GROUNDWATER AND NUTRIENT FLUX ASSESSMENT

Leschenault Inlet, Bunbury

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1 INTRODUCTION

1.1 Preliminaries

This groundwater assessment was undertaken in accordance with RPS' proposal ref. L16056.003 dated 7 November 2019 pertaining to a groundwater assessment for the southwestern section of the Leschenault Inlet that is located close to Koombana Bay in Bunbury (herein referred as the "project site").

The objectives of this desktop assessment are to estimate the:

- Groundwater flux(es) reporting to the Leschenault Inlet
- Nutrients reporting to the Leschenault Inlet, in consideration of potential seasonal variations.

It is understood that the information and results provided from this assessment will be used as input to the project's hydrodynamic modelling being developed by other consultant(s).

1.2 Our approach

This assessment comprised the following components:

- Desktop review of available reports and documents
- Conceptualisation of hydrogeological model
- Groundwater modelling
- Water quality assessment.

1.3 Limitations

This groundwater assessment was undertaken based on available reports and/or documents that were made available to RPS, including unpublished and publicly accessible reports and data. There are limited site-specific data within and surrounding the project site, and no field investigation was commissioned as part of this assessment. Some assumptions have been made to estimate the nutrient loading to the inlet, for example, the maximum concentrations of the nutrients.

Site conditions, such as water levels, geomorphology and/or land use, may have changed over time, which RPS may not be aware of or do not have the opportunity to assess or evaluate their impacts.

This report was prepared for the intended objectives mentioned above and the contents of this report may not satisfy the needs for other purpose(s), of which the risk of using the information other than its intended use lies with the user(s) of this report.

2 EXISTING ENVIRONMENT

2.1 Site location

The project site is located about 150 km south of Perth, i.e. approximately at 374205mE 6311667mN (GDA94 Zone 50), see Figure 1 below.

Figure 1: Leschenault Inlet and surrounding areas

The Leschenault Inlet encompasses an area of approximately 44 ha and a perimeter estimated to be around 4.5km.

2.2 Climate

The climate in Bunbury is relatively similar to Perth, i.e. Mediterranean climate with warm to hot summers and cool winters with higher rainfalls typically between May and August (close to and exceeding 200mm in monthly rainfalls). Based on 1996 to 2019 records from Bureau of Meteorology (BoM) Bunbury station no. 9965, the long-term average (LTA) of annual rainfall is 716.7mm.

Average daily minimum temperature ranges between 7.2 and 15.9ºC across the year, whilst average daily maximum temperature ranges between 17.3 and 30.1ºC. See Figure 2 below for the monthly variations of rainfall and temperatures.

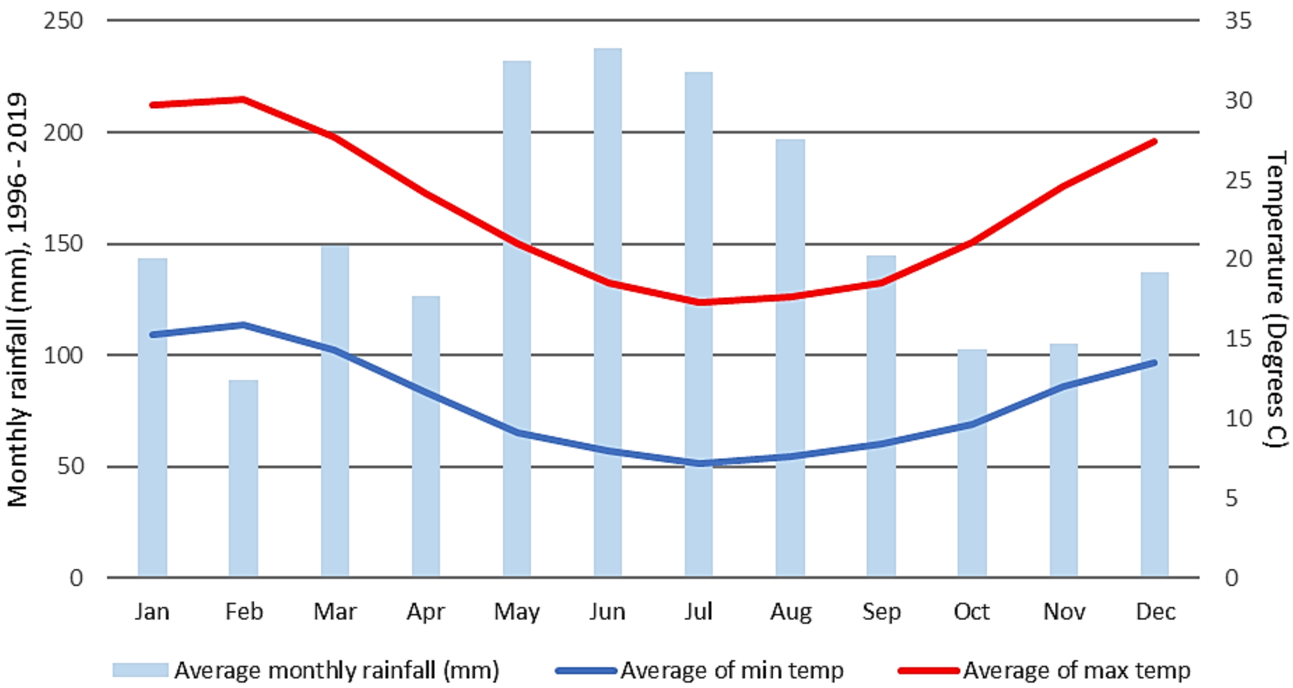


Figure 2: Monthly averages of rainfall, minimum and maximum temperatures

Rainfall records between 1996 and 2019 indicate a general decline of rainfall over the years of monitoring at BoM station 9965, see Figure 3 below.

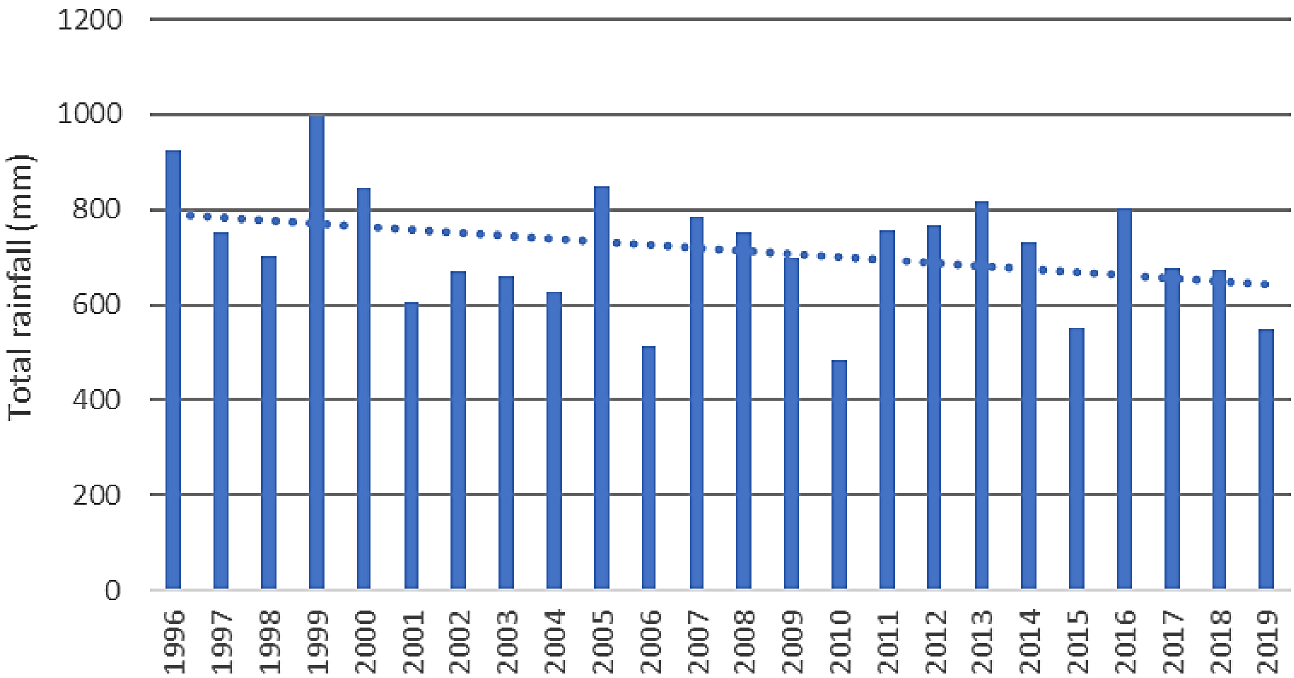


Figure 3: Annual rainfall (1996–2019)

Annual evapotranspiration for Bunbury is approximately 1400mm, i.e. based on BoM's calculated evapotranspiration for 2019. Evapotranspiration rates are typically higher during summer and lower during the cooler wetter months.

