APPENDIX A

Balannup Sewer Pressure Main Anstey-Keane Dampland Hydrological Assessment (GHD)

Water Corporation

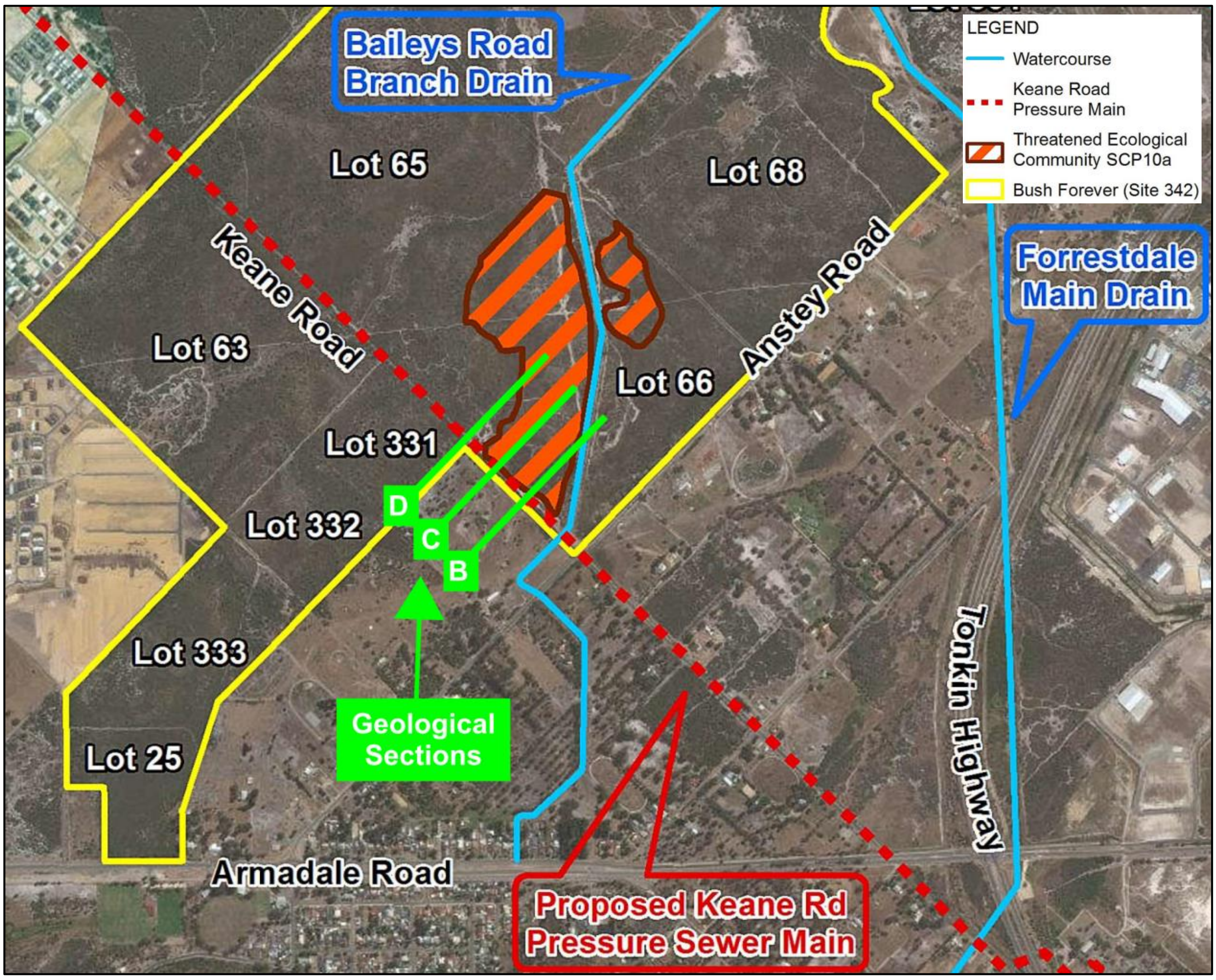
Balannup Sewer Pressure Main

Anstey-Keane Dampland Hydrological Assessment

December 2015

Executive Summary

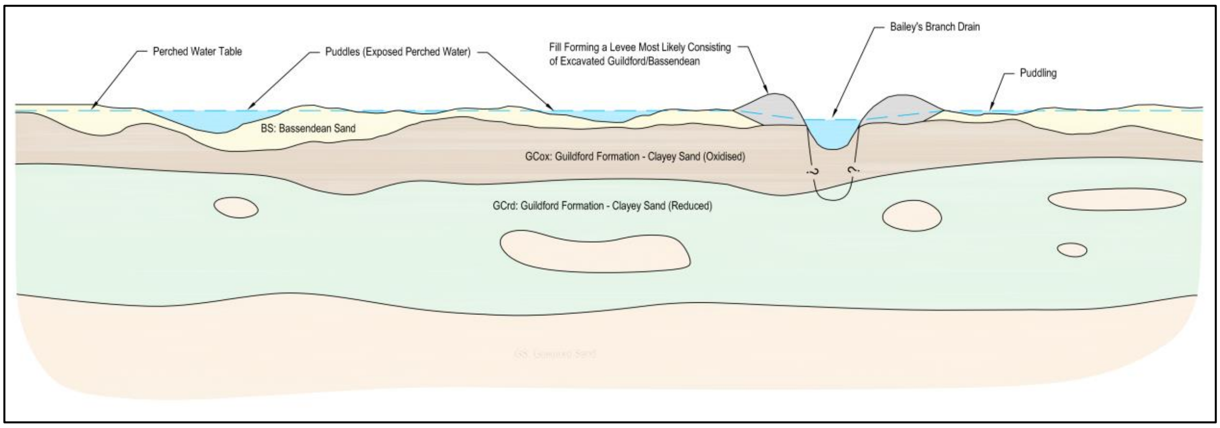
The Water Corporation proposes to construct a subsurface sewer pressure main along the Keane Road easement, which forms part of the southern boundary of Bush Forever Site 342 (see below). The Anstey-Keane Dampland, located within the Bush Forever Site 342, is a seasonal wetland identified as a Threatened Ecological Community (TEC). Given the proximity of the TEC, the Water Corporation is proposing to install the sewer main using an EcoPlough, which is a trenchless construction technology aimed at impact minimisation for environmental management.



The Anstey-Keane Dampland differs from the nearby Forrestdale Lake or Baileys Wetland in that it does not contain a body of open shallow water in winter and spring that dries out in summer. The dampland is rather a vegetated depression where moisture is diffused through the upper soil horizons and is not usually visible on the surface. The vegetation within the TEC comprises low herb type shrubs known as heathland, sedgeland or herbland, which is a primary indicator of a dampland.

The Water Corporation, in consultation with the Office of the Environmental Protection Authority (OEPA) and the DPaW, commissioned this study to gain a greater understanding of the hydrological functioning of the dampland and the impacts (if any) that the installation of the sewer main may have on the hydrological function. The issues considered necessitated an assessment of the stratigraphy along the proposed sewer main in the vicinity of the TEC, interpretation of the hydrology of the TEC and development of a conceptual model thereof and an assessment of any potential change to the vertical and horizontal groundwater flow gradients or recharge mechanisms.

The study commenced with a field investigation where the stratigraphy of the site was investigated by drilling 17 push probe boreholes within and adjacent to the TEC. The majority of the boreholes were drilled to the target depth of 3 mBGL. Recovered soil samples were photographed and logged, where after representative samples of soil were taken at approximately 250 mm intervals in uniform stratum or at changes in material type for laboratory testing. Laboratory testing was required to improve the definition of the site stratigraphy and included particle size distribution, Atterberg limits, moisture content and organic content. A conceptual geotechnical model of the TEC derived from the interpretation of the stratigraphic logs is presented below.



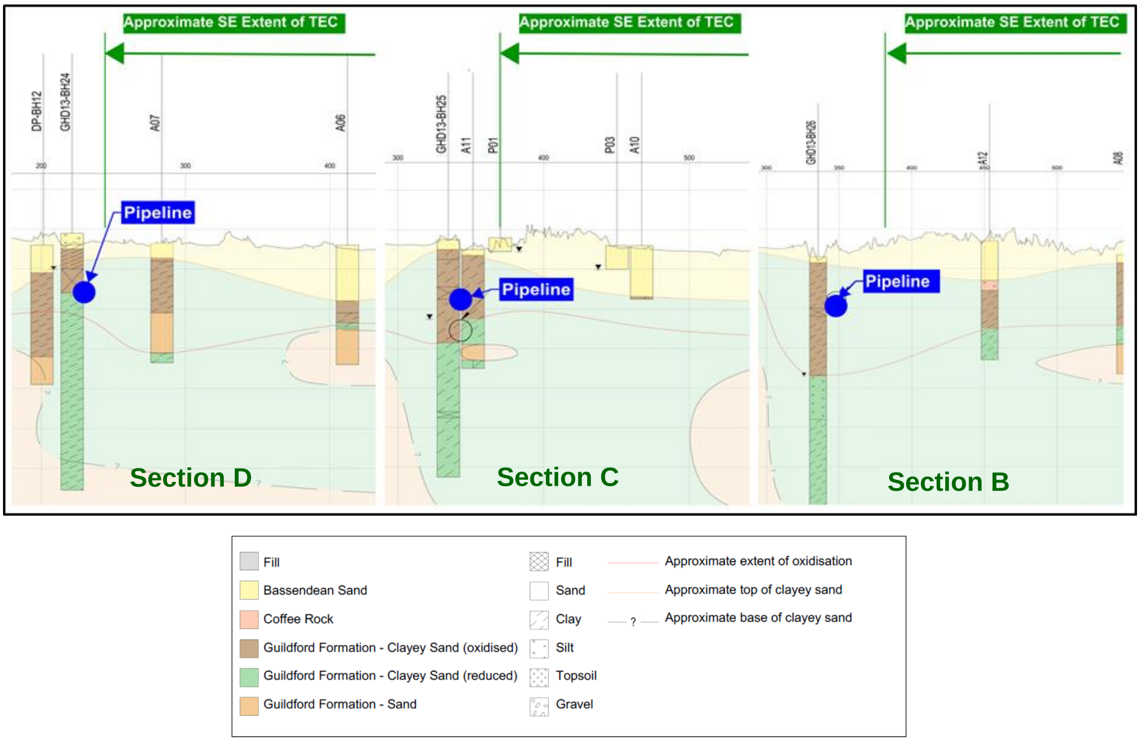
Hydraulic conductivities were determined through in-situ testing of the surficial sands using a Guelph (constant-head) permeameter, rising head tests of both existing and newly installed monitoring bores and empirical estimates from particle size distribution. The ranges in estimated hydraulic conductivity summarised below indicate an order of magnitude differences between and within the various sand and clayey sand units.

Formation	Range of hydraulic conductivity (m/day)
Bassendean Sand	3.7 – 13.8
Guildford Formation clayey sand	0.01 – 0.21
Guildford Formation sand	4.53 – 9.33

The interpreted geology for cross sections from the proposed sewer main through the south eastern extent of the TEC is provided below. The locations of these sections are depicted in the locality plan above.

The site investigations indicate that an ephemeral aquifer system forms within the Bassendean Sands in the vicinity of the TEC, which is perched on the confining Guildford Formation clayey sands. This system aligns reasonably well with the mapped extent of the TEC.

The ephemeral nature of the perched aquifer system is evidenced by both groundwater level monitoring data and the transition of the soils from oxidised to reduced states (~2 to 3 mBGL). The thickness of the underlying clayey sands (~6 m), the different groundwater chemistries and the increase in salinity with depth indicate that the perched and confined aquifers are distinct groundwater systems with limited hydraulic connectivity.



Given the fresh shallow groundwater quality and the maintenance of a downwards hydraulic head potential, rainfall is likely to be the dominant mechanism and water source for recharge and maintenance of the perched aquifer. Stored water will be dissipated through soil evaporation and plant evapotranspiration, with vertical drainage unlikely to occur. Hydraulic connectivity of this perched aquifer system to the Baileys Branch Drain is likely to be limited. Accordingly, it is highly unlikely that there will be any impacts to the recharge of the perched ephemeral aquifer system resulting from the installation of the sewer main.

In winter, ponding is common in the topographical lows in the TEC where water accumulates due to rainfall, near horizontal drainage from adjacent sandy areas and surplus water runoff. Lidar surface level data indicates a catchment divide along the proposed alignment of the sewer main. Surplus surface water will shed into the areas adjacent to the track and flow on to the low lying remnant wetland in the vicinity of the Anstey Rd and Keane Rd intersection. Installation of the sewer main will not interrupt surface water flow paths in the vicinity of the TEC.

The sewer main is aligned on a ridge of elevated Guildford Formation clayey sand along the existing fire access at the inferred southern extent of the ephemeral perched aquifer system. Installing the sewer main within this clayey sand formation is highly unlikely to have any influence on the horizontal drainage to the perched system in the vicinity of the TEC.

The thickness of the underlying clayey sands along the sewer main alignment appears to be in the order of 6 m. Installing the sewer main into the top ~1.5 m of this material should still result in sufficient residual thickness to maintain the hydraulic integrity of the perched aquifer system. The alignment is in close proximity to a pocket of more sandy material which, if intersected, could further reduce the effective residual thickness. It should be noted that any reduction in effective thickness resulting from disturbance during installation will be limited to the sewer main corridor only.

Given the alignment and installed depth of the sewer main in relation to the ephemeral perched aquifer system associated with the TEC, the main is unlikely to pose a risk of increased hydraulic connectivity between the perched aquifer system and the underlying confined aquifer system. It is noted that there are pockets of more sandy material within the Guildford Formation clayey sand at ~2.5 mBGL. It is recommended that these lenses should be avoided by installing the sewer main higher in the soil profile.

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1. Introduction and background

1.1 Overview

The Water Corporation proposes to construct a subsurface sewer pressure main along the Keane Road easement, which forms part of the southern boundary of the Bush Forever Site 342, adjacent to Anstey Road in Forrestfield (see **Figure 1** overleaf). The Anstey-Keane Dampland, located within the Bush Forever Site 342, is a seasonal wetland which supports conservation status vegetation communities. According to the Department of Parks and Wildlife[1] (DPaW), the Anstey-Keane Dampland has been identified as Threatened Ecological Community (TEC) and is referenced SCP10a. This area is described as shrublands on dry clay flats and the TEC is listed in the critically endangered category under the Commonwealth *Environment Protection and Biodiversity Conservation Act, 1999*.

In consultation with the Office of the Environmental Protection Authority (OEPA) and the DPaW, the Water Corporation commissioned further investigations to gain a greater understanding of:

- The hydrological functioning of the dampland and the respective interactions with local surface water and groundwater systems and the regional superficial aquifer; and
- The impacts (if any) that the installation of the sewer main may have on the hydrological functioning of the dampland.

1.2 Purpose of this report

The purpose of this report is to document the site investigations undertaken and to assess if the installation of the sewer main would alter the local water balance and change the hydrology of the dampland in the vicinity of the TEC. This work was carried out in accordance with the scope of work outlined in GHD's proposal to the Water Corporation dated the 22 July 2015 (GHD ref 61\32259\150533 Rev. 4)

The main issues considered were:

- An assessment of the stratigraphy along the proposed sewer main in the vicinity of the TEC;
- Interpretation of the hydrology of the TEC and development of a conceptual model thereof to provide an understanding of the likely water balance of the TEC; and
- Whether the installation of the sewer main would result in any change to the vertical and horizontal groundwater flow gradients or recharge mechanisms.

The report presents the factual data acquired by GHD during the investigation and interpretation of the factual data to assess the hydrology of the site and the potential impact of the sewer main on the site processes.

