TECHNICAL MEMORANDUM

DATE 13 November 2019 **Reference No.** 1777197-051-M-Rev1

TO State Resource Development Manager, Akina Holdings Pty Ltd

CC Alan Kietzmann

FROM Alan Puhalovich **EMAIL** apuhalovich@golder.com.au

GREAT SOUTHERN LANDFILL INLAND WATERS – HYDROGEOLOGICAL CONCEPTUALISATION AND CONTINGENCY PLANNING

1.0 INTRODUCTION

Alkina Holdings Pty Ltd proposes to construct and operate the Great Southern Landfill, located on Allawuna Farm lots 4869, 5931, 9926 and 26934 Great Southern Highway, St Ronans (approximately 80 km east of Perth). It is anticipated the landfill will receive 150,000 to 250,000 tonnes per annum of Class II or III waste, with a lifetime capacity of approximately 5.6 million cubic metres. The cells for the landfill will be developed in stages, with the construction of up to seven cells.

This technical memo outlines the requested information for the *Inland Waters* requirements as outlined in Section 3 items 29e, 35 and 36 of the Draft Environmental Scoping Document (ESD) issued by the Environmental Protection Authority (EPA). The work was conducted in accordance with Proposal 1777197-047-L-RevB dated 31 July 2019. These items are summarised below.

2.0 ITEM 29E – HYDROLOGICAL AND HYDROGEOLOGICAL CHARACTERISATION OF LANDFILL PROJECT SITE

2.1 Pre-landfill hydrology and hydrogeology

2.1.1 General setting

The proposed landfill site is situated 15 kilometres west of York on the Darling Plateau and approximately 80 kilometres east of Perth. The site is within the sub-catchment of Thirteen Mile Brook which drains into Spencers Brook and the Avon River. Locally, the project site is adjacent to a small, westerly draining intermittent tributary that runs into the northerly draining Thirteen Mile Brook. The proposed landfill sits upslope of Thirteen Mile Brook, approximately 400 m east. Figure 1 shows the location and local drainage in the immediate vicinity of the landfill.

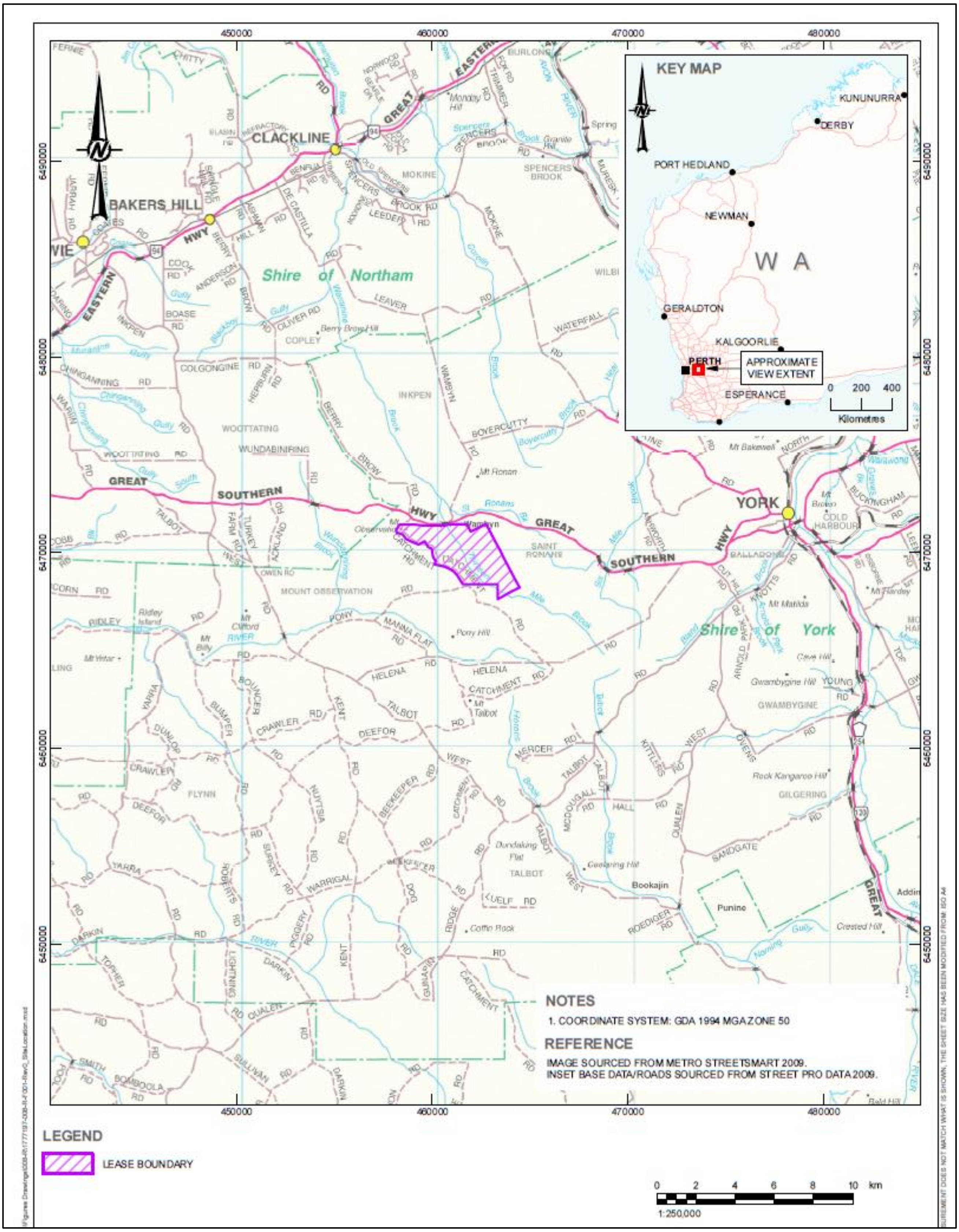


Figure 1: Site location for the proposed Great Southern Landfill

2.1.2 Climate and hydrology

Rainfall and climate data from SILO database and Bureau of Meteorology for the surrounding region have been collated and analysed in order to develop surface water, groundwater, and stormwater management (Golder, 2015b). A summary of surrounding long-term rainfall series data is provided in Table 1. The analysis by Golder (2015) adopts the SILO long-term average annual rainfall of 599 mm, noting a high level of inter-annual variability ranging from 286 mm (2010) to a maximum of 998 mm (1955).

Annual evaporation was also estimated using SILO class A pan evaporation data, and dam evaporation calculated using a coefficient relationship (Golder, 2015b). Annual pan evaporation is estimated to be around 1813mm/a (Table 2).

Table 1: Summary of regional long-term rainfall data for sites within 20 km of project

Location	Period of Available Record	Elevation (m)	Distance from Site (km)	Median Annual Rainfall (mm)
SILO	1900-2015	325	<1 km	590
Berry Brow	1907-1950	276	12.5	614
Quadney	1995-2015	310	14.0	397
York (combined)*	1877-2015	179	15.5	434
Muresk Ag College	1226-1981	166	19.0	448

Notes: *York combined rainfall includes rainfall data from stations: York Post Office (1877-1996) and York (1996-2015)

Table 2: Estimated monthly average evaporation losses for Allawuna Farm

Month	Evaporation (Class A Pan) E_{pan}	Estimated Open Water Dam Evaporation E_{OD}
January	288	225
February	241	188
March	205	160
April	122	95
May	75	59
June	52	41
July	53	41
August	66	52
September	93	72
October	150	117
November	204	159
December	264	206
Annual	**1,813**	**1,415**

2.1.3 Geological setting

The local geology and hydrogeology is described in detail in Golder (2017b). A summary of this conceptual model is presented here.

The project area is situated east of the Darling Fault over Archaean granitic and gneissic rocks of the Yilgarn Block (Figure 2). Beneath the project site the basement comprises porphyritic granite (Agp) and fine- to medium-grained adamellite and granites (Agv). Overlying the Archaean basement is an extensive weathering profile, formed *in situ* during what was a wetter climate. A schematic of the weathered profile is shown in Figure 3. Locally this weathering profile overlies granitic basement and includes a 2 to 4-metre-thick zone of weathered basement comprising granitic cobbles in clay and ‘grit’ at the base, saprolite and clays up to 15 metres thick in the middle, and a top layer of iron-rich mottled and iron-cemented sands, gravels (including pisolites) and clays. Saprolite is mostly clayey, however in isolated locations (e.g. GMB5, GMB6) has a higher quartz content, owing to the basement quartz/feldspar content.

Quaternary quartz-rich sands and clays unconformably overlay the basement and weathered profile, as alluvial and colluvial deposits. These are situated on hillslopes and valley floor. No palaeovalleys are mapped in the vicinity of the project site (Golder, 2017c).

