Tuckean Swamp Wetland Remediation: Cost Benefit Analysis

WRL TR 2022/05, May 2023

By A J Harrison and D S Rayner

UNSW Water Research Laboratory

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Project manager	A J Harrison
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Client address	Suite 14 - Harrington Building Level 1 41 Belgrave St, Kempsey, NSW 2440
Client contact	Max Osborne max.osborne@dpi.nsw.gov.au
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UNSW
Water Research Laboratory

www.wrl.unsw.edu.au
110 King St Manly Vale NSW 2093 Australia
Tel +61 (2) 8071 9800 ABN 57 195 873 17

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1 Introduction

The Tuckean Swamp floodplain is located on the left bank of Richmond River estuary, approximately 25 km upstream of Ballina (Figure 1-1. Historically, the Tuckean Swamp floodplain was habitat for a mosaic of freshwater and estuarine wetlands, with large areas remaining near permanently inundated (Tulau, 1999). Artificial drainage networks on the Tuckean Swamp floodplain were first constructed in the 1900’s, with the aim of improving flood mitigation and aiding agricultural expansion. However, the efficient drainage also allowed the ingress of saline tidal waters into the drainage system and overbank onto low lying areas of the floodplain (Kijas, 2019; Patterson Britton & Partners, 1996). The drainage works as they exist today (Figure 1-2) were largely completed in 1971 with the construction of the Bagotville Barrage. The barrage is a large, tidal exclusion floodgate at the confluence of Tuckean Swamp and the Tuckean Broadwater. These floodgates effectively exclude tidal connectivity between Tuckean Swamp and the wider Richmond River.

The changes to the drainage network and hydrology have allowed the development of dryland agriculture at Tuckean Swamp. The majority of the low-lying areas are used for cattle grazing or the production of sugar cane, although much of the lowest lying land is known as the Tuckean Nature Reserve, which is managed by NSW National Parks and Wildlife Services (NPWS, see Figure 1-2). However, the hydrological changes have had unintended environmental consequences. The area is known to be a hotspot for acid generation from acid sulfate soils and low dissolved oxygen “blackwater” (Harrison et al., 2021; Moore, 2007; Rayner et al., 2020b; Tulau, 1999), which has been associated with fish kills and reduced biodiversity in the Richmond River (Moore, 2007; Sammut, 1996a; Sammut et al., 1995). Improving water quality discharged from the Tuckean Swamp floodplain has been the subject of numerous studies since the 1990’s. Some on-ground remedial works have been completed, including liming trials and the installation of sluice gates on the Bagotville Barrage. However, the scale of poor water quality generated on the floodplain remains an on-going issue. Addressing acid and blackwater discharges from floodplain backswamps, including Tuckean Swamp, has been identified as a high priority in the Richmond River Coastal Zone Management Plan (Hydrosphere Consulting, 2011).

This study forms part of the next stage towards improving hydrological function and water quality within Tuckean Swamp. The aim of this study is to complete an economic analysis comparing the costs and benefits of the current management of the area (e.g. continued agricultural practices and management of the Tuckean Nature Reserve) with the costs and benefits associated with broadscale wetland remediation of the low lying areas of the swamp (including capital costs, changed land use practices, and ecosystem services).

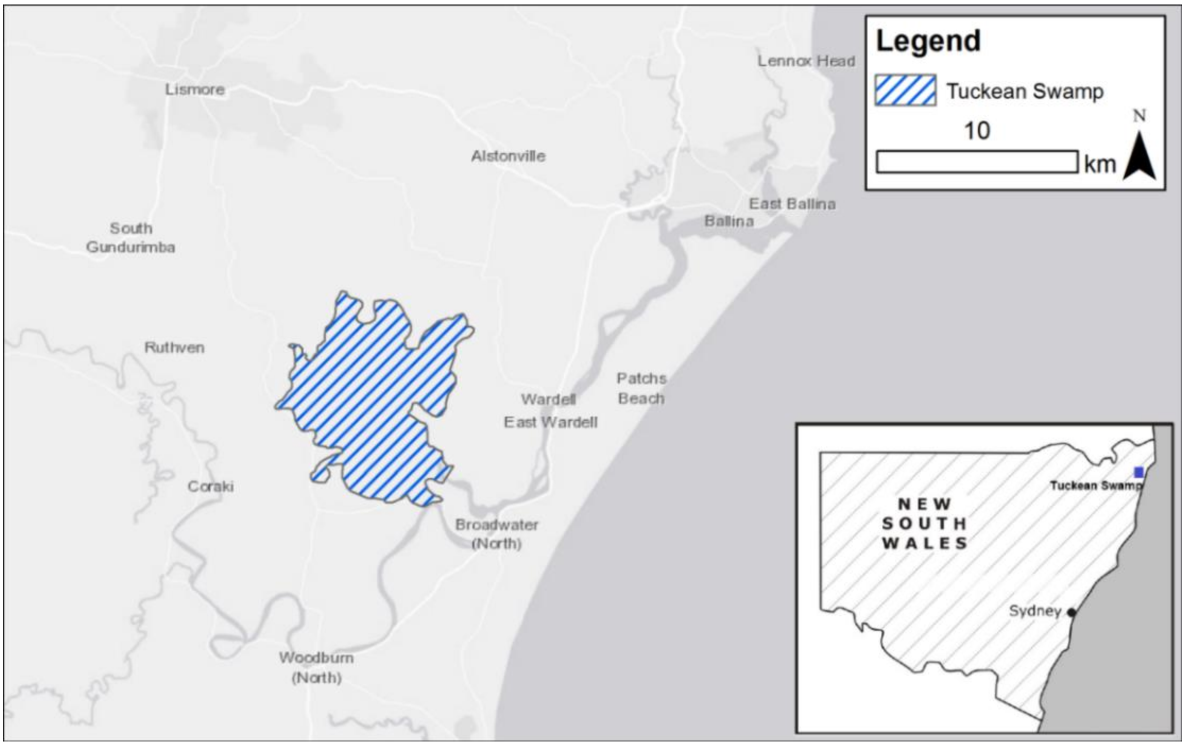

Figure 1-1: Location of Tuckean Swamp on the Richmond River estuary

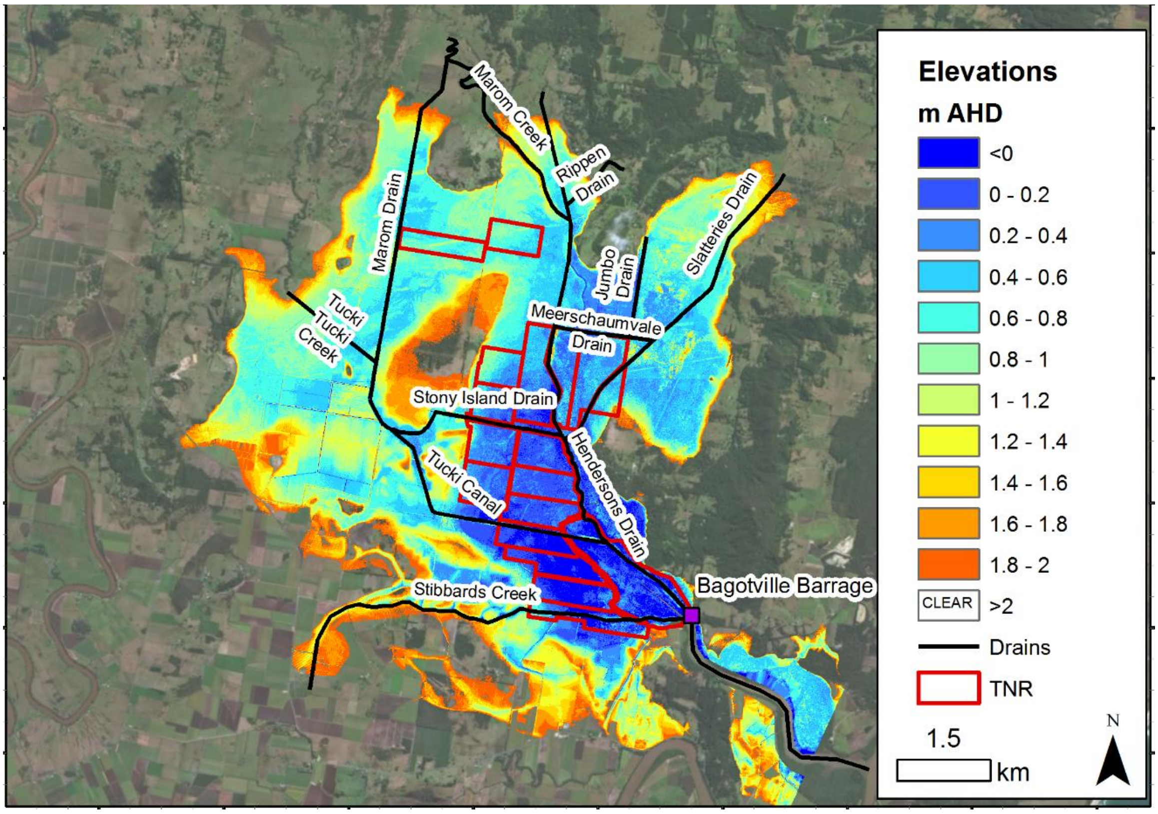

Figure 1-2: Key infrastructure and drains

The purpose of this cost benefit analysis is to investigate the economic feasibility of environmental remediation and aid decision makers. It does not seek to prescribe the exact nature or scale of on-ground works to be completed. It is acknowledged that there is presently no agreed plan for environmental remediation on the Tuckean floodplain. Any on-ground works will need to consider a sustainable pathway for the project, incorporating an understanding of environmental change, stakeholder feedback and social and cultural concerns. This study has been completed alongside numerous other studies, all of which should be considered in decision making, including:

- Tuckean Swamp Hydrologic Options Study (Rayner et al., 2020a) - Hydrodynamic modelling of six potential wetland remediation options for the Tuckean floodplain
- An implementation toolkit commissioned by OzFish Unlimited and completed by GHD:
    - Values Assessment Tuckean Swamp: Implementation Toolkit (GHD, 2022c)
    - Design and Cost Report Tuckean Swamp: Implementation Toolkit (GHD, 2022a)
    - Toolkit for Change Tuckean Swamp: Implementation Toolkit (GHD, 2022b)

Where relevant, these studies have been used to underpin the assumptions in this study.

1.1 About this report

This report comprises of the following sections:

- **Section 2** provides an overview of the important economic concepts and methods that are used for this study
- **Section 3** describes the alternatives considered in the economic analysis and how the various costs and benefits have been valued
- **Section 4** presents the results of the cost benefit analysis and includes an assessment of the sensitivity to key assumptions
- **Section 5** provides more detail on the distribution of the costs and benefits to investigate the impact on stakeholders
- **Section 6** provides a summary of the key findings

In addition, appendices have been included to provide further background on the assumptions and methods used in this study.

- **Appendix A** summarises the environmental profiles associated with the two management scenarios
- **Appendix B** provides more details on the valuation methods and estimates developed for this project

2 Cost Benefit Analysis background

2.1 Preamble

This section provides an overview of a cost benefit analysis and key economic principles that underpin the analysis in this report.

2.2 What is a cost benefit analysis?

A cost benefit analysis is an economic instrument used to understand the change in economic welfare that might occur due to a change in management (DPIE, 2020a). NSW Treasury (2017) states that a "cost benefit analysis measures the change attributable to a government action, relative to a situation without the proposed action". The general aim of the analysis is to compare a number of potential management scenarios and establish which option provides the greatest net-benefit, relative to the costs.

Determining the perspective of a cost benefit analysis is an important step of the analysis. It is understood that this analysis will be used to support the Coastal Management Programs (CMP) being developed for the Richmond River estuary. Where a cost benefit analysis is being used by local Councils support tool for councils assessing coastal management options, DPIE (2020a) recommends that the scope of the cost benefit analysis should be limited to the individual local government area. Tuckean Swamp spans across two local government areas (Ballina Shire Council and Lismore City Council), and flood mitigation is managed by Rous County Council, which also includes Richmond Valley Council. The Richmond River Coastal Management Program, including Tuckean Swamp, is being coordinated by Rous County Council, in partnership with Ballina Shire Council, Lismore City Council and Richmond Valley Council (with the participation of three other local government areas). As such, these four local government areas will be considered in the scope of the cost benefit analysis.

A cost benefit analysis can be undertaken using any common unit, although costs and benefits are typically described in dollar terms. While this is easily determined for goods and services that are commonly traded, such as labour or materials, a cost benefit analysis must also capture social, environmental and ecological costs and benefits that are sometimes more difficult to quantify. Though monetary value estimations of non-market goods can be difficult to assess, it is important they are considered in the analysis because the results should reflect all costs and benefits to society.

For transparency, all assumptions used to arrive at the estimates for this study are clearly stated in the analysis and accompanying appendices. Of particular relevance to this project are the benefits provided by various ecosystems, generally referred to as 'ecosystem services', and are discussed further in Section 2.3.

