Management Options for Teal Lagoon Berm, Boyters Lane, South West Rocks

FINAL REPORT TO KEMPSEY SHIRE COUNCIL

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Introduction

Teal Lagoon is a natural wetland located in an area often referred to in reports as the *Boyters Lane Playing Fields and Wetlands site,* about which much has been written in response to development applications (Sandpiper Environmental, 2005; Kempsey Shire Council, 2007, 2008; Darkheart Eco-consultancy, 2008a, 2008b). The lagoon itself is situated within a palaeo- meander scroll of the Lower Macleay River at South West Rocks, NSW. Its morphology and spatial relationship to nearby waterways provides geomorphic evidence of a dynamic river system that has progressively migrated across its floodplain since the last sea level transgression. It is located immediately adjacent to Boyters Lane on Pelican Island, which is bounded by the Macleay River to the south and west and by Spencers Creek to the north and east (Figure 1). Spencers Creek is a small anabranch of the Macleay, and receives up-catchment flows from the Macleay River, as well as Saltwater Inlet which drains back-swamps to the south between Hat Head National Park and the Macleay. Both the Macleay River and Spencers Creek are located within the marine zone at this location, according to WMA Water (2009), by which the waterways are dominated by tidal processes and the presence of marine sediments. However, field assessments for this report suggest a more transitional environment reflecting both fluvial and tidal influences. This will be described in a later section.

The lagoon is one of myriad shallow, estuarine wetlands in the Lower Macleay. In contrast to many other wetlands in the area, it has been the focus of numerous studies due to changing land tenure and landuse along its boundaries, and to site-specific environmental values (Walker et al, 2004; Australian Wetlands, 2005; Sandpiper Environmental, 2005; Flanagan et al, 2007; Kempsey Shire Council, 2005, 2006, 2007, 2008; Darkheart Eco-consultancy, 2008a, 2008b; Gardner et al, 2011). This study specifically examines the implications of a number of management options that relate to a degrading berm that bisects the lagoon. The berm was constructed in 1965 to provide passage, across the tidally controlled Juncus Inlet, for cattle grazing the area. The structure was made of building rubble and fill with soil overburden. Initially, the berm limited the inflow of tidal water into the upstream section of the inlet (Teal Lagoon). This created conditions whereby the water chemistry and quality of the two sections of the lagoon became increasingly different: the upstream section was fresh to brackish whilst the downstream section was saline and controlled by tidal effects. In response, freshwater dependant biota, particularly birds, started to colonise the water body upstream of the berm, and mangrove die-back occurred. Over time, the site has developed into a favoured observation area for local and visiting ornithologists, and is now perceived by some members of the community as having important conservation, educational and recreational values.

However, as the berm degrades, hydrological connectivity between the two sections of the lagoon increases. Consequently, the site is reverting back to an estuarine dominated system, with mangrove colonisation occurring along the lagoon perimeters and associated changes to habitat for aquatic and bird species. In response, Kempsey Shire Council wishes to initiate an adaptive management approach which balances biodiversity and social values of the site. Within this context, a number of management options are available:

(i) Retention of the berm in its current condition, allowing it to continue to degrade over time
(ii) Repair of the berm to improve its structural integrity with the intention of hydrologically separating the two sections of the lagoon
(iii) Repair of the berm to allow for controlled exchange of waters between the two sections of the lagoon
(iv) Repair of the berm to allow the upstream section of the lagoon to maintain water level at a given level
(v) Remove the berm to establish a tide dominated estuarine wetland.

Each of these options has implications for the ecological, social and visual amenity values of the site, as well as quite disparate financial requirements. The stated aim of the project is *to provide Kempsey Shire Council with management options for Teal lagoon berm that are based on sound scientific assessment, are realistic and achievable, are both socially and ecologically acceptable and conform to relevant legislative requirements.* To satisfy this aim, this report briefly describes the history of landuse and tenure. It then characterises the biophysical condition of the lagoon and the salient controls that define the system. It also examines the values that key stakeholders have identified, and refer those back to the evolving nature of the site. This information is then used to provide the basis for recommending preferred management option(s) with reference to relevant policy and legislation.

A number of previous studies of the Boyters Lane Playing Fields and Wetlands site have provided extensive lists of flora and fauna that have been identified in the vicinity of Teal Lagoon (Sandpiper Environmental, 2005; Darkheart Eco Consultancy, 2008). It is outside the scope of this report to repeat these lists. However, a vegetation survey was undertaken because of its relevance overall to the water quality of Teal Lagoon. This survey was very specific in its objectives and is not intended to be either comprehensive or to replace those lists presented in other, previous studies. In addition, observations here have focussed on specific, contrasting aspects of fauna upstream and downstream of the berm.

Figure 1: Site of Teal Lagoon, NSW (Google Earth, 2012; Kempsey Council, 2009).

Physical setting

Teal Lagoon is the upstream section of a waterway that is linked to Spencers Creek. This waterway comprises a downstream section, Juncus Inlet, which is a tidal creek, and the upstream section as Teal Lagoon. They are separated by a berm which is 40m long, and trapezoidal in cross section with a 6m wide base, and 3m wide top surface. Teal Lagoon itself is 260m long and 96m across at its widest point. It has a total area of 2.24 ha, depths between 0.1-0.75m (Kempsey Shire Council, 2012), and a mean depth of 0.3m. This equates to a total volume of water of approximately 6720 m^3 or 6.7ML. As noted above, Teal Lagoon is situated within the Boyters Lane Playing Fields and Wetlands site which has a total area of 25.8 ha.

Climate

The area has a warm temperate to subtropical climate with a dry season in late winter to spring and a wet season in summer to autumn (Figure 2). Whilst extended dry periods are uncommon, there is a soil water deficit from July to December (Atkinson, 1999).The wet season is characterised by heavy rainfall events that can generate significant flooding across the Lower Macleay catchment. This flooding is controlled not only by climatic factors but also by the geology and geomorphology of the total catchment, which is characterised by high drainage density and steep slopes in the upper reaches. Consequently, the Macleay River responds quickly to rainfall, generating high velocity flows. The funnel shape of the catchment imposes a hydrological constraint on such flows at the bottom of the catchment with the consequence that the valuable agricultural and urban land of the Lower Macleay Valley is flood prone. Flood risks have been addressed by the construction of a complex network of artificial drains, flood control structures and levees, all of which have modified the hydrology of the floodplain (WMA Water, 2009).

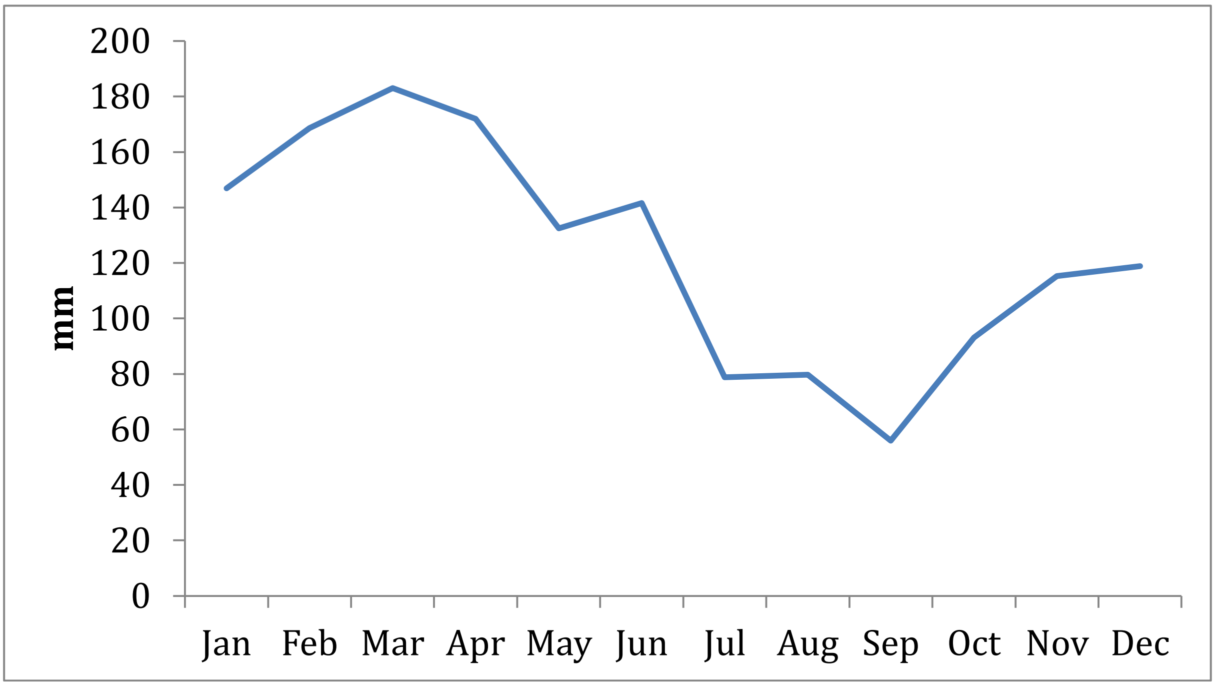

Figure 2: Mean monthly rainfall at South West Rocks (climate station 59030) (BOM, 2013).

Figure 3 demonstrates the highly variable annual rainfall of the area. The mean annual rainfall at South West Rocks (Smoky Cape Lighthouse) is 1,488 mm and the mean annual evaporation is 1,502 mm (BoM, 2013). This variability is a function of global circulations such as ENSO (El Niňo Southern Oscillation) and IPO (Inter-decadal Pacific Oscillation), which generate a regime of alternating wetter and drier than average conditions so characteristic of Australia's eastern seaboard (Warner and Erskine, 1988).

In addition to these longterm trends, plotting the cumulative residual rainfall provides further evidence for cyclical rainfall patterns (Figure 4). Drier than average years have a negative residual value[1], and a series of dry years will generate an increasingly negative trend downwards in the plot. Conversely, a consecutive sequence of wetter than average years (with positive residual values) will trend upwards. In Figure 4 the cumulative residual rainfall plots[2] as a sinusoidal curve over a 100 year period. In particular, it is evident that the first half of the 20th century was drier than average, whilst the second half was wetter

[1] The residual is the difference between the annual rainfall and the longterm mean.

than average. Interestingly, there appears to be a tipping point at which the trend changes rapidly from one regime into another (for example, the tipping point ~1949-1950 when there was a rapid change from drying to increasingly wetter conditions). Generally this tipping point is associated with extreme climatic conditions, such as the widespread, catastrophic floods of 1949-51 and the severe, prolonged droughts of 1896-1913 and 2000-2009. The most recent change apparent in Figure 4 can be attributed to La Niňa, whereby the plot shows increasingly wetter conditions. However, the longer term trend suggests that the region is undergoing an increasingly drier environment. If this is the case, then there may be subtle shifts over time in the up- and down-stream boundaries of stream reaches where fluvial, estuarine or marine processes dominate. In particular, the dominance of marine and estuarine processes should progress in an upstream direction, with potential implications for water quality in Juncus Inlet and Teal Lagoon. This would be additional to the effects of sea level rise associated with climate change.

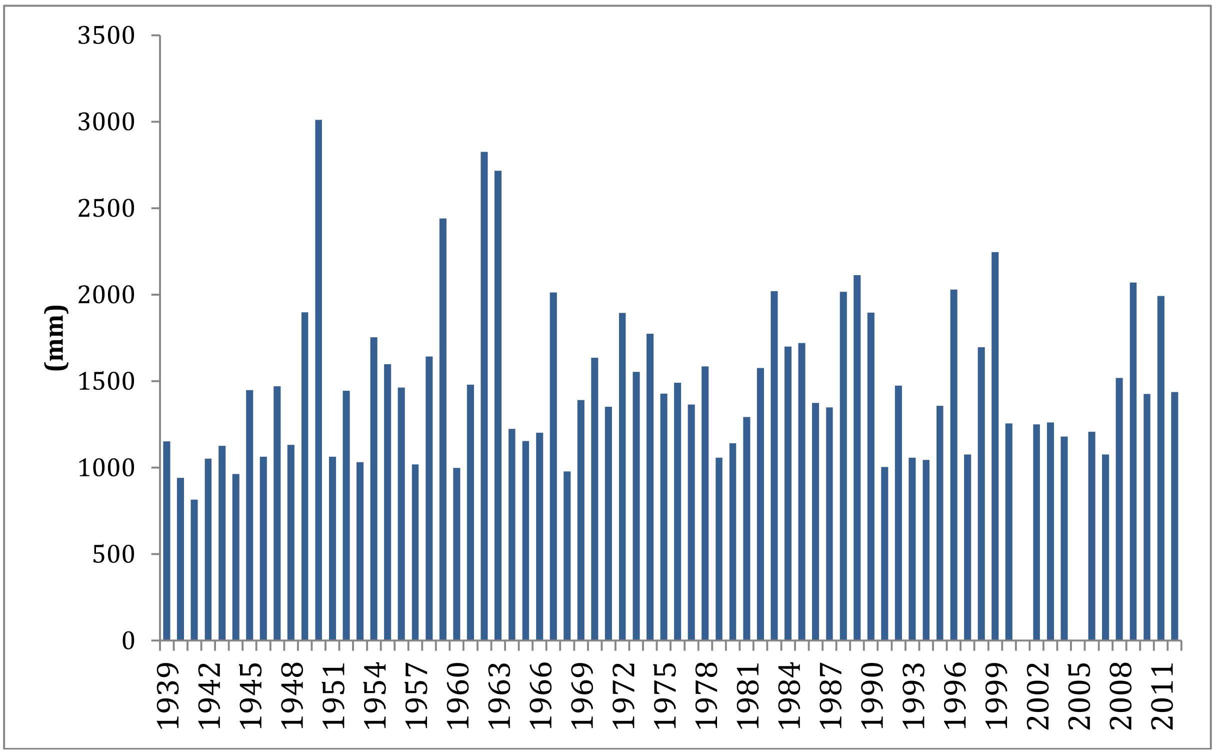

Figure 3 Total annual rainfall at South West Rocks (climate station 59030) (BOM, 2013)