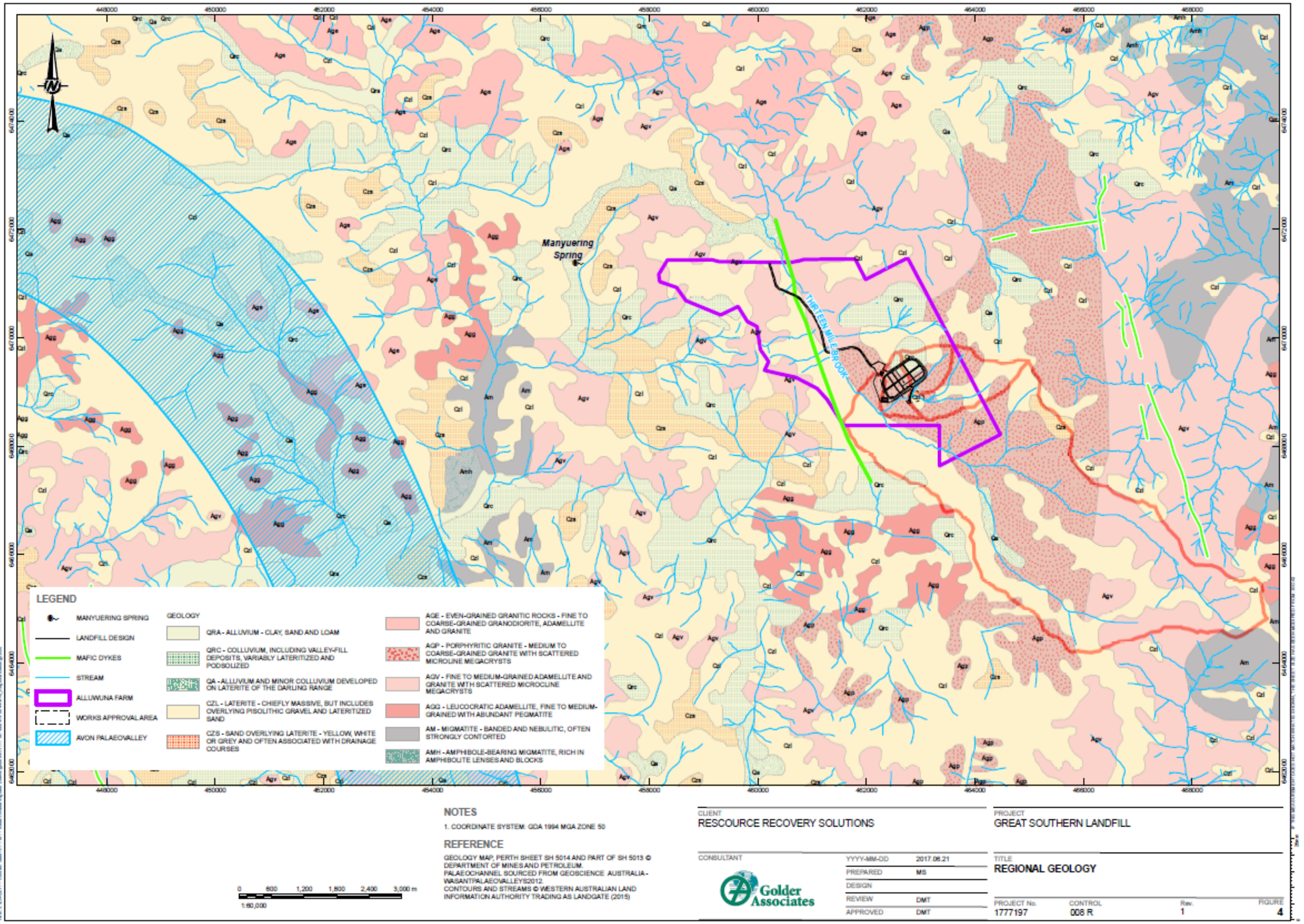
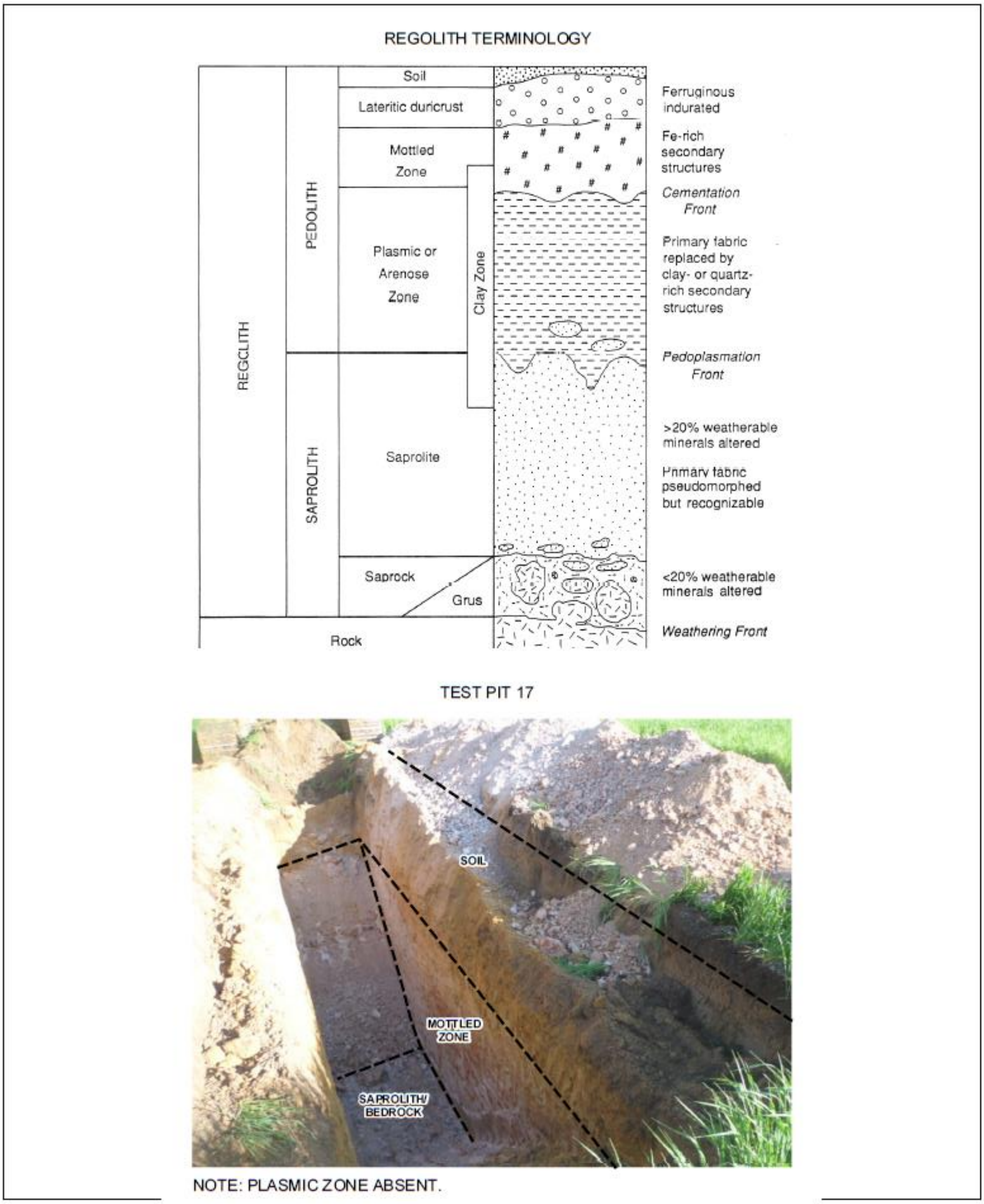


Figure 2: Regional geological setting



REFERENCE

PROFILE SOURCE: C.R.M BUTT, D.J. GRAY, M.J. LINTERN, I.D.M. ROBERTSON, G.F. TAYLOR AND K.M. SCOT, GOLD AND ASSOCIATED ELEMENTS IN THE REGOLITH - DISPERSION PROCESSES AND IMPLICATIONS FOR EXPLORATION, FINAL REPORT, CSIRO/AMIRA WEATHERING PROCESSES PROJECT, SEPTEMBER 1991.

Figure 3: Typical regolith profile over weathered Archaean Yilgarn Craton

2.1.4 Hydrogeology

Groundwater below the project site is conceptualised as an unconfined to semi-confined aquifer. Local perching above consolidated clays or bedrock may result in isolated, ephemeral shallow groundwater systems. There is lateral and vertical variation in aquifer hydraulic conductivity as observed in bore lithology and slug testing. At the base of the weathered profile, crystalline basement may host fractures filled with groundwater.

2.1.4.1 Aquifer units

A review of groundwater bore logs, water level monitoring data, and geotechnical data has been undertaken as part of this work and from this several layers have been identified to characterise the 'typical' hydrogeological units (Table 3). These are shown schematically on hydrogeological sections A-A' and B-B' (Figure 4 and Figure 5). A sandy, gravelly layer is typically encountered in the upper three to five metres of the geology (Unit 1). Beneath Unit 1 the material grades into a clayey layer, up to 15 metres thick (Unit 2). Unit 2 is believed to be a leaky confining layer in places, particularly to the south of the project site, due to its consistently high clay content and consolidation.

Unit 2a, a lateral variation stratigraphically equivalent to Unit 2, has been included to account for the atypical lithology intercepted in bores GMB5 and GMB6. In these bores, a deeper sand was encountered that was continuous to the basement. Deeper sands may exist to the north of GMB06 and south of GMB01, however there is no data to support this. These are believed to represent isolated patches of quartz-rich parent material within the weathered profile. Overlying crystalline basement is a quartz rich, gravel-textured layer, which is up to four metres thick (Unit 3). Unit 3 is the most prospective unit as an aquifer given its coarse-grained texture. Unit 4 is the unweathered, crystalline basement comprising fractured granitic-textured rocks. The upper part of this profile is absent in places, likely eroded within creek lines and around topographic highs.

Table 3: Hydrogeological units beneath project site

Unit	Typical thickness (metres)	Lithology	Properties	Aquifer/aquitard
1	2-4	Soil, alluvium, or colluvium, lateritised in places.	Sands and gravels, clayey in places.	Unsaturated
2	10-15	Weathered basement (saprolite or plasmic zone Figure 3).	Clays, sandy or gravelly in places.	Low permeability, leaky aquitard
2a	10-15	Weathered basement (saprolite or plasmic zone Figure 3).	Isolated sandy clays/clayey sands.	Unconfined aquifer.
3	2-4	Weathered basement (Saprock Figure 3).	Gravel-texture comprising residual quartz, feldspar, within a clay matrix.	Porous aquifer, low yield.
4	>10 m	Archaean basement.	Fractured, crystalline rock.	Fractured rock aquifer?

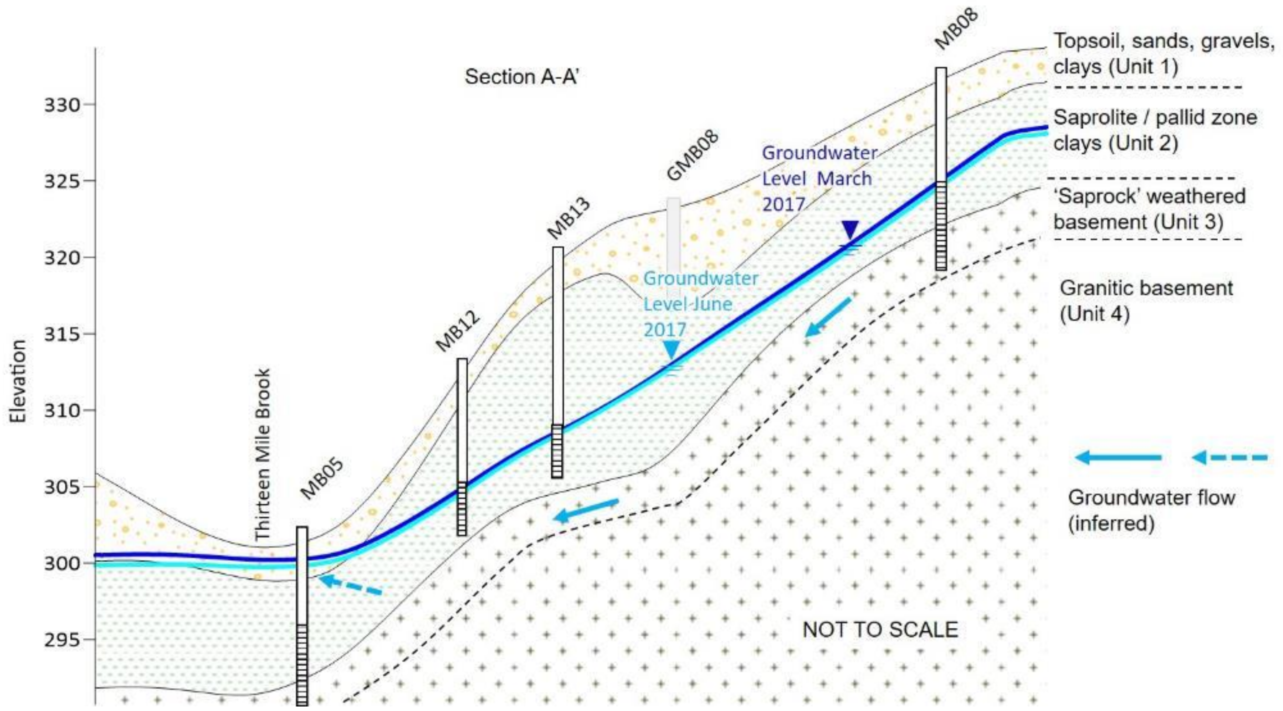


Figure 4: Hydrogeological section A-A'

