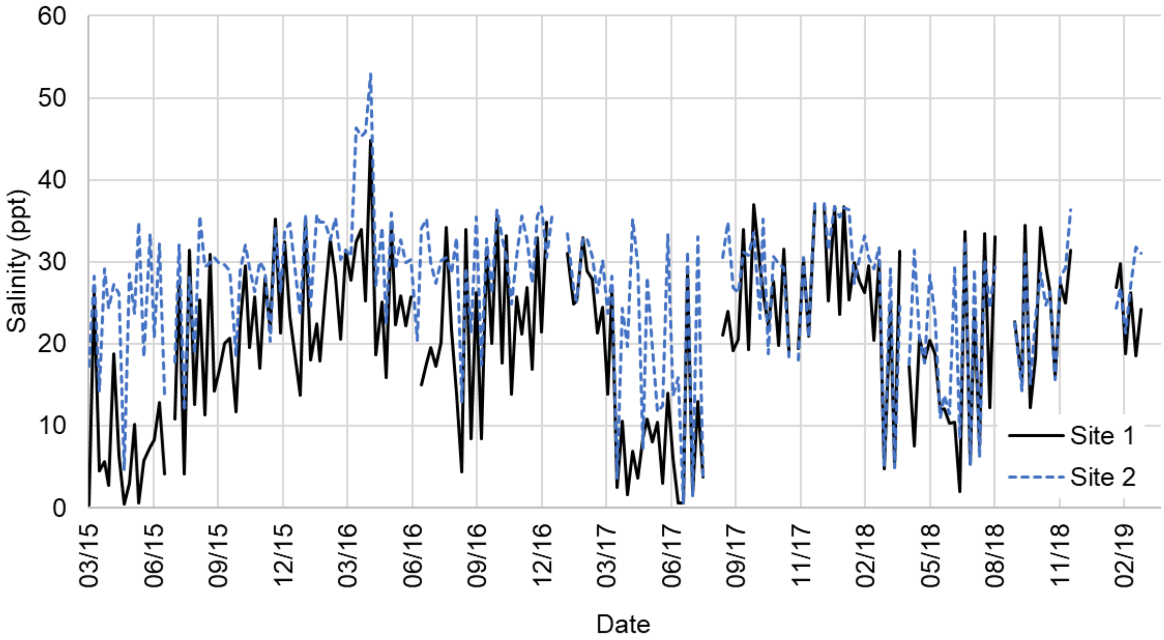
Levels of pH (Figure B.2) did not indicate any influence of acid sulfate soils, however, levels of dissolved oxygen (Figure B.3) were regularly below acceptable levels for aquatic life (6mg/L) as defined by ANZECC & ARMCANZ (2000). Salinity levels showed both sites have good connectivity with the ocean (Figure B.4).



B.2: pH data for Korogoro Creek (Source: Kempsey Shire Council)

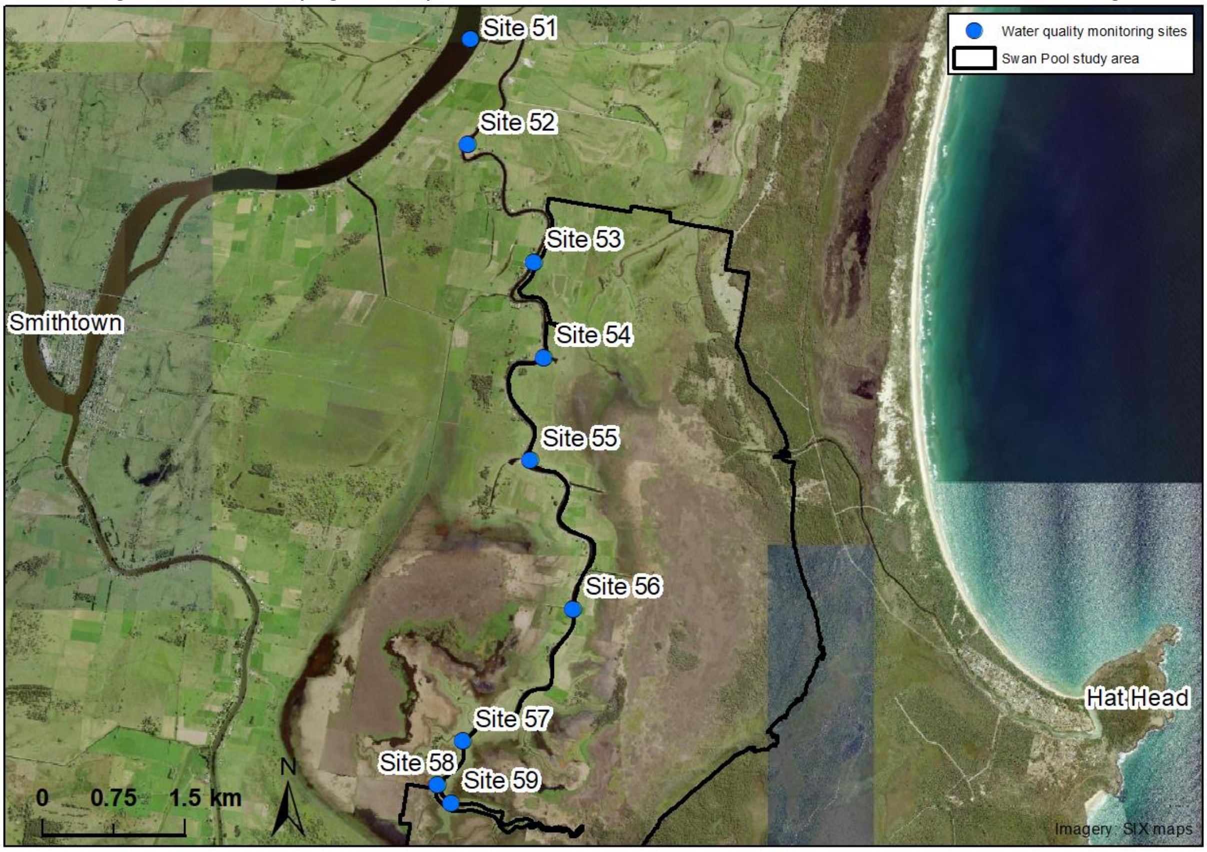


B.3: Dissolved oxygen data for Korogoro Creek (Source: Kempsey Shire Council)



B.4: Salinity data for Korogoro Creek (Source: Kempsey Shire Council)

Allsop and Kadluczka (2004) monitored water quality at nine locations within Kinchela Creek on 15 April 2003 at high and low tide (Figure B.5). Measurements are shown in Table B.1, Table B.2 and Figure B.6



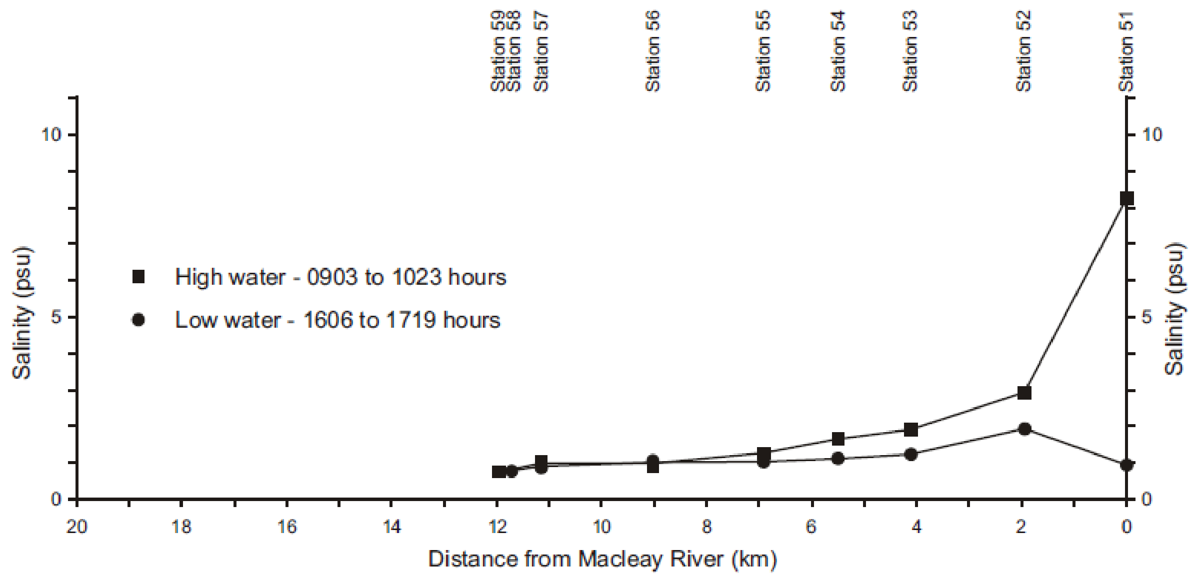
B.5: Location of Allsop and Kadluczka (2004) water quality monitoring sites on Kinchela Creek

B.1: High tide water quality for Kinchela Creek on 14 April 2003 (Allsop and Kadluczka, 2004)

Station No.	Time (EST)	Depth (m)	Density (kg/m³)			Temperature (°C)			Salinity (psu)			Dissolved O_2 (% sat)			pH			Backscatterance (NTU)		
			Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
51	0903	2.9	1003.9	1004.0	1004.0	22.08	22.10	22.09	8.18	8.22	8.21	79.20	79.88	79.49	7.28	7.29	7.28	6.35	7.81	6.84
52	0916	2.4	999.7	1000.2	1000.0	22.01	22.20	22.07	2.56	3.14	2.93	71.06	74.51	71.89	7.09	7.12	7.10	5.86	6.84	6.06
53	0928	2.5	998.9	999.5	999.3	21.73	21.96	21.81	1.53	2.15	1.90	48.33	65.93	58.45	6.70	6.94	6.82	6.35	8.79	7.37
54	0936	2.0	999.0	999.1	999.0	21.63	22.20	21.95	1.53	1.75	1.65	32.28	50.25	38.32	6.57	6.59	6.58	10.74	11.72	11.17
55	0946	3.4	998.8	998.8	998.8	21.73	21.75	21.74	1.26	1.27	1.26	20.38	68.10	28.76	6.50	6.50	6.50	10.74	12.21	11.10
56	1001	2.2	998.6	998.7	998.7	21.23	21.37	21.26	0.96	0.97	0.97	37.21	42.33	39.12	6.58	6.59	6.58	12.21	13.68	12.73
57	1011	1.6	998.6	998.9	998.8	20.41	21.59	20.61	0.96	0.97	0.97	56.67	67.37	61.48	6.32	6.43	6.36	27.35	30.77	28.47
58	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
59	1023	1.2	998.5	998.7	998.6	20.16	21.14	20.66	0.73	0.76	0.75	106.65	133.29	126.74	6.29	6.50	6.42	47.38	67.89	55.74

B.2: Low tide water quality for Kinchela Creek on 14 April 2003 (Allsop and Kadluczka, 2004)

Station No.	Time (EST)	Depth (m)	Density (kg/m³)			Temperature (°C)			Salinity (psu)			Dissolved O_2 (% sat)			pH			Backscatterance (NTU)		
			Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
51	1606	1.7	998.4	998.4	998.4	22.43	22.44	22.44	0.94	0.94	0.94	66.15	75.48	73.69	7.00	7.01	7.01	9.77	10.74	10.24
52	1616	1.6	999.1	999.1	999.1	22.65	22.74	22.70	1.91	1.98	1.93	33.37	37.52	34.78	6.46	6.46	6.46	11.23	12.70	11.49
53	1627	1.6	998.5	998.6	998.6	22.68	22.71	22.70	1.23	1.24	1.23	22.55	56.90	26.25	6.37	6.38	6.37	11.72	13.68	12.62
54	1636	1.8	998.5	998.5	998.5	22.68	22.68	22.68	1.11	1.11	1.11	23.24	35.41	25.66	6.44	6.45	6.45	11.23	15.63	12.70
55	1650	4.1	998.4	998.5	998.4	22.52	22.56	22.54	1.01	1.04	1.02	32.97	79.87	36.34	6.46	6.48	6.47	10.74	11.23	11.09
56	1700	0.7	998.2	998.2	998.2	23.45	23.47	23.46	0.99	1.00	1.00	84.56	89.09	87.35	6.71	6.71	6.72	20.02	21.98	20.84
57	1709	0.9	998.5	998.5	998.5	21.75	21.78	21.76	0.89	0.91	0.89	104.50	108.91	107.94	6.35	6.38	6.37	44.44	77.66	56.54
58	1719	0.6	998.5	998.5	998.5	21.33	21.34	21.33	0.78	0.78	0.78	66.98	81.84	74.19	6.03	6.03	6.03	45.91	46.40	46.06
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

