APPENDIX E. HYDROLOGY AND NUTRIENTS STUDY

WATER TECHNOLOGY
WATER, COASTAL & ENVIRONMENTAL CONSULTANTS

Final Report

Pardoo Stage 3 Irrigation Project Hydrology and Nutrient Assessment

Pardoo Beef Corporation

November 2017

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1 INTRODUCTION

Pardoo Station is located north of the Great Northern Highway, approximately 100 kilometres (km) east-north-east of Port Hedland and 365 km south west of Broome. The owner of Pardoo Station, Pardoo Beef Corporation Pty Ltd (PBC), is proposing to expand the development of a pivot irrigated feed crop production facility to improve cattle welfare, condition and throughput.

This project relates to Stage 3 of the project only, as Stages 1 and 2 are approved. The site is located adjacent to the Eighty Mile Beach Ramsar Wetland, shown in Figure 1-1. The regulators have indicated that flooding across and adjacent to the site may create temporary important habitat for migratory waterbirds (hence the location of the Ramsar boundary being 4 km inland).

The aim of this study is to investigate the following:

- Hydrology and soil types of the study area;
- Extent, frequency, and duration of flooding that has occurred in the past and may in the future extend close to the Stage 3 project area;
- Stage 3 water balance; and
- Nutrient balance and impact assessment for the proposed irrigation project based on fertiliser application rates and known hydrology/hydrogeology of the area.

Figure 1-1 Location of Pardoo Station Stage 3 Development

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1.1 Site Description

The Stage 3 development site is situated approximately 4 km from the coast (Figure 1-1). The soils along the coastal strip of Pardoo Station can be divided into two key categories:

1. Soils of the coastal floodplain (within the Ramsar wetland boundary) which were formed by an ancient paleo-tidal system, have a high silt/clay content and as a result have a low infiltration rate.
2. Soils of the Sandy Desert (including the Stage 3 Project area) - a red sandy "Pindan" soil with a high infiltration rate.

These two soil categories are clearly seen on the aerial photography as different colour soils (Figure 1-2). The Stage 3 project area sits on top of sandy red Pindan soils at approximately 7 - 8 m AHD. The adjacent low lying Ramsar area is comprised of grey silty clay soils and sits at approximately 4 – 6 m AHD (Figure 1-3).

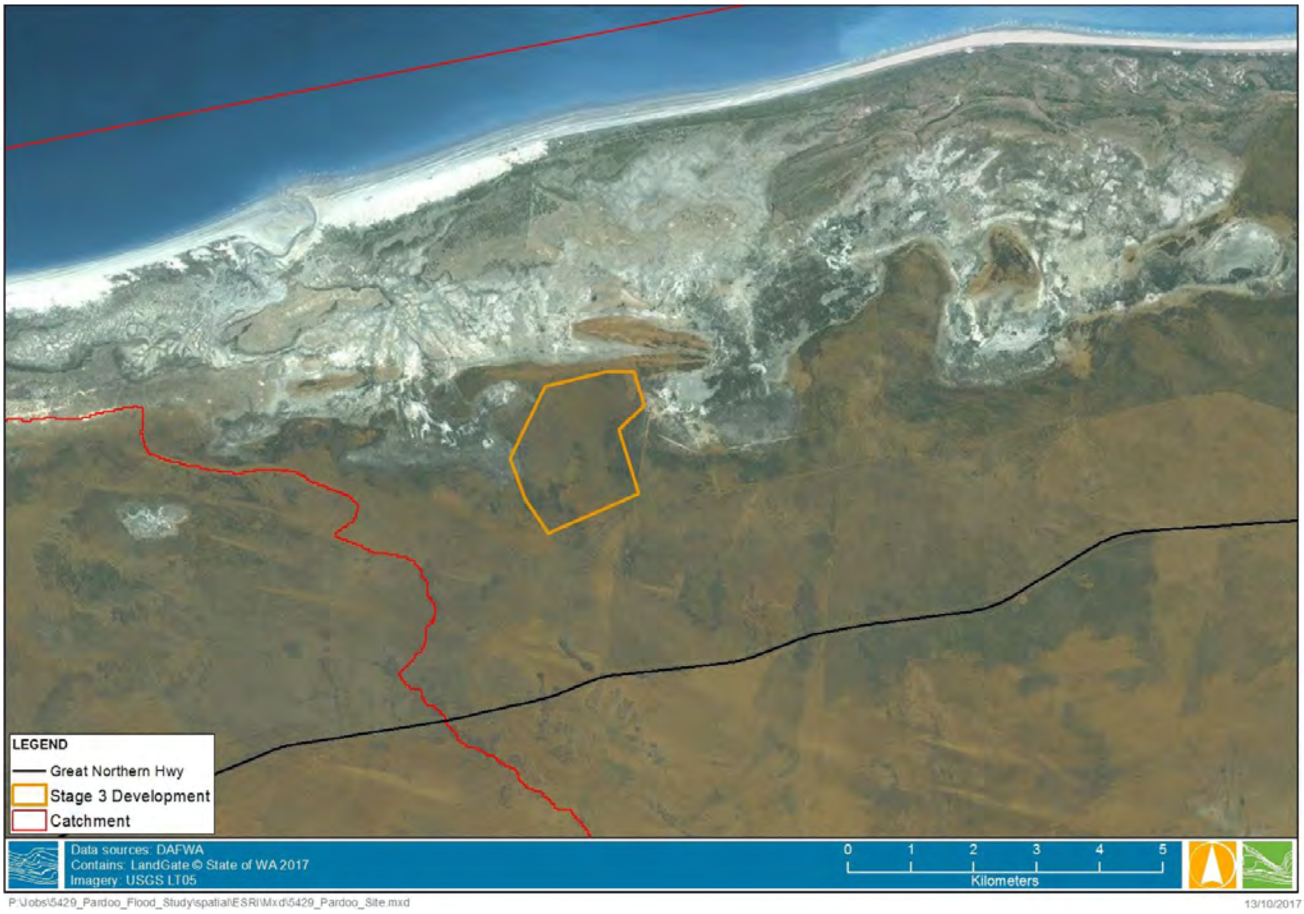

Figure 1-2 Stage 3 Development Site Description

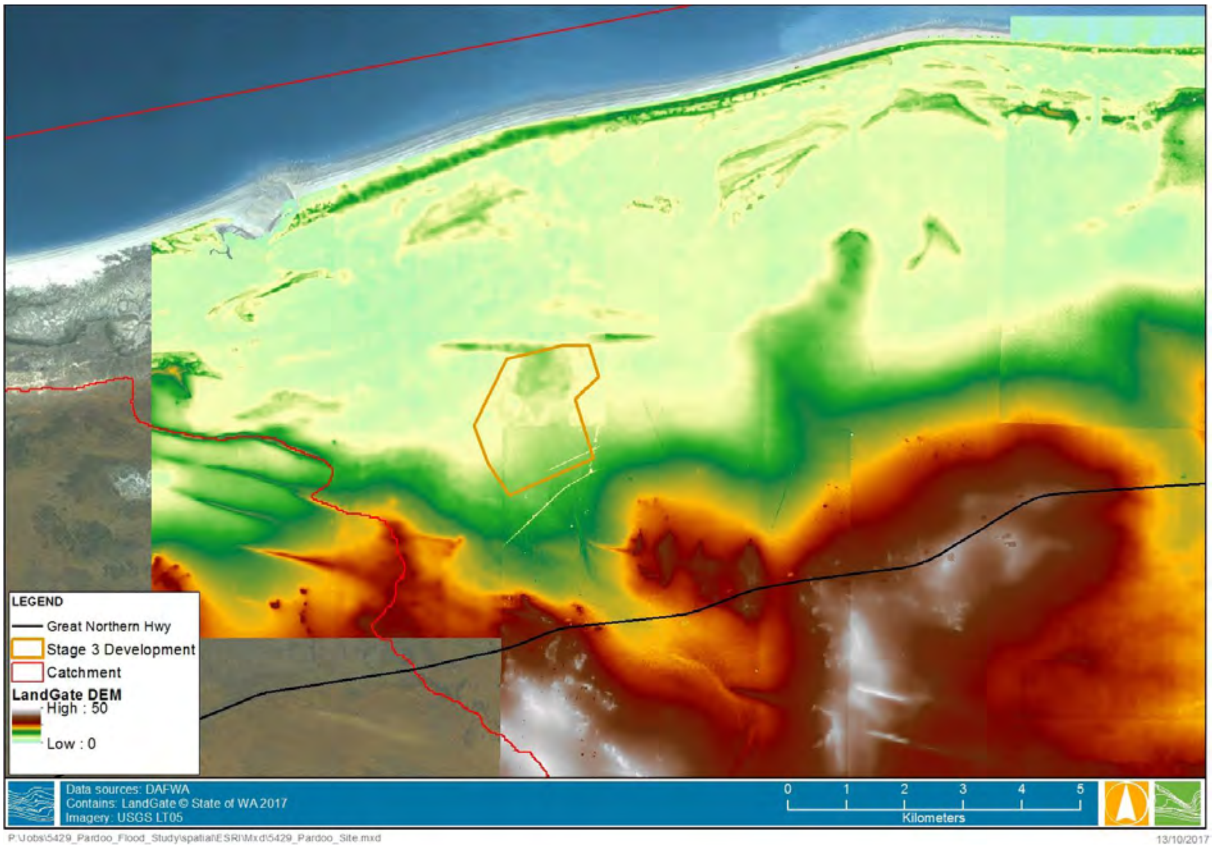

Figure 1-3 Stage 3 Development Site Topography

1.2 Hydrology

The project occurs in an un-named hydrological sub-catchment (28,900,000 ha in size) within the Sandy Desert Lake Dora catchment (29,360,000 ha in size). There are no major river systems within the Sandy Desert, just low lying lake systems, sand dunes and a very long uninterrupted beach front.

A sub-regional catchment of 250,000 ha (2,500 km^2) was defined by Water Technology utilising best available topography data (Figure 2-1).

The inland portion this sub-regional catchment (including the Stage 3 project area) is characterised by red sandy 'Pindan' soils with high infiltration rates. The relatively flat nature of the terrain coupled with the high soil permeability means that runoff is negligible (as is typical of desert catchments). Streamlines are not well defined and there are no signs of concentrated flow paths. This is demonstrated by the lack of waterway infrastructure under the Great Northern Highway, with a 2,500 km^2 catchment draining to just two small box culverts, which are likely fed by road runoff rather than catchment runoff. The depth to groundwater in the vicinity of the Stage 3 project is in excess of 3 m (Groundwater Consulting Services, 2017a), hence with an average annual rainfall of approximately 320 mm, the land is unlikely to become saturated.

A small strip of coastal floodplain occurs within the sub-regional catchment, coinciding with the Ramsar listed wetland area, characterised by grey clayey/silty soils. Again, this area is very flat, with few signs of formed drainage lines. These soils have much lower infiltration rates. Water is likely to pond in the lower parts of coastal floodplain after heavy, prolonged rainfall, with runoff being generated from the slightly raised areas. Average daily recorded evaporation within the region (at Port Hedland) is approximately 0.009 m/day (9 mm/day), hence a significant amount of water will evaporate from the ponded areas.

2 DATA REVIEW

A review of the available information was completed, which included local meteorological data, terrain data and satellite imagery. Field measurements were also collected for the project to determine the infiltration capacity of the local soils.

2.1 Meteorological Data

Daily rainfall data is available for the nearby Pardoo Station rainfall gauge from the Bureau of Meteorology, which is approximately 35km south west of the Stage 3 Development site. There are also gauges at Wallal Downs Station approximately 80km north east and Yarrie Station approximately 80km inland to the south. All three gauges have data records over 100 years, with data coverage over 80%, up to 90% at Pardoo Station.

Notable missing data occurs in 1981 and 1982, which coincided with a significant rainfall event. However, the Department of Water and Environmental Regulation (DWER) also have data for two daily rainfall stations in the area that were maintained for a period between 1978 and 1983, which fortunately covers the rainfall event in 1982. These gauges are called Canning and West Canning and are located approximately 25km and 30km south east of the site respectively. The locations of these sites are shown in Figure 2-1.

Department of Transport also maintain tidal gauges at Port Hedland and Broome, which were analysed in recent coastal hazard assessments. Reports for these assessments are available and contain relevant estimates of storm tide that can be used as coastal water level boundaries (Cardno, 2015), (Cardno, 2011).

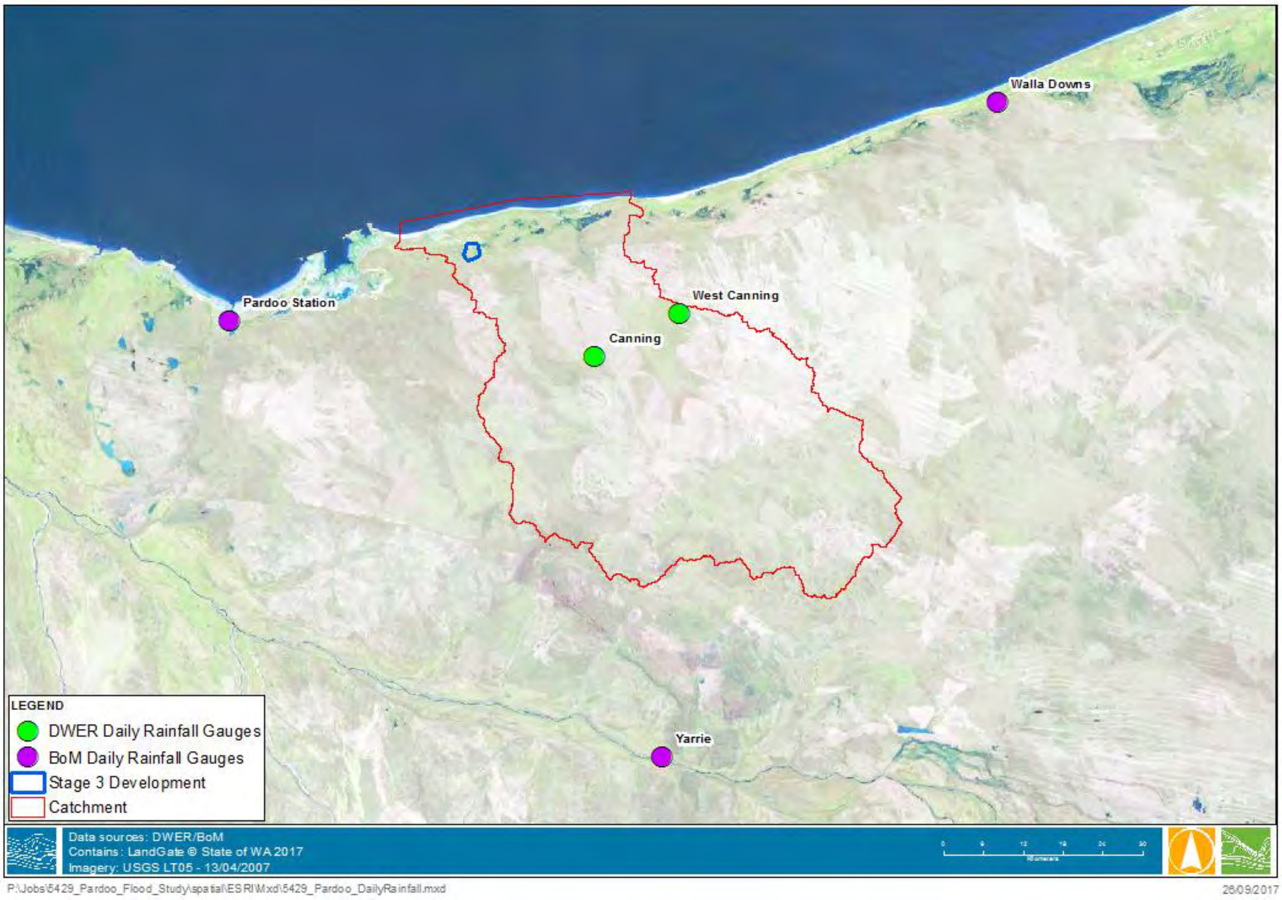

Figure 2-1 Sub-regional Catchment and Location of Daily Rainfall Gauges

The nearest evaporation gauge is located in Port Hedland, with daily data going back 50 years to 1967. The average daily evaporation over the whole period of record is 9 mm, with the highest month being November with 11.5 mm, and the lowest in June with 6.5 mm.

2.2 Terrain Data

The terrain data available for this study included coarse catchment scale satellite data supplemented with finer scale photogrammetry data.

The following terrain data sets were available for this study:

- SRTM 1s DEM (Satellite)
- LandGate 10m DEM (Photogrammetry)
- LandGate 5m DEM (Photogrammetry)

The differences in the elevation of the different data sets was compared using available surveyed spot heights within the study area. The SRTM data was found to be approximately 1m higher than the LandGate DEMs, and was adjusted accordingly. The extent of the different datasets used in the study is shown in Figure 2-2.

Whilst the LandGate data has a higher resolution, there is significant 'banding' across the terrain, which has the potential to alter the local flow patterns across the area of interest. The LandGate DEMs with the banding issues are shown in Figure 2-3.

However, as infiltration and evaporation have a significant influence on the depth and duration of flooding in this area, the impacts of this banding on the flow of water across the terrain is not likely to have a major overall impact. Therefore, an accurate assessment of the flood extent can still be obtained using this data.

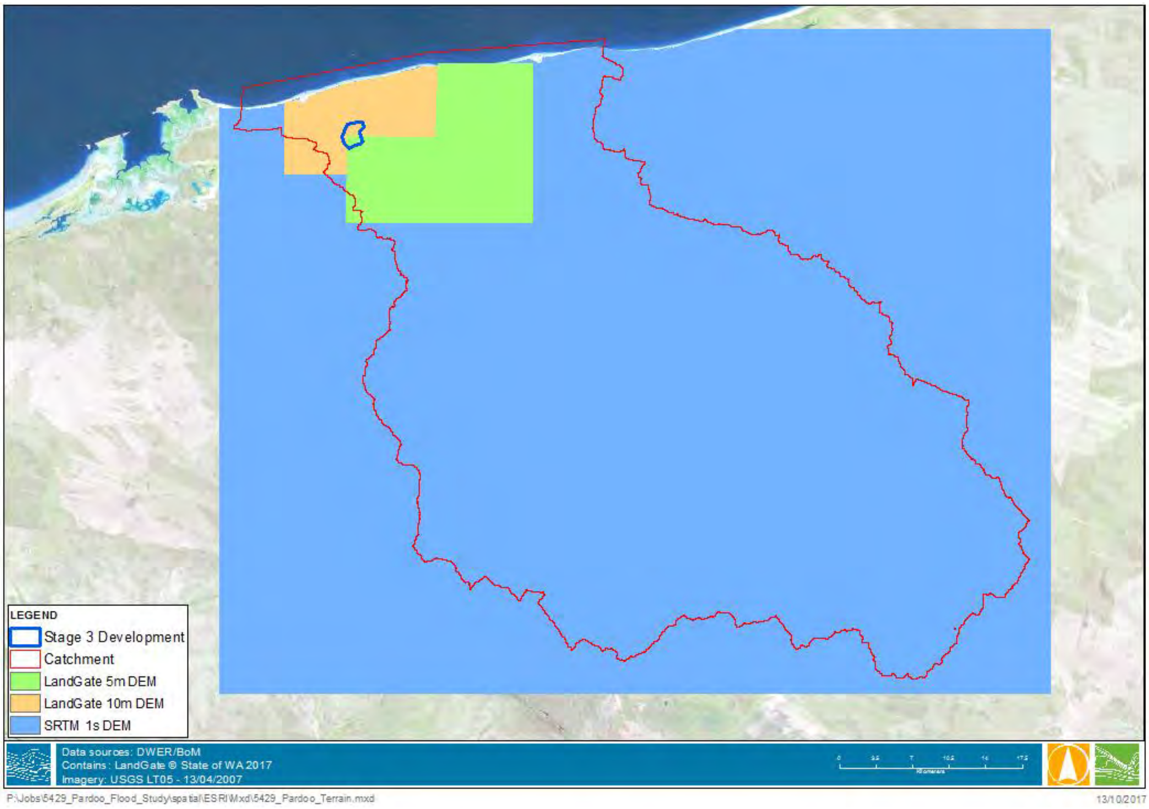

Figure 2-2 Extent of Terrain Data Sets

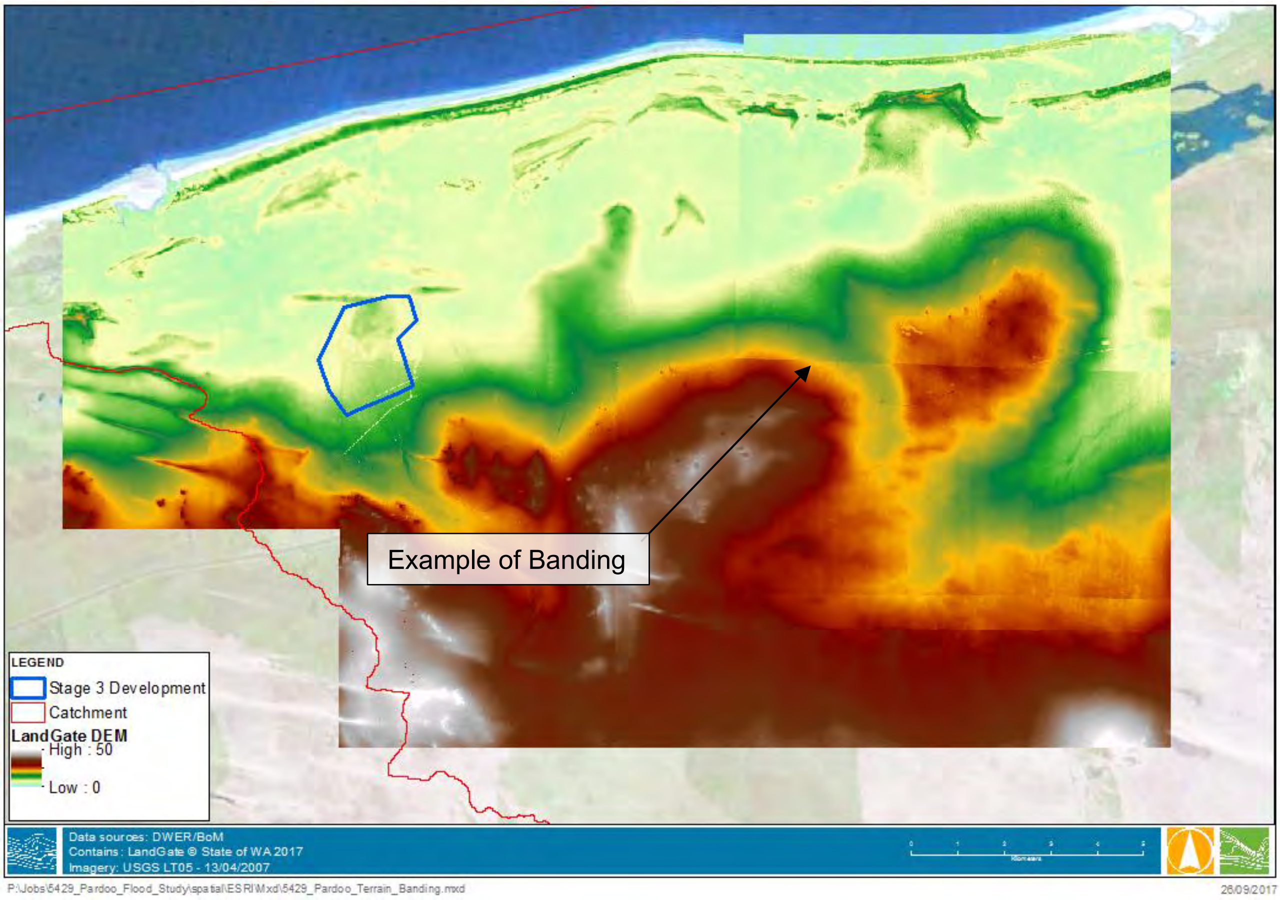

Figure 2-3 LandGate DEM Showing Banding Issues

2.3 Satellite Imagery

Satellite imagery showing the extent of flooding is a valuable source of information. As a joint initiative between the U.S. Geological Survey (USGS) and NASA, the Landsat Project captures and makes available satellite imagery from across the globe. Imagery of the study area is captured approximately once per week and data is available from the 1990s. The more recent imagery is of a suitable resolution to accurately map flood extents. The quality of the imagery is heavily dependent on cloud cover, which is often an issue when assessing flood extents during a storm. High quality imagery was available for a storm event during March 2007, which coincided with the highest monthly rainfall total on record for the area. An example of the available imagery was shown in Figure 2-1, which was captured on 13th April 2007, approximately two weeks after the final peak of the rainfall.

2.4 Soil Mapping

Soil landscape mapping data covering Western Australia is available from the Department of Primary Industries and Regional Development at the best available scale. It is a compilation of different surveys at various scales, and supplied online as an ESRI shapefile. The data includes a description of the soils along with references to the source of the data.

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3 SOIL INFILTRATION TESTING

Soil infiltration testing was undertaken at the site to determine the saturated hydraulic conductivity of the soil. Four sites were chosen, two being within the Stage 3 development, and the other two within the Ramsar wetland listed area. Figure 3-1 shows the test locations, Table 3-1 summarises the results, and the calculations are in Appendix A. The test locations within the Stage 3 development area are representative of the sandy Pindan soils of the wider catchment, which have very high infiltration rates, as opposed to the lower lying clayey silt areas within the wetland.

TABLE 3-1 SUMMARY OF INFILTRATION TEST RESULTS

Test	Easting	Northing	Soil	Infiltration Rate (mm/hr)
1	804828	7787463	Pindan - red/brown silty sand	157
2	804492	7786201	Pindan - red/brown silty sand	155
3	803465	7788539	Pale grey clayey silt with minor fine sand with the presence of mud cracks.	17
4	804082	7788650	Pale grey clayey silt with minor sand. No evidence of ponding or mud cracks.	1

Figure 3-1 Infiltration Test Locations

4 RAINFALL EVENTS

Three historical rainfall events were selected for this study based on the magnitude of the events and the available data. These events were March 2007, February 2013, and January - February 1982.

The March 2007 event was the largest on record, both in terms of the highest monthly rainfall total, and the highest daily total. At Pardoo Station, 630 mm of rain fell during the month, including 285 mm on 27th March. Significant rainfall totals were recorded at other nearby gauges as well. Wallal Downs showed a similar trend of consistent rainfall followed by a very large daily total, however the inland gauge at Yarrie missed the rainfall event at the end of the month. The daily rainfall for March 2007 is shown in Figure 4-1. This event also had very good satellite imagery for the period of inundation, hence this was used as the main flood model calibration event.

The February 2013 event also recorded very high daily rainfall totals, with 520 mm falling at Pardoo Station over a three-day period. Yarrie recorded 377 mm of rain over the same period, whilst Wallal Downs recorded only 162 mm. All three gauges received very little rainfall both before and after this event, as shown in Figure 4-2.

The third event assessed was a longer period of rainfall through January and February 1982. During this period, the Bureau's gauges were not active, however the nearby gauges of Canning and West Canning were. Data for these gauges is now available from the Department of Water and Environmental Regulation. This period saw 494 mm fall at Canning, and 532 mm at West Canning, with peak daily totals of around 115 mm on 1st February, as shown in Figure 4-3. Whilst peak event totals were less for this event, the cumulative total rainfall for the period was close to the highest on record.

