Eco-hydrological Investigation and Restoration Planning for Big Marsh

The Spit Nature Conservation Reserve, Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site

Report to Port Phillip and Westernport Catchment Management Authority

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Disclaimer

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Earlier drafts of the recommendations within this report were presented at a workshop on 25th February 2020, hosted by Mark Bachmann (NGT) and Ben Taylor (NGT), and attended by Geoff Carr, Tim Allen (DAWE), John Nolan (Nolan Consulting), Regan East (DELWP), Suelin Haynes (MW), Andrew Morrison (PPWCMA), Jake Manning (work experience student, PPWCMA), Will Steele (MW) and Kathryn Stanislawski (Parks Victoria).

The draft recommendations were also presented to the Western Treatment Plant Biodiversity Conservation Advisory Committee on 4th August 2020 and the draft report was circulated to several of the project stakeholders named above. Their comments and feedback resulted in a number of improvements and have been incorporated into this finalised version of the report.

Executive Summary

Numerous ecological assessments have identified The Spit Nature Conservation Reserve and Big Marsh in particular, as one of the most significant areas of saltmarsh in Victoria due to the diversity of the site's flora and vegetation. The majority of the Big Marsh area falls within the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site, a wetland of international importance. In the 1980s, the area was also known to be an important feeding area for the now critically endangered orange-bellied parrot (*Neophema chrysogaster*), at times being a reliable overwintering site for half the population. However, the diversity and general condition of saltmarsh vegetation, particularly in the upper saltmarsh, is understood to have declined since and orange-bellied parrots are no longer observed.

Nature Glenelg Trust were engaged by the Port Phillip and Westernport CMA, with funding from the Australian Government's National Landcare Program, to investigate the potential hydrological causes of the observed decline in ecological health, with 29 Mile Road of particular interest, as it bisects the site and includes a major embankment and culverts. In the course of undertaking this project, it also became apparent from an early stage that a number of issues in addition to 29 Mile Road were and are capable of influencing the hydrology and condition of vegetation of Big Marsh. These include seepage from the adjoining T-section ponds, the redirection and/or modification of freshwater surface inflows, sheep grazing and future sea level rise.

As well as collecting a range of new data to contribute to understanding of the site, the project used available literature, expert consultation, biological data, GIS mapping layers, aerial photographic analysis, a digital elevation model (DEM) and a range of historical information to contribute to its findings.

Despite being of modest size, the issues surrounding Big Marsh are complex, have accumulated over time and dynamically interact with each other. As a result, they are now difficult to disentangle:

<table>
<tr><th>Broad Era</th><th>Issue 1:
Tidal flow restriction to saltmarsh caused by road</th><th>Issue 2:
Streamflow diversion of Avalon Creek</th><th>Issue 3:
Seepage from T-section lagoons</th><th>Issue 4 and 5:
Grazing by livestock and tenure</th><th>Issue 6:
Sea level rise</th></tr>
<tr><td>Pre-1830</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>1830-1870</td><td></td><td></td><td></td><td rowspan="4">Port Phillip colony commences 1830s Sheep grazing throughout this period</td><td></td></tr>
<tr><td>1870-1920</td><td rowspan="2">Early possible evidence of road</td><td></td><td></td><td></td></tr>
<tr><td>1920-1950</td><td rowspan="2">Flow modified but still discharging into the saltmarsh</td><td></td><td></td></tr>
<tr><td>1950-1970</td><td rowspan="2">Modern road and causeway built in 1950s with limited culverts in place</td><td></td><td></td></tr>
<tr><td>1970-1980</td><td rowspan="3">Full diversion away from saltmarsh, except for 2001-2002</td><td>Sewage Pond Treatment begins 1973</td><td>Sheep grazing officially ends 1979</td><td></td></tr>
<tr><td>1980-2005</td><td>Larger 1998 culverts (albeit still with restricted capacity) left open 1998-1999</td><td>Sewage Pond Treatment ends 2004</td><td>Grazing trial in 2006-07. Some stock grazing still occurring</td><td>Rate of global increase in sea level rise detected</td></tr>
<tr><td>2005-2020</td><td>Boards removed and culverts left fully open from Nov 2019</td><td>Ponds maintained for habitat value only</td><td>Some stock grazing still occurring</td><td>Accelerating impact predicted into the future</td></tr>
</table>

Broad impact categories (for illustrative purposes)	
	No or minor impact
	Some impact likely
	Definite impact

Despite this temporal complexity, predicted lag effects, inter-dependencies in ecological systems and the large number of uncertainties, we have explored each of these issues in a level of detail commensurate with project duration. As a result of this investigation, we have developed a fresh perspective on the eco-hydrology of the site and proposed recommended actions (including, for two issues, multiple options) for consideration by land managers. The key findings of this report are as follows:

Issue 1 - The 29 Mile Road:

- The configuration of the 29 Mile Road culverts as encountered at the commencement of the project, with stoplogs placed in the culverts, has been causing a measurable restriction in tidal movement to and from the saltmarsh on the inland side of the road.
- This current configuration appears to have been the prevailing management regime for much of the past 20 years, despite the fact that enlarged culverts were installed in 1998 to increase the capacity for tidal movement.
- Prior to this, from modern road construction in the mid-1950s to 1998 there was also a restriction, likely similar in effect to having the stoplogs in place.
- Before the 1950s, prior to modern road construction, there was also likely a restriction due to the presence of an elevated track.
- In summary, natural tidal movement has been restricted for at least seven decades, and possibly dates back much earlier, potentially to the late 1800s.
- Since all stoplogs were removed (in November 2019), tidal inflows have measurably improved, but the long road embankment (i.e. the causeway) itself still has a limited number of openings and is therefore capable of constricting and restricting shallow flows of brief duration. This is especially true of tidal movements, but may also restrict freshwater surface flows to the Bay during high rainfall events.

Recommendations:
- Achieve tidal movements and freshwater flow dynamics that are as close as possible to natural conditions, by:
    - ensuring that the stoplogs are left permanently out, to enable the culverts to freely convey maximum flows in either direction, with no further action required at this time.
    - furthering assessment of the hydraulic impact of the road embankment itself. This is necessary as it is unlikely that the existing culverts have the ability to effectively convey the volume and spatial distribution of flows associated with the full range of natural tidal movements. Monitoring this impact more broadly across the saltmarsh in a wider range of tidal events, now that the stoplogs have been removed, is recommended over the next five years and the data re-evaluated. This is particularly relevant if further modification to the road is deemed a viable future management option.

Issue 2 - Redirection of streamflow:

- The natural minor seasonal waterway within the catchment for Big Marsh, called Avalon Creek in this report, had its natural alignment interrupted by the development of the T-section irrigation paddocks several decades ago.
- The artificial drainage waterway (the T-section paddocks perimeter drain) that now conveys concentrated flows towards Big Marsh has, since the late 1960s, been diverted away from the saltmarsh, except for a period of two years (2001-2002) when flows were temporarily re-instated.
- Without modification or restoration works taking place, the current infrastructure is incapable of mimicking more natural catchment conditions, as it delivers concentrated flows to a single point of discharge below natural surface.

Recommendations:

- Achieve streamflow dynamics that are as close as possible to natural conditions, by:
    - re-instating seasonal catchment streamflow to Big Marsh by recreating shallow, diffuse, slower surface flow conditions that ideally would mimic the original natural stream conditions.
    - subject to the consent of neighbouring landholders, implementing works according to one of three options as outlined in this report (Option A, B or C, as per the thumbnail images from left to right shown below – see Section 10.2 for additional detail).

-
    - undertaking detailed designs for the preferred option and implement these works.
    - monitoring outcomes from the streamflow restoration work to inform management.

Issue 3 - Seepage from T-section Lagoons:

- The T-section lagoons are causing freshwater seepage and creating a zone of elevated groundwater level and reduced groundwater salinity in Big Marsh immediately adjacent to the lagoons.
- Despite this measured impact, the effect of seepage appears to be highly localised, but there are still options available to manage this, as explored in the recommendations.

Recommendations:

- As both neighbours and the responsible land managers for environmental values in the Ramsar site relevant to this issue, Parks Victoria and Melbourne Water have the choice of three future management strategies, depending on how the ecological outcomes being sought for the Ramsar site, as a whole, are prioritised and considered against criteria like cost, ecological values and "naturalness". In ascending order of cost and intervention towards a more natural outcome, these three options are:

Option WL1: No change in management.

Option WL2: Reduce static freshwater levels in the ponds adjacent to Big Marsh, via two possible means:

(a) Manage T-section Ponds 3 and 4 with lower water levels throughout, or**;**

(b) Install an additional, east-west aligned bund (e.g. marked red, right) across Ponds 3 and 4, and keep the pond area south of this new bund dry or with very low water levels to further reduce or eliminate seepage.

Option WL3: Complete removal of Ponds 3 and 4 to facilitate restoration of this area as saltmarsh habitat.

To illustrate, the southern portion of Ponds 3 and 4 is shown here supporting saltmarsh habitat in 1947, prior to the development of the lagoons.

Although listed here as an option (WL3), we understand that full restoration is unlikely to be supported as it would require a significant ecological trade-off, with the complete loss of freshwater pond habitats currently managed specifically by Melbourne Water for values associated with the Ramsar site listing. However, please also note that a combination or integration of these options is also possible to reduce or adjust the magnitude of ecological trade-off required.

Issue 4 - Improved fencing and grazing management:

- As a result of fences being in a state of poor repair, sheep are still accessing the saltmarsh (at least on occasions) within Big Marsh across both public and private land.
- Further, some current fences on both public and private land are either redundant or inappropriately aligned.

Recommendations:

- Fencing should be upgraded as a priority to prevent livestock grazing of saltmarsh vegetation in Big Marsh.
- Achieve uniformity of fencing across the entire Big Marsh site, by:
    - improving fencing on the western side of Big Marsh, with the consent of the Barro Group, to more closely match the landform and identify locations where repairs are required.
    - removing redundant fencing on Public Land to fence the saltmarsh into a single management unit that better aligns with the landform across public and private land.

Issue 5 - Tenure consolidation:

- Approximately half of the western (dry) saltmarsh portion of Big Marsh is situated on private land, outside the Ramsar site boundary.

Recommendations:

- In consultation with the Barro Group, consider options for the remaining saltmarsh area being set aside for conservation in perpetuity either ahead of or upon the eventual closure of Mountain View Quarry.
- It is noted that the precise mechanism for how and when this might be achieved has not yet been discussed, but the goodwill to discuss this issue in the future exists.

Issue 6 – Sea level rise:

- The issue of sea level rise is an essential background issue that needs to be factored into all options.
- Where relevant, this will impact design considerations and the time horizons set for the recommended actions in this report. For example, preparing for and facilitating a future saltmarsh footprint that can move up-slope to ‘creep’ with rising sea levels and avoid the ecological community being lost is an important consideration for finalising proposed fencing and future tenure discussions.

Next steps and monitoring

Short term steps (next 3 years):

- **Issues 2 (Redirection of streamflow) and 3** (**Seepage from T-section Lagoons)** require consensus ahead of next steps (i.e. a decision made by the land managers with input from project stakeholders) to nominate the preferred options for implementation. Once those options have been chosen then design, costing and implementation can follow.
- **Issue 4 (Improved fencing and grazing management)** can be resolved by negotiation with the Parks Victoria and the Barro Group, subject to funding for fencing removal and/or realignment and repair being available.

Medium term monitoring implementation (next 5 years):

- All issues, but particularly **Issues 1 (29 Mile Road), 2 (Redirection of streamflow) and 3 (Seepage from T-section Lagoons)** require various degrees and forms of hydrological and ecological monitoring to inform our understanding and/or their design and implementation, as detailed in this report. This in turn will also provide vital feedback to inform future management decisions.

Long term issues (no fixed timetable):

- **Issue 5 (Tenure consolidation)** is an important but not urgent long-term matter that can be revisited at any time by the relevant parties.
- **Issue 6 (Sea level rise)** is an essential background issue to factor into all options, especially Issue 4 and 5.

Ongoing communication tasks:

- The process of communication undertaken for this project illustrates the importance of ongoing collaboration between the public land managers and private landowners of Big Marsh and its catchment. There is an opportunity to build upon the goodwill already demonstrated in identifying common interests and working towards achieving improved conservation outcomes for the site.
- The PPWCMA can play an important ongoing coordination role given (a) its independence from other parties, and (b) its relationship with the Australian Government which, by virtue of its legislative responsibilities, has a strong interest in Ramsar site management across Australia.

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1. Introduction

The Spit Nature Conservation Reserve (NCR) is a 678.5 ha reserve managed by Parks Victoria. The Reserve incorporates approximately 11.4 km of the western shoreline of Port Phillip Bay from approximately 2.3 km north of Point Wilson to the mouth of the Little River. The reserve protects coastal and marine habitats and forms part of the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site (see Figure 1), listed by the Australian Government as a wetland of international importance in 1982.

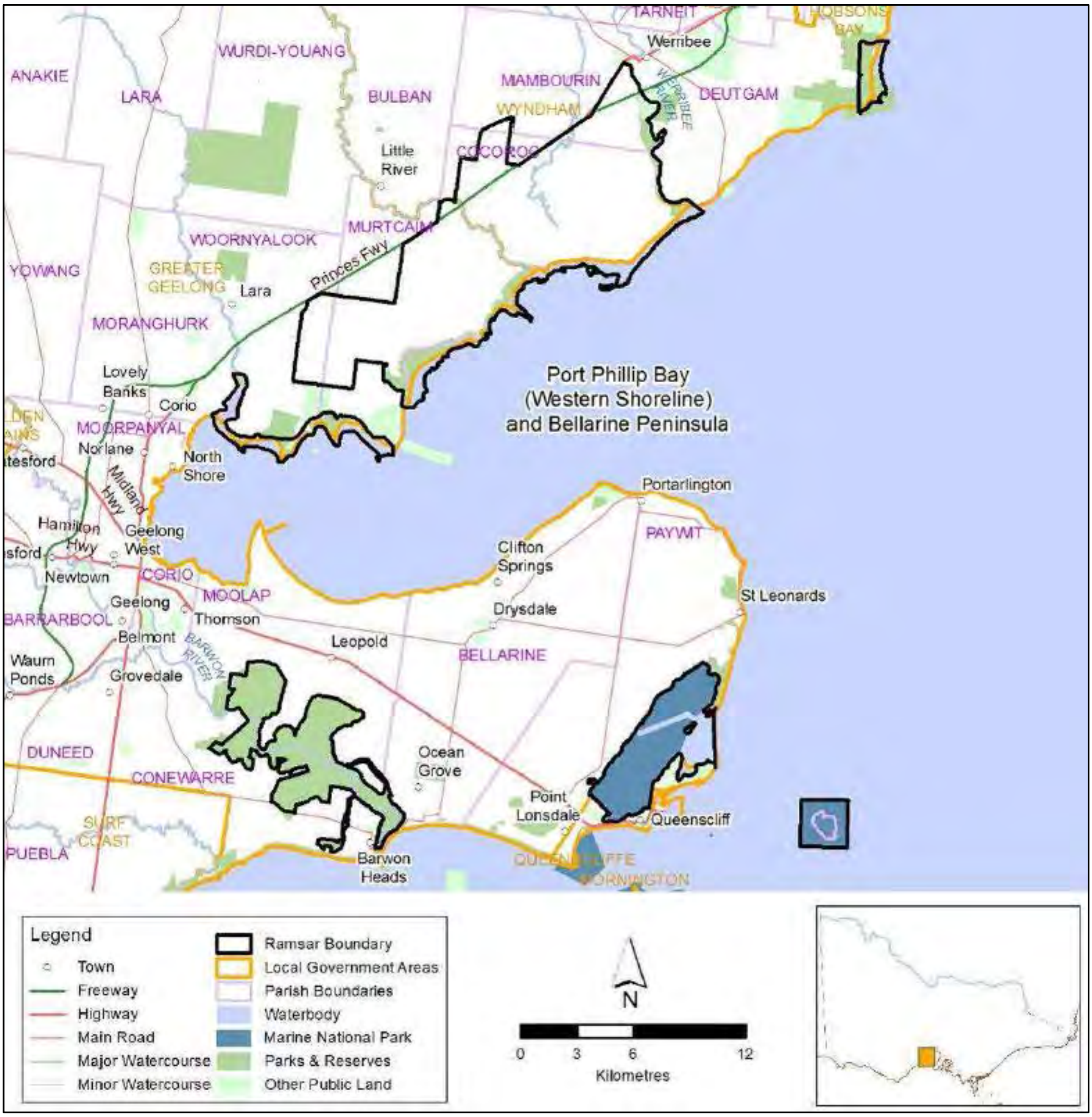

Figure 1. The Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site. Map from DEPI (2013).

The south of the reserve includes an area of saltmarsh that extends approximately 1.5 km inland (Figure 2). In this area, the saltmarsh vegetation extends beyond the boundaries of The Spit NCR into a more extensive zone of low relief that straddles adjoining properties and is subject to inundation under very high tides and/or freshwater runoff from inland. The saltmarsh community of this area is segregated by the north-south aligned 29 Mile Road. The west, or inland, side of the road is referred to variously as Big Marsh, the upper saltmarsh, or dry saltmarsh (herein as Big Marsh). To the east, or seaward side of 29 Mile Road is the lower saltmarsh.

In the early 1980s, biological assessments identified The Spit, and Big Marsh in particular, as one of the most significant areas of saltmarsh in Victoria due to the diversity of its flora and vegetation (e.g. Kinhill 1982). At this time the area was also known to be an important feeding area for the now critically endangered orange-bellied parrot (*Neophema chrysogaster*), at times supporting close to half the known population (Loyn *et al.* 1986). However, the diversity and general condition of saltmarsh vegetation, particularly in the upper saltmarsh, is understood to have declined in recent decades (Carr *et al.* 2002, Mueck *et al.* 2007) and orange-bellied parrots are no longer observed there (Loyn, R., pers. comm. 28/11/2019). For important context, it must also be noted that this species has declined in abundance markedly across its entire range over the same period, now making it a less than reliable indicator species.

A visibly sharp, possibly unnatural, ecological boundary exists at 29 Mile Road, with markedly different saltmarsh vegetation on either side of the road. This has led to speculation that:

- 29 Mile Road, although culverted, restricts water movement between the lower and upper saltmarsh;
- the resultant differences in water regime experienced on either side of the road have caused differences in the vegetation to develop; and
- this has possibly contributed to degradation of saltmarsh condition (Brett Lane and Associates 2006, Carr *et al.* 2002).

The objectives of this project were to:

- assess the influence of 29 Mile Road upon the hydrology of Big Marsh;
- investigate any other issues identified as potentially influencing the hydrology and condition of vegetation of Big Marsh; and
- if relevant, recommend actions to recover, maintain and/or restore saltmarsh habitat over a 50 year timeframe in the face of multiple historic, ongoing and emerging threats.

The project used available literature, expert consultation, biological data, GIS mapping layers, aerial photographic analysis, a digital elevation model (DEM) and a range of historical information.

In the course of undertaking this project, it became apparent from an early stage that a number of issues in addition to 29 Mile Road were and are capable of influencing the hydrology and condition of vegetation of Big Marsh. These include seepage from the adjoining T-section ponds, the redirection and/or modification of freshwater surface inflows, sheep grazing and future sea level rise.

These issues were explored and are also examined in further detail in this report.

Figure 2. The Big Marsh area of The Spit Nature Conservation Reserve.

The future expansion of Barro Group's Mountain View Quarry may also affect the future hydrology of The Spit, however the quarry expansion has been assessed via an Environmental Effects Statement (EES) (Barro Group 2008), is approved (Minister for Planning 2009) and remains subject to ongoing monitoring under that approval (e.g. Nolan Consulting 2019) and under an Environmental Management Plan (EMP) (Nolan Consulting 2011).

It is therefore beyond the scope of this report or the wider project to examine the potential influence of the quarry expansion upon the hydrology and/or vegetation of The Spit. Rather, this report has noted the requirements of the approved EMP and sought to make recommendations complementary to it.

2. Surrounding Land Use and Tenure

The Spit NCR comprises five land parcels managed by Parks Victoria for nature conservation. In the southern area of The Spit NCR, i.e. in the Big Marsh area that was the focus of this project, the Parks Victoria land adjoins, or is in the vicinity of, land managed by three organisations (Figure 3).

- Melbourne Water manage the adjoining T-section ponds, filtration paddocks and grassland areas to the north and north-east of Big Marsh. The T-section ponds and an area of grassland to their immediate south are managed for conservation, while the filtration paddocks, west of the ponds, are lightly grazed by cattle under agistment.
- Barro Group Pty Ltd own land parcels to the west and south of The Spit. The Barro Group land includes the current and future proposed footprint of the Mountain View quarry. Areas not currently mined are predominantly grassland, grazed by sheep under agistment. The Barro Group land also includes saltmarsh habitat, the western portion of Big Marsh, contiguous with that located within The Spit NCR. The Barro Group parcels are excluded from the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar site, while the Parks Victoria, Melbourne Water and Fox Group parcels are included (Figure 3).
- Fox Group owns land parcels to the west of the Melbourne Water and Barro Group land. These areas comprise Avalon Airport and surrounding land that appears to be predominantly grassland grazed by livestock. A natural, unnamed watercourse, arising in the vicinity of the airport, carries surface water in an easterly direction to the boundary of Fox Group land, where flows currently enter a perimeter drain on Melbourne Water land. This natural watercourse is hereafter referred to as "Avalon Creek" (Figure 3).

Figure 3. Land tenure (labelled) in the vicinity of Big Marsh. The extent of saltmarsh vegetation (Sinclair 2010) and the Ramsar boundary is also shown. Ramsar site is north of the pink line.

3. Vegetation, Flora and Changes Through Time

The conservation value of The Spit, and of Big Marsh in particular, is due in part to the floristic diversity of the saltmarsh vegetation that the area supports. Big Marsh was, in the early 1980s, one of the most floristically diverse areas of saltmarsh in south-eastern Australia (Geoff Carr, pers. comm., 14/11/19). Carr (1982) mapped the vegetation of the Big Marsh area in 1980, describing 13 plant communities. This work was completed prior to the development of the Ecological Vegetation Class (EVC) system for describing and mapping saltmarsh vegetatation throughout Victoria. Sinclair (2010) mapped (at 1:5000 scale) the following eight Ecological Vegetation Classes (EVCs) at Big Marsh, including the lower saltmarsh (abbreviation labels are shown in Figure 4). :

- Coastal Dry Saltmarsh (CDS);
- Coastal Hypersaline Saltmarsh (CHS);
- Coastal Saline Grassland (CSG);
- Coastal Tussock Saltmarsh (CTS);
- Estuarine Flats Grassland (EFG);
- Saline Aquatic Meadow (SAM);
- Wet Saltmarsh Herbland (WSH); and
- Wet Saltmarsh Shrubland (WSS).

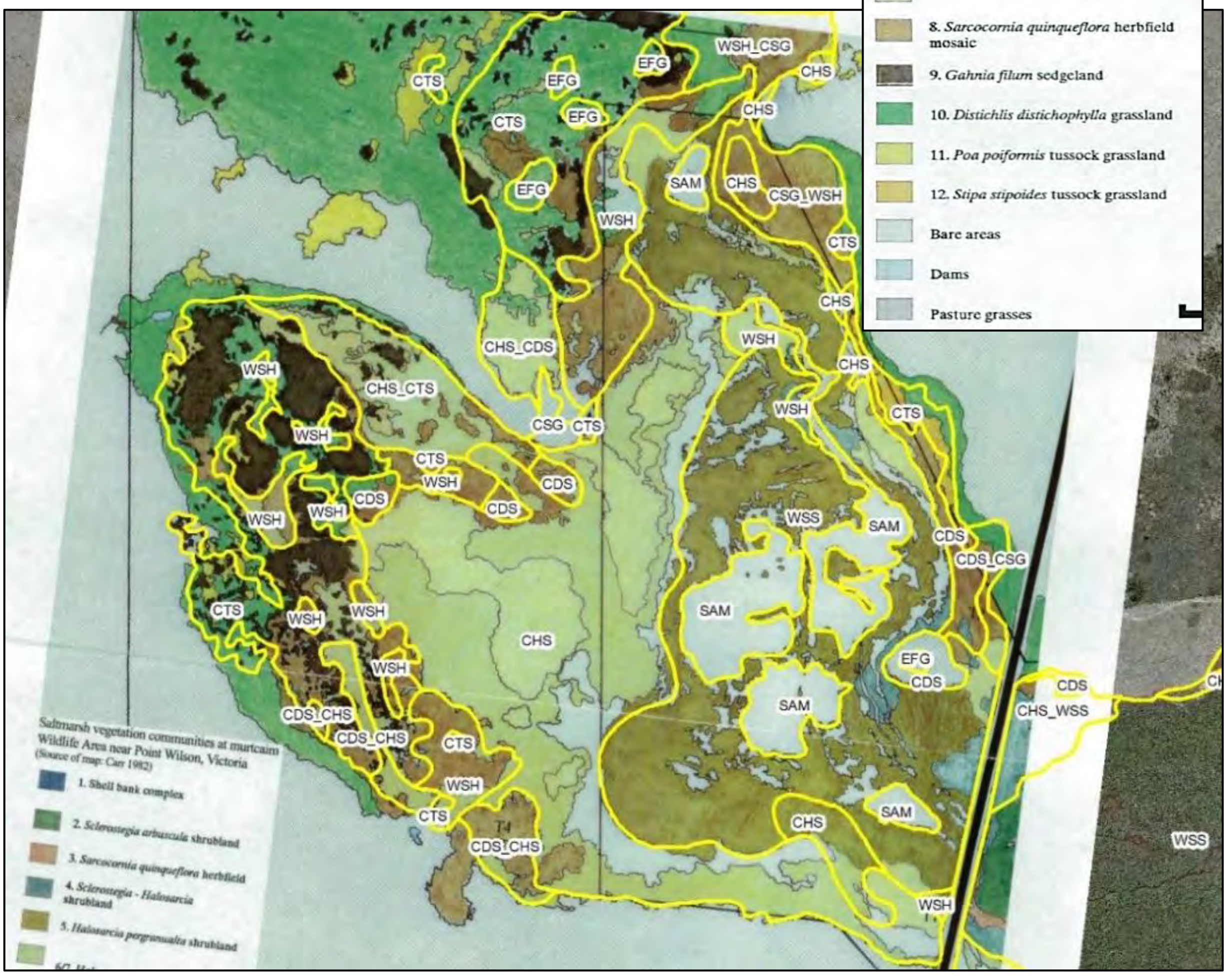

Figure 4. The changing vegetation of Big Marsh. Carr's geo-rectified map from (1982) is the underlying coloured image (with key shown above right), whereas Sinclair's (2010) map is represented by the super-imposed yellow outline with labels.

The mapping of Carr (1982) and Sinclair (2010) is difficult to compare due to differences in methodology, however one notable difference between the two maps is the extent of *Tecticornia pergranulata* (formerly *Halosarcia pergranulata*) shrubland west of 29 Mile Road (Figure 4).

This community described by Carr (1982) best corresponds with the EVC Coastal Hypersaline Saltmarsh. Carr (1982) maps an extensive area of this community abutting the western side of 29 Mile Road and extending westward and northward. Sinclair (2010) maps the same area as Wet Saltmarsh Shrubland, an EVC "almost always dominated by Shrubby Glasswort *Tecticornia arbuscula*". Our observations for the current investigation were that this area is in fact dominated by *Tecticornia pergranulata*, as mapped by Carr (1982), and that *Tecticornia arbuscula* dominated Wet Saltmarsh Shrubland is only present east of 29 Mile Road. Indeed, this sharp ecological boundary is a key feature of the site and raises questions regarding the hydrological impact of the road, as discussed in Section 1 and further examined in Section 7.1.