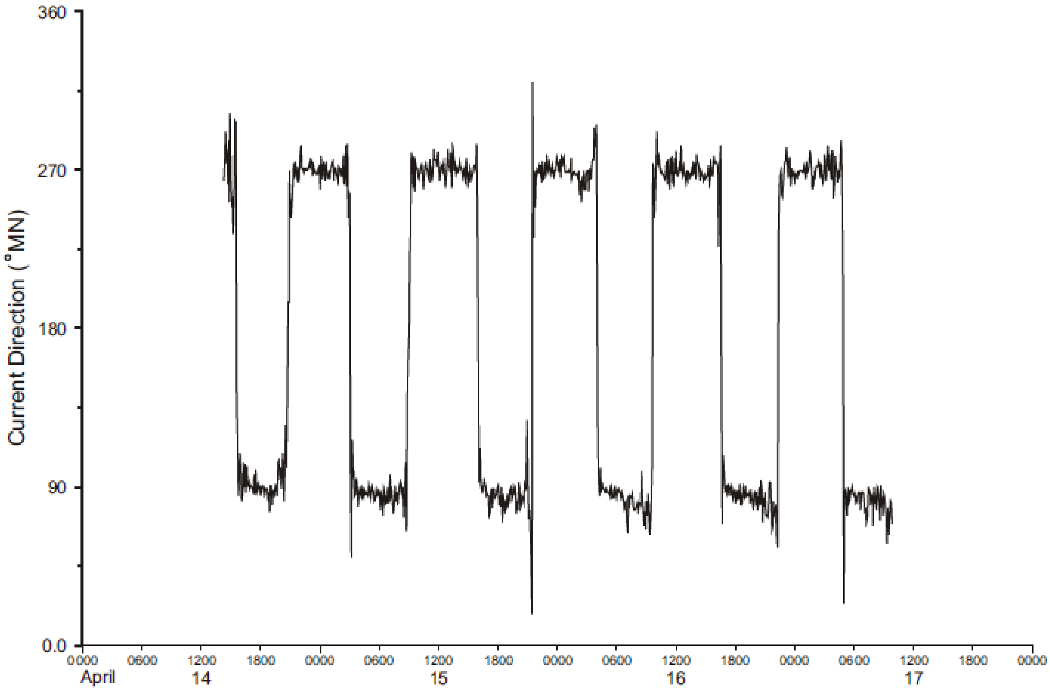


B.6: Salinity measurements within Kinchela Creek on 14 April 2003 (Allsop and Kadluczka, 2004)

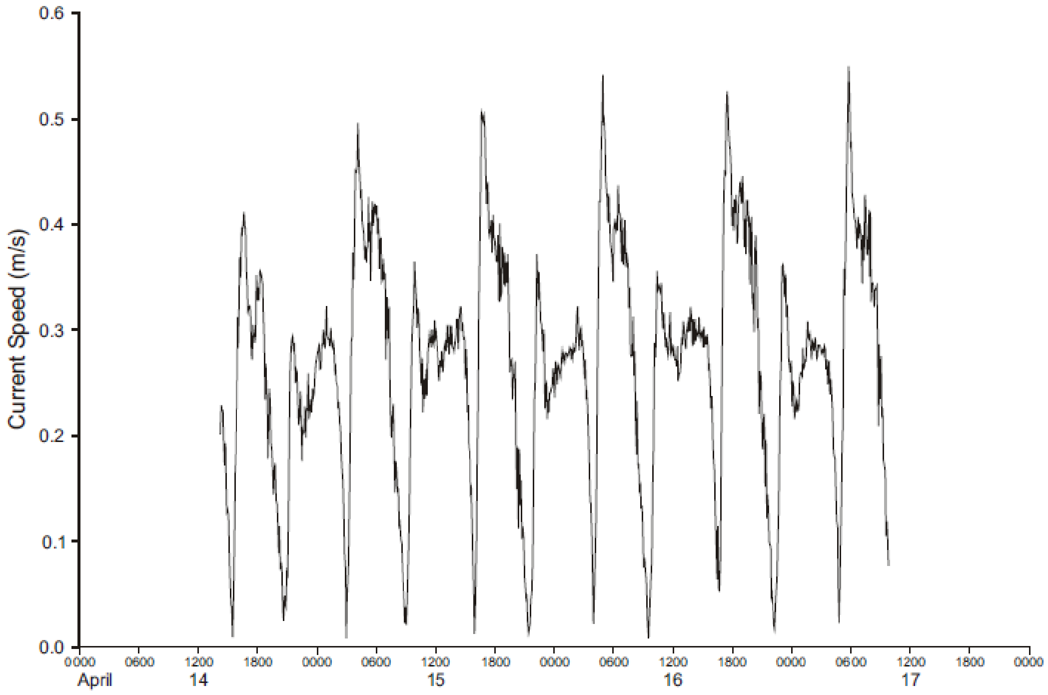
Kempsey Shire Council currently maintains a network of water quality monitoring instrumentation across the Macleay River estuary (KSC, 2021b). It is unclear if this network includes long-term measurements within Kinchela Creek.

B2 Discharge

No discharge data for Kinchela Creek or Korogoro Creek was identified. Allsop and Kadluczka (2004) did however collect current direction and velocity data in Kinchela Creek just upstream of its confluence with the Macleay River from 14 to 17 April 2003 (Figure B.7 and Figure B.8, respectively).



B.7: Current direction data for Kinchela Creek (Allsop and Kadluczka, 2004)



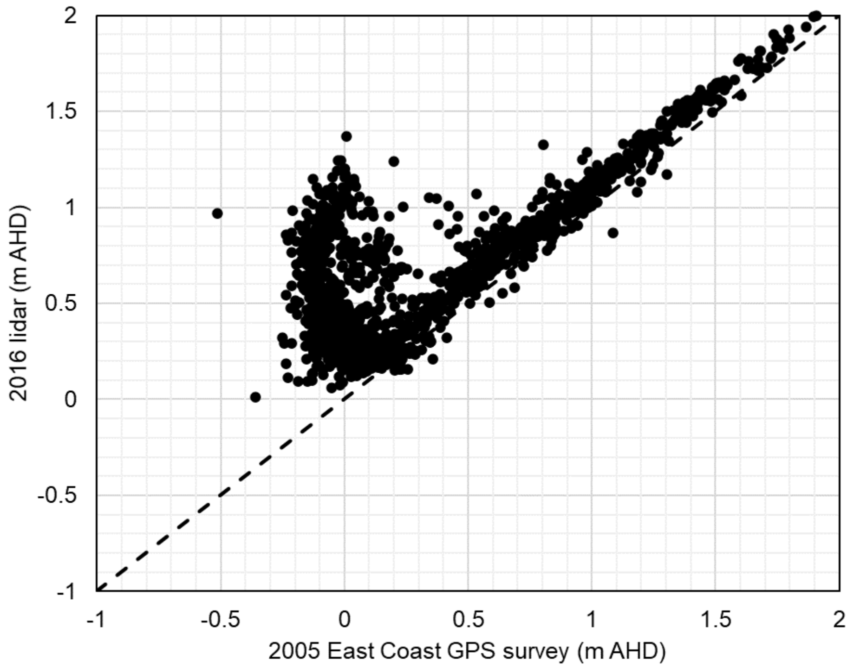
B.8: Velocity data for Kinchela Creek (Allsop and Kadluczka, 2004)

B3 Topography

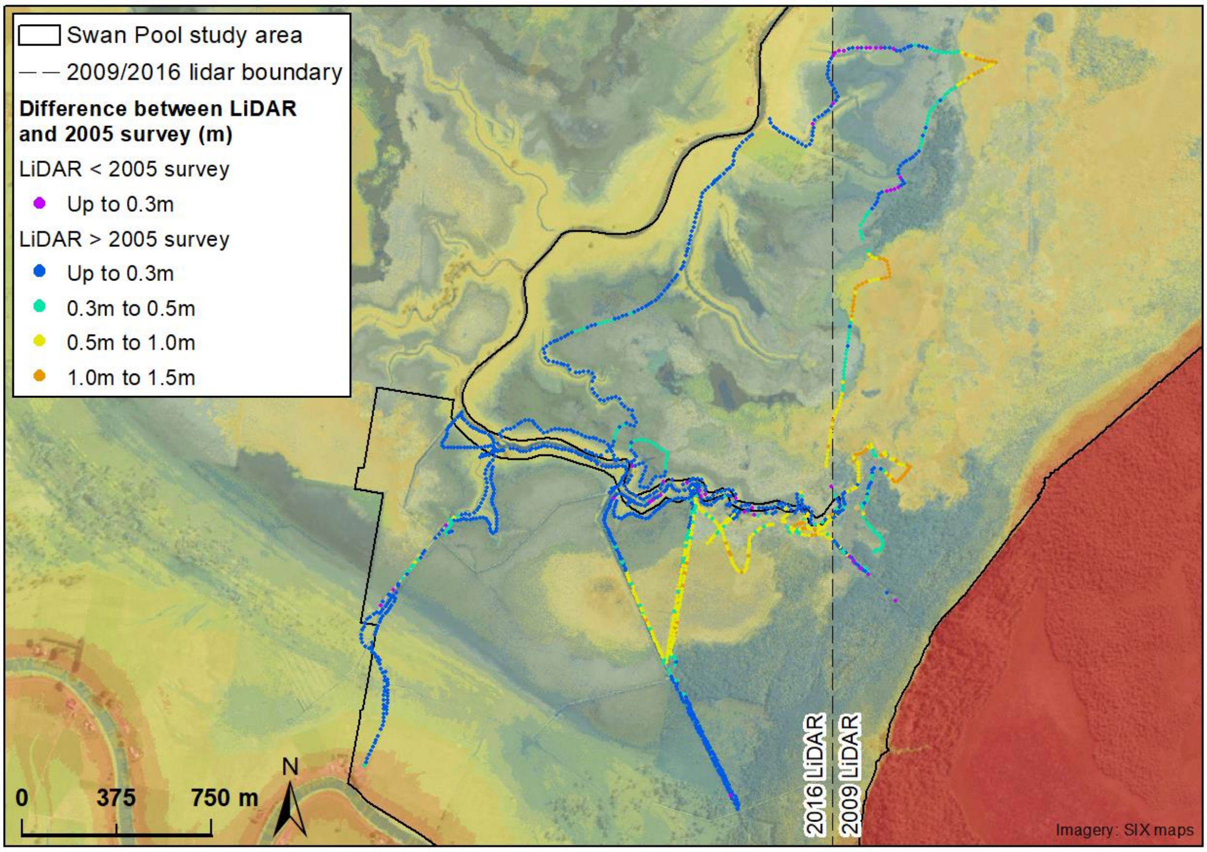
Topographic data for the Swan Pool area was collected by Spatial Services, a division of the NSW Department of Customer Service, using light detection and ranging (LiDAR) technology. Two datasets were available; collected in 2009 for the eastern side of the floodplain and in 2016 for the western side of the floodplain. All elevation data was collected relative to the Australian Height Datum (AHD) 71. The horizontal resolution of the data was processed into a 1 m grid across the study area, known as a digital elevation model (DEM). The vertical accuracy of each DEM grid point was determined to be ±0.30 metres with a 95% confidence interval.

East Coast GPS Surveys collected 1,532 individual real time kinematic (RTK) GPS survey measurements across the floodplain surface in 2005. A review of the data by Tulau (2013) found that due to dense vegetation the 2009 LiDAR data had poor accuracy for certain sections of the floodplain. They identified that lowest LiDAR measurements were found to be around 0.0 m AHD, whereas RTK-GPS survey measurements were as low as -0.5m AHD.

Comparison of the East Coast GPS Surveys from 2005 with the most up to date LiDAR data (including 2016 measurements for the west of the floodplain) found similar inaccuracies (Figure B.9). On average the LiDAR measurements were observed to be +0.33 m above the 2005 survey measurements with discrepancies up to 1.49 m at some locations across the floodplain (Figure B.10). It is likely these larger discrepancies are due to the LiDAR capturing the top of dense vegetation instead of the ground surface of the floodplain.

