# LAKE WARDEN WETLAND SYSTEM: SURFACE HYDROLOGY REVIEW

## Lake Warden Natural Diversity Recovery Catchment

*Prepared for*

## Department of Parks and Wildlife

Esperance District and Science & Conservation Branch

15 April 2015

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## 1. Background: hydrology

The Lake Warden catchment, which effectively drains south, is approximately 212 000ha in size (See Figure 1). 75% if this area has been cleared of remnant vegetation (and 85% of native vegetation) for 148 000ha of crop land and other human use.

Due to geological formations north of the LWWS, it was established that the hydrology of large portions of the landscape were relatively unresponsive to revegetation. Thus, targeted revegetation of the upper catchment, although having a direct impact on the immediate area and downstream environment, did not benefit the greater LWWS. This information was utilised to establish priority zones based on the responsiveness of the landscape to target revegetation prioritisation. The priority zones were re-evaluated and adapted in 2012 to include the strategic importance of Lake Warden's direct catchment. The current priority zones are displayed in Figure 2.

The Lake Warden Wetland System (LWWS) was listed as a Ramsar listed wetland of international importance on 7 January 1990. Importance of the system includes:

- Biological values
  - migratory waterbirds & macro-corridor linkages
- Water quality ecosystem functions
- Infrastructure protection values
  - buffer for flood events
- Production values
  - salt mining on Pink Lake (not currently in operation)
- Indigenous and European heritage
- Recreational and tourism values
  - walk trails; water trails; bird watching; fishing
  - water sports (e.g. swimming, kayaking, skiing, etc.) & other sport (e.g. golf, cycling, jogging, etc.)
- Educational values
  - interpretative trails & student curriculum package
- Aesthetic landscape values

The system has been described in great detail in a variety of publications ((Hydroconcept 2014), (Maunsell-Aecom 2008), (Watkins 2009) etc.). As understanding of the system grew, the need to change the hydrology descriptions arose. A summary of the current understanding of the hydrology of the system is explained in more detail in this document.

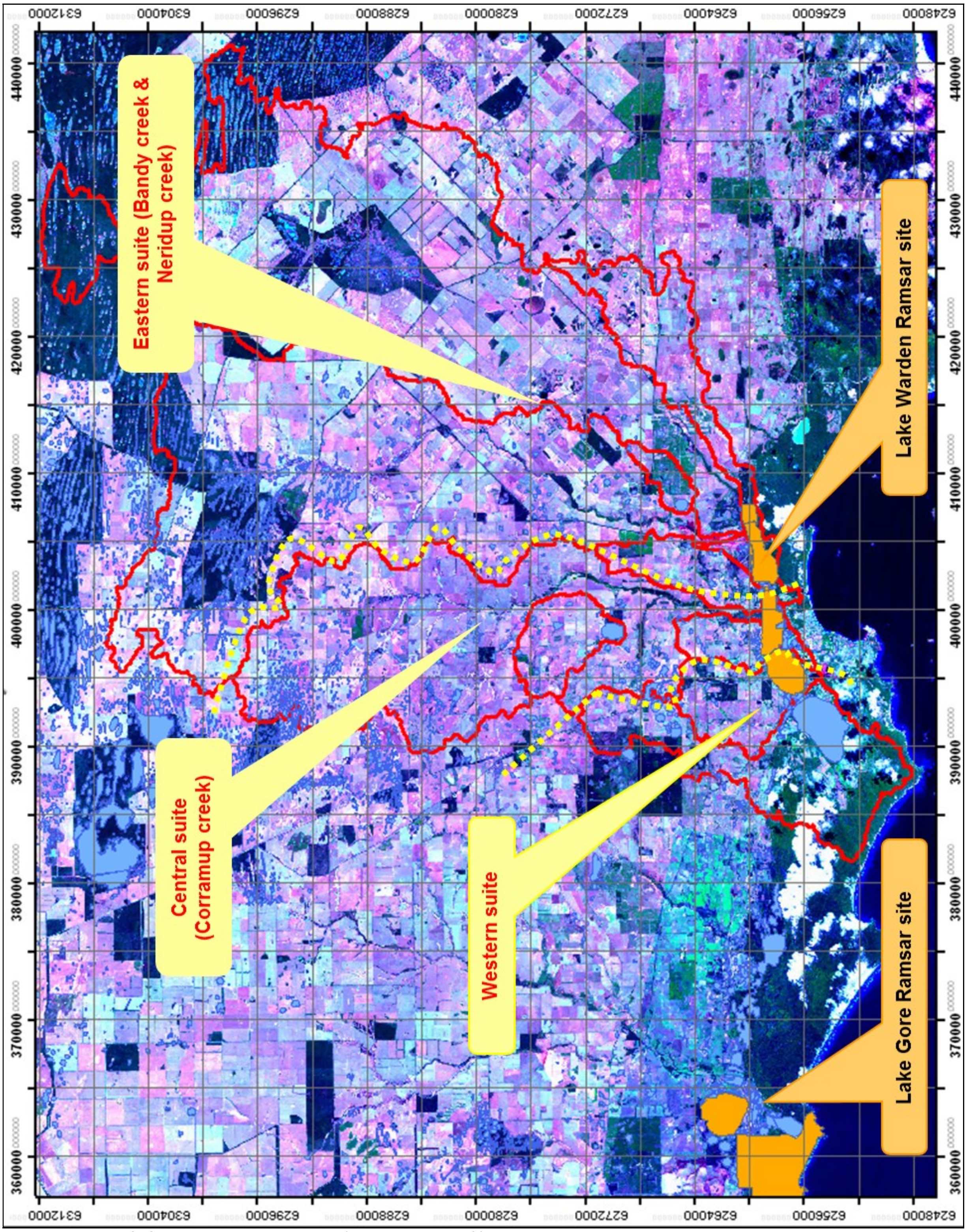


Figure 1. LWWS Catchment Boundaries. (North on the left)

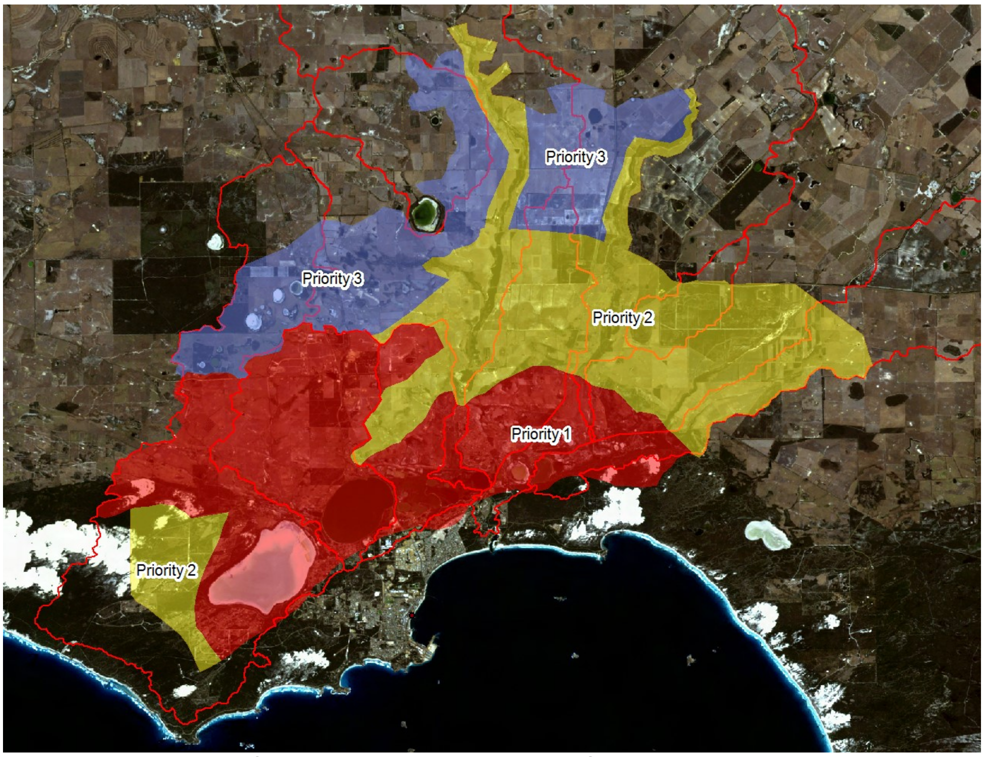

Figure 2. Priority zones for revegetation within the LWWS

## 2. Overall characterisation: hydrological suites

The lake system is located approximately 5km north of the centre of the town of Esperance, but the township itself has systematically developed around the lakes, resulting in a variety of impacts (direct and indirect).

The Lake Warden Wetland System is comprised of eight major named lakes and around 90 satellite lakes. Not all of the LWWS falls within the Ramsar boundaries. Some of the system falls on freehold land and UCL. A current mining lease on Pink Lake is also in effect.

The LWWS can be divided hydrologically into three zones described in more detail in Sections 2.1-2.3. Hydrological barriers between these are extenuated by infrastructure development, in particular Fisheries Road, Coolgardie Highway, Southcoast Highway and the railway line.

Groundwater flow is predominantly east to west and north to south, with the majority of lakes acting as flowthrough systems, but some (like Pink Lake and possibly now Lake Warden) acting as terminal lakes. However, water movement through the deeper aquifers is slow, and unlike previously described in literature (Marimuthu 2005) & (Maunsell-Aecom 2008), the contribution of these to the system are not very great and possibly ignorable with regards to quantity. Studies were underway to quantify the geochemical influence of groundwater contributions to the Western Suite, but not completed. This included the establishment of a new series of bore around Lake Warden and Pink Lake (upstream and downstream of the system).

Secondary salinity (and nutrient enrichment) at Lake Warden remains a major concern. This aspect is described and discussed in more detail in Section 3.

### *2.1 The Eastern Suite,*

The flowpaths of the Eastern suite are indicated in Figure 3-4. The Eastern Suite is fed by Neridup and Bandy Creek catchments (Figure 1). The suite consists of Lakes Ewans, Mullet, Station and various unnamed satellite lakes. Neridup Creek and Bandy Creek join up within a complex of lakes east of Ewans Lake.

All previous literature based on stable isotope tests reported that Bandy creek discharges into Station Lake whilst bypassing Ewans and Mullet Lakes. This is incorrect, as there is a well-defined channel from Bandy creek to Ewans Lake and through to Station Lake. Possible hypothesis for this mistake include:

- Sampling occurred during flooded conditions whilst the entire floodplain was under water, resulting in the main body of water flowing north of Ewans and Mullet Lakes and thus byspassing the system.
- The original flowpath of Bandy creek was through the area now known as Myrup flying estate. Bandy creek was later diverted to flow into Ewans Lake.
- The sampling point at Ewans Lake was located on the southern side of the lake, whilst the flow channel (Bandy Creek) and overflow of the lake is on the northern side. Flow occurred through the northern side of the lake without significant mixing of water from the south side of the lake.
- A combination of the above listed factors.

In turn, Ewans Lake discharges through a floodplain system to Station Lake. Station Lake discharges through Bandy Creek into Bandy Creek harbour and on into the southern ocean.

Mullet Lake is a terminal lake with a minor flowthrough component that receives water from Ewans Lake if the water level is Ewans Lake exceeds certain threshold values.

Previously, Bandy Creek weir downstream of Station Lake had a damming effect on the Eastern suite, preventing free drainage to the ocean. As a result, water from Station Lake sometimes entered Lake Wheatfield during flooding conditions. The original Bandy Creek weir washed away in the floods of 2007 (Figures 8-9). Figure 5 indicates old Bandy creek weir before the 2007 flood, and Figure 6 during the flood (after being washed away).

