Tharbogang Waste Management Centre Groundwater Annual Environmental Performance Report 2018-19. Environmental Protection Licence 5875

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Document Control

Business Unit	Stygoecologia		
Project No.	201907		
Document Description	**Environment Performance (Groundwater) Assessment of the Tharbogang Waste Management Centre (TWMC), 2019**.		
Supervising Director	**Name**	**Signed**	**Date**
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Executive Summary

4.0 Introduction

Griffith City Council (Council) operates the Tharbogang Waste Management Centre (TWMC), located at Lot 202 DP 756035 Hillside Drive, Tharbogang. The Facility has been in operation since 1984. Expansion of the landfilling and quarrying operations received Ministerial approval in July 2010, but it has not yet commenced. The approval allows Council to extract up to 315,000 tonnes per year of gravel and landfill 35,000 tonnes per year of general solid waste. The project approval has been modified twice. These modifications are detailed later in this plan. The quarry and landfill operation will also require an updated Environmental Protection Licence (EPL) from the Environment Protection Authority (EPA).

4.1 Purpose of this Report

This report summaries the Environment Performance of Tharbogang Waste Management Centre for the reporting period 1 September 2018 to 31 August2019.

1.2. Program Objectives

- To determine the contaminant concentration trends in the surface and groundwater sources in and around the Tharbogang Waste Management Centre.
- Verify if any off-site migration of contaminants is occurring

1.4. Approach to this Report

The report investigates chemical trends for the identified COPCs at each of the landfill sites. The report provides site specific data on 'Chemicals of Potential Concern' (COPCs) and general water quality trends.

The framework outlined in the following guideline documents were used in this report.

- ANZG 2018. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Governments and Australian state and territory governments, Canberra ACT, Australia. Available at www.waterquality.gov.au/anz-guidelines

Note that the ANZG (2018) guidelines are an update to the ANZECC (2000) water quality guidelines, which includes an updated framework and proposal to update some of the default guideline values.

1.5 Source, pathways and receptors

Precipitation is the major source of moisture within landfills which encourages the generation of leachate. This is certainly the case within the Tharbogang Waste Management Centre as it is a semi-arid area with no significant waterway through or near the facility. Infiltration of water (rain) into the landfill can act as a transport medium for contaminants both into the local groundwater table and local surface waterways if the underlying lithology is sufficiently porous (Venkatraman et al. 2014). Natural groundwater within the landfill may also be a source of moisture. Presence of water and anaerobic conditions within the landfill promotes waste degradation, leading to leachate production and methane generation (Venkatraman and Ashwath, 2007).

Rain and shallow groundwater can therefore influence contaminant levels within the leachate and may increase contaminant concentration by increased dissolution/transport or decrease contaminant concentration by increased dilution of the leachate (Lin and Li, 2009; Baziene et al. 2013). The actual impact rainfall may have on contaminant levels within the leachate would generally depend on local climatic conditions, type of wastes within the landfill and types of contaminants present within the landfill. Sufficient continuous monitoring data may therefore be required to discern the effect of local rainfall on leachate quality.

Landfill leachates can have relatively high amounts of salts, which can give leachates high electrical conductivity (EC). This conductivity is the result of contributions from individual anions and cations. Salinity trends can provide an indication of landfill leachate transport as increasing salinity at downstream locations may indicate contribution from the leachate. However, in such cases, individual anion and cation ratios may become increasing similar between the leachate and the downstream sample.

5.0 General Description

2.1. Site Data

Figure 1-1. Location of Tharbogang Waste Management Centre in relation to the City Centre

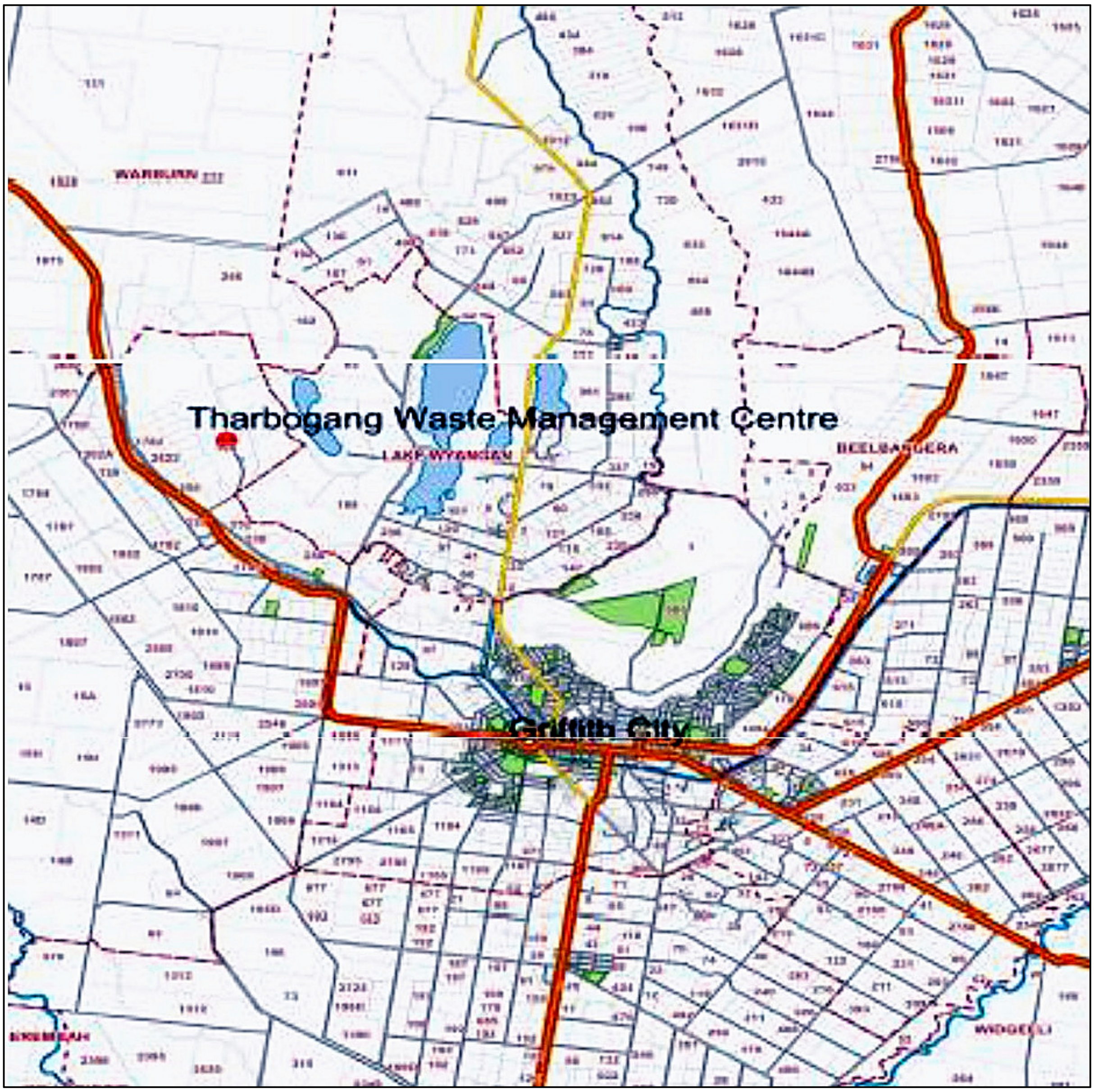


Figure 1-2. Property boundary and structure of the Tharbogang Waste Management Centre (2018).

