North Torquay Constructed Wetland Assessment

Version 2.3

DesignFlow

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Summary

The purpose of this investigation was to review existing stormwater treatment wetlands located in the north Torquay catchment.

This involved reviewing wetland designs, assessing wetland condition and performance and recommending measures to improve wetland function to better protect the downstream Karaaf wetland ecosystem.

The review found that the wetlands are generally in good condition with strong vegetation growth, with a couple of exceptions where Typha growth has completely dominated the wetlands. There were also a number of wetland design and configuration improvements identified.

An overall finding from the investigation is that all of the wetlands are smaller than required to meet best practice stormwater treatment objectives. This could be related to underestimates of predicted catchment imperviousness (compared to what has been constructed) in early planning of the urban areas.

While smaller than ideal, improvements to the current treatment performance of the wetlands are possible within the existing footprints. These involve:

- Cleaning and deepening sediment (inlet) ponds to the wetlands
- Reducing short circuiting and improving interaction of stormwater with water plants
- Creating shallower areas and increasing the emergent plant coverage
- Checking the operation and modifying extended detention depth controls (i.e. the outlet structures for the wetlands).

Two of the wetland systems are currently being re-set to remove significant stands of Typha (Esplanade and The Quay) and these works offer good opportunities to implement these modifications.

Upon review, there seems limited value in continuing a current stormwater quality monitoring program in its current form. It is recommended this be replaced with a wetland condition audit program that will identity particular actions to address wetland performance.

Outflows from the north Torquay catchment reaching the Karaaf wetlands (including the Sands development), even when accounting for existing irrigation use, generates approximately four times more runoff than the pre-development conditions. It is highly likely that the increased volume of water being discharged to the Karaaf wetlands results in an altered salinity regime that may impact the saltmarsh ecosystem.

The water balance model indicated that approximately 500-600 ML per year would need to be removed from the north Torquay catchment flow to the Karaaf to return inflow volumes to the Karaaf to pre-development rates.

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1 Introduction

Extensive urban development in north Torquay catchment has resulted in increased stormwater volumes and associated pollutants being discharged to the Karaaf compared to pre-development conditions. The north Torquay catchment is the largest and only urbanised catchment draining to the Karaaf and is the focus of this report.

As part of the urban development, a network of Water Sensitive Urban Design (WSUD) assets has been constructed, the majority of which are stormwater treatment wetlands.

Despite the implementation of the treatment wetlands in most catchments, the health of the Karaaf wetland ecosystem (that ultimately receives stormwater runoff from the north Torquay area) has notably declined.

The purpose of this investigation was to review existing WSUD assets in north Torquay area to assess wetland condition and performance and to determine what improvements to the wetlands are required to achieve the maximum potential treatment performance.

Catchment modelling was undertaken to determine the annual stormwater volume and pollutant loads being discharged to the Karaaf wetlands via The Sands development. Importantly, this enabled the additional volume of water being discharged to the Karaaf following urbanisation of the north Torquay catchment to be estimated.

The assessment is based on:

- review of wetland design plans
- background reports including stormwater masterplans for north Torquay, audits of wetlands and assessments of the Karaaf catchment
- review of catchments draining to wetlands and their configurations
- site visits to assess current conditions and particular components
- discussions with council officers regarding operations
- modelling of the systems performance and interpretation of the results.

In addition, a water quality monitoring program intended to assess wetland performance is reviewed and recommendations made.

2 Catchment description

The north Torquay urban catchment flowing to the Karaaf is approximately 620 hectares of mainly residential development, low density residential and some agricultural land (Figure 1). The catchment was divided into discrete sub-catchments as drainage was formalised during urbanisation.

Runoff from the north Torquay catchment generally drains in easterly direction and is discharged into the Karaaf wetland via a network of lakes, wetlands and storages through The Sands development (golf course and residential development).

The majority of catchment conveys stormwater through a piped stormwater drainage network. The Torquay Heights rural-residential catchment and adjoining rural areas are not connected to a formal drainage network. Surface runoff from these sub catchments enters a formal drainage network in the Zeally Sands catchment.

All runoff from the north Torquay residential catchment area is discharged to the Karaaf via The Sands lake system (Figure 1). Stormwater from Stretton, Dunes and Zeally Sands Estates is discharged to The Sands northern lake system, whereas stormwater runoff from the Quay Estate combines with runoff from the Golden Beach Estate and flows into the Sands southern lake system. A proportion of the stormwater (low flows only) from the Wombah Park catchment are diverted to the Esplanade wetland, with high flows from this catchment discharging to Deep Creek.

Figure 1 North Torquay catchment and treatment summary.

The majority of the stormwater from the north Torquay catchment flows into the Karaaf. A minimum of 12.5 ML per year is harvested from the Stretton and The Dunes wetlands and used for horticultural purposes, and a further 180 ML per year is estimated to be used by The Sands to irrigate the golf course.

Stormwater runoff from each of the estates is treated using constructed stormwater wetlands. The wetlands are generally located at the lowermost points in the drainage network for each estate, except Stretton Estate where the catchment is divided into wetlands for west and east sub catchments (Figure 1). The west catchment will be developed later with urban development.

There are nine stormwater treatment wetlands in the north Torquay catchment:

- Stretton Estate - east wetland
- Stretton Estate - west wetland (yet to be built)
- The Dunes wetland
- Quay Estate – north wetland
- Quay Estate – south wetland
- Golden Beach - Esplanade wetland
- Zeally Sands – wetland 1
- Zeally Sands – wetland 2
- Zeally Sands – wetland 3

In addition, there are some stormwater treatment wetlands in The Sands, however these were not included as part of this performance review.

3 Stormwater treatment

Potential impacts caused by stormwater from urban areas needs to be managed to reduce the risk of flooding and to protect downstream ecosystems such as waterways, wetlands and marine environments.

This section outlines the statutory requirements for stormwater quality management in Victoria and describes the key features and how natural systems such as wetlands are used to treat stormwater runoff quality.

3.1 Best Practice Stormwater Treatment

3.1.1 Victorian Planning Provisions

Clause 56.07-4 (Integrated water management) of the Victorian Planning Provisions requires that all stormwater runoff from new residential subdivisions to meet the stormwater quality objectives outlined in Urban Stormwater Best Practice Environmental Management Guidelines (BPEM) (Victorian Stormwater Committee, 1999).

Current stormwater quality objectives include:

- 80% reduction in the annual suspended solids load
- 45% reduction in the annual total phosphorus load
- 45% reduction in the annual total nitrogen load
- 70% reduction in the annual gross pollutant (litter) load.

3.1.2 State Environment Protection Policy (Waters of Victoria)

Clause 34 (Management of urban stormwater) of the State Environment Protection Policy (Waters of Victoria) requires that:

- urban stormwater must be managed to minimise risks to beneficial uses of receiving waters
- Councils as the responsible authority must ensure that all new development meet the stormwater management objectives set out in the BPEM
- Owners and managers of assets created to protect water quality such as sediment ponds and wetlands must ensure that they are:
    - Designed and managed so that they are not harmful to humans and animals, and their risks to beneficial uses of receiving waters are minimised, and
    - Maintained for the purposes for which they were constructed

The management of stormwater quality under Clause 56.07 of the VPP contributes to achieving the objectives of the State Environment Protection Policy (Waters of Victoria).

3.2 Stormwater treatment options

A wide range of stormwater treatment options, often referred to as Water Sensitive Urban Design (WSUD), can be used to achieve the BPEM stormwater quality objectives. These include: gross pollutant traps, sediment basins, constructed wetlands, raingardens, swales, rainwater tanks and proprietary treatment devices.

Stormwater harvesting systems are often integrated with WSUD systems and can be effective for reducing stormwater runoff volumes and pollutant loads.

Stormwater management systems must be designed and managed in accordance with the requirements of the relevant drainage authority.

Natural treatment systems such as constructed wetlands are often used to treat stormwater runoff from urban developments as they provide multiple benefits such as wildlife habitat, landscape amenity, passive recreation opportunities and can be integrated with flood management assets such as retarding basins.

3.3 Constructed wetlands

Constructed wetlands are shallow, extensively vegetated freshwater bodies that use enhanced sedimentation, fine filtration, chemical and biological uptake processes to remove pollutants from stormwater.

Constructed wetlands rely heavily upon microbial processes to intercept, transform and remove pollutants from stormwater. They are robust systems that can cope with large variations in flow and water quality. The presence of emergent water plants within constructed wetlands is crucial to the long term performance of a wetland system, as the plants play a major role in the uptake of nutrients, and the health of the wetland sediments and microbial communities. Constructed wetlands therefore need to be carefully designed and managed to provide the best conditions for plant growth to ensure the long term performance of the wetland.

A well-designed and constructed wetland can remove pollutants under varying hydraulic conditions. If a constructed wetland is not designed appropriately, the wetland vegetation may fail to establish, sediment/microbial health will be poor, and the wetland may provide limited treatment of pollutants, or actually become a source of pollutants itself.

Treatment wetlands comprise two major components: a sediment basin and a macrophyte zone (densely planted zone) (Figure 2).

<u>Sediment basin</u>

The sediment pond is an open water body where stormwater runoff enters the constructed wetland system. The sediment basin reduces the velocity of inflows, traps coarse sediments and generally protects the macrophyte zone from being smothered with sediments.

Generally, gross pollutants are removed using gross pollutant traps (GPTs) located in the catchment upstream of a sediment basin.

<u>Macrophyte zone</u>

The function of a macrophyte (plant) zone is to provide a low velocity environment where the smaller suspended particles are able to settle out of suspension or adhere to the vegetation. Soluble pollutants, such as nutrients, are adsorbed onto the surfaces of suspended solids and entrained within the wetland sediments, or biologically absorbed by the biofilms (algae, bacteria) present on the macrophytes or by the macrophytes themselves. Microbial activity within the biofilms or within the sediment helps to decompose organic matter and is crucial to the transformation and export of carbon, nitrogen and sulphur (in gaseous forms) from the wetland.

The bathymetry of a macrophyte zone is designed so that stormwater passes through a sequence of densely vegetated planting zones. The planting zones are arranged in a banded manner, perpendicular to the flow direction, so that stormwater can flow evenly through the vegetation, and interact with the biofilms present upon the surfaces of the water plant stems. The treatment performance of a wetland is highly dependent upon flows passing through dense vegetation distributed across the entire macrophyte zone.

<u>Hydrology</u>

As stormwater enters a wetland during a rainfall event, water is temporarily stored above the wetland normal water level (NWL). The water storage depth above NWL is termed the extended detention depth and generally varies between 0.25-0.35m. The upper limit of the extended detention depth is termed the top of extended detention (TED).

Outflows from a wetland are regulated by a riser pipe or weir located within outlet pit, which sets the normal water level within a wetland and is configured so that stormwater will take approximately three days to drain from through the wetland (residence time).

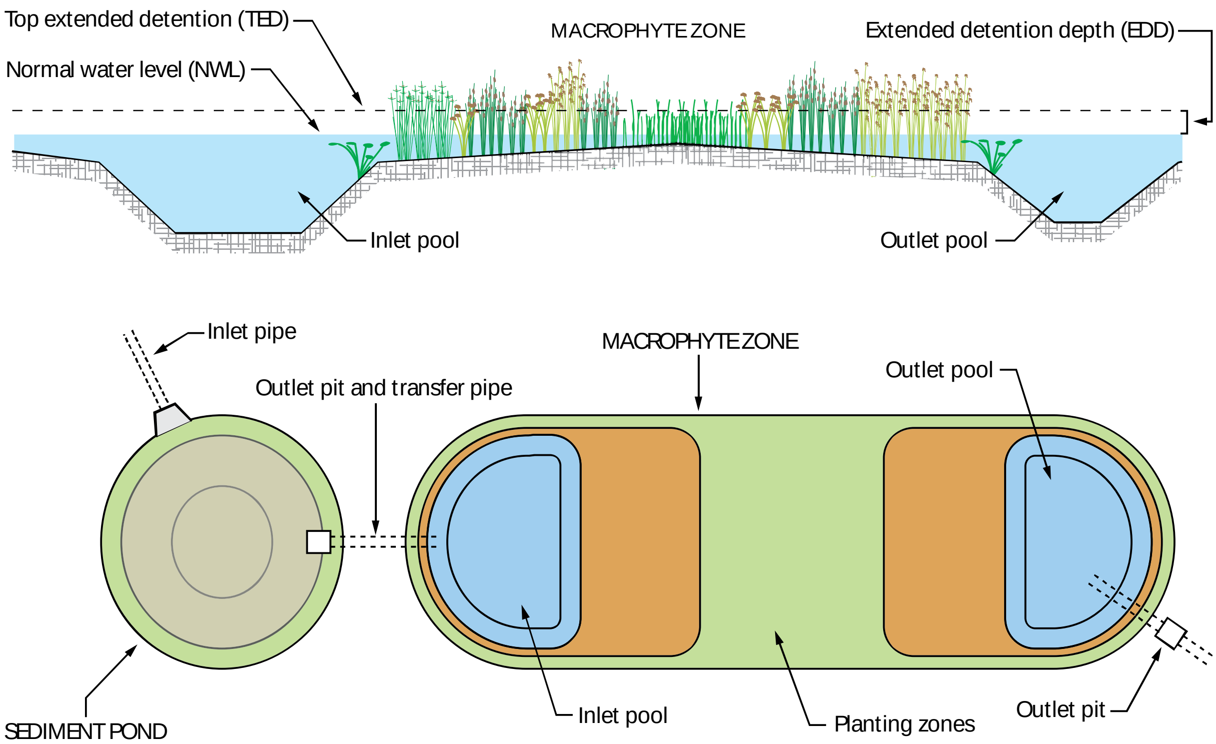

Figure 2 Typical layout of a constructed treatment wetland.

4 Wetland assessment

The north Torquay wetland assessments involved reviewing wetland design plans, consulting with Council staff, visiting each wetland and undertaking a condition assessment for each system.

The following sections provide an overview of the design review outcomes and then provide more detailed descriptions for particular designs and audit results for each wetland system.