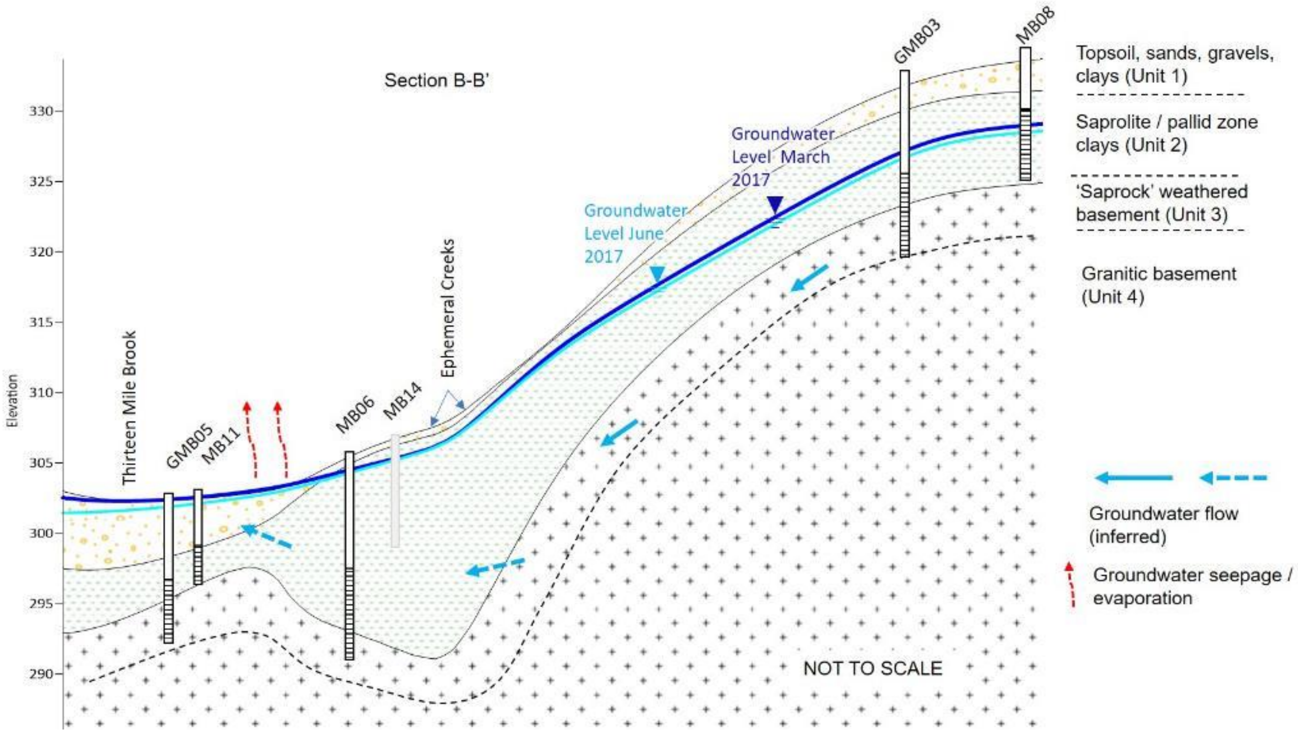


Figure 5: Hydrogeological section B-B'

2.1.4.2 Groundwater levels, seasonal variations, and flow

Groundwater levels were intermittently monitored in bores between 2012 and 2017 by Golder and others. Groundwater level contours for June 2017 are shown on Figure 6. Groundwater beneath the surface generally mimics topography, with higher groundwater in the top part of the catchment to the east and gradually declining in a westerly direction towards Thirteen Mile Brook valley floor. Generally, groundwater flow occurs perpendicular to the groundwater level contours, thus flow is inferred towards Thirteen Mile Brook. From there groundwater may move from the weathered profile into the alluvial system flow downstream. However, it is unclear whether the alluvial sediments (Unit 1) within Thirteen Mile Brook are laterally connected to Unit 3 (weathered basement 'saprock') or separated by Unit 2. Section B-B' also shows possible upward seepage due to local, seasonal artesian pressure in the aquifer surrounding bore MB11, where groundwater levels are observed to be ~0.1 m above ground surface.

Depth to groundwater ranges from less than 5 m near the unnamed flowline south of the project site and in the valley floor, between 5 to 10 m below the proposed landfill footprint and increasing to more than ten metres to the north-west (GMB01). Groundwater levels within individual bores across the monitoring period fluctuate seasonally from less than 0.1 m (MB11) to in excess of 2.5 m (MB09).

Where the water table intersects the ground surface, seeps or springs may develop. One such area identified during a site inspection (9 September 2014), where a substantial area of topographically low ground occurs within the footprint of the proposed landfill, was observed to have seepage water discharging at the ground surface. This water joined the local surface water drainage system, discharging ultimately into Thirteen Mile Brook (Golder, 2017c).

Shallow groundwater seepage between 2 to 4 m depth below ground level was encountered during geotechnical work in November 2014 (Golder 2015a), frequently coinciding with excavation 'refusal' at less than target depth. This seepage is believed to be localised perching in the upper sandy, gravelly layer (Unit 1) above consolidated clays or cemented zones, as it occurs in the upper 3 m of the stratigraphy. However, in topographically lower areas surrounding the creek line (MB06, MB11) the seepage may be from artesian pressure beneath Unit 2. This seepage concentrates around the unnamed tributary south of the proposed landfill footprint, in the vicinity of bores MB14, MB11, and GMB03. It is understood to be intermittent and may cause localised waterlogging of the soils and underlying geology.

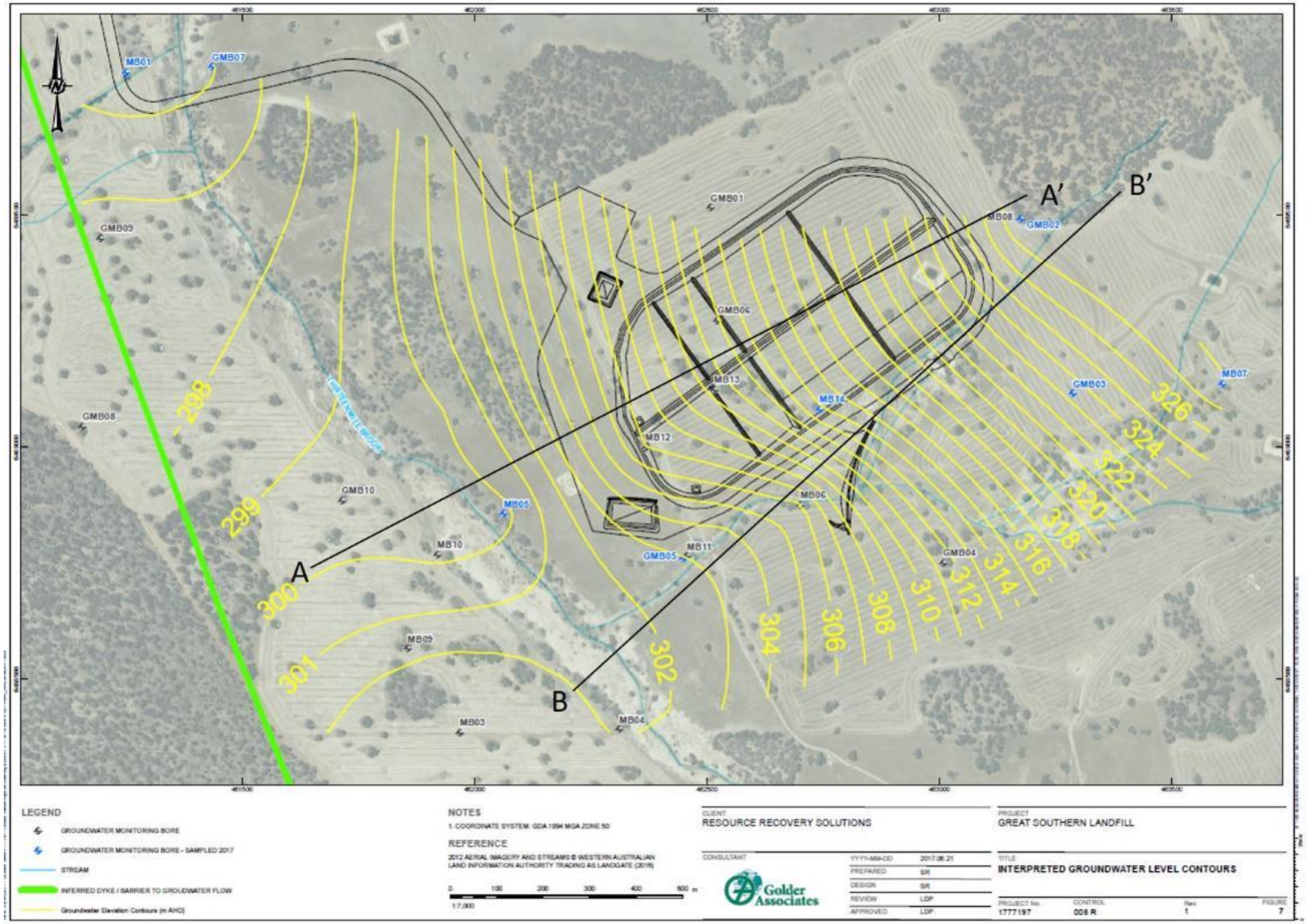


Figure 6: Groundwater levels June 2017

2.1.4.3 Aquifer properties

Slug testing has been carried out in nine of the 22 monitoring bores installed at the site. The results are summarised in Table 4 below. This involved installing an automatic water level logger into the test bore and introducing or removing a slug or bailer of known displacement volume, into and out of the bore. The resulting displacement in water level was recorded and analysed using proprietary hydraulic test analysis software (Aqtesolve) to provide an estimate of the hydraulic conductivity (K) of the screened and/or gravel packed, saturated interval (test interval).

Hydraulic conductivity for these groundwater monitoring bores ranges across three orders of magnitude, from 0.02 m/d to 3.0 m/d. Based on the characterisation of hydrogeological units in Table 3, the following observations can be made:

- Unit 1 – no data for hydraulic conductivity, K. Unit 1 is believed to be mostly unsaturated, with intermittent subsurface flow following rainfall.
- Unit 2 – bores screened in this material are generally screened across lower Unit 1/upper Unit 2, including MB01, MB03, MB06, MB07. The K range for Unit 2 is of 0.02 m/d to 0.6 m/d.
- Unit 2a – GMB05 is screened in this deeper, sandy material with a K range from 1.9-4.5 m/d. GMB06 is also screened across a sandy profile (?Unit 2a), also across clay (possibly Unit 2) and sand overlying granite (Unit 3), with a K of 0.3 m/d.
- Unit 3 – bores in this material are screened across the overlying clay (Unit 2) into the gravelly 'saprock' (Unit 3) (GMB02, GMB03, GMB04) with K range from 0.1 to 0.6 m/d.