[1] http://www.dpaw.wa.gov.au/plants-and-animals/threatened-species-and-communities/wa-s-threatened-ecological-communities

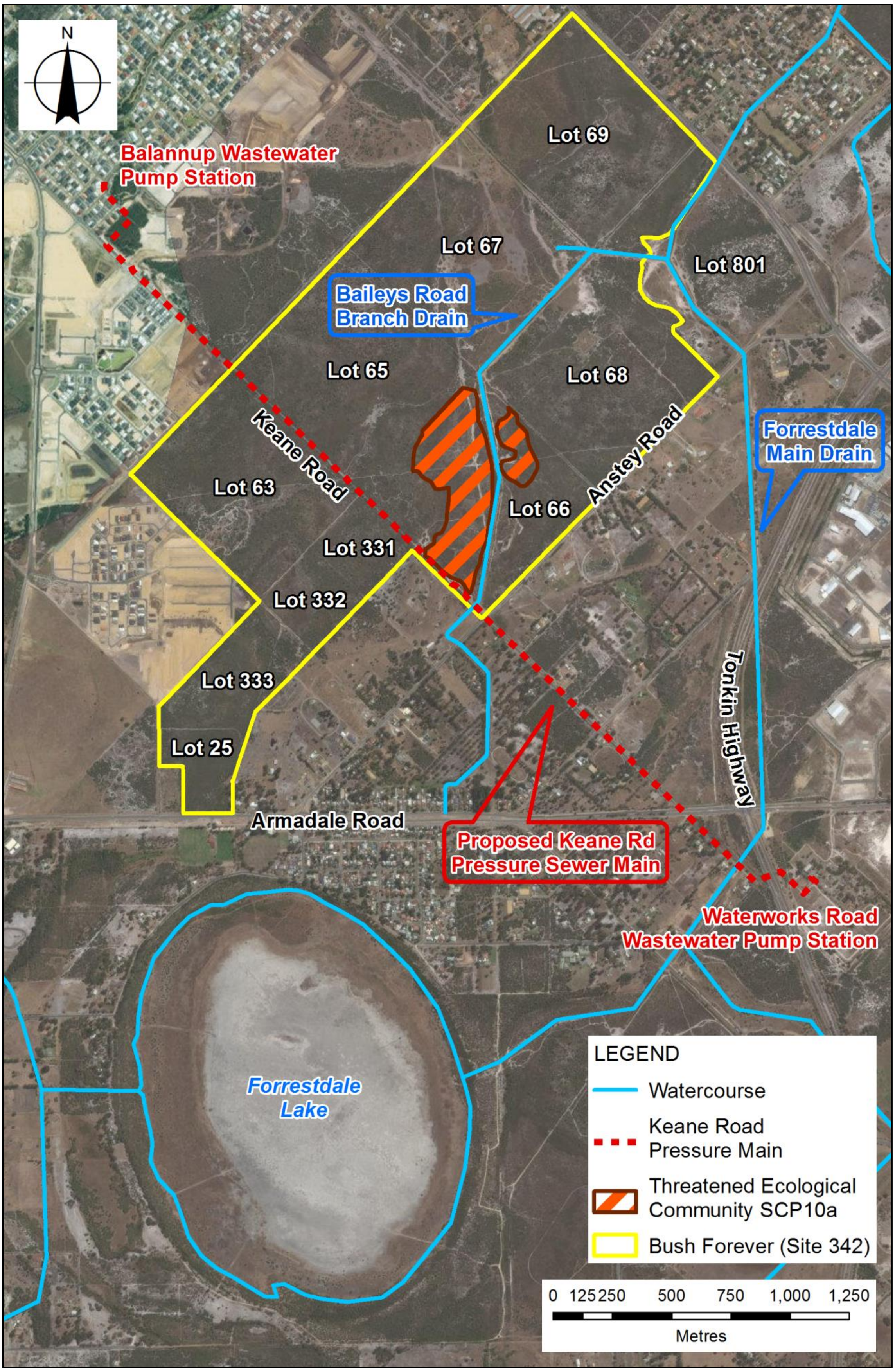

Figure 1: Site locality plan

1.3 Project background

To meet increased capacity requirements, the Water Corporation plans to refit the Balannup Wastewater Pump Station with new pumps and construct ~4.5 km of DN450 PE sewer pressure main to the Waterworks Road Wastewater Treatment Plant (WWTP). Approximately 3 km of the proposed sewer main will be aligned within existing road corridors through residential areas and can be constructed by conventional open trenching techniques. The remaining ~1.5 km of the sewer main is proposed to cross Bush Forever Site 342 on the alignment of Anstey Road in Forrestfield (see **Figure 1**).

Given the proximity of the TEC, the Water Corporation is proposing to install the sewer main using an EcoPlough, which is a trenchless construction technology aimed at impact avoidance for environmental management (see **Figure 2**). This technology has been identified as being both capable of installing a sewer main according to the Water Corporation's design and operation standards and also addressing environmental constraints during construction, including:

- Requires minimal clearing;
- Negates open trenching;
- Results in minimal disturbance to the soil profile and density;
- Does not expose potential Acid Sulphate Soils (ASS); and
- Will not require dewatering.

Figure 2: EcoPlough installing a PE pipeline

The EcoPlough drags a vertical plough through the ground, creating a narrow furrow in which the sewer main is inserted. The machine then returns to the start of the furrow where the pipeline is mounted on the side of the EcoPlough and is ploughed into the previously created furrow. The plough vibrates at high frequency as it inserts the pipeline to encourage smaller particulate matter to accumulate around the pipe to form bedding material. The process is completed within the width of the EcoPlough track, which is less than 4 m. The current design requires the sewer main to be installed at depths of between 1.5 m and 1.8 m below the existing ground surface level.

The Bush Forever Site 342 is crossed by and can be accessed via a number of fire access tracks. The alignment of the proposed sewer main follows the existing track along the route of the proposed Keane Rd extension to avoid further clearance of vegetation (see **Figure 3**).

Figure 3: Existing fire access track on pipeline alignment (facing southeast)

1.4 Limitations

This report has been prepared by GHD for the Water Corporation and may only be used and relied on by Water Corporation for the purpose agreed between GHD and Water Corporation, as set out in Section 1.2 of this Report.

GHD otherwise disclaims responsibility to any person other than Water Corporation arising in connection with this Report. The services undertaken by GHD in connection with preparing this Report were limited to those specifically detailed in the Contract and are subject to the scope limitations set out in the Contract.

The opinions, conclusions and any recommendations in this Report are based on conditions encountered and information reviewed at the date of preparation of the Report. GHD has no responsibility or obligation to update this Report to account for events or changes occurring subsequent to the date that the Report was prepared.

2. Regional setting

2.1 Geomorphology

The Swan Coastal Plain forms a large area within the Perth Basin bordered on the east by the Darling Scarp, on the west by the Indian Ocean, the Hill River Scarp to the north and Cape Naturaliste to the South. The Swan Coastal Plain has been built up by the accumulation of marine, aeolian and alluvial sediments over time.

Five main geomorphic units have been identified on the Swan Coastal Plain, these being (from east to west) the Ridge Hill Shelf, the Pinjarra Plain and the Bassendean, Spearwood and Quindalup Dune systems (Seddon, 1972). These deposits generally show a progressive decrease in age and elevation passing from east to west. The TEC is located within the Bassendean Dune system.

The Bassendean Dune System is the oldest of the dune systems of marine origin and today consists of a series of low hills varying from 20 m in height to almost flat. The dunes were formed as a belt of coastal dunes and associated shoreline deposits which accumulated mostly during a period of high sea level, about 115,000 years ago (McArthur and Bettenay, 1974). The dunes were probably largely calcareous with a smaller proportion of quartz sand but over time the soluble calcium carbonate has been leached out leaving the infertile grey quartz sand found today (Seddon, 1972). The present shape of the dunes is largely inherited from the original coastal dunes but the relief has been much diminished as a result of the leaching (Playford *et al*, 1976).

The high permeability of the sands leads to a characteristic lack of drainage channels but the dunes often lie over an almost impermeable organic hard pan (coffee rock) which is close to the surface in many of the interdunal depressions, so while the sand ridges are excessively drained the swales become saturated with water, creating seasonally inundated basins (Semenuik, 1988).

2.2 Geology

The geology in the vicinity of the TEC, as indicated on the ‘Armadale’ 1:50,000 scale Environmental Geology Series map sheet, is shown on **Figure 4**. The map sheet reveals that the site is predominantly underlain by fine to medium grained quartz sand of eolian origin, associated with the Bassendean Sand unit (S_8 on the map). A thin layer of friable variably cemented iron and/or organic rich sands colloquially known as “coffee rock” is commonly encountered within the vicinity of the water table within this geological unit.

The Bassendean Sand is underlain at variable depth by alluvial clayey, silty and sandy soils of the Guildford Formation (S_{10}). Small pockets of peaty sand (Sp_1) associated with swamps subject to seasonal flooding are indicated as being present at or near surface in the southern corner of the site. The geology of the individual geotechnical units according to the ‘Armadale’ 1:50,000 scale Environmental Geology Series map sheet is summarised in **Table 1**.

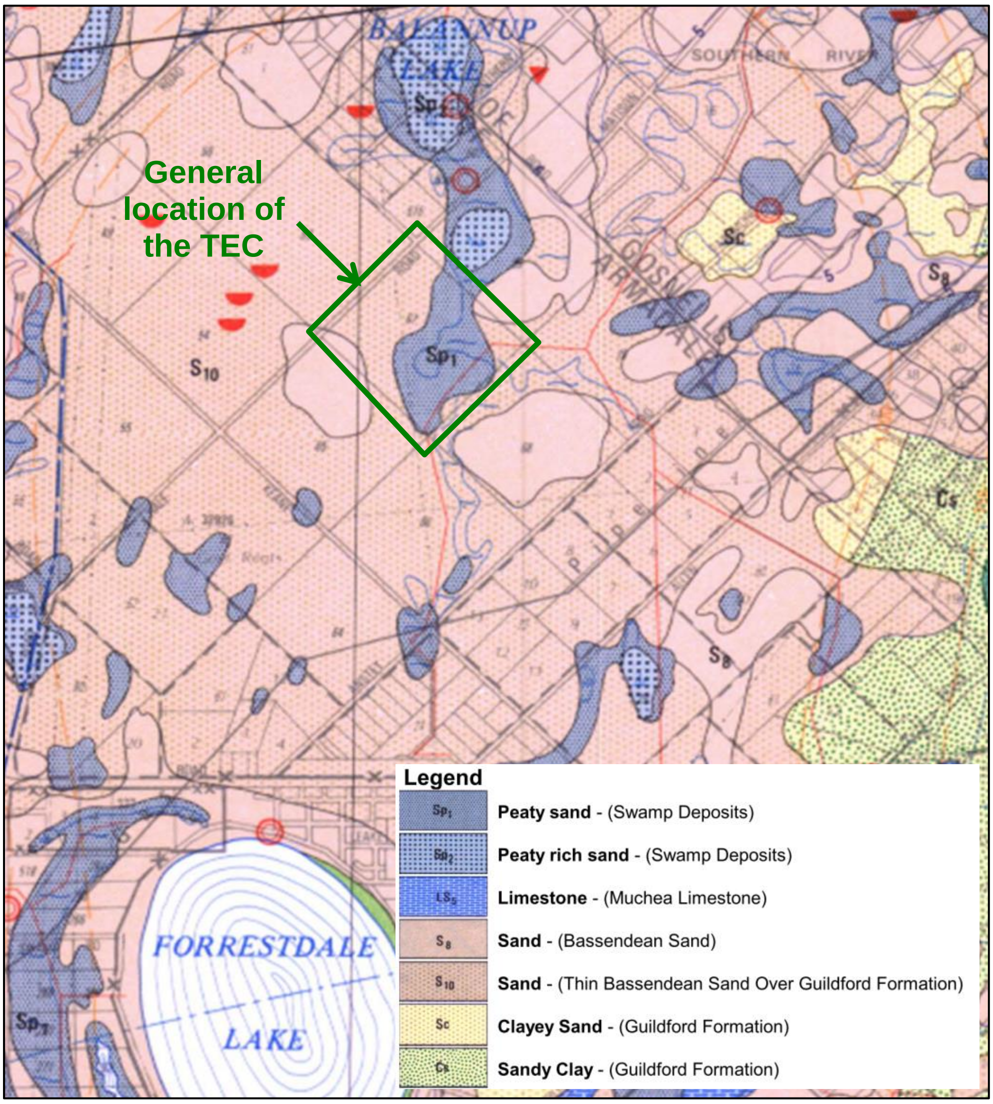

Figure 4: Regional geology (1:50,000 Environmental Geology Series map)

Table 1: Summary of geotechnical units

Geo-technical unit ID	Map unit name	Geotechnical unit description
BS	Bassendean Sand	This unit generally corresponds to the S_8 and S_{10} units described in the Environmental Geology Series map. The unit was generally found to be the host of a seasonal perched water table (W1).
GC_{ox} and GC_{rd}	Guildford Formation – clayey sand	The Guildford Formation directly underlies the Bassendean Sand. The GC unit generally consists of clayey sand and appears to form an aquitard between the perched water table in the Bassendean Sand and the water table observed in the underlying sandy facies of the Guildford Formation (W2). A distinct colour change occurs within the unit from pale grey brown to green with depth. This is inferred to be the change in soil oxidation condition (from oxidising to reducing) with depth. The reduced zone was observed to have an organic odour and occasional pockets of black organic material.
GS	Guildford Formation - sand	The sandy facies of the Guildford Formation is fine to medium grained with a trace (and locally some) clay. This unit was found to be the host for a semi-confined groundwater table (W2).

2.3 Hydrogeology

Groundwater flow in the area is dominated by flow in the Holocene and Pleistocene aged superficial formations which contain a predominantly unconfined regional groundwater flow system. The superficial aquifers are recharged mainly by direct infiltration of rainfall supplemented by both seepage from runoff and upward leakage from the underlying Mesozoic aquifers. Significant downward leakage also occurs from the superficial formations and into the underlying Osborne Formation, which occurs at depths of around 30 m below the site.

Data from the Perth Groundwater Atlas (online edition) indicates the regional groundwater flow in the superficial formations is generally in a north easterly direction, from the Jandakot Groundwater Mound towards Southern River, which represents a line of groundwater discharge (see **Figure 5**). Forestdale Lake is also seen to influence groundwater levels in this area.

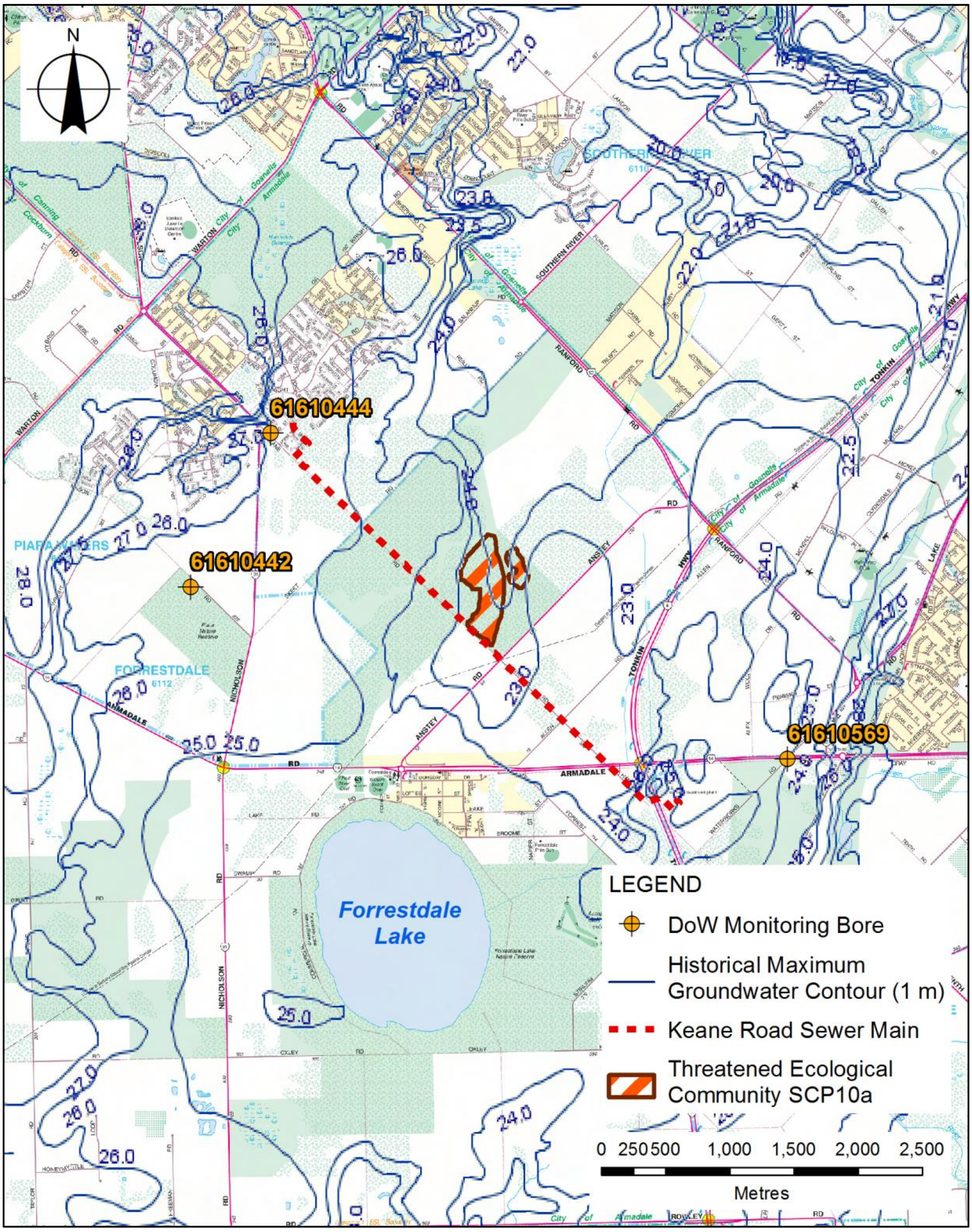

Figure 5: Regional groundwater contours (Perth Groundwater Atlas)

The Perth Ground Water Atlas (online edition) indicates that the historical maximum groundwater level in the vicinity of the TEC varies from ~23 m AHD in the southwest to around ~22.5 m AHD in the northeast, with a relatively flat hydraulic gradient. This is characteristic of relatively conductive formations. Historical water levels of the regional superficial aquifer observed in the Department of Water (DoW) monitoring bores depicted in **Figure 5** are presented in **Figure 6**, which indicates the following:

- The observed groundwater gradient is consistent with that documented in the Perth Groundwater Atlas; and
- The seasonal variability in the level of the regional superficial aquifer is ~1 m to the west of the TEC increasing to ~2 m in the east.