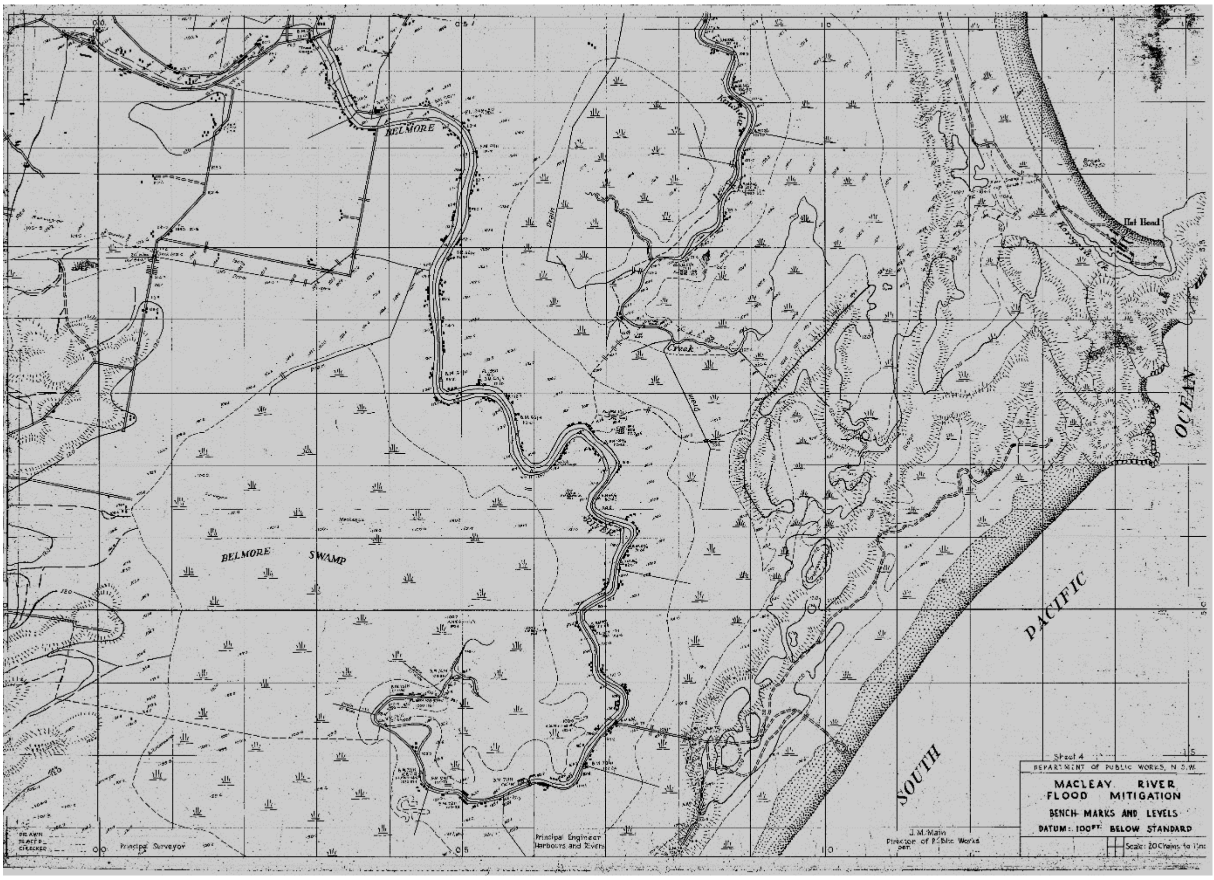


B.9: Comparison of the 2016 LiDAR data with survey data collected on 31 August 2005 by East Coast GPS Surveys (see locations in Figure B.10)



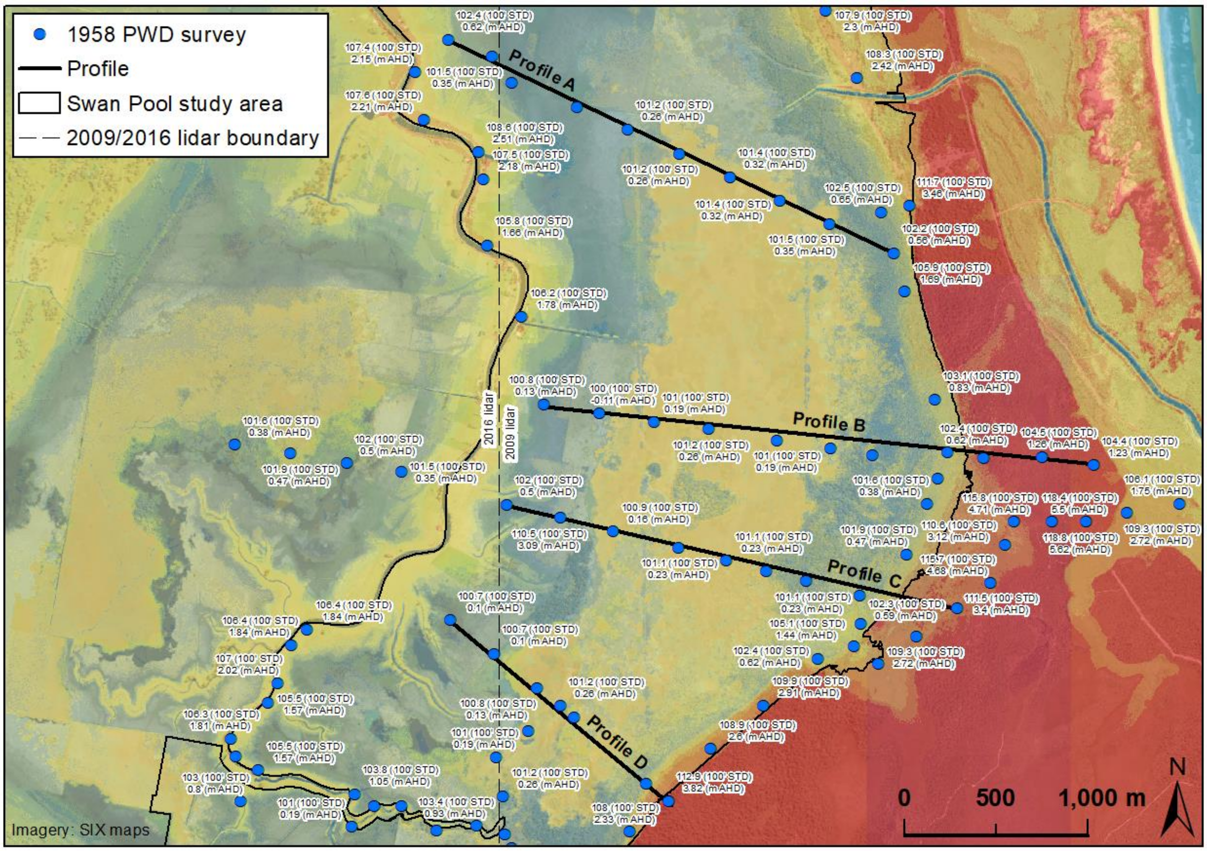
B.10: Difference between the LiDAR and 2005 RTK-GPS survey completed by East Coast GPS Surveys

Historical survey data for Swan Pool was also collected by the NSW Department of Public Works (PWD) in 1958 as part of the flood mitigation scheme (see example in Figure B.11). This data is relative to 100 feet below standard datum (STD). To convert between standard datum and AHD a 0.11 m offset can be subtracted from the standard datum heights using the correction provided by NSW Land and Property Information for the closest benchmark (PM7460).

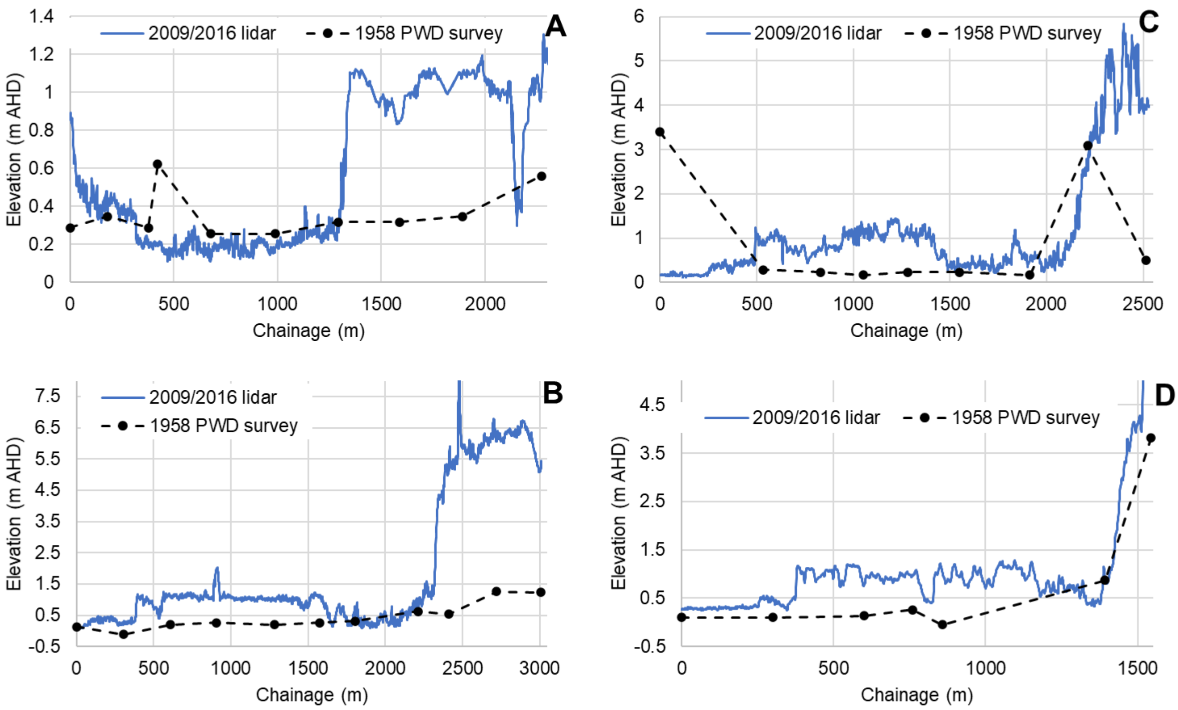


B.11: Example of flood mitigation plans with floodplain elevations relative to the standard datum (PWD, 1961)

The 1958 PWD data has been digitised and geo-rectified for comparison against the LiDAR data. Note, while this provides an indicative comparison, the locations of the PWD data are only approximate due to discrepancies involved with digitising the flood mitigation drawings. Comparison of the two data sets also indicates that the LiDAR has a higher elevation compared to what actually occurs across the Swan Pool floodplain (Figure B.12). Chainages in the profiles presented in Figure B.13 begin from the west.