2.2.1 Discount rates

Discounting converts costs and benefits that occur in the future into today's dollars using a discount rate. Discount rates account for the time value of money, which gives more weight to impacts in the present or near present (NSW Treasury, 2017). A higher discount rate places a greater weight on present or near present impacts, while a lower interest rate results in more value being placed on costs and benefits that occur in the future. It is worth noting that the discount rate can have a substantial impact on the results of a cost benefit analysis.

For coastal management in NSW, guidance for the application of cost benefit analysis is provided by two primary documents:

- NSW Treasury – NSW Government Guide to Cost-Benefit Analysis. This document was revised during the progress of this study, from NSW Treasury (2017) to NSW Treasury (2023)
- NSW Department of Planning and Environment – Guidelines for using cost benefit analysis to assess coastal management options (DPIE, 2020a), which currently refers to the recommendations of the superseded NSW Treasury (2017)

One of the major updates in NSW Treasury (2023) was a change of the recommended discount rates for all NSW government projects, as summarised in Table 2-1. Note that all costs, benefits and discount rates are expressed in 'real' terms (i.e. without the inclusion of inflation). At the time of writing, no updates have followed in the NSW Department of Planning and Environment guidelines, so the recommended discount rates are in conflict with each other. For the purpose of this report, the base results are presented at a 7% discount rate, with additional sensitivity tests at 3%, 5% and 10% to provide the reader with a comprehensive understanding of adopting alternative discount rates.

Table 2-1: Recommended discount rates

Source	Central, recommended discount rate	Sensitivity tests
NSW Treasury (2017) **DPIE (2020a)**	7%	3% and 10%
NSW Treasury (2023)	5%	3% and 7%

There is a substantial body of literature that suggests using the same discount rate for built infrastructure as ecosystem services fails to recognise the self sustaining nature of natural capital. As such, current literature would suggest that even adopting the reduced discount rates in NSW Treasury (2023), which are conventionally used for infrastructure, may underestimate the total present value of ecosystem services. This must be considered in assessing the cost benefit analysis of this project.

2.2.2 Defining the base case

The first part of a cost benefit analysis is the development of a base case, often the scenario in which there is no planned change in management or a 'business as usual' case. The base case for this study is described in Section 3.2. Once this is defined, one or more proposed alternatives can be developed for comparison against the base case. Costs and benefits of proposed alternatives are only counted where there is a forecast change from the defined base case. As the cost benefit analysis is a measure of relative change, only those costs and benefits that result in a net change in welfare are counted, which may not include all transactions. Many transactions are a transfer of wealth. For example, a government purchase of property does not result in a net change in wealth, as it is simply a transfer of money from the government to a private citizen and an equivalent transfer of property value.

There are two important concepts that are significant to understand when comparing an alternative option to a base case, described below:

- Opportunity costs: in most instances, a business-as-usual base case has some (sometimes substantial) benefits. Relevant to this study, an example of these benefits might be agricultural production from existing land uses. When considering alternative options, if you have to forgo these benefits, they are said to be an opportunity cost. That is, the value of the lost benefit is included as a cost in any alternative management scenarios.
- Avoided costs: similarly, the base case will likely include costs, such as running costs of farms. If an alternative management option is considered these costs will no longer occur, they are referred to as an avoided cost. Avoided costs are considered as a benefit to alternative management options.

It is therefore important to understand the costs and benefits of the base case itself.

2.2.3 Benefit Cost Ratio and Net Present Value

Benefit Cost Ratio (BCR) and Net Present Value (NPV) are two common measures used to compare scenarios in a cost benefit analysis. The BCR is defined as the time weighted benefits divided by the time weighted costs (shown in Equation 1) and is a measure of the value for money. A BCR value greater than one indicates that the option is economically preferable to the base case, and can be seen as an indicator of value for money. If all else is equal and there is a choice between two mutually exclusive projects, the project with the highest BCR would yield higher net benefits to the community.

NPV is the time weighted benefits minus the time weighted costs (shown in Equation 2). By definition, the base case has a NPV of zero (no change from itself), and therefore a project with a NPV greater than zero indicates that the option is economically preferable to the base case. If all else is equal and there is a choice between two mutually exclusive projects, the one with the highest NPV will be preferred.

For this project, both the NPV and BCR will be compared to assist decision making. A BCR of greater than one is equivalent to a positive NPV.

$$BCR = \frac{\sum_{i=0}^{n} \frac{B_i}{(1+r)^i}}{\sum_{i=0}^{n} \frac{C_i}{(1+r)^i}} \qquad \text{Equation (1)}$$

$$NPV = \sum_{i=0}^{n} \frac{B_i}{(1+r)^i} - \sum_{i=0}^{n} \frac{C_i}{(1+r)^i} \qquad \text{Equation (2)}$$

Where:
N = number of years
B_i = benefits in year i
C_i = costs in year i
r = discount rate

2.2.4 Time period

Cost benefit analyses are typically undertaken over a defined time period, so that the stream of benefits or costs are finite. NSW Treasury (2017) and DPIE (2020a) recommend a 20 – 30 year timeframe is appropriate for cost benefit analysis, although this traditionally relates to infrastructure projects.

Environmental projects, such as the remediation of coastal floodplains, typically result in long-term benefits, sometimes with initially high costs. The adopted timeframe for this project is 30 years to account for some of the long-term benefits that could be derived from the remediation project. It is important to recognise that the benefits of environmental projects can actually improve over extended periods of time as ecosystems mature and extend potentially indefinitely, which is not reflected in the 30 year timeframe. The updated NSW Treasury (2023) guidelines allows for alternative timeframes from 60 – 100 years for projects where significant benefits occur over a long period, however the shorter timeframe has been adopted in this study to remain compliant with DPIE (2020a) as well.

2.3 Ecosystem services

Environmental resources and natural capital have historically not been consistently included in economic decision making, as they are not generally bought or sold in traditional markets and therefore may be difficult to monetise. However, there is an increasing awareness that natural capital interacts with human environments and provides a positive contribution to human welfare.

Ecosystems services is the term used to refer to the "benefits people obtain from ecosystems", including both the direct and indirect contributions of ecosystems to human welfare (Costanza et al., 1997). These services are typically categorised into one of three types of services, as summarised in Table 2-2.

Table 2-2:Types of ecosystems services (adapted from Haines-Young and Potschin-Young (2018))

Service type	Definition	Relevant services
Provisioning	Products derived from ecosystems	Food, including commercial fisheries
Regulation and maintenance	Benefits derived from the regulating capacity of ecosystems processes	Water treatment Flood mitigation Climate regulation and carbon sequestration Habitat and biodiversity
Cultural	Non-material benefits from ecosystems	Recreational use, including recreational fishing

There is an increasing body of research that looks to provide a monetary value for a variety of ecosystems across the world. Typically this research is targeted at valuing a particular service(s) (such as fisheries production or flood protection) from a specific type of ecosystem (such as coastal wetlands or oceans) at a single location. There are a number of different methods that are used to provide an estimate for the value of ecosystem services, some of which are summarised in Table 2-3.

For the purpose of this study, it is appropriate to adopt the 'benefit transfer' technique, as there have not been any studies to date that specifically value the ecosystem services anticipated on the Tuckean Swamp floodplain after restoration. The ecosystem service values adopted in this study are largely based on a recent study (Harrison et al., 2022a) which reviewed local and international literature to suggest a range of ecosystem service values most relevant to the NSW context (where possible, otherwise relying on median values from international literature). Further information has been provided in Appendix B and discussed in Section 3.

Table 2-3: Valuation techniques (adapted from Foundation for Sustainable Development (2021))

Valuation technique	Description
Market based	Some environmental goods/services may be sold in a commercial market, and the value can be directly inferred
Avoided cost/replacement cost	Estimates the value by assessing the cost of damages resulting from lost ecosystems (e.g. increase flood damage), or by pricing an alternative replacement to serve the same function (e.g. a waste treatment plant to replace the waste treatment function of a wetland)
Travel cost	Infers the value of an ecosystem by assessing how much people are willing to pay to travel to visit
Hedonic pricing	Infers value through changes in prices of market goods due to benefits from an ecosystem (e.g. proximity of a house to the beach)
Contingent valuation	Estimates value based on surveys of people asking how much they are willing to pay for an ecosystem service
Choice modelling	Similar to contingent valuation, choice modelling involves stated preferences in regard to ranking a series of pre-defined options
Benefit transfer	Estimates economic value based on existing valuation studies for other sites or issues which are similar to those in question

3 Defining the options

3.1 Preamble

In this cost benefit analysis, a single representative broadscale wetland remediation option has been compared against a 'business as usual' base case. The indicative remediation area in Figure 3-1 represents the boundaries of land use change in the cost benefit analysis, and it is assumed that existing land uses will continue without significant change outside this area. All values in this section have been converted to 2022 Australian dollars, unless otherwise specified. While this section provides an overview of the base case and remediation option, further supporting information is also provided in:

- Appendix A – includes an environmental and land use profile of the base case and remediation option. This includes the information on the data and interpretation used to define the landscape in both cases, including the justification of the indicative remediation area in Figure 3-1.
- Appendix B – provides detailed information on the monetary valuations of the two cases.

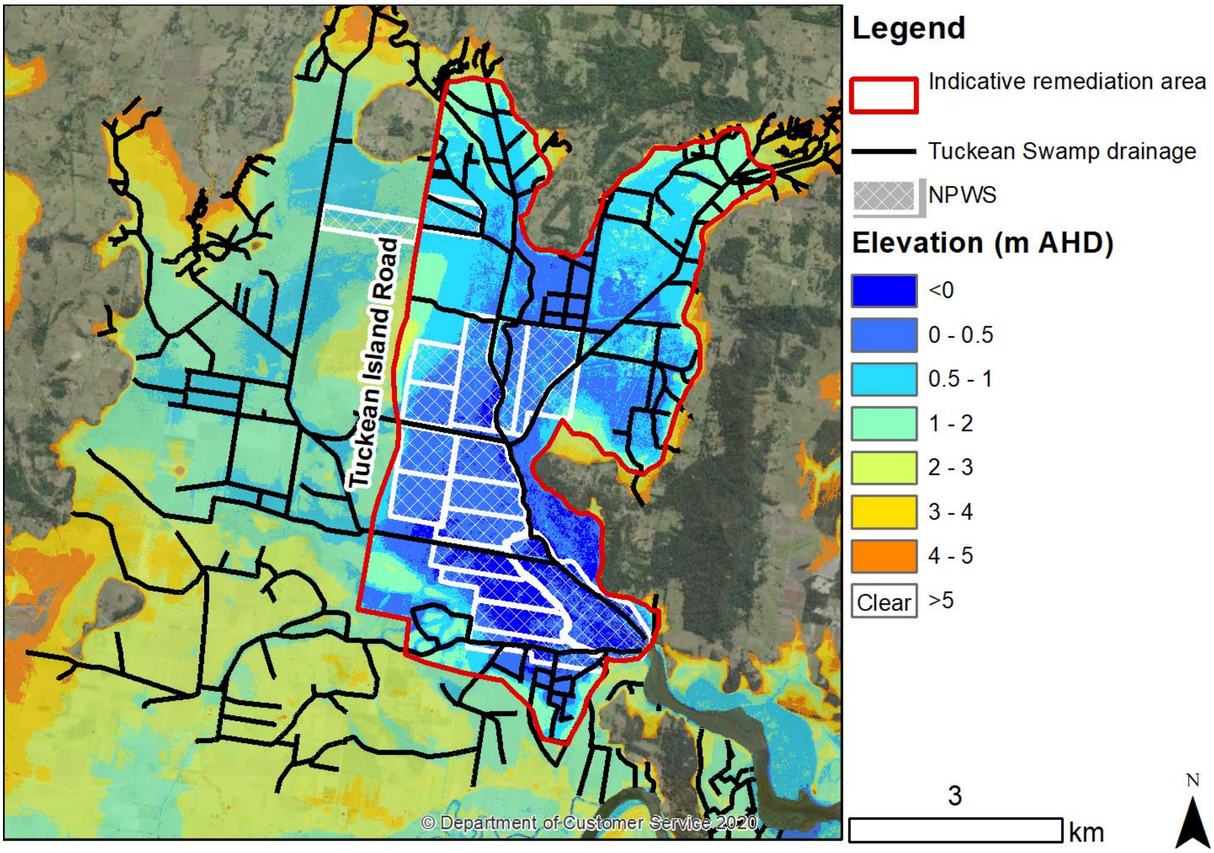

Figure 3-1: Area of interest for the purpose of the cost benefit analysis

For the purposes of this project, a conservative estimate has been used to refer to assumptions that have been made that favour the business as usual.