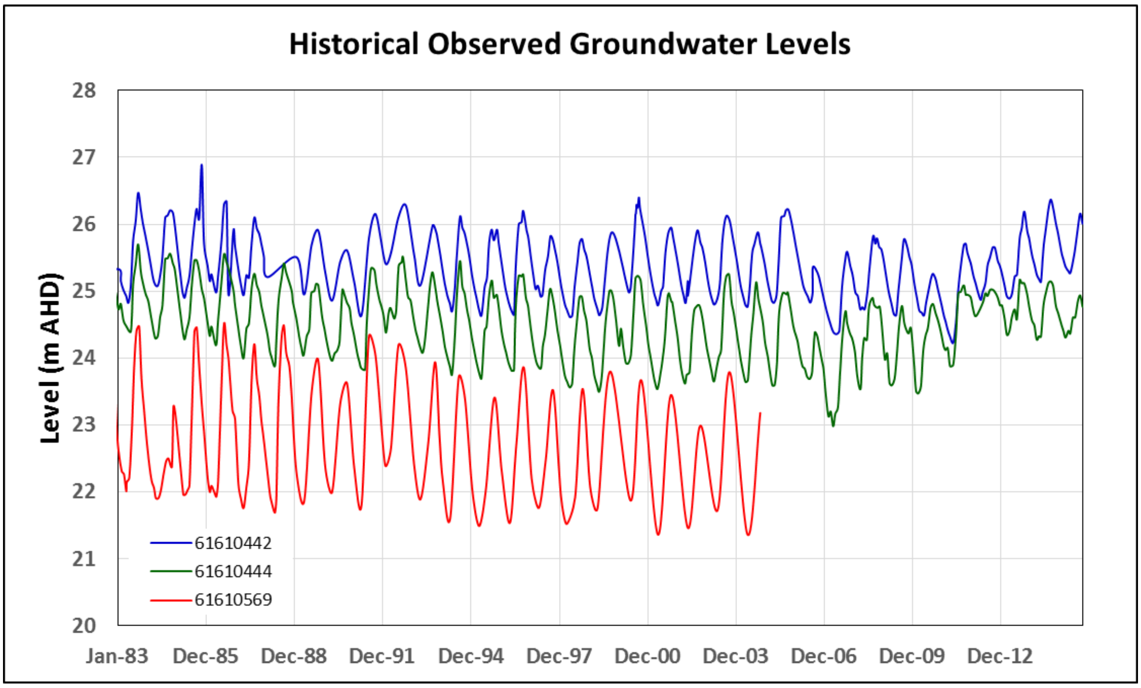

Figure 6: Regional groundwater levels

2.4 Historical development

The historical development of the site, from natural bushland to areas of urban development surrounding the Bush Forever site is documented in a series of aerial photographs presented in **Appendix A**. Of note in the timeline of photographs is:

- The major feature is the string of ephemeral wetlands running northwards from the intersection of Anstey and Keane Roads through the Bush Forever Site 342;
- These wetlands remain a feature of the area, with the exception of the southernmost wetland, which was impacted by clearing and land development in the late 1980's;
- Baileys Branch Drain is in evidence crossing the northern wetland and traversing the Bush Forever Site 342 from the earliest photograph of the site (November, 1953);
- Further development and alignment of the drain in the late 1970's is evident; and
- The majority of the urban development has been undertaken since the mid 1990's when the Dampier to Bunbury Natural Gas pipeline was constructed through the area and the first of the larger acreage blocks were subdivided and built upon.

2.5 Anstey-Keane Dampland

The Anstey-Keane Dampland differs from the nearby Forrestdale Lake or Baileys Wetland in that it does not contain a body of open shallow water in winter and spring that dries out in summer. The dampland is rather a vegetated depression where moisture is diffused through the upper soil horizons and is not usually visible on the surface.

The land in this area is generally flat and the vegetation in the vicinity of the TEC comprises low herb type shrubs as depicted in **Figure 7**. This vegetation, also known as heathland, sedgeland or herbland, is a primary indicator of a dampland. The vegetation associated with the more conventional ephemeral wetlands in this area is woody in nature and includes banksia, bottlebrush, swamp cypress as well as several species of melaleucas, including the saltwater paperbark (*Melaleuca cuticularis*) as shown in **Figure 8**.

Figure 7: Typical heathland type vegetation

Figure 8: Typical shrub and small tree type vegetation

3. Study methodology

3.1 Scope of work

The scope of work was developed by GHD in consultation with the Water Corporation and taking into account comments received from the OEPA and the DPaW.

The scope of works entailed both field investigations and a hydrological assessment. The field investigations comprised:

- Direct Push Probe boreholes at the 17 locations with target depths of ~3 m and selected boreholes extended based on site conditions;
- Photographic recording of the cores prior to sampling;
- Recovery of soil samples at ~250 mm intervals (or change of stratigraphy) using 70 mm diameter sample tubes;
- Logging of the recovered samples in accordance with *AS1726 – Geotechnical Investigations*;
- A program of laboratory testing comprising soil moisture content, particle size distribution (PSD) by sieve, PSD by sieve and hydrometer and organic content;
- Installation of seven permanent monitoring bores with lockable steel covers (nested bores at three locations);
- Installation of a PVC wedge wire sand spear in the bed of the Baileys Branch Drain to monitor drain water levels;
- Installation of water level recorders and data loggers in the permanent monitoring bores and sand spear;
- Permeability testing of soil horizons using constant head and rising head techniques;
- Monthly water quality sampling and downloads of logged data;
- Review of logs from previous investigations (Douglas Partners, 2009, GHD, 2013, Hyd2o, 2013 and Galt, 2013); and
- Analysis of the field test results to determine representative physical hydraulic parameters of the defined geological units.

The key objectives of the hydrological assessment were to determine what stratigraphy would be disturbed by the construction and placement of the sewer main and if the disturbance would change vertical and horizontal groundwater flow gradients or water quality. This necessitated 3D stratigraphic mapping and assigning physical parameters to the mapped materials. The following steps were taken in this regard:

- Acquisition and modelling of Lidar data to assess surface catchments and flow paths;
- Assessment of soil logs to confirm the site domain and boundary conditions;
- Review historical regional water level data to ascertain the typical seasonal groundwater levels;
- Develop a 3D site geological and conceptual hydrogeological model depicting surface water - groundwater interactions, typical seasonal water levels and flow paths based on interpretation of the soil properties; and

- Document the conceptual understanding of dampland function and broadly assess the potential impact of the installation of the sewer main on the surface water - groundwater interactions.

3.2 Borehole investigations

The stratigraphy of the site was investigated by drilling 17 push probe boreholes at the locations shown in **Figure B1** in **Appendix B** and summarised in **Table 2**. Preliminary mapping of the proposed drilling locations was confirmed by the DPaW prior to the investigation and the locations were further refined during a site walkover with the DPaW. Most bores were drilled in the TEC with four being drilled on Lot 101 south of the TEC. All bores within the TEC were located on the edges of existing fire access tracks or in non-vegetated areas.

Table 2: Summary of push probe boreholes

Bore ID[2]	Co-ordinates[3]		Elevation (mAHD)[4]	Depth (mBGL)	Reason for Termination
	Easting	Northing			
A01*	400486.191	6444182.026	22.480	9.0	Target depth
A02	400606	6444198	22.6	3.0	Target depth
A03	400497	6444074	22.3	3.0	Target depth
A04	400587	6444028	22.3	3.0	Target depth
A05*	400501.270	6443962.714	22.501	12.0	Target depth
A06	400391	6443950	22.6	3.0	Target depth
A07*	400267.013	6443890.944	22.647	3.0	Target depth
A08	400519	6443847	22.3	3.0	Target depth
A09	400566	6443862	22.3	3.0	Target depth
A10[5]	400405	6443824	22.6	?	Target depth
A11*	400299.767	6443761.272	22.500	3.0	Target depth
A12	400486	6443746	22.7	3.0	Target depth
A13	400255	6443707	22.6	3.0	Target depth
A14	400433	6443642	22.3	3.0	Target depth
A15*	400422.411	6443556.639	22.092	4.5	Target depth
A16	400316	6443549	22.5	3.0	Target depth
A17	400355	6443410	22.0	3.0	Target depth

The push probe drilling was undertaken by Direct Push Probing Pty Ltd using their smallest push probe rig, the Geoprobe 6620DT. The machine is track mounted and has a footprint of approximately 1.5 m by 2.4 m, which made it suitable for moving around on the sandy soils within the tracked areas.

The majority of the bores were drilled to the target depth of 3 mBGL, with bores A1, A5 and A15 drilled to depths of 9 m, 12 m and 4.5 m respectively to allow installation of piezometers in the lower sand units.

2 Locations of monitoring bores A01, A05, A07, A11 and A15 surveyed with remainder located using hand held GPS
3 Co-ordinates GDA94, Zone 50
4 Elevations of the boreholes estimated from the Lidar data
5 Borehole drilled using a hand auger due to access issues

Soil samples were recovered using 70 mm diameter pushed sample tubes and the recovered samples were photographed and logged in accordance with *AS1726 – Geotechnical investigations.*

Once photographed and logged, representative samples of soil were taken at approximately 250 mm intervals in uniform stratum or at changes in material type (whichever was more appropriate) for laboratory testing. On completion, the bores were either backfilled with drill cuttings or piezometers installed for ongoing monitoring.

It should be noted that it is not possible to ascertain depth to groundwater with push probe drilling given the mode of sample recovery.

3.3 Laboratory testing of soil samples

An extensive program of laboratory testing was undertaken on the recovered samples to improve the definition of the site stratigraphy by determining the fines (silt and clay sized particles) content of each sample and to measure quantify the clay and silt content of selected samples. Limited Atterberg Limits testing was undertaken to determines the soil plasticity and therefore provide additional data on whether the samples were predominantly silty or clayey.

Tests were also completed to determine the in-situ moisture content (gravimetric water content) of the site soils. The results of these tests are considered valid for the more clayey samples of soil, which retained their pore moisture while being transferred to the sample bags. However the pore water in the clean sands drained from the samples as they were being sampled.

The soil tests, which were completed to Australian Standards, are summarised in **Table 3**. Laboratory testing for this project was carried out by Cardno Pty Ltd, a National Association of Testing Authorities (NATA) accredited soil testing laboratory in Bunbury, Western Australia.

Table 3: Summary of laboratory tests

Test	Standard	Number planned	Number completed
Soil moisture content (g/g)	AS 1289.2.1.1	145	95
PSD by sieve	AS 1289.3.6.1	145	174
PSD by sieve and hydrometer	AS 1289.3.6.3	34	31
Atterberg limits	AS 1289.3.1.2, 3.3.1 and 3.4.1	-	29
Organic content	ASTM: D2974-07a Test Method C	34	31

3.4 Installation of monitoring bores

Seven permanent monitoring bores were installed as detailed in **Table 4**, with nested piezometers provided at sites A01 and A05, and single piezometers at sites A07, A11 and A15. All piezometers were installed with DN50 PVC casing and screened at intervals determined during initial logging of the borehole stratigraphy. The annulus around each screen was backfilled with gravel pack and bentonite seals placed above each screen to ensure hydraulic isolation of each screen. Lockable steel covers were installed at each monitoring bore to prevent vandalism and to protect the installed equipment. All of these bores have been equipped with water level loggers.

Table 4: Summary of new piezometers installed

Bore ID[6]	Top of casing (mAHD)	Depth casing (mBGL)	Depth to top of screen (mBGL)	Depth to bottom of screen (mBGL)	Depth to top of seal (mBGL)	Depth to bottom of seal (mBGL)
A01S	23.097	3.0	2.0	3.0	1.0	2.0
A01D	23.147	9.0	4.0	9.0	1.0	3.0
A05S	23.148	1.5	0.0	1.5	0.0	0.0
A05D	23.066	12.0	3.5	12	2.5	1.5
A07	23.203	1.0	0.0	1.0	0.0	0.0
A11	23.231	1.5	1.0	1.5	0.0	1.0
A15	22.801	3.0	2.0	3.0	0.5	2.0

A number of monitoring bores were installed during previous studies in the vicinity of the TEC. These bores were located and inspected with a view to utilise them for longer term water resources monitoring. Details of the existing boreholes and installed piezometers are provided in **Table 5**, and **Table 6** respectively, the locations of which are shown in **Figure B1** in **Appendix B.** These bores have also been equipped with water level loggers.

Table 5: Summary of existing boreholes

Bore ID[7]	Co-ordinates[8]		Elevation (mAHD)[9]	Depth (mBGL)
	Easting	Northing		
Hyd2o-AR5	400425.426	6443568.802	22.075	6.0
Hyd2o-AR6	400197.709	6443792.365	23.131	5.5
BH06N	400565	6443495	22.5	6.0
BH06S	400563	6443483	22.5	6.5
BH25	400303	4663757	22.8	6.0

Table 6: Summary of existing installed piezometers

Bore ID	Top of casing (mAHD)	Depth casing (mBGL)	Depth to top of screen (mBGL)	Depth to bottom of screen (mBGL)	Depth to top of seal (mBGL)	Depth to bottom of seal (mBGL)
Hyd2o-AR5	22.705	5.9	2.0	5.9	0.0	1.0
Hyd2o-AR6	23.713	5.8	2.0	5.8	0.0	1.0
BH06N	-	6.0	3.0	6.0	2.5	3.0
BH06S	-	6.0	3.0	6.0	2.5	3.0
BH25	-	6.0	3.0	6.0	2.5	3.0

6 D = deep
S = shallow
7 Locations of monitoring bores Hyd2o-AR5 and Hyd2o-AR6 surveyed with remainder located using hand held GPS
8 Co-ordinates GDA94, Zone 50
9 Elevations of the boreholes estimated from the Lidar data

A 600 mm PVC wedge wire sand spear will be installed in the bed of the Baileys Branch Drain to facilitate monitoring of the drain flows. This will occur when winter water levels in the drain drop to a low enough level to allow safe entry into the drain.

3.5 Hydraulic conductivity

3.5.1 In-situ constant head testing

In-situ hydraulic conductivity tests were carried out using a Guelph (constant-head) Permeameter. It was originally intended to undertake the hydraulic conductivity tests at the locations of all of the installed monitoring bores. The waterlogged site conditions at the time of testing limited the extent to which testing could be undertaken. In-situ tests were successful at only four sites and only in the upper sand unit, details of which are provided in **Table 7**.

Table 7: Summary of bores tested for permeability

Bore ID	Co-ordinates[10]		Elevation (mAHD)[11]	Depth (mBGL)	Depth to Groundwater (m)
	Easting	Northing			
P01	400345	644728	22.8	0.15	0.35
P02	400219	6443840	22.8	0.25	0.40
P03	400400	6443822	22.6	0.30	0.60
P04	400513	6443596	22.5	0.25	0.35

Testing commenced with auguring a shallow bore to test depth. Soils from the auger bores were logged in accordance with *AS1726 – Geotechnical investigations*. Each bore was then pre-saturated and testing was conducted using the dual reservoir configuration and the two-head procedure. The test was carried out until a steady flow rate was measured, based on obtaining five consistent readings.

3.5.2 Rising head testing

The hydraulic conductivities of the formations screened in the various monitoring bores were also estimated through slug testing. Water level loggers were installed in the monitoring bores following well development. Groundwater was purged from the bores using a small battery powered submersible pump and the recovery of the groundwater levels was recorded. The logged data were checked and rectified for barometric pressure variations and the resulting response curves assessed to provide empirical estimates of hydraulic conductivities. A summary of the tested formations is provided in **Table 8**, from which it is noted that the screened formations of three bores could not be tested for the reasons set out.

10 Co-ordinates GDA94, Zone 50, determined using hand held GPS
11 Elevations of the boreholes estimated from the Lidar data

Table 8: Summary of bores tested for hydraulic conductivity

Bore ID	Screened Formation[12]	Notes
A01S	GC/GS	Test successful
A01D	GS	Test successful
A05S	BS	Test successful
A05D	GS	Logged data unreliable, logger checked and reinstalled
A07	BS/GC	Test successful
A11	GC	Bore almost dry, no water level data
A15	GS	Test successful
AR5	GS	Logged data unreliable, logger checked and reinstalled
AR6	GS	Test successful
BH06N	GC	Test successful
BH06S	GC	Test successful
BH25	GC	Test successful

3.5.3 Estimate from particle size distribution

Empirical estimates of hydraulic conductivity were also made based on the PSD test results reported in **Section 3.3**. This approach is premised on hydraulic conductivity being a function of water content based on the assumption that soil pores can be represented by equivalent capillary tubes and that the water flow rate is a function of pore size.