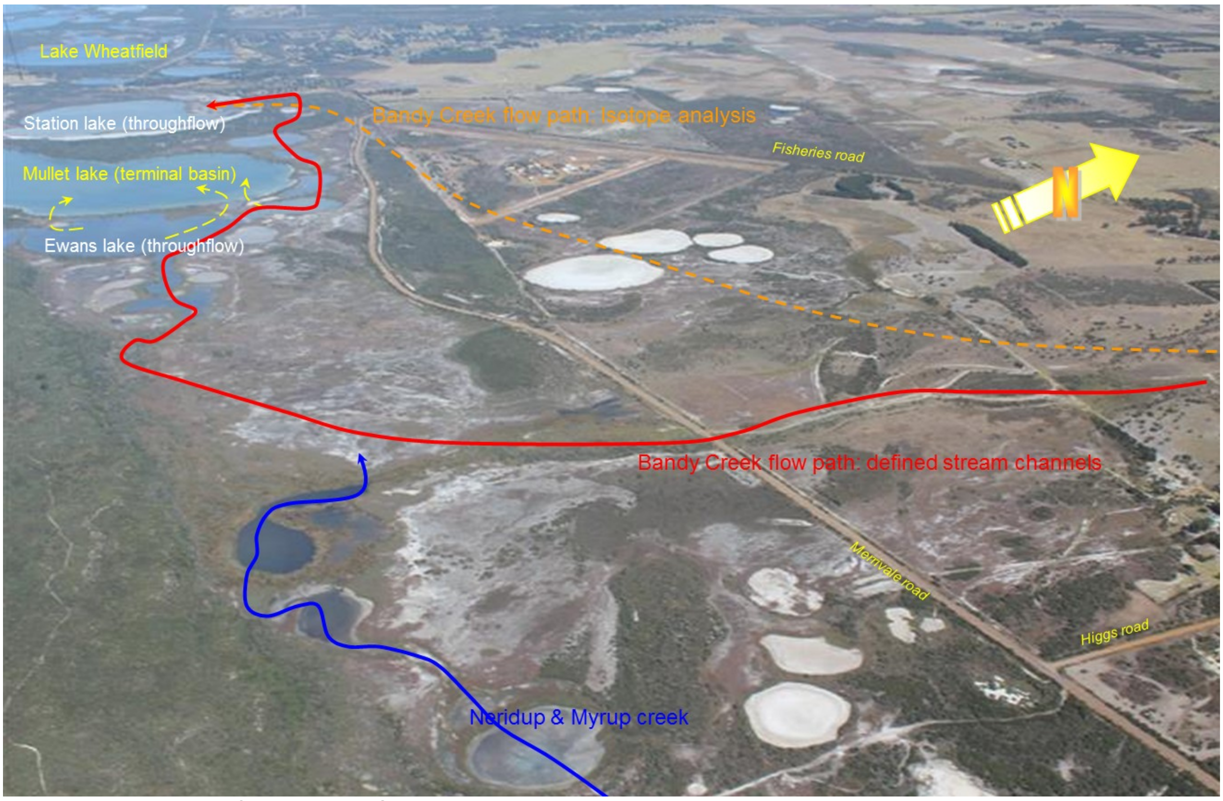

Figure 3. Flow paths of the Eastern Suite, as seen looking west-north-west.

A new weir was completed in 2010 (Figure 7). Apart from being designed to withstand a much greater flood capacity of >80m³/s (pers. Comms. DOT), it featured 40 open pipes that allowed tidal effect to move through the weir >50% of the time, whilst eliminating the previously experienced damming situation. As a result, the Eastern Suite now drains freely to the Southern ocean, without impacting or affecting the Central Suite.

All the lakes are naturally saline and alkaline, with pH values of 7.5~8.8 in winter and 8~10 in summer when algae activity is much higher. Salinity values vary from brackish (≈5g/l) during flooded conditions to hypersaline (>170g/l) when lake levels are low (e.g. end of summer).

Ewans Lake is the only lake that can be classed as perennial, being constantly supplied by Bandy Creek. Station Lake normally dries up in summer. Mullet Lake may or may not dry up, depending on summer rainfall and flooding events.

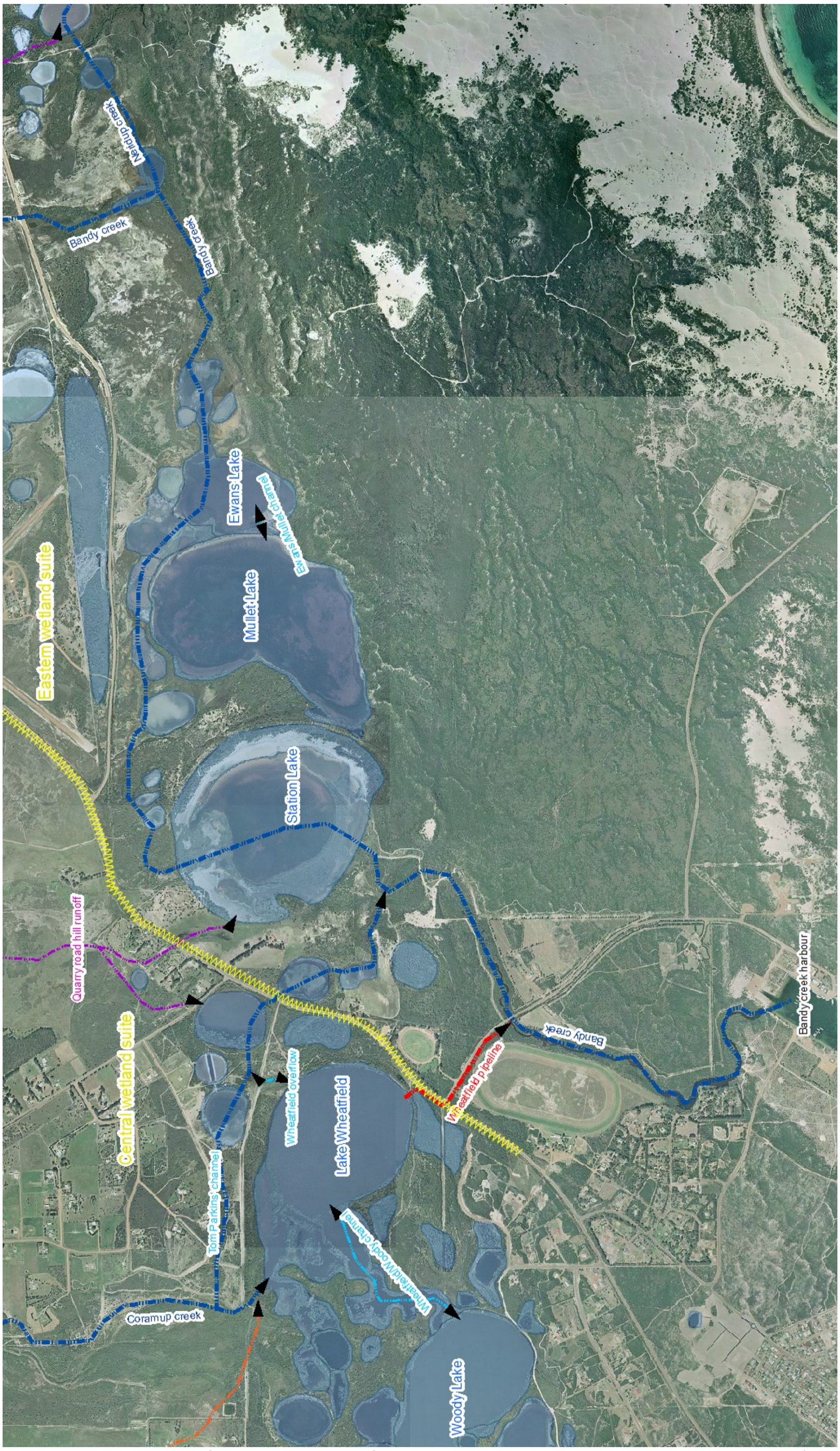


Figure 4. Flow paths of the Eastern and Central suite where they interact and converge. (North on the left)

Figure 5. Bandy Creek weir before 2007 flood (Photo by Tilo Massenbauer).

Figure 6. Bandy Creek weir during 2007 flood (Photo by Tilo Massenbauer).

Figure 7. Current Bandy Creek weir.

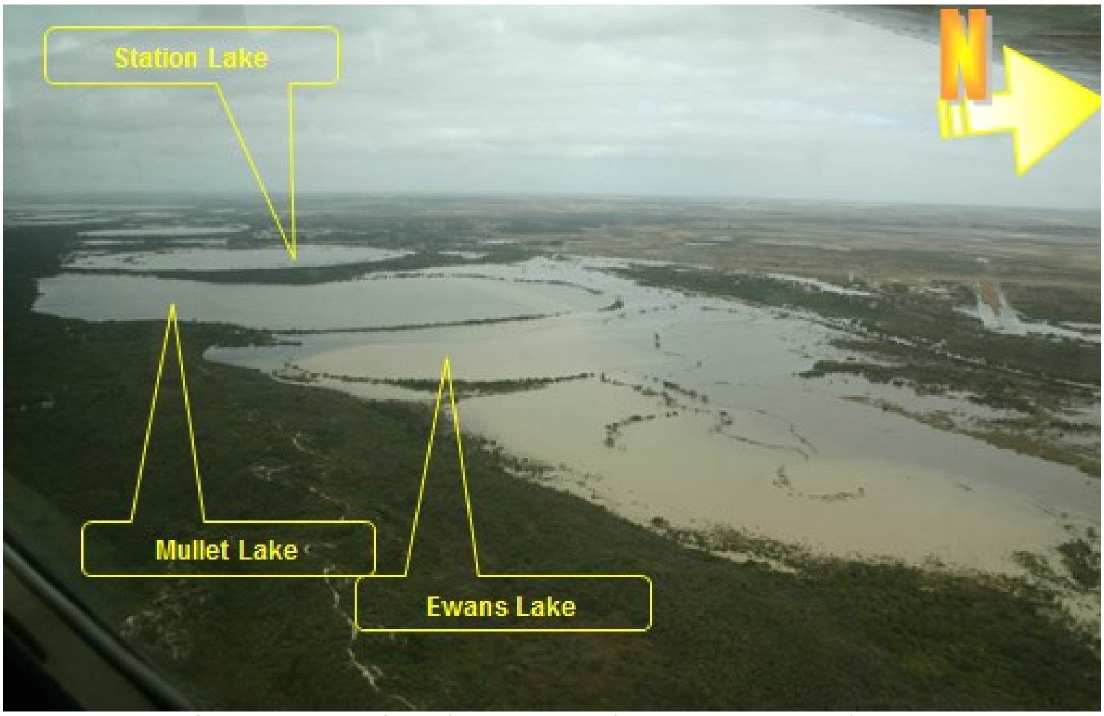


Figure 8. Eastern Suite during 2007 flood  (Photo adapted from Tilo Massenbauer).

