# Assessing coastal wetland rehabilitation: Clybucca wetlands

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**Abstract**
The Clybucca wetlands are located on the Macleay River floodplain on the New South Wales mid-north coast. Historically they comprised an extensive network of freshwater backswamps that were abundant with aquatic life. Large-scale drainage works completed during the 1960s and 1970s resulted in significant changes to the low-lying backswamp areas. An extensive network of deep drains and one-way floodgate infrastructure mitigated flood impacts and improved agricultural productivity but resulted in the oxidation of underlying acid sulfate soils and a loss of wetland biodiversity. Regular highly acidic discharge and low dissolved oxygen 'blackwater' runoff significantly affects downstream waterways, resulting in impacts to aquatic ecology including fish kills and oyster mortality.

Rehabilitation of low-lying acid sulfate soil affected coastal floodplains requires careful consideration of a range of processes and factors including; overall floodplain drainage, the sources, fate and transport of poor water quality in downstream waterways, adjacent floodplain land uses and tenure, remediation options, constructability and maintenance, and long-term land management. In recent years, the opportunity to rehabilitate some of the worst acid affected floodplain areas has presented itself.

Extensive field investigations were completed to understand overall floodplain hydrology, drainage connectivity, and identify the sources of poor water quality. Detailed survey and monitoring data were collated to construct a 'paddock scale' hydrodynamic model to assess rehabilitation strategies. Using the model, a number of remediation options were assessed to determine the optimum rehabilitation strategy, including: freshwater options that resulted in wetland rehabilitation while maintaining current floodplain land uses, tidal options that would result in extensive development of coastal wetlands across the floodplain, and sea level rise options. Into the far-future, as sea level rise impacts reduce drainage across the floodplain, conversion to a connected tidal ecosystem, or natural large scale backswamp system, would have the greatest environmental benefit to the broader estuary.

*Keywords: Floodplain, wetland, habitat, rehabilitation, water quality, hydrodynamics.*

## 1. Introduction

The Collombatti-Clybucca floodplain (hereafter the Clybucca floodplain) inclusive of the Clybucca wetlands, is located on the Macleay River estuary floodplain. The floodplain is located approximately 15 kilometres from the ocean entrance at South West Rocks and has a contributing catchment area of approximately 26,000 hectares (Figure 1). Runoff from the catchment is channelled across the floodplain through a complex network of natural creeks and constructed drainage channels. Downstream water levels within this network are controlled by a tidal floodgate barrage structure located at Menarcobrinni that drains the upstream waters and prohibits tidal inundation from the river.

Historically, the Clybucca wetlands were a large freshwater wetland complex that extended across the floodplain and were disconnected from the estuary. During the early 1960s, large drainage construction works were completed across the Macleay River estuary, including at Clybucca, for flood mitigation purposes (Figure 2). These on-ground works modified the creek system and enhanced drainage. This resulted in improved connectively with downstream tidal waters and a tidal barrage was subsequently required at

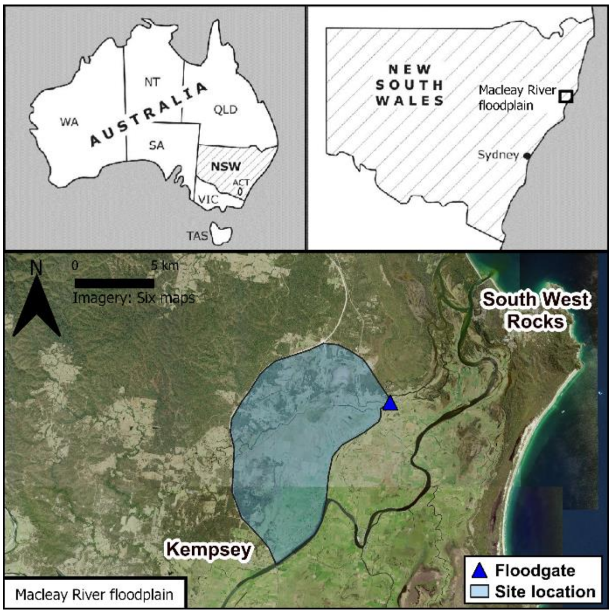


Figure 1: Location of the Clybucca study site including the Menarcobrinni floodgates which control the water level within the site and prevent tidal inundation.

Menarcobrinni to prevent tidal inundation. In addition to flood mitigation, this infrastructure enhanced the agricultural productivity of the low-lying land for pasture grazing.