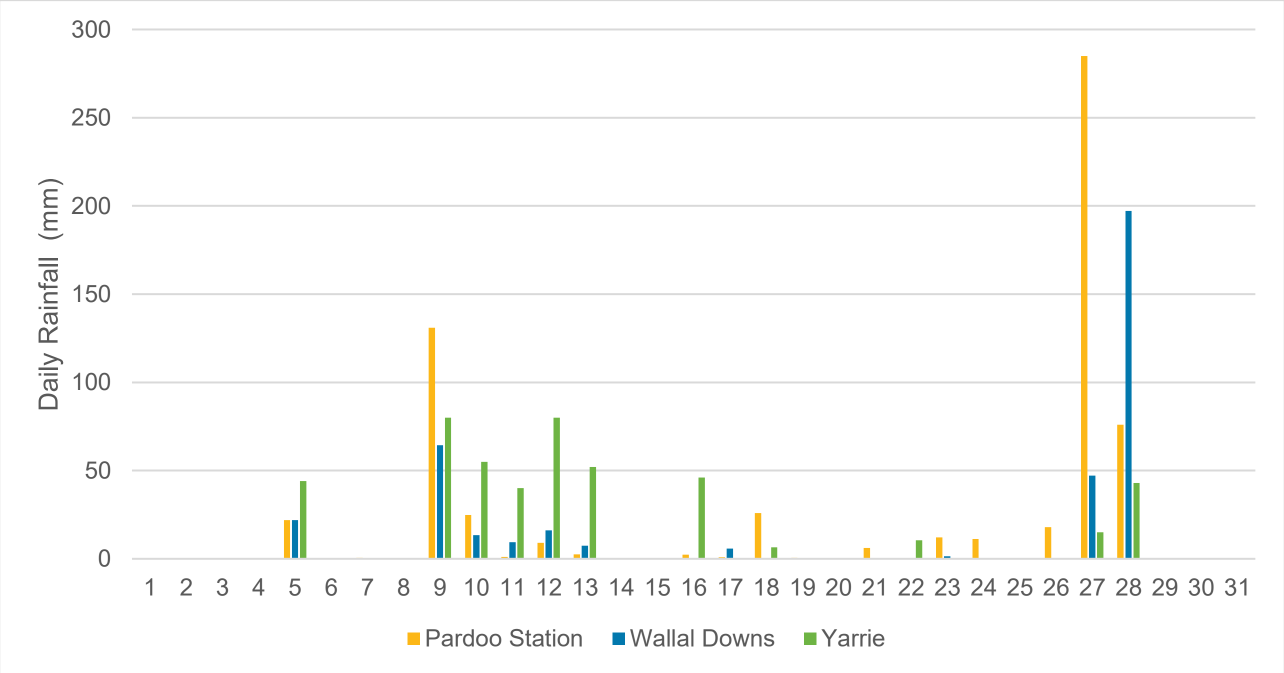

Figure 4-1 Bureau of Meteorology Daily Rainfall for March 2007

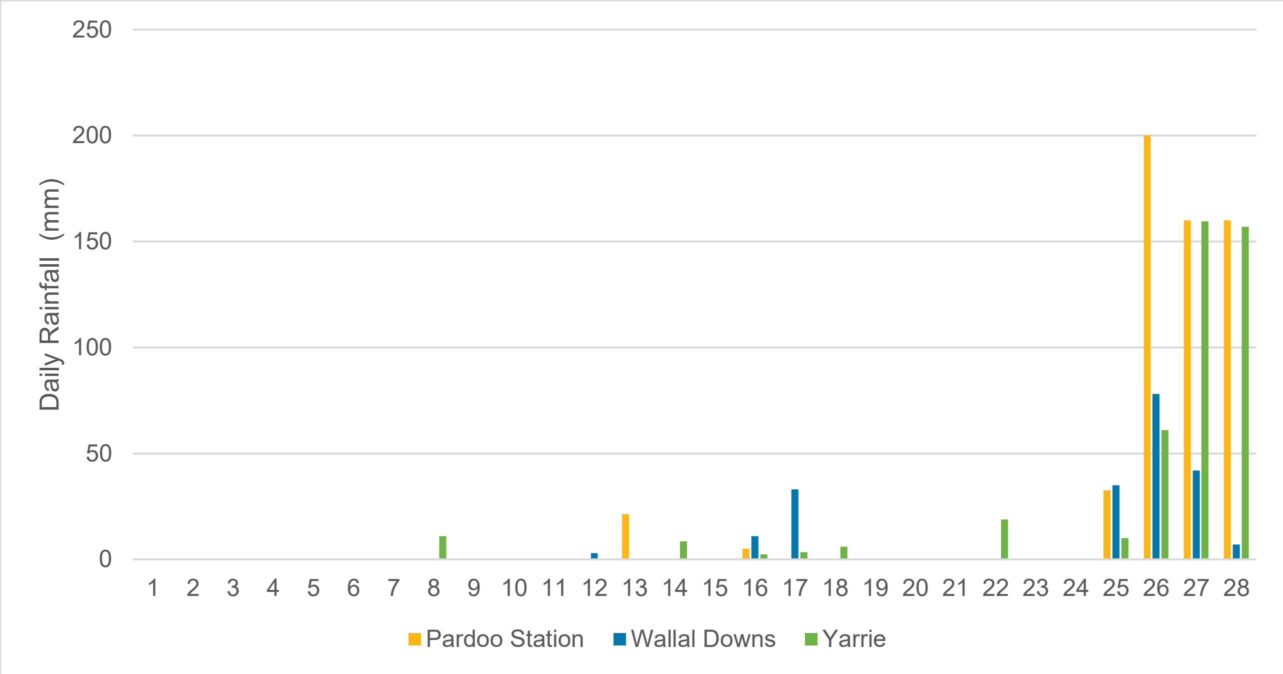

Figure 4-2 Bureau of Meteorology Daily Rainfall for February 2013

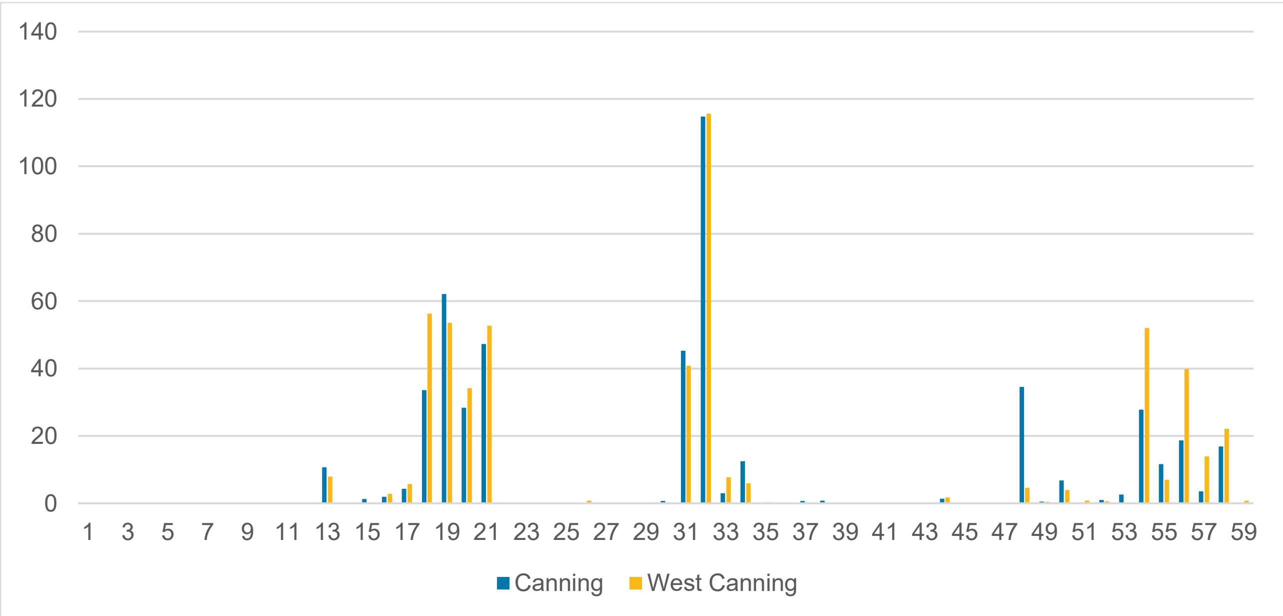

Figure 4-3 Department of Water and Environmental Regulation Daily Rainfall for January – February 1982

5 HYDRAULIC MODEL

A hydraulic model was developed to determine the extent, duration and frequency of flooding of the Ramsar listed area surrounding the Stage 3 Development. A TUFLOW GPU model of the entire catchment was initially developed, using a two-dimension grid with rainfall applied directly onto each grid cell. This was subsequently refined to provide a more localised assessment.

5.1 Grid Extent and Resolution

Topography for the catchment was available from Satellite and Photogrammetry data as presented in Section 2.2.

An initial model was schematised that extended from the top of the catchment to the south as shown in Figure 2-1, to downstream of the proposed Stage 3 development at the coast to the north. A 30 m resolution grid was adopted for this initial model, covering the 2,500 km^2 sub-regional catchment. At this grid size small floodplain features, such as creeks and roads, are not well represented. However, there is only one major road within the catchment and no major creek systems, just wide, flat surface depressions. Hence, the initial grid size allowed for adequate modelling of the dominant features of the site whilst maintaining manageable model run times.

Following the initial model testing and analysis, a revised smaller model extent (of 19,500 ha) was established covering the low lying Ramsar listed areas, the Stage 3 site, and extending to just upstream of the Great Northern Highway. This smaller model size was selected because it was determined to be the key area that determined flooding of the coastal floodplain adjacent to the Stage 3 project. The initial model testing established that the upper catchment (those areas upstream of the highway) did not generate significant surface runoff which would impact the surface ponding in the low-lying areas downstream (as would be expected of a desert catchment). Several other factors also supported this finding, including:

- No evidence of concentrated flow paths;
- No major waterway crossings on Great Northern Highway;
- No overland flow detected in satellite imagery; and
- Very high saturated conductivity rates for the dominant catchment soils from the infiltration test results.

Therefore, it was concluded that the upper catchment did not contribute any significant runoff to the downstream low-lying areas surrounding and including the Stage 3 development and these areas were therefore excluded from the final model extent. This is consistent with the recommended 10 mm/hr continuing loss rate from the Australian Rainfall and Runoff (ARR) online Data Hub.

The final model extent is shown in Figure 5-1, which is approximately 195 km^2. The grid resolution in the smaller model was reduced to 20m, which allowed for adequate resolution of the catchment features, whilst maintaining reasonable run times given the very long durations of rainfall events being modelled.

5.2 Manning's Roughness

The Manning's 'n' roughness parameter impacts on flood velocities, flow paths, flood depths and extents. The catchment is a predominantly natural rural landscape, with the only manmade feature being the Great Northern Highway. The lack of historic flood data for this area and the relative homogeneity of the landscape make it difficult to categorise spatially variable roughness areas with any certainty. For this reason, and from previous experience in nearby catchments, a constant manning's 'n' roughness coefficient of 0.05 was selected. This was deemed suitable because it represents sparse to moderately vegetated natural land, which is consistent with the surrounding landscape.

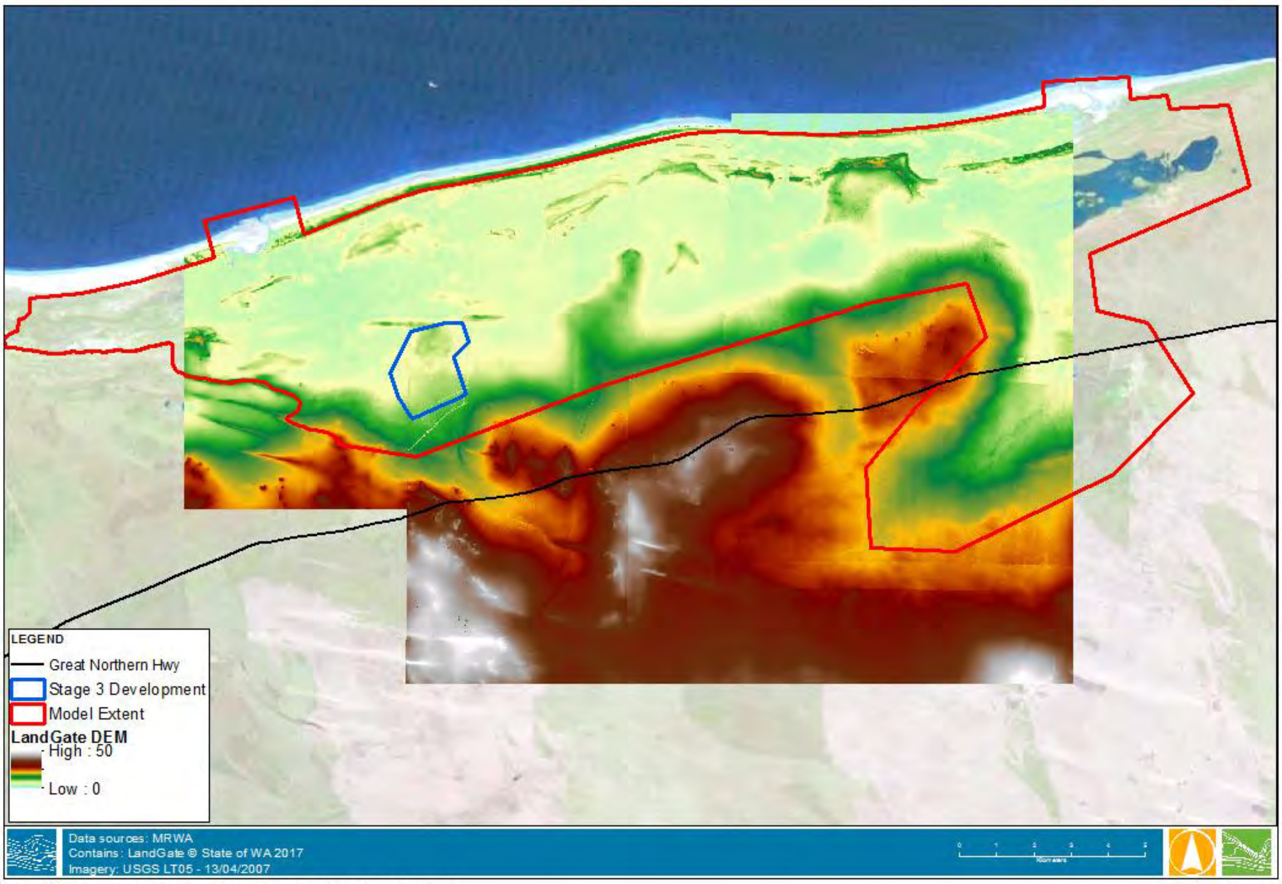

Figure 5-1 Final Hydraulic Model Extent

5.3 Boundary Conditions

5.3.1 Rainfall

The rainfall was applied for the three events from the daily rainfall gauge data presented in Section 4, for March 2007, February 2013, and January-February 1982. Point daily rainfall totals were extrapolated across the model extent using Inverse Distance Weighted (IDW) interpolation through the inbuilt tools in TUFLOW.

5.3.2 Tidal Levels

The nearest tide gauge to the site is in Port Hedland, approximately 140km west, with another gauge at Broome approximately 330 km north east up the coast. Recent Coastal Vulnerability Studies have been completed for both Port Hedland (2011)[1] and Broome (Cardno, 2015). The Port Hedland study covered the area of Shellborough, which is just 55 km west of the Stage 3 Development, which will have similar coastal conditions. Table 5-1 summarises the key tide and storm surge levels at Port Hedland, Shellborough and Broome from these two studies.

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[1] http://www.porthedland.wa.gov.au/Assets/Appendix_XIV_-_Cardno_Coastal_Vulnerability_Report.pdf

TABLE 5-1 SUMMARY OF PEAK TIDE AND STORM SURGE LEVELS

Tidal Plane	Port Hedland (m AHD)	Shellborough (m AHD)	Broome (m AHD)
Highest Astronomical Tide (HAT)	3.6	-	5.24
Mean High Water Springs (MHWS)	2.8	3.4	3.96
10% AEP Design Peak Total Still Water Level (TSWL)	3.8	4.7	5.26
1% AEP Design Peak Total Still Water Level (TSWL)	4.7	5.9	5.39

The low-lying ground within the Ramsar listed area is almost all above the Mean High Water Spring (MHWS) tide at Shellborough of 3.4 m AHD. Parts of the Ramsar site would become inundated in the 10% Annual Exceedance Probability (AEP) Design Peak Total Still Water Level (TSWL), with extents increasing for higher event magnitudes. The extent of flooding from coastal inundation due to storm surge within the modelled area is likely to be minor due to the restricted openings to the ocean through the extensive coastal dune system and the limited volume and duration of any storm tide event.

For flooding to occur at this location, a very large amount of rain needs to occur over multiple days, resulting in pools that slowly recede over several weeks. Whilst a large storm tide may inundate this area, the duration of flood impact would be less than 24 hours, with very little impact on the recession of flood waters. Hence the most relevant ocean boundary condition is the MHWS level. The extent and duration of inundation at the Stage 3 site is unlikely to be affected by peak storm surge events due to the elevation of the land being above 7 m AHD and the relatively short duration and timing of the storm tide events compared to rainfall events. Hence, the MHWS level of 3.4 m AHD was adopted for the ocean boundary condition.

5.3.3 Infiltration Losses

The infiltration losses have a significant impact on the extent and duration of flooding. Soil mapping data was sourced from the Department of Primary Industries and Regional Development at the best available scale. This data was classified for the purposes of this model into two broad classes, being the sandy 'Pindan' red earth soils, and the silty clay grey soils, shown in Figure 5-2. The infiltration of water into the soils is represented in the model using a continuing loss applied in the soils layer. This ensures the infiltration losses are still being applied after the rainfall stops, as opposed to taking the continuing loss directly out of the rainfall.

The recommended continuing loss from the Australian Rainfall and Runoff (ARR) data hub for this area is 10 mm/hr, which equates to 240 mm/day. Given the highest daily rainfall total on record is 285 mm, this means infiltration excess runoff is unlikely. Saturation excess runoff is also unlikely given the depth to groundwater is typically greater than 3 m (Groundwater Consulting Services, 2017a).

The infiltration tests demonstrated that the Pindan soils were very permeable, with rates upwards of 150 mm/hr, which does mean it is unlikely that any runoff would be generated from these areas. This is consistent with the lack of defined concentrated flow paths and the lack of waterway openings under the Great Northern Highway. However, infiltration testing and satellite observations indicate that the grey silty clay soils are much less permeable and have the capacity to pond water at the surface for periods of time.

5.3.4 Evaporation Losses

During the recession periods for flooding, evaporation also contributes to losses along with infiltration. The nearest evaporation records are from Port Hedland, which has a record going back to 1967, covering the three rainfall events discussed in Section 4. The evaporation rates for these three events are summarised in Table 5-2, showing the mean, maximum and minimum daily pan evaporation rates across the events including the following month as the flooding recedes. The table shows the average evaporation losses are approximately 8-10 mm/day, which equates to less than 0.5 mm/hour. For the Pindan soils the evaporation is insignificant compared to infiltration, however the grey silty clay soils will cause water to pond and evaporation to occur.

TABLE 5-2 SUMMARY OF PAN EVAPORATION RATES AT PORT HEDLAND

Event	Mean Daily Evaporation (mm)	Maximum Daily Evaporation (mm)	Minimum Daily Evaporation (mm)
March 2007	7.9	16.4	2.2
February 2013	9.9	17.8	0.8
Jan-Feb 1982	8.7	15.6	2.2

5.3.5 Adopted Continuing Loss Rate

The extent and duration of flooding is very sensitive to the assumed continuing loss rates due to infiltration and evaporation. Through the values derived above and testing of the hydraulic model, the following loss rates were assumed to represent the combined losses due to infiltration and evaporation.

TABLE 5-3 ADOPTED CONTINUING LOSS RATES

Soil Type	Continuing Loss Rate
Red Sandy ‘Pindan’	10 mm/hr
Grey Silty Clay	0.5 mm/hr

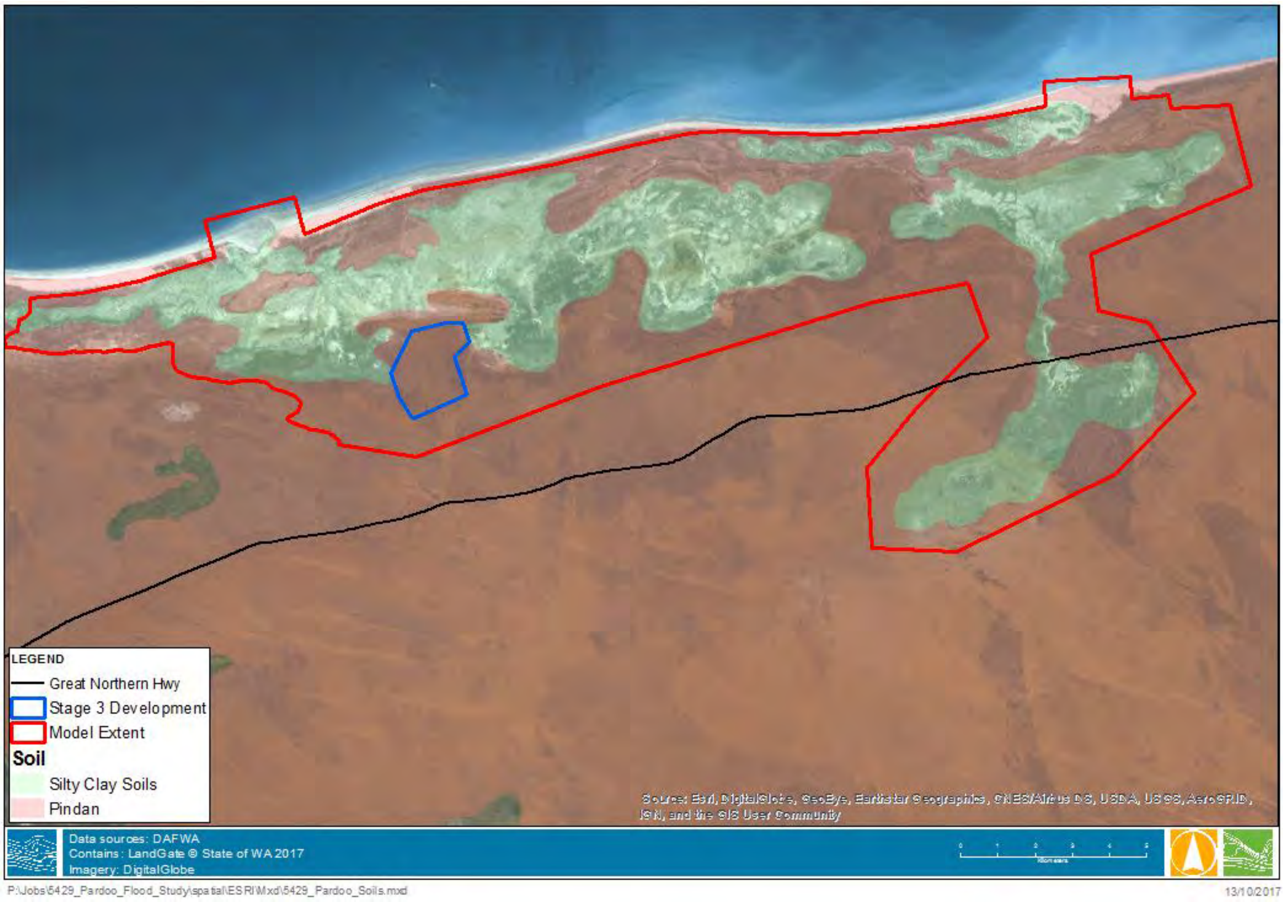

Figure 5-2 Classification of Model Soil Types

6 HYDRAULIC MODEL RESULTS

The hydraulic model was run for the three historical rainfall events from March 2007, February 2013 and January-February 1982. The March 2007 event had very good satellite imagery for the weeks after the rainfall event, hence it was used to verify the modelling assumptions.

The following set of figures (Figure 6-1 to Figure 6-4) show the comparison between model results and satellite imagery flood extents for March 28th, April 5th, April 13th and April 29th. The first image was captured shortly after the final rainfall burst and shows widespread flooding, which is well represented in the model. The next few images show the weeks after the event, with the model results reflecting the observed slow shrinking of the pooled flood water.

Whilst there are some discrepancies in the results, this can mostly be attributed to the quality of the available terrain data, and the banding effects discussed previously. The overall extent and rate of retreat of the modelled flood water matches reasonably well with the observed satellite imagery and validates the model assumptions. These same assumptions were used to model the other two events.

No significant surface flows occur across the proposed Stage 3 area due to the high infiltration rates of the Pindan soils. Ponding occurs across parts of the adjacent Ramsar wetland due to the presence of the more clayey soils, however there is no obvious interaction between the two areas.

Plots of depth versus time at locations east and west of the site are shown in Figure 6-6 and Figure 6-7 for the March 2007 and Jan-Feb 1982 events, with the locations shown in Figure 6-5. The clay pan to the east of the Stage 3 site gets to approximately 1 m deep before it overflows to the nearby lower ground, then slowly infiltrates and evaporates over time. The clay pan to the west of the Stage 3 site is lower and maintains a slightly deeper depth of water before it also slowly recedes.

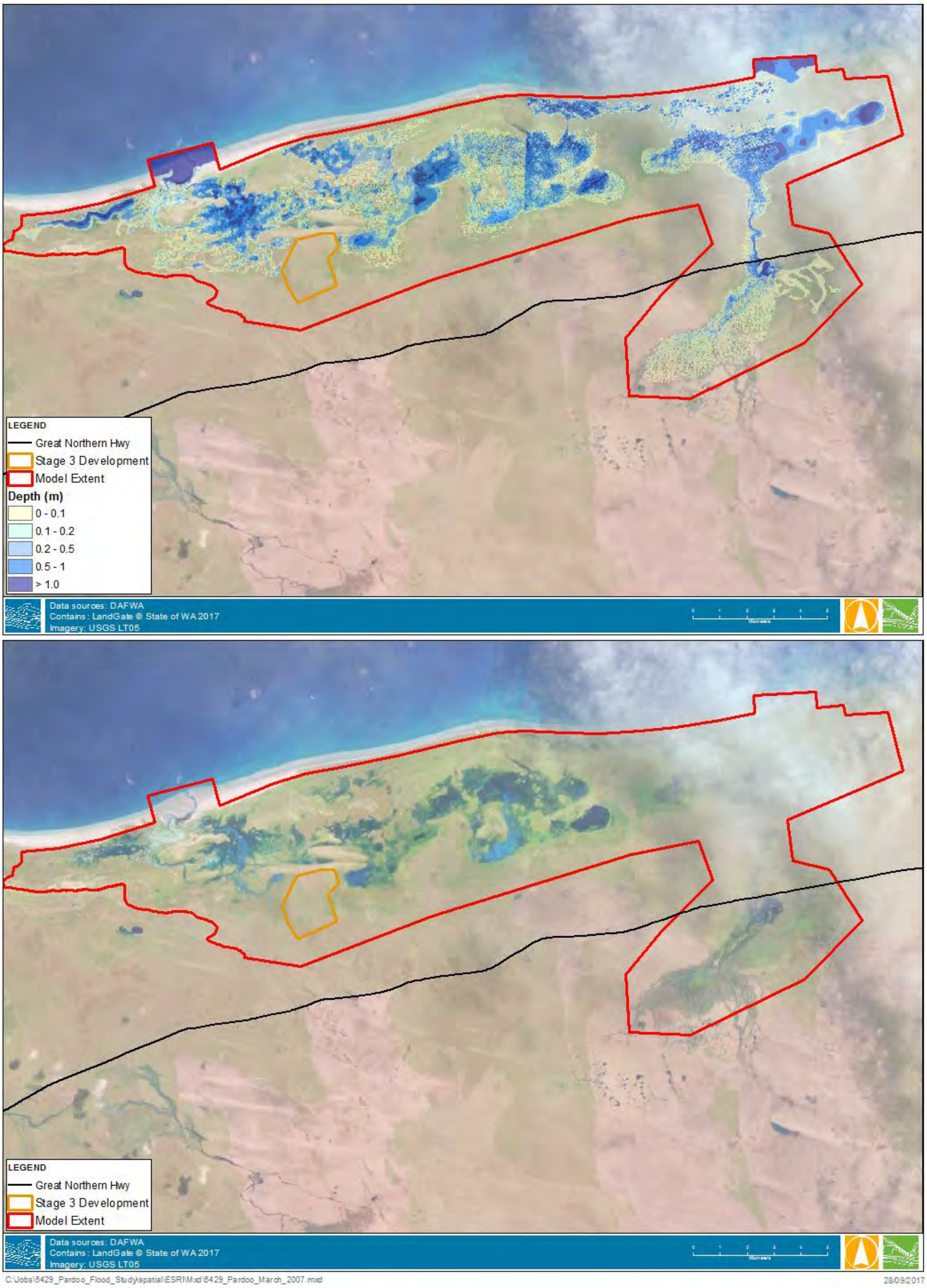

Figure 6-1 March 2007 Flood Event – Modelled (upper) Vs Satellite (lower) – 28th March

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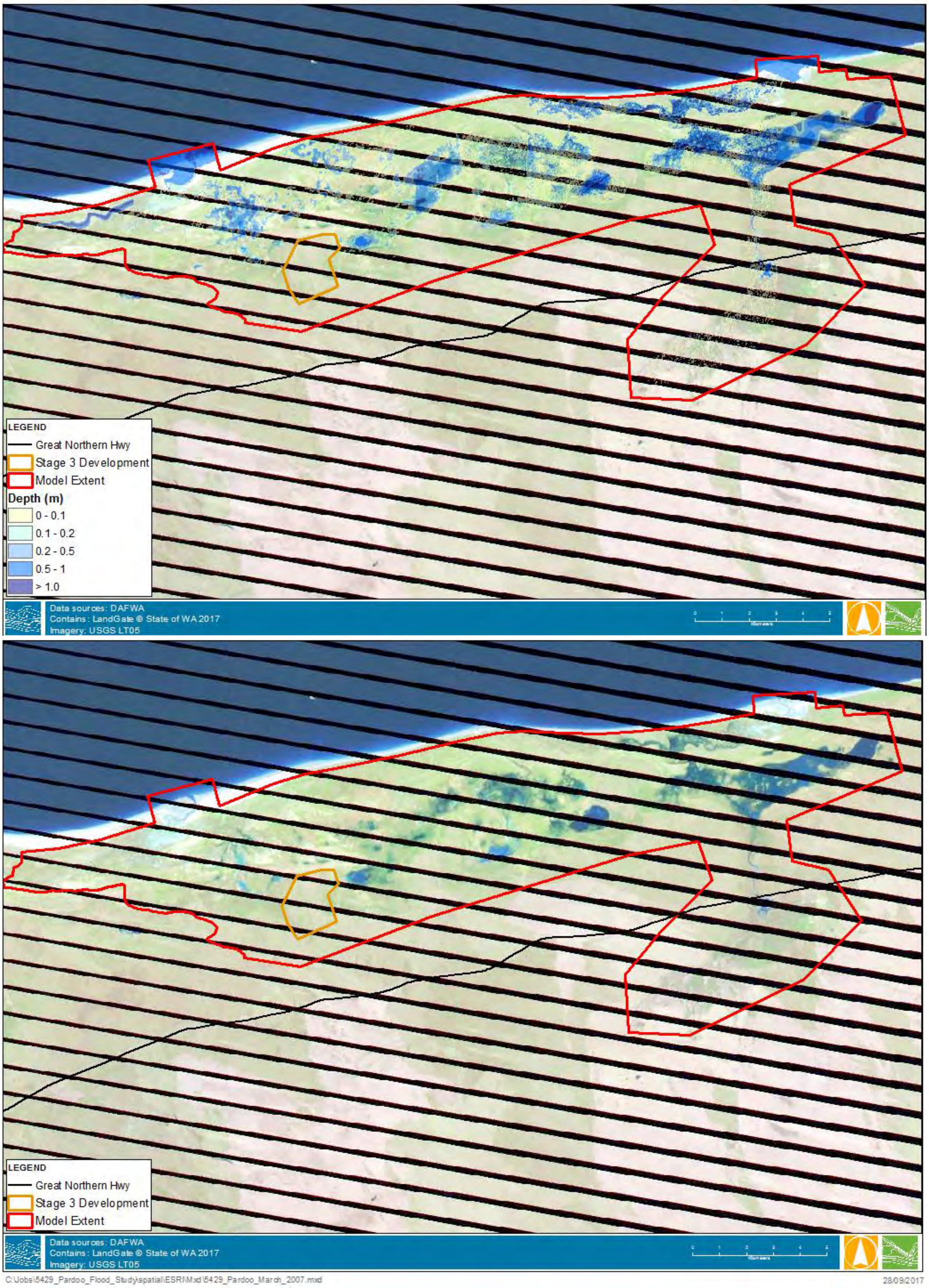

Figure 6-2 March 2007 Flood Event – Modelled (upper) Vs Satellite (lower)– 5th April

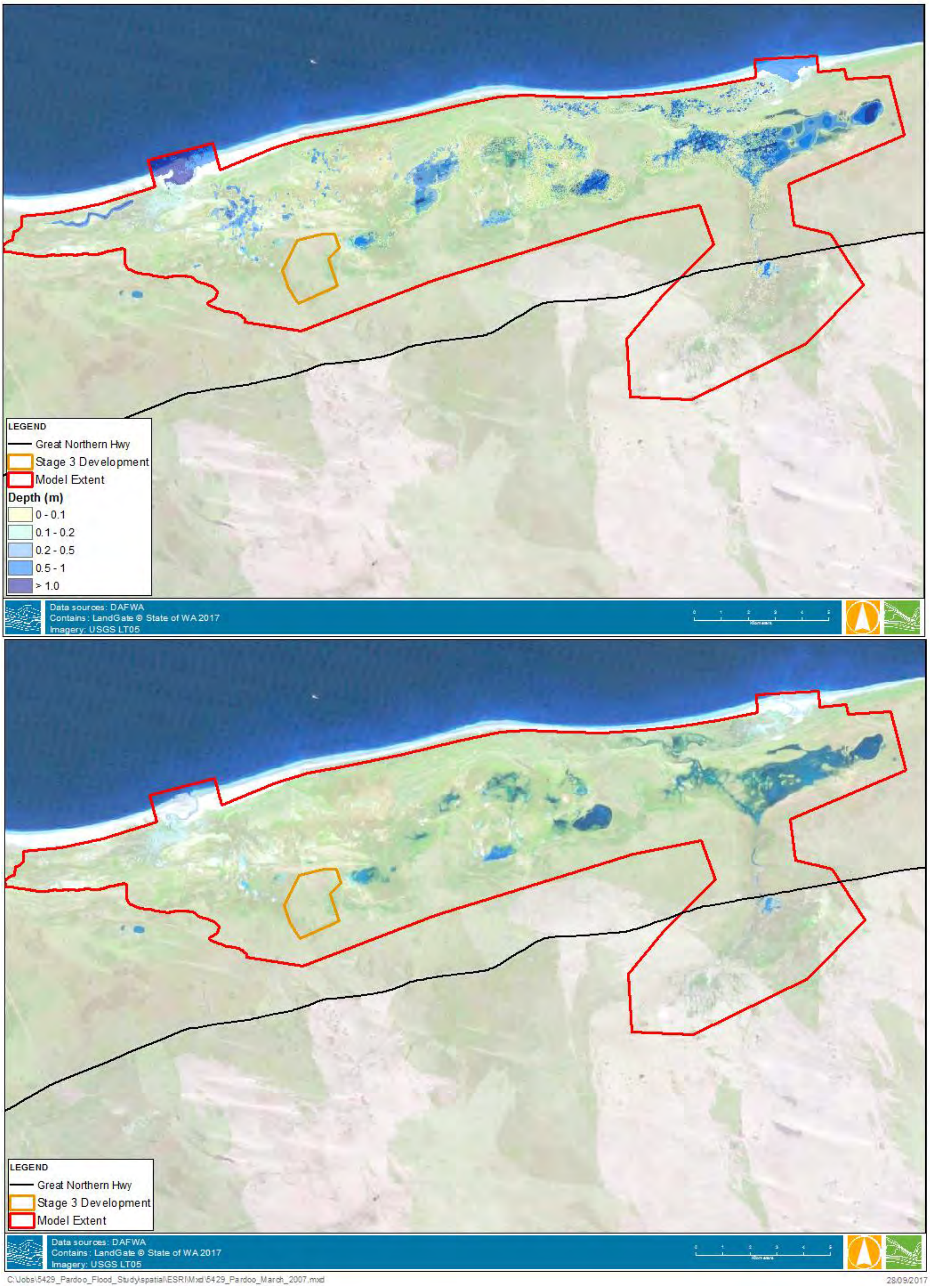

Figure 6-3 March 2007 Flood Event – Modelled (upper) Vs Satellite (lower) – 13th April

