Environmental Water Requirements of Wetlands within the Torbay Catchment, South Coast Region

Study sites: Lake Powell, Manarup Lagoon, Ewart Swamp, Marbellup Brook Drain and North Creek Drain.

FINAL

Photograph: Kylie McKay

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EXECUTIVE SUMMARY

Background

The South Coast Regional Office of the Department of Water (DoW) is currently undertaking allocation planning for priority water resources located within the Torbay Catchments (within the Albany Drainage District). The program is being prepared with the purpose of preventing over-allocations and associated potential environmental, social and cultural impacts.

The Torbay Drainage System was highly modified during the 1950's to protect infrastructure from flooding and increase the area of productive horticultural land on the valley floor. Modifications consequently separated the lower section of the Torbay Catchments into three different hydraulic levels and local wetlands now have altered inflows, managed outflows and are kept at artificial levels

The Centre for Ecosystem Management has been contracted to provide an assessment of the environmental water requirements within the Torbay Drainage System (TDS). The original contract brief identified two study sites, **Lake Powell** and **Manarup Lagoon**[1]. However, the scope of work was revised to include **Marbellup Brook Drain**, **North Creek Drain** (NCD) and **Ewart Swamp** since it seemed management of the larger wetlands could not be considered unless in the context of other significant structural components of the system.

Desk-based and field assessments were used to compile a knowledge base for the TDS and to identify ecological values and gaps. With this information, the level of water dependency of identified ecological values and the risks of impacts from changes in water regimes were evaluated and Ecological Water Requirements (EWRs) determined for all ecological values, features and processes.

Literature Review and Compilation of Existing Knowledge

Prior to European settlement in 1831 the TDS was a connected system, with surrounding lands prone to water logging and flooding for the better part of the year. The TDS included the Torbay Inlet (which previously consisted of two basins connected by a channel; now the northern basin is known as Manarup Lagoon), Lake Grasmere (now Lake Powell), Grasmere Swamp (to the south of the Lake) creeks and associated swamps, along with Marbellup Brook and associated drainage channels (that have since been modified) all feeding Lake Powell. This Lake functioned as storage basin, slowing the natural flow of the surrounding rivers and creeks. As a result, Lake Grasmere was predominantly fresh, while Manarup Lagoon, being estuarine, experienced brackish to saline conditions. The associated swamps and creeks were predominantly fresh. Continuous, natural sedimentation of the Torbay Inlet resulted in a seasonally open-closed estuarine system, connected to an open palusplain with drainage channels and wetlands occupying the minor valleys. At this time Lake Powell received inflow via the Marbellup Brook, and overflowed into the swampy area (Grasmere Swamp) to its south and south east. These swamps drained into Manarup Lagoon, before entering the Torbay Inlet.

Within the last 200 years the TDS has undergone major physical changes including:
- The introduction of drainage controls and altered drainage lines,
- Increased sedimentation and eutrophication resulting from land use practices,
- Increased groundwater levels from widespread clearing, and
- Drying of the larger palusplain due to the altered drainage system.

Superimposed on these is climate change. While rainfall measurements for Elleker in the Torbay region only commenced in 1992, the last five years the average annual rainfall has changed, with a reduction in monthly rainfall during winter months and a slight increase in rainfall events during the summer months. This trend can be confirmed with the longer rainfall data for Albany, showing that winter rainfall has decreased during the latter half of the twentieth century, and it has been argued that both natural variability and the enhanced greenhouse effect have contributed to this decrease.

[1] For reasons explained in more detail elsewhere in the report, while this inland part of the Torbay Inlet is commonly regarded as "Lake Manarup", we will use the term Manarup Lagoon here to emphasise its continued functioning as a shallow, lagoonal estuarine basin.

Today the TDS is markedly different with the Torbay Inlet separated into two distinct systems. The Inlet is estuarine, and Manarup Lagoon has evolved different salinities and differing functionality. A salt wedge still moves upstream but the drainage and barriers to flow diminish its influence on Manarup Lagoon. Apart from leakages in the system, saline water from the estuary only enters the Lagoon when the inlet is open and the water levels are below the critical level management level (0.2 mAHD). Lake Powell is disconnected from the lower reaches by drainage controls preventing saline water from reaching the freshwater system. Additionally changes in flows received by the wetland and the altered water regime have resulted in widespread degradation and changes to wetland function. To confound matters each wetland is operated at a differing water level, the TDS having a high, medium and low water level section and a complex drainage network to maintain these water levels.

- The high-level sub-system comprises the Marbellup high level drain (drainage from the Marbellup Brook catchment) and the Torbay Inlet.
- The mid-level sub-system is comprised of the Grasmere Drain, Lake Powell and the section of the original Marbellup Brook between the Marbellup Plug (controlling the natural channel to Lake Powell) and Lake Powell. Lake Powell stores water from the catchment of the Grasmere Drain and drains excess water to Torbay Inlet through the mid-level sub-system.
- In the low-level sub-system Manarup Lagoon stores water from a local sub-catchment and the North Creek Drain catchment and drains excess to Torbay Inlet.

To ensure all agricultural, infrastructure and residential constraints are met, water levels in the three sub-systems are controlled by the Water Corporation using penstocks to hold water in each of the basins and floodgates to flush the system and remove excess water as follows:

- Lake Powell not to exceed 1.0 mAHD.

During summer the Bridge 45 penstock remains closed when levels are below 0.8 mAHD to maintain groundwater at levels appropriate for the potato growing season (October – March). In winter they are kept open and floodgates operate automatically when Inlet levels fall below 0.3 mAHD. The Marbellup Plug opens occasionally during summer to allow limited stream flow and flushing of the channel. However, it remains closed throughout winter.

- Torbay Inlet not to exceed 1.4 mAHD.

Artificial breaching of the sandbar is avoided during February and March at the request of the commercial fishing industry in Torbay Bay. To minimise flooding during winter, the sandbar is opened between May and October.

- Manarup Lagoon not to exceed 0.4 mAHD or fall below 0.2 mAHD.

The water level is maintained at a low level during the potato growing season to enable the Lagoon to function as a compensation basin. The Manarup penstocks are kept closed at this time to prevent saltwater intrusion into North Creek Drain should the sandbar be breached. During winter the penstocks remain open to keep water levels low as long as possible and to hold run-off from the Low and Medium level sub-systems.

Groundwater levels

Groundwater level data in the TDS are limited: one official monitoring bore is listed within a 1km radius of the study wetlands, plus a significant number of inactive and active bores in the vicinity. The datasets are incomplete for most relevant bores within the area (monitored only 1978 – 1998, or monitoring only conducted for a short period of time from 1999/ 2000). These bores are not within close range of one another and metadata concerning ground level (mAHD), casing heights, slotted depths and converted water levels are often not available. The best data revealed the following:

- Available data (2003-2006) showed groundwater levels north of Lake Powell ranged from a mean winter maximum of 1.3 m AHD to a summer low of 0.0 mAHD. South of the lake, where the water table is lower, levels rose to a winter peak of <1.0 mAHD, falling below sea level during summer.
- Longer term data (1978-2005), available for a bore north-east of Manarup Lagoon, indicated a decline in groundwater levels since 1998: the mean minimum has declined from 2.82 mAHD (1978-1998) to 1.85 mAHD (2003-2005).
- Groundwater levels recorded between 2003 and 2006 in the vicinity of Marbellup Brook ranged from a maximum of 2.2 mAHD to 0.2 mAHD. Levels here are much higher than those recorded north and south of Lake Powell and may be influenced by groundwater mounding under Manarup Lagoon and Torbay Inlet during the winter months.