2.3 Topography and drainage

The project site lies on relatively flat terrain within the Coast sub-catchment of the Leschenault catchment. The Coast sub-catchment is located immediately downstream of Lower Preston sub-catchment, which is drained by the perennial Preston River (refer Figure 1).

The ground surface generally grades toward the north toward Koombana Bay with a dune ridge (trending almost northeast-southwest) on the Geographe Bay coast to the west, see Figure 4 below. Cross-sectional ground profiles (north-south and west-east) across the project site and ground elevations based on Shuttle Radar Topography Mission (SRTM) data are presented in Figure 5.

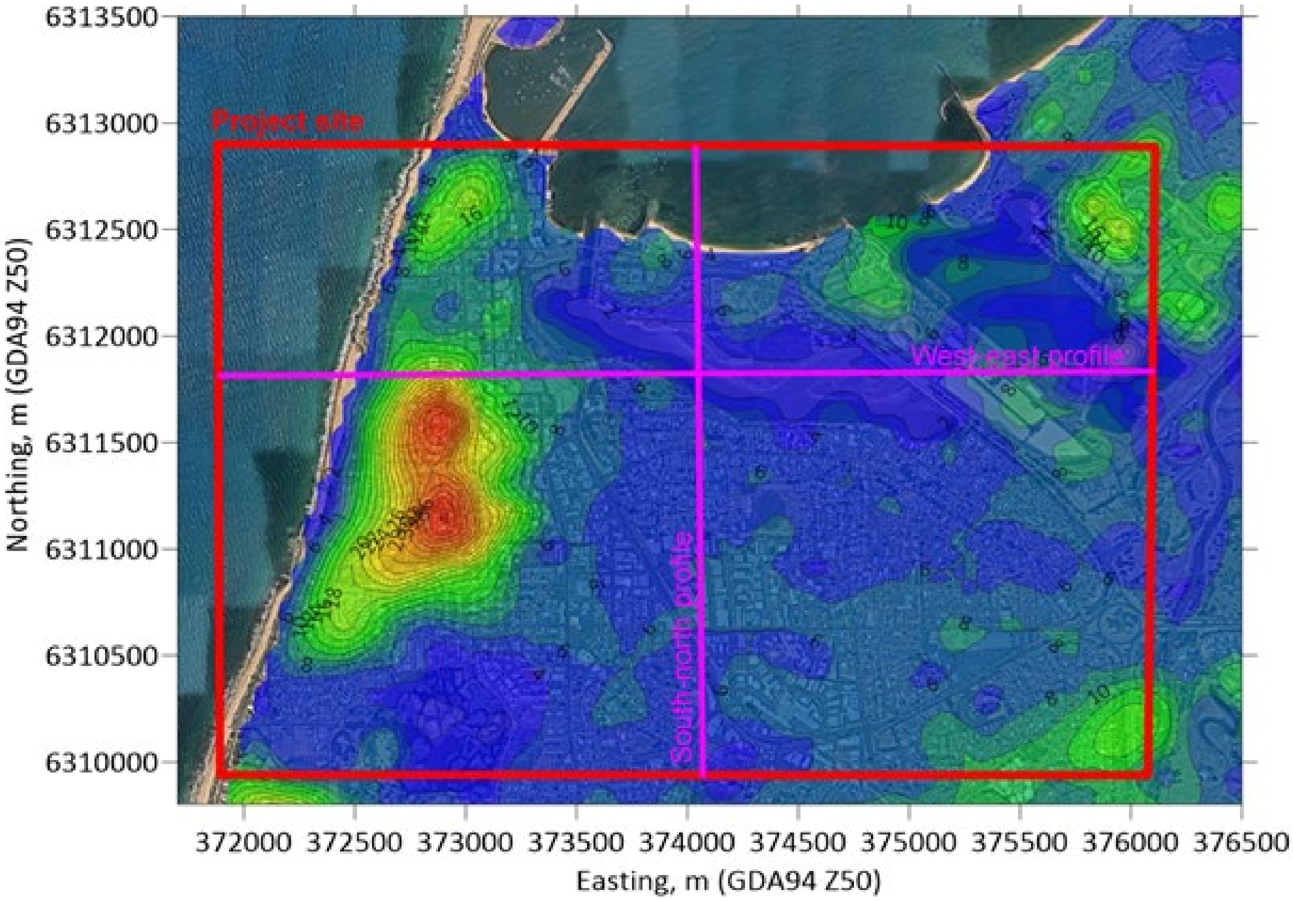


Figure 4: Topographic profile across the project site and surrounding areas

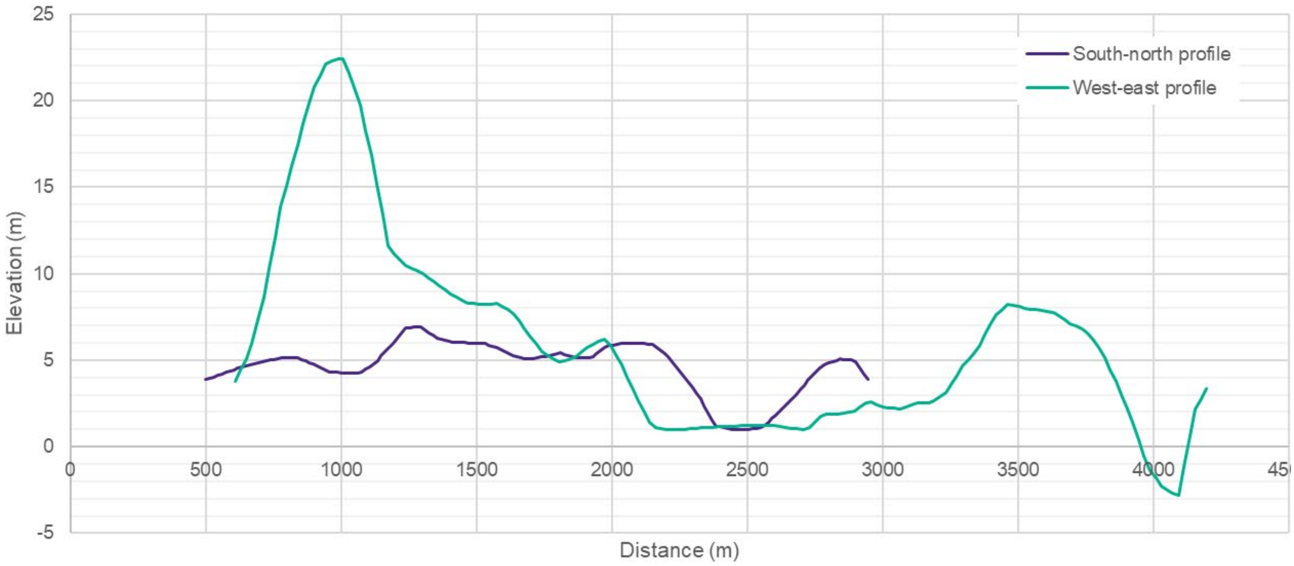
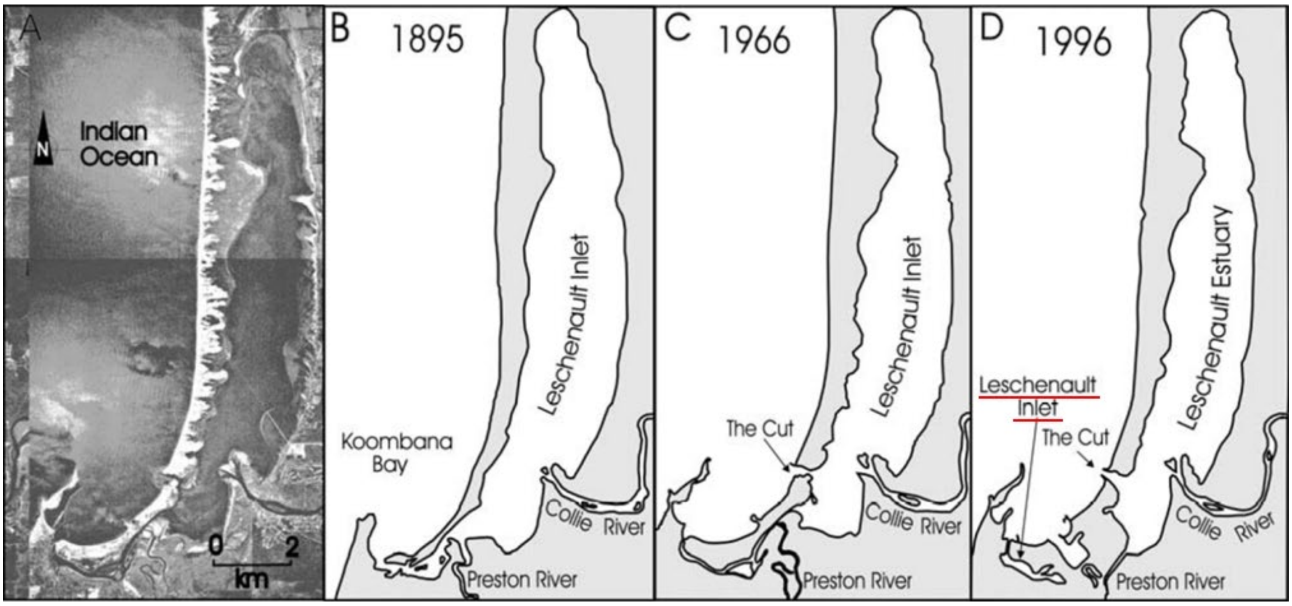


Figure 5: Cross-sectional ground profiles across the project site

2.4 Geomorphology

The Greater Leschenault Inlet is a estuarine water body that has been highly modified in the southwestern portion, including diversion of the Preston River and by the installation of "The Cut", an artificial waterway connection to the ocean to enable better flushing of the inlet. The extent of the modifications has resulted in the inlet now being a controlled estuary with high value residential property on its banks and significant recreational and social importance to the city of Bunbury (SKM, 2004).