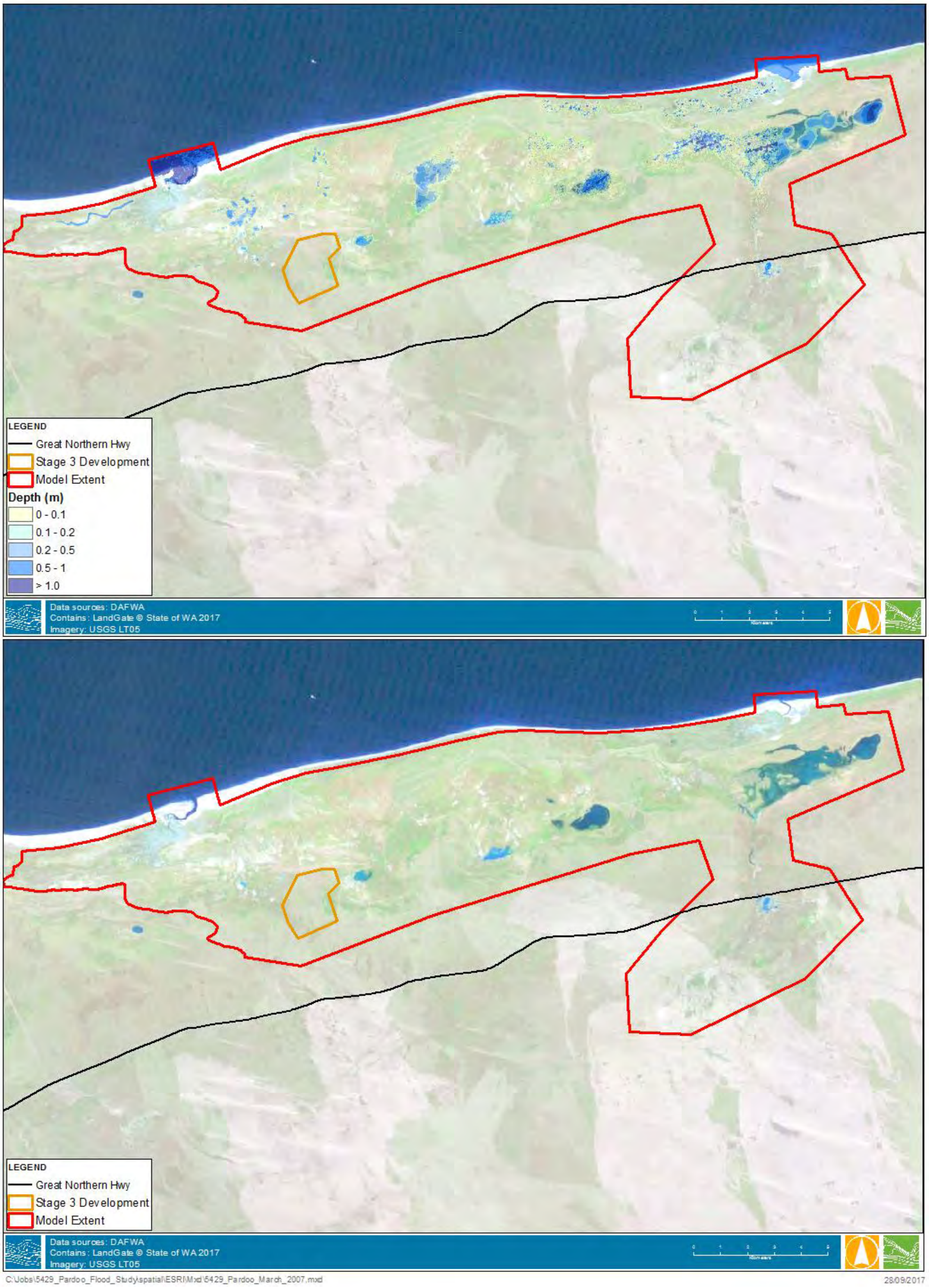

Figure 6-4 March 2007 Flood Event – Modelled (upper) Vs Satellite (lower) – 29th April

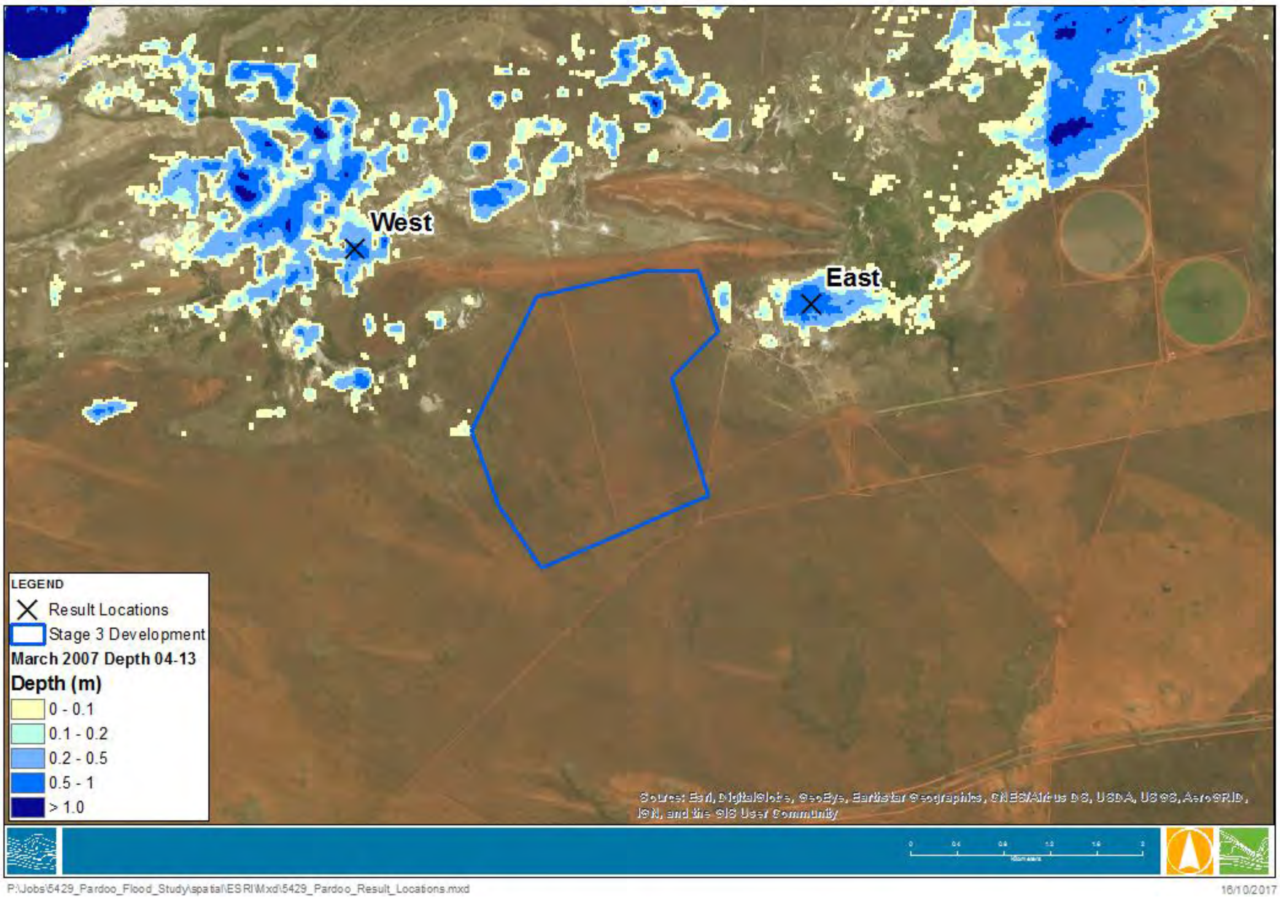

Figure 6-5 Location of Plot Outputs East and West of Stage 3 Development

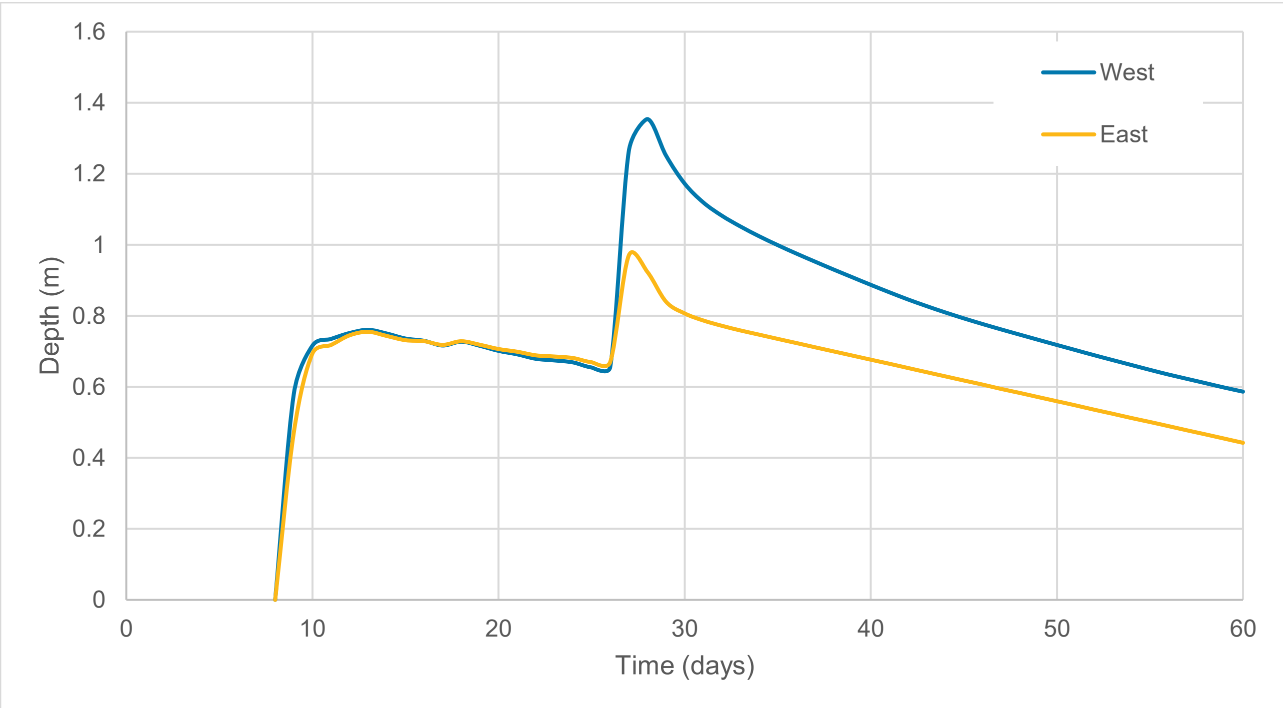

Figure 6-6 March 2007 Flood Depths at Nearby Locations

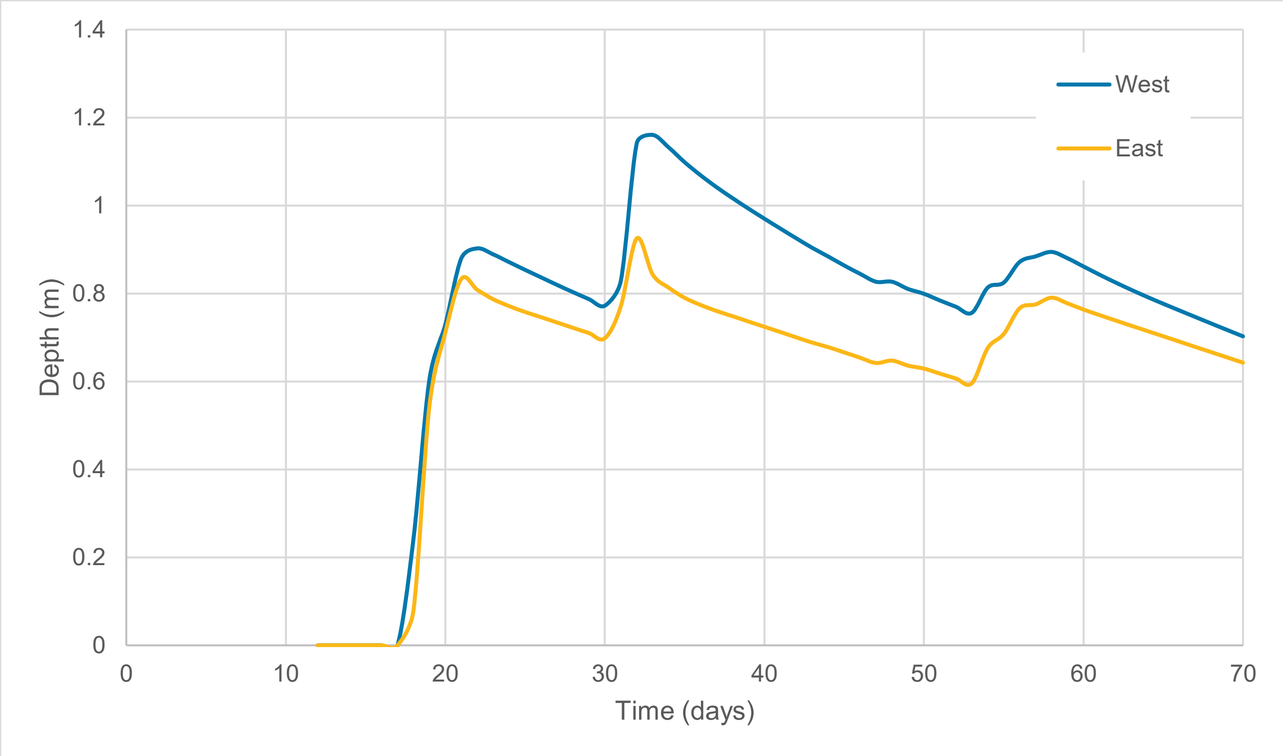

Figure 6-7 January-February 1982 Flood Depths at Nearby Locations

6.1 Frequency, Extent and Duration of Flooding

An analysis of historical rainfall patterns indicates that historically prolonged heavy rainfall events sufficient to produce flooding of the Ramsar wetland adjacent to the Stage 3 project area occur approximately every 10 years. Climate change predictions for the area indicate that rainfall events are to increase in intensity by between 9.5% and 19.4% by the year 2090, meaning prolonged flooding could possibly occur every 5 years by the year 2090 (Ball, et al., 2016).

The 2007 event is the largest monthly rainfall record available and provides a good basis for estimating flood extents and duration. Based on this event, within the modelled area (of 19,500 ha) when flooded, it is estimated that approximately 1,100 ha of open shallow ponds occur which are flooded for periods of 1 – 2 weeks and approximately 350 ha of open shallow ponds occur which are flooded for periods of 3 – 5 weeks. Figure 6-8 provides a map of these areas.

Figure 6-8 Duration of maximum inundation in vicinity of Stage 3 Development

6.2 Water Balance

Clearing and earthworks will affect approximately 280 ha of land, within the Pindan red sandy soil type. Irrigation will be carried out on 266 ha of the Pindan red sandy soil type. A site water balance was undertaken to understand the impacts of the changed land use conditions on the overall hydrology of the site.

The Stage 3 developments site is primarily the Pindan red sandy soil type, which has a very high infiltration rate of around 155 mm/hour (Section 4.4.3.5). After clearing, earthworks, and crop establishment, it is expected that the infiltration rate in these areas will not change significantly, because the soil will remain in situ. The site experiences an average annual rainfall of approximately 320 mm.

Irrigation is expected to add 4.123 GL annually to the pivots over the 266 ha irrigation area, which equates to 1,550 mm of water applied annually per m^2, as summarised in Table 6-1. The combination of annual rainfall and irrigation on the pivot areas results in 1,870 mm/m^2 of water falling on the pivot areas annually (320 mm of rainfall and 1,550 mm of irrigation water).

Water will be lost through evaporation and evapotranspiration. The average evaporation rate for Port Hedland is approximately 9 mm per day (3,285 mm per year). Evapotranspiration can be estimated using the Areal Potential Evapotranspiration Rate (APER). Assuming a crop factor for grazed pasture up to 300 mm is 0.85 – 1.0, the APER for the site is around 1,755 mm/yr. The proposed Rhodes Grass crop has a height of 0.5 m when fully grown and around 0.2 -0.3 m when grazed.

The net water balance for the site (excluding evaporation) is provided in Table 6-1. Evaporation has not been included due to the high infiltration rates of the soil however some loss to evaporation is likely to occur, and hence the net water load for the site is a conservative estimate.

TABLE 6-1 WATER BALANCE SUMMARY

Parameter	Value	Units
Irrigation Area	266	ha
Annual Water Applied	4.123	GL
Total Annual Water Applied	4,123,000,000	L
Annual Water Applied per ha	15,500,000	L/ha
Annual Water Applied per sq meter	1,550	mm/m^2
Annual Rainfall	320	mm
Total Water Load to Stage 3 per year	**1,870**	**mm/m^2/year**
Evapotranspiration	1755	mm/year
Net Water Load (excluding evaporation)	**115**	**mm/m^2/year**

The results indicate that the annual 1,550 mm/m^2 of irrigation water being applied to the crops will be used by the plants and lost to the atmosphere via evapotranspiration.

It is unlikely that irrigation water will infiltrate to groundwater as it will be captured in the plant root zone and utilised in evapotranspiration.

This is the aim of Pardoo Station as the application of irrigation water is expensive and the economic objective is to apply no more water than is necessary for plant growth. As such irrigation is ceased when rainfall is predicted or has recently occurred.

7 NUTRIENT IMPACT ASSESSMENT

7.1 Nutrient Balance and movement

Nutrient balances provide information about environmental pressures. A nutrient deficit indicates declining soil fertility. A nutrient surplus indicates a risk of polluting soil and/or water. The nutrient balance is defined as the difference between the nutrient inputs entering the plant root zone system (mainly livestock manure and fertilisers) and the nutrient outputs from the system (the uptake of nutrients for crop and pasture production).

The key indicators of nutrient load are nitrogen and phosphorus, and are measured in tonnes of nutrient and in kilograms of nutrient per hectare of agricultural land.

7.2 Grazing Crop - Rhodes Grass

Rhodes Grass will be grown within the irrigated area and separated into zones for progressive grazing. Rhodes Grass has a high nutritive value and provides environmental benefits such as providing soil stabilisation and competing with weed species (Tables 7-1 and 7-2).

The Stage 3 cattle stocking rate will be determined in the field based on crop performance and yield. As such the nutrient credits for organic matter (OM) and manure input prevents a conventional nitrogen balance calculation, i.e. application rate N/ha = yield – OM – N_{soil}, where N_{soil} is the total nitrogen in the plant root zone.

The proposed nutrient application rates for Rhodes Grass to be applied for the Stage 3 project have been provided in Table 7-3 (DPIRD, 2017).

TABLE 7-1 NUTRITIVE VALUE FOR RHODES GRASS

Dry matter digestibility	61-65% (monthly cuts), 49-56% (when cut after 105-140 days)
Crude protein	6.3% (unfertilised), 10.4-13.8% (low to high fertiliser N with monthly cuts)

Source (DPIRD, 2017)

TABLE 7-2 ENVIRONMENTAL BENEFITS FOR RHODES GRASS

Soil erosion control	Creeping habit provides good soil stabilisation
Weed control	Competes well with summer weeds

Source (DPIRD, 2017)

TABLE 7-3 RHODES GRASS NUTRIENT APPLICATION RATES

Nutrient	Nutrients Required (kg/ha/year)
Nitrogen	700
Phosphorus	20
Potassium	200

7.3 Factors Affecting Site Nutrient Balance

Factors affecting irrigation water quality concern physical, chemical and biological characteristics that may affect the soil environment and crop growth.

7.3.1 Background Water Quality

Water for irrigation is groundwater sourced from the artesian Wallal aquifer with salinity (total dissolved solids) ranging from 500 - 680 mg/L with negligible nutrients (Groundwater Consulting Services, 2017a), (Table 7-4). The nutrient balance would exclude source water as a contributor to nutrient loads from irrigation.

There is a shallow aquifer beneath the station (Broome aquifer) which will receive infiltrating water. The depth to water is likely to range from 3-10m depending on topography within the Stage 3 area. The salinity at the water table ranges from about 750mg/L in the southern areas to over 2,500mg/L beneath the edge of the coastal plain in the Ramsar zone. The Broome aquifer contains nutrients naturally throughout the region (refer to monitoring bores BMB2 and BMB2 chemistry data for representative conditions of the Stage 3 project area – Table 7-4), (Groundwater Consulting Services, 2017a).

TABLE 7-4 SUMMARY OF GROUNDWATER MONITORING OF SELECTED BORES

Analyte	Wallal Aquifer (Bores PB1, PB2, PB3, PB4 and WCB17C)	Broome Aquifer (Bores BMB2 and BMB3)
pH	6.52 – 7.5	7.6 – 8.1
Electrical Conductivity (µS/cm)	910 – 1270	1560 - 2560
Total Dissolved Solids (mg/L)	500 - 680	1000 - 1600
Hardness (mg $CaCO_3$/L)	80 - 180	20 - 100
Nitrate (NO_3) (mg/L)	<0.01 – 0.09	0.9 - 22
Nitrate (N) (mg/L)	<0.002 – 0.5	0.2 – 4.9
Total Nitrogen (N) (mg/L)	<0.1 – 0.5	0.4 - 5.3
Phosphate (mg/L)	<0.005 – 0.02	<0.01 – 0.09
Total Phosphorus (P) (mg/L)	<0.01 – 0.2	0.01 – 0.13

7.3.2 Soil Conditions

Soils logging for shallow leach bores (MB1-3) indicate fine-grained non-dispersive red pindan sands with increasing clay fraction and gravels approximately 1.5 to 7 metres deep over sandstone in the proposed irrigation site. Depth of sand varies according to location, greater further inland. The Average depth to ground water is around 3-10 metres. Sands are free draining and permeability has been measured at approximately 3.7 metres/day, as described in Section 3. On this basis, the risk of nutrient leaching especially nitrates would be considered high.

7.3.3 Nutrient Leaching below the Root Zone

Soils with high water infiltration rates and low nutrient retention capacity, such as sandy soils and well-structured ferrallitic soils with low activity clays and low organic matter contents, are particularly conducive to nutrient leaching (Von Uexkull, 1986). Leaching can also occur as a result of a large rainfall event causing mineralization of organic nitrogen to flush below the root zone. Phosphorus is relatively immobile, and adsorption will occur mainly within the root zone, especially given the low Phosphorous Buffering Index (PBI) results of soils testing which makes the phosphorus available for plant uptake in the root zone (Table 7-5).

To understand the potential increase of nutrients leaching into the groundwater, soil samples were retrieved and tested (Table 7-5) in locations:

- Within the existing irrigated pivots;
- In soil outside and adjacent pivots;
- In natural (pre-development) soils in the Stage 3 project area; and
- In the Ramsar wetland.

Note that soil samples were taken in the root zone and in shallow soils. Elevated levels within the irrigation areas (P01, P03 and P05) are expected (refer to yellow highlighted cells in Table 7-6). Nutrient levels outside of the irrigation areas (P02, P04 and P06) indicate little to no migration laterally (refer to purple highlighted cells in Table 7-6).

The Ramsar soils contain elevated levels of nutrients, organics and salts which are several orders of magnitude higher than the soils within the irrigation project area (refer to blue highlighted cells in Table 7-6). This is expected given the paleo-tidal nature of the clays and silts within the Ramsar area which would naturally contain higher levels of these analytes, given their origin as ancient saline tidal mudflats. In addition, these areas flood occasionally after heavy prolonged rainfall and natural evaporation processes would lead to the concentration of salts within the soils. The nutrient levels in the Ramsar area are indicative of the background water quality of the Broome aquifer in the shallow clay soils in the wet zone, downstream of the site.

TABLE 7-5 SOIL ANALYSIS RESULTS

Analyte		P01	P02	P03	P04	P05	P06	S301	S302	S303	R01	R02	R03	R04
	Location	Stage 1 Pivot 1	Stage 1 Pivot 1 outside	Stage 1 Pivot 2	Stage 1 Pivot 2 outside	Stage 1 Pivot 6	Stage 1 Pivot 6 outside	Stage 3 1	Stage 3 2	Stage 3 3	Ramsar 1	Ramsar 2	Ramsar 3	Ramsar 4
Ammonium	mg/Kg	< 1	1	< 1	< 1	< 1	< 1	< 1	2	2	2	< 1	< 1	2
Nitrate Nitrogen	mg/Kg	4	2	2	< 1	5	< 1	< 1	< 1	2	8	3	4	12
Phosphorus	mg/Kg	26	3	5	3	11	4	< 2	2	3	5	40	17	30
Potassium	mg/Kg	41	75	50	36	34	25	33	32	42	659	733	342	571
Sulphur	mg/Kg	6.2	1.2	36.4	1	7.8	0.8	0.7	1.1	1.3	435.2	30.6	1496	189
Organic Carbon	%	0.52	0.59	0.67	0.29	0.68	0.29	0.37	0.37	0.65	2.49	1.46	0.83	2.23
Conductivity	dS/m	0.073	0.014	0.265	0.011	0.06	0.013	<	0.013	0.017	7.807	0.499	6.233	0.678
pH Level (CaCl2)	pH	6.8	5.1	7	5.8	7.2	6.7	6.1	6	5.6	7.5	8.7	8.2	8.3
pH Level (H2O)	pH	7.6	6.3	8.1	7	7.7	7.5	7.1	7.1	6.6	7.4	9.9	8.5	9.4
DTPA Copper	mg/Kg	0.53	0.33	0.63	0.36	0.66	0.29	0.27	0.33	0.27	0.18	0.49	0.19	0.6
DTPA Iron	mg/Kg	8.1	7.94	19.2	3.15	7.94	1.65	3.38	3.12	10.09	2.26	6.02	4.88	14.41
DTPA	mg/Kg	1.66	6.38	2.53	3.53	2.19	2.88	3.12	4.61	7.81	12.19	3.33	1.03	3.18
DTPA Zinc	mg/Kg	0.85	0.07	0.73	0.06	1.07	0.09	0.05	0.06	0.1	0.15	0.12	0.06	0.17
Exc. Aluminium	meq/100g	0.067	0.158	0.139	0.175	0.11	0.093	0.114	0.19	0.099	0.022	0.018	0.029	0.033
Exc. Calcium	meq/100g	1.7	1.45	1.96	1.01	1.99	1.29	1.47	1.48	2.34	30.42	9.98	9.88	14.52
Exc. Magnesium	meq/100g	0.39	0.37	0.59	0.23	0.69	0.19	0.25	0.23	0.48	8.82	2.12	2.81	3.97
Exc. Potassium	meq/100g	0.08	0.14	0.1	0.05	0.07	0.03	0.05	0.05	0.07	1.6	1.8	0.76	1.42
Exc. Sodium	meq/100g	0.32	0.02	1.51	0.05	0.21	< 0.01	< 0.01	0.02	0.03	17.17	9.55	27.51	9.65
Boron Hot CaCl2	mg/Kg	0.53	0.18	0.69	< 0.10	0.54	0.11	< 0.10	0.12	0.12	2.34	6.05	3.47	15.73
PBI		8	11.5	8.7	10.2	5.7	5.9	6.8	8.7	9.8	94.2	509	180.4	143.5

Table Note: Green highlighted cells show naturally elevated levels of nutrients, organics and salts within the Ramsar soil sampling locations.

7.3.4 The Broome Aquifer

The Broome Aquifer lies in the sandstone below approximately 5m depth declining with the surface slope to the north east. Groundwater flux would be expected to be slow due to the gradient, and rainfall and surplus irrigation water would permeate to the water table quickly through the sand profile (Groundwater Consulting Services, 2017a).

7.3.5 Groundwater flow

Groundwater Consulting Services (pers. comm, 2017) estimated groundwater through-flow in the Broome aquifer using Darcy's Law which describes water flow through porous media based on knowledge of the aquifer locally (Groundwater Consulting Services, 2017a); (Groundwater Consulting Services, 2017b). The flow rate is related to the aquifer thickness, width and permeability and the hydraulic gradient. The purpose of the calculation is to gain perspective on the rate of nutrient leaching during irrigation at Stage 3.

- The aquifer width for the purposes of the throughflow calculations is taken as the width of the irrigated area, measured perpendicular to the direction of groundwater flow. Groundwater flows to the north, and the Stage 1 project area is approximately 1,800m wide west to east (Figure 7-1).
- The aquifer saturated thickness was determined from the thickness of the Broome sandstone intersected in bores PB8, PB9 and PB10 installed for irrigation of Stage 3, less 5m which is taken as an average depth to water under the irrigation area (Groundwater Consulting Services, 2017b). The average thickness is 68m.
- The hydraulic conductivity is assumed to be 8m/day which is the average hydraulic conductivity determined for the Broome Sandstone from pumping tests conducted by (Leech, 1979) for the four bores nearest to Stage 3. Visual observations of materials intersected during drilling at Stage 3 indicate that the Broome Sandstone has a hydraulic conductivity estimated at 8m/day or greater. Hydraulic testing has not been conducted in the Broome aquifer by Groundwater Consulting Services.
- The hydraulic gradient taken from Leech (1979) for the area upgradient of Stage 3 is approximately 0.0026 (20m in 7.7km). A hydraulic gradient calculated from recent monitoring data collected by Groundwater Consulting Services is 25m in 10km (Groundwater Consulting Services, 2017a). Therefore, 0.0025 is adopted for the calculation.

The calculated annual groundwater through-flow is the product of the aquifer cross-sectional area, hydraulic conductivity and hydraulic gradient and is 890,000kL/annum.

7.4 Nutrient Balance Calculation

The methodology used to assess the risk to the Broome aquifer is based on the increased nutrient level present within the pivot area soils, compared with background groundwater nutrient level present naturally at the Stage 3 area. The highest level of nitrogen present of 5 mg/Kg in soil sample P05 (Table 7-6) has been applied.