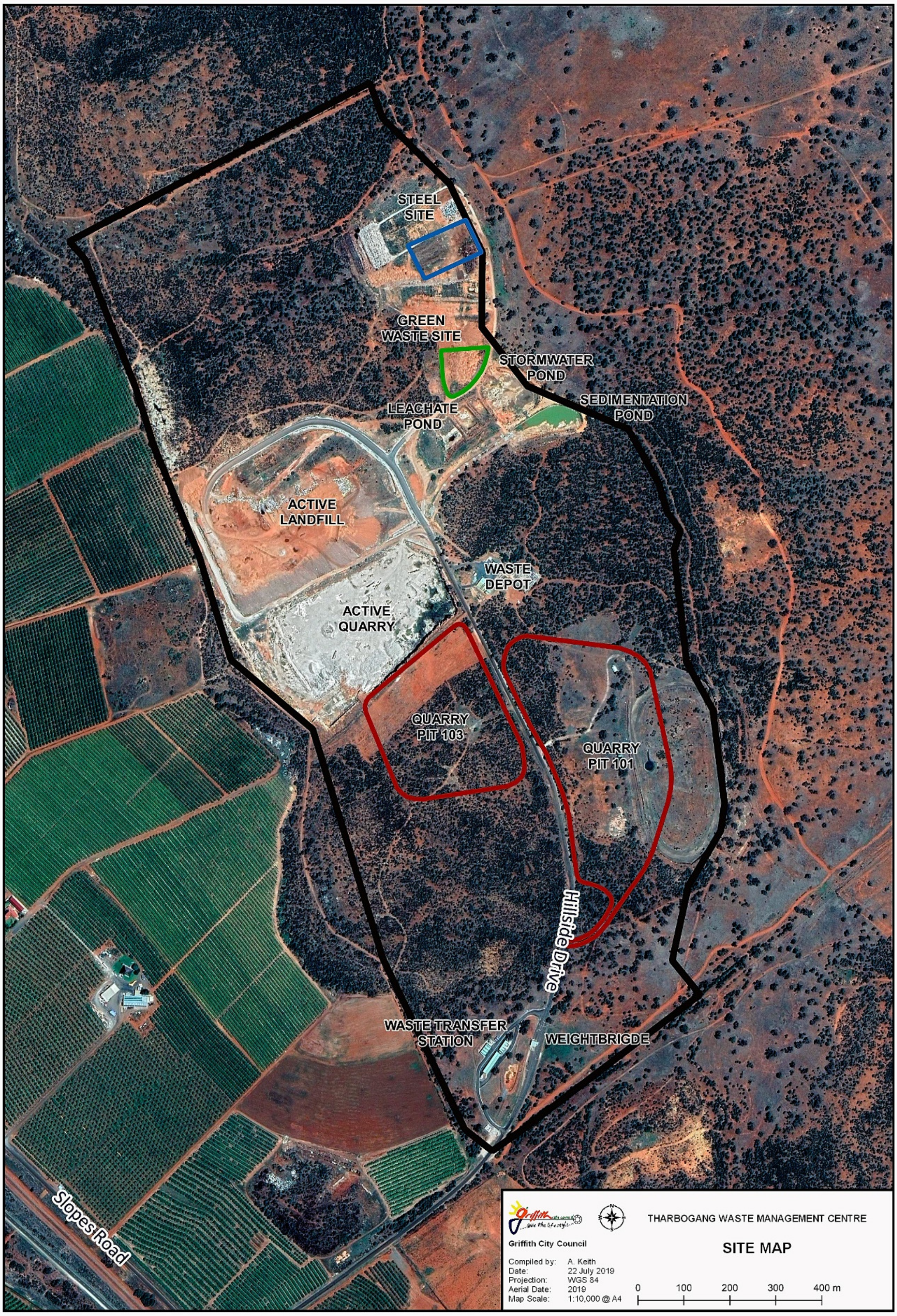
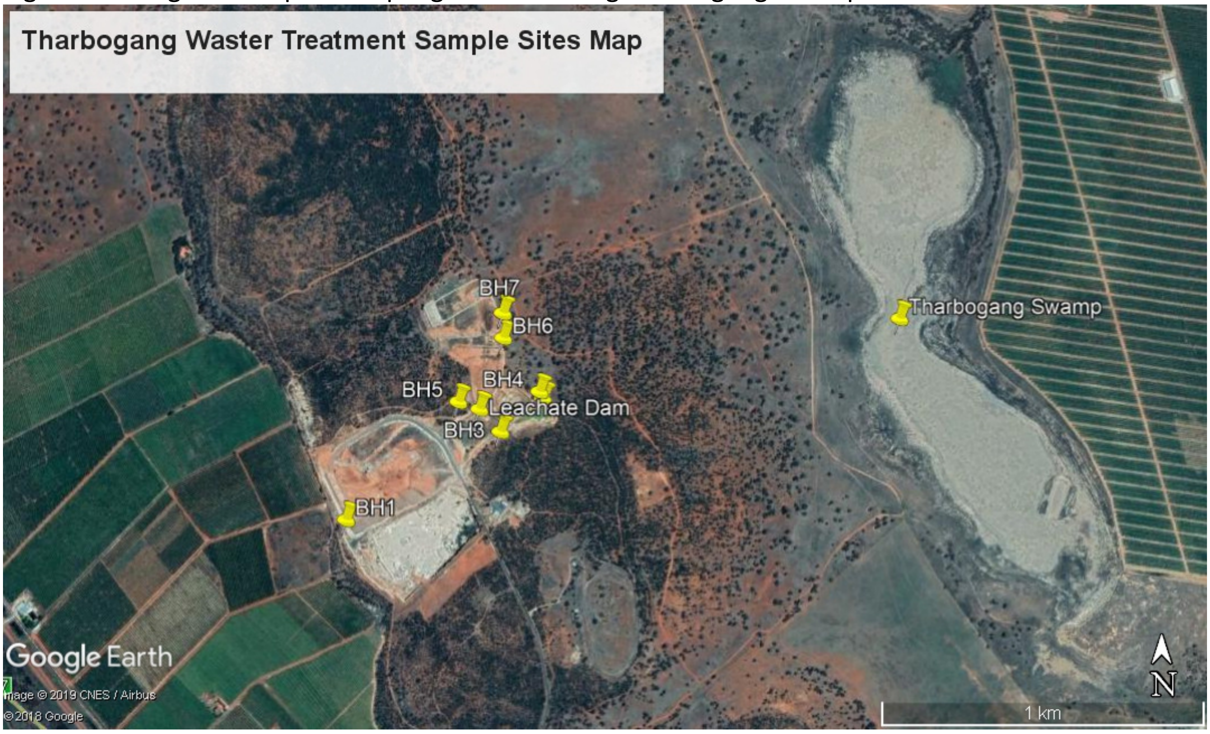


Figure 1-3. Location of sampling sites in the Tharbogang Waste Management Centre.

Figure 1-4. Regional map of sampling sites including Tharbogang Swamp.



6.0 Methodology

3.2. Study Area and Sampling Sites

The Study Area for the purposes of this report encompasses the Tharbogang Waste Treatment Centre (refer to Map 1-2). The monitoring sites are displayed in Maps 1-3, 1-4.

3.2 General Description

The Waste treatment Centre is located 12 kilometres west of Griffith (Map 1-1) on the MacPherson Range (off the Kidman Way Tharbogang). The nearest urban centre is the Tharbogang village, four (4) kilometres from the site. The site is not visible from the village. The Waste Depot was established on Crown Land reserved for Municipal Purposes - Reserve Number R.97172 on 16 March, 1984 (Government Gazette) with Council being created as the Trustee on the same gazettal date. The dimensions of the land, speedway location and current contours occupies an area of 7.5ha on the north eastern portion. The site is also operated as a Council quarry extracting hard rock for road sub-base, with crushing activities as needed (Griffith City Council, 1999).

3.2.1. Topography

The site is upon the northern slopes of the MacPherson Ranges and is traversed by two spurs and slopes to the north. The waste depot disposal is within the re-entrant depression between the spurs (Griffith City Council, 1999).

3.2.2. Soils and Geology

Griffith is within a geological transition zone. The MacPherson's Range comprise older rocks with younger deposits of colluvial and windblown (aeolian) sandy deposits near the range. Upon the ranges, the soils are well aggregated, crumbly and subplastic in nature, usually with a high lime content.

The southern part of the MacPherson's Range which traverses the site shows evidence of folding with well-developed cols. These cols were responsible for directing calcareous clays into the Lake Wyangan and Tharbogang area, by acting as wind funnels. The Range displays structural features which are common to upper Devonian formations and its unusual alignment is evidence that extensive faulting has occurred. The geology rocks include conglomerate, sandstone and quartzite with thin beds of argillaceous sequence.

The massive conglomerate contains rounded water worn pebbles which are siliceous in nature. They consist of white quartz often coated with reddish iron oxide, fine and course grained quartzites bright rod jaspilite and course siliceous grit, black siliceous hornfels and dark tourmaline-rich rock. Many of the pebbles are like quartz but are metamorphosed products of colloidal deposits. Pebbles of pink colour which appeared to consist of quartz but are found to contain sponge like structures common in chalcedony. Many of the sandstones contain kaolinite materials.

Soils are described as "Gradational (Non-Calcareous) soils of the MacPherson Range.
Soils are not calcareous throughout; surface textures commonly range from sandy loam to clayey loam, less commonly loamy sand, clayey sand and sand, and occasionally sandy clay, silty clay or light clay. There is a gradual increase in texture grade (clayiness) with depth, sometimes followed by a decrease below the B Horizon; acid, neutral and alkaline soil reaction trends occur.
The soils would appear to result from mainly physical and chemical weathering of the parent material and from aeolian deposition. The parent material is sedimentary, primarily conglomerate and siliceous sandstone. The soil has tendencies towards mod-high permeability with implications for plant growth and recharge.

The site has extensive removal of soil and gravel on the slopes prior to its occupation by the Council. Most of the slopes on site are bedrock with a mantle of yellow course textured colluvial material overlaying the bedrock in the re-entrants and slope to a depth of 3 metres. In a geotechnical investigation of the site commissioned by the Council in January, 1996, Coffey Partners found: -

- The geology as being part of the Cocoparra and Griffith Synclines and comprising sandstones and siltstone with conglomerate bands. The overlying surfical soil generally comprised: -
- Slopewash and residual sandy clay, clayey sands; Gravelly sandy clays and clayey sandy gravels
- The plasticity of the surficial soils ranged from low to medium
- The depth of surficial soil over the basement rock ranged from 0.2 metres on the upper hill slopes to 3 metres in the lower foot slope area.
- The soil has tendencies towards mod-high permeability with implications for plant growth and recharge.

3.2.3. Surface Waters

The Waste Management Centre occurs in a semi-arid region with low annual rainfall (average 409mm 2015-19). The soils have been identified in the Calm report as having poor to marginal water holding ability. The soils are susceptible to tunnelling and water erosion. Erosion was evident prior to landfill commencing. The catchment is limited to the ridgeline of the terrain which coincides with the Southern lot boundary. The lot is traversed by three natural drainage depressions i.e. the east boundary, west boundary and the quarry/the current landfill platform and drains to the "perched" drainage depression - The Tharbogang Swamp.

This pondage is affected by marked salinity degradation from rising saline watertables.

The major source of water catchment in this locality is from aerial irrigation of pastures growing lucerne and grains on lands to the north and east of the basin.

Surface waters from the quarry floor/catchment runoff is diverted to a detention basin to the east of the garbage depot leachate detention basis. A further 3rd stormwater siltation basin is located downstream of the quarry and leachate detention basins. The 3rd basin is filled infrequently and is usually dry. Surface intercept and diversion berms have been provided to the east of the landfill. Further bunding has also been provided, in conjunction with trenches to the northern alignment of the "old" putrescible pits (trenches) in the western slopes of the Waste Depot. (Griffith City Council, 1999).

3.2.4. Groundwater

A pattern of ground water piezometers has been located downstream of the landfill and "old putrescible pit" area, in the northern part of the Depot between the northern boundary. See Map 1-3 and 1-4 for locations. The depth of any infrequent groundwater has been relative to sporadic incidents of preceding heavy rainfall. The salinity in groundwaters generally in the locality can vary from 1.5 dS/m to 16 dS/m. In the Tharbogang swamp basin, the salinity of the groundwater could range from 10-20 dS/m. An adjacent basin at Lake Wyangan liquid salinity readings of 1,200-1,800 E.C. µs/cm have been obtained in comparison to the ANZECC Guidelines of 1,500 E.C. µs/cm (Protection of freshwater ecosystems) and 1,750 E.C. µs/cm (Direct adverse effects in freshwater wetlands). (Griffith City Council, 1999).

3.3. Site Data

There are 9 sites that have been sampled as part of the six-monthly monitoring program encompassing Autumn and Spring surveys. These sites consist of 6 groundwater bores that are distributed at strategic locations around the landfill area and general facility and 3 surface water sites. There is groundwater monitoring data for the bores commencing in December 2000 however the current sampling program report deals only with sampling records commencing in August 2014 and ongoing. A description of each sampling site is given in Table 1.