- Longer-term data (1978-2005) recorded near North Creek Drain also showed a decline in water levels. The mean minimum fell from 1.33 mAHD (1981-1998) to 0.36 mAHD (2003-2005).
- No active monitoring bores could be located within close proximity to Ewart Swamp. Data from the nearest bore therefore only provided a general idea of recent (2003-2005) groundwater levels, which ranged from a maximum of 1.5 mAHD to a minimum of 0.11 mAHD.

Recommendation: *The number of official monitoring bores near the wetlands be increased and a programme of data quality management and frequent and regular monitoring be implemented.*

Surface water levels

Surface water levels are recorded at staff gauges up and down-stream of the Lake Powell and Manarup Lagoon drainage controls (penstocks and floodgates) on a weekly basis. Elleker rainfall data and Torbay Inlet opening times are recorded simultaneously. Surface water levels are not currently recorded at Marbellup Brook, North Creek Drain (NCD) or Ewart Swamp.

Lake Powell surface water levels are affected by groundwater levels, rainfall and primarily water level criteria through opening and closing of the Torbay Inlet and associated drainage controls.

- Although pre-drainage water levels are unknown, they were frequently high and the entire region was prone to flooding (water levels were at least 1m higher). Lake Powell also reflected regional seasonal patterns with maximum water levels in winter/ spring and minimum water levels in summer/ autumn. The water regime experienced under the current management framework is one of semi-permanent inundation, but *seasonally switched* - with periods of drying mainly occurring in the winter months. Drainage into and out of Lake Powell has also changed from a protracted slow increase in water levels associated with seasonal saturation of a catchment, to increased runoff volumes following rainfall due to drains, filling the lake quicker. The aim then would also have been to drain the excess water from the lake quicker, to prevent unpredictable and potentially damaging overflows.
- Approximately 80% of the original wetland sediments within Lake Powell are almost permanently inundated, increasing to 100% during most summers. However, drainage management can result in water level fluctuations of 0.4 – 0.8 m within a few days.
- The critical level of 1.00 mAHD results in the opening of the Torbay Inlet, which subsequently reduces water levels in Lake Powell unless, during the summer months drainage controls let out excess water but keep sufficient levels for the growing season (0.8 mAHD). Contrary to management criteria the water level in Lake Powell often exceeds the Torbay Inlet levels for limited periods of time annually with the average number of days each year calculated at 89, the longest period being 168 days in 1996/1997.
- The average annual maximum and minimum water levels (1992 – 2006) are 0.97 mAHD and 0.21 mAHD respectively. However, since 2001 average maximum water levels at Lake Powell have decreased, while average minimums have risen. These changes may be attributed to minor management modifications, such as increasing water levels in winter to aid system flushing and achieve reductions in the incidence of algal bloom in the following growing season. Thus the management of Lake Powell in recent years ensures that a significant number of low water levels occur throughout the year, although water levels in winter months have become erratic.

Manarup Lagoon surface water levels: opening and closing of the Torbay Inlet and associated drainage controls and rainfall also have significant and dramatic impacts on surface water levels in Manarup Lagoon.

- Connected to Torbay Inlet, Manarup Lagoon has at different times been completely estuarine in a permanently open system, and at times a seasonally open-closed estuarine system that exists today. By European settlement, Manarup Lagoon was considered to be predominantly estuarine in character, experiencing tidal influences only during periods when the estuary mouth was open. Winter flushing and the isolation from the ocean would have seen water conditions gradually become less saline (more brackish).
- Water levels prior to 1950 are unknown; however it is assumed they were frequently high and the entire region was prone to flooding. It is also assumed that levels often reached and

exceeded holding capacity as indicated by the re-routing of Marbellup Brook and the construction of levee banks in the 1950s.

- The management of the current drainage system results in Manarup Lagoon operating as an overflow wetland system rather than a tidally influenced lagoon. The semi-permanent nature of the latter-day wetland has also been maintained with water levels more representative of natural seasonal water regime, ensuring that sufficient capacity exists should the region experience a higher than usual rainfall volume during the potato growing season (October to March) and Lake Powell requires draining. Water levels are also maintained at a higher level during winter to ensure that Manarup Lagoon does not empty completely when the inlet is opened. The critical level of 0.4 mAHD in Manarup Lagoon results in the opening of the Torbay Inlet, reducing water levels unless drainage controls (penstocks) are used to maintain them. Thus Torbay Inlet still has a much higher influence over Manarup Lagoon than Lake Powell.
- The average annual maximum water level (1992 – 2006) is 0.648 mAHD, with a minimum of -0.169 mAHD. However, since 2001 average minimum levels have decreased, while average maximums have risen. As management has remained unchanged, declines in water levels might be attributed to small changes in rainfall.
- Bathymetry of Manarup Lagoon indicates in-wetland elevations range from -0.6 to 0.0 mAHD. When compared to current average 2002/06 maximum and minimum water levels (-0.25 mAHD and -0.65 mAHD) it is evident that up to 80% of the lake sediments are inundated even during summer.

Marbellup Brook surface water levels should equate to those experienced in Lake Powell as the staff gauge is downstream of both wetland systems. Thus water levels within the current management framework are essentially the same for Lake Powell and the lower reaches of Marbellup Brook.

North Creek Drain surface water levels are less well recorded, but since it feeds directly into Manarup Lagoon, forming part of the 'low level system' mean surface water levels should equate.

Ewart Swamp has not been inundated for a number of years, possibly due to drainage lines along its southern edge which channel water into North Creek Drain.

Surface water quality

Water quality for the Lake Powell/ Torbay catchments is considered to be among the poorest in Western Australia, with eutrophication, acidification, sedimentation and algal blooms common within the wetlands and drainage channels. The combination of previous surveys and datasets from the AQWA database provides an overall picture of wetland health. The largest source of nutrient enrichment in the lower Torbay catchments is the oxidation and continuous degradation of organic matter in soils resulting from extensive drainage of a former coastal back swamp environment. Water column nutrient concentrations (NH_4^+, PO_4^{3-} ,NO_X) in Lakes Powell, Manarup Lagoon and Marbellup Brook were generally very high. Dissolved oxygen was generally depleted in all the waterways, except Lake Powell.

Sediments

Wetland sediments have been an important focal point for previous studies. Sediments of the low-lying, near-coastal areas, consisting primarily of estuarine and shallow marine silty and sandy sediments, are particularly important for TDS management and restoration.