This is a coarse approximation, because the soil samples were taken at the surface, however the nutrient levels below the root zone would be considerably less, given much of the nutrients would be taken up by the plants themselves. Therefore, a factor of 50% has been applied which conservatively assumes 50% of the nitrogen applied would be taken up by crop plants and 50% would leach to the groundwater (however it is likely that more nitrogen would be taken up by the plants than this).

Assuming therefore that 2.5 mg/Kg of Nitrates would be transported to groundwater. Based on an application rate of 700kg/ha/year over an area of 266ha, up to 466 kg/year would leach into the aquifer over the entire Stage 3 irrigation area.

In terms of the concentration of nitrates of nitrogen in the aquifer, based on an annual groundwater through-flow of 890,000kL, approximately 0.0005 mg/L would be present from fertilisation of Stage 3 pivots in the waters down gradient of the irrigation site. This is an insignificant amount of nitrate in the context of the naturally occurring nitrate levels in the Broome aquifer which range from 0.4 to 4.9 mg/L (Nitrates N) (Table 7-4).

Similar contributions of nitrogen to groundwater are likely to occur from Pivot Stages 1 and 2 which each will have similar flows of Broome Aquifer groundwater beneath them based on their width and the groundwater flow direction (Figure 7-1). Cumulatively the three stages are not likely to increase nitrates in groundwater significantly, given the large flow of groundwater beneath the sites (due to annual aquifer replenishment from rainfall) and the modest amounts of fertiliser application which as demonstrated above for Stage 3, is unlikely to raise nutrient levels above natural background.

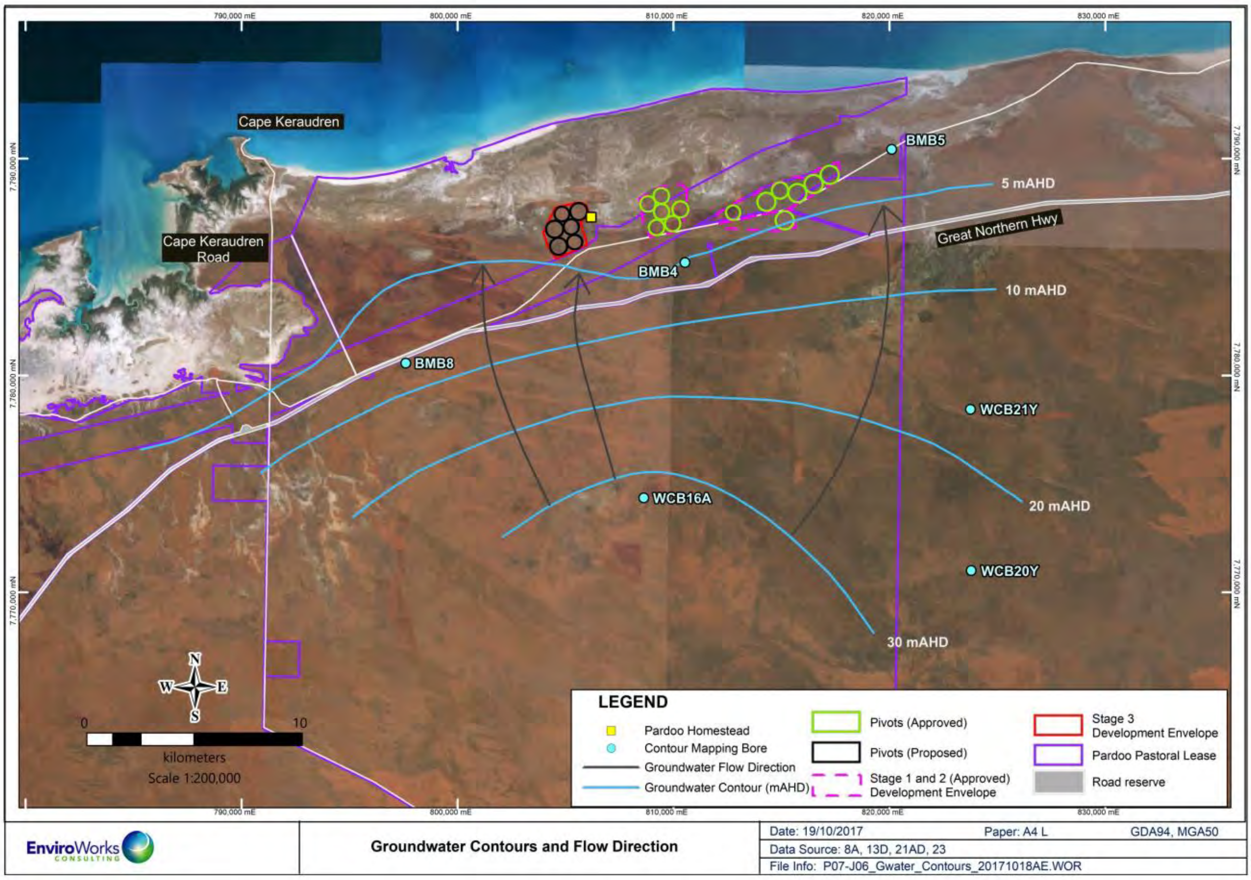

Figure 7-1 Local Groundwater Contours and Flow (provided by Groundwater Consulting Services)

7.5 Monitoring

7.5.1 Groundwater Monitoring

There is a comprehensive groundwater monitoring programme of the Broome aquifer from shallow monitoring bores in locations up gradient and down gradient of each of the development clusters as well as control bores remote from irrigation in similar landscape positions. Levels of nutrients will continue to be monitored in groundwater levels downstream of developed pivots, to confirm nutrient levels in the groundwater are not being artificially raised due to fertiliser application practices (Groundwater Consulting Services, 2017b).

7.5.2 Nutrition Management

Plant tissue testing is being used by Pardoo Beef Corporation to determine fertiliser application rates and ensure no more fertiliser than is needed, is being applied to crops. The methodology is to monitor nutrient uptake through tissue testing to, and monitor nutrient levels and soil moisture in the soil profile /root zone. The resulting data allows for fertiliser application to be minimised and only applied when necessary. This may allow for lower fertiliser application rates than outlined in Table 7-3.

7.5.3 Fertigation Methodology

The following methodology for application of fertilizers used for previous Pivots, will be applied to Stage 3 to minimise risks of nutrient leaching:

- Application matched to the seasonal growth needs of the crops;
- The nutritional solution is maintained at a constant pH;
- Introduced into the irrigation water to allow for metered dosing;
- Application to be significantly reduced when the groundcover is less than 70%;
- Fertilizer will not be applied if heavy rain is forecast;
- Fertilizer will not be applied to waterlogged soils (as determined by soil moisture monitoring) or to areas likely to flood soon after application (fertiliser will not be applied prior to rainfall and flood areas are excluded from the production area);
- Will be prevented from entering waterways and water storage areas during application, as these areas are not included in the irrigation area; and
- Will be stored in a manner so as not to be affected by run-off.

8 CONCLUSIONS

The aim of this study was to investigate the following:

- Hydrology and soil types of the study area;
- Extent, frequency, and duration of flooding that has occurred in the past and may in the future extend close to the Stage 3 project area;
- The Stage 3 water balance, and
- Nutrient balance and impact assessment for the proposed irrigation project based on fertiliser application rates and known hydrology/hydrogeology of the area.

Key findings are summarised below.

Hydrology and Soils

The Stage 3 irrigation project development site is situated approximately 4 km from the coast. The soils along the coastal strip of Pardoo Station can be divided into two key categories:

1. Soils of the coastal floodplain (within the Ramsar wetland boundary) which were formed by an ancient paleo-tidal system, have a high silt/clay content and as a result have a low infiltration rate.
2. Soils of the Sandy Desert (including the Stage 3 Project area) - a red sandy “Pindan” soil with a high infiltration rate.

A sub-regional catchment of 250,000 ha (2,500 km^2) was defined by Water Technology utilising best available topography data. The inland portion this sub-regional catchment (including the Stage 3 project area) is characterised by red sandy ‘Pindan’ soils with high infiltration rates. The relatively flat nature of the terrain coupled with the high soil permeability means that runoff rarely occurs (as is typical of desert catchments). Streamlines are not well defined and there are no signs of concentrated flow. The depth to groundwater in the vicinity of the Stage 3 project is in excess of 3 m (Groundwater Consulting Services, 2017a), hence with an average annual rainfall of approximately 320 mm, the land is unlikely to become saturated. A small strip of coastal floodplain occurs within the sub-regional catchment, coinciding with the Ramsar listed wetland area, characterised by grey clayey/silty soils. Again, this area is very flat, with few signs of formed drainage lines. These soils have much lower infiltration rates. Water is likely to pond in the lower parts of coastal floodplain after heavy, prolonged rainfall, with runoff being generated from the slightly raised areas. Average daily recorded evaporation within the region (at Port Hedland) is approximately 0.009 m/day (9 mm/day), hence a significant amount of water will evaporate from the ponded areas.

Extent, Duration and Frequency of Flooding

An initial hydraulic model, utilising 30 m resolution grid, was prepared covering the 2,500 km^2 sub-regional catchment. At this grid size small floodplain features, such as creeks and roads, are not well represented. However, there is only one major road within the catchment and no major creek systems, just wide, flat surface depressions. Hence, the initial grid size allowed for adequate modelling of the dominant features of the site whilst maintaining manageable model run times.

Following the initial model testing and analysis, a revised smaller model extent (of 19,500 ha) was established covering the low lying Ramsar listed areas, the Stage 3 site, and extending to just upstream of the Great Northern Highway. This smaller model size was selected because it was determined to be the key area that determined flooding of the coastal floodplain adjacent to the Stage 3 project.

The hydraulic model was run for the three historical rainfall events from March 2007, February 2013 and January-February 1982. The March 2007 event had very good satellite imagery for the weeks after the rainfall event, hence it was used to verify the modelling assumptions.

Modelling shows that no significant surface flows occur across the proposed Stage 3 area due to the high infiltration rates of the Pindan soils. Ponding occurs across parts of the adjacent Ramsar wetland due to the presence of the more clayey soils, however there is no obvious interaction between the two areas.

The clay pan to the east of the Stage 3 site gets to approximately 1 m deep before it overflows to the nearby lower ground, then slowly infiltrates and evaporates over time. The clay pan to the west of the Stage 3 site is lower and maintains a slightly deeper depth of water before it also slowly recedes

An analysis of historical rainfall patterns indicates that historically prolonged heavy rainfall events sufficient to produce flooding of the Ramsar wetland adjacent to the Stage 3 project area occur approximately every 10 years. Climate change predictions for the area indicate that rainfall events are to increase in intensity by between 9.5% and 19.4% by the year 2090, meaning prolonged flooding could possibly occur every 5 years by the year 2090 (Ball, et al., 2016).

The 2007 event is the largest monthly rainfall record available and provides a good basis for estimating flood extents and duration. On the basis of this event, within the modelled area (of 19,500 ha) when flooded, it is estimate that approximately 1,100 ha of open shallow ponds occur which are flooded for periods of 1 – 2 weeks and approximately 350 ha of open shallow ponds occur which are flooded for periods of 3 – 5 weeks.

Water Balance

Based on the water balance (Section 6.2), it can be concluded that the clearing, earthworks, and irrigation will not result in any changes to surface flows from the project area because there are no surface flows existing from the project area (due to the high infiltration rate of the soil) and no additional surface flows will be generated by the project (irrigation water will infiltrate to the plant root zone and will not create surface flow). Therefore, there will be no erosion due to surface water flows and no surface run-off related changes to flooding in the adjacent Ramsar wetland. The contours of the land will not be altered, therefore erosion and drainage lines will not be created. There will also not be an artificial ecosystem created outside the project boundary as surface flows will not exist to sustain such an ecosystem.

Similarly, there will be no significant changes in groundwater recharge or flows beneath the project due to surface irrigation. Irrigation application of water will be minimal (and timed to occur during periods of no rainfall). Irrigation water will infiltrate to the plant root zone. Very little (or none) of the irrigation water will infiltrate to groundwater as it will instead be utilised by the crop plants for evapotranspiration. Heavy rainfall will still infiltrate through the crop root zone to the groundwater (as is the case naturally within the Pindan soils prior to crop establishment). Therefore, the pivot areas are unlikely to have a significant impact on groundwater hydrological processes.

Nutrient Balance and Impact Assessment

The methodology used to assess the risk to the Broome aquifer is based on the increased nutrient level present within the pivot area soils, compared with background groundwater nutrient level present naturally at the Stage 3 area. It is assumed therefore that 2.5 mg/Kg of Nitrates would be transported to groundwater. Based on an application rate of 700kg/ha/year over an area of 266ha, up to 466 kg/year would leach into the aquifer over the entire Stage 3 irrigation area.

In terms of the concentration of nitrates of nitrogen in the aquifer, based on an annual groundwater through-flow of 890,000kL, approximately 0.0005 mg/L would be present from fertilisation of Stage 3 pivots in the waters down gradient of the irrigation site. This is an insignificant amount of nitrate in the context of the naturally occurring nitrate levels in the Broome aquifer which range from 0.4 to 4.9 mg/L (Nitrates N).

Similar contributions of nitrogen to groundwater are likely to occur from Pivot Stages 1 and 2 which each will have similar flows of Broome Aquifer groundwater beneath them based on their width and the groundwater flow direction (Figure 7-1). Cumulatively the three stages are not likely to increase nitrates in groundwater significantly, given the large flow of groundwater beneath the sites (due to annual aquifer replenishment from rainfall) and the modest amounts of fertiliser application which as demonstrated above for Stage 3, is unlikely to raise nutrient levels above natural background.

The risk of groundwater contamination with nutrients should be able to be effectively managed through:

- The extensive groundwater monitoring program proposed
- Plant nutrition management including, plant leaf tissue analysis
- Fertigation methods designed to minimise fertiliser application rates.

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APPENDIX A
INFILTRATION TEST RESULTS

Single ring infiltration test

Site: 1 804828 7787463
Date: 8/11/2017

radius (m)	0.0515
depth (m)	0.05
Head 1 (m)	0.05
Head 2 (m)	0.15

K_{fs} (m/s)	4.4E-05
K_{fs} (mm/h)	157
ϕ	6.0E-06
α (m^{-1})	7.3

G	0.490796117

Constant water level = 50 mm		
time (min)	Volume (mL)	Q (mL/s)
2	160	1.33
4	150	1.25
6	150	1.25
8	155	1.29
10	145	1.21
12	155	1.29
14	140	1.17
16	145	1.21
18	140	1.17
20	145	1.21
AVERAGE LAST 8		1.22

Q_1 (ml/s)	1.22
Q_1 (m/s)	1.22E-06

Constant water level = 150 mm		
time (min)	Volume (mL)	Q (mL/s)
2	195	1.63
4	200	1.67
6	200	1.67
8	205	1.71
10	200	1.67
12	205	1.71
14	200	1.67
16	205	1.71
18	200	1.67
20	200	1.67
AVERAGE LAST 8		1.68

Q_2 (ml/s)	1.68
Q_2 (m3/s)	1.68E-06

Single ring infiltration test

Site: 2 804492 7786201
Date: 8/11/2017

radius (m)	0.0515
depth (m)	0.05
Head 1 (m)	0.05
Head 2 (m)	0.15

K_{fs} (m/s)	4.3E-05
K_{fs} (mm/h)	155
ϕ	2.7E-06
α (m^{-1})	16.0

G	0.490796117

Constant water level = 50 mm		
time (min)	Volume (mL)	Q (mL/s)
2	75	0.63
4	175	1.46
6	105	0.88
8	120	1.00
10	105	0.88
12	110	0.92
14	90	0.75
16	115	0.96
18	85	0.71
20	105	0.88
AVERAGE LAST 8		0.87

Q_1 (ml/s)	0.87
Q_1 (m/s)	8.70E-07

Constant water level = 150 mm		
time (min)	Volume (mL)	Q (mL/s)
2	195	1.63
4	180	1.50
6	190	1.58
8	185	1.54
10	170	1.42
12	175	1.46
14	170	1.42
16	170	1.42
18	155	1.29
20	160	1.33
22	160	1.33
24	155	1.29
26	155	1.29
28	160	1.33
30	155	1.29
AVERAGE LAST 8		1.32

Q_2 (ml/s)	1.32
Q_2 (m3/s)	1.32E-06

Single ring infiltration test

Site: 3 803465 7788539
Date: 8/11/2017

radius (m)	0.0515
depth (m)	0.05
Head 1 (m)	0.05
Head 2 (m)	0.15

K_{fs} (m/s)	4.6E-06
K_{fs} (mm/h)	17
ϕ	-3.5E-07
α (m^{-1})	-13.3

G	0.490796117

Constant water level = 50 mm		
time (min)	Volume (mL)	Q (mL/s)
15	20	0.02
30	20	0.02
45	30	0.03
60	25	0.03
AVERAGE LAST 8		0.03

Q_1 (ml/s)	0.03
Q_1 (m/s)	2.64E-08

Constant water level = 150 mm		
time (min)	Volume (mL)	Q (mL/s)
7.5	45	0.10
15	40	0.09
22.5	25	0.06
30	35	0.08
37.5	30	0.07
45	30	0.07
52.5	35	0.08
60	30	0.07
AVERAGE LAST 8		0.08

Q_2 (ml/s)	0.08
Q_2 (m3/s)	7.50E-08

Single ring infiltration test

Site: 4 804082 7788650
Date: 8/11/2017

radius (m)	0.0515
depth (m)	0.05
Head 1 (m)	0.05
Head 2 (m)	0.15

K_{fs} (m/s)	2.6E-07
K_{fs} (mm/h)	1
ϕ	2.2E-07
α (m^{-1})	1.2

G	0.490796117

Constant water level = 50 mm		
time (min)	Volume (mL)	Q (mL/s)
15	25	0.03
30	30	0.03
45	20	0.02
60	20	0.02
AVERAGE LAST 8		0.03

Q_1 (ml/s)	0.03
Q_1 (m/s)	2.64E-08

Constant water level = 150 mm		
time (min)	Volume (mL)	Q (mL/s)
15	30	0.03
30	25	0.03
45	25	0.03
60	25	0.03
AVERAGE LAST 8		0.03

Q_2 (ml/s)	0.03
Q_2 (m3/s)	2.92E-08

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APPENDIX F. SOIL CHEMISTRY ANALYSIS

Soil Chemistry Analysis

Analyte		P01	P02	P03	P04	P05	P06	S301	S302	S303	R01	R02	R03	R04
	Location	Stage 1 Pivot 1	Stage 1 Pivot 1 outside	Stage 1 Pivot 2	Stage 1 Pivot 2 outside	Stage 1 Pivot 6	Stage 1 Pivot 6 outside	Stage 3 1	Stage 3 2	Stage 3 3	Ramsar 1	Ramsar 2	Ramsar 3	Ramsar 4
Ammonium	mg/Kg	< 1	1	< 1	< 1	< 1	< 1	< 1	2	2	2	< 1	< 1	2
Nitrate Nitrogen	mg/Kg	4	2	2	< 1	5	< 1	< 1	< 1	2	8	3	4	12
Phosphorus	mg/Kg	26	3	5	3	11	4	< 2	2	3	5	40	17	30
Potassium Colwell	mg/Kg	41	75	50	36	34	25	33	32	42	659	733	342	571
Sulphur	mg/Kg	6.2	1.2	36.4	1	7.8	0.8	0.7	1.1	1.3	435.2	30.6	1496	189
Organic Carbon	%	0.52	0.59	0.67	0.29	0.68	0.29	0.37	0.37	0.65	2.49	1.46	0.83	2.23
Conductivity	dS/m	0.073	0.014	0.265	0.011	0.06	0.013	< 0.010	0.013	0.017	7.807	0.499	6.233	0.678
pH Level (CaCl2)	pH	6.8	5.1	7	5.8	7.2	6.7	6.1	6	5.6	7.5	8.7	8.2	8.3
pH Level (H2O)	pH	7.6	6.3	8.1	7	7.7	7.5	7.1	7.1	6.6	7.4	9.9	8.5	9.4
DTPA Copper	mg/Kg	0.53	0.33	0.63	0.36	0.66	0.29	0.27	0.33	0.27	0.18	0.49	0.19	0.6
DTPA Iron	mg/Kg	8.1	7.94	19.2	3.15	7.94	1.65	3.38	3.12	10.09	2.26	6.02	4.88	14.41
DTPA Manganese	mg/Kg	1.66	6.38	2.53	3.53	2.19	2.88	3.12	4.61	7.81	12.19	3.33	1.03	3.18
DTPA Zinc	mg/Kg	0.85	0.07	0.73	0.06	1.07	0.09	0.05	0.06	0.1	0.15	0.12	0.06	0.17
Exc. Aluminium	meq/100g	0.067	0.158	0.139	0.175	0.11	0.093	0.114	0.19	0.099	0.022	0.018	0.029	0.033
Exc. Calcium	meq/100g	1.7	1.45	1.96	1.01	1.99	1.29	1.47	1.48	2.34	30.42	9.98	9.88	14.52
Exc. Magnesium	meq/100g	0.39	0.37	0.59	0.23	0.69	0.19	0.25	0.23	0.48	8.82	2.12	2.81	3.97
Exc. Potassium	meq/100g	0.08	0.14	0.1	0.05	0.07	0.03	0.05	0.05	0.07	1.6	1.8	0.76	1.42
Exc. Sodium	meq/100g	0.32	0.02	1.51	0.05	0.21	< 0.01	< 0.01	0.02	0.03	17.17	9.55	27.51	9.65
Boron Hot CaCl2	mg/Kg	0.53	0.18	0.69	< 0.10	0.54	0.11	< 0.10	0.12	0.12	2.34	6.05	3.47	15.73
PBI		8	11.5	8.7	10.2	5.7	5.9	6.8	8.7	9.8	94.2	509	180.4	143.5

Table Note: Blue highlighted cells show elevated levels of nutrients, organics and salts within the Ramsar soil sampling locations.

APPENDIX G. TERRESTRIAL FAUNA STUDY

Pardoo Stage 3 Irrigation Project and 80 Mile Beach Ramsar Site Fauna Assessment

View from P5 in Stage 3 (photo: Tim Gamblin)

Prepared for: Pardoo Beef Corporation Pty Ltd
Level 5, 189 St. Georges Terrace
Perth Western Australia 6000

Prepared by: Mike Bamford, Katherine Chuk and Tim Gamblin
M.J. & A.R. Bamford Consulting Ecologists
23 Plover Way
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28th January 2018

Executive Summary

The owner of Pardoo Station, Pardoo Beef Corporation Pty Ltd, is seeking approval for the development of a pivot irrigation system (Stage 3 project area). Bamford Consulting Ecologists (BCE) was commissioned to provide information on the fauna values of this area, particularly for significant species, and to provide discussion on the interaction of the proposal with these fauna values and functions. In addition, the Stage 3 area is adjacent to the 80 Mile Beach Ramsar Site, and that part of the Ramsar site closest to Area 3 was assessed for its value and function specifically for waterbirds (for which the overall Ramsar site is designated). This was in order to determine the potential for impact of the Stage 3 project upon significant waterbirds.

The site was visited on 12th – 14th July 2016 and 18th – 21st September 2017. During both visits, as much of the study area as possible was inspected on foot.

Fauna values within the study area can be summarised as follows:

Fauna assemblage. Largely intact and moderately rich, but highly variable seasonally and annually. Assemblage includes elements of the Great Sandy Desert, Pilbara and Kimberley. The desktop study identified 235 vertebrate fauna species as potentially occurring in the project area: 5 frogs, 44 reptiles, 148 birds and 38 mammals.

Species of conservation significance. While 43 species of conservation significance could be present, most are expected only as vagrants or irregular visitors, with few species expected to be regularly reliant on the project area. The most notable of these are the Bilby (a regular visitor to Stage 3) and some grassland-dependent migratory waterbirds (Oriental Plover, Little Curlew and Oriental Pratincole) that can be expected to be regular migrants visiting the dry grasslands of the adjacent Ramsar site.

Vegetation and Substrate Associations (VSAs). The Stage 3 area and Ramsar site represent quite different landscapes and support few but distinct VSAs.

Patterns of biodiversity. Within the Stage 3 area, vegetation that has not been subject to excessively frequent fires and/or grazing are likely to be most important for fauna. In the Ramsar site, grasslands are of most interest as they will support migratory waterbirds in some seasons and years. Note that the abundance of waterbirds is not expected to be high and the likelihood of meeting the criteria for Ramsar listing in terms of numbers of birds is extremely low. The criteria for Ramsar listing are met by the coastal mudflat areas of Eighty Mile Beach 4 km away.

Key ecological processes. The main processes which may affect the fauna assemblage is likely to be local hydrology, the fire regime and the presence of feral predators.

Potential impacts upon fauna and recommendations

Potential impacts to fauna include:

- mortality during clearing
- degradation of habitat due to weed invasion
- increased grazing pressure around pivots
- hydrological change due to groundwater abstraction and irrigation
- impacts of feral species
- altered fire regimes.

Because of the small area of clearing involved in a largely intact landscape, potential impacts are mostly considered to be negligible.

Recommendations to manage potential impacts include:

- Pre-clearing surveys and displacement or relocation of conservation significant fauna (Bilby and Mulgara) that may be present within the Stage 3 disturbance footprint.
- Weed management to prevent invasion of native vegetation with crop species and monitoring to ensure effectiveness.
- Protecting native vegetation by fencing the project area, so that cattle movement is restricted to prevent additional grazing/trampling pressure to native vegetation outside the fenced areas.
- Hydrological management and monitoring to prevent hydrological impacts which may affect fauna habitat.
- Feral fauna management and monitoring. If the cane toad spreads to the region, Pardoo should work with local regulatory authorities as part of regional efforts to control its spread and implement a cane toad detection, eradication and reporting system.
- Fire management measures.

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1 Introduction

Pardoo Station is located north of the Great Northern Highway, approximately 100 kilometres (km) east-north-east of Port Hedland and 365 km south west of Broome. The owner of Pardoo Station, Pardoo Beef Corporation Pty Ltd, is proposing to develop a multi-stage pivot irrigated hay production facility to improve cattle welfare, condition and throughput, and is seeking approval for part of the proposed irrigation area (Stage 3 project area). The purposes of this report are to provide information on the fauna values of this area, particularly for significant species, and to provide discussion on the interaction of the proposal with these fauna values and functions. In addition, the Stage 3 area is adjacent to the 80 Mile Beach Ramsar Site, and that part of the Ramsar site closest to Area 3 was assessed for its value and function specifically for waterbirds (for which the overall Ramsar site is designated). This was in order to determine the potential for impact of the Stage 3 project upon significant waterbirds.

1.1 General Approach to Fauna Impact Assessment

The purpose of impact assessment is to provide government agencies with the information they need to decide upon the significance of impacts of a proposed development. BCE uses an impact assessment process with the following components:

- The identification of fauna values:
  - Assemblage characteristics: uniqueness, completeness and richness;
  - Species of conservation significance;
  - Recognition of ecotypes or vegetation/substrate associations (VSAs) that provide habitat for fauna, particularly those that are rare, unusual and/or support significant fauna;
  - Patterns of biodiversity across the landscape;
  - Ecological processes upon which the fauna depend.
- The review of impacting processes such as:
  - Habitat loss leading to population decline;
  - Habitat loss leading to population fragmentation;
  - Degradation of habitat due to weed invasion leading to population decline;
  - Ongoing mortality from operations;
  - Species interactions including feral and overabundant native species;
  - Hydrological change;
  - Altered fire regimes; and
  - Disturbance (dust, light, noise).
- The recommendation of actions to mitigate impacts.

Descriptions and background information on these values and processes can be found in Appendices 1 to 5. Based on this impact assessment process, the objectives of investigations are to: identify fauna values; review impacting processes with respect to these values and the proposed activity; and provide recommendations to mitigate these impacts.

1.2 Description of Project Area

Pardoo Station, including the area proposed for a new Pivot irrigation system (Stage 3) and the nearby Ramsar site, falls into the western extremity of the Dampierland bioregion – Figure 1 (Thackway & Cresswell 1995). The climate is semi-arid tropical monsoonal with a hot, wet summer and a warm, dry winter. Median and mean annual rainfall in this region is 327 mm and 341 mm respectively. Annual evaporation is c. 3400- 3600 mm. There is a high degree of variability in rainfall events with significant variations in rainfall between years as well as the period when the bulk of the rain falls (Graham 1999).

The Dampierland bioregion can be sub-divided as follows: (1) Quaternary sandplain overlying Jurassic and Mesozoic sandstones with Pindan Hummock grasslands on hills. (2) Quaternary marine deposits on coastal plains, with Mangal, samphire - *Sporobolus* grasslands, *Melaleuca acacioides* low forests, and *Spinifex* - *Crotalaria* strand communities. (3) Quaternary alluvial plains associated with the Permian and Mesozoic sediments of Fitzroy Trough support tree savannas of *Crysopogon* - *Dichanthium* grasses with scattered *Eucalyptus microtheca* and *Lysiphyllum cunninghamii*. Riparian forests of River Gum and Cadjeput fringe drainages. (4) Devonian reef limestones in the north and east supporting sparse tree steppe over *Triodia intermedia* and *T. wiseana* hummock grasses. (Thackway & Cresswell 1995).

The Stage 3 area and nearby Ramsar site (Figure 2) lie across two of these major components of the Dampierland bioregion: Stage 3 - Quaternary sandplain overlying Jurassic and Mesozoic sandstones; and Ramsar site - Quaternary marine deposits on coastal plains with samphire - *Sporobolus* grasslands, and *Melaleuca acacioides* low forests (although most thickets and low forest were composed of a tall *Acacia* species). Vegetation and Substrate Associations are described in detail in Section 3.1.

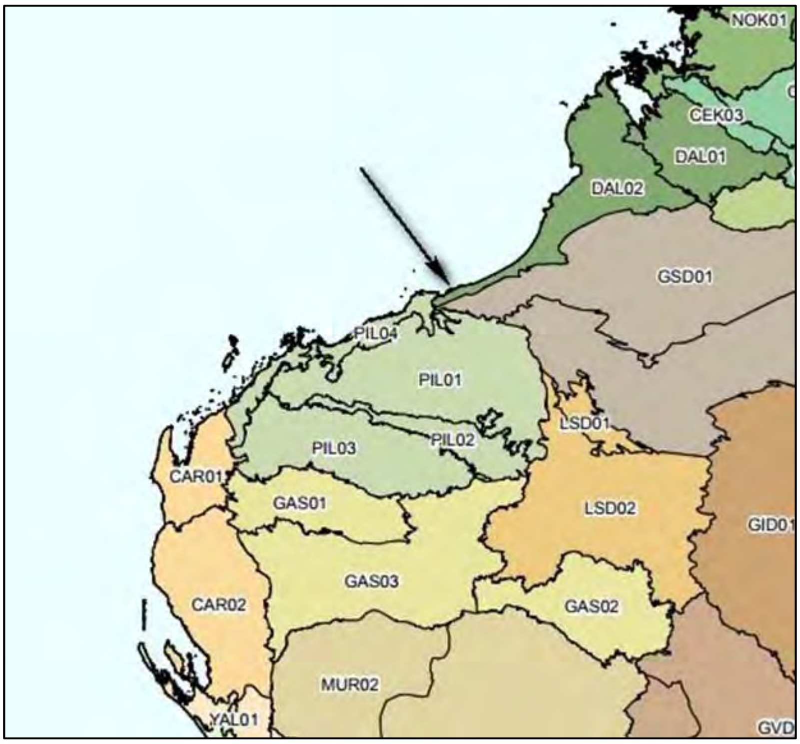

Figure 1. Bioregions across Western Australia, indicating the location of the project area in the Dampierland bioregion.