3.4. Physico-Chemical Data

Groundwater chemical sampling was conducted using existing bores, dams and swamps at and adjacent to the Waste Management Centre. The parameters measured are presented in Table 1. Rainfall and water chemistry data is supplied by Griffith City Council from data from their regular water quality monitoring program.

The following steps describe the sampling procedure:

- Bore gauging was the first step in the procedure. Depth to water, bore depth and stand pipe heights were measured using a depth meter. The water column depth or thickness in the bore was used to estimate water volumes for bore purging
- Disposable plastic bailers were used to purge the bore to a total of three bore volumes or until the bore is dry in shallow bores. Groundwater samples were taken after removing the required bore volume.
- Where required the water sample was filtered using a 0.45 µm filter in the field. Collected samples were cooled to <4 ˚C using either ice or ice brick when available.
- The samples were submitted to Australian Laboratory Services (NATA accredited and EPA approved) for analysis within contaminant holding time.

- All field data was recorded in field sheets along with any specific observations and or descriptions.
- New uncontaminated bailers and strings were used for each day groundwater bore sampling, and any other equipment was decontaminated between bores.

The following sample analysis parameters and monitoring frequency were provided by Griffith Council for the water sample analysis. Threshold Criteria are primarily sourced from Australian and New Zealand guidelines for fresh and marine water quality (ANZW 2018) 95% trigger values and National Environment Protection (Assessment of Site Contamination) Measure (NEPM) 2013. Other indicative threshold values (N/A) were calculated as the 80th percentile value of recorded values from 2014-2019 field data and is used as an Interim working level, in absence of reliable trigger values

Table 1: Analytes, Threshold Criteria for Groundwater Monitoring sites.

Water Chemistry Parameters	ANZECC Trigger Values for freshwater	Tharbogang Trigger Values
Depth (m)	N/A	N/A
pH (pH Unit)	6.5-8.5	6.5-8.5
Alkalinity (mg/L)	N/A	744
Fluoride (mg/L)	N/A	0.7
Chloride (mg/L)	N/A	2794
Sulphate (mg/L) SO4	N/A	513
Sp. Conductance (µS/cm)	350	350
Suspended.Solid (mg/L)	N/A	138
Total Org Carbon-filtered (mg/L)	4	4
Total Phenol (mg/L)	0.32	1
Dissolved Iron (mg/L)	0.3a	0.3
Dissolved Manganese (mg/L)	1.9b	1.9
Dissolved Calcium (mg/L)	N/A	102
Dissolved Magnesium (mg/L)	N/A	184
Dissolved Potassium (mg/L)	410c	410
Dissolved Sodium (mg/L)	N/A	1775
Ammonia (as N) (mg/L) N	0.9b	0.9
Total Oxidised Nitrogen (as N) (mg/L)	0.4	0.4
Volatile Organics (ug/L)	N/A	50

N/A - 80% of recorded values is used as an Interim working level, in absence of reliable trigger values

a - Interim working level, in absence of reliable trigger value

b - Trigger value may not protect key species from chronic toxicity, refer to ANZECC & ARMCANZ (2000) for further guidance

c - Poor (acceptable) drinking water criteria, World Health Organisation Guidelines for Drinking-water Quality 2009.

4.0 Results

The range and variation of the physico-chemical parameters figures for the Tharbogang Waste Management Centre can be seen in Appendix 1 and displayed in Figures 1-21.

4.1 Rainfall

Rainfall data used in this report was downloaded from CSIRO weather data website for Griffith (https://weather.csiro.au/?aws_id=8&view=download). Rainfall values are displayed below (Figures 1-3). over the last twelve months there has been a significant decrease in rainfall compared with the previous twelve months. This period has recorded rainfall readings lower than the previous three years and are comparable to the 2014-15 period (Figures 1 and 2). The rainfall over the last 5 years has demonstrated a declining trend as illustrated in Figure 2. This has resulted in the some of the driest conditions observed throughout the Councils monitoring program. Over the last twelve months generally dry conditions (Figure 3) have continued with only a small number of small rainfall events during in October 2018 and April/May 2019. This was followed by almost no rain up until the survey in August.

The rainfall total over the last twelve months was 350.8mm. This value represents a below average annual rainfall. The average rainfall value from years 2014-19 is 409mm.

Figure 2-0. Monthly total rainfall values for the area since 2014.

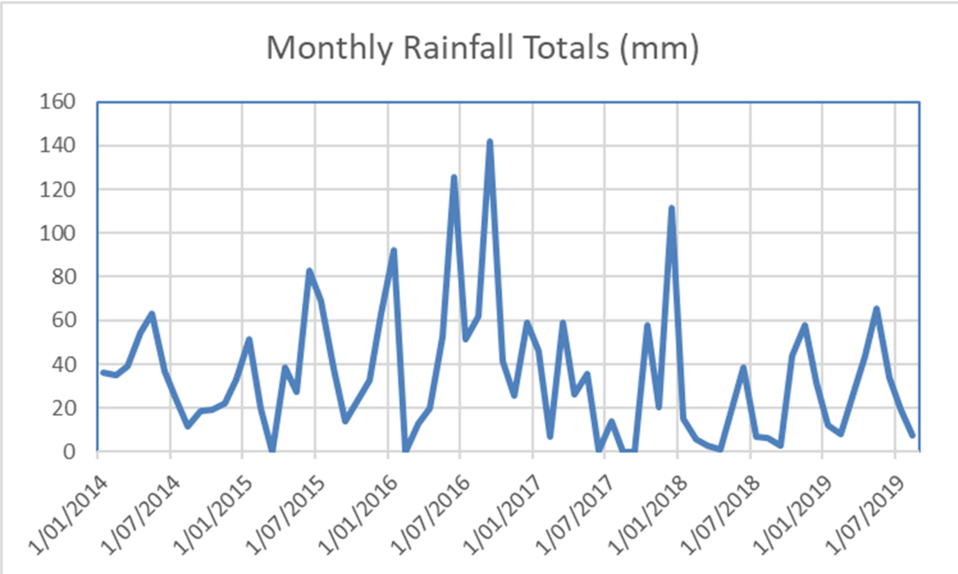


Figure 2-1. Six-monthly total rainfall values for the area since 2014.

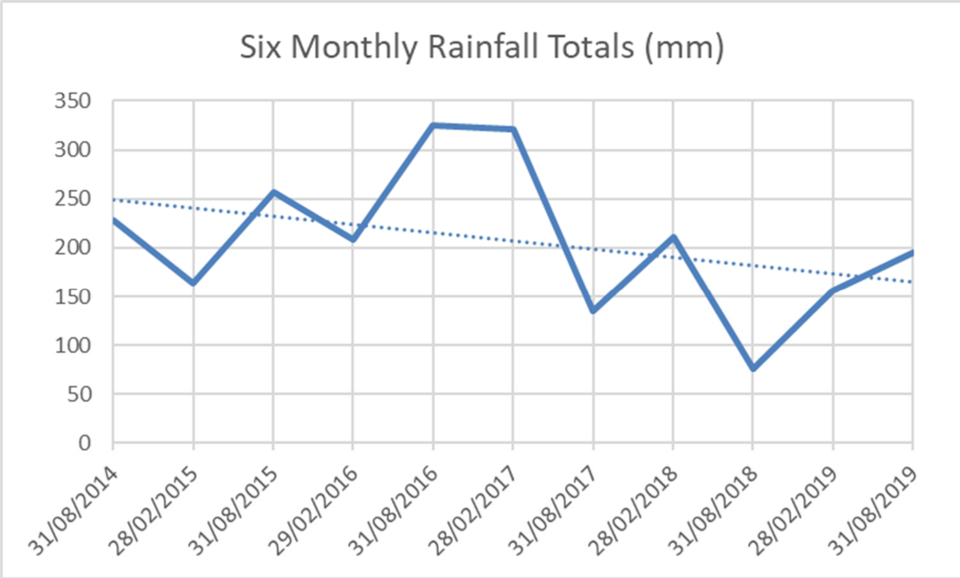
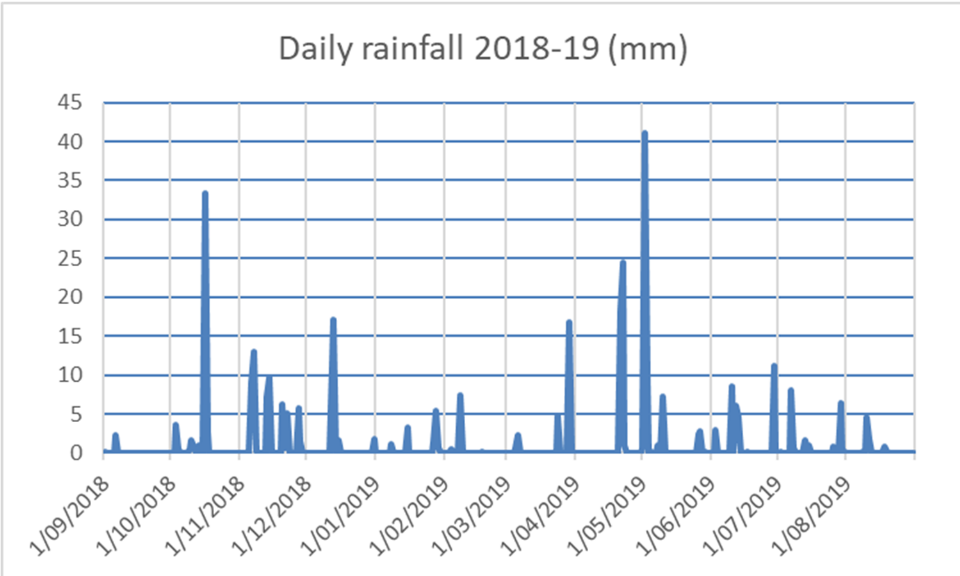