In 1980, a considerable portion of the native floristic species richness of Big Marsh consisted of 15 non-aquatic annuals occurring principally within "Beaded Glasswort (*Sarcocornia quinqueflora* ssp. *quinqueflora*) Herbfield Mosaic" (Carr *et al.* 2002). From the description of Carr (1982), this community may be a grouping of two EVCs; Wet Saltmarsh Herbland and Coastal Dry Saltmarsh. Between 1980 and 2002 these 15 native annuals largely disappeared from Big Marsh. This is consistent with a trend observed for Coastal Dry Saltmarsh, summarised by Sinclair (2010); "A wide range of annual species can be present in relatively intact sites, but since the 1980s these have been largely displaced by invasions of introduced species, notably Sea Barley-grass *Hordeum marinum*."

While the precise cause of this change in vegetation composition and diversity at Big Marsh has not been established, Carr *et al.* (2002) attributed exotic invasion of this community to reduced salinity, hypothesising that this was caused by declining ingress of seawater into the upper saltmarsh due to flow restriction under 29 Mile Road. Three species of exotic gastropods known to occur in the area may also have contributed to the decline of native annuals (Geoff Carr, pers. comm. 25/02/2020).

Areas mapped by Carr (1982) as *Distichlis distichophylla* (Australian Salt-grass) grassland in 1980, mostly on the western and northern margins of Big Marsh (Figure 4), were by 2002 "eliminated in all locations where previously mapped except for a small area near the T-section lagoon" (Carr *et al.* 2002). "Elimination" in this instance was via invasion and displacement by exotic grasses (e.g. **Lolium, *Bromus, *Phalaris, *Dactylis*).

During the 2000s, in response to the changing vegetation structure, and particularly the invasion of non-native grasses, Parks Victoria implemented a salt application trial. This trial took place across three plots of saltmarsh, where varying concentrations of salt were applied, to ascertain the effects on exotic grasses growing in the saltmarsh, a potential alternative to spraying with chemicals. Initial results of the trial demonstrated potential effectiveness of the approach, but resourcing constraints meant that it was not continued in the longer term (Bernie McCarrick, Parks Victoria, pers comm., 2020).

The reduced extent of *D. distichophylla* grassland observed by Carr *et al.* (2002) is quite consistent with the more recently completed EVC mapping of Sinclair (2010). The *Distichlis distichophylla* grassland described by Carr (1982) is analogous to the EVC Coastal Saline Grassland (CSG).

Sinclair (2010) comprehensively mapped the native vegetation of Big Marsh but did not recognise most of the formerly described *Distichlis distichophylla* grassland as native vegetation any longer (Figure 4). However, an area of Wet Saltmarsh Herbland / Coastal Saline Grassland complex was mapped abutting the T-section ponds, consistent with the statement from Carr *et al.* (2002).

While Carr *et al.* (2002) attributed the loss of Coastal Saline Grassland from Big Marsh to the cessation of sheep grazing, our observations during field studies suggest that light sheep grazing currently occurs throughout the Barro Group property, which includes both areas where Coastal Saline Grassland persists and from where it has been displaced. Given its persistence adjacent to the T-section ponds, it is also possible that the loss of Coastal Saline Grassland from other areas has, at least in part, some relationship to hydrology.

4. Fauna

The Spit was historically recognised as a hotspot for the critically endangered orange-bellied parrot (OBP), *Neophema chrysogaster*, but they have not been observed feeding or roosting at The Spit, despite recent releases of captive bred birds adjacent to the reserve (in Melbourne Water grassland area between Big Marsh and 29 Mile Rd) and follow up monitoring, including radio tracking (Peter Menkhorst, pers. comm., 11/12/19). The use of the saltmarsh by blue-winged parrots (*Neophema chrysostoma*) and a very common saltmarsh bird, white-fronted chat (*Epthianura albifrons*), has also declined over this period (Richard Loyn, pers. comm., 1/8/20). In the late 1970s hundreds of chats were sometimes observed at Big Marsh but now only small numbers are seen.

The decline in OBPs has been recorded in various reports and studies conducted over the past 40 years. Prior to 1980, OBP's were known to regularly feed in areas of grazed saltmarsh in The Spit west of 29 Mile Road (Woodward *et al.* 1996), while the saltmarsh to the east of the road was a regular roosting area for the species (Richard Loyn, pers. comm., 28/11/19). Favoured feeding areas were the EVC Saline Aquatic Meadow and Carr's 6/7 community of *Tecticornia halocnemoide*s and *Sarcocornia quinqueflora* with lots of bare saline mud (Peter Menkhorst, pers. comm. 22/7/20).

Following the cessation of sheep grazing in 1979/1980 there was an initial increase in OBP abundance observed in the upper saltmarsh (Richard Loyn, pers. comm., 28/11/19). In 1981, fifty OBP were recorded using the upper saltmarsh (western section) (Carr *et al.* 2002). However, there was a steady decline over the next decade and OBP use of the upper saltmarsh declined and feeding appeared to shift to the saltmarsh east of 29 Mile Road (Richard Loyn, pers. comm., 28/11/19). Suggestions linking the removal of sheep grazing at the time with these declines, led to the initiation of grazing trials, but the results were inconclusive (Richard Loyn, pers. comm., 28/11/19).

Despite the documented decline and now apparent absence of OBPs from the site, The Spit remains an important site for other fauna, including blue-winged parrots (*Neophema chrysostoma*) and brolga (*Grus rubicunda*) (Peter Menkhorst, pers. comm., 11/12/19). In what is considered atypical behaviour, brolga were observed nesting in the saltmarsh habitat of The Spit, west of 29 Mile Road during the Millennium Drought (Will Steele, pers. comm., 20/2/19).

Another species which has been recorded in the saltmarsh habitat (in approximately 2001), despite its typical preference for freshwater habitat, is the nationally vulnerable Growling Grass Frog (*Litoria raniformis*) (Geoff Carr, pers. comm.). This species is well established in the Western Treatment Plant lagoons and drains (DELWP 2018), including the central drain through the T-section lagoons (Will Steele, pers. comm., 02/2019).

The expansion of *L. raniformis* into The Spit NCR may have been an episodic response to temporary freshening of the saltmarsh, in the area adjacent to the T-section, which occurred when surface flows were redirected into the area from an adjacent drain on Melbourne Water land in approximately 2001-2002. These past hydrological changes will be explored later in more detail.

The Altona Skipper butterfly has also been recorded at the site (Brett Lane and Associates 2006).

5. Background and a general introduction to site history

5.1. 1800s: Original character of the landscape around The Spit

The pre-European condition and subsequent changes to the biodiversity values of the land in the vicinity of Geelong has been the subject of ongoing interest and discussion by a number of authors (for some good recent examples and wide range of further references, please refer to Jones and Roös (2019).

The rapidly growing settlements of Melbourne and Geelong were a frequent point of early migration to this newly formed mainland European colony from the 1830s. As a result, Port Phillip Bay itself also happens to be an area where the arrival of squatters with their livestock and the dispossession and disruption of life for the Wadawurrung Traditional Owners was especially comprehensive and rapid. The subsequent transition to forms of private land tenure that we are familiar with and have inherited today also took place much earlier than many other parts of the state. All of these factors can influence the reliability and accuracy of information we assess to tell us exactly what the landscape was like. What we do know however with increasing certainty and clarity, is that this is a landscape that was actively managed and shaped by the Traditional Owners, often in such a way that favoured grassy vegetation communities. Ironically this is the very character that made the land especially attractive for Europeans to forcibly occupy and utilise for their grazing livestock. For an excellent, very detailed analysis that demonstrates vegetation changes over time and the influence of Aboriginal land management practices to the south at the nearby Bellarine Peninsula, please refer to Lunt (1998).

There are a large number of small fragments of information contained within many early descriptions of the general area around The Spit (from the first-hand accounts of early European observers), but so far none of these have revealed a detailed description of the saltmarsh in the project area. However, in order to provide a general picture of the original character of the land in the vicinity of the project site, we'll take a few early perspectives, and set them against the backdrop of the earliest written account of Matthew Flinders, who trekked on foot through this general area in May 1802.

In 1802, Matthew Flinders first landed on the opposite side of Port Phillip Bay (where he climbed the peak he named *Arthur's Seat*) to record observations of his surroundings, before later setting off with provisions to last three days in a smaller vessel with crew to explore the rest of Port Phillip Bay (Flinders 1814).

On the 30th of April 1802 he was approaching the western shore of Port Phillip Bay, where he said:

> "*At noon, I landed to take an observation of the sun… my position being nearly at the northern extremity of Indented Head. Some bearings were taken from the brow of a hill a little way back; and after a dinner of which the natives partook, we left them on friendly terms, to proceed westward in our examination. The water became very shallow abreast of a sandy point, whence the shore trends nearly south-west; and there being no appearance of an opening to the sea this way, I steered across the western arm, as well to ascertain its depth as with the intention of ascending the hills lying behind the northern shore. Two of the peaks upon these hills had been set from the ship's deck at sunset of the 25th, at the distance of thirty-seven miles; and as their elevation must consequently be a thousand feet, or more, I expected to obtain from thence such a view of the upper parts of the port, as would render the coasting round it unnecessary.*
>
> *The width of the western arm was found to be six miles; and the soundings across augmented regularly to 6 fathoms in mid-channel, and then decreased in the same way; but there was less than 3 fathoms at two miles from the northern shore. That side is indeed very low and marshy, with mud banks lying along it; and we had difficulty in*

> *finding a dry place to pitch the tent, and still more to procure wood wherewith to cook the ducks I had shot upon the banks."* (Flinders 1814)

While this appears to be a little further around the coast to the west (within Corio Bay) from our project location, it is clearly nearby. From his description, we can ascertain that this area was not generally covered with woody vegetation suitable for burning – which indicates a lack of trees and larger shrubs. This was confirmed the next day, on the 1st of May 1802, when the party set off towards what is now called the You Yangs:

> *"At day dawn I set off with three of the boat's crew, for the highest part of the back hills called Station Peak. Our way was over a low plain, where the water appeared frequently to lodge; it was covered with small-bladed grass, but almost destitute of wood, and the soil was clayey and shallow."* (Flinders 1814)

This description of the landscape adjacent to the saltmarsh is shown in the map of Flinders exploration of Port Phillip Bay (Figure 5).

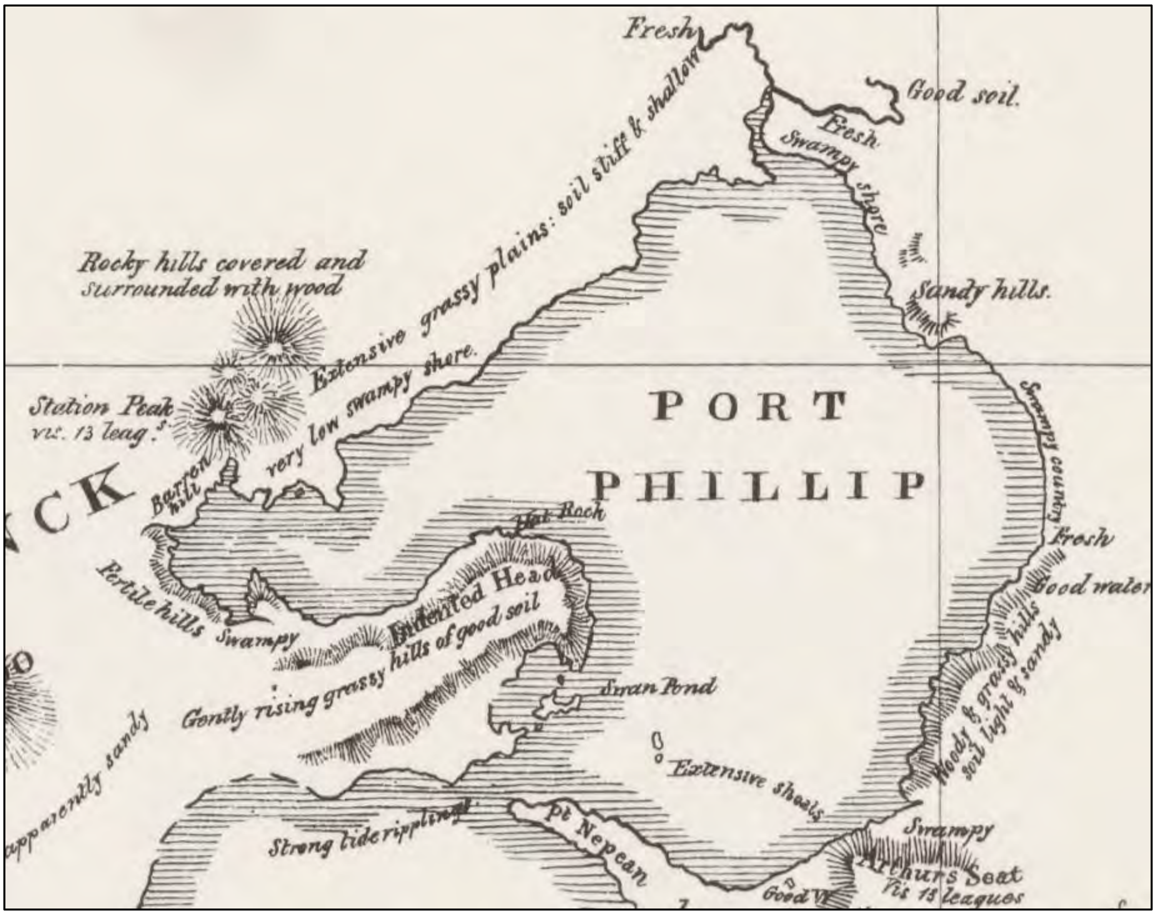

Figure 5. Inset of Matthew Flinders' "Chart of Terra Australis"

This is also consistent with the annotations made on a more detailed map drawn by Acting Surveyor General of NSW, Charles Grimes, who was sent to assess Port Phillip a year later. He noted this area of land was "Swampy in general near the shore, grassy plains back to the foot of the Mountains. The soil very bad and stony. No Timber." (Grimes 1803)

Returning to Matthew Flinders' account, as he approached the You Yangs on the 1st May 1802, he said:

> "*One or two miles before arriving at the feet of the hills, we entered a wood where an emu and a kanguroo were seen at a distance; and the top of the peak was reached at ten*

o'clock… Towards the interior there was a mountain… eleven leagues distant; and so far the country was low, grassy, and very slightly covered with wood, presenting great facility to a traveller desirous of penetrating inland. I left the ship's name on a scroll of paper, deposited in a small pile of stones upon the top of the peak; and at three in the afternoon reached the tent, much fatigued, having walked more than twenty miles without finding a drop of water." (Flinders 1814)

Reaching that peak provided Flinders with a great vista that people continued to visit over the years (and still do today). Fortunately, one of those relatively early visitors was landscape artist Eugene von Guérard in 1858 (Figure 6).

Figure 6. "View of Geelong, the Corio Bay and Indented Heads from the southern declivity of Station Peak" by Eugene von Guérard in 1858. Geelong is in the right of image and the project area is beyond the open plains in the far left of the image.

Despite over 20 years of sheep grazing since the 1830s and significant changes in land use, the general landscape character at this time still seems to broadly fit with the descriptions by Matthew Flinders almost six decades earlier.

Beyond these descriptions, of note, the plains in the specific vicinity of our project area correspond with a very clear gap in the formally mapped and defined pastoral runs that otherwise existed more or less continuously across most of western Victoria. Considering its proximity to Geelong, and with neighbouring runs nearby to the north (Chirnside and Black Forest) and west (Duck Ponds Station), this is an interesting anomaly that appears to be explained by it being subdivided and offered for private sale earlier than these neighbouring lands, and hence ahead of the majority of Victorian pastoral runs being accurately mapped in the 1850s. Outstations belonging to Henry Grass and Sons, and another to Daniel North and W Grass have been noted in the vicinity of the Spit on the earliest maps of the area. These references are corroborated by depasturing licences in the Port Phillip District re-issued to these gentlemen, as recorded in the Port Phillip Government Gazette of 22nd of October 1844, implying this land had already long been occupied and grazed (as would be expected based on its location) prior to being resumed and offered for private sale.

Land in the vicinity of Point Wilson and The Spit was later sub-divided and offered for public sale in December 1849 (as opposed to a grazing licence where the Crown retained ownership), and all five lots in the Parish of Murtcaim were purchased by James Walsh (Argus 1849). The bulk of the saltmarsh in the project area falls partly within Lot 4 (see top right corner of Figure 7).

Figure 7. Lots 1-5 in the Parish of Murtcaim, which includes part of the project area, were purchased by James Walsh in 1849 (Map is from Garrard and Shaw (1850)).

The remaining northern portion of the Parish of Murtcaim was eventually subdivided and sold in December 1854, when James Austin and Henry Phillips purchased the remaining lots in the project area (Geelong Advertiser and Intelligencer 1854). A map produced around that time captures a little more useful detail of the project area; an era when the land, despite being grazed, had not yet been drastically modified. This is the earliest map we have been able to source that illustrates the broad extent of saltmarsh at The Spit (Figure 8 and see Figure 9 for the entirety of the coastline to Little River).

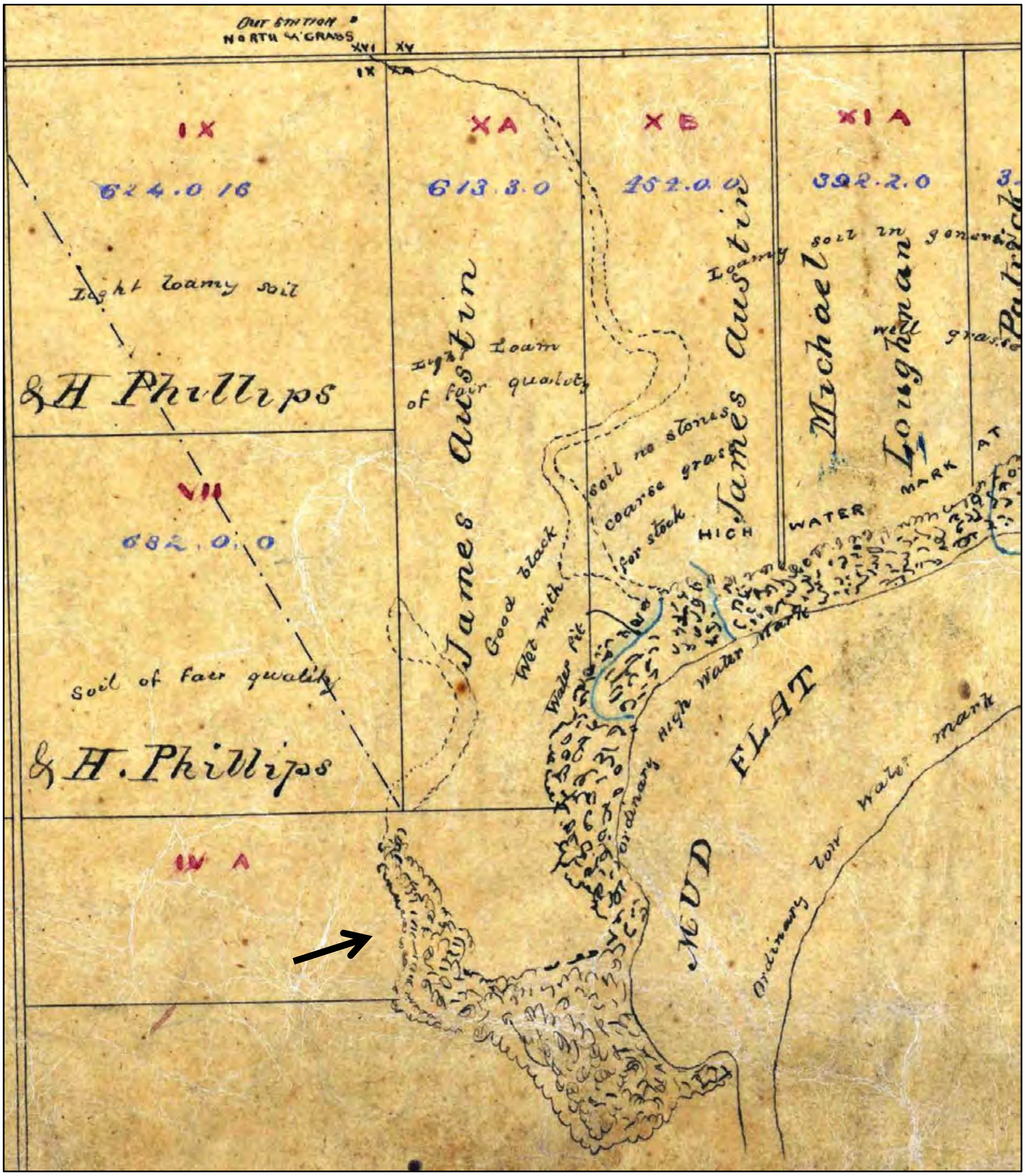

Figure 8. The Parish of Murtcaim in c. 1854, showing the extent of the saltmarsh in the project area. A larger portion of this map is reproduced in over the page.

The Big Marsh area is very clearly mapped (marked with an arrow above), as is an interesting extended (apparent feeder) waterway or saltmarsh area to the north. This will be explored in more detail later. Otherwise, the general view of the wider open surrounding landscape appears consistent with other earlier accounts.

Figure 9. The Parish of Murtcaim in c. 1854, full map

5.2. Early 1900s: Melbourne's expansion and the Western Treatment Plant

The history of what was originally called the Metropolitan Sewage Farm, managed by the Melbourne and Metropolitan Board of Works, has been comprehensively documented by other authors (e.g. Penrose 2001) and will not be expanded upon greatly here.

In brief, the development of the sewage farm in the 1890s was a massive project, necessitated by the need to safely address the health problems associated with the volume of human waste being generated by a rapidly growing population in Melbourne. The sewage farm development started in the north, initially on land at Werribee purchased from the Chirnside family (in what had been their pastoral run since 1853), and was expanded gradually over the years to keep up with population growth in Melbourne. The extent of the sewage farm in 1916 is shown in Figure 10.

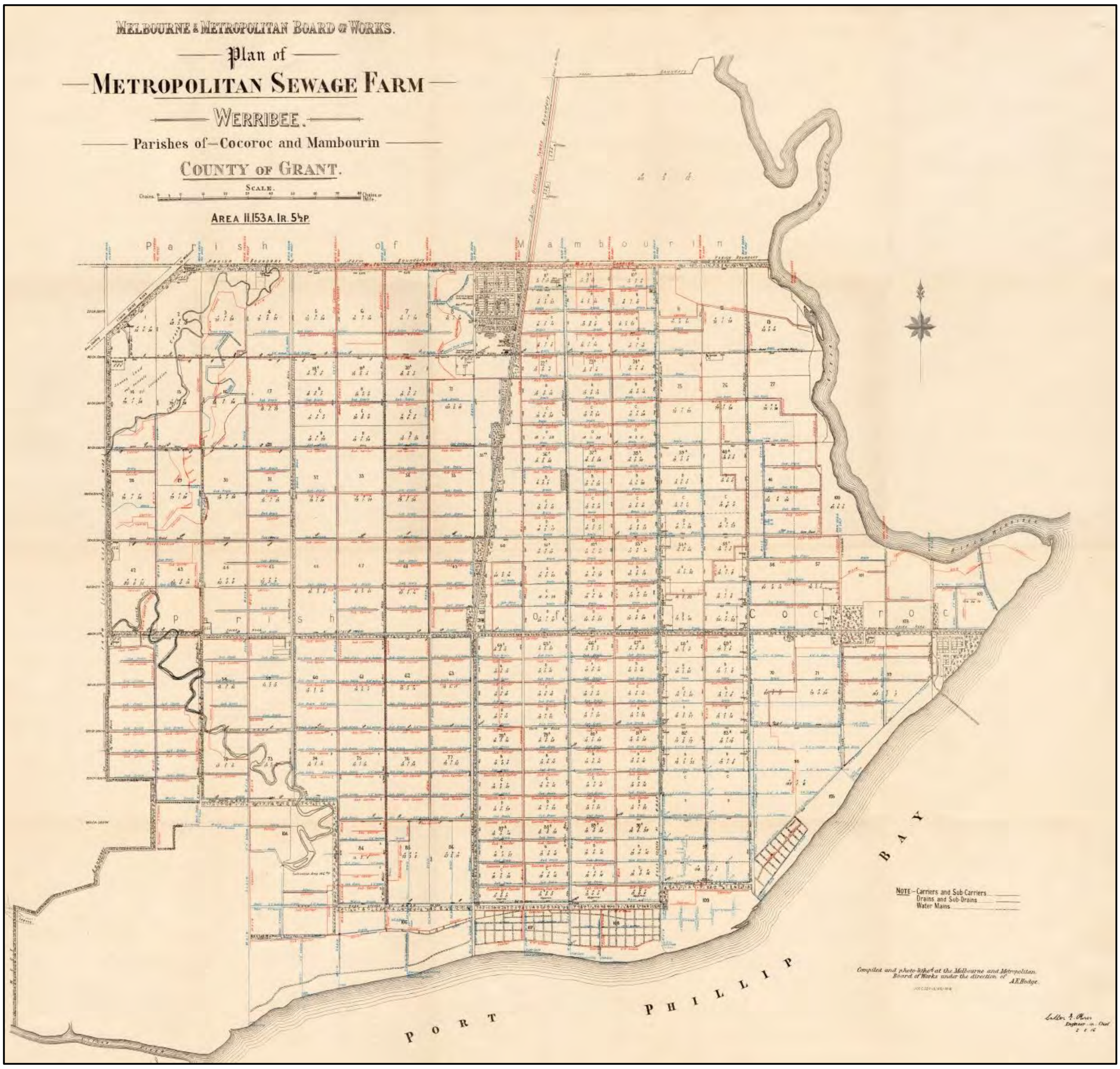

Figure 10. The Metropolitan Sewage Farm in 1916. Map courtesy of Schott (2020).

The final major expansion of the sewage farm to the south and west in the 1910s and 1920s resulted in the land adjacent to the Big Marsh project area being purchased (Figure 11). This had previously formed part of the Austin family's Avalon Estate which, until it was subdivided in 1907, extended from Little River to Lara and then south to Corio Bay (Bacchus Marsh Express 1907), taking in the project area at The Spit.

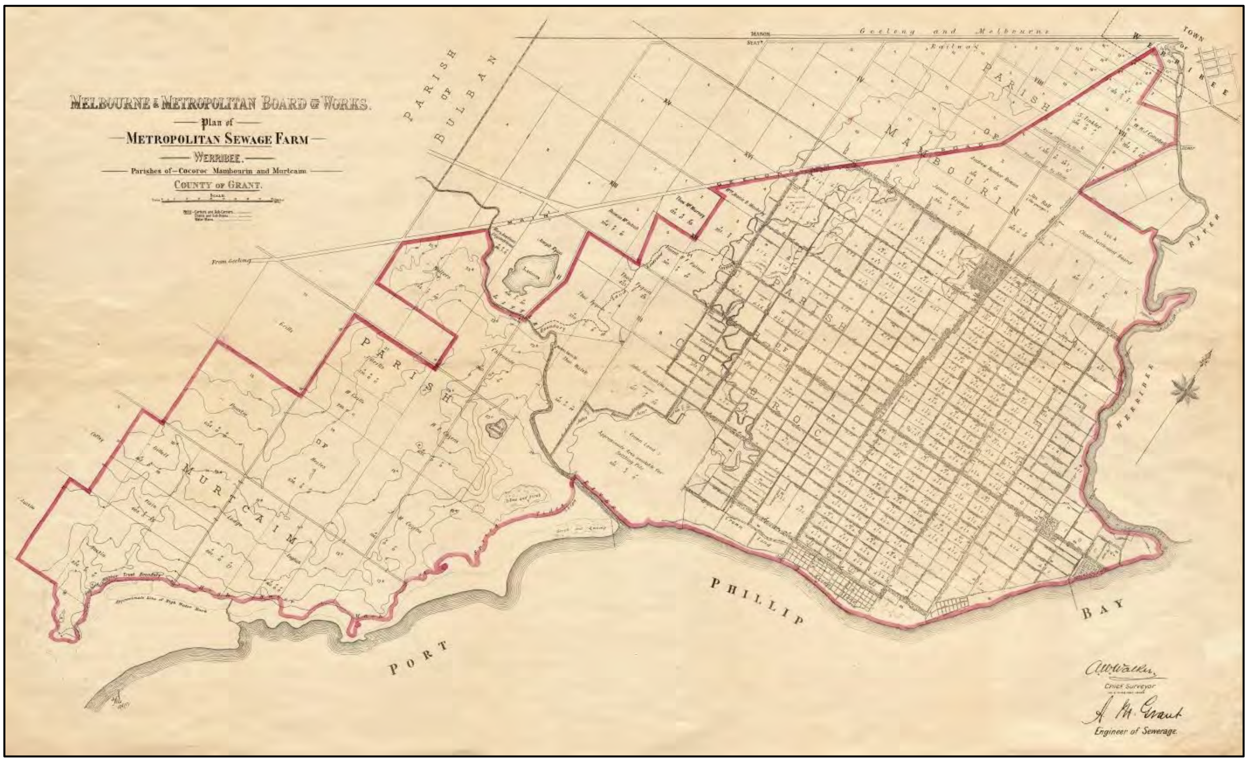

Figure 11. The Metropolitan Sewage Farm in 1916. Map courtesy of Schott (2020).