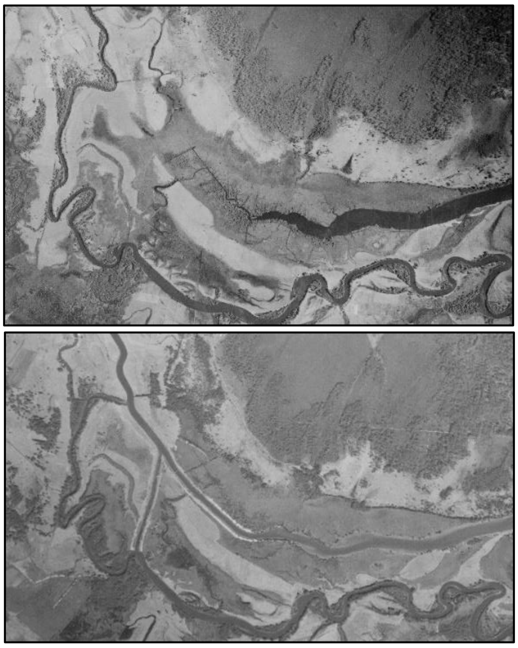

Figure 2: (Source [1]) Changes to Anderson's Inlet from 1956 (top) to 1967 (bottom). These changes increased the conveyance to Clybucca meaning that floodgates were required to prevent tidal inundation of low-lying land.

The extensive drainage network has had unintended environmental impacts, including the production of acidic by-products from the drainage of acid sulfate soils and exacerbation of low-oxygen 'blackwater' runoff into the estuary which has been extensively documented in previous studies [2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15,16]. As such, the Clybucca floodplain was identified as an acid sulfate soil hotspot priority area in NSW [17]. On-ground remediation efforts during the 1990s resulted in the construction of low elevation sills/weirs in the trunk drain network. These works were applied on an individual farm scale and aimed to raise groundwater levels and reduce acid export in local areas without impacting agricultural productivity. The remediation of large acid scalds was also undertaken. Despite these efforts, poor water quality, including low pH and low dissolved oxygen water, continues to discharge from the low-lying floodplain areas at Clybucca. Figure 3 shows a large acid scald, known as Yerbury's Scald, which still exists adjacent to Seven Oaks Drain, a large trunk drain which lowers the groundwater table across the floodplain.

During the Oxley Highway to Kempsey Pacific Highway upgrade project, Transport for NSW (TfNSW) purchased a large proportion of the Clybucca wetland complex as part of the biodiversity offset requirements of the project. This provided a unique opportunity whereby one entity owned the majority of the worst affected acid sulfate soil land across the Clybucca floodplain. Further voluntary acquisitions of low-lying land have occurred over the proceeding years to extend the area owned by TfNSW. This has led to the opportunity whereby large-scale remediation across the site has become feasible, as opposed to localised farm scale remediation as has previously occurred. For the first time remediation can target alteration of the floodplain hydrology on a catchment scale to mitigate the impacts of acid sulfate soil drainage and blackwater.

Figure 3 Yerbury's Scald in March 2018. A large acid scald with an elevation between -0.65 and -0.20 metres AHD located on the Clybucca floodplain. A large trunk drain (Seven Oaks Drain) runs along the northern side of the scald (to the right of the image). A low elevation weir can be seen across Seven Oaks Drain (bottom right of the image), constructed as part of remediation efforts in the 1990s.

The aim of this study was to develop, investigate and assess the feasibility of management options to improve water quality, increase the wetland habitat, and identify potential impacts on floodplain inundation, drainage and saltwater intrusion. To achieve this aim, a detailed methodology was developed including a site conceptualisation, extensive fieldwork and data collection, and the development of a validated hydrodynamic and advection dispersion numerical model, all of which were used to complete a thorough assessment of management options.

## 2. Methodology

A detailed methodology was developed to ensure that water quality and habitat creation objectives could be achieved while managing constraints such as those associated with inundation, drainage and saltwater intrusion. The methodology developed comprised the following stages:

1. Site conceptualisation
2. Fieldwork and data collection
3. Numerical model development and validation
4. Assessment of management options

Each of these stages provided valuable insight into the development and feasibility of management options.