The Greater Leschenault Inlet estuary is an elongate shore-parallel, shallow water, back barrier estuarine lagoon with distinctive patterns of bathymetry and geomorphology. The water body is framed to the east by the Mandurah-Eaton Ridge, to the west by a dune barrier, and to the south by the deltas of the Collie and Preston Rivers (V Semeniuk et al., 2000). The geomorphological changes of the southwestern section of estuary over time are illustrated in Figure 6 below.



(Source: Commander 1984)

Figure 6: Evolution of the Leschenault Inlet estuary

The Preston River floodplain lies to the eastern flank of the inlet, which comprise of wetlands and oxbow lake systems. A wetland reserve (~27 ha. of Big Swamp Parkland) is located approximately 1.5 km to the southwest of the inlet, whilst a smaller oxbow lake is located about 1.2 km to the southeast.

2.5 Geology

2.5.1 Regional geology

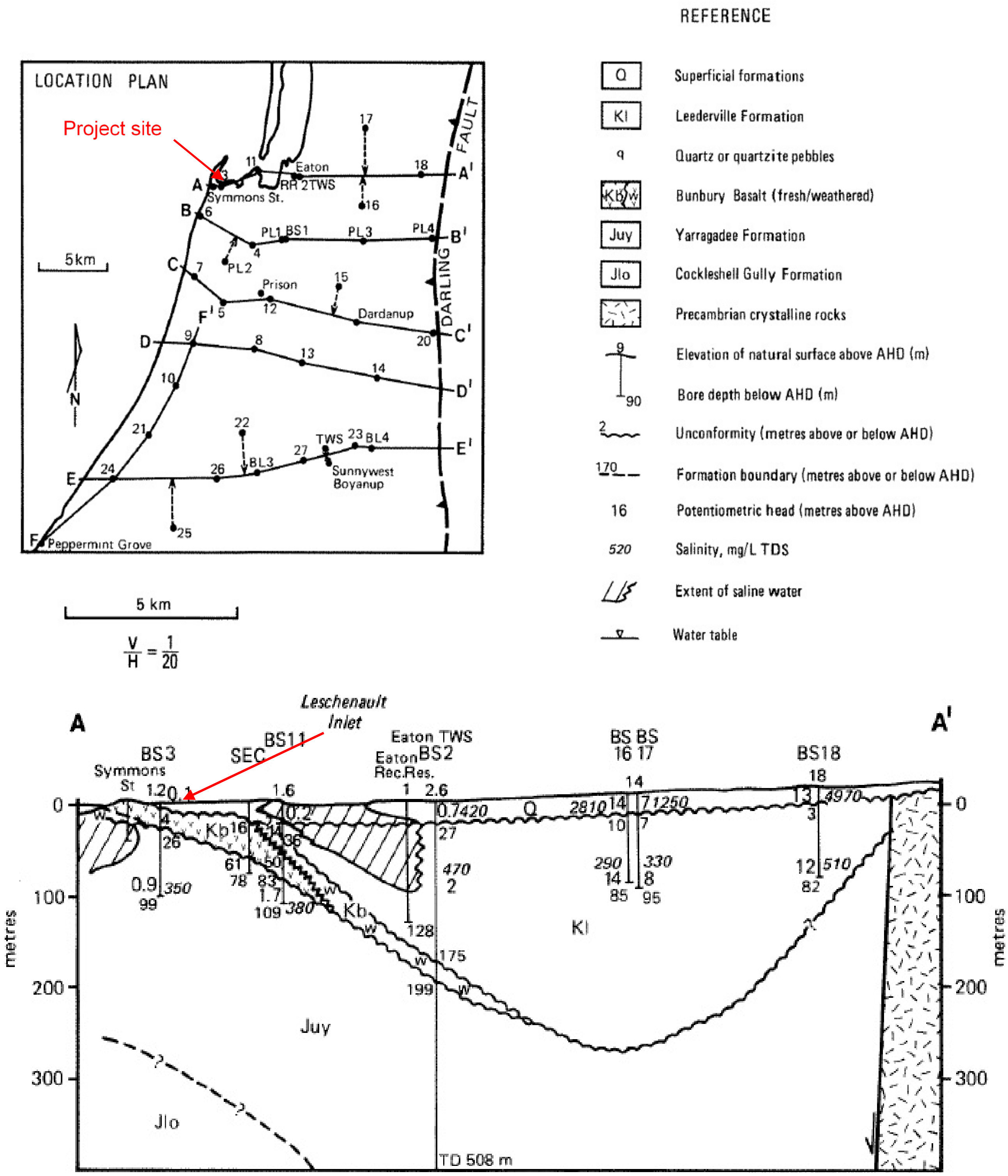
Regionally, the project site lies within the Swan Coastal Plain, which is underlain by unconsolidated Cainozoic sediments. The shallow Cainozoic deposits overlie the Cretaceous-aged Bunbury Basalt (westward) and Leederville Formation (eastward), and below these formations lies the Yarragadee Formation (Jurassic-aged).

Key lithologies of the Bunbury area and in the vicinity of the project site are summarised below:

- Superficial soils – sand, peat, loam and clay
- Consolidated rocks (bedrock geology) – sedimentary (sand, siltstone, shale); basalt.

A schematic cross-sectional profile of the stratigraphy across the project site is provided in Figure 7 below.

Structurally, there are two main folding axes with an almost north-west–south-east trending strike that influences the bedrock geology close to the project site, i.e. the Dardanup Syncline (folding axis located about 3.4 km to the north-east) and the Capel Anticline (folding axis located about 1.2 km to the west-south-west). Both regional folding structures are probably developed over fault blocks in the Jurassic sediments (Commander, 1984).



Adopted from Commander (1984)

Figure 7: Regional geology, cross-section A-A'