4.1 Design review summary

Since 2016 it is generally recommended that stormwater treatment wetlands are designed in accordance with the Melbourne Water Wetland Design Manual (2016). The design manual outlines specific design requirements that focus upon ensuring that treatment wetlands are functional, cost effective, consider user safety and sustainable. This review compares the designs of the north Torquay systems to the Melbourne Water guideline (even though most designs were complete before that guideline was published).

The design review of the north Torquay wetlands indicated many common design issues, many off which simply reflect advice provided in older wetland design guidelines.

4.1.1 Wetland sizing

One of the clearest observations from the design review (and performance modelling) is that the wetlands (all except the Esplanade) are too small to deliver best practice treatment.

Wetland designs that follow current industry advice are typically required to be a size of between 2.5-3.5% of the contributing urban catchment area to achieve best practice treatment levels. Critical components of the wetland and catchment characteristics, such as percentage of impervious cover in a catchment, wetland extended detention depths and durations, are covered in guidelines such as *Melbourne Water MUSIC Guidelines* and *Melbourne Water Wetland Design Guidelines*. While the size of wetlands to achieve best practice varies in different climatic regions and with differing catchment characteristics, the minimum size required is generally more than 2% of the urban catchment area when these guidelines are followed.

Wetland sizes in north Torquay are between 0.4 – 2.0% (Table 1). This means the treatment systems are generally too small to reach best practice treatment levels.

It is unknown why the wetlands are undersized, but may relate to earlier work (GHD, 2010) that estimated only 45% imperviousness for developed catchments (i.e. the hard paved area in a catchment such a rooves, roads and footpaths). This significantly underestimates flow and pollutants (and therefore required wetland sizes) compared to typically constructed urban areas (that are 70-80% impervious, e.g. as recommended in *Melbourne Water MUSIC Guidelines*).

An obvious response is to make the systems bigger so they can treat more stormwater and achieve best practice treatment outcomes. However, this is not practical, affordable or feasible given the extent of urban development around the wetlands. The focus here, therefore, is to maximise the levels of treatment each wetland can achieve within its current footprint using current best practice wetland design guidance. Particular components are described in the following sections.

Future designs should consider best practice modelling and sizing using catchment assumptions that relate to the final built form.

Table 1 Wetland to catchment area ratio

Wetland	Catchment area (Ha)	Wetland area (Ha)	Wetland: Catchment Ratio
Stretton East	28.5	0.57	2.0
Stretton West [1]	37.5	0.33	0.9
The Dunes	48.6	0.34	0.7
Quay North	19.6	0.22	1.1
Quay South	56.4	0.37	0.7
Esplanade [2]	82.3	1.43	1.7
Zeally Sands - W1	21.3	0.26	1.2
Zeally Sands - W2	10.3	0.21	2.0
Zeally Sands - W3	16.3	0.06	0.4

[1] Stretton West wetland yet to be developed.

[2] Includes both Golden Beach and Quay Estate (untreated catchment).

4.1.2 Sediment basins

Sediment basins are designed to remove at least 95% of the course particles ≥125 µm diameter for the peak three-month Average Recurrence Interval (ARI) and have sufficient sediment storage volume to store between 4-5 years sediment (i.e. have a minimum cleanout frequency of once every 4-5 years). This generally requires that the sediment basin has minimum 1.5-2m depth.

The configuration of a sediment basin also needs to ensure that the stored sediments are protected during high flow events. The maximum allowable velocity through the sediment basin during the peak 100 year ARI event is 0.5 m/s based upon the flow area cross-section at the narrowest width of the sediment pond.

One of the most important components of a sediment basin is an access track to enable maintenance vehicles and personnel to safely access and exit the site. Without adequate access sediment basins cannot be cleaned and continually accumulate sediments.

General observations in north Torquay are that the sediment basins are typically too shallow and therefore are unlikely to have sufficient sediment storage volumes for a 5-year cleaning frequency.

Overloading of a sediment basin means it gets shallow enough for plants (e.g. weeds) to grow and they have limited future sediment capture potential. Sediments can be resuspended and transferred into macrophyte zones and later bathymetry and can smother plants.

Access to sediments basins is adequate in the wetlands observed.

Cleaning sediment basins to remove accumulated sediments and deepen the basins is recommended to maintain function and protect macrophyte zones.

4.1.3 Wetland bathymetry

Macrophyte zones are intended to support extensive emergent and submerged water plants to maximise treatment in wetlands.

At least 80% the macrophyte zone should have varying depths less than 0.35m deep (at normal water level - NWL) to enable emergent water plants to grow. This means 20% or less of a macrophyte zone can be more than 350 mm deep and is suitable for submerged water plant growth.

Sequences of open water pools (too deep for water plants) provide a short circuit for the stormwater through a macrophyte zone and limit the interaction of stormwater with water plants (and their biofilms) and therefore reduce pollutant removal.

Many of the wetlands in north Torquay are designed as a series of connected deep pools that reduces the total plant coverage in the wetland footprints. While water plants were in good health and densities generally (except for the Dunes and Esplanade) their coverage overall is limited by the number of deep pools.

There are limited ways to address this without major interventions (except Stratten where short circuiting is caused with a flooded bypass channel).

With major reworking of Esplanade and Quay wetlands to remove Typha in the near future, some modification of the bathymetry to achieve more shallow depths to support more emergent water plants is encouraged.

4.1.4 Extended detention depth (EDD)

The wetland EDD is integral to wetland functional performance, as it enables stormwater to be temporarily stored and treated within the wetland before being slowly released through the wetland outlet pit. It maximises how much water is treated for a given size of wetland.

The EDD, both its depth and duration are critical to water plant health.

Current design guidance recommends a maximum EDD of 0.35m for treatment wetlands. Water plants are extremely sensitive to water level variations and extended detention depths over 0.35m are a risk to the long term viability of the water plants.

Extended periods of inundation can be extremely detrimental to water plant health, and it is crucial that the wetland outlet control is carefully designed manage the EDD and to ensure that the EDD volume is drawn down over 72 hours.

Expended detention depths (EDD) in north Torquay wetlands are between 0.2 – 0.6m. An EDD of 0.6m is likely to be problematic for plant health, however, from site observations it would appear the outlets are not controlling this magnitude of EDD variations. This has benefits for water plant health but is limiting the quantity of stormwater treated.

The inspections of water plant conditions and edge characteristics suggest the outlet structures are not varying EDD as designed. These should be further investigated and modified to maximise stormwater treatment but also maintain plant health. Typically, modifying outlet control structures is relatively straightforward and doesn’t require major investment.

4.1.5 Outlet pit access

It is important that all wetland outlet pits are readily accessible so that the outlet control devices such as riser pipes and weirs can be regularly checked during maintenance works or wetland audits.

Some systems were observed with sealed pit lids where plans showed grated pit covers that allow observation. These should be investigated and modified accordingly.

4.1.6 Safety

The edge profile of wetlands must consider public safety, structural stability and maintenance access requirements.

Wetland edge profiles should be designed to prevent access to deep water areas by incorporating safety edges which typically include:

- Vegetated approach batters no steeper than 1:5, with a 1:8 sloped vegetated safety bench down to 350 mm deep
- Steeper batters or areas with safety benches should adopt permanent fencing to preclude public access to the wetland.

Wetland designs in north Torquay all had safety benches or were fenced.

4.2 Stretton East Wetland

4.2.1 Design Overview

The Stretton East Wetland comprises of an elongated basin located within the base of a retarding basin (Figure 3). The wetland has (one metre deep) sediment basins located at either end. Stormwater enters the wetland via inlets at each of the sediment basins. Stormwater discharged from the southern sediment basin passes through a series of macrophyte cells (separated by earthen berms) before being discharged into the wetland outlet pipe.

The wetland is currently managed by the developer and is likely to be handed over to council once development in the catchment is complete.

The wetland design plans indicate that flows discharged from the northern sediment basin were intended to be conveyed to the southern end of the wetland via a channel through the elongated ephemeral wetland zone. The wetland outlet pipe appears to have been constructed higher than designed (it is understood, as a result of a road culvert being constructed higher than anticipated because of services constraints), resulting in permanent inundation of the ephemeral zone, and essentially transforming the ephemeral zone into a shallow marsh.

Outflows from Stretton east wetland flow to a pump well that is also connected to the Dunes wetland. From there, some flow is harvested for irrigation (refer to Section 4.3.1).

The Stretton East Wetland had been recently planted at the time of the inspection. The wetland vegetation cover was good, with high species diversity present. The water plants appeared to be healthy and growing vigorously.

<u>Wetland levels</u>

Normal water level	14.43 m AHD
Top of extended detention	NA
Top retarding basin	15.9 m AHD

Figure 3 Stretton east wetland.

4.2.2 Audit results

A summary of the key observations and actions for Stretton East Wetland are:

1. The wetland outlet is built higher than designed resulting in a deeper which limits plan growth
2. The deeper water causes the bypass channel to backwater and provides a short circuit route from the northern sediment basin to the outlet – the bypass channel should be reprofiled to avoid short-circuiting ad support emergent plants
3. There is no EDD which limits the volumes of storm flows being treated – a structure could be installed in the outlet pipe to control outflows and regulate an EDD
4. The sediment ponds are too small and shallow meaning they overflow sediments into the macrophyte zone – these should be cleaned
5. Some Typha was observed establishing in the wetland – this should be removed as apriority before it establishes further.

More detailed descriptions are provided in Table 2.

Table 2 Summary of the key issues identified for Stretton East Wetland.

Component	Issue	Action
Sediment basins	Both of the sediment basins are 1m deep. This is too shallow to efficiently trap course sediments. The lack of storage capacity will result in course sediments overwhelming the basin and being transferred to the macrophyte zone and being deposited within the wetland.	The depth of the sediment basins should be increased to minimum 1.5m depth.
Normal water level	It is noted that the As Constructed plans for the wetland indicate that the NWL for the wetland has been set at 14.43 m AHD, not 14.30 m as per the design plans (because of the downstream road culvert levels).	No action required. Increasing the wetland water level has resulted in the ephemeral areas between the north sediment basin and main wetland macrophyte zone being permanently inundated, notably increasing the overall shallow marsh area. The ephemeral water plants planted in this zone appear to be thriving well in the shallow water.
Extended detention	The wetland has no extended detention depth. Stormwater flows entering the wetland are discharged directly from the wetland via the 600mm pipe (i.e. there is no outlet control to regulate outflows from the wetland). This reduces the volume of water that can be treated from each storm event.	An outlet control should be constructed at the wetland outlet to regulate both the extended detention depth and residence time. This could be achieved by installing a pit across the existing outlet pipe. Flows from the wetland would be regulated via a slotted weir plate located within the pit to provide 350mm extended detention depth and approximately 72 hrs drawdown time. The pit would need to be configured to enable overflows from the wetland and outflows from the retarding basin to be discharged to the existing outlet pipe.
By-pass channel	A bypass channel is present between the north sediment basin and the southern section of the wetland macrophyte zone. It should be noted that the channel was original designed to convey flows from the sediment basin the wetland macrophyte zone, however due to the increase in NWL, the channel now functions to bypass flows through the large shallow marsh zone. This provides a short circuit for flows and reduces treatment efficiency.	The bypass channel should be infilled, topsoiled (min 150mm depth) and planted with shallow marsh water plant species. This will ensure that all flows from the north sediment basin are distributed across the entire wetland profile and get treatment. This will significantly improve the treatment function of the wetland system.
Bathymetry	The bathymetry of the wetland generally appears to be complicated, excessively deep and leads to short circuiting. A significant area of the wetland macrophyte zone is more than 350mm deep, which is considered to be the maximum planting depth for emergent water plants. The increase in NWL (noted above) has also increased the depth of the wetland planting zones. Generally, no more than 20% of the wetland macrophyte zone should be more than 350mm depth, as this ensure that the majority of the wetland has dense emergent water plant cover. Extensive areas between 0.35-0.6m depth are likely to promote Typha growth, as most emergent plants cannot permanently grow within this depth range. Incoming flows short circuit to the outlet and do not interact with water plants.	The wetland is currently well vegetated with a broad range of water plant species, particularly in the deeper planting zones of the wetland. Many of these species are unlikely to persist when extended detention is provided. Plant health and coverage should be monitored when EDD is introduced. Options to reduce the depth of macrophyte zone should be considered if 75-80% vegetation cover is not achieved. It is recommended that submerged water plants are planted in all planting zones deeper than 0.35m depth. Filling of the bypass channel will also increase the area of water plants.

	When the wetland is full, water flows over the earthen berms to the wetland outlet. The earthen berms between each of the planting zones reduces the overall wetland planting area and provides areas for waterbirds to roost/loaf. It was noted during the site inspections that the berms are now permanently inundated due to the increased NWL, and have effectively transitioned to shallow marsh zones.	
Weeds	Juvenile Typha sp. Seedlings were observed growing within the sediment ponds and inlet areas to the macrophyte zone.	All Typha seedlings should be removed immediately, as this species is very difficult to control once established and has the capacity to dominate the wetland vegetation cover.
Safety bench	The sediment basins and open water areas within the wetland macrophyte zone do not have submerged safety bench to prevent unauthorised access to deep water areas. Best practice wetland design standards require that a 1:8 submerged safety bench to 0.35m depth be provided adjacent to all deep water areas of a wetland.	It is noted that the wetland is fully fenced, and it would be impractical to retrofit submerged safety benches. It is recommended that the margins of all deep water areas are densely vegetated with tall, dense emergent water plants or edge vegetation to prevent unauthorised access.

4.3 The Dunes Wetland

4.3.1 Design Overview

The Dunes wetland comprises of a narrow wetland located within the base of a retarding basin (Figure 4). The wetland has three inlets: a large inlet at the southern end discharging into a sediment basin, and two smaller inlets discharging into a large open water body adjacent to the wetland outlet from the west and north (Figure 4). The wetland comprises of two distinct zones (upper and lower wetlands) separated by a rock spillway spanning the width of the wetland (Figure 4). It is currently managed by the developer and is likely to be handed over to council once development in the catchment is complete.