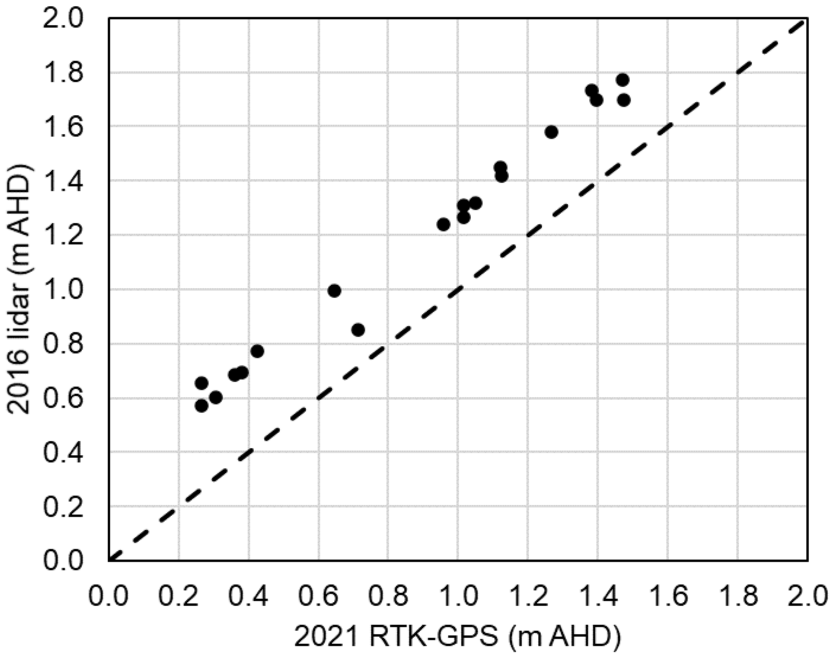


B.12: 1958 PWD survey digitised and corrected to AHD



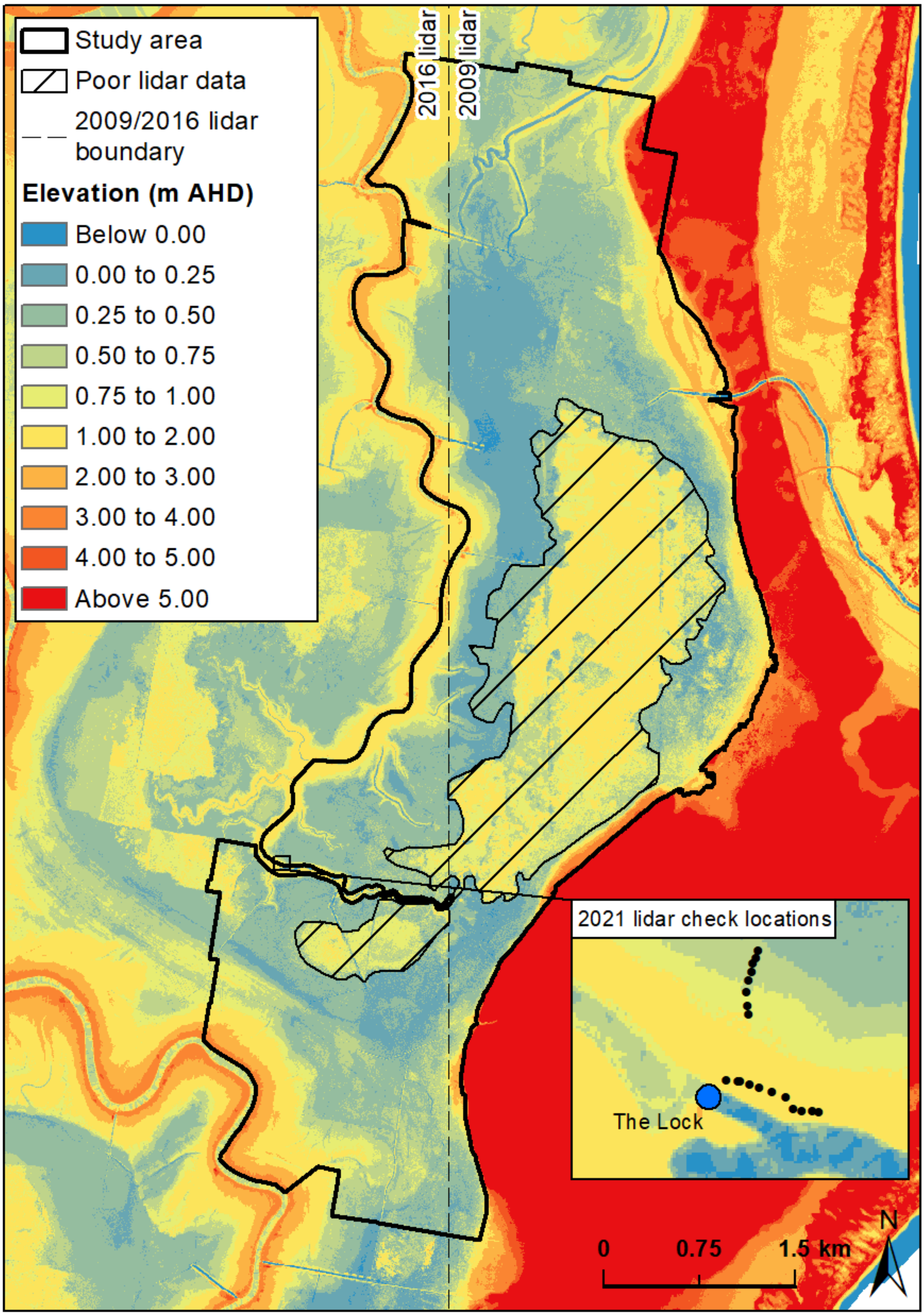
B.13: Comparison of 1958 PWD survey and 2009/2016 LiDAR (see profile locations in Figure B.12)

During a site inspection completed for this study, LiDAR data was compared to 19 RTK-GPS measurements of the Kinchela Creek levee at the Lock. These preliminary investigations indicate that the 2016 LiDAR measurements have an offset of approximately +0.3 m (Figure B.14).



B.14: Comparison of the 2016 LiDAR data with survey data collected on 10 June 2021 during the site inspection (see locations in Figure B.15)

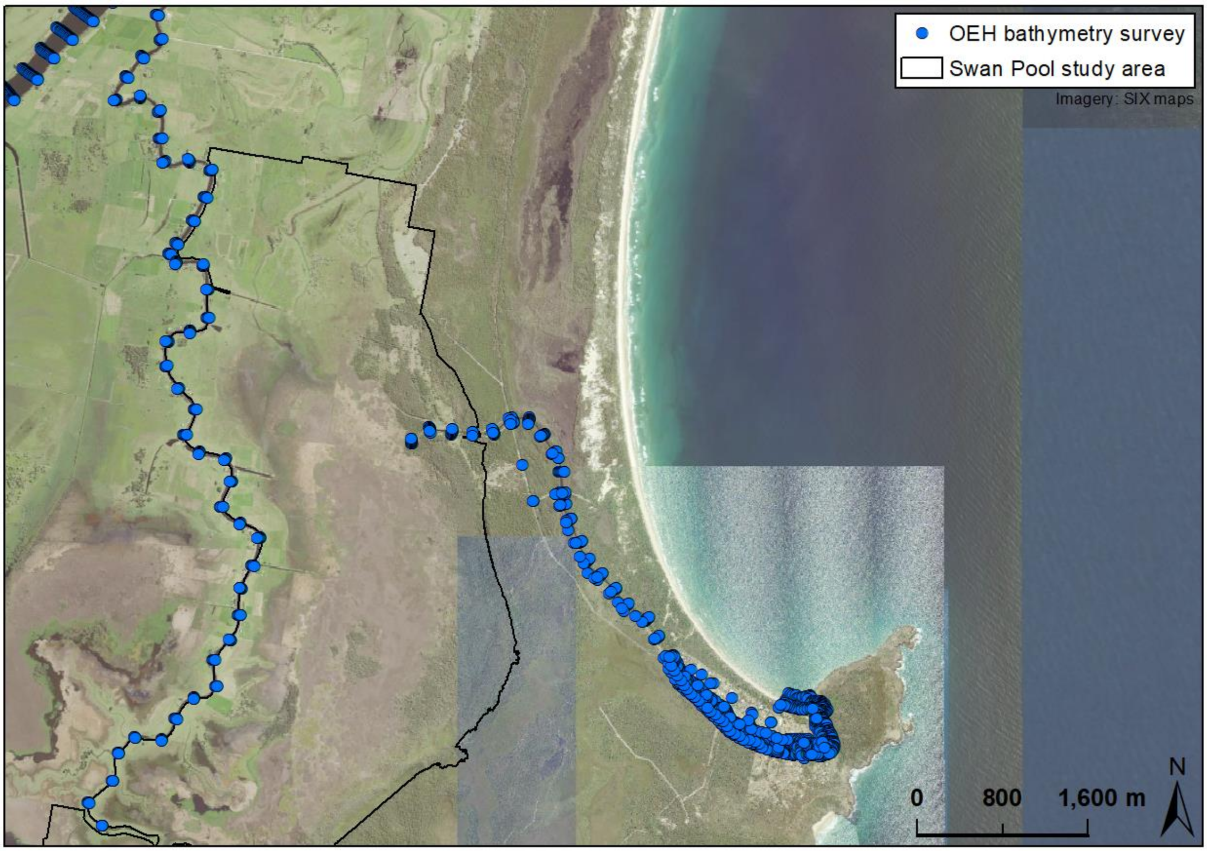
The LiDAR data collected by Spatial Services for the Swan Pool study area is shown in Figure B.15. The area where accuracy is suspected to be worse than ±0.30m due to dense vegetation has been highlighted.



B.15: Swan Pool LiDAR data

B4 Bathymetry

Bathymetry data collected by Environment, Energy and Science (EES, formerly the Office of Environment and Heritage) within the NSW Department of Planning, Industry and Environment is available for Kinchela Creek and Korogoro Creek (OEH, 2021) (Figure B.16). Data for Kinchela Creek was collected in 2003 and stretches from immediately downstream of The Lock to the creek's confluence with the Macleay River. Data for Korogoro Creek was collected in 2005 and includes the channel excavated during flood mitigation works and extends all the way to the ocean.



B.16: Bathymetry data collected by OEH

In addition to natural waterways, design drawings for flood mitigation drains are available for Hoffman's Drain and Korogoro Creek (MRCC, 1960; MRCC, 1967). Drawings indicate the design invert elevations of the drains relative to standard datum. In addition to this information, Tucker et al. (2021) surveyed one cross-section of Slaughterhouse Drain in 2019.

B5 Structures

A number of key flood mitigation structures have been surveyed by Tucker et al. (2021). Their survey included measurements of the dimensions and invert elevations for the headworks structures on:

- Slaughterhouse Drain
- Schoolhouse Drain
- Kinchela east floodway
- Kinchela Creek
- Hoffman’s Drain
- McNally’s Drain

KSC (2007) reported that a concrete sill was created on the upstream side of The Lock at an elevation of 0.00 m AHD. A site inspection conducted on 10 June 2021 found that this weir and the weir on North Drain have been removed.

Kempsey Shire Council provided dimensions and invert information for Kinchela No. 2 Drain, however, this information is out of date as the structure was replaced since the time of measurement in the year 2000. More recent information outlined by KSC (2006) specified Kinchela No. 2 Drain now has a circular culvert with a diameter of 1.5 m. No information on invert or obvert elevations for this structure were provided.

A site inspection was conducted on 10 June 2021. During this inspection the invert dimensions of The Lock and Korogoro Creek floodgates were measured using the same methods outlined by Rayner et al. (2021). The North Drain weir was also inspected and only remnants were found. Despite this there was significant sedimentation in the drain which was measured to have an invert of -0.15 m AHD.

A summary of known structure measurements is provided in Table B.3. Locations of each structure are shown in Figure B.17.

B.3: Structure dimension and invert data available for Swan Pool*

Structure name	KSC ID	No. of culverts	Dimensions (height x width or diameter) (m)	Invert (m AHD)	Notes	Data Source
Slaughterhouse Drain	028G1	3	1.86 x 1.2	-0.41		Tucker et al. (2021)
Schoolhouse Drain	027G1	5	1.8 x 1.2	-0.67		Tucker et al. (2021)
Kinchela east floodway	026G1	3		-0.26	Sluice structure with two triangular gates.	Tucker et al. (2021)
Kinchela Creek	024G1	3	2.6 x 1.8	-1.21		Tucker et al. (2021)
Hoffman's Drain	029G1	5	2.15 x 2.05	-1.44		Tucker et al. (2021)
McNally's Drain	032G1	4	1.86 x 1.5	-0.48		Tucker et al. (2021)
The Lock		4	1.0 x 1.0	-0.48 to -0.43	Concrete sill upstream of structure removed. Top of headwall at elevation of 1.81 m AHD to 1.84 m AHD	This study
Kinchela No. 2 Drain	030G1	1	1.5			KSC (2006)
Korogoro Creek	033G1	9	3.0 x 1.8	-0.75	Dimensions from design drawings not measured.	This study

* Locations of structures are shown in Figure B.17

Tulau (2013) also provided elevation measurements for the inverts for Korogoro Creek, Hoffman's Drain and McNally's Drain (-0.63, -1.33 and -0.41 m AHD, respectively). These measurements had an offset of between +0.07 m and +0.11 m compared to those measured in this study and by Tucker et al. (2021). This level of discrepancy is likely due to accuracy of RTK-GPS instrumentation.

Other dimension and invert data is available from Kempsey Shire Council who have a database of design dimension and invert measurements for a number of their structures. Invert dimensions for these structures are provided relative to 100 feet below standard datum and appear to be based on flood mitigation design drawings. To convert between standard datum and AHD a 0.11 m offset can subtracted from the standard datum invert heights using the correction provided by NSW Land and Property Information for the closest benchmark (PM7460). Accuracy of these invert levels are questionable as surveys completed by Tucker et al. (2021) found that often there were large discrepancies between design and constructed invert levels.