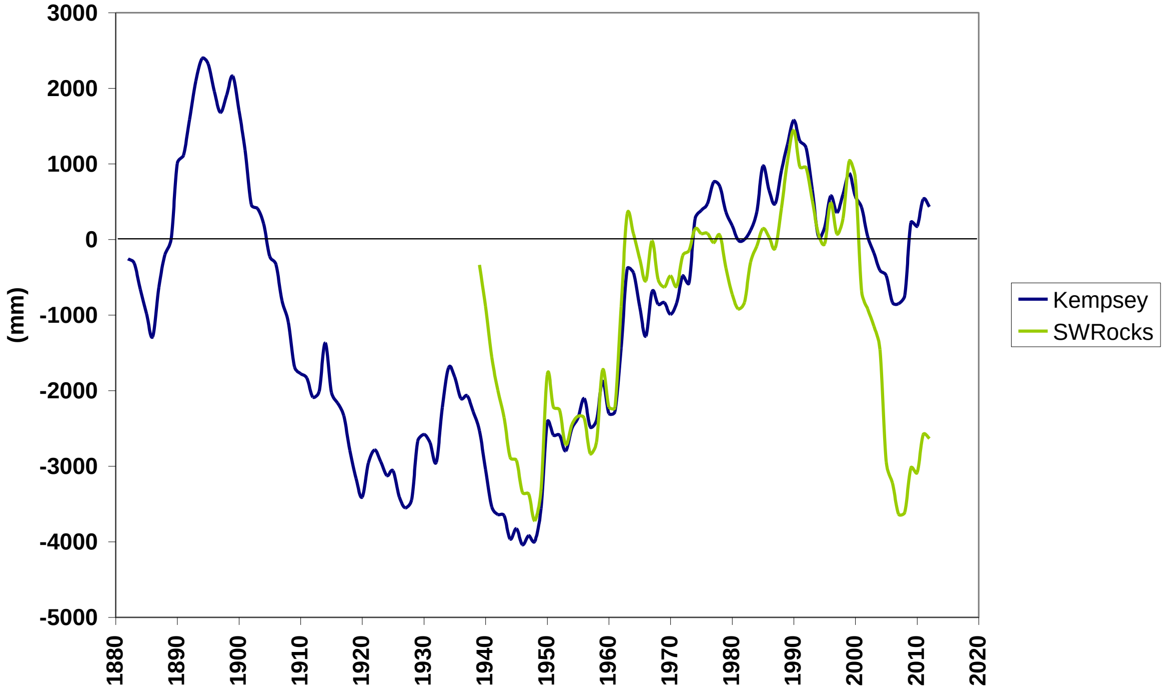

Figure 4 Cumulative residual rainfall for Kempsey (Station 59017) 1880-2012 and South West Rocks (Station 59030)1939-2012. Source data: BoM, 2013.

Soils

Soil landscape mapping of the area has identified two soil types, both of which represent Quaternary depositional sequences. Atkinson (1999) described the Maria River soil type, comprising grey and yellow chromosols of fluvial origin, which can overlie buried Holocene estuarine sediments. These latter materials will contain sulfur and therefore there is the potential for acid sulfate soils to be present. Eddie (2000) identified the Toormina soil type which includes sulfidic intertidal and supratidal hydrosols and arenaceous intertidal hydrosols. Despite not being identified as an acid sulfate soil hotspot priority management area, the Boyters Lane Playing Fields and Wetlands site is included in acid sulfate soils mapping (Figure 5). Acid sulfate soils are a significant environmental issue in coastal environments because of the impact on water quality, ecosystem function and agricultural productivity (White et al, 1997; Cook et al, 2000; Johnston et al, 2009). Acid sulfate soil analysis carried out in 2007 failed to identify the presence of either actual or potential acid sulfate soils (Kempsey Shire Council, 2007b), but this was based on limited sampling. During field studies for this current report, a number of sites along the shoreline of Teal Lagoon were characterized by monosulfidic black ooze (MBO), emitted noxious sulfurous odours (H_2S), and the pH of the overlying water was ~pH5. Soils mapping was outside the scope of this report, however, it is recommended that such mapping should take place prior to adaptive management practices which may impact on the surrounding soil moisture regime.

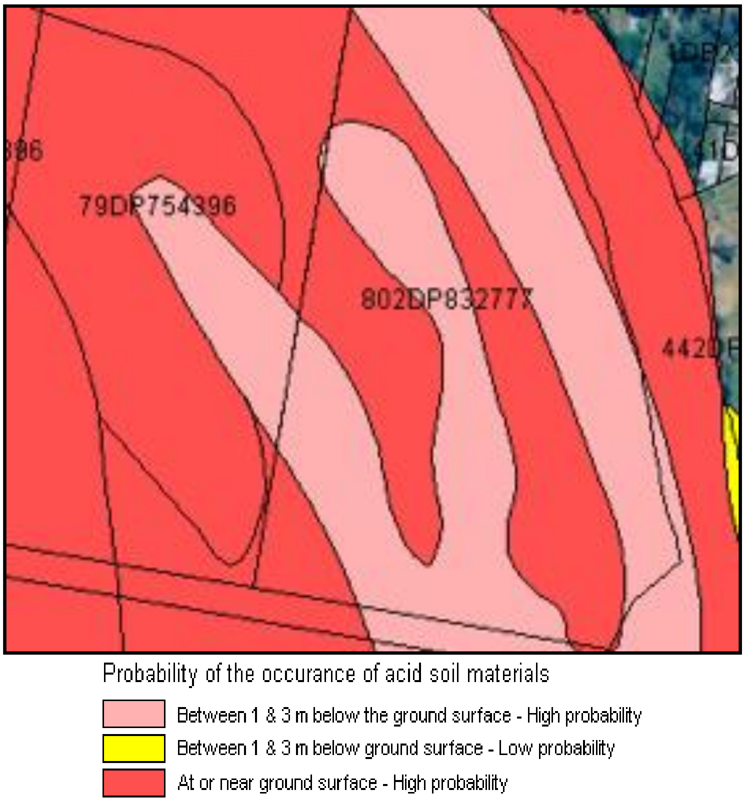

Figure 5: Acid sulfate soil risk map showing the site has high probability of acid sulfate soil material being at or near the ground surface or between one and three metres below the ground surface (Source: Kempsey Shire Council, 2005)

Landuse history

Prior to European settlement, the Lower Macleay was inhabited by the Dunghatti people. By the late 1830s, however, European settlers had followed the earlier explorers and commenced pastoral activities running beef cattle. Cedar cutters had also started to clear the native timber, opening up the country for further agricultural development. In these early stages of development, one of the earliest European records describing the area provides evidence of dense vegetation along the Macleay River:

From Kempsey down to beyond Pelican Island the river was completely shut in by gigantic trees matted and interwoven together almost to their summits by wild vines and creepers and often presenting the appearance of an enormous wall covered from top to bottom with ivy and forming an impenetrable barrier for a man to pass unless he were to hew his way through; it would puzzle a bird to pass through. (Hodgkinson, *in* Kempsey Shire Council, undated)

However, clearing for timber production and agriculture as well as the inter-sowing of native grasses and understory by introduced *paspalum spp* as a pasture crop had profound and long-term impacts on the vegetation. This was consolidated by agricultural development including, from the 1880s, extensive maize cropping, with some plantings of potatoes, pumpkin and citrus (*ibid*). It was during this period of landuse intensification that Drainage Unions were established by farmer collectives to support the draining of land affected by swamps, which were viewed as unproductive wastelands. This practice, once established, became an important process by which swampy land was dried out, flood recession rates increased and the risks associated with acid sulfate soils started to slowly emerge. By the turn of the twentieth century, when there was a downturn in beef cattle and maize, dairy farming was opportunistically established and ultimately became a major rural industry of the area, particularly in terms of butter production, continuing to prosper until deregulation in 2000.

Over the twentieth century, the landscape of the Lower Macleay progressively changed as native vegetation was depleted, and agricultural practices intensified with the subdivision of larger runs into smaller rural properties. Native fauna were also affected, due not only to loss of habitat but also from the practice of killing, for a bounty, wild birds and animals (deemed noxious animals) under the NSW Pastures Protection Act (Macleay Argus, 11 May 1901, *in* Macleay Regional Co-operative Limited, 2005). The net result of these changes is the current, highly modified landscape where the vegetation, biota and hydrology are significantly different to that which existed prior to European settlement.

These past landuse practices are evident on Pelican Island, including the Boyters Lane Playing Fields and Wetlands site within which Teal Lagoon is located. Patches of remnant vegetation exist, as do abandoned drains, floodgates and agricultural infrastructure. At Teal Lagoon, the berm itself, and a dairy ruin on the perimeter of the proposed playing fields, are testament to past pastoral activities. Grazing ceased in 2001.

Kempsey Shire Council purchased the Boyters Lane Playing Fields and Wetlands site in 2002. The intended purpose of that acquisition was to develop playing fields for the South West Rocks community, and for the wetlands to be rehabilitated in order to provide: visual amenity; educational opportunities for local community groups including schools; bird watching opportunities; and, biodiversity conservation. Urban and suburban development of the township of South West Rocks extends as far as the eastern banks of Spencers Creek, immediately adjacent to the Boyters Lane site. The area, zoned as Rural 1 (1a), is therefore increasingly within a peri-urban zone of South West Rocks.

After purchase, the playing fields site was considered unsuitable for the purpose, and development halted. Despite this, Council still has responsibilities to conserve, protect and develop the site's aesthetics and natural environment (Kempsey Shire Council, 2007a). For example, during the consent review process associated with Development Applications for this site, it was discovered in 2004 that coastal saltmarsh existed which was being listed as an Endangered Ecological Community under the *NSW Threatened Species and Conservation Act 1995.* This discovery prompted the commissioning of a Plan of Management (Australian Wetlands, 2005). A direct outcome of this Plan of Management was the construction of (i) plant buffers between the proposed playing fields and Teal Lagoon, and (ii) two stormwater wetlands to receive runoff and nutrients from the playing fields. These constructed freshwater wetlands and the buffer strip are located to the immediate west of Teal Lagoon. In addition, a vegetation rehabilitation program by Kempsey Shire Council has established extensive plantings of trees and understory plants throughout the vicinity of Teal Lagoon in an attempt to improve its amenity and ecological values. The council has marked a walking track around the wetland to create an educational learning facility. This track, initially intended to link the playing fields to the township, will ultimately pass through a range of environments. Figure 6 shows this track, together with the bird hide, constructed in 2006 by South West Rocks Rotary Club, to accommodate growing interest from ornithologists. Over 15,000 rainforest and 'bush-tucker' plants have been introduced since 2006 to regenerate and diversify the environment (pers. comm. Ron Kemsley).

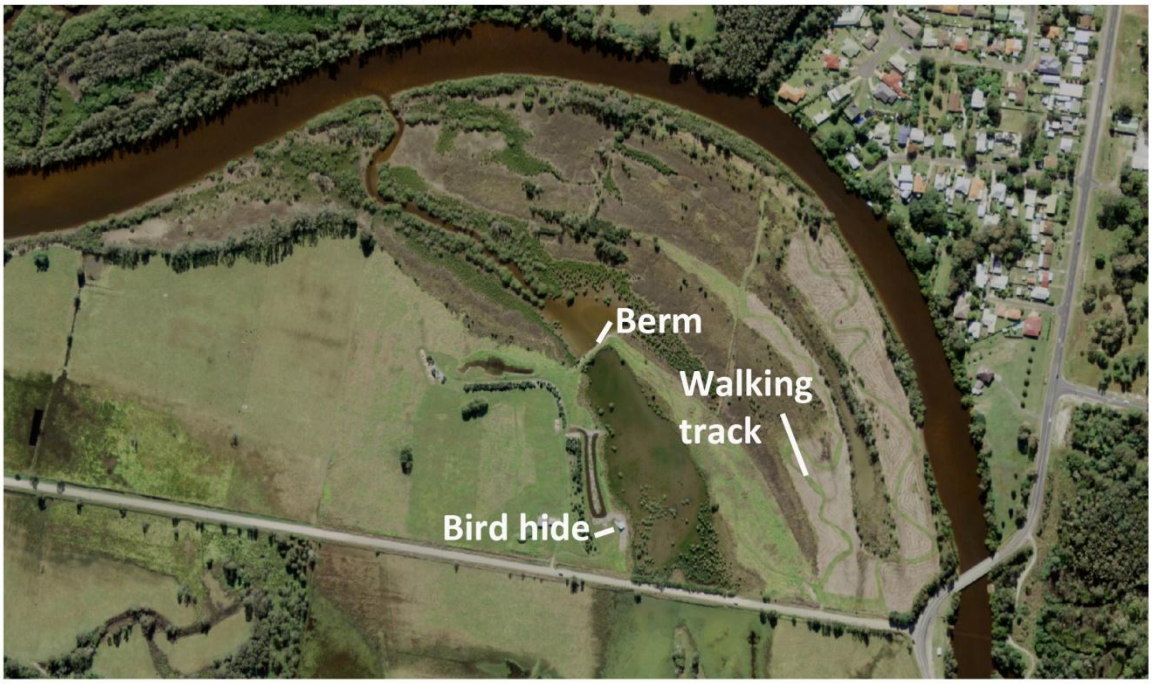

Figure 6 Teal Lagoon showing the locations of the bird hide, berm and walking track. The stream is Spencers Creek which imposes a boundary to the township of South West Rocks.