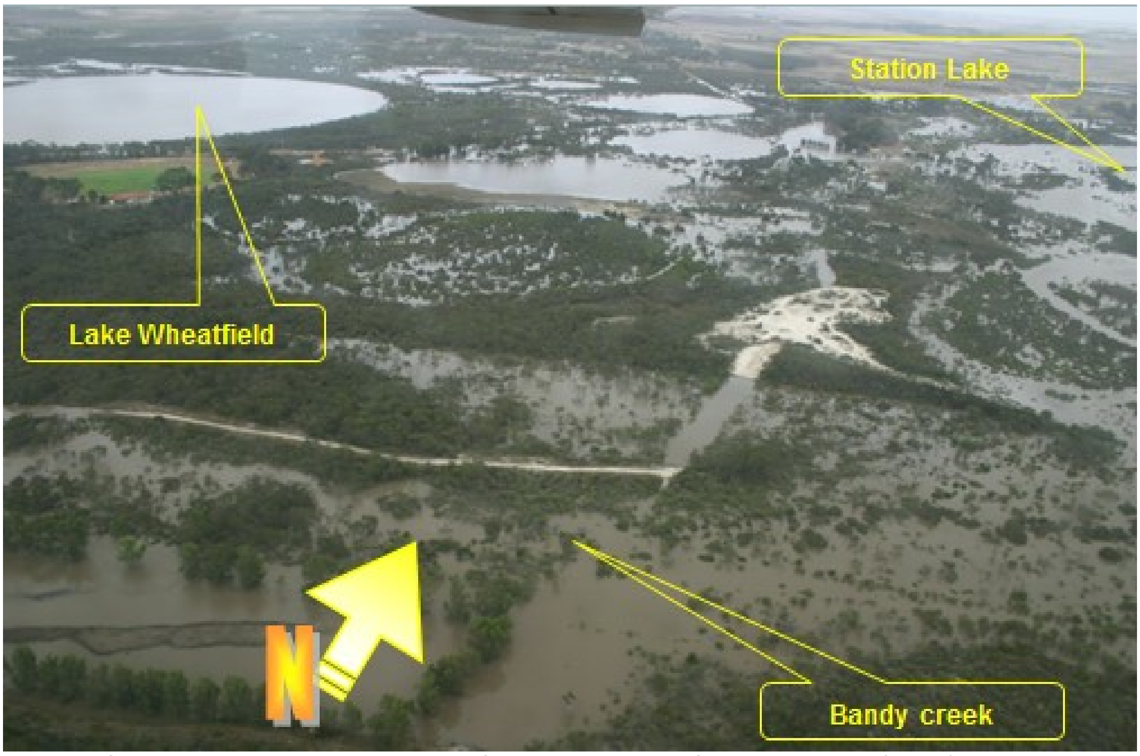


Figure 9. Sattalite lakes and linkage between Central and Eastern Suite during 2007 flood (Photo adapted from Tilo Massenbauer).

## *2.2 The Central Suite*

Flowpaths of the Central Suite are indicated in Figures 4, 10 & 16. The Central suite consists of Lakes Wheatfield, Woody, Windabout and various satellites. It is fed by the Coramup Creek catchment (Figure 1). Coramup Creek flows through a floodplain system north of the lakes into Lake Wheatfield. An artificial canal (Parkins channel) diverts some water from Coramup Creek into a series of playa lakes through to Station Lake in the Eastern Suite. Once the water has entered into Lake Wheatfield, it cannot naturally exit the system to the east or south unless the system is in flood.

Lake Wheatfield connects to Woody Lake and Lake Windabout to the west though a series of flowthrough lakes. A gravity pipeline, installed in 2009, allows water to be discharged from Lake Wheatfield for control of the water levels within the Central Suite. If the water depth in Lake Windabout exceeds a threshold of $\approx$1.8m, water will flow to Lake Warden in the Western Suite through the culverts underneath the Coolgardie highway.

The hydrology of the Coramup Creek Floodplain to the north of the lakes have been altered significantly through diversions, drainage and erosional incising as a result of large floods experienced between 1997 and 2009 (Figures 11 & 12).

Figure 10. Flow paths of the Central Suite, as seen looking north.

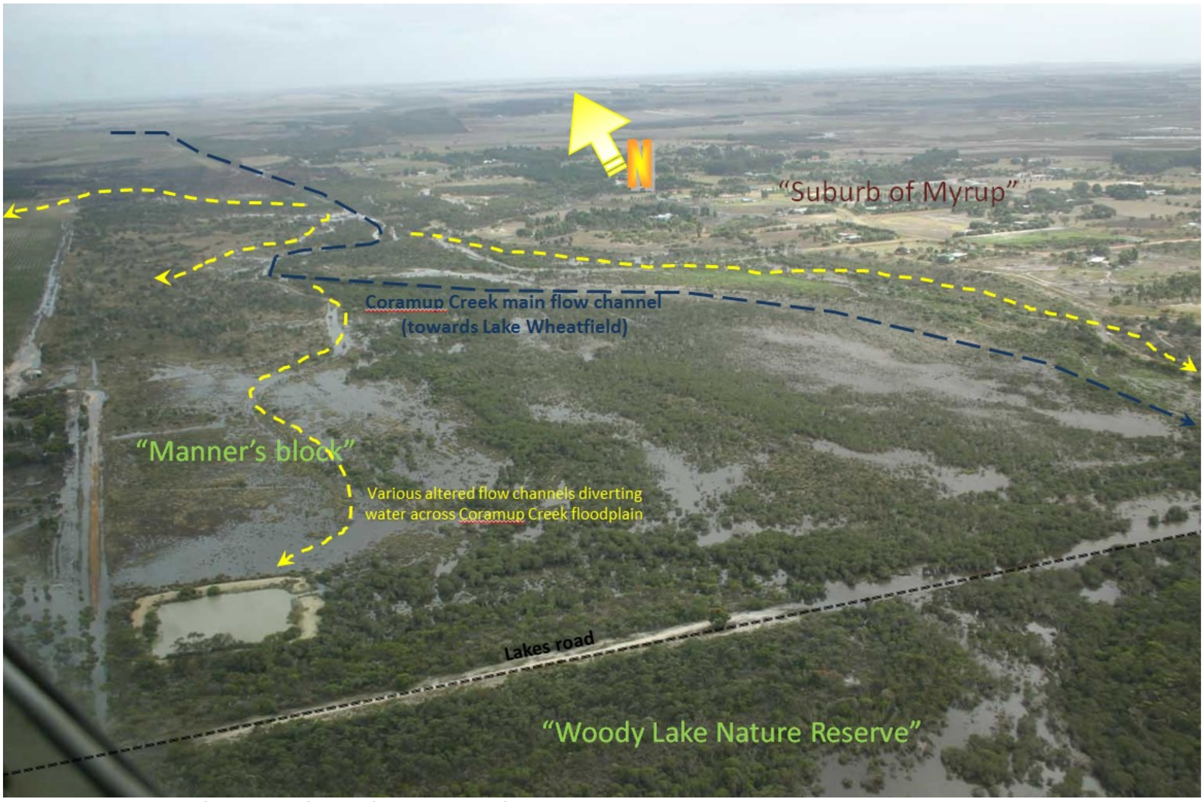

Figure 11. Coramup Creek floodplain in flood


Figure 12. Coramup Creek erosional incision

Although the surface water hydrology of the system is significantly altered, some of these assist with ecological management (e.g. Parkin's channel diverts some of the water from Coramup creek around Lake Wheatfield, thus reducing the need to use the Lake Wheatfield pipeline to reduce water levels within the central suite). Other activities that have improved the hydrology include the construction of several larger culverts underneath Fisheries road between Parkin's Lake and Golden Lake (Figure 13). This allows flood water flows from the Coramup Creek and Myrup floodplains to exit the system rather than flow into the Lake Wheatfield.

The Lake Wheatfield gravity pipeline was completed in 2009 and has successfully lowered the water level within the central suite and allows the maintenance of this water level as described by Maunsell (2008). Figure 14 indicates the water levels to date within the suite (before and after intervention). The 400mm PVC pipeline (location indicated in Figure 4) is approximately 850m long, has a fall 2~3.5m depending on waterlevel, and discharges into Bandy Creek just downstream of the Wylie Bay Road bridge (Figure 15).

All the major lakes within the Central Suite can be described as perennial, whilst the satellite lakes around them tend to dry up over summer (unless summer flooding persist). Salinities increase from east to west (e.g. Lake Wheatfield is the lowest and Lake Windabout the highest) and vary throughout depending on the dilution experienced as associated with an increase and decrease in lake levels. The lakes are all naturally saline, with lowest levels being recorded in Lake Wheatfield directly after high rainfall events (<3g/l) compared to normal winter values of 5~9g/l. Summer salinity at Lake Wheatfield may be as high as 22g/l. Woody Lake tends to closely follow Lake Wheatfield as a result of being almost permanently connected via a flowthrough channel that only dries up under extreme dry events.

It's normal for Lake Windabout to become cut-off from Woody Lake during summer. Possibly due to its peculiar shape, Lake Windabout also tends to display varying salinity values for the various basins within, ranging from 7g/l to 43g/l. All lakes are naturally alkaline with winter and summer values ranging 8~10.

Figure 13. Fisheries road 'flow barrier' upgrade at Lake Wheatfield.

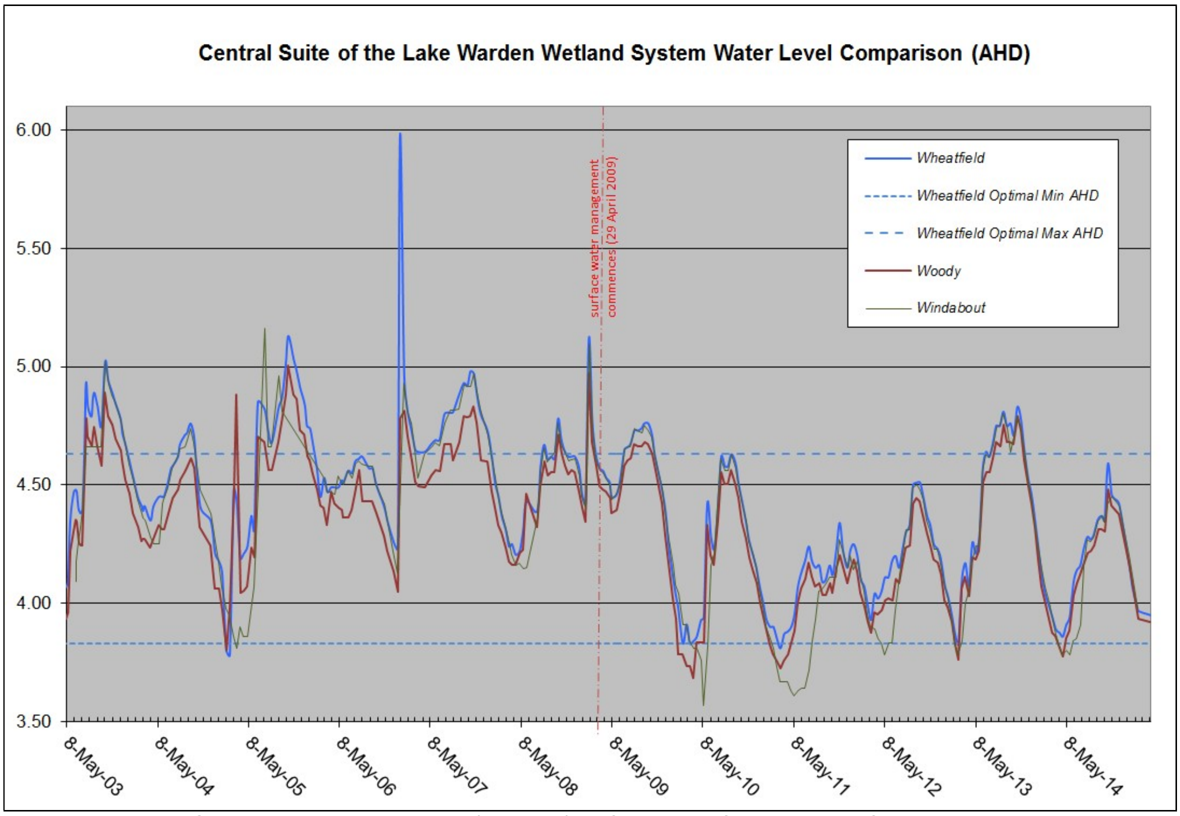


Figure 14. Central suite water levels (as AHD) before and after active surface water management commenced.

Figure 15. Lake Wheatfield pipeline discharge point in Bandy Creek.

## *2.3 The Western Suite,*

The western suite is fed by a relatively small direct catchment as well as overflow from Lake Windabout (Figures 10 & 16). Historically, Pink Lake and Lake Warden were connected through a series of flowthrough lakes. Pink Lake is the original terminal lake of the system and, with a height datum equivalent to mean seal level, there is no hydrological gradient for further flow. Presumably, the construction of the railway line north to Kalgoorlie from Esperance and thereafter the South-Coast highway, destroyed the flowpath.