Table 4: Slug-test analysis hydraulic conductivity (K) range for individual bores (from Golder, 2017c)

Monitoring Bore	Material in Test Interval	K Range (m/day)
MB01	Gravelly Clay and Gravelly Sand*	0.03-0.5
MB03	Sandy, Silty, Clay*	0.1
MB06	Gravelly, Sandy, Clay*	0.02-0.6
MB07	Sandy Clay and Gravelly, Sandy Clay*	0.02-0.6
GMB2	Sandy Clay/Sandy Clayey Gravel	0.1-0.2
GMB3	Sandy Clay/Sandy Gravel	0.3-0.5
GMB4	Clayey Sand/Gravel	0.4-0.6
GMB5	Sand/Gravel	1.9-4.5
GMB6	Clayey Sand/Sandy Clay/Sand	0.3-0.3

Notes: *ENV sample descriptions based on grab samples and may not be representative of drilled intervals.

2.1.4.4 Recharge to aquifers

Rain falling on sandier, more permeable materials will infiltrate vertically to the watertable whereas rain falling on more clayey materials will either infiltrate slowly through low permeability clays, gravity flow in the subsurface within Unit 1, or perch on the less-permeable material. For this reason, after rainfall, some locations at the site may appear damp or boggy until the transient shallow groundwater attenuates and groundwater levels decline due to a combination of vertical infiltration and lateral migration.

2.1.4.5 Groundwater chemistry

Groundwater chemistry has been discussed in detail in Golder (2017a) and will not be discussed in this section of the report. However, some points will be included in discussion of impacts to surface water and groundwater systems to allow comparison of the groundwater baseline chemistry to possible leachate contaminants.

2.1.4.6 Surface-groundwater interactions

Water logging and groundwater seepage has been observed near the unnamed tributary that flows into Thirteen Mile Brook, south of the landfill site. Section B-B' (Figure 5) shows the potentiometric surface is very close to or slightly above ground level in bores MB11 and GMB05, indicating locally confined or semi-confined conditions. However, during drier months, no groundwater has been reported at surface in this location, thus any seepage from the groundwater system is likely to be slow. Therefore, the waterlogging at ground level, reportedly observed following rainfall and streamflow, is likely to be from surface water runoff and surface ponding following rainfall.

The groundwater connectivity between Thirteen Mile Brook alluvial materials and the aquifers within the weathered profile on the valley slope are unclear. Groundwater levels in bores MB04, MB05, MB10 near the Brook are around 0.5 m to 1 m below ground level, and lithology in these bores is mostly clays underlying a 0.5 m to 2 m thick gravelly sand at the surface. The hydraulic gradient in Thirteen Mile Brook lessens and groundwater flow appears to follow the valley floor, thus it is possible that the deeper weathered profile aquifer (Unit 3) discharge by slow, upward seepage through the clays (Unit 2) at the interface with the Brook, and a shallow alluvial system exists within the alluvial sediments beneath Thirteen Mile Brook. However, it is likely there is some interconnection to the alluvial groundwater system through sandier materials within the weathered profile (Unit 2a) encountered in bores GMB05, GMB06.

2.1.4.7 Environmental receptors and other groundwater users

Thirteen Mile Brook is within the Avon River Catchment, flowing into the Avon River at Spencers Brook township via Warranine Brook and Spencers Brook. River pools of the Avon River are priority assets to be managed within the greater Avon Catchment (DoW, 2007). Downstream of Spencers Brook town, several pools including Northam Pool, Katrine Pool, and Glen Avon Pool are noted for ecological and social value. Key management priorities for these pools are improving water quality by reducing total Phosphorus (sediment and water), reducing sediment transport within the catchment, and managing salinity. These priorities are proposed to be used as the guiding principles for managing water quality at Allawuna Farm.

A search of the Atlas of Groundwater Dependant Ecosystems (Bureau of Meteorology – online) shows Helena River as an identified GDE approximately 6.5 km to the south-west of the site. The groundwater system beneath the proposed landfill site is contained within the Avon River catchment and is unlikely to be connected to Helena River. Aquifers within the weathered profile above Archaean granites of the Yilgarn Craton are generally constrained by surface water catchment boundaries. Crystalline basement has topographic highs and lows that also mimic present-day topography. In addition, Thirteen Mile Brook sits atop of a large magnetic anomaly believed to be a regional dyke striking north (Golder, 2017c). This dyke is very likely to be a barrier to westerly groundwater flow within the basement rocks.

The results of a search of the (former) Department of Water's borehole databases indicates that there are no groundwater bores reported to exist within the Thirteen Mile Brook catchment, in the vicinity of the proposed landfill (Golder, 2017c).

2.2 Post – landfill contamination risk assessment for groundwater and surface water systems

2.2.1 Site description for proposed landfill

The proposed landfill is situated on the eastern valley slope of the Thirteen Mile Brook sub-catchment (Figure 6). The landfill cell design has been revised slightly since the previous works were carried out, and the revised layout is described in Golder (2017a) and shown in Figure 7. The design for this landfill is described in Golder (2017a) in detail with reference to supporting documents, and a summary of the features relevant to managing impacts to environmental receptors and groundwater is provided here. The key elements of the landfill design are:

- Design is guided by best practice as outlined in the Victoria EPA Publication 788.3 (EPA, 2015).
- Cell design incorporates:
  - elevated floor elevation in cells to ensure a minimum separation of 2 metres from the sump to maximum predicted groundwater level,
  - subsurface drainage system,
  - multi-layer liner including compacted 500 mm thick subgrade, geosynthetic liner incorporating geosynthetic clay liner, HDPE geomembrane and cushion geotextile,
  - perimeter embankment surrounding the landfill cells and stormwater management bunding to divert stormwater away from landfill cells, and
  - leachate collection system comprising sidewall drainage layer, base drainage layer, leachate collection pipes and leachate collection sump.
- Leachate pond lined and constructed upstream of the landfill to store collected and pumped leachate.
- Subsurface (groundwater) drainage system (trenches, drains, and sum) beneath landfill to ensure subsurface groundwater levels are kept at least 2 m from the base of the landfill.
- Retention pond to collect subsurface (groundwater) drainage.
- Stormwater managed via diversion bunding, diversion into stormwater dam and sediment controlled using a sediment control device downstream of the stormwater dam.

These features have been included in the landfill design to ensure groundwater, surface water and leachate are separated, and leachate is contained within the landfill site. The design life of this landfill is up to 37 years.

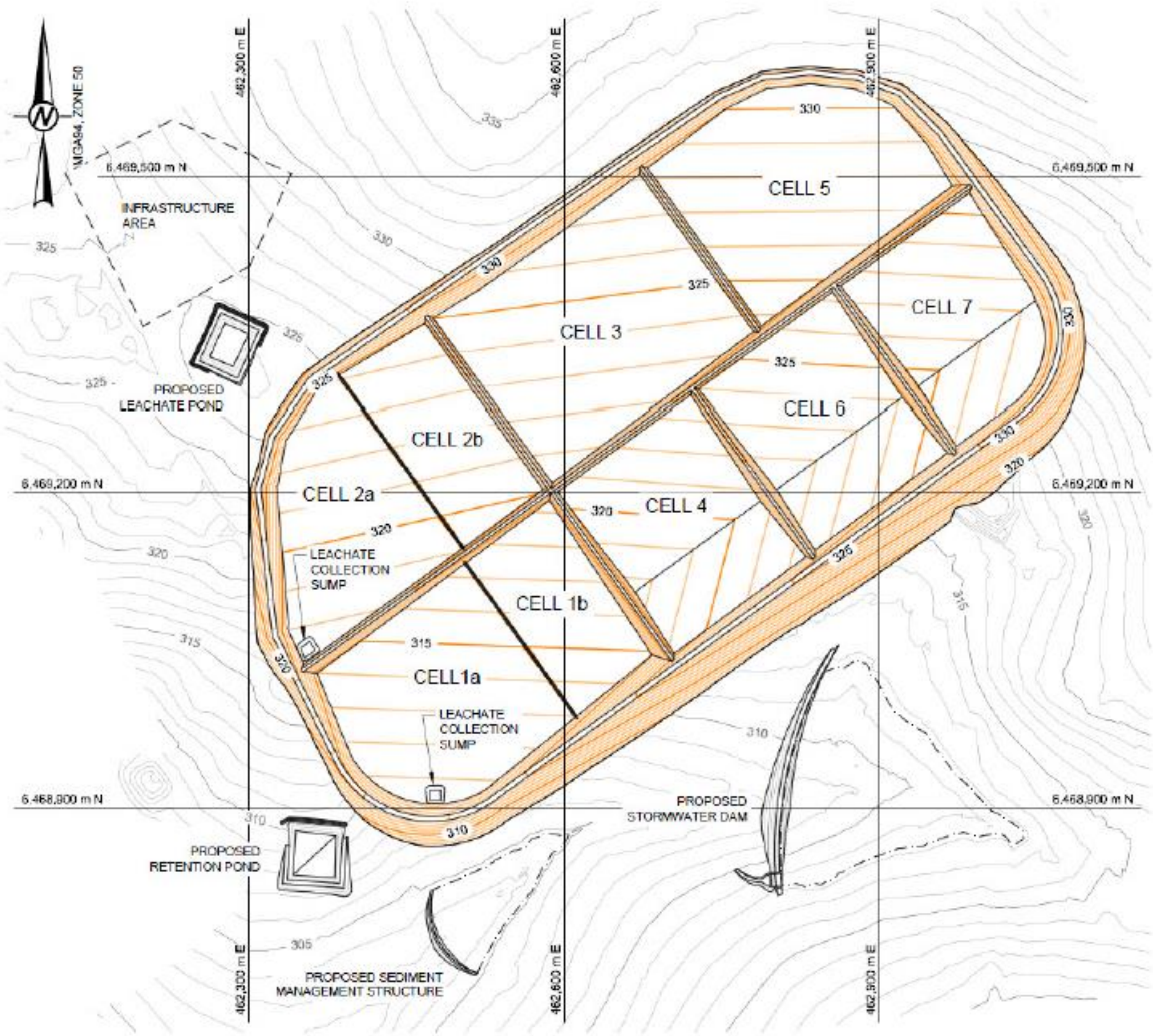


Figure 7: Layout of Great Southern Landfill cells and ancillary works

2.2.2 Groundwater quality

Golder (2017b) has undertaken analysis of groundwater chemistry for discrete groundwater sampling events in 2014 and 2017. The groundwater beneath and surrounding the proposed landfill site is acidic with pH range from pH 3.2 to pH 6.0. The electrical conductivity (EC) ranges from 1,300 µS/cm to 30,600 µS/cm and the water is classified as brackish to saline. The EC in approximately half of the monitoring wells (GMB2, GMB5, GMB7, MB01, MB06, MB08, MB10, MB11, MB13 and MB14) is an order of magnitude higher than the EC measured in remaining monitoring bores.