2.5.2 Local geology

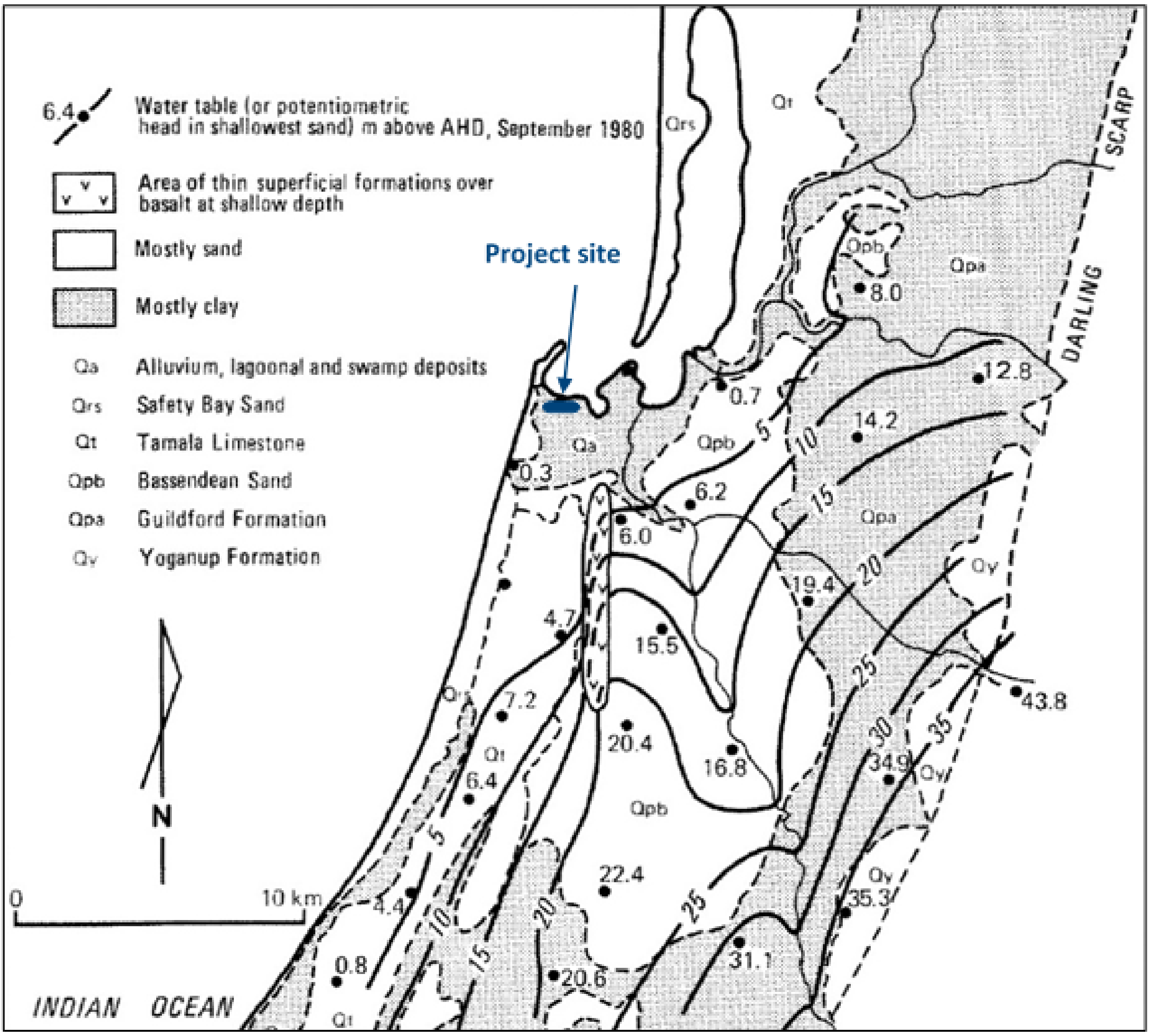
A review of lithology (RPS, 2018) of available DWER bores (WIN bore ref. 61118027 and 61111506) located close to the inlet indicated that sand was detected at the surface with measured thickness between 5 and 6 m.

In the immediate project area, the surface materials are expected to comprise of mixed soils attributed to alluvium-lagoonal and swamp-lacustrine peaty and clayey sediments with minor discontinuous lenses of sand. Additionally, fine sandy clays of Guildford Formation and fine- to coarse-grained sub-angular to sub-rounded sand (likely to be Bassendean Sand based on Collie geological map interpretation) were reported in Calibre (2019) for an investigation undertaken on the east-south-eastern flank (some 2 km away) from the project site.

2.6 Hydrogeology

2.6.1 Water levels and flow direction

Regionally, groundwater within the superficial formations is expected to flow towards the north-northwest, i.e. based on the potentiometric head map shown in Figure 8 below.



(Commander, 1984)

Figure 8: Groundwater heads and lithology within superficials

The following excerpts were adopted from Commander (1984):

> Near Leschenault Inlet, groundwater flow is northwestward and groundwater discharge presumably takes place along the inlet above a body of intruding sea-water. This is present in the upper part of the formation and overlies fresh water (in deeper formations). The sea-water interface in the Leederville Formation occurs along the southeast shore of Leschenault Inlet, and extends to depths of 45 m in the Bunbury Foods bore (Commander 1981), 100 m in the Eaton Recreation Reserve bore and to about 100 m in the Laporte 5 bore, but is west of the Australind town-water-supply bores.

> West of the Capel Anticline the direction of groundwater flow is probably northwestwards. Recharge takes place from the superficial formations east of the Bussell Highway where there are downward hydraulic-heads, and there is possibly some flow from the main flow-system in the Dardanup Syncline between the subcropping areas of Bunbury Basalt and Yarragadee Formation.

Based on available literature and field data (circa 2016 - 2017), the depth of groundwater level at the project site is expected to vary slightly from east to west, and from south to the north. Groundwater levels close to the inlet are expected to vary between 1 and 3 mbgl and are likely to be tidally influenced towards the Koombana Bay to the north and Geographe Bay to the west.

Groundwater levels measured (RPS, 2018) from four (4) DWER bores within 3km radius from the inlet averages to about 2.2 meters below ground level. The bore locations are indicated in Figure 9 below.

(RPS, 2018)

Figure 9: DWER bore locations

2.6.2 Groundwater quality

Salinity within the superficial aquifer is expected to increase towards the coast as indicated from RPS' sampling events at DWER bores between October 2016 and January 2017. Salinity, based on calculated Total Dissolved Solids (TDS) from field measured Electrical Conductivity (EC; assuming TDS mg/L = 0.64 x EC μS/cm), ranged from fresh (234 mg/L, further inland) to moderately saline (4,422 mg/L, closest to coast).

Salinity (TDS) was reported to be 4,460 mg/L at a sampling point between the inlet and Koombana Bay, i.e. in reference to the salinity map for superficial formations in Commander (Figure 9, p. 47, 1984). This reported salinity is comparable to the calculated TDS (4,422 mg/L) for the DWER bore closest to the coast.

2.7 Key water control feature

A key water control feature that provides flood mitigation management of the Leschenault Inlet is the Bunbury Storm Surge Barrier within the "Plug". Originally constructed in 1980 to address the threat of coastal flooding, the Bunbury Storm Surge Barrier that is located on the western end of the inlet forms a part of the levee systems which effectively isolates low-lying sections of Bunbury (PLACE, 2014).

The Plug of approximately 50m width and 400m length provides the water passage between the inlet and Koombana Bay, see Figure 10 below for an overview of Leschenault Inlet (aerial looking towards west-northwest).

(PLACE, 2014)

Figure 10: Leschenault Inlet, the Plug and Koombana Bay

3 CONCEPTUAL HYDROGEOLOGICAL MODEL

The Leschenault Inlet can be considered as a groundwater sink, and groundwater in the upgradient areas of the inlet is expected to flow from topographic highs on the south and west to topographic low points (i.e. discharge areas) at the inlet area and towards Koombana Bay to the north. The closest surface water drainage is the Preston River, which is located about 1 km to the east of the inlet area (refer Figure 1). The inlet area of approximately 0.44 km^2 lies within the Coast sub-catchment of the larger Leschenault catchment that encompass a total surface water catchment area of ~ 2,000 km^2.

The inlet area and its immediate surroundings are expected to be underlain by:

- Superficial soils – sand, peat, loam and clay
- Consolidated rocks (bedrock geology) – sedimentary (sand, siltstone, shale); basalt

The sandy superficials (Safety Bay Sand and Bassendean Sand) in the vicinity and adjacent to the inlet are considered to be unconfined aquifers, whilst the unconsolidated sediments underlying the inlet and its immediate surroundings are expected to be underlain predominantly by alluvium that may comprise of fine and/or clayey sediments, i.e. based on the geomorphology of the inlet area. The hydraulic connectivity between the inlet and sandy deposits within the superficials is subjected to the likely presence of confining or semi-confining unit(s) within the alluvium. The hydraulic conductivity of the sandy superficials is expected to be around 15 m/d based on the permeability value adopted in previous studies (Rockwater, 2015 and RPS, 2018).

Immediately underlying the shallow and sandy superficials, and alluvium is the sedimentary Yarragdee Formation (potentially moderate to high yielding confined aquifer and may contribute to upward hydraulic heads) and Bunbury Basalt (low yielding and relatively impermeable). An upward hydraulic head of 2 m was indicated within the superficial formations near the inlet area based on Commander (Figure 8, p.46, 1984). There are no known or existing field data to validate this observation.

Based on the review of available information, an initial conceptual hydrogeological model was developed as part of this assessment, see Figure 11 and Figure 12 below.