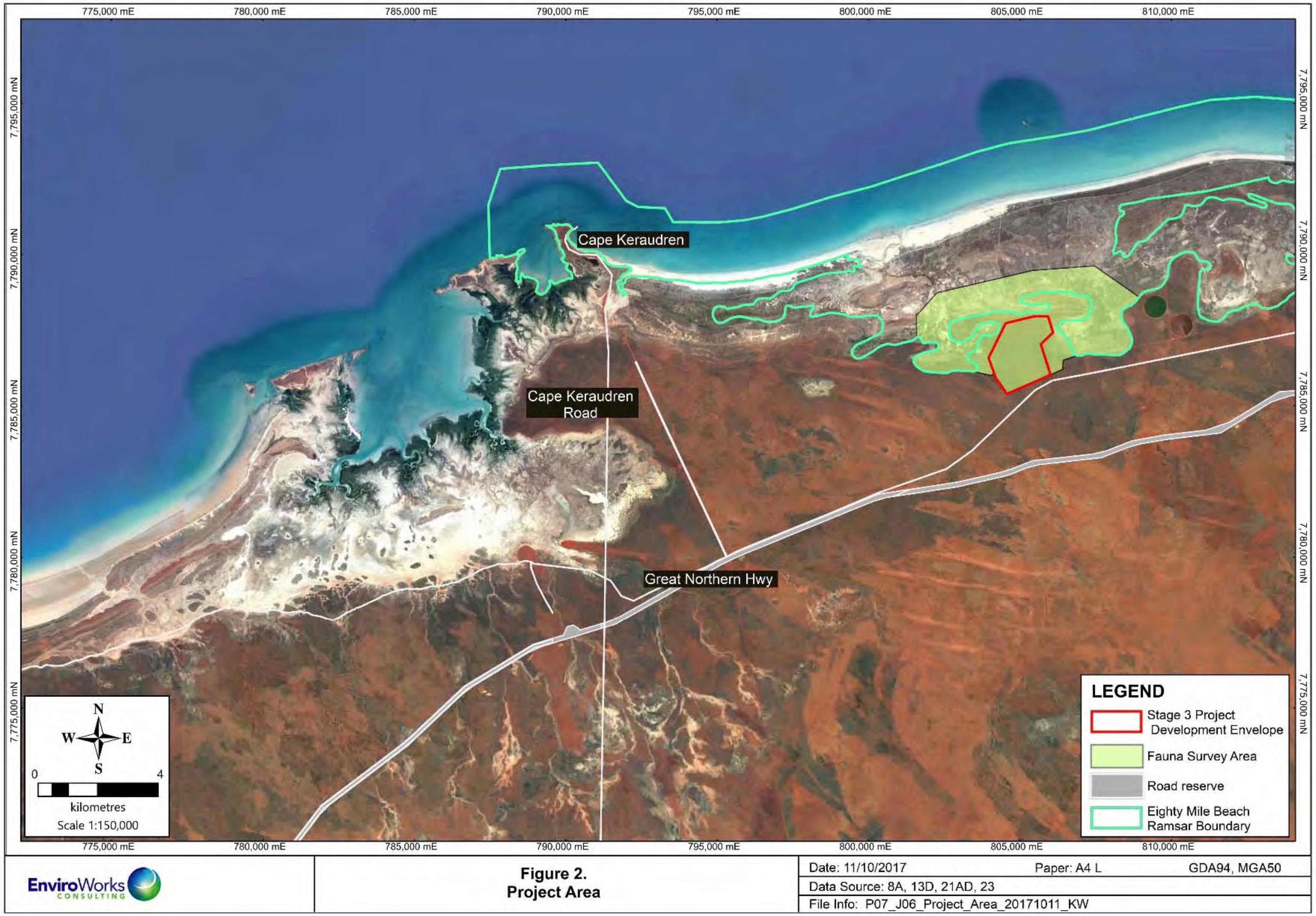

Figure 2. The project area, showing adjacent Ramsar wetlands to the coast.

2 Methods

2.1 Desktop Assessment

2.1.1 Sources of information

Information on the fauna assemblage of the survey area was drawn from a wide range of sources. These included state and federal government databases and results of regional studies. Databases accessed were the Atlas of Living Australia (ALA), the Wa Department of Biodiversity, Conservation and Attractions (DBCA) NatureMap (incorporating the Western Australian Museum's FaunaBase and the DBCA Threatened and Priority Fauna Database), BirdLife Australia's Birdata (Atlas) Database (BA), the EPBC Protected Matters Search Tool and the Bamford Consulting Ecologists (BCE) Database (Table 1). Information from the above sources was supplemented with species expected in the area based on general patterns of distribution. Sources of information used for these general patterns were:

Frogs: Tyler *et al.* (2000) and Anstis (2013);
Reptiles: Storr *et al.* (1983, 1990, 1999 and 2002) and Wilson and Swan (2013);
Birds: Blakers *et al.* (1984); Johnstone and Storr (1998, 2004) and Barrett *et al.* (2003); and
Mammals: Menkhorst & Knight (2004); Churchill (2008); and Van Dyck and Strahan (2008).

Table 1. Sources of information used for the desktop assessment.

Database	Type of records held on database	Area searched
Atlas of Living Australia (ALA 2017)	Records provided by collecting institutions, individual collectors and community groups	19.97974°S, 119.96374°E – plus 20 km buffer.
NatureMap (DBCA 2017)	Records in the WAM and DPaW databases. Includes historical data and records on Threatened and Priority species in WA.	19.97974°S, 119.96374°E – plus 20 km buffer.
BirdLife Australia Birdata (Atlas Database)	Records of bird observations in Australia, 1998-2017.	19.97974°S, 119.96374°E – plus 20 km buffer.
EPBC Protected Matters	Records on matters of national environmental significance protected under the EPBC Act.	19.97974°S, 119.96374°E – plus 40 km buffer.

2.1.2 Previous fauna surveys

BCE has conducted multiple fauna surveys at Pardoo Station and nearby stations such as Anna Plains and the adjacent Wallal Downs Station. These surveys have included targeted significant species investigations. Two of these surveys were in the Stage 3 project area (12th – 14th July 2016 and 18th – 21st September 2017) and the methods of these Stage 3 surveys are described in Section 2.2. Other surveys conducted by BCE further afield on Pardoo and Wallal Downs Stations have been used as background information only to inform potential species lists compiled during desktop studies (however they are not considered project specific surveys for the Stage 3 project area and therefore the methods of these surveys are not included in Section 2.2). There have also been studies by other consultants in the region. Species records from these studies are contained in the Naturemap database which was consulted as part of the desktop study. In addition, BCE maintains a detailed database and annotated species lists that were available for reference as part of the desktop study. Some of the BCE records pre-date Naturemap. Previous reports consulted for background information include Bamford *et al.* (2016), and Bamford and Shepherd (2017). All species records used to inform the expected species list for the Stage 3 project (and the source of the records) are included in Appendix 3.

2.1.3 Nomenclature and taxonomy

As per the recommendations of EPA (2004), the nomenclature and taxonomic order presented in this report are based on the Western Australian Museum's (WAM) Checklist of the Fauna of Western Australia 2016. The authorities used for each vertebrate group were: amphibians (Doughty *et al.* 2016a), reptiles (Doughty *et al*. 2016b), birds (Johnstone and Darnell 2016), and mammals (Travouillon 2016). In some cases, more widely-recognised names and naming conventions have been followed, particularly for birds where there are national and international naming conventions in place (e.g. the BirdLife Australia working list of names for Australian Birds). English names of species where available are used throughout the text; Latin species names are presented with corresponding English names in tables in the appendices.

2.1.4 Interpretation of species lists

Species lists generated from the review of sources of information are generous as they include records drawn from a large region and possibly from environments not represented in the survey area. Therefore, some species that were returned by one or more of the data searches have been excluded because their ecology, or the environment within the survey area, meant that it is highly unlikely that these species will be present. Such species can include, for example, seabirds that might occur as extremely rare vagrants at a terrestrial, inland site, but for which the site is of no importance. Species returned from databases but excluded from species lists are presented in Appendix 4.

Species returned from the databases and not excluded on the basis of ecology or environment are therefore considered potentially present or expected to be present in the survey area at least occasionally, whether or not they were recorded during field surveys, and whether or not the survey area is likely to be important for them. This list of expected species is therefore subject to interpretation by assigning each a predicted status in the survey area.

The status categories used are:

- Resident: species with a population permanently present in the survey area;
- Migrant or regular visitor: species that occur within the survey area regularly in at least moderate numbers, such as part of annual cycle;
- Irregular Visitor: species that occur within the survey area irregularly such as nomadic and irruptive species. The length of time between visitations could be decades but when the species is present, it uses the survey area in at least moderate numbers and for some time;
- Vagrant: species that occur within the survey area unpredictably, in small numbers and/or for very brief periods. Therefore, the survey area is unlikely to be of importance for the species; and
- Locally extinct: species that would have been present but has not been recently recorded in the local area and therefore is almost certainly no longer present in the survey area.

These status categories make it possible to distinguish between vagrant species, which may be recorded at any time but for which the site is not important in a conservation sense, and species which use the site in other ways but for which the site is important at least occasionally. This is particularly useful for birds that may naturally be migratory or nomadic, and for some mammals that can also be mobile or irruptive, and further recognises that even the most detailed field survey can fail to record species which will be present at times, or may have been previously confirmed as present. The status categories are assigned conservatively. For example, a lizard known from the general area is assumed to be a resident unless there is very good evidence that the site will not support it, and even then it may be classed as a vagrant rather than assumed to be absent if the site might support dispersing individuals.

2.1.5 Short Range Endemics (SRE's)

SREs are included within the above the databases that were checked as part of desktop investigations, but no SRE's were identified during the desktop study for this area. This is expected as the landscape does not have the types of features conducive to the evolution of SRE species which includes sheltered, relatively mesic environments such as slopes with south-west facing aspects, vine thickets, rock piles, drainage systems, deep gorges, mound springs/natural springs, fire refuge areas such as cliffs/isolated rock piles, and other similar habitats or habitat isolates (EPA, 2016b). The Pardoo Stage 3 project is located on a relatively uniform, flat, continuous Pindan sands habitat which does not contain such features conducive to the evolution of SRE species.

Therefore, no SRE species are included within potential species lists compiled via desktop studies and consequently field investigations for SRE species were not conducted.

2.2 Field Investigation Methodology and Personnel

The project area was visited on 12th – 14th July 2016 by Dr Mike Bamford - BSc (Biol.), Hons (Biol.), PhD (Biol.) and Cameron Everard - BSc (Env. Sci.), MSc (Env. Mgt.), and on 18th – 21st September 2017 by Dr Mike Bamford (B.Sc. Hons. Ph.D. Biol.) and Mr Tim Gamblin (B.Sc. Zool. Cert. Env. Man.); Katherine Chuk (B. Sc. Zool. Hons.) assisted with report production.

The assessment on 12th — 14th July 2016 involved targeted surveys for Greater Bilby and Brush-tailed Mulgara at both Stage 2 and 3. Opportunistic fauna observations were made and the study area was systematically searched for evidence of the two species. This involved trained personnel walking transects spaced 200 m apart across the study area.

The 18th – 21st September 2017 site visit involved traversing as much of the project area as possible, including the nearby Ramsar site. This enabled environmental descriptions to be prepared and opportunistic observations on fauna to be made. Targeted searching was undertaken for several significant species known from the general area, in particular the Greater Bilby, Mulgara and significant waterbirds. In addition, one evening (night of 20th September) was spent listening for rare fauna (including the Night Parrot) and spotlighting for reptiles.

Table 2 below provides a summary of survey methodology for the above investigations including dates, purpose, survey effort, survey level and methods, whilst Figures 3 and 4 map survey locations.

Table 2. Stage 3 Survey Methods

Date	Purpose	Survey Effort	Survey Level	Methods
12th – 14th July 2016	To collect information on Bilby distribution and abundance within the Stage 3 project area, and to identify areas of suitable habitat that may support the species.	2 people walked transects 200 m apart for 3 days (Figure 3)	Targeted Fauna Survey	Bilby activity was confirmed by searching for evidence such as scats, tracks, diggings and burrows. Searching was approached systematically by two personnel walking transects about 200m apart. A closer spacing was to be used in areas of suitable habitat or where some evidence was found. All personnel involved in searching were familiar with the evidence of the species. The survey was conducted on the 12th, 13th and 14th of July 2016 by Dr Mike Bamford - BSc (Biol.), Hons (Biol.), PhD (Biol.) and Cameron Everard - BSc (Env. Sci.), MSc (Env. Mgt.).
18th – 21st September 2017	To provide information on the fauna values of the Stage 3 project area, particularly for significant species, and to provide discussion on the interaction of the proposal with these fauna values and functions. In addition, the adjacent Ramsar site was assessed for its value and function specifically for waterbirds.	2 people traversed the survey area as much as possible for 4 days and 1 evening (Figure 4). 19 survey waypoints were established where photographs were taken and habitat descriptions recorded.	Level 1 Fauna Survey	The survey involved traversing as much of the project area as possible, including the nearby Ramsar site. This enabled environmental descriptions to be prepared and opportunistic observations on fauna to be made. Targeted searching was undertaken for several significant species known from the general area, in particular the Greater Bilby, Mulgara and significant waterbirds. In addition, one evening (night of 20th September) was spent listening for rare fauna (including the Night Parrot) and spotlighting for reptiles. The survey was conducted on the 18th, 19th, 20th and 21st of September 2017 by Dr Mike Bamford - BSc (Biol.), Hons (Biol.), PhD (Biol.) and Cameron Everard - BSc (Env. Sci.), MSc (Env. Mgt.).

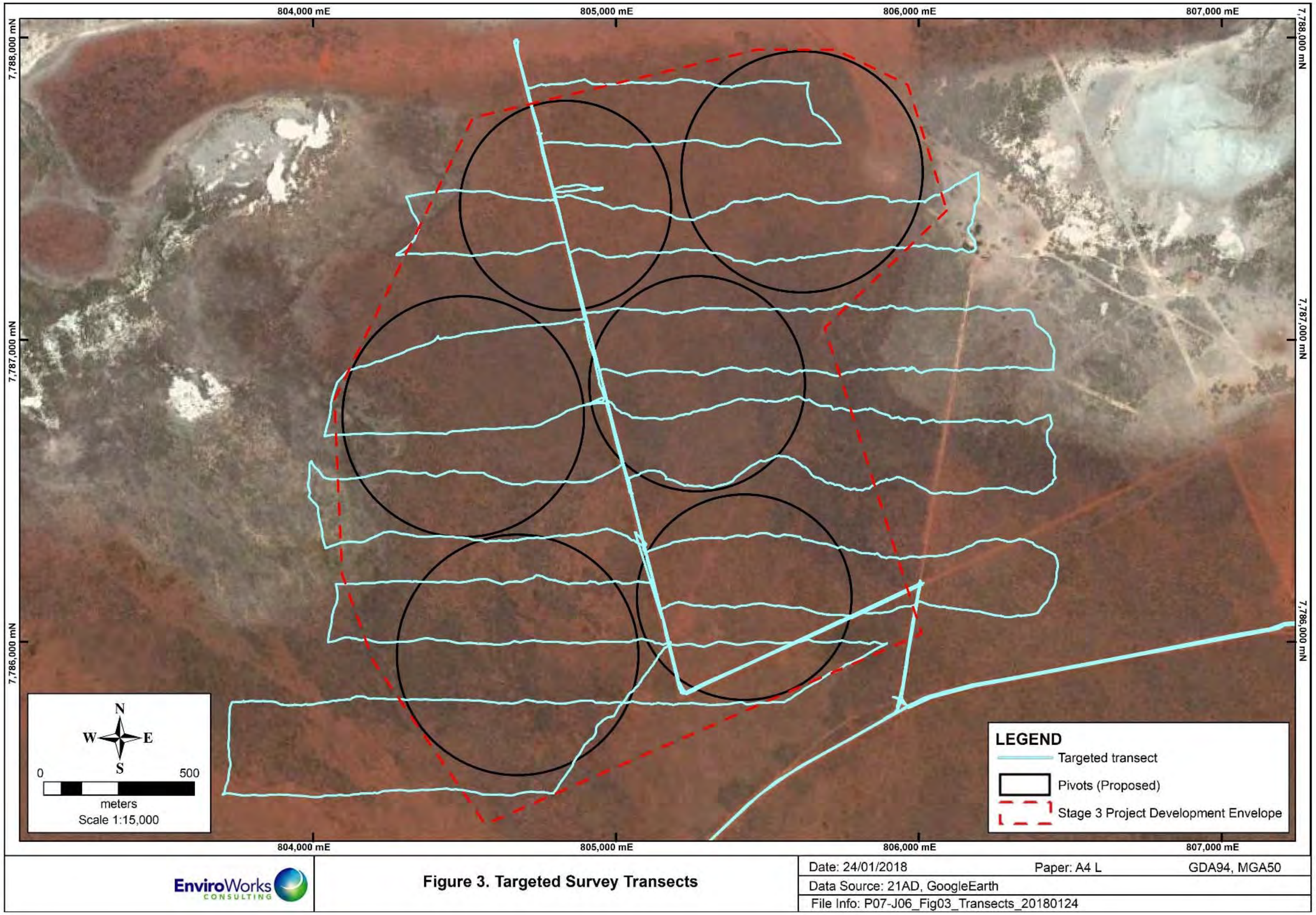

Figure 3. Targeted Survey Transects July 2016

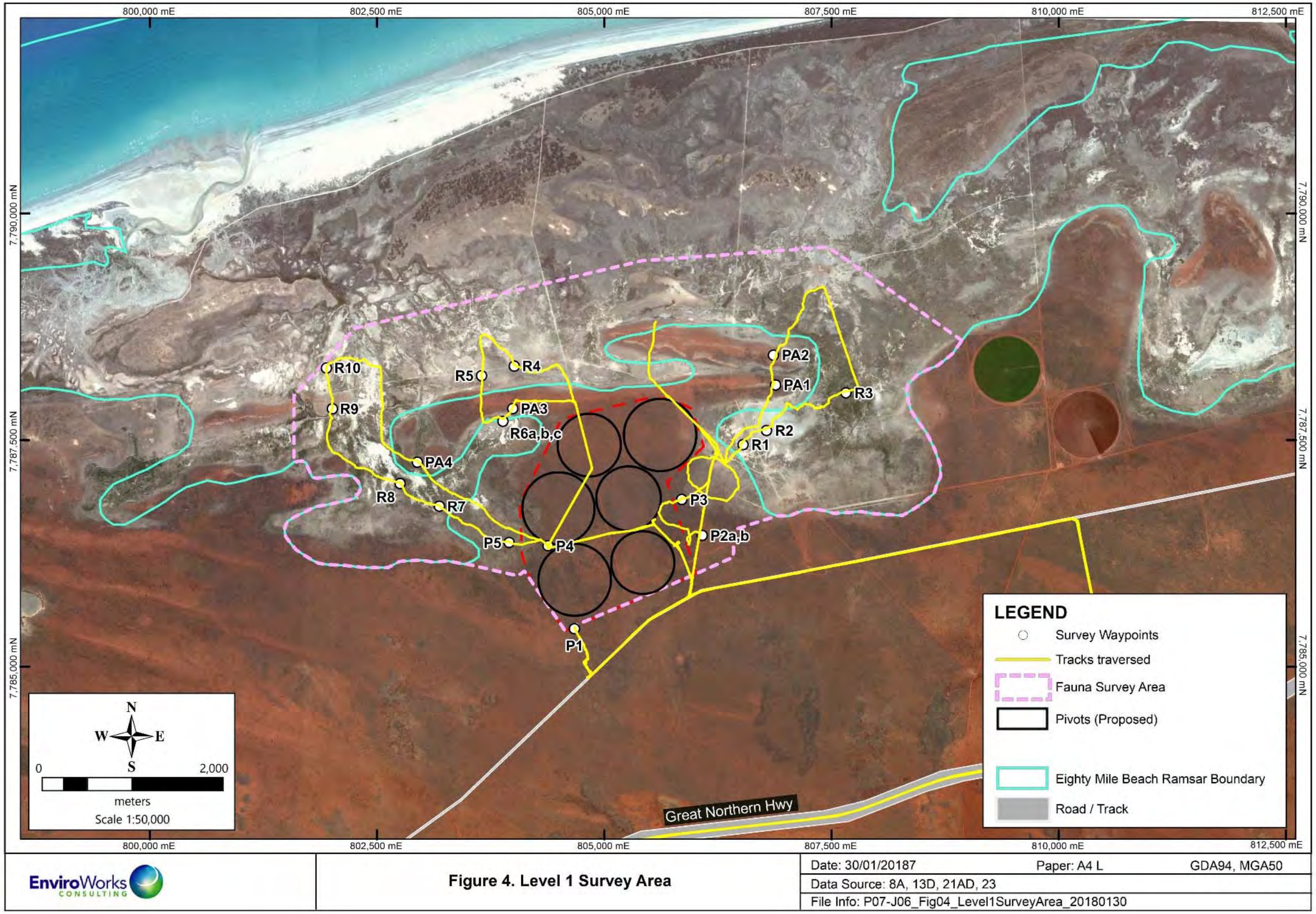

Figure 4. Level 1 Survey Area, Tracks and Waypoints September 2017

2.3 Survey Limitations

The EPA Guidance Statement 56 (EPA 2004, now EPA, 2016a) outlines a number of limitations that may arise during surveying. These survey limitations are discussed in the context of the BCE investigation of the survey area in Table 3.

Table 3. Survey limitations as outlined by EPA.

EPA Limitation	BCE Comment
Level of survey.	Level 1 (desktop study and site inspection). Survey intensity was deemed adequate due to the scale of the project and the amount of data available in the region.
Competency/experience of the consultant(s) carrying out the survey.	The ecologists have had extensive experience in conducting fauna surveys and have conducted several fauna studies within the immediate region.
Scope. (What faunal groups were sampled and were some sampling methods not able to be employed because of constraints?)	The survey focussed on vertebrate fauna and fauna values.
Proportion of fauna identified, recorded and/or collected.	All vertebrate fauna observed were identified.
Sources of information e.g. previously available information (whether historic or recent) as distinct from new data.	Abundant information from databases and previous studies.
The proportion of the task achieved and further work which might be needed.	The survey was completed and the report provides fauna values for the project area.
Timing/weather/season/cycle.	Timing is not of great importance for level 1 investigations.
Disturbances (e.g. fire, flood, accidental human intervention etc.) that affected results of survey.	None
Intensity. (In retrospect, was the intensity adequate?)	All major VSAs were visited and significant species habitat and traces were identified.
Completeness (e.g. was relevant area fully surveyed).	Site was fully surveyed to the level appropriate for a level 1 assessment and for the proposed impact. Fauna database searches covered a 20 km radius beyond the survey area boundary. Detailed field investigations covered the VSAs present.
Resources (e.g. degree of expertise available in animal identification to taxon level).	Field personnel have extensive experience with fauna and habitat in the region.
Remoteness and/or access problems.	There were no remoteness/access problems encountered.
Availability of contextual (e.g. biogeographic) information on the region.	Regional information was available and was consulted.

3 Results

3.1 Vegetation and Substrate Associations

The Stage 3 area and the Ramsar site represent two very different environments that reflect two major components of the Dampierland Bioregion, and these have a rapid transition marked by a small fall in altitude but a great change in substrate. Vegetation and Substrate Associations (VSAs) are as follows.

The Stage 3 project area occurs within an area characterised by Pindan (red sandy) soils which support acacia and mixed species shrublands over spinifex grasslands. The area does not flood and is not seasonally wet, due to the high infiltration rates of the pindan soil (Water Technology, 2017). The Stage 3 project area provides habitat values for species which utilise the dry, sandy, shrubland environment such as Bilby and Mulgara.

The Ramsar area to the north of the Stage 3 project contains a mixture of grasslands and shrublands, as well as small salt pans on white to grey clayey soil. This area can be categorised as a coastal floodplain which is seasonally damp and floods infrequently for short periods after heavy prolonged rainfall (Water Technology, 2017). Its elevation is slightly lower in the landscape than the Stage 3 project area to the south. This area provides habitat values for grassland-dependent migratory waterbirds (Oriental Plover, Little Curlew and Oriental Pratincole) that can be expected to be regular migrants visiting the dry grasslands.

Vegetation mapping has been provided by EnviroWorks Consulting (2017) (Figure 5) and broadly corresponds to Vegetation and Substrate Associations (VSAs) identified by BCE:

1. Pindan shrublands – mixed acacia shrubland and hummock grassland occur on red pindan sands predominantly within the Stage 3 project area and are located at a higher elevation in the landscape than the adjacent coastal plain vegetation types. They consist of open Low woodland B (to 4m) of *Bauhinia cunninghamii, Erythrophleum chlorostachys* and *Dolichandrone heterophylla* and other mixed species over low scrub/scrub to 2m over a variable ground layer of herbs and grasses.
2. Coastal Plain thickets and shrublands - occur predominantly in the Ramsar site on grey to white clayey silty soil and brown sandy loam, at a lower elevation in the landscape compared with the Pindan shrublands. They consist of *Melaleuca alsophila* and *Acacia ampliceps* thickets/shrublands (to 6m) over grasses (*Sporobolus australasicus, Cenchrus ciliaris*), low herbs (commonly *Pluchea spp. Trianthema sp*p.) and disturbed bare ground, on grey/white clays which are seasonally wet and may be occasionally flooded.
3. Coastal Plain grasslands and low shrublands - occur predominantly in the Ramsar site on grey to white clayey silty soil, at a lower elevation in the landscape compared with the Pindan shrublands. These grasslands form a mosaic with the coastal plain thickets and shrublands described above. They consist of grasses (*Cenchrus cilliaris, Sporobolus australasicus, Eragrostis sp, Whiteochloa airodies*) and low shrubs to 1.5m (*Indigofera oblongifolia, Salsola australis, Trianthema* spp., *Triodia spp*.) which are sparse to dense in cover, and occur on grey/white clays. Some areas are likely to be seasonally wet and may occasionally flood after heavy prolonged rainfall.

4. Salt pans - occur in minor depressions in the landscape within the Ramsar site at slightly lower elevation than surrounding areas on grey to white clay. These depressions naturally collect rainfall from surrounding areas after rainfall and evaporation results in the build-up of salts over time. They consist of bare salt pan areas and associated low samphire, herblands and shrublands (*Trianthema turgidifolia, T. pilosa T cussackiana, Tecticornia auriculata, Frankenia ambiata, Salsola australis*). They are likely to be seasonally wet and subject to occasional flooding after heavy prolonged rainfall. Sometimes salt pans occur in conjunction with grasslands.
5. Low limestone ridges - occur in localised areas within the Ramsar study with limestone cap rock visible at the surface. They are sparsely vegetated and occur with shallow red or brown sands. Common plant species include *Ptilotus axillaris, Trainthema spp, Cenchrus ciliaris* and *Cleome uncifera* with occasional emergent shrubs of, *Acacia coleyi* and *A. stellaticeps*.
6. Completely degraded - vegetation is completely degraded around stock watering points and when adjacent to agricultural structures (e.g. fence lines, tracks, buildings).

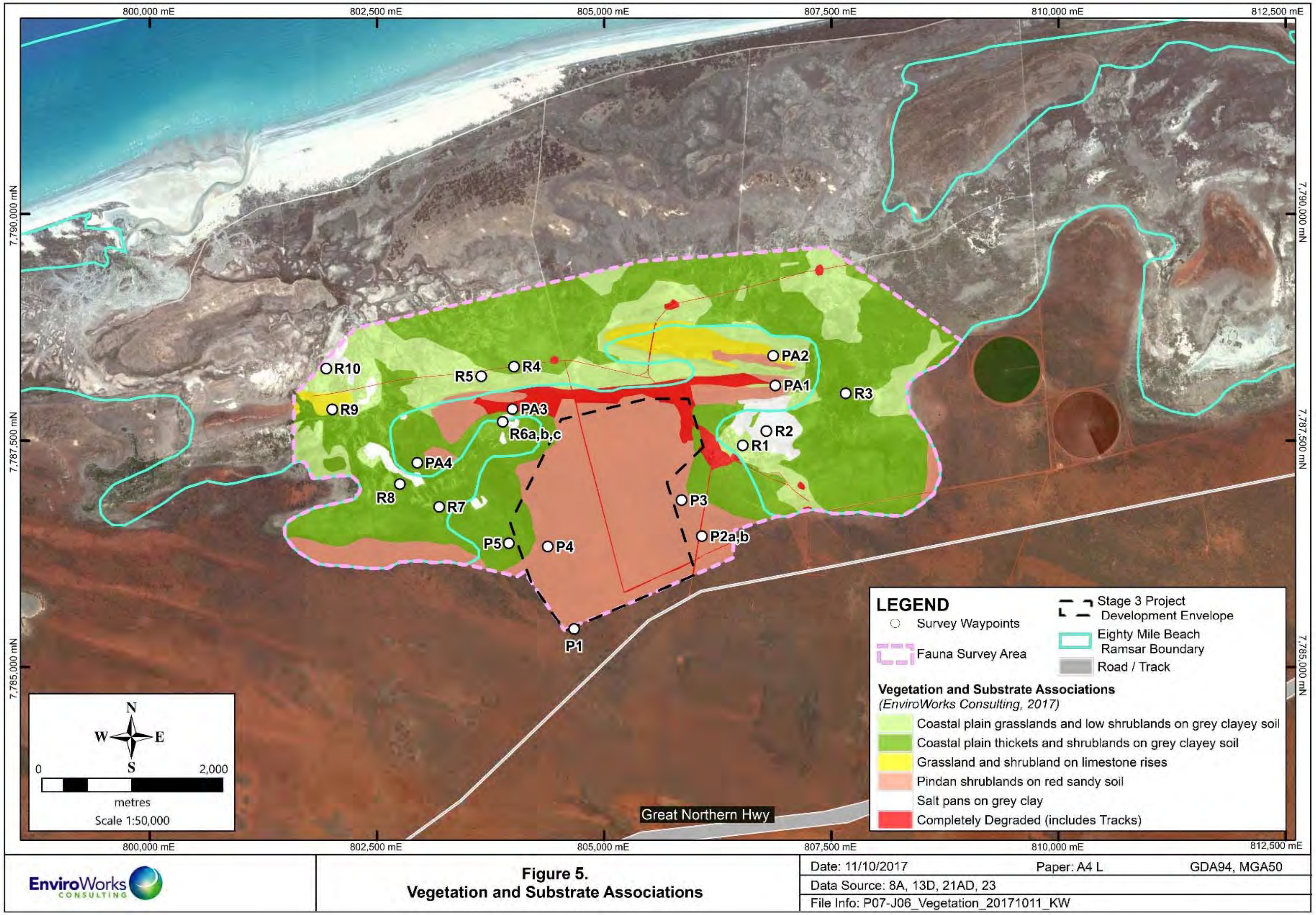

Figure 5. Distribution of VSAs in the survey area. VSA descriptions are given is Section 3.1.

Plate 1. Stage 3 (P1 on Figure 5). VSA 1. Pindan shrublands - Scattered acacia over smaller shrubs including *Senna notabalis* on hummock grasslands of *Triodia sp.* on red pindan sands. This may be an area regenerating after fire.