Groundwater is sodium-dominant with sodium (Na) ranging from 450 mg/L to over 4,400 mg/L. Magnesium is the second highest cation concentration ranging from 30 mg/L up to 1,300 mg/L in some bores. Potassium (K) is typically low across the site, mostly less than 50 mg/L. The exception being GMB2, where potassium is less than 80 mg/L. Dissolved metals were measured in selected bores and arsenic (As), boron (B), cadmium (Cd), chromium (Cr) III and VI, copper (Cu), lead (Pb), manganese (Mn), nickel (Ni) and zinc (Zn) range from 0.1 mg/L to 0.8 mg/L. Many of the analytes were below detection limits in samples.

Chloride (Cl) is the dominant anion ranging from 710 mg/L to 11,300 mg/L, followed by sulfate (SO_4), with SO_4 ranging from 80 mg/L to 800 mg/L. Bicarbonate and carbonate are below detection in most bores. Total nitrogen generally ranges from 0.1 mg/L to 5 mg/L. Nitrate (NO_3) is high in bore GMB3 up to 4 mg/L, but speciation of nitrogen seems mixed in other bores between nitrate and ammonium (NH_4) and concentrations of both anions are generally 0.1 mg/L to 0.2 mg/L.

The groundwater quality results were compared with Department of Health Domestic non-potable groundwater use criteria, ANZECC Livestock low risk trigger values, and ANZECC Long term irrigation water criteria (Golder, 2017c). Dissolved metals boron, cobalt, manganese and zinc exceeded the ANZECC long-term irrigation criteria in some bores. This is likely due to naturally higher concentrations of these metals in groundwater rather than anthropogenic inputs. Total phosphorus also exceeded the long-term irrigation criteria in one sample from bore GMB07, an order of magnitude higher than any other sample.

The median EC of groundwater at the site is 18 mS/cm and the median chloride concentration is 6,130 mg/L, which excludes use for potable (drinking) and non-potable domestic use. Most livestock can only tolerate water with ECs of up to 10 mS/cm, but this value is less for poultry and pigs. Groundwater can be used for irrigation where the EC is as high as 6 mS/cm, with values of up to 10 mS/cm acceptable for short-term emergency use. No beneficial use for groundwater at the site has been identified.

Groundwater samples were also analysed for potential organic contaminants including polycyclic aromatic hydrocarbons, monocyclic aromatic hydrocarbons, total recoverable hydrocarbons, organochlorine and organophosphorus pesticides, solvents, volatile organic compound and halogenated benzenes. With the exception of total recoverable hydrocarbons, the analysis did not detect any of these organic compounds. Only two of the 60 samples (one sample each from MB07 and MB14) collected from 22 bores across the site recorded total recoverable hydrocarbons. These two detections both occurred during the March 2017 sampling round and, in each case, the subsequent (June 2017) sampling round did not detect total recoverable hydrocarbons in either well. The detections of TRH recorded in March 2017 may be due to contamination during sampling/transport and follow up sampling should be undertaken to confirm this.

2.2.3 Leachate water quality

An analysis of leachate from two other landfill sites in Western Australia has provided an understanding of likely leachate hydrochemistry (Golder, 2019 *in prep*). The leachate is saline, up to 13,700 mg/L for a mature landfill (~11 years) with potassium the dominant cation up to 1,300 mg/L and chloride dominant anion up to 4,590 mg/L. Leachate is generally high in nitrogen, sodium, and iron. Several other notable characteristics are summarised below.

- Low dissolved oxygen (<1 mg/L), high chemical oxygen demand exceeding 6,500 mg/L, indicating anaerobic conditions.
- pH neutral to slightly alkaline ranging pH 7.4-8.4.
- Dominant metal include iron (max 19 mg/L), with detectable levels of As, Cd, Cr(III, VI), Cu, Pb, Mn, Ni and Zn generally ranging from less than 0.1 mg/L to 0.8 mg/L.
- Total nitrogen up to 3,400 mg/L with ammonia as the dominant species, low nitrate and nitrite.
- No phosphorus data was provided.

Several organic chemicals were detectable within the leachate samples (Table 5).

Table 5: Organic carbon compounds detected in leachate water samples from two putrescible waste landfills in Western Australia (Golder, 2019 *in prep*)

Chemical Group	Chemical Name	Minimum concentration ug/L	Median concentration ug/L	Maximum concentration ug/L
Organic	TRH C6 – C9 Fraction	500	500	930
	Methane	21	3,690	7,150
Organochlorine pesticides	Dieldrin	0.025	0.7	0.7
BTEX	Benzene	1	4	10
	Toluene	1	58.5	210
	Ethylbenzene	1	52.5	130
	Xylene (o)	1	48	92
	Xylene (m & p)	2	95	350
	TRH C6-C10 less BTEX	0.025	0.3275	1.3
	Naphthalene	1	7	10
VOC	1,2,4-trimethylbenzene	52	60.5	69
	Isopropylbenzene	3	3.5	4
	Styrene	2	4	6
	1,3,5-trimethylbenzene	14	16	18
	2-butanone (MEK)	10	35	60
	Acetone	40	50	60
	Chlorobenzene	1	2	3
	cis-1,2-dichloroethene	2	2.5	3
	Dichloromethane	2.5	2.5	2.5
	p-isopropyltoluene	99	105	111

2.2.4 Analysis of impacts to surface water, groundwater, and environmental receptors

An analysis of potential impacts to surface water, groundwater and environmental receptors is outlined below using the **SOURCE – PATHWAY – RECPTOR** model. Leachate chemical properties that are likely to impact the environment are described in the section above. These include salinity, nutrients, metals, organo-carbon compounds, and are assumed to be relevant to all systems. Other potential impacts arise from point source contamination due to landfill operations, changes in water levels resulting from seepage, and erosion and sediment runoff entering the environment as a result of ineffective stormwater management.

SOURCE: A number of potential sources of contamination exist at the proposed landfill site:

- Leachate seepage from landfill into underlying soil and groundwater.
- Leachate seepage or overflowing from leachate pond.
- Leachate mixing with stormwater.
- Contaminants point source: operations (e.g. vehicle washdown, refuelling).
- Erosion and sediments (possibly containing nutrients) entering the surface water system/aquatic environment.

PATHWAY: Source contaminants may enter the natural environment through the following pathways:

- Seepage through the liner beneath the landfill into the groundwater system or retention pond.
- Overflow due to a severe rainfall event overtopping leachate pond into the surface water environment.
- Use of potentially contaminated water from the retention pond for operations (e.g. dust suppression).

RECEPTOR: Several receptors have been identified.

- Thirteen Mile Brook, and greater Avon River surface water and aquatic ecosystems.
- Alluvial groundwater system beneath Thirteen Mile Brook.
- Aquifers and unsaturated soils/geology directly beneath and (mostly) downgradient of the landfill site.
- Flora and fauna surrounding the landfill site (not discussed here).
- Other groundwater users (none identified in the vicinity of Great Southern Landfill).

2.2.5 Discussion of potential impacts to receptors

2.2.5.1 Surface water

The key surface water and environmental receptor is Thirteen Mile Brook and greater Avon River surface water and aquatic ecosystems. Leachate from the proposed landfill may enter these systems via subsurface seepage from beneath the landfill into the surface water system, leachate entering via stormwater runoff, or inadvertent introduction of contaminated water into the environment.

In addition to the physical environment, flora and fauna may be directly or indirectly impacted by leachate contaminants. Leachate water chemistry is likely to be dominated by organic carbon, ammonium (NH_4), potassium (K), and chloride (Cl) ions. Potentially toxic metals including As, Cd, Cr (III, VI), Cu, Pb, Mn, Ni and Zn, and a range of organo-carbon compounds, may impact the natural environment or persist in groundwater systems. Contaminants from point-sources are likely to be predominantly organo-carbon compounds. Impacts to flora and fauna may arise due to toxicity, environmental harm arising from salinity or nutrients entering waterways, or poisoning due to organo-carbon compounds.

The key identified risk to the surface water system is from leachate seepage entering the subsurface and creating a seepage front below the proposed landfill site and into Thirteen Mile Creek, discussed below.

2.2.5.2 Groundwater

There are two groundwater systems, possibly connected that have potential to be impacted by the proposed landfill. The first is the weathered profile beneath the site, and the second is the shallow alluvial groundwater system believed to exist directly beneath Thirteen Mile Brook. Leachate and other contaminants may enter these systems by any of the three identified pathways. Groundwater from these systems may be used by others, or end up interacting with groundwater dependent ecosystems, flora, and fauna.

Groundwater mounding beneath the proposed landfill site may present a risk to surface water and environmental receptors. If seepage were ongoing, unsaturated Unit 1 (sands, gravels) beneath the landfill may become saturated and create leachate seepage at the ground surface, west to south-west of the proposed landfill. This would present a source of enriched leachate just upslope of Thirteen Mile Creek. Any contaminants within the leachate would likely be flushed into the creek via runoff and potentially direct seepage.

Groundwater quality within the aquifers may be impacted by contaminants from the site including leachate, sediments, and point source contaminants. Leachate water may contain organic carbon chemicals, ammonium (NH_4), potassium (K), and chloride (Cl) ions. In addition, potentially toxic metals including As, Cd, Cr(III, VI), Cu, Pb, Mn, Ni and Zn, and a range of organo-carbon compounds may impact the natural environment or persist in groundwater systems. Contaminants from point-sources are likely to be predominantly organo-carbon compounds.

3.0 ITEM 35 – MODELLING OF GROUNDWATER FLOW AND SOLUTE TRANSPORT USING CONSIM

3.1 Introduction

The EPA requested an analysis of groundwater flow and solute transport to evaluate likely contingency actions. Golder has assessed the currently available information for the proposed landfill and determined a suitable simulation approach to model the groundwater system and demonstrate what contingency actions can be effectively implemented.

ConSim was utilised to model flow and solute transport through the unsaturated zone and groundwater system for key parameters ("contaminants of concern"). Following on from the hydrogeological and hydrological discussion above, it is apparent there are several leachate parameters that may be harmful to the environment or potentially contaminate aquifers and surface water systems. Whilst landfill design strives to minimise impacts of leachate and contaminants entering the natural environment, there is nonetheless a very low to low probability of environmental impact.

These are likely to occur where:

- Leachate seeps from the lined cells entering the groundwater and/or surface water systems, introducing new contaminants.
- Point source contamination enters the soil, groundwater, and/or surface water system.

Golder has focussed the ConSim modelling on landfill contaminants (aqueous chemical parameters) that pose risks to the downstream environment, likely to be highly mobile and behave conservatively within aquifer systems (i.e. not undergo retardation while migrating), and are at concentrations that are above baseline levels.