The way the sewage farm has been managed over time has changed significantly as a result of the evolution in technologies used to treat wastewater. This means that not only were the newer parts of the farm developed differently to the older sections, but it also means that the overall configuration of the treatment plant has significantly changed over time, as can be seen by comparing Figure 11 and Figure 12.

Figure 12. The Western Treatment Plant in 2020. Image from Google Earth. Same extent as previous Figure.

5.3. Late 1900s: Protection of environmental values in the vicinity of Big Marsh

There has long been recognition of the environmental values across both the Western Treatment Plant and the adjacent coastal Crown Lands of The Spit. The former has seen various forms of increasing recognition and protection since the first parts of the site were set aside as a native fauna sanctuary in 1921 (Penrose 2001). The latter was dedicated as a Nature Conservation Reserve.

Together in the vicinity of Big Marsh both sites, along with areas of adjacent neighbouring private land, were also given additional recognition in 1980 within the Murtcaim Wildlife Area Agreement. The bulk (but not all) of this Wildlife Area is now within the boundary of the much larger Ramsar site, which came into effect in 1983 (Figure 13).

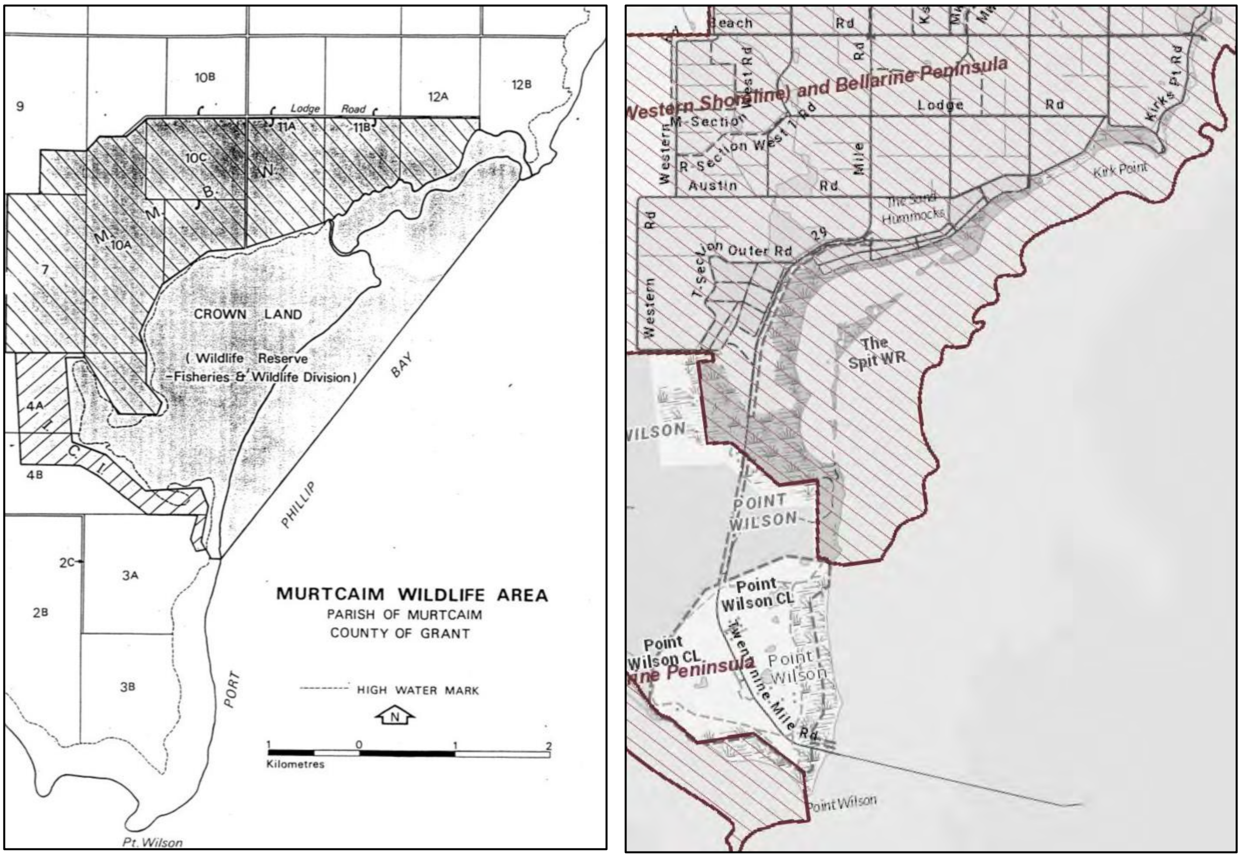

Figure 13. The 1980 Murtcaim Wildlife Area Agreement (left), and the Ramsar site today (right), in the vicinity of The Spit and the saltmarsh habitat of Big Marsh.

The areas of the treatment plant adjacent to Big Marsh are known as the T-section paddocks and lagoons (noting that all paddocks across the farm were systematically labelled from north to south according to the alphabet (Figure 14). The T-section lagoons (shown in detail later in Figure 16) were commissioned in 1973.

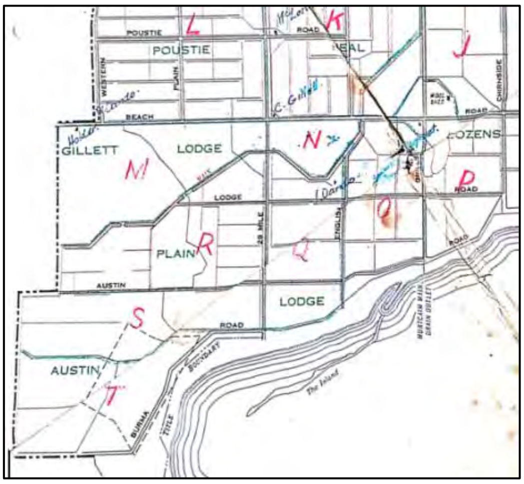

Figure 14. Right.
T-section is at the very far southern portion of the Treatment Plant, adjacent to Big Marsh.
Map courtesy of Schott (2020).

The lagoons in this portion of the treatment plant are now managed specifically to provide environmental values to support the wide range of wetland dependant species that utilise the Ramsar site (W. Steele pers. comm. 2019). Nearby, immediately adjacent to the coast, this has also included some work over the past decade to rehabilitate saltmarsh habitat by removing artificial banks that were impeding tidal flows, and removing sediment, accumulated from its previous use as treatment lagoons, with some excellent results (Figure 15).

Figure 15. Restored saltmarsh habitat on Melbourne Water land approximately 2 km north-east of Big Marsh.

On the basis of Melbourne Water's ongoing commitment to biodiversity outcomes, the possibility of sympatheic management of the T-section paddocks and lagoons has been taken into account in this options assessment, and as reflected in the dicussions that have taken place with Melbourne Water staff.

6. Past catchment modifications

Based on the sequence of historic events outlined in the previous section, for the majority of its early history (prior to the 1920s) the main impact upon Big Marsh introduced after European colonisation was sheep grazing. While this is likely to have caused changes to vegetation composition and structure, and also potentially soil characteristics in the catchment for the site, more significant impacts were yet to come. Throughout the mid-late 1900s, as various forms of more intensive development occurred nearby, the range of eco-hydrological threats emerged and these continue to impact the site today. These are explored in this and subsequent sections.

The extent and characteristics of saltmarsh within The Spit are indicative of a tidally influenced seawater expansion zone, transitioning through different salinity gradients in response to also receiving hydrological contributions from rainfall fed, freshwater surface inflows. A minor watercourse, arising in the vicinity of what is now the Avalon Airport and referred to hereafter as "Avalon Creek", would have historically directed seasonal freshwater flows into the saltmarsh habitat in the vicinity of The Spit, but for several decades has been intercepted by a boundary drain around the edges of the T-section paddocks (Figure 16).

Figure 16. The location of the minor seasonal watercourse, named here as Avalon Creek, and the T-section lagoons in the centre/top of the image. The red arrows show the direction of flow down the drain that intercepts Avalon Creek (blue arrow)

The general appearance of this minor watercourse on the ground, looking west from the boundary of Melbourne Water land, is shown in Figure 17.

Figure 17. Looking west up Avalon Creek, a minor seasonal watercourse whose natural path is intercepted at the western boundary of the T-section treatment paddocks. The concrete spillway prevents erosion where the flows reach the boundary drain. Natural flow direction is shown in blue arrow, before reaching the perimeter drain and being diverted away (red arrow).

Beyond this point to the east, the precise original route of Avalon Creek on Melbourne Water land can no longer be ascertained on the ground as a result of the significant earthworks and levelling that was done many decades ago to prepare the T-section paddocks for sewage treatment (this work pre-dates the earliest aerial photography in 1947). However, by assessing a range of historic sources in conjunction with modern tools, we can interrogate the sources of information available and significantly improve our level of confidence in determining its original route.

Firstly, a direct comparison between the 1854 survey and modern aerial photography is shown in Figure 18.

Figure 18. The 1854 survey (left) and the transparent overlay of that survey on the modern aerial image (right)

This analysis reveals some interesting general insights, as well as clues about the path of Avalon Creek:

- The area of saltmarsh mapped along the coast has barely changed since 1854.
- Of note, there is no distinction in the way the saltmarsh is mapped either side of where the 29 Mile Road is now situated.
    - Note: The matter of this road, which is one of the unresolved hydrological issues that precipitated the need for this project, is explored in detail in the next section of this report.
- West of the road, the lower (eastern) portion of Big Marsh (within the present-day Nature Conservation Reserve) is mapped, but the dry saltmarsh (the western portion, higher up the elevation gradient) is not.
    - Note: One possible explanation is that this simply reflects the fact that the surveyor well understood the upper limit of tidal influence, which appears to have been mapped quite accurately.
- While Avalon Creek is not mapped (probably because it is such a minor watercourse), there is a clearly defined “northern arm” of either saltmarsh or wetland habitat seamlessly adjoining the lower saltmarsh of Big Marsh (see dotted line circled in Figure 18).
    - Note: Like the other watercourse in the image, this indicates a zone of wetland vegetation potentially above the lower saltmarsh zone and outside of tidal influence.
- Low points in the T-section lagoons overlay perfectly with parts of the apparent flowpath demarcated by the “northern arm”.
- Both watercourses shown in 1854 have been significantly disrupted as a result of the creation of the S-section and T-section paddocks and lagoons.

Next, we’ll assess the same area using a high resolution Digital Terrain Model (DTM) based on LiDAR, as well as the earliest aerial photograph we have for this area from 1947 (Figure 19).

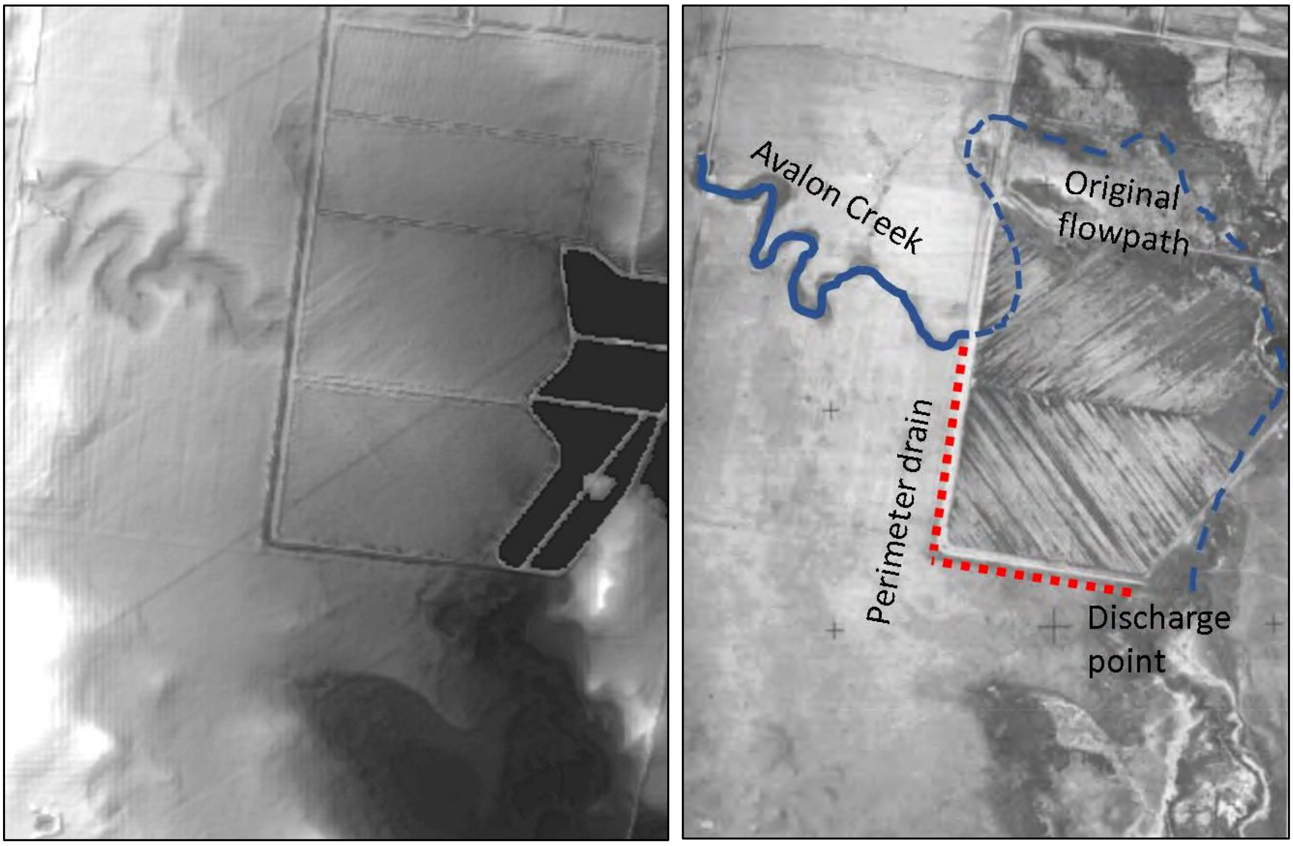

Figure 19. Modern Digital Terrain Model (left) and historical aerial imagery from 1947 (right) showing development of infiltration paddocks and diversion of Avalon Creek. The inferred original flowpath is marked on the 1947 image, and the red dashed line shows the alternative pathway for flow down boundary drains around the T-Section paddocks.

Based on the DTM, the 1947 image and the analysis of 1854 survey diagram, it appears most likely that:

- the original route of Avalon Creek was sinuous and meandering across the S-section and T-section paddocks, before swinging south and connecting into the "northern arm" mapped in 1854.
- the gentle gradients involved, explain the lack of an obvious "watercourse" in the information sources and why work on those paddocks have made the watercourse so difficult to now define – hence the blue dotted line is indicative only and broad, shallow, slow moving sheet flows along this alignment were highly likely.

Over the last century, there have clearly been a number of changes to the alignment of Avalon Creek. The earliest available aerial imagery (1947) shows that infiltration paddocks had already been constructed by this time. Flows from Avalon Creek were diverted via a perimeter drain around these paddocks and discharged via a concentrated point source into the north of Big Marsh.

Development of the Avalon Creek catchment, in line with establishment of Avalon Airport and surrounding industrial and commercial areas, has likely reduced permeability and contributed to higher runoff which, combined with the perimeter drain diversion, is capable of leading to inflows which are flashier and more episodic than may have originally occurred. However, despite this, complete inundation of the site is considered extremely rare, having only been observed once in the past 40 years (Geoff Carr, pers. comm. 14/11/19).

Having constructed the T-section paddocks and later (by 1973) the T-section lagoons, a series of ongoing alterations to site hydrology along the northern margin of Big Marsh became possible as a result of the discharge and/or impounding of water in this area. Further consideration of the potential impacts from the range of hydrological changes that this caused is provided in subsequent sections.

6.1. Summary of the Timeline of Key Eco-hydrological Events at Big Marsh

1920s: T-section and surrounding land added to the Western Treatment Plant.

Pre-1947: T-section infiltration paddocks constructed (as per aerial image). Flows from "Avalon Creek" contained within the original perimeter drain around infiltration paddocks and discharged as a point source into the north of Big Marsh.

Mid 1950s: 29 Mile Road culverted and causeway constructed across The Spit saltmarsh (Carr *et al.* 2002) on the location of an existing track through the saltmarsh that was present well before 1947.

Late 1960s: At some point after 1963 but before 1970 (based on aerial photos) the perimeter drain diversion is constructed and flows are diverted away from Big Marsh and back through internal drains in the MW T-section area of land.

1973: T-section lagoons commissioned (Penrose 2001).

1977: ICI propose petrochemical plant adjacent The Spit, initiating the Victorian Government planning process and the first organised OBP winter counts at Big Marsh (Brown and Wilson 1984).

1979: Sheep grazing ceases (Loyn *et al.* 2010).

1980: Saltmarsh vegetation mapped and transects established (Carr in Kinhill, (1982). Saltmarsh vegetation in excellent condition compared to today.

1980: More OBPs were observed using the saltmarsh than at any time previously (74 birds, or approximately 50% of the known population at the time) (Orange-bellied Parrot Recovery team unpublished data, cited in Loyn *et al.* (2010).

In 1980 and 1981 the area was also used by many Blue-winged Parrots and an Elegant Parrot for several weeks (forming a single flock separate from the OBP flock most of the time) (Richard Loyn, pers. comm., 1/8/20).

1981: Fifty OBP were recorded using the upper saltmarsh (western section), but they have not been observed there since (Carr *et al.* 2002).

1981-1990: OBP numbers decline (Richard Loyn, pers. comm., 28/11/19).

1991: Study by Carr *et al.* (1991) focussed on habitat requirements of OBP and changes to veg since 1980 mapping.

1998: 29 Mile Road culvert upgrades, increasing the potential capacity for movement of water in both directions.

No restrictions on flows in either direction in place until 2000.

1999-2001: Brolga breeding in Big Marsh (Minutes of the WTP Wildlife Consultative Committee, 14 May 2002).

2000-2002: Perimeter drain flows blocked from entering T-section, all flows committed to Big Marsh. This was done due to concerns of *E. coli* entering the saltmarsh from T-section. Triggers temporary changes in fauna observations in Big Marsh (Brolga and Growling Grass Frog). (W. Steele pers. comm.)

2000-2013: Period of active hydrological management of 29 Mile Road culverts with stoplogs. Likely partial flow obstruction still occurring due to stoplogs being in position for the majority of this period.

2001: An uncontrolled fire in January 2001 which originated to the south or south-west, burnt part of the south-western and western parts of the saltmarsh. There was an attempt to control the fire at the time by grading a firebreak in the saltmarsh which resulted in considerable damage (Carr 2001, Carr *et al.* 2002).

July 2002: Carr and MacMillan subjectively assess vegetation changes since 1982. Examined relationship between soil EC and weed cover with mixed results.

Dec 2002: Perimeter drain flows diverted away from saltmarsh and back through MW T-section land. This was done due to concerns of over-freshening and weed invasion of Big Marsh (W. Steele pers. comm.).

2004: Sewage treatment role of T-section lagoons ended, and no more sewage applied to land across the Western Treatment Plant due to change in water treatment techniques. Since then T-section lagoons have received treated water purely to maintain Ramsar values (W. Steele pers. comm.).

2007-2008: Sheep grazing trials conducted to see if habitat quality improves for OBP feeding but results are inconclusive (Loyn *et al.* 2010).

2013-2019: Period of no active hydrological management of 29 Mile Road culverts with stoplogs left in position and potentially causing a partial obstruction of flows.

2017-2019: Captive bred OBPs released at WTP and The Spit for three years in a row, however these birds were not subsequently observed within the formerly favoured areas of Big Marsh.

Nov 2019: All stoplogs removed (during this project) after a period of monitoring water levels both side of the road, to allow for the impact of the stoplogs to be measured and compared before and after removal.

7. Defining and Understanding Site Eco-hydrological Issues

In order to better understand the context for vegetation changes observed at The Spit over the past 40 years, it is necessary to further explore some of the key changes that have occurred to flow patterns, both in terms of freshwater contributions and tidal ingress. These typically relate to physical alteration of the wetland's bathymetry by virtue of engineering modifications, and are described in the following section.

7.1. Flow Restriction, 29 Mile Road

The sharp and relatively uniform ecological boundary corresponding with the location of 29 Mile Road (Figure 20) strongly suggests the road may be having a hydrological effect that is in turn influencing the distribution and composition of native vegetation.

Figure 20. Looking south towards Point Wilson down 29 Mile Road. Note the clear difference in colour of the saltmarsh either side of the road, which illustrates the suddenness of this apparently artificial ecological boundary. To the east (left) is the seaward side under regular tidal influence and to the west (right) is the inland side and Big Marsh.

East of the road the saltmarsh is dominated by dense *Tecticornia arbuscular* (shrubby glasswort), a species typical of lower, wet saltmarsh subject to more or less daily tides (Carr 2012). To the west of the road the dominant shrub is *Tecticornia pergranulata* subsp. *pergranulata* (blackseed glasswort), a species tolerant of hypersalinity (Carr 2012), and there are areas of low shrub density, or lacking shrubs, dominated by *Sarcocornia quinqueflora* subsp. *quinqueflora* (beaded glasswort), and open, unvegetated (when dry) pans in the lowest lying areas.

The abrupt difference in vegetation on either side of the road suggests a different water regime operating, in terms of flows, levels and/or salinity, with the road acting as a clear boundary between two hydrologically distinct zones and little evidence of an ecotone between them.

The 1947 aerial image, showing The Spit prior to the construction of 29 Mile Road and its associated causeway, is compared to the contemporary aerial image in Figure 21. The 1947 image already reveals a clear difference in the vegetation on either side of the future 29 Mile Road alignment. The darker area to the immediate east of the alignment, extending towards the coast, is likely to be dense *Tecticornia arbuscula* shrubland that persists today. To the west of the alignment the vegetation is clearly different, with lighter colours suggesting a much more open structure.

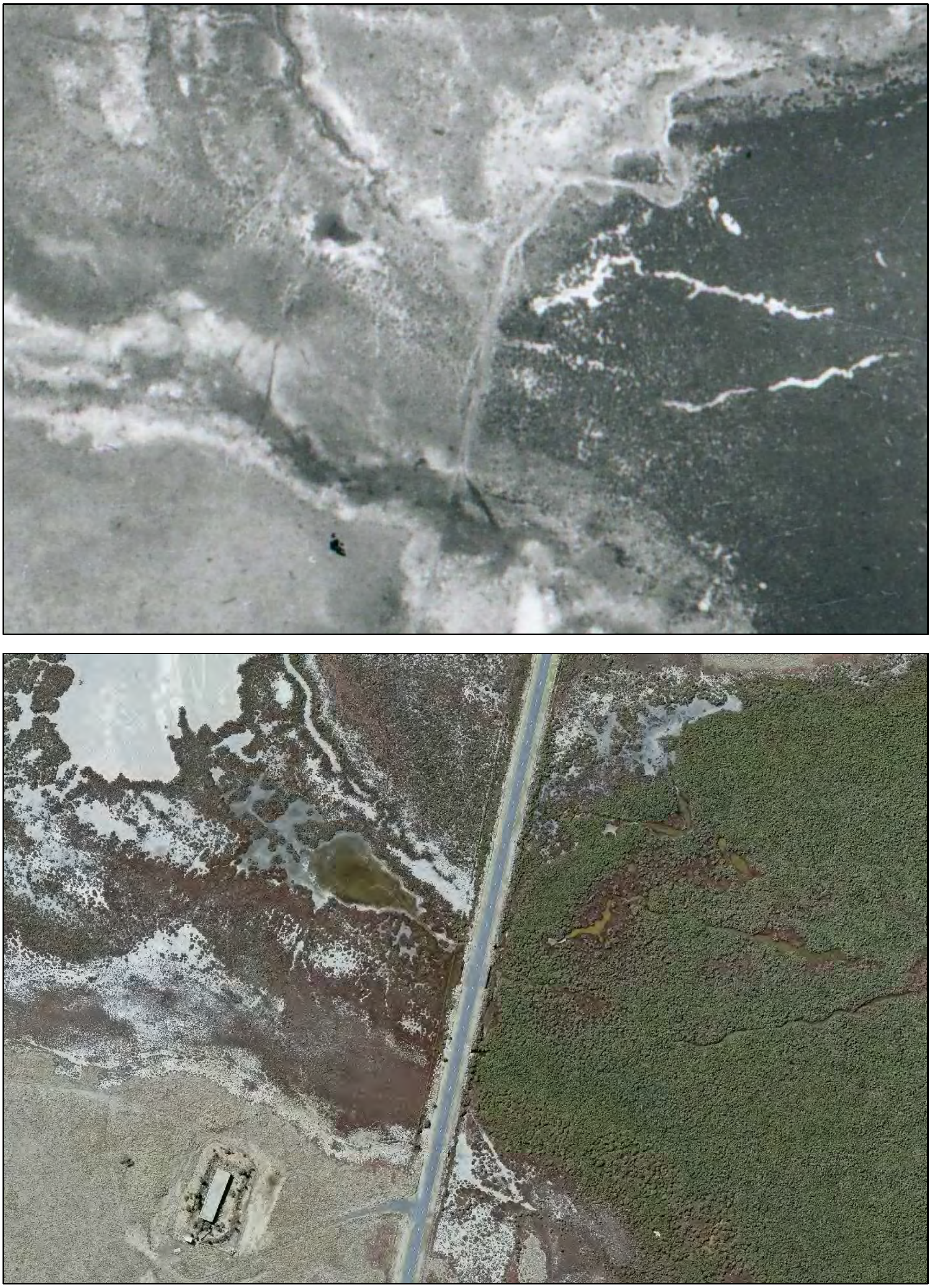

Figure 21. Aerial images of the location of the 29 Mile Road causeway in 1947 (above) and today (below).