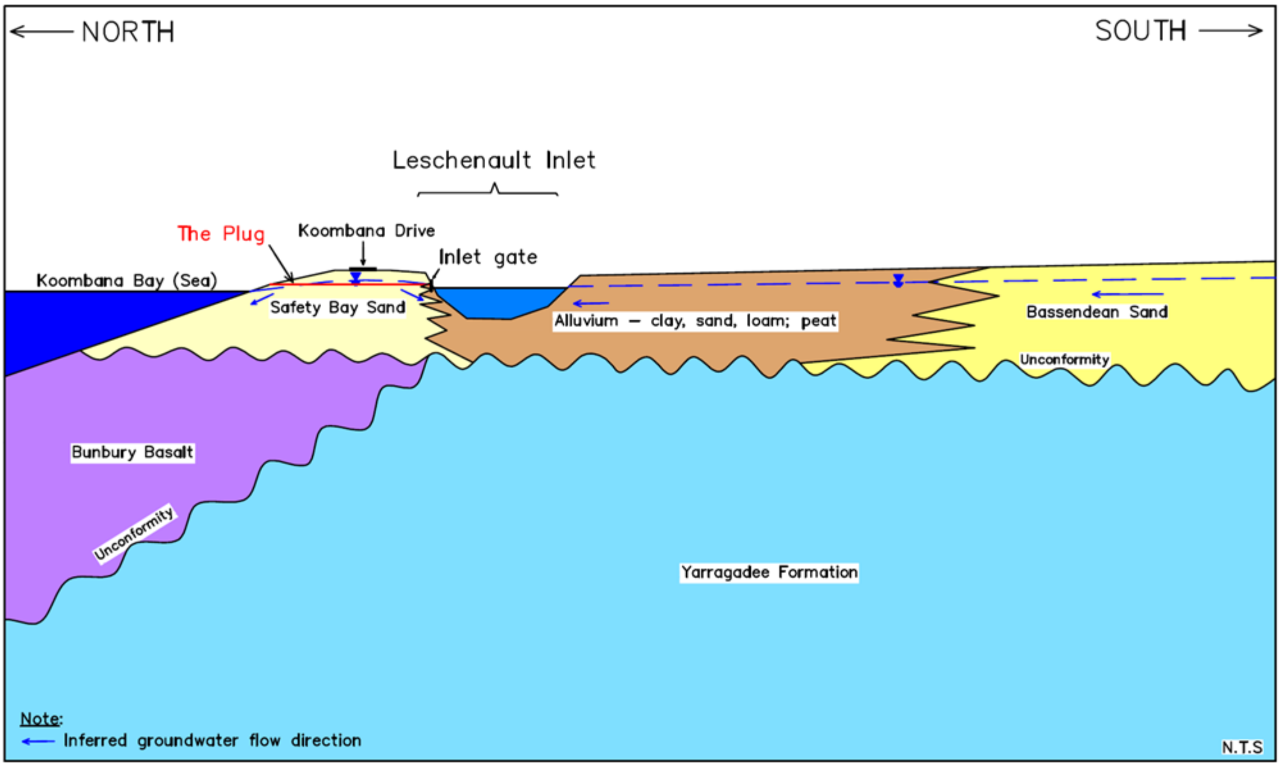


Figure 11: Preliminary conceptual hydrogeological model for Leschenault Inlet (N–S profile)

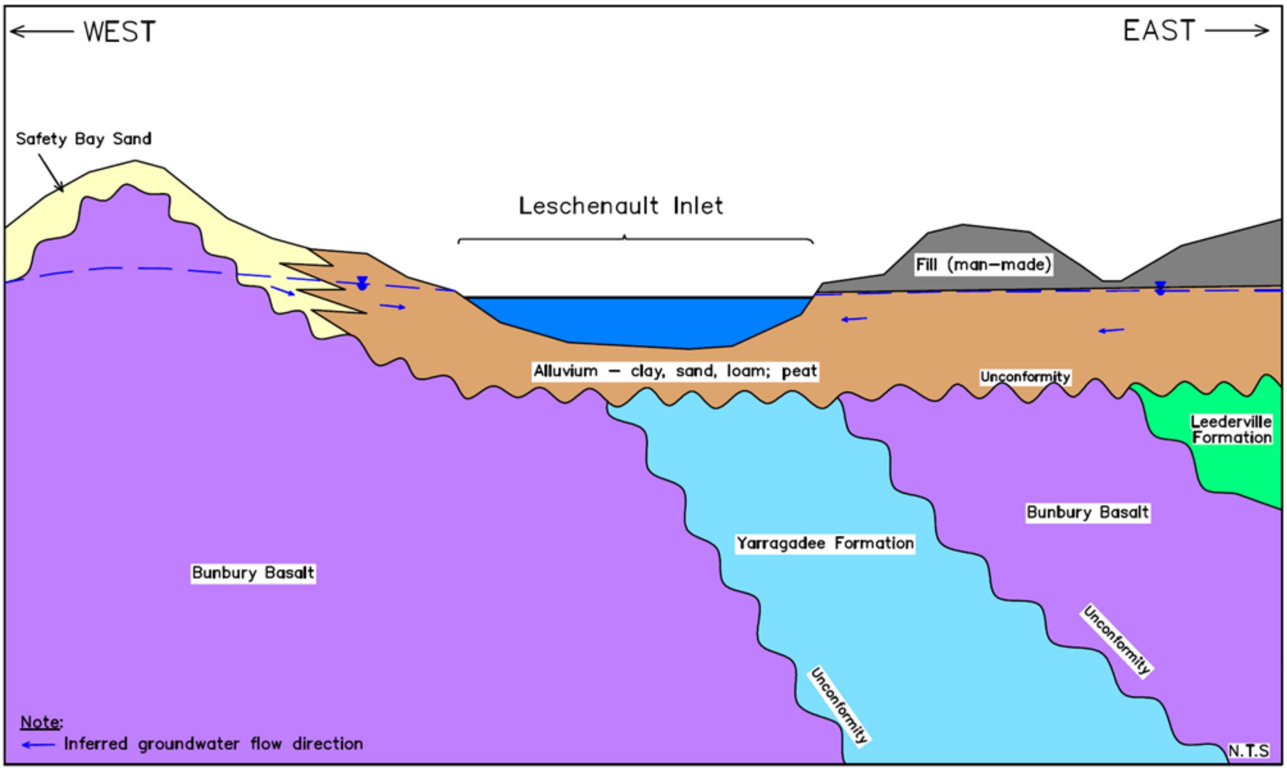


Figure 12: Preliminary conceptual hydrogeological model for Leschenault Inlet (W–E profile)

4 GROUNDWATER MODELLING ASSESSMENT

4.1 Objective

The objective of this groundwater modelling assessment is to predict seasonal groundwater and nutrient flows into the inlet. The results of the groundwater modelling will inform hydrodynamic modelling of flushing dynamics that are likely to occur within the inlet area.

4.2 Modelling scenarios

The following scenarios were modelled as part of the assessment:

- Base case: Transient modelling of one-year period using seasonal rainfall and evapotranspiration variations, and high (50% of LTA) rainfall rates as recharge input. This scenario would allow the calculations of upper bound nutrient loading to the inlet
- Sensitivity modelling #1: Similar to the base case but applied lower hydraulic conductivity for the superficials and 'maximum' recharge rate (60% of LTA)
- Sensitivity modelling #2: Similar to the base case but with lower recharge (35% of LTA).

4.3 Model set-up

4.3.1 Model extent

A preliminary 3-D MODFLOW model was developed for the assessment of shallow groundwater underlying the project site (see Figure 13). The model extent is 3 km (latitudinal) x 4 km (longitudinal) and with model grid spacing of 100m.

Figure 13: Model extent and the area of interest (Leschenault Inlet)

4.3.2 Boundary conditions

A fixed head (Dirichlet) boundary condition was applied as ‘0’ mAHD (metres height in reference to the Australian Height Datum) throughout the coastal line, inlet area and the ‘Plug’.

4.3.3 Assumptions and limitations

There is limited site-specific data pertaining to groundwater levels and site characterizations (e.g. heterogeneity of the sediments) underlying and surrounding the inlet. Other model uncertainties include the actual and variable thickness of superficials, actual depths of the inlet and hydraulic parameters for the superficials and underlying aquifers.

It was assumed for this preliminary groundwater model that there is limited vertical hydraulic contact between the superficials and underlying formations (e.g. Yarragadee and basalt), and groundwater flow is predominantly horizontal within the shallow superficials. The base of the inlet was assumed to be at -2 mAHD, and the base of the model is at -5 mAHD. The shallow superficials were assumed to be undifferentiated (clay / sand / loam / peat).

The operation of the inlet gate (as a water control feature) at the ‘Plug’ alongside with tidal effects or changes was not modelled.

Recharge across the model domain was assumed to range between 35% and 60% of LTA annual rainfall (717 mm), which was based on 24 years of BoM rainfall records. The adopted recharge rates are deemed reasonable based on typical recharge rates (as percentage of rainfall, ranges from 37% to >50%) for ‘urban’ settings as reported in Appleyard (1995) and Xu et al. (2003).

4.3.4 Model parameters and input

Hydraulic parameters applied to the groundwater model are summarized in Table 1 below, whilst seasonal recharge (as a percentage of rainfall) and evapotranspiration (calculated) input based on BoM records for Bunbury are presented in Table 2 below.