The chemical parameters identified are Ammonia (as N), Potassium and Sodium. Measured (median) groundwater concentrations and estimate landfill leachate (median) concentrations are presented in Table 6. Nitrate and chloride were also considered but their median leachate concentrations are lower than median groundwater concentrations. Other possible contaminants are soluble metals and organo-carbon compounds but these are likely to be highly degraded when migrating in the subsurface. The modelling undertaken provides a 'worst-case' evaluation of aqueous solute transport to inform contingency planning.

Table 6: ConSim: Measured and estimated values for chemical parameters

Parameter	Groundwater (median) (mg/L)	Leachate (median) (mg/L)
Nitrate as N	0.14	0.03
Ammonia as N	0.5	2,500
Sodium	2,010	2,200
Potassium	23.5	960
Chloride	6,130	3,350

3.2 ConSim overview

ConSim is purpose-built software for assessing risk posed to groundwater by leaching contaminants, developed in the United Kingdom (by Golder) to support the UK Environment Agency's risk-based assessment of potential for groundwater contamination. The software has been validated/verified over many years and has been utilised globally. It models contaminant mobilisation and transport along 1D plane with superposition of estimates across a 2D area, utilising commonly available site investigation data for soil, aquifer, and contaminants.

ConSim is a probabilistic model that uses the Monte Carlo simulation technique to select values randomly from each parameter range for use in the calculations. Repeating the calculations many times gives a range of output values, the distribution of which reflects the uncertainty inherent in the input values. This approach enables the user to determine the likelihood of the output values being realised. The probabilistic methodology allows full incorporation of data uncertainty and natural variability. The analysis of uncertainty and variability in data can assist in informing future investigation and monitoring.

3.2.1 Flow and solute transport model development

A "Level 3a" modelling approach was utilised whereby set leachate concentrations were assumed enter the subsurface beneath Cells 1 and 2 of the landfill (shown with "blue hatching" in Figure 8). Receptor nodes were established along the creek line (representing Thirteen Mile Brook), downstream of the landfill to assess groundwater concentrations at the creek line and solute migration travel times.

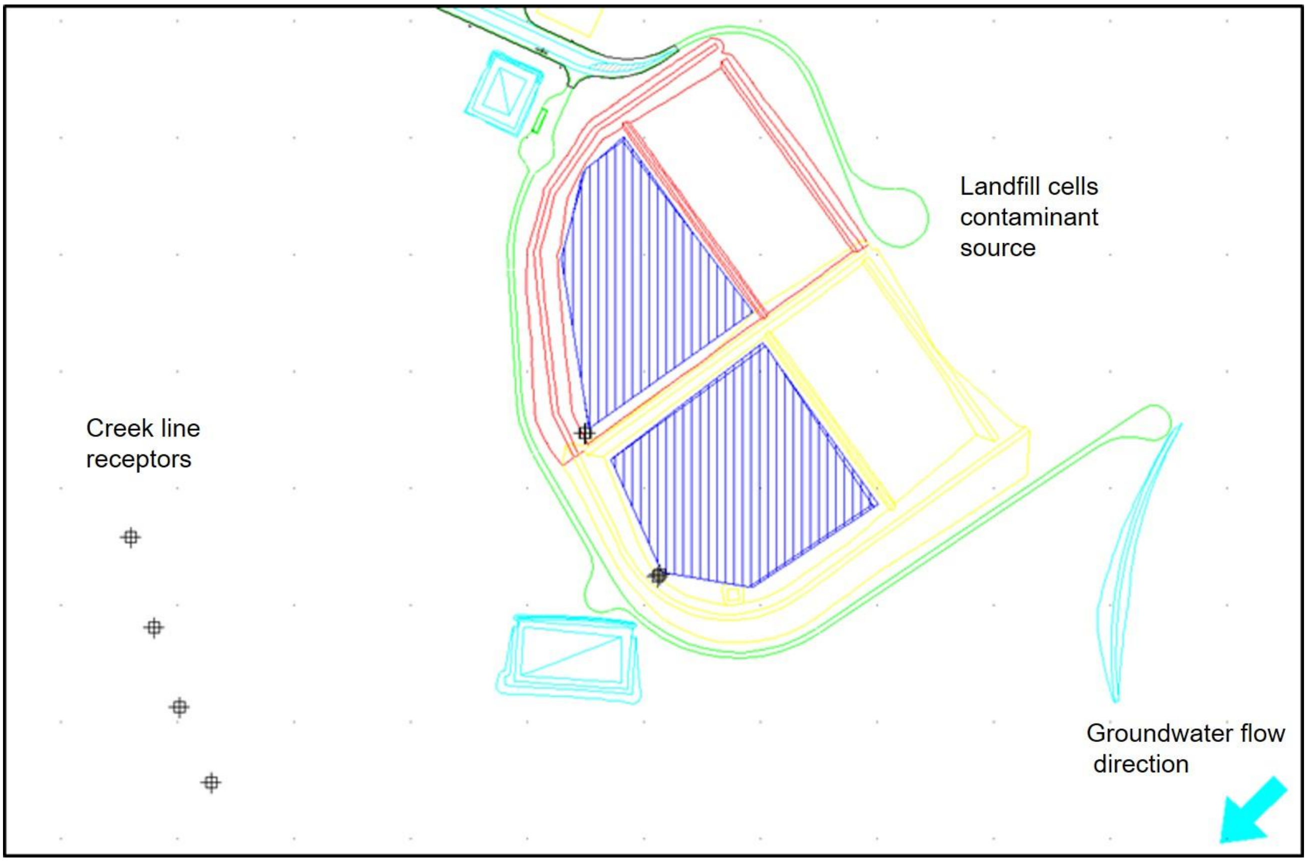


Figure 8: ConSim Model Layout

The leachate contaminants are assumed to instantaneously enter the underlying hydrogeological unit (vertically) and migrate laterally and not undergo retardation or biodegradation. The site conceptualisation identifies that the key migration pathway (for potential seepage from the landfill) is the uppermost soil/lateritic duricrust (“sand”) horizon above a confining clay layer. This sand horizon is mostly unsaturated.

Chemical parameters for baseline groundwater and leachate, for Ammonia as N, Potassium and Sodium as presented in the above table, were used. Key model (physical) parameters adopted are presented in Table 7.

Table 7: ConSim: Assumed Physical Parameters

Parameter	Assumed Value
Aquifer Thickness (m)	3.0
Effective Porosity	20%
Median Hydraulic Conductivity	2.3×10^{-6} m/s
Measured Hydraulic Gradient	0.023 (to south-west)
Longitudinal Dispersivity	36 m (10% of flow path from source to receptor)
Lateral Dispersivity	3.6 m
Infiltration Rate	300 mm/year (conservatively high assumption)

3.2.2 Output results

The model results include estimates of concentrations for the key contaminants of concern (at the creek line receptors) and durations for these contaminants to reach the creek line.

Un-retarded travel times for the contaminant plumes to the creek line are similar for each of the chemical parameters tested and show that there is a >95% confidence that the centroid of the contaminant plume is likely to reach the creek after 45 years (Figure 9 to Figure 11).

Contaminant breakthroughs, the initial time when concentrations for chemical parameters begin to rise, are similar for Potassium, Sodium and Ammonia as N (Figure 12 to Figure 14). The results indicate that the contaminant plume migrates slowly and would travel a distance of 360 m over a period of 20 years before it would reach the creek receptor.