Woodward *et al.* (1996) suggested this difference may have always existed due to natural factors. However, the old Point Wilson road/track across the saltmarsh is evident in the 1947 image, in the exact future location of 29 Mile Road. There are many references to road works on the Point Wilson Road in the late 1800s, including the following which is strongly suggestive:

> *"From Messrs Thomas Walsh and Robert Sneddon, calling attention to the very bad state of the Point Wilson road, a portion of which being totally unfit for traffic, and stating that a crossing-place was wanted near Mr Austin's farm, as Mr Bullivant was now fencing his run and the recent track could not be used. The surveyor was instructed to inspect and report at next meeting."*
>
> (Geelong Advertiser 1868)

There are many further references after that date (over a number of decades) to works taking place on the Point Wilson Road. Based on the condition of this swampy ground, the presence of a track to Point Wilson and this supporting evidence, it is highly probable that some form of early, rudimentary causeway or crossing was constructed long before 1947 to facilitate transport.

If that track had been elevated above natural surface for many decades and was causing any impediment to the natural movement of water between the upper and lower saltmarsh, it would explain the vegetation differences that are already evident before the construction of 29 Mile Road in the 1950s.

29 Mile Road was constructed in the mid-1950s and included an elevated 320 metre long causeway across saltmarsh habitat at The Spit. The causeway initially featured four box culverts (Mueck *et al.* 2007), but it appears from the available aerial imagery (Figure 21) that, despite these culverts being in place, 29 Mile Road has caused a prolonged restriction to water movement, affecting both the water and salinity regime of the upper saltmarsh.

A study undertaken on behalf of ICI Australia Ltd in 1979, to inform the environmental assessment for a proposed petrochemical plant at Point Wilson, found that the 29 Mile Road causeway was preventing all but the highest of tides to penetrate into the inland saltmarsh (Woodward *et al.* 1996).

The 1996 report of the Commonwealth Commission of Inquiry into the proposed East Coast Armaments Complex at Point Wilson (Woodward *et al.* 1996) includes the following quote attributed to a member of the Orange-bellied Parrot Recovery Team:

> *"The main concern with the* [29 Mile] *road is in fact the causeway and the manner in which it impedes tidal flow and so the saltmarsh, which is on the inland side of the road is, we think, not getting the natural regime of flooding that it should be getting and the quality of the saltmarsh vegetation is slowly and steadily degrading. So my immediate concern would be that the causeway be removed or else some engineering be done so that the movement of water in and out of the saltmarsh is not impeded."*

A key finding of the Commission of Inquiry (Woodward *et al.* 1996) stated:

> *"The 29 Mile Road causeway has influenced the hydrology of the wetlands in the Murtcaim* [The Spit] *Wildlife Area and may be contributing to degradation on the inland (western) side of the causeway. Further research is required to determine whether the causeway is contributing to the degradation of salt marsh. The available evidence suggests that engineering works are needed to improve flows."*

This provided the impetus for an upgrade of the 29 Mile Road culverts to improve hydrological connectivity. These works were undertaken in 1998 (Carr *et al.* 2002), resulting in the infrastructure present today. There are currently 12 box culverts under the road, each 1.4 m wide, 1.1 m high and 14.7 m long. As part of our investigations, each of these box culverts was assigned a unique identity number for this study (Figure 22). Culverts 3 - 10 are aligned together in a central location and the remaining four are placed singly and spaced relatively evenly from south to north within the causeway.

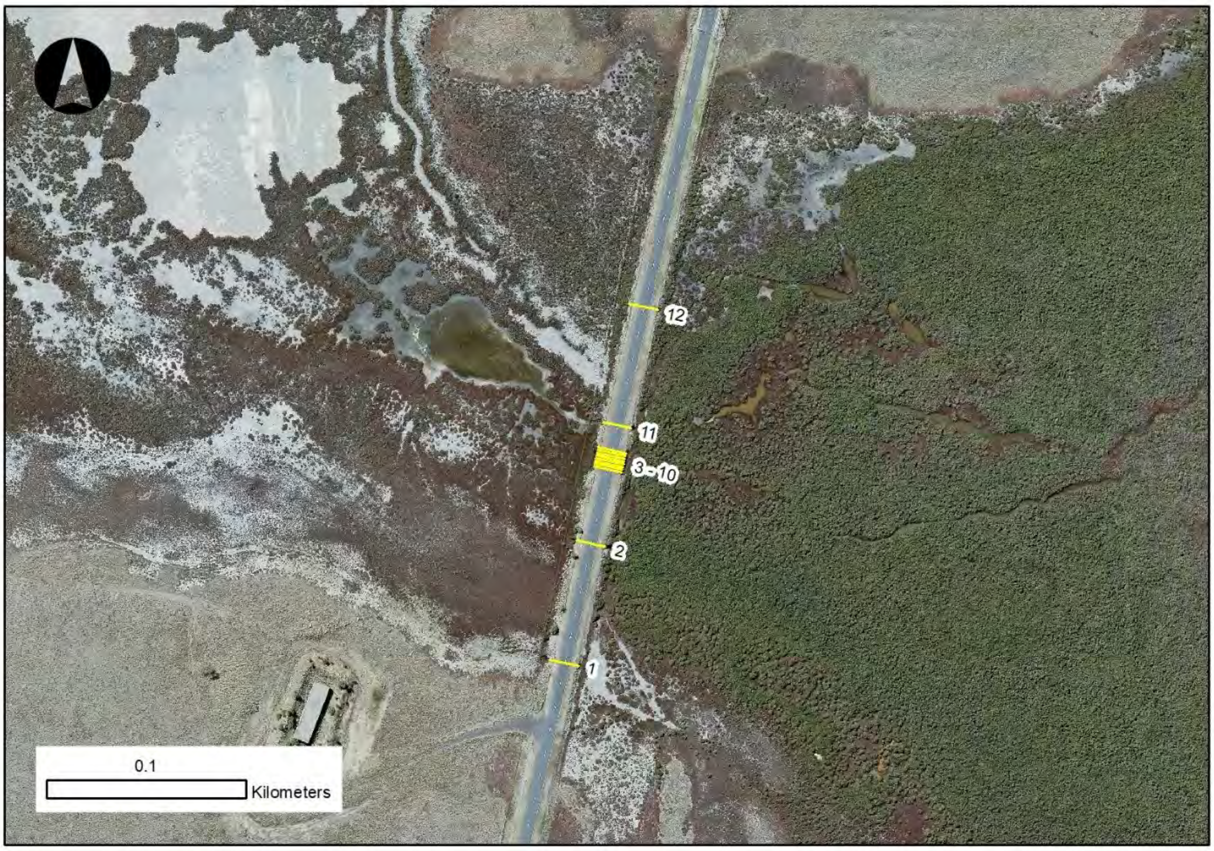

Figure 22. Box culvert identity numbers (for this study) and arrangement, 29 Mile Road.

Despite the culvert upgrades undertaken in 1998, concerns about flow restriction remained. Carr *et al.* (2002) noted that “some areas on the western [inland] side of the saltmarsh are lower than the culvert inverts, thus water entering the western saltmarsh on a rising tide remains ponded after drainage has occurred on the falling tide; more importantly perhaps, freshwater runoff is trapped on the western [inland] side of the culverts”. However, according to Mueck *et al.* (2007), the average invert level of the culverts is 0.23 mAHD, which is generally below the saltmarsh floor. This was interpreted to suggest that the 29 Mile Road causeway poses no elevation barrier to water movement in either direction. Resolving this ambiguity of past investigations was a key objective of the current study.

The concerns outlined above relate to the elevation of the culvert inverts relative to the natural surface and the potential for shallow flows in either direction to be prevented. However, an additional consideration with regard to the influence of the road and culverts is the way in which the 29 Mile Road causeway may influence hydraulics i.e. through a reduced capacity to pass flows, even below higher water levels, well above the elevation of the culvert inverts. By limiting potential flow to just a 12 × 1.4 m (total 16.8 metres) cross sectional length of the saltmarsh, where the saltmarsh is in fact 320 metres wide, the culverts certainly have great potential to reduce the rate and total volume of flows in either direction – which would influence the ability of those flows to result in the equalisation of water levels in the saltmarsh either side in a rapid, responsive way.

Periods of high water, in the form of either very high (king) tides from the seaward side or high runoff and inflows from the inland side, are always likely to be brief in duration, i.e. minutes to hours, not days. Therefore, restricted capacity could reduce the volume of seawater able to penetrate the upper saltmarsh during the high tide event, resulting in lower water levels and frequency of inundation in the upper saltmarsh than would occur if the causeway was absent. Similarly, under a scenario of high runoff from inland, such as an intense rainfall event, discharge rates from the upper to the lower saltmarsh may be lower than if the causeway was absent, temporarily causing deeper and more prolonged (and possibly fresher) inundation of the upper saltmarsh. According to Mueck *et al.* (2007), the hydraulic capacity of the 29 Mile Road culverts has been calculated at 26 m^3/s, while the maximum tidal inflow to the dry salt marsh during their 2006 study was 5.8 m^3/s, observed in May. At first glance, this suggests that the overall capacity of the 29 Mile Road culverts is unlikely to restrict these high flows, but does not account for the fact that these tidal movements are a sluggish, fleeting, sheet-flows across a broad area, not a concentrated, point-source flow. Hence this issue requires further investigation. Additionally, a further complicating factor in this interpretation was the attachment of stoplogs to the culverts.

Galvanised frames to support stoplogs were installed on all 12 box culverts by Parks Victoria in 2000 (Mueck *et al.* 2007), i.e. approximately 2 years after the 1998 culvert upgrades, and were actively operated from installation until approximately 2013 according to records provided by Parks Victoria employee Bernie McCarrick, who was responsible for operations during this period. The intention was to improve the condition of vegetation in the upper saltmarsh by overcoming the perceived impact of 29 Mile Road in restricting seawater movement from east to west (despite the upgrade that had recently occurred in an attempt to address that issue) and freshening caused by runoff being diverted into the saltmarsh from Melbourne Water land.

As discussed previously (see Section 3), in the early 2000s the application of crystalline salt to the saltmarsh was trialled as a weed control measure (Bernie McCarrick, pers. comm.). Minutes of the WTP Wildlife Consultative Committee Meeting of 18 February 2004 suggest that the application of salt was viewed as a weed control measure and had some success in this regard. However, the minutes of the WTP Wildlife Consultative Committee Meeting of 2 May 2006 indicate that by this date the salt trials had ceased because "Melbourne Water had diverted stormwater run-off away from the Big Marsh, which had done much to alleviate the problem". This refers to the redirection of perimeter drain flows back into the internal drain through the Melbourne Water T-section land (see Section 7.3).

Stoplog operation, in theory, involved dropping stoplogs into place to temporarily retain seawater in the upper saltmarsh after high tides and removal when water levels on either side of the road had re-aligned, in readiness for the next high tide (Brett Lane and Associates 2002). In practice, as indicated by Bernie McCarrick's records and confirmed by John Nolan's recollections, limited stoplog adjustment appears to have been undertaken and stoplogs were simply left in place most of the time, although the precise number and arrangement is not stated in the records.

At the commencement of the current study, stoplogs were in place and left as arranged and described in Table 1 and as shown (partly) in Figure 23. This arrangement closely matches the description of Mueck *et al.* (2007), who noted that all culverts were open except "culvert 3", by which is meant the central group of culverts we have numbered 3 to 10. According to Mueck *et al.* (2007), "Culvert 3 is comprised of 8 box culverts … The northern two and southern three box culverts are closed". The similarity between the arrangement of the stoplogs in 2007 and 2019 suggests this arrangement may have been in place for the entire 12 year intervening period. Furthermore, the records of stoplog operation from 2000 to 2013 suggest this arrangement may have been typical for the entire period 2000 to 2019. Thus, since the upgrade of the 29 Mile Road culverts in 1998 there appears to have been only brief periods without stoplogs in place. Indeed, from at least the mid-1950s when 29 Mile Road was constructed, to the present day, the evidence suggests there has been an engineered impediment to the natural movement of water between the upper and lower saltmarsh almost continuously.

For the current project we investigated the influence of 29 Mile Road upon flows between the lower and upper saltmarsh under a range of water levels both with and without stoplogs in place. We measured water levels on either side of 29 Mile Road with the stoplogs in place (Table 1, Figure 23) and following their removal, which occurred on 13th November 2019 (Figure 24, Section 0).

The removed stoplogs were placed in the T-section Ponds area near the southern edge of Pond 5. It should be noted that at the commencement of the current study, the stoplogs and the slides into which they were positioned, were in a state of disrepair and did not provide a watertight seal. Despite this, we still consider that the overall arrangement had the potential to create a hydraulic impediment and restrict flows under 29 Mile Road.

Table 1. Arrangement of stoplogs, from south to north, at the commencement of study, January 2019.

Culvert no.		No. stoplogs in place	Total height of stoplogs (cm above culvert invert)
1 (southernmost)		0	0
2		1	20
3	central group	5	87
4		5	102
5		4	82
6		1	16
7		1	16
8		1	16
9		5	94
10		4	76
11		1	13
12 (northernmost)		0	0

Figure 23. View of the western (inland) side of culverts 3-10 (right to left), showing stoplog arrangement at the commencement of the study, January 2019.

Figure 24. View of the western (inland) side of culverts 3-10 (right to left) on the day of stoplog removal, 13th November 2019.

In summary, the key questions the current study set out to answer in relation to the 29 Mile Road causeway were:

1. Do the existing culverts impede flow across the natural surface of the saltmarsh, causing water to pond more deeply on either side before flowing, in either direction, under the road?
2. When water levels on either side rise above the culvert inverts, is the combined cross sectional area of the culvert system adequate to pass the flows unimpeded (i.e. allow for immediate equalisation of levels either side)?
3. How does the presence or absence of stoplogs influence point 2 above?

In answering the above questions, the study sought to inform the following questions related to future restoration and management:

1. Do the culvert inverts need lowering?
2. Do additional culverts need to be added?
3. How should the stoplogs be operated, if at all?

The investigation into these questions is described in Section 0.

7.2. Seepage from T-section Lagoons

The T-section lagoons (as opposed to the adjacent much older irrigation paddocks) were commissioned by Melbourne Water in 1973 for the treatment of sewage (Penrose 2001). The lagoons were constructed using a "turkey nest" design in which bunds were built and the natural surface became the submerged bed of each pond. Much of the area now occupied by the T-section lagoons was formerly coastal saltmarsh (Sinclair and Boon 2012), as can be observed in aerial imagery from 1947 (Figure 26) and this is supported by the 1854 mapping (Figure 18).

The lagoons were used for sewage treatment from 1973 to 2004 (Will Steele, pers. comm., 20/2/19). Thereafter, treated water has been supplied to the lagoons for ecological purposes, in keeping with the ecological character of the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site, listed in 1982 and incorporating the lagoons. Water levels in Ponds 3 and 4, those closest to Big Marsh, are maintained approximately 1.5 metres above the natural surface of Big Marsh most of the time (Figure 25), although lower water levels occasionally occur.

Figure 25. Looking west along the bund/boundary track that separates the T-section Ponds 3 and 4 (right) from the Big Marsh (left).

Concerns that the hydraulic pressure created by the lagoons being retained to that depth was causing lagoon water to slowly but continuously leach via groundwater flows into the adjacent saltmarsh have been raised by several authors (Brett Lane and Associates 2006, Carr *et al.* 2002, Nolan-ITU 2005, Woodward *et al.* 1996). The likely effects of this could include a more elevated, fresher and more nutrient enriched permanent groundwater zone within the adjacent saltmarsh, which has the potential to negatively impact the adjacent saltmarsh vegetation which formed under very different conditions.

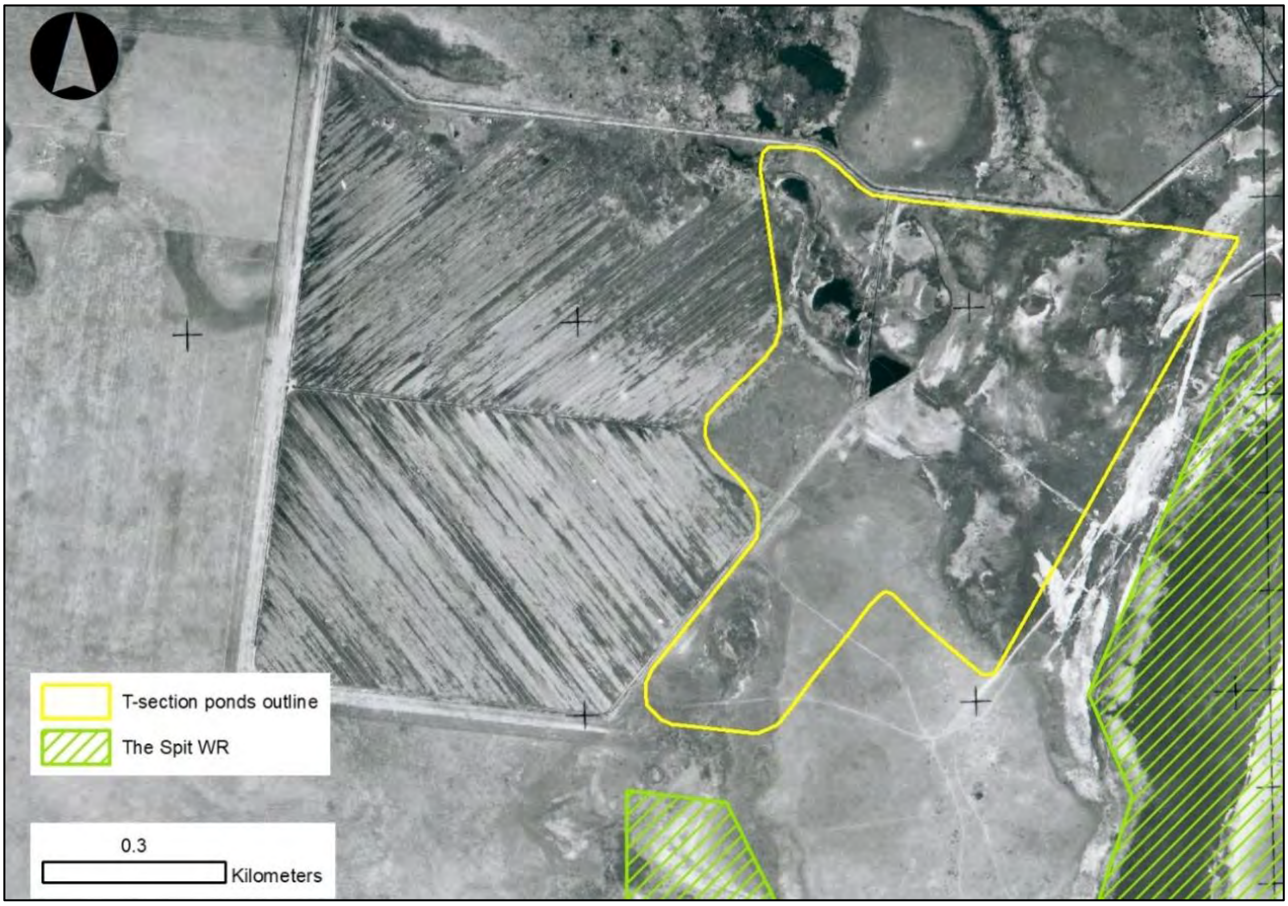

Figure 26. 1947 aerial image showing the future outline of the T-section ponds (yellow polygon) and future extent of The Spit NCR (green hatch) in the vicinity.

Carr *et al.* (2002), in assessing changes to vegetation between 1982 and 2002, noted changes to saltmarsh vegetation in the vicinity of the T-section lagoons and attributed this to:

- continuously available moisture during summer: very abundant, luxuriant, standing dead crop of Hastate Orache (**Atriplex prostrata*) (annual), several large (expanding) clumps of Sea Club-sedge (*Bolboschoenus caldwelli*) (perennial) and abundant growth of Austral Seablite (*Suaeda australis*) and *Distichlis distichophylla*;
- eutrophication: luxuriance of the above species and a prominent filamentous algal bloom; and
- depressed salinity: abundant standing crop of young Water Buttons (*Cotula coronopifolia*).

Nolan-ITU (2005) noted that, to their knowledge "nutrient monitoring of groundwater entering the dry saltmarsh itself from the north is not undertaken. It is however recognised that the total P and total N of the groundwater below the lagoons would be elevated above background levels due to seepage and there is a risk that this may impact upon the dry saltmarsh."

Despite these past concerns, there is very limited data available that directly examines the influence of the T-section lagoons upon groundwater elevation and quality. Therefore, for the current study we investigated the elevation, salinity and nutrient concentration of groundwater in the vicinity of the T-section ponds and whether the effect is attenuated with increasing distance from the ponds. The objective was to inform any requirement for changed management of lagoon levels or indeed whether a set-back distance might be required to reduce the impact upon the saltmarsh. Our investigation is described in Section 9.3.

7.3. Redirection of Streamflow

Prior to the creation of the T-section filtration paddocks, freshwater flows from Avalon Creek would have entered the saltmarsh as outlined in Section 6.

Creation of the T-section filtration paddocks sometime between the 1920s and 1940s necessitated the construction of the perimeter drain, which intercepted inflows from Avalon Creek along the western and southern boundary of the Melbourne Water land. Aerial imagery shows that rather than these flows reaching the saltmarsh via the previous sinuous route (refer to Figure 19 in Section 6), this broad and shallow drain initially discharged flows directly into Big Marsh via a channel that simply graded out to natural surface (Figure 27).

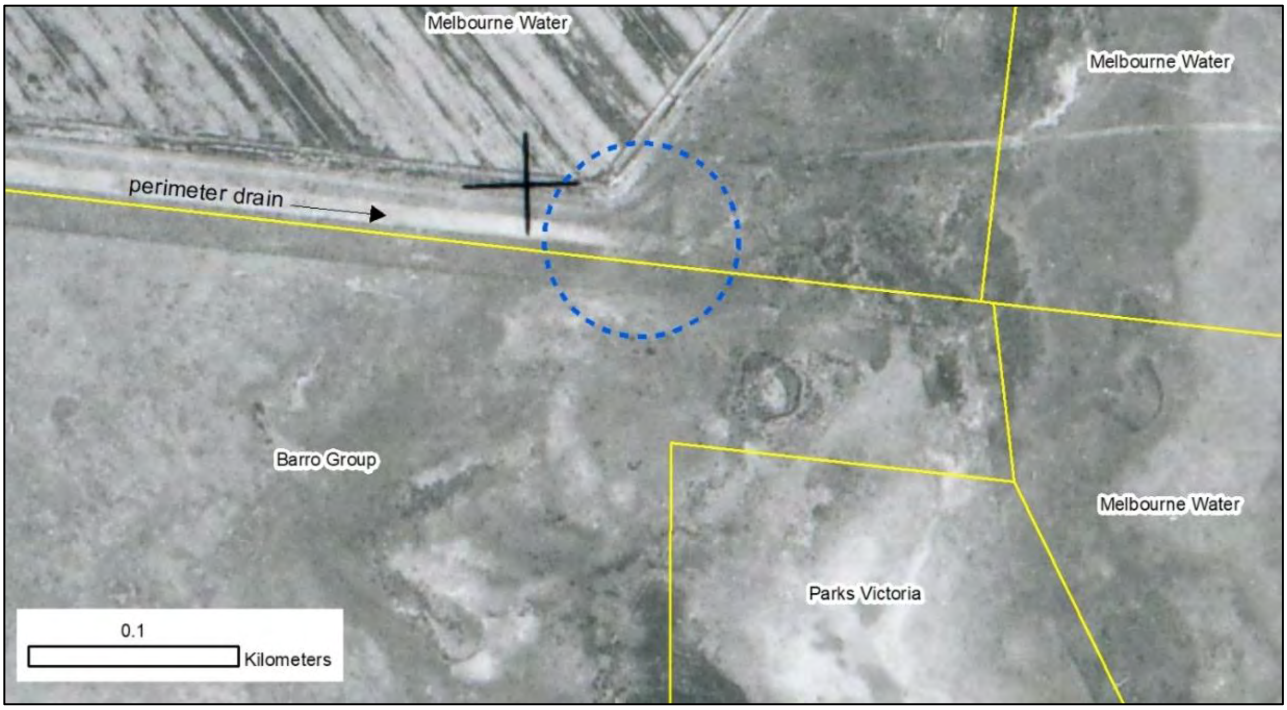

Figure 27. 1947 aerial image showing downstream terminus of perimeter drain (blue circle) within Big Marsh. Contemporary cadaster (yellow lines) and tenure are shown for reference.

Construction of the perimeter drain and channelisation of flows also likely changed the nature of these inflows from more diffuse, broad, shallow flows, with a naturally dampened peak flow rate and an extended duration, to more direct, high velocity and shorter duration flows. The perimeter drain also intercepts and channelises other diffuse overland flows from the adjacent landscape in high rainfall events.

Historic aerial photographs indicate that sometime after 1963, but prior to 1970, the present day concrete diversion structure along the southern perimeter drain was installed (Figure 28). Prior to that point in time, it is reasonable to suggest that all flows from Avalon Creek still entered the saltmarsh directly.

Figure 28. Location of the perimeter drain diversion structure in 1963 (left), 1970 (centre) and 2018 (right). 1970 image quality is poor but the structure is observable, however it is absent in 1963.

The installation of the diversion point also appears to correspond with a change in the design of the diversion drain itself. What would have been the original broad and shallow c. 1940 drain appears to have had a narrow, deeper channel constructed within it around that time (Figure 29).

Figure 29. Looking south along the western perimeter drain that carry inflows from Avalon Creek. The white dotted line shows the profile of what appears to have been the original c. 1940 drain, while the black dotted line is the deeper channel that was constructed within the original drain, presumably c. 1970, around the time the diversion structure was installed downstream.

Drain flows (including Avalon Creek catchment flows) were thereafter diverted away from Big Marsh, back through the T-section central drain and discharged to the sea approximately 3.8 km to the north east, near the intersection of Austin and Grills Roads (Figure 30).

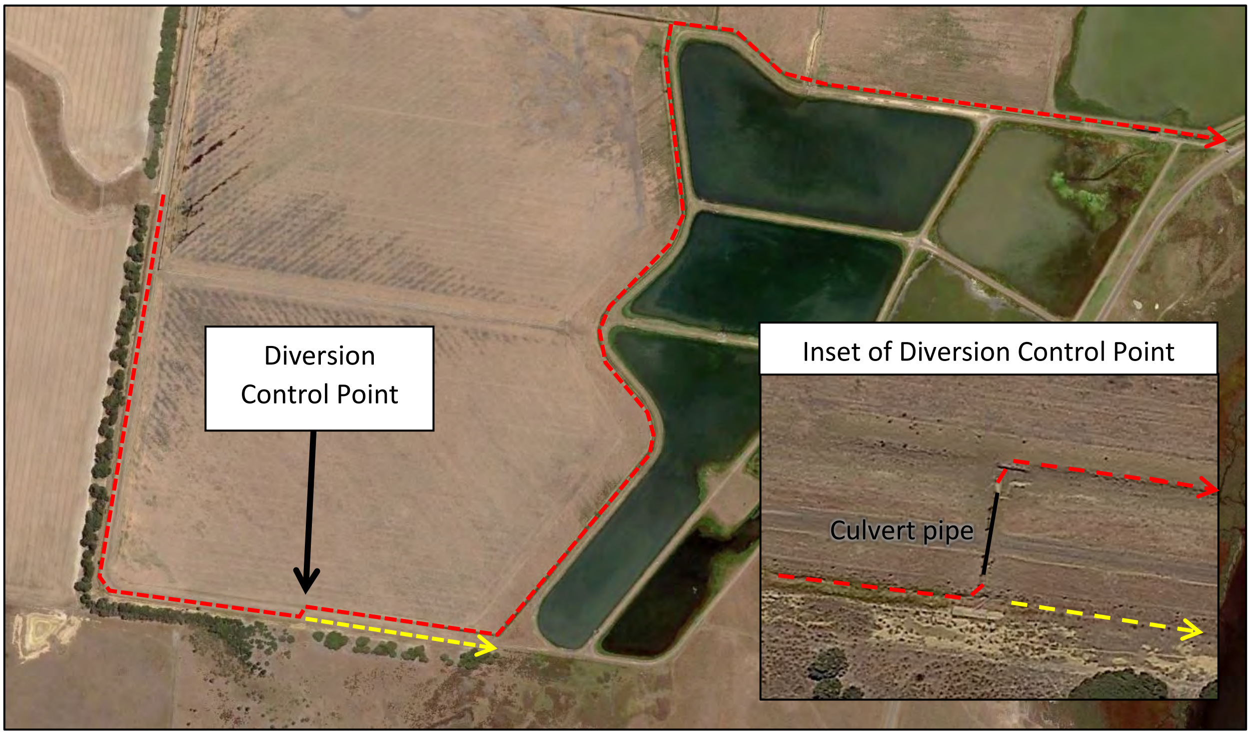

Figure 30. Operation of the perimeter drain diversion structure. Red line is the direction of all low flows between since c.1970 and 2000 and from 2003 to present. The yellow line indicates the direction of flow in 2001 and 2002, and for any larger flows that overtop the diversion structure.