### 2.1 Site conceptualisation

To develop management options, it was important that a conceptual understanding of the Clybucca floodplain was established. This initial process required a detailed analysis of existing empirical datasets. Examples of data analysed include:

- Soil hydraulic conductivity
- Acid sulfate soil profiles
- Drainage
- Five structure dimensions and inverts
- Water quality
- Digital elevation models

In addition to assessment of these datasets, preliminary site investigations were completed. These investigations validated existing data sets and allowed for an appreciation of the site to be established. All this information was then used to build a detailed understanding of the hydrological conditions on-site. This in turn allowed for preliminary management options to be developed.

### 2.2 Fieldwork and data collection

Data collection is an important requirement for developing a numerical model. Having empirical data from which to develop and validate a numerical model ensures that the hydraulic conditions on-site are accurately represented during simulations. As such, considerable effort was spent to collect high quality data for use in developing and validating the numerical model and to further verify the conceptual understanding of the floodplain. This data included:

- Digital elevation model validation surveys (>30,000 points)
- Structure dimension and invert surveys (60)
- Cross-sectional surveys of waterways (359)
- Water level and quality monitoring (10 locations)
- Hydraulic conductivity measurements (1)
- Acid sulfate soil profiles (5)

Survey data was collected in 2018 and 2019. Accuracy of measurements was ±5cm (90$^{th}$ percentile). Data collection was targeted to characterise day-to-day drainage conditions.

### 2.3 Numerical model development and validation

To assess the feasibility of management options a numerical model was developed for the study site. The model enabled the assessment of changes to the floodplain during day-to-day conditions without any physical on-ground works being constructed. A coupled one-dimensional (1D) and two-dimensional (2D) numerical model was developed. The extent of the model domain was from the east of the Pacific Highway to the Menarcobrinni floodgates. Cross-section surveys along with structure dimension and invert surveys collected during fieldwork were used to develop the 1D model. A digital elevation model (1m$^2$ resolution) corrected using data collected during fieldwork was used to build a flexi-mesh 2D model.

Model boundary conditions were determined from water level data collected downstream of the Menarcobrinni floodgates during fieldwork. An Australian Water Balance Model (AWBM) was created to determine catchment inflows from the upper catchment to the model domain [18]. Since there were no inflow data available for the catchment this was verified against flows across a broad crested weir calculated using water level data collected during fieldwork (Figure 3). While timing of the AWBM runoff was suitable for day-to-day scenarios, discrepancies in peak flows highlights the value of flow data for verifying catchment runoff. Other boundary conditions considered during numerical modelling included evaporation and rainfall within the model domain, groundwater inflows, and leaking from the floodgates.

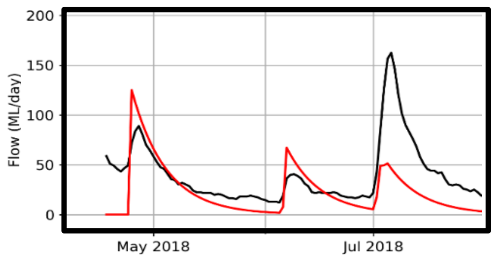


Figure 3 Verification of AWBM model simulations (red) and calculated flow across a broad crested weir (black). This was used to determine catchment inflows for the numerical model's boundary conditions. Note, discrepancies highlight the importance of flow data to provide known uncertainty for catchment runoff.

The numerical model was verified through comparison with water level measurement data to be suitable for simulating day-to-day drainage across the floodplain. Adjustments were made to the manning's coefficient across the model domain to ensure the numerical model best simulated the measured hydraulic conditions (Figure 4).

There was a lack of data concerning numerical dispersion coefficients that control the mixing of saltwater for the study site. To overcome this a range of dispersion coefficients were tested to provide uncertainty bounds and indicate the potential likely range of salinity. These values were based upon literature [19, 20], a sensitivity analysis incorporating drainage measurements collected during fieldwork, and previous experience modelling similar environments. These maximum and