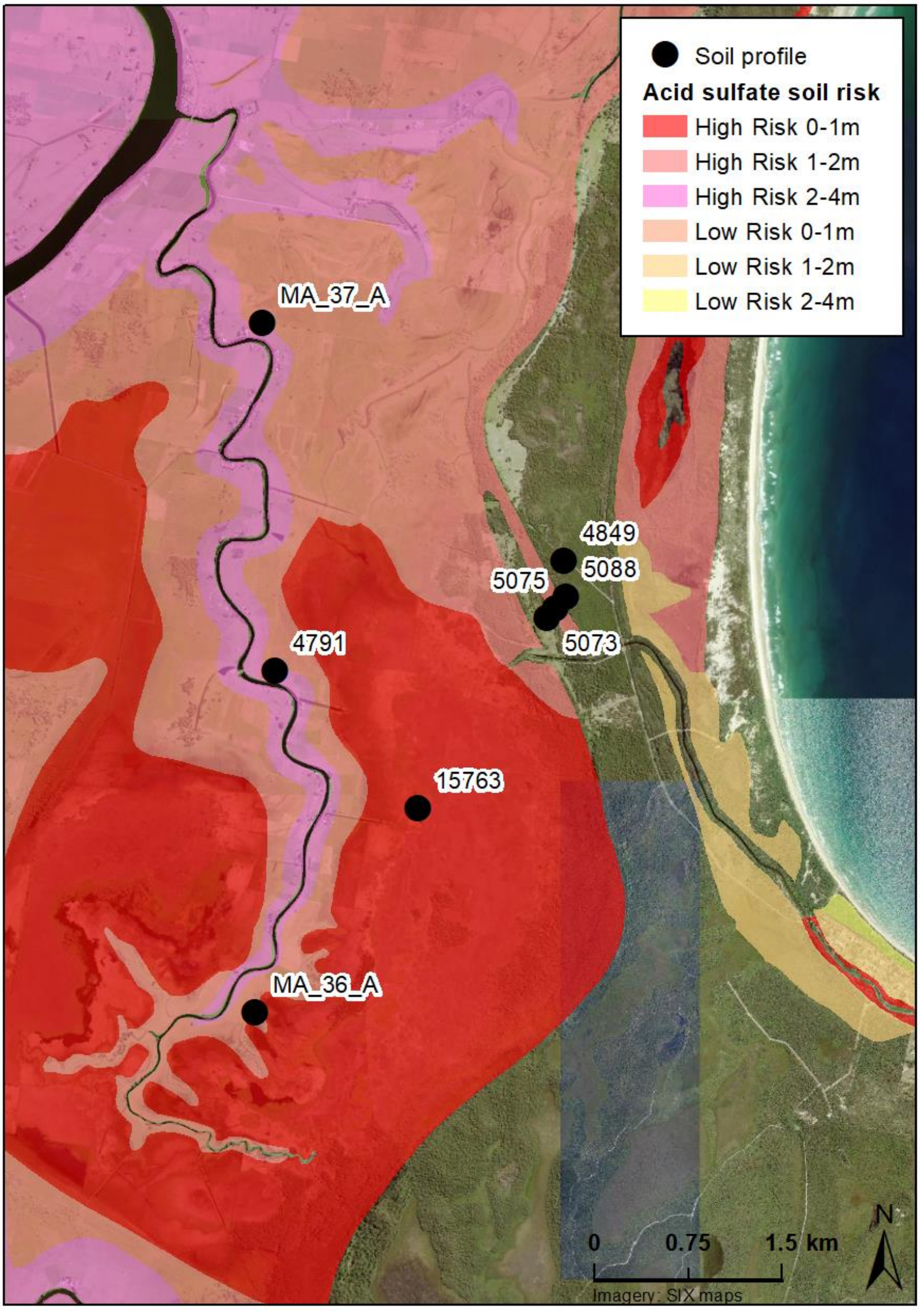
B.17 : Location of structures at Swan Pool

B6 Acid sulfate soils

Acid sulfate soil risk maps have been developed to identify the probability of acid sulfate soil occurrence across NSW (Naylor et al., 1999). The Kempsey and Korogoro risk maps are relevant for Swan Pool (Atkinson, 1997a; Atkinson, 1997b). Soil profile data collected and used for the development of the acid sulfate soil risk maps is available through eSPADE (DPIE, 2020). Tucker et al. (2021) also collected soil profile data in the Swan Pool area. Table B.4 summarises the soil profile data available for the Swan Pool area. Acid sulfate soil risk mapping and soil profile locations are presented in Figure B.18.

B.4: Soil profile data available for Swan Pool

Profile ID	Easting	Northing	Surface elevation (m AHD)	Total depth (m)	Minimum soil pH	Source
MA_36_A	499550	6564150	0.10	1.5	4.1	Tucker et al. (2021)
MA_37_A	499608	6569673	1.48	2.5	6.1	Tucker et al. (2021)
15763	500854	6565788	0.41	2.0	4.0	DPIE (2020)
4791	499704	6566888	0.93	0.9	5.5	DPIE (2020)
5073	501884	6567308	1.80	2.3	4.5	DPIE (2020)
5075	502404	6565808	2.05	0.9	4.0	DPIE (2020)
4849	502024	6567768	5.10	2.0	3.5	DPIE (2020)
5088	502034	6567478	3.56	2.0	4.5	DPIE (2020)



B.18: Soil profile locations and acid sulfate soil risk maps for Swan Pool (Atkinson, 1997a; Atkinson, 1997b).)

B7 Hydraulic conductivity

Hydraulic conductivity data has been collected in the Swan Pool area by Tucker et al. (2021). Data has been collected using the pit bailing method outlined by Johnston and Slavich (2003) and the auger hole method outlined by Bouwer and Rice (1976). Table B.5 summarises hydraulic conductivity measurements observed by Tucker et al., (2021). Note, locations of hydraulic conductivity measurements correspond to the soil profiles with the same ID in Figure B.18.

B.5: Hydraulic conductivity data for Swan Pool

ID	Easting (m) (GDA 94 MGA 56)	Northing (m) (GDA 94 MGA 56)	Hydraulic conductivity (m/day)	Method
MA_36_A	499550	6564150	22.5	Pit bailing
MA_36_A	499550	6564150	0.7	Auger hole
MA_37_A	499608	6569673	0.2	Auger hole

Hydraulic conductivity measurements were observed at location MA_36_A using both the pit bailing method and the auger hole method. Variance in hydraulic conductivity values highlights how spatially variable hydraulic conductivity on coastal floodplains can be. It is likely that the discrepancy in measurements at location MA_36_A can be explained by local variance in soil features, such as macropores.

B8 Vegetation/habitat

A vegetation survey of the wetlands on both the east and west sides of Kinchela Creek was completed by Pressey (1987) in 1983 and 1984. They identified 50 individual vegetation/habitat types across the floodplain. Thirty-four (34) of these vegetation/habitat types covered an area of less than 0.1 ha each. The remaining vegetation/habitat types are shown in Table B.6.

B.6: Swan Pool vegetation/habitat types (Pressey, 1987)

Vegetation/Habitat type*	Common name	Area (ha)	Percentage (%)
Bolboschoenus Fluviatilis	March clubrush (river bulrush)	350	13.89
Casuarina glauca	Swamp oak	40	1.59
Eleocharis equisetina	Spike-rush	680	26.98
Eleocharis sphacelata	Tall spike-rush	2	0.08
Juncus polyanthemus/usitatus	Australian grey rush/common rush	50	1.98

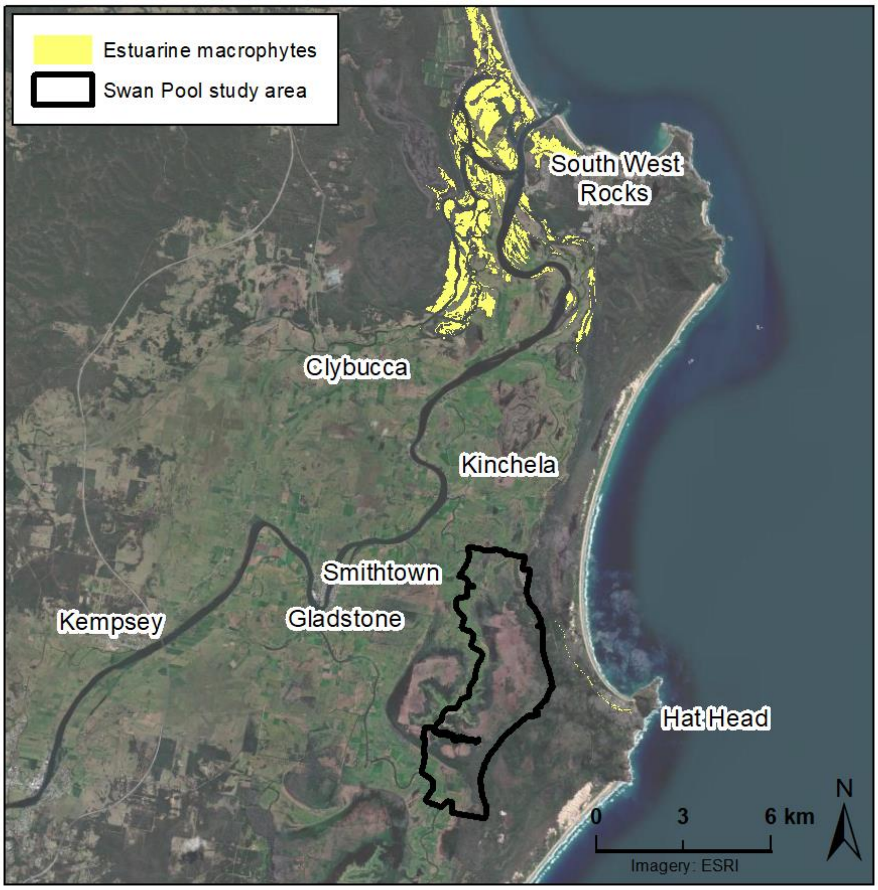
Vegetation/Habitat type*	Common name	Area (ha)	Percentage (%)
Juncus usitatus	Common rush	7	0.28
Melaleuca quinquenervia	Broad-leaved paperbark	140	5.56
Myriophyllum latifolium	Water milfoil	2	0.08
Paspalum paspalodes	Water couch (Buffalo)	550	21.83
Persicaria hydropiper	Smartweed	300	11.90
Phragmites australis	Common reed	350	13.89
Salvinia molesta	Kariba weed	20	0.79
Schoenoplectus validus	Marsh clubrush	1	0.04
Triglochin procera	Water ribbons	5	0.20
Typha orientalis	Bullrush	3	0.12
Shallow open water		20	0.79

* Vegetation/habitat identified with an area less than 0.1 ha included: Alternanthera denticulata, Azolla pinnata, Bacopa monniera, Baumea articulata, Bolboschoenus medianus, Carex appressa, Cladium procerum, Cotula coronopifolia, Cyclosorus interruptus, Cyperus platystylis, Cyperus polystachyos, Echinochloa crus-galli, Eichhornia crassipes, Eleocharis minuta, Enydra fluctuans, Hibiscus diversofolius, Hydrocotylre bonariensis, Isolepis inundata, Juncus planifolius, Juncus polyanthemus, Juncus prismatocarpus, Leersoa hexandra, Ludwigia peploides, Marsilea mutica, Nymphaea capensis, Persicaria decipiens, Persicaria praetermissa, Persicaria strigosa form1, Philydrum lanuginosum, Plantago major, Ranunculus inundatus, Rumex conglomeratus, Spirodela oligorrhiza, Triglochin procera.

Smith (2002) and Tulau (2013) identified that there were observable changes to the vegetation at Swan Pool that resulted from floodplain drainage. Tulau (2013) identified that *Melaleuca quinquenervia* (broad-leaved paperbark), which can survive inundation of 0.5 m for two to six months, has encroached on areas of the wetland that would have historically been inundated to depths that would have resulted in mortality. They also observed similar encroachment from *Casuarina glauca* (swamp oak). Smith (2002) highlighted how visible changes in vegetation are evident when comparing satellite imagery taken before (1942) and after (1990s) drainage works with *Schoenoplectus validus* (marsh club rush) now encroaching on historically inundated land (Figure B.19).

B.19: Swan Pool in 1942 (left) and the 1990s (right) showing significant encroachment of marsh club rush into historically inundated floodplain

Estuarine macrophyte mapping has been completed by Creese at al., (2009) for the Macleay River and Korogoro Creek estuaries (Figure B.20). Mapping indicates that mangrove and saltmarsh habitat does not occur within Kinchela Creek. Mangrove habitat is however observed downstream of the Korogoro Creek floodgates.