3.2 Base case – business as usual

The Tuckean Swamp floodplain is primarily privately owned and used for agricultural production, except for a 919 ha section that is owned and managed by National Parks and Wildlife Services (NPWS) (shown in Figure 3-1, known as the Tuckean Nature Reserve). Assumed existing land uses across the floodplain is shown in Figure 3-2, which has been adapted from state level land use data from 2017 (DPIE, 2020b) (more information on land use data can be found in Section A2.1), and primarily consists of widespread grazing land, sugar cane production and marsh/wetlands (largely within the Tuckean Nature Reserve). The economic basis of the base case involves two main components:

- Agricultural benefits and costs
- Ecosystem service values

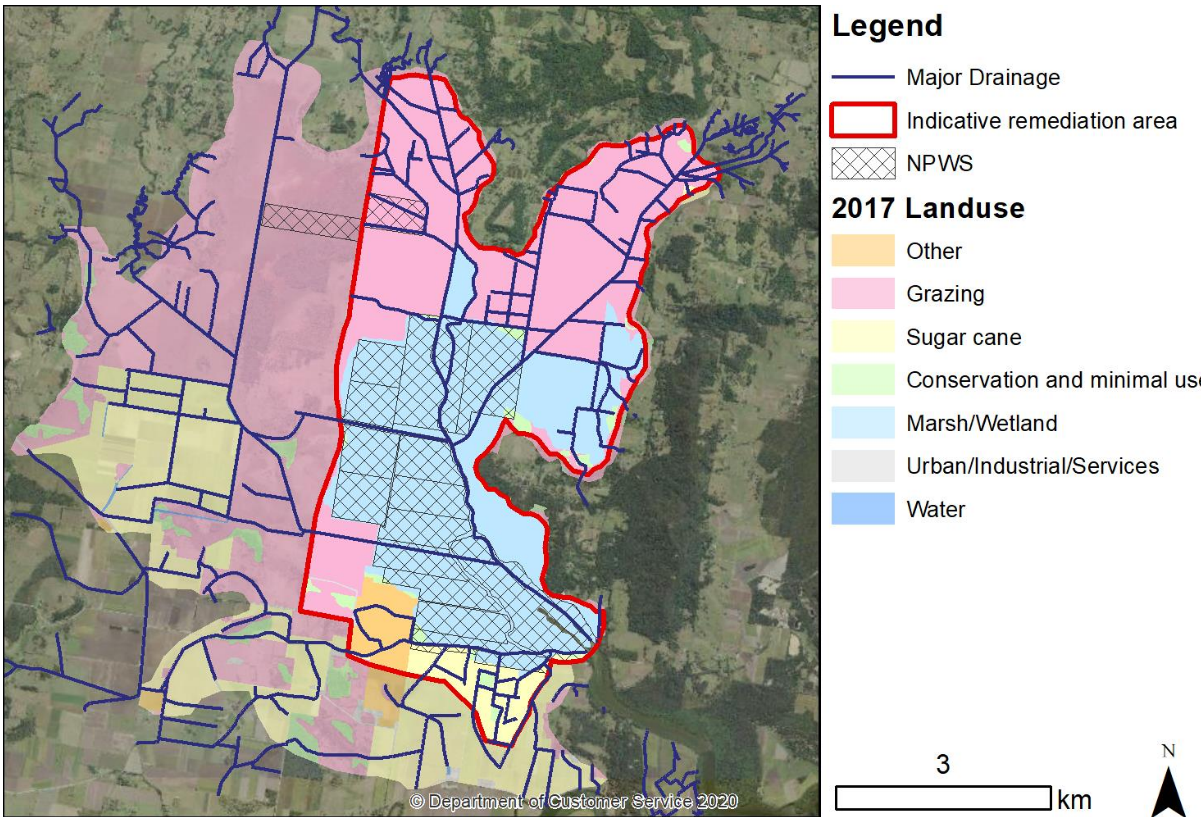

Figure 3-2: Existing land use within the Tuckean Swamp floodplain

3.2.1 Agricultural benefits and costs

Of the private properties used for agriculture, the primary land uses are grazing of cattle and sugar cane. The primary benefit associated with these properties is the value of primary production. Based on regional total production valuations, unit production value of in these two types of land use has been estimated to be:

- Sugar cane: $1,820/ha/year, with sensitivity testing at the higher rate of $3,017/ha/year
- Grazing: $401/ha/year, with sensitivity testing at the higher rate of $468/ha/year

More details on the data and methods for developing these estimates can be found in Section B2.1. A small area (86 ha) of the floodplain to be remediated is currently used for tea tree (classified as 'Other' in Figure 3-2). However, as the state level landuse data available does not include information on tea tree areas on the wider floodplain, the methods used to estimate productivity per land area were not appropriate for estimating tea tree production. For the purpose of the CBA, this area has been assumed to have the same productivity as sugar cane (the higher of the two production values). This lot was previously used for sugar production.

Agricultural production incurs many costs, including the cost of feed, fertiliser, services and labour. ABRES (2022a) provides data on the average farm cash receipts and cash costs aggregated across coastal NSW (including all aspects of primary production on farms). On average, total cash costs are 79% of cash receipts on farms in coastal NSW, although it has been as low as 65% in the last five years. For grazing agricultural production costs, the per unit area costs have therefore been estimated as $317/ha/year (79% of $401), with sensitivity testing at $304/ha/year (65% of $468).

In a specific study into the performance of sugar cane farms, ABRES (2022b) estimate cash costs on NSW sugar cane farms in 2013-14 and 2020-21 was 76% and 56% of cash receipts, respectively. The more recent estimate has been used, and cost of sugar cane production has been assumed to be $1,019/ha/year (56% of $1,820/ha/year), however sensitivity tests have been completed with $1,690/ha/year (56% of $3,017/ha/year).

More details on the data and methods for developing these estimates can be found in Section B2.2.

3.2.2 Ecosystem service values

There are a variety of ecosystems throughout the Tuckean floodplain, including within the Tuckean Nature Reserve which is habitat for Ecologically Endangered Communities (EECs), as well as the farmland itself. It is important to recognise that the existing system does provide some positive ecological value, including habitat and climate regulation. Ecosystem services have been adopted using the benefit transfer principal (see Section 2.3) based primarily on two existing studies (Costanza et al., 2014; Harrison et al., 2022a) which collated and reviewed a wide range of literature for a range of ecosystem services for numerous environments. The established or average value was adopted from these studies for the services relevant to the Tuckean floodplain. Using this method, three separate ecosystems have been considered:

- Sugar cane land: $862/ha/year
- Grazing land: $190/ha/year
- Freshwater wetlands (largely within the Tuckean Nature Reserve): $1,877/ha/year

While more information can be found about the foundations of these values in Section B2.3 and B2.4, it is important to recognise that no value has been included for water treatment or water quality services. The presence of acid sulfate soils and blackwater has a negative impact on water quality in the Richmond River and has been shown to contribute to fish kills and other environmental damage (Moore, 2007; Sammut et al., 1995; Walsh et al., 2004), which has a negative social, environmental and economic impact. Due to the difficulties in estimating these cost, the negative costs of these impacts have not been included in the base case.

3.3 Broadscale wetland remediation

The broadscale wetland remediation option focuses on discontinuation of agricultural land uses in areas east of Tuckean Island Road and below 1 m AHD in elevation. On-ground works, including modification of the Bagotville Barrage, installation of new upstream floodgate infrastructure and earthworks would be completed to re-connect the remediation area with the wider estuary and encourage a proliferation of a mixture of freshwater and estuarine wetlands, as shown in Figure 3-3. The extent of inundation and distribution of freshwater and saline estuarine waters was based off modelling by Rayner et al. (2020a) and examination of topography. A buffer zone has been included within the indicative remediation area to assist in mitigating any impacts on adjacent properties. Further description of the strategies that could be used to achieve this outcome are detailed in Section A3.

For the purpose of this study, it is assumed that impacted land within the remediation area is purchased and the land is managed by government agencies, funded through specific grants awarded for environmental remediation (government or private grants). It is acknowledged that this is not the only pathway for land use and tenure change and is not intended to represent a recommended pathway. GHD (2022b) provides more details on some potential options, including land purchases or biodiversity conservation trust agreements/conservation covenants with the existing landholders. The primary purpose of this study is to demonstrate potential net benefits or costs of broadscale remediation. Other factors, including community consultation and landholder concerns will require consideration when determining both the detailed design of potential works or pathways for land use change.

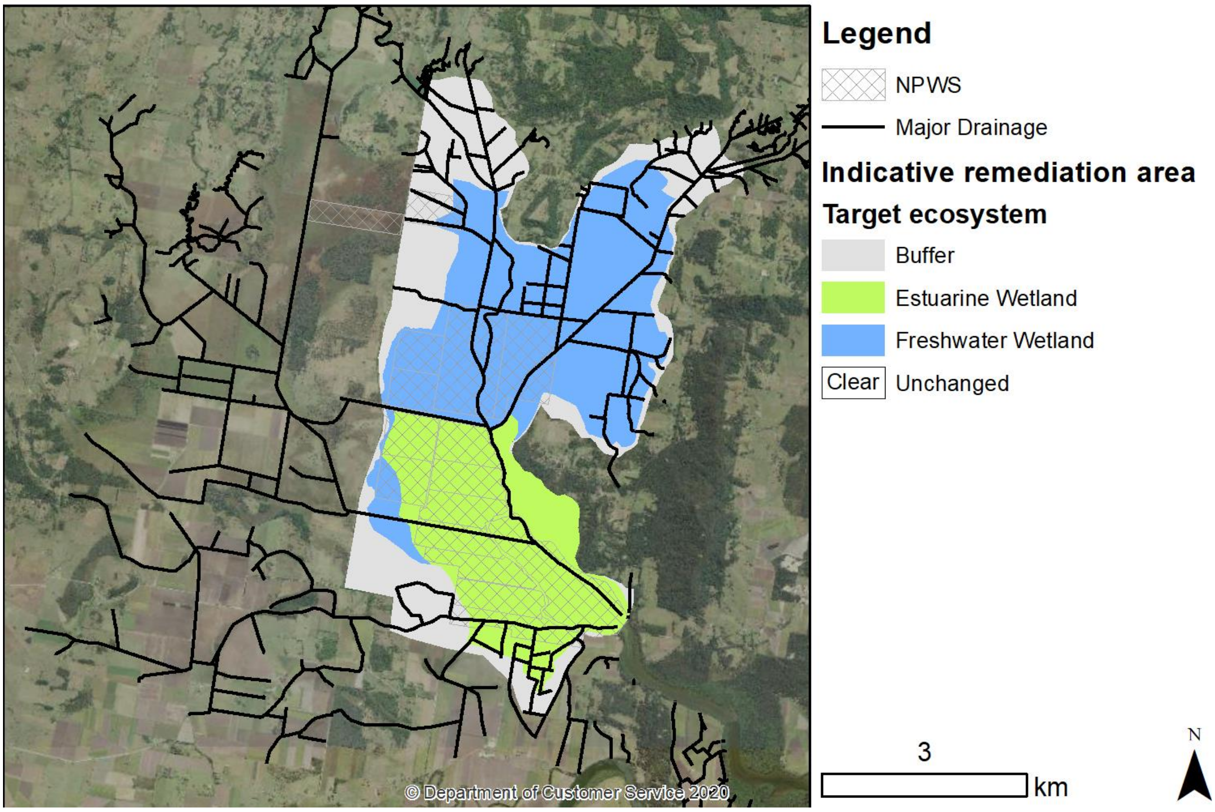

Figure 3-3: Target ecosystems within the remediation area

3.3.1 Remediation costs

Significant on-ground works would be required to achieve the target ecosystems highlighted in Figure 3-3. The type, scale and cost of works have been based on previous modelling (Rayner et al., 2020a) and costing (GHD, 2022a). This includes:

- Capital construction costs: $5,087,800
- On-going maintenance, management and monitoring costs: $101,264/year (indefinitely)

An additional cost of $500,000 has been included for technical studies (including modelling and design) required to ensure the on-ground works would have no impact on surrounding properties and to ensure the success of the project.

Regardless of whether land purchases occur, costs of land acquisition do not need to be directly included in the context of the cost benefit analysis, as the value of the land simply changes hands (the land holder is compensated with money which is equal to the value of their land). As such, purchases are considered a transfer, not a cost (consistent with NSW cost benefit analysis guidelines). However, other than the area owned and managed by NPWS, there will be a net loss in land improvements (such as existing drainage networks and infrastructure and levees) and does need to be included in the costs of any alternative management. An allowance of 20% of the unimproved land value has been included to account for the losses in improved values, resulting in an upfront cost of $1,800,000. This is included as an upfront cost in year zero.

Further information on the remediation costs is detailed in Sections B3.1 and B3.2. The total assumed upfront costs is $7,207,800 and on-going costs are $101,264/year.