- Some contain significant amounts of the iron sulphide mineral pyrite and are highly reactive when exposed to air. Consequently, drainage and excavation of these materials have created widespread acid sulfate soils which began discharging acidity and metals into drainage in the early 1920s. Lake Powell, Manarup Lagoon, Ewart Swamp, Marbellup Brook and North Creek Drain have been affected by both ground and surface water acidification events.
- Lake Powell has been shown to have a flocculant layer of fine, black/ brown organic muds of varying thickness, extent and mobility, overlying sticky clays. Benthic flux values calculated for Lake Powell have indicated the presence of microbenthic algal species facilitating highly efficient reduction of bioavailable nitrogen, through denitrification. This high release of nutrients from sediments to the water column has the potential to negatively impact water quality.

- The sediments of Manarup Lagoon have been described as mainly organic muds with small, sand lenses and muddy sands between, deposited over grey clays. Lateritic deposits occur throughout the north west area of the wetland, while organic sands dominate the south west. Studies have shown a reduced release of nutrients from sediments and a dominance of photosynthesis rather than microbial reduction.
- The sediments of Marbellup Brook are heavily influenced by overhanging vegetation, flow volume and flushing of the system at times, with woody debris and leaf litter covering much of the visible benthos, and sediments of predominately black organic-rich muds, containing plant and leaf material.
- Benthic fluxes were found to be higher in Marbellup Brook than in both Lake Powell and Manarup Lagoon, with the muddy sediments releasing nutrients continuously, using up available oxygen and accumulating nitrogen.
- No further data were available on the sediments of North Creek Drain and Ewart Swamp.

Ecology

Desktop assessments were undertaken to ascertain the main elements of the ecology within the Torbay Drainage System. Searches of Department of Environment and Conservation (DEC) databases revealed a general absence of groundwater dependent Declared Rare Flora and Threatened Ecological Communities within the study area boundaries however, numerous rare fauna species occur in the region.

High levels of algal bloom have been recorded within the study wetlands. Previous studies have shown that blooms in both Lake Powell and Marbellup Creek Drain, are driven by a number of factors in particular nutrient release of soluble inorganic phosphate (FRP) and ammonia (N-NH3) from sediments and periodic influxes of nutrients from catchment sources. Physical factors, including mixing of water, turbidity, a variable light regime and temperature also influence phytoplankton growth.

Aerial photographs, available from 1947 to 2003 and other relevant data were examined to assess long-term clearing of native vegetation and the expansion of agricultural land. Results showed that large tracts of mixed Eucalyptus forest and woodland in the Torbay catchment has been cleared for agriculture and the majority of this, especially around Lake Powell, was completed prior to 1947.

Limited surveys of current vegetation composition have been undertaken. To date, results have shown that remnant vegetation surrounding Lake Powell is structured in bands comprised of *Banksia, Agonis, Melaleuca* and *Baumea* spp., with widespread invasion of exotic *Typha* and grasses such as *Cynodon dactylon.* Vegetation of Manarup Lagoon remains dense and in good condition and is dominated by several species of sedge and rush. No vegetation data were available for Ewart Swamp, North Creek Drain or Marbellup Brook.

Limited data were available on invertebrate fauna of the study wetlands. A 1992 survey of Lake Powell indicated distinct seasonality of invertebrate communities, despite the wetland's permanent nature. Species richness was relatively high at this time however, recent surveys (2004-2006) have shown a decline in richness, possibly attributable to combined effects of eutrophication, algal blooms and urban development A narrow range of macroinvertebrates are known from Manarup Lagoon. A more representative assemblage of freshwater invertebrates has been described from Marbellup Brook. No macroinvertebrate data were identified for North Creek Drain or Ewart Swamp.

Information on vertebrate fauna including waterbirds, fish, amphibians, marsupials and mammals, have been collated from known distribution lists and searches of rare and threatened fauna, as well as previous work completed on the Torbay Coastal Research Project. Data obtained from Museum of WA records indicates that 30 mammal species, including 4 introduced species, have been recorded within the boundaries of the Torbay Coastal Reserve. Of these species the Western Ring-tailed Possum (*Pseudocheirus occidentalis*), Water Rat *(Hydromys chrysogaster)* and the Quenda *(Isoodon obesulus fusciventer*) are listed as 'rare and threatened' or in need of special protection.

Few consistent waterfowl surveys have been conducted in the study area. However, the Lake Powell Reserve was noted as an important breeding area for the Spotless Crake, Australasian Bittern and Red-necked Avocet and considered important for supporting large number of breeding pairs and as a stop-over for migratory species. A lack of data for the remaining wetlands indicates the need for additional surveys to be completed, particularly for Manarup Lagoon, where shallow water levels, invertebrate fauna, fringing vegetation and macrophytes provide valuable habitats for waterbirds, especially waders and ducks, and birds recognised under Migratory Bird agreements.

At least seven fish species are known to inhabit the wetlands of the TDS. Data obtained from Museum of WA records in 1997 and subsequent surveys, indicate that 13 amphibian and 34 reptile species, have been recorded within the boundaries of the Torbay Coastal Reserve: of these Guenther's Froglet (*Pseudophryne guentheri*) is recognised as being of conservation significance due to its local distribution, and the South-west Python (*Morelia spilota imbricate*) is classified as Specially Protected Fauna under the Wildlfie Conservation Act.

Recommendation: *Implementation of a sampling and analysis program covering the entire drainage system and the calculation of an accurate water balance is suggested, for the collection of comparable and reliable data and complete system understanding. Crucial elements to the success of EWR determination for the TDS include a thorough knowledge of soils and sediments underlying the system, flora and fauna communities driving the system and the understanding of ground and surface water levels and subsequent water quality.*

Field Surveys

The principle aim of field surveys was to supplement the existing knowledge base through strategic sampling, including:

- Water chemistry and quality: once-off sampling for comparison to existing datasets.
- Macroinvertebrate assessments: to support existing surveys and identify key groups for EWR determination.
- Sediment coring: indicative determination of chemical composition of sediments and sediment stratigraphy, determination of the water regime required to maintain sediment functionality.
- Vegetation assessments: determining dominant species and water requirements;
- Understanding the 'on ground' management protocols: for comparison to previous work.

Wetland sediments

Sediment samples were collected in study wetlands to maximise the area covered while remaining comparable to previous studies. Sampling and description of the physical structure and chemistry of key stratigraphic layers facilitated the identification of potential changes associated with sediments drying and rewetting, and therefore water regimes required to reduce or prevent possible impacts.

Cores were collected to a depth of 500 mm and key stratigraphic layers selected for biogeochemical analysis. Samples were analysed for total nitrogen and phosphate, LOI 550 & 1000 (loss on ignition), a metals/ metalloids suite, the total sulphur content (TS %), and the buffering capacity (S:(Ca + Mg) ratio). Trigger levels or EIL (environmental investigation levels) described in ANZECC Marine and Freshwater Guidelines (2000) were used to assess the status of metals and metalloids in the sediments.