All of these landuse changes over the last two centuries have generated a highly modified landscape that would be in stark contrast to the natural pre-European settlement environment. Over time, particularly since grazing ceased, some species have opportunistically adapted to the new regime. As a result, new ecological values have been generated due to the role that the lagoon and its surrounds play in providing habitat and refugia.

Legislation and policy settings

Three tiers of legislation and policy are relevant to the management of the Boyters Lane Playing Fields and Wetlands site, and *specifically* to Teal Lagoon. These include:

Commonwealth

Environmental Protection and Biodiversity Conservation Act (EPBC) 1999

New South Wales (State)

Environment Planning and Assessment Act 1979

Local Government Act 1993

Fisheries Management Act 1994

Threatened Species Conservation Act 1995

Rural Fires Act 1997

NSW Wetlands Management Policy

NSW Estuary Management Policy

Local Government

Local Environmental Plan 1987

Purchase of the Boyters Lane site by Kempsey Shire Council in 2002 converted it to public land requiring management specific to its environmental and social uses, as defined by a management plan, under the requirements of the *Local Government Act 1993.* This has been achieved through the *Boyters Lane Playing Fields and Wetlands Plan of Management* completed in 2005 (Australian Wetlands, 2005).

Any future activities or works that take place on the site which impact on the biota and their habitat must comply with the relevant acts, and are the responsibility of Council. For example, works that may impact fish passage or aquatic vegetation, including mangroves, need approval from NSW Fisheries in accordance with the *NSW Fisheries Management Act*.

In addition, works that could affect threatened species require a licence under the *NSW Threatened Species Conservation Act, 1995*, or be deemed an activity under the *Commonwealth EPBC Act, 1999*. However, there may be some uncertainty as to the requirements under the EPBC Act 1999 because the site is highly modified, the ecosystem protection of which is not as clearly defined as natural systems. Finally, the requirements of the *NSW Rural Fires Act, 1997* need to be met by management of the vegetation (ie fuel reduction by slashing grass) in the revegetated area near Teal Lagoon.

Under the *Kempsey Local Environmental Plan 1987*, Rural 1 (a1) zoning of the Boyters Lane site, including Teal Lagoon, places a responsibility on Council to ensure that the land is used for passive recreation, conservation and protection of the environment, and visual amenity. This LEP also requires consent for any works that may impact on groundwater levels in areas associated with acid sulfate soils.

It is noted here that Teal Lagoon is *not* a SEPP14 wetland, although there is potential for a corridor to develop through vegetation rehabilitation of the site linking it to SEPP 14 wetlands on the other side of Spencers Creek and on the western side of Pelican Island (Australian Wetlands, 2005). Aerial connectivity for birds and bats already exists. It has been assumed that the site would ultimately develop *as* a SEPP 14 Wetland (*ibid.*), but this does not necessarily imply that the requirements of that policy would need to be met for Teal Lagoon. It should also be noted that the revegetation of the site will transition it into a 'constructed' forest, and therefore protection under SEPP 26 (littoral rainforests) should not be relevant.

Teal Lagoon

Values and uses

Teal Lagoon has a number of values including:

- **Biodiversity conservation**:
    - endangered ecological communities of coastal saltmarsh, and some limited remnant and self-sown Swamp Oak trees.

- the site is a fish nursery for estuarine species within the broader Macleay River system
- bird surveys have indicated a number of bird species listed on the *NSW Threatened Species Conservation Act 1995* and the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)

- **Recreation**
- **Visual amenity**

Since the development of the Boyters Lane Playing Fields and Wetlands site by Kempsey Shire Council, local and visiting ornithologists have observed birds on Teal Lagoon with the aid of a constructed bird hide that gives a ~180^{o} field of view across the lagoon. The use of the site by bird watchers is considered to be a significant economic benefit to the community of South West Rocks with over 600 visits in 2012 (Ken Shillington, pers. comm., 2013). Interviews with local stakeholders also suggest that the site is visited by recreational fishers collecting estuarine weed for bait.

Discussions were held with State agency staff and local landholders to identify their values of the site[3]. The ecological values included: bird habitat (including migratory species); fish nursery for estuarine species; and habitat for estuarine crustacea and shellfish, including prawns and mudcrabs. One stakeholder suggested that there were broader financial rewards for developing commercial and recreational fishery habitat.

The social values identified by these stakeholders included: recreational bird-watching; visual amenity, and passive recreation (for example, walking along the pathways through the vegetation rehabilitation site). It was noted by some stakeholders that although the recreational value exists, it is not known what the visitation rates are, and who, apart from bird watchers, uses the site. There appeared to be some potential conflicts based on the social aspects of the site: for example, some visitors have walked beyond the perimeters of

[3] Discussions were held with staff from a number of agencies including Kempsey Shire Council, the NSW Departments of Primary Industry (DPI), Environment and Heritage (DE&H), and Northern Rivers CMA, members of local Rotary Clubs, landholders in the locality of Pelican Island, and members of the broader community including bird watchers. Names and details have been withheld to ensure anonymity.

Council land onto private land without seeking permission. This has prompted some stakeholders to recommend clearer signage of the site to minimise this risk. Overall, there was very strong support for the site, and the general belief that the site should either (i) return to its natural state as a marine-dominated estuarine wetland; or (ii) continue to be maintained as a 'freshwater' system to optimise its usefulness for bird watching. As one stakeholder noted, this latter approach requires management of a highly modified system that is transitioning to a functional wetland, but this needs to be undertaken whilst accommodating social objectives. For it to be managed sustainably it would need to be manipulated to retain its recreational values: and in this sense, it would ultimately represent a 'constructed wetland.' Overall, and significantly, all stakeholders that were contacted held the view that the site had an inherent value regardless of how it might be managed in the future.

All stakeholders interviewed were aware of the evolving nature of the site, and the effort being made by Council to both re-establish vegetation and support the needs of the broader community. Some stakeholders expressed concerns about the changing characteristics of the site, and the possible implications for bird-watching activities. However, most stakeholders saw temporal change as an inherent feature of the broader landscape, particularly with reference to climate change impacts.

Vegetation

The spatial distribution of vegetation in the vicinity of Teal Lagoon is controlled by elevation and tidal waters. As elevation decreases and tidal influence increases the vegetation grades from grassland to saltmarsh to mangroves. Coastal saltmarsh is the assemblage of succulents, sedges and grasses which occur in the intertidal zones on the shores of estuaries and lagoons. A full description including typical species can be found in Adam et al. (1988). Saltmarshes are threatened across the world by infilling, changed tidal flow, exotic species, climate change and human disturbance (Adam, 2002; NSW Department of Environment and Heritage, 2012). Coastal saltmarsh is an endangered ecological community under the *Threatened Species Conservation Act 1995* (NSW) and is at risk of becoming extinct unless circumstances improve (NSW Department of Environment and Heritage, 2012). Saltmarsh within the wider Macleay was found to be expanding in 2010 (Aquatic Science and Management (2010), and within the Boyters Lane site, saltmarsh has been a dominant feature, expanding between 2004 and 2008 (Darkheart Eco-consultancy, 2008). In this time however, the vulnerable species *Maundia triglochinoides* disappeared from the site. This freshwater plant has been listed in the *Threatened Species Conservation Act 1995* (NSW) since it was observed at the site by Sandpiper Environmental (2005). Increasing salinity at the site and extended dry periods are thought to have made the site unsuitable for freshwater plants such as *M. triglochinoides*.

The grey mangrove (*Avicenna marina*), is a dominant species on the site, and is protected under NSW Fisheries Legislation so that any modifications to the site which may impact this species must be licensed. In 2004, it was noted that mangroves were increasing in the lagoon due to the removal of cattle. They reached a maximum height of 4.5 m and cover was less than 10%, with most plants located at the southern end (ie, closest to Boyters Lane)(Sandpiper Environmental, 2005; Walker et al., 2004). Seedlings up to 1 m were noted around the edges of the lagoon, again with more at the southern end (*Sandpiper Environmental, 2005*). The majority of the lagoon was open water with a narrow strip of littoral habitat dominated by *Juncus spp*. and *Sporobolus spp*. (*ibid.*). By 2008, the windbreak planting had become established and reached a height of five to six m (Darkheart Eco-consultancy, 2008a). However, the Council's attempts to reduce the area of mangroves since 2006 were noted to be unsuccessful (*ibid.*).

For this report, vegetation at Teal Lagoon has been assessed to establish:

(i) changes over time, which can be related to landuse practices and the influence of tidal water ingress; and

(ii) current distribution of the key vegetation communities

This information will be used later in the report to support recommendations for specific management options of the berm.

Vegetation changes over time

Two approaches were used to establish how vegetation has changed over time. First, aerial photography of the study area was examined to assess the changes in vegetation communities. The shadow, tone, colour, height and texture of vegetation were used to categorise the dominant vegetation communities. Images from January 1964, October 2001, September 2003, November 2010 and an unknown month in 2009 were used. All images except those from September 2003 and November 2010 were obtained from Kempsey Shire Council. The remaining images were downloaded from Google Earth (2012). The 2010 image was used to ground truth the interpretations during field work in September, 2012.

The second approach compared data gathered during field work in 2012 with data derived from the literature (Walker et al. (2004); Sandpiper Environmental (2005); Darkheart Eco-consultancy (2008a) and Gardner et al. (2011)). During fieldwork, the borders of vegetative communities were mapped with the aid of a Navman etrex GPS and 2010 aerial photography. Species within each community were identified using Fairley and Moore (2010), Rose and Rose (2012), and Rose et al. (2011). Additionally, comparisons were made between photographs taken by the council in 2003 and field observations of the current vegetation.

Figure 7 demonstrates the spatio-temporal changes in vegetation communities over the period 1964-2010. Grazing and the construction of the berm in 1965 is associated with a decrease in the area of mangroves. Much of this was replaced with saltmarsh, particularly in the north-east corner, towards Dotterel Inlet. The area of saltmarsh in the south east of the lagoon also decreased under grazing pressure and was replaced with pasture.

Restoration work by Kempsey Shire Council is evident in the post 2002 aerial imagery. However, it is also evident that mangroves started to recolonise the along the edges of the lagoon by September 2003. They also started to extend into (i) the open water of the lagoon,(ii) the saltmarsh bounding the lagoon both upstream and downstream of the berm. These mangroves provide habitat for juvenile fish, invertebrates and birds.

The impacts of the Council's remediation and rehabilitation efforts are clear in the time-slice for 2009, in Figure 7d. As noted earlier, the windbreak of *Casuarina glauca* and the constructed wetland were built in 2006 to protect the lagoon from impacts of runoff generated by the proposed playing field. By 2009, the mangroves have filled in the saltmarsh and mudflats in the south east of the lagoon. However, the total area of saltmarsh also increased. This is particularly evident on the north east and western shores where saltmarsh progressed inland and widened. This generated 5-10m belts of saltmarsh along the western shore of the lagoon.

Between 2009 and 2010 there were only marginal changes in the distribution of mangroves, with new saplings progressing inwards and along the remaining edges of the lagoon. The mangroves also appear to be recolonising some of the saltmarsh which had regenerated, reducing its extent. This is particularly evident in the south east of the lagoon. The saltmarsh however, is continuing to expand inland, returning to its distribution prior to the construction of the berm. The windbreak thickened substantially between 2009 and 2010 whilst the artificial wetland matured, with grassland filling in the cleared gaps. Additionally, saltmarsh appears to have become more well-established in the north east corner of the map, with a previously clearly defined track merging into the landscape.