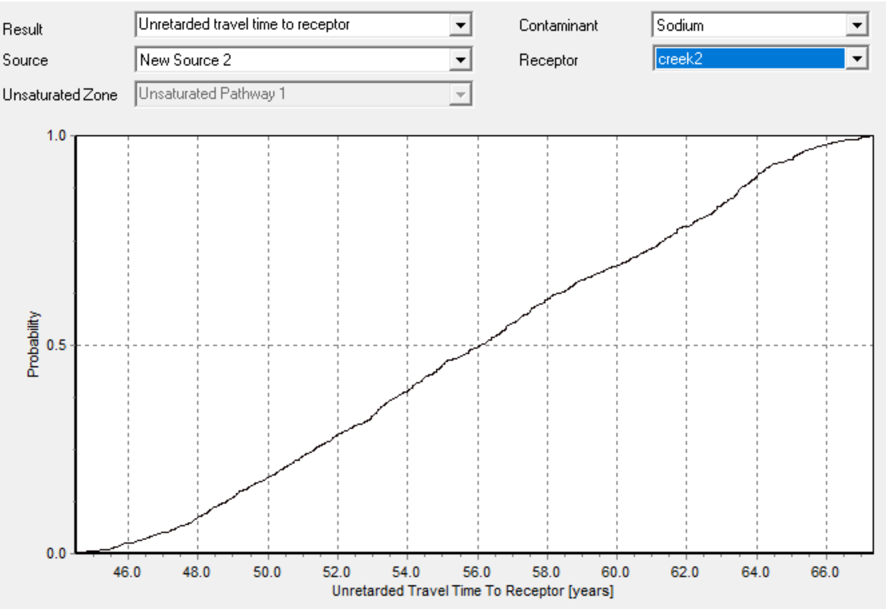


Figure 9: Travel time for Sodium contaminant plume to creek line

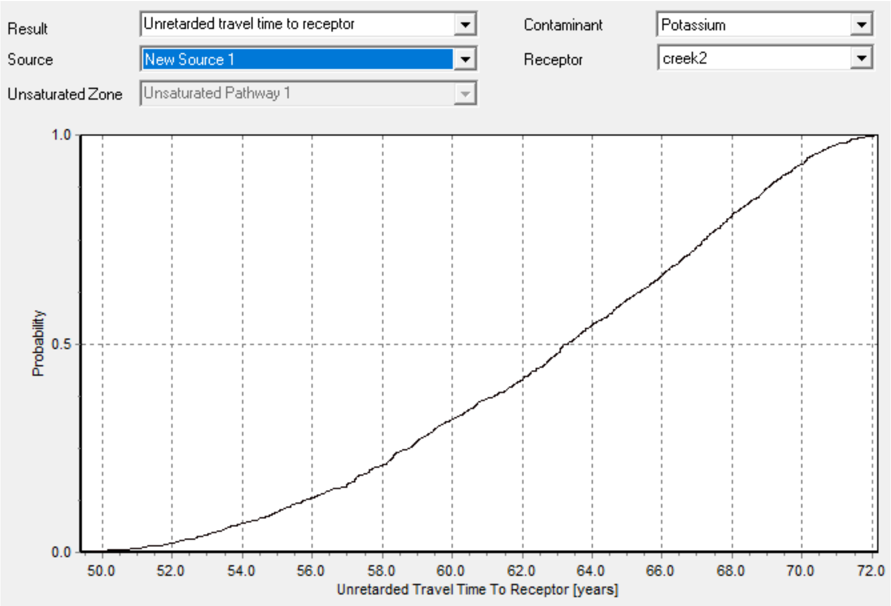


Figure 10: Travel time for Potassium contaminant plume to creek line

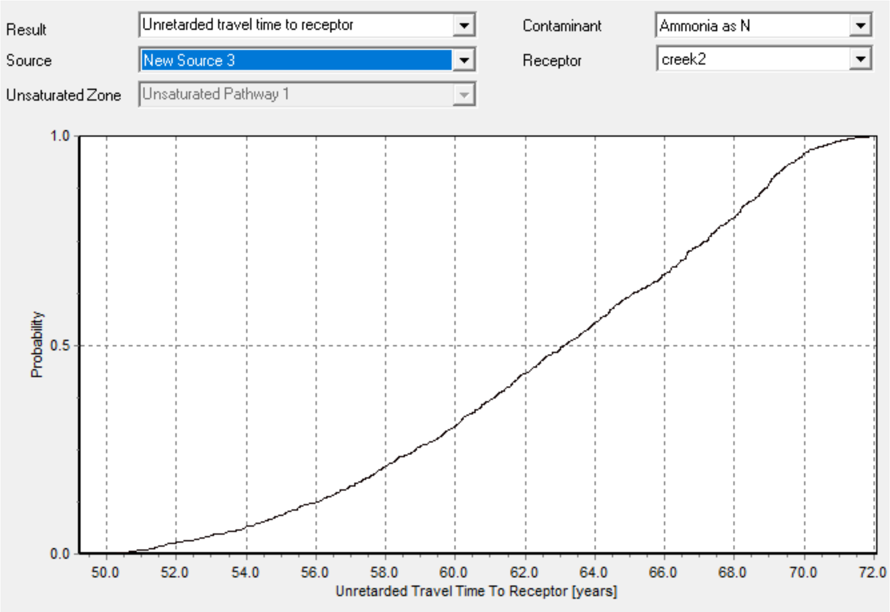


Figure 11: Travel time for Ammonia as N contaminant plume to creek line

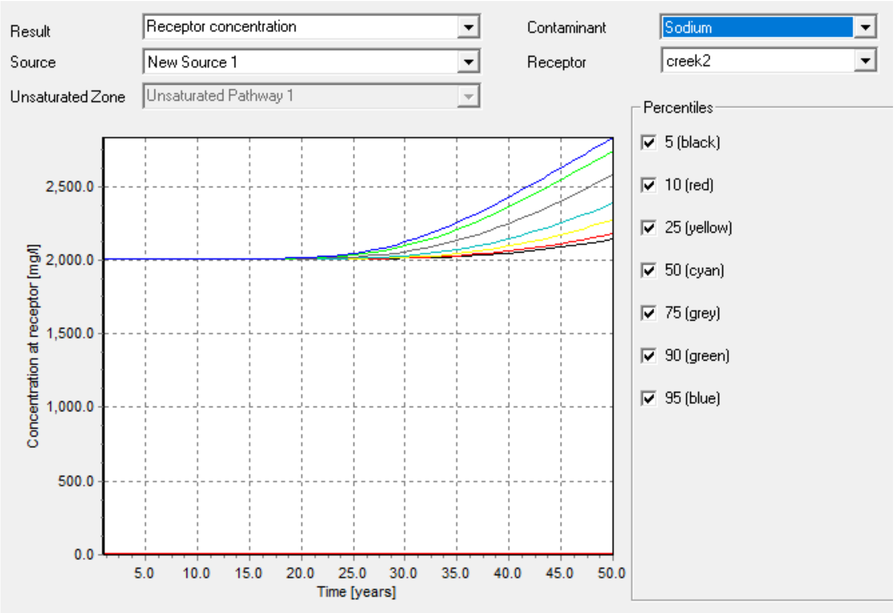


Figure 12: Model predicted receptor concentrations for Sodium

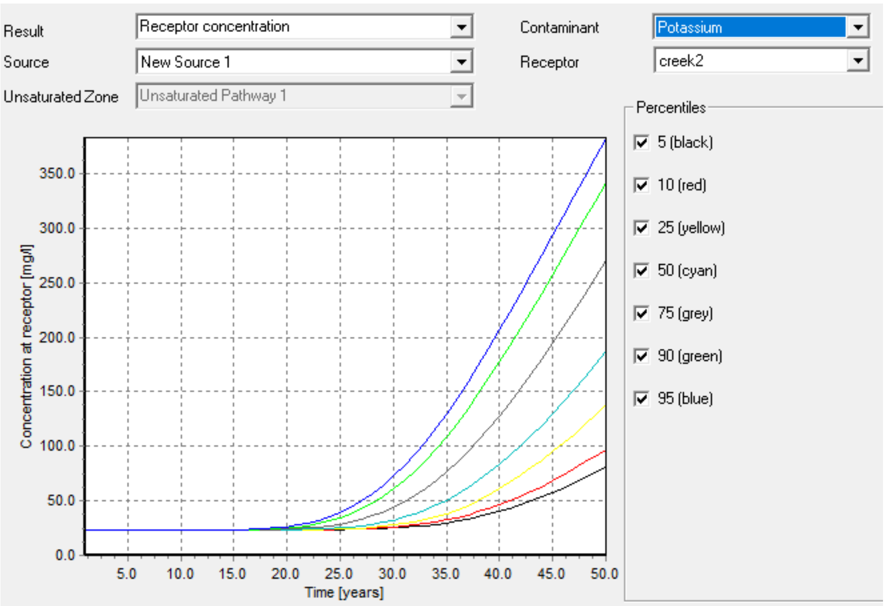


Figure 13: Model predicted receptor concentrations for Potassium

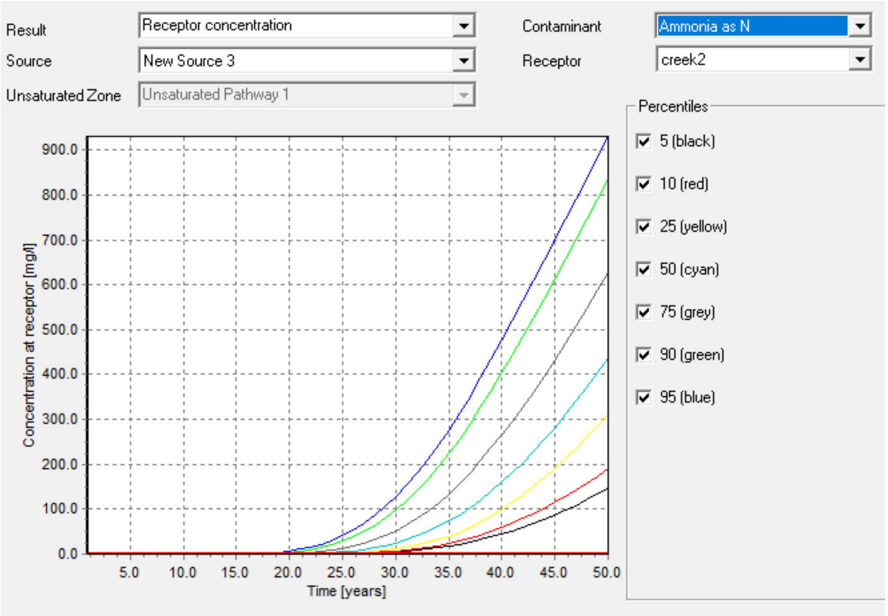


Figure 14: Model predicted receptor concentrations for Ammonia as N

3.2.3 Key findings

Leachate from the landfill would likely partly or fully saturate the upper sand hydrogeological unit that exists at the site. This unit is mostly unsaturated and could therefore not be considered to be an "aquifer", in the sense that it could be used as the basis for a water supply.

Leachate would migrate to the south-west, where it would likely discharge to alluvial sediments beneath the creek line. These sediments are considered the key environmental receptor to landfill seepage, in the unlikely event it was to occur.

The results of the ConSim modelling indicate that un-retarded contaminant plumes (Potassium, Sodium and Ammonia as N) would take more than 20 years to reach this creek line receptor. Groundwater monitoring should be implemented downstream of the landfill to detect if seepage were to be occurring. Given the very slow rates of contaminant migration, a seepage recovery system could be readily established, if it is deemed necessary before the contaminant plume would migrate a considerable distance from the landfill. The lack of saturated thickness within the upper sand pathway, and its shallow depth, would likely mean that seepage recovery would be more effective by way of an interception trench with sumps.

4.0 ITEM 36 – CONTINGENCY ACTION PLAN FOR PREVENTING CONTAMINATED WATER MIGRATION INTO AQUIFERS

4.1 Managing identified risks to groundwater and surface water systems and environmental receptors

The most likely risk to groundwater and surface water systems and environmental receptors arise from leachate escaping the landfill cells, point source contamination, and sediments entering the surface water system.

The Great Southern Landfill design report (Golder, 2017a) outlines the detailed planning and design requirements that will ensure containment of leachate within the cells and this is not discussed here. Recommended monitoring of groundwater and stormwater management ponds is however included in the contingency plan. Likewise, the Surface Water Management Plan (Golder, 2015b) discusses separation of leachate/stormwater and management of erosion and sedimentation so this is not discussed here. Similarly addressing point source contamination and impacts to flora and fauna is outside the scope of this assessment. However, some monitoring of surface and groundwater systems is recommended to monitor for point source contaminants and is included in the monitoring plan.

The identified potential impacts, environmental management outcomes and proposed management strategies are summarised in Table 8 below. In order to manage these potential impacts, regular monitoring, sampling, and analysis of surface water and groundwater is necessary to ensure early detection of contaminant sources and activation of a contingency plan. The recommended monitoring, sampling, and analysis is outlined in Table 9. Surface water and groundwater monitoring and sample results will be compared with established water quality guidelines. The recommended guidelines for surface water quality is the 'Australian and New Zealand Guidelines for Fresh and Marine Water Quality Volume 1' (ARMCANZ and ANZECC, 2000). For groundwater the recommended guidelines are ANZECC 2000 Freshwater Slightly-Moderately Disturbed Ecosystems; the Department of Health, Non-Potable Groundwater Use Criteria; and the ANZECC and ARMCANZ 2000 Long-term irrigation criteria.

The environmental objective for surface water is to have no measurable impact on the surface water quality in Thirteen Mile Brook or the groundwater quality beneath the site. The groundwater environmental objective is to ensure contaminants do not enter the aquifers beneath the landfill, or downstream into the alluvial aquifer. If any of the environmental objectives are identified as at risk of not being met, a contingency action may be required. The proposed contingency plan for managing risk to surface and groundwater systems and environmental receptors is summarised in Table 10. A regular monitoring and sampling program for surface water and groundwater will alert to a potential impact to these systems. Surface water and groundwater sampling are to be conducted in accordance with the relevant Australian Standards, referenced below.

The contingency plan for groundwater and surface water quality guideline exceedances includes the following:

- Identify the type of contamination
- Review assessment criteria applicability
- Identify the contamination source
- Assess the immediate and long-term risk
- Isolate the contamination source
- Report contamination to DWER within an agreed timeframe
- Determine if recovery of seepage-affected groundwater or treatment or remediation is required
- Undertake groundwater monitoring following treatment/remediation
- Review management measures
- Potentially amend management measures.

Several potential remediation measures have been included in Table 10. Remediation may include one or more of the following:

- Isolation or removal of the contamination source
- Installation of a cut-off trench or sumps to recover groundwater
- Additional investigation and/or monitoring to better define a potential risk.