The T-section central drain, which the perimeter drain contributes flows towards, supports a population of nationally vulnerable Growling Grass Frog. However, it is likely that flows generated from the T-section lagoons alone are sufficient to support this population (Will Steele, pers. comm., 20/2/19).

During the year 2000, the diversion structure was deliberately blocked due to concerns of *E. coli* entering the Big Marsh from treated effluent within the T-section ponds. A period during which all perimeter drain flows once again discharged directly into Big Marsh followed, as shown by the yellow arrow in Figure 30.

In December 2002, the culvert blockage was removed and perimeter drain flows were again diverted away from Big Marsh, back through the T-section internal drains (red lines in Figure 30).

The impetus for this further change of management was concern that drain flows were over-freshening the saltmarsh (as evidenced by records of Growling Grass Frog and Brolga breeding) and the observation that this was also facilitating weed invasion.

The configuration of the infrastructure at the control point is shown in Figure 31.

Figure 31. Looking east at the southern perimeter drain low flow diversion structure, being inspected here by Will Steele and Ben Taylor in 2019. Red line is the direction of all low flows between since c.1970 and 2000 and from 2003 to present. The yellow line indicates the direction of flow in 2001 and 2002, and for any larger flows that overtop the diversion structure. The orange arrow shows the original bed of the drain that can still carry high flows towards Big Marsh. The white dotted line shows the profile of what appears would have been the original c. 1940 drain, while the black dotted line shows the deeper channel that was constructed within the original drain, presumably c. 1970, around the time the diversion structure was installed.

Additionally, at some point in time the diversion point has been "topped up" with an additional concrete lip put in place to increase the proportion of flows directed away from Big Marsh and into the T-section drain (Figure 32). Except for the 2001-2002 period when the culvert was blocked, this would otherwise require larger episodic rainfall events to cause over-topping flows towards Big Marsh.

Figure 32. Evidence that the low flow diversion structure has been modified sometime after its c. 1970 construction. Raising the level of the concrete lip at the diversion point is likely to have increased the proportion of flows directed away from Big Marsh and into the T-section drain, requiring larger episodic rainfall events to cause over-topping flows.

The catchment of Avalon Creek is not currently proposed for future development under the Western Growth Corridor Plan for greater Melbourne (VPA 2012). However, expansion of hard surfaces within Avalon Airport and/or adjoining land owned by Fox Group has occurred in the past and could increase, with potential implications for water quality (decline) and peak flows (increase) in the Avalon Creek catchment. An example of runoff in the catchment of Avalon Creek is shown in Figure 33.

Figure 33. Water flowing into the perimeter drain from adjacent land during wet conditions in July 2003. Avalon airfield is visible in the distance (photo: Trevor Gulovsen).

Note in this image how:

- Water is in the landscape adjacent to Avalon Creek (the sedgy vegetation in the distance beyond the fence) is a shallow diffuse surface flow.
- The narrow, deepened portion of the perimeter drain is capturing all of these flows, and converting them from a diffuse surface flow into a channelised flow that will be discharged downstream as a point source flow.

The flow on effects for the saltmarsh community in The Spit, as a result of these and the other changes previously outlined remains unclear.

Carr *et al.*(2002) wrote, presumably during the period that the perimeter drain was discharging directly into the saltmarsh: "There is an urgent need to prevent the input of surface and ground water from the Western Treatment Plant to the north. In the case of surface water inputs to the Saltmarsh these may be natural but surface drainage structures may concentrate surface runoff, rather than it being spread over a much larger area. This needs to be rectified as a matter of urgency because of fresh water inputs, resulting decreased salinity and nutrient enrichment."

The drain diversion system has been reported to "function very well under wet weather conditions" (Trevor Gulovsen, 24 July 2003, Melbourne Water internal memorandum to Will Steele) and implies that freshwater inputs from Avalon Creek can largely be limited as a result of diversion. However, there is considerable evidence (including the historic condition of the site, original alignment of Avalon Creek and long history of fresh flows directly into the saltmarsh up until c. 1970) to suggest that natural diffuse freshwater inflows can be beneficial and some capacity to maintain inflows should be considered.

For example, direct rainfall and freshwater inflows from the hinterland can be ecologically important in saltmarsh communities, causing temporary freshening of surface waters which can trigger biological responses in both flora and fauna that grow within what are otherwise continuous highly saline environments. Many perennial saltmarsh plants require periods of reduced salinity to germinate and seasonal reduction in salinity can prompt annuals to divert resources to reproduction (Victorian Saltmarsh Study 2011), particularly in-lieu of a potential 50% reduction in freshwater catchment associated with expansion of the Mountain View Quarry (Minister for Planning 2009).

Further discussion on reinstatement of surface flows from Avalon Creek is contained in Section 10.2.

7.4. Changes to The Spit Barrier Islands

The Spit NCR gets its name from a series of approximately eight barrier islands and two spits, composed of shell grit (Brett Lane and Associates 2006), located up to 500 metres offshore, behind which lies a shallow, coastal lagoon (Figure 34). As the tide rises in Port Phillip Bay, seawater enters the coastal lagoon via channels that separate these barrier islands and spits. The height and duration of tides in the coastal lagoon is one of the factors influencing the volume of seawater that penetrates into Big Marsh.

An aerial image of The Spit from 1970 (Figure 35) reveals that, at that time, the barrier islands consisted of just two, long spits, one extending 2.4 km from the north-east, the other 1.3 km from the south, with a single opening between them into the coastal lagoon behind. The opening was at that time approximately 85 metres wide and, judging from the aerial image, quite shallow.

The changes that have occurred to the spits since 1970 and the coastal lagoon behind them (Figure 35) is visually quite dramatic. This separation into a series of islands with multiple channels may also be influencing the hydrology of Big Marsh. The combined channel width has increased to approximately 540 m, albeit shallow in places. This evidence indicates that the movement of seawater from Port Phillip Bay into the coastal lagoon behind the spits, and in the opposite direction, has likely become less restricted. This in turn has the potential to more closely align the tidal fluctuations (in timing and duration) within the coastal lagoon with those of greater Port Phillip Bay. It may be that high and low tides in the coastal lagoon have become more responsive (i.e. shorter in duration, with less lag), since the 1970s, which would in turn influence the dynamics of tidal flows reaching Big Marsh.

The break-up of the spits into a series of islands may have occurred more recently than the early 1980s, when it was still possible to "walk from Murtcaim to the south of North Spit without getting wet feet" (Danny Rogers, ARI, pers. com, 7/8/20).

We have not investigated this potential source of hydrological change to Big Marsh in detail for this study. However, we highlight the changes to the spits as a likely further cause of hydrological impact (through influence on tides), and subsequent ecological change, to Big Marsh.

Figure 34. The Spit barrier islands, 2020 aerial image. White arrows indicate channels between the islands into the coastal lagoon.

Figure 35. The Spit, 1970 aerial image. Black arrow indicates the single channel between the north and south spits into the coastal lagoon.

7.5. Sea-level Rise

The Victorian Coastal Strategy forecasts an average sea level rise of 80 cm by 2100, although updated modelling suggests this may be conservative and that recent forecasts suggest a rise of 110 cm under low greenhouse gas representative concentration pathway (RCP) scenarios by 2100 (NCCARF, 2017) (Figure 36). Under these scenarios, assuming unrestricted tidal movement, Big Marsh will be exposed to a greater depth, extent and regularity of saltwater inundation. This may act to squeeze out the fringing communities unless surrounding land is managed to allow expansion upslope.

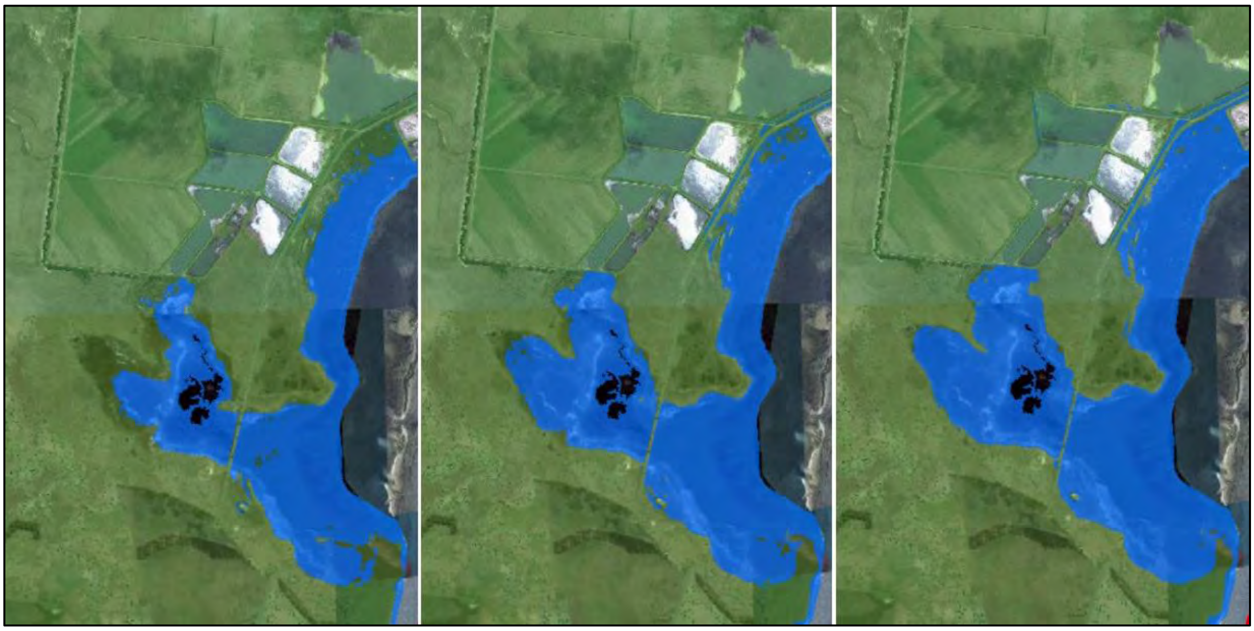

Figure 36. Predicted mean sea levels under very high 2050 (left), low 2100 (middle) and very high 2100 (right) greenhouse gas representative concentration pathway (RCP) scenarios. (NCCARF, 2017).

8. Other Issues

8.1. Grazing

The appropriateness of sheep grazing of saltmarsh vegetation and surrounding terrestrial grassland at Big Marsh has been the subject of considerable debate over several decades (see Section 4). A sheep grazing trial conducted at Big Marsh in 2006-07 indicated a grazing preference for terrestrial grassland vegetation over saltmarsh vegetation, although some grazing of the latter did occur (Loyn *et al.* 2010). This study was not continued and its findings are not conclusive.

Accidental or uncontrolled stock grazing of saltmarsh had been recognised as an issue by (Brett Lane and Associates 2006) and sheep were observed grazing within The Spit NCR during site this study (04/02/2020). Sheep access (inferred via pugging) is also evident in some locations within the Reserve (Figure 37). Big Marsh is also grazed by rabbits, hares and (for the last 15 years or so) small numbers of kangaroos (Richard Loyn, pers. comm., 1/8/20).

Figure 37. Evidence of sheep access along an internal fence line within The Spit NCR (E280874, N5785507). The ungrazed area to the right is within a small (3 ha) fenced area established for a grazing trial in 2006 (photo Ben Taylor 3/2/2020).

Whilst sheep grazing may provide some strategic benefits with regard to biomass/weed management on high ground not subject to inundation, it is probably not required within saltmarsh communities, where weedy species are unlikely to establish and/or dominate. Furthermore, larger native tussock species, generally outside the influence of tidal inundation (*Poa*, *Austrostipa*) or at the upper limit of the rare tidal influence (*Gahnia*) have fared better upon cessation of sheep grazing (Carr *et al.* 2002).

Given a lack of conclusive support for grazing, and the apparent improvements observed following cessation, an ongoing priority for the site is a more targeted effort at excluding stock access from areas where vegetation communities are relatively intact.

9. Investigations as part of this project

The following section outlines investigations which address knowledge gaps associated with hydrological patterns across the study site.

These relate to determining:

(1) the effect that culverts under 29 Mile Road are having on movement of water through culverts; and also,
(2) the influence of the T-Section lagoons as a source of freshwater and nutrients into upper, inland regions of the wetlands.

In order to undertake these investigations, additional data has been collected to inform the following components:

- elevation (mAHD) of the inverts of all culverts under 29 Mile Road and comparison to the surrounding natural surface of the wetland;
- measurement of water levels at short time intervals to determine trends in water levels and flows relating to both tidal and rainfall/runoff events, and any effect of stoplog removal on these trends;
- depth to groundwater across the wetland in relation to proximity to the T-section lagoons; and
- nutrient concentrations across the wetland in relation to proximity to the T-section lagoons.

Methodology, results and interpretation of each of these components of the investigation is outlined below.

9.1. Culvert Elevation Survey

9.1.1. Aims

To determine elevation (mAHD) of the inverts of all culverts under 29 Mile Road and compare to surrounding natural surface to determine if the culverts are preventing shallow flows under the road.

9.1.2. Methods

A government survey mark on the verge of 29 Mile Road (Murtcaim PM 59), 250 metres from The Spit NCR, with known elevation was used as a reference location. The elevations of culvert inverts and nearby natural surface locations were obtained from the reference location using a Lufkin laser level. Culvert invert elevations were measured on the inland (western) side of culverts as most culverts slope slightly downwards towards the eastern side.

A digital elevation/terrain model (DEM/DTM based on LiDAR derived data) of the area provided by PPWCMA was also examined to compare surrounding natural surface elevation to culvert invert elevations.

For future reference, the uppermost surface of culvert 11, on the inland (western side), was determined to have an elevation of 1.415 mAHD. This surface was marked to enable its future identification.

9.1.3. Results

The surveyed culvert invert elevations are shown in Table 2 and compared to the surrounding natural surface, as shown over the page in Figure 38.

Table 2. Culvert invert elevations.

Culvert no.	Invert (mAHD)
1	0.40
2	0.29
3 – 10	0.31
11	0.36
12	0.45

9.1.1. Discussion

The elevation of the 29 Mile Road culvert inverts is broadly at or below the surrounding natural surface elevation. Natural surface on the western (inland) side was generally above 0.30 mAHD, very similar to the invert elevations of Culverts 2 (0.29 mAHD) and 3-10 (0.31 mAHD). Natural surface on the eastern (seaward) side of the road was generally above 0.40 mAHD.

Notably, there were occasions during fieldwork when a continuous pool of water existed from the eastern side to the western side of the road, with shallow, still water within culverts 3-10 and 11, yet it was possible to walk around this pool, approximately 100 metres west of the road, without walking through water. This suggests a minor natural sill between the lower (eastern) and upper (western) saltmarsh exists west of 29 Mile Road. This observation is broadly consistent with the DEM.

The DEM also indicates that lower ground exists within the upper saltmarsh further to the northeast, closer to the T-section ponds. This is consistent with past observations of water, of either marine of inland origin, being trapped in the upper saltmarsh (Carr *et al.* 2002). Our data suggest this is a natural phenomenon that is not affected by the invert elevations of 29 Mile Road. However, to be clear, this finding does not preclude other effects due to overall culvert capacity – see Section 9.2).

Although our elevation data differ slightly from those of Mueck *et al.* (2007), who stated that the average invert elevation of the 29 Mile Road culverts is 0.23 mAHD, our data and observations are consistent with their finding that the culvert inverts are “generally below the saltmarsh floor”.

It was observed during elevation surveys that natural surface elevation is markedly lower in areas adjacent close to the western and eastern ends of Culvert 11 (0.18 and 0.21 metres lower than the culvert respectively). These localised depressions are likely to be scour pools formed by accelerated flows through this culvert. Similar pools exist at either ends of Culverts 3-10. Flows across the natural surface are impeded and slowed by dense, low lying saltmarsh vegetation, while water within the culverts flows over smooth concrete and therefore likely accelerates, causing erosion as it exists the culverts in either direction. These scour pools give the casual observer the impression that the culverts are elevated above natural surface. However, this is only a localised effect and not relevant at a broader scale.

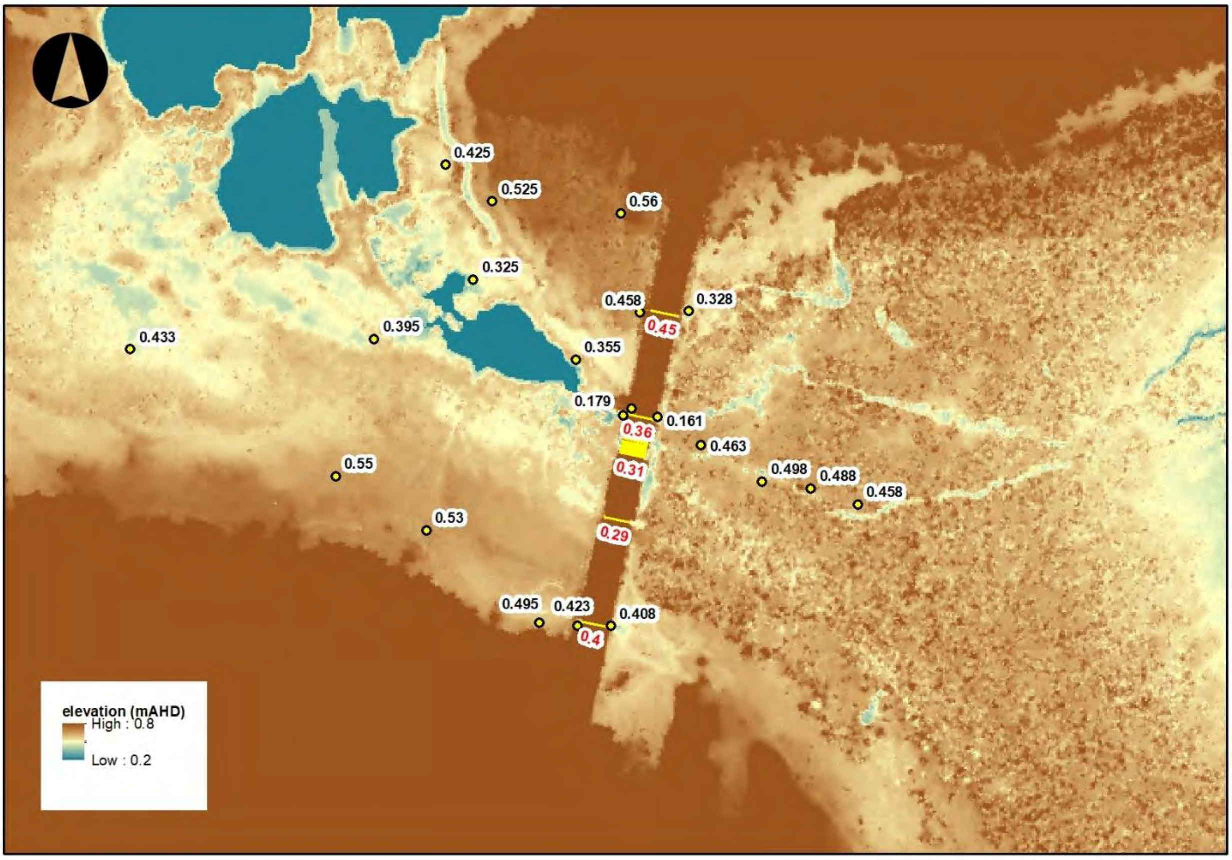

Figure 38. Elevation (mAHD) of culvert inverts (red numbers, yellow lines) and natural surface (black numbers, yellow circles) over aerial imagery (top) and DEM (bottom).

9.2. Water Surface Elevation Monitoring

9.2.1. Aims

To determine if 29 Mile Road causeway is causing an impediment to flows between the lower (western) and upper (eastern) saltmarsh, in either direction, under two scenarios:

1. with stoplogs in place, precisely as they were encountered at the beginning of the study; and
2. with all stoplogs removed.

9.2.2. Methods

Six U20L -04HOBO loggers and 13 cork tubes were installed on 4th April 2019 to provide the basis for assessing water level trends on either side of 29 Mile Road. An additional logger was set on the coast, to capture a background baseline of tidal patterns. Loggers were set to record at 15 minute intervals. Loggers were arranged in pairs, with one on the seaward side and one on the inland side of three culverts. The locations of loggers and cork tubes referred to in the following section are shown in Figure 39.

Natural surface elevations, in mAHD, were determined for each logger as described in Section 9.1. At the commencement of monitoring, on 4th April 2019, stoplogs were in place as described in Table 1. On 13th November 2019 all stoplogs were removed.

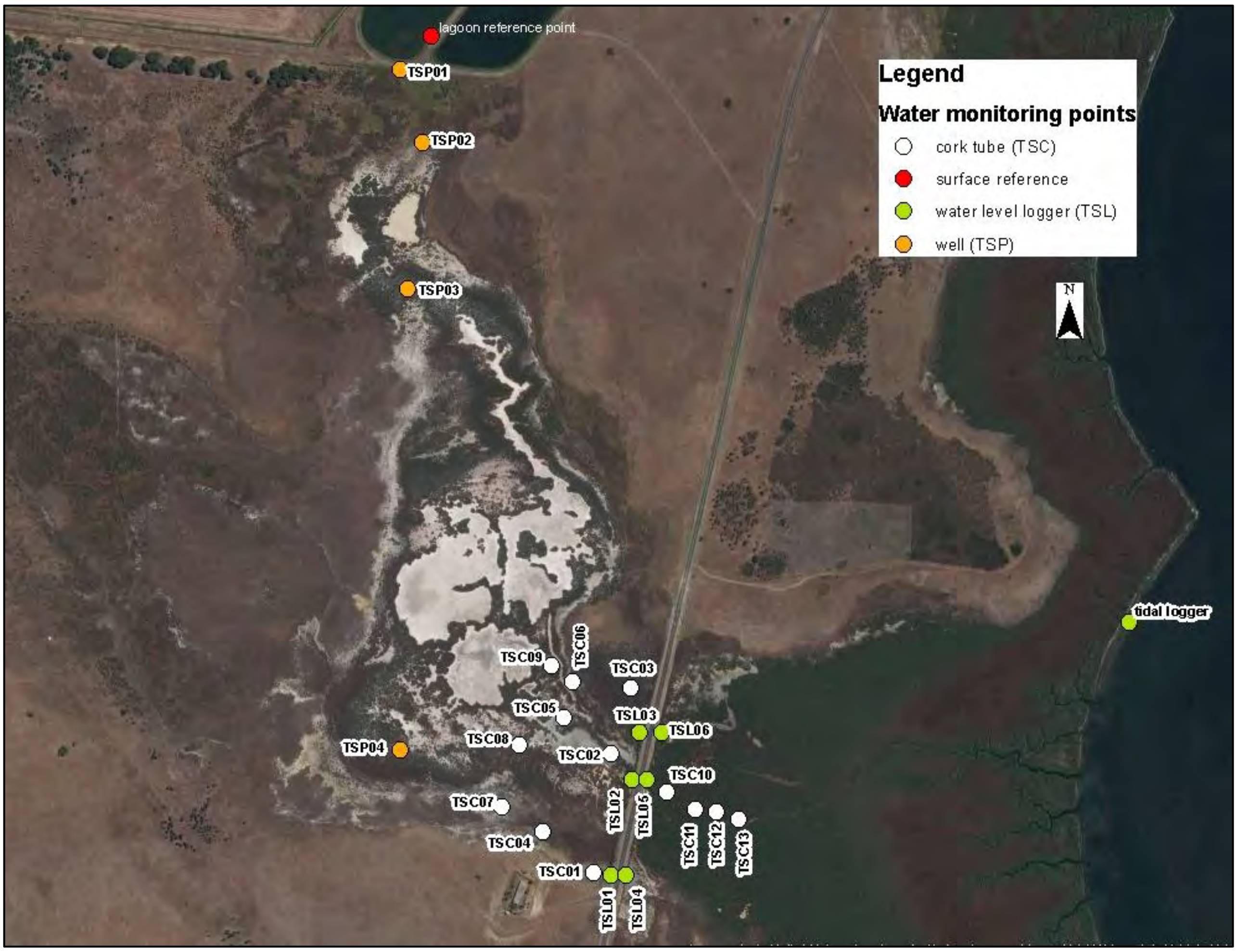

Figure 39. Surface water monitoring points

9.2.3. Results and Discussion

During the period of the study, depth and extent of inundation were influenced by sea water incursion to a greater extent than rainfall and/or freshwater inflow. This is clearly shown by a comparison of maximum water levels recorded for a given day, against maximum recorded sea level (Figure 40) and daily rainfall (Figure 41).

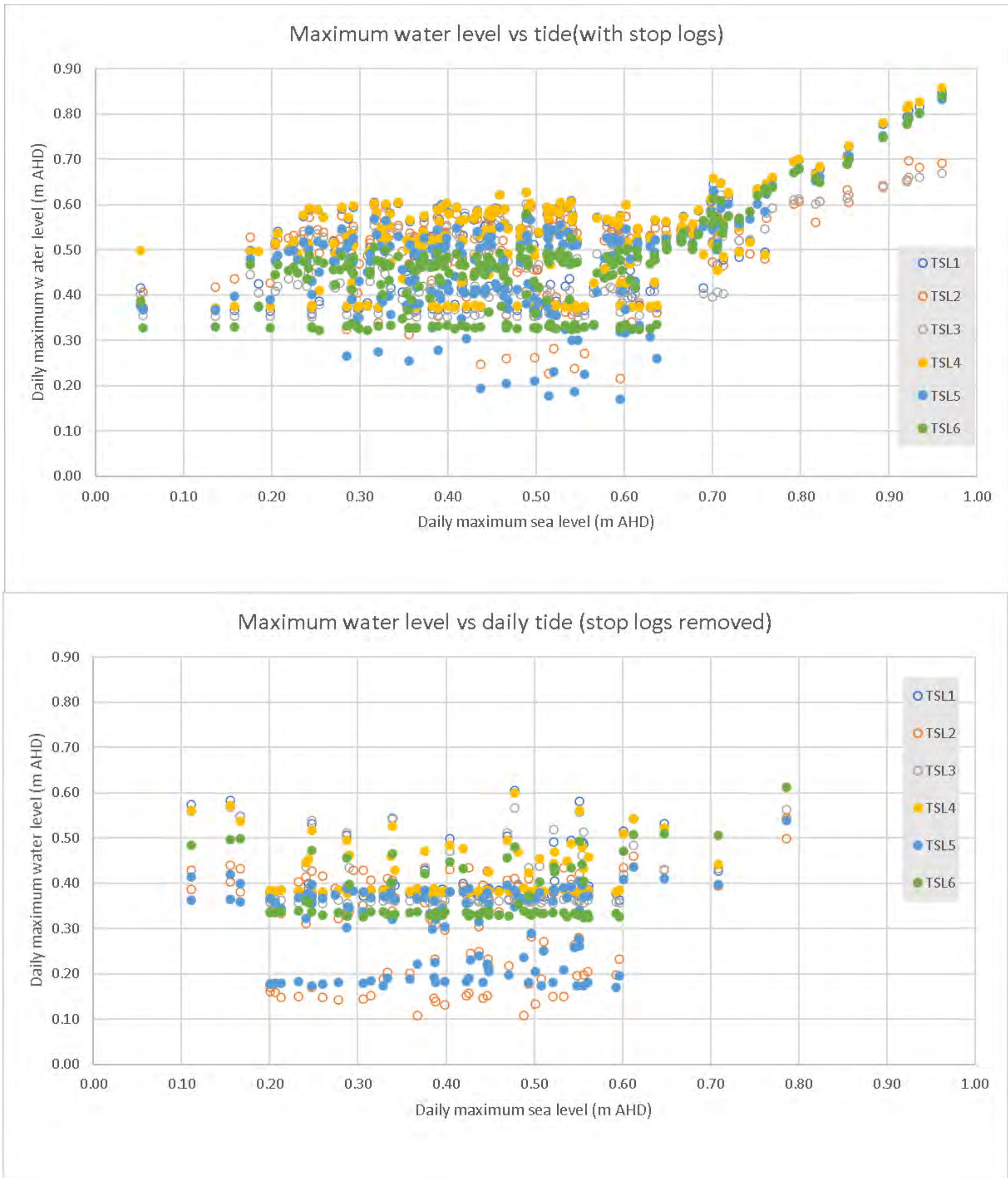

Figure 40. Comparison of sea level and maximum wetland level before and after stoplog removal. Open circles denote inland (west) of 29 Mile Road and closed circles denote seaward (east) of 29 Mile Road.