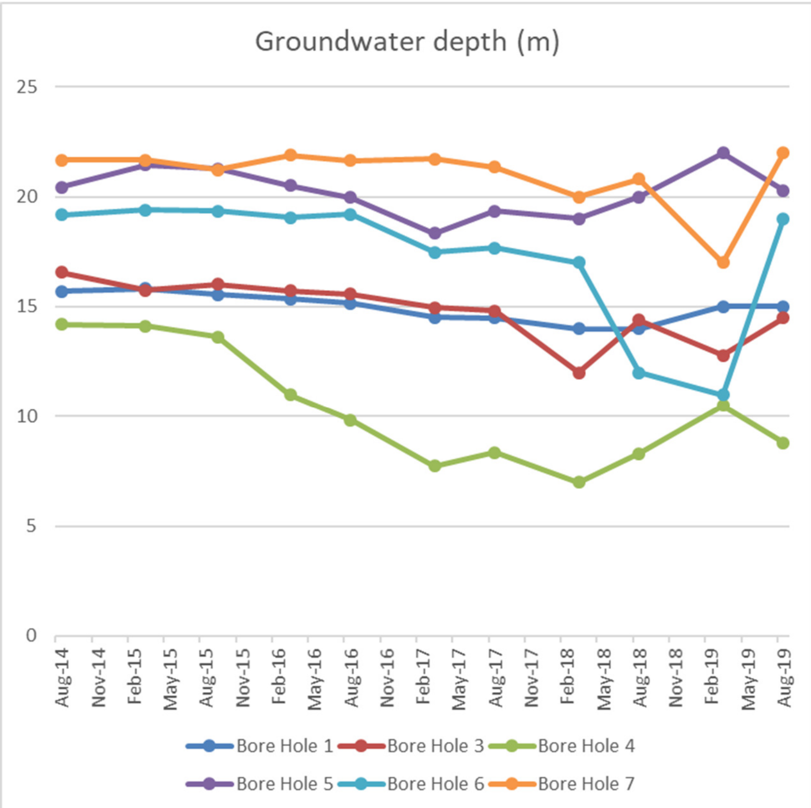
Figure 2-2. Daily rainfall values for the area over the last 12 months 2018-19.



4.2. Groundwater Levels

Groundwater levels have demonstrated a general increase over the last 5 years comparable to the higher rainfall over the same period followed by a declining trend during the lower rainfall periods of 2014-15 and 2018-19 (Figure 2). The water level trends for each bore is variable with some bore levels remaining relatively stable while others increase or decrease over the same period. The variability is an indication of surface or surface water/groundwater connectivity. The most significant drawdown in groundwater levels over the 2018-19 year occurred in Bores 4 and 5 whereas bores 6 and 7 recorded higher values. Bore 1 and 3 remained relatively stable over the last 5 years. The bores 4, 5 and 3 appear most responsive to major rainfall events, respectively, and indicate a strong connection and rapid recharge of the groundwater within 1-2 weeks. These bores are located adjacent to the Sediment Pond and Main Landfill pit respectively. Bores 6, 7 and 1 on the other hand, demonstrate a delayed or minor (Bore 1) response of approximately 12 months to rainfall and are therefore predominantly disconnected from surface flows.

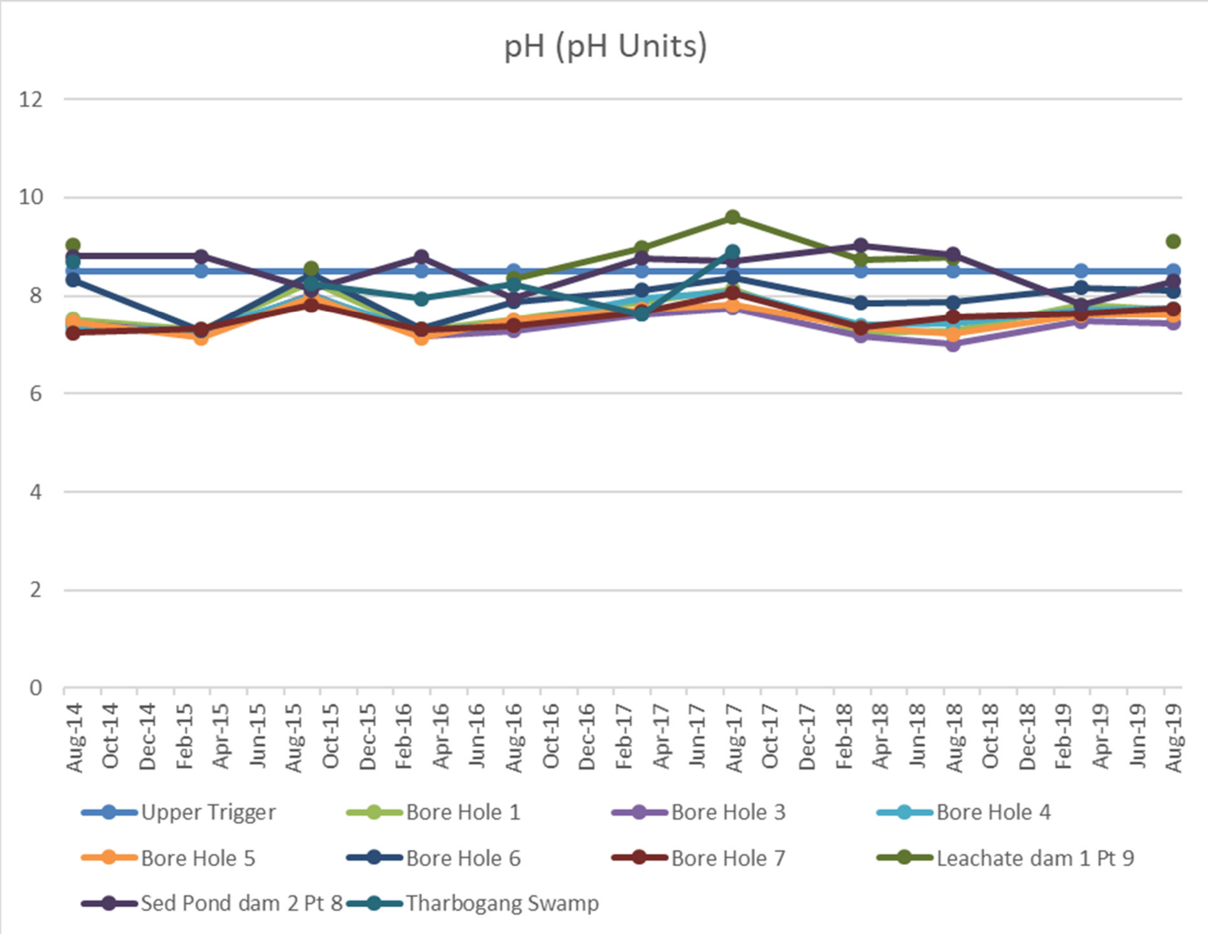
Figure 2-3. Bore Surface water levels and bore depths recorded for all sites since August, 2014.



4.3. pH

pH values between 6.5 and 8.5 are within ANZECC guidelines. The pH at each of the sample sites over the last 5 years has ranged from 7.01 at Bore 3 in August 2018 to 9.6 in the leachate dam in August 2017. The pH across the sites is mildly to higher alkaline and was remarkably consistent over time. Over the last twelve months the pH has ranged from 7.4 in Bore 3 consistently to 9.10 in the Leachate dam. This high value recorded in the leachate dam is not reflected in the surrounding bores (3, 4 and 5) where the average pH is 7.59. The pH has remained very constant over time, varying less than 1.6 pH units throughout the entire monitoring program (see Figures 4). It is suggested there is little to no connection between the leachate dam waters and groundwaters at these locations.

Figure 2-4. pH for all sites since August, 2014.

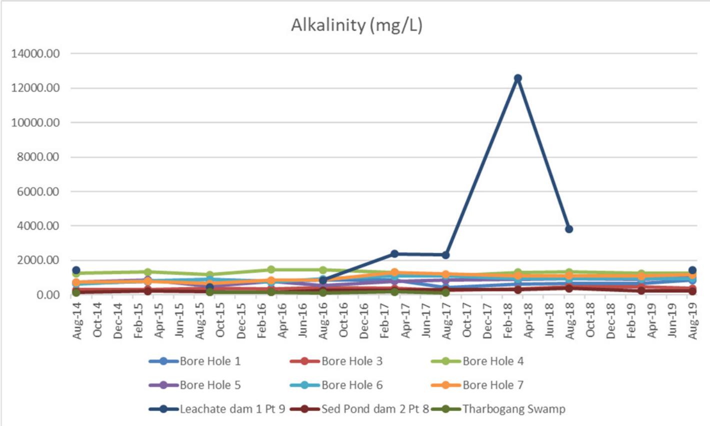


4.4. Alkalinity

Alkalinity is a measure of the waters ability to buffer changes in pH i.e. the acid-neutralising capacity of water. Alkalinity in freshwater systems is derived from several sources: weathering of rocks and soil, exchange reactions in soils, biological uptake and reduction of strong acid anions, evaporation and precipitation of minerals, and atmospheric deposition of dust. Rainfall has little if any alkalinity. This accounts for the inverse relationship between high rainfall and low alkalinity.

In the period, up to August, 2019 survey alkalinity was very consistent within each of the groundwater bores. The only variation was a large increase occurring in the Leachate Dam only peaking in March 2018. This peak quickly subsided by August 2018. The cause of this peak is unknown however as there was minimal rainfall at the time it is suggested to be an input from an anthropogenic source. The lack of values throughout 2019 demonstrate that the Leachate Dam was dry over this period. The consistent values recorded for the each of the other sites indicate there has been no connectivity with the Leachate Dam and therefore no contamination of either the groundwater or surrounding surface waters. The consistent higher than 80% threshold values in Bores 4-7 are considered natural background levels within the groundwater at these sites due to the higher clay content of the substrate.

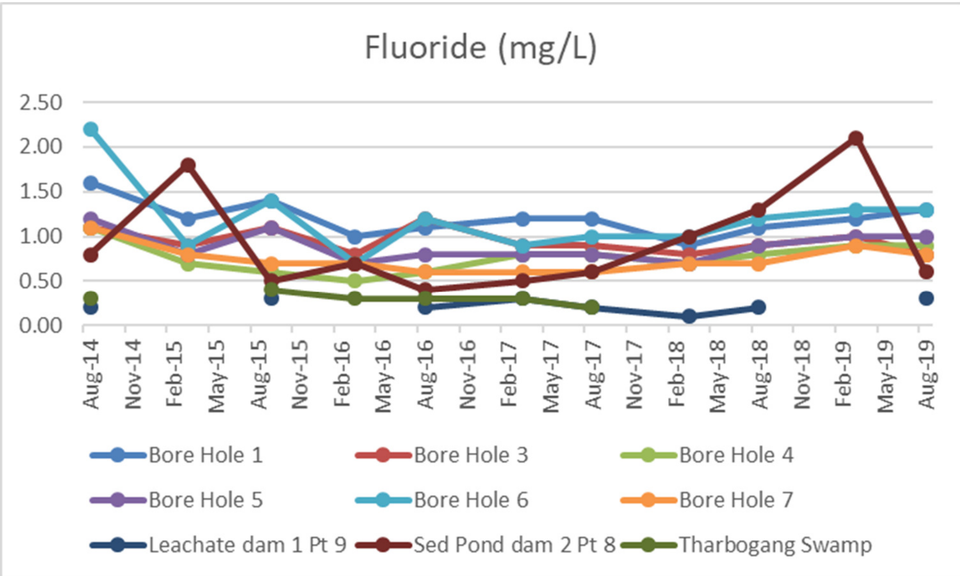
Figure 2-5. Alkalinity (mg/L) for all sites since August, 2014.