Sediments throughout the TDS were relatively high in organics across all the wetlands, however those with macrophyte dominated primary production had much lower levels of TP. Sediments high in organics created a sink for nutrients and in some cases a continuous flow of nutrients into the water column. Mineral sediments occurring in Lake Powell and in Manarup Lagoon facilitated high rates of denitrification. Sediments showed a high incidence of TS, Fe, and Al levels throughout the catchment.

The key finding for sediments in the TDS is that they variously display organic and nutrient enrichment, iron pyrite in different stages of oxidation and mineralisation and an excess of salts principally sodium (chloride) in places. These sediments therefore foreshadow any or all of eutrophication, acidification and/or salinisation depending on the prevalent hydrological conditions.

The management stakes, therefore, in terms of the sediments in the TDS, are high, and trade-offs between these processes may not be possible.

Recommendation: *Removing organic loading and nutrient sources must be considered a priority but this should not be performed by allowing sediments high in iron and sulphur to dry out (and therefore oxidise). Maintaining anaerobia in organic rich sediments is essential (particularly in Manarup Lagoon) but should not proceed unless organic loading in the system is reduced.*

Recommendation: *Further work is required as only a selected few metal and metalloid elements were analysed; others ie. arsenic, selenium in particular, maybe important for the biota. In addition the limited number of samples per wetland probably did not fully embrace the internal variation in the systems and assumptions have been made about the representativeness of those analysed.*

Water quality

To enhance the existing water quality dataset, physiochemical properties (pH, electrical conductivity, dissolved oxygen and temperature) were remeasured at each wetland (April 2007) and samples collected for analysis of anionic and cationic ions.

Study wetlands fell within known historical ranges (taking into account the limit historical data set) for salinities, pH and dissolved oxygen. Salinities (measured as electrical conductivity) at Lake Powell were high, at one-sixth sea water, about one third to one half sea water at Manarup Lagoon and North Creek Drain, and comparatively fresh (but still brackish) at Marbellup Brook sites.

Cationic dominance of waters in the TDS are similar and show the influence of oceanic ions (dominance of Na) and leaching with a proportional decline of Ca, possibly under the influence of periodic acidification events: Na>>Mg>Ca> or =K. Previous studies taken at Lake Powell in winter and spring 1991/2 suggested that Ca is more abundant than Mg. The significance of this apparent switch is unclear at present.

Levels of lead, tin and arsenic were below detection limits for all samples. Copper was detectable in Marbellup Brook and North Creek Drain, sometimes in appreciable amounts. Cadmium was found in appreciable amounts in Lake Powell, zinc was present in all samples, as was aluminium but in elevated concentrations at one site in Manarup Lagoon. Manganese was generally present in lower concentrations but correlated with iron.

The April 2007 snapshot confirmed the water column nutrient concentrations and water quality issues within the TDS, with Lake Powell showing elevated TP and TKN, North Creek Drain elevated TKN, NOx and NH_4^+, and Marbellup Brook elevated TP. Lake Powell and Marbellup Brook were notable for their elevated chlorophyll *a* levels.

Phytoplankton

The existing dataset, produced by DoW's Phytoplankton Evaluation Unit, was considered reliable and was adequate to enable exploration of relationships between water regimes and timing of phytoplankton blooms (ie. phytoplankton population >20 000 cells/ mL). This was achieved through consideration of the timing of inlet opening and drainage control operation and occurrences of algal blooms. The wetlands of the TDS have a rich phytoplankton community, with a diverse and abundant assemblage present in all the wetlands studied. The presence of Cyanophyta blooms during the summer and autumn months and the dominance of Chlorophyta and diatom blooms during winter months may be the product of the dynamic surface water levels experienced by the wetlands of the TDS. The increase in bloom events after dramatic water level changes and the associated increase in eutrophic condition prior to these bloom events can be seen to be a product of the current management of the surface water levels within the system. Periods of surface water stagnation during the summer months (Lake Powell) and the reduction of surface water levels over summer in Marbellup Brook might all contribute to the increase of blooms over the summer and autumn periods. Blooms occurring during winter months may be attributed to increased nutrient loads entering the system, and in the case of Lake Powell the lowered water levels increasing light penetration of the water column.

The combination of these factors and the dis-connectivity of flow throughout the TDS will continue to contribute to the harmful and benign bloom events of the TDS. The slight decrease in bloom events in recent years can be attributed to improvements in the management of nutrient input into the system; however the continuation of these bloom events indicates that further research is required to fully understand the drivers behind algal bloom events within the TDS wetlands.

Recommendation: *Further investigation and research is required to determine the drivers behind algal blooms and the potential benefits of reinstating seasonality and connectivity of flow throughout the TDS.*

Vegetation

Field surveys were conducted to measure the hydrological range of selected wetland plant species and determine quantitative criteria for key ecological attributes of emergent, littoral and fringing vegetation components of the wetlands. Two to three permanent wetland vegetation transects, comprised of a series of 10 x 10 m contiguous plots and varying in length to encapsulate areas representative of all potentially groundwater dependent vegetation, were established at each wetland. Distributions of key wetland species were determined across entire transects while overstorey species health and understorey cover and abundance were assessed in each quadrat.

Lake Powell
Typha orientalis is invading Lake Powell, colonising areas of open water and out-competing and often replacing *Baumea articulata* (Bourne, 2002). Eutrophication coupled with long periods of low surface water levels is generally considered the main causes for this expansion. The resultant domination of *T. orientalis* in the littoral zone was reflected in its presence on or adjacent to all three monitoring transects. Although *B. articulata* was also recorded on the north and west transects, cover and abundances values were generally low in comparison to *T. orientalis*.

Canopy condition of the four wetland tree species, *Melaleuca rhaphiophylla, M. cuticularis, Banksia littoralis* and *Taxandria juniperiana*, was generally good condition across all transects. The exception were mature *B. littoralis* on a dune crest on the north transect which appear to have lost connection with underlying groundwater and young of the same species on the west transect in an area that has experienced recent inundation of depths or duration beyond the species' tolerance limits. Although *M. rhaphiophylla* are not common around much of Lake Powell, a dense stand persists on the south side of the wetland in the vicinity of the southern transect. These mature, healthy trees effectively occur as a monospecific stand in an area that is likely to experience inundation during periods of high water level.

A total of 36 species, including nine introduced taxa, from 17 families were identified across the transects. Although not as prevelant as *T. orientalis*, the exotic grass, *Cynodon dactylon* (water couch), was recorded in dense patches around the lake, where it often appeared to smother native species and prevent recruitment. Understorey species richness was relatively low across the monitoring transects with rush and sedge species and/ or exotics dominating most plots.

Manarup Lagoon
Manarup Lagoon has been described as being surrounded by dense, native vegetation in good condition. Monitoring results generally supported this, however as some fences on the western side of the wetland were in disrepair (although being replaced at the time) allowing stock access, there was a high degree of soil disturbance and weed invasion in the vicinity of the northern transect.