Stormwater discharges from the sediment pond to the upper wetland via a pit and pipe that goes under a "porous" rock wall. The stormwater flows through the upper wetland and into the lower wetland via balance pipe system which ensures that both wetlands have the same water level. The crest of the rock spillway is set at the TED level. The purpose of the rock spillway/weir is unclear given that the two wetland zones share a common NWL and EDD and levels would balance through the pipe.

Flows from the lower wetland pass into an outlet pit via a submerged pipe. The wetland NWL is set by a small hole located in a weir wall within the pit, and the crest of the weir sets TED for the wetland system.

Outflows from both the Dunes and Stretton wetlands flow into the pump well (located between the Stretton east and The Dunes wetlands). The pump well is manually operated and is used to pump the stormwater via a rising main to a storage 'Pintail' dam located at the nearby Flower Farm.

Treated flows discharged from the Dunes wetland outlet pit pass into a low flow pipe that is connected to the pump well. Outflows in the Stretton east wetland outlet pipe are diverted to the pump well via a diversion sump within the wetland outlet pipe.

When the pump well is full, additional outflows from both wetlands are discharged to a pipe that runs in an easterly direction through the linear reserve between Horseshoe Bend and Ripple side Drive and are discharged into the Zeally Sands wetland.

An existing licence requires that a minimum 12.5 ML per annum of wetland outflows is harvested from the Dunes/Stretton wetland system (i.e. pumped to the nearby flower farm). It is understood that in some years up to 70ML has been harvested from the system.

The Dunes wetland is characterised by dense, healthy water plant cover along the wetland margins, with the open water areas supporting submerged water plants. The sediment basin has been recently cleaned and extensive rock works have been undertaken to the overflow weir. A floating curtain has been recently placed on either side of the two smaller inlets to enhance sediment capture within the lower wetland.

<u>Wetland levels</u>

Sediment pond	Normal water level	13.80 m AHD
	Top of extended detention	14.1 m AHD
Wetland	Normal water level	13.5 m AHD
	Top of extended detention	13.85 m AHD
	Top retarding basin (Q_{100})	15.51 m AHD

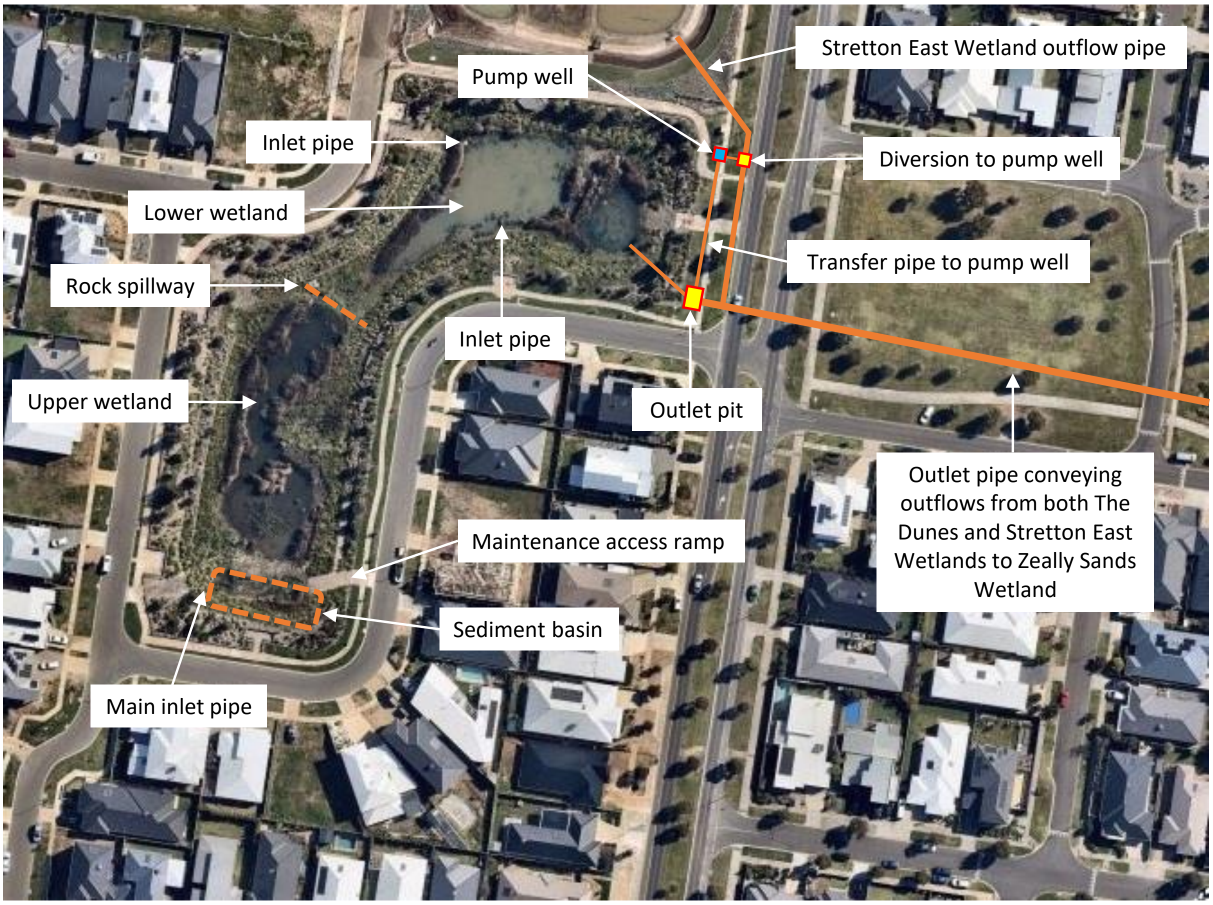

Figure 4 The Dunes Wetland.

4.3.2 Audit results

A summary of the key observations and actions for The Dunes wetland include:

1. The sediment pond is too shallow – consider deepening to increase sediment capture storage and reworking connection to the wetland (e.g. remove existing pit/pipe and replace with simpler weir)
2. Inlet pipe blockages on small inlets – remove vegetation and sediment build up around the inlet and install cement treated rubble to prevent future growth
3. There are more open water pools than best practice - plant more robust submerged plants to improve treatment
4. Remove some stands of Typha.

A more detailed description of the issues identified during the review of wetland design plans and site inspection is provided in Table 3.

An audit of The Dunes wetland conducted by Water Insights (2022) found similar results including:

- Potentially elevated wetland water levels and potential blockage of the wetland outlet
- Inadequate storage capacity within the sediment basin
- Lack of sediment dewatering area
- Blockage of the NW inlet pipe.

Table 3 Summary of the key issues identified for The Dunes wetland.

Component	Issue	Action
Sediment basin	The sediment basin is approximately 0.95m deep. This is too shallow to effectively trap course sediments, particularly considering the size of the catchment draining to the sediment basin (42 ha). The lack of storage capacity will result in course sediments being conveyed to the wetland macrophyte zone. Notable backwatering of the inlet pipe observed. This appears to be a permanent condition.	The depth of the sediment basins should be increased to minimum 1.5m depth (preferably 2-2.5m depth), and where possible the overall area of the sediment basin increased. It is noted that there has been recent works to re-instate the rock weir between the sediment basin and the wetland macrophyte zone, and to provide maintenance access from both sides of the sediment basin. The rock weir could be re-configured to enable the sediment basin to be both deepened and widened. Alternatively the rock weir could be replaced with a narrower earth bank and weir to convey flows to the wetland. The transfer pit and pipe could be decommissioned allowing more space for sediment capture.
Sedimentation	There is notable sediment accumulation adjacent to both small inlets to the wetland. It is likely that there has also been significant sedimentation throughout the wetland, as indicated by the extensive growth of water plants in areas which designed as open water areas.	Remove the accumulated sediment adjacent to the inlet areas.
Blocked inlet pipe	The NW inlet pipe to the lower wetland was blocked with vegetation and sediment. Consider clearing the inlet pipe opening but where possible retaining the sediment as it is enabling emergent water plants cover to extend into the open water zone. It was noted that Council have recently installed a screen below each of the lower inlet pipes to trap sediment. The growth of emergent water plants into this zone would raise the question as to whether there is merit in removing the sediment given the scale of the adjacent sub catchments and/or the benefit that the vegetation cover will provide to wetland function.	Unblock the pipe entries, remove sediment and plants and install cement treated rubble to prevent future plant growth at the pipe outlet.
Blocked balance pipe/pit	The water level on the upstream side of the rock spillway appears to be sitting at the top of extended detention (crest of the spillway), indicating that the balance pipe system may be blocked. It is likely that this has been the case for some period of time, given the growth form of the emergent water plants (particularly groundcovers) present within the upper wetland zone. We did not inspect the wetland outlet pit, however a similar observation was made during the recent wetland audit (Water Insights, 2022).	The balance pipe system needs to be unblocked to re-instate NWL within the upper wetland. This will lower the water level by approximately 0.3m, and provide conditions for water plants to grow throughout the wetland zone. Note: it is important that any water plants and accumulated sediments adjacent to the balance pipe inlets/outlets are also removed during this task to prevent future blockage.
Bathymetry	The design of the wetland comprises of a series of interconnected deep pools ranging between 0.7-1.2 m depth. This design provided for shallow zones around the margins of the pools for water plant growth, however the majority of the wetland comprised of submerged/open water areas (nearly 60%). Wetlands with interconnected open water zones are generally	While the wetland design has too many deep pools and not enough shallow vegetated areas compared to best practice it is not recommended to make wholesale changes. Rather it is recommended to plant robust submerged water plants to improve treatment (e.g. Valiseneria australis).

	characterised by short circuiting, as the water rapidly passes from pond to pond before being discharged via the wetland outlet. It appears that many of the open water areas within the wetland have filled with sediment, enabling the growth of emergent water plants across the wetland. This is particularly evident in the upper wetland zone. The lower wetland zone is characterised by large areas of open water with densely vegetated margins. Whilst the wetland vegetation is extremely healthy, the overall vegetation cover is low compared to the open water area. At the time of inspection, the open water areas of the wetland zone were colonised by a submerged water plant – Myriophyllum crispus. Submerged water plants such as this species provide excellent water treatment, however Myriophyllum crispus growth can be erratic and its persistence in the wetland cannot be guaranteed.	
Weeds	Notable stands of *Typha* sp. are present throughout the wetland. A potentially invasive introduced species, *Leucanthemum aestivum*, was observed growing on the edges of the spillway amongst a native groundcover (*Hydrocotyle verticillata*?).	All Typha growth should be immediately controlled, as this species is very difficult to control once established and has the capacity to dominate the wetland vegetation cover.
Backwatering	Low flow discharges from the Stretton catchment can backwater into The Dunes wetland. The Stretton and Dunes wetlands both flow into a pump pit station on Horseshoe Bend Road. When the pump isn't flowing water levels can rise from Stretton outflows to level where they backwater into Dunes wetland outlets pond.	No recommended actions.

4.4 The Quay Wetlands

The Quay wetland complex comprises of two wetland systems that are interconnected by a balance pipe system underneath Quay Boulevard. The wetland systems comprise of a sediment basin and wetland zone. Stormwater flowing through the sediment ponds is discharged to the wetland zone via an overflow weir. The stormwater passes through the wetland and is discharged from the wetland via an outlet control pit which regulates outflows from the wetlands. Outflows from The Quay wetlands is discharged along Horseshoe Bend Rd to the Esplanade wetland.

The original wetland designs for the Quay were complex and comprised of cascading wetland zones and large areas of open water. The wetlands have experienced a major Typha infestation which severely compromised the functional performance and amenity of the wetlands.

In response, Council is currently undertaking a rectification program which will result in modifying the wetlands to enhance functionality (stormwater treatment) and provide enhanced passive recreational opportunities for the community. Therefore, a detailed condition assessment of current conditions is not performed for this study.

The wetland rectification plans are currently being developed by Council, and it is beyond the scope of this assessment to review the plans in detail.

The proposed wetland rectification/ renewal designs have been used to inform the stormwater treatment modelling outlined in Section 5.

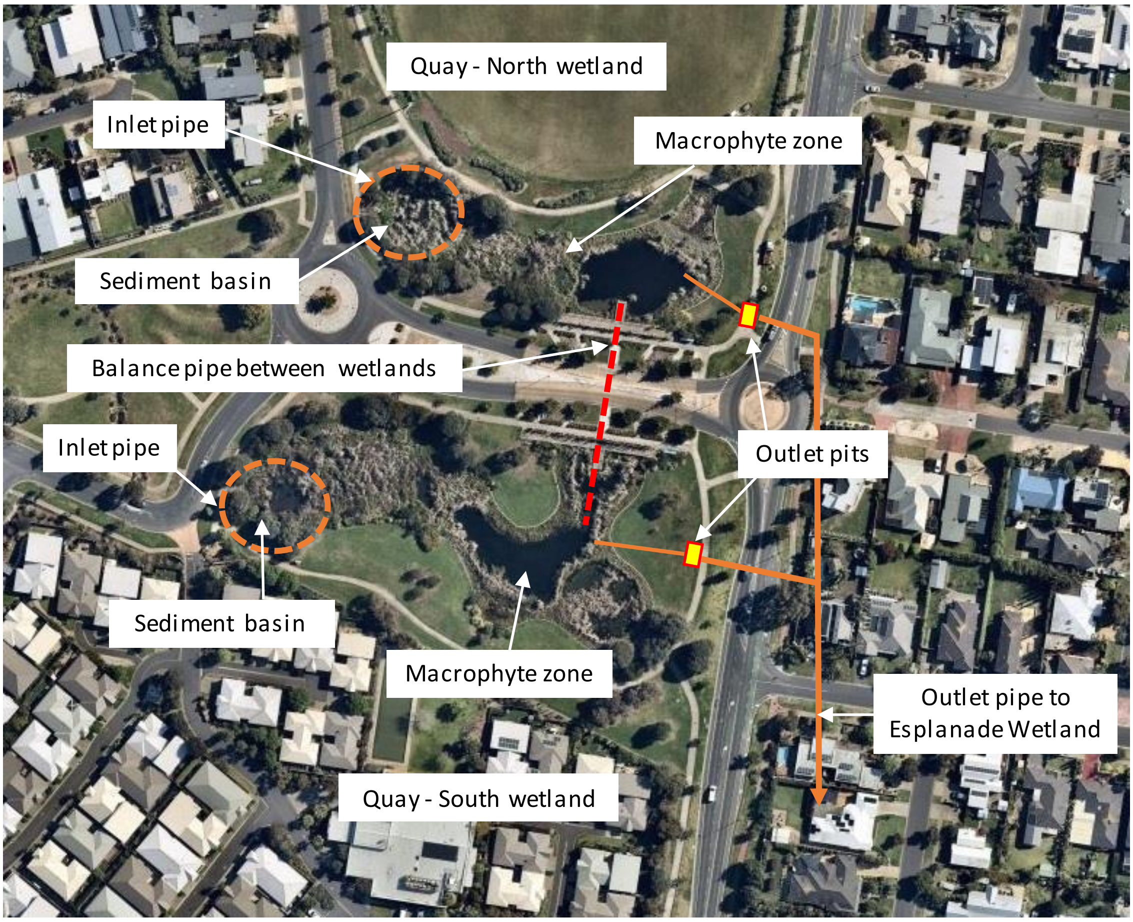

Figure 5 The Quay Wetland complex – north and south wetlands.