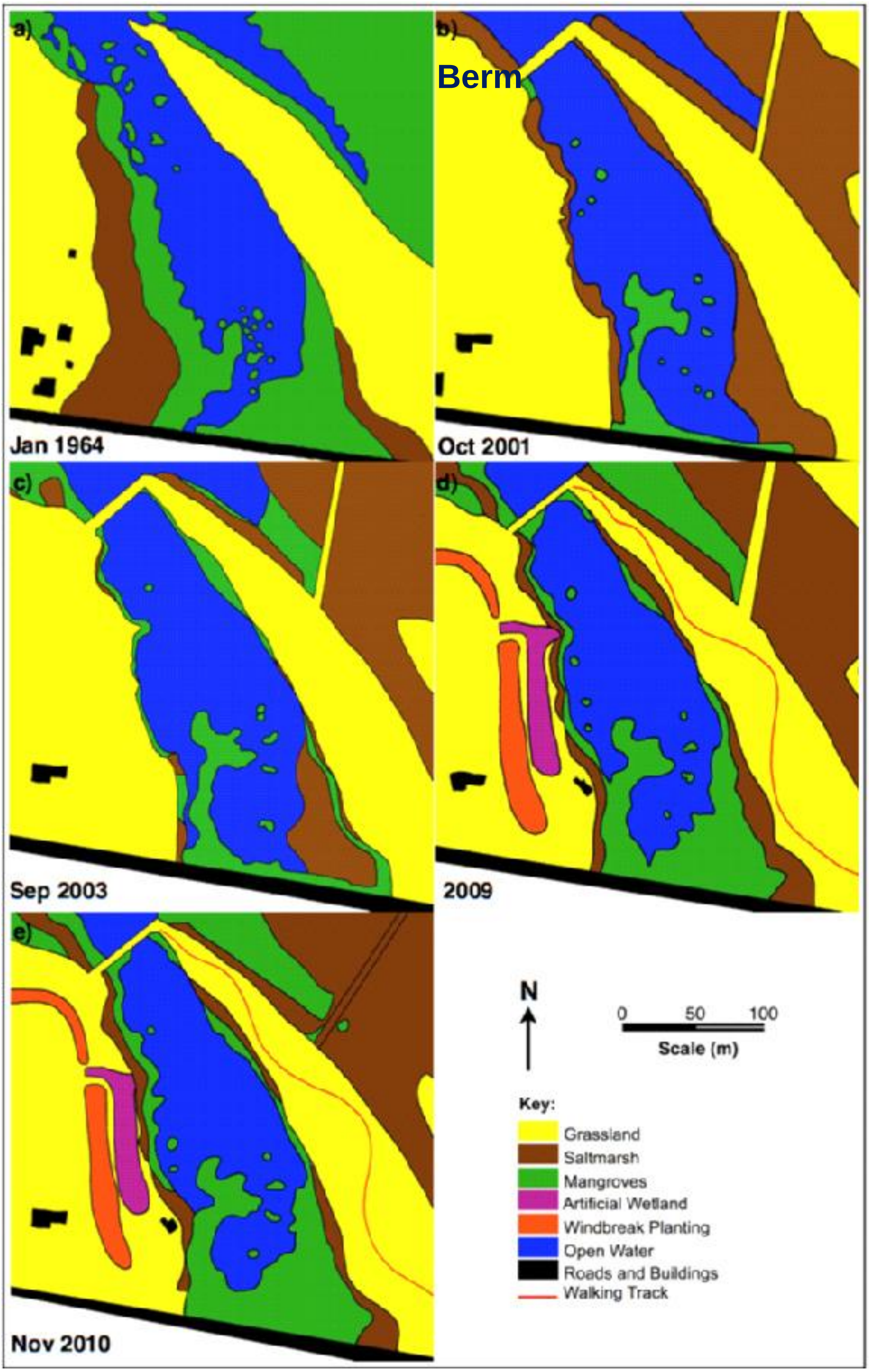

Figure 7 Spatio-temporal changes to vegetation communities of Teal lagoon 1964-2010

Current vegetation distribution

The distribution of vegetation communities in 2012 is shown in Figure 8. Since 2010, saltmarsh has increased along the lagoon's western shore, creating a continuous boundary between the grassland and mangroves, and surrounding the bird hide and artificial wetland. By comparing the 1964 and 2012 imagery, it is evident that the saltmarsh is reverting to its earlier distribution pattern. However, it is also clear that the artificial wetland, windbreak and bird hide represent constraints on the saltmarsh recolonising those specific areas. Since 2010, the area covered by mangroves has also expanded, with new saplings spreading towards the lagoon.

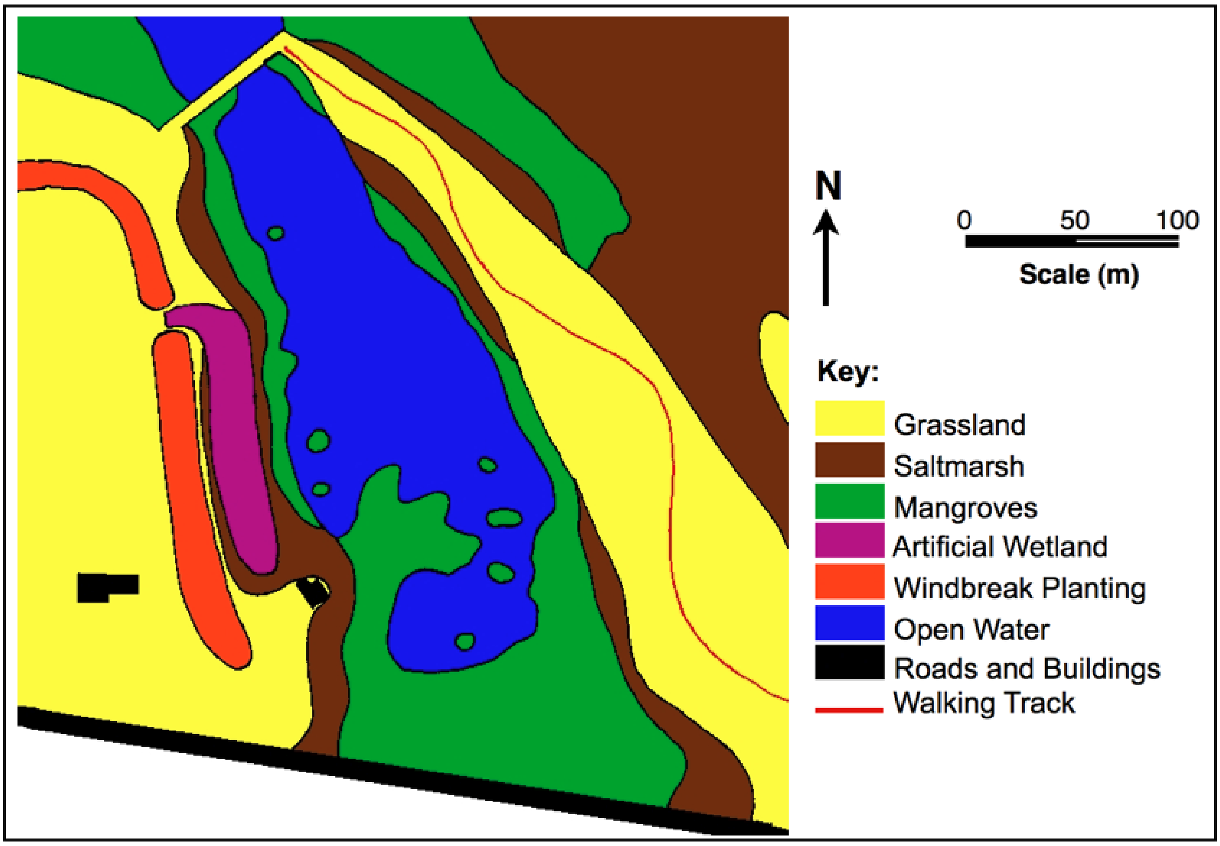

Figure 8: Vegetation community distribution at Teal Lagoon as of September, 2012.

Views of Juncus Inlet downstream of the berm and Teal Lagoon upstream of the berm, provide evidence of how dramatically the local environment has changed with the removal of grazing in 2001 (Figures 9 and 10). The mapping shown in Figures 7 and 8 provide evidence for the lateral spread of mangroves, but Figures 9 and 10 demonstrate the significant change in mangrove height since 2003. The many saplings visible in 2003 have grown to heights of 2-3m by 2012, and there is evidence to suggest that the trees are more robust with denser foliage. The lines of sight in the earlier images are much more open, with houses visible in the background of Figure 10. Sandpiper Environmental (2005) noted that some of the bird species recorded for the lagoon require open lines of sight for foraging. The growth of mangroves may therefore be reducing the habitability of the lagoon for species such as the Black-Necked Stork. Conversely, the mangroves now screen the lagoon, potentially reducing impacts from the houses and road. In Figure 10, dead mangrove trunks can be seen in the lagoon. The trunks of 84 mangroves were counted in the middle of Teal Lagoon and are indicative of the dieback that occurred when the berm was constructed.

Figure 9: Views of Juncus Inlet from the berm facing north-west in March 2003 (top) and September 2012 (bottom). The growth and spread of mangroves is evident (Sources: Kempsey Shire Council, 2003; Alice Woodforth, 15/11/2012).

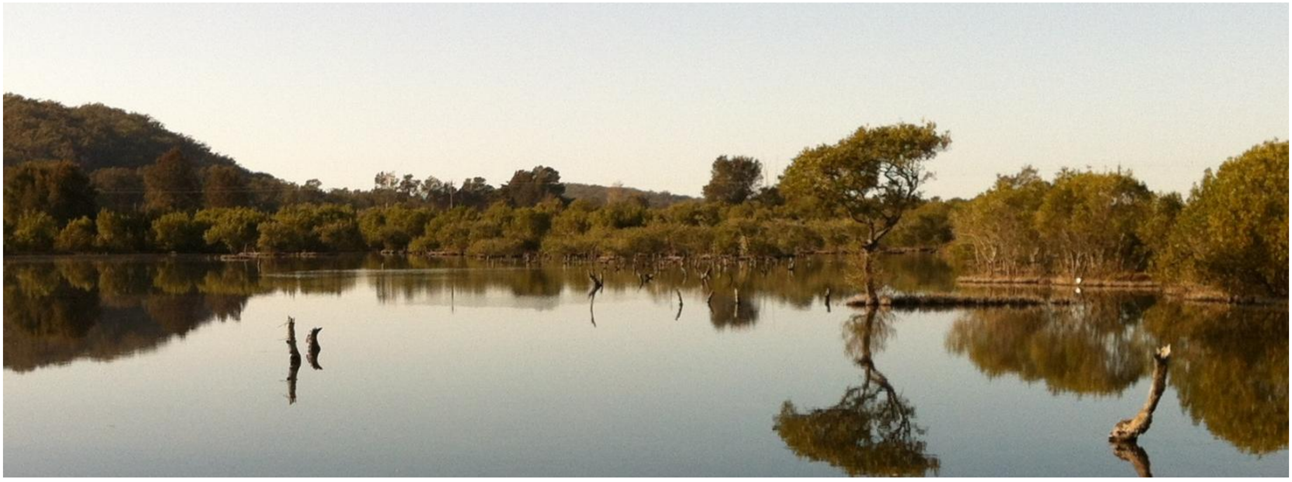

Figure 10: View from the berm towards the south east of the lagoon in March 2003 and September 2012. Note that the 2003 image was taken from slightly further west (Sources: Kempsey Shire Council, 2003; Alice Woodforth, 2012).

Further vegetation changes can be seen in Figure 11. These images, taken from the eastern corner of the berm in 2003 and 2012 demonstrate the increasingly sheltered position of the lagoon. The defoliated, twiggy mangroves have grown with new saplings colonising the lagoon edges in each location (Figures 11a, b and c. In Figure 11b the most striking difference is the apparent increase in species diversity over the nine years, with many more species present in the saltmarsh in 2012. Figure 11c shows extensive colonisation and growth of mangroves along the shoreline of Juncus Inlet, and some evidence of degradation of the berm.

Figure 11: Photos taken from the eastern corner of the berm in March 2003 (left column) and September 2012 (right column) showing changes in vegetation. a) South facing, showing the western shore of the lagoon. b) South-east facing, showing the eastern shore of the lagoon. c) South-west facing, showing the western shore of Juncus Inlet (Sources: Kempsey Shire Council, 2003; Alice Woodforth, 2012).

Vegetation communities

A list of all flora species identified at Teal Lagoon and its immediate surrounds during field work in September, 2012 is provided in Table 1. The most diverse communities were the saltmarsh and grassland (14 species each), with the saltmarsh having the most native species. Seven species were identified in the artificial wetland, with only one of these an exotic species. The lagoon was dominated by the grey mangrove (*Avicennia marina*), with green nori (*Ulva spp*.) and a red algae (*Rhodophyta spp*.) in the water.

The green nori observed in the lagoon is often indicative of high levels of nitrogen (Sainty and Jacobs, 1981). The source of nutrients is assumed to be roosting birds. At the southern end of the lagoon, significant amounts of red algae were draped and decomposing over the mangrove pneumatophores and in pools of water. In addition there were abundant biofilms over the water surface. These algae and biofilms were not present near the berm.

Species that were present in 2004 but were not observed during this study are listed in Table 2. These data suggest that 13 species, including some exotic species, are now absent from the site. As noted in Darkheart Eco-consultancy (2008a), the freshwater species *Maundia triglochinoides* was not present. Whilst it was thought that the plant may re-germinate after rains, there is no field evidence to that this has occurred. Given the brackish nature of the lagoon water, which will be described in a later section, it is not expected that this species or other freshwater species will occur at the site, except under conditions of prolonged freshwater inundation after major flooding.