The majority of the wetland is surrounded by dense bands of native sedges, predominately *Juncus kraussii*, generally grading into shrub understorey dominated by *B. sparsa* with *M. cuticularis* forming the overstorey. However, the construction of a levee bank across the southern sector of the Lake separated the sedges from upgradient vegetation. Although *M. cuticularis* is adapted to the brackish conditions of Manarup Lagoon, *M. rhaphiophylla* was also noted further from the wetland edge. The health of wetland trees on monitoring transects was described as good. A total of 23 species, including only four introduced taxa, from 12 families were identified across two transects established during 2007 monitoring.

Marbellup Brook
A narrow band of riparian vegetation, dominated by introduced species, fringed the majority of Marbellup Brook especially in its northern reaches. However, an area of intact, healthy *M. rhaphiophylla* woodland above dense *Baumea juncea*/ *Juncus kraussii* sedgeland was recorded (and monitored) in the southern reaches of the creek.

A total of 37 species, including nine introduced taxa, from 18 families were identified across the two transects established during 2007 monitoring. The health of wetland trees on monitoring transects was described as good.

North Creek Drain
Both transects on North Creek Drain occurred in areas surrounded by various agricultural pursuits (potato farming, livestock). Given their location, the high diversity, cover and abundance of exotics, including *Rumex obtusifolius* (Blackberry), *Solanum nigra*, and *Poaceae sp*., was expected. *M. rhaphiophylla,* of moderate to good health, were dominant in the overstorey of both transects despite mildly eutrophic surface water.

A total of 16 species, including eight introduced taxa, from 11 families were identified across the two transects established during 2007 monitoring. The health of wetland trees on monitoring transects was described as good.

Ewart Swamp
The overstorey at Ewart Swamp was dominated by dense *T. juniperiana* with occassional *M. rhaphiophylla* and *B. littoralis*. The southern sector of the wetland was species poor with a dense build up of dry debris in the understorey, suggesting recent drying, possibly as a result of drainage works. Vegetation on the northern side of the wetland was denser and more species rich, but remained very dry.

Nine native species from seven families were recorded across the two monitoring transects. Wetland tree health on transects was described as good.

Recommendation: *Further monitoring and assessment is required to determine the impact of water level regulation on wetland vegetation recruitment and population maintenance of key species.*

Recommendation: *Reinstatement of wetland water regime seasonality to enhance recruitment and reduce the spread of invasive environmental weed species.*

Macroinvertebrates

The relative health or status of a wetland can be measured through the response of biota to changes in wetland function. Aquatic macroinvertebrate population and species assemblages are commonly used as indicators of change in water quality as they are influenced by colour, nutrient status, ionic composition and seasonality of a wetland.

The sampling protocol used in this study was habitat based, identified principally by vegetation structure (eg. *Baumea articulata, Melaleuca rhaphiophylla*, open water with submerged macrophytes) and described by percentage composition of bare substrate, submerged and emergent macrophytes and algal coverage. Samples were collected using baseline assessment techniques.

Total numbers of taxa recorded for each wetland were low compared to previous studies conducted at Lake Powell and Marbellup Brook. However, the current survey was conducted in autumn which is typically a time of lower diversity, especially in ephemeral wetlands, which are drying or are experiencing their absolute minimum water level, and prior surveys were conducted over winter and spring months preventing a direct comparison of datasets. Furthermore, as a result of drainage controls, hydrological regimes do not follow seasonal hydrological cycles, which may have dramatic effects on the community structure of invertebrate populations, especially seasonally driven species.

A compilation of species lists from previous and current works (Lake Powell and Marbellup Brook) provides an annual baseline assessment and a tally of all the species that have occupied the system (LP = 51; since 1992 and Marbellup Brook = 46; since 2000, Manarup Lagoon = 16 and North Creek Drain = 20). Constant alterations to water levels within the TDS wetlands through drainage control were reflected in the presence of highly mobile taxa and species adapted to both permanent and semipermanent water regimes.

Lake Powell assemblages were dominated by predators and filter collectors, typical of high levels of detritus and algae, and moderate to high nutrient enrichment. Manarup Lagoon taxa were typical of a wetland with elevated salinities exhibiting species from marine and brackish systems, with the dominant groups being predators and gathering collectors. Marbellup Brook was dominated by predators and filter collectors which were indicative of flowing water and high levels of detritus visible along the channel. North Creek Drain taxa were exclusively predacious species, indicative of flowing water and high levels of rotting vegetation. The high incidence of predatory species may be attributed to algal blooms and the top down effect following high productivity, or even a shift in water regime or quality. Further surveys are required to describe community structure and seasonal changes that occur in the NCD.

TDS wetlands exhibit varying degrees of disturbance or degradation. The influences of agricultural and urban development appear to have resulted in simplified lentic and lotic ecosystems exhibiting depauperate macroinvertebrate communities. The combination of acidity, eutrophication and salinity define the ecological character of the wetlands and the limitations placed on the fauna inhabiting them.

Recommendation: *Further surveys are required to describe community structure and seasonal changes.*

Recommendation: *Reinstatement of seasonal hydrological cycles to enhance habitat diversity, water quality and macroinvertebrate community complexity.*

Ecological values, functions/ processes and features

The ecological values, functions/ processes and features of the study wetlands were described based on the findings of the literature review, compilation of existing knowledge and field surveys. Values were initially categorised as biotic, wetland functional values and land/ waterscape values, before being further divided as follows:

- Biotic – intrinsic, biodiversity contribution, instrumental and indigenous or cultural values.
- Functional (wetland functionality or ecosystem services) – maintenance of key ecological functions and provision of water resources.
- Land/ waterscape (landscape connectivity, representativeness, habitat provision, uniqueness, ecosystem integrity and resilience) – habitat values, waterscape ecology, ecological integrity and Indigenous cultural values.

Documentation of these wetland values is not dissimilar to the emerging schemes for gauging 'ecological character' of wetlands as recognised by the Ramsar Convention on Wetlands.

Ecological features of the study wetlands were described through consideration of issues of particular relevance to management including drainage controls, water quality and sediment issues and hydrological features. A summary of key findings is presented in Table A. As values are determined by agreement, it is probably best to subject the features regarded here as 'significant' to a process of dialogue with local and regional stakeholders. The constituents in the table, therefore, are less absolute than they appear and require further investigation.

Table A: Summary of key ecological values, processes/ functions and features.