Currently, Lake Warden acts as the terminal lake for the LWWS and has been for the last 50 years or more. Although previous literature indicated a potential for waterflow from Lake Warden to Lake Windabout, this is extremely unlikely, as the catchment for Lake Warden is too small and only plausible if the lake system is already in flood.

The Eastern Suite is largely free draining to the southern ocean, whilst the Central Suite can be drained artificially with the Lake Wheatfield pipeline to a certain extent. In contrast, and for all practical arrangements, the Western Suite is the sump of the system and drainage is by evaporation only. In addition, the disconnection between Lake Warden and Pink Lake has resulted in a significant increase in salt load in Lake Warden, whilst the mining of salt from Pink Lake has resulted in a significant decrease in salt load in Pink Lake. This aspect is described in more detail in Section 5.

Until such time as the hydrological surface water link between Pink Lake and Lake Warden are restored, the two lakes operate as separate terminal lakes within minimal groundwater interaction between them. The two lakes will be described separately below:

### 2.3.1. Lake Warden

Lake Warden has a direct surface water catchment of approximately 5600~6800ha (depending on how much of the catchment are considered to be free-draining or not). Figure 17 indicates the direct catchments of the Western Suite. The Lake Warden catchment is bordered by several other non-draining systems (e.g. Davies Lakes Complex and Shark Lake) that may contribute groundwater to the system. In cases of extreme flooding, these catchments may also discharge surface water to Lake Warden. Nestled between Warden and Pink Lake catchments are a series of isolated lakes between the Southcoast highway and the railway line. It is thought that these lakes formed part of the flowthrough system linking Lake Warden with Pink Lake. These lakes are probably currently only connected by groundwater to Lake Warden and Pink Lake, but apart from desktop surveys, no investigations of this hypothesis have been undertaken.

Lake Warden's salinity ranges from approximately 70g/l at a depth of $\approx$2.1m, to >400g/l at depth $\approx$0.2m. The secondary salinity currently experienced is described in more detail in Section 5 below. Several stratification surveys were undertaken under different depth scenarios, but all have proven to be negative. pH values (during stratification surveys) changed rapidly during the day as algae activity intensified, starting at $\approx$7.5 immediately after sunrise and increasing through the day and peaking just around sundown with pH>9. The lake is naturally alkaline, but when salinity exceeds 200g/l, pH tends to drops below 7.5, with lowest recorded pH$\approx$7.

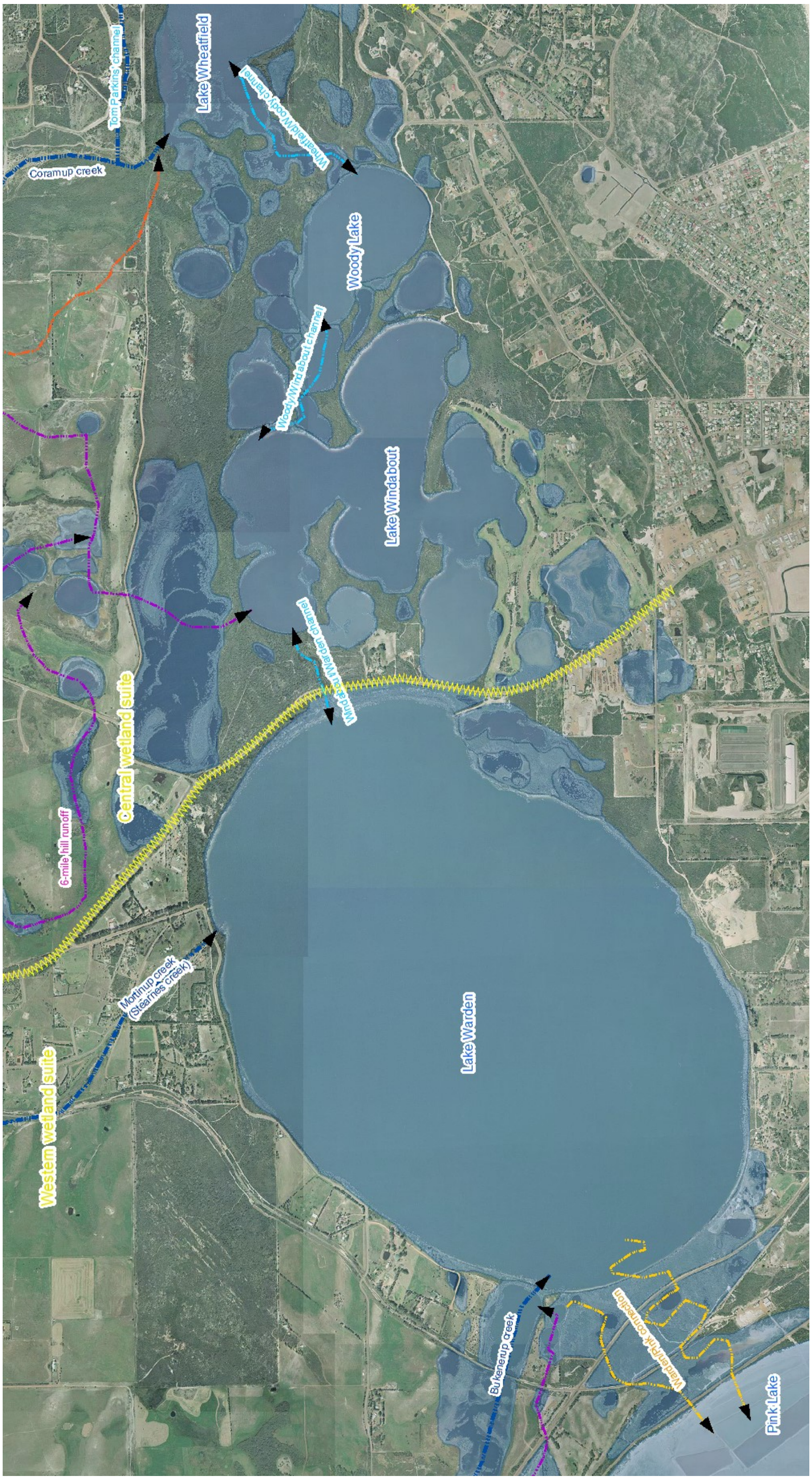
Lake Wheatfield
Tom Parkins channel
Coramup creek
Wheatfield/Woody channel
Woody Lake
Woody/Windabout channel
Lake Windabout
Windabout/Warden channel
Central wetland suite
6-mile hill runoff
Mortinup creek
(Stearnes creek)
Western wetland suite
Lake Warden
Bukenerup creek
Warden/Pink connection
Pink Lake

Figure 16. Flow paths of the Western and Central suite where they interact and converge. (North on the left).

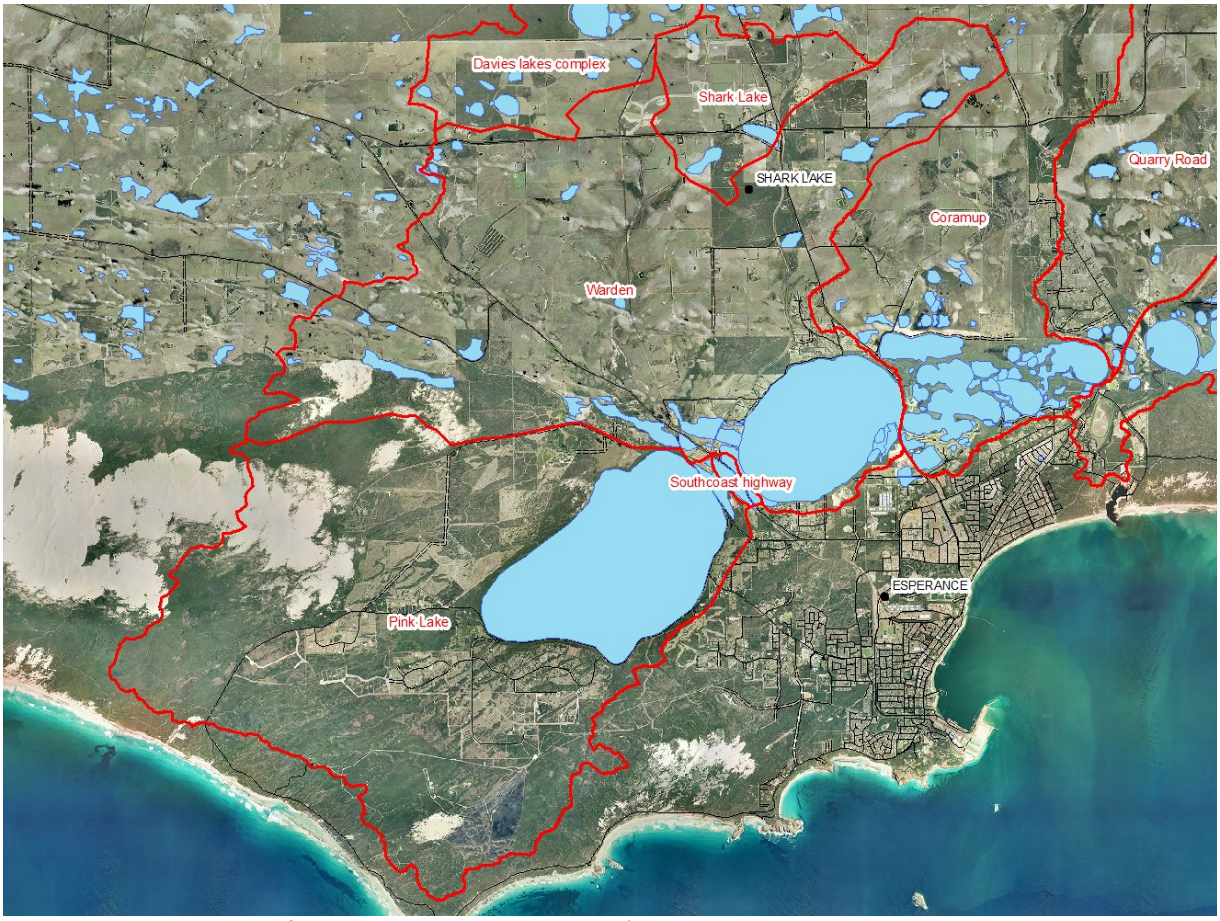


Figure 17. Western Suite catchments: Lake Warden & Pink Lake

### 2.3.2. Pink Lake

Pink Lake has a direct surface water catchment of approximately 7000ha (Figure 17). There are no creeks or streams feeding surface water into Pink Lake, and the entire water supply is by direct rainfall and seepage only. Pink Lake has a hyper-saline aquifer feeding water from East to West through Lake Warden and the Palinup channel. The Pink Lake catchment to the west and south of the lake supplies fresh to brackish water to the lake, and this contribution is thought to greatly exceed the eastern contribution, thus forming the major supply.

Analysis of water samples collected at the Pink Lake gauge plate, which was established on the eastern side of the lake, indicated salinity levels of seepage water to the lake to range from 11~31g/l in April and May ($1^{st}$ rains of the wet season after summer) compared to salinity concentrations of the lake water itself of 105~210g/l (depending on lake level and dilution experienced).

## 3. Managing altered hydrology in the central suite:

An extensive list of literature

## 4. Biodiversity recovery as a result of managing system hydrology

Despite the program focus changing from time-to-time as a result of implementing adaptive management principles, several important program milestones were achieved (in relation to the target objective as described in Section 2 above). Arguably, the most important of these relate to successfully managing waterlevels within the LWWS to facilitate shorebird and fringing vegetation recovery.