Of particular interest is an almost linear relationship between sea level and wetland depth when sea levels exceed approximately 0.8m. This suggests that above this level, sea water is achieving hydrological connectivity throughout the saltmarsh habitat in general, including through the culverts and influencing inundation of the wetland on the inland side of 29 Mile Road. This level is consistent with observations by Barro Group (2008).

Exploration of hydrograph behaviour for logging stations either side of 29 Mile Road during these high tide events show a change in response between pre and post stoplog removal periods. Prior to removal, water level rose more rapidly and to a higher level on the seaward side of the road with the exception of TCL1, which is on the inland side but appeared more connected with the tide.

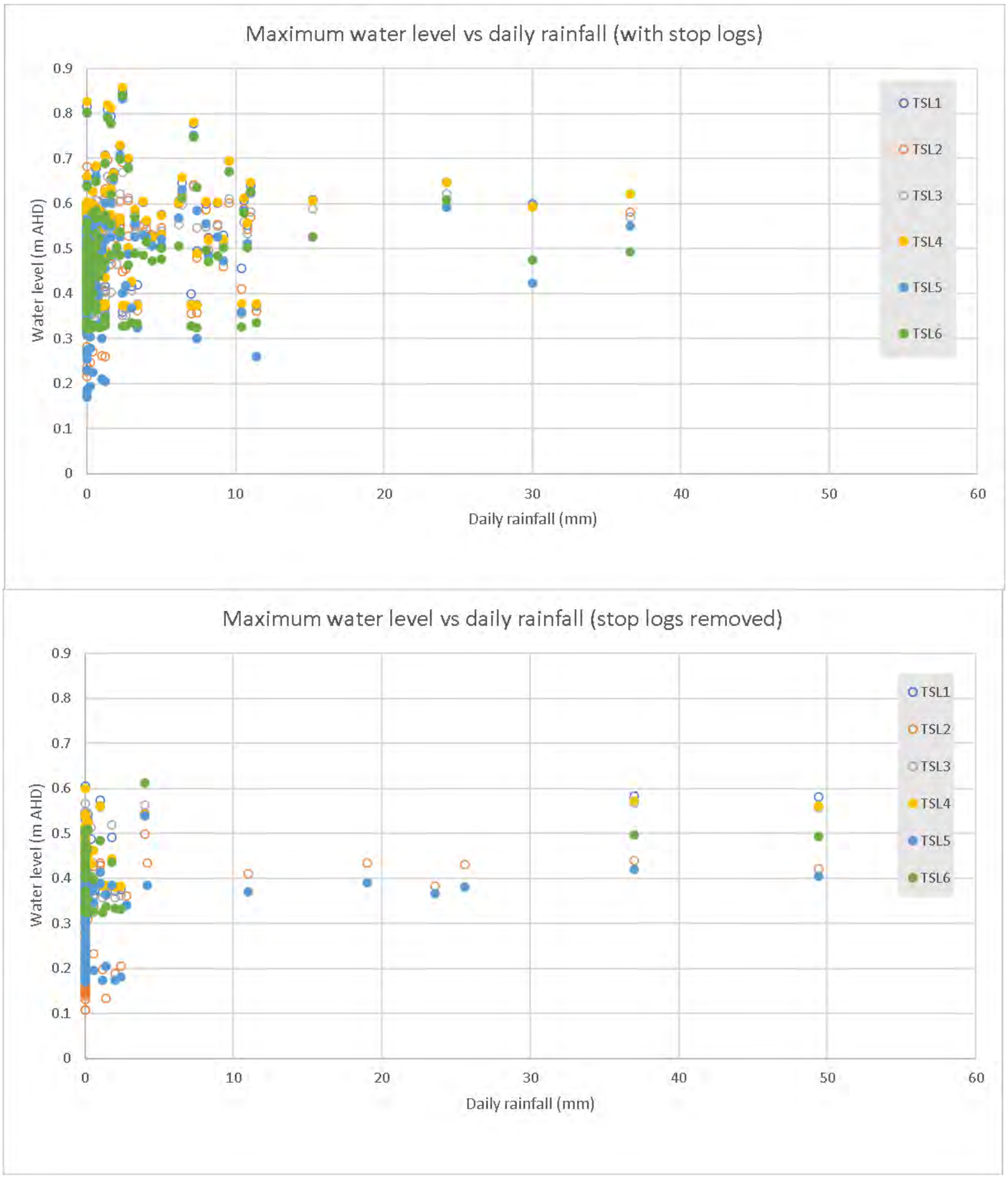

Figure 41. Comparison of daily rainfall and maximum wetland level before and after stoplog removal
Open circles denote inland (west) of 29 Mile Road and closed circles denote seaward (east) of 29 Mile Road.

Of note, a high tide event in December 2019, after stoplog removal, showed a uniform rise in levels either side of the road (Figure 42). Additional monitoring of response following stoplog removal is currently being undertaken at culvert 11 (i.e. TSL 02 (inland) and TSL 05 (seaward)) although data has not been collected or analysed since March 2020.

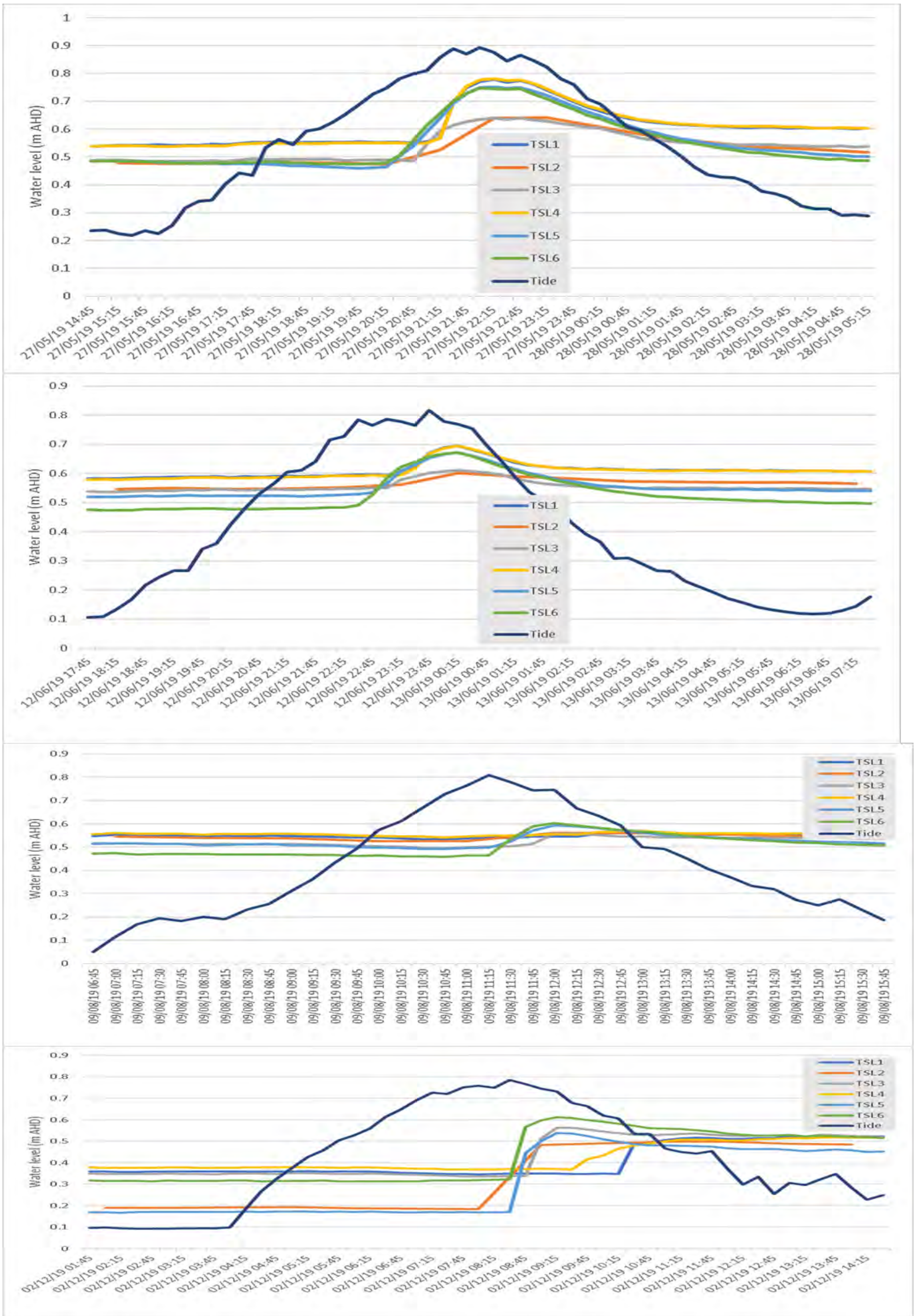

Figure 42. Water level response to high tides, in order from top to bottom: May, June, August and December 2019. The first three tide events were prior to stoplog removal, which the final tide event was after all stoplogs were removed.

Daily rainfall events experienced during the study did not cause any inundation depths greater than what was observed associated with sea level (tidal) events. However, significant rainfall events were recorded following stoplog removal and allow some interpretation of the effect of removal of stoplogs with regard to conveyance of freshwater into wetland areas east or seaward of 29 Mile Road.

All of these observations however must be interpreted and understood against the background context of the diversion of flows from Avalon Creek, away from Big Marsh and into the T-section drain, remaining in place at the present time. So they represented local rainfall and runoff impacts only, without the bulk of natural watercourse inflows.

The rate of rise from these rainfall events during the study appears to be partly influenced by how low the water level is across the wetland prior to any given rainfall events.

For large events in January 2020, the pools where loggers were located were initially dry and so rapid rates of rise appear in response as those pools are first filled by rainwater, particularly at the central TCL2 and TCL5 loggers (Figure 41).

Across the four highest events recorded during this study (Figure 41), there was no difference in timing or overall rate of rise on either side of the road, following stoplog removal (Figure 41) and rises were insufficient to provide surface connection between more defined depressions across the wetland.

It is also noteworthy that overall rises occurred within the 24 hour period for which rainfall occurred.

These combined observations indicate that the influence of rainfall is primarily precipitation on the wetland and immediate adjacent sheet flow and the absence of a more delayed response or lag suggests no contribution from inflows derived from further afield / higher in the catchment (i.e. as would be delivered by point source inputs, such as the perimeter drain if it were discharging into the saltmarsh). Previous occurrences of sheet inundation following significant rainfall events (e.g. 1983) are anecdotally reported however these appear to be infrequent.

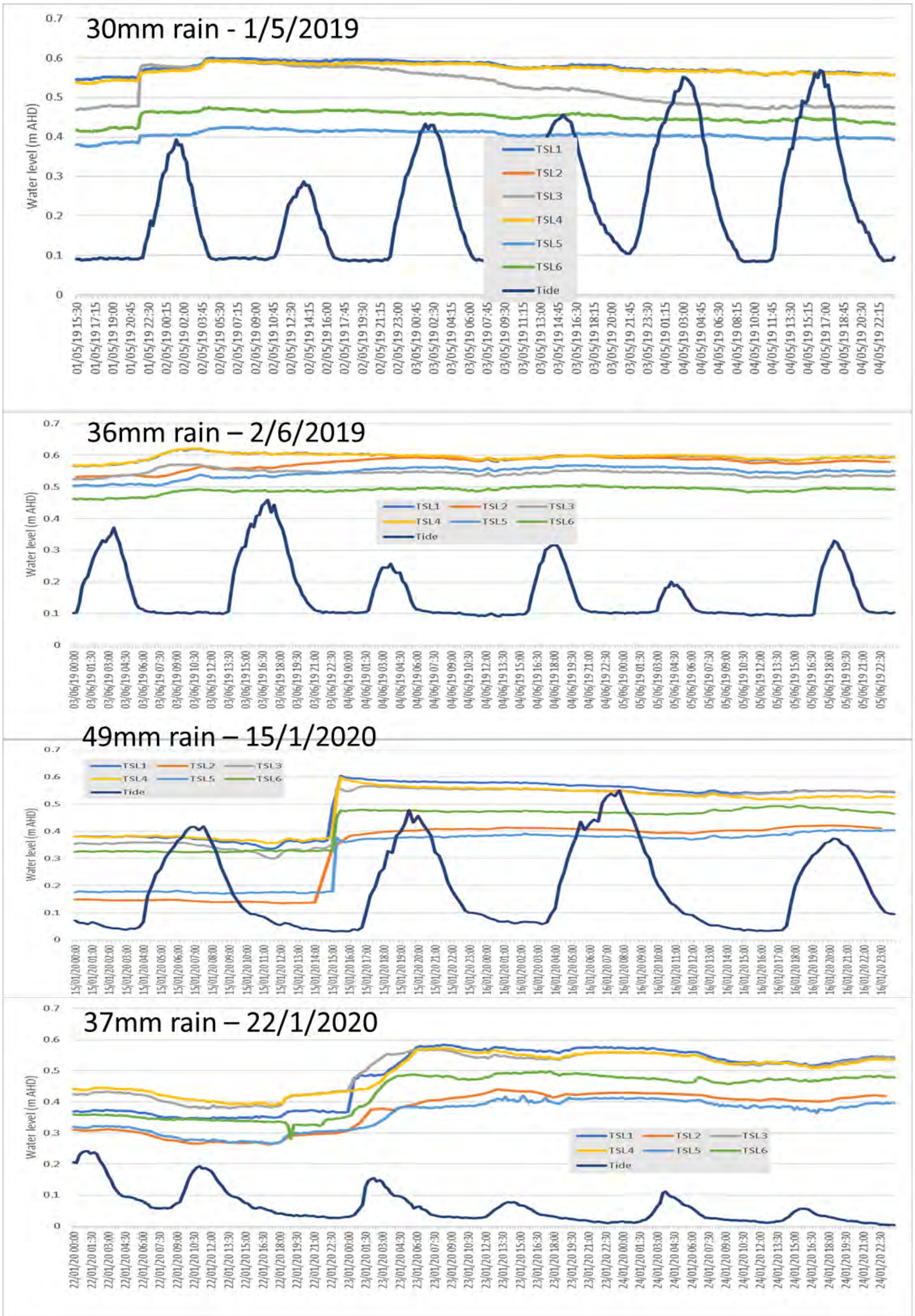

Figure 43. Water level response to rainfall events

To determine if there is a lag effect for tidal flows penetrating further inland into the saltmarsh of Big Marsh, away from the culverts themselves, additional estimates of inundation levels across the wider wetland area have been derived through the installation of PVC pipe with ground cork. For the spatial placement of these observation points, see white dots in Figure 39.

This method simply indicates the maximum water level recorded during a specified time period, as they require physical observation, manual checking and resetting. Three time periods have been investigated under the current study (Figure 44). In interpreting variation within wetland zones during discrete time periods, it should be noted that some tubes were at higher elevations and hence the recorded level is simply the dry surface, as noted.

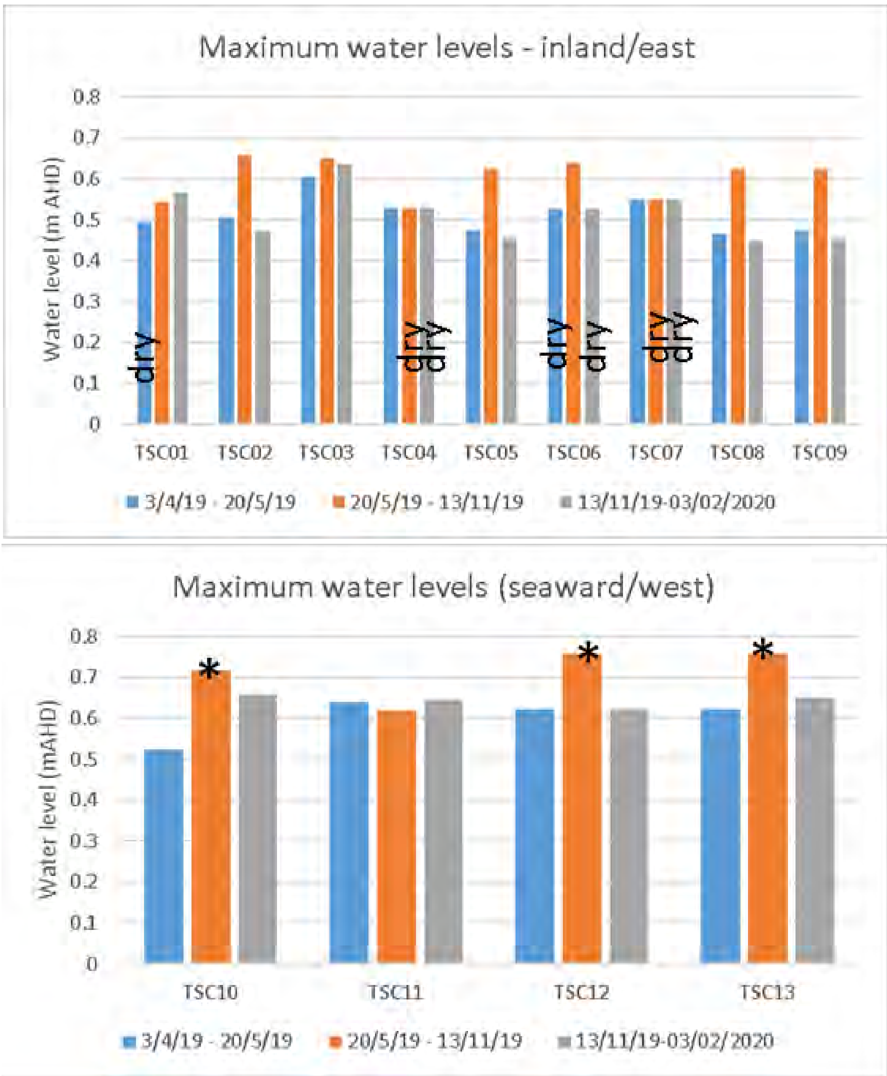

Figure 44. Maximum water levels recorded across the inland (left) and seaward (right) areas of saltmarsh.
** denotes water level exceeded height of tube.*

The observations indicate that maximum levels on the seaward side of 29 Mile Road reach higher levels than the inland area and, in the limited data so far, there was no change to this pattern following stoplog removal (Figure 44). There are two effects potentially at play to cause this result:

a. The natural delay and attenuation of the tidal peak that increases with increasing distance inland from the coast, as shown in (Figure 42); and
b. A restriction caused by the 29 Mile Rd causeway (with stoplogs removed) that, although undetectable by paired loggers at the culverts, reduces the total volume of water able to pass through to the inland side during the (typically brief) tidal peak, thereby reducing peak water levels on the inland side, particularly away from the road culverts.

Our monitoring design and data to date do not enable the disentanglement of these two possible causes at this stage, although additional data to be collected in the second half of 2020 may shed further light on the issue. A more detailed investigation into the issue could be undertaken by the installation of an east-west transect of 8-10 water level loggers at increasing distances from the sea, with 4-5 on the seaward side and 4-5 on the inland side of 29 Mile Rd.

However, if 29 Mile Rd is the cause, then, short of pulling up the entire causeway to reinstate the natural bathymetry of the saltmarsh, it is very difficult to compensate for the change that has taken place. Logically it certainly makes sense that attempting to funnel a shallow tidal movement of water through these narrow points of constriction in this way could be problematic, compounded by the fact that this is an irregular, hydraulically sluggish saltmarsh surface, with very gentle gradients. As described earlier in this report, and shown below in Figure 45, 320 metres of original potential connectivity for shallow tidal movement across the footprint of the current road, has been replaced instead by a maximum area of only 16.8 metres of culvert openings.

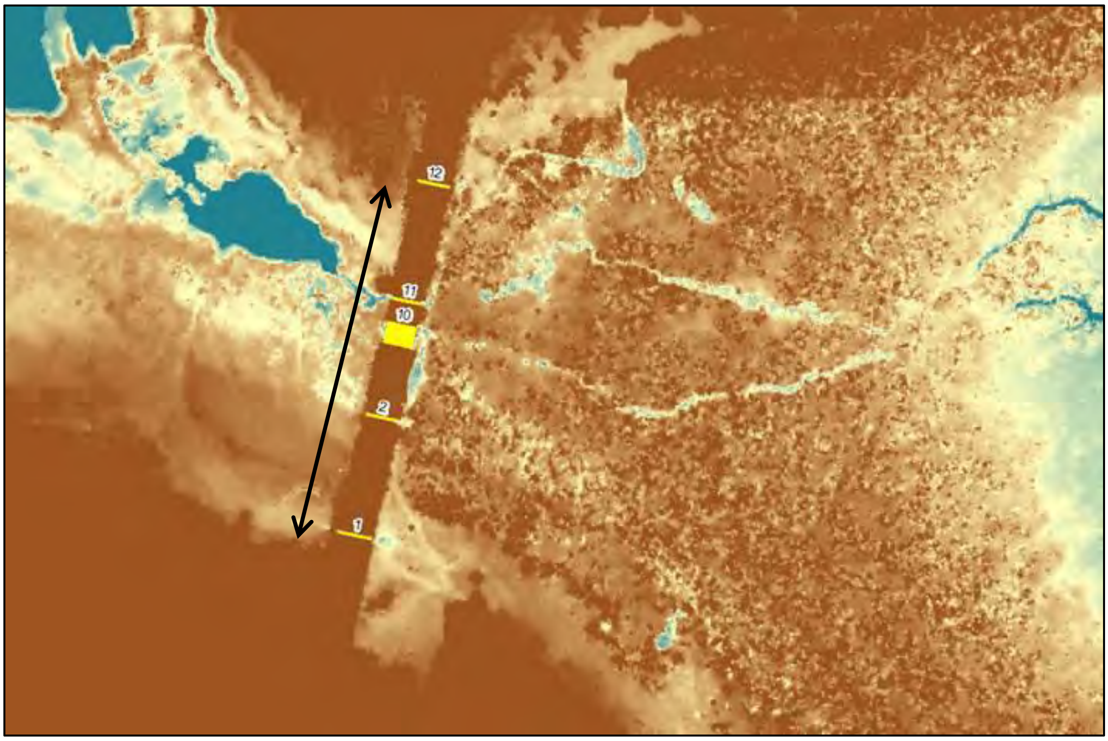

Figure 45. A glance at the high resolution DTM/DEM for the area illustrates just how significant the causeway is in creating a physical, hydraulic barrier, capable of preventing even sheetflow penetration of tides into Big Marsh on the western side of the road. The 320 metre zone of potential sheet flow (black arrow), has been replaced by culverts openings totalling just 16.8 m.

If this is the case, then the height (and hypothetical volumetric capacity) of the culverts is largely irrelevant, because the majority of tidal events are unlikely to be able fully equalise water levels across the entire saltmarsh west of the road, before the tide turns. This is because a typical tidal surge is not high enough (in depth) to create the driving head, or long enough (in duration) to push through the required volume of water through those restrictive openings, in the short space of time available.

With some constriction of tidal flows at this point potentially dating as far back as the 1870s, as outlined earlier in this report, this could explain why the original tidal saltmarsh mapping from 1854 (despite its coarseness) appears more uniform either side of the present road, where today there are stark differences in composition and physical appearance (Figure 46). By effectively choking it off at this narrow point, this area of outer (upper) tidal saltmarsh has been deprived of connectivity with the natural tidal regime/rhythm that drove its formation and likely pre-European condition.

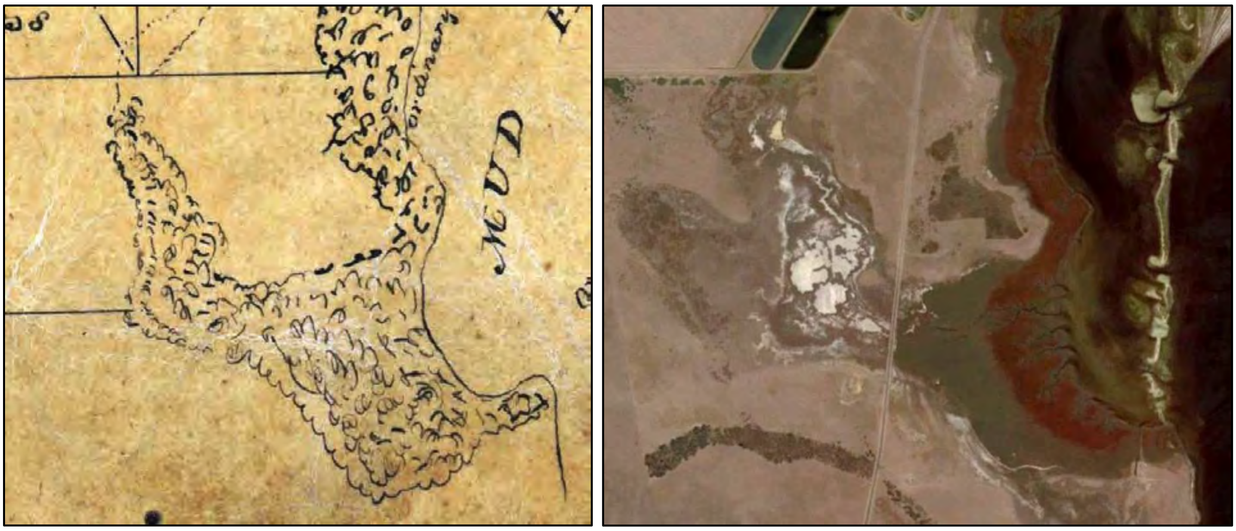

Figure 46. Apparent uniformity of appearance in the coarse 1854 survey map of tidally influenced saltmarsh, is no longer evident today or at any other time in the aerial photographic record dating back to 1947.

With the first aerial imagery in 1947 also showing the same broad pattern as today, and while this limited form of evidence from 1854 can only be considered suggestive at best, it may help explain the gradual ecological changes (with lag effects) being witnessed. The possibility that these changes were triggered by the construction of the first causeway, an event that may date back 150 years, cannot be discounted.

In summary, while removing the boards is a positive step, the ongoing hydraulic impact of the causeway on the saltmarsh within Big Marsh may still be significant, even accounting for the removal of the boards. Data currently (as at mid-2020) being collected will help to inform this issue in more detail and test the hypotheses stated above.