Table 1: Predicted monthly groundwater inflows into inlet and estimated nutrients loading

	Horizontal hydraulic conductivity (m/d)	Horizontal to vertical anisotropy	Specific storage (1/m)	Specific yield	Porosity
Base case (50% of LTA)	15	10	1E-05	0.2	0.2
Sensitivity modelling #1 (60% of LTA)	5	10	1E-05	0.2	0.2
Sensitivity modelling #2 (35% of LTA)	15	10	1E-05	0.2	0.2

Table 2: Recharge and evapotranspiration rates applied in the groundwater model

Month	Recharge (m/d)			Evapotranspiration
	35% LTA	50% LTA	60% LTA	(m/d)
January	1.37E-04	1.95E-04	2.34E-04	6.55E-03
February	8.68E-05	1.24E-04	1.49E-04	6.27E-03
March	2.15E-04	3.07E-04	3.68E-04	4.82E-03
April	4.08E-04	5.84E-04	7.00E-04	3.13E-03
May	1.08E-03	1.54E-03	1.85E-03	2.01E-03
June	1.59E-03	2.27E-03	2.72E-03	1.80E-03
July	1.59E-03	2.27E-03	2.72E-03	1.43E-03
August	1.36E-03	1.94E-03	2.33E-03	2.18E-03
September	9.23E-04	1.32E-03	1.58E-03	1.94E-03
November	3.73E-04	5.33E-04	6.40E-04	3.78E-03
December	2.55E-04	3.64E-04	4.37E-04	5.82E-03

LTA – Long term average rainfall (1996 – 2019). Variation in recharge input (as percentage of rainfall) was to allow the representations of seasonal variability and/or sensitivity modelling.

Evapotranspiration based on 2019 BoM records for Bunbury Extinction depth was assumed to be 2 m.

4.4 Modelling results

Modelled groundwater levels inlet and immediate surroundings are presented in Figure 14, and a summary of predicted groundwater fluxes towards the inlet are graphically presented in Figure 15.

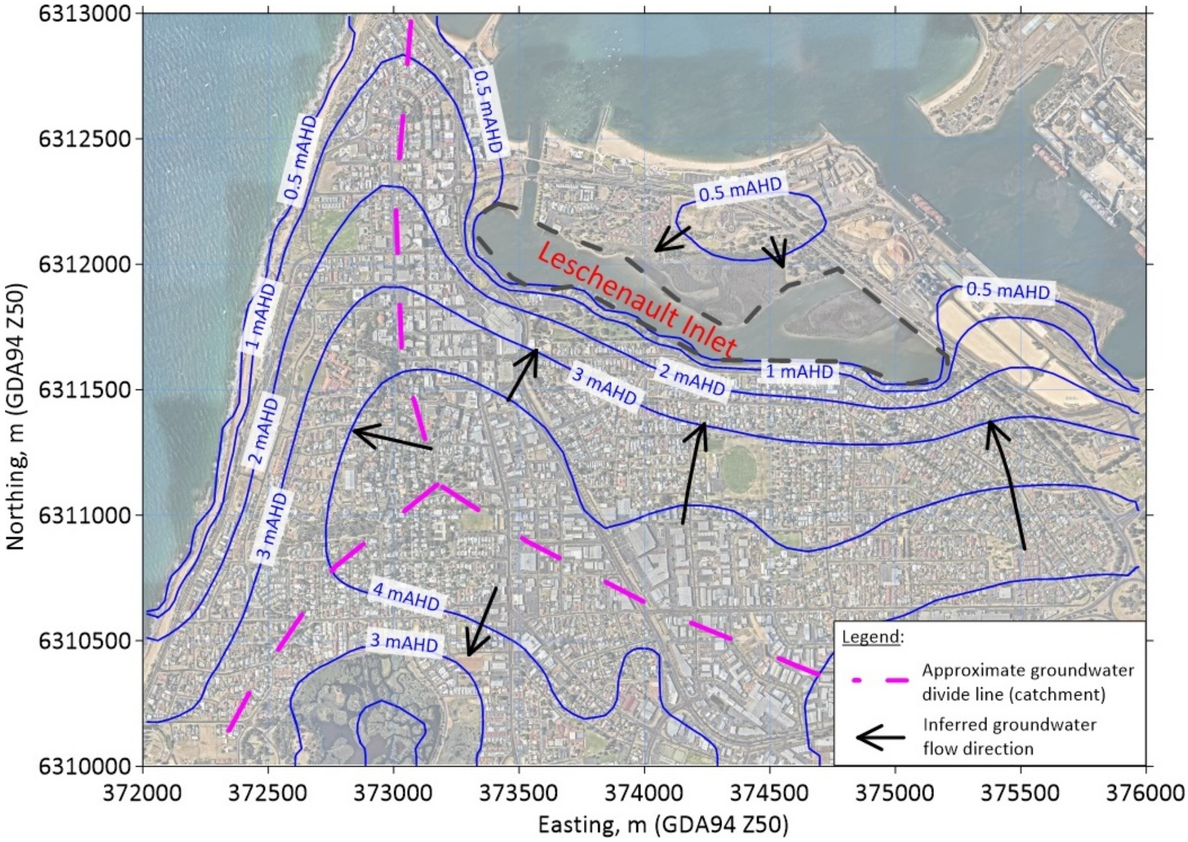


Figure 14: Modelled water table (potentiometric heads) – base case

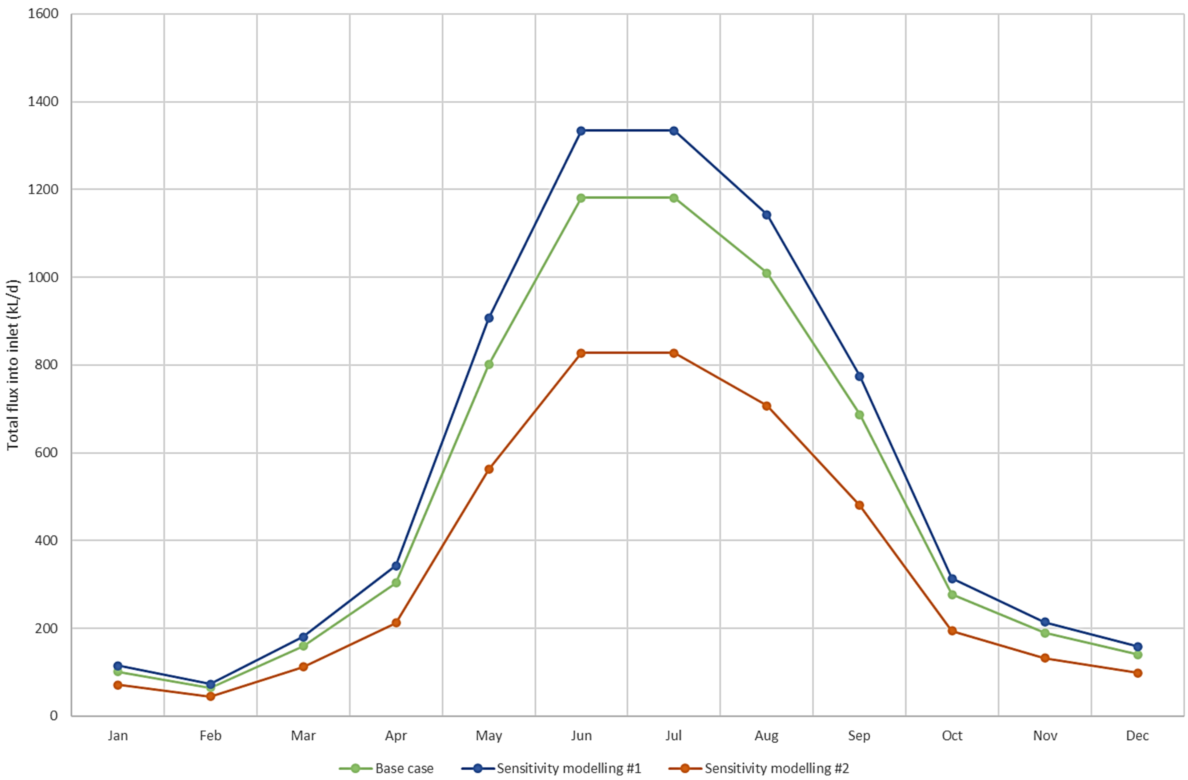


Figure 15: Estimated groundwater flux(es) towards inlet over one-year modelling period

As indicated in Figure 13 above, the groundwater flows within the shallow superficials are predominantly towards the inlet and northeast of the model domain. Groundwater levels in close vicinity of the inlet are expected to be <1 mAHD as the groundwater discharges to the inlet at ~0 mAHD.

Higher groundwater fluxes as noted between May and August period (refer Figure 14) can be directly attributed to the higher percentage of rainfall during the wetter/cooler months. Higher groundwater fluxes can also be associated with upper bound hydraulic conductivity with high anisotropy bias (horizontal permeability) and a higher recharge input that was based on upper bound value (i.e. 50% of long-term average rainfall for the base case). This upper bound estimate of groundwater flux(es) into the inlet would allow conservative prediction of nutrient loadings into the inlet. The calculations of nutrient loadings are provided in the following Section 5.3.