Table 1 Flora observed at Teal Lagoon September, 2012. The dominant species in each environment are identified in bold. * Denotes a noxious weed species within NSW (no control orders within Kempsey Shire Council) (NSW Department of Premier and Cabinet, 2011).

	Scientific Name	Common Name
Saltmarsh	*Callistemon salignus*	Willow Leaved Bottlebrush
	Calochlaena dubia	Common Ground Fern
	Carex appressa	Tall Sedge
	Casuarina glauca	Swamp She-Oak
	Epilobium billardierianun	Variable Willow Herb
	*Ipomea indica**	Morning Glory*
	Juncus krausii subsp. australiensis	Sea Rush
	Paspalum distichum	Knotgrass
	Paspalum urvillei	Giant Paspalum
	Phragmites australis	Common Reed
	Ranunculus inundatus	River Buttercup
	Sporobolus virginicus	Saltwater Couch
	*Tradescantia albiflora**	Wandering Jew*
	Viola banksii	Native Violet
Grassland	*Calochlaena dubia*	Common Ground Fern
	Cenchrus clandestinus	Kikuyu Grass
	*Cirsium vulgare**	Spear Thistle*
	Cynodon dactylon	Common Couch
	*Ipomea indica**	Morning Glory*
	Paspalum dilatatum	Common Paspalum
	*Rubus ulmifolius**	Blackberry*
	*Senecio madagascariensis**	Fireweed*
	*Taraxacum officinale**	Dandelion*
	*Tradescantia albiflora**	Wandering Jew*
	Trifolium fragiferum	Strawberry Clover
	Trifolium michelianum	Balansa Clover
	Trifolium repens	White Clover
	Viola banksii	Native Violet
Lagoon	*Avicennia marina*	Grey Mangrove
	Ulva spp.	Green Nori
	Rhodophyta spp. (?)	Red Algae
Artificial Wetland	*Azolla filiculoides*	Pacific Azolla
	Calochlaena dubia	Common Ground Fern
	Carex appressa	Tall Sedge
	Gahnia clarkei	Tall Saw-Sedge
	*Ipomea indica**	Morning Glory*
	Juncus kraussii subsp. australiensis	Sea Rush
	Typha orientalis	Cumbungi/Bullrush

Table 2: vegetation previously observed at Boyters Lane, but not present in the vicinity of Teal Lagoon in 2012. * Denotes exotic species.

Walker et al. (2004)	Sandpiper Environmental (2005)
Cotula coronopifolia - Water Buttons *Cynodon incompletes* - Couch *Juncus pallidus* - Pale Rush *Lythrum salicaria* - Purple Loosestrife *Paspalidium spp.*	*Baccharis halimifolia* - Groundsel Bush* *Cinnamomum camphora* - Camphor Laurel* *Conyza spp.* - Fleabane* *Juncus usitatus* - Common Rush *Lantana camara* - Pink Lantana* *Maundia triglochinoides* *Schoenoplectus validus* - River Club-Rush *Triglochin procerum* - Water Ribbons *Verbena spp*. - Purple Top*

Distinct boundaries generally exist between the vegetation communities, with little ecotone present (Figure 12). However, the eastern side of the lagoon has less distinct community boundaries, with dense stands of the common reed (*Phragmites australis*) grading into the grassland. This side of the lagoon also has more weed species at a higher density compared to the western side of the lagoon. Some of the hundreds of coastal rainforest flora which have been planted are shown in Figure 12d. These were not included on the vegetation map as they are not yet considered to be established, are in varying stages of maturity and more are being planted. The plantings stretch along the majority of the eastern isle of grassland. Full list of species planted can be seen in Kempsey Shire Council (2006; 2007 and 2008).

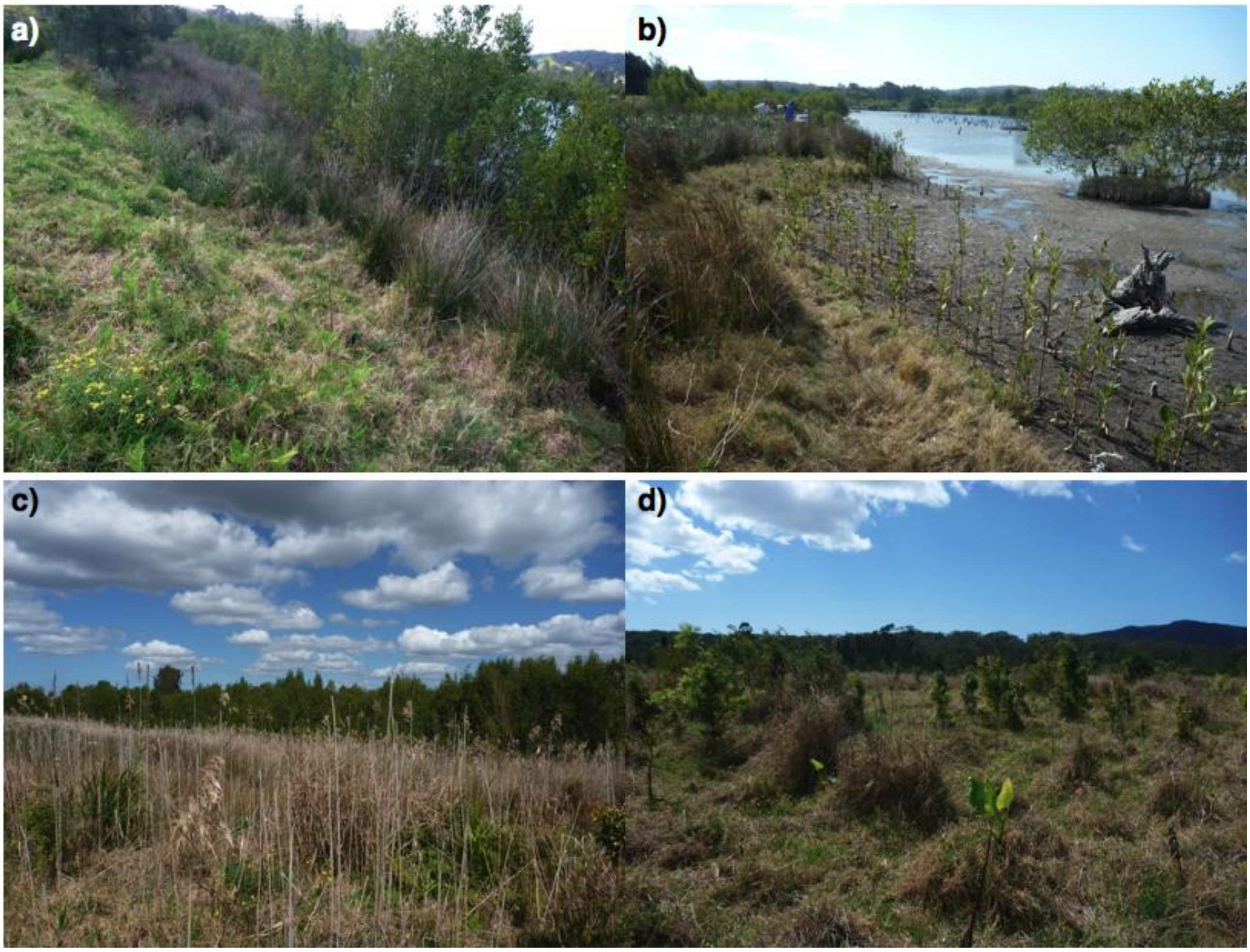

Figure 12: a) The change from grasslands to saltmarsh to mangroves is visible with decreasing elevation. b) Mangrove seedlings are colonising the lagoon's mudflats. c) Dense stands of *Phragmites australis* on the south east of the lagoon. d) Lowland rainforest plantings are being planted in the eastern grassland area (Source: Alice Woodforth, 2012).

During this vegetation survey, a distinct difference in vegetation growth inside and outside the lagoon was evident. Within the northern end of the lagoon, the mangrove saplings were around 60 cm high whilst the trees were between two and three metres. In comparison, the mangroves in Juncus Inlet reached a height of four metres and the saplings were around 70 cm. Assuming the young generation of mangrove saplings are pene-contemporaneous, those outside the lagoon have grown faster, indicating that the environment outside the lagoon is more conducive to mangrove growth. Inside the lagoon, the mangrove pneumatophores ranged in size from around 10 cm close to shore up to 35 cm furthest from shore. By contrast, in Juncus Inlet, the pneumatophores were a constant 25-30 cm tall. This difference could be the result of either the mangroves spreading preferentially inland in the lagoon and the pneumatophores being less mature, or due to varying inundation levels. As

Figure 13 shows, only the pneumatophores in the lagoon remain uncovered by water at high tide. Since the pneumatophores are critical in oxygen uptake for the plants root systems, and have implications for redox conditions in the rhizosphere, this difference will have implications for soil chemistry in the intertidal zone.

Figure 13: Photos taken at the same time, during high tide, showing mangrove pneumatophores on either side of the berm. It can be seen that the pneumatophores on the inlet side (left image) are inundated whilst those on the lagoon side (right image) are uncovered (Source: Alice Woodforth, 2012).

Fauna

Fauna surveys have been undertaken at this site for a number of previous reports (Walker et al, 2004; Sandpiper, 2005; Darkheart Eco-consultancy, 2008; Gardner et al, 2011), and have not been repeated here. However field observations were made. to elucidate the contrasting ecology of Juncus Inlet, Teal Lagoon and the freshwater wetland to the immediate south of Boyters Lane, and particularly to consider the role of mangroves in providing habitat or refugia for birds.

The pipes that hydrologically link Juncus Inlet and Teal Lagoon are used by some estuarine species to access the lagoon. As an example, an eel (*Anguilla spp*.) was observed in Teal lagoon immediately next to one of the berm pipes on an evening incoming tide during field work for this study. It was assumed by the direction of movement and behavior that the eel had just entered the lagoon via the pipe. Additionally, juvenile fish were seen around both ends of the pipe, particularly during incoming tides. Larger fish, however, were only observed in Juncus Inlet. During low tide, many crabs emerged on the mud flats in Juncus Inlet to feed. By contrast, due to limited variation in water level in Teal Lagoon, crabs were only seen to emerge from the perimeters of the lagoon and in the vicinity of the berm at the evening incoming tide.

Birds were not observed foraging in the lagoon, whereas a number of species of birds[4] frequented the freshwater wetland further to the south throughout the day. However, overall, the contrasts in bird presence/absence and abundance between Teal lagoon, Juncus Inlet and the freshwater wetland (Figure 14), were consistent with the findings of Gardner et al, 2011. In that study, the number of species and individuals recorded at the three sites over a four day period were recorded, the results of which are presented here to support the assertion that the three sites differ significantly in use and visitation by birds (Figures 15 and 16).

Figure 14: The freshwater wetland on the southern side of Boyters Lane. Note birds on the water body in the mid distance (Source: Alice Woodforth, 2012).

[4] Including ducks, spoonbills, oyster catchers, moorhens and common ibis.

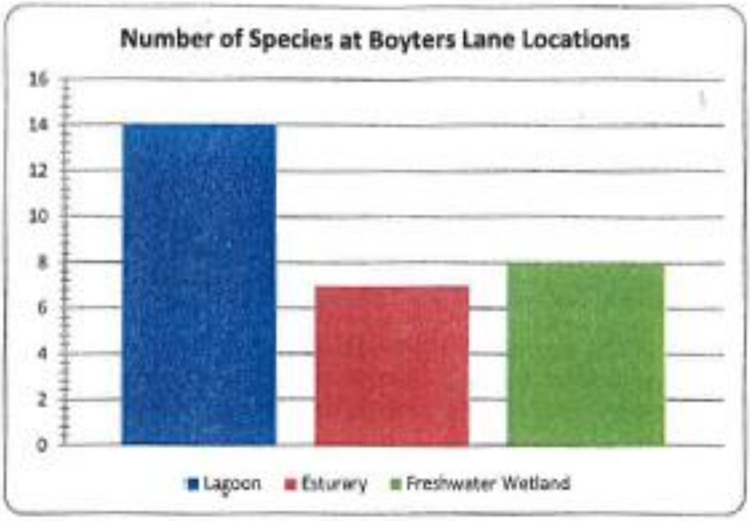

Figure 15 Comparison of species richness across Juncus Inlet, Teal Lagoon and the freshwater wetland on Boyters Lane (source: Gardner et al, 2011)

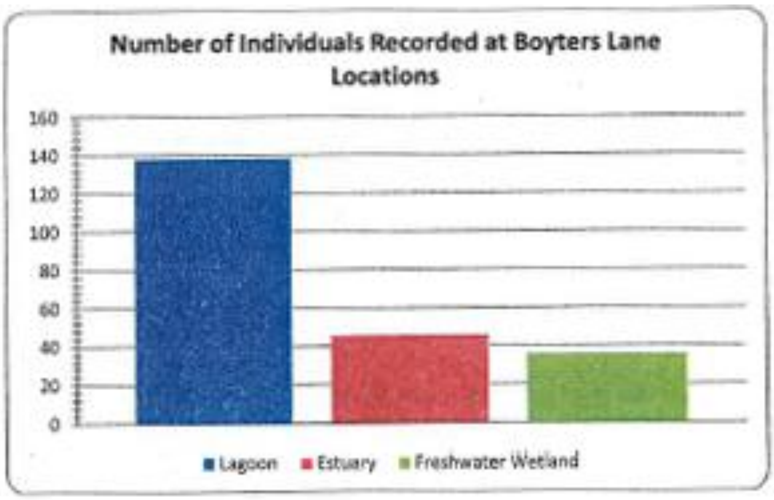

Figure 16 Comparison of the total number of birds counted at Juncus Inlet, Teal Lagoon and the freshwater wetland on Boyters Lane (source: Gardner et al, 2011).