Table 1 Management options developed and assessed for the Clybucca wetlands complex

| Management option | | Freshwater/tidal | Description |
|---|---|---|---|
| **1** | Land management only | Freshwater | Only land management actions such as fencing, weed control, native bush regeneration and acid scald remediation. No modifications to be made to the drainage network. |
| **2** | Shallow freshwater on low-lying wetland areas | Freshwater | Modification of weirs and levees to allow for freshwater inundation across low-lying wetland areas. |
| **3** | Shallow freshwater on low-lying wetland areas with extension of McAndrews Drain | Freshwater | The same as management option 2 with a new swale drain constructed to bypass the low-lying floodplain land during flood events and assist in transport of floodwaters from the floodplain. |
| **4a** | Modified floodgates to allow controlled in-drain tidal flushing | Tidal in-drain only | Modification of eight of the Menarcobrinni floodgates to allow tidal water into the drainage network up to an elevation of -0.4 m AHD. |
| **4b** | Modified floodgates to allow controlled overland tidal flushing | Tidal | Modification of eight of the Menarcobrinni floodgates to allow tidal water into the drainage network and onto the floodplain up to an elevation of 0.0 m AHD. |
| **5a** | Decentralise floodgates to multiple locations – overland inundation | Tidal | Decommission the Menarcobrinni floodgates after installing four smaller floodgate structures upstream to allow overland inundation within low-lying floodplain areas. |
| **5b** | Decentralise floodgates to multiple locations – in-drain only | Tidal | Decommission the Menarcobrinni floodgates after installing two smaller floodgate structures upstream to allow in-drain only tidal flushing. |
| **6** | Fully open floodgates | Tidal | Hinge the floodgate flaps at Menarcobrinni open to allow unrestricted tidal flow upstream. |

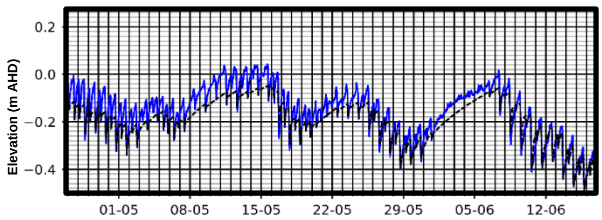


Figure 4 Verification of numerical model results (black dashed) against measured water levels (blue) collected during the data collection campaign. Model results were ±0.1m of measured data and clearly followed the shape of water surface fluctuations across the model domain.

minimum coefficients allowed bounds for possible salinity intrusion to be determined.

## 2.4 Assessment of management options

Once the numerical model was verified against data collected during the fieldwork, simulations were completed to assess the management options developed for the site. Six final management options were developed in consultation with project stakeholders. These ranged from land management options with minimal impacts on floodplain hydrology to options that would completely alter the floodplain hydrology such as fully opening the Menarcobrinni floodgates and allowing uncontrolled tidal flushing upstream. Management options are summarised in Table 1.

For each management option, where applicable, numerical simulations were completed. The numerical model results were then used to assess the feasibility of each option regarding the project objectives, that is, improving water quality and wetland habitat while considering inundation, drainage and saltwater intrusion.

The final management options chosen were designed to provide a range of options in terms of upfront and ongoing capital cost, impacts to the floodplain hydrology and impacts from saltwater intrusion. This was designed so that implementation of management options would be scalable allowing for some management options to be implemented in shorter time frames than others or with less capital allocation. Note for management option 1, changes in roughness across the floodplain may occur, however, the effect of this is likely to be negligible on floodplain hydrology. Subsequently, no numerical modelling has been completed for this management option.

## 3. Results

Assessment of management options determined that for remediation at the Clybucca wetlands complex a staged approach would be the most effective. In the immediate future, management option 1 could be implemented to achieve immediate environmental benefits.

In the short-term (future one to 10 years) management option 2 was considered the most feasible. Moving into the long term (more than 10 years into the future) management options 4b and 6 were determined to provide the highest benefit. Results of the numerical modelling for these three scenarios is shown in Figure 5.

Effectiveness of the management options at improving water quality and habitat differ for freshwater and tidal options. Freshwater options