4.5 Esplanade Wetland

4.5.1 Design Overview

The Esplanade wetland is approximately 1.4 hectares located in the foreshore reserve adjacent to The Esplanade west of Horseshoe Bend Road (Figure 6. The wetland functions to treat stormwater runoff quality and for flood storage (as a retarding basin).

The wetland has two large sediment basins; one at the western end, and another in the centre of the wetland for a secondary inlet and generally flows to the east. The wetland system receives stormwater runoff from the Golden Beach Estate, part of the Torquay Sands Development and outflows from The Quay wetlands. Therefore, stormwater from The Quay Estate is effectively treated twice.

Stormwater runoff enters the wetland system via the sediment basins and flows through the macrophyte zone towards the eastern end of the wetland. The treated stormwater is discharged from an outlet pit to a transfer pipe and conveyed to The Sands lake system (Amenity lake 4). A riser pipe located within the outlet pit controls the wetland NWL, TED and drawdown of water from ED storage. A riser pipe located in the outlet pit controls the wetland NWL, TED and drawdown of water from extended detention storage.

At the time of the site inspections, extensive works to remove *Typha orientalis* infestations from the wetland had been recently undertaken, resulting in substantial disturbance to the wetland batters and internal bathymetry.

A diverse suite of water plant species were observed growing around the margins of the wetland. The removal of Typha from the wetland has notably disturbed the remaining beneficial water plants and removed almost all of the vegetation cover from the macrophyte zone. The health and vigour of the remnant water plants indicates that the wetland was likely to be functioning well, despite the excessive growth of Typha throughout the wetland.

Figure 6 The Esplanade Wetland

<u>Historical context</u>

The Esplanade wetland was originally a pondage constructed within a natural depression in the foreshore zone. The waterbody was originally used to store stormwater runoff from the adjacent catchments, which was then pumped via a rising main to the intersection of Horseshoe Bend Road and The Esplanade and discharged via gravity to Deep Creek. When the capacity of the pump system was exceeded (i.e. during flood events), outflows from the waterbody were discharged into the ocean via Whites Cut. The waterbody was reconfigured to divert outflows as part of The Sands development. This included the construction of the current outlet pit and a 750mm piped gravity connection to The Sands lake system (Amenity Lake 4), and re-configuring the wetland overflow to ensure that flood flows discharge overland into The Sands golf course to protect Whites Cut.

Wetland levels

Normal water level	4.7 m AHD
Top of extended detention	5.0 m AHD
Top retarding basin	6.4 m AHD

4.5.2 Audit results

A summary of the key observations and actions to consider as part of the current wetland reworking for The Esplanade wetland include:

1. Ensure sediment basins are 1.5-2m deep and have access tracks for maintenance
2. Reconfigure the deep pools so they are shallower (<350mm) to support more water plants
3. Install a hard base around the outlet pit to prevent plant growth blocking flows
4. Continue to remove all Typha.

A more detailed description of the issues identified during the site inspection is provided in Table 4. The issues outlined in relate to observations made during the site inspections as design plan s were not available.

Table 4 Summary of the key issues identified for the Esplanade wetland.

Component	Issue	Action
Sediment basin	Sediment basin depths	Check the depth for the reconfigured sediment ponds to ensure at least 1.5m deep.
Bathymetry	It was observed during the site inspections that many sections of the wetland macrophyte zone appear to be excessively deep (i.e. more than 0.5m depth). The Craigie and Condina (2001) report indicated that the wetland base is 3.0m AHD, which would indicate a depth of 1.7m. This is too deep for water plants. The majority of emergent water plants are adapted to growing in shallow water (i.e. less than 0.35m depth). The current wetland bathymetry is not conducive to emergent water plant growth, except for the shallow areas along the wetland margins.	It is recommended that sections of the wetland macrophyte zone are infilled to enable a range of water depths less than 0.35m to be established. This will enable beneficial range of water plant species to be established throughout the macrophyte zone. The establishment of dense bands of emergent vegetation will substantially increase the functional performance of the wetland. Note: Ideally, at least 80% of the macrophyte zone should be covered with emergent water plants. Providing extensive shallow areas throughout the wetland will also enable the wetland to be more readily accessible, enabling maintenance staff to safely access the wetland to undertake weed control.
Outlet pit	Significant water plant growth is present around the margins of the outlet pit. The vegetation is potentially impacting overflows into the outlet pit.	Remove water plants and accumulated sediment from the margins of the outlet pit. Install a rock/rubble apron (1m width) around the outlet pit to prevent water plant growth that could block flows.

Contamination **Riser pipe**	A notable biofilm of fungus is present on the PVC riser pipe and walls of the outlet pit. The fungus appears to bear resemblance to 'sewer' fungus commonly associated with sewage pipes.	It is recommended that the fungus be tested to ascertain whether there are potential sewer inflows to the wetland.
Maintenance access	There is no formal maintenance access to either of the sediment basins. This makes it very difficult for the basins to be accessed for sediment removal.	It is recommended that formal maintenance access ramps are constructed into each of the sediment basins. The basins should also have a hard base to enable entry for cleaning.
Weeds	Notable stands of *Typha orientalis* remain throughout the wetland, particularly areas within the macrophyte zone which are difficult to reach from the wetland margins.	All Typha growth should be immediately removed/controlled. The remaining plants within the wetland represent a major risk to the long term viability of the wetland, as they will continue to expand into the adjoining areas via rhizomatous growth and seed production.
Filamentous algae	Extensive mats of floating filamentous algae were present throughout the wetland macrophyte zone.	No action required. The presence of filamentous algae is most likely related to the removal of Typha and the associated release of nutrients from the disturbed sediments.

4.6 Zeally Sands Wetlands

4.6.1 Design Overview

The Zeally Sands wetlands has three treatment wetlands and a sediment basin that flow into an "amenity lake". Outflows from the amenity lake discharge to The Sands lake system. An overview of the layout is shown in Figure 7.

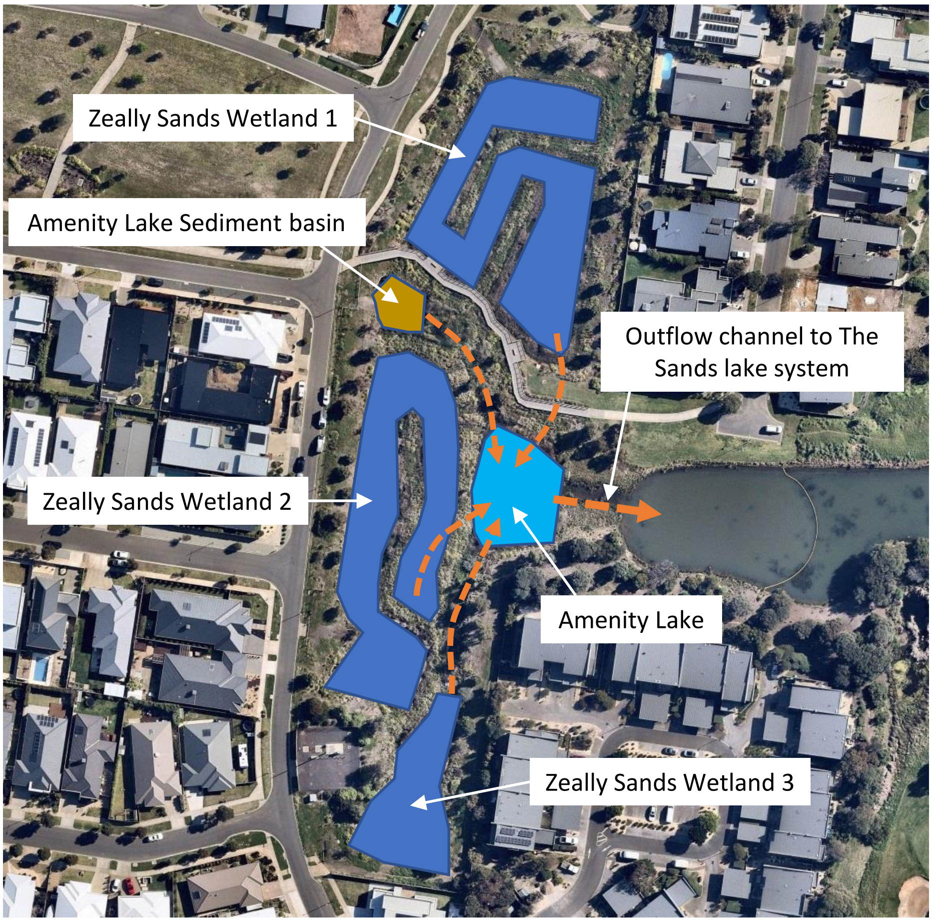

Figure 7 Layout of the Zeally Sands wetland complex.

4.6.2 Audit results

A summary of the key observations and actions for the Zeally Sands wetland system overall include:

1. Wetland designs seem overly complex leading to a lot of area given up to batters
2. Generally in healthy condition with robust vegetation cover
3. All wetlands are designed with very deep (600mm) EDD that is likely to affect plant health (it is likely it is not currently operating as designed – this should be investigated and reconfigured to achieve 350mm if possible
4. Wetland 3 is very small for its catchment but still in good condition
5. Inlets ponds all need cleaning (particularly the amenity pond sediment basin)
6. There appears to be backwater from the lakes in The Sands which may affect wetland levels and outflows- needs further investigation.

A more detailed description of the issues identified during for each of the wetland components is described below and more detailed diagram of their operations are shown in Figure 8 and Figure 9.

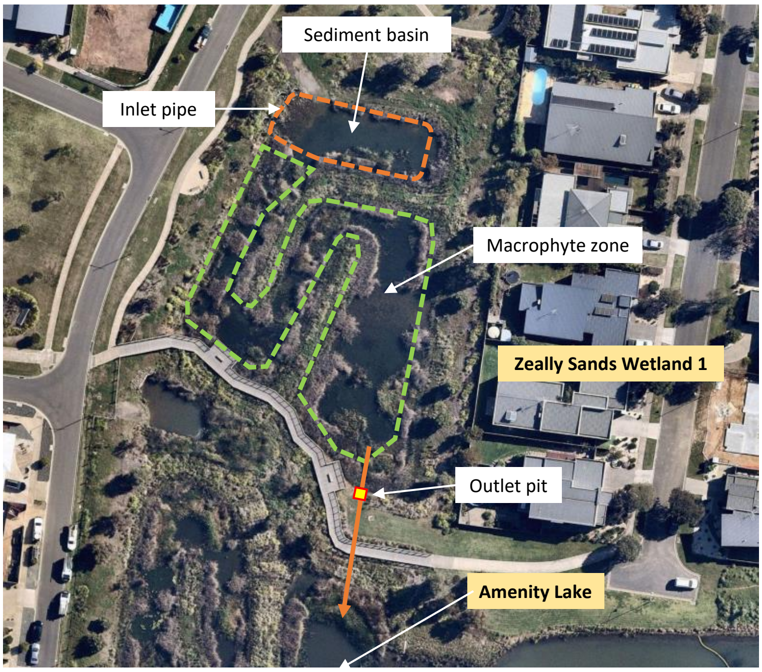

Figure 8 Zeally wetland 1

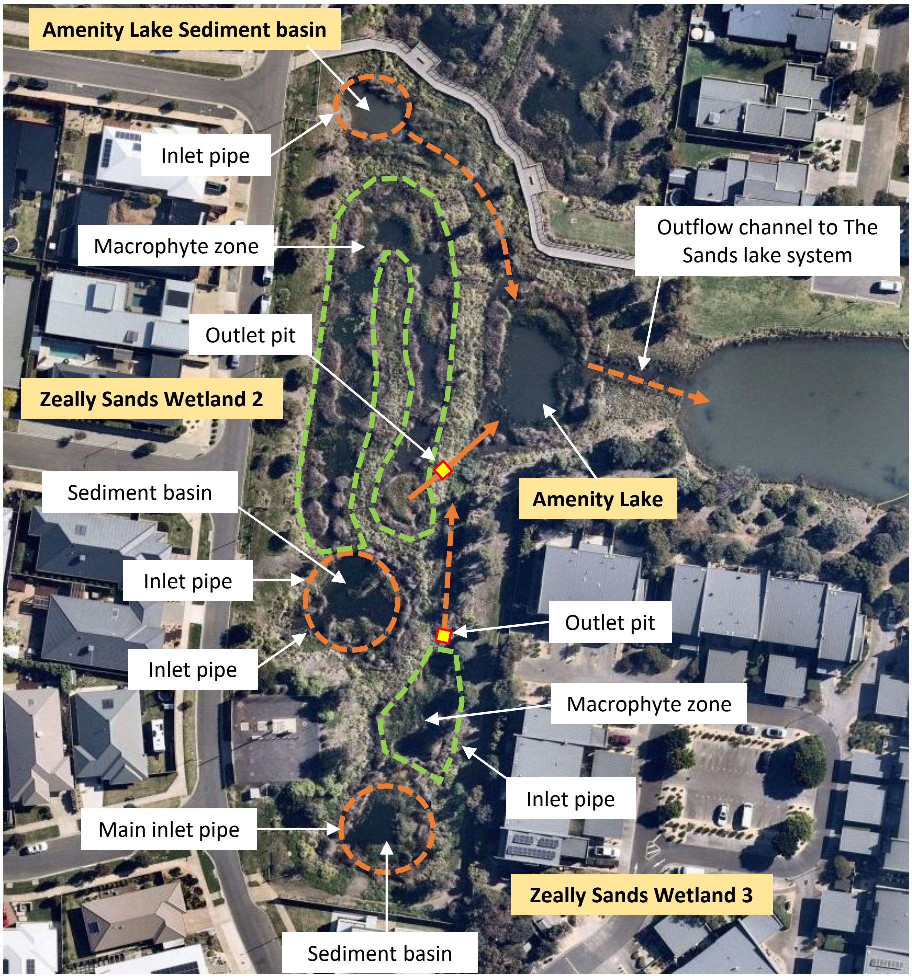

Figure 9 Zeally wetlands 2 & 3

An audit of the Zeally Sands wetlands conducted by Water Insights (2022) had similar observations, including:

- the wetland system was generally well vegetated
- the sediment basins were functioning well but will need cleaning in the next 1-2 years
- a blockage to the Wetland 3 sediment basin inlet requires immediate cleaning
- elevated water levels were observed throughout wetland system indicating that the outlet pits may be blocked.