4.5 Fluoride

Fluoride levels were relatively consistent over the last 5 years except for elevated peaks in the Sedimentation dam during periods of low rainfall. The values at this site dropped significantly during periods of higher rainfall indicating a dilution during these periods and an increased concentration of Fluoride during dryer periods. The consistent values recorded for the each of the bore sites over time indicate there has been no connectivity with the Sedimentation Dam and therefore no contamination of either the groundwater or surrounding surface waters. The consistent higher than 80% threshold values in Bores 1-7 are considered natural background levels within the groundwater at these sites due to the higher clay content of the substrate.

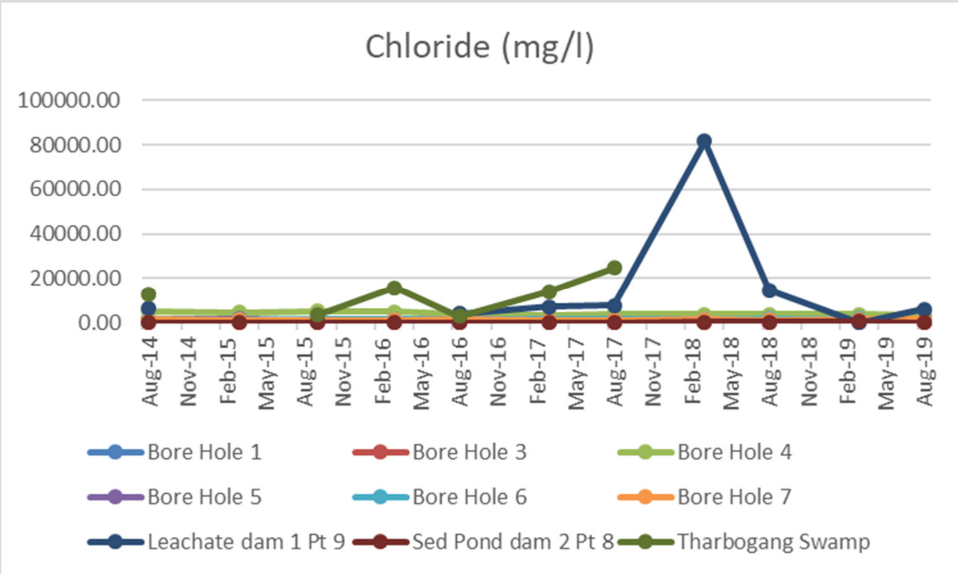
Figure 2-6. Fluoride (mg/L) for all sites since August, 2014.



4.6 Chloride

In the period, up to August, 2019 survey Chloride was very consistent within each of the groundwater bores. The only variation was a large increase occurring in the Leachate Dam only peaking in March 2018 and smaller peaks in Tharbogang Swamp during Feb 2016 and August 2017. The remainder of the period throughout 2019 the swamp has been dry. The peak in the Leachate dam quickly subsided after August 2018. The cause of this peak is unknown however as there was minimal rainfall at the time and no elevation in the bore vales it is suggested to be an input from an anthropogenic source. The consistent values recorded for the each of the bore sites indicate there has been no connectivity with the Leachate Dam and therefore no contamination of either the groundwater or surrounding surface waters. The consistent slightly elevated values above the 80% threshold values in Bores 4 are considered natural background levels within the groundwater at these sites due to the higher clay content of the substrate.

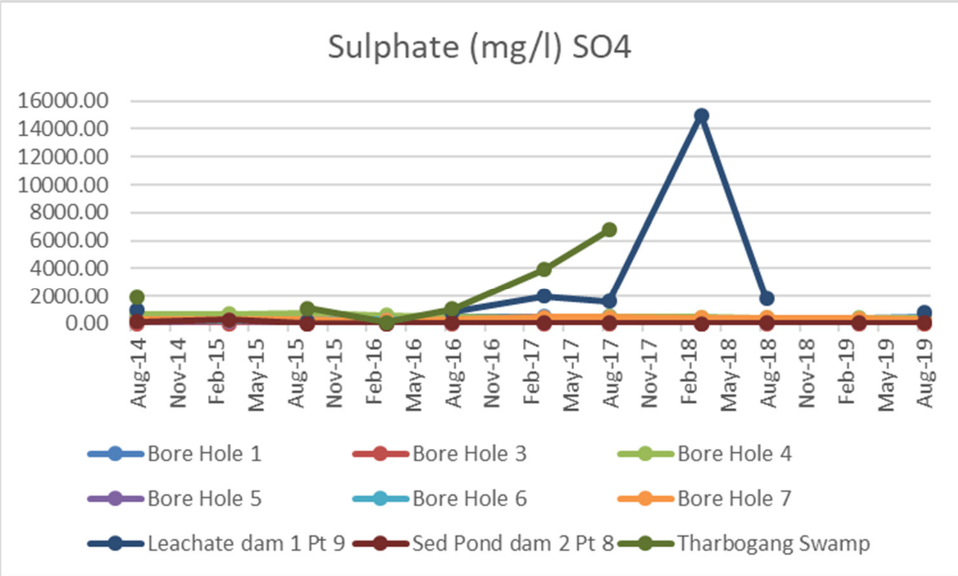
Figure 2-7. Chloride (mg/L) for all sites since August, 2014.



4.7 Sulphate

The values recorded for sulphates over the period up to August, 2019 survey replicated the pattern exhibited by Chloride by having very consistent values within each of the groundwater bores. The only variation as with Chloride was a large increase occurring in the Leachate Dam only peaking in March 2018 and smaller peaks in Tharbogang Swamp during Feb 2016 and August 2017. The remainder of the period throughout 2019 the swamp has been dry. The peak in the Leachate dam quickly subsided after August 2018. The cause of this peak is unknown however as there was minimal rainfall at the time and no elevation in the bore vales it is suggested to be an input from an anthropogenic source. The consistent values recorded for the each of the bore sites indicate there has been no connectivity with the Leachate Dam and therefore no contamination of either the groundwater or surrounding surface waters. The consistent slightly elevated values above the 80% threshold values in Bores 4 are considered natural background levels within the groundwater at these sites due to the higher clay content of the substrate.

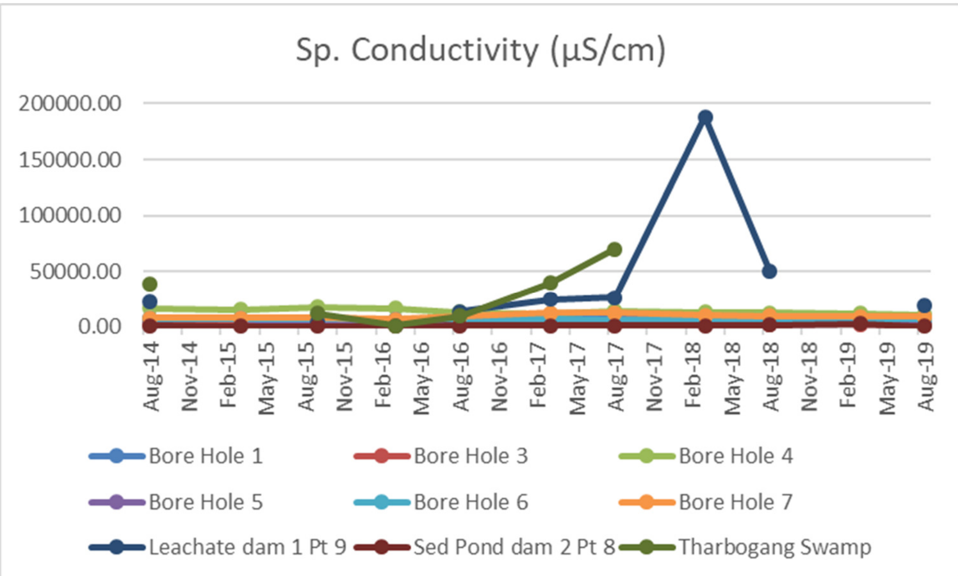
Figure 2-8. Sulphate (mg/L) SO4 for all sites since August, 2014.



4.8. Specific Electrical Conductivity

The values recorded for Specific Electrical Conductivity over the period up to August, 2019 survey replicated the pattern exhibited by Chloride and Sulphate by having very consistent values within each of the groundwater bores and elevated levels recorded in the Leachate dam March 2018 and smaller peaks in Tharbogang Swamp during lower rainfall period in Feb 2016 and August 2017. The remainder of the period throughout 2019 the swamp has been dry. The peak in the Leachate dam quickly subsided after August 2018. The cause of this peak is unknown however as there was minimal rainfall at the time and no elevation in the bore values it is suggested to be an input from an anthropogenic source. The consistent values recorded for the each of the bore sites indicate there has been no connectivity with the Leachate Dam and therefore no contamination of either the groundwater or surrounding surface waters. The consistently elevated values above the ANZECC guidelines threshold values in all sites are considered natural background levels within the groundwater due to dryland salinity.