Wetland	Description of value, process/ function or feature
TORBAY DRAINAGE SYSTEM	
Value	• Supports rare/threatened mammal species: Western Ring-Tailed Possum, Water Rat, Quenda • Supports rare/threatened bird species: Red & White-Tailed Black Cockatoos, Australian Bustard • Supports rare/threatened fish species: Black Stripped Minnow • Supports frog of local conservation significance: Guenther's Froglet • Supported extant taxa: Western Trout Minnow • Fringing and emergent vegetation provides habitat & breeding areas for fauna • Wetlands are linked either naturally or through drainage modifications
Function/ process	• Assimilation or exportation of excess nutrients • Hydrological maintenance of anaerobic sediments • Processing & storage of organic carbon
Feature	• Maintenance of moist fertile soils suitable for horticulture • Surface & groundwater levels managed through series of drainage controls to meet requirements of potato farmers, fishermen & local residents • Wetlands managed to reflect different water regimes & levels
LAKE POWELL	
Value	• Supports rare/threatened bird species: Australian Bittern & White-tailed Black Cockatoo • Extensive, intact *Melaleuca rhaphiophylla* open forest in southern sector of lake • Presence of highly mobile invertebrate taxa & species adapted to both permanent & semipermanent water regimes • Supports invertebrate taxa adapted to eutrophic conditions & high pH levels • Invertebrate assemblages dominated by predators and filter collectors, typical of high levels of detritus & algae, & moderate to high nutrient enrichment • Fringing & emergent vegetation provides habitat & breeding areas for fauna • Used in studies of *Typha orientalis* • Provides opportunities for bird watching • Provides important avian breeding grounds, stop over for migratory species & refuge for waterbirds. • Provides breeding ground for bird species: Spotless Crane, Australasian Bittern & Red-necked Avocet. • Provides stop-over for migratory bird species • Important refugee for waterbirds.
Function/ process	• Shallow well-mixed water column ensures maintenance of aerobic water-sediment interface preventing mobilisation of phosphorus • Maintains surface water throughout summer, thereby ensuring maintenance anaerobic sediments preventing oxidation of pyrite & erosion of buffering capacity • Storage of carbon in saturated sediments – proposed accumulation due to anaerobic conditions ensuring production exceeds respiration • Dense fringing & emergent vegetation provide biofiltration & reduce sediment mobilisation • Submergent vegetation in channel provide biofiltration & reduce sediment mobilisation • Freshwater basin discharges to ensure seasonal freshwater flows to estuarine areas; saturated sediments prevent fire in sediments
Feature	• *Typha orientalis* invading & out competing *Baumea articulata* • Surface water levels kept artificially high in summer to maintain groundwater in adjacent farmlands. 'Excess' water drained off in winter. • High water column nutrient concentrations (NH_4^+, NO_X and PO_4^{3-} exceed ANZECC guidelines) • Experiences toxic and non-toxic algal blooms, predominately in winter months. • Overlies potential acid sulphate soils (PASS) & sediments that generally do have sufficient buffering capacity to neutralise acidification.
MANARUP LAGOON	
Value	• Supports *Ruppia* beds • Supports extensive, dense, intact bands of fringing *Juncus kraussi* • Supports long-necked turtles • Presence of highly mobile invertebrate taxa & species adapted to both permanent & semipermanent water regimes • Supports invertebrate taxa adapted to high pH and salinity levels including Polychaeta. • Invertebrate taxa typical of elevated salinities exhibiting species from marine and brackish systems, with the dominant groups being predators & gathering collectors • Fringing and emergent vegetation provides habitat & breeding areas for fauna • Ruppia beds provide primary & secondary production • Used in algal bloom studies
Function/ process	• Maintains seasonal water regime • Active detrital food web whereby organic carbon does not necessarily accumulate but respiration processes allow it to be used at the sediment/water interface • Seasonal water regime allowing for (albeit limited) tidal flushing • Dense fringing, emergent & submergent vegetation provide biofiltration & reduce sediment mobilisation • Both of the above provide for a relatively clear water column • Flood mitigation • Proposed Groundwater recharge zone
Feature	• Surface water maintained at low levels from October to March to act as compensation basin. • High water column nutrient concentrations (NH_4^+, NO_X and PO_4^{3-} exceed ANZECC guidelines)

	• Depleted dissolved Oxygen concentrations in water column • Experiences toxic and non-toxic algal blooms in summer/ autumn • Overlies PASS & sediments generally do have sufficient buffering capacity to neutralise acidification.
EWART SWAMP	
Value	• Southern sector of wetland supports dense stands of *Taxandria juniperiana* & sparse *B. articulata* • Northern sector supports low density *M. rhaphiophylla* & *Banksia littoralis* • Fringing vegetation provides habitat for fauna
Function/ process	• Current drained status maybe ensuring that applied and accumulated nutrients are not mobilised by saturation/inundation. • Past conditions ensure maintenance of anaerobic sediments preventing oxidation of pyrite & preventing further erosion of buffering capacity. Current conditions (drained and burnt) prevent rehydration thereby preventing permanent & widespread acidification. • Storage of organic carbon in saturated sediments (may have ceased due to current drainage) • Fringing vegetation reduces sediment mobilisation beyond wetland bed • Proposed groundwater recharge zone
Feature	• Drains into Manarup Lagoon via North Creek Drain • No surface water recorded in recent years • Overlies PASS & sediments do not have sufficient buffering capacity to neutralise acidification.
MARBELLUP BROOK	
Value	• Southern reaches of creek support area of dense, intact *M. rhaphiophylla* woodland over very dense mixed sedgeland • Supports remnant *Eucalyptus diversicolour* (Karri) • Supports macroinvertebrate assemblage adapted to wide range of salinities • Invertebrate taxa dominated by predators & filter collectors indicative of flowing water & high levels of detritus • Fringing & emergent vegetation provides habitat & breeding areas for fauna • Fringing & emergent vegetation provide biofiltration & reduce sediment mobilisation.
Function/ process	• Maintains surface water throughout summer
Feature	• 'Plug' opened in summer to allow limited stream flow, closed in winter. • High water column nutrient concentrations (NH_4^+, NO_X and PO_4^{3-} exceed ANZECC guidelines) • Depleted dissolved Oxygen concentrations in water column • Overlies PASS and sediments do have sufficient buffering capacity to neutralise acidification.
NORTH CREEK DRAIN	
Value	• Supports areas of fringing, mature *M. rhaphiophylla* & *M. cuticularis* • Supports remnant *Eucalyptus diversicolor* (Karri) • Supports limited fringing sedgelands • Supports invertebrate species tolerant of a range of salinities, pH & organic pollutants. • Invertebrate taxa exclusively predacious species, indicative of flowing water & high levels of rotting vegetation • Fringing & emergent vegetation provides habitat & breeding areas for fauna
Function/ process	• Sediments have some buffering capacity to neutralise acidification from proposed potential acid sulphate soils • Flow & detrital processes ensure no local build up of organic carbon • Sparse fringing & emergent vegetation provide some biofiltration & reduce sediment mobilisation • Flood mitigation
Feature	• Receives inflow from Ewart Swamp & low lying farmland • High water column nutrient concentrations (NH_4^+ and PO_4^{3-} exceed ANZECC guidelines) • Depleted dissolved Oxygen concentrations in water column • Overlies PASS & sediments do have sufficient buffering capacity to neutralise acidification.

Recommendation: *Initiate a process of dialogue with local and regional stakeholders and develop an agreed set of values for the TDS.*

Level of Groundwater Dependence and Risk to Ecological Values from Water Regime Change

A qualitative assessment of the dependence of previously defined ecological values, functions and features of each study wetland on groundwater levels or surface water flows were determined and the potential impacts and/ or changes to these from changes in water regime under varying management scenarios were described.

Degree of flow or water level dependency

The study followed the approach applied by Braimbridge and Malseed (2007) and identified hydrology-ecology linkages, that is, the influence on, or relationship between, different water regime components and the ecology of an ecosystem. Hydrology-ecology linkages addressed management objectives based on values, functions and features and, for each, a relevant level/ flow consideration was defined to allow assessment of water regime modifications. A summary of the hydrology-ecology linkages is presented in Table B.