Wetlands 1 and 2

Both wetlands 1 & 2 are designed with sediment basins and macrophyte zones before transferring flows to the amenity lake.

Stormwater is transferred from each sediment basin to the macrophyte zones via porous rock weirs. The stormwater then flows through well vegetated, elongated macrophyte zones and is discharged from the wetland via an outlet control pit. A riser pipe (an upright pipe with numerous holes) located within the outlet pit regulates the TED and the drawdown of water within the wetland. Outflows from the outlet pits are conveyed via pipes to the amenity pond. When the capacity of the outlet pipes are exceeded, overflows from the wetlands pass over the earthen bunds (near the wetland outlets) and into the amenity pond.

The wetlands have healthy, dense emergent water plant cover throughout both the sediment basins and macrophyte zones and little evidence of Typha. The sediment basins appear to be functioning well. The macrophyte zones appear to be in excellent condition, with good vegetation cover around the margins and with little to no floating litter. Maintenance access to the sediment basins and macrophyte zones is good.

Wetland levels

Wetland 1	Normal water level	5.02 m AHD
	Top of extended detention	5.62 m AHD
Wetland 2	Normal water level	5.02 m AHD
	Top of extended detention	5.52 m AHD

Table 5 Summary of the key issues identified for the Zeally Sands wetlands 1 & 2.

Component	Issue	Action
Sediment basin	The sediment basins vary in depth between 1.3-1.4m. The sediment basins appear to be functioning well.	No action required (continue to monitor sediment build up)
Extended detention depth	The design EDD for the wetlands varies between 0.5- 0.6m. This is too deep to sustain water plants within a constructed treatment wetland.	It is recommended that a maximum EDD of 0.35m be adopted for the wetlands. This will require that the outlet riser pipes within the outlet pits are modified to accommodate both reduced EDD and 72 hr drawdown.
Outlet pit	The wetland water levels appear to be very stable, with little evidence of water level variation on the stems of the emergent water plants. The outlet pits were unable to be opened during the inspection due to heavy concrete lids, however water could be heard passing through the pits. It is suspected that the outlet riser pipes within the pits may be partially blocked,	The outlet control pits should be inspected and the wetland EDD verified. Blockages present within the pit should be removed and the design NWL for the wetland re-engaged. It is recommended to consider replacing the concrete lids with grated lids which are more accessible for maintenance staff. Note: The wetland design plans indicate that the outlet pits should have a grated pit lid.

	resulting in wetland water levels being maintained at or near the TED.	
Bathymetry	The bathymetric design of the macrophyte zones comprises of a series of interconnected deep pools ranging between 0.4-1.0 m depth. This design provides for shallow zones around the margins of the pools suitable for water plant growth, however the majority of the macrophyte zones comprise of open water areas. Whilst the macrophyte zones appear to be well vegetated when viewed from the margins, a review of aerial imagery indicates that both wetlands have significant open water areas. These are generally consistent with the wetland design plans which indicate a series of deep pools. Wetlands with interconnected open water zones tend to short circuit as water flow directly to outlets. Some of the open water areas within the wetlands may have filled with sediment, enabling the growth of emergent water plants across parts of the macrophyte zones which is beneficial.	Ideally, some of the open water areas should be infilled to enable lateral bands of emergent water plants to be established within the macrophyte zones. This would increase the interaction with water plants to improve treatment. However, filling these areas would disturb the existing vegetation. It is recommended to retain the existing bathymetry and just modify the outlets to increase the volume of stormwater treated.

Wetland 3

Wetland 3 has a sediment basin, a small macrophyte zone and vegetated channel to transfer flows to the amenity pond. The macrophyte zone is very small compared to its catchment, however, is still in reasonable condition.

Stormwater enters the sediment pond via two inlets and then flows through a porous rock weir to the macrophyte zone. The stormwater flows through the sediment basin and into the macrophyte zone via a porous rock weir. Flow from the wetland is controlled by an outlet control pit (containing a small hole in the wall to regulate the wetland outflows) that transfers flows to a vegetated channel to the amenity pond.

The wetland system also has healthy, dense emergent water plant cover. The margins of the sediment pond are extremely well vegetated and provide a good barrier to water access. Despite its relatively small size, the macrophyte zone is densely vegetated and functioning well. The outlet channel is well vegetated and is providing additional treatment of the wetland outflows before reaching the amenity pond.

Wetland levels

Normal water level	4.95 m AHD
Top of extended detention	5.25 m AHD

Table 6 Summary of the key issues identified for Zeally Sands wetland 3.

Component	Issue	Action
Sediment basin	One of inlets to the sediment basin is partially blocked with sediment and vegetation.	Remove accumulated sediment and associated vegetation.
Litter	Notable litter (gross pollutants) were present adjacent to the inlets in the sediment basin.	Gross pollutants should be removed as part of regular maintenance. Persistent gross litter accumulation within the wetland may

		require that GPT collection opportunities within the catchment be reviewed.
Batters	Minor erosion was evident along some batters of the wetland, particularly the eastern margin. Vegetation cover on the batters is limited, generally due to the lack of topsoil cover. Notable weed cover is present in some areas.	No action required.

4.6.3 Amenity lake sediment basin

The amenity lake sediment basin receives flow from the Stretton and The Dunes wetlands, as well as runoff from two small residential catchments and green open space within the Zeally Sands Estate. The sediment basin is the only treatment before the amenity pond because most flows are treated in Stretton and Dunes wetlands.

Flow from the basin is regulated in an outlet pit containing a riser pipe (upright pipe with numerous holes) that regulates the TED and the drawdown of water within the sediment basin. The outlet pit flows to a rock lined channel which conveys the flows to the amenity lake. When the sediment basin is full (at TED), all further inflows go over a rock weir into the channel leading to the amenity lake.

Note: The amenity lake sediment basin and channel are part of the overland flow path for flood flows from the Stretton, The Dunes and Zeally Sands Estates. Flood flows from these catchments are conveyed along the drainage line located within the reserve between Horseshoe Bend Rd and Rippleside Drive, flow over Rippleside Drive and through the sediment basin and amenity lake, and into The Sands lake system.

The sediment basin appears to be functioning well. The basin is heavily vegetated with emergent water plants, indicating that it has performed well but is full of sediment and needs to be cleaned.

Sediment basin levels

Normal water level	5.02 m AHD
Top of extended detention	5.22 m AHD

Table 7 Summary of the key issues identified for the Zeally Sands amenity lake sediment basin.

Component	Issue	Action
Sediment basin	The sediment basin has limited sediment storage capacity due to the relatively shallow design depth (1m). There is notable emergent water plant growth in the basin indicating that needs to be cleaned.	Remove accumulated sediment and associated vegetation from the sediment basin.
Extended detention depth	The design of the sediment basin includes 0.2m EDD. Extended detention is not strictly required for a sediment basin to capture course sediments but does improve performance.	No action required.
Outlet pit	The wetland water levels within the sediment basin appear to be very stable, with little evidence of water level variation on the stems of the emergent water plants. The outlet pit was unable to be opened during the inspection due to the heavy concrete lid.	The outlet control pit should be inspected and the wetland EDD verified. Blockages present within the pit should be removed and the design NWL for the sediment basin re-engaged. It is recommended to consider replacing the concrete lid with a grated lid which is more accessible to maintenance staff.

		Note: The wetland design plans indicate that the outlet pit should have a grated pit lid.
Channel	The outlet channel is heavily vegetated with vegetation. It is likely that there has been significant sediment accumulation within the base of the channel. The growth of plants upon the sediment will further increase sediment accumulation.	Inspect the channel and outlet pit to confirm whether the presence of sediment and vegetation in the channel is impeding outflows from the sediment basin. Note: There is approximately 0.1m difference between the sediment basin and amenity lake NWL. Any changes to the NWL of the lake will impact on the water level in the sediment basin (refer to Amenity Lake issues)

4.6.4 Amenity lake

The amenity lake receives inflows from the three Zeally Sands wetlands and sediment basin and transfers flows to the lakes in The Sands.

The design depth of the amenity lake is 1.25m, which is intended to discourage the growth of emergent water plants and to maintain open water. There is signification water plant cover around the margins of the lake indicating that it may be accumulating sediments (i.e. it is shallower than designed).

The lake NWL is set by a concrete weir across the outflow channel connecting to The Sands Lake 1. It was noted during the inspections that the weir appeared to be permanently inundated (0.1-0.15m) with back water from the Sands Lake 1.

Lake levels

Normal water level	4.91 m AHD
Top of extended detention	NA
The Sands lake 1	4.86 m AHD

Table 8 Summary of the key issues identified for Zeally Sands amenity lake.

Component	Issue	Action
Sediment accumulation	The extensive growth of emergent water plants around the margins of the lake indicative that the lake may be filling with sediment.	It is recommended that sediment levels within the lake are surveyed to establish the level of sediment accumulation. If less than 800mm then the lake should be cleaned The growth of water plants within the lake is highly beneficial to water treatment, however, continual accumulation will reduce its capacity to further prevent sediments reaching The Sands. Removal of accumulated sediments will ensure that the lake continues to effectively trap the sediments.
Lake water level	The lake water level was observed to exceed the crest of the overflow weir by 0.1-0.15m. A similar observation was made during the wetland audit (Water Insites, 2022) which found the water level exceeded NWL by 0.17m. It is understood that the lake water levels throughout The Sands lake system were recently increased to enable additional storage capacity within the system. It is possible that modifications to The Sands Lake 1 overflow weir has increased the NWL of the amenity lake.	Undertake further investigation of the amenity lake water level. Confirm that the overflow weir below The Sands Lake 1 is free of obstructions. A permanent increase in the amenity lake NWL may impact the operating water levels in all three wetlands and the amenity lake sediment pond.

4.7 Wetland rectification recommendations

Outcomes from the site inspections and wetland design review suggest that there are numerous issues impacting wetland treatment performance within the north Torquay catchment.

It is recommended that opportunities to improve the performance of the wetlands be explored to ensure that they are providing the highest standard of water quality treatment possible given space constraints.

The wetland condition assessment indicated that the majority of the wetlands have robust water plant growth and the fundamentals for wetland function such as outlet control and extended detention are generally present.

The challenge is to target priority works to improve the performance of each wetland asset. Key works identified as part of the wetland review are summarised in Table 9. The works have been prioritised according to the following system:

🔴	High	Rectification or maintenance works that are essential to wetland functional performance.
🟠	Medium	Rectification or maintenance works required to improve wetland functional performance.
🟢	Low	Rectification or maintenance works to sustain wetland functional performance.

Note: it is beyond the scope of this study to provide a comprehensive schedule of rectification works for each of the wetlands. Each of the priority works highlighted in Table 9 have been covered in more detail in the respective wetland assessments above.

Table 9 Summary of priority works required to optimise wetland treatment performance (Red – high priority, Amber – medium priority, Green – low priority).

	Increase sediment basin capacity	Improve wetland bathymetry	Rectifiy short circuiting	Modify outlet control (EDD)	Sediment removal	Weed removal	Additional planting	Maintenance access
Stretton East								
Stretton West	Update stormwater management plan							
The Dunes								
Quay North	Refer to wetland rectification plans (Spiire, 2022)							
Quay South	Refer to wetland rectification plans (Spiire, 2022)							
Esplanade								
Zeally Sands - W1								
Zeally Sands - W2								
Zeally Sands - W3								
Amenity Lake Sediment Basin								
Amenity Lake								

5 Stormwater treatment modelling

The Model for Urban Stormwater Improvement Conceptualisation (MUSIC) was used to model stormwater runoff and the performance of the treatment wetland systems in the north Torquay catchment. The model included all residential catchment areas (including The Sands Estate), Torquay Heights and adjoining agricultural areas that flow to the Karaaf via The Sands lake system (Figure 1)

5.1 MUSIC model

The Geelong North rainfall template (1971-1990, 6-minute periods) provided as part of the City of Greater Geelong MUSIC modelling guidelines was used for the MUSIC model. The dataset was deemed suitable as the mean annual rainfall (MAR) for this period was 531 mm, which is comparable to the MAR recorded at the Torquay Golf Club (BOM station 087160) = 554.8mm. Using the Geelong North rainfall dataset also enabled the MUSIC modelling results to be compared to recent modelling of the north Torquay catchment which also utilised the same rainfall template (GHD (2010), Water Technology (2021)).

A sensitivity analysis of the catchment water balance was undertaken using rainfall datasets representing low and high mean annual runoff scenarios. The datasets used were:

- Little River (BOM Station 087033, 1992-2001) MAR = 485mm (Low rainfall scenario)
- Melbourne Airport (BOM Station 086282, 1971-1980) MAR = 575 (High rainfall scenario)

CSIRO long term climate predictions are that mean annual rainfall will generally decrease by 10-15% during the course of this century due to climate change, so the Little River dataset is within that range.