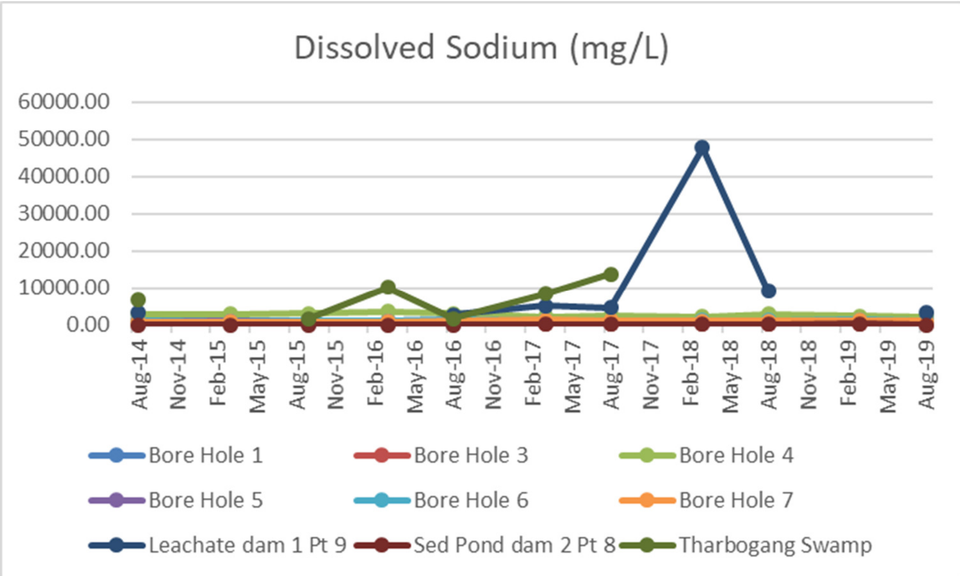
Figure 2-9. Sp. Conductance (µS/cm) for all sites since August, 2014.



4.9 Dissolved Sodium

The values recorded for Sodium replicate those for Chloride up to August, 2019 survey. The same rationale therefore applies to Sodium levels in the groundwater and surface waters. The consistent values recorded for the each of the bore sites indicate there has been no connectivity with the Leachate Dam and therefore no contamination of either the groundwater or surrounding surface waters. The consistent slightly elevated values above the 80% threshold values in Bores 4 are considered natural background levels within the groundwater at these sites due to the higher clay content of the substrate.

Figure 2-10. Dissolved Sodium (mg/L) for all sites since August, 2014.

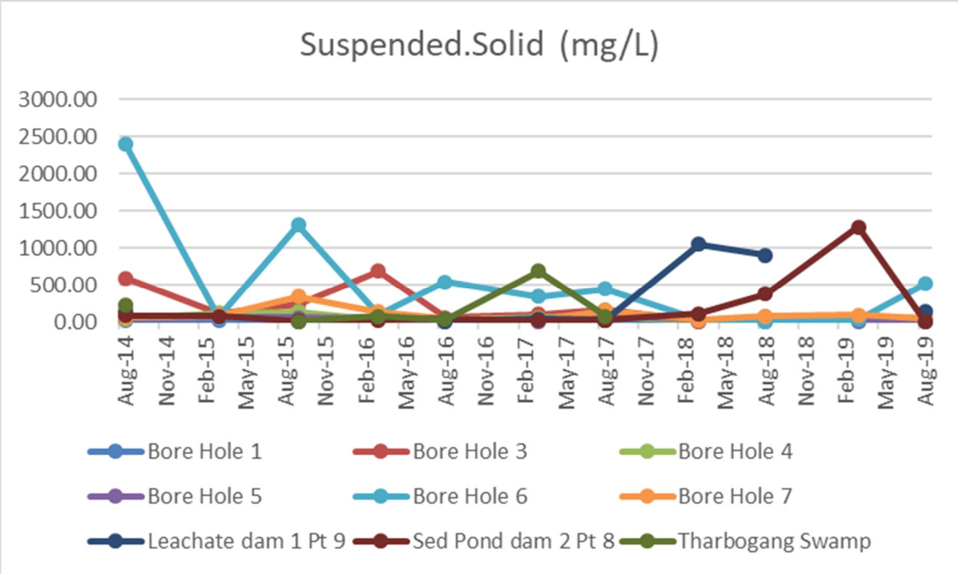


4.10 Total Suspended Solids

TSS or total suspended solids is the measure of particulates in the water column. Although it is similar to turbidity TSS is more useful because it provides an actual weight of the particulate material present in the sample and represents the amount of sediment being transported along the stream and can be an indication of erosion or bed disturbance. The trigger level in Table 7 for TSS has been assigned the 80th percentile value (TSS) using all of the recorded data as an indicator of the higher level experienced across all sites. It not intended as an indicator of environmental harm or impact.

Total suspended solids (TSS) levels increased substantially in the surface water sites particularly during periods of lower rainfall. This is suggested to be as a result of greater concentrations of chemicals during periods of higher evaporation as the values reduced during periods of higher rainfall. During the 2018-19 survey period most sites recorded consistently low values except for Bore 6 and the Sedimentation Dam that recorded values above the 80% threshold values. The values for Bore 6 are considered natural background levels within the groundwater due to the higher clay content of the substrate.

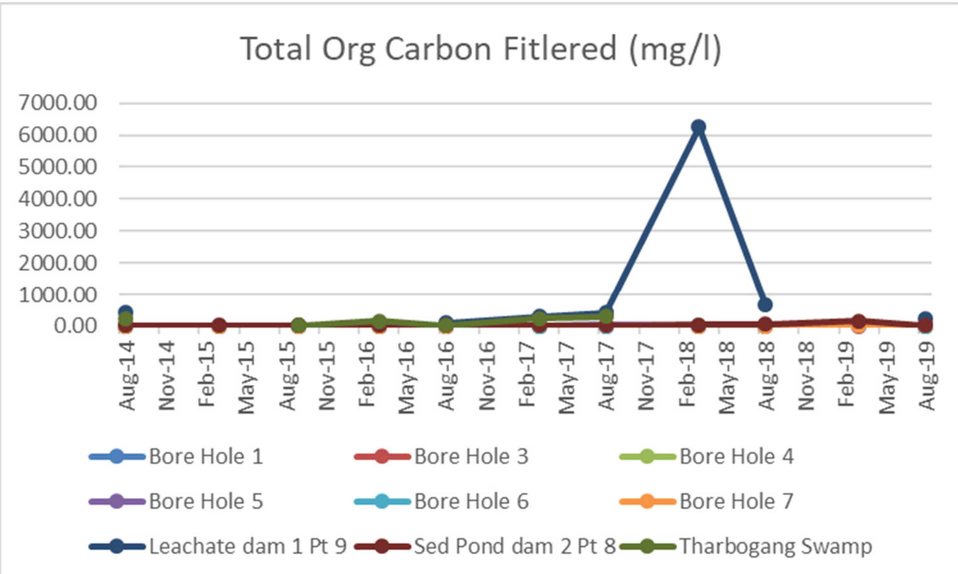
Figure 2-11. Suspended Solids (mg/L) for all sites since August, 2014.



4.11 Total Organic Carbon

The values recorded for Total Organic Carbon replicate those for Chloride up to the August, 2019 survey. The same rationale therefore applies to Total Organic Carbon levels in the groundwater and surface waters. The consistent values recorded for the each of the bore sites indicate there has been no connectivity with the Leachate Dam or either the groundwater or surrounding surface waters. The consistently elevated values above the ANZECC guidelines threshold values in all sites are considered natural background levels.

Figure 2-12. Total Org Carbon-filtered (mg/L) for all sites since August, 2014.



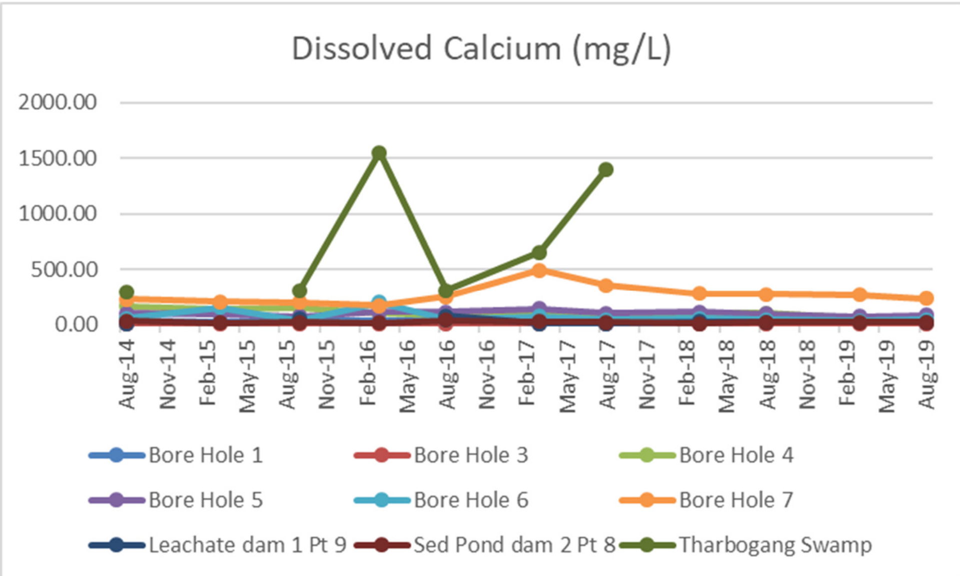
4.12 Total Phenol

Total Phenols were consistently recorded as 1 over time and each site. This value is above the value of 0.32 for the ANZECC Guidelines trigger value. As there is no variation across sites it must be assumed to be natural background levels.

4.13 Dissolved Calcium

The values recorded for Dissolved Calcium over the period up to August, 2019 survey differ in trend pattern from other analytics such as Chloride and Fluoride in that while groundwater values were low and very consistent over time, elevated values were recorded at Tharbogang Swamp and Bore 7. The peak value in Tharbogang Swamps corresponds to a low rainfall period closely following a high rainfall event with the implication that the rainfall event stimulated overland flow producing and input or turbidation of clay sediments into the swamp. The soils, as outline in Section 3.2.2. have a naturally high calcium content. This suggestion is corroborated by elevated levels of suspended solids and pH during the same time period. The elevated levels in Bore 7 is suggested to be the result of the higher clays in the substrate surrounding the bore and a similar response to the higher rainfall events in 2016-17. The consistently elevated values above the 80th percentile threshold values in Bore 7 is considered natural background levels for this location.