Table B: Summary of values, processes and features and associated hydrology-ecology linkages.

Value/ process/ feature	Hydrology-ecology linkage
TORBAY DRAINAGE SYSTEM	
Biodiversity	
- water birds and waders	Permanent surface water with seasonal fluctuation to provide seasonal variation in depths & shoreline
- macroinvertebrates	Emergent macrophyte habitat inundated & available for a range of macroinvertebrate species
- fish	Shallow macrophyte habitat inundated & available for small bodied fish species
- frogs	Permanent surface water with seasonal fluctuation
- reptiles	Permanent surface water with seasonal fluctuation to provide frog habitat
- vegetation	a) Seasonal inundation of sedgelands b) Seasonal waterlogging of lowlands & occasional inundation of all fringing vegetation
Connectivity	
- drainage linkage	Increase seasonal connectivity between wetlands and drainage channels
LAKE POWELL	
Biodiversity	
- water birds and waders	Permanent surface water with seasonal fluctuation to provide seasonal variation in depths & shoreline
- macroinvertebrates	Emergent macrophyte habitat inundated & available for a range of macroinvertebrate species
- frogs	Permanent surface water with seasonal fluctuation
- vegetation	a, b & d) Seasonal waterlogging of lowlands and occasional inundation of all fringing vegetation c) Return to seasonal water regime to improve water quality & reduce impacts during summer inundation
- recreation	Return to seasonal water regime and sufficient water for recreational usage & elimination on of harmful algal blooms
Key processes	
- nutrient cycling	a) Sufficient water exchange during dry periods to ensure DO levels do not reduce to anoxia b) Return to seasonal water regime
- soil biogeochemistry	Sufficient seasonal water exchange to maintain processes & prevent sediment oxidisation and erosion
- ecological processes	Sufficient seasonal water exchange to maintain processes & prevent sediment oxidisation and erosion
Water quality	Sufficient water exchange during dry periods to ensure DO levels do not reduce to anoxia
- biofiltration	a) Seasonal waterlogging of lowlands & occasional inundation of all fringing vegetation b) Sufficient seasonal water levels to maintain submerged vegetation
- sediment immobilization	Sufficient water levels to prevent mobilisation via wind action
Water resource	
- freshwater to estuary	Sufficient seasonal water levels in 5 and 7 Mile Creeks
Uniqueness	
- fauna use	Permanent surface water with seasonal fluctuation to provide seasonal variation in depths and shoreline
Habitat value	
- sanctuary	Permanent surface water with seasonal fluctuation to provide seasonal variation in depths & shoreline
MANARUP LAGOON	
Biodiversity	
- water birds and waders	Permanent surface water with seasonal fluctuation to provide seasonal variation in depths & shoreline
- macroinvertebrates	Submerged and emergent macrophyte habitat inundated & available for a range of macroinvertebrate species
- frogs	Permanent surface water with seasonal fluctuation
- reptiles	Near permanent surface water available for long-necked turtles
- vegetation	a) Seasonal inundation of sedgelands b) Seasonal waterlogging of lowlands and occasional inundation of all fringing vegetation
Key processes	
- soil biogeochemistry	Sufficient seasonal water exchange to maintain processes & prevent sediment oxidisation & erosion
- ecological processes	Sufficient seasonal water exchange to maintain processes & prevent sediment oxidisation & erosion
Water quality	
- tidal flushing	Seasonal water regime allowing for tidal flushing
- sediment immobilization	a) Sufficient water levels to meet vegetation requirements b) Sufficient water levels to prevent mobilisation via wind action
- biofiltration	a) Seasonal inundation of sedgelands b) Seasonal waterlogging of lowlands & occasional inundation of all fringing vegetation
Water resource	
- flood mitigation	Surface water levels sufficient to allow flood mitigation

- groundwater recharge	Surface water levels sufficient to allow groundwater recharge
EWART SWAMP	
Biodiversity	
- vegetation	Higher groundwater levels required to meet requirements of fringing vegetation
Key processes	
- nutrient cycling	Water level sufficient to support remediation (TBA)
- soil biogeochemistry	Water level sufficient to support remediation (TBA)
- ecological processes	Water level sufficient to revegetate wetland basin
Water quality	Sufficient water levels to support remediation
- sediment immobilization	Water level sufficient to revegetate wetland basin
Water resource	
- groundwater recharge	Surface water levels sufficient to allow groundwater recharge
MARBELLUP BROOK	
Biodiversity	
- macroinvertebrates	Emergent macrophyte habitat inundated & available for a range of macroinvertebrate species
- vegetation	Seasonal inundation of lower riparian terrace
Key processes	
- soil biogeochemistry	Sufficient seasonal water exchange to maintain processes & prevent sediment oxidisation & erosion
- ecological processes	Sufficient seasonal water exchange to maintain processes & prevent sediment oxidisation
Water quality	a) Sufficient flows to ensure DO levels do not reduce to anoxia & reduce stratification b) Occasional high level flows to scour sediment
- sediment immobilization	Seasonal waterlogging of lowlands & occasional inundation of all fringing vegetation
- biofiltration	Seasonal waterlogging of lowlands & occasional inundation of all fringing vegetation
NORTH CREEK DRAIN	
Biodiversity	
- macroinvertebrates	Emergent macrophyte habitat inundated & available for a range of macroinvertebrate species
- vegetation	Seasonal inundation of lower riparian terrace
Key processes	
- soil biogeochemistry	Sufficient seasonal water exchange to maintain processes & prevent sediment oxidisation & erosion
- ecological processes	Sufficient seasonal water exchange to maintain processes & prevent sediment oxidisation
Water quality	a) Sufficient flows to ensure DO levels do not reduce to anoxia & reduce stratification b) Occasional high level flows to scour sediment c) Flows sufficient to prevent further salt water intrusion
- sediment immobilization	a) Seasonal waterlogging of lowlands & occasional inundation of all fringing vegetation b) Permanent flows to prevent sedimentation
- biofiltration	Seasonal waterlogging of lowlands & occasional inundation of all fringing vegetation

Risk to ecological values from water regime change

A number of alternate management scenarios have been suggested for the TDS. Preliminary comment was made on possible changes in ecological values of study wetlands under each scenario and potential changes to values under general water regime change.

The following potential benefits of opening floodgates were adopted from the literature:

- Improved fish passage and habitat
- Better water quality
- Reduced acidity, iron and aluminium
- Higher dissolved oxygen levels
- Less monosulfidic black ooze
- Fewer nutrients and algal blooms
- Healthier drain bottom sediments
- Improved weed control in drains
- Enhanced wetlands

However, the risks of opening floodgates included a re-instigation of tidal flows and tidal surges and areal flooding under certain circumstances, increased salt levels in some parts, as well as saline water overtopping, and lateral salt seepage. These are of course in addition to the impacts associated with flushing stored materials into estuaries and near shore areas.