If contingency action is required, it will be necessary to tailor it to the situation. Thus at this stage, detailed design of the remediation options listed above is not warranted. The results of the ConSim modelling suggest that a shallow cut-off trench and/or sump arrangement would be the most practical method to recover seepage affected groundwater.

5.0 CONCLUSIONS AND RECOMMENDATIONS

This memo provides a summary of key hydrogeological information required to support Alkina Holdings Pty Ltd environmental scoping document for items 29e, 35 and 36. These items include hydrological and hydrogeological site characterisation, two-dimensional groundwater flow and solute transport modelling of potential contaminants, and recommendation for groundwater and surface water monitoring.

The hydrology and hydrogeology conceptualisation is fit-for-purpose and provides, with confidence, a suitable assessment of local conditions. If the proposed landfill goes ahead, future work is recommended to improve understanding in a few areas and to expand the groundwater monitoring network. The lateral connectivity between the alluvial aquifer beneath Thirteen Mile Brook and the weathered profile overlying the granite bedrock is not well-understood. If further conceptualisation of groundwater flow is required (e.g. for contaminant transport modelling), it is highly recommended to investigate and map the interconnection of the two systems and undertake additional analysis of hydraulic conductivity of the various lithological units using specifically designed groundwater monitoring wells screened in discrete aquifer layers (e.g. Unit 2, Unit 3). At this stage, Golder considers it unnecessary to re-evaluate any aquifer parameters or hydrogeological conceptual model.

The current groundwater monitoring network is considered sufficient to broadly map groundwater levels and provide local information on groundwater quality in the interim. During construction several groundwater monitoring bores will be lost (e.g. MB12, MB13, MB14, GMB06). If the proposed landfill proceeds to construction, a review of the appropriateness of the remaining bores and installation of new monitoring bores is recommended for future monitoring of the landfill to a) detect contaminants entering the groundwater system down-gradient of the landfill and b) to provide groundwater level and water quality monitoring data surrounding the landfill. This includes addition of bores between Thirteen Mile Brook and the west-north-west of the landfill embankment. It is also recommended to undertake a bore census and decommission any unusable groundwater bores.

Table 8: Managing impacts to surface water, groundwater and environmental receptors

Item	Identified Potential Impact to Groundwater/Surface Water/Environment	Environmental Management Outcome	Strategy to Meet Environmental Outcome	Reference to Other Management Documents
SW	**Surface Water**			
SW01	Leachate entering Thirteen Mile Brook from landfill site increasing nutrient load and salinity.	Prevent leachate seepage entering surface water system.	On-site management of leachate generation, capture, storage and removal. Monitor surface water quality (Table 9). Contingency actions identified (Table 10).	DoW (2007) as a guide to water quality objectives for Avon River catchment. Desktop environmental and social risk assessment (Golder, 2017b). Landfill Surface Water, Groundwater, and Leachate Management Plan (Golder 2015 report 147651033-015-R-Rev0)
SW02	Point source contaminants entering Thirteen Mile Brook.	Prevent contaminants entering surface water system.	On-site management of contaminants in stormwater. On-site management of operations involving use of chemicals and managing spills. Monitor surface water quality (Table 9). Contingency actions identified (Table 10).	Desktop environmental and social risk assessment (Golder, 2017b).
SW03	Sediment entrainment into Thirteen Mile Brook	Prevent sediments entering surface water system.	On-site management of stormwater. On-site erosion controls. Monitor surface water quality (Table 9). Contingency actions identified (Table 10).	Landfill Surface Water, Groundwater, and Leachate Management Plan (Golder 2015 report 147651033-015-R-Rev0) Section 4. DoW (2007) as a guide to water quality objectives for Avon River catchment

Item	Identified Potential Impact to Groundwater/Surface Water/Environment	Environmental Management Outcome	Strategy to Meet Environmental Outcome	Reference to Other Management Documents
GW	**Groundwater**			
GW01	Groundwater seepage below landfill cells 1, 4, and 6 degrading liner.	Prevent groundwater mounding arising from leachate seepage interacting with landfill liner.	Subsoil drainage system designed to lower groundwater levels beneath cells 1, 4, and 6. Raised base height of cells to be minimum 2.0 m from groundwater level. Groundwater recovery to retention pond (on-site reuse of water or disposal if contaminated). Monitor groundwater quality (Table 9). Contingency actions identified (Table 10).	Landfill Surface Water, Groundwater, and Leachate Management Plan (Golder 2015 report 147651033-015-R-Rev0) Section 5.
GW02	Leachate contamination to groundwater	Prevent leachate seepage entering aquifers.	Leachate management according to best practice (Vic BPEM (EPA, 2014). Monitor groundwater quality (Table 9). Contingency actions identified (Table 10).	Landfill Surface Water, Groundwater, and Leachate Management Plan (Golder 2015 report 147651033-015-R-Rev0) Section 6.
GW03	Point source contaminants entering groundwater.	Prevent contaminants entering groundwater.	On-site management of contaminants in stormwater. On-site management of operations involving use of chemicals and managing spills. Monitor surface water quality (Table 9). Contingency actions identified (Table 10).	Desktop environmental and social risk assessment (Golder, 2017b).

Table 9: Monitoring requirements for managing identified risks to environmental receptors

Monitoring Requirement	Monitoring/Sampling Point	Parameters for Analysis	Monitoring Frequency
Surface Water			
Collect baseline data for surface water quality.	Surface water sampling Thirteen Mile Brook (nearby and downstream locations to be identified)	Field pH, EC, TDS, TSS, N as NO_3, NH_4, nitrite, Total N. Salinity as TDS. Basic anions/cations.	Opportunistic – when flowing, preferably within the 'first flush' post-onset of rainfall.
Monitor surface water receptors for nutrients, salinity, sediments.	Stormwater dam, sediment retention dam, retention pond.	Field pH, EC, TDS, TSS, water level?	Monthly
		N as NO_3, NH_4, nitrite, Total N. Salinity as TDS. Basic anions/cations.	6-monthly
Monitor surface water receptors for contaminants.	Stormwater dam, retention pond.	Visual check for contamination (e.g. oily film, odour, colour, clarity etc. – site specific procedure to be developed)	Prior to water being taken from dam/pond.
		Hydrocarbons (suite dependent on site-specific analysis of on-site chemicals).	6-monthly
Groundwater			
Collect baseline data	MB04, MB05, MB06, MB10, MB11, MB12, GMB05, GMB03 MB13*, MB14*, GMB06* *bores may be destroyed during landfill construction.	Field pH, EC, water level.	Monthly
		Field pH, EC, water level. Salinity as TDS. Basic anions/cations.	6-monthly
Monitor groundwater bores for chemistry, nutrients, salinity, contaminants.	MB04, MB05, MB06, MB10, MB11, MB12, GMB05, GMB03 MB13*, MB14*, GMB06* *bores may be destroyed during landfill construction.	N as NO_3, NH_4, nitrite, Total N. Salinity as TDS. Hydrocarbons (suite dependent on site-specific analysis of on-site chemicals).	6-monthly

Table 10: Contingency action plan for managing risk to environmental receptors

Contingency Trigger	Management Criteria	Management Response	Potential Remediation Options
Leachate or other contaminants detected in surface water monitoring.	■ Surface water sampling is to be conducted in accordance with AS/NZS 5667.4 and water samples are to be collected and preserved in accordance with AS/NZS 5667.1. ■ Water quality must not exceed the surface water guidelines listed in the 'Australian and New Zealand Guidelines for Fresh and Marine Water Quality Volume 1' (ARMCANZ and ANZECC, 2000) or an alternative appropriate trigger.	If contamination of surface water/groundwater occurs, the following actions will be undertaken: ■ Identify the type of contamination ■ Review assessment criteria applicability ■ Identify the contamination source ■ Assess the risk ■ Isolate the contamination source ■ Report contamination to DWER within 48 hrs ■ Determine if treatment or/remediation is required ■ Undertake groundwater monitoring following treatment/remediation ■ Review management measures ■ Potentially amend management measures.	Potential remediation measures include: ■ Source isolation/removal ■ Recovery bores ■ Cut-off trench/sumps ■ Combination of the above ■ Ongoing monitoring.
Leachate detected in groundwater monitoring.	■ Groundwater sampling is to be conducted in accordance with AS/NZS 5667.11. ■ All water samples are collected and preserved in accordance with AS/NZS 5667.1. ■ Compare the monitoring data to ANZECC 2000 Freshwater Slightly-Moderately Disturbed Ecosystems.		
Groundwater levels beneath landfill rising to within two metres (2 m) of base of liner	■ Monitoring bore levels indicate excessive, ongoing groundwater level rise (see note 1). ■ Waterlogging near base of landfill, change in landfill structure (e.g. salt forming, dispersion). ■ Seepage in area beneath landfill site beyond pre-site landfill conditions.		
Leachate or other contaminants detected in stormwater dam or groundwater retention pond (from landfill interceptor drainage)	■ Surface water sampling is to be conducted in accordance with AS/NZS 5667.4 and water samples are to be collected and preserved in accordance with AS/NZS 5667.1. ■ Water quality must not exceed the surface water criteria listed in the 'Australian and New Zealand Guidelines for Fresh and Marine Water Quality Volume 1' (ARMCANZ and ANZECC, 2000).		

Notes: [1] Additional monitoring bores are required to monitor for leachate seepage near the landfill structure to be installed once construction is complete.

6.0 REFERENCES

ANZECC & ARMCANZ. (2000). *Australian and New Zealand Guidelines from fresh and marine water quality.*

Department of Water. (2007). *Assessment of the status of river pools in the Avon Catchment.* Perth: Government of Western Australia.

Department of Water. (2008). *Avon River Catchment Water Quality and Nutrient Monitoring Program for 2006.* Perth: Government of Western Australia.

Environmental Protection Authority (Victoria). (2015). *Siting, design, operation and rehabilitation of landfills.* Melbourne: State Government Victoria.

Golder. (2015a). *Allawuna Farm Landfill - Geotechnical investigations for landfill development.* Perth: Golder.

Golder. (2015b). *Allawuna Farm Landfill - surface water, groundwater and leachate management plan.* Perth: Golder.

Golder. (2017a). *Design report - Great Southern Landfill Cell 1, Cell 2 and Ancillary works.* Perth: Golder.

Golder. (2017b). *Desktop environmental and social risk assessment.* Perth: Golder.

Golder. (2017c). *Hydrogeological site characterisation - Great Southern Landfill.* Perth: Golder.

Golder. (2019). *Technical memorandum 1777197-049-M-RevA_Geochem: Desktop geochemical risk characterisation.* Perth: Golder.

GOLDER ASSOCIATES PTY LTD

Alan Puhalovich
Principal Hydrogeologist

RI/AP,EWC/hsl

https://golderassociates.sharepoint.com/sites/101511/shared documents/06 deliverables/correspondence out/051 - esd responses - inland waters/1777197-051-m-rev1 inland waters.docx