3.6 Laboratory testing of groundwater quality

Water quality provides an indication of aquifer behaviour confinement through geochemical separation. To this end, water samples were retrieved from the monitoring bores listed in **Table 8** (except for bore A11 where insufficient sample retrieved) for analysis for the following analytes:

- Total Dissolved Solids
- Electrical conductivity (lab)
- Chloride
- Calcium (Filtered)
- Magnesium (Filtered)
- Potassium (Filtered)
- Sodium (Filtered)
- Sulphate (Filtered)
- Anions Total
- Cations Total
- Ionic Balance

[12] BS - Bassendean Sand Formation
GC - Guildford Formation Clayey Sand
GS - Guildford Formation Sand

3.7 Groundwater level monitoring

Continuous water level data were recovered from the loggers installed in the monitoring bores to assess groundwater dynamics. It should be noted that this monitoring is part of a longer term program by the Water Corporation and only initial data collected were assessed for this study.

3.8 Site topography

Lidar surface level data were acquired and processed to understand the subtle topographical variations of the surface elevations in the vicinity of the TEC. The elevation data were used to delineate contributing catchments and to assess site drainage.

3.9 Existing information

A significant body of correspondence and published and unpublished data was also considered in the formulation of this report. The various publications included:

- Environmental Geology Series 1:50,000 map sheet of Armadale (Geological Survey of Western Australia, 1986);
- Perth Groundwater Atlas (Department of Water, 2013);
- Information Sheet detailing the ephemeral clay-based wetlands of the South West Department of Environment and Conservation (2010); and
- Survey of rural lands in the vicinity of the Greater Brixton Street Wetlands (Tauss and Weston, 2010)

The following data and information were also considered in the formulation of the investigation scope and the hydrological assessment:

- Geotechnical, groundwater and geological studies documented by Douglas Partners (2009), Galt Geotechnics (2013), GHD (2013) and Hyd2o (2013);
- Reports on the site hydrology by Worley Parsons (2009), Enviroworks (2012), Water Technology (2013 and 2014) and RPS (2014); and
- An excerpt from the TEC Recovery Plan describing a conceptual model of the TEC (currently unpublished) provided by DPaW (2015).

Detailed references of these and other sources are provided in **Section 7**.

4. Analysis results

4.1 Bore logs

4.1.1 Conceptual geological model

The bore logs from the 17 push probe boreholes are provided included in **Appendix C** and the photographs of the recovered drill cores are provided in **Appendix D**. The logs from the previous geotechnical investigations (Douglas Partners, 2009, GHD, 2013, Hyd2o, 2013 and Galt, 2013) are provided in **Appendix E**.

The locations of all logged sites are depicted in **Figure B1** in **Appendix B** For clarity, sites from other investigations are prefixed with a letter (e.g. DP for the Douglas Partners (2009) investigation and GHD13 for the GHD (2013) investigation etc.) to make identification of the investigation points being referred to as clear as practical.

Geological interpreted cross-sections of the site have been derived from the borehole logs from this investigation, which have been corrected using the laboratory test data (summarised in **Section 4.2**). Existing borehole, test pit and hand auger logs from the previous investigations have been (in some cases) re-interpreted, or their current geology confirmed by comparison with the more detailed geological data from this investigation.

A conceptual geotechnical model of the TEC derived from the interpretation of the stratigraphic logs is presented as **Figure 9**. The geology of the individual geotechnical units is described in more detail in the following sections.

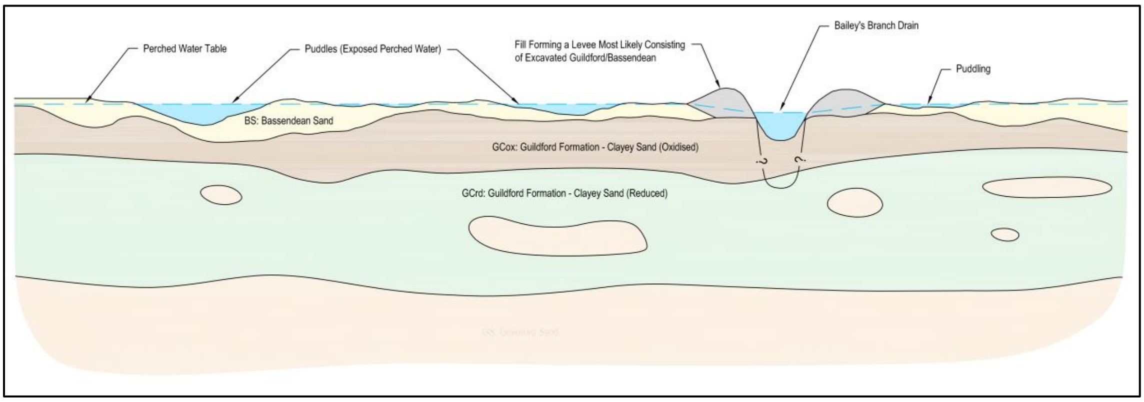

Figure 9: Conceptual geological model of the TEC

4.1.2 Bassendean Sand

The Bassendean Sand unit as found at this site comprises a grey to light grey, fine to medium grained, predominantly medium grained moderately sorted, sub-rounded to rounded quartz sand which commonly exhibits slight fining upward textures.

Examination of the various logs indicates the Bassendean Sand varies in thickness from a minimum of 0.2 m, which was recorded in a number of areas, with an average thickness of approximately 0.6 m.

A contour plan of the elevations of the approximate top of the Guildford Formation is presented in **Figure B3** in **Appendix B**. Comparison between this and the Lidar elevation contours detailed in **Figure B2** in **Appendix B** indicates that the thickest sands were recorded as follows:

- In the approximate centre of the TEC (e.g. boreholes A05, A06 and A10;
- In the vicinity of the remnant wetland located near the intersection of Anstey Rd and Keane Rd; and
- Within Lot 101 immediately south of the existing fire access track (e.g. borehole A13).

These areas are likely to be coincident with deflated dunes of the Bassendean Dune system.

4.1.3 Guildford Formation clayey sands

The Guildford Formation underlies the entire site and is made up almost entirely of fine to medium grained, predominantly low to medium plasticity clayey sand soils containing occasional bands of sandy clay and sometimes cleaner (less clayey) sand. Coffee Rock was intersected in boreholes DP-BH10, DP-BH11 and GHD13-BH23 located to the west of the TEC. Within the TEC, coffee rock was only intersected in borehole A12.

The upper part of the unit is generally pale brown, sometimes mottled orange in colour, indicating the soils have been oxidised. Lower in the unit, generally at a depth of between 2 to 4 mBGL, and often co-incident with the water table, the soil changes to a darker brown, often green colour and a noticeable organic / sulphur dioxide odour is apparent from the borehole. This is thought to represent an anoxic or reducing environment in the soils. A contour plan depicting the approximate extent of oxidation within the Guildford Formation is provided in **Figure B5** in **Appendix B**.

To separate these units on the geological sections they have been given the Geotechnical Unit IDs of GC_{ox} and GC_{rd}, respectively. Small pockets (10 mm to 20 mm in size) of black organic material were found in the lower part of the clayey sand layer in a number of locations (e.g. A05, A06, A08).

The top of the clayey Guildford Formation soils are found at a depth of between 0.2 m and 1.4 m across the site as discussed above. The locations of the thickest Bassendean Sands align with the low elevations of the top of the Guildford Formation which are noted in **Figure B3** in **Appendix B**. These are likely to be the locations of perched water systems associated with damplands and wetlands.

The borehole data indicates the clayey sand unit varies in thickness and there is evidence of isolated sand lenses within the unit as depicted in the conceptual model in **Figure 9**. The contour data indicates the thickest sequences of clayey sand are found along the alignment of the existing fire access track running adjacent to Lot 101, which is co-incident with the proposed location of the proposed sewer main. The thickness of the unit in the vicinity of the TEC seems to be ~6 m with sand lenses being evident in the logs of bores A05, A08 and A09. The borehole data indicates that the thickness of the unit decreases in a south-westerly direction across Lot 101.

4.1.4 Guildford Formation sand

Layers, lenses and pockets of a sand unit inferred to be the sandy facies of the Guildford Formation were found to occur within and/or below the clayey Guildford Formation unit across the entire study area, although it was not intersected in a number of the shallower investigation holes. The sandy Guildford Formation soils tend to be shallower to the south and west of the TEC. This level of variation is not uncommon in an alluvial deposit.

Where intersected, the sandy facies of the Guildford Formation are described as being brown, green or grey green, fine to medium grained, sub-rounded quartz sand.

4.2 Soil test results

A summary of the laboratory test results is provided in **Appendix F**, the details of which are discussed in the following sections.

4.2.1 Particle size distribution

Particle size distribution (PSD) tests were undertaken for soil samples recovered from the push probe boreholes, the details of which are provided in **Appendix G**. The analysis results were separated according to the formations from which they were taken as identified from the bore logs. The PSDs for the Bassendean Sand, Guildford Formation Clayey Sand and Guildford Formation Sand are presented in **Figure 10**, **Figure 11** and **Figure 12** respectively.

This laboratory testing indicates the following:

- The Bassendean Sand unit in this area contains between 1 % and 11 % (average 4 %) predominantly clayey fines;
- The Guildford Formation Clayey Sand in this area have a fines content in the range of 11% to 52% (average 21%) with the remainder of the samples being made up of quartz sand; and
- The Guildford Formation Sand contains between 3% and 12% (average 9%) predominantly clayey fines.

The cut-off between sand and clayey sand is as defined in *AS 1726 – Geotechnical investigations* and is considered to be a fines (silt and clay) content of 12 %. A soil is classified as being a clay when it has a fines content of greater than 50 %.

The fines content derived from the PSD tests were mapped against depth, the results of which are presented in **Appendix H**. The results for a selection of the deeper bores aligned across the TEC from north-northeast to south-southwest are also presented in **Figure 13**. These results were used to correct the borehole logs as interpreted in the field.