5 WATER QUALITY ASSESSMENT

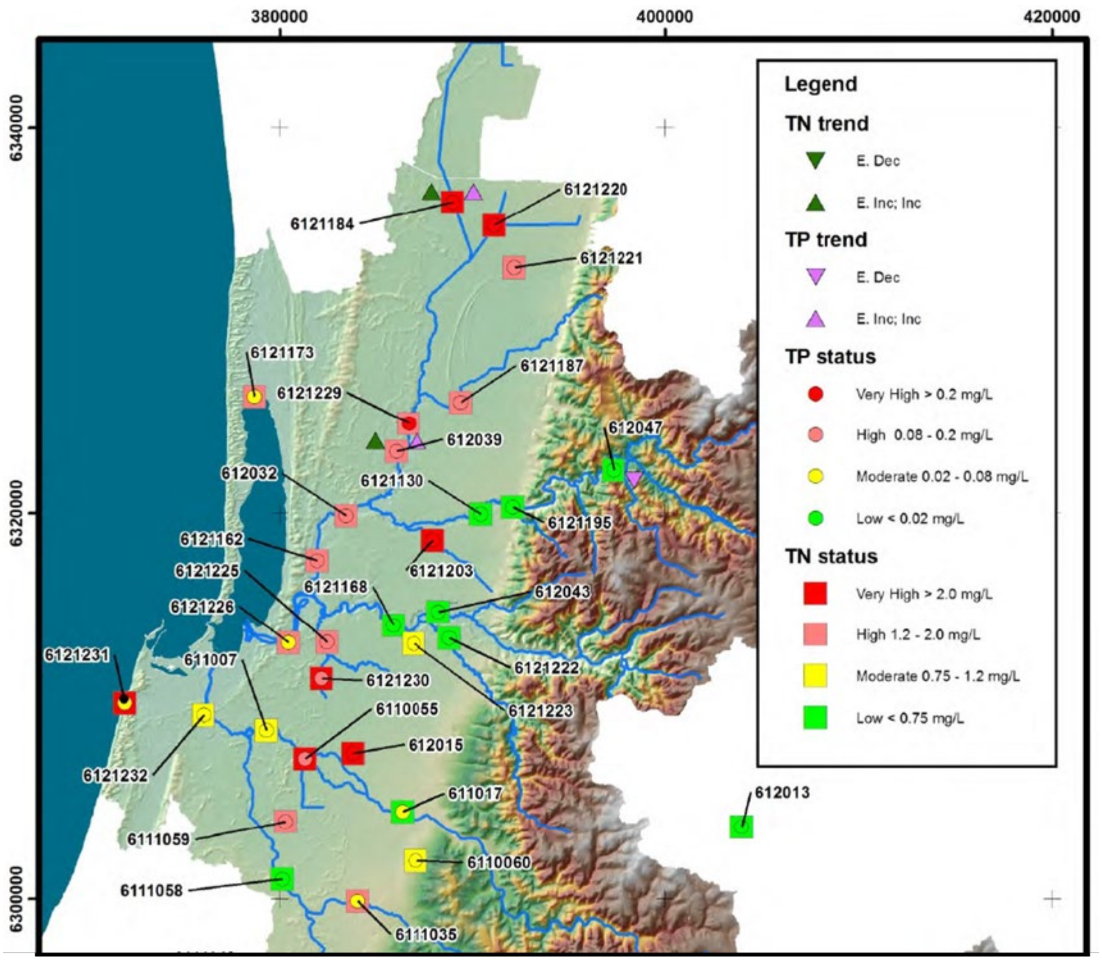
5.1 Catchment water quality

The Leschenault Inlet lies within the Coast sub-catchment that is located immediately downstream of the Lower Preston sub-catchment. Both sub-catchments are drained by the perennial Preston River and are located on the lower reaches of the larger Leschenault catchment.

Historical water sampling within the Leschenault catchment has indicated that the lower reaches of the Preston River had moderate status for both total nitrogen (TN) and total phosphorus (TP), which were reportedly due to dilution by low concentration flow from the upper catchment (DoW, 2012). The nutrients classification used in DoW (2012) are presented in Table 3 below, and nutrient levels based on historical sampling within the Leschenault catchment is presented in Figure 16.

Table 3: General classification for TN and TP (DoW, 2012)

TN	Status	TP
> 2.0 mg/L	Very high	> 0.2 mg/L
> 1.2 - 2.0 mg/L	High	> 0.08 - 0.2 mg/L
0.75 - 1.2 mg/L	Moderate	0.02 - 0.08 mg/L
< 0.75 mg/L	Low	< 0.02 mg/L



(DoW, 2012)

Figure 16: Nutrients level based on historical data by Kelsey and Hall 2010

5.2 Previous sampling events

5.2.1 pH and salinity

Results from two sampling events undertaken at four DWER bores (within 3km radius from the inlet) by RPS in 2016 - 2017 indicated the following:

- pH ranged between 6.6 and 9.1, with an average of 7.6.
- EC ranged between 366 and 6,910 µS/cm, with an average of 1,825 µS/cm.
- Calculated TDS (based on field EC) ranged between 234 and 4,422 mg/L, with an average of 1,825 mg/L.

These results indicated that the shallow groundwater is typically slightly acidic to slightly alkaline (with the exception of one bore that was moderately to strongly alkaline), and the salinity as indicated by EC and TDS ranged between fresh and moderately saline (brackish).

5.2.2 Nutrients

Sampling results from the two sampling events in 2016 - 2017 indicated the following:

- Total nitrogen (TN) ranged between 0.2 and 0.9 mg/L, with an average of 0.43 mg/L. TN concentrations were generally above the marine inshore guidelines (MIG) for South-west Australia (ANZECC 2000) value of 0.23 mg/L.
- Total phosphorus (TP) ranged between 0.07 and 0.29 mg/L, with an average of 0.15 mg/L. Detected TP concentrations were generally above the MIG value of 0.23 mg/L.
- Dissolved inorganic nitrogen (DIN) which consists of ammonia (NH_4-N and NO_x-N), ranged between 0.04 and 0.63 mg/L, with an average of 0.20 mg/L. The DIN value generally represents bioavailability of the nitrogen levels in the sampled groundwater. The DIN values were generally above the MIG value of 0.005 mg/L for NH_4-N / NO_x-N.
- Detected filterable reaction phosphorus (FRP) was 0.05 mg/L at one bore closest to the inlet. The FRP value generally represents bioavailability of the phosphorus levels in the sampled groundwater, and the detected concentration exceeded the MIG value of 0.005 mg/L.

Nutrient concentrations at the four DWER bores in comparison with recorded rainfall (BoM station 9965) are presented in Figure 17 below. It can be observed that nutrient levels typically indicate a slight decrease of concentrations in tandem with reduced recharge (via rainfall and subsequent percolation into the ground) with the exceptions of TN and DIN at one bore located about 2.2 km to the southwest of the inlet and adjacent to the wetland reserve (Big Swamp Parkland).

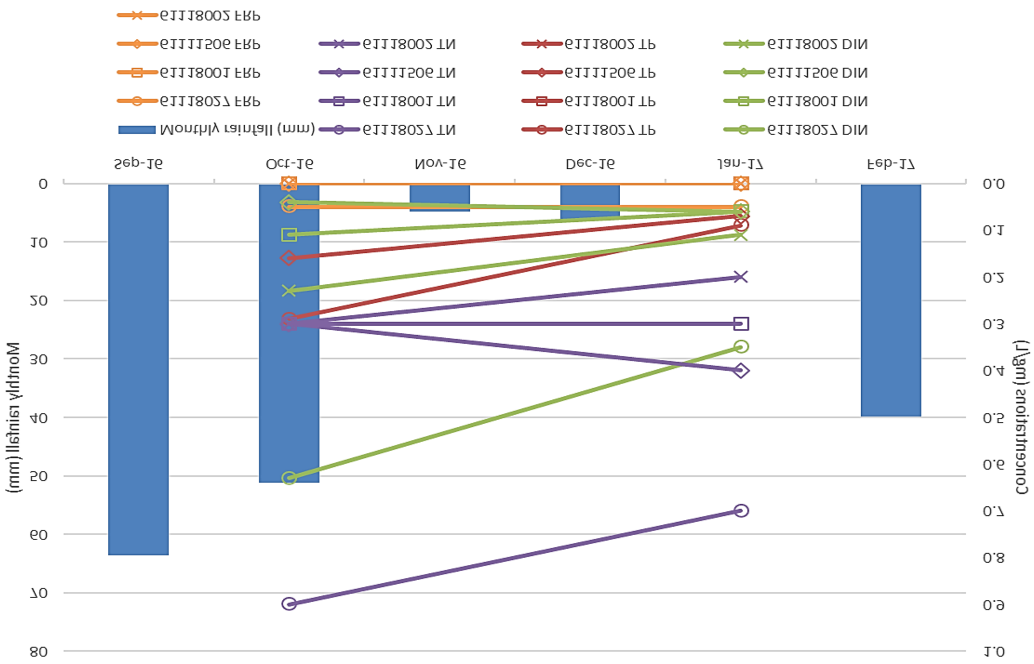


Figure 17: Nutrient concentrations and monthly rainfall (2016–2017)

The observation noted above implies that the nutrient levels are expected to rise when there is greater recharge (attributed to rainfall and subsequent percolation into the subsurface) and attributed to the greater mobilization of nutrients in the shallow groundwater.