The pervious area rainfall runoff parameters from the City of Geelong MUSIC modelling guidelines were adopted. Default MUSIC values for all other catchment parameters were used.

The catchments used for the MUSIC model were derived from the GIS data provided by Council. Rural residential and agricultural catchments (including Torquay Heights) adjacent to the north Torquay urban area were based on GIS contours and the RORB catchments outlined in GHD (2020).

5.1.1 North Torquay catchment

The MUSIC model assumed fully developed conditions in the north Torquay catchment. Percentage catchment imperviousness was estimated using aerial imagery. Sub-catchments yet to be fully developed were assumed to have similar catchment imperviousness as adjacent residential areas.

The wetland node parameters used in the MUSIC model are summarised in Table 11. The wetland parameters were generally derived from wetland design plans, and the wetland areas verified using aerial imagery. The Stretton stormwater masterplan (GHD, 2011) indicates that three wetlands were to be initially constructed, however the stormwater drainage network has been reconfigured to convey stormwater to two wetlands: the existing Stretton East Wetland (located adjacent to Horseshoe Bend Road) and to the Stretton West Wetland which is yet to be constructed.

The wetland design plans for The Dunes Wetland indicated that the wetland system comprises of two small wetlands nested within the base of the retarding basin. The Dunes wetlands have been modelled as one wetland system given that they share a common NWL and outlet control. An irrigation demand of 12 ML/year was used to model pumping of outflows from The Dunes Wetland to the Pintail dam. The wetland parameters used for the Quay North and South Wetlands reflect the proposed wetland rectification designs (Spiire, 2022).

The catchment draining to the Quay Estate - South Wetland flows along a swale as part of the stormwater treatment train. The swale receives stormwater runoff from the adjacent road surfaces and was assumed to comprise of 0.6m base, 2.5m top width and 490m length.

Low flows of untreated stormwater from the Wombah Park Estate catchment are diverted to the Esplanade wetland via a diversion pit arrangement located within The Esplanade (just west of the Horseshoe Bend Road intersection). Low flows from the catchment are diverted to the wetland, whereas high flows are discharged to Deep Creek. It was assumed that low flows up to 50 L/s are diverted to the Esplanade Wetland.

Table 11 shows the wetland parameters assumed.

5.1.2 The Sands stormwater systems

The Sands catchment was included in the MUSIC model to enable the total annual stormwater volume discharged to the Karaaf via The Sands to be estimated. The Sands water management system includes five cascading amenity lakes (located within a natural drainage line), two irrigation storage lakes and several wetlands (Table 10). It is noted that a network of ephemeral and permanent wetlands is located throughout the golf course. Some of these wetlands may receive stormwater from impervious areas, however, it is understood that they are not formally connected to the amenity lake system (and therefore are not included in the model).

The Sands Development is made up of discrete residential sub-catchments that discharge either via treatment wetlands or directly to the amenity lake system. Under normal operating conditions, the irrigation storage lakes (IRL 5 & 6) are topped up by pumping water from the amenity lake system when excess water is available in amenity lakes 4 & 5 (AML 4 & 5). This scenario was considered difficult to accurately simulate in MUSIC, and therefore the irrigation storage lakes were combined with amenity lake 5 in the model (i.e. no change to the overall system volume or evaporative surface area).

There was limited information on pervious catchments available in the The Sand (i.e. outside of the residential catchments) and the approach taken for this report was based on Craigie & Condina (2001) and GHD (2015) and drainage directions have not been verified on site.

The performance of the treatment wetland system was not modelled as the specific outlet control parameters for the wetlands are unconfirmed. The wetlands were included in the model for the purposes of the water balance and to account for evapotranspiration from these water surfaces. Craigie and Condina (2001) report that the wetlands were designed to meet the BPEM water quality objectives. For the MUSIC model, it was assumed that the wetlands have an average depth of 0.5m, 0.3m EDD and 72hr extended detention time.

Approximately 180 ML per year is diverted from the amenity lake system and used to irrigate The Sands golf course (Andrew McCauley (*The Sands Owners Corporation*) pers com., 2022). A proportion of irrigation water was originally pumped to an off-site storage dam, however this has recently been decommissioned and all irrigation water is now sourced from the irrigation storage lakes and amenity lake system.

The irrigation demand profile used in the model is shown in Figure 10. The irrigation profile shown is considered reflective of typical irrigation application rates for the Melbourne region and was deemed suitable for The Sands Golf course (discussions with the Golf Course management indicated the majority of irrigation occurs during the summer period).

The lake volumes were estimated based on 1.5m depth for Lakes AML1-3 and 2m lake depth for lakes AML4-5 and the irrigation storage lakes, as the original lake areas detailed in Craigie and Condina (2001) did not align with the constructed lakes current information. It is understood that outlet weirs from each of the amenity lakes were recently increased in height to provide additional storage capacity within the system.

The configuration of the north Torquay MUSIC model is shown in Figure 11. The sub-catchment areas and estimated imperviousness are summarised in Appendix A. External agricultural catchments were assumed to have 3% catchment imperviousness. Pre-development catchment imperviousness was assumed to be 2% for the purpose of modelling runoff volumes.

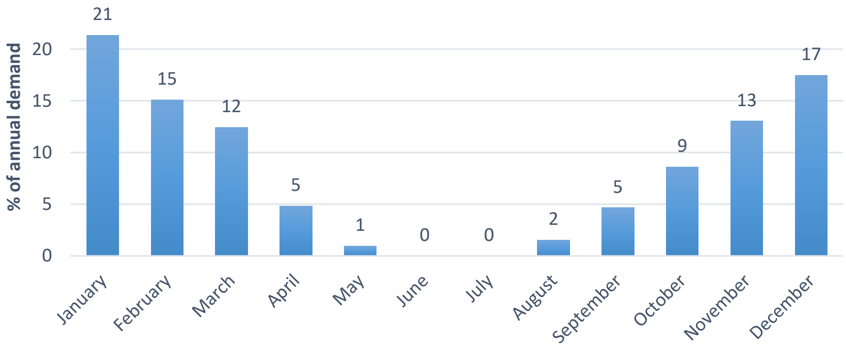

Figure 10 Monthly irrigation demand profile used in the MUSIC model.

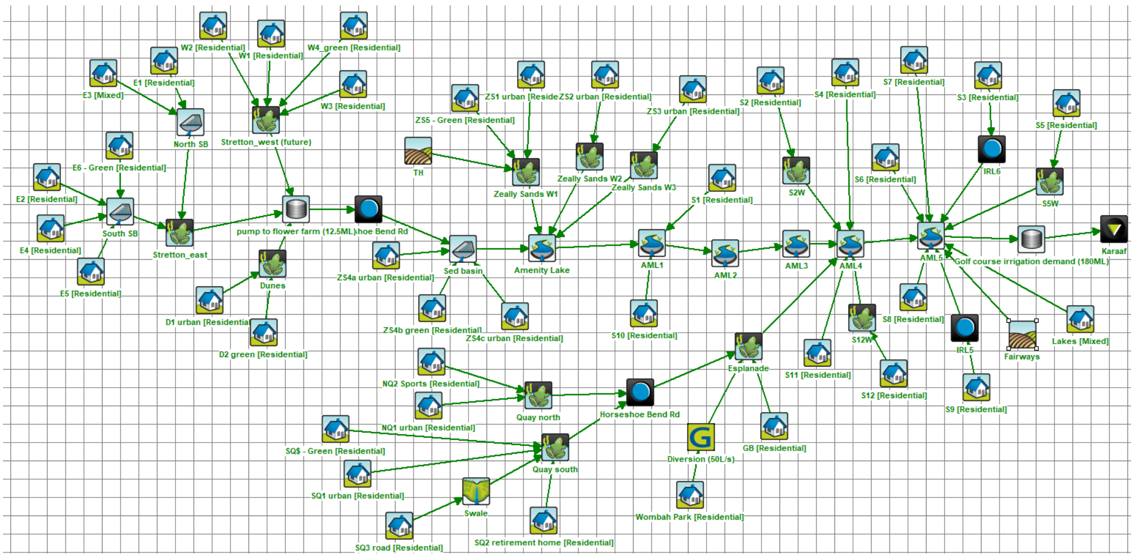

Figure 11 MUSIC model for wetland performance within the north Torquay catchment.

Table 10 Summary of The Sands waterbody parameters used in the MUSIC model (data sourced from Craigie and Condina (2001), GIS and aerial imagery)

Waterbody		Area (m²)	Design Volume (ML)	Estimated volume (ML)
Amenity lakes	AML1	3630	8	5.5
	AML2	5598	10	8.4
	AML3	3520	7	5.3
	AML4	22,610	52	45
	AML5	18,234	40	36
Irrigation lakes	IRL5	2406	-	5
	IRL6	3930	-	8
Wetlands [1]	S2W	700	0.35	-
	S5W	800	0.4	-
	S12W	370	0.18	-

Table 11 Summary of wetland parameters used in MUSIC model.

	Sediment basin			Macrophyte zone			
Wetlands	Area (m^2)	Depth (m)	Volume (m^3)	Area (m^2)	Extended detention depth (m)	Permanent pool depth [4] (m)	Volume (m^3)
Stretton - east wetland	305 [1]	1	225	5094	0	0.3	1528
	342 [2]	1	259				
Stretton - west wetland [3]			333	3000	0.5	0.5	1500
The Dunes	175	0.95	105	3295	0.35	0.5	1648
Quay - north wetland	290	1.5	238	1962	0.2	0.6	1177
Quay - south wetland	405	1.5	357	3354	0.2	0.6	2012
Esplanade	900	1.0	600	13472	0.3	0.6	8080
Zeally Sands – Wetland 1	535	1.3	384	2040	0.6	0.6	1224
Zeally Sands – Wetland 2	462	1.4	344	1610	0.5	0.4	644
Zeally Sands – Wetland 3	375	1.29	253	245	0.3	0.4	98
Other assets							
Zeally Sands sediment basin	290	1.0	160				
Zeally Sands amenity pond	815	1.25	622				

[1] North sediment basin
[2] South sediment basin
[3] Wetland yet to be constructed, parameters sourced from GHD (2011)
[4] Estimated from wetland design plans

5.2 Results

5.2.1 Annual catchment runoff

The modelled annual average stormwater volumes reaching the Karaaf from the north Torquay catchment is shown in Table 12 and Figure 12.

Table 12 Summary of annual average stormwater runoff volumes from the north Torquay catchment.

Location	Catchment runoff (ML/yr)
Outflow from Stretton wetlands [1]	183
Outflow from Dunes wetlands	141
Outflow from Zeally Sands wetlands	519
Outflow from Quay wetlands	222
Outflow from Esplanade wetlands [2]	360
Outflow from The Sands Development	855

[1] Includes areas yet to be constructed
[2] Includes low flows diverted from Wombah Park to the Esplanade Wetland

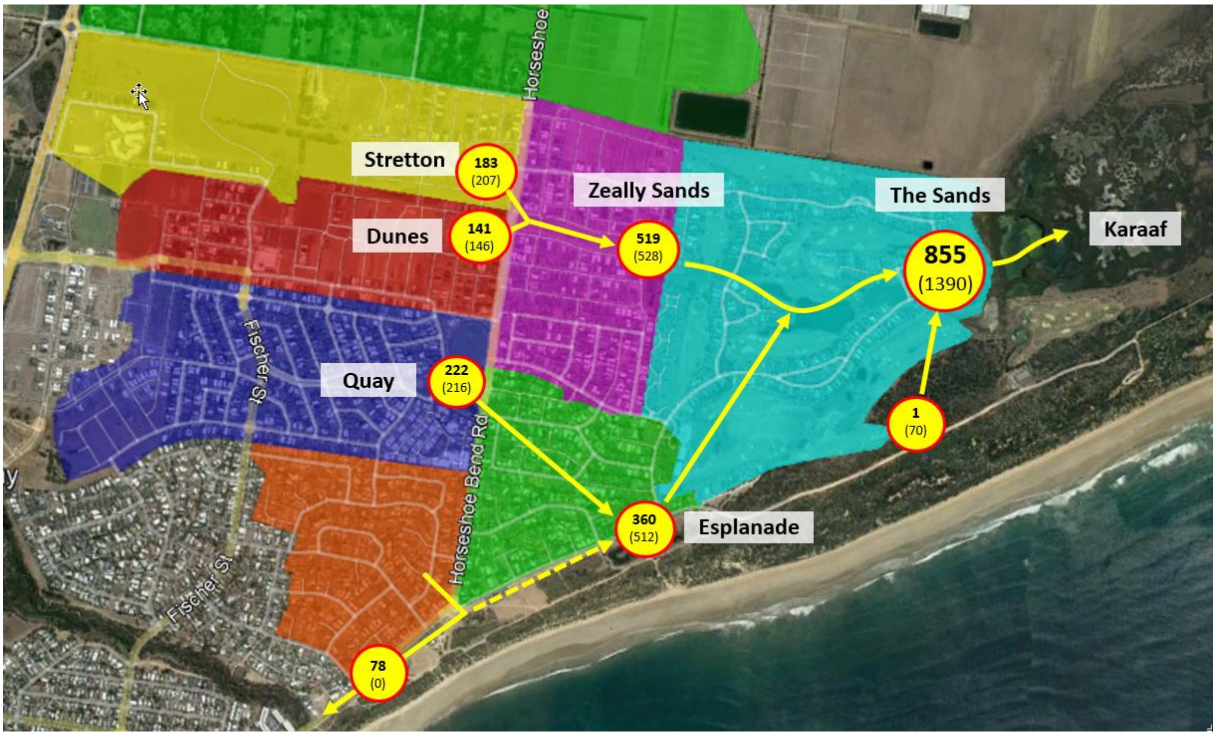

Figure 12 Estimated outflow runoff volumes (ML/year) from the north Torquay treatment wetlands and The Sands Development (volumes reported by Water Technology (2021) are shown in brackets for comparison).

The modelling indicates that approximately 850 ML per year of stormwater flows into the Karaaf wetlands via The Sands under a full development scenario (Table 12), compared to 250 ML per annum for the pre-development scenario (Table 13).