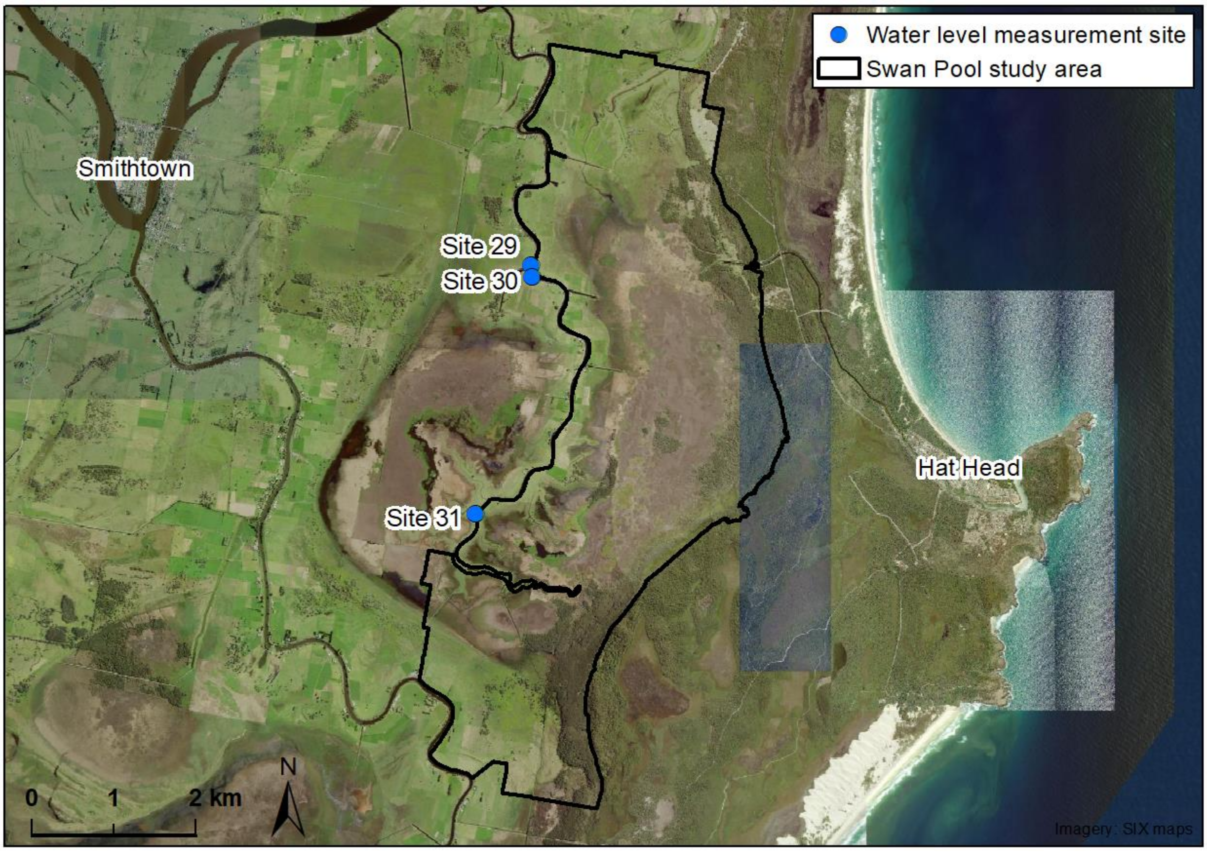
B.20: Estuarine macrophytes

B8.1 Aquatic weeds

Smith (2002) noted that Salvinia, water hyacinth and other aquatic weeds grew throughout the drains within Swan Pool. LMP (1980) also reported significant growth of *Salvinia molesta* across the Swan Pool floodplain. They attributed its prevalence due to the changes in floodplain hydrology associated with the flood mitigation infrastructure.

B9 Water levels

Water levels within Kinchela Creek were measured by Allsop and Kadluczka (2004) at three locations between April and May 2003 (Figure B.21). Using this data Allsop and Kadluczka (2004) determined the tidal planes at each monitoring location (Table B.7, Table B.8 and Figure B.22). Comparisons were also completed to determine any differences in the tide phase between monitoring sites (Figure B.23). Note, Site 0 is the ocean tide levels as measured at Coffs Harbour and Site 3 is the tide level of the Macleay River measured at the Macleay Arm entrance.



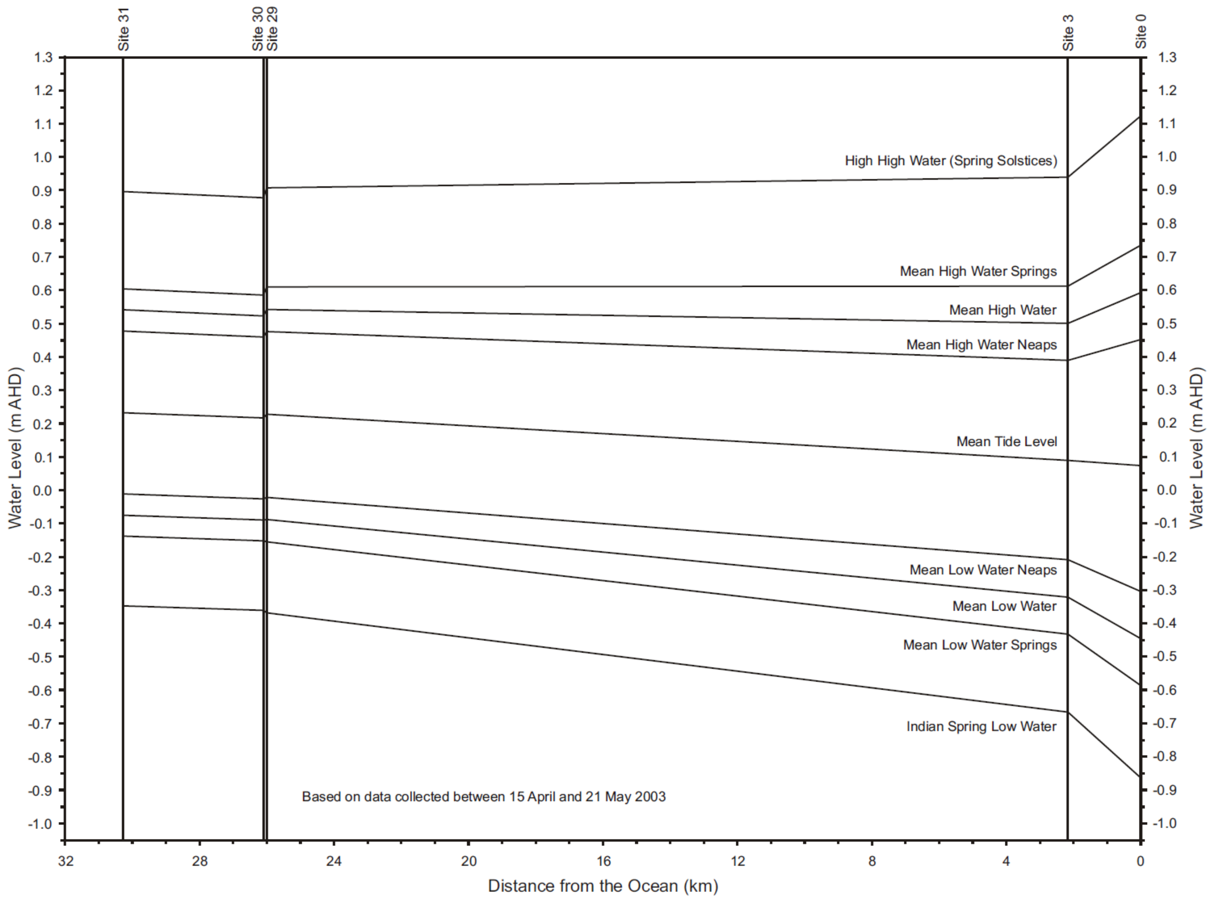
B.21: Location of Allsop and Kadluczka (2004) water level monitoring sites

B.7: Tidal planes within Kinchela Creek (Allsop and Kadluczka, 2004)

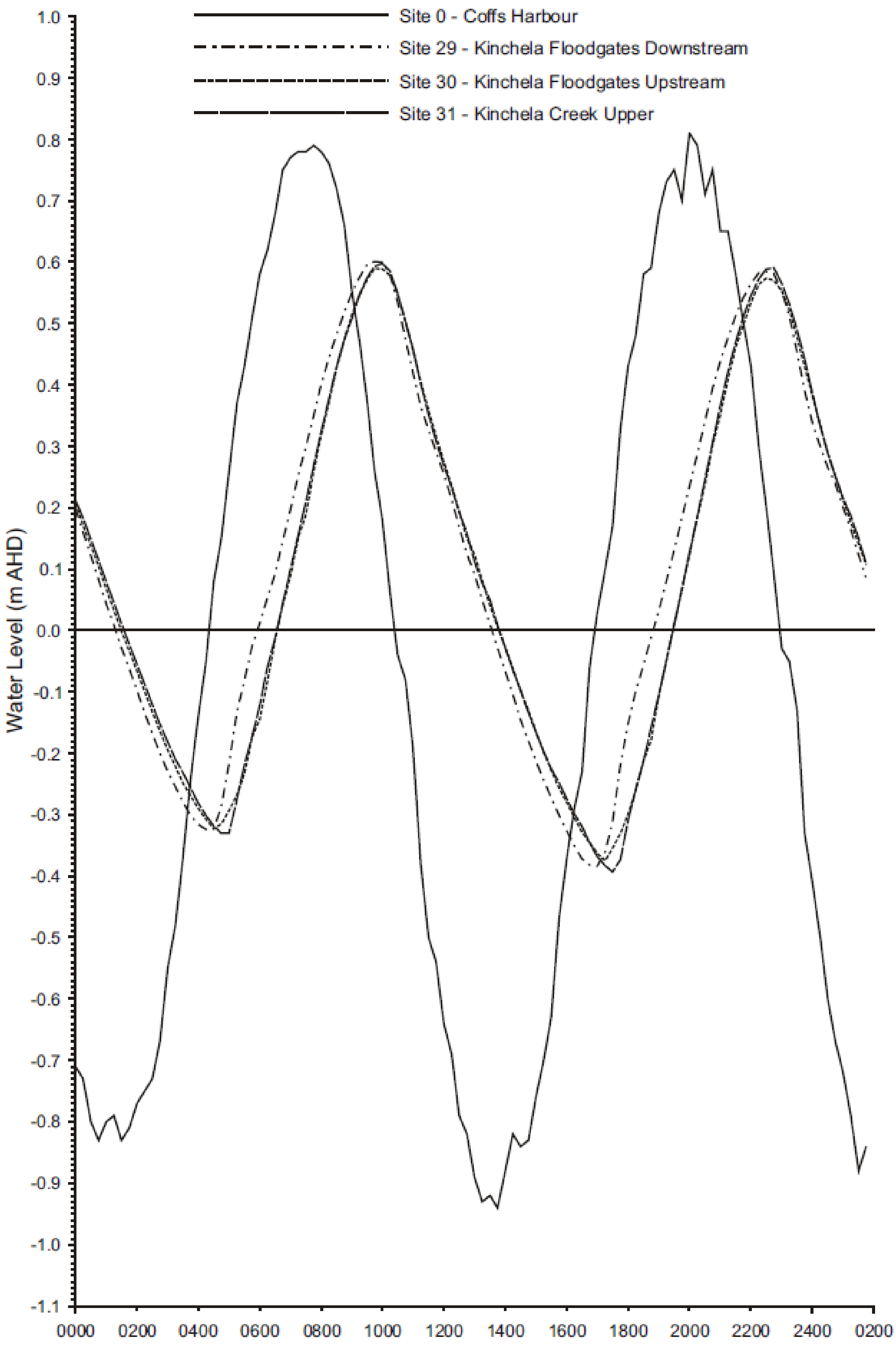
Tidal Planes	Ocean Site 0 (m AHD)	Site 3 (m AHD)	Kinchela Creek Site 29 (m AHD)	Site 30 (m AHD)	Site 31 (m AHD)
HHW(SS)	1.124	0.940	0.908	0.878	0.897
MHWS	0.736	0.613	0.611	0.586	0.605
MHW	0.594	0.501	0.543	0.523	0.542
MHWN	0.453	0.390	0.476	0.460	0.478
MTL	0.074	0.090	0.228	0.217	0.233
MLWN	-0.304	-0.209	-0.021	-0.026	-0.011
MLW	-0.446	-0.321	-0.088	-0.089	-0.075
MLWS	-0.587	-0.432	-0.155	-0.152	-0.138
ISLW	-0.864	-0.666	-0.368	-0.361	-0.347

B.8 Tidal plane comparisons for Kinchela Creek (Allsop and Kadluczka, 2004)

Tidal Range	Ocean Site 0 (m AHD)	Site 3 (m AHD)	Kinchela Creek Site 29 (m AHD)	Site 30 (m AHD)	Site 31 (m AHD)
HHW(SS) to ISLW	1.988	1.606	1.276	1.239	1.244
Mean Spring	1.323	1.045	0.766	0.738	0.743
Mean	1.040	0.822	0.631	0.612	0.616
Mean Neap	0.757	0.599	0.497	0.486	0.490