As a result, the LWWS now regularly has >1% global population of some shorebirds again (Ramsar criteria) and waterbird communities using Lake Warden have returned to a composition similar to that present in the 1980s, including a return to high diversity and abundance of shorebirds. However, at the current time and the program end, we did not succeed in the successful amelioration of the secondary salinity problem. This however is not seen as program failure, as the program was ended before the salt loading problem could be dealt with and it is generally accepted that the program was well ahead of target deliverable requirements.

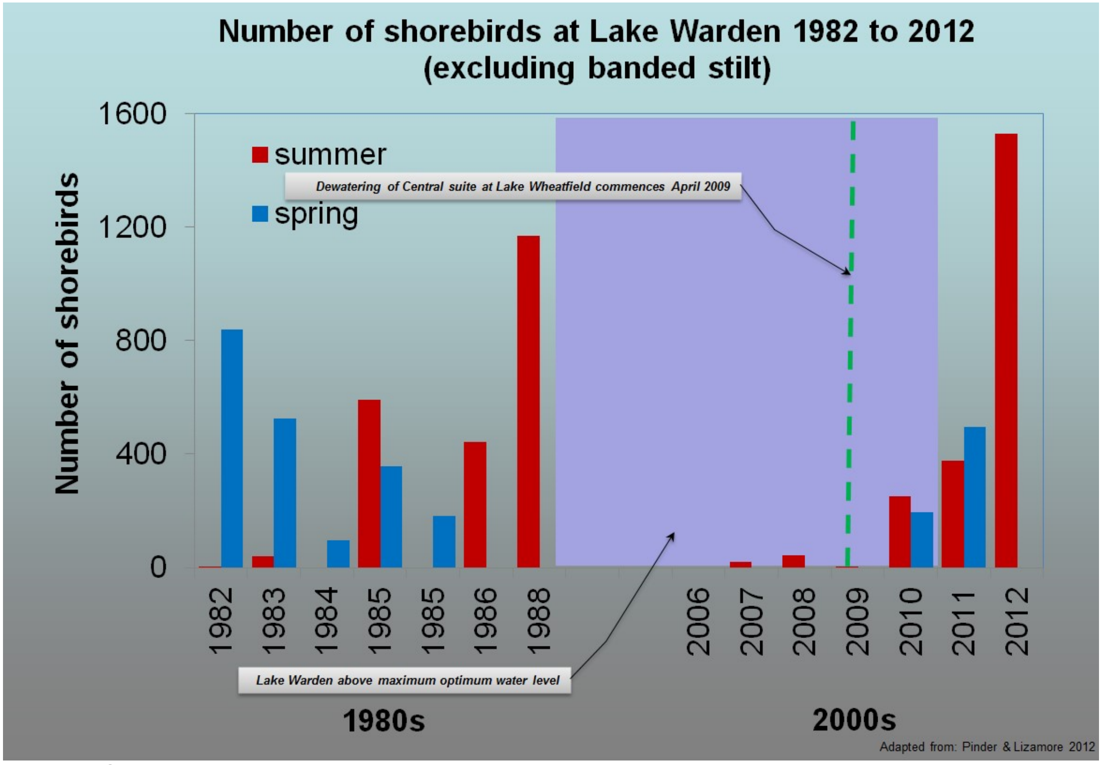

Figure 5: Shorebird numbers at Lake Warden

## 5. Managing secondary salinity and altered hydrology at Lake Warden

The optimum depths for waterbirds at Lake Warden derived by Massenbauer (2007) were based on historical lake depths and waterbird census data, but did not take into account increased salt loads from the catchment between the 1980s and the present. Thus, returning depths to those considered optimal for waterbirds appears to have resulted in higher salinity for equivalent depths. This higher salinity is thought to have resulted in a decline in aquatic invertebrate food resources for waterbirds. Balancing the need for low lake depth (to create shallow habitat for shorebirds) with the need to keep salinity sufficiently low, was considered the main current challenge in the LWWS.

Water depth and salinity at Lake Warden was recorded and monitored infrequently from 1979 to 2002. As a result, no information is available on stratification, large rainfall events or runoff/inflow parameters. In addition, data was reported as ppt (parts per thousand) value and not an electrical conductivity value. No accurate information is available on how this value was determined (i.e. which formula was utilised for calculation, or whether these values were ascertained through evaporative measurement or what type of equipment was used to measure the value). As a result, interpreting the data over this period, particularly in relation to more recent data, is problematic.

Do the higher salinity values currently recorded since 2010 reflect an increase in lake salinity compared to the earlier period, or is the current equipment just more accurate at the higher salinity concentrations? Or were the values calculated correctly? Depending on the formulae used (and the chemical makeup of the salts/minerals), this can have as much as a 40% variation in the results (Figure 6). From 2002 onwards, monitoring frequency increased and provided more consistent data. Despite the possible uncertainty described, salinity levels do appear to have increased.

As a further complication, it would appear that the salinity ratio follows a hysteresis curve, with salt crystallising at values as low as 220 g/l, which often relates to a drop in conductivity measurement, whilst salinity concentrations increase.

In addition, Lake Warden was already flooded when detailed sampling started in 2002 (Figure 7). As a result, no accurate baseline data for Lake Warden isavaialble for comparrison with current measured parameters.

In 2012, Lake Warden developed a salt crust. This appears to be the first time this has been recorded. Despite the lake drying up in the 1980’s and previously, no record of any salt deposits could be found. Massenbauer (2007) set waterlevel targets for Lake Warden based on historical waterbird and shorebird abundance data. This indicated optimum bird habitat for Lake Warden to be between 0.4 and 1.4m, which roughly equates to 68ha of optimum (shallow) depth zone around the perimeter of the lake (Figure 10). This optimum waterlevel was confirmed by Pinder (2012), who showed that highest diversity occurred when the lake depth was between 0.5 and 1.5m.

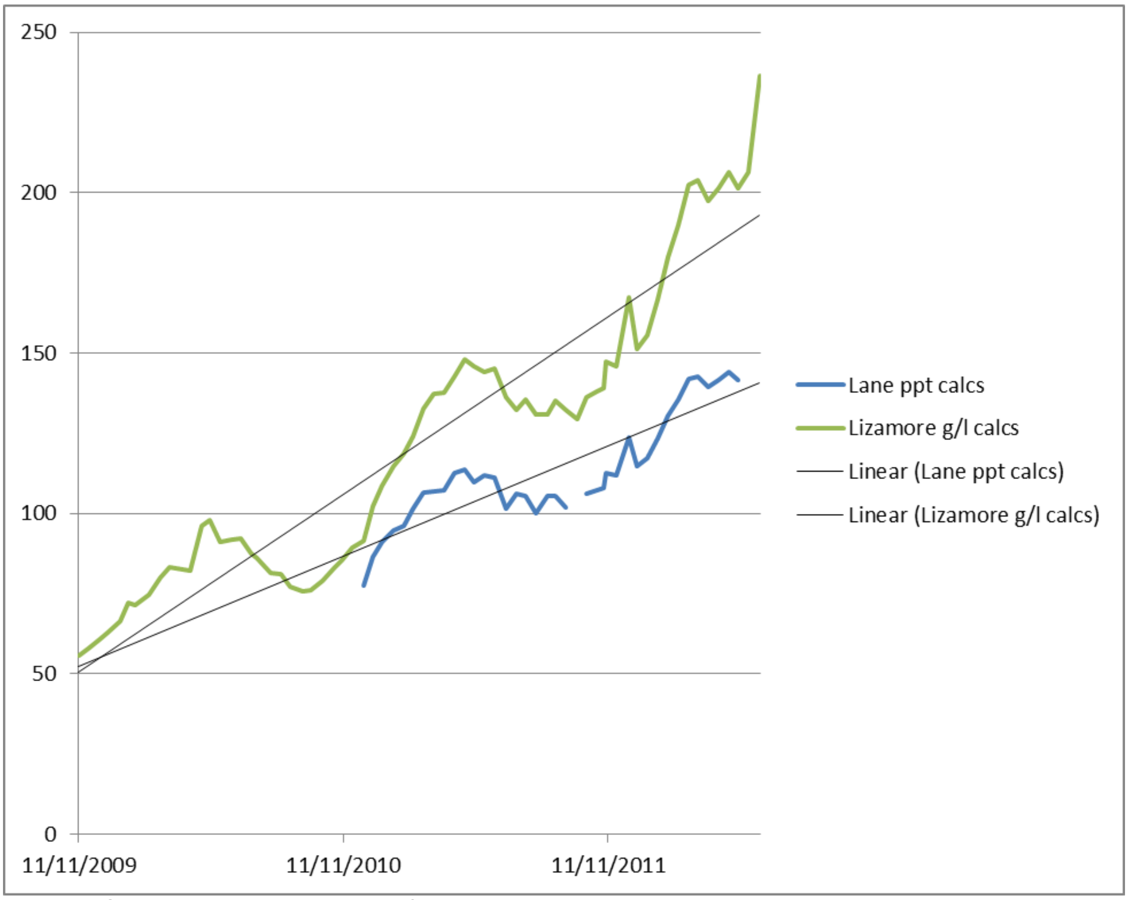

Figure 6: Salinity calculation variations for Lake Warden based on same conductivity values

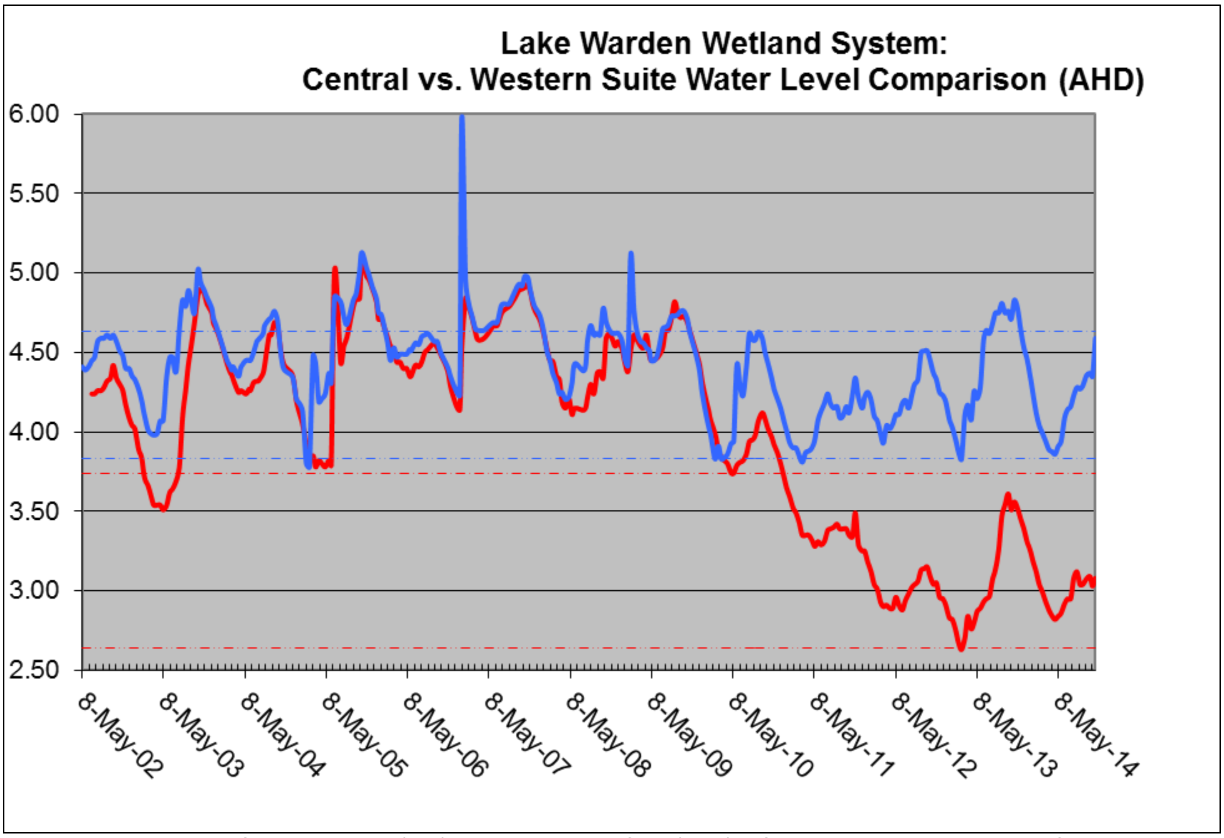


Figure 7: Lake depths of Lake Warden (red) and Lake Wheatfield (blue) reflected as AHD. Lake Wheatfield pipeline drainage commenced in May 2009, resulting in a separation of the hydrographs (i.e. the central and western suite started to operate as two individual hydrological units again and not as one).