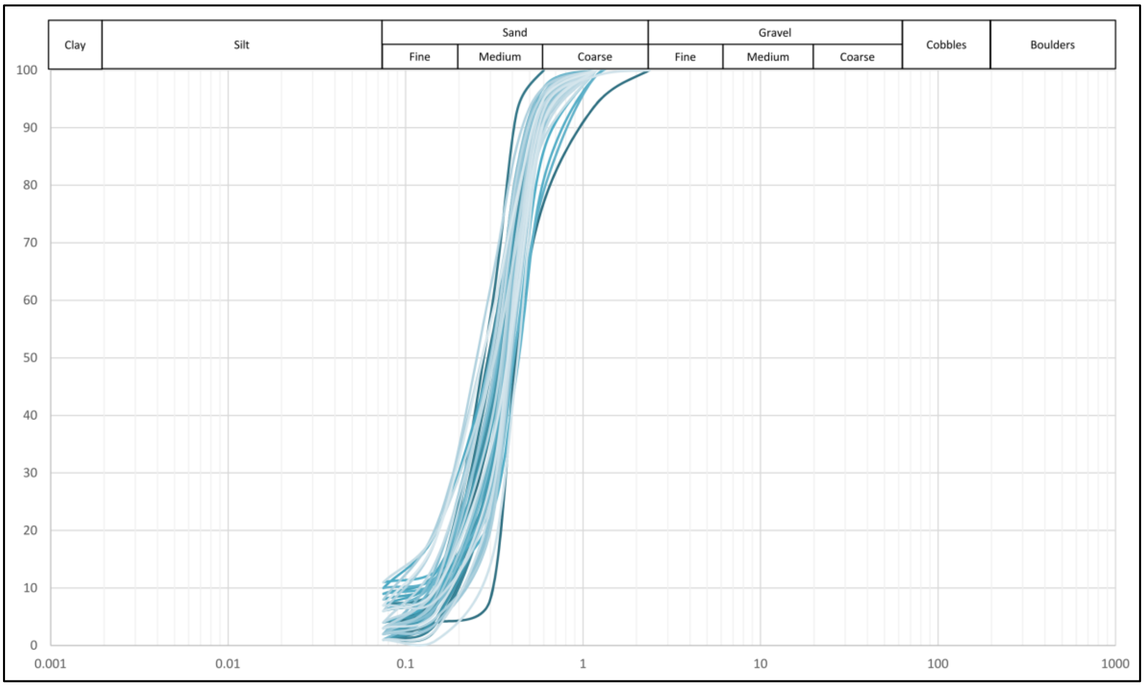

Figure 10: PSD for Bassendean Sand

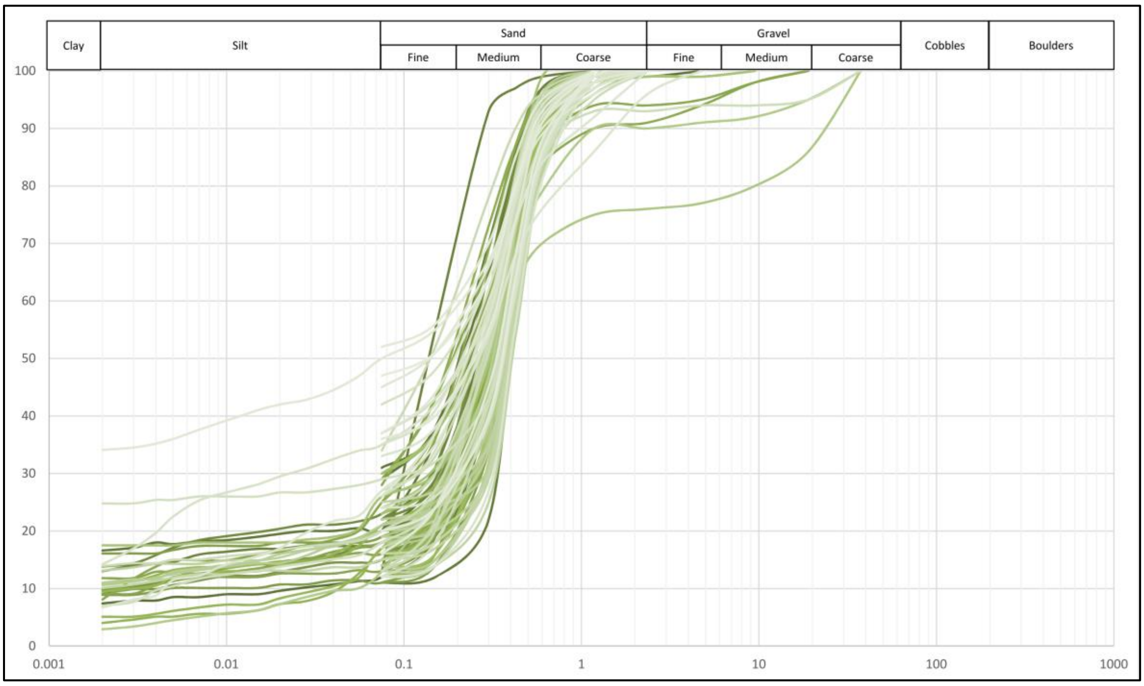

Figure 11: PSD for Guildford Formation Clayey Sand

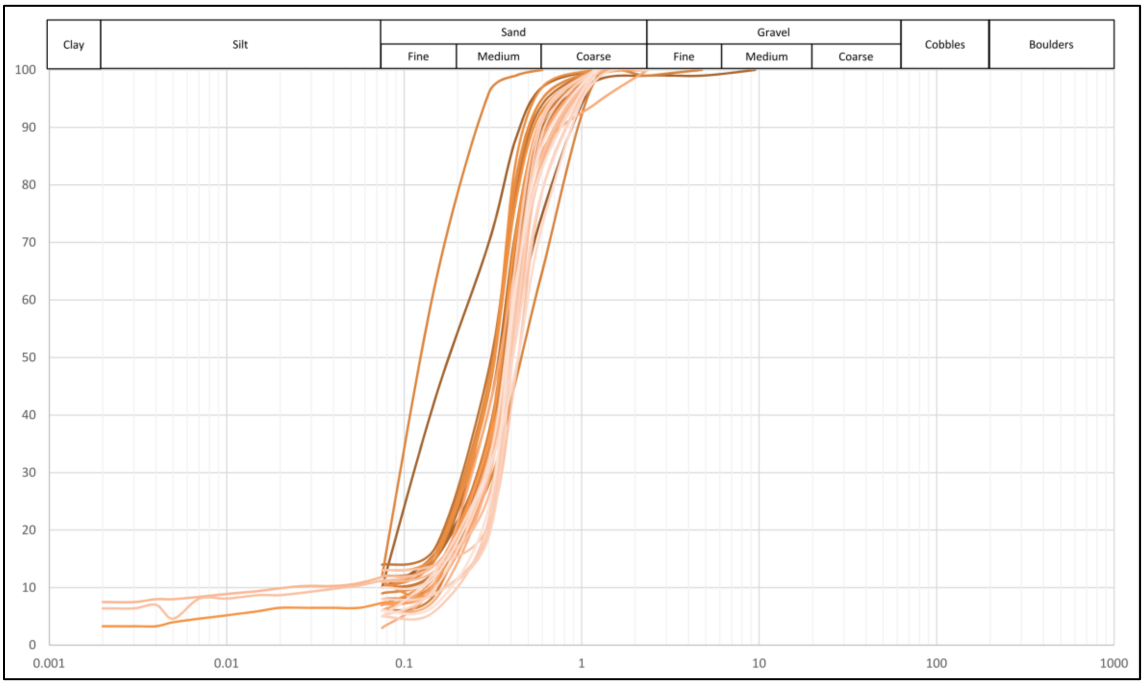

Figure 12: PSD for Guildford Formation Sand

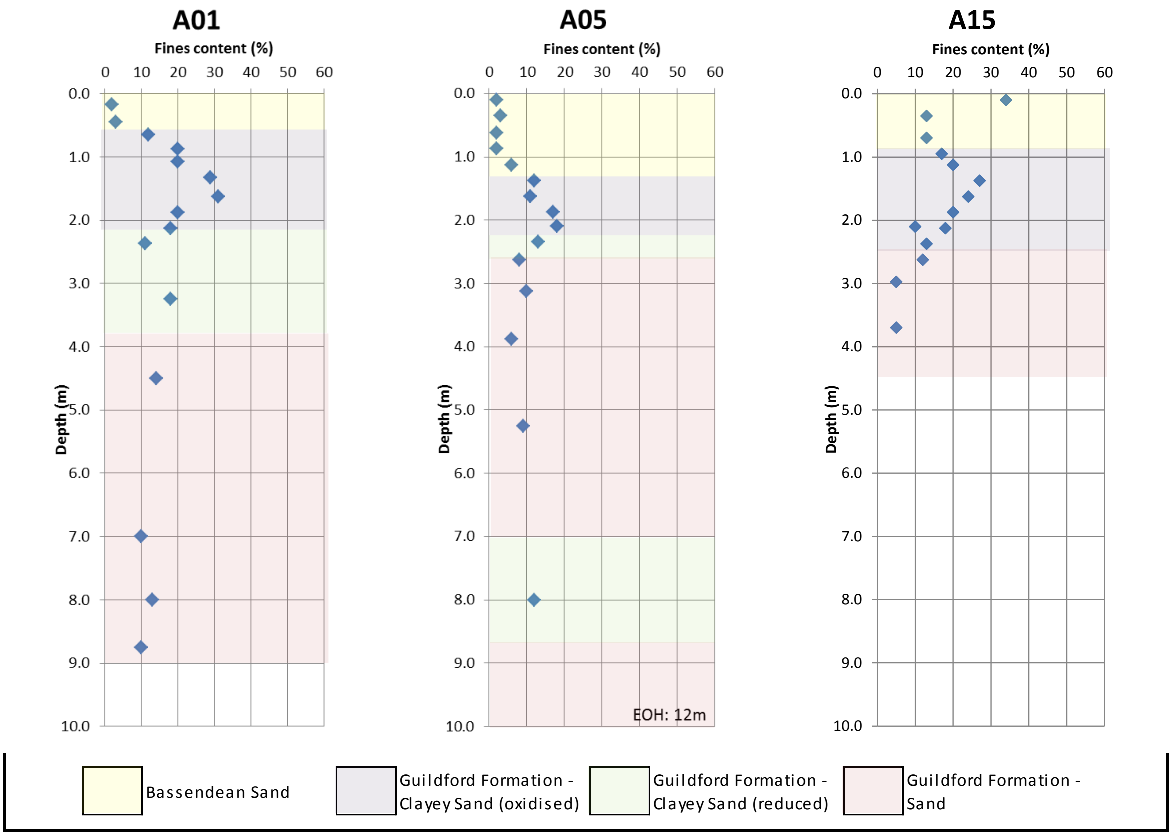

Figure 13: Fines content versus depth for selected bores

4.2.2 Atterberg limits

Atterberg limit testing was undertaken on samples recovered from the Guildford Formation Clayey Sands. These tests produced Liquid Limit (LL) values generally in the range of 22% to 45% (average 38%), Plastic Limit (PL) from 10% to 25% (average 13%) and Linear Shrinkage (LS) from 3.5% to 9.5% (average 6%). The exception to the above, were three randomly distributed samples of high plasticity which had Liquid Limits in the range of 67% to 72%. It is unclear why these samples are so different to the remainder of the Guildford Formations samples collected.

The results of the Atterberg Limit tests are presented in **Figure 14**, from which it is noted that all results plot above the 'A-Line' indicating that the fines fraction of the soils is predominantly clayey in behaviour.

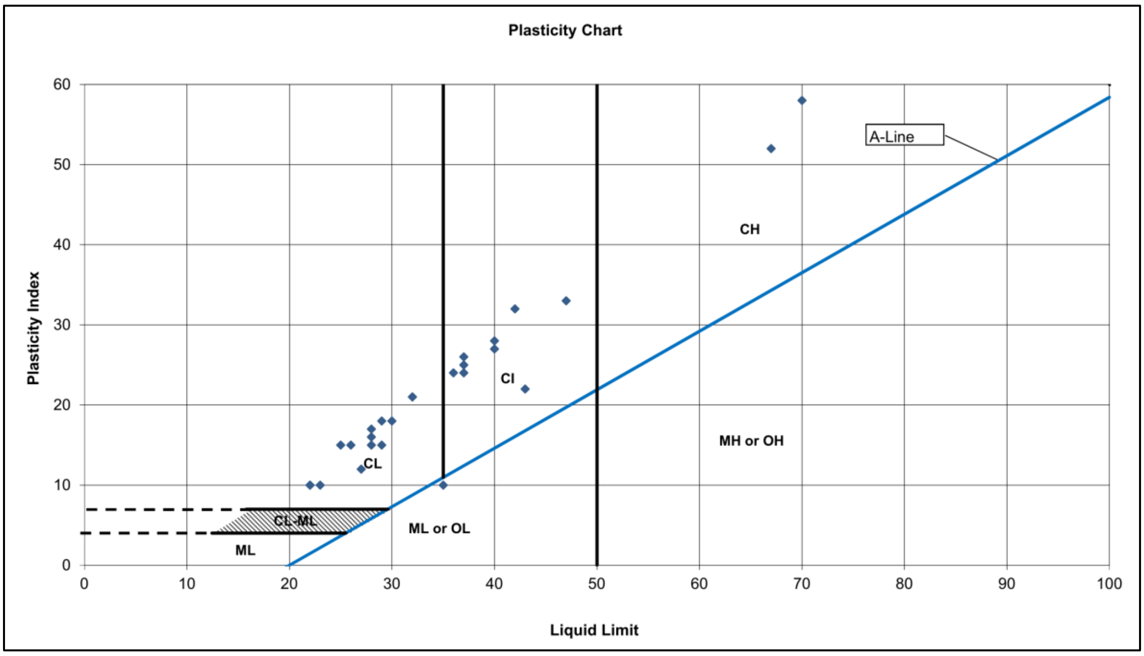

Figure 14: Plasticity Chart for Guildford Formation Clayey Sand

4.2.3 Soil Moisture

Moisture content (gravimetric water content) tests were undertaken on recovered soil samples, the details of which are provided in **Appendix I**. As already noted, the test results for the more clayey samples only are considered valid. The soil moisture contents in the clayey sand soils ranged from 9.7% to 30.7% (average 16.8%) and are consistent with what is normally recorded for soils of this clay / sand content.

Soil moisture content was mapped against depth, the results of which are presented in **Appendix J**. The results for a selection of the deeper bores aligned across the TEC from north-northeast to south-southwest are also presented in **Figure 15**. No definite trend was discernible in the moisture content data, with no general increase in soil moisture content with depth and only a weak correlation between soil moisture and fines content observed.

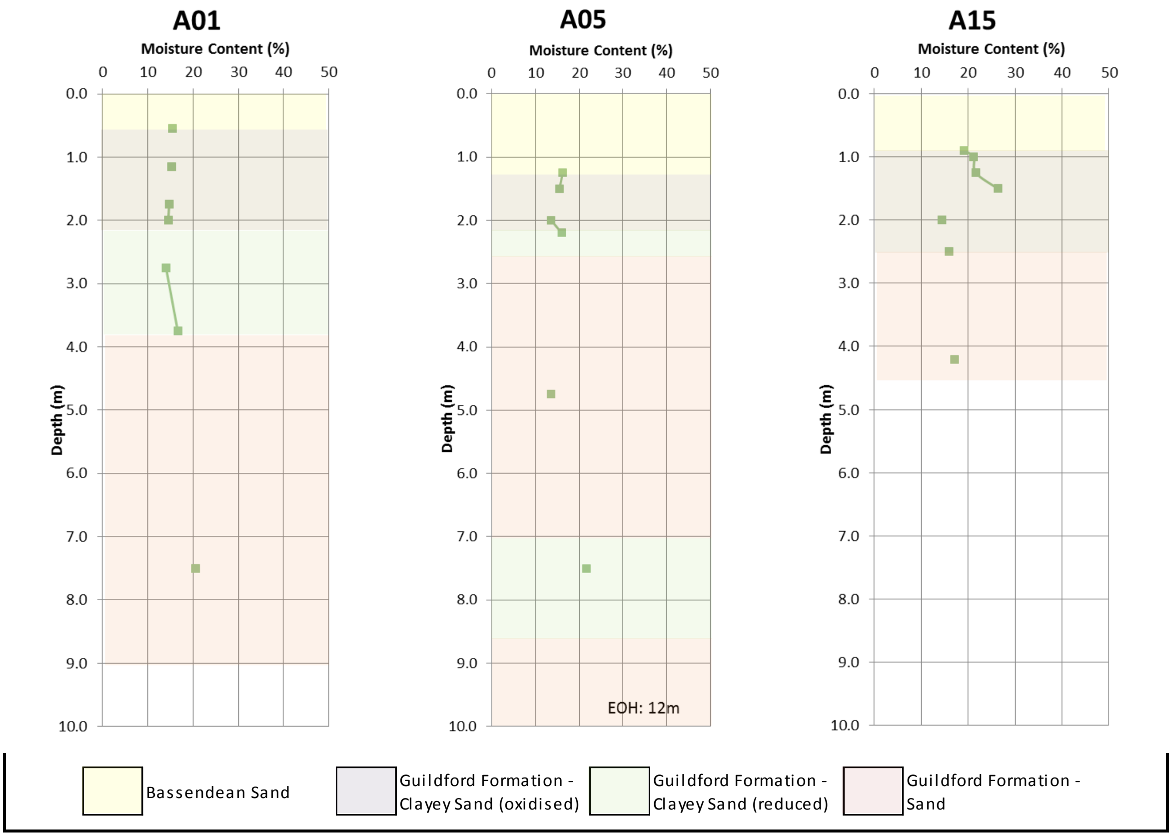

Figure 15: Moisture content versus depth for selected bores

4.2.4 Organic content

Samples from sequences indicating the presence of organic matter were analysed for organic matter and total organic carbon, the results of which are provided in **Appendix K**. All samples returned a results of <0.5%.

4.3 Hydraulic conductivity tests

4.3.1 Constant head tests

The logged soils from the auger bores used for the in-situ hydraulic conductivity tests are presented in **Appendix L**. It is noted that all testing was undertaken within the Bassendean Sand unit. The soil hydraulic conductivity for each test was determined using a calculation spreadsheet provided by the equipment manufacturer. The test results are summarised in **Table 9**, which indicates that the hydraulic conductivity of this unit ranges from between 3.7 and 13.0 m/day. These results are in line with the expected permeability of fine to medium gained sands.

Table 9: Measured near-surface hydraulic conductivities

Bore ID	Screened Formation[13]	Hydraulic Conductivity (m/day)
P01	BS	12.1
P02	BS	3.7
P03	BS	9.5
P04	BS	13.0

4.3.2 Rising head tests

The Bouwer-Rice and Hvorslev empirical models were used to assess the rate of groundwater level recovery following purging of the bores. The model which produced the best fit of the individual recovery response curves was applied to estimate the hydraulic conductivities. The resulting response curves were assessed using AQTESOLV to provide empirical estimates of hydraulic conductivities. The AQTESOLV analysis results are detailed in **Appendix M** and the resulting hydraulic conductivities listed in **Table 10**.

Table 10: Estimated hydraulic conductivities of screened formations

Bore ID	Screened Formation	Hydraulic Conductivity (m/day)	Calculation Method[14]
A01S	GC/GS	15.32	BR
A01D	GS	4.53	BR
A05S	BS	13.76	BR
A07	GC	0.21	Hv
A15	GS	9.33	Hv
AR6	GS	4.58	BR
BH06N	GC	0.01	Hv
BH06S	GC	0.02	BR
BH25	GC	0.11	BR

The resulting hydraulic conductivities are as follows:

- Bassendean Sand Formation: 13.76 m/day;
- Guildford Formation clayey sand: 0.01 to 0.21 m/day; and
- Guildford Formation sand: 4.53 to 9.33 m/day.

Data published in Davidson (1995) indicates the Bassendean sand unit has a transmissivity generally in the range of 200 m^2/day to 1,000 m^2/day, while the more clayey Guildford Formation unit has a transmissivity with an average value of around 100 m^2/day.

[13] BS - Bassendean Sand Formation
GC - Guildford Formation Clayey Sand
GS - Guildford Formation Sand

[14] BR - Bouwer-Rice
Hv - Hvorslev

4.3.3 Particle size distribution

The following empirical methods were applied to estimate hydraulic conductivity from PSD:

- Hazen method (Hazen, 1892);
- Breyer method (Kresic, 1998); and
- Sauerbrei method (Sauerbrei, 1932)

An average of the estimated hydraulic conductivities from these methods was calculated and a summary of the ranges in is given in **Table 11**. It is noted that relatively large changes in hydraulic conductivity may occur over relatively small incremental changes in depth.

Table 11: Summary of PSD based estimates of hydraulic conductivities

Unit	Minimum	Average	Maximum
Bassendean Sand Formation	3.28	26.78	146.88
Guildford Formation Clayey Sand	0.00003	1.47	19.87
Guildford Formation Sand	0.20	14.69	37.15

Logs of the estimated hydraulic conductivities through the soil profiles are presented in **Appendix N** for the push probe borehole sites. The results for a selection of the deeper bores aligned across the TEC from north-northeast to south-southwest are also presented in **Figure 16**. The estimated conductivities are consistent with the interpreted geology.

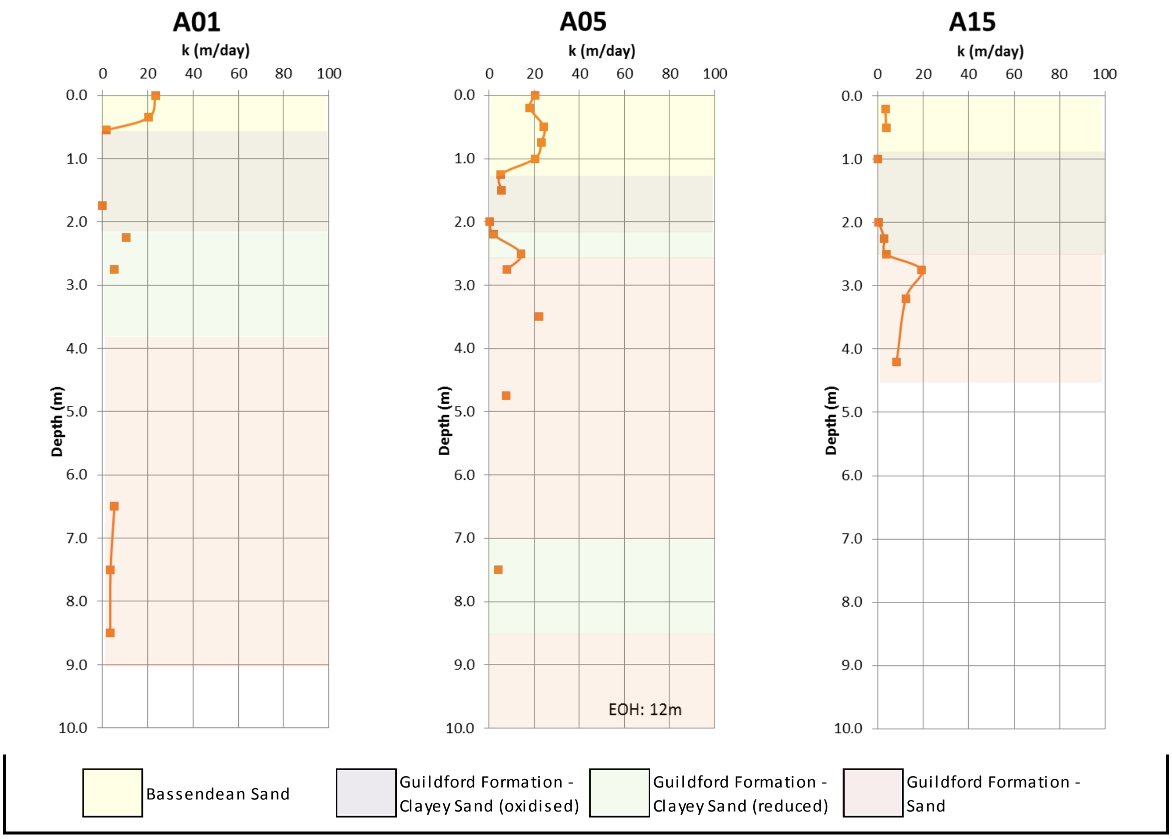

Figure 16: Hydraulic conductivity versus depth for selected bores

4.4 Groundwater Quality

Samples of groundwater were retrieved for laboratory analysis, the results of which are provided in **Table 12** and **Table 13**. Inspection of these results, particularly those from the nested bores (A01 and A05), reveals that:

- The salinity of the groundwater seems to increase with depth (which is consistent with an ephemeral perched groundwater system); and
- The major-ions indicate that the groundwater in the upper Bassendean Sands/Guildford Formation is geochemically distinct to that of the lower Guildford Formation.