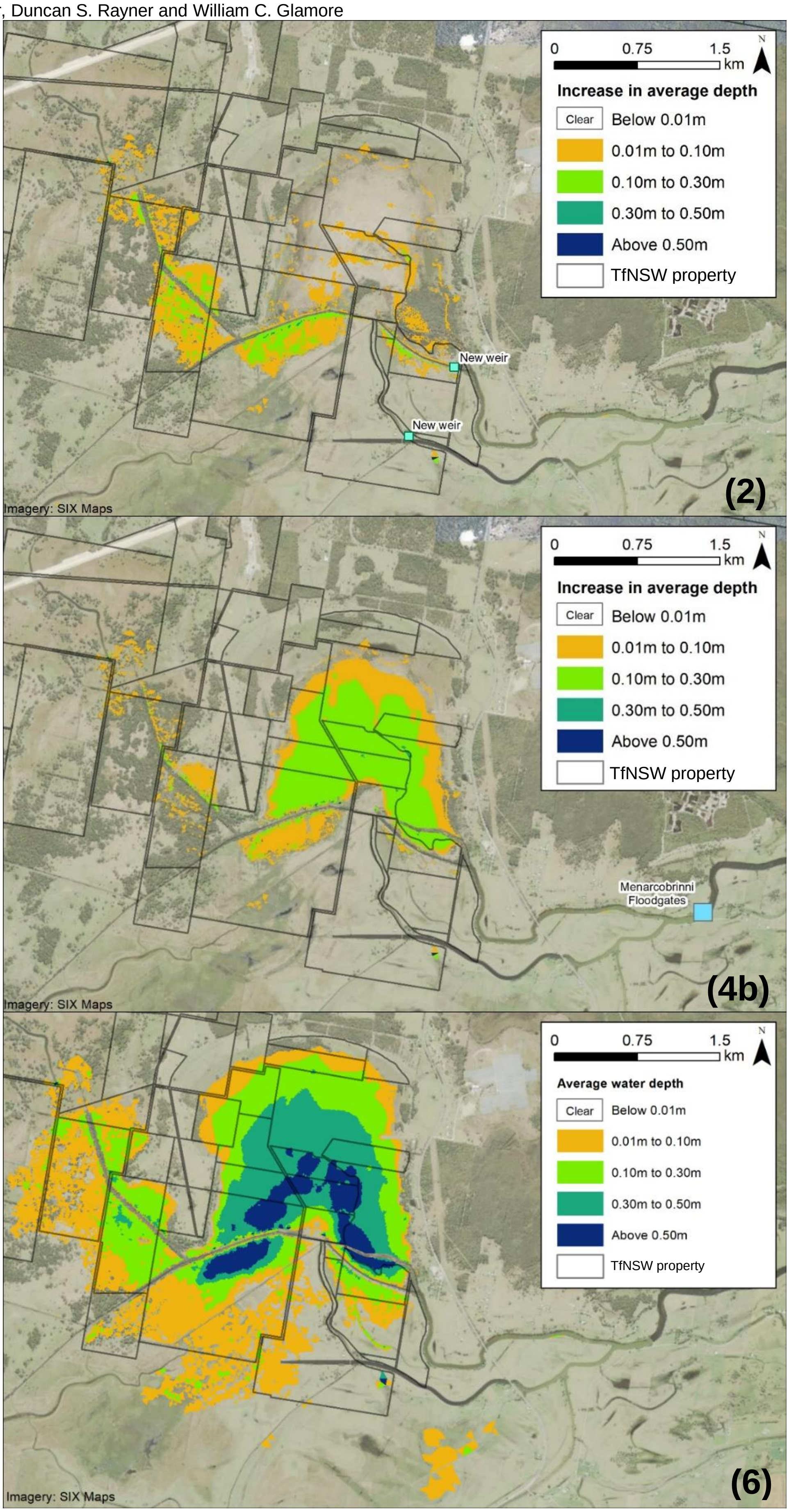


Figure 5 Numerical model results showing the average water depth across the floodplain for management option 2 (top), management option 4b (middle), and management option 6 (bottom). Note, management options 4b and 6 involve inundation of the floodplain with tidal water while management option 2 only involves freshwater inundation.

seek to restore the natural floodplain hydrology preventing the export of poor quality water and encouraging wetland habitat. Tidal options are able to provide different benefits through neutralisation of acidic water in addition to increased wetland habitat creation, albeit estuarine habitat. Note, further consideration will be required for changes from the existing freshwater ecology to estuarine ecology.

### 3.1 Management option 2: Shallow freshwater on low-lying wetland areas

Overall, the optimised design for management option 2 successfully promotes an increase in inundation depth, extent, and frequency on wetland management areas (Figure 5 top). Modelling indicated that there would be a minor increase in drainage times (i.e. hours) for nuisance (day-to-day) flooding. Changes to inundation depth, extent and frequency would only occur within the low-lying floodplain at shallow depths (1 cm to 10 cm).

Note, management option 3 was found to provide similar results to management option 2. Since there would be considerable capital expenditure required to implement management option 3 it was determined not to be feasible.