As a result of weekly shorebird counts started in May 2012 at Lake Warden, it became apparent that abundance at Lake Warden was relatively low in comparison to 2011 recordings, despite the waterlevel being within the optimum range. It was hypothesised that this was as a result of the increased salt load (creating higher salinity at the same depth compared to the 1980s) and that abundance and diversity was thus greatest when the salinity concentrations were less than 160g/l. As a result, it was decided to manipulate the waterlevels to test this hypothesis and during winter period 2013, the central suite was allowed to flood to augment the surface water supply to Lake Warden. Results indicated that the hypothesis was supported and it was decided to repeat the process in 2014. Unfortunately, as a result of a dry winter in 2014, there was insufficient depth in the Central Suite to allow for an overflow into Lake Warden. Figure 9 shows salinity vs. abundance as monitored at Lake Warden for this period.

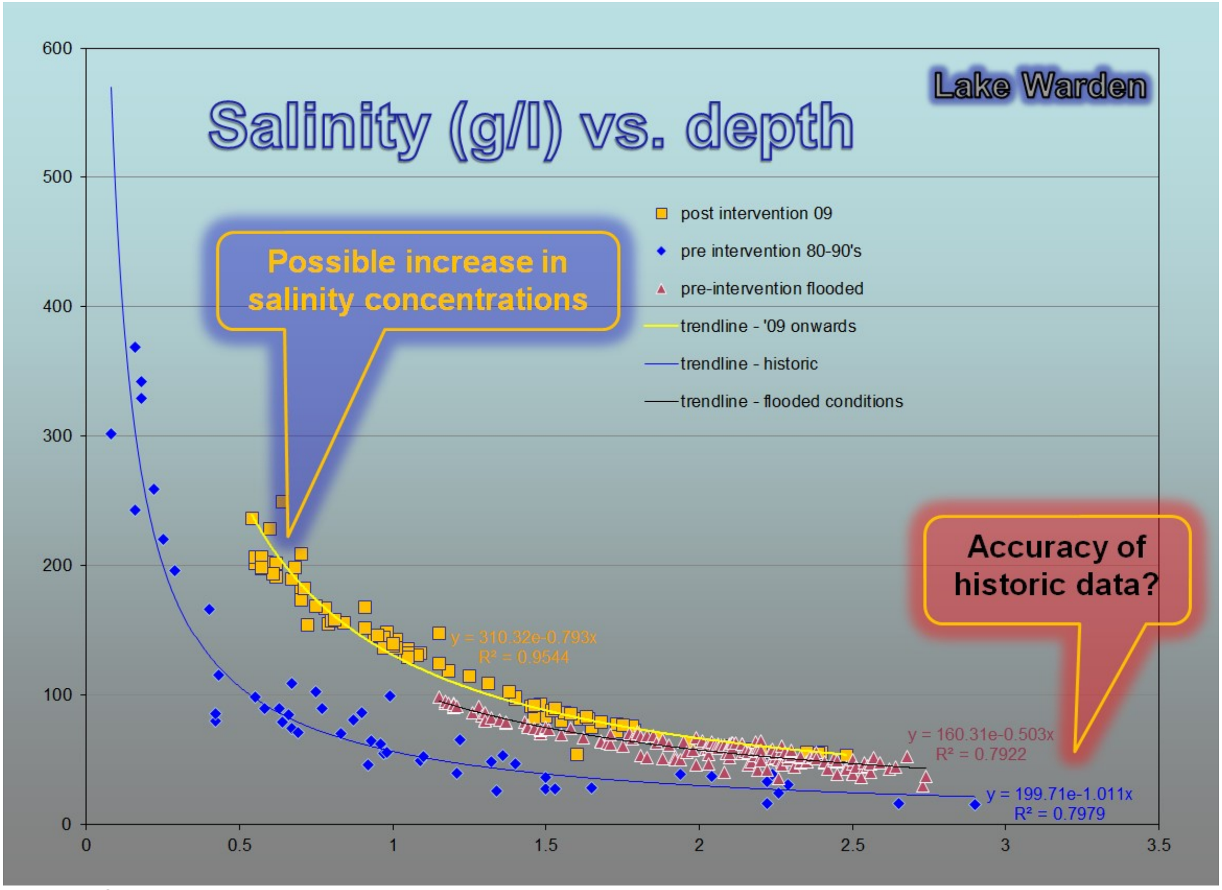


Figure 8: Salinity concentrations at Lake Warden

Accepting a higher water depth at Lake Warden reduces salinity concentrations but reduces available shore habitat to between 26 and 48ha (Figure 8). Unfortunately, this is not a stable figure, as salt load increases annually, with water from surface water supplies fluctuating between 2.5 and 3.3 g/l for Mortijinup creek to 15.8 to 23.4g/l from Windabout Lake. As Lake Warden has no discharge point currently (see above), any salts coming into the system will remain, thus increasing salinity over time.

The recovery program was in process of updating the bathymetry of the lake basin, while also collecting detailed salt and nutrient information in order to produce a solute model to predict the rate of eutrophication and salinisation and possible impacts. It was envisaged that model building could be completed in the 2014/2015 financial year, but the additional funds were not available. In response, it was envisaged the modelling could be completed over the 2014/2015 and 2015/2016 financial years, upon completion of the pink lakes project. With the cessation of the program, the model is unlikely to be produced. The Department has agreed to continue work to facilitate minimum management requirements, as indicated in Table 1 and described in Section 9.

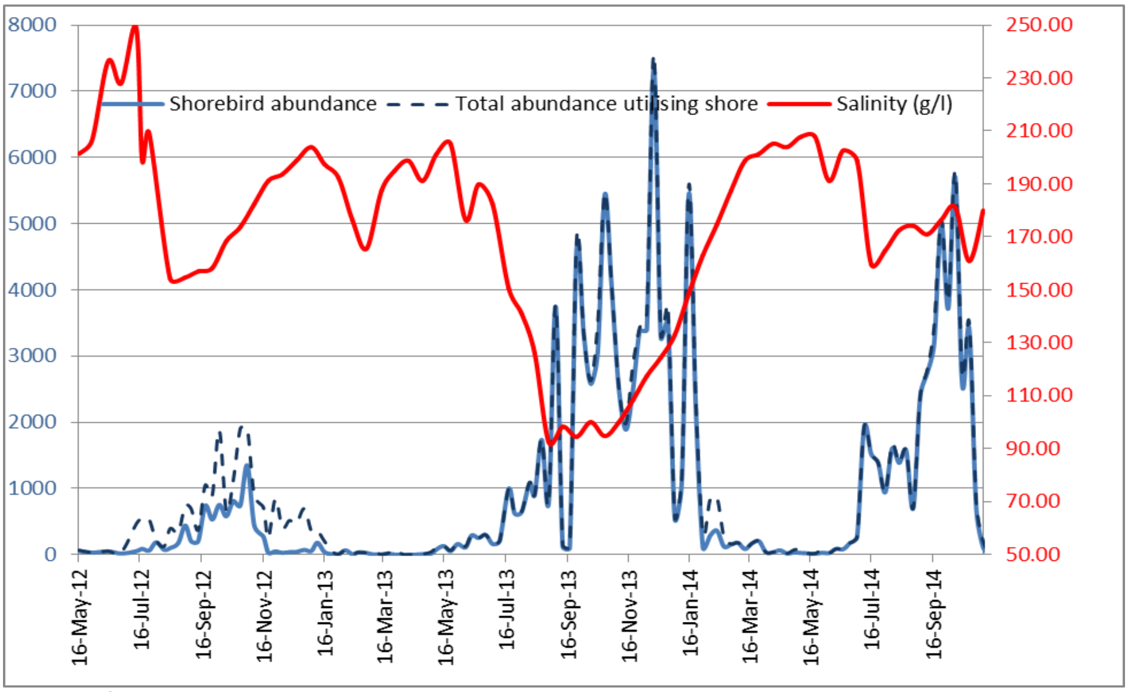


Figure 9: Shorebird and Waterbird abundance vs. salinity concentrations at Lake Warden

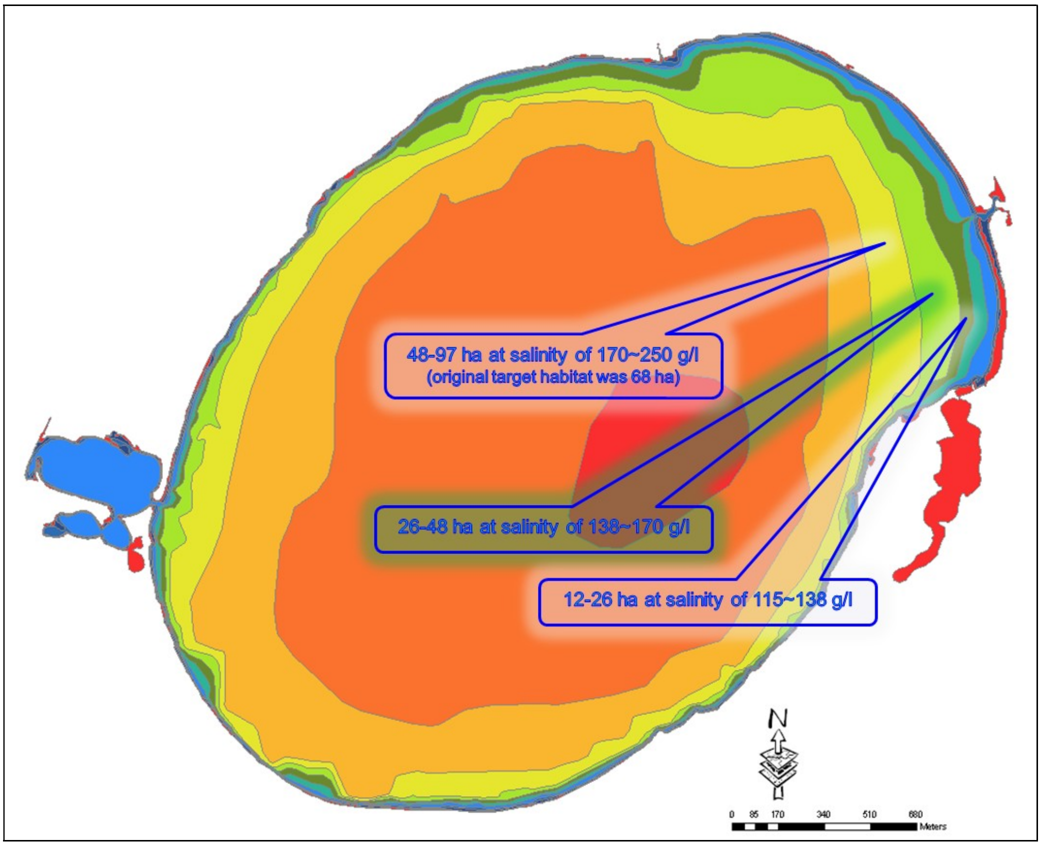


Figure 10: Projected shorebird habitat based on salinity concentrations and water depth in Lake Warden (as in 2013).