Table 12: Groundwater quality test results

Determinand	Unit	A01D	A01S	A05D	A05S	A07	A15
		8 Sep 2015					
Screened interval	mBGL	4-9	2-3	3.5-12	0-1.5	0-1	2-3
Screened formation		GS	GC/GS	GS	BS	BS/GC	GS
Total Dissolved Solids	mg/L	2940	654	4820	2360	1880	2490
Electrical conductivity (lab)	µS/cm	2430	286	5450	166	3410	3710
Chloride	mg/L	690	32	1820	17	1020	668
Calcium (Filtered)	mg/L	10	23	36	7	15	16
Magnesium (Filtered)	mg/L	35	5	126	4	32	26
Potassium (Filtered)	mg/L	5	7	9	<1	8	8
Sodium (Filtered)	mg/L	429	42	891	29	622	738
Sulfate (Filtered)	mg/L	112	<10	64	<1	30	541
Anions Total	meq/L	24.7	2.9	54.8	1.62	33.4	38.5
Cations Total	meq/L	22.2	3.56	51.2	1.94	30.6	35.2
Ionic Balance	%	5.41	10.3	3.41	-	4.38	4.42

Table 13: Groundwater quality test results (cont.)

Determinand	Unit	AR5	AR6	BH25	BH06N	BH06S
		8 Sep 2015			2 Oct 2015	
Screened interval	mBGL	2 - 5.9	2 - 5.8	3 - 6	3 - 6	3 - 6
Screened formation		GS	GS	GC	GC	GC
Total Dissolved Solids	mg/L	2000	2790	6900	5510	12,100
Electrical conductivity (lab)	µS/cm	3360	2860	12,300	9610	19,600
Chloride	mg/L	724	556	4270	2890	6710
Calcium (Filtered)	mg/L	11	16	52	45	129
Magnesium (Filtered)	mg/L	37	79	224	140	521
Potassium (Filtered)	mg/L	6	4	13	13	20
Sodium (Filtered)	mg/L	624	432	2220	1610	3770
Sulfate (Filtered)	mg/L	147	643	143	75	830
Anions Total	meq/L	34.1	29.1	125	92.3	219
Cations Total	meq/L	30.9	26.2	118	84.1	214
Ionic Balance	%	4.96	5.23	2.82	4.67	1.19

Plans are being developed for a housing estate on Lot 101 by Cedar Woods Properties Ltd, who undertook groundwater monitoring to establish the ambient water quality conditions. The laboratory test results of this monitoring are provided in **Appendix O**. The changes in groundwater salinities over the monitoring period are depicted in **Figure 17**. The following observations are of note:

- A seasonal change in salinity seems to occur in bores Hyd2o-AR5 and Hyd2o-AR6 which are adjacent to the TEC (this is also consistent with an ephemeral perched groundwater system);
- Salinity is increasing in bore Hyd2o-AR3; and
- Salinity reduces in a southwesterly direction moving away from the TEC.

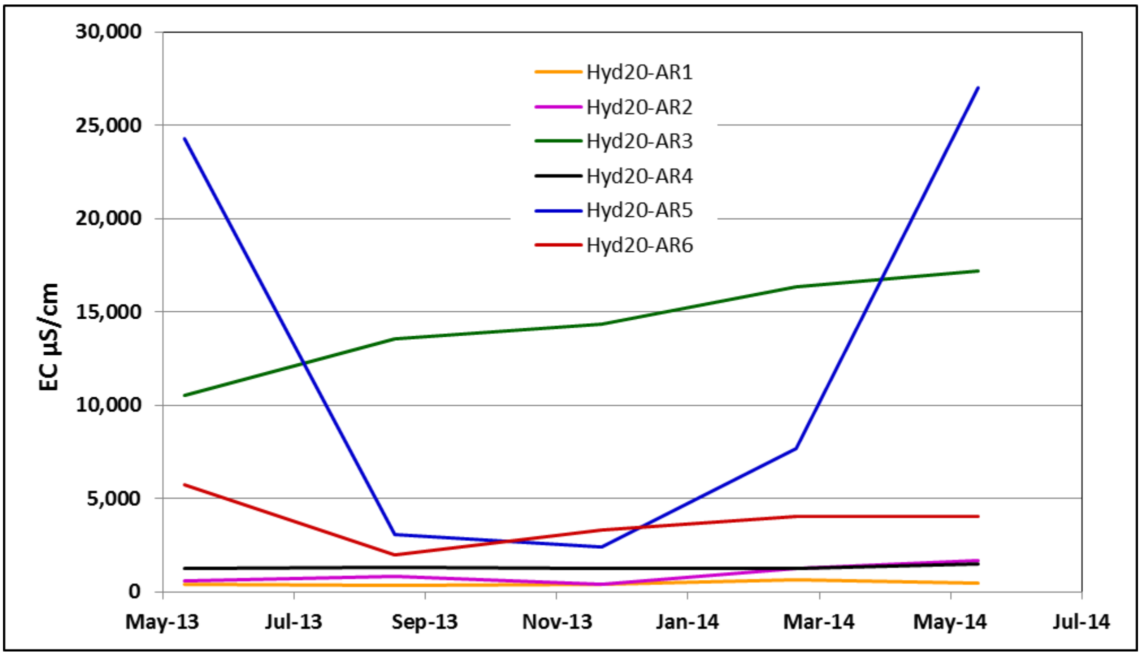

Figure 17: Change in groundwater salinity on Lot 101

4.5 Groundwater levels

Historical water level monitoring data from the Department of Water and Hyd2o (2013) are presented in **Figure 18** and **Figure 19**, which indicate the following:

- Water levels in bores Hyd2o-AR1 and Hyd2o-AR2 (located almost 1 km southwest of the TEC) are consistent with the regional superficial aquifer response indicating a high level of connectivity;
- Water levels observed in the bores closer to the TEC (bores Hyd2o-AR5 and Hyd2o-AR6) indicate a far greater seasonal variability than the regional superficial aquifer with minimum levels reducing some 1-2 m below that of the regional system, which is consistent with a rained aquifer system perched on a confining layer; and
- Hydraulic connectivity to Baileys Branch Drain is likely to be limited given that the response observed in bore Hyd2o-AR6, which is adjacent to the drain, is similar to that observed in bores located further afield.

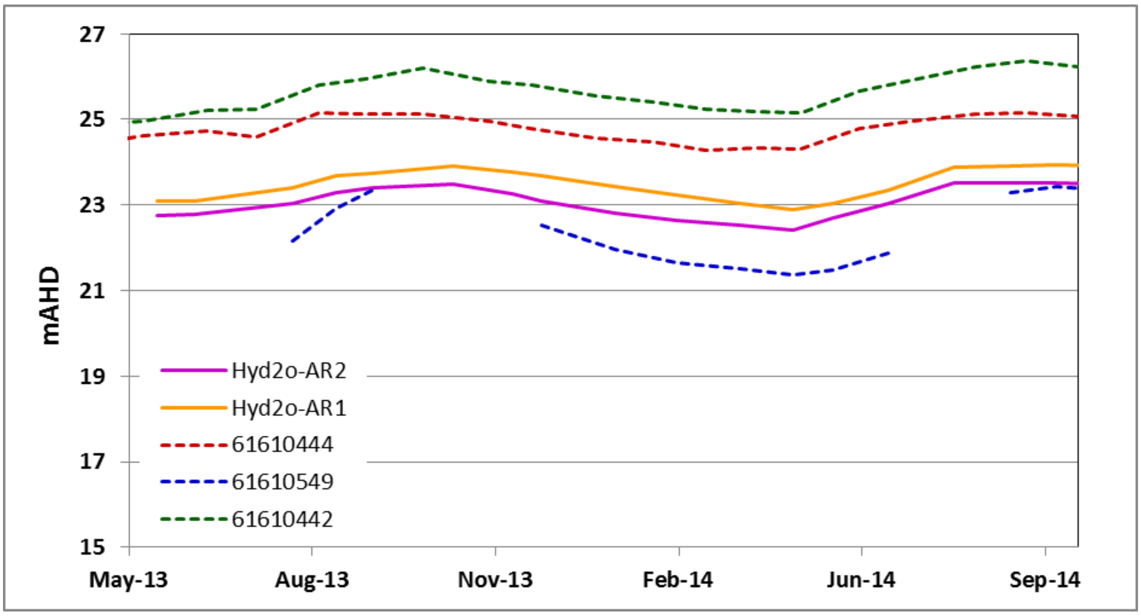

Figure 18: Groundwater levels to the southwest of the TEC

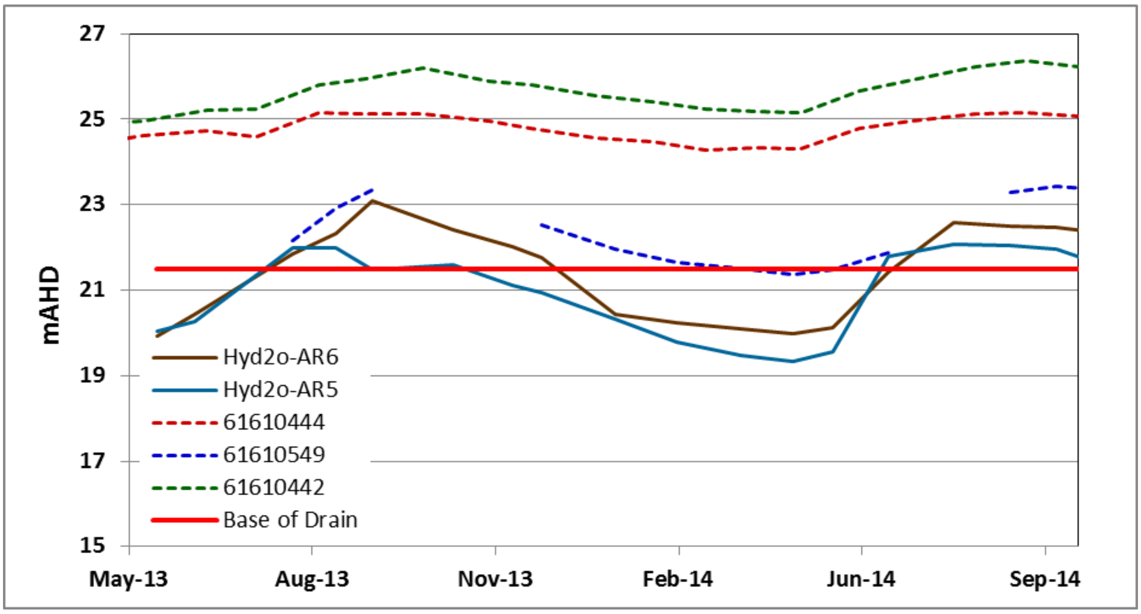

Figure 19: Groundwater levels at the southwestern boundary of the TEC

Groundwater levels within the nested piezometers at boreholes A01 and A05 (see **Table 14**) reveals a downwards hydraulic head potential, which indicates a perching of shallow waters.

Table 14: Measured groundwater levels (m from top of casing)

Borehole	8 Sep 2015	2 Oct 2015
A01 Deep	1.72	1.65
A01 Shallow	0.90	0.71
A05 Shallow	1.72	1.56
A05 Deep	1.09	0.91

4.1 Site drainage

The elevation surface derived from the Lidar surface level data has been depicted on an aerial photograph in **Figure B2** in **Appendix B** along with the delineations of the contributing catchments. It is noted that the topography drops to a minimum along the alignment of the Baileys Branch Drain, effectively cutting through the ephemeral wetlands along its alignment. Surface water from these low lying areas seems to be prevented from entering the drain by levees (see **Figure 20**).

Figure 20: Baileys Branch Drain with levee banks

Baileys Branch Drain was constructed to manage regional groundwater and to prevent flooding in urbanised areas, but does surcharge surplus water in extreme events. According to previous studies (Worley Parsons, 2009) the drain flows full with no free board for a 10 year ARI design flood event. The levee banks overtop during the 100 year ARI design flood event resulting in large volumes of storm water passing into the TEC and dampland areas.

The elevation surface indicates that the existing roads (Anstey and Keane Roads) are built up with embankments. These embankments would effectively become catchment divides should there be no culverts.

The elevation surface also indicates that surplus surface water emanating from the TEC will drain both towards the southeast and northwest. A small catchment divide is noted along the existing fire access track between Lots 66 and 101, which is the proposed alignment of the sewer main. It was noted during the site investigations that the base of this track is lower than the surrounding terrain, which is possibly due to soil movement and compaction arising from vehicle use (see **Figure 3**). Accordingly, surplus surface water arising from this alignment is likely to shed into the areas adjacent to the track and on to low lying remnant wetland as depicted in **Figure B2** in **Appendix B**.

Site investigations have revealed that the eastern end of the track is characterised by standing water in Winter, the level of which increases following rainfall events. This is consistent with the remnant wetland in the vicinity of the Anstey Rd and Keane Rd intersection.

5. Site interpretation

5.1 Overview

Based on the data available from this and previous investigations, the superficial formations at this site were found to contain an unconfined aquifer within the Bassendean Sand unit and a semi-confined aquifer within the sandy facies of the Guildford Formation.

The upper surface of the unconfined aquifer is the perched groundwater table, whose variations in depth depend on the topography. In areas of subdued topography, the groundwater table breaks the surface and causes inundation (in the form of large puddles of standing water). The unconfined water table fluctuates seasonally and is believed to disappear entirely following periods of low rainfall and high temperatures. Recharge of this aquifer is almost entirely from rainfall with minor upward flow possibly occurring from the lower, semi-confined aquifer for some of the year.

The sandy facies of the Guildford Formation hosts what is, within the study area, a semi-confined aquifer, but what is anecdotally (pers. comms. Direct Push Probing Pty Ltd) a confined aquifer in the urban development areas further to the north. Limited drilling data from the south of the study area (Hyd2o, 2013) indicates the clayey facies of the Guildford Formation may disappear and that this aquifer may become unconfined in this area.