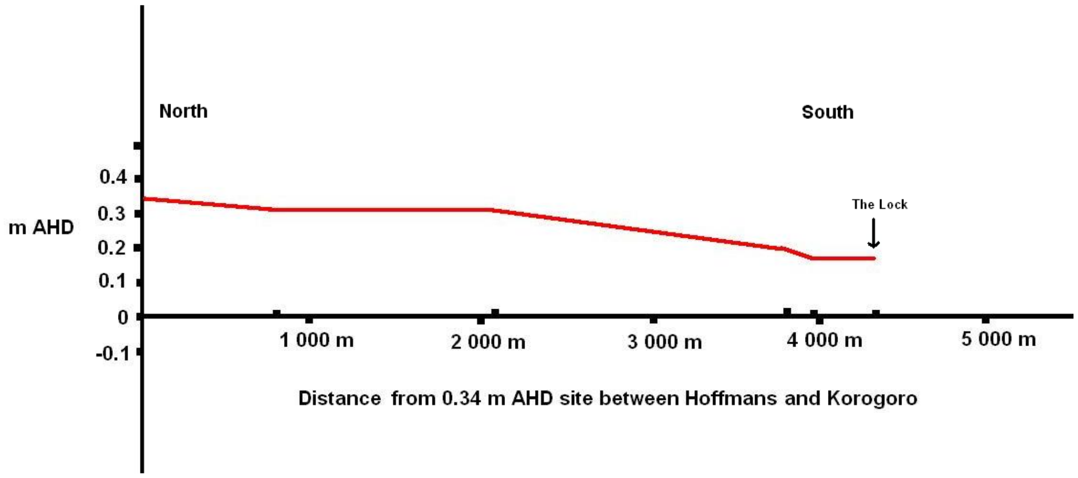
B.22: Tide profile within Kinchela Creek (Allsop and Kadluczka, 2004)



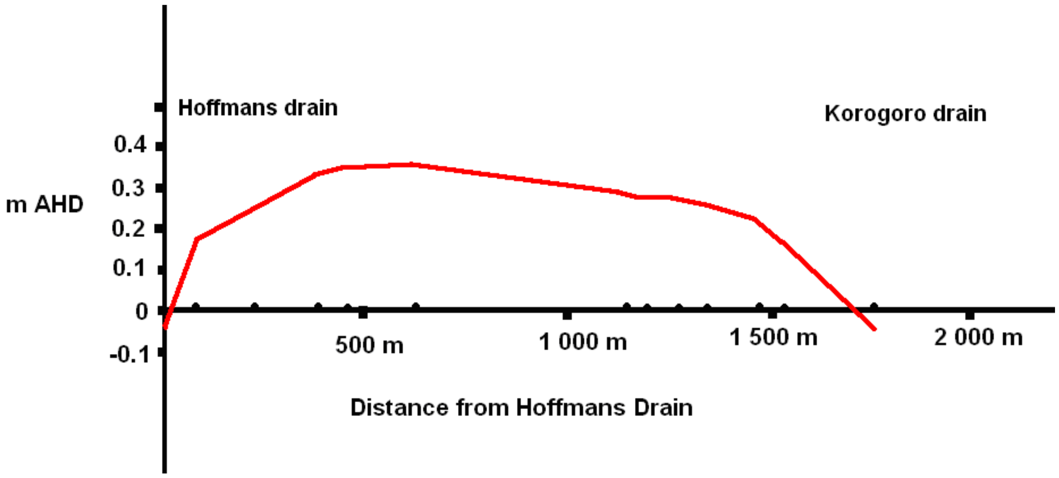
B.23: Tide phase within Kinchela Creek (Allsop and Kadluczka, 2004)

Tulau (2013) captured 38 water level measurements across the Swan Pool floodplain in June 2013 (Figure B.24). They used this data to develop a profile of water level elevations across the floodplain in the north-south and east-west directions (Figure B.25 and Figure B.26, respectively). Note, the weir on the upstream side of The Lock was still in place when these measurements were taken. A single water level measurement observed on North Drain during the site inspection conducted on 10 June 2021 observed the water level at -0.09 m AHD, compared to 0.24 m AHD during the Tulau (2013) survey.

B.24: Water level observation sites in June 2013 (Tulau, 2013)



B.25: North-South water level elevation profile for Swan Pool (Tulau, 2013)



B.26: East-west water level elevation profile for Swan Pool (Tulau, 2013)

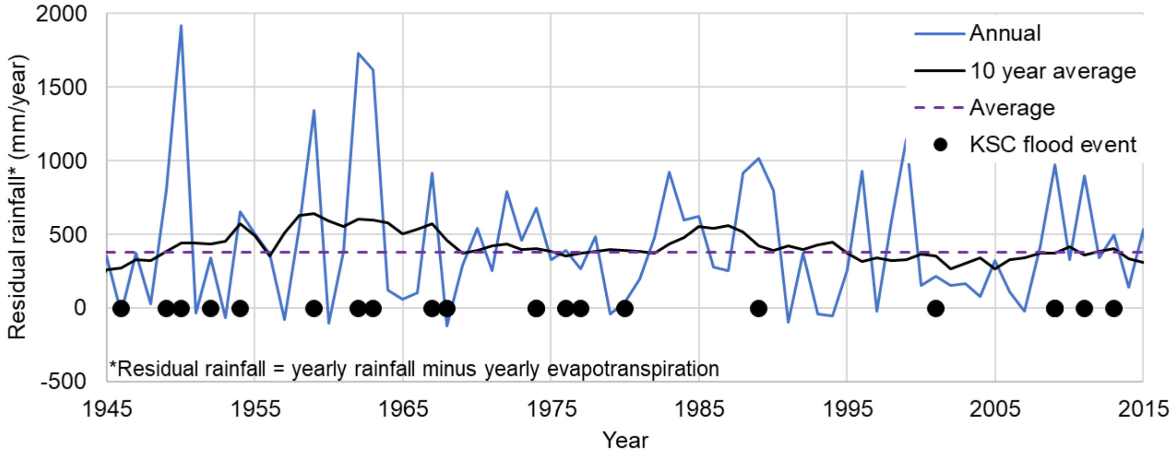
B10 Climate

The closest active weather station to Swan Pool is located at the Smoky Cape Lighthouse (Station 059030). Monthly and annual climate data statistics for this site are provided in Table B.9. Evapotranspiration data has been calculated using the Penman-Monteith method as per Allen et al. (1998). Long-term data for rainfall is shown in Figure B.27 taking into account evapotranspiration.

B.9: Climate data from Smoky Cape Lighthouse (Station 059030) (BOM, 2021)

Parameter	Monthly												Annual
	January	February	March	April	May	June	July	August	September	October	November	December	
Mean max temperature (°C)	27	27	26	24	22	19	19	20	22	23	25	26	23
Mean min temperature (°C)	20	20	19	17	14	12	11	12	14	15	17	19	16
Mean rainfall (mm/month) or (mm/year)	143	171	187	168	128	139	76	78	56	92	112	122	1485
Mean number of days of rain (days)	13	14	16	13	11	11	8	8	8	11	12	13	137
Mean daily solar exposure (MJ/m^2)	24	21	17	15	12	10	11	15	18	21	23	23	18
Mean 9 am relative humidity (%)	81	84	81	77	73	71	65	65	68	72	76	79	74
Mean 3 pm relative humidity (%)	75	77	75	72	70	68	63	62	67	71	73	75	71
Mean 9 am wind speed (km/h)	18	17	17	17	20	22	22	19	18	18	19	18	19
Mean 3 pm wind speed (km/h)	22	21	21	19	18	19	19	21	24	25	24	23	21
Mean daily evapotranspiration (mm)*	4.6	4.1	3.3	2.5	1.7	1.3	1.5	2.1	2.9	3.6	4.1	4.4	3.0

*Calculated using the Penman-Monteith method as per Allen et al. (1998)



B.27: Rainfall and evaporation records for Swan Pool (1945 to 2015). Years where KSC (2021a) identified a flood event have occurred.

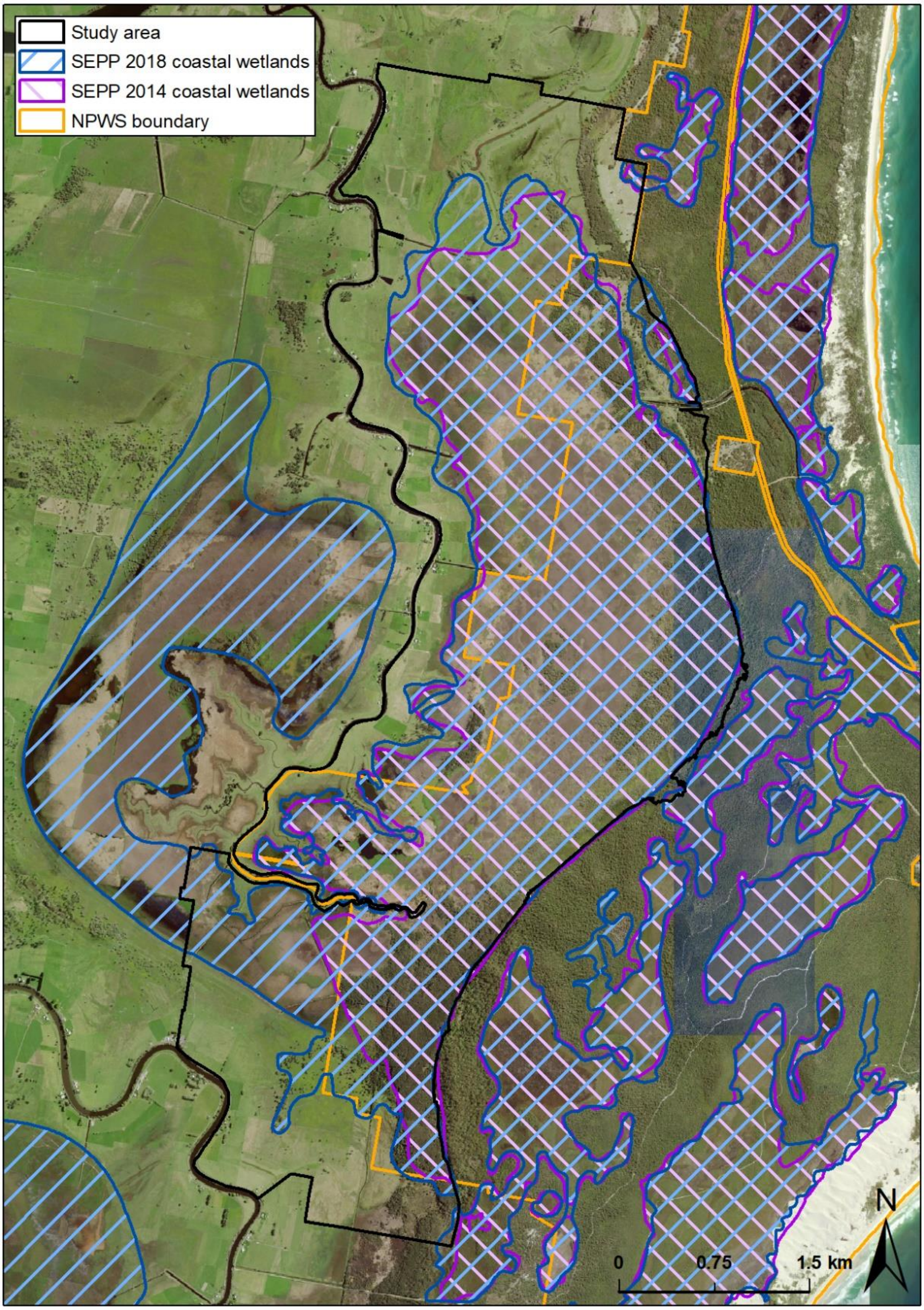
B11 Heritage

Heritage listings in NSW are protected by law under the Heritage Act, 1977 (amended 1998) and the Environmental Planning and Assessment Act 1979. Nationally significant heritage items are protected under the Environment Protection and Biodiversity Conservation Act 1999. A preliminary review of the NSW State Heritage Inventory, the Kempsey Shire Council Local Environmental Plan (LEP) 2013, Aboriginal Heritage Information Management System, and the Maritime Heritage Database for the Swan Pool study area did not indicate any heritage items. Note that new heritage items are continuously being registered. Subsequently, anyone seeking to identify the most recent information on heritage listed items will need to consult the relevant registers which contain current information, including:

- Items listed in local councils Local Environmental Plan (LEP) or Regional Environmental Plan (REP)
- Items listed on the State Heritage Register
- Items listed on State Agency Heritage Registers (under Section 170 of the Heritage Act, 1977)
- Items listed on Interim Heritage Orders
- Items listed on the Aboriginal Heritage Information Management System (AHIMS)
- Items listed on the Maritime Heritage Database
- Items listed on the Commonwealth Heritage List
- Items listed on the National Heritage List

B12 State Environment Planning Policy (SEPP)