Urbanisation has resulted in approximately 600 ML of additional runoff being discharged to the Karaaf per year. This reflects a significant change to the hydrological regime of the Karaaf from the north Torquay catchment. Ecological implications of the altered wetland hydrological regime are being investigated by others.

Previous modelling undertaken (Water Technology, 2021) estimated that 1,390 ML per annum is discharged to the Karaaf from The Sands. While different to the current findings, it shows a similar trend of much more water reaching the Karaaf compared to pre-development conditions from the north Torquay catchment.

The annual runoff volumes reported in this modelling represent surface flows from the north Torquay catchment that enter the Karaaf via The Sands and are reflective of the analysis described in this report. The net catchment area used for model was approximately 620 hectares (including urban and non-urban areas) and did not include the foreshore areas which are assumed to be highly pervious and relatively unchanged from the pre-developed conditions.

Differences in the reported annual runoff volumes between the two analyses can partly be explained by different catchment areas contributing to north Torquay catchment. For example, the north Torquay catchment area reported by Water Technology (2021) is 734 hectares (Table 7-1), whereas this report found it to be 620 Hectares. The main differences are in the lower catchment areas (to the Esplanade wetland and in The Sands area).

The annual runoff volumes reported at key nodes within the north Torquay catchment are similar between the two analyses, however notably higher outflow volumes from the Esplanade Wetland and The Sands are predicted by Water Technology (2021), shown in Figure 12.

Differences in outflow volumes from the Esplanade wetland can partly be explained by different catchment assumptions draining to the wetland. Water Technology (2021) included additional catchment to the south of The Esplanade and assumed that all of Wombah Park runoff flows to the wetland (not just low flows).

The most notable difference between the two analyses was in the outflow volumes predicted from The Sands catchment. Accounting for the differences in the outflow volumes for Zeally Sands and the Esplanade wetlands, Water Technology (2021) predicted that an additional 400 ML per year would be discharged from The Sands catchment into the Karaaf (Figure 12).

Differences between the analyses can be partly explained by the catchment areas and their characteristics assumed by Water Technology draining to The Sands. In particular "catchment C" (70Ha) is an area of fairway and coastal vegetation and assumed to be 20% impervious by Water Technology. The modelling for this study assumes almost no runoff from this area.

The modelling undertaken for this report assumed that all catchment runoff from the golf course areas were either infiltrated or diverted to wetlands and storages located within the golf course. Surface runoff from golf course areas were assumed to be isolated from the amenity lake system and the Karaaf in accordance with the assumptions outlined in Craigie and Condina (2001).

Another potential difference is the quantity of irrigation estimated to be used by The Sands. This report estimates 180 ML per year (based on conversations with The Sands), whereas Water Technology assumed 102ML per year.

While there are differences in the two modelling approaches, the results for the majority of the residential urban area of the north Torquay catchment align, or small differences can be explained. They both show the same trend of more runoff being discharged from The Sands into the Karaaf than pre-urbanisation.

5.2.2 Average monthly runoff

The average monthly runoff discharges to the Karaaf are summarised in Table 13 and Figure 13 for both pre and post development (using Geelong North rainfall data) as well as for low rainfall (using Little River rainfall data) scenarios. The modelling indicates that discharges to the Karaaf gradually increase during winter and peak in October.

Table 13 Average monthly surface flows to the Karaaf for pre- and post-development scenarios for the north Torquay catchment.

Month	Pre-development (ML/month)		Post development (ML/month)		Post development Low rainfall (ML/month)	
January	11	4%	53	6%	61	9%
February	23	9%	64	8%	54	8%
March	10	4%	34	4%	47	7%
April	9	4%	50	6%	65	10%
May	14	6%	86	10%	38	6%
June	17	7%	69	8%	39	6%
July	40	16%	83	10%	29	4%
August	45	18%	85	10%	36	5%
September	28	11%	89	10%	65	10%
October	22	9%	113	13%	97	15%
November	15	6%	74	9%	77	12%
December	12	5%	53	6%	57	9%
Total	248		853		665	

A comparison of the monthly inflow volumes for the pre-development and post-development conditions indicates that monthly discharges to the Karaaf are generally 3-4 times more under post-development conditions, with the exception of July and August where the difference is approximately twice (Table 13). In addition, proportional seasonal patterns vary with post development showing a lower proportion of annual flows from July to September and a higher proportion from October to December.

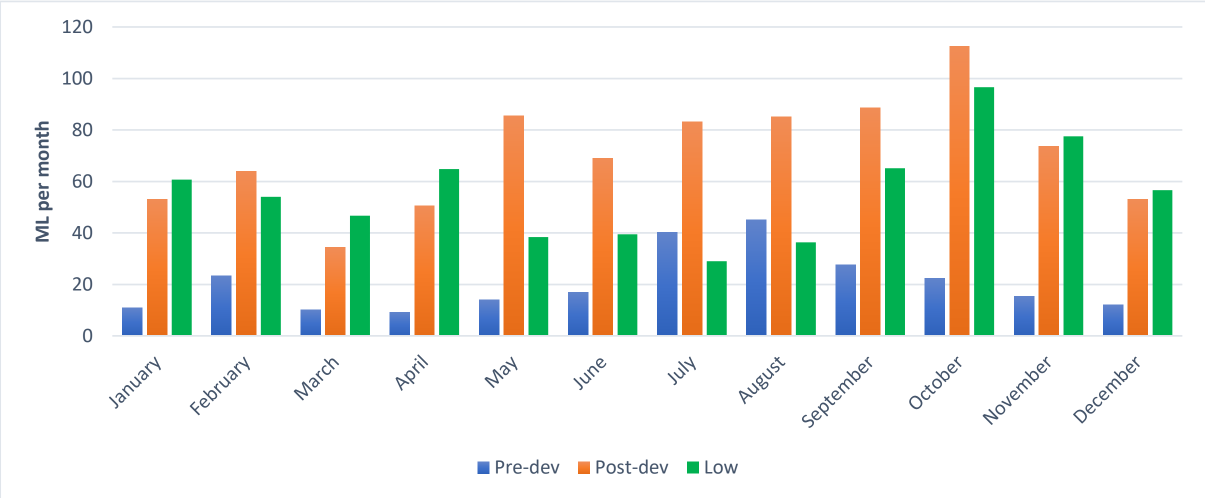

Figure 13 Monthly stormwater runoff volumes discharged to the Karaaf (based on Geelong North rainfall dataset).

5.2.3 Pollutant removal

The modelled treatment performance for each of the north Torquay wetlands is summarised in Table 14 and Figure 14. The modelling shows that none of the treatment wetlands achieve current best practice objectives for water quality. This is primarily considered to be a reflection of all wetlands being smaller than best practice compared to their catchment sizes (rather than any fundamental flaws in the designs).

The modelling indicates that Zeally Sands Wetland 2 provides a high level of stormwater treatment (close to best practice). However, this is because the high extended detention depth (0.5m) is contributing to the treatment and in reality (if it was operating this way) is likely to be detrimental to the long term sustainability of the wetland vegetation.

A comparison of the wetland to catchment area ratios indicates that the majority of the wetlands are less than 2% of their respective catchments (Table 1). As a rule of thumb, treatment wetlands should be sized to at least 3% of the urban catchment area. This indicates that most of the wetlands are too small to achieve the desired treatment of stormwater runoff.

This is similar to the findings in Water Technology, 2021.

The north Torquay stormwater management strategy outlined in GHD (2010) indicates that the initial modelling undertaken to determine the treatment wetland sizes for the north Torquay development area (Stretton and Zeally Sands Estates) adopted a catchment imperviousness of 45%. This is not consistent with the built catchment conditions for which catchment imperiousness ranges between 60-85%. As a result, modelling undertaken by GHD under-estimated the stormwater volumes and pollutant loads which are discharged from these catchments (and therefore planned areas for wetlands treatment were too small).

The original stormwater management strategy for the Stretton Estate included three treatment wetlands. It would appear that one of these wetlands has been removed and the respective catchment runoff diverted to the Stretton East Wetland. Whilst the area of the Stretton East Wetland is larger than initially designed, there are a number of fundamental design issues that are currently compromising the performance of the system, notably:

- Lack of EDD
- Shallow sediment basins (no storage capacity)
- Bypass channel running through the wetland macrophyte zone
- Short circuiting due to the bathymetric design.

It is recommended that the stormwater management plan for the Stretton West catchment is updated to ensure that the treatment wetland design (Stretton West - yet to be constructed) reflects the expected catchment characteristics (e.g. percentage impervious) outlined in the development masterplan.

The modelling indicates that the wetland areas for The Dunes, Zeally Sands Wetland 1 & 3, The Quay wetlands are too small. The sediment basins are generally too shallow (limited storage capacity) and the wetland macrophyte zones are of insufficient size. This is most apparent for Zeally Sands Wetland 3 which has a wetland to catchment area ratio of 0.4%, and where the sediment basin area is larger than the macrophyte zone.

The wetland designs indicated that the majority of the macrophyte zones were constructed as a chain of ponds, resulting in a high proportion of open in the macrophyte zones, unsuitable depths for water plant growth and low wetland hydraulic efficiency. This most likely results in these modelled performances being an overestimate of what is actually achieved because he MUSIC model assumes best practice bathymetry design.

Table 14 Summary of the modelled wetland treatment performance.

Wetland	TSS removed (kg/yr)	TSS removed (%)	TP removed (kg/yr)	TP removed (%)	TN removed (kg/yr)	TN removed (%)
Best practice objective		**80**		**45**		**45**
Stretton East	560	9	2.1	13	21	13
Stretton West	11,700	61	15.2	48	68	29
The Dunes	10,300	40	13.7	33	62	20
Quay North	5,010	53	6.2	40	26.4	22
Quay South	11,100	36	13.0	26	49	13
Esplanade	25,900	51	34.9	38	175	23
Zeally Sands - W1	8,530	72	11.05	57	49.4	35
Zeally Sands - W2	4,700	81	6.13	66	28.7	42
Zeally Sands - W3	3,940	46	3.99	29	12.2	12

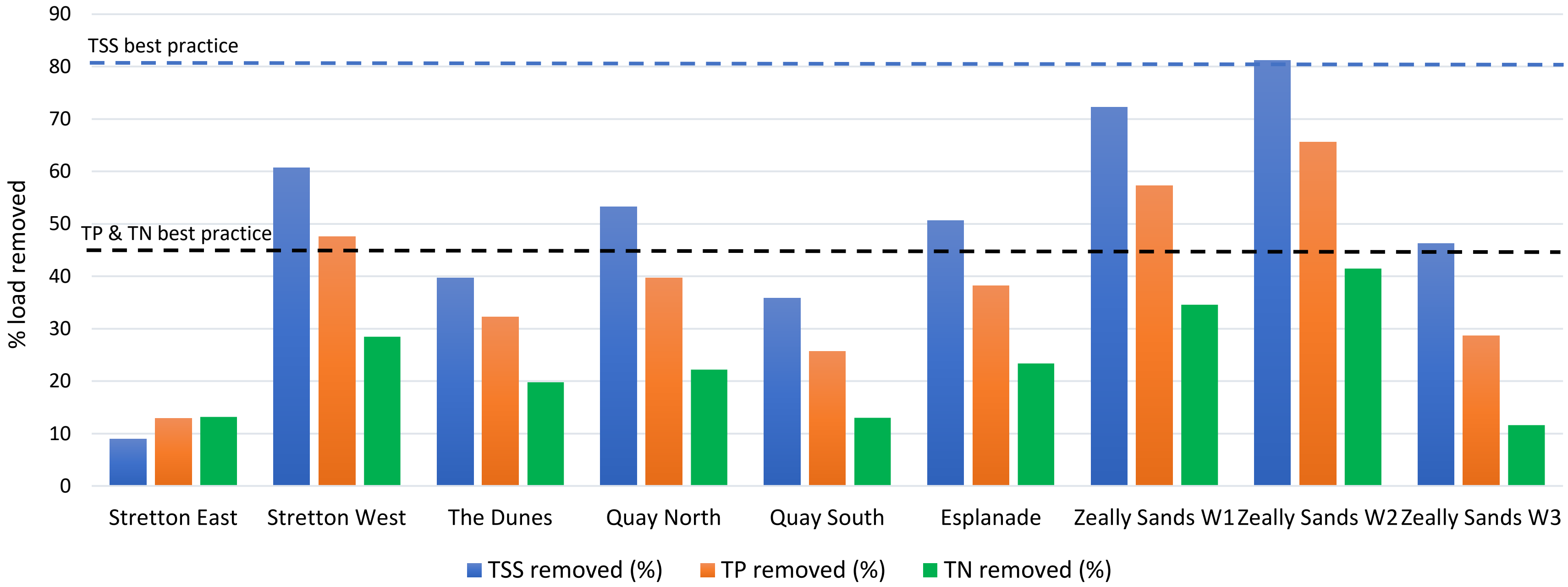

Figure 14 Modelled wetland pollutant removal compared to BPEM best practice objectives.

6 Water quality monitoring

This section reviews water quality monitoring performed by ouncil to assess the performance of the wetlands.

6.1 Existing wetland WQ data

Water quality is monitored monthly (grab samples) at seven wetland locations within the north Torquay catchment. It is understood that the objective of the water quality monitoring program is to assess the treatment performance of the wetlands by comparing the water quality at inlet (untreated) vs outlet (treated) locations. The water quality monitoring data were collected between Dec 2020-Apr 2022 and is summarised in Table 15.

The key water quality parameters that relate to the wetland performance are TP, TN and TSS which are modelled in MUSIC. These water quality parameters varied substantially between wetlands. It can be seen that the median and 25th percentile concentrations for TP, TN and TSS approached the respective MUSIC C* concentrations, indicating that the maximum measured concentrations are biasing the average concentrations.

With the exception of TP at Zeally Sands Wetland 1 and Esplanade Wetland, the average concentrations for TP, TN and TSS exceed both the ANZECC and SEPP (WoV) objectives.

Of note, EC (salinity) varied notably between the main inlet and outlet locations within The Dunes Wetland. Higher EC concentrations were present at the main inlet, potentially indicating ingress of groundwater to the stormwater network. Inflows from the two small inlets adjacent the wetland outlet may be diluting the EC concentration.