### 3.2 Management option 4b: Modified floodgates to allow controlled overland tidal flushing

Model results for management option 4b showed that overland tidal inundation would occur across the low-lying floodplain with the extent and depth of inundation dependent on the magnitude of tidal flushing (Figure 5 middle). Inundation depth, extent and frequency modelling indicated that there would be a significant increase in water depth (up to 0.3 m) and duration that will occur due to modification of the floodgates to allow tidal inundation to a level of 0.0 m AHD. Inundation would occur across the floodplain with tidal water that could have salinities of up to 80% of that which would occur at the Menarcobrinni floodgates. In-drain model results showed that saline water would extend approximately 1km up the trunk drainage network.

Note, management option 4a provided similar results to 4b without any floodplain inundation. Option 4a could be considered as a preliminary stage for the implementation of option 4b.

### 3.3 Management option 6: Fully open floodgates

Model results indicated that hinging open the Menarcobrinni floodgates would result in significant tidal inundation across the floodplain (Figure 5 bottom). Inundation would be permanent on the eastern sections of floodplain and range in depth from 0.10 m to above 0.50 m. Inundation would also occur up to 0.30 m across various other sections of floodplain. Salinity on the floodplain would reach a maximum of between 60% and 100% of that which would occur at the Menarcobrinni floodgates.

The model results highlighted that in terms of floodplain management there would need to be careful consideration of impacts to existing land uses before the Menarcobrinni floodgates could be opened. Opening the floodgates would allow tidal water onto the floodplain which would have negative effects on the production value of agricultural land which, in turn, would need to be weighed against potential environmental benefits. Land use changes across large areas of floodplain would need to occur for management option 6 to be feasible. Nevertheless, the assessment found that management option 6 would have the greatest environmental benefit to the broader estuary particularly when the floodplain becomes further stressed due to the impacts of sea level rise.

## 4. Sea level rise assessment

In the future, climate change will pose a significant risk to estuaries [21]. It is within estuaries that impacts of climate change from the ocean (e.g. sea level rise) and upstream catchments (e.g. extreme rainfall events) will meet and have the most severe effect [21]. Quantifying the changes of these impacts on the estuary is multi-faceted and extremely complex.

As part of this study, sea level rise has been determined as a key climate driver that will alter hydrological and environmental conditions across the Clybucca floodplain into the future. Numerical modelling was completed to assess how the increase in downstream water levels due to sea level rise would affect floodplain drainage. Results showed that present day floodplain hydrology and drainage is predominantly controlled by the estuarine tidal levels, with the low tide elevation determining drainage potential. Future sea level rise, and future low tide elevations, will reduce drainage significantly altering the floodplain hydrology and the corresponding environmental values and agricultural practices.

It is important that the future management of the Clybucca floodplain considers management approaches which are adaptable with regards to sea level rise and the uncertainty surrounding the future climate. This will ensure that the floodplain can continue to positively contribute to the health of the broader Macleay River estuary. In designing the management options and remediation strategies, a flexible approach was taken. This approach was adopted so that as the climate changes, adaptive management of the floodplain can ensure wetland habitats persist, resulting in the safekeeping of the health of the estuary into the future.

The recommended management options have been outlined in a way that would allow for their implementation considering the current and future nature of the floodplain. Immediate and short-term options (1 and 2) can be implemented with limited impacts on existing floodplain land uses. Option 4 could be implemented in two stages. Stage 4a could be implemented simultaneously with option 2. As the characteristics of the floodplain begin to change and shift in the future, option 4b could be implemented. Option 6 considered the far-future nature of the floodplain. Modelling indicated that under sea level rise there would be reduced drainage, particularly for the low-lying floodplain. In this scenario when current land uses no longer become feasible the largest benefit to the floodplain in terms of environmental values could be achieved through fully opening the Menarcobrinni floodgates and creating an estuarine wetland ecosystem.

## 5. Summary

For many years, water quality within the Macleay River estuary has been significantly impacted by runoff from degraded backswamps including the Clybucca floodplain. Historically, remediation of the floodplain has been conducted on a farm scale, however, for the first time, catchment wide remediation of the Clybucca floodplain has been made possible due to acquisition of the majority of the worst acid sulfate soil affected low-lying land by one landowner.

This study has shown through detailed numerical modelling based on extensive datasets, that there are several management options which consider existing and future floodplain conditions and allow for remediation of the Clybucca wetland complex. Considering inundation, drainage and saltwater intrusion across the floodplain, these options provide pathway forward for large scale remediation of the Clybucca wetlands to improve water quality and create wetland habitat.

## 6. Acknowledgements

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