## 6. Pink lakes project

The optimum depths for waterbirds at Lake Warden derived by Massenbauer (2007) were based on historical lake depths and waterbird census data, but did not take into account increa

## 7. Maintenance and care phase

As of 7 October 2014, the Lake Warden Natural Diversity Recovery Program has entered a maintenance phase where the very basic obligations regarding the program can be met and maintained. The main factors that would influence the basic obligations are:

- The Lake Warden Wetland System is a Ramsar listed wetland of international importance, with applicable federal and international reporting requirements.
- The responsibility to continue operation of the infrastructure considering the success that it has achieved and the level of investment - i.e. Lake Wheatfield pipeline operations and EPA water quality monitoring requirements.

Through discussions with the several key stakeholders and technical specialists, recommendations were made to the Esperance District Office. A technical discussion took place on 14 October 2014 at Kensington in order to produce guidelines and minimum requirements. The recommended program is indicated in Table 1 below.

| | **Locations** | **Parameter(s)** | **Frequency** |
|---|---|---|---|
| Surface water quantity | All depth gauged wetlands within NDRC and Ramsar | depth at gauge | monthly |
| Surface water quality | All depth gauged wetlands within NDRC and Ramsar | salinity, pH | monthly |
| | Larger wetlands plus major creeks | TN, TP, Orthophosphate, Nitrates and chlorophyll A | quarterly |
| Groundwater quantity | All bores | depth to groundwater | monthly |
| Groundwater quality | Shallow bores | salinity, pH and RDO | monthly |
| | Deep bores/pisos | salinity, pH and RDO | quarterly |
| Surface water quality | Lake Wheatfield, Bandy creek at discharge point (B2), Bandy creek at harbour (B3) | TN, TP, Orthophosphate, Nitrates and chlorophyll A | monthly while pipeline operating |
| Operation of pipeline | Lake Wheatfield | - | As per SOP |
| Data review | Surface, groundwater and biological data | Review hydrological, chemistry and biological data to amend SOP for Best Environment Practise (BEP) | Biannual |
| Waterbirds | Whole Warden and Gore wetland systems (minimum is Warden wetlands) | Abundance of all species | Late spring/late summer in 2014/15, then either same in outward years or a minimum of a single annual late summer survey |
| Vegetation - salinity monitoring transects at Wheatfield | Mike Lyons' transects at Wheatfield | basal area of trees, recruitment, canopy cover and condition | once every three years as long as Wheatbelt Wetland Monitoring project continues |
| Vegetation quadrats | Lake Warden | Remote sensed … and ground surveys | Biannual |

Table 1: Minimum recommended monitoring for the maintenance phase of the Lake Warden Recovery Program

Three scenarios were investigated, particularly in relation to operation of the pipeline and a risk assessment matrix compiled (Table 3 and Figure 11).

1. Implementation of the monitoring program as recommended/suggested in Table 1, including operation of the pipeline as it has been since installation.
2. Implementation of a reduced monitoring program, based on a three-five year review of system, including operation of the pipeline only after such reviews.
3. Implementation of a ‘do nothing’ scenario.

The discussion makes the following assumptions

- $0-based budget. There are/will be no funding from outside of the district for the implementation of the program.
- No personnel are available currently to undertake the activities.

Table 2 lists the scoring system used.

| **Likelihood** | | **Impact** | |
|---|---|---|---|
| **Score** | **Description** | **Score** | **Description** |
| 1 | Very small chance of happening. | 1 | Very small impact. Even if the risk becomes reality, there will be negligible effect on the RF |
| 10 | Small chance of happening. | 10 | |
| 20 | | 20 | Impact is small, and manageable. |
| 30 | Moderate chance of happening. | 30 | |
| 40 | | 40 | |
| 50 | This will happen about half the time. | 50 | Impact is significant and noticeable. If financial risk, dollar amount is significant but fixable with current resources; if strictly operational, it will affect operations but can be worked around. |
| 60 | | 60 | |
| 70 | Likely to happen. | 75 | Very serious impact; challenges with working around it. |
| 80 | | 80 | |
| 90 | Very high chance of happening. | 90 | |
| 100 | Certainty – this will happen! | 100 | Can prevent RF mission from being realized. |

Table 2: description of likelihood and impact values for risk assessment matrix. The matrix was adapted from: *https://portal.rfsuny.org/...**risk**.../**risk**.../**risk_assessment_template**.xls*

Table 3 and Figure 11 show the results of the risk assessment.

| Risk # | Risk | x<br>Likelihood | y<br>Impact | Risk Factor (automatically calculated) |
|---|---|---|---|---|
| 1 | Do Nothing: Political fallout / stakeholder acceptance | 90 | 75 | 165 |
| 2 | Do Nothing: Environmental risk | 70 | 75 | 145 |
| 3 | Do Nothing: Value for money | 100 | 60 | 160 |
| 4 | Do Nothing: Federal obligations | 100 | 50 | 150 |
| 5 | Do Nothing: EPA requirements | 1 | 1 | 2 |
| 6 | 3-5 year review: Political fallout / stakeholder acceptance | 90 | 50 | 140 |
| 7 | 3-5 year review: Environmental risk | 70 | 50 | 120 |
| 8 | 3-5 year review: Value for money | 70 | 60 | 130 |
| 9 | 3-5 year review: Federal obligations | 50 | 50 | 100 |
| 10 | 3-5 year review: EPA requirements | 50 | 20 | 70 |
| 11 | Annual care & Maintenance: Political fallout / stakeholder acceptance | 30 | 45 | 75 |
| 12 | Annual care & Maintenance: Environmental risk | 30 | 40 | 70 |
| 13 | Annual care & Maintenance: Value for money | 30 | 50 | 80 |
| 14 | Annual care & Maintenance: Federal obligations | 30 | 30 | 60 |
| 15 | Annual care & Maintenance: EPA requirements | 30 | 20 | 50 |

Table 3: risk assessment matrix values for identified options and probability of risk

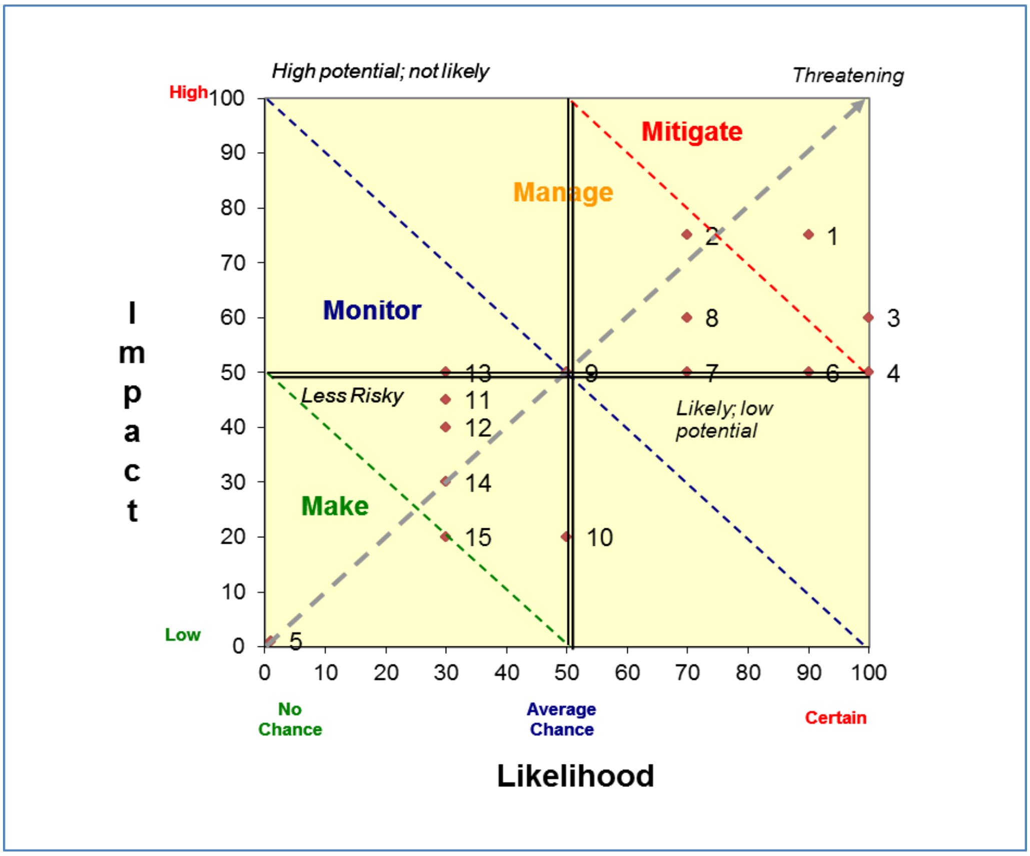


Figure 11: Risk assessment matrix- graphical representation

Based on the risk assessment above, the option proposed in Table 1 provides the greatest return on investment and (overall) poses the least amount of risk to the Department.

The three-five year option falls within the “manage” category, and indicates that, although at a much higher risk and lower return of investment, could still be acceptable if the Department is willing to accept the potential consequences (reversal of biodiversity gains) and can field a management plan for these impacts.

The “Do nothing” option (apart from direct cost benefit), will not be acceptable and will need addressing.

Before the program can enter the maintenance phase, standard operating procedures have to be developed and/or updated for all these activities. The proposed deadline for this 01 December 2014. Based on this modelling and further discussions, the personnel time will be assigned to district personnel through a re-ordering and prioritisation of current work programs. The on ground management aspect will continue to be the responsibility of the district with the technical and science component undertaken by Science and Conservation branch.

## 8. Recommendations for future work

An operational review was held in 2011. The effectiveness of the Lake Wheatfield gravitational pipeline, various proposed scenarios, Ecological Character Description Knowledge Gaps and new scenarios were modeled in a Bayesian Probability Analysis. As a result, the following three priority aspects were identified for further study:

- Updated water balance reflecting hydrology changes in the catchment
- Salt and nutrient balance to establish the rate of eutrophication within the western and central suites respectively
- Aquatic invertebrates:
    - what reaction to management activities were there as a result of salinity changes / concentrations as a result of lower water level
    - what waterbird populations could be sustained by aquatic invertebrate biomass

This fed into a monitoring regime consisting of:

- 56 bores, monitored monthly for
    - Water level
    - pH, EC, Eh
- 6 floating evaporation pans (monitored twice a week).
- 12 surface water sites, monitored and sampled fortnightly for:
    - Water level
    - pH, EC, Eh, alkalinity
    - Major nutrients TN, N, TP, TDP
    - Minor nutrients, cations and anions (e.g. Al)
- Weekly shorebird surveys at Lake Warden – 4 sites
- Monthly aquatic invertebrate surveys at Lake Warden – 4 sites

Following a 12 month review, the program was evaluated for effectiveness and amended to the following:

- 70 bores, monitored monthly for:
    - Water level
    - pH, EC, Eh
- 16 bores, sampled monthly for:
    - alkalinity
    - Major nutrients TN, N, TP, TDP
    - Minor nutrients, cations and anions (e.g. Al)
- 6 floating evaporation pans (monitored twice a week).
- 8 surface water sites, monitored and sampled fortnightly for:
    - Water level
    - pH, EC, Eh
- 9 surface water sites, monitored and sampled fortnightly for:
    - Water level
    - pH, EC, Eh, alkalinity
    - Major nutrients TN, N, TP, TDP
    - Minor nutrients, cations and anions (e.g. Al)
- Weekly shorebird surveys at Lake Warden – 4 sites

In late 2012, another review was undertaken and the monitoring regime was amended to include newly identified priorities (lack of resources forced certain aspects to be dropped temporarily). These new priorities resulted from:

- Despite target waterlevels being reached, shorebird abundance decreased as Lake Warden's salinity levels increased dramatically. Through artificial manipulation of the waterlevel in the central suite and as a result the western suite, salinity levels were diluted and the impact thereof monitored on the shorebird assemblages and abundance.
- Lake Warden developed a salt crust (not something that was ever recorded previously).
- Lake Warden turned pink. Pink Lake has not been pink for more than decade.