9.3. Influence of T-section lagoons upon groundwater elevation and quality

At the outset, it is worth clarifying that this component of the project was treated as a side-investigation that, given time and resource constraints, is exploratory only in nature. In order to improve confidence in its outcomes, this component requires replication.

9.3.1. Aims

- To determine if groundwater levels within the saltmarsh are elevated in proximity to T-section Ponds 3 and 4.
- To determine if groundwater quality, in particular nutrient concentrations, within the saltmarsh is different in proximity to T-section Ponds 3 and 4.
- To investigate a potential set-back distance for T-section Ponds 3 and 4 that would minimise their influence (if any) upon groundwater level and quality within the saltmarsh.

9.3.2. Methods

Piezometers were installed 3rd February 2020 at locations shown in Figure 47, along a transect to capture distance from T-section ponds. Piezometer TSP04 and existing well OB7 were incorporated as reference locations to measure background levels beyond the likely influence of the T-section ponds. Well OB7 was installed by John Nolan for Barro Group and access was generously provided for this study.

Piezometers consisted of 65 mm diameter PVC pipe with 5 mm diameter holes drilled, approximately four per 10 cm length, in the below ground length (none above ground). Pipes were covered in nylon stocking (for screening) and capped top and bottom. Holes were augured using a hand held, motorised auger with a 100 mm diameter bit to a depth of approximately 1.5 m. Piezometers were placed into holes with approximately 0.6 metres of standpipe protruding above natural surface.

The below-ground void between the hole and piezometer tubing was packed with coarse sand, except at the surface where excavated clay and bentonite were used to seal the below/above ground interface from surface percolation. Surface level at each well was surveyed to AHD, referenced to a datum point (Murtcaim PM 53). After 24 hours groundwater elevation within each piezometer was measured (on 4th February) and U20L -04HOBO logger was suspended within each piezometer (except OB7) near its base level by a wire cable attached to the standpipe cap. Loggers were set to record at one-hourly intervals.

Groundwater samples were obtained from each piezometer on 4th and 24th February 2020 using an electric pump. All water samples were analysed for a range of standard nutrient parameters by the Geelong laboratory of ALS Global.

TSP04 was problematic. Shallow (c. 0.5 metres below surface) groundwater was observed during installation but the piezometer failed to fill with water during the first 24 hours, likely due to clogging of the screening (sand and stocking) by high silt content. However, by the 24th of February sufficient groundwater was present to measure water table elevation and obtain a sample for analysis.

Water samples were also obtained from T-section Ponds 3 and 4, on 4th February 2020, for comparison with groundwater quality.

Figure 47. Piezometer locations for groundwater investigation.

9.3.3. Results

Surface water levels in the T-section ponds were approximately 1.5 metres higher than the natural surface of the adjacent saltmarsh.

As anticipated, the groundwater elevation was highest at TSP01 in close proximity to the ponds and declined from north to south with increasing distance from the ponds (Table 3, Figure 48). Similarly, depth to groundwater increased with increasing distance from the ponds. At TSP01, depth to groundwater was just 5 cm and the ground in this vicinity, at the toe of the bund containing Ponds 3 and 4, was clearly waterlogged despite being elevated approximately 0.3 metres above the natural surface of much of the saltmarsh (at TSP02, TSP03 and TSP04). In contrast, at the reference locations TSP04 and OB7, depth to groundwater was over 0.5 m, which may be more reflective of natural baseline groundwater conditions over the summer months.

Table 3. T-section pond surface water and saltmarsh groundwater elevations, 24th February 2020.

location	natural surface (mAHD)	water surface elevation (mAHD)	Depth to groundwater (m)
Pond 3		(surface water) 1.99	
Pond 4		(surface water) 1.94	
TSP01	0.65	(groundwater) 0.60	0.05
TSP02	0.43	(groundwater) 0.31	0.12
TSP03	0.42	(groundwater) 0.27	0.15
TSP04	0.43	(groundwater) -0.09	0.52
OB7	0.84	(groundwater) -0.22	0.62

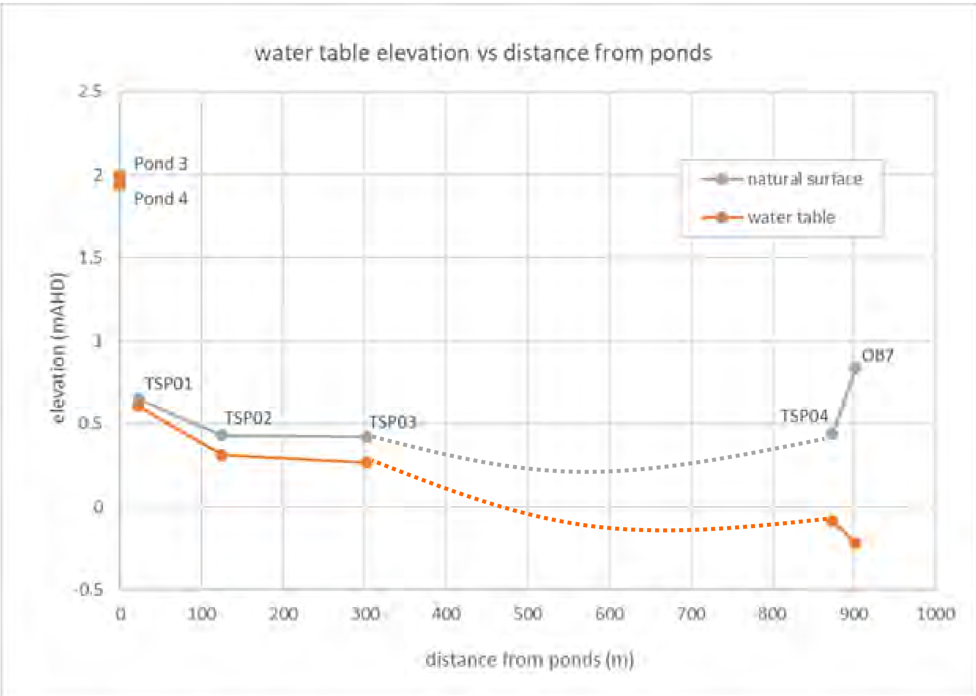

Figure 48. Saltmarsh water table elevation vs distance from T-section ponds, 24th February 2020.Dotted lines are inferred surfaces between these points to account for the basin profile of the middle of the saltmarsh.

Note that the dotted line between TSP03 and TSP04 indicates that the water table is likely to be lower between these two locations than would be represented by a straight line between them (John Nolan, pers. comm., 25/02/2020). This is because the zone between these monitoring sites is the lowest part of the saltmarsh (represented here by a grey dotted line) and as a result of the general direction of groundwater flow being from the east (towards the coast).

Water level trends across the wetland, as indicated by piezometer logger data, show fluctuation with rainfall but also indicate a strong influence from seepage from the T-Section lagoons into the area adjacent (Figure 49).

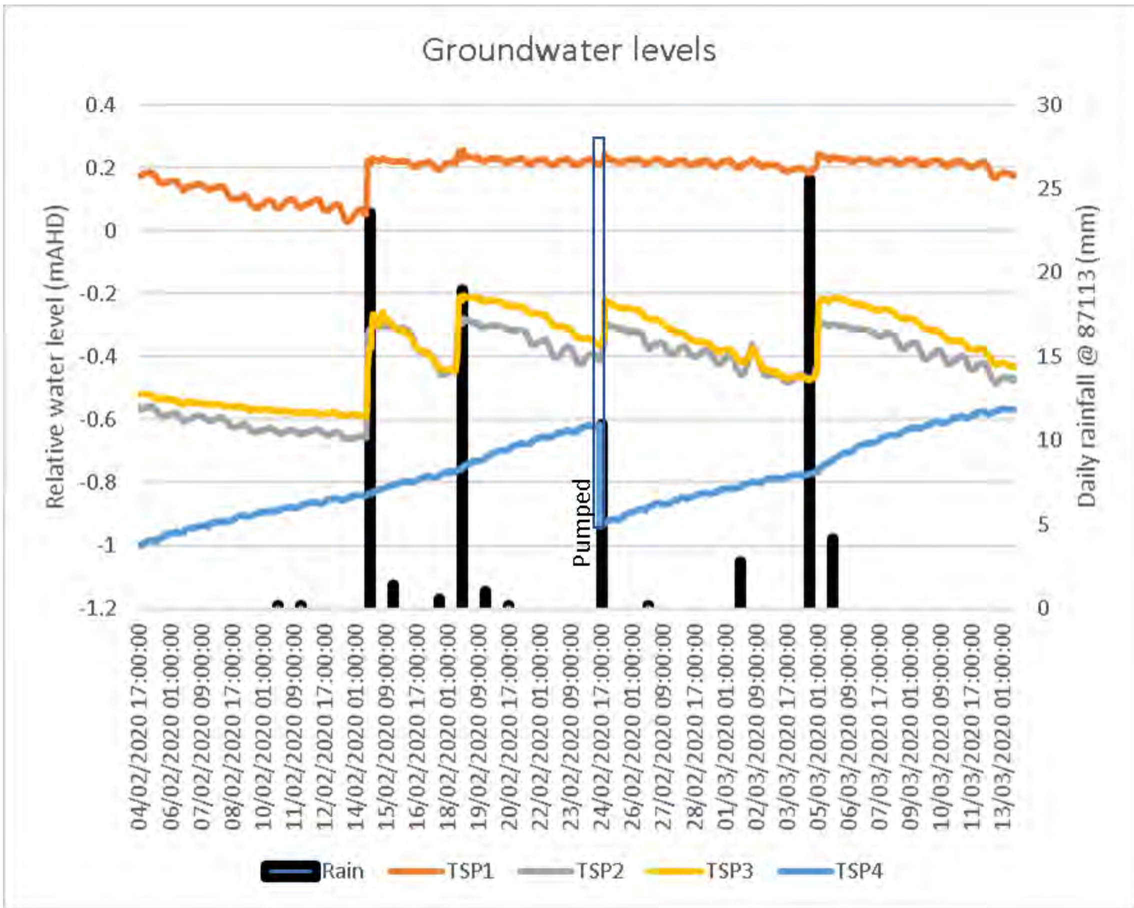

Figure 49. Groundwater level trends across the wetland. Timing of pumping indicated

This seepage maintains continuous elevated water levels at the TSP01 well. The influence appears reduced but present at TSP02 and TSP03, 125 and 300 metres from the T-section lagoons respectively. Piezometer TSP04 has failed due to screen clogging, as indicated by a slow rate or recovery after pumping (Figure 49). However stabilised (maximum) water levels likely reflect true ground water elevations at this point.

Salinity in the T-section ponds was an order of magnitude lower than groundwater salinity in the saltmarsh at a distance of 125 metres or greater from the ponds (Figure 50).

However, at TSP01, just 23 metres from the ponds, groundwater salinity was much lower than elsewhere and was very similar the salinity of surface water within the ponds. Groundwater salinity in the saltmarsh at distances of 125 metres or greater from the T-Section ponds was at or above seawater salinity (35,000 mg/L).

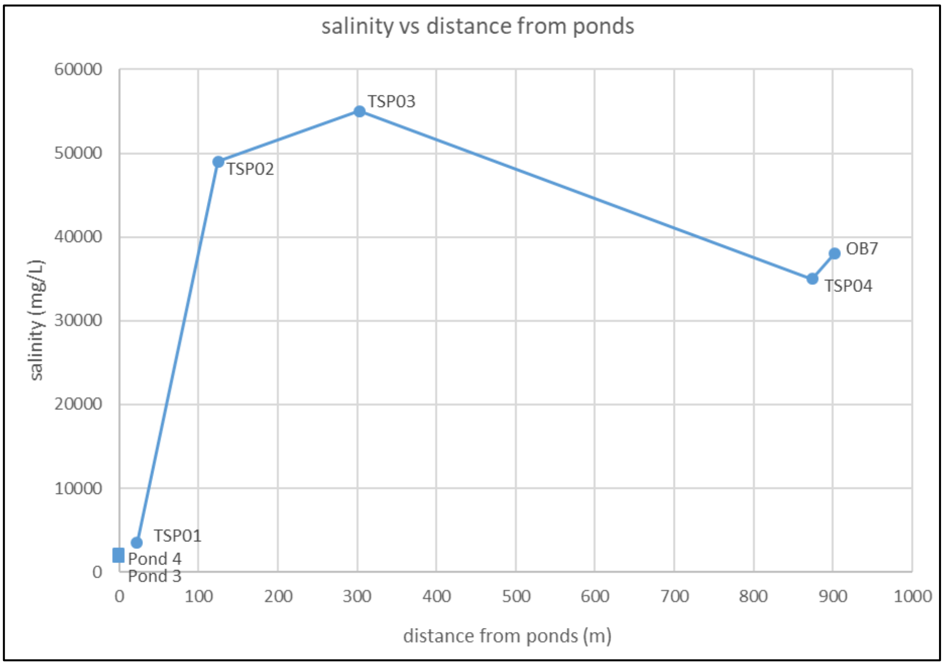

Figure 50. Saltmarsh groundwater salinity vs distance from T-section ponds, 4th and 24th February 2020.

Total phosphorus in the surface waters of the T-section ponds was 3.9 and 6.1 mg/L for ponds 3 and 4 respectively (Figure 51). These are high values, well above the ANZECC trigger values for aquatic ecosystems in south-eastern Australia, which lie within the range 0.01 to 0.05 mg/L (ANZECC 2000). However, total phosphorus in groundwater underlying the saltmarsh was generally less than 0.2 mg/L, i.e. an order of magnitude lower than the ponds, and there was no obvious trend related to distance from the ponds. The elevated total phosphorous level in TSP04 compared to the other piezometers is unclear, although the sample obtained from this piezometer was noticeably more turbid than other samples, which may have influenced the result.

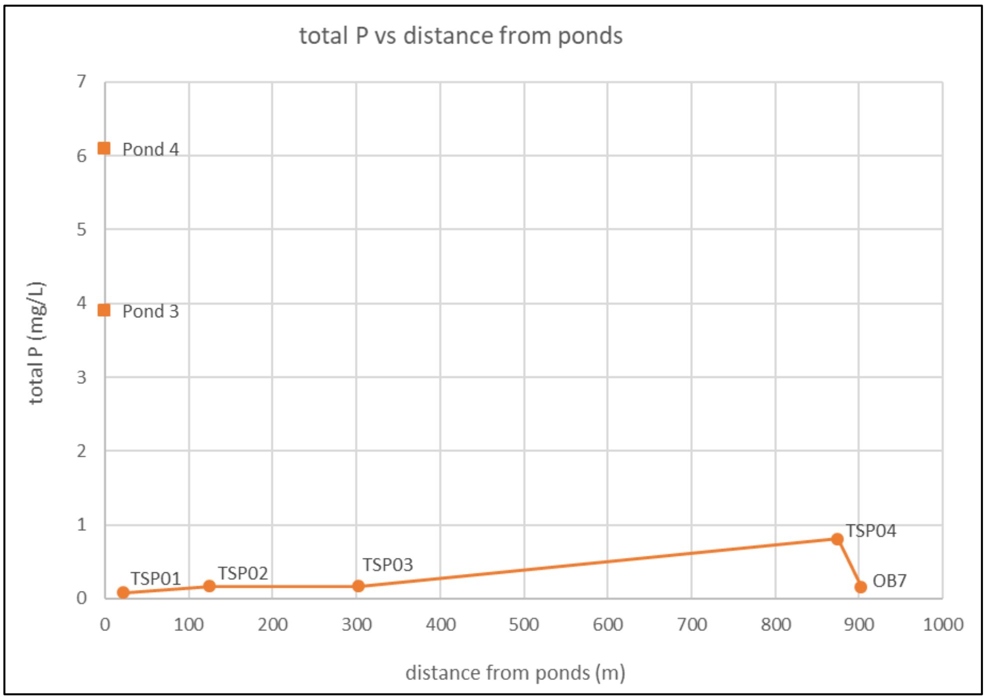

Figure 51. Saltmarsh groundwater total phosphorus concentration vs distance from T-section ponds, 4th and 24th February 2020.

Reactive phosphorous was high in the surface waters of the T-section ponds, 3.5 and 5.1 mg/L in ponds 3 and 4 respectively (Figure 52), well above the ANZECC rigger values for aquatic ecosystems in south-eastern Australia, which lie within the range 0.005 to 0.02 mg/L (ANZECC 2000). However reactive P in groundwater underlying the saltmarsh was less than 0.05 mg/L in all piezometers, i.e. two orders of magnitude lower than the ponds, and there was no obvious trend related to distance from the ponds.

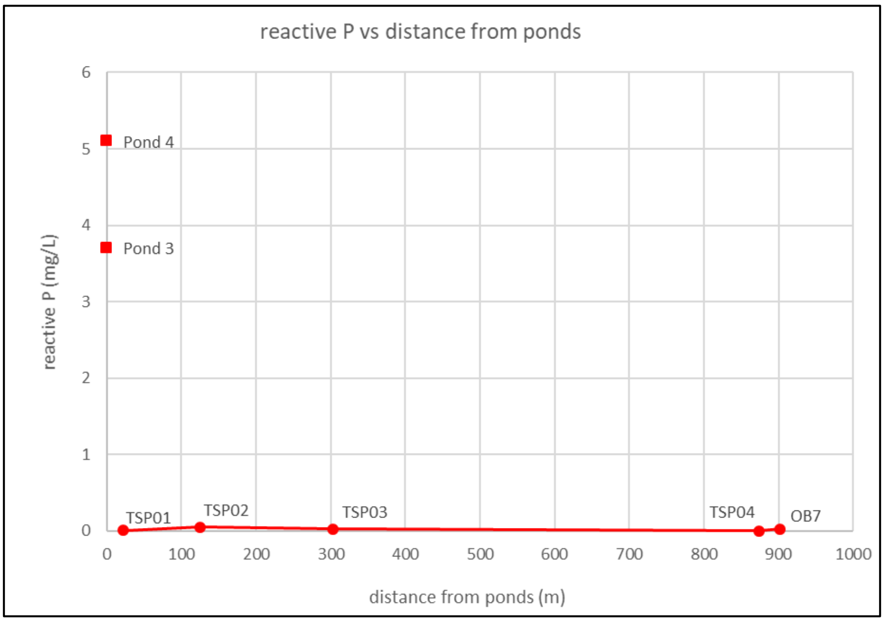

Figure 52. Saltmarsh groundwater reactive phosphorus concentration vs distance from T-section ponds, 4th and 24th February 2020.

Total nitrogen was 3.1 and 3.8 mg/L in the surface waters of ponds 3 and 4 respectively but varied considerably in groundwater underlying the saltmarsh, ranging from 1.05 to 8.4 mg/L (Figure 53). Unexpectedly, total nitrogen in groundwater was lowest at TSP01, the piezometer closest to the T-section ponds. However, at more distant locations TSP02, TSP03 and OB7, total nitrogen was between 2.4 and 3.1 mg/L, similar to the ponds. TSP04 is an outlier that may have been contaminated; the groundwater sampled from this piezometer was highly turbid compared to other locations.

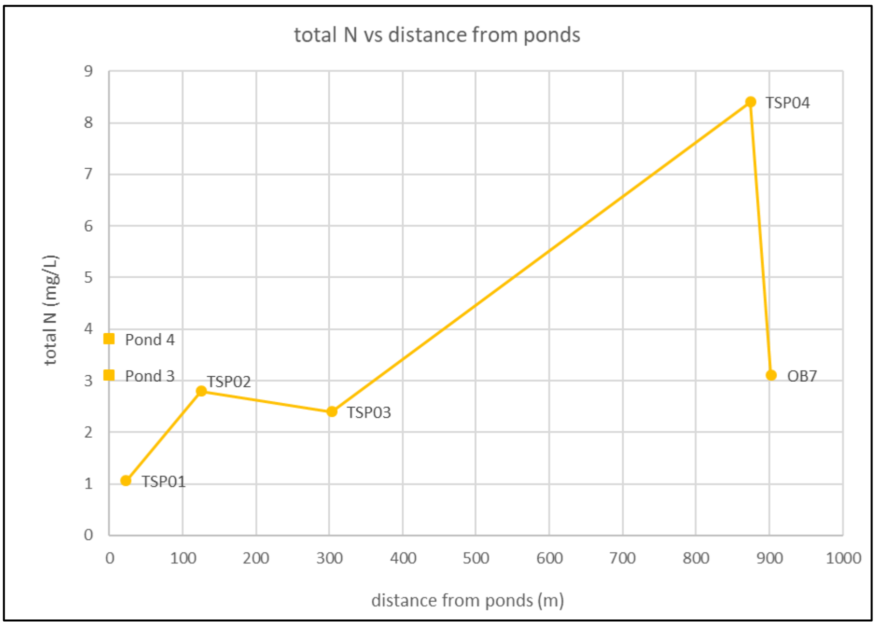

Figure 53. Saltmarsh groundwater total nitrogen concentration vs distance from T-section ponds, 4th and 24th February 2020.

Inorganic nitrogen was 0.06 and 0.11 mg/L in the surface waters of ponds 3 and 4 respectively but, as for total nitrogen, varied considerably in groundwater underlying the saltmarsh, ranging from 0.075 to 1.48 mg/L (Figure 54). Inorganic nitrogen concentrations in groundwater were similar to concentrations in the ponds at TSP01, TSP02 and TSP03, i.e. within 300 metres of the ponds. Unexpectedly, inorganic nitrogen concentration was highest at the reference locations (TSP04 and OB7), located over 850 metres from the ponds, where it was an order of magnitude higher (1.48 and 1.09 mg/L respectively). As discussed above, TSP04 may have been contaminated, but the result for OB7 is more compelling.

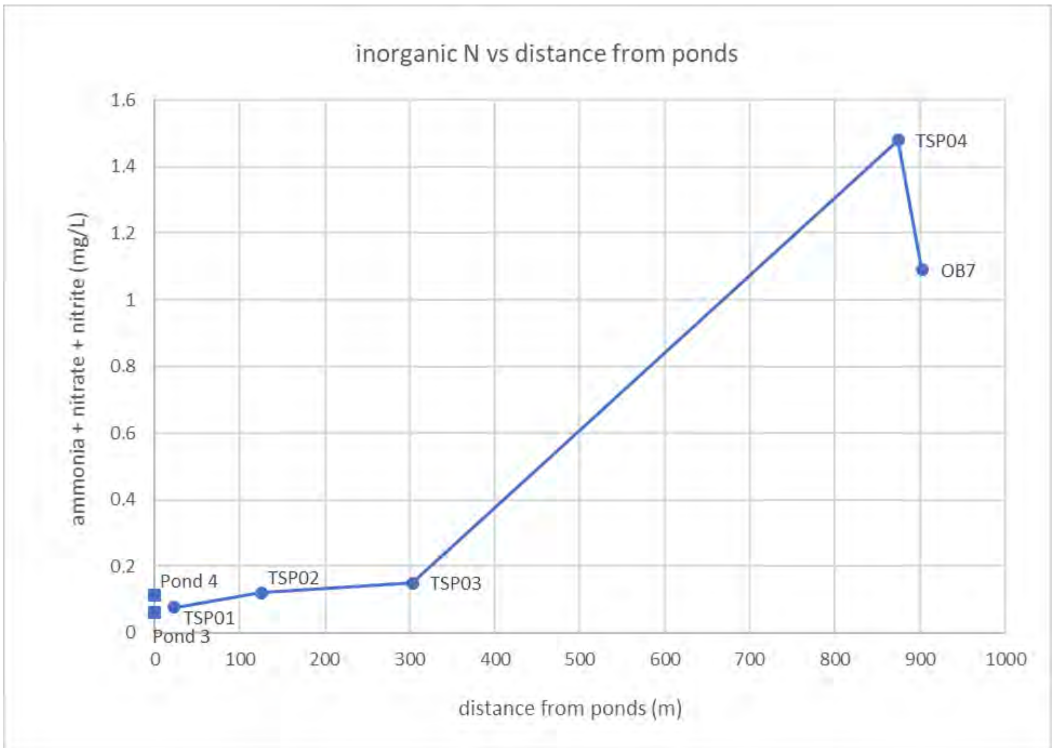

Figure 54. Saltmarsh groundwater inorganic nitrogen (ammonia + nitrate + nitrite) concentration vs distance from T-section ponds, 4th and 24th February 2020.

Based on the groundwater data collected during this study, the ponds have likely caused the watertable to freshen and rise in the saltmarsh area immediately adjacent to the treatment plant. This freshening effect appears to be very localised, contained within a zone approximately 100 metres from the ponds or less (on the eastern side). The influence of the pond on groundwater elevation is strongest within 25 metres of the ponds but still discernible 300 metres away. Analysis of groundwater quality suggests the ponds are not leaching nitrogen or phosphorus into the surrounding groundwater.

10. Recommendations

Despite a relatively short time period for this investigation, the current study has allowed a fresh assessment of hydrological parameters associated with ecological values within the Big Marsh saltmarsh area at The Spit. While ongoing data collection, particularly in terms of tidal and freshwater inflow trends under the current "stoplogs removed" management regime, will need to continue to inform knowledge regarding flow behaviours under 29 Mile Rd, several future recommendations or management options are presented here for consideration.

10.1. Twenty-nine Mile Road Causeway

Short of pulling up the causeway material and reinstating the natural bathymetry of the saltmarsh, or progressively adding more and more culverts at natural surface, there may be no way to fully eliminate the hydraulic impacts of the causeway itself on restricting the volume of tidal flows capable of reaching the saltmarsh west of the road.

As a result, the following recommended actions are considered to be the most feasible at this time:

- Leave stoplogs removed to maximise capacity to convey flows in either direction, by minimising (as much as possible) the hydraulic impediment to flows associated with the causeway.
- Continue monitoring water levels with the stoplogs removed and under a wider range of natural tidal and rainfall conditions (including associated with any other management actions) over a period of time. Note NGT data loggers, as well as tidal logger on shoreline of Bay, remain in place (as at mid-2020).
- As a result no further action, beyond continuation of monitoring to ascertain the impact of and ongoing increase in culvert capacity, is currently proposed or recommended.

10.2. Restore Freshwater Inflows

One of the most complex elements of this eco-hydrological investigation has been disentangling the history of modifications to Avalon Creek. This in turn has required some exploration of the nature and potential impact of different freshwater inflow regimes to the saltmarsh habitat of Big Marsh over time.

The key question to be addressed is:

- should these freshwater flows be re-instated, and if so, how, so as to avoid negative impacts?

Without a doubt, the natural freshwater flows from Avalon Creek to the saltmarsh have been interrupted. Yet at the same time, the modifications to drainage now mean that reinstatement of those flows is no simple matter, as flows are currently channelised via artificial drains where they were not naturally concentrated in this way. The inferred original alignment we have uncovered demonstrates that the watercourse has been interrupted in a number of ways, including via the T-section lagoons themselves, which (despite being artificial) are now Ramsar listed wetland habitat in their own right.

Rather than seeking an exact restoration or reinstatement of the original system that has been interrupted, as that would mean completely decommissioning at least some of the T-section lagoons, we propose three alternative options be considered for improving the condition of Avalon Creek and its relationship with the saltmarsh. In order (A-C), each of the options seeks to achieve outcomes that provide an increasing number of peripheral benefits, and edge us closer to re-creating a system that delivers the most "natural" outcome for this minor catchment.

Fundamental to the success of all options is the need to 'lift' Avalon Creek flows back out of the artificial drainage network that has been in place since the 1940s and allow it to be discharged as a diffuse surface flow into the saltmarsh, more closely mimicking the likely original nature of this catchment.

How much of that drainage network is altered to facilitate this outcome, and the precise path for flows to take to get there, are the main variables in the options provided. The preferred option will need to be determined by negotiation and consensus between the three main landholders involved: Melbourne Water and, subject to the option, Barro Group and possibly the Fox Group.