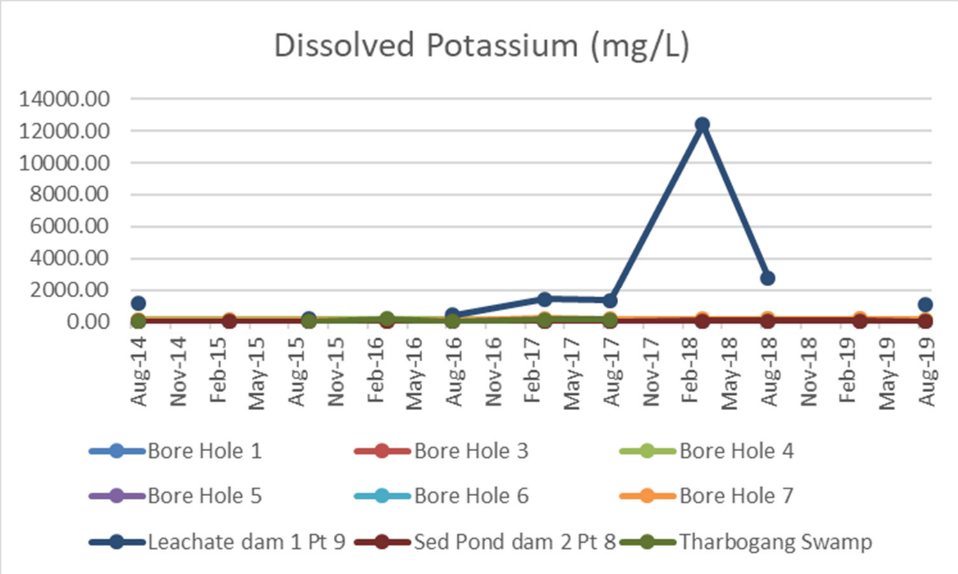
Figure 2-13. Dissolved Calcium (mg/L) for all sites since August, 2014.



4.14. Dissolved Potassium

The values recorded for Dissolved Potassium replicate those for Chloride and Calcium up to the August, 2019 survey. The same rationale therefore applies to Dissolved Potassium levels in the groundwater and surface waters. The consistent values recorded for the each of the bore sites indicate there has been no connectivity with the Leachate Dam or either the groundwater or surrounding surface waters. The consistently elevated values below the ANZECC guidelines threshold values in all sites, except for the Leachate Dam in August 2019, are considered natural background levels.

Figure 2-17. Dissolved Potassium (mg/L) for all sites since August, 2014.

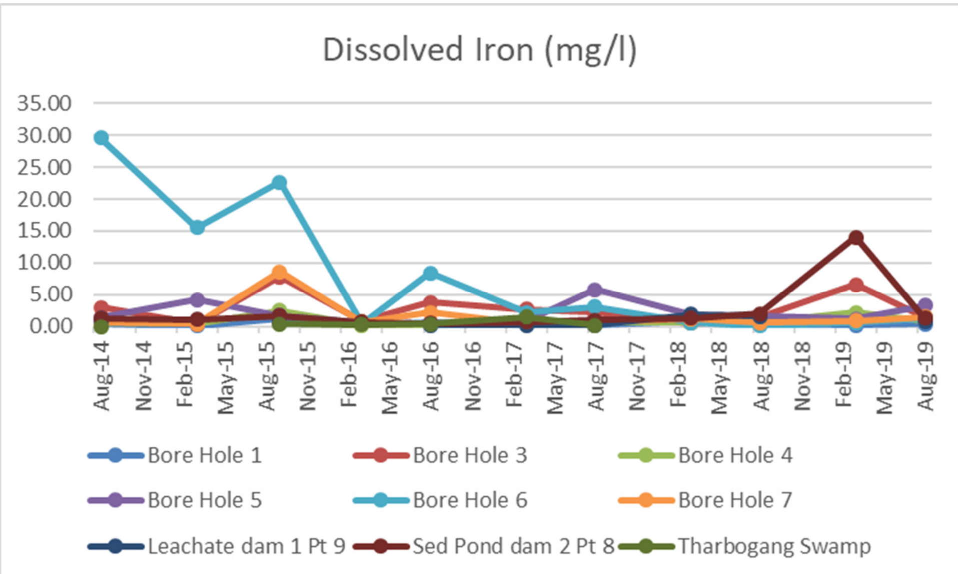


4.15. Metals

4.15.1 Dissolved Iron

Dissolved Iron levels demonstrate a similar trend pattern to Total Suspended solids with an increase values occurring in the surface water sites (Sedimentation Dam) although the pattern is also replicated in Bore 6 and Bore 3 and is particularly evident during periods of lower rainfall. This is suggested to be as a result of greater concentrations of chemicals in surface waters during periods of higher evaporation as the values reduced during periods of higher rainfall and a time delay increase in groundwater flow following on from periods of higher rainfall. During the 2018-19 survey period most sites recorded consistently low values except for Bore 6 and the Sedimentation Dam that recorded values above the 80% threshold values. The values for all sites are higher than the ANZECC Guidelines Trigger values are therefore considered natural background levels within the groundwater due to the higher clay content of the substrate and geology.

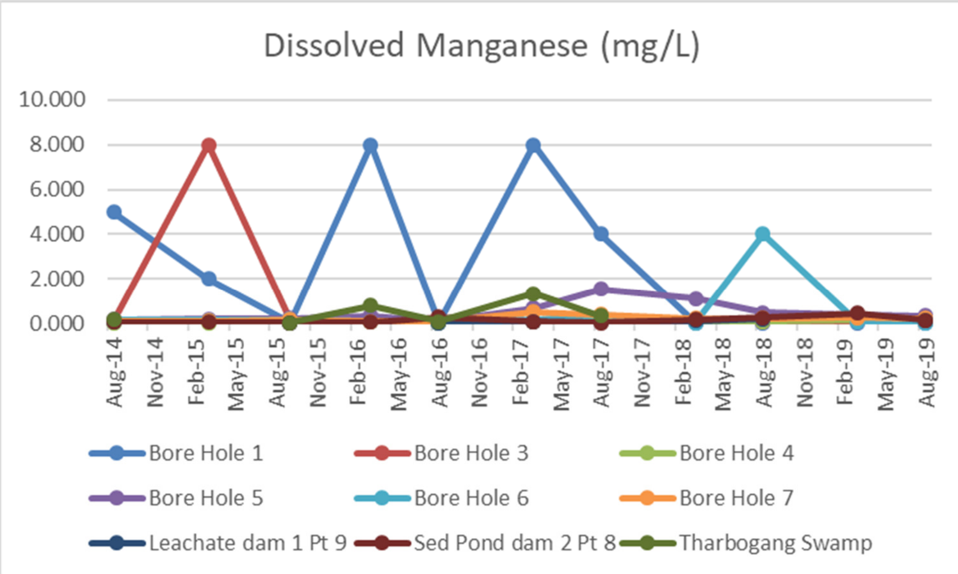
Figure 2-14. Dissolved Iron (mg/L) for all sites since August, 2014.



4.15.2 Dissolved Manganese

All sites recorded values that are below the ANZECC Guidelines Trigger value of 1.9 mg/l particularly during the 2018-9 reporting year. The only site to have historically exceeded the trigger value was Bore 1 and Bore 3. The values for all other sites are therefore considered natural background levels within the groundwater due to the higher clay content of the substrate and geology.

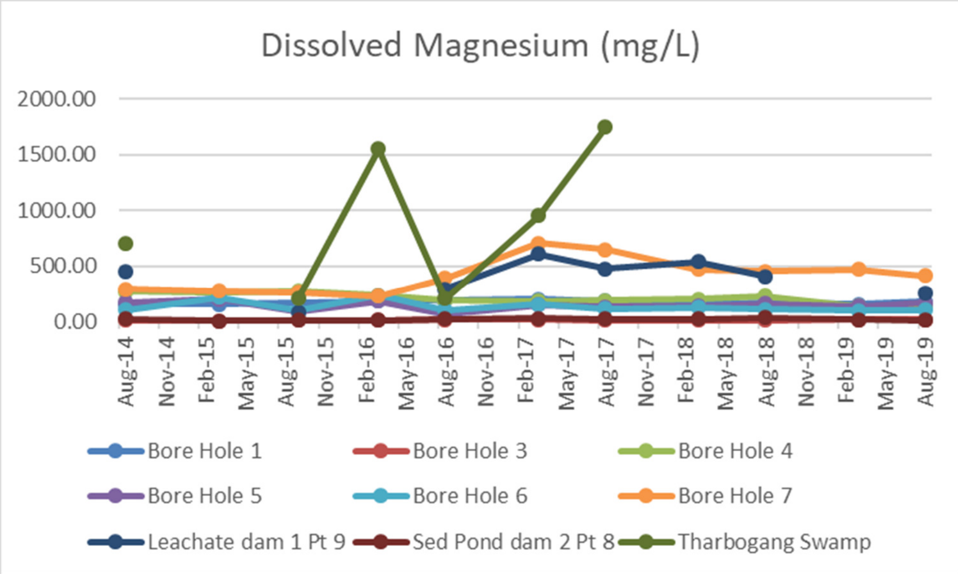
Figure 2-15. Dissolved Manganese (mg/L) for all sites since August, 2014.



4.15.3 Dissolved Magnesium

The values recorded for Dissolved Magnesium over the period up to August, 2019 survey is almost identical to that of Calcium therefore the same rational applies. The groundwater values were low and very consistent over time, with elevated values were recorded at Tharbogang Swamp and Bore 7. In addition, slightly elevated levels were recorded in the Leachate Dam. The peak value in Tharbogang Swamps corresponds to a low rainfall period closely following a high rainfall event with the implication that the rainfall event stimulated overland flow producing and input or turbidation of clay sediments into the swamp. The soils, as outline in Section 3.2.2. have a naturally high calcium and magnesium content. This suggestion is corroborated by elevated levels of suspended solids and pH during the same time period. The elevated levels in Bore 7 is suggested to be the result of the higher clays in the substrate surrounding the bore and a similar response to the higher rainfall events in 2016-17. The consistently elevated values above the 80th percentile threshold values in Bore 7 is considered natural background levels for this location.

Figure 2-16. Dissolved Magnesium (mg/L) for all sites since August, 2014.



4.16 Nutrients

Nutrients are one of the main constituents of landfill leachate, generated primarily by bacterial decomposition of waste material. Nutrients primarily consist of nitrogen and phosphorus; however, it is the nitrogen-based nutrients (ammonia and nitrate) that have previously been found to be of concern at Cabramurra and Geehi sites. Under anaerobic or low oxygen decomposition, the main nitrogenous nutrient generated is ammonia. Ammonia can be discharged from the landfill as part of the landfill gases or with the leachate. Nitrate can be generated directly from the decomposition process or from ammonia oxidation when sufficiently high oxygen concentration is present. This can either be within the landfill cell or as ammonia migrates away from the landfill.