As a result, the "pink lakes project" was established in December 2013 and implemented January 2014. The aim was to better understand the dynamics and ecology of pink lakes to allow the recovery program to make better informed decisions with specific regard to what is considered as the optimum habitat criteria for Lake Warden. At the same time, it was decided to further investigate previously identified engineering options, in particular the re-establishment of the surface-hydrological link between Lake Warden and Pink Lake, with the hypothesis being: if Pink Lake is restored as the terminal lake of the system it will decrease salt loads in Lake Warden, thus improving waterbird habitat. At the same time, it may result in restoring the pink colouration and characteristics of Pink Lake (a previous tourist attraction).

As of January 2013, the program was amended to the following:

- 70 bores, monitored monthly for:
    - Water level
    - pH, EC, Eh
- 16 bores, sampled monthly for:
    - alkalinity
    - Major nutrients TN, N, TP, TDP
    - Minor nutrients, cations and anions (e.g. Al)
- 7 surface water sites, monitored and sampled fortnightly for:
    - Water level
    - pH, EC, Eh
- 14 surface water sites, monitored and sampled fortnightly for:
    - Water level
    - pH, EC, Eh, alkalinity
    - Major nutrients TN, N, TP, TDP
    - Minor nutrients, cations and anions (eg. Al)
- 4 surface water sites, monitored and sampled monthly for:
    - Water level
    - pH, EC, Eh, alkalinity
    - Major nutrients TN, N, TP, TDP
    - Minor nutrients, cations and anions (eg. Al)
- Weekly water and shorebird surveys at Lake Warden – 5 sites
- Fortnightly surveys at 7 lakes
    - water and shorebird
    - aquatic invertebrates
    - rainfall
    - colour
    - chlorophyll
    - light intensity
- Monthly water and shorebird surveys at 4 lakes
    - water and shorebird
    - aquatic invertebrates
    - rainfall
    - colour
    - chlorophyll
    - light intensity

The *Pink Lakes Project* has a finite lifespan and was destined to run until the start of the wet season 2015 (envisaged to be around May 2015, but subject to climatic variables). The results of the abovementioned programs were to be written up in 2015 and 2016 into various science reports and papers. Amongst others, the results were to be included in one Master's Degree write-up for University of Johannesburg and one PhD through

University of Western Australia. Funding has been received from Science and Conservation branch to finalise this project. The continuation of this project is uncertain at this stage, as the relevant personnel may be declared redundant.

Several recommendations for further recovery implementation have been made. ((Maunsell-Aecom 2008); (Robertson and Massenbauer 2005); (Walshe, Jones et al. 2007); etc.). These recommendations were all based on an already flooded system. Following better than predicted and modelled results after the current level of recovery implementation, these recommendations may longer be priorities. As such, the recovery program was currently focused on capturing data to support the following hypothesis:

> *Restoring the surface water hydrological link between Lake Warden and Pink Lake will redress the impacts of secondary salinity at Lake Warden, whilst allowing the recovery of Pink Lake as a result of decades of salt mining. This would not only restore valuable shorebird habitat at Lake Warden, but also by returning salt to Pink Lake, restore its ecological and tourism values by restoring its pink colour (currently blue and has been so for more than two decades)*

It is strongly recommended that any future research focus on understanding and restoring the hydrological link between Lake Warden and Pink Lake. Figure 12 indicates the most likely flow pathway, as identified through aerial photography interpretation and Lidar bathymetry (2013). This was also supported in the recent hydrology review (Hydroconcept 2014). In addition, the Ecological Character Description of the Lake Warden Wetland System describes various aspects that need to be studied (Watkins 2009), Table 13).

Not included in the Lake Warden Natural Diversity Recovery Program, but always monitored by the recovery program, was the Lake Gore Wetland System located approximately 30km west of the LWWS. Lake Gore is also a Ramsar listed wetland of international importance and it is accepted that these two systems function in symbiosis with regards to waterbird communities. Apart from the recommendations contained within the Ecological Character Description of the Lake Gore Wetland System, it is recommended that research be conducted to understand and describe the waterbird movement and dependence on these two systems, as well as the other more than 10,000 small lakes in the South Coast district.

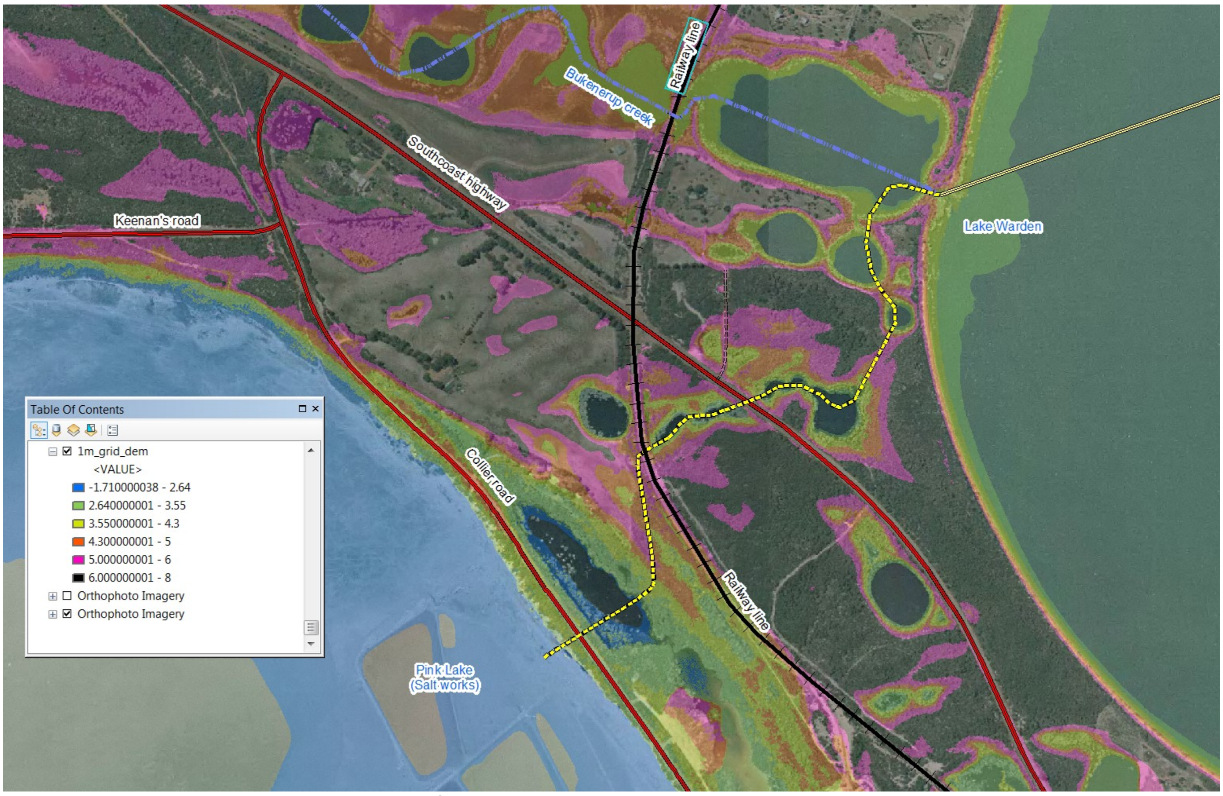

Figure 12: Possible hydrological pathway from Lake Warden to Pink Lake

## 9. Conclusion

During the course of the 18 years of the program, potential and actual threats were identified that could impact on the realisation of the goal. Altered hydrology and secondary salinity was identified as being the greatest risk and the majority of effort went into combating these two threats.

Various interventions were implemented in partnership with government and community groups, such as Department of Food and Agriculture, Department of Water, Department of Transport, South Coast National Resource Management, Shire of Esperance and Esperance Regional Forum. Interventions included targeted revegetation and engineering options. To date, this has led to target water levels being achieved in the eastern and central suites of the lake system, with apparent successful recovery of fringing vegetation and shorebird assemblages throughout the system.

Although target water levels were achieved in the western suite, rising salinity poses a major threat to biodiversity. The project ended whilst in the midst of researching various engineering solutions for the recovery and management of salinity in Lake Warden and Pink Lake. With the closure of the project, this aspect is unaddressed and will negatively impact and alter the system in the immediate future.

The maintenance and care phase will aim at continuing the management of the central suite water level for optimum habitat and recovery.

## 10. Acknowledgements

This project would not have been possible without the guidance and assistance of the following people:

Adrian Pinder; Alan Clarke; Anna Leung; Andrew Maughan and Department of Water team; Bill Willson & UWA team; Bob Kent; Bruce Bone; Cameron Hennessey; Caroline McCormick; Cindy & Graham Hage; Coral Turley & Esperance Wildflower Society; Dave & Megan Stagg; Dave Thornburg; David Cale; Don Cater; George Sutter; Graham Gath; Greg Freebury; Ian Gardner; Ian Hartley; Ian Hughes; Jasmine Rutherford; Jim Lane; John Simons; Julie Waters; Karthik Rajagopal; Ken McGrath; Ken Wallace; Kimberley Oswald; Kirsty Quinlan; Klaus Tiedemann; Ken Read & EBOG team; Kylie Bishop & SCNRM team; Lindsay Bourke; Lisa Wright; Matt Forbes; Michael Coote; Melita Pennifold; Mike Lyons; Laurent Gaillard; Laurent Marsol; Liezl de Beer; Lyndsay Joyce; Martin Lizamore; Matt Harvey; Matt Hypsey; Michael Smith; Mick Rose; Nathan Rugless; Nikki Cowcher; Nigel Johnston; Owen Massenbauer; Paul Clifton and Shire of Esperance; Peter Greyling; Reed May; Rob Blok; Rob Jose; Robyn Cail; Rose Riley & ERF team; Ryan Duncan; Sarah Davies; Selva Marimuthu; Serina Shaddick; Stephanie Lizamore; Stephen Butler; Tilo Massenbauer; Wayne Gill.

**11. References:**

Hydroconcept (2014). *Hydrogeological assessment of Lake Warden. Esperance, Western Australia*. Report for Department of Parks and Wildlife. October 2014. Hydroconcept Pty Ltd. Mount Pleasant, WA.

Marimuthu, S. (2005). *Interaction between Surface Water and Groundwater in a Coastal Wetlands System.* PhD, University of Western Australia.

Massenbauer, T., K. Wallace and C. Lloyd (2009). *APPENDIX #: Lake Warden Natural Diversity Recovery Catchment*, Department of Environment & Conservation.

Maunsell-Aecom (2008). *Lake Warden Wetland System, Esperance. Initial Environmental Impact Assessment.* G. M. Prepared by Steven Thomas, Lisa Chappell, ELisabeth Zajc, Shirley Connelly, Lara Jefferson, Tilo Massenbauer (DEC), T. M. D. Reviewed by Steven Thomas, Troy Collie and A. b. S. S. T. L.-P. Advisory). Perth, WA, Department of Environment & Conservation.

Robertson, D. and T. Massenbauer (2005). *Applying Hydrological Thresholds To Wetland Management For Waterbirds, Using Bathymetric Surveys And GIS.*

Wallace, K., Connell, K., Vogwill, R., Edgely, M., Hearn, R., Huston, R., Lacey, P., Massenbauer, T., Mullan, G., and Nicholson, N. 2011. *Natural Diversity Recovery Catchment Program: 2010 Review*. Department of Environment and Conservation, Perth, Western Australia.

Walshe, T., S. Jones and T. Massenbauer (2007). *Decision Framework for Natural Diversity Recovery Program (Implementation)* Melbourne, Australia, University of Melbourne.

Watkins, G. (2009). *Ecological character description of the Lake Warden System Ramsar site, Esperance,* Western Australia. D. o. E. Conservation. Perth, WA, Department of Environment & Conservation