5.2 Alignment of the Sewer Main

The cross section of the interpreted geology along the alignment of sewer main (Section A) is presented in **Figure 21**, the orientation of which is depicted in **Figures B3**, **B4** and **B5** in **Appendix B** for ease of reference. The location of the proposed sewer main is also depicted on Section A. Inspection of these figures and reference to the analysis results detailed in **Section 4** indicates the following with regard to the proposed sewer main:

- The sewer main will be located along a ridge of elevated Guildford Formation clayey sand that seems to be aligned with the fire access track adjacent to Lot 101 in the vicinity of the TEC;
- The depth of the Bassendean Sand overlying the Guildford Formation clayey sands in the vicinity of the TEC varies from about 0.2 to around 1.2 m and, as such does not offer significant water storage;
- Given the high hydraulic conductivities of the Bassendean Sands, stored water will drain rapidly to the areas where clayey sands are at lower elevations on both sides of the track;
- Site observations on 8 September 2015 revealed standing water on the track (see **Figure 3**) and a water level in borehole GHD13-BH25 of 1.84 mBGL, indicating that clayey sand facies outcrop and the surficial sand facies in this area drain rapidly;
- The thickness of the clayey sands of the Guildford Formation along this alignment is around ~6 m with there being evidence of isolated pockets of more sandy material;
- The alignment of the sewer main is in close proximity to one of these pockets of more sandy material which may have increased hydraulic conductivity (test results reported in **Section 3.5** indicate that the hydraulic conductivity of the Guildford Formation sand is likely to be an order of magnitude greater than that of the Guildford Formation clayey sand); and

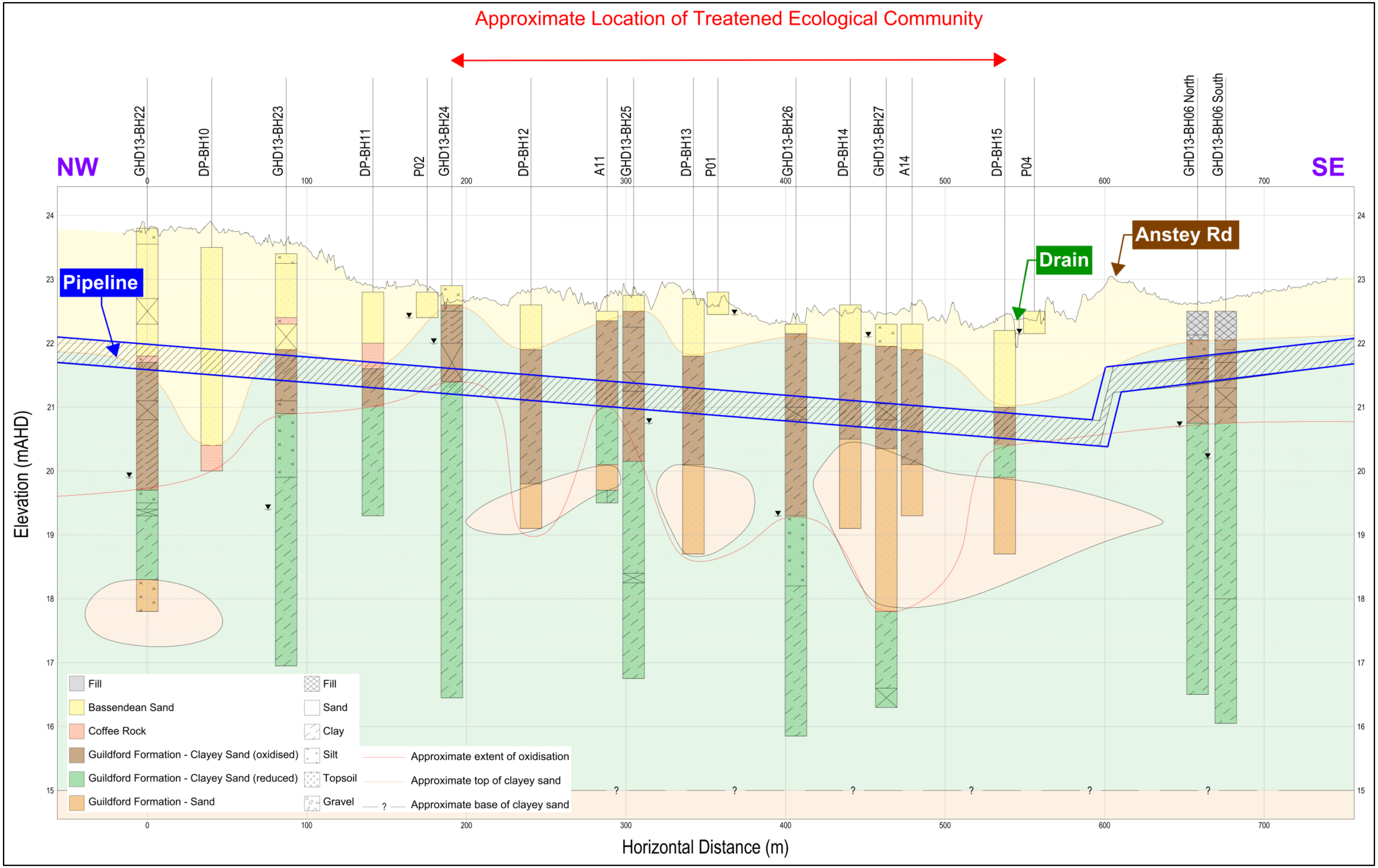

Figure 21: Section A along sewer main alignment

- The approximate limit of the oxidised soils is between 0 and 3 m below the sewer main, indicating that the water table frequently drops below this invert level (the water levels observed in bores Hyd2o-AR5 and Hyd2o-AR6 presented in **Figure 19**, indicate minimums of 19 and 20 m AHD, which supports this observation).

5.3 Threatened ecological community

Sections B, C and D of the interpreted geology across the TEC are presented in **Figure 22** and **Figure 23** and **Figure 24** respectively, the alignments of which are also depicted in **Figures B3**, **B4** and **B5** in **Appendix B**. The location of the proposed sewer main is also depicted on the various cross sections. These figures and analysis results detailed in **Section 4** indicate the following:

- The depth of the Bassendean Sand overlying the Guilford Formation clayey sands across the TEC seems to be reasonably consistent with a maximum depth of around 1.2 mBGL;
- The thickness of the underlying clayey sands is some ~6 m, with evidence of isolated lenses of more sandy material at approximately 2.5 mBGL;
- The approximate limit of oxidised soils is 2 to 3 mBGL, indicating frequent drying of the upper part of the clayey sands within the TEC;
- Indications are that an ephemeral perched aquifer system forms on the confining clayey sand layer which is both rain-fed and receives drainage from the higher lying parts of the clayey sand layer (this system aligns reasonably well with the mapped extent of the TEC as depicted in **Figures B3** in **Appendix B**);
- Groundwater quality (see **Section 4.4**) sampled in the nested piezometers at borehole A05 (which is roughly at the point of lowest clayey sand elevation) indicates that salinity increases with depth and the major-ions indicate geochemically distinct groundwater systems;
- Given the fresh shallow groundwater water quality and the maintenance of a downwards hydraulic head potential (see **Section 4.5**), rainfall is likely to be the dominant mechanism and water source for recharge and maintenance of the perched aquifer;
- Given the location of the sewer main on the ridge of elevated Guildford Formation clayey sand at the southern extremity of the inferred ephemeral perched aquifer system, this is highly unlikely to impact recharge of the groundwater systems in the vicinity of the TEC; and
- Given the location and installed depth of the sewer main in relation to the ephemeral perched aquifer system associated with the TEC, this is unlikely to pose a risk of increased hydraulic connectivity between the perched aquifer system and the underlying semi-confined system.

The delineations of the contributing catchments based on the Lidar surface level data presented in **Figure B2** in **Appendix B** indicates a catchment divide roughly along the existing fire access track between Lots 66 and 101, which is the proposed alignment of the sewer main. Surplus surface water arising from this alignment is likely to shed into the areas adjacent to the track and on to low lying remnant wetland in the vicinity of the Anstey Rd and Keane Rd intersection. Accordingly, installation of the sewer main will almost certainly not interrupt surplus surface water flow paths in the vicinity of the TEC.

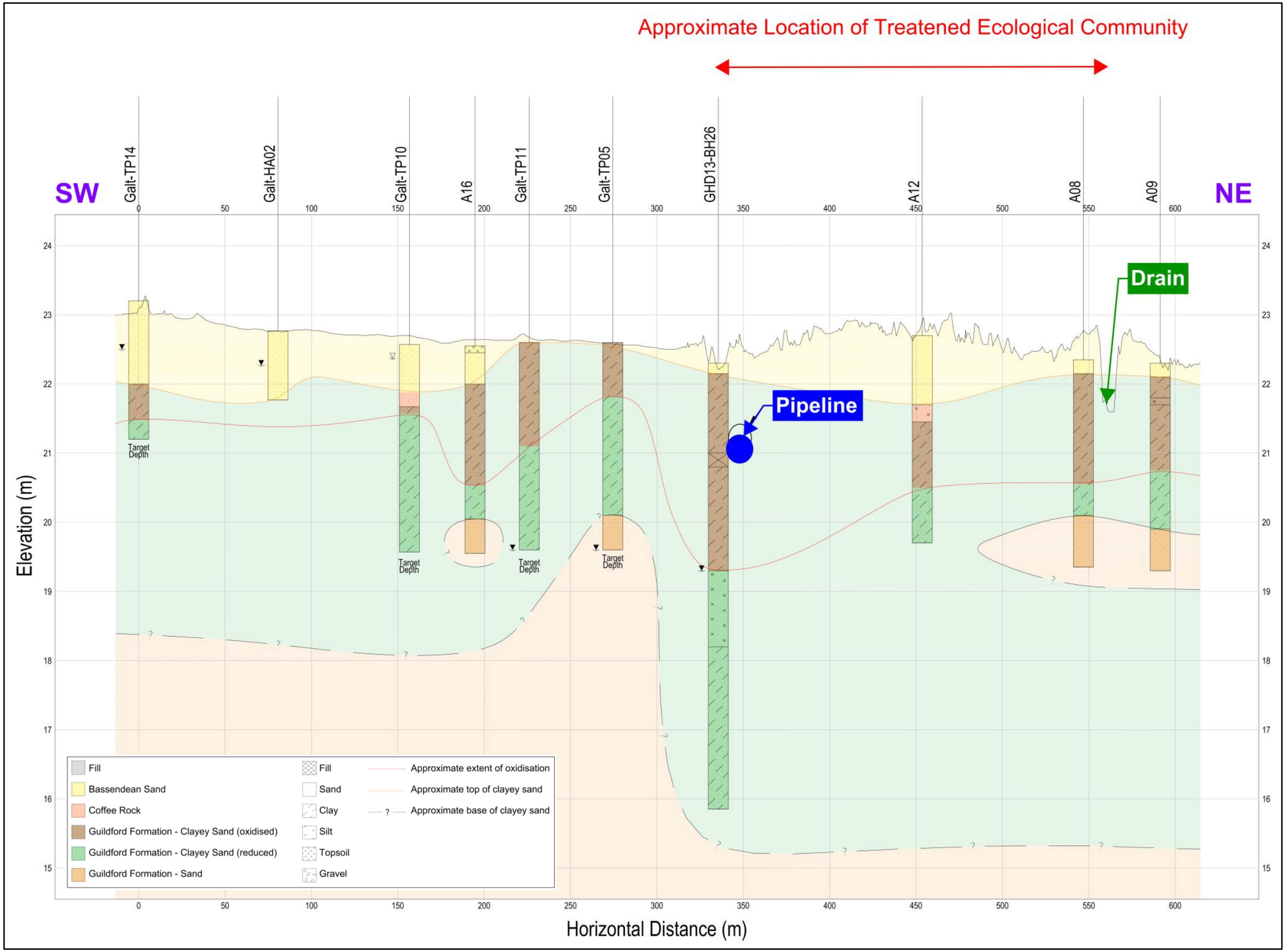

Figure 22: Section B through the TEC

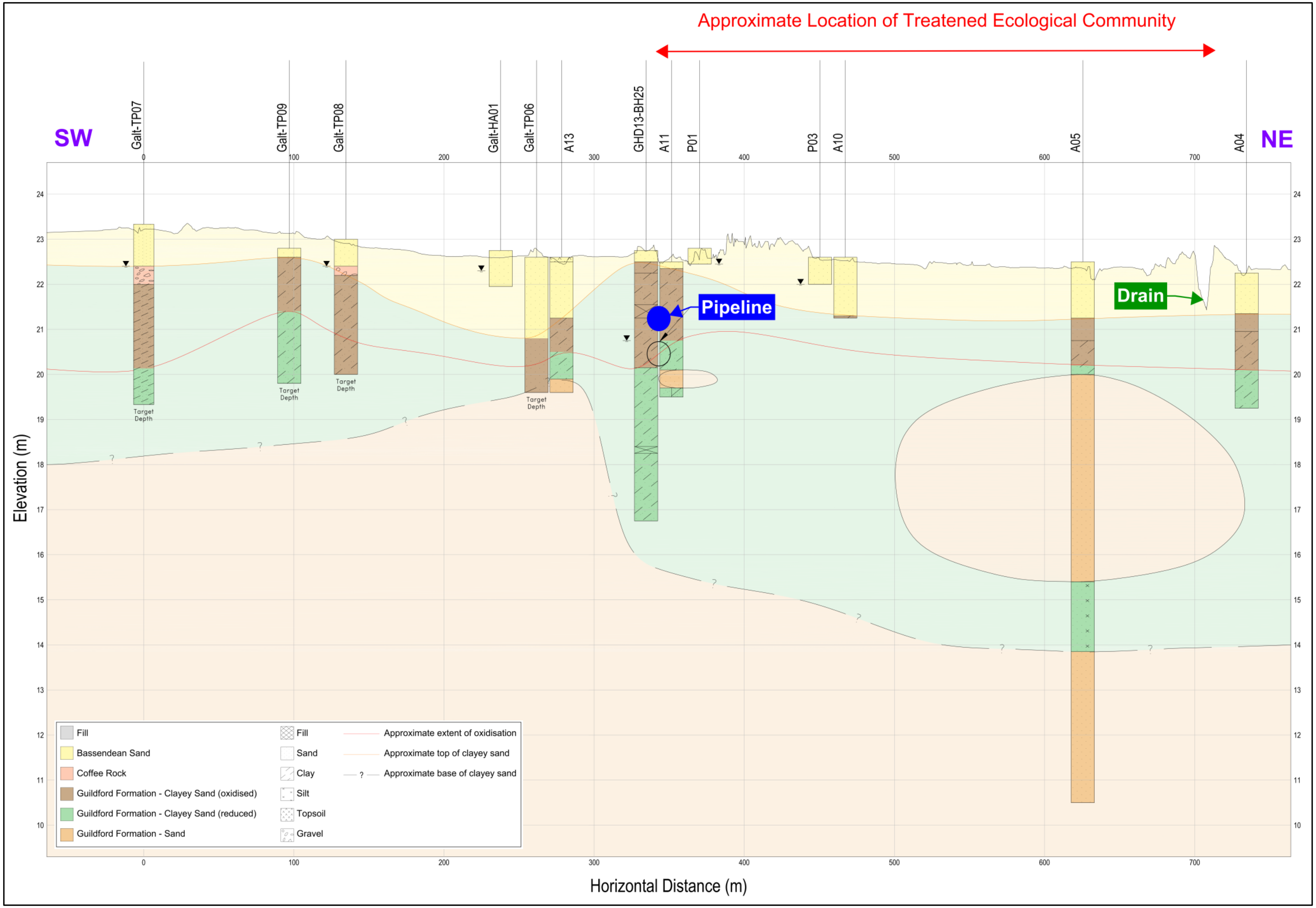

Figure 23: Section C through the TEC

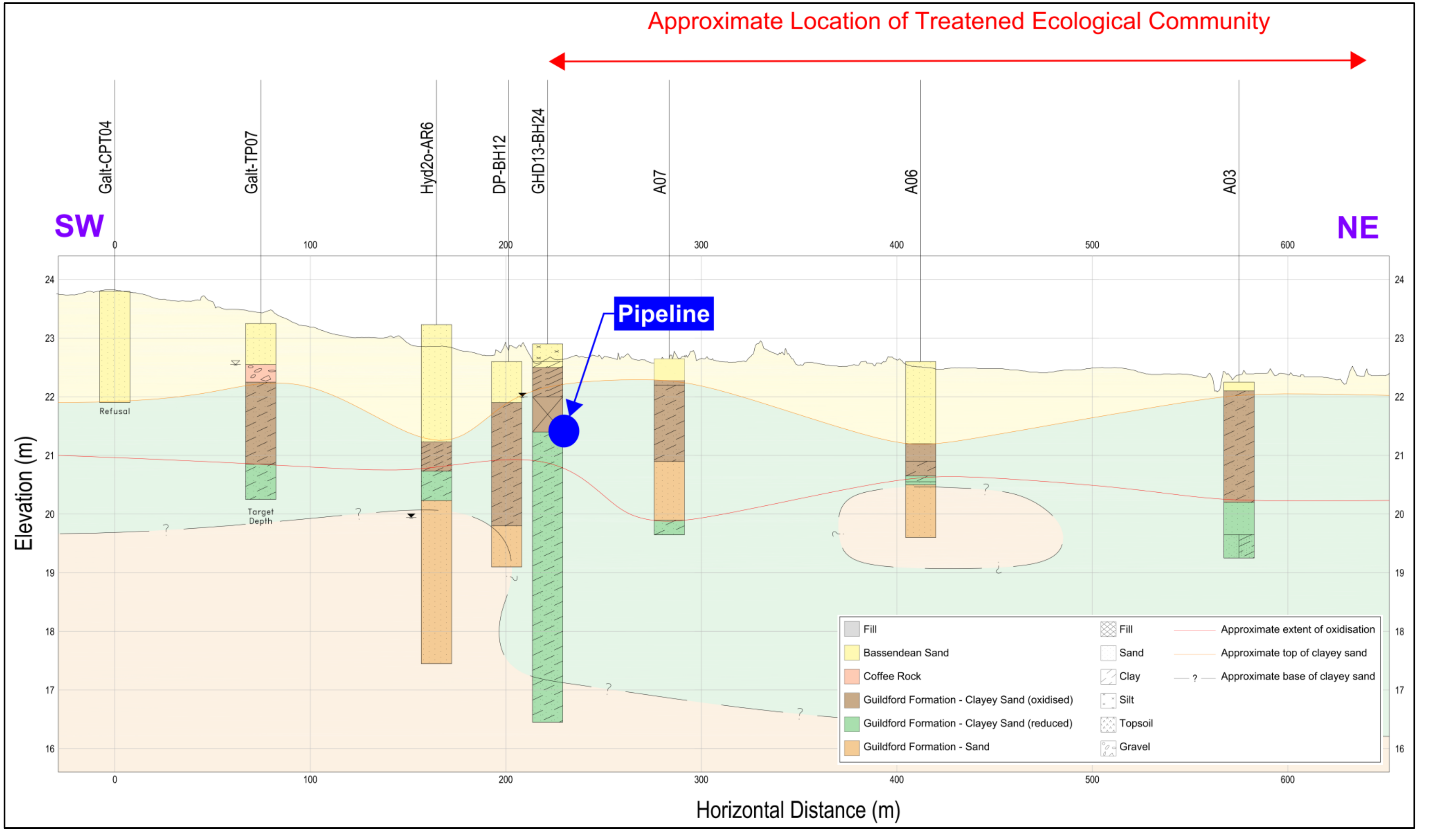

Figure 24: Section D through the TEC

6. Conclusions and recommendations

6.1 Conclusions

The site investigations indicate that an ephemeral aquifer system forms within the Bassendean Sands in the vicinity of the TEC, which is perched on the confining Guildford Formation clayey sands. This system aligns reasonably well with the mapped extent of the TEC as depicted in **Figures B3** in **Appendix B**.