3.3.2 Ecosystem service values

It is anticipated that the works will have local impacts on the floodplain, including creation of new habitat, improved biodiversity, fish passage and connectivity and improved water quality. However, the wider Richmond River estuary will also ecologically benefit from the works, primarily from water treatment services. Wetlands are important ecosystems which are natural filter systems for downstream waterways. Conventionally, water treatment from wetlands typically focusses on nutrient filtration, such as the capacity to remove nitrogen and phosphorous, which is relevant at Tuckean Swamp due to surrounding land uses. However, the re-introduction of substantial wetland areas at Tuckean Swamp will also specifically address a high priority issue in the Richmond River estuary: the drainage and mobilisation of acid and low oxygen blackwater. On coastal backswamps with the presence of acid sulfate soils, rewetting the landscape can reduce the mobilisation of acid from the soils, while saline water in estuarine wetlands can neutralise the acid through natural bicarbonates. Encouraging the growth of wetland vegetation and near permanent inundation can also reduce the production and mobilisation of blackwater.

Similar to the ecosystem service values adopted for the base case, the value of these benefits have been determined through the benefit-transfer principal based primarily on a recent literature review by Harrison et al. (2022a). The adopted values are:

- Freshwater wetlands: $15,296/ha/year
- Estuarine wetlands: $19,913/ha/year
- Buffer area: $190/ha/year (assumed no change from grasslands)

It is recognised that wetland vegetation and associated benefits may take time to establish and mature. In this analysis, it is assumed that there will be no services provided until year 5, and they will then increase linearly until year 15. Sensitivity tests have been completed to determine the minimum value of ecosystem services to achieve a net benefit from the broadscale wetland remediation.

Further information on the ecosystem service values adopted can be found in Section B3.3 and B3.4.

4 Valuation and sensitivity testing

4.1 Preamble

This section presents the results of the cost benefit analysis completed, as well as a summary of sensitivity testing of key variables. When interpreting the results of a cost benefit analysis, particularly this study where only one alternative management scenario is considered, it is important to recognise that the base case has real benefits (and costs) and is still a viable ongoing option. By definition, an alternative management scenario with a net present value less than zero (or benefit-cost ratio less than 1) indicates that the base case is economically preferable.

4.2 Results

Based on the adopted values discussed throughout the previous section, the NPV and BCR have been calculated for a discount rate of 7% and a project timeframe of 30 years. These results are summarised in Table 4-1 (also including a discount rate of 5%, as per the updated NSW Treasury (2023) guidelines), and in Figure 4-1. Both the NPV and BCR indicate that the broadscale wetland remediation option is preferable to the base case under the assumptions of this study. Cost benefit analysis are sensitive to the assumed time period of the analysis. Figure 4-1 shows that there are large, upfront costs associated with the broadscale wetland remediation option. For planning periods less than 11 years, the NPV of this option is less than zero, which implies that the net benefits from continued agricultural land uses exceeds that of the remediation. However, the NPV is greater than zero (i.e. broadscale wetland remediation is preferable to the base case) for time periods greater than 11 years (including the adopted 30 year timeframe recommended by NSW guidelines).

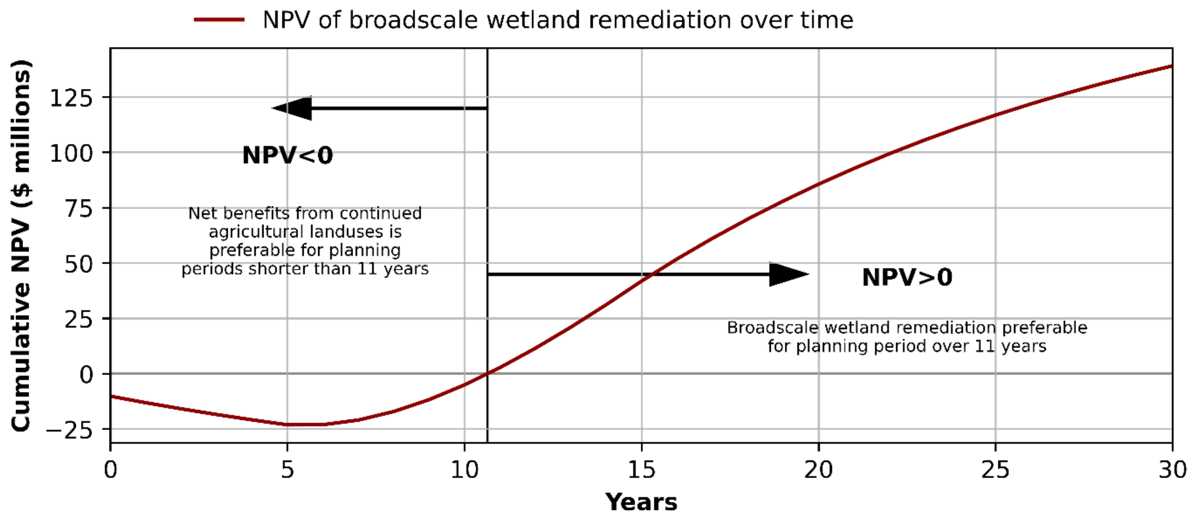

Figure 4-1: Net Present Value over time of broadscale wetland remediation (7% discount rate)

Table 4-1: Option Net Present Values (NPV) and Benefit Cost Ratios (discount rate 5% and 7%, 30 Years)

Metric	Broadscale wetland remediation (5% discount rate)	Broadscale wetland remediation (7% discount rate)
Net Present Value	$204,673,659	$139,023,685
Benefit Cost Ratio	4.00	3.4

4.3 Sensitivity tests

All sensitivity tests presented in the following section have been compared to the base assumptions, including a discount rate of 7% and timeframe of 30 years.

4.3.1 Discount rate

Sensitivity tests have been completed based on the discount rate, consistent with the various guidelines considered (DPIE, 2020a; NSW Treasury, 2017; NSW Treasury, 2023). Sensitivity tests have been completed at alternative discount rates of 3%, 5% and 10%. The impact of the discount rate (with all other values remaining equal to the adopted values) on the BCR and NPV results are shown in Figure 4-2 and Figure 4-3. These figures show that the updated discount rates recommended by NSW Treasury (2023) substantially increases both the NPV and BCR of the restoration option. As the broadscale wetland remediation involves significant upfront costs and delayed benefits, the discount rate has a strong influence on the BCR and NPV. The higher the discount rate, the lower the two measures are.

While the discount rate impacts the NPV and BCR, Figure 4-2 and Figure 4-3 show that regardless of the rate, the broadscale wetland remediation remains preferable to the base case.

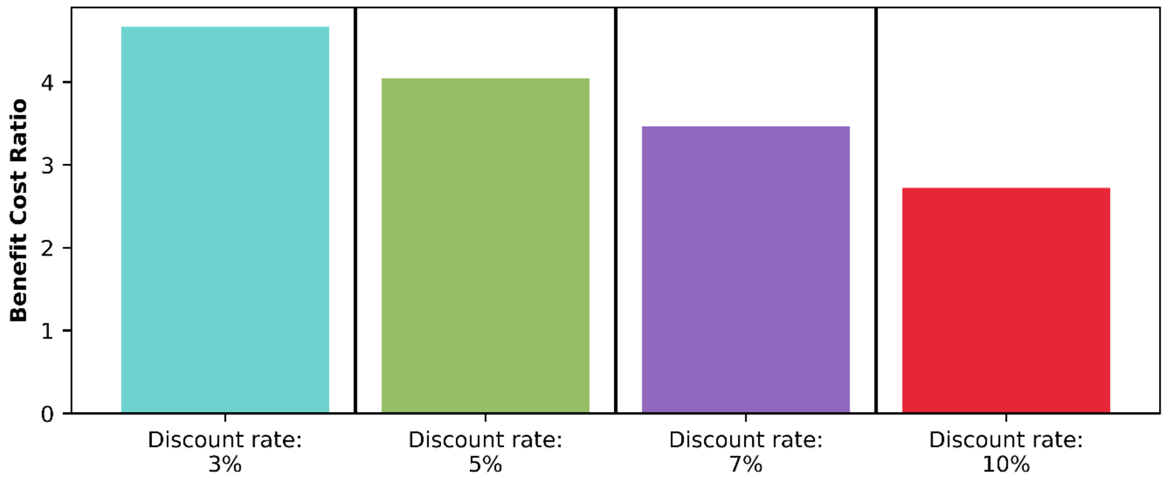

Figure 4-2: Sensitivity to discount rate on BCR for broadscale wetland remediation

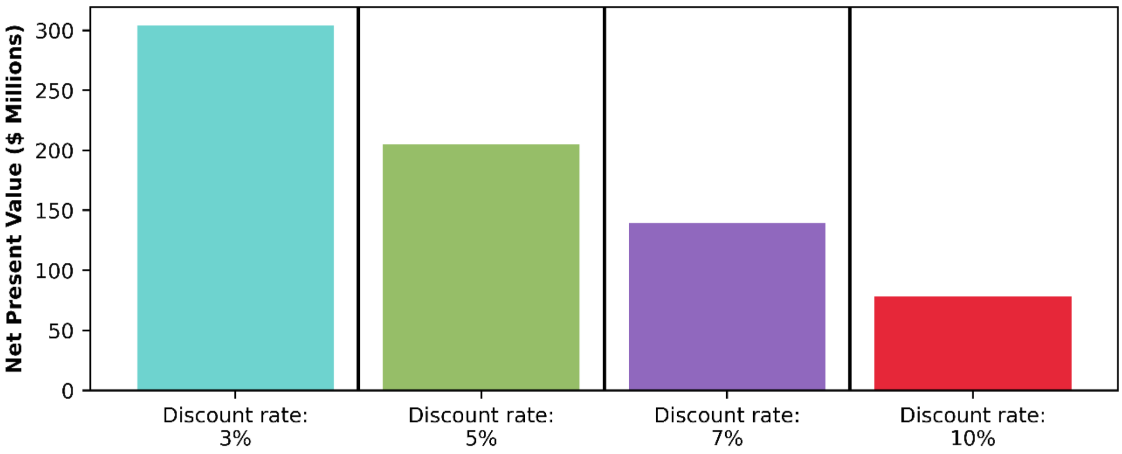

Figure 4-3: Sensitivity to discount rate on NPV for broadscale wetland remediation

4.3.2 Agricultural productivity and costs

The agricultural gross production values and costs adopted were based on the most representative available data. However, there is annual variability in the benefits and costs. Sensitivity tests have been completed by increasing the agricultural production values, while maintaining or reducing the ratio of costs. This will increase the opportunity costs and decrease the avoided costs under the broadscale wetland remediation scenario. Figure 4-4 shows that the difference in NPV is marginal, while there is a slight decrease in BCR under the alternative assumptions. This shows that the annual variations in agricultural productivity does not significantly impact on the results of this study.

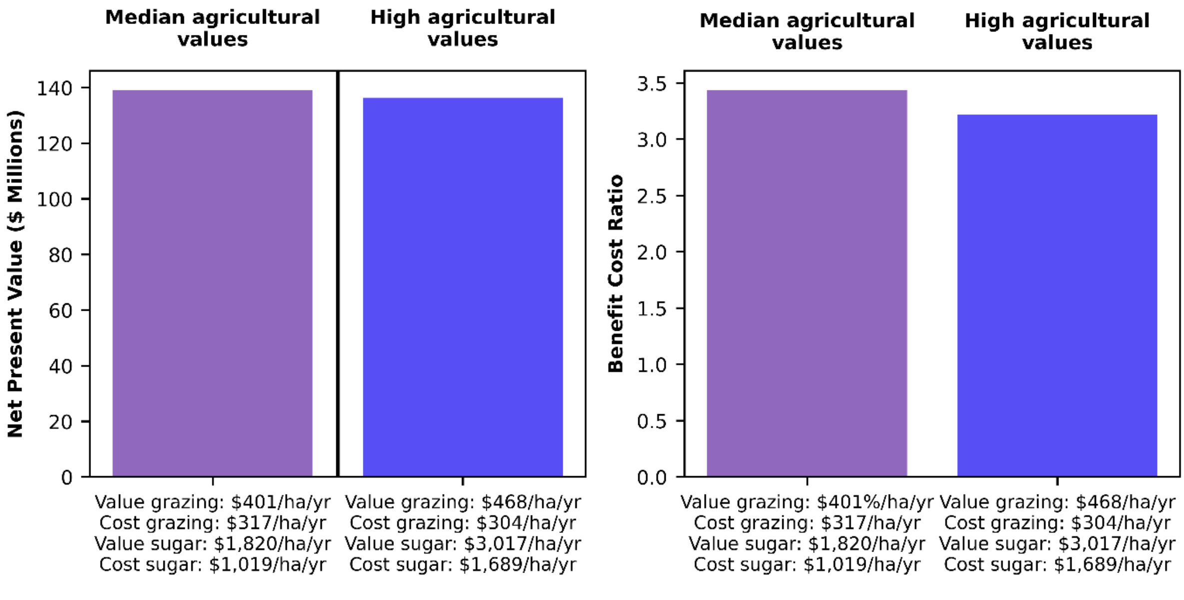

Figure 4-4: Sensitivity of broadscale wetland remediation results to agricultural value

4.3.3 Ecosystem service values

The primary objective of the broadscale wetland remediation is to improve environmental outcomes and increase ecosystem service values. As this is the primary benefit of the option, it is anticipated that the dollar value of ecosystem services will influence the results. The values adopted for ecosystem services are substantial and there is a risk that these values, which are derived from similar ecosystems in different locations, are not achieved by the project. To better understand how ecosystem service values impact the results, the minimum ecosystem service value (for both estuarine and freshwater wetlands combined) that is required to ensure there is a net benefit from the broadscale wetland remediation option was analysed, as shown in Figure 4-5 and Table 4-2. As long as the remediated ecosystems deliver more $4,390/ha/year, the remediation option remains preferable to the base case (NPV>0, BCR>1). This requires the remediated wetlands to have approximately $2,000/ha/year more ecosystem service value than the existing freshwater wetlands (all other assumptions fixed). The ecosystem service value would have to be more than 70% lower than is suggested in the literature for comparable environments. The value required ($4,390/ha/year) is exceeded by water treatment services alone, based on the available literature. As the water treatment services of the target wetlands at Tuckean Swamp implicitly included the avoided costs associated with existing acid and blackwater drainage (which have not been explicitly accounted for in the base cases due to limited information for valuation), it is assumed that they will be able to achieve this outcome.