Plate 2. Stage 3 (P3 on Figure 5). VSA 1. Pindan Shrublands - Mixed Acacia Shrubland and Hummock Grassland on red pindan sand.

Plate 3. Stage 3 (P5 on Figure 5). VSA 2 Coastal Plain Thickets and Shrublands - Low Acacia thickets including *A. stellaticeps* over *Triodia sp.* and grasses.

Plate 4. Stage 3 (P4 on Figure 5). VSA 1 Pindan Shrublands - Burnt open plains (fire history of 18months to two years) low and occasional tall acacia species over grasses and *Triodia* sp on red pindan sand.

Plate 5. Stage 3 (P2 on Figure 5). VSA 1Pindan Shrublands - Melaleuca thickets over small shrubs and spinifex (*Triodia sp.*) on red sands.

Plate 6. Ramsar Site (R1 on Figure 5). VSA 2 and 4. Coastal Plain grasslands and low shrublands - Melaleuca and Acacia thickets over scattered grasses on grey clayey-loam, with the edge of a salt-pan (VSA 4) in the foreground.

Plate 7. Ramsar Site (R4 on Figure 5). VSA 3. Very low shrubland to grassland on grey clayey-loam flats, subject to occasional waterlogging.

Plate 8. Ramsar Site (PA2 on Figure 5). VSA 5. Grasslands and shrublands on limestone rises - Shrubs and grassland of Buffel Grass on shallow grey-brown sand over limestone on slight rises.

3.2 Fauna

3.2.1 Overview of fauna assemblage of the Stage 3 area and adjacent Ramsar site

The desktop study identified 235 vertebrate fauna species as potentially occurring in the Stage 3 area and adjacent Ramsar site (see Table 4 and Appendix 3): 5 frogs, 44 reptiles, 148 birds and 38 mammals. The assemblage includes 43 species of conservation significance, discussed in Section 3.2.2. Extinct species are also discussed in Section 3.2.2.

The five frog species are all considered resident except one, the Green Tree Frog. Two species of tree frog, the Green Tree Frog and Desert Tree Frog, are likely to take advantage of artificial structures and water sources as habitat; both have been recorded in the general region by BCE. The others are burrowing species that spend long periods inactive below ground during naturally extended dry periods. These species breed following rain. Note that while not recorded in the area, it is likely that the Cane Toad *Rhinella marina* will colonise the area in the next ten to 15 years (based upon the maximum spread rate of >50 km/year reported by Tingley *et al. (*2012) and the presence of the species well into the eastern Kimberley in summer 2016/2017 (M. Bamford pers. obs.).

The 44 reptile species are mostly considered resident but one, the Ring-tailed Dragon, is classed as vagrant (because the survey area has few rocky outcrops, the preferred habitat of this species) while the Common House Gecko is more or less limited to occupied human dwellings, but may occur in nearby buildings. The fauna assemblage includes elements of the Great Sandy Desert, Pilbara and Kimberley. Fifteen reptile species have been recorded in the general region by BCE, including 13 species in September 2017 either in Stage 3 or the nearby Ramsar site.

The bird assemblage of 148 species includes 41 classed as residents (32 (67%) observed in September 2017) and a very high number (49) considered to be vagrants. Many of these vagrants are waterbirds and the function of the Stage 3 area and adjacent Ramsar site for migratory waterbirds is discussed below. In brief, however, the Stage 3 area is of limited value to migratory waterbirds, while the nearby Ramsar area may be of very occasional value for a wide range of migratory waterbirds (i.e. during rare flooding events), but is likely to be regularly used by grassland-dependent migratory species (principally Oriental Plover and Little Curlew). The bird assemblage is a mixture of Pilbara and arid-zone species, with migratory waterbirds present at least as vagrants, and some more regularly, because the area is close to tidal flats of the coastline.

The mammal assemblage of 28 native species is poorly documented and some of the species included are based upon the general literature rather than nearby database records. At least two additional native species are locally extinct (these are discussed in the following section). Over half the native species are bats that roost in tree hollows. With eight species (not including domestic livestock), introduced species are a major component of the mammal fauna. Four native and three introduced species were recorded in September 2017.

Documenting the invertebrate assemblage is beyond the scope of even a level 2 investigation, but no invertebrate species of conservation significance are expected in the survey area based on database searches.

Key features of the fauna assemblage expected in the Stage 3 area and nearby Ramsar site are:

- Uniqueness: The assemblage is typical of a broad region of overlap between the Pilbara, Great Sandy Desert and Kimberley. It is notable for the presence of large numbers of migratory waterbird species associated with the coastal areas of the Ramsar site, with the majority of these species reliant on the tidal coastline 4 km away from the Stage 3 project area.
- Completeness: The assemblage of species from the survey area is almost complete, with perhaps one bird and at least two mammals species locally extinct.
- Richness: The assemblage appears rich but the number of species present will vary greatly seasonally and annually such that many species are absent for periods of time

Table 4. Composition of vertebrate fauna assemblage of the survey area.

Taxon	Number of species expected	Number of species in each category				
		Resident	Regular visitor or migrant	Irregular visitor	Vagrant	Locally extinct
Frogs	5	4	1			
Reptiles	44	42			2	
Birds	148	41	39	19	49	1
Native Mammals	30	8	10	7	4	2
Introduced Mammals	8	3	4		1	
Total	**235 (including 8 int.)**	**95**	**50**	**19**	**56**	**3**

3.2.2 Species of conservation significance

The current vertebrate assemblage includes 43 species of conservation significance; three further species of conservation significance are considered to be locally extinct (Tables 5 and 6). The overall list of significant species includes 35 CS1, 5 CS2 and 3 CS3 species. As outlined in Appendix 2, species classed as CS1 are those listed under WA State and/or Commonwealth legislation, while those classed as CS2 are listed as Priority by the Department of Parks and Wildlife. The CS3 class is more subjective and is assigned by BCE (not any regulatory listing), but includes species that have declined extensively across the Pilbara region, and some species that occur at the edge of their range. This makes their presence in the survey area significant as populations on the edge of a species' range are often less abundant and more vulnerable to local extinction than populations at the centre of the range (Curnutt *et al*. 1996).

Most of the significant species are expected in the project area only as vagrants, and therefore the area is probably of low importance for them. Notes on species that are considered to be at least irregular visitors are provided below. Locally extinct species are also briefly discussed.

Figure 6 maps the locations of conservation significant species observed during the surveys.

Table 5. Composition of extant conservation significant vertebrate fauna.

Taxon	Conservation Significant (CS) fauna		
	CS1	CS2	CS3
Frogs	-	-	-
Reptiles	1	1	1
Birds	27	-	2
Native Mammals	7	4	-
Invertebrates	-	-	-

(CS1 – listed under legislation; CS2 – listed as priority by DBCA; CS3 – locally significant).

Table 6. Conservation significant fauna species expected to occur in the project area. The expected habitat indicates if the species is most likely to occur in the Stage 3 areas (S3) or the Ramsar site (Ram); or both.

CS Species		Status	CS Level	Confirmed	Expected Status	Expected Habitat
REPTILES						
Airlie Island Ctenotus	*Ctenotus angusticeps*	V S3	CS1		Resident	S3, Ram
Dampierland Plain Slider	*Lerista separanda*	P2	CS2		Resident	S3, Ram
Woma	*Aspidites ramsayi*		CS3		Resident	S3
BIRDS						
Fork-tailed Swift	*Apus pacificus*	M S5	CS1	3 R	Migrant	S3, Ram
Oriental Plover	*Charadrius veredus*	M S5	CS1	R	Migrant	Ram
Sharp-tailed Sandpiper	*Calidris acuminata*	M S5	CS1		Vagrant	Ram
Broad-billed Sandpiper	*Calidris falcinellus*	M S5	CS1		Vagrant	Ram
Curlew Sandpiper	*Calidris ferruginea*	Cr M S3 S5	CS1		Vagrant	Ram
Pectoral Sandpiper	*Calidris melanotos*	M S5	CS1		Vagrant	Ram
Red-necked Stint	*Calidris ruficollis*	M S5	CS1		Vagrant	Ram
Swinhoe's Snipe	*Gallinago megala*	M S5	CS1		Vagrant	Ram
Pin-tailed Snipe	*Gallinago stenura*	M S5	CS1		Vagrant	Ram
Little Curlew	*Numenius minutus*	M S5	CS1		Migrant	Ram
Wood Sandpiper	*Tringa glareola*	M S5	CS1		Vagrant	Ram
Common Greenshank	*Tringa nebularia*	M S5	CS1		Vagrant	Ram
Marsh Sandpiper	*Tringa stagnatilis*	M S5	CS1		Vagrant	Ram
Australian Painted Snipe	*Rostratula australis*	E S2	CS1		Vagrant	Ram
Oriental Pratincole	*Glareola maldivarum*	M S5	CS1		Migrant	Ram
Bush Stone-curlew	*Burhinus grallarius*		CS3	3 R	Resident	S3, Ram
White-winged Black Tern	*Chlidonias leucopterus*	M S5	CS1		Vagrant	Ram

CS Species		Status	CS Level	Confirmed	Expected Status	Expected Habitat
Australian Gull-billed Tern	*Gelochelidon macrotarsa*	M S5	CS1		Vagrant	Ram
Eastern Great Egret	*Ardea modesta*	S5	CS1		Irregular visitor	Ram
Cattle Egret	*Ardea ibis*	S5	CS1		Irregular visitor	Ram
Glossy Ibis	*Plegadis falcinellus*	M S5	CS1		Vagrant	Ram
Osprey	*Pandion haliaetus*	M S5	CS1		Vagrant	Ram
Peregrine Falcon	*Falco peregrinus*	S7	CS1		Irregular visitor	S3
Rainbow Bee-eater	*Merops ornatus*	S5	CS1	3 R	Resident	S3
Night Parrot	*Pezoporus occidentalis*	E S1	CS1		Locally extinct	S3, Ram
Eastern Grass Owl	*Tyto longimembris*		CS3		Vagrant	S3, Ram
Grey Wagtail	*Motacilla cinerea*	M S5	CS1		Vagrant	S3, Ram
Yellow Wagtail	*Motacilla flava*	M S5	CS1		Vagrant	S3, Ram
Barn Swallow	*Hirundo rustica*	M S5	CS1		Migrant	S3, Ram
MAMMALS						
Brush-tailed Mulgara	*Dasycercus blythi*	P4	CS2	2 3	Regular visitor	S3
Northern Quoll	*Dasyurus hallucatus*	E S2	CS1		Vagrant	S3
Greater Bilby	*Macrotis lagotis*	V S3	CS1	2 3	Regular visitor	S3
Golden Bandicoot	*Isoodon auratus*	V S3	CS1		Locally extinct	S3
Northern Brushtail Possum	*Trichosurus arnhemensis*	S3	CS1		Irregular visitor	S3
Boodie	*Bettongia lesueur*	Ex V S4 S6	CS1		Locally extinct	S3
Spectacled Hare-Wallaby	*Lagorchestes conspicillatus leichardti*	P3	CS2		Regular visitor	S3
Ghost Bat	*Macroderma gigas*	V S3	CS1		Vagrant	S3
Pilbara Leaf-nosed Bat	*Rhinonicteris aurantia (Pilbara form)*	V S3 P4	CS1		Vagrant	S3
Loria's Mastiff Bat	*Mormopterus loriae*	P1	CS2		Vagrant	S3, Ram
Lakeland Downs Mouse	Leggadina lakedownensis	P4	CS2		Irregular visitor	S3, Ram
Total Number of Species:	**43**			**6**		

See Appendix 1 and 2 for descriptions of conservation significance levels. Species recorded are indicated and the predicted status of each species in the survey area is also given.
EPBC Act listed species: V = Vulnerable, E = Endangered, C = Critically Endangered, Mig = Migratory, Mar = Marine.
WC Act listed species: S1 – S7 = Schedule 1 - 7; DPaW Priority Species: P1 - P5 = Priority 1 - 5.
Confirmed species: 1 = Confirmed in Pardoo Station, 2 = Confirmed in Stage 2, 3 = Confirmed in Stage 3, R = Confirmed in Ramsar site.

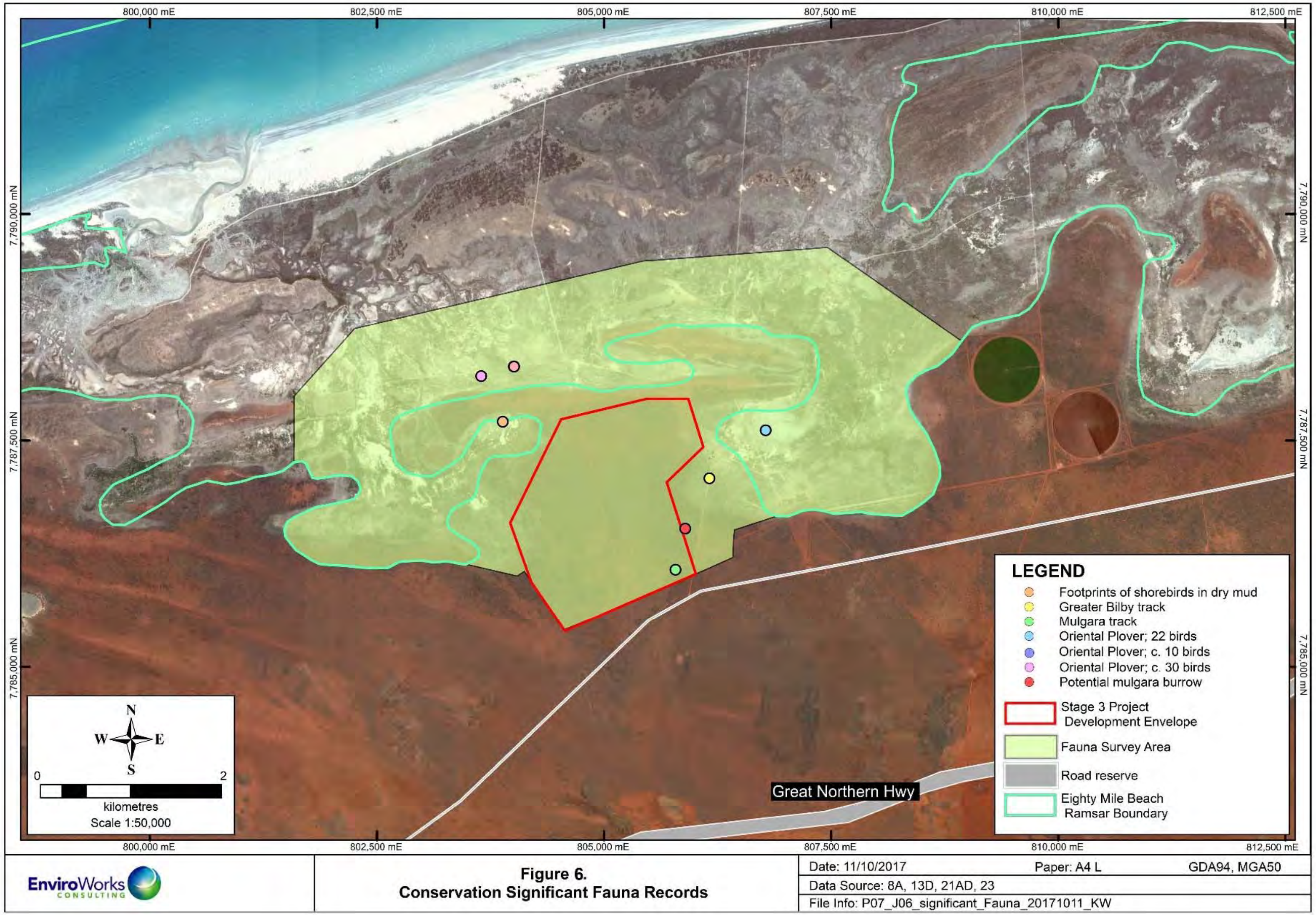

Figure 6. Map of the locations of the conservation significant fauna recorded

Conservation significance level 1

Airlie Island Ctenotus

The Airlie Island Ctenotus has a restricted distribution, being confined to fragments of the Pilbara and southern Kimberley coast. Prior to 2012 it was known from only a few locations but is now known to occur in coastal areas and islands between Onslow and Broome, including four records from 2012 at Cape Keraudren, 15km to the west. The Arlie Island Ctenotus is described as occurring in low open samphire shrubland, coastal tussock or hummock grasslands and mangrove margins. Within the Stage 3 project area, it is therefore possible that the species occurs in low open grasslands.

Migratory Waterbirds

Only three listed migratory waterbirds are likely to occur regularly, and all are grassland-dependent species that forage (mostly on invertebrates) on dry grasslands. These are the Oriental Plover, Little Curlew and Oriental Pratincole, and while only the Oriental Plover was recorded in September 2017 (in the Ramsar site (Figure 6) in VSAs 3 and 4 – grasslands and salt pans), the Little Curlew and Oriental Pratincole arrive later in the year so can be expected regularly from about late October. An additional grassland-dependent waterbird, the Australian Pratincole, was present on the grasslands (VSA3) in September 2017, but this is abundant and not listed as migratory.

Stage 3 itself is of limited value to waterbirds, including migratory species, as it provides almost no habitat, although some birds may visit bare ground around stock watering points occasionally. The Brolga (not a listed migratory species) was abundant in September 2017, with over 200 birds present around stock watering points in the Ramsar site and recent tracks around stock watering points in Stage 3.

The adjacent Ramsar site is seasonally inundated (damp) but appears only to be extensively flooded after exceptional rainfall events. Water Technology (2017) conducted a flood study for the area which showed that flooding occurs locally approximately every 10 years. Localised flooding is short lived with some areas flooded for periods of 1 – 2 weeks, whilst other areas are inundated for 3 – 5 weeks after heavy prolonged rainfall (Water Technology, 2017).

Much of the adjacent Ramsar site supports dense acacia and melaleuca thickets. This means that even when flooded, migratory waterbirds that rely on wetland environments would find only small areas of open, shallow wetlands in grasslands and salt pans.

By cross-referencing vegetation types (EnviroWorks Consulting, 2017), with flood modelling conducted (Water Technology, 2017), within a 1 km buffer from the Stage 3 Development Envelope, there are 20.8 ha of salt pans/grasslands which would flood for 1 – 2 weeks and 12.6 ha of salt pans which would flood for 3-5 weeks (Figure 7) (when the area floods approximately every 10 years). The abundance of waterbirds that use these short lived, ephemeral wetlands adjacent to the project is not expected to be high due to the small area of suitable habitat and infrequency of flooding. In summary these areas would be used by small numbers of a wide range of migratory waterbird species intermittently when flooded.

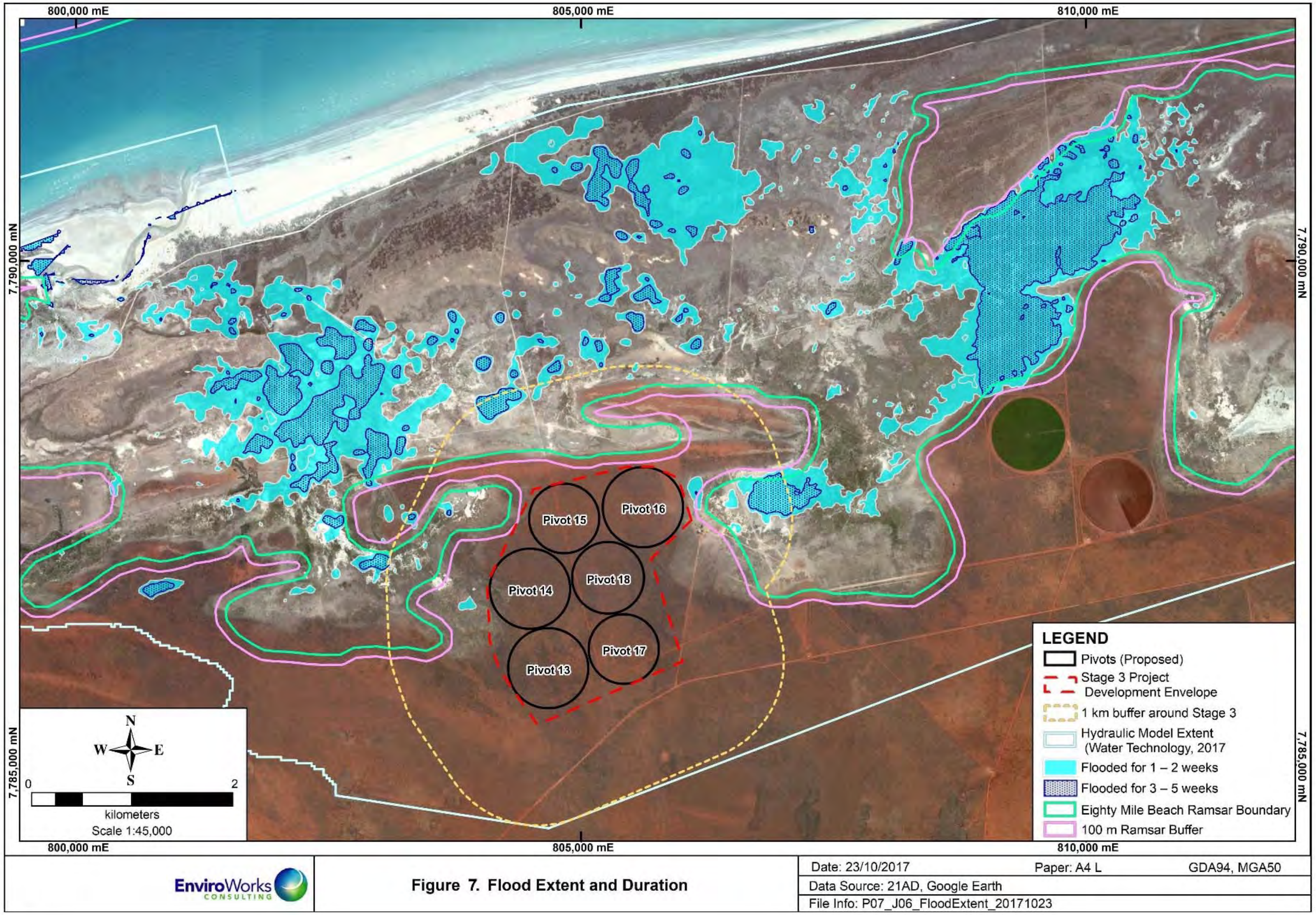

Figure 7. Flood Extent and Duration (Water Technology, 2017)

The dry grassland areas, however, would be used regularly (i.e. annually) by the grassland-dependent migratory waterbirds, as these species use the grassland and low shrubland VSA (VSA 3) when it is dry. They abandon this environment when it floods. It is not possible to reliably estimate numbers, but about 30 Oriental Plovers were counted at any one time in September 2017, and more may have been present.

Bamford *et al.* (2008) identify the 1% criterion (i.e. criterion under the Ramsar Convention to identify an internationally important site on the basis of supporting >1% of a species' population) for the Oriental Plover, Little Curlew and Oriental Pratincole as 700, 1800 and 20000 respectively. Such large numbers would seem very unlikely on the small areas of grassland in the adjacent Ramsar site. Note, however, that the very high 1% criterion for the Oriental Pratincole is based upon a very high population estimate derived from a rare massive aggregation of the species along the 80 Mile Beach, so the species is at least occasionally extremely abundant in the general region and therefore a temporary, rare but very large aggregation could occur in any suitable environment in the general area. Both Oriental Plovers and Little Curlews will also occasionally form large, temporary aggregations in suitable habitat. Any such aggregation of these three species would be very rare, and such aggregations are often associated with sources of drinking water (M. Bamford; pers. obs).

In summary, the abundance of waterbirds that actually use wetlands is not expected to be high due to the small area of suitable habitat and infrequency of flooding. The abundance of grassland-dependent waterbirds is also not expected to be high, as the area of dry grassland is small, but such species are likely to occur regularly in the September to November period (pre-Wet season). Large but very rare aggregations of these grassland species are possible, but the likelihood of such aggregations meeting the Ramsar criterion for any of these species adjacent to Stage 3 is extremely low. The Eighty Mile Beach Ramsar Site is listed on the basis of large aggregations of migratory waterbirds on the coastal flats and beaches.

Rainbow Bee-eater, Barn Swallow and Fork-tailed Swift

These three species are listed as Migratory: the bee-eater under the WA Wildlife Conservation Act only, the swift and swallow under this and the EPBC Act. In this area the bee-eater is likely to be a resident and will breed in the area, especially on open ground. Therefore, open ground within Stage 3 could be used for breeding. The Barn Swallow breeds from the eastern Himalayas to Japan and is a non-breeding summer visitor to northern Australian coasts; it occurs in open country in coastal lowlands and may occur in the survey area for part of the year. The Fork-tailed Swift is less predictable but could be a regular, non-breeding summer visitor that would overfly the area and thus would be more or less independent of terrestrial environments. Both the Rainbow Bee-eater and Fork-tailed Swift were recorded in the site visit.

Peregrine Falcon

This species is known to occur over a wide range of environments across Australia. Preferred nesting locations include a range of elevated locations with steep bisected topography such as rocky hills, breakaways, cliffs and high artificial structures. It will also nest in very large, horizontally-aligned tree hollows, and in old Raven nests in tall trees (M. Bamford pers. obs.). The Stage 3 area may be within the hunting range of a pair of Peregrine Falcons, but as the project area lacks elevated landscapes/cliffs and tall trees, it is unlikely to support nesting.

Night Parrot

The Night Parrot is one of the rarest and most enigmatic of Australia's birds. It has been recorded only from arid landscapes of Australia's interior and while seen fairly regularly in the late 19th Century, it was considered by some authorities to be extinct by the middle of the 20th Century despite occasional unconfirmed sightings. Since then there have been several confirmed sightings of Night Parrots including at two locations in WA, the closest to the Pardoo area being on the Fortescue Marsh in the eastern Pilbara in 2005 (Davis and Metcalf 2008). Recent unpublished observations at a second location indicate the species favours long unburnt spinifex close to salt marsh. The general region around Pardoo and along the 80 Mile Beach includes areas of spinifex close to saline flats and marshes, but the frequency of fire is high. Recent observations on Night Parrots mean that recordings of their distinctive call are now available and it is known they call fairly reliably just after sunset; listening was carried out on the edge of Stage 3 (near the Ramsar site) on the evening of September 2017, but the species was not heard. This does not constitute a comprehensive survey for the species, but the fire frequency and lack of any unconfirmed records in the broader region suggest it is very unlikely to be present and thus is classed as locally extinct.

Greater Bilby

The Bilby is listed as Vulnerable under the relevant state and federal legislation (DotEE 2016). The species formerly utilised a wide range of environments across the continent. Extant populations are restricted to a variety of "tall shrublands, open woodlands, and hummock grasslands" (Maxwell *et al*. 1996). The species appears to occur in scattered populations across the northern Pilbara, including close to Port Hedland (Thompson and Thompson 2008). The Greater Bilby has been recorded in Pardoo Station in previous surveys (Stage 2 area in July 2017; Bamford and Shepherd 2017), and was recorded in Stage 3 in the September 2017 survey (Figure 7). Locations of all Bilby records on Pardoo are given in Table 7, and the location of the 2017 record in Stage 3 is illustrated on Figure 6. Bamford and Shepherd (2017) concluded that the Bilby is a regular visitor to the Pardoo area.

Plate 9. Greater Bilby *Macrotis lagotis* tracks in Stage 3 site.

Northern Brushtail Possum

While not recorded during surveys to Pardoo and not listed in databases for the area, BCE has two records from the greater area: inland of Sandfire Roadhouse (September 1997) and on Shelamar Station to the east-north-east (August 2017). These records suggest that the species is present in the general region and thus it was concluded that it may be an irregular visitor to the survey area.

Locally extinct mammals

Two species are thought to be locally extinct from the area, the Golden Bandicoot and the Boodie. While these species are not expected to be present, they may have persisted in the area until the middle of the Twentieth Century. Their local extinction is likely due to a combination of factors including altered fire regimes, grazing impacts and feral predators.

Conservation significance level 2

Dampierland Plain Slider

The Dampierland Plain Slider occurs in sandy areas generally in coastal south-western Kimberley from Kimbleton to Nita Downs, however there are a few isolated records in the Pilbara including one 40km south of the survey area. If present this species is likely to be resident in the survey area.

Brush-tailed Mulgara

This species are generally associated with mature Spinifex hummock grasslands on sandplains and/or sand ridges, but have been recorded from other VSAs. Evidence of Mulgara was found during the 2016 site inspection, and the species is considered likely to be at least a regular visitor to the area.

Spectacled Hare-Wallaby

The Spectacled Hare-Wallaby is found in tussock or hummock grasslands, particularly where these are large and long-unburnt. The Stage 3 area has experienced frequent fires so the environment is probably not suitable, but the species could occur nearby with a recent potential (2017) record from Anna Plains Station (BCE database). Therefore it is assumed to be at least a visitor.

Lakeland Downs Mouse

This species is often associated with Gilgai and clay soils in the Pilbara, and has been found around the lower slopes of rocky hills in the Great Sandy Desert (Bamford and Davies 1996). Although it does not appear to have declined, the species does show large fluctuations in population numbers (Moro and Kutt 2008). It may be present in the survey area as an irregular visitor.

Conservation significance level 3

Bush Stone-curlew

This species was recently removed from the DPaW priority fauna list (CS2). A widespread species over much of northern Australia, it has almost disappeared from the southern half of its range. particularly arid northern half from a range of open shrubland vegetation types including. Recorded during the field survey at both Stage 3 and the Ramsar site. Expected to be a resident.

Woma

The Woma is widespread at low densities throughout sand plains of the semi-arid and arid inland of Western Australia. The southern population has suffered significant declines and is classed as a Priority species by DBCA (therefore CS2), but the northern population is considered stable (Maryan, 2002). It is considered to be resident in the Stage 3 area, and BCE has records from near Sandfire Roadhouse (1981), the mouth of Petermarer Creek (1995) and Shelamar Station (2017).

Eastern Grass Owl

While expected only as a vagrant, there were reports from Pardoo staff of 'barn owls' being flushed during the day in existing pivot irrigated pasture. This is behaviour more typical of the Eastern Grass Owl, and suggests that the species may have colonised the area in response to the development of pivot irrigation. It otherwise is restricted to the Kimberley and has a patchy and uncertain distribution.

Table 7. Locations of significant species recorded in Stage 3 area on Pardoo Station (July 2016 and September 2017).

Date	Evidence	Easting (Zone 50K)	Northing
13/7/2016	Mulgara track	805786	7786086
14/7/2016	Potential mulgara burrow	805893	7786540
18/09/2017	Greater Bilby track	806159	7787096
19/09/2017	Oriental Plover; 22 birds	806778	7787626
19/09/2017	Oriental Plover; c. 10 birds	804008	7788329
19/09/2017	Oriental Plover; c. 30 birds	803647	7788224
19/09/2017	Australian Pratincole	804008	7788329
20/09/2017	Footprints of shorebirds in dry mud	803884	7787720

3.2.3 Introduced species

Eight introduced species could occur in the survey area and the species of greatest interest is the Red Fox, due to the threat it poses to the Bilby. The Fox is already a confirmed visitor and any increase in its abundance or persistence would be a risk to the Bilby.