The ephemeral nature of the perched aquifer system is evidenced by both groundwater level monitoring data and the transition of the soils from oxidised to reduced states (~2 to 3 mBGL). The thickness of the underlying clayey sands (~6 m), the different groundwater chemistries and the increase in salinity with depth indicate that the perched and confined aquifers are distinct groundwater systems with limited hydraulic connectivity.

Given the fresh shallow groundwater water quality and the maintenance of a downwards hydraulic head potential, rainfall is likely to be the dominant mechanism and water source for recharge and maintenance of the perched aquifer. Stored water will be dissipated through soil evaporation and plant evapotranspiration, with vertical drainage unlikely. Hydraulic connectivity of this perched aquifer system to Baileys Branch Drain is likely to be limited. Accordingly, it is highly unlikely that there will be any impacts to the recharge of the perched ephemeral aquifer system resulting from the installation of the sewer main.

In winter, ponding is common in the topographical lows in the TEC where water accumulates due to rainfall, near horizontal drainage from adjacent sandy areas and surplus water runoff. The delineations of the contributing catchments based on the Lidar surface level data presented in **Figure B2** in **Appendix B** indicates a catchment divide roughly along the proposed alignment of the sewer main. Surplus surface water will shed into the areas adjacent to the track and flow on to the low lying remnant wetland in the vicinity of the Anstey Rd and Keane Rd intersection. Installation of the sewer main will not interrupt surface water flow paths in the vicinity of the TEC.

The sewer main is aligned on a ridge of elevated Guildford Formation clayey sand along the existing fire access at the inferred southern extent of the ephemeral perched aquifer system. Installing the sewer main within this clayey sand formation is highly unlikely to have any influence on the horizontal drainage to the perched system in the vicinity of the TEC.

The thickness of the underlying clayey sands along the sewer main alignment appears to be in the order of 6 m. Installing the sewer main into the top ~1.5 m of this material should still result in sufficient residual thickness to maintain the hydraulic integrity of the perched aquifer system. The alignment is in close proximity to a pocket of more sandy material which, if intersected, could further reduce the effective residual thickness. It should be noted that any reduction in effective thickness resulting from disturbance during installation will be limited to the sewer main corridor only.

Given the alignment and installed depth of the sewer main in relation to the ephemeral perched aquifer system associated with the TEC, this is unlikely to pose a risk of increased hydraulic connectivity between the perched aquifer system and the underlying confined aquifer system. The pockets of more sandy material within the Guildford Formation clayey sand at ~2.5 mBGL should be avoided.

6.2 Recommendations

Routine monitoring of the groundwater systems prior to, during and following construction of the sewer main is recommended and should entail:

- Target boreholes A01D, A01S, A05D, A05S, A07, A11, A15, GHD13-BH06S, GHD13-BH25, Hyd2o-BHAR5 Hyd2o-BHAR6 and Baileys Brach Drain for monitoring and sampling;
- Retrieval and analysis of water quality samples for the analytes detailed in **Section 3.6**, as well as for potential contaminants that could emanate through construction and operation of the sewer main; and
- Download and review of water level data.

Although the thickness and permeability of the Guildford Formation clayey sands should maintain the hydraulic integrity of the perched aquifer system, breaching the sandy lenses within the Formation may have the potential to influence or change groundwater migration. It is recommended that such lenses be avoided by installing the sewer main higher in the soil profile.

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Appendices

Appendix A – Historical aerial photographs

1953, February

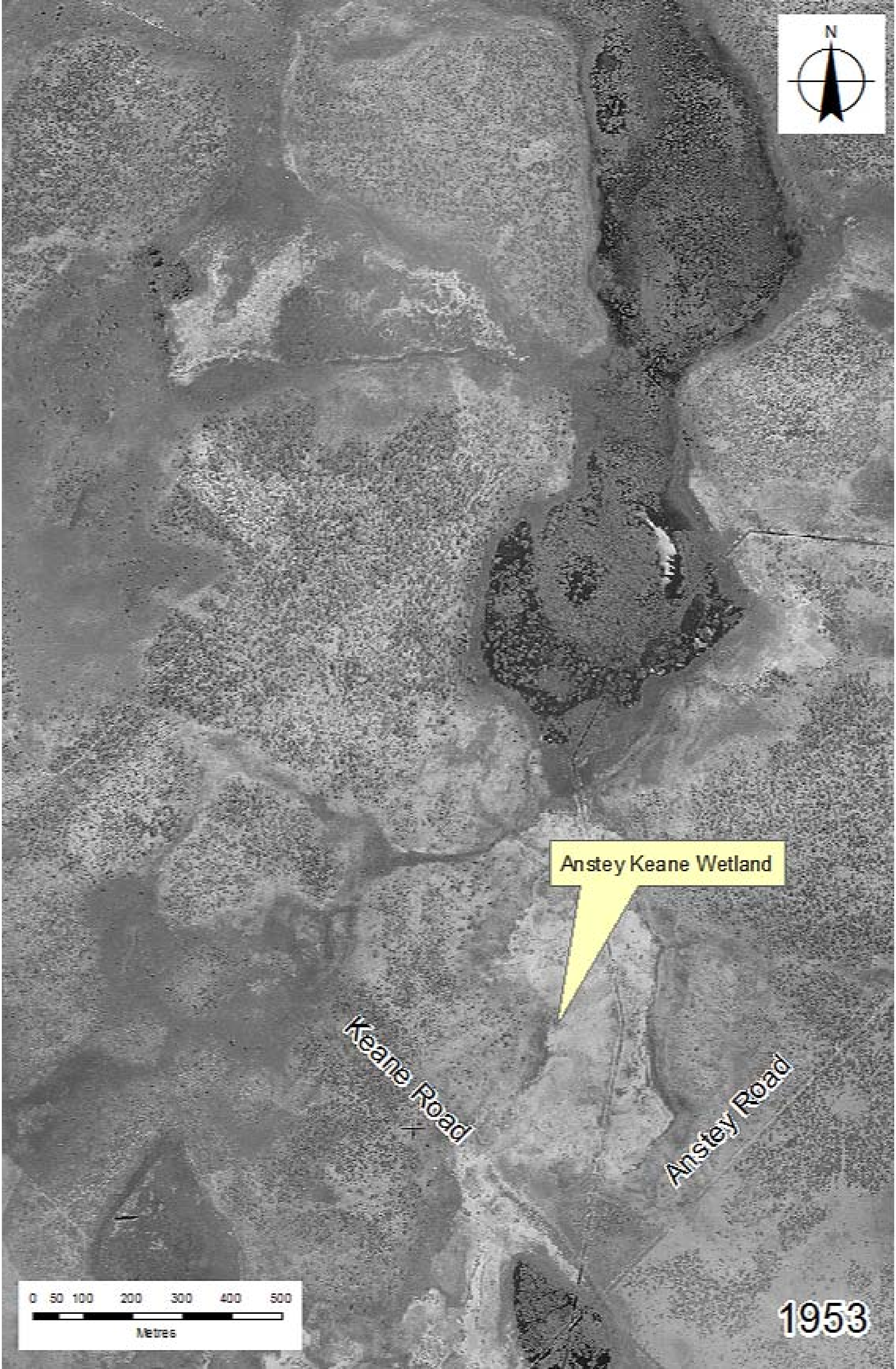
1965, March

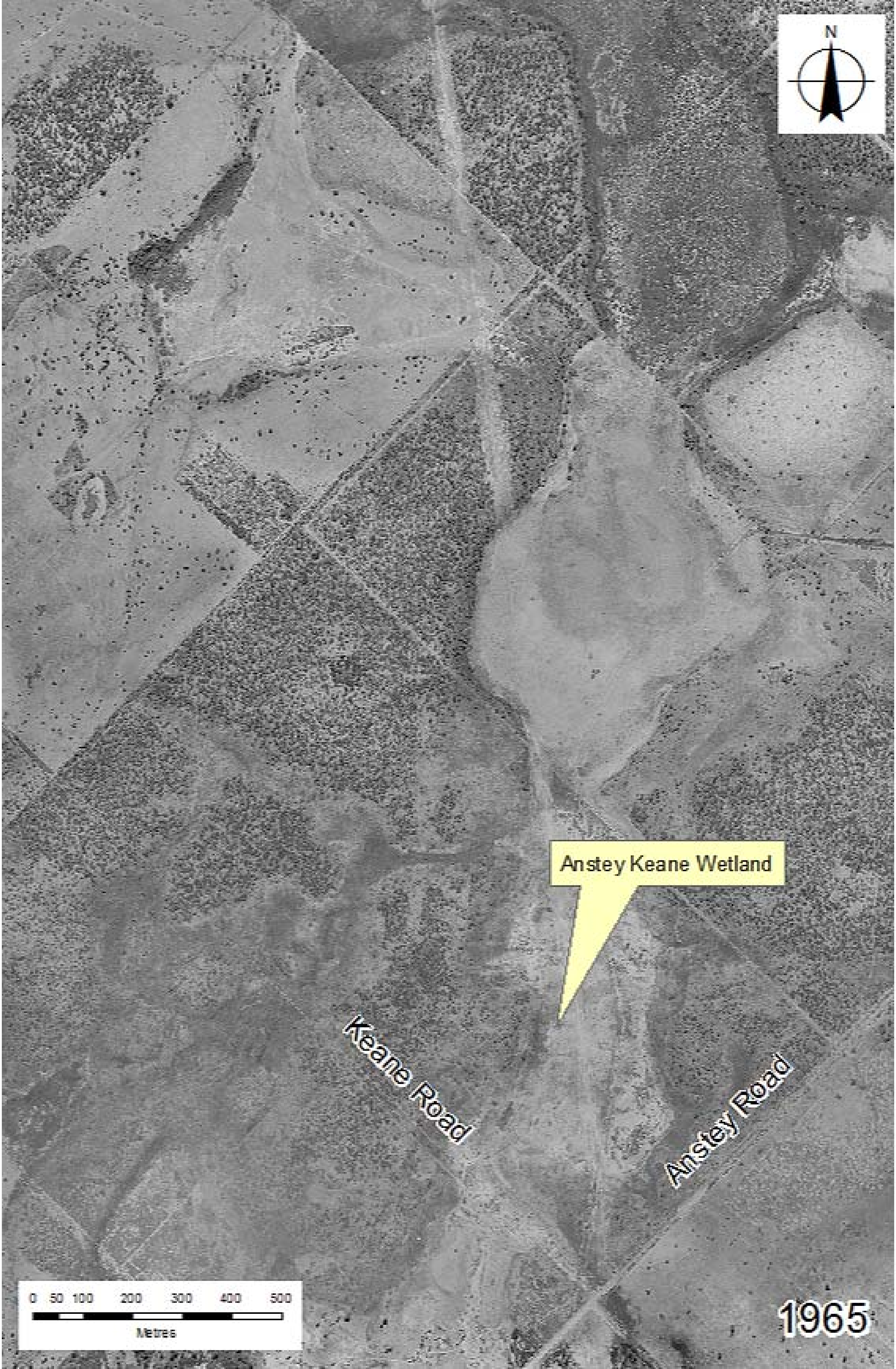
1974, September

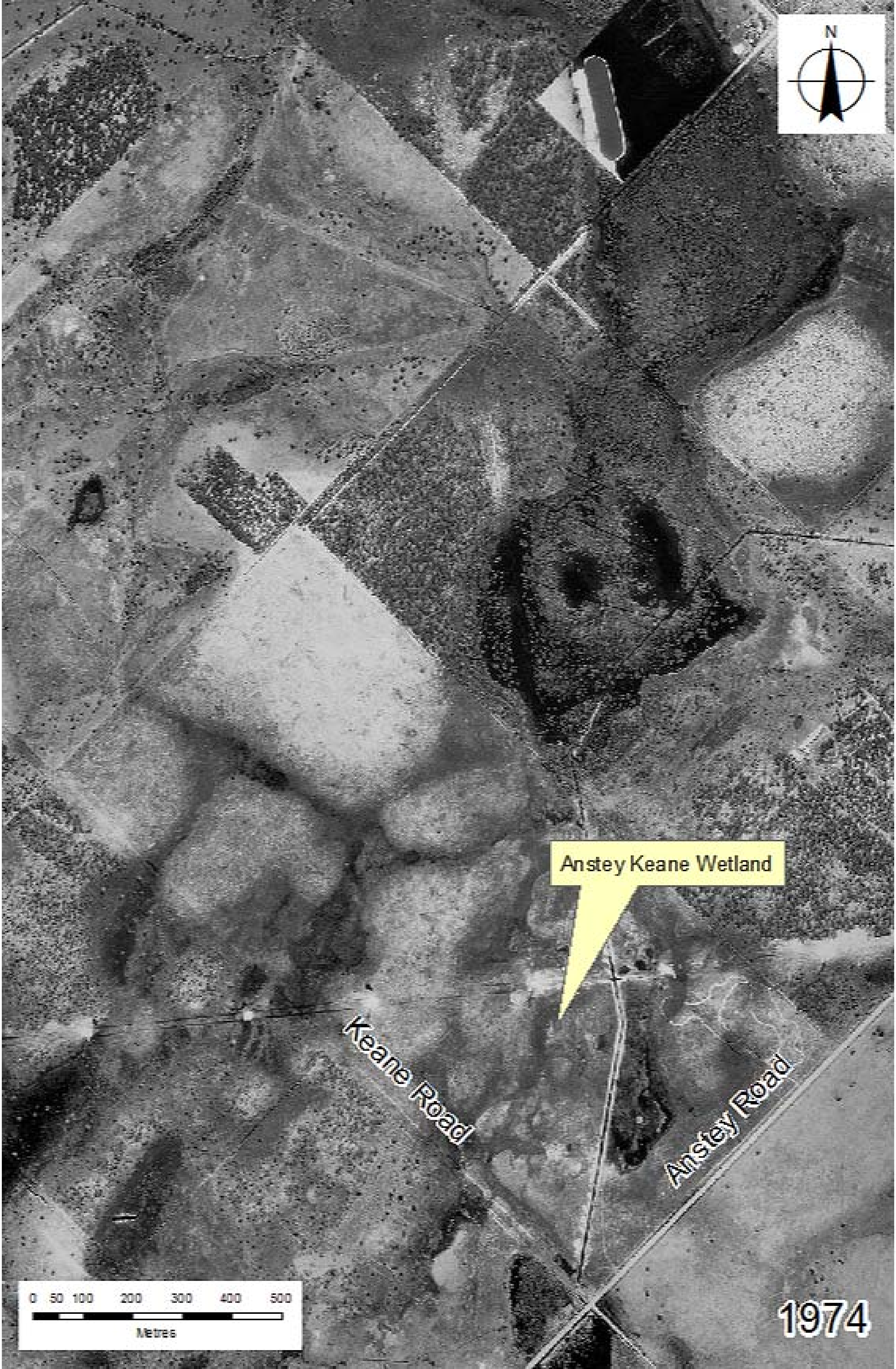
1981, August

1995, February

2014, September


N
Anstey Keane Wetland
Keane Road
Anstey Road
0 50 100 200 300 400 500
Metres
1953


N
Anstey Keane Wetland
Keane Road
Anstey Road
0 50 100 200 300 400 500
Metres
1965


N
Anstey Keane Wetland
Keane Road
Anstey Road
0 50 100 200 300 400 500
Metres
1974


N
Anstey Keane Wetland
Keane Road
Anstey Road
0 50 100 200 300 400 500
Metres
1981


N
Anstey Keane Wetland
Keane Road
Anstey Road
0 50 100 200 300 400 500
Metres
1995


N
Anstey Keane Wetland
Keane Road
Anstey Road
0 50 100 200 300 400 500
Metres
2014