Another method to test the sensitivity of the results to the ecosystem service value provided by the remediated wetland is to test the sensitivity to the area of remediated wetlands. Unlike estuarine wetlands which have reliable flushing and replenishment through tides, freshwater wetlands are naturally variable with inter-annual climate variations. Therefore, the BCR was also calculated assuming no freshwater wetlands establish as a result of the remediation (e.g. the land labelled freshwater wetlands in Figure 3-3 is assumed to remain grasslands). This decreases the BCR substantially to 1.65, all other assumptions remaining unchanged. While this is significantly lower than the base assumptions, the wetland remediation option remains a preferable outcome.

Table 4-2: Ecosystem service sensitivity test

Ecosystem type	Assumed value ($/ha/year)	Minimum value to achieve a NPV>0*
Remediated freshwater wetlands	15,296	4,390
Remediated estuarine wetlands	19,913	4,390
Buffer area	190	-

* For these tests, the value of both estuarine and freshwater wetlands were assumed to be the same

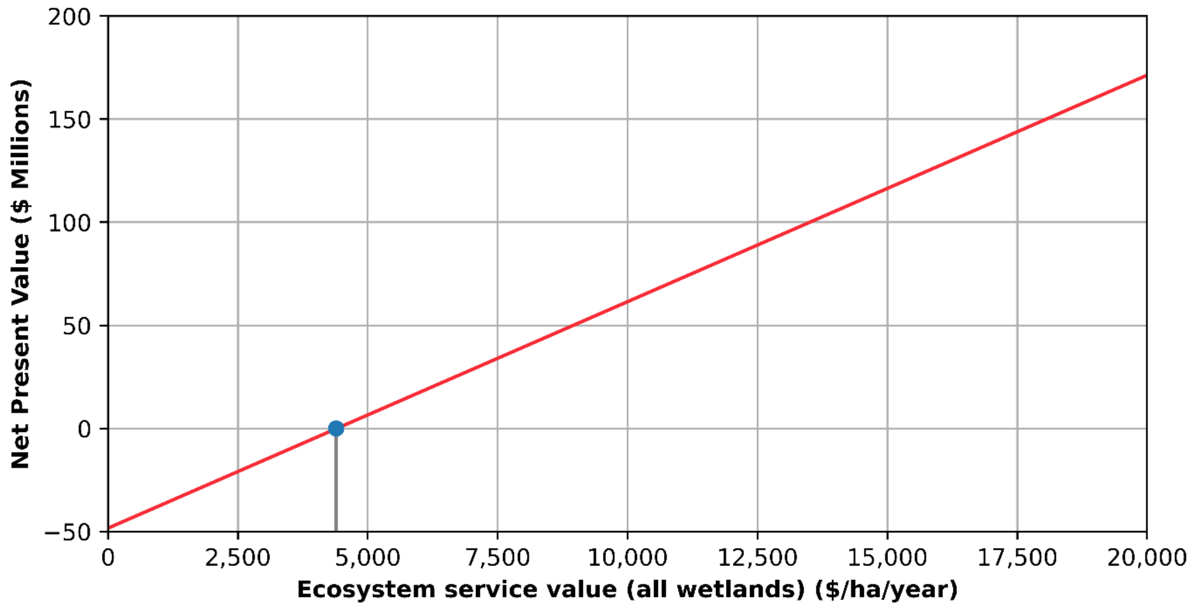

Figure 4-5: Relationship between ecosystem service value of wetlands and NPV of broadscale wetland remediation

4.4 Climate change and sea level rise

There is no consideration for sea level rise in the economic analysis presented in this report, however it is understood that water levels across the Tuckean floodplain are controlled by downstream tidal water levels. As ocean levels rise, it is anticipated day to day drainage of estuarine backswamps like the Tuckean Swamp will become increasingly difficult without significant intervention (e.g. pumping infrastructure). Harrison et al. (2022b) showed that with 67 cm of sea level rise (based on 2100 sea level rise benchmarks outlined in Glamore et al. (2016)), the majority of the indicative remediation area will be below median downstream tidal water level. As a consequence, it is anticipated that water will remain on the floodplain for longer periods, either reducing agricultural productivity or requiring significant costs to remove the water from the floodplain through other means.

Conversely, under a broadscale remediation scenario, sea level rise will change the elevation to which tidal waters could inundate the floodplain. This would change the distribution of freshwater and tidal wetland environments that could be expected, but the wetland would be expected to gradually change and adapt over time. As tidal flushing and tidal inundation are effective ways to treat and mitigate the impacts of acid sulfate soils (Glamore, 2003), and the adopted value for tidal wetlands exceeds the value for freshwater wetlands in this study, increasing sea levels is likely to increase the benefits that could be derived from natural capital on the floodplain.

4.5 Comparison with cost benefit analysis of Big Swamp, Manning River

A comparable cost benefit analysis (Harrison et al., 2019) was completed for Big Swamp, a degraded coastal floodplain on the Manning River in NSW. There are many parallels between Tuckean Swamp and Big Swamp. Both were historically thriving freshwater wetlands that were drained for agricultural land uses following European settlement. This un-knowingly mobilised acid discharge from acid sulfate soils and blackwater resulting in impacts on water quality on their respective downstream estuaries.

Some areas of Big Swamp has successfully been remediated to estuarine wetlands and Harrison et al. (2019) assessed the economic feasibility of remediating a further 650 ha.

Due to the similarities in the two studies, it is anticipated that comparisons may be made. However, there is an important difference between this study and Harrison et al. (2019) in the way the base case was defined. Harrison et al. (2019) used an arbitrary base case in which the land remains in private ownership, but is not used for agricultural production, with two options then considered (a business as usual case and a broadscale wetland remediation option). While this is method allows benefits of the 'business as usual' case can be readily identified in the presentation of the results, this current study adopted the business as usual as a base case, which is more consistent with state guideline recommendations (DPIE, 2020a; NSW Treasury, 2017). Opting for greater consistency will enable future studies to be compared with the results of this study.

The two alternative methods of analysis are mathematically similar. In this Tuckean Swamp study, the costs and benefits of the business as usual base case are accounted for as opportunity costs and avoided costs, rather than an option themselves. For ease of comparison, the results from the Big Swamp study were re-analysed adopting similar assumptions about the base case used in this study, summarised in Table 4-3. While the BCR of both sites are very similar, which is expected due to the similarities in the two sites, the NPV of remediation of Tuckean Swamp is higher. This is predominantly a result of the greater area (~2,700 ha at Tuckean Swamp compared to ~650 ha at Big Swamp) of remediation, and the economies of scale of remediating larger areas.

Table 4-3: Option Net Present Values (NPV) and Benefit Cost Ratios from this study with a re-analysis of the Harrison et al. (2019) study (discount rate of 7%, timeframe 30 years)

Metric	Tuckean Swamp Broadscale wetland remediation	Big Swamp Broadscale wetland remediation (Reanalysed with consistent base case scenario)
Net Present Value	$139,023,685	$24,214,584
Benefit Cost Ratio	3.4	3.6

5 Distributional analysis

A distributional analysis examines the changes in welfare to individual sub-groups of the community. This helps to identify whether the costs and benefits are equitably shared. At this stage, there are a number of key considerations which will require further investigation (many of which have been discussed in a concurrent study by GHD (2022b)) and consultation, including:

- How to facilitate remediation on land that is presently privately owned
- Who will own and be responsible for the management of the remediated site (e.g. private landholders, NPWS and/or local government)
- Where funding for capital works and on-going maintenance are sourced

While these important aspects of the implementation of remediation are determined, a detailed quantitative distributional analysis is not possible. Nonetheless, key stakeholders have been identified and potential costs and benefits have been identified in Table 5-1 to aid decision makers.

Table 5-1: Qualitative distributional analysis

Stakeholder	Potential impacts of broadscale remediation
Individual landholders of private property	Individual landholders with properties within the indicative remediation area are amongst those most obviously impacted by any change in management. The agricultural land on the floodplain is a source of income, as well as cultural heritage for many land owners. Their cooperation and support for the project will rely on a solution they view as equitable in which they are compensated (not necessarily with money) for the changes occurring on their land. Engagement with the affected landholders may assist in understanding their potential preference for a pathway towards land use change, which may vary between lots.
National Parks and Wildlife Services	National Parks and Wildlife Services already manage a 919 ha area of the Tuckean Swamp floodplain. Should ownership and management of the additional broadscale wetland area fall to NPWS, a sustainable, on-going allocation of resources will be required to ensure long-term success of any remediation.
Local and County Councils	On the Richmond River, flood mitigation infrastructure is largely owned and maintained by Rous County Council. Ownership and obligations for maintenance of any new structures would require sustainable resourcing, particularly if expected to be managed by Council. Funding mechanisms will need to consider the long-term management of these structures.
Surrounding land holders on the Tuckean floodplain	The detailed design and modelling for this project must be sufficient to ensure that there will be no negative impacts on the drainage of the surrounding properties. There is not expected to be a significant change in welfare as a result of the remediation of the lower floodplain to the surrounding property owners, other than those that accrue to the greater local community.
Local community	The local community will benefit from the improved estuarine health as a result of the remediation works. It will improve opportunities for recreational fishing, boating, swimming and other recreational uses of the lower estuary (including tourism throughout the estuary). The local community (along with commercial fishery

	operations) are expected to be the main beneficiaries of the ecosystem service benefits generated from the remediation. It is recognised that the local community may also be impacted by the loss in agricultural land. However, the area of agriculture lost is considered a sufficiently small portion of the agricultural land uses on the Richmond River floodplain that it is unlikely to have a significant impact on industry in the regional area.
Local commercial fishing in the Richmond River estuary	Commercial fisheries operations are expected to see positive impacts from the remediation as a result of improved water quality and increased habitat for juvenile fish. Commercial fishing has been temporarily prohibited in the Richmond River as a direct result of blackwater plumes discharging from the mid-estuary causing a mass fish kill event. While such issues may still occur from other subcatchments of the Richmond River, Tuckean Swamp is well documented to have contributed to these events. Similarly, Tuckean Swamp is the largest contributor of acid drainage into the estuary, which is associated with fish disease and mortality, as well as a degradation of habitat. While there is a loss of agricultural land, there would be an increase in fisheries production as a result of the remediation, which is included in the ecosystem services values for saltmarsh in the economic analysis.

6 Conclusions

Agricultural development of the Tuckean floodplain has occurred since European settlement. Drainage works have allowed dryland farming to exist on the floodplain on land that was once a thriving freshwater/brackish wetland. While this has contributed to agricultural productivity in the region, it has also had unintended consequences for water quality both within the swamp and for downstream waterways, mobilising acid from acid sulfate soils and lower dissolved oxygen levels through the release of blackwater. Both acid and blackwater drainage have been shown to have a significant impact on downstream waterways, including fish disease and mortality, reduced biodiversity and degradation of natural and built infrastructure. Substantial evidence exists identifying Tuckean Swamp as a key contributor to poor water quality in the Richmond River estuary (Harrison et al., 2022b; Moore, 2007; Rayner et al., 2020a; Rayner et al., 2020b; Sammut, 1996b; Southern Cross GeoScience 2019; Tulau, 2011).

This study has investigated the economic feasibility of broadscale wetland remediation on the Tuckean Swamp floodplain, compared with existing land uses. While there is presently no agreed plan for remediation, the purpose of this study was to demonstrate the net benefits or costs of a hypothetical remediation of the floodplain. While historically economic analyses have not included the contribution of ecosystems to human welfare, there is a growing body of research that suggests that coastal wetlands, have a large economic benefit to society through various services they provide (including primary production e.g. fisheries, improved water quality regulation, recreation and climate regulation). This study has incorporated these benefits to better understand the potential community benefits of environmental remediation.