Option A (Figure 55): Retain perimeter drain to a location where creek flows would be diverted into the saltmarsh across Barro land, backfill the perimeter drain downstream of this point. Undertake minor works to ensure broad, shallow flows spill from the perimeter drain into saltmarsh on Barro land upstream of the backfilled drain.

This options assumes Avalon Creek water quality is fit for direct diversion into the saltmarsh.

This option is likely to be less costly than Options B and C.

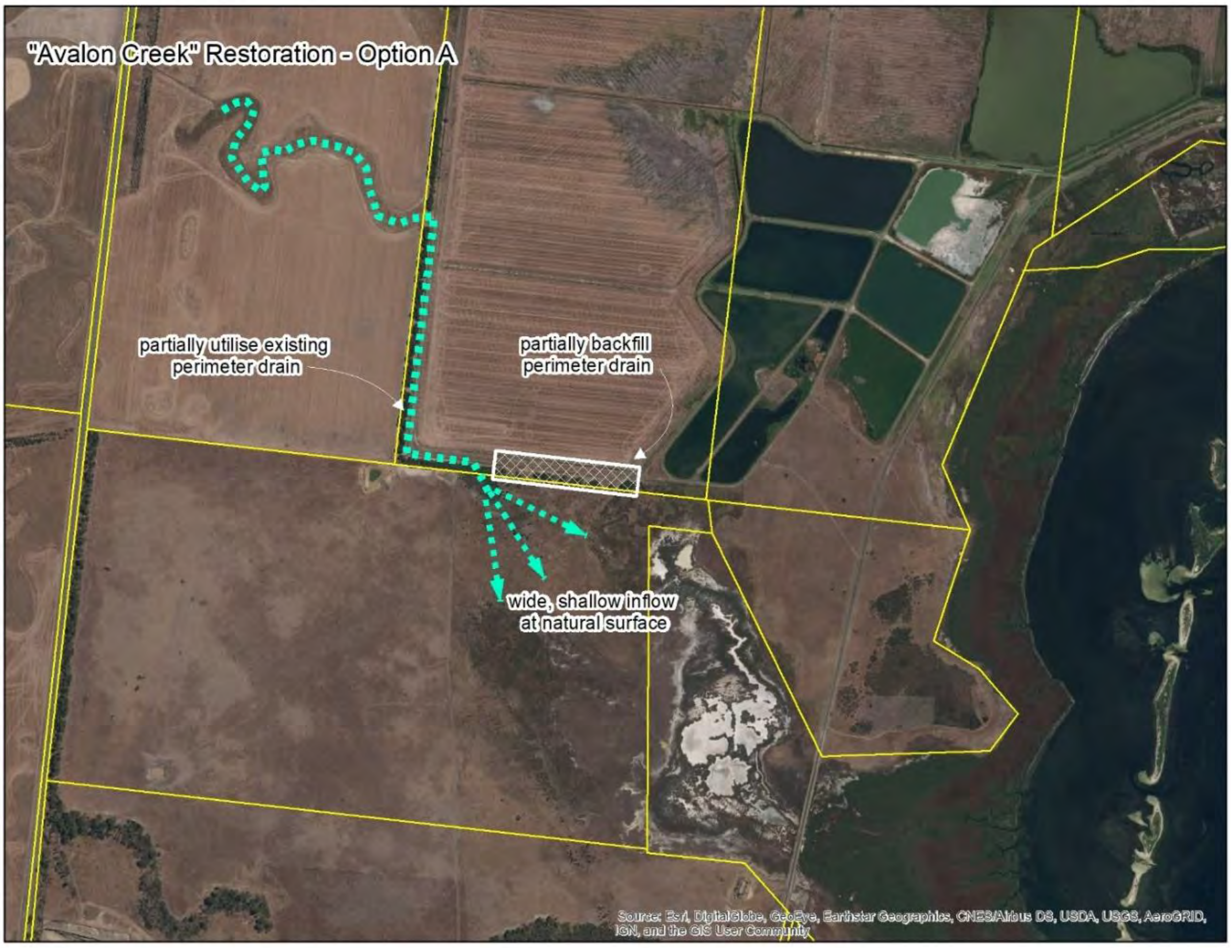

Figure 55. "Avalon Creek" restoration Option A.

Option B (Figure 56): Completely backfill the perimeter drain that currently carries flows first south and then east. Instead, allow flows to follow the existing perimeter drain alignment to the north, and then west, where (part of the way along) it can be 'lifted' out of the drain through the use of a regulating structure to inundate the already saturated paddocks in the vicinity.

This provides a natural means for attenuating the flow and providing shallow freshwater meadow or marsh habitat. From this location and subject to water quality, surplus water can either be allowed to discharge out of the system via the existing T-section drainage network, or (preferably) permitted to find its course overland across the T-section paddock (west of the T-section lagoon bund) in a southerly direction. Once the water reaches the location of the perimeter drain (now backfilled to natural surface) flows will simply spill over in a diffuse manner into the saltmarsh at Big Marsh.

This option is likely to be less costly than Options C.

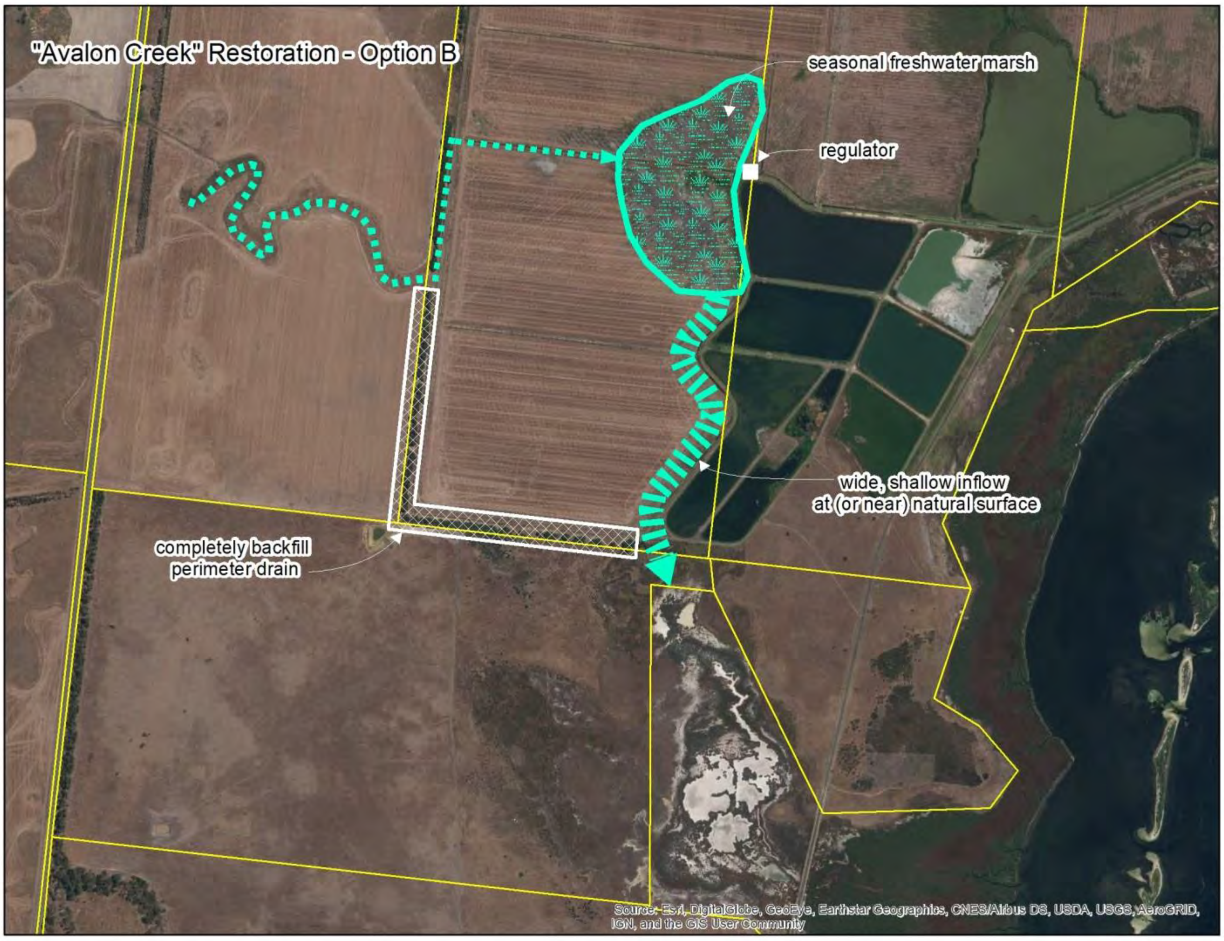

Figure 56. "Avalon Creek" restoration Option B.

Option C (Figure 57): Completely backfill the perimeter drain around the T-section paddocks, and allow for the recreation of the "natural" creek through T-section and S-section paddocks – reinstating a broad, shallow meandering watercourse. Part of this flow-path is likely to cross back into Fox Group land, before flowing east towards the naturally wet area at the north-west corner of the T-section Lagoons. In an enhanced way compared to the previous option, this provides a natural means for attenuating the flow and providing shallow freshwater meadow or marsh habitat.

Like Option B, from this location and subject to water quality, surplus water can either be allowed to discharge out of the system via the existing T-section drainage network which would be kept in place east of that point, or (preferably) permitted to find its course overland across the T-section paddock (west of the T-section lagoon bund) in a southerly direction. Once the water reaches the location of the perimeter drain (now backfilled to natural surface) flows will simply spill over in a diffuse manner into the saltmarsh at Big Marsh.

This option is the most expensive but is likely to maximise watercourse, wetland habitat and water quality benefits.

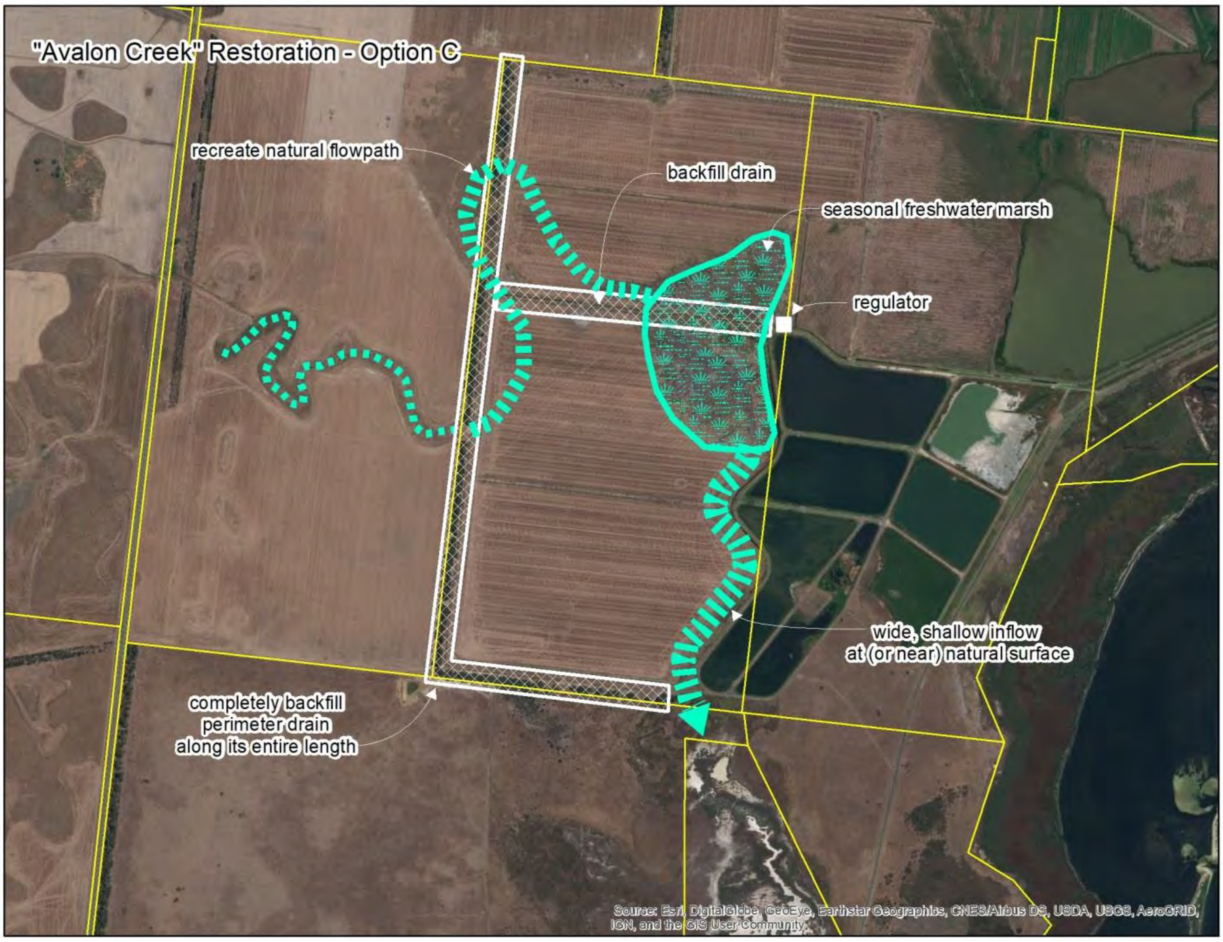

Figure 57. "Avalon Creek" restoration Option C.

Note that these three options can be implemented in stages if necessary – that is, Option A can be implemented first and then later upgraded to Option B or C. In this way, in ascending order, they are complementary – i.e. no option is mutually exclusive from the option that could follow it.

The reinstatement of seasonal (or possibly less frequent) freshwater inflows to Big Marsh from Avalon Creek may seem contrary to the objective of reducing the freshening impact of the T-section Ponds (see Section 10.3 below). However, the hydrological effect of Avalon Creek inflows would be quite different to the impact of the Ponds. Avalon Creek inflows would provide temporary, seasonal (or occasional) freshening of shallow, surface waters, overlying saline groundwater and soil conditions. The effect may be ecologically significant, i.e. it may trigger certain biological responses in saltmarsh biota, but it would be short lived. In contrast, the freshening effect of the T-section Ponds is permanently impacting soil and groundwater conditions and has persisted over a multi-decadal timeframe. This in turn is likely favouring species intolerant of salinity, including invasive introduced plant species, and leading to localised changes to floristic composition (Carr *et al.* 2002).

10.3. Management of Water Levels in T-section Ponds

The project has found that freshwater being held in the T-section ponds constantly well above natural surface is causing seepage south, and in doing so is maintaining a zone of elevated groundwater that extends into Big Marsh. Despite this, the zone of impact is relatively narrow and the measurable effects do not extent far into the saltmarsh. One way of measuring the success of the options below would be to set a target for both groundwater level and salinity for the observation bore at TSP01, and to continue to monitor it through time as the management regime changes.

As neighbours and land managers responsible for environmental values in the Ramsar site, Parks Victoria and Melbourne Water have a choice of three future management strategies across a spectrum, depending on how the ecological outcomes being sought for the Ramsar site, as a whole, are prioritised:

Option WL1: No change in management.

This options recognises that the habitat sustained in the T-section lagoons is valued as freshwater habitat contributing to a range of Ramsar site values in its own right, and that the detrimental impact of elevated fresh groundwater along the Big Marsh northern fringe is considered acceptable in that context.

Option WL2: Reduce static freshwater levels in the ponds adjacent to Big Marsh.

This option would reduce seepage, but still maintain some freshwater habitats in the lagoons, potentially more favourable to waders. This could be done in two ways:

(a) Manage T-section Ponds 3 and 4 with lower water levels throughout, or
(b) Install an additional, east-west aligned bund across Ponds 3 and 4, and keep the pond area to south of this new bund dry or with very low water levels to further reduce or eliminate seepage. The ideal location for this new bund would be 100 metres to the north of the existing southern bund (i.e. boundary with Big Marsh) (Figure 58). This distance is likely to overcome most of the influence of the ponds upon groundwater within Big Marsh according to our piezometer data. The narrow area of Ponds 3 and 4 to the north of the proposed bund should be avoided as it is a known wader roost, a preferred set of reedbeds for crakes and rails and may provide habitat for growling grass frogs (Danny Rogers, ARI. Pers. comm., 7/8/20).

Figure 58. The potential bund location (red) for Option WL2 (b)

The idea of a potential set-back for the ponds is not new, having been previously raised by Will Steele at a meeting of the WTP Wildlife Consultative Committee Meeting as early as 18 February 2004.

Lower sustained water levels would have benefits for both saltmarsh vegetation condition within Big Marsh and shorebird foraging within the ponds (in shallower water), but may result in a trade-off for species currently utilising the deeper freshwater habitat typical of the ponds with the current management regime.

Option WL3: Removal of Ponds 3 and 4 to facilitate restoration of this area as saltmarsh habitat.

In line with the 1947 image, this option would re-incorporate the partially restored Avalon Creek flowpath, building upon the watercourse restoration concept shown in Option B and C over the previous pages. Full watercourse reinstatement and restoration of Big Marsh across its original footprint to the north would also require removal of Ponds 1 and 2 and has been deemed unacceptable to the reviewers of this report due to the loss of important, albeit artificial, waterbird habitat within the Ramsar site.

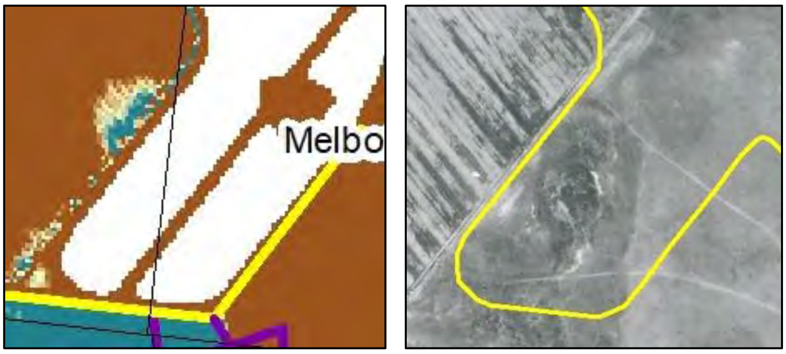

Figure 59. Example restoration area: southern portion of Ponds 3 and 4 (left) showing the area of saltmarsh in in 1947 (right)

Note: if this option is selected it has implications that would require design changes to Option B and C in the previous section.

Although listed here as an option (WL3), we understand that full restoration is unlikely to be supported as it would require a significant ecological trade-off, with the complete loss of freshwater pond habitats currently managed specifically by Melbourne Water for values associated with the Ramsar site listing. However, please also note that a combination or integration of these options is also possible to reduce or adjust the magnitude of ecological trade-off required.

In saying this however we note the documented value of the artificial habitats of the area compared to natural habitats: during studies undertaken "in the summer of 1999, conditions on managed habitats (particularly the 35E conservation ponds and T-section Lagoon) supported between 40% and 85% of the shorebirds. Their usage of these managed habitats was so consistent that during neap tides, they continued foraging at them rather than exposed intertidal mudflats." (Brett Lane and Associates 2006).

The Ponds also provide habitat for very large numbers of waterfowl when rainfall or flooding events have not attracted them elsewhere and continuing sympathetic management of the Ponds has been recommended to maintain the value of the Western Treatment Plant for waterfowl (Loyn *et al.* 2014).

Also note that combination or partial integration of the three options provided is also possible, meaning that the indicative options provided here can be adjusted if necessary at the detailed design stage.

10.4. Improved Fencing and Grazing Management

Whilst impacts of grazing were not a focus of this study, the issue has been raised with stakeholders including Barro Group and Parks Victoria. During the course of the study, sheep were observed within saltmarsh (seemingly as a result of fences being in a state of poor repair) as well as on adjacent terrestrial grassland. Although the previous grazing trial was inconclusive (Loyn *et al.* 2010), on the balance of evidence available, grazing of saltmarsh vegetation is not currently recommended.

For the purposes of grazing management going forward, we recommend that:

- with the relevant landholders consent, both private and public (Crown) parcels of Big Marsh be treated uniformly.
- on parcels where grazing is occurring, fencelines be reconfigured to separate saltmarsh vegetation from the adjacent terrestrial grassland (which also includes elements of upslope *Gahnia* sedgeland). This can include existing fencing (repair if required) and new fencing (Figure 60). However, the ultimate alignment for fencing should not be finalised until the restoration options in Section 10.2 and 10.3 are determined, to ensure it is configured in a way that is complementary.
- unnecessary internal fencing within the saltmarsh is removed (Figure 60). This fencing serves no purpose given it was installed for the discontinued grazing trial and/or it separates an area of Melbourne Water land from Big Marsh that is ungrazed and managed for conservation.

The above recommendations have been endorsed in principle by Barro Group.

Figure 60. Approximate alignment of proposed new fence (blue line), existing fence to be maintained (yellow line) and existing fence to be removed (purple line) at Big Marsh. The DEM is displayed to differentiate between saltmarsh (blue) & higher ground (brown).

10.5. Tenure

The western (dry) saltmarsh portion, which comprises roughly half of Big Marsh is situated on private land. The concept of consolidating the tenure of this area, in recognition of its environmental values, is not new. Note these excerpts from the minutes of the WTP Wildlife Consultative Committee Meeting, 9 March 2005:

> *"Maarten Hulzebosch asked if Barro Group would agree to their 'buffer strip', lying between the proposed new extent of quarry works and the property boundary, being rezoned for Conservation use. Peter [Barro] thought the land already had an ESO overlay but agreed to consider developing a management plan for the buffer strip that was in line with the WTP / Spit Ramsar Conservation Management Plan. [Peter later confirmed that this strip of land is subject to an ESO.]"*
>
> ESO = Environmental Significance Overlay, a Victorian planning provision designed to identify areas where the development of land may be affected by environmental constraints.

While no timeline has been discussed, all parties remain open to the option of the adjoining Barro land (outside of the Stage 2 quarry expansion footprint) being set aside for conservation in perpetuity in the future, either ahead of or upon the eventual closure of Mountain View Quarry. The precise mechanism for how and when this might be achieved has not yet been discussed, but the goodwill to revisit this issue exists.

10.6. Sea level rise

The issue of sea level rise is an essential background issue that needs to be factored into all options.

Where relevant, this will impact design considerations and the time horizons set for the recommended actions in this report. For example, preparing for and facilitating a future saltmarsh footprint that can move up-slope to 'creep' with rising sea levels and avoid the vegetation community being lost is an important consideration for finalising proposed fencing and future tenure discussions.

10.7. Monitoring

Proposed monitoring is designed to be sensitive to the effects of the suggested management changes and restoration works (outlined previously) and to inform an adaptive management approach. Monitoring will be very important to the ongoing cooperative relationship between stakeholders. It is also required to help disentangle the effects of restoration from other potential influences upon the condition of Big Marsh.

10.7.1. Monitoring the effect of stoplog removal, 29 Mile Road Causeway

Surface water elevation monitoring is currently ongoing at the paired loggers TSL02 (inland) and TSL05 (seaward) at culvert 11 and the 13 cork tube locations. This should continue until one year of data with stoplogs removed has been obtained as a minimum, i.e. until 13th November 2020. Higher tides have generally been recorded in winter and this period is currently missing from the "without stoplogs" data.

An optional addition to the current water level monitoring would be the installation of an east-west transect of 8-10 water level loggers at increasing distances from the sea, with 4-5 on the seaward side and 4-5 on the inland side of 29 Mile Rd. The intent would be to disentangle the effects of natural tidal attenuation from the effect of 29 Mile Rd (without stoplogs) upon water levels inland. However, if there is no future prospect or intention to further upgrade (via the installation of more culverts) or replace 29 Mile Rd (by removing the causeway base material and installing a bridge over the saltmarsh), this further investigation becomes largely academic.

The salinity of surface water has considerable ecological significance in wetlands. Improved transfer of seawater from the seaward to the inland side, and of fresher water from the inland to the seaward side of 29 Mile Rd would be anticipated to effect surface water salinity. An east-west transect of 4-5 salinity loggers would be informative in relation to the effect of 29 Mile Rd and other restoration proposals before and after implementation. At least one should be located on the seaward side and the remainder on the inland side, including low lying areas over 300 metres distant from the road.

Improved condition of saltmarsh vegetation in Big Marsh is the overriding objective of management and restoration and as such should be monitored. A detailed monitoring design should be:

- informed by and complementary to previous mapping and monitoring (e.g. Carr 1982, Carr *et al.* 1991, Carr *et al.* 2002, Sinclair 2010) and ongoing monitoring being undertaken on the Barro Group land (e.g. Nolan Consulting 2019); and
- sensitive to the likely floristic changes arising from changes to water level and salinity.

The monitoring of saltmarsh birds (e.g. blue-winged parrot, white-fronted chat, striated fieldwren) within Big Marsh is also recommended.

10.7.2. Monitoring to inform restoration of freshwater inflows

Prior to the restoration of freshwater inflows from "Avalon Creek", the water quality of this source should be investigated through a range of seasons and flow scenarios. Key parameters include salinity and species of nitrogen and phosphorous. As these flows arise from Avalon Airport, consideration should be given to pollutants (and associated spill risks) specific to that land use.

Additionally, if option B or C are adopted, initial monitoring of water quality is recommended for the freshwater wetland recreated in the restored flowpath adjacent to the T-section lagoon. At this location there will be an ongoing opportunity to choose whether flows are conveyed southwards to the saltmarsh by an overland diffuse flowpath, or discharged east via a drainage outlet (i.e. the regulator proposed for placement in the T-section drainage infrastructure shown in Figure 56 and Figure 57).

While water quality presents a potential risk to the restoration of freshwater inflows from Avalon Creek, it is noteworthy that a population of nationally vulnerable growling grass frogs (*Litoria raniformis*) exists in the network of drains that currently receives these flows (Brett Lane and Associates 2006). The perimeter drain “extension”, running north to the west of T-Section Lagoon, is known to provide suitable habitat for growling grass frogs (Will Steele, MW, pers. comm., 13/8/20).

Monitoring of inflows from Avalon Creek is also recommended to improve understanding of the timing, duration, frequency and volume of these inflows. This could be simply achieved by the installation of a water level logger within the drain. Water level provides an indication of flow rate. Water level in the perimeter drain could be converted to flow rate by measuring drain cross sections and flow velocities under a range of flow conditions, however this would require considerably more effort.

Surface water level and salinity (within Big Marsh), saltmarsh vegetation and saltmarsh bird monitoring have been captured in the previous section but are also relevant to the restoration of diffuse freshwater inflows.

Optional monitoring elements that may be considered subject to the adopted preferred actions that may stem from this work, include monitoring ecological responses of flora and fauna in the restored flowpaths and within the freshwater marsh habitat created/enhanced in the T-section paddock (for Options B and C).

10.7.3. Monitoring to inform water level management in T-section ponds

Monitoring of groundwater elevation in the saltmarsh established for this study (transect of piezometers with water level loggers) will continue for the foreseeable future and will be important to obtain baseline data for a before-after comparison of the effect of any future changes to the management of the T-section ponds (and other restoration measures). Loggers have a battery life of approximately 5 years and will continue to record data for that period. However, data can only be obtained via manual download so regular site visits for this purpose, and to generally check on the status of the monitoring infrastructure, are recommended.

Groundwater salinity within the saltmarsh, as another key issue related to the management of T-section ponds, is recommended for monitoring. This could be achieved via regular manual sampling or via the placement of salinity loggers into the existing transect of piezometers established for this study.

Should alternative water level management options for the T-section ponds be pursued, the installation of water level loggers within ponds 3 and 4 is recommended. Our understanding is that Melbourne Water is currently giving consideration to this.

The monitoring of saltmarsh vegetation condition within Big Marsh is relevant to water level management in the T-section ponds, as it is to all potential restoration actions. An emphasis on the vegetation within the current zone of groundwater influence of the ponds is recommended in this case. Additionally, should the ponds be managed with lower water levels, or partially decommissioned, monitoring of the vegetation response within the ponds themselves is recommended.

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