The Cane Toad is also of concern as while not currently present, pivot irrigation systems may provide it with habitat. The expansion of pivot irrigation along the coast from Broome to Port Hedland may provide the species with a series of 'stepping stones' by which it could cross what has been identified as a major barrier to its spread in Western Australia (Tingley *et al.* 2012). The large distance between the pivot irrigation projects in the region may make it extremely difficult for Cane Toads to travel unassisted between them, but Tingley *et al.* (2012) identified stock watering points as a 'risk' in this regard even in the absence of pivot systems. Nevertheless, unintentional transport of the species by vehicles probably presents a major threat.

Spread of Cane Toads is a regional issue which should be managed on a wholistic basis by regulatory authorities and cannot be attributed to one project. The responsibility for regional management cannot placed on one pastoral station. However, Pardoo should participate in regional efforts coordinated by the regulators. The pivot irrigation systems and the workforce that will be established to operate these can assist with management by providing a detection, eradication and regulatory reporting system that could be used to prevent spread of the toad. This is discussed further below (Recommendations).

3.2.4 Patterns of biodiversity

Analysing patterns of biodiversity requires massive levels of field studies, especially in an annually variable environment, but some patterns can be deduced even from a short period of field investigations. Within the study area (but outside the Stage 3 Development Envelope), a grove of Tamarisk trees supported several bird species not or rarely seen elsewhere, including Eastern Barn Owl (a pair), nesting Brown Falcons, a pair of Brown Goshawks, Yellow-throated Miner and Grey-crowned Babbler. Elsewhere across the Stage 3 area, the level of degradation and fire history may determine levels of biodiversity with unburnt and intact vegetation likely to be richest in species.

In the Ramsar site, the main biodiversity significance is the presence of waterbirds and particularly migratory species. As noted above (under migratory waterbirds), the presence of most waterbirds is likely to be infrequent, intermittent and dependent upon exceptional rains that flood the open grasslands to form ephemeral wetlands. In all years, however, the grasslands in the Ramsar site can be expected to support grassland-dependent waterbirds in small numbers, mostly in the late spring period (October to December). Numbers of waterbirds in these areas are not expected to be high as the area of habitat is small.

3.2.5 Ecological processes

The nature of the landscape and the fauna assemblage indicate some of the ecological processes that may be important for ecosystem function (see Appendix 3 for descriptions and other ecological processes). These include:

<u>Local hydrology</u>. Local inundation patterns are affected by rainfall and surface hydrology. Effectively all the local environment is thus sensitive to hydrological change.

<u>Fire</u>. Based upon the appearance of vegetation, especially in the Stage 3 area, fires are frequent and often extensive, and may be altering vegetation structure and composition. Fire is natural in this landscape but changes to the fire regime can impact upon the fauna. Some fauna, including Bilbies, are reliant on occasional fires.

<u>Feral species and interactions with over-abundant native species</u>. Feral species are a major component of the mammal fauna and as noted above, Foxes and Cane Toads may be of particular concern. Domestic livestock (Cattle) are not part of the fauna assemblage but they do impact upon the landscape through grazing and trampling.

<u>Connectivity and landscape permeability.</u> The survey area is part of a much greater area of native vegetation that is largely continuous. There are no distinct linear environmental features likely to be important for connectivity. Therefore, landscape permeability is not currently a constraint for the fauna assemblage.

3.2.6 Summary of fauna values

The desktop study identified 235 vertebrate fauna species as potentially occurring in the Stage 3 area and adjacent Ramsar site: 5 frogs, 44 reptiles, 148 birds and 38 mammals. One bird and at least two mammal species may be locally extinct. The vertebrate assemblage includes 43 species of conservation significance, including the Bilby (a regular visitor) and a few migratory waterbirds that will use dry grasslands in the Ramsar site.

Fauna values within the study area can be summarised as follows:

Fauna assemblage. Largely intact and moderately rich, but highly variable seasonally and annually. Assemblage includes elements of the Great Sandy Desert, Pilbara and Kimberley.

Species of conservation significance. Only a small number of the many significant species that may be present occasionally are actually reliant on the project area. The most notable of these are the Bilby (a regular visitor to Stage 3) and some grassland-dependent migratory waterbirds (Oriental Plover, Little Curlew and Oriental Pratincole) that can be expected to be regular migrants visiting the dry grasslands of the adjacent Ramsar site.

Vegetation and Substrate Associations (VSAs). The Stage 3 area and Ramsar site represent quite different landscapes and support few but distinct VSAs.

Patterns of biodiversity. Within the Stage 3 area, vegetation that has not been subject to excessively frequent fires and/or grazing are likely to be most important for fauna, while the Tamarisk grove, while consisting of an introduced species, is locally important for a range of birds. In the Ramsar site, grasslands are of most interest as they will support migratory waterbirds in some seasons and years. Note that the abundance of waterbirds is not expected to be high.

Key ecological processes. The main processes which may affect the fauna assemblage is likely to be local hydrology, the fire regime and the presence of feral predators.

3.3 Impact assessment

Impacting processes have to be considered in the context of fauna values and the nature of the proposed action, and are examined below. Predicted impacts need to be considered in the light of recommendations made in Section 6.

Habitat loss leading to population decline.
The area of habitat loss across the largely intact landscape is proportionately small, and therefore the impact upon fauna biodiversity from habitat loss is predicted to be negligible. The 1028 ha of disturbance/impact from Stages 1, 2 and 3 at Pardoo represents 1.7% of the 61,143 ha of native vegetation from the Nita Land System the within a 15km buffer around the three project areas (Figure 8).

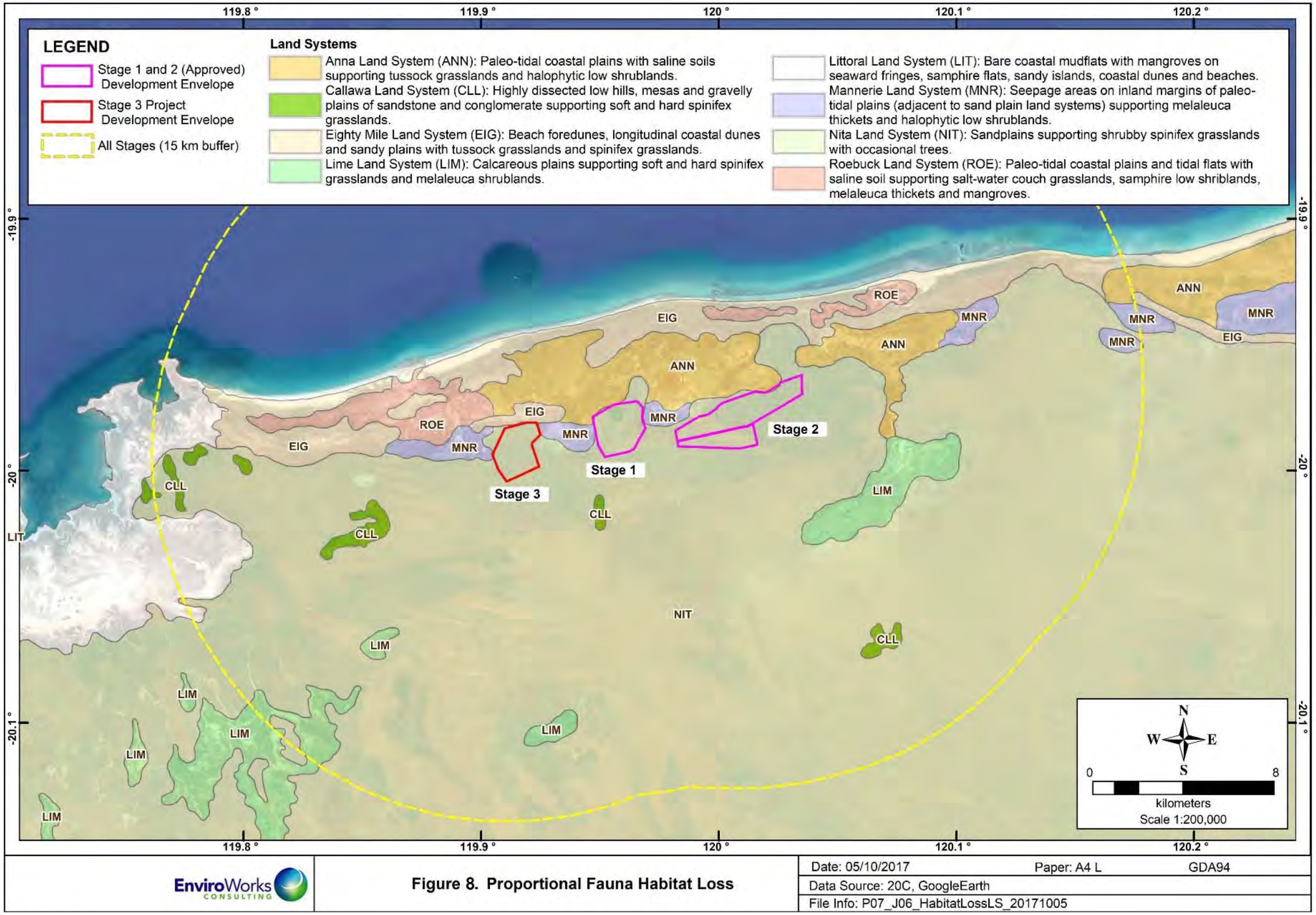

Figure 8. Similar habitat (Nita land system) in a 15 km buffer around project stages 1, 2 and 3

Habitat loss leading to population fragmentation.

The fauna assemblage does not appear to be reliant upon connectivity or existing habitat corridors, and therefore the threat from population fragmentation due to pivot development appears negligible.

Mortality during clearing

Mortality of fauna during clearing is inevitable and can be a conservation concern if the species are of conservation significance or naturally occur at low population densities. Management strategies will be required to minimise mortality risk for species such as the Bilby and Mulgara (see Recommendations below). For the Bilby, the impact of even a few deaths could affect the local population (and would thus be a major impact).

Degradation of habitat due to weed invasion.

This impact should be negligible assuming standard hygiene and monitoring procedures are employed.

Contamination of surrounding areas by agricultural chemicals

The use of agricultural chemicals will be restricted to fertilizers and therefore the risk of spray drift is negligible. Fertilizer use will need to be managed and monitored to ensure spread outside the pivot areas is minimal and nutrients do not build up to unacceptable levels in the groundwater.

Ongoing mortality from operations.

Increased traffic may increase the risk of roadkill for species such as the Bush Stone-curlew. It is understood operations (including driving of vehicles) will not occur at night – this should minimise risk to nocturnal species such as the Bilby. Impact can be assumed to be minor with some management in place (see recommendations).

Species interactions.

Some of the fauna is sensitive to feral species such as Foxes and wild dogs/Dingoes. The pivots may represent an environment where such feral species will increase in abundance, either due to increased access to water or increased access to food.

If Cane Toads spread to the area, native species that eat Cane Toads would decline.

Given the pivot areas will be fenced to contain the cattle, there will be no additional trampling or grazing by cattle outside the fenced Development Envelope. Cattle movement frequency and density is unlikely to change outside the fenced areas as cattle already move and graze freely within the local area as part of normal station activities and installation of the pivots will not change this. Cattle will be herded into the Stage 3 Development Envelope via a fenced track from existing cattle station holding yards to the south east.

Note that some native species not restricted by fencing may increase in abundance at the pivots, as these provide a new environment, but it does not appear likely that this would affect fauna populations significantly given the relatively small area of pivots and the fact that species attracted to the pivots would also probably be restricted to this novel environment.

Hydrological change

Assuming that groundwater abstraction is managed to prevent drawdown, this risk should be negligible. It is understood that surface hydrology will not be affected given the very high infiltration rate of the soils, which will result in all irrigation water infiltrating directly to the groundwater and no surface run-off (Water Technology, 2017). Contamination of groundwater with hydrocarbons or nutrients (from fertiliser) should be prevented and effectiveness of management measures monitored (see recommendations below).

Altered fire regimes

The vegetation in general is fire-dependent but can be degraded if subjected to too-frequent fires. Increased human activity in the area could result in an increase in fire frequency, and therefore a strict fire management measures need to be developed to keep this risk low (see recommendations).

Disturbance (dust, noise, light).

The level of dust, noise and light from operation of the pivots should be minimal, if managed appropriately. Operations will not occur at night (therefore no night time lighting will be needed) and the major source of noise will be generators and pumps set among the pivots and associated infrastructure, and thus away from natural areas.

4 Recommendations

Potential impacts to fauna include:

- mortality during clearing
- degradation of habitat due to weed invasion
- increased grazing pressure around pivots
- hydrological change due to groundwater abstraction and irrigation
- impacts of feral species
- altered fire regimes.

Because of the small area of clearing involved in a largely intact landscape, potential impacts are mostly considered to be negligible.

Recommendations to manage potential impacts include:

- Pre-clearing surveys and displacement or relocation of conservation significant fauna (Bilby and Mulgara) that may be present within the Stage 3 disturbance footprint.
- Weed management to prevent invasion of native vegetation with crop species and monitoring to ensure effectiveness.
- Protecting native vegetation by fencing the project area, so that cattle movement is restricted to prevent additional grazing/trampling pressure to native vegetation outside the fenced areas.
- Hydrological management and monitoring to prevent hydrological impacts which may affect fauna habitat.
- Feral fauna management and monitoring. If the Cane Toad spreads to the region, Pardoo should work with local regulatory authorities as part of regional efforts to control its spread and implement a Cane Toad detection, eradication and reporting system. Wild dogs are already controlled. Foxes represent a threat to the coastal population of the Bilby but would require a coordinated control program including all local stations.
- Fire management measures.

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6 Appendices

6.1 Appendix 1. Explanation of fauna values.

Fauna values are the features of a site and its fauna that contribute to biodiversity, and it is these values that are potentially at threat from a development proposal. Fauna values can be examined under the five headings outlined below. It must be stressed that these values are interdependent and should not be considered equal, but contribute to an understanding of the biodiversity of a site. Understanding fauna values provides opportunities to predict and therefore mitigate impacts.

Assemblage characteristics

Uniqueness. This refers to the combination of species present at a site. For example, a site may support an unusual assemblage that has elements from adjacent biogeographic zones, it may have species present or absent that might be otherwise expected, or it may have an assemblage that is typical of a very large region. For the purposes of impact assessment, an unusual assemblage has greater value for biodiversity than a typical assemblage.

Completeness. An assemblage may be complete (i.e. has all the species that would have been present at the time of European settlement), or it may have lost species due to a variety of factors. Note that a complete assemblage, such as on an island, may have fewer species than an incomplete assemblage (such as in a species-rich but degraded site on the mainland).

Richness. This is a measure of the number of species at a site. At a simple level, a species rich site is more valuable than a species poor site, but value is also determined, for example, by the sorts of species present.

Vegetation/substrate associations (VSAs)

VSAs combine broad vegetation types, the soils or other substrate with which they are associated, and the landform. In the context of fauna assessment, VSAs are the environments that provide habitats for fauna. The term habitat is widely used in this context, but by definition an animal's habitat is the environment that it utilises (Calver et al. 2009), not the environment as a whole. Habitat is a function of the animal and its ecology, rather than being a function of the environment. For example, a species may occur in eucalypt canopy or in leaf-litter on sand, and that habitat may be found in only one or in several VSAs. VSAs are not the same as vegetation types since these may not incorporate soil and landform, and recognise floristics to a degree that VSAs do not. Vegetation types may also not recognise minor but often significant (for fauna) structural differences in the environment. VSAs also do not necessarily correspond with soil types, but may reflect some of these elements.

Because VSAs provide the habitat for fauna, they are important in determining assemblage characteristics. For the purposes of impact assessment, VSAs can also provide a surrogate for detailed information on the fauna assemblage. For example, rare, relict or restricted VSAs should automatically be considered a significant fauna value. Impacts may be significant if the VSA is rare, a large proportion of the VSA is affected and/or the VSA supports significant fauna. The disturbance of even small amounts of habitat in a localised area can have significant impacts to fauna if rare or unusual habitats are disturbed.

Patterns of biodiversity across the landscape

This fauna value relates to how the assemblage is organised across the landscape. Generally, the fauna assemblage is not distributed evenly across the landscape or even within one VSA. There may be zones of high biodiversity such as particular environments or ecotones (transitions between VSAs). There may also be zones of low biodiversity. Impacts may be significant if a wide range of species is affected even if most of those species are not significant per se.

Species of conservation significance

Species of conservation significance are of special importance in impact assessment. The conservation status of fauna species in Australia is assessed under Commonwealth and State Acts such as the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) and the Western Australian Wildlife Conservation Act 1950 (Wildlife Conservation Act). In addition, the Western Australian Department of Environment and Conservation (DEC) recognises priority levels, while local populations of some species may be significant even if the species as a whole has no formal recognition. Therefore, three broad levels of conservation significance can be recognised and are used for the purposes of this report, and are outlined below. A full description of the conservation significance categories, schedules and priority levels mentioned below is provided in Appendix 2.

<u>Conservation Significance (CS) 1: Species listed under State or Commonwealth Acts.</u>

Species listed under the EPBC Act are assigned to categories recommended by the International Union for the Conservation of Nature and Natural Resources (IUCN) and reviewed by Mace and Stuart (1994), or are listed as migratory. Migratory species are recognised under international treaties such as the China Australia Migratory Bird Agreement (CAMBA), the Japan Australia Migratory Bird Agreement (JAMBA), the Republic of South Korea Australia Migratory Bird Agreement (ROKAMBA), and/or the Convention on the Conservation of Migratory Species of Wild Animals (CMS; also referred to as the Bonn Convention). The Wildlife Conservation Act uses a series of Schedules to classify status, but also recognizes the IUCN categories and ranks species within the Schedules using the categories of Mace and Stuart (1994).

<u>Conservation Significance (CS) 2: Species listed as Priority by the DEC but not listed under State or Commonwealth Acts.</u>

In Western Australia, the DEC has produced a supplementary list of Priority Fauna, being species that are not considered threatened under the Wildlife Conservation Act but for which the DEC feels there is cause for concern. Some Priority species are also assigned to the Conservation Dependent category of the IUCN.

<u>Conservation Significance (CS) 3: Species not listed under Acts or in publications, but considered of at least local significance because of their pattern of distribution.</u>

This level of significance has no legislative or published recognition and is based on interpretation of distribution information, but is used here as it may have links to preserving biodiversity at the genetic level (EPA 2002). If a population is isolated but a subset of a widespread (common) species, then it may not be recognised as threatened, but may have unique genetic characteristics. Conservation significance is applied to allow for the preservation of genetic richness at a population level, and not just at a species level. Species on the edge of their range, or that are sensitive to impacts such as habitat fragmentation, may also be classed as CS3, as may colonies of waterbirds. The Western Australian Department of Environmental Protection, now DPaW, used this sort of interpretation to identify significant bird species in the Perth metropolitan area as part of the Perth Bushplan (DEP 2000).

Invertebrate species considered to be short range endemics (SREs) also fall within the CS3 category, as they have no legislative or published recognition and their significance is based on interpretation of distribution information. Harvey (2002) notes that the majority of species that have been classified as short-range endemics have common life history characteristics such as poor powers of dispersal or confinement to discontinuous habitats. Several groups, therefore, have particularly high instances of short-range endemic species: Gastropoda (snails and slugs), Oligochaeta (earthworms), Onychophora (velvet worms), Araneae (mygalomorph spiders), Pseudoscorpionida (pseudoscorpions), Schizomida (schizomids), Diplopoda (millipedes), Phreatoicidea (phreatoicidean crustaceans), and Decapoda (freshwater crayfish). The poor understanding of the taxonomy of many of the short-range endemic species hinders their conservation (Harvey 2002).

Introduced species

In addition to these conservation levels, species that have been introduced (INT) are indicated throughout the report. Introduced species may be important to the native fauna assemblage through effects by predation and/or competition.

Ecological processes upon which the fauna depend

These are the processes that affect and maintain fauna populations in an area and as such are very complex; for example, populations are maintained through the dynamic of mortality, survival and recruitment being more or less in balance, and these are affected by a myriad of factors. The dynamics of fauna populations in a project may be affected by processes such as fire regime, landscape patterns (such as fragmentation and/or linkage), the presence of feral species and hydrology. Impacts may be significant if processes are altered such that fauna populations are adversely affected, resulting in declines and even localised loss of species. Threatening processes as outlined below are effectively the ecological processes that can be altered to result in impacts upon fauna.

6.2 Appendix 2. Categories used in the assessment of conservation status.

IUCN categories (based on review by Mace and Stuart 1994) as used for the Environment Protection and Biodiversity Conservation Act 1999 and the Western Australian Wildlife Conservation Act 1950.

Extinct	Taxa not definitely located in the wild during the past 50 years.
Extinct in the Wild (Ex)	Taxa known to survive only in captivity.
Critically Endangered (CR)	Taxa facing an extremely high risk of extinction in the wild in the immediate future.
Endangered (E)	Taxa facing a very high risk of extinction in the wild in the near future.
Vulnerable (V)	Taxa facing a high risk of extinction in the wild in the medium-term future.
Near Threatened	Taxa that risk becoming Vulnerable in the wild.
Conservation Dependent	Taxa whose survival depends upon ongoing conservation measures. Without these measures, a conservation dependent taxon would be classed as Vulnerable or more severely threatened.
Data Deficient (Insufficiently Known)	Taxa suspected of being Rare, Vulnerable or Endangered, but whose true status cannot be determined without more information.
Least Concern.	Taxa that are not Threatened.

Schedules used in the WA Wildlife Conservation Act 1950

Schedule 1 (S1)	Critically Endangered fauna.
Schedule 2 (S2)	Endangered fauna
Schedule 3 (S3)	Vulnerable Migratory species listed under international treaties.
Schedule 4 (S4)	Presumed extinct fauna
Schedule 5 (S5)	Migratory birds under international agreement
Schedule 6 (S6)	Conservation dependant fauna
Schedule 7 (S7)	Other specially protected fauna

WA Department of Biodiversity, Conservation and Attractions Priority species (species not listed under the Wildlife Conservation Act 1950, but for which there is some concern).

Priority 1 (P1)	Taxa with few, poorly known populations on threatened lands.
Priority 2 (P2)	Taxa with few, poorly known populations on conservation lands; or taxa with several, poorly known populations not on conservation lands.
Priority 3 (P3)	Taxa with several, poorly known populations, some on conservation lands.
Priority 4. (P4)	Taxa in need of monitoring. Taxa which are considered to have been adequately surveyed, or for which sufficient knowledge is available, and which are considered not currently threatened or in need of special protection, but could be if present circumstances change.

6.3 Appendix 3. Vertebrate fauna expected to occur in the survey area (Stage 3 area and adjacent Ramsar site)

These lists are derived from the results of database and literature searches and from previous field surveys conducted in the local area. These are:

- ALA = Atlas of Living Australia, searched September 2017;
- N = Naturemap Database, searched September 2017;
- EPBC = EPBC Protected Matters, searched September 2017;
- DBCA = DBCA Significant species search, searched September 2017;
- Bird Data = Birdlife Australia's Birdata database, searched September 2017;
- BCE 1 = BCE surveys undertaken previously in the general area (BCE database records 1981 to 2017);
- BCE 2 = BCE surveys undertaken previously in Pardoo Station (Bamford *et al.* 2016; Bamford and Shepherd 2017); and
- BCE 3 = Current site inspection September 2017. Species records are: 1 = nearby but not in Stage 3 or Ramsar, 3 = in Stage 3; R = in Ramsar site.

Status codes:

- CS1, CS2, CS3 = (summary) levels of conservation significance. See Appendix 2 for full explanation.
- EPBC Act listings: E = Endangered, V = Vulnerable, Mig = Migratory, Mar = Marine (see Appendix 2).
- Wildlife Conservation Act listings: for all CS1 species S1 to 7 = Schedules 1 to 7 respectively, (see Appendix 2) with rankings shown in square parentheses: [e] = endangered, [v] = vulnerable.
- DBCA Priority species: P1 to P4 = Priority 1 to 4 (see Appendix 2).

Frogs

FROGS		CS	ALA	N	EPBC	DBCA	BCE 1	BCE 2	BCE 3	Expected status in project area
HYLIDAE										
Main's Frog	*Cyclorana maini*		X	X						Resident
Green Tree Frog	*Litoria caerulea*						X			Visitor
Desert Tree Frog	*Litoria rubella*						X			Resident
MYOBATRACHIDAE										
Northern Burrowing Frog	*Neobatrachus aquilonius*		X	X						Resident
Desert Spadefoot Toad	*Notaden nichollsi*									Resident
Total Number of Species Expected:	**5**	**0**	**2**	**2**	**0**	**0**	**2**	**0**	**0**	**5**

Reptiles

REPTILES		CS	ALA	N	EPBC	DBCA	BCE 1	BCE 2	BCE 3	Expected status in project area
AGAMIDAE										
Ta-ta, Gilbert's Dragon	*Amphibolurus gilberti*		X	X						Resident
Long-nosed Dragon	*Amphibolurus longirostris*		X	X						Resident
Ring-tailed Dragon	*Ctenophorus caudicinctus*		X							Vagrant
Military Dragon	*Ctenophorus isolepis*		X	X						Resident
Central Netted Dragon	*Ctenophorus nuchalis*		X	X					3, R	Resident
Pindan Dragon	*Diporiphora pindan*		X	X						Resident
Dwarf Bearded Dragon	*Pogona minor mitchelli*		X	X					R	Resident
DIPLODACTYLIDAE										
Fat-tailed Gecko	*Diplodactylus conspicillatus*								#	Resident
Crowned Gecko	*Lucasium stenodactylum*		X							Resident
Western Beaked Gecko	*Rhynchoedura ornata*		X	X						Resident
Northern Spiny-tailed Gecko	*Strophurus ciliaris aberrans*		X							Resident
CARPHODACTYLIDAE										
Smooth Knob-tailed Gecko	*Nephrurus levis*		X							Resident
GEKKONIDAE										
Pilbara Dtella	*Gehyra pilbara*			X						Resident
Tree Dtella	*Gehyra variegata*		X	X						Resident
Common House Gecko	*Hemidactylus frenatus*								1	Vagrant
Bynoe's Gecko	*Heteronotia binoei*		X	X					3	Resident
PYGOPODIDAE										
Neck-barred Delma	*Delma haroldi*		X	X						Resident
Excitible Delma	*Delma tincta*								R	Resident
Burton's Legless Lizard	*Lialis burtonis*		X	X						Resident

REPTILES		CS	ALA	N	EPBC	DBCA	BCE 1	BCE 2	BCE 3	Expected status in project area
SCINCIDAE										
Airlie Island Ctenotus	*Ctenotus angusticeps*	V S3	X	X	X	X				Resident
Bar-shouldered Ctenotus	*Ctenotus inornatus*		X							Resident
Leopard Ctenotus	*Ctenotus pantherinus*		X	X						Resident
Rock Ctenotus	*Ctenotus saxatilis*			X					R	Resident
North-western Sandy-loam Ctenotus	*Ctenotus serventyi*			X						Resident
Mosaic Desert Skink	*Eremiascincus musivus*		X							Resident
North-western Sandslider	*Lerista bipes*		X	X						Resident
Dampierland Plain Slider	*Lerista separanda*	P2				X				Resident
Common dwarf skink	*Menetia greyii*		X	X					3	Resident
Lined Fire-tailed Skink	*Morethia ruficauda*								3	Resident
Central Blue-tongue	*Tiliqua multifasciata*		X	X					3	Resident
VARANIDAE										
Spiny-Tailed Monitor	*Varanus acanthurus*								R	Resident
Pygmy Desert Monitor	*Varanus eremius*		X							Resident
Gould’s Goanna	*Varanus gouldii*						X			Resident
TYPHLOPIDAE										
Long-beaked Blind Snake	*Anilios grypus*		X						1	Resident
BOIDAE										
Stimson's Python	*Antaresia stimsoni*		X	X						Resident
Black-headed Python	*Aspidites melanocephalus*								3	Resident
Woma	*Aspidites ramsayi*	CS3	X				X			Resident
ELAPIDAE										
Desert Death Adder	*Acanthophis pyrrhus*		X							Resident
Yellow-faced Whipsnake	*Demansia psammophis cupreiceps*		X	X						Resident

REPTILES		CS	ALA	N	EPBC	DBCA	BCE 1	BCE 2	BCE 3	Expected status in project area
Moon Snake	*Furina ornata*		X	X						Resident
Mulga Snake	*Pseudechis australis*						X		3	Resident
Western Brown Snake	*Pseudonaja mengdeni*			X						Resident
Ringed Brown Snake	*Pseudonaja modesta*		X	X						Resident
Desert Banded Snake	*Simoselaps anomalus*		X	X						Resident
Total Number of Species Expected:	**44**	**3**	**31**	**25**	**1**	**2**	**3**	**0**	**14**	

Birds

BIRDS		CS	ALA	N	EPBC	DBCA	BA	BCE 1	BCE 2	BCE 3	Expected status in project area
CASUARIIDAE											
Emu	*Dromaius novaehollandiae*										Irregular Visitor
PHASIANIDAE											
Brown Quail	*Coturnix ypsilophora*		X	X			X				Regular Visitor
TURNICIDAE											
Little Button-quail	*Turnix velox*		X	X			X		2	3 R	Resident
ANATIDAE											
Grey Teal	*Anas gracilis*		X	X			X				Vagrant
Pacific Black Duck	*Anas superciliosa*		X	X			X				Vagrant
Hardhead	*Aythya australis*		X				X				Vagrant
Black Swan	*Cygnus atratus*			X							Vagrant
Plumed Whistling-Duck	*Dendrocygna eytoni*		X				X				Vagrant
Pink-eared Duck	*Malacorhynchus membranaceus*		X	X			X				Vagrant
PODICIPEDIDAE											
Hoary-headed Grebe	*Poliocephalus poliocephalus*			X			X				Vagrant
Australasian Grebe	*Tachybaptus novaehollandiae*		X	X			X				Vagrant
COLUMBIDAE											
Diamond Dove	*Geopelia cuneata*		X	X			X		2	3	Resident
Bar-shouldered Dove	*Geopelia humeralis*		X	X			X				Regular Visitor
Peaceful Dove	*Geopelia placida*		X	X			X				Visitor
Spinifex Pigeon	*Geophaps plumifera*		X	X							Vagrant
Crested Pigeon	*Ocyphaps lophotes*		X	X			X		1 2	1 3 R	Resident

BIRDS		CS	ALA	N	EPBC	DBCA	BA	BCE 1	BCE 2	BCE 3	Expected status in project area
Common Bronzewing	*Phaps chalcoptera*		X	X			X		2		Resident
Flock Bronzewing	*Phaps histrionica*									1	Vagrant
CUCULIDAE											
Pallid Cuckoo	*Cacomantis pallidus*		X	X			X		1 2		Migrant
Pheasant Coucal	*Centropus phasianinus*		X	X			X		1	R	Resident
Horsfield's Bronze-Cuckoo	*Chalcites basalis*		X				X		2	R	Migrant
Black-eared Cuckoo	*Chrysococcyx osculans*									3	Migrant
OTIDIDAE											
Australian Bustard	*Ardeotis australis*		X	X			X		1 2	1 3 R	Resident
APODIDAE											
Fork-tailed Swift	*Apus pacificus*	M S5	X	X	X	X	X			3 R	Migrant
RALLIDAE											
Banded Rail	*Gallirallus philippensis*		X	X							Vagrant
Purple Swamphen	*Porphyrio porphyrio*		X	X							Vagrant
Australian Spotted Crake	*Porzana fluminea*		X	X							Vagrant
Spotless Crake	*Porzana tabuensis*		X	X							Vagrant
RECURVIROSTRIDAE											
Black-winged Stilt	*Himantopus leucocephalus*			X	X		X				Vagrant
Red-necked Avocet	*Recurvirostra novaehollandiae*		X	X	X		X				Vagrant
CHARADRIIDAE											
Red-capped Plover	*Charadrius ruficapillus*		X	X	X		X				Irregular visitor
Oriental Plover	*Charadrius veredus*	M S5	X	X	X	X	X			R	Migrant
Black-fronted Dotterel	*Elseyornis melanops*			X			X				Irregular visitor