The cost benefit analysis shows that under a range of justifiable assumptions, a broadscale wetland remediation of Tuckean Swamp has a net benefit to the local area, as indicated in the positive NPV and BCR greater than 1. Despite large initial costs, the predicted establishment of wetland vegetation (expected to take 15 years) and the associated ecosystem service benefits yield a $3.40 welfare return for every dollar invested over a 30 year period, using a discount rate of 7%. This increases to $4 of welfare return per dollar invested for a discount rate of 5%, as per the updated NSW Government Guide to Cost-Benefit Analysis (NSW Treasury, 2023). The sensitivity analysis showed that this result is robust under a range in variations in key variables, such as discount rate or present day agricultural productivity. The result is most sensitive to assumptions about the ecosystem service value of the remediated wetland. However, the sensitivity analysis showed that the adopted ecosystem service value could be lowered by more than 70% and still conclude the broadscale wetland remediation option of benefit.

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Appendix A Environmental Profile

A1 Preamble

This section provides an overview of the environmental profile for the Tuckean Swamp floodplain in both its existing state (base case) and in its potential broadscale wetland remediation state.

A2 Base case

The Tuckean floodplain was once a poorly drained, predominantly freshwater backswamp. Since the 1880's extensive drainage works have been completed at Tuckean Swamp providing efficient drainage of floodwaters from the naturally low-lying floodplain (Tulau, 1999). However, ingress of tidal waters through efficient drainage caused an increased salinity of surface waters, impacting of agricultural productivity. In 1971, the existing major drainage was finalised with the construction of the Bagotville Barrage, a large, tidal exclusion structure which enables drainage from the Tuckean Swamp subcatchment, while limiting downstream tidal waters and backwater flooding from the Richmond River.

The constructed drainage system, including the Bagotville Barrage, has facilitated agricultural development of Tuckean Swamp, mostly comprised of grazing and sugar cane. However, it has also caused unintended environmental impacts including the lowering of groundwater levels across the connected upstream floodplain, production of highly acidic discharges from the drainage of ASS, as well as 'blackwater' (low-oxygen water) runoff into the broader estuary (Moore, 2007). The Tuckean Swamp floodplain has been shown to be the highest contributor of acid drainage in the Richmond River estuary, and the third highest contributor of blackwater drainage (Harrison et al., 2022b).

A2.1 Land use classifications and land coverage

Land use data was sourced from the NSW Department of Planning and Environment (DPE). The dataset is based on land use in 2017 and is the most up-to-date (released in June 2020) and spatially comprehensive land use dataset available for NSW (DPIE, 2020b). The land use definitions in this dataset use the Australian Land Use and Management (ALUM) classification, which separates land-use into six primary categories, and subsequently into 32 secondary classifications and over 100 tertiary classifications.

For this study, the ALUM secondary classifications have been simplified in to seven categories which are relevant to the cost benefit analysis and are summarised in Table A-1. Note that some of these classifications, such as assuming all cropping is sugar cane, is a site specific assumption that is based on existing experience on the Tuckean floodplain and may not be suitable elsewhere. Classifications simplified as 'other' represent a small portion of the area of interest, and have therefore been grouped together for ease of mapping.

To ensure that appropriate areas are accounted for as agricultural production, land use data has been adjusted to reflect experience on the floodplain by WRL staff in 2017 and 2018. Notably, the changes include:

- Under the ALUM classifications system, water features (including Marsh/Wetland secondary classifications) take precedence over other land uses. Across the Tuckean floodplain, this means that some areas that are privately owned and actively used for grazing are classified as wetland areas, which have been changed to grazing. Areas which are heavily vegetated have been left as Marsh/Wetland, even if the land is privately owned.
- While the majority of the Tuckean Nature Reserve is in a continuous block of land, there are two lots that are separate, which have been classified as "Conservation and minimal use" due to land tenure. However, these blocks are not fenced and are known to be traversed by cattle from adjacent properties, so have been classified as grazing.
- There is one lot in the north-east quadrant of the floodplain that has been classified as 'Other' (or Land in Transition under the ALUM classifications). This property was being actively used for cattle grazing in 2017, and the classification of the land use has been adjusted.
- There is a property on Stibbards Creek (approximately 120 ha), on the south-west edge of the floodplain. This was classified as sugar cane in the 2017 landuse data. Based on information provided, this land is most likely currently used for tea tree (p. comms C. Clay 1/5/2023).

The resulting land use types within the remediation area is summarised in Figure A-1 and Table A-2.

Table A-1: Simplified land use categories in this study

Land use in this study	ALUM Secondary Classifications
Conservation and minimal use	Nature conservation Managed resource protection Other minimal use
Grazing	Grazing native vegetation Grazing modified pastures Irrigated grazing modified pastures
Sugar cane	Cropping Irrigated cropping
Urban/Industrial/Services	Intensive animal husbandry Manufacture and industrial Residential and farm infrastructure Services Utilities Transport and communications Mining
Marsh/wetland	Marsh/wetland
Other	Land in transition Irrigated land in transition Intensive horticulture Perennial horticulture Seasonal horticulture Irrigated perennial horticulture Irrigated seasonal horticulture Plantation forestry Production forestry Irrigated plantation forestry
Water	Lake Reservoir/dam River Channel/aqueduct Estuary/coastal water

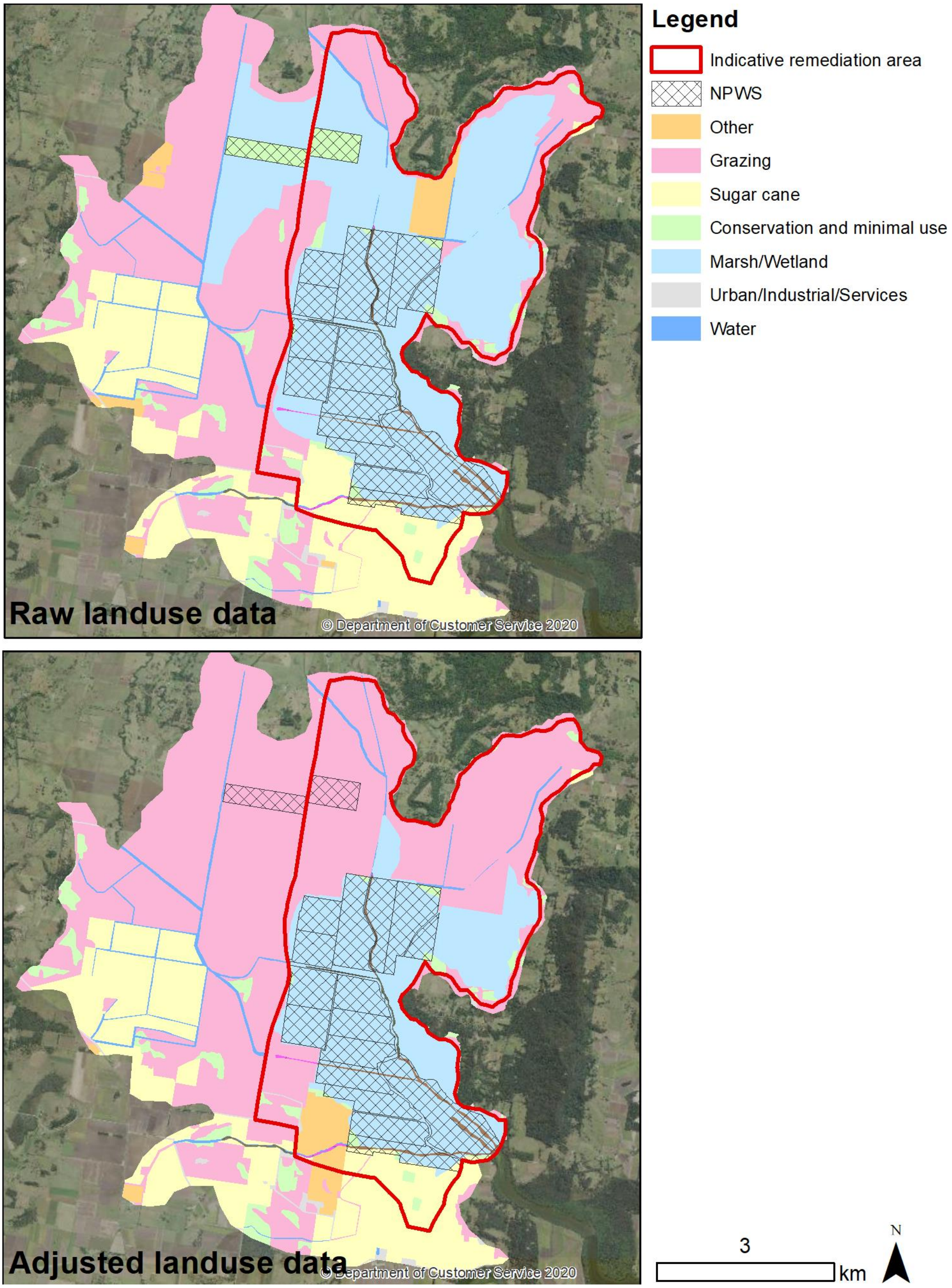

Figure A-1: DPIE (2020) raw land use (top) and adjusted land use data for use in the cost benefit analysis (bottom)

Table A-2: Breakdown of land uses within the remediation area

Land use	Area (ha)	Percentage of remediation area
Conservation and minimal use	56	2%
Grazing	1,149	42%
Marsh/wetland	1,269	47%
Sugar cane	127	5%
Other (tea tree)	86	3%
Urban	7	0.2%
Water	27	1%

A2.2 Tuckean Nature Reserve

As shown in Section A2.1, a significant portion of the existing Tuckean floodplain is considered marsh/wetland, including the majority of the area within the Tuckean Nature Reserve managed by National Parks and Wildlife Services. While there is evidence that both acid and blackwater drainage occurs from the NPWS owned areas (Harrison et al., 2022b; Rayner et al., 2020a), it is important to acknowledge that this land does have ecological value.

This project does not intend to provide a comprehensive analysis of the ecological significance of the Tuckean Nature Reserve. However, it is acknowledged that much of the Nature Reserve is classified as Coastal Management SEPP coastal wetland under the Costal Management Act 2016 and are habitat for Ecologically Endangered Communities (including Freshwater wetlands on coastal floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions and Swamp Sclerophyll Forest on Coastal Floodplains of the New South Wales North Coast, Sydney Basin and South East Corner Bioregions). It is important to acknowledge the value of these systems in this assessment, as changes to the hydrology of the swamp will likely result in changes of some of these areas from freshwater systems to estuarine systems.

A3 Broadscale wetland remediation

There is presently no agreed plan for the remediation of Tuckean Swamp. This study does not intend to specify the exact nature of the remediation works. The remediation works considered are generic in nature but are intended to reflect the type and scale of works that would be required to achieve meaningful change in the swamp's hydrology and ecology. The Tuckean Swamp floodplain has been the subject of numerous studies, notably hydrodynamic and water quality modelling completed in 2020 by Rayner et al. (2020a). The extent of the remediation has been assumed to be the area below 1 m AHD, east of Tuckean Island Road. This area has been targeted as:

- Tuckean Island Road provides an existing boundary for the wetland, with existing culverts that can be fitted with one-way floodgates as required. It will also be maintained as a public thorough fare
- This area includes the highest priority areas for remediation to reduce both blackwater and acid drainage (Harrison et al., 2022b)
- The area below 1 m AHD has been shown to be the highest contributor to both blackwater and acid

While the large scale remediation considered in this study is not exactly represented by any remediation options considered in Rayner et al. (2020a), the proposed works are similar to a combination of Scenario 6 (hinging open the Bagotville Barrage, while mitigating impacts to upstream properties through installing structures upstream of the Tuckean Nature Reserve on all the major drains) and Scenario 5, reshaping of drains in the north-east corner of the floodplain, and encourage catchment flows to inundate the floodplain. The only main difference is that Scenario 5 only involved limited floodplain reflooding, reducing the impact on agricultural productivity in the north-east corner. For this study, it is assumed agricultural production below 1 m AHD is entirely ceased, and reflooding of the wider north-east corner (around Slatteries Drain) is feasible.

The target ecosystems (freshwater and estuarine wetlands) extent has been determined primarily through interpretation of model results from Rayner et al. (2020a) and topographic information, shown in Figure A-2 and areas summarised in Table A-3. Land below 0.5 m AHD has been assumed to be achievable wetland habitat, with areas expected to be within 60% of the salinity of the Tuckean Broadwater assumed to be estuarine wetland (the remainder freshwater wetland). The flood mitigation capacity of the existing drainage system was assumed to remain unchanged for the areas outside the indicative remediation area, and a buffer zone from 0.5 to 1.0 m AHD in most locations is expected to be included in the design of the remediation to assist in mitigating impacts to surrounding land.