Large numbers of birds roosted in the dense mangroves in the south of the lagoon during the evening (Figure 17). It is assumed that birds roosting at this site will move between the lagoon and other wetlands and estuaries during the day. It is notable that birds only roosted on the trees separated from the shore, protecting them from predators. In this sense, the mangroves that have colonized the water body of the lagoon, rather than the peripheries, provide important refugia.

The presence of birds is associated with nutrient inputs to the lagoon. Droppings and feathers are generally present on the water surface due to wind action transporting the material from the roosting sites across the water body (Figure 18). These will build up, encouraging algae to grow and reducing water quality. Despite the dense stands of mangrove in Juncus Inlet, similar roosting behavior of birds was not observed in this part of the system.

Figure 17: Birds coming in to roost on the mangroves in the lagoon in the early evening. Birds only settled on those trees isolated from the shore, protecting them from predators (Source: Alice Woodforth, 2012)

Figure 18: Bird feathers, droppings, algae and biofilm visible on the surface of the lagoon (Source: Alice Woodforth, 2012).

Geomorphology

Teal Lagoon is situated within Pleistocene and Holocene sediments of the lower Macleay floodplain (Kempsey Shire Council, 2005). The sedimentology of the area will be highly complex due to the depositional and erosional history associated with sea level changes, the progradation of marine derived sediments, the evolution of the estuary from an embayment to a delta, and the migration of the Macleay river both laterally and down valley. Previous reports suggest that the sediments at Teal Lagoon consist of gravel beds overlain by silt and clay (WMA, 2009;Darkheart Ec0-consultancy, 2000a). This would reflect fluvially dominated processes including: (i) deposition of coarse stream bed material and their abandonment as the stream has meandered laterally across the valley; and/or (ii) deposition of fluvial deltaic sediments across sharp flow velocity gradients. The overlying clays and silts would be associated with overbank deposition during large flood events. In the absence of detailed stratigraphy of deep bores in the local area, it must be assumed that these fluvial sequences overlie marine sediments associated with the last sea level high. Sea level transgression since the Holocene has been accompanied by progressive infilling of estuarine reaches creating shallow estuarine (brackish to saline) lagoons, freshwater swamps and broad, low-elevation alluvial plains that characterise the Lower Macleay valley. Pelican Island, on which Teal lagoon is located, is part of that floodplain and provides ample evidence of a river system that migrated both laterally and down valley, depositing and reworking sedimentary sequences. Teal Lagoon itself represents a relict meander scroll and its associated (relatively elevated) levee bank. Given the position and morphology of the sequence of meander scrolls at this location, Teal Lagoon is the oldest scroll with a younging end of the other scrolls towards Spencers Creek. The location of the mouth of Juncus Inlet is at odds with the overall orientation of the Juncus-Inlet-Teal lagoon scroll, and it is assumed that this is due to some anthropogenic activity in the past.

Transects of the longitudinal and cross sectional profiles of the lagoon (Figures 19-22) demonstrate that this is a shallow water body, with a gentle bed gradient sloping in a downstream direction with evidence of a relict levee to the east.

Figure 19 Location of transects for mapping longitudinal and cross sectional profiles.

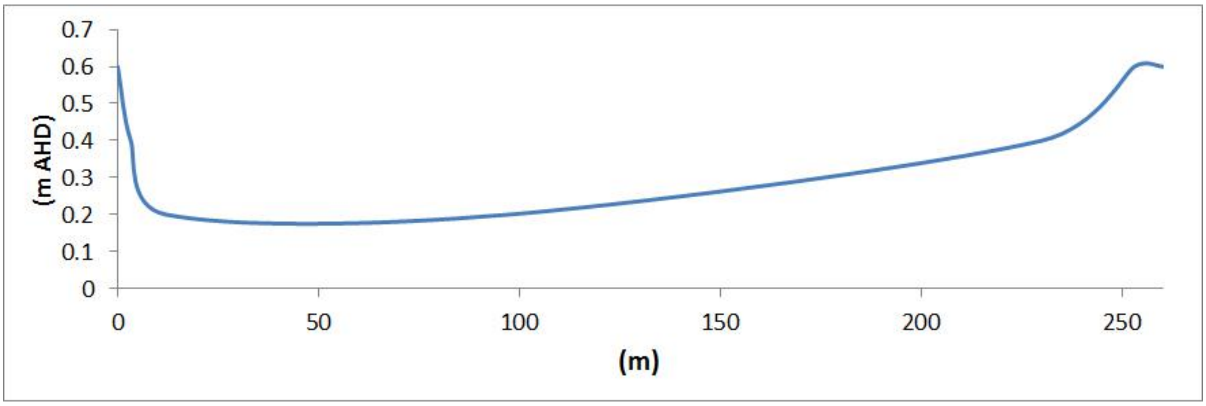

Figure 20 Longitudinal profile of Teal Lagoon bed from the berm (0m) to the fenceline (260m) on Boyters Lane

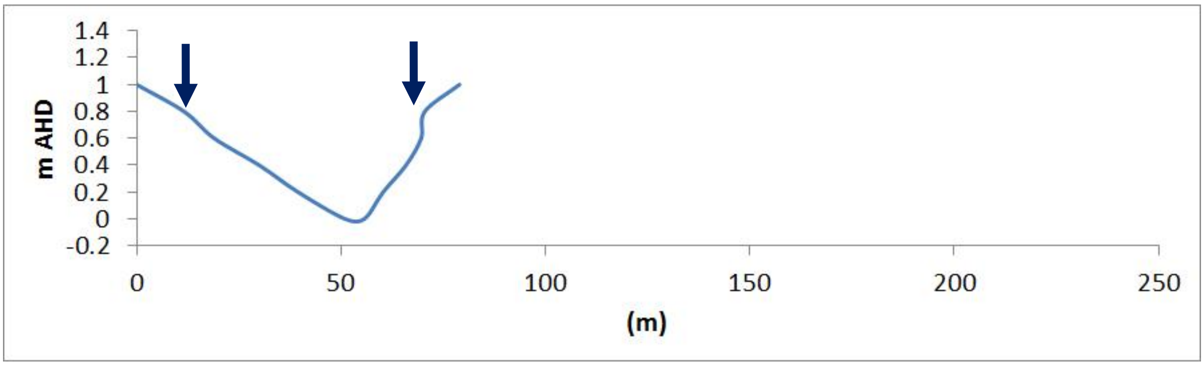

Figure 21 West-east cross sectional profile of Teal lagoon bed 5m upstream of the berm, looking downstream. Note that the location of the left and right banks, indicated with arrows, coincides with a clear change in gradient

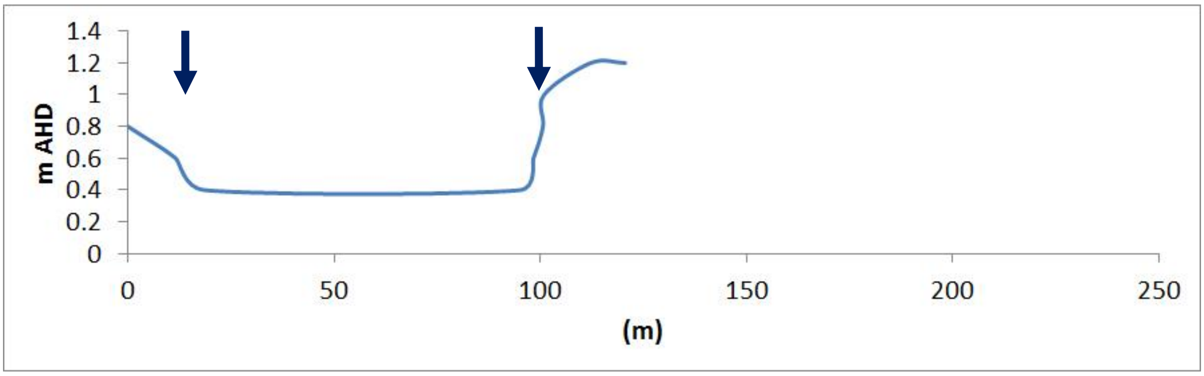

Figure 22 West-east cross sectional profile of Teal Lagoon bed at the bird hide, looking downstream. Note that the location of the left and right banks, indicated with arrows, coincides with a clear change in gradient

The gradient of the longitudinal profile suggests aggradation in the upper reaches of the lagoon (that is, the southern end adjacent to Boyters Lane). This will be a function of the lower flow energy in this part of the system. Trapping of sediment and organic matter by mangroves around their roots and pneumataphores could also be a contributory factor. However, the lack of supporting evidence in the cross sectional transects suggests that such a process is reliant on longer term and very dense mangrove colonisation. Nevertheless, it would be expected that continued colonisation of the water body by mangroves will be associated with accelerated rates of aggradation relative to those periods in which they were not present. A relatively steep slope grading up towards the berm could relate to sediment being trapped by the structure during ebb tides or flood recession, but it is also likely to be a function of deterioration of the berm.

Water quality and hydrodynamics

Water quality was assessed to establish a number of salient characteristics of this site. Firstly, the nutrient status of Teal Lagoon, relative to the freshwater wetland to the south and Juncus Inlet, was analysed to determine the possible relationship with ecological uses of the waterbodies. Secondly, analysis of electrical conductivity, water density and dissolved oxygen provided the basis for interpreting the salient controls on water quality. This information has then been used to understand the significance of the berm in defining the hydrodynamics of the lagoon

Water quality was measured *in situ* using a Thermo-Orion multi-meter for electrical conductivity (EC), dissolved oxygen, temperature and pH, and an Anton-Paar DMA 35 portable density meter for water density and temperature. Samples were also taken at the same locations as the *in situ* measurements, filtered and analysed for phosphorus (P), using a Hach spectrophotometer. The sites at which sampling occurred are shown in Figure 23, and the data are presented in Table 3.

While P is an essential nutrient for plants, excessive amounts can stimulate nuisance growth of aquatic plants, with consequent impacts on water quality and ecological function. Low energy estuarine lagoons have limited flushing capabilities and are therefore at risk of the build-up of nutrients. The Australian and New Zealand Water Quality Guidelines (ANZECC, 2000) recommend that concentrations of phosphorus (as Filterable Reactive P) in NSW estuarine systems should be <5µg/L. Values measured in Teal Lagoon ranged from 30-1560µg/L. The highest values occurred at the berm, in the constructed wetlands, and in the areas where birds roost. These are all areas characterized by: high bird activity; the accumulation of bird debris and waste due to wind action; or, low energy conditions. The lowest concentrations occurred nearest Boyters Lane, and were comparable to the value in the freshwater wetland immediately to the south of the lane. It should be noted, however, that P values for Juncus Inlet were also very high indicating that this whole system is nutrient-enriched.

Dissolved Oxygen (DO) measured at the site proved problematic. Constant clogging of the probe by biofilms generated erroneous values and ultimate failure of the instrument. For the purposes of this study, therefore, dissolved oxygen *trends* are used from Gardner et al (2011). In that study, it was found that waters on the incoming tide had higher DO than on the outgoing tide. In that study, DO concentrations at some locations within the lagoon approached ANZECC (2000) guideline limits for aquatic ecosystems, at values <6mg/L. This was attributed to shallow water conditions and the decomposition of organic matter accumulating in the lagoon. It is suggested here that the limited flushing, long residence time of water, and the relatively constant water level within the lagoon imposes significant constraints on the effective oxygenation of the water

Figure 23 Sampling sites for water quality, Teal lagoon, Juncus Inlet and freshwater wetland, Boyters Lane.