5.3 Estimation of nutrients loading

Based on the groundwater modelling assessment, total groundwater flux towards the inlet (perimeter of approximately 4.5 km and encompassing an area about 44 ha) is estimated to range between approximately 70 and 1190 kL/d, being controlled by seasonal influences.

Monthly nutrient loading to the inlet was calculated as the product of groundwater flux and nutrient concentration, as summarized in Table 4 and graphically presented in Figure 18.

Table 4: Predicted monthly groundwater inflows into inlet and estimated nutrients loading

Month	Estimated flux into inlet (kL/d)	Predicted groundwater		Estimated loading towards inlet	
		TN (kg/month)	TP (kg/month)	DIN (kg/month)	FRP (kg/month)
January	101	2.83	0.91	1.98	0.16
February	65	1.63	0.52	1.14	0.09
March	160	4.46	1.44	3.12	0.25
April	304	8.21	2.64	5.74	0.46
May	801	22.36	7.20	15.65	1.24
June	1181	31.89	10.28	22.33	1.77
July	1181	32.96	10.62	23.07	1.83
August	1010	28.17	9.08	19.72	1.56
September	687	18.55	5.98	12.98	1.03
October	277	7.74	2.49	5.42	0.43
November	189	5.11	1.65	3.58	0.28
December	141	3.92	1.26	2.74	0.22
Total loading (maximum) (kg/yr)	-	167.8	54.1	117.5	9.3
Average loading (kg/d)	-	0.46	0.15	0.32	0.03

TN - Total Nitrogen; TP - Total Phosphorus; DIN - Dissolved Inorganic Nitrogen; FRP - Filterable Reaction Phosphorus

Maximum referenced concentrations from RPS' groundwater sampling (2016-2017): TN (0.9 mg/L); TP (0.29 mg/L); DIN (0.63 mg/L); FRP (0.05 mg/L)

Predicted nutrients loading was based on 'worst-case' scenario assuming maximum referenced concentrations were used for the predictions and that the nutrients are not attenuated (e.g. via dilution) along the groundwater flow path(s) towards the inlet.

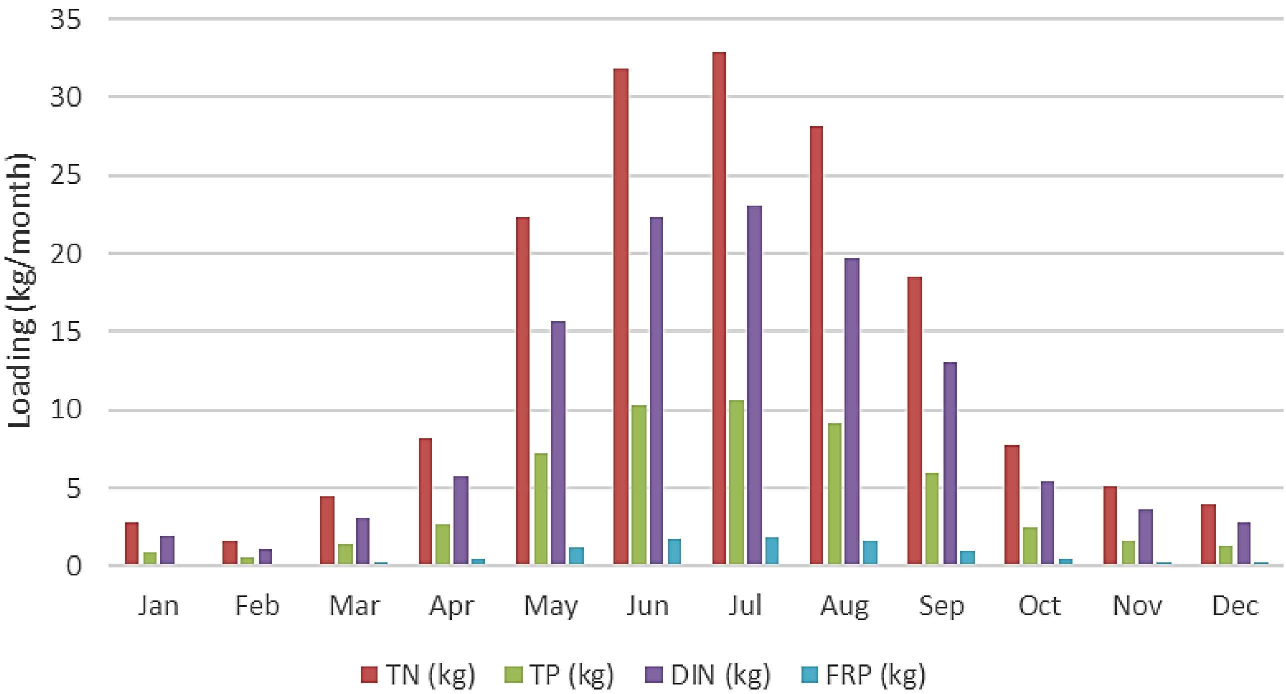


Figure 18: Estimated maximum loading into the inlet

It can be noted from the graph above that the nutrient levels are expected to rise with higher rainfall (particularly between May and August, refer Figure 2), which can be attributed to greater mobilization of nutrients in the shallow groundwater discharge at the inlet during these periods.

6 DISCUSSION AND CONCLUSION

This desktop-modelling study was undertaken in accordance to RPS' proposal ref. L16056.003 dated 7 November 2019 pertaining to a groundwater assessment for the southwestern portion of Leschenault Inlet that is located close to and directly south of Koombana Bay, Bunbury. The inlet encompasses an area of approximately 44 hectares with a perimeter of around 4.5km.

Following reviews of all available information including unpublished and published reports, a preliminary conceptual hydrogeological model was developed as part of this groundwater assessment. The development of the preliminary conceptual hydrogeological model allows the initial conceptualization of the subsurface geology and hydrogeology underlying and in the vicinity of the inlet, noting that there are limited site-specific data available during this assessment. The conceptual model should be updated accordingly should new subsurface information or knowledge becomes available.

A simple single-layered three-dimensional groundwater flow (MODFLOW) model was developed to estimate the groundwater flux(es) reporting to the Leschenault inlet and in view of potential seasonal variations pertaining to rainfall and evapotranspiration rates. The modelling results were subsequently used to analytically estimate the nutrients reporting to the Leschenault inlet by multiplying groundwater discharge (flux) with the nutrients' concentration in groundwater. No solute transport modelling was undertaken as part of this groundwater assessment.

Based on the groundwater modelling assessment, total groundwater fluxes toward the inlet area were estimated to range approximately between 70 and 1190 kL/d. By referencing to the previously recorded maximum nutrient concentrations in groundwater (RPS, 2018), annual TN loadings is estimated to be around 167.8 kg/year, while TP loadings is estimated to be around 54.1 kg/year. DIN and FRP loading rates are estimated to be around 117.5 kg/year and 9.3 kg/year, respectively. It should be noted that only the nutrients loading estimations provided herewith are deemed conservative whereby the upper bound groundwater fluxes and maximum nutrient concentrations (previously recorded) were adopted in the estimation of nutrients loading towards the inlet. In line with the previous nutrient loading modelling for the proposed Koombana Marina project undertaken by RPS in 2018, the nutrient loading estimations herein are likely to differ throughout the year in tandem with varying groundwater fluxes that can be directly linked to the seasonal recharge (and rainfall) rates.

It is understood that the information and results provided from this groundwater assessment for the Leschenault Inlet may be used as input for the hydrodynamic model as part of the proposed marina developments at Koombana Bay. The estimated nutrient loading values and estimated groundwater fluxes provided in this report should be adopted as an approximation only given that there is limited subsurface information for the inlet and its immediately adjacent areas.

7 RECOMMENDATIONS

Additional field investigation and site-specific data will be essential if further refinement is required for the preliminary three-dimensional groundwater model. For example, stratigraphical drilling to delineate the sandy superficials and alluvium underlying the inlet and its surrounding areas, as well as new shallow monitoring bores to provide groundwater levels within the extent of the groundwater model domain for the purpose of groundwater head calibrations. In addition to water levels, these bores would provide for water quality sampling to confirm groundwater nutrient levels.

Other information that would be useful could comprise of seasonal groundwater levels upgradient and surrounding the inlet, bathymetry data for the entire inlet basin, thickness and hydraulic parameters (e.g. permeabilities) of the sediments below and surrounding inlet's basin.

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