Table A-3: Area of target ecosystems

Ecosystem type	Indicative area (ha)
Freshwater wetlands	1,172
Estuarine wetlands	729
Buffer	820

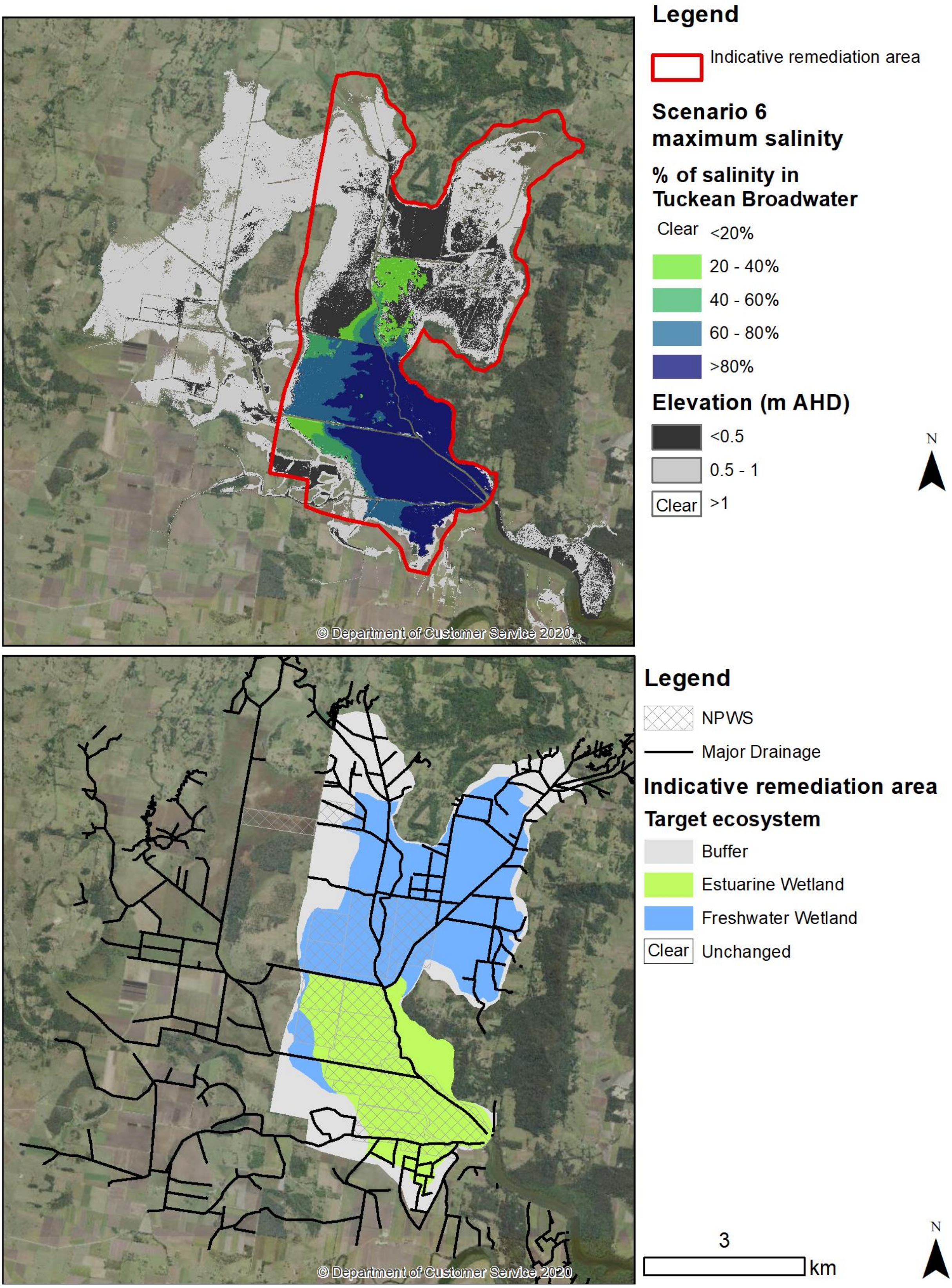

Figure A-2: Key information for determining key remediated ecosystems (top) and target remediated ecosystems (bottom)

Appendix B Valuation and assumptions

B1 Preamble

This section summarises the values adopted for the cost benefit analysis, including a discussion of the required assumptions. A key concept in this project is the idea of ecosystem services, or the benefits of natural capital to human societies. This is an emerging field that has only recently gained significance in decision making, as discussed in Section 2.3. All values in this section have been converted to 2022 Australian dollars, unless otherwise specified.

B2 Base case

B2.1 Productivity values

Significant agricultural value is produced from coastal floodplains in NSW. Where land uses are significantly impacted by potential changes in land management, it is important to understand and acknowledge that there may be a loss in agricultural productivity. The Australian Bureau of Statistics releases annual data relating to the Value of Agricultural Commodities Produced (VACP). The data is released over a variety of spatial areas, referred to as “Statistical Areas”. For this project, the relevant statistical area is Statistical Area Level 4 (SA4): SA4 areas generally cover 100,000 – 300,000 people in regional areas, and 300,000 – 500,000 people in metropolitan areas. SA4 areas are specifically designed to reflect labour markets, relating to the availability of employment and labour. SA4 areas typically span more than one LGA. The Tuckean floodplain is in SA4 area referred to as “Richmond-Tweed”. VACP data was downloaded from ABS website for the six most recent available periods (from 2015/16 to 2020/21). All data has been converted to 2022 Australian dollars using the Reserve Bank of Australia inflation calculator.

The raw 2017 ALUM land use data discussed in Section A2.1 (unadjusted land use has been used), used in conjunction with the VACP, allows for estimates of production value per unit area ($/ha) to be made. Ideally, the land use categories would be identical to those in the ABS VACP data. However, this is not the case. Table B-4 summarises how the two datasets have been matched to accommodate the analysis. Note that it is acknowledge that use of this data does not account for changes in land area used for types of agricultural productivity over time, which has been assumed to be minor over the six year period (assumed to be as per the 2017 land use data).

The estimate value of grazing and sugar cane production is summarised in Table B-4. The median value of agricultural production from grazing land is estimated to be $401/ha/year (with a range between $385 and $468/ha/year) and $1,820/ha/year (with a range between $1,162 and $2,117/ha/year) for sugar cane. Median values have been used for the base cost benefit analysis.

For sugar cane, ABRES (2022b) was commissioned to complete a comprehensive survey to assess the financial performance of sugar cane farms in the 2020-21 financial year. Based on this analysis, the average cash income on sugar cane farms in NSW was $3,017/ha/year. However, this study uses the base area as the actual area planted, rather than the total farm footprint (with an estimated total area of 18,286 across the whole of NSW). As the land use data available identifies the whole farm area as sugar cane, this value is likely to overestimate the total value of sugar cane substantially. Nonetheless, this value has been used as an upper bound for sensitivity testing. Sensitivity testing for grazing uses the upper bound of values in Table B-5.

A small area (86 ha) of the floodplain to be remediated is currently used for tea tree (classified as 'Other' in Figure A-1), based on information provided by local floodplain managers. While this land use has been identified through local knowledge, classification of tea tree is beyond the capacity of the existing 2017 ALUM landuse data available. As such, the methods used to estimate productivity per land area were not appropriate. For the purpose of the CBA, this area has been assumed to have the same productivity as sugar cane (the higher of the two production values). This lot was previously used for sugar production.

Table B-4: Richmond-Tweed estimated value of production for grazing and sugar cane

Land use	Estimated area (ha)	Years	Total value of commodities	Estimated Production Value ($/ha)
Grazing	533,763	2015-2016	$241,651,551	$453
		2016-2017	$249,964,040	$468
		2017-2018	$201,285,186	$377
		2018-2019	$206,866,618	$388
		2019-2020	$220,723,918	$414
		2020-2021	$205,398,516	$385
Sugar cane	34,381	2015-2016	$39,946,894	$1,162
		2016-2017	$72,783,188	$2,117
		2017-2018	$64,979,573	$1,890
		2018-2019	$45,025,855	$1,310
		2019-2020	$65,542,176	$1,906
		2020-2021	$60,154,680	$1,750

Table B-5: Land use categories and corresponding ABS VACP categories

Category	Land use categories (Tertiary Codes)	ABS VACP categories
Grazing	• Grazing native vegetation (210) • Grazing modified pastures (320-321-322-323-324-325) • Grazing irrigated modified pastures (420-421-422-423-424-425)	• Livestock products – Total • Livestock slaughtered and other disposals - Total
Sugar cane	• Sugar (335) • Irrigated sugar (435)	• Broadacre crops - non-cereal crops - sugar cane - cut for crushing
Other broadacre crops	• Cropping, excluding sugar (330-331-332-333-334-336-337-338) • Irrigated cropping, excluding irrigated sugar (430-431-432-433-434-436-437-438-439)	• Broadacre crops – Total (excluding Broadacre crops - non-cereal crops - sugar cane - cut for crushing) • Hay - Total
Horticulture	• Perennial horticulture (340-341-342-343-344-346-347-348) • Seasonal horticulture (350-351-352-353-354) • Irrigated perennial horticulture (440-441-442-443-444-446-447-448-449) • Irrigated seasonal horticulture (450-451-452-453-454-455)	• Vegetables for human consumption – Total • Fruit and nuts (excluding grapes) – Total • Nurseries, cut flowers or cultivated turf - Total

B2.2 Agricultural production costs

Agricultural production incurs many costs, including the cost of feed, fertiliser, services and labour. ABRES (2022a) provides data on the average farm cash receipts and cash costs aggregated across coastal NSW from 2010 – 2021. The values from the most recent five year period are provided below in Table B-6. On average, total cash costs are 79% of cash receipts on farms in coastal NSW, however there is significant variation year to year, between 65% and 89%. For grazing production, the cost/value of productivity ratio will be assumed to be 79% in the cost benefit analysis, with sensitivity tests at 65%.

Table B-6: Average farm cash receipts and costs for the coastal NSW region

Year	Average farm cash receipts	Average farm cash costs	Cost as a percentage of cash receipts
2017	$151,368	$113,816	75%
2018	$115,063	$99,223	86%
2019	$113,855	$100,852	89%
2020	$155,691	$127,503	82%
2021	$144,997	$94,589	65%

As discussed in Section B2.1, ABRES (2022b) completed a study specifically on the cash costs and receipts of sugar cane farms across Australia in 2013-14 and 2020-21. This showed that in 2020-21, average farm cash costs on sugar cane farms in NSW were relatively low, at 56% of total cash receipts. In contrast, this ratio was 76% in 2013-14. ABRES (2022b) suggests that this is partly due to increased productivity and sugar cane yields, but also due to lower interest payments due to record low interest rates over the 2020-21 period. For sugar cane, cost/value of productivity ratio will be assumed to be 56% in the cost benefit analysis, with sensitivity tests at 76%.

A small portion of the floodplain to be remediated is currently used for tea tree

B2.3 Ecosystems services of agricultural land

Agricultural land provides some environmental value which needs to be considered in this analysis. However, there is limited available literature that provides specific estimates for ecosystem services derived from grazing land similar to Australia, particularly those affected by ASS. Costanza et al. (2014) provided mean ecosystem services values for both croplands and grasslands based on the Ecosystem Service Value Database, categorised into 17 service sub-categories. As no single specific study provides an appropriate value for agricultural land similar to that at Tuckean Swamp, the mean values from a substantial body of literature provided the most reasonable approximation. By assessing each sub-category, and deciding whether or not it was applicable to the agricultural land at Tuckean Swamp, an ecosystem service value of $190/ha/year and $862/ha/year was adopted for grazing land and sugar cane properties respectively, excluding the agricultural return for the value of food production (which is included in the agricultural productivity estimates, discussed in Section B2.1). The values and rationale are described in Table B-7.

B2.4 Ecosystem services of existing wetland habitat

The basis of ecosystem service values for wetland systems in this report is a review of literature relevant to NSW in Harrison et al. (2022a). This study reviewed a range of Australian and international literature to develop a range of ecosystem service values most relevant to the NSW context (where possible, otherwise relying on median values from international literature) for a range of ecosystems, including freshwater wetlands, mangroves and saltmarsh. The study considered six service types:

- Provisioning of food (predominantly fisheries production)
- Cultural value (predominantly tourism and recreational fishing)

- Climate regulation
- Storm and erosion protection
- Water treatment
- Habitat and biodiversity values

While Harrison et al. (2022a) did not consider the same number of services as Costanza et al. (2014), it is a more recent review of literature and is considered to include a range of relevant ecosystem services in the context of this study. In lieu of site specific data on the value of the Tuckean Swamp existing freshwater wetlands, the ecosystem service values of the existing wetlands has been derived from the values presented in Harrison et al. (2022a), while also considering the specific circumstances and capacity of this wetland to contribute each service, as explained in Table B-8.