Table 3 Water quality data for sampling sites at Juncus Inlet, Teal Lagoon and the Boyters Lane freshwater wetland

Site	Latitude	Longitude	EC (mS/m)	pH	Density (g/cm^3)	Temp (*C)	FRP (µg/L)
Berm	-30.914083	153.03775	19.69	6.5	1.006	25	1560
TL1	-30.915933	153.03815	47.8	6.67	1.004	28.5	210
TL2	-30.915667	153.038117	40.1	7.25	1.0169	26.8	90
TL3	-30.915483	153.03785	0.295	6.6	0.9978	24	120
TL4	-30.915483	153.037917	39	7.12	1.0166	25.9	70
TL5	-30.914917	153.037783	0.2502	6.66	0.997	22.7	120
TL6	-30.914467	153.03765	39.6	6.73	1.0175	20.8	220
TL7	-30.914167	153.038067	40.2	6.83	1.0192	17.2	140
TL8	-30.914283	153.038183	40.4	6.98	1.0192	16.2	80
TL9	-30.9148	153.038533	40.9	6.96	1.0198	16.4	70
TL10	-30.915183	153.03885	41.2	6.89	1.0195	16.7	190
TL11	-30.91565	153.039117	43.6	6.58	1.0191	19.3	90
TL12	-30.916133	153.03925	48.6	6.35	1.021	21.7	90
TL13	-30.916383	153.039217	51.4	6.29	1.0221	21	40
TL14	-30.916383	153.039083	44	6.24	1.0205	19.5	30
TL15	-30.916317	153.038883	44	6.26	1.02	19.5	50
TL16	-30.915967	153.038883	40.9	6.76	1.0183	21.6	180
TL17	-30.916583	153.038283	42	6.53	1.0191	22.6	40
TL18	-30.9162	153.0383	41.6	6.47	1.0186	23.1	50
TL19	-30.913633	153.037067	33.3	7.07	**	**	100

** detailed data for density for this site are provided in a later section of this report

Electrical conductivity is used to measure salinity. At the study site, the dominant salts are chloride, sulfate, sodium and magnesium, with some variation across the system. Geochemical analysis, using an AquaChem platform, of samples in Juncus Inlet (TL19), Teal lagoon immediately upstream of the berm (TL7) and at the southern end of Teal Lagoon (TL16) indicate that the waters are all Na-Cl type. Reference to Tables 3 and 4 demonstrate that the waters of Juncus Inlet, Teal Lagoon and even the freshwater wetland on the southern side of Boyters Lane range are saline. The constructed wetlands within the Boyters Lane Playing Fields and Wetlands site are the only water bodies that are fresh, indicating that they receive surface runoff from upslope.

Table 4 Classification of water according to electrical conductivity (Waterwatch, 2005)

Water type	Electrical conductivity (µS/cm)
Freshwater rivers	0-800
Marginal river water	800-1600
Brackish water	1600-4800
Saline water	>4800
Seawater	52000-54000

Although the system is saline, spatial variability occurs, indicating two processes: (i) mixing of estuarine water and freshwater; and (ii) concentration of salts by evaporation in shallow water conditions. With reference to Figure 24, the highest salinities occur in the southern section of the lagoon, where there is less tidal flushing and the water is generally shallower. By contrast, the electrical conductivity of water on the incoming tide in Juncus Inlet is much lower at 33.3mS/cm whilst in Spencers Creek the EC was measured at 35.9mS/cm. This suggests that fresher waters, derived from upcatchment, flow through Spencers Creek and into Juncus Inlet. This conclusion is supported by Gardner et al (2011) (Figure 25). Furthermore, a time-series of density measurements taken at the berm show that water on the incoming tide through Juncus Inlet has a lower density (ie is fresher) than water within the lagoon (Figure 26). This evidence challenges the perception that the water body within Teal Lagoon is necessarily fresher than Juncus Inlet. It can be assumed that the inputs of fresh water into the system will vary temporally according to stream responses to rainfall upcatchment (see notes in the caption to Figure 25).

Figure 24 Values of electrical conductivity (mS/cm)

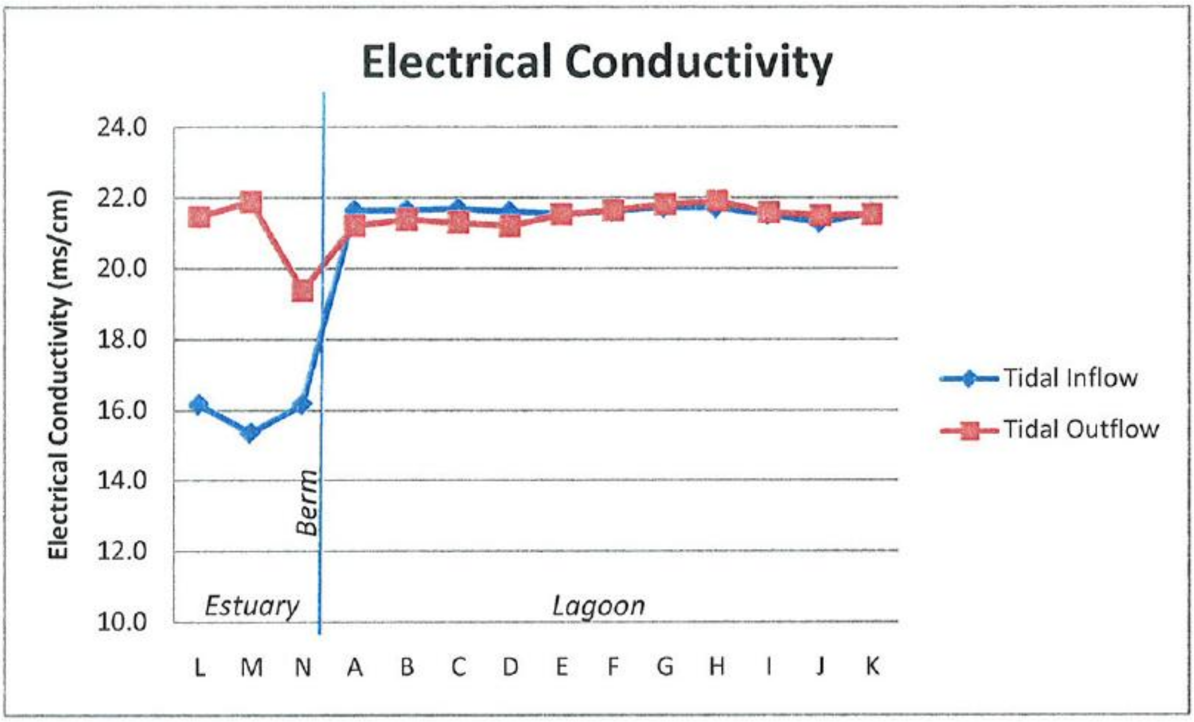

Figure 25 Spatial trends of electrical conductivity from Juncus Inlet through to the southern end of Teal lagoon (from Gardner et al, 2011). Note the much lower EC values in this plot in contrast to those reported in the present study. Rainfall data for the two periods in which these studies were undertaken indicate that total rainfall in the catchment was two orders of magnitude greater in the month prior to Gardner et al's, 2011 study relative to the equivalent period when field work for this report was undertaken.

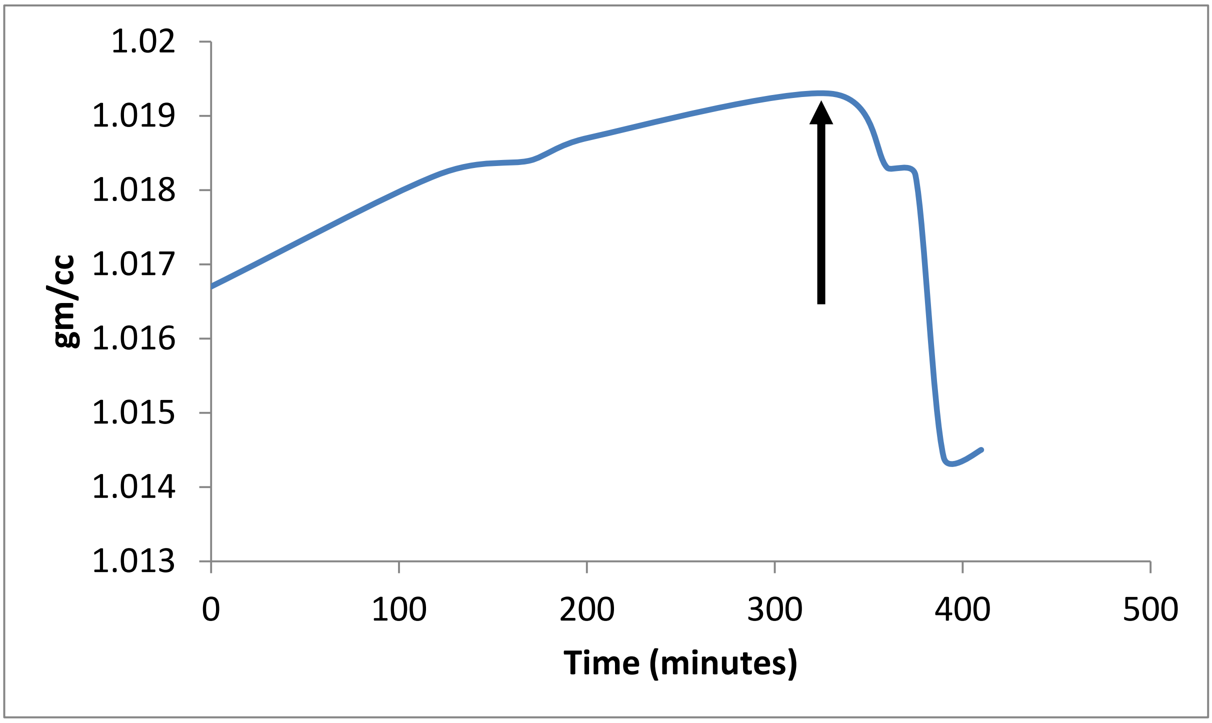

Figure 26 Temporal trends in water density below the berm during ebb tide and change of tide. The arrow shows the time of change of tide.

Observations of water flow through the berm were made on both the outgoing and incoming tides. On the outgoing tide, water flowed from the two pipes[5] that connect Teal Lagoon and Juncus Inlet, and from discrete points along the berm (Figure 27). The flow was constant, of low velocity and channelised (Figure 28). By contrast, on the incoming tide, water started to seep through several points along the berm until the development of a hydraulic gradient across the berm when the Teal Lagoon depth at the staff was 0.40m and the Juncus Inlet water depth reached 0.50m. This generated tide forced water-flow across the entire width of the berm increasing in volume and velocity until an equilibrium rate was reached. During that tidal cycle, the low water mark (LWM) measured on the Teal Lagoon staff was 0.40m and the high water mark (HWM) was 0.43m. This change in height equates to an inflow of approximately 672m^3 or 0.67ML, which represents 10% of the total volume of water in Teal Lagoon.

Figure 27 Location of points of discharge through berm into Juncus Inlet during low tide conditions

[5] The two pipes that connect Juncus Inlet and Teal Lagoon are both emplaced in the upstream berm wall at an elevation of 0.2m. However, on the downstream side of the berm, the west pipe has an elevation of 0.01m and the east pipe 0.16m. The hydraulic gradient that this imposes would influence local hydrodynamics of the system , but only under conditions by which structural integrity of the berm was intact.

Figure 28 Water discharging through pipes and berm during low tide conditions

Salinity of the water within the lagoon is also a function of concentration of salts due to evaporation. Estimates of evaporative water loss, based on mean annual potential evaporation and surface area of the lagoon equal 5.28ML/annum[6]. Concentration of salts by this process will be particularly evident in shallow, still-water conditions as occur in the upstream section adjacent to the road. This is also the area of water which has the highest density of mangroves. The species of mangrove that occurs at this site is characterised by salt exudation as a mechanism by which the plant copes with saline waters. Although minor, this will still be a contributory factor in defining the salinity of water in the lagoon.

[6] This equates to 14,465L/day

Management of the berm

Management of Teal Lagoon with specific reference to the berm involves a number of challenges due to the need to balance the different uses of the site. As noted in the introduction of this report, the options to be considered for management of the berm include:

(i) Retention of the berm in its current condition, allowing it to continue to degrade over time

(ii) Repair of the berm to improve its structural integrity with the intention of hydrologically separating the two sections of the lagoon

(iii) Repair of the berm to allow for controlled exchange of waters between the two sections of the lagoon

(iv) Repair of the berm to allow the upstream section of the lagoon to maintain water level at a given level

(v) Remove the berm to establish a tide dominated estuarine wetland.

Retention of the berm and allowing it to continue to degrade is not an option. Tide forced flows pass through the structure, eroding the overburden and causing the soil to cave in, leaving collapsed tunnels as holes at the berm surface (Figure 29). These holes, and other discontinuities that are not visible at the surface, represent a danger of injury to people visiting the site, with associated risks of litigation against Kempsey Shire Council.

Figure 29 Collapsed tunnels on Teal Lagoon berm, caused by sub surface erosion of the soil overburden

Repair of the berm to establish hydrologic separation of Juncus Inlet and Teal Lagoon is also not an option. As a closed system, the shallow waters of Teal Lagoon would be vulnerable to decreasing water quality as a function of (i) evaporation and consequent increased concentration of salts; and (ii) eutrophication due to an accumulation of organic material and nutrients. The loss of any tidal inflows would result in mangrove die-back and reduction of roosting places for birds.

Fluctuating water levels are important in maintaining the ecological functions of intertidal areas, including saltmarsh. Inundation of mangrove pneumatophores, as noted earlier, may have important implications for the biogeochemistry of the mangrove rhizosphere within anaerobic sediments. This remains a knowledge gap that requires further research. However, given that field evidence suggested that acid sulfate soils may occur at this site, fluctuating water levels to optimize oxygen uptake by mangrove pneumatophores is likely to have beneficial outcomes. Repair of the berm to allow the upstream section of the lagoon to maintain water level at a given height would therefore not be desirable as this option would result in the loss of the ecological and social values of the site.

Due to the significant social values of this site, removing the berm to return the system to a tide dominated site is also not feasible. In addition, this option is associated with the risk of estuarine waters discharging into the freshwater wetland to the south of Boyters Lane with consequent deleterious impacts on the wetland itself and the surrounding land, particularly during high tides.