The following potential benefits associated with detaining water in drains derived from the literature match these risks: it reduces acid export, increases grazing productivity of backswamps, some wetland values are enhanced, reduces fire risk, gives less export of 'black' water, and reduces impacts of invasive species. Risks of retaining water in drains in someways match potential benefits of opening floodgates: an impeded fish passage, the reformation and oxidation of surface sulfides, and the accumulation of acidity in surface soils.

This framework is useful for considering the benefits and risks to ecological values associated with any water regime change in the TDS.

Removal of the Bridge 45 penstocks and the Marbellup Plug and relocation of the drainage control to the mouth of Lake Powell would increase flow in Marbellup Brook and return the system to a more seasonal water regime. Increased seasonal flows should allow periodic inundation of lowlands and fringing vegetation, improve seasonal water exchange, and ensure DO levels do not reduce to anoxia, with occasional high flows scouring sediment, and mobilise organic and nutrient rich sediment from the channel. In general, ecological values should improve under this management scenario.

The construction of the levee banks around Lake Powell would synchronise the high water level system (Marbellup Brook/Torbay Inlet) with the mid water level system (Grasmere Drain/Lake Powell) and both systems would operate at a common water level simplifying management operation and predictable improvement in Lake Powell, but it is expected that the flow and volume of water in Marbellup Creek Drain would not be improved. Benefits would be the maintenance of a higher water level than currently experienced in Lake Powell and possible reductions in algal bloom.

Connection of Lake Powell to the Low Level system by construction of a channel may improve water quality in Lake Powell if it allows the system to return to a seasonal regime. That is, if excess waters usually drained artificially from the lake in winter are allowed to flow through the system and drain naturally into the low level system. The increased seasonal flow may also be of benefit to North Creek Drain (increased flushing) and Manarup Lagoon (increased depth, although the Lagoon may be negatively affected by increased sediment input and nutrient flow from the Lake and Creek). However, if surface water is still artificially maintained in Lake Powell over summer, algal blooms and other associated water quality issues would remain unaddressed.

The diversion of flow from the North Creek Drain to the Torbay Inlet through disconnection of the siphon and installation of flow controls at the Grasmere-Elleker Road Bridge over North Creek will increase seasonal flows in the Marbellup Brook high level drain where the new flow controls are open. When the controls are shut, water will be retained in North Creek. Flows into Manarup Lagoon will be reduced regardless. While increased flows may improve water quality in lower parts of the Marbellup Brook and the retention of water in North Creek may also be beneficial, the drying of Manarup Lagoon will result in declines in ecological values through exposure of ASS, and reduction in the diversity and extent of aquatic habitats.

Various locations in the Marbellup Brook are lower than the position of the pipe within the earthen bank i.e. the “Marbellup Plug”. Since high concentrations of soluble phosphate are released at the depressions that are subject to periodic anoxia, the Marbellup Brook could be filled in to remove deep depressions. Possible benefits include the reduction in soluble phosphate and the reduced chance of PASS in the deeper parts of the channel coming into contact with air.

The breaking of the sand bar affects system water levels and thus the water regime of the entire drainage system. It has been argued that having only sporadic opening of the sand bar prevents management authorities from reducing algal blooms and improving water quality through management of the water regime, water volume and flow rate. A risk associated with this is changing the mounding of groundwater below the TDS which relies on the ponding of water within the TDS, thus adequate volumetric capacity would be required to maintain existing groundwater regimes. In addition, maintaining an open estuary mouth could induce a change in water regime, the intrusion of saline waters throughout the lower TDS, and the resulting shift in the existing ecology of the TDS. A clear benefit would be that it would reduce management requirements and maintenance of the drainage controls.

The removal of all drainage controls, over a period of time, would return the entire TDS to a similar water regime to that which operated prior to the 1950’s. This has not been suggested in previous work as the task is complicated and extensive. In addition further study of TDS ecological interactions, TDS volumetric capacity and an accurate water balance would need to be achieved before preliminary modelling could begin. It is envisaged that these changes would severely alter the current water regime and would require staged implementation. Benefits would possibly include improvements to water quality, algal bloom frequency, nutrient cycling and TDS maintenance. The removal of all drainage controls at this junction may not be possible as a result of current social and economic constraints.

Recommendation: *Preliminary modelling of TDS hydrology be conducted to ascertain the hydrological and ecological response to a staged removal of drainage controls.*

Ecological Water Requirements

The water requirements of the previously described ecology-hydrology linkages and thus the ecological values, processes and features of the study wetlands were described in terms of water regime component, season and/ or timing and finally as a stage height, surface water or groundwater level. This was achieved through consideration of available wetland bathymetry and field measurements of habitat ranges, which enabled the identification of hydrological conditions that will meet each requirement. In instances where one or more value, process of feature at the same wetland share an ecology-hydrology linkage, water requirements were considered overarching.

Recommendations: *The EWRs listed here represent the water regimes required to maintain or enhance existing ecological values and as such may not be sympathetic to current drainage management objectives, which should be addressed by the EWP process.*

Although six hydrology-ecology linkages were identified for Lake Powell, all can be addressed through the following three overarching water requirements:

1. Annual summer/ autumn minimum of 0.3 mAHD
2. Annual winter/ spring maximum of 0.8 mAHD
3. Winter/ spring maximum of 1.2 mAHD 1 year in 5.

The six hydrology-ecology linkages identified for Manarup Lagoon can be addressed through the following three overarching water requirements:

1. Annual summer/ autumn minimum of -0.1 mAHD
2. Annual winter/ spring maximum of 0.6 mAHD
3. Winter/ spring maximum of 1.2 mAHD 1 year in 5.

It must be noted that meeting recommended winter maximum water levels will breach the current management criteria levels required to maintain Manaraup Lagoon's flood mitigation role.

Two management scenarios were postulated for Ewart Swamp. To address a maintenance scenario current water levels and drainage management are sufficient. This equates to the following depths measured in the centre of the wetland:

1. Annual summer/ autumn minimum of -0.95 m
2. Annual winter/ spring maximum of 0.28 m (with drainage controls removing surface flows and higher groundwater levels).

An enhancement scenario and associated hydrology-ecology linkages can be addressed through the following three overarching water levels measured in the centre of the wetland:

1. Annual summer/ autumn minimum of 0.0 m
2. Annual winter/ spring maximum of 0.2 m (with reduction in usage of drainage controls)
3. Winter/ spring maximum of 0.3 m 1 year in 5.

Although seven hydrology-ecology linkages were identified for Marbellup Brook, all can be addressed through the following three overarching water requirements:

1. Annual summer/ autumn minimum of 0.4 mAHD
2. Annual winter/ spring maximum of 1.5 mAHD
3. Winter/ spring maximum of 2.0 mAHD 1 year in 5.

The seven hydrology-ecology linkages identified for North Creek Drain are addressed through the following three overarching water requirements:

1. Annual summer/ autumn minimum of 0.10 mAHD
2. Annual winter/ spring maximum of 0.45 mAHD
3. Winter/ spring maximum of >0.45 mAHD 1 year in 5.