BIRDS		CS	ALA	N	EPBC	DBCA	BA	BCE 1	BCE 2	BCE 3	Expected status in project area
Red-kneed Dotterel	*Erythrogonys cinctus*			X			X				Irregular visitor
Masked Lapwing	*Vanellus miles*			X			X			R	Resident
SCOLOPACIDAE											
Sharp-tailed Sandpiper	*Calidris acuminata*	M S5		X	X	X	X				Vagrant
Broad-billed Sandpiper	*Calidris falcinellus*	M S5			X	X	X				Vagrant
Curlew Sandpiper	*Calidris ferruginea*	Cr M S3 S5	X	X	X	X	X				Vagrant
Pectoral Sandpiper	*Calidris melanotos*	M S5			X						Vagrant
Red-necked Stint	*Calidris ruficollis*	M S5	X	X	X	X	X				Vagrant
Swinhoe's Snipe	*Gallinago megala*	M S5			X						Vagrant
Pin-tailed Snipe	*Gallinago stenura*	M S5			X						Vagrant
Little Curlew	*Numenius minutus*	M S5			X		X				Migrant
Wood Sandpiper	*Tringa glareola*	M S5	X	X		X					Vagrant
Common Greenshank	*Tringa nebularia*	M S5	X	X	X	X	X				Vagrant
Marsh Sandpiper	*Tringa stagnatilis*	M S5		X	X	X	X				Vagrant
ROSTRATULIDAE											
Australian Painted Snipe	*Rostratula australis*	E S2			X						Vagrant
GLAREOLIDAE											
Oriental Pratincole	*Glareola maldivarum*	M S5	X	X	X	X	X				Migrant
Australian Pratincole	*Stiltia isabella*		X	X	X		X			R	Migrant
LARIDAE											
Whiskered Tern	*Chlidonias hybrida*		X	X			X				Vagrant
White-winged Black Tern	*Chlidonias leucopterus*	M S5	X				X				Vagrant
Silver Gull	*Chroicocephalus novaehollandiae*		X	X			X				Vagrant

BIRDS		CS	ALA	N	EPBC	DBCA	BA	BCE 1	BCE 2	BCE 3	Expected status in project area
Australian Gull-billed Tern	*Gelochelidon macrotarsa*	M S5	X	X			X				Vagrant
CICONIIDAE											
Black-necked Stork	*Ephippiorhynchus asiaticus*		X	X			X				Vagrant
GRUIDAE											
Brolga	*Grus rubicunda*		X	X			X		1	3 R	Resident
BURHINIDAE											
Bush Stone-curlew	*Burhinus grallarius*	CS3	X	X						3 R	Resident
ARDEIDAE											
Eastern Great Egret	*Ardea modesta*	S5	X	X	X	X	X				Irregular visitor
Cattle Egret	*Ardea ibis*	S5			X						Irregular visitor
Intermediate Egret	*Ardea intermedia*		X	X			X				Irregular visitor
White-necked Heron	*Ardea pacifica*		X	X			X				Irregular visitor
Little Egret	*Egretta garzetta*		X	X			X				Irregular visitor
White-faced Heron	*Egretta novaehollandiae*		X	X			X				Irregular visitor
PLATALEIDAE											
Royal Spoonbill	*Platalea regia*			X							Vagrant
Glossy Ibis	*Plegadis falcinellus*	M S5	X	X		X					Vagrant
White Ibis	*Threskiornis molucca*		X						2		Regular visitor
Straw-necked Ibis	*Threskiornis spinicollis*		X				X		1	1 R	Regular visitor
ACCIPITRIDAE											
Collared Sparrowhawk	*Accipiter cirrocephalus*		X	X			X				Resident
Brown Goshawk	*Accipiter fasciatus*		X	X						3	Resident
Wedge-tailed Eagle	*Aquila audax*		X	X					1 2		Regular visitor

BIRDS		CS	ALA	N	EPBC	DBCA	BA	BCE 1	BCE 2	BCE 3	Expected status in project area
Swamp Harrier	*Circus approximans*		X	X							Vagrant
Spotted Harrier	*Circus assimilis*		X	X					2	3 R	Resident
Black-shouldered Kite	*Elanus axillaris*		X	X			X		2		Resident
White-bellied Sea-Eagle	*Haliaeetus leucogaster*		X	X	X						Vagrant
Brahminy Kite	*Haliastur indus*		X	X			X				Vagrant
Whistling Kite	*Haliastur sphenurus*		X	X			X		1 2	1 3 R	Resident
Black-breasted Buzzard	*Hamirostra melanosternon*		X	X			X				Regular visitor
Little Eagle	*Hieraaetus morphnoides*								2		Regular visitor
Black Kite	*Milvus migrans*		X	X			X		2	1	Resident
Eastern Osprey	*Pandion cristatus*	M S5	X	X	X						Vagrant
FALCONIDAE											
Brown Falcon	*Falco berigora*		X	X			X		1 2	1 3 R	Resident
Nankeen Kestrel	*Falco cenchroides*		X	X			X		1 2	1	Resident
Australian Hobby	*Falco longipennis*		X	X			X		2		Resident
Peregrine Falcon	*Falco peregrinus*	S7	X	X		X					Irregular visitor
STRIGIDAE											
Southern Boobook	*Ninox boobook*		X				X				Resident
Barking Owl	*Ninox connivens*										Irregular visitor
TYTONIDAE											
Barn Owl	*Tyto alba*									3	Regular visitor
Eastern Grass Owl	*Tyto longimembris*	CS3									Vagrant
MEROPIDAE											
Rainbow Bee-eater	*Merops ornatus*	S5	X	X	X	X	X		2	3 R	Resident

BIRDS		CS	ALA	N	EPBC	DBCA	BA	BCE 1	BCE 2	BCE 3	Expected status in project area
ALCEDINIDAE											
Collared Kingfisher	*Todiramphus chloris*		X	X			X				Vagrant
Red-backed Kingfisher	*Todiramphus pyrrhopygius*		X	X			X		1		Regular visitor
Sacred Kingfisher	*Todiramphus sanctus*		X	X			X				Irregular visitor
CACATUIDAE											
Little Corella	*Cacatua sanguinea*		X	X			X				Regular visitor
Galah	*Eolophus roseicapilla*		X	X			X		2	3 R	Regular visitor
Cockatiel	*Nymphicus hollandicus*		X	X					2	3	Regular visitor
PSITTACIDAE											
Budgerigar	*Melopsittacus undulatus*		X	X			X		2		Regular visitor
Night Parrot	*Pezoporus occidentalis*	E S1			X						Locally extinct
PTILONORHYNCHIDAE											
Western Bowerbird	*Ptilonorhynchus guttatus*		X	X			X				Vagrant
MALURIDAE											
Variegated Fairy-wren	*Malurus lamberti*		X	X					1 2	3	Resident
White-winged Fairy-wren	*Malurus leucopterus*		X	X					1 2	3 R	Resident
MELIPHAGIDAE											
Spiny-cheeked Honeyeater	*Acanthagenys rufogularis*		X	X			X				Irregular visitor
Pied Honeyeater	*Certhionyx variegatus*		X	X			X				Regular visitor
Orange Chat	*Epthianura aurifrons*		X								Irregular visitor
Crimson Chat	*Epthianura tricolor*		X	X					2	3 R	Resident
Singing Honeyeater	*Gavicalis virescens*		X				X		1 2	3 R	Resident
Brown Honeyeater	*Lichmera indistincta*		X	X			X			R	Resident

BIRDS		CS	ALA	N	EPBC	DBCA	BA	BCE 1	BCE 2	BCE 3	Expected status in project area
Yellow-throated Miner	*Manorina flavigula*		X	X			X		1 2	3 R	Resident
Red-headed Honeyeater	*Myzomela erythrocephala*		X								Vagrant
Grey-headed Honeyeater	*Ptilotula keartlandi*		X				X				Irregular visitor
White-plumed Honeyeater	*Ptilotula penicillata*		X				X		1		Regular visitor
Black Honeyeater	*Sugomel niger*		X				X				Regular visitor
PARDALOTIDAE											
Red-browed Pardalote	*Pardalotus rubricatus*		X	X			X			1	Regular visitor
ACANTHIZIDAE											
Dusky Gerygone	*Gerygone tenebrosa*		X	X			X				Vagrant
Weebill	*Smicrornis brevirostris*		X	X			X				Irregular visitor
POMATOSTOMIDAE											
Grey-crowned Babbler	*Pomatostomus temporalis*		X							3	Resident
CAMPEPHAGIDAE											
Black-faced Cuckoo-shrike	*Coracina novaehollandiae*		X	X			X		1	3 R	Resident
White-winged Triller	*Lalage tricolor*		X				X		1	3	Resident
PACHYCEPHALIDAE											
Grey Shrike-thrush	*Colluricincla harmonica*		X	X			X				Resident
White-breasted Whistler	*Pachycephala lanioides*		X	X			X				Vagrant
Mangrove Golden Whistler	*Pachycephala melanura*		X	X			X				Vagrant
Rufous Whistler	*Pachycephala rufiventris*		X	X			X		2	R	Resident
OREOICIDAE											
Crested Bellbird	*Oreoica gutturalis*		X	X			X				Regular visitor
ARTAMIDAE											

BIRDS		CS	ALA	N	EPBC	DBCA	BA	BCE 1	BCE 2	BCE 3	Expected status in project area
Black-faced Woodswallow	*Artamus cinereus*		X	X			X		1 2	3 R	Resident
White-breasted Woodswallow	*Artamus leucorynchus*		X	X			X				Regular visitor
Masked Woodswallow	*Artamus personatus*		X	X			X			3	Regular visitor
Pied Butcherbird	*Cracticus nigrogularis*		X	X			X		1 2	3 R	Resident
Australian Magpie	*Cracticus tibicen*		X	X			X				Regular visitor
RHIPIDURIDAE											
Grey Fantail	*Rhipidura fuliginosa*		X	X			X				Regular visitor
Willie Wagtail	*Rhipidura leucophrys*		X	X			X		1 2	3	Resident
Mangrove Grey Fantail	*Rhipidura phasiana*		X	X			X				Vagrant
Northern Fantail	*Rhipidura rufiventris*		X								Vagrant
CORVIDAE											
Little Crow	*Corvus bennetti*		X								Regular visitor
Torresian Crow	*Corvus orru*		X	X			X		1 2	3 R	Resident
MONARCHIDAE											
Magpie-lark	*Grallina cyanoleuca*		X	X			X		1 2	3 R	Resident
PETROICIDAE											
Mangrove Robin	*Eopsaltria pulverulenta*			X							Vagrant
NECTARINIIDAE											
Mistletoebird	*Dicaeum hirundinaceum*		X	X			X				Regular visitor
ESTRILDIDAE											
Painted Finch	*Emblema pictum*		X	X			X				Vagrant
Zebra Finch	*Taeniopygia guttata*		X	X			X		1 2	3 R	Resident
MOTACILLIDAE											

BIRDS		CS	ALA	N	EPBC	DBCA	BA	BCE 1	BCE 2	BCE 3	Expected status in project area
Australasian Pipit	*Anthus novaeseelandiae*		X				X		1	R	Resident
Grey Wagtail	*Motacilla cinerea*	M S5			X						Vagrant
Yellow Wagtail	*Motacilla flava*	M S5	X		X		X				Vagrant
ALAUDIDAE											
Horsfield's Bushlark	*Mirafra javanica*		X	X			X		1 2	R	Resident
LOCUSTELLIDAE											
Brown Songlark	*Cincloramphus cruralis*		X				X		1	R	Resident
Rufous Songlark	*Cincloramphus mathewsi*		X				X				Resident
HIRUNDINIDAE											
Welcome Swallow	*Hirundo neoxena*		X	X			X				Irregular visitor
Barn Swallow	*Hirundo rustica*	M S5	X	X	X	X	X				Regular migrant
Fairy Martin	*Petrochelidon ariel*		X	X			X			R	Regular visitor
Tree Martin	*Petrochelidon nigricans*		X	X			X		1	R	Regular visitor
ZOSTEROPIDAE											
Yellow White-eye	*Zosterops luteus*		X	X			X			R	Regular visitor
Total Number of Species Expected:	**148**	**29**	**122**	**111**	**27**	**15**	**106**	**0**	**44**	**49**	

Mammals

MAMMALS		CS	ALA	N	EPBC	DBCA	BCE 1	BCE 2	BCE 3	Expected status in project area
TACHYGLOSSIDAE										
Echidna	*Tachyglossus aculeatus*						X			Resident
DASYURIDAE										
Brush-tailed Mulgara	*Dasycercus blythi*	P4						2 3		Regular visitor
Northern Quoll	*Dasyurus hallucatus*	E S2			X	X				Vagrant
Stripe-faced Dunnart	*Sminthopsis macroura*									Resident
THYLACOMYIDAE										
Greater Bilby	*Macrotis lagotis*	V S3		X	X	X		2	3	Regular visitor
PERAMELIDAE										
Golden Bandicoot	*Isoodon auratus*	V S3								Locally Extinct
PHALANGERIDAE										
Northern Brushtail Possum	*Trichosurus arnhemensis*	S3					X			Irregular visitor
POTOROIDAE										
Boodie	*Bettongia lesueur*	Ex V S4 S6								Locally Extinct
MACROPODIDAE										
Spectacled Hare-Wallaby	*Lagorchestes conspicillatus*	P3				X	X			Regular visitor
Agile Wallaby	*Macropus agilis*							2	R	Resident
Red Kangaroo	*Macropus rufus*									Irregular visitor
Euro	*Macropus robustus*								3 R	Resident
PTEROPODIDAE										
Little Red Flying-fox	*Pteropus scapulatus*						X			Irregular visitor

MAMMALS		CS	ALA	N	EPBC	DBCA	BCE 1	BCE 2	BCE 3	Expected status in project area
EMBALLONURIDAE										
Yellow-bellied Sheathtail Bat	*Saccolaimus flaviventris*									Regular visitor
Common Sheath-tailed Bat	*Taphozous georgianus*		X	X						Regular visitor
MEGADERMATIDAE										
Ghost Bat	*Macroderma gigas*	V S3	X	X	X	X				Vagrant
HIPPOSIDERIDAE										
Pilbara Leaf-nosed Bat	*Rhinonicteris aurantia (Pilbara form)*	V S3 P4			X					Vagrant
MOLOSSIDAE										
White-striped Free-tailed Bat	*Austronomus australis*		X							Regular migrant
Northern Free-tailed Bat	*Chaerephon jobensis*		X	X						Regular visitor
Loria's Mastiff Bat	*Mormopterus loriae*	P1	X	X						Vagrant
Beccari's Free-tailed Bat	*Mormopterus beccari*									Irregular visitor
VESPERTILIONIDAE										Irregular visitor
Yellow-bellied Sheathtail Bat	*Saccolaimus flaviventris*									Regular visitor
Gould's Wattled Bat	*Chalinolobus gouldii*		X	X						Resident
Northern Long-eared Bat	*Nyctophilus arnhemensis*		X	X						Regular visitor
Lesser Long-eared Bat	*Nyctophilus geoffroyi*		X	X						Resident
Little Broad-nosed Bat	*Scotorepens greyii*									Regular visitor
MURIDAE										
Spinifex Hopping Mouse	*Notomys alexis*		X	X					3	Resident
Lakeland Downs Mouse	*Leggadina lakedownensis*	P4					X			Irregular visitor
Western Chestnut Mouse	*Pseudomys nanus*									Irregular visitor
Sandy Inland Mouse/Mingkiri	*Pseudomys hermansbergensis*									Resident

MAMMALS		CS	ALA	N	EPBC	DBCA	BCE 1	BCE 2	BCE 3	Expected status in project area
INTRODUCED MAMMALS										
Dromedary Camel	*Camelus dromedarius*	Int.			X					Regular visitor
Dog, Dingo	*Canis lupus dingo*	Int.						2 3	1	Resident
Horse	*Equus caballus*	Int.							R	Regular visitor
Donkey	*Equus asinus*	Int.			X					Regular visitor
Cat	*Felis catus*	Int.			X			2 3	1	Resident
House Mouse	*Mus musculus*	Int.	X	X	X					Resident
Pig	*Sus scrofa*	Int.			X					Vagrant
Red Fox	*Vulpes vulpes*	Int.			X			2 3		Regular visitor
Total Number of Native Species Expected:	**30**	**11**	**10**	**10**	**10**	**4**	**4**	**6**	**7**	

6.4 Appendix 4. Vertebrate species returned in database searches but unlikely to occur in the project area

Database searches often return species found nearby but that are unlikely to be present in the survey area due to lack of suitable habitat (e.g. aquatic species) or ecological barriers preventing them from reaching the area (e.g. island species). There are also some errors, out-of-date Latin names, zoo specimens and subtleties of distribution that are not recognised in databases. The species listed below are considered highly unlikely to be found in the survey area (although some species could occur as very rare vagrants).

FISH	
Helen's Pygmy Pipehorse	*Acentronura larsonae*
Narrow Sawfish	*Anoxypristis cuspidata*
Braun's Pughead Pipefish	*Bulbonaricus brauni*
Three-keel Pipefish	*Campichthys tricarinatus*
Great White Shark	*Carcharodon carcharias*
Pacific Short-bodied Pipefish	*Choeroichthys brachysoma*
Muiron Island Pipefish	*Choeroichthys latispinosus*
Pig-snouted Pipefish	*Choeroichthys suillus*
Banded Pipefish	*Doryrhamphus dactyliophorus*
Cleaner Pipefish	*Doryrhamphus janssi*
Many-banded Pipefish	*Doryrhamphus multiannulatus*
Flagtail Pipefish	*Doryrhamphus negrosensis*
Ladder Pipefish	*Festucalex scalaris*
Tiger Pipefish	*Filicampus tigris*
Spotted Moray Eel	*Gymnothorax isingteena*
Brock's Pipefish	*Halicampus brocki*
Mud Pipefish	*Halicampus grayi*
Glittering Pipefish	*Halicampus nitidus*

Spiny-snout Pipefish	*Halicampus spinirostris*
Ribboned Pipehorse	*Haliichthys taeniophorus*
Beady Pipefish	*Hippichthys penicillus*
Western Spiny Seahorse	*Hippocampus angustus*
Spiny Seahorse	*Hippocampus histrix*
Spotted Seahorse	*Hippocampus kuda*
Flat-face Seahorse	*Hippocampus planifrons*
Three-spot Seahorse	*Hippocampus trimaculatus*
Shortfin Mako	*Isurus oxyrinchus*
Longfin Mako	*Isurus paucus*
Reef Manta Ray	*Manta alfredi*
Giant Manta Ray	*Manta birostris*
Tidepool Pipefish	*Micrognathus micronotopterus*
Black Rock Pipefish	*Phoxocampus belcheri*
Dwarf Sawfish	*Pristis clavata*
Freshwater Sawfish	*Pristis pristis*
Green Sawfish	*Pristis zijsron*
Whale Shark	*Rhincodon typus*
Pallid Pipehorse	*Solegnathus hardwickii*
Gunther's Pipehorse	*Solegnathus lettiensis*
Robust Ghostpipefish	*Solenostomus cyanopterus*
Rough-snout Ghost Pipefish	*Solenostomus paegnius*
Double-end Pipehorse	*Syngnathoides biaculeatus*
Bentstick Pipefish	*Trachyrhamphus bicoarctatus*
Straightstick Pipefish	*Trachyrhamphus longirostris*

REPTILES	
Horned Seasnake	*Acalyptophis peronii*
Short-nosed Seasnake	*Aipysurus apraefrontalis*
Dubois' Seasnake	*Aipysurus duboisii*
Spine-tailed Seasnake	*Aipysurus eydouxii*
Olive Seasnake	*Aipysurus laevis*
Brown-lined Seasnake	*Aipysurus tenuis*
Stokes' Seasnake	*Astrotia stokesii*
Loggerhead Turtle	*Caretta caretta*
Green Turtle	*Chelonia mydas*
Leatherback Turtle	*Dermochelys coriacea*
Spectacled Seasnake	*Disteira kingii*
Olive-headed Seasnake	*Disteira major*
Turtle-headed Seasnake	*Emydocephalus annulatus*
North-western Mangrove Seasnake	*Ephalophis greyi*
Hawksbill Turtle	*Eretmochelys imbricata*
Black-ringed Seasnake	*Hydrelaps darwiniensis*
Elegant Seasnake	*Hydrophis elegans*
	Hydrophis mcdowelli
Spotted Seasnake	*Hydrophis ornatus*
Flatback Turtle	*Natator depressus*
Yellow-bellied Seasnake	*Pelamis platurus*
	Aipysurus laevis
	Ephalophis greyi
Olive Python (Pilbara subspecies)	*Liasis olivaceus barroni*

BIRDS	
Sooty Oystercatcher	*Haematopus fuliginosus*
Australian Pied Oystercatcher	*Haematopus longirostris*
Greater Sand Plover	*Charadrius leschenaultii*
Lesser Sand Plover	*Charadrius mongolus*
Pacific Golden Plover	*Pluvialis fulva*
Grey Plover	*Pluvialis squatarola*
Whimbrel	*Numenius phaeopus*
Ruff	*Philomachus pugnax*
Grey-tailed Tattler	*Tringa brevipes*
Spotted Redshank	*Tringa erythropus*
Common Sandpiper	*Actitis hypoleucos*
Ruddy Turnstone	*Arenaria interpres*
Sanderling	*Calidris alba*
Red Knot	*Calidris canutus*
Great Knot	*Calidris tenuirostris*
Asian Dowitcher	*Limnodromus semipalmatus*
Bar-tailed Godwit	*Limosa lapponica menzbieri*
Black-tailed Godwit	*Limosa limosa*
Eastern Curlew	*Numenius madagascariensis*
Common Redshank	*Tringa totanus*
Terek Sandpiper	*Xenus cinereus*
Red-tailed Tropicbird	*Phaethon rubricauda*
Streaked Shearwater	*Calonectris leucomelas*
Southern Giant-Petrel	*Macronectes giganteus*
Wedge-tailed Shearwater	*Puffinus pacificus*

Common Noddy	*Anous stolidus*
Caspian Tern	*Hydroprogne caspia*
Little Tern	*Sternula albifrons*
Roseate Tern	*Sterna dougallii*
Common Tern	*Sterna hirundo*
Lesser Crested Tern	*Thalasseus bengalensis*
Crested Tern	*Thalasseus bergii*
Beach Stone-curlew	*Esacus magnirostris*
Striated Heron	*Butorides striata*
Eastern Reef Egret	*Egretta sacra*
Lesser Frigatebird	*Fregata ariel*
Great Frigatebird	*Fregata minor*
Brown Booby	*Sula leucogaster*
Little Pied Cormorant	*Microcarbo melanoleucos*
Little Black Cormorant	*Phalacrocorax sulcirostris*
Pied Cormorant	*Phalacrocorax varius*
Australasian Darter	*Anhinga novaehollandiae*
Australian Pelican	*Pelecanus conspicillatus*
Red-backed Fairy-wren	*Malurus melanocephalus*
White-bellied Cuckoo-Shrike	*Coracina papuensis*
MAMMALS	
Northern Marsupial Mole	*Notoryctes caurinus*
Western Pebble-mound Mouse	*Pseudomys chapmani*
Bryde's Whale	*Balaenoptera edeni*
Blue Whale	*Balaenoptera musculus*
Common Dophin	*Delphinus delphis*

Dugong	*Dugong dugon*
Risso's Dolphin	*Grampus griseus*
Humpback Whale	*Megaptera novaeangliae*
Orca	*Orcinus orca*
Indo-Pacific Humpback Dolphin	*Sousa chinensis*
Spotted Dolphin	*Stenella attenuata*
Spotted Bottlenose Dolphin	*Tursiops aduncus*
Bottlenose Dolphin	*Tursiops truncatus s. str.*
Total Number of Species:	**125**

6.5 Appendix 5. Annotated species list

BIRDS

1. Straw-necked Ibis. Few around irrigated crops and a flock of about 40 birds over crops on 20/09. Dead bird found in Ramsar area.
2. Brolga. Fresh tracks in area 3. About 120 in north and east of Ramsar area (19/09), and a possibly separate group of 30 birds around watering point in west (20/09).
3. Galah. Pairs and small flocks occasionally in Area 3 and Ramsar area.
4. Cocketiel. Flock of about five birds near Tamarisk Grove in Area 3 (19/09).
5. Crested Pigeon. Occasional groups of 4-5 birds around irrigated areas and near temporary pools and stock watering points throughout, including rea 3 and Ramsar area.
6. Diamond Dove. Occasional groups of 2-5 birds seen in Area 3.
7. Flock Bronzewing. One flew out of existing pivots (20/09).
8. Whistling Kite. One near Tamarisk grove at Outcamp in area 3 and over Ramsar area. Nest with three large chicks at Pardoo Roadhouse.
9. Black Kite. One along nearby highway and existing pivot areas.
10. Nankeen Kestrel. Pair at Pardoo Roadhouse; caught a large *Ctenophorus nuchalis*.
11. Brown Falcon. One near Outcamp (18/09; 20/09) in area 3 and over Ramsar area. Nest in Tamarisk in Area 3.
12. Brown Goshawk. One in Tamarisk grove at Outcamp in area 3.
13. Spotted Harrier. Occasional birds foraging over low vegetation in area 3. One over Ramsar area. Most appeared to be juveniles. Five to 10 birds seen in total.
14. Australian Bustard. Several groups of 2-3 birds seen throughout, including area 3 and Ramsar area.
15. Little Button-quail. Seen occasionally in Acacia thickets of Ramsar area.
16. Oriental Plover. Loose flocks in herbfields of the Ramsar area. Total count about 100 but only part of the herbfields visited. May only be visiting herbfields in cool of morning and evening so largest numbers may have been missed.
17. Masked Lapwing. Pair near water tank and stock watering point in north-east of Ramsar area.
18. Australian Pratincole. Few among Oriental Plovers in herbfields of Ramsar area; perhaps 10 birds.
19. Bush Stone-curlew. Fresh footprints on tracks throughout area 3 and in Ramsar area. Birds may be attracted to cleared lines.
20. Rainbow Bee-eater. Few along fencelines between area 3 and Ramsar area.
21. Horsfield's Bronze-Cuckoo. One calling from tall acacias in west of Ramsar area (20/09).
22. Black-eared Cuckoo. One seen and heard near Tamarisk grove in Area 3 (20/09).
23. Pheasant Coucal. One in Melaleuca thicket on edge of Ramsar site north-west of Area 3. Feather found in Acacia thicket in Ramsar area west of area 3. Up to four birds calling in evening of 20/09.
24. Eastern Barn Owl. Pair seen daily in Tamarisk grove at Outcamp in Area 3.
25. Fork-tailed Swift. About six birds over sand ridge in north between Area 3 and Ramsar area (19/09).
26. White-winged Fairy-wren. Parties seen regularly in areas of spinifex and low acacia in Area 3 and Ramsar area. One coloured male seen.

27. Variegated Fairy-wren. Several parties in areas of dense acacia in Area 3. Coloured males present.
28. Red-browed Pardalote. One calling in garden of Pardoo roadhouse.
29. Yellow-throated Miner. Few groups in areas of tall acacia and in Tamarisk grove in Area 3 and Ramsar area.
30. Singing Honeyeater. Common in shrublands of Area 3 and Ramsar area.
31. Brown Honeyeater. Few in Acacia and Melaleuca thickets in Ramsar area west.
32. Crimson Chat. Loose flocks of up to 40 birds in recently burnt areas and along tracks in Are 3 and Ramsar area.
33. Grey-crowned Babbler. Small group in Tamarisk grove at Outcamp in Area 3.
34. Rufous Whistler. Few calling from Melaleuca and Acacia thickets in Ramsar area.
35. Willie Wagtail. Few pairs present in Area 3.
36. Black-faced Cuckoo-shrike. Occasional single birds and pairs flying past over Area 3 and Ramsar area.
37. White-winged Triller. Few pairs seen in shrublands of area 3.
38. Magpie-lark. Few pairs seen, particularly near existing pivots but also near watering points in Area 3 and Ramsar area.
39. Pied Butcherbird. Few pairs seen in areas of tall acacia in Area 3 and Ramsar area.
40. Torresian Crow. Single birds seen occasionally over Area 3 and Ramsar area.
41. Black-faced Woodswallow. Few seen over Area 3 and Ramsar area.
42. Masked Woodswallow. Flock of about 20 birds flying and perching in south of area 3 (18/09).
43. Tree Martin. Few over acacia thickets of Ramsar area.
44. Fairy Martin. Loose flocks or herbfields of Ramsar area.
45. Zebra Finch. Small parties throughout; Area 3 and Ramsar area.
46. Brown Songlark. Several pairs in herbfields of Ramsar area.
47. Horsfield's Bushlark. Pairs and groups of up to four birds throughout acacia shrubland and spinifex, and in herbfields of Ramsar area.
48. Australasian Pipit. Seen regularly in herbfields of Ramsar area.
49. Yellow White-eye. Small flock in acacia thicket of Ramsar area east of Area 3 (19/09); and in west of Ramsar (20/09).

REPTILES

Hemidactylus frenatus. Common around accommodation at Pardoo station.

Heteronotia binoei. Few under debris in Tamarisk grove in Area 3.

Diplodactylus conspicillatus. Skin with diagnostic tail found in Tamarisk grove in area 3.

Delma ? tincta. One under sheet of corrugated iron in herbfield in Ramsar area (19/09).

Ctenophorus isolepis. Abundant in Area 3 and Ramsar area.

Ctenophorus nuchalis. Several seen in Area 3 and Ramsar area. Seemed to be very active along recently-cleared tracks.

Pogona minor. Sub-adult found in Acacia thicket in Ramsar area.

Varanus acanthurus. Freshly-killed specimen (by bird of prey?) and an active pair in acacia thicket in Ramsar area.

Ctenotus robustus/helenae. One under sheet of corrugated iron in herbfield in Ramsar area (19/09).

Egernia sp. One dark specimen, about the size of *E. napoleonis* under debris at Tamarisk Grove in area 3 (20/09).

Tiliqua multifasciata. Recent tracks in Area 3.

Menetia sp. Very pale specimen with long, single supra-ocular and fused supraciliaries in herbfield on pale grey loam.
Morethia ruficauda. One under debris at Tamarisk Grove in Area 3 (20/09).
Ramphotyphlops . Slender with dark head and tail. On highway near Pardoo Roadhouse (20/09).
Skin of large python found under corrugated iron in Tamarisk grove in Area 3. No indication of dark bands so possibly Woma.
Pseudechis australis. Sub-adult under debris at Outcamp in Area 3.

MAMMALS
Macropus agilis. Small group seen in Ramsar area east of Outcamp.
Macropus robustus. Tracks in Area 3 and Ramsar area.
Notomys alexis. Burrows as tracks regularly across area 3.
Dingo. Tracks found regularly.
Feral cat. Tracks found regularly.
Bilby. Tracks about a week old near Outcamp (18/09) in Area 3.
Horse. Tracks seen in Ramsar site and two reported by botanists (S. Connell pers. comm.).