Table 15 Summary of water quality data collected from the north Torquay wetlands between 12/2020-4/2022.

Statistic	TEMP °C	EC uS/cm	TDS mg/L	DO mg/L	pH	TURB NTU	TP mg/L	TKN mg/L	TN mg/L	TON mg/L	NH_3 mg/L	TSS mg/L
MUSIC_C*							0.06		1.0			6
ANZECC [1]		20-30			6.5-8.0	1-20	0.01		0.35	0.01	0.01	
SEPP WoV		<1500	<1000	6-12		10	<0.045		<0.06	<0.05	<0.5	
Location 1 - Stretton Wetland @ outlet pipe												
Average	16.4	531	414	9.0	8.1	55.6	0.18	0.75	1.55	0.86	0.15	15
Median	15.6	465	290	9.1	8.2	38.5	0.09	0.95	1.2	0.24	0.09	8
Minimum	8.8	230	190	7.2	7.6	7.4	0.03	0.24	0.3	0.01	0.02	6
Maximum	19	1600	860	10.8	8.5	110	0.6	1.3	7	6.1	0.51	40
25th PCTL	11.5	350	240	7.85	7.8	32	0.05	0.55	0.65	0.07	0.05	8
75th PCTL	15.6	650	460	9.85	8.35	80.5	0.18	0.96	1.35	0.68	0.18	20
Location 2 - The Dunes Wetland @ inlet to sediment basin												
Average	14.9	1137	661	7.3	7.8	19.8	0.18	1.31	3.69	2.38	0.16	24.8
Median	15.8	1300	760	8.1	7.9	20	0.10	0.84	3.2	1.7	0.08	17
Minimum	8.9	270	220	1.9	7.2	4	0.05	0.55	1	0.19	0.02	6
Maximum	25	1500	970	9.6	8.3	76	0.7	6.4	6.6	4.9	0.74	110
25th PCTL	12.4	1060	422	7.3	7.7	9.1	0.06	0.74	2.82	1.06	0.06	10.7
75th PCTL	16.2	1500	892	8.2	8.1	22	0.11	1.02	4.42	3.3	0.15	18
Average	14.9	1137	661	7.3	7.8	19.8	0.18	1.31	3.69	2.38	0.16	24.8
Location 3 - The Dunes Wetland @ outlet pipe												
Average	14.6	385	233	8.6	7.5	19.8	0.20	0.61	0.66	0.06	0.04	32
Median	16	410	230	8	7.5	10	0.07	0.69	0.7	0.02	0.02	16

Minimum	8.5	150	130	3.6	6.9	1.6	0.03	0.05	0.1	0.01	0.01	8
Maximum	22	710	380	12.5	8.6	69	0.97	1.1	1.5	0.39	0.1	130
25th PCTL	11.8	287	165	7.5	7.3	2.6	0.04	0.46	0.5	0.01	0.02	14
75th PCTL	16.5	430	280	9.8	7.7	34.2	0.06	0.83	0.82	0.05	0.05	30
Location 4 - Zeally Sands Wetland 1 @ sediment basin inlet												
Average	14.1	712	433	7.6	7.7	7.4	0.06	0.56	1.71	1.15	0.07	9.75
Median	15.5	750	390	8	7.7	4.7	0.07	0.51	1.5	0.6	0.07	8
Minimum	9	140	100	3.5	7.1	0.8	0.04	0.3	0.5	0.13	0.01	4
Maximum	20.1	1300	890	9.6	8.5	20	0.1	1.3	4	3.1	0.21	29
25th PCTL	11.3	452	275	6.8	7.5	3.3	0.04	0.43	0.97	0.23	0.04	6
75th PCTL	16.1	915	550	9.2	7.9	8.1	0.09	0.58	2.125	1.675	0.08	9.75
Location 5 - Zeally Sands Wetland 3 @ sediment basin inlet												
Average	14.3	465	263	4.8	7.1	5.2	0.07	0.57	0.78	0.22	0.07	9.6
Median	16	470	220	4.5	7	2.3	0.07	0.61	0.7	0.13	0.06	8.5
Minimum	9	200	140	0.8	6.8	1.1	0.02	0.23	0.4	0.01	0.01	2
Maximum	24.1	970	510	7.7	8	32	0.12	1	1.4	0.78	0.2	27
25th PCTL	11.2	297	150	4	6.9	1.5	0.05	0.45	0.6	0.03	0.02	5
75th PCTL	16.2	555	327	6.3	7.2	3.4	0.09	0.67	0.925	0.38	0.07	13
Location 6 - Zeally Sands Amenity Lake Sediment Basin @ inlet												
Average	14.2	710	434	9.3	14.5	19.3	0.27	0.72	1.16	0.45	0.07	24
Median	16.1	610	330	8.9	7.9	14	0.09	0.68	1	0.22	0.07	13
Minimum	9.3	240	260	7	7.3	1.5	0.04	0.2	0.2	0.01	0.02	2
Maximum	20.4	1100	710	12	87	76	0.8	1.3	2.1	1.2	0.16	140
25th PCTL	11.8	520	307	8.8	7.9	3.6	0.07	0.58	0.77	0.08	0.03	8.2
75th PCTL	16.4	992	590	9.5	8.15	23.7	0.39	0.92	1.55	0.76	0.09	15
Location 7 - The Esplanade Wetland @ outlet												
Average	14.3	253	145	6.4	7.0	5.6	0.02	0.65	0.3	0.02	0.03	14.1
Median	16	260	140	6.3	7	4.2	0.03	0.4	0.4	0.01	0.03	6
Minimum	8	130	82	4	6.6	1.8	0.01	0.14	0.1	0.01	0.01	2
Maximum	24	420	220	10	7.7	14	0.04	4.3	0.5	0.05	0.08	95
25th PCTL	11	225	117	5.3	6.8	3.6	0.01	0.23	0.2	0.01	0.01	3.5
75th PCTL	16.4	282	172	7.2	7.1	7.1	0.03	0.4	0.4	0.02	0.03	8

[1] ANZECC objectives based on freshwater lakes & reservoirs, there are no objectives for wetlands.

6.2 Discussion on water quality monitoring

6.2.1 Wetland performance standards

There a no water quality standards/benchmarks for constructed treatment wetlands in Australia. Three water quality benchmarks are presented in Table 14, the MUSIC C* concentrations for TP, TN and TSS, ANZECC guidelines (2000) and SEPP (Waters of Victoria, 1997).

The MUSIC C* concentrations represent the baseline concentration that TP, TN and TSS decay to in the model, and are representative of water quality data measured from constructed wetlands within Australia.

In comparison, it can be seen that the water quality threshold concentrations for TP and TN are notably less than the MUSIC C* concentrations, as these objectives are derived from generally healthy waterways/waterbodies. The application of benchmarks such as the ANZECC and SEPP (WoV) guidelines to constructed wetlands is questionable, given that most constructed wetlands will unlikely meet these concentration thresholds.

6.2.2 Grab sampling to assess water quality

Assessing the performance of constructed wetlands based on regular grab samples for water quality sampling can be misleading and should be interpreted with caution.

The vast majority of stormwater treatment within a constructed wetland occurs within the 48-72 hr period following a rainfall event, During this period, stormwater that is stored within the extended detention zone is filtered through the wetland vegetation and is subject to a complex range of physical, biological and chemical processes which act to remove or transform pollutants from the stormwater (refer to Section 3.3).

Stormwater quality varies enormously depending on flow rates, timing during storm events, time between storms and catchment activities. Stormwater quality monitoring is a very complex process to fully understand how a system is performing. Extensive samples collected at regular intervals during storm events are required. These data can then be used to form a picture of how the systems are operating during flow events when the vast majority of flow and pollutants are moving through a wetland.

Intensive water quality sampling is required during and after stormwater events to measure the removal of pollutants from stormwater. This typically requires the use of specialist auto-samplers which are programmed to sample the water at pre-set intervals. The process requires the measurement of wetland water quality at both inlets and outlets, and is extremely expensive to undertake.

Water quality in most constructed treatment wetlands are not monitored, as it is difficult to correlate the water quality data to wetland treatment performance. Typically, water quality monitoring to assess performance is left to research facilities.

In contrast, most wetland asset owners use regular (e.g. 2-5 years) audits of the condition of particular aspects of wetlands to assess the wetland condition.

A constructed treatment wetland system is generally considered to be in a functional condition providing that the following key wetland performance indicators are met:

- Minimum 80% water plant cover
- Maximum 0.35m EDD
- Outlet control (e.g. riser pipe or weir) – no blockage – with 48-72 hours detention time
- Sediment basin has minimum 0.5m free water depth plus adequate storage
- Inlet and outlet pipes – no blockage.

6.2.3 Current stormwater quality monitoring program

The value of the current water quality monitoring program to inform wetland management is questionable, as the data provide limited information that will trigger management intervention or rectification actions.

It is highly likely there would be greater value to Council by implementing a regular wetland audit program that focuses upon key wetland performance indicators.

It is noted that regular water quality monitoring of the Karaaf wetlands is undertaken as part of The Sands program. Monitoring sensitive downstream ecosystems such as the Karaaf is extremely important, as changes in water quality may trigger ecosystem change, and can point to subtle changes in catchment runoff characteristics. In addition, it is the ambient condition that may affect the Karaaf and these can be readily assessed using regular grab samples.

6.2.4 Recommended wetland performance assessment

It is recommended that Council:

1. Discontinue wetland grab sample monitoring program to assess wetland performance
2. Continue a 3-yearly comprehensive wetland audit program to assess wetland performance indicators and determine management actions
3. Address audit outcomes to ensure key performance indicators are met in all wetlands.

7 References

The following technical reports were provided by Council for review:

Beveridge Williams (2016) Dunes Retarding Basin Wetland. Civil Drawings. Prepared for The Dunes, Torquay Pty Ltd.

Beveridge Williams (2016) The Dunes Stormwater Diversion System & Pumpwell Detailed Design.

Craigie and Condina (2001) Torquay Sands Development: Surface Water Management System. Concept for management of quality and quantity of surface waters for irrigation supply and feature lakes and wetlands. Report for MHY Handbury Pty Ltd.

Earthtech (2005) The Esplanade Constructed Wetland Review.

Esplanade Wetland design scans. Scan provided by Council

GHD (2010) Report for Stormwater Master Plan – North Torquay Technical Report.

GHD (2015) Investigation of The Sands Torquay storm water system to determine its suitability for Council to assume responsibility.

GHD (2020) North Torquay Stormwater Master Plan Flood Flow Updates - Zeally Sands Site. Report for Surfcoast Shire Council.

Peter Berry & Associates (2001) Torquay Sands. Loch Ard Drainage Diversion. Design Drawings.

Peter Berry & Associates (2019) South Beach Farm Estate, Horseshoe Bend Road Basin Detail Design Plans.

Reeds Consulting (2005) The Quay Stage 1. Wetland North and South Pond Detail Plans.

Spiire (2022) WSUD004 & WSUD005 The Quay Wetland Rectification. Report for Surf Coast Shire Council.

TGM (2014) 1095 Horseshoe Bend Road, Drainage Outfall – Wetland. Civil Drawings.

Water Insites (2022) Rippleside (Zeally Sands) wetland audit for Surf Coast Shire.

Water Insites (2022) Dunes Estate wetland audit for Surf Coast Shire.

Water Technology (2021) Karaaf Wetlands Catchment – Ecological and Stormwater Assessment, Report for The Sands Owners Corporation.

WBCM (2015) The Dunes Estate, Torquay, Stormwater Management Strategy. Report for The Dunes, Torquay Pty Ltd.

8 Appendix A

The table below summarizes the key catchment parameters used for the MUSIC model developed to model stormwater treatment and catchment runoff volumes that enter the Karaaf via The Sands.

Table 16 Sub catchment details used in the MUSIC modelling

Catchment	Sub catchment	Area (Ha)	Catchment imperviousness (%)	Land use
Torquay Heights	TH	172.00	3	Agricultural/ rural res
Stretton - east	E1	12.45	75	Residential
	E2	4.72	45	Primary school
	E3	3.16	40	Catholic primary
	E4	6.20	75	Residential
	E5	1.51	80	High density residential
	E6	0.49	0	Green spaces
	Wetland	1.45		
Stretton – west	W1	27.57	75	Residential
	W2	6.23	40	Secondary college
	W3	2.86	45	Green/Sports
	W4	0.89	0	Green spaces
	Wetland	2.67		
The Dunes	D1	42.62	75	Residential
	D2	6.01	5	Sports grounds
	Wetland	1.00		
Quay - north	NQ1	16.62	70	Residential
	NQ2	3.01	5	Sports grounds
	Wetland	0.67		
Quay – south	SQ1	48.52	70	Residential
	SQ2	6.18	80	Retirement home
	SQ3	0.49	0	Green (combined reserve areas)
	SQ4	1.29	0	Road draining to swale
	Wetland	1.33		
Zeally Sands – Wetland 1	ZS1	21.0	70	Residential
	Green	0.27	0	Green spaces
Zeally Sands – Wetland 2	ZS2	10.31	70	Residential
Zeally Sands – Wetland 3	ZS3	16.29	65	Residential
Zeally Sands – Sediment Basin	ZS4a	1.17	70	Residential
	ZS4b	3.79	7	Residential

	ZS4c	0.92	70	
	ZS5	0.28	0	Green spaces
	Wetland	1.73		
Wombah Park	WP	40.8	65	Residential
Golden Beach	GB1	41.5	60	Residential
	Wetland	1.40		
The Sands	S1	3.36	75	Residential
	S2	6.48	75	Residential
	S3	5.69	75	Residential
	S4	0.88	85	Residential
	S5	2.72	75	Residential
	S6	0.91	75	Residential
	S7	0.97	75	Residential
	S8	0.89	75	Residential
	S9	1.98	75	Residential
	S10	4.31	70	Residential
	S11	5.64	75	Residential
	S12	4.69	70	Residential
	Lakes	6.40	100	Mixed
	Fairways	67.62	0	Golf course

Figure 15 Sub-catchment layout used in the MUSIC model