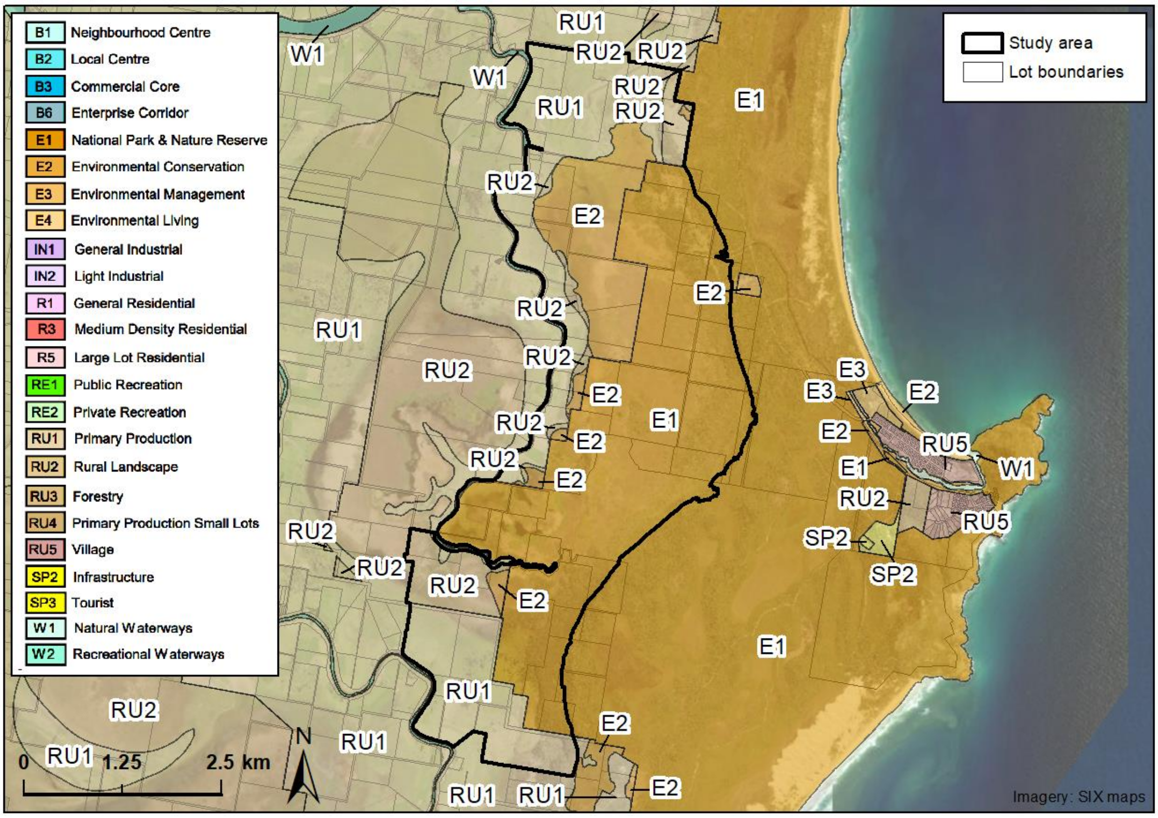
Certain areas in the NSW coastal zone, including coastal wetlands, are subject to specific development controls under the Coastal Management Act 2016. Mapping of these areas is outlined in the State Environment Planning Policy (Coastal Management) 2018 (Coastal Management SEPP). At Swan Pool there are extensive coastal wetlands mapped in the Coastal Management SEPP. The former (2014) and current (2018) maps for Coastal Management SEPP coastal wetlands is shown in Figure B.28.



B.28: Current (2018) and former (2014) Coastal Management SEPP coastal wetlands mapping

B13 Land zoning

The most recent land zoning information for Swan Pool is outline in the Kempsey Local Environmental Plan (LEP) 2013 (Figure B.29). When this was updated, low-lying land surrounding Hat Head National Park and Swan Pool was reclassified as E2 (environmental conservation).



B.29: Swan Pool land zoning (Kempsey LEP 2013)

B14 Data gaps

Review of the data available for the Swan Pool study site found the following data gaps:

- Accurate topographic/bathymetry data for low-lying areas of the Swan Pool floodplain
- Long-term water level timeseries data across the Swan Pool floodplain and receiving waters
- Cross-section data for flood mitigation drains and Kinchela Creek upstream of The Lock
- Invert elevation for Kinchela No. 2 Drain
- Discharge at drainage points across the Swan Pool floodplain
- Long-term water quality data for Kinchela Creek
- Groundwater inflow data
- Updated vegetation/habitat data

These datasets would provide further understanding of the hydrology at Swan Pool and allow for the development of a water balance model for the site and/or development of a numerical model. These tools could be used to guide the future management of the site such as assessing remediation options, identifying risks to private landowners, identifying risks to the environment, and predicting likely habitat and biodiversity outcomes.

Appendix C Review of current Swan Pool remediation strategies

Recommendations, actions, and strategies for the remediation of Swan Pool have been outlined in the following studies:

- Swan Pool drainage management project (Smith, 2002)
- Macleay River coastal zone management plan (GeoLINK, 2012)
- Korogoro Creek estuary management plan (Telfer and Birch, 2009b)

A review of the recommendations specified by Smith (2002) is outlined in Table C.1. A review of the actions and strategies specified by GeoLINK (2012) and Telfer and Birch (2009b) is outlined in Table C.2 (where they differed from the recommendations specified by Smith (2002)). In both cases the current status or success of recommendations/actions/strategies has been noted.

C.1: Review of remediation recommendations for Swan Pool by Smith (2002)*

Recommendation (Smith, 2002)	Status	Notes
NPWS adopt a medium term strategy (5-10 years) to reinstate the natural hydrology of the Swan Pool in co-operation with DLWC and KSC.	No action	As of September 2021 NPWS are in the process of updating the Hat Head National Park plan of management which may address this recommendation.
Decisions made by KSC and landholders regarding maintenance and improvement works on floodgates and drains that impact on the Swan Pool ensure that the wetland values of the area are considered.	Attempted unsuccessfully	KSC installed a buoyancy gate on The Lock, a weir on the upstream side of The Lock, and a weir on North Drain. Due to lack of support from upstream landowners all of these modifications have been removed. A management plan has been developed for the Kinchela Creek floodgates which does consider wetland values (KSC, 2015a). Similar plans for The Lock and Kinchela No. 2 Drain are now outdated (KSC, 2006; KSC, 2007)
NPWS adopt existing floodgate and drain maintenance 'Best Management Practice Guidelines' into their management plans to improve communication both within and without the organisation on these matters.	No action	As of September 2021 NPWS are in the process of updating the Hat Head National Park plan of management which may address this recommendation. Note, KSC has developed a plan of management for The Lock and a weir on North Drain (KSC, 2007) which is owned by NPWS, however, the plan is now outdated.

Recommendation (Smith, 2002)	Status	Notes
NPWS explores with private landholders in the Swan Pool study area, the potential to incorporate all wetlands into the Hat Head National Park to the 0.5m AHD contour.	Attempted partial success	NPWS have contacted landowners regarding acquisition. To date a number of lots to the south of Swan Pool have been acquired.
KSC and NPWS seek funding to modify the entrance to the Korogoro Cut to limit further groundwater drawdown.	No action	No modifications identified.
The NSW Government assists the NPWS in completing the acquisition of the remaining freehold land that constitutes the Swan Pool wetland.	Attempted partial success	NPWS have contacted landowners regarding acquisition. To date a number of lots to the south of Swan Pool have been acquired. Unclear if further intervention from NSW Government has been provided.
NSW Fisheries considers funding the replacement of the 'Lock' with a new floodgate structure on Kinchela Drain #2 to allow reinstatement of tidal flows in Kinchela Creek.	Attempted unsuccessfully	This recommendation was implemented by KSC. Buoyancy floodgates have since been removed due to lack of support from upstream landowners.

*NPWS = NSW National Parks and Wildlife Service; DLWC = NSW Department of Land and Water Conservation, which is now part of various other NSW departments; KSC = Kempsey Shire Council

C.2: Review of actions/strategies recommended for Swan Pool from coastal management programs for the Macleay River and Korogoro Creek estuaries*

Action/strategy	Source	Status	Notes
Investigate further changes to the drainage infrastructure in the Belmore and Kinchela Swamps that could increase water retention and reduce groundwater drawdown.	GeoLINK (2012)	No action	Rollason (2020a) notes there has been no action due to lack of landholder support, lack of clarity on jurisdiction, and lack of a whole of (Macleay) system approach.
Strategies to reduce the formation of MBOs in drains: • Reducing the nutrient availability in drains • Reduce the light availability in drains • Harvesting and removing in-drain vegetation • Reducing drain depth	GeoLINK (2012)	No action	Rollason (2020a) notes there has been no action due to lack of landholder support, lack of clarity on jurisdiction, and lack of a whole of (Macleay) system approach.
Create a Project Officer position within NRCMA or KSC to manage high priority actions associated.	GeoLINK (2012)	Attempted unsuccessfully	Rollason (2020a) notes there has been lack of funding for such a position.

Action/strategy	Source	Status	Notes
Prioritise, develop, and implement management plans for unmanaged major floodgates: • Slaughterhouse Drain • Schoolhouse Drain • McNally's Drain • Kinchela Creek East Flood Control Structure • Kinchela Creek Floodgate • The Lock Include flood, post-flood; and non-flood operating regimes.	GeoLINK (2012)	Attempted partial success	A management plan was developed for the Kinchela Creek floodgates (KSC, 2015a). There are also existing plans for The Lock (KSC, 2007) and Kinchela No. 2 Drain (KSC, 2006). The plan for The Lock is outdated and refers to modifications which are no longer in place on The Lock.
Assess Effectiveness of Drainage Works-to-Date.	GeoLINK (2012)	No action	Rollason (2020a) notes future projects may address this action, however, none are identified.
Continue to encourage wet pasture management in the drainage catchments.	GeoLINK (2012)	No action	Rollason (2020a) notes there has been no action due to lack of landholder support, lack of clarity on jurisdiction, and lack of a whole of (Macleay) system approach.
Encourage the uptake of private conservation measures on floodplain wetlands.	GeoLINK (2012)	No action	Rollason (2020a) notes there has been no action due to lack of landholder support, lack of clarity on jurisdiction, and lack of a whole of (Macleay) system approach.
Continue to control *Salvinia molesta* in East Kinchela Wetland and apply successful techniques to other wetlands and drains.	GeoLINK (2012)	Attempted partial success	The NPWS plan of management for Hat Head National Park (NPWS, 1998) specifies a control program should be implemented to manage introduced weeds. It is unclear if management occurs outside of the national park on private land. No assessment has been completed to determine the success of weed management.
Amend Council LEP Land Zoning to Protect Important Habitat.	GeoLINK (2012)	Attempted successfully	Land zoning has been adjusted in the Kempsey Local Environmental Plan (LEP) 2013.
Encourage Incentive Property Vegetation Plans or Biobanking for Important Habitat Areas.	GeoLINK (2012)	No action	Rollason (2020a) notes there has been no action due to lack of landholder support, lack of clarity on jurisdiction, and lack of a whole of (Macleay) system approach.
Encourage Landholder Management of Important Habitat Areas.	GeoLINK (2012)	No action	Rollason (2020a) identified this as an action to continue in the future

Action/strategy	Source	Status	Notes
			Macleay River coastal management.
Undertake a 'dry time' assessment of water quality effects of the flood mitigation scheme.	Telfer and Birch (2009b)	No action	A literature review (Appendix A) did not identify any investigations addressing this action item.
Schedule an event based assessment of the water quality effects of the flood mitigation scheme.	Telfer and Birch (2009b)	No action	A literature review (Appendix A) did not identify any investigations addressing this action item.
Investigate the source of observed water quality in the upper estuary. If the source of poor water quality is found to be above the floodgates undertake appropriate actions.	Telfer and Birch (2009b)	No action	A literature review (Appendix A) did not identify any investigations addressing this action item. Some investigations have identified sources of poor water quality in the lower Korogoro Creek estuary (Rollason, 2020b).
Investigate other potential options for changes in the management of the floodgates, the Korogoro Cut and the Swan Pool.	Telfer and Birch (2009b)	No action	A literature review (Appendix A) did not identify any investigations addressing this action item.
Identify specific water quality and acid sulfate soils issues within the Swan Pool wetland that impact upon Korogoro Creek.	Telfer and Birch (2009b)	No action	As part of a broader study, Tucker et al. (2021) identified the environmental risk Swan Pool poses in terms of diffuse runoff of acid (from acid sulfate soils) and blackwater. This was not completed on a localised scale.
Continue existing efforts by Kempsey Council, NPWS and landholders to address acid sulfate soil and wetland management issues and improve the quality of water entering Korogoro Creek during flood times.	Telfer and Birch (2009b)	No action	KSC has investigated clearing vegetation at Korogoro Cut (Tulau, 2015), however, no modifications to the system to improve water quality have been identified.

*Note: A review of the recommendations has also been completed by Rollason (2020a; 2020b) in the context of the Macleay coastal management program. NRCMA = Northern Rivers Catchment Management Authority, now NSW Local Lands Services; KSC = Kempsey Shire Council; NPWS = NSW National Parks and Wildlife Service; DECC = Department of Environment and Climate Change, now part of the Office of Environment and Heritage (OEH); LEP = Local Environmental Plan.