Given these arguments, the most appropriate option available for this site, which meets ecological and social requirements, is to have a structurally sound berm that optimises water quality through tidal flushing. This flushing is required to reduce both the nutrient load and the concentration of salts in the lagoon. In addition, the inflows would need to emulate the tidal cycle, so that water depth in the lagoon varied diurnally. The challenge in adopting this approach is the need to manage the lagoon for waterbirds, enabling fish passage and maintaining good water quality while providing low maintenance and low cost solutions.

An automatic structure would not be a cost effective method, however, a manual drop board structure could be manipulated to suit the continuing and changing needs of the lagoon. A previous study by Australian Wetlands (2005) also suggested this as an option, with the additional recommendation that mangrove seeds should be prevented from flowing into the lagoon by the seasonal emplacement of 20mm mesh. Although this would prevent the inflow of mangrove seeds from downstream, *in situ* propagation would still be occurring within Teal Lagoon. It needs to be stressed here that the mangroves play an important ecological role in terms of providing refugia for roosting birds, habitiat for a range of intertidal fauna, and driving important biogeochemical processes within the host sediments. They should not be removed, but rather, their growth should be managed to provide the line of sight desired for birds.[7] Higher volumes of flow between the lagoon and inlet would decrease the residence time and flush nutrients and organic matter out of the lagoon. It could also impact on the longitudinal salinity gradient within the system. This would increase the habitability for invertebrate communities and have a beneficial flow-on effect, providing more food for birds.

Additional benefits of such an option would include:

- (i) maintaining the site for bird watching, visual amenity and passive recreation; and
- (ii) preserving the access point between the educational walkway and the site of the proposed playing fields, enabling access from the town if the playing fields are constructed in the future;

Due to these considerations, two options are presented here:

- (a) a manual dropboard mechanism and paired pipe system;
- (b) a manual dropboard mechanism and single pipe system.

These options would enable a high level of control and adjustment of the inflows and water level as well as being inexpensive to construct, manage and maintain (NSW Department of Industry and Investment, 2009). It is outside the scope of this report to provide detailed engineering specifications for the berm, but the following structural elements are described to highlight the key elements of a reconstructed berm, and their value in optimizing ecosystem function in Teal Lagoon.

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[7] Removal of mangroves has the associated risks of reducing DO concentrations, eutrophication of the lagoon, and the development of algal blooms. This would dramatically reduce the ecological, educational and ornithological benefits for which the area is becoming increasingly valuable. If concerns continue regarding the growth of mangroves, a pruning program would reduce their height and maintain bird sight lines. This would keep the mangroves required by roosting birds whilst encouraging foraging behaviour.

The combination of a dropboard and paired pipes would allow less-dense surface waters flowing from Spencers Creek to enter the lagoon, the volume of which could be manipulated by the dropboard to optimize water quality, whilst also managing the upper limits of water level in, and therefore the areal extent of, Teal lagoon under non-flood conditions. Given the temporal changes to vegetation, and the vulnerability of the saltmarsh community, the manipulation of the dropboard could be managed to ensure that water levels in Teal Lagoon do not exceed 0.55m AHD. At the same time, management of the system should aim to prevent drying out of the lagoon, even during prolonged drought. The height of the invert of the lower pipe will maintain a minimum depth of water across the lagoon, due to tidal inflows of at least 0.3m AHD.

It is recommended that two sets of paired pipes, as shown in Figure 30 should be emplaced. The pipes should have zero gradient and be allowed to partially fill with natural substrate (this will need some maintenance to ensure blockages do not develop). The paired pipes, one above the other as shown in Figure 30 would complement the dropboard mechanism, by controlling the inflow and outflow of waters under different tidal height conditions. The lower pipe would have an invert at 0.3m AHD, and a flap on the downstream side (that is, the Juncus Creek and Spencers Creek side) to prevent saltwater inflow whilst allowing drainage from the lagoon. The upper pipe, with an invert of 0.7m AHD, would allow for free inflow and outflow to and from the lagoon when tides exceeded this level. Where the pipes extend out into Juncus Inlet, the batter toeslope should be at a lower gradient to minimize drop of any fish exiting at this point, and also provide some protection to the bed from the erosional force of outflows. Rocks placed on the batter toeslope and bed sediments will further dissipate erosional energy.

The second option would include the dropboard mechanism as described above, but with the lower set of pipes only (Figure 31). This option means that a constant rate of exchange will occur through the berm across the full range of tidal heights.

In terms of the berm itself, it is recommended that the following be considered:

- The reconstructed berm should comprise compacted, low permeability core material, with an overburden of semi-pervious material.
- The height of the current berm is 1.14m AHD. This will be slightly lower than the original height at the time of construction, due to subsidence of the structure over time. The reconstructed berm could be raised to 1.3m AHD .
- The batter slopes of the current berm are highly variable, with the upstream (Teal Lagoon) batter slope approaching near vertical in places. Slopes with a lower gradient offer greater stability (for example, ~1V:1.5H to 1V:2.5H).

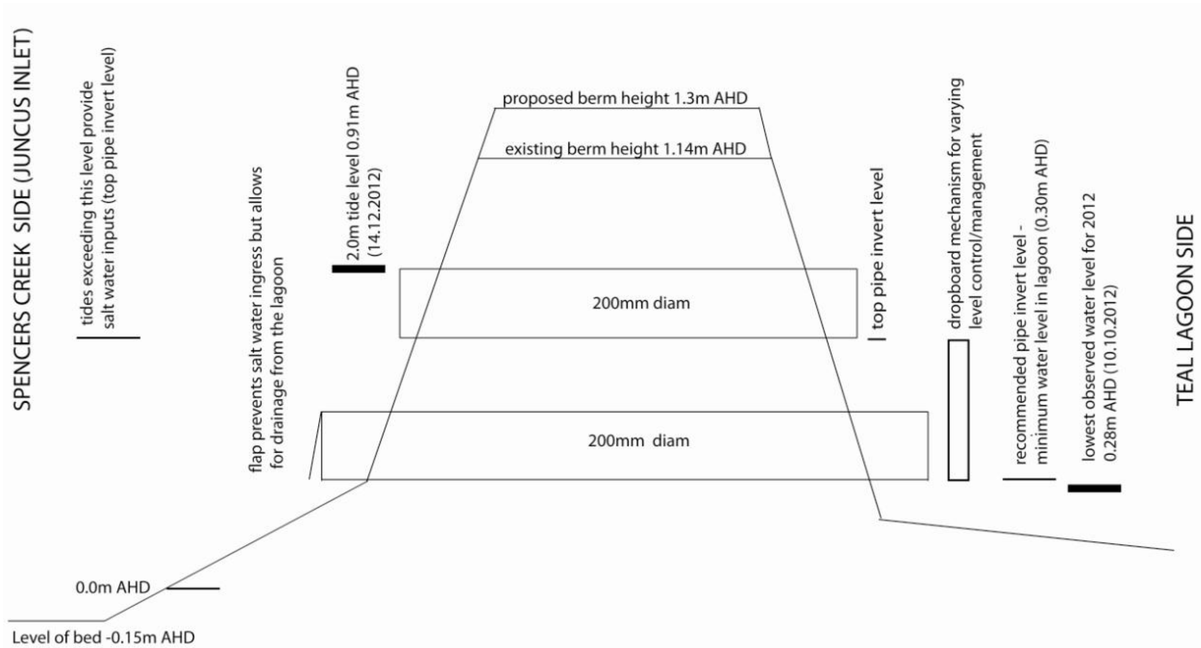

Figure 30 Simplified diagram of berm structure including paired pipes and dropboard mechanism. *This diagram is provided as a guide only*. Angles of slope batters are not provided according to the recommended ratio range of 1V:1.5-2.5H, however, note reduced slope gradient beneath lower pipe on Juncus Creek side to facilitate safe fish passage and reduce erosional energy of outflowing water. This slope needs to be protected with rocks/gravel.

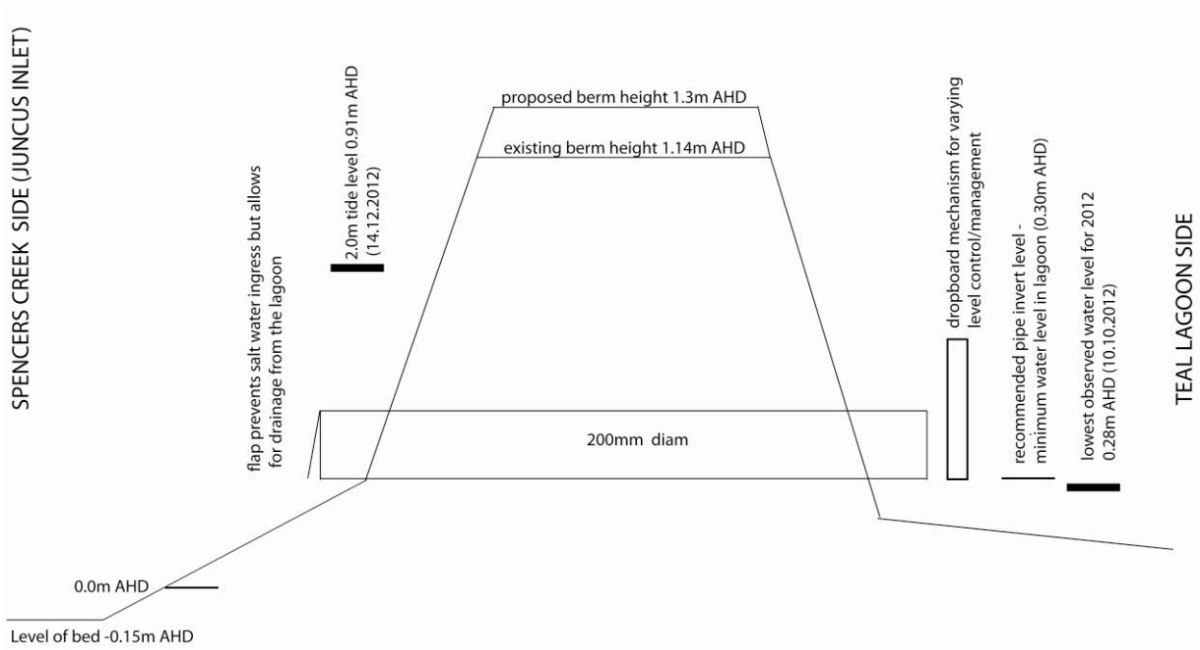

Figure 31 Simplified diagram of berm structure including single pipe and dropboard mechanism. *This diagram is provided as a guide only*. For example, angles of slope batters are not provided according to the recommended ratio range of 1V:1.5-2.5H, however, note reduced slope gradient beneath the pipe on the Juncus Creek side to facilitate safe fish passage and reduce erosional energy of outflowing water. This slope needs to be protected with rocks/gravel.

Within this set of recommendations it should be noted that, regardless of the mode of rehabilitation and subsequent management of the berm, periodic flooding of the site occurs in response to (a) freshwater flooding of the Macleay River system due to high rainfall in the catchment and (b) ingress of more saline waters under tidal forcing during king tides. Overtopping of the berm during these events will be associated with rapidly changing water quality within the lagoon, followed by a period of flood recession and recovery. These conditions are a part of the natural regime, although it could be expected that the frequency and magnitude of such events may change in the long term in response to climate change.

Conclusion

This study has provided evidence for changes in the vegetation of Teal Lagoon and its environs since Council purchased the land in 2002. Data gathered in the field have elucidated the controls on, and current status of, water quality at the site and provide the basis for recommendations to Kempsey Shire regarding rehabilitation and management of the berm.

Aerial photograph interpretation and field surveys demonstrated how the flora within the Boyters Lane site has changed dramatically since it was purchased by the Council in 2002. After the berm was constructed, the area of saltmarsh and mangroves decreased dramatically as the site was used for cattle grazing. Since the exclusion of cattle, the site's saltmarsh has regenerated significantly, creating a zone around the lagoon up to ten metres wide. This is important as saltmarsh is an endangered ecological community which is decreasing in area. The mangroves have also extended further into the lagoon and spread around the majority of the shore, providing a safe roosting site for birds. The artificial wetland and rainforest plantings are providing additional diversity.

Whilst the vegetation has regenerated, the water in the lagoon has decreased in quality. The limited tidal flow in the lagoon has contributed to a buildup of salts and nutrients which cannot be effectively flushed out. This causes a decrease in the lagoon's habitability for water plants and invertebrates, reducing its value for foraging birds. The increased nutrients also lead to a risk of eutrophication within the lagoon.

The key recommendation of this report is that the functionality of the berm should be restored. The design of the berm would require adequate width and load bearing to allow vehicular access to the vegetation rehabilitation site. The structure will enable tidal inflow to be adjusted in response to water quality conditions within the lagoon, whilst also allowing less saline surface water to enter the lagoon. The paired pipes would have the added benefit of allowing fish passage from Spencers Creek up through Juncus Inlet and into the lagoon, increasing the total area available as a fish nursery. This would also increase the lagoon's amenability to foraging birds and satisfy requirements under the *Fisheries Management Act 1994* (NSW). These conditions would improve the habitability of the site, increasing its environmental, educational and recreational values.

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