Table B-7: Ecosystem services for grasslands and croplands, and application to Tuckean Swamp (adapted from Costanza et al., 2014)

Ecosystem service sub-category	Grassland (average value $AUD/ha/yr)	Croplands (average value $AUD/ha/yr)	Assumed value for grazing ($AUD/ha/yr)	Assumed value for sugar cane ($AUD/ha/yr)	Rationale
Gas regulation	14	-	14	14	Only value available
Climate regulation	74	763	74	763	Most similar ecosystem
Disturbance regulation	-	-	0	0	-
Water regulation	5	25	0	0	Presence of ASS, drained for grazing
Water supply	93	619	0	0	highly drained, and presence of ASS
Erosion control	68	166	0	0	Cattle cause issues with erosion. Sugar cane farms burnt following harvest exacerbating sediment transport into waterways.
Soil formation	824	3	0	0	presence of ASS
Nutrient cycling	-	-	0	-	-
Waste treatment	116	615	0	0	Presence of ASS, blackwater

Pollination	54	34	54	34	Most similar ecosystem
Biological control	48	51	48	51	Most similar ecosystem
Habitat	1,879	-	0	0	Presence of domesticated animals, or limited diversity
Food production	1,845	3,596	N/A	N/A	Food production is considered in the agricultural productivity
Raw materials	84	339	0	0	Unlikely to be a source of raw materials due to agricultural use
Genetic resources	1879	1613	0	0	Unlikely to be a unique source of genetic material due to poor soils and water quality
Recreation	40	127	0	0	Privately owned
Cultural	259	-	0	0	Privately owned
Total			**190**	**862**	

Table B-8: Value of existing freshwater wetlands in Tuckean Swamp, adapted from Harrison et al. (2022a)

Service	Value ($/ha/year) Harrison et al. (2022a)	Value adopted for existing Tuckean Swamp freshwater wetlands ($/ha/year)	Rationale
Provisioning – commercial fisheries	4,078	0	Tidal barrage prevents fish passage and connectivity with wider estuary where commercial fisheries occur
Habitat and biodiversity	1,793	1,793	There is provision of habitat, and the system is an EEC
Climate regulation	84	84	Climate regulation, including carbon storage and sequestration, assumed to be well represented by literature
Erosion and storm protection	4,203	0	Flood mitigation systems prevent backwater flooding and allow efficient drainage, mitigating storm protection services
Water treatment	9,341	0	Presence of drained ASS, as well as evidence that the Nature Reserve area contributes significantly to blackwater production indicates that the area contributes significantly to poor water quality, therefore no water treatment services have been included.

Cultural – tourism	166	0	While the Tuckean Nature Reserve is part of NPWS, it has limited access for tourism
Total		**1,877**	

B2.5 Cost of poor water quality in the Richmond River

As shown in Sections B2.3 and B2.4, no value has been include for any water quality related services in the existing system. It is well documented that the presence of acid sulfate soils and the ready release of deoxygenated blackwater has a negative impact on water quality in downstream water ways, and the Tuckean Swamp floodplain has long been understood to be a significant contributor of these issues (Harrison et al., 2022b; Moore, 2007; Rayner et al., 2020b; Sammut, 1996b). Importantly, the impacts of these issues extend beyond the floodplain itself. In the Richmond River, large scale fish kills have been linked to poor water as a result of acidification and low oxygen conditions (Moore, 2007; Sammut et al., 1995; Walsh et al., 2004), and these issues are also understood to cause a series of other environmental issues including habitat degradation, disease, oyster mortality and degradation of natural and built infrastructure.

It is acknowledged that the water quality impacts from drainage at Tuckean Swamp have a negative impact on the Richmond River estuary. However, it is difficult to accurately estimate the contribution of the region to poor water quality issues due to the presence a number of similar large backswamp systems that also frequently discharge acidified and anoxic water (such as Rocky Mouth Creek, Bungawalbin and Sandy Creek and Swan Bay). For this study, no negative costs of these impacts have been included at this stage. This will result in an overestimation of the value of the base case, which would require further consideration if the result marginally preferences no remediation works.

B3 Broadscale wetland remediation

B3.1 Property costs

There may be a number of different pathways to completing on-ground properties. Remediation on a large scale on other comparable coastal floodplains, such as the Big Swamp remediation works in 2014 (Glamore et al., 2014; Harrison et al., 2019), has typically occurred through property acquisition either by local or state government agencies. However, there are other possible pathways for land use change, including biodiversity conservation trust agreements or conservation covenants. These different pathways are discussed in detail in GHD (2022b).

For the purpose of this study, it is assumed that impacted land within the remediation area is purchased and the land is managed by government agencies, funded through specific grants awarded for environmental remediation (government or private grants). However, the cost benefit analysis focuses on net changes to wealth within the LGA. When the property is sold, there is typically no net change in total wealth, as the sale price is assumed to be equal to the worth of the property, particularly if the land use remains unchanged. It has been assumed that property subdivisions will be permitted for lots with both high and low areas, as has occurred in other local government areas for environmental conservation.

However, it is acknowledged that significant land use changes are proposed under the remediation option and therefore some loss of land improvements must be considered on private land which will no longer be utilised for agriculture. Harrison et al. (2022b) analysed land values in the Tuckean Swamp floodplain, and showed that the average land values (without improvements) for land below 1 m AHD is $4,900/ha, while for land above 1 m AHD is $7,700/ha. The majority of the private property within the remediation area is below 1 m AHD. While the true value of land improvements is not known, an allowance of $1,000/ha (~20% of land value below 1 m AHD) has been included in the upfront costs. Note that the 919 ha of NPWS land is not included in this assessment, so allowance for $1,800,000 for land improvements for the low-lying land was included in this study, which is considered conservative as there is minimal built infrastructure, other than drains, levees and small dams.

B3.2 Capital and on-going costs

As discussed in Section A3, the on-ground works associated with the broadscale remediation option is based on the options for remediation described and modelled in Rayner et al. (2020a). GHD (2022a) completed a design and costing report based on a series of six potential remediation options that were originally modelled by Rayner et al. (2020a), which are summarised in Table B-9. The exact nature of the works is not the subject of this study, however it includes the works proposed in Scenario 6 and Scenario 5, although a greater volume of catchment flows is anticipated to re-flood the north-east corner of the floodplain, under the assumption that all agricultural productivity in the area is ceased.

Table B-9: Scenarios and associated costs (GHD, 2022a; Rayner et al., 2020a)

Scenario	Description	Capital Cost ($)	Maintenance Costs ($/year)
1	Reshaping of major drains in the north-eastern corner of the floodplain (Slatteries, Meerschaum Vale and Jumbo Drains)	2,260,000	21,120
2	Weir implementation at the downstream end of Meerschaum Vale Drain	369,000	10,560
4	Hinging open the Bagotville Barrage	396,000	7,680
5	Reshaping of drains (as per Scenario 1), but encouraging small catchment flows onto the floodplain	2,629,000	21,120
6	Hinging open the Bagotville Barrage, and installing structures upstream of the Tuckean Nature Reserve on all the major drains	1,933,000	25,920

Based on this understanding, costs assumed in the cost benefit analysis include 100% of the costs associated with Scenario 6, plus 120% of the cost of Scenario 5 to account for the additional earthworks required to actively reflood a larger portion of the floodplain. Therefore, the costs associated with the works have been assumed to be:

- Capital construction costs: $5,087,800
- On-going maintenance costs: $51,264/year

While GHD (2022a) included costs management of weeds, site inspections and general maintenance, it did not consider general monitoring (e.g. water quality or ecological monitoring), or general site management. This has been included at a nominal cost of $50,000/year, approximately equivalent to an individual working on the site for 50% of their time at median annual salaries in Australia.

The works included in this cost include:

- Modification and operation of the Bagotville Barrage
- Construction and operation of four new tidal control structures
- Significant reshaping of Slatteries Drain
- Additional earthwork to encourage catchment flows to spill onto the floodplain around Slatteries Drain

In addition to these costs it is assumed that up to five technical studies, valued at $100,000 each will be required to complete the works. This might include fire management plans, flood modelling, assistance with governance or vegetation surveys. Therefore an additional upfront cost of $500,000 has been included.

B3.3 Ecosystem services of remediated wetlands

As discussed in Section B2.4, the ecosystem services for wetlands in this study are based on a literature review in Harrison et al. (2022a). Table B-10 and
Table B-11 summarise the ecosystem service values adopted for freshwater and estuarine wetlands respectively in this study. These tables include the rationale for the values adopted, where they differ from the literature.

The cost of acid and blackwater drainage into the Richmond River under continued agricultural land uses has not been explicitly valued, due to the complexity of estimating the social and environmental costs. Water treatment services from wetlands is typically associated with nutrient removal. However, these values are considered to implicitly include the avoided cost of acid and blackwater drainage into the Richmond River estuary, and the associated negative impacts. As this is in addition to nutrient removal services, it is unlikely that the value incorporates the full water treatment services provided by the remediated wetlands.

Note that while the systems will be remediated, no value has been included for erosion and storm protection. This is based on the assumption that the Bagotville Barrage will remain operationally in flood situations (as per the corresponding scenario in Rayner et al. (2020a)) and therefore limited connectivity is expected in such events. Similarly, no cultural value (e.g. tourism) has been included as no costs for making the NPWS area more accessible have been included. Harrison et al. (2022a) also included mangroves and saltmarsh separately. It is anticipated that the Tuckean Swamp estuarine wetland will be a mix of saltmarsh and mangroves, the extents of which may flux with climate variations including sea level rise. As a result, the median value of the two ecosystems has been adopted for this study, unless otherwise stated. Note that no additional benefits associated with potential carbon or biodiversity credits that could be generated from remediation have been included as it is assumed to have been incorporated in the Tuckean Nature Reserve. However, alternative land use change arrangements may be able to generate income for private landholders on the floodplain.

Table B-10: Value of remediated freshwater wetlands, adapted from Harrison et al. (2022a).

Service	Value ($/ha/year) Harrison et al. (2022a)	Value adopted for remediated freshwater wetlands ($/ha/year)	Rationale
Provisioning – commercial fisheries	4,078	4,078	Increased connectivity with the wider Richmond River will support increased fisheries production
Habitat and biodiversity	1,793	1,793	Habitat and biodiversity assumed to be well represented by literature
Climate regulation	84	84	Climate regulation, including carbon storage and sequestration, assumed to be well represented by literature
Erosion and storm protection	4,203	0	Assuming flood mitigation systems continue to be operated to prevent backwater flooding during extreme events and allow efficient drainage
Water treatment	9,341	9,341	The increased water table will reduce the prevalence of ASS drainage. The proliferation of water tolerant vegetation will help to reduce blackwater production. Additional nutrient processing can also be expected. This also accounts for some of the 'avoided costs' of acid and blackwater drainage
Cultural - tourism	166	0	Assuming no additional ease of access, so no increase in tourism has been included.
Total		**15,296**	

Table B-11: Value of remediated estuarine wetlands, adapted from Harrison et al. (2022a).

Service	Saltmarsh value ($/ha/year) Harrison et al. (2022a)	Mangroves value ($/ha/year) Harrison et al. (2022a)	Value adopted for remediated estuarine wetlands ($/ha/year)	Rationale
Provisioning – commercial fisheries	1,080	350	716	Increased connectivity with the wider Richmond River will support increased fisheries production. Average of saltmarsh and mangrove
Habitat and biodiversity	14	3,126	1,570	Habitat and biodiversity assumed to be well represented by literature. Average of saltmarsh and mangrove

Climate regulation	6,040	17,280	11,160	Climate regulation, including carbon storage and sequestration, assumed to be well represented by literature. Average of saltmarsh and mangrove
Erosion and storm protection	4,203	4,203	0	Assuming flood mitigation systems continue to be operated to prevent backwater flooding during extreme events and allow efficient drainage
Water treatment	11,234	1,700	6,467	The increased water table will reduce the prevalence of ASS drainage. Natural bicarbonates in marine water will also help to neutralise remaining acid. The proliferation of water tolerant vegetation will help to reduce blackwater production. Additional nutrient processing can also be expected. This also accounts for ‘avoided costs’ of acid and blackwater drainage
Cultural - tourism	224	486	0	Assuming no additional ease of access, so no increase in tourism has been included.
Total			**19,913**	

B3.4 Timing of ecosystem services

Following the initiation of on-ground works, there will be a period in which the wetland systems within Tuckean Swamp are evolving. There will likely be an initial die off some non-water tolerant or non-salt tolerant species on the floodplain as hydrology and water quality changes. While evidence from other tidal wetland rehabilitation projects suggests changes to the hydrology through the removal or modification of flood mitigation structures leads to rapid changes in water quality, fish passage and bird visitation, vegetation recruitment continues over a number of years (Russell et al., 2012). In recognition that wetland vegetation and associated benefits may take time to establish and mature, it is assumed in the analysis that there will be no ecosystem services provided until year 5, and they will then increase linearly until year 15.