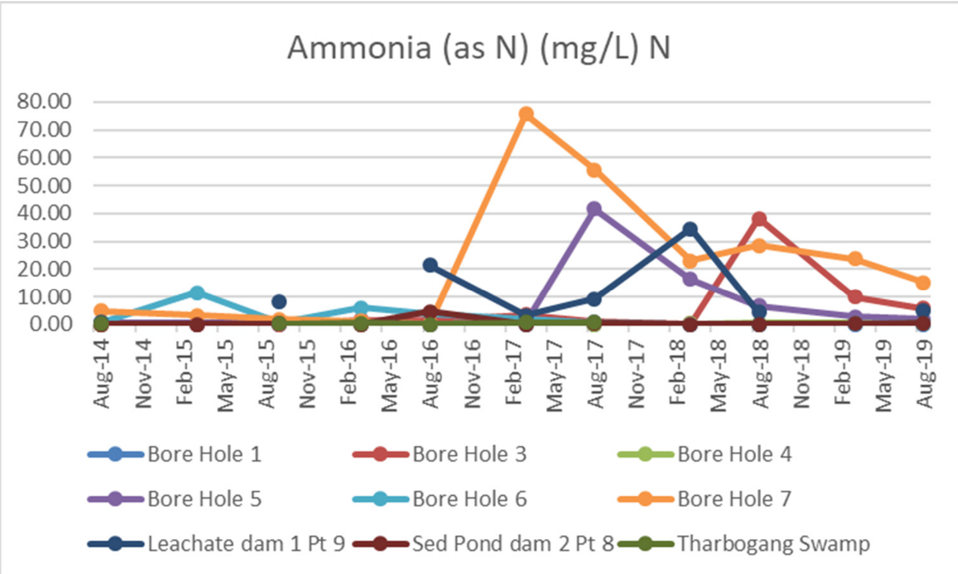
4.16.2 Ammonia

Ammonia is a product of human and animal wastes. Domestic sewage and industrial effluents are the most common sources of ammonia entering surface waters. Other natural sources of ammonia are decomposition of plant material. Ammonia is a non-persistent and non-cumulative toxicant to aquatic life. Its toxicity is dependent on pH, temperature and the ionic composition of exposure water. In general, toxicity is greater at higher pH. Ammonia is also a nutrient for plant growth and excessive levels stimulate growth of algal blooms. In natural waters ammonia oxidises to form nitrate and nitrite – collectively known as NO_x.

Plants are more tolerant of ammonia toxicity than animals, and invertebrates are more tolerant than fish. Hatching and growth rates of fishes may be affected. In the structural development, changes in tissues of gills, liver, and kidneys may also occur. The majority of freshwater invertebrate and fish species are sensitive to ammonia above 5000 and 2000 µg/L, respectively. Acute toxicity to fishes may cause loss of equilibrium, hyperexcitability, increased breathing rate, cardiac output and oxygen uptake and death.

Ammonia values exceeded the ANZECC Guidelines trigger levels in four locations including Bores 3, 5 and 7 as well as the leachate Dam. Prior to August 2016 all sites were below the guidelines however increased substantially post the higher rainfall event in late 2016 through to early 2017. These elevated levels have reduced significantly post this period and are predicted to continue to drop during the current low rainfall period. It is suggested these elevated records were the result of either an increase in sewage discharge into the Waste Treatment Facility or the application of fertilisers on the surround landscape or from leaching of the Green waste area following the rainfall events. The fact that the highest values were recorded at Bore 7, which is geographically isolated from the Leachate Dam or other sewage discharge locations and is directly adjacent to the Green Waste area would indicate that the rainfall event stimulated overland flow that contained high levels of Ammonia or fertilisers and potentially entered the bore from the surface. The other sites were consistently low over the monitoring period.

Figure 2-18. Ammonia (as N) (mg/L) N for all sites since August, 2014.

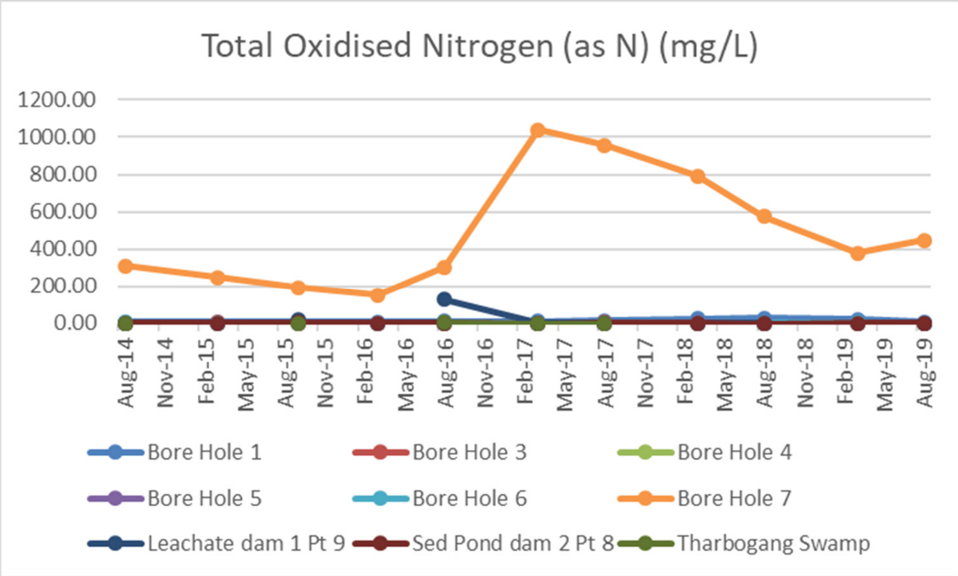


4.16.3 Total Oxidised Nitrogen (as N)

Nitrogen oxide (NOx) is principally a chemical associated with agricultural fertiliser runoff from agricultural lands as well as from urban areas and some industrial discharge. It also forms from the oxidisation of ammonia in waters. The impact to freshwater environments is as-a growth stimulant for algae and another aquatic. The ANZECC guidelines trigger level for NOx is 40µg L-1.

The values recorded for Total Oxidised Nitrogen over the period up to August, 2019 survey is almost identical to that of Ammonia except that the elevated levels are only recorded from Bore 7. Therefore, the same rational applies. The groundwater values were low and very consistent over time.

Figure 2-19. Total Oxidised Nitrogen (as N) (mg/L) for all sites since August, 2014.



4.16.4 Volatile Organics

Volatile Organics were consistently recorded as 50 ug/L over time and each site. As there is no ANZECC Guidelines trigger value for this parameter and there is no variation across sites it must be assumed to be natural background levels.

5. Conclusions

In summary the following points are noted:

- Groundwater levels have demonstrated a general increase over the last 5 years comparable to the higher rainfall over the same period followed by a declining trend during th lower rainfall periods of 2014-15 and 2018-19 (Figure 2).
- The variability in groundwater levels is an indication of surface or surface water/groundwater connectivity.
- The bores 4, 5 and 3 appear most responsive to major rainfall events, respectively, and indicate a strong connection and rapid recharge of the groundwater within 1-2 weeks.
- Bores 6, 7 and 1 demonstrate a delayed or minor (Bore 1) response of approximately 12 months to rainfall and are therefore predominantly disconnected from surface flows.
- It is suggested there is little to no connection between the leachate dam waters and groundwaters at these locations.
- Alkalinity, Fluoride, Chloride, Dissolved Potassium, Sulphates, Total Organic Carbon, Specific Electrical Conductivity and Sodium levels are consistently higher than 80% threshold values in Bores 4-7 and is considered natural background levels within the groundwater at these sites due to the higher clay content of the substrate.
- Dissolved Calcium and Dissolved Magnesium were recorded at elevated values were recorded at Tharbogang Swamp and Bore 7. And are considered natural background levels for this location.
- Total suspended solids (TSS) levels increased substantially in the surface water sites particularly during periods of lower rainfall.

- Dissolved Iron levels demonstrate a similar trend pattern to Total Suspended solids with an increase values occurring in the surface water sites (Sedimentation Dam) although the pattern is also replicated in Bore 6 and Bore 3 and is particularly evident during periods of lower rainfall.
- Elevated nutrient levels were record in Bore 7 specifically as well as Bores 3, 5 and the Leachate Dam and is the result of either an increase in sewage discharge into the Waste treatment Facility or the application of fertilizers on the surround landscape or from leaching of the Green waster area following the rainfall events.

6. Acknowledgements

We wish to thank John Roser for his assistance in the field and for providing background information on water quality and site history.

7. References

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Appendix 1. Water chemistry Results for 2018-19.

Light green colour indicates values that have exceeded the trigger values presented in Table 1.

Depth (m)	Mar-19	Aug-19
Bore Hole 1	15	15
Bore Hole 3	12.80	14.50
Bore Hole 4	10.5	8.8
Bore Hole 5	22	20.3
Bore Hole 6	11	19

Bore Hole 7	17	22
pH	**Mar-19**	**Aug-19**
Bore Hole 1	7.82	7.72
Bore Hole 3	7.47	7.43
Bore Hole 4	7.7	7.73
Bore Hole 5	7.61	7.61
Bore Hole 6	8.17	8.10
Bore Hole 7	7.63	7.74
Leachate dam 1 Pt 9	dry	9.10
Sed Pond dam 2 Pt 8	7.82	8.30
Tharbogang Swamp	dry	dry
Alkalinity (mg/L)	**Mar-19**	**Aug-19**
Bore Hole 1	672.00	848.00
Bore Hole 3	447.00	383.00
Bore Hole 4	1250.00	1260.00
Bore Hole 5	889.00	1010.00
Bore Hole 6	922.00	953.00
Bore Hole 7	1080.00	1160.00
Leachate dam 1 Pt 9	dry	1430.00
Sed Pond dam 2 Pt 8	241.00	217.00
Tharbogang Swamp	dry	dry
Fluoride (mg/L)	**Mar-19**	**Aug-19**
Bore Hole 1	1.20	1.30
Bore Hole 3	1.00	0.80
Bore Hole 4	0.90	0.90
Bore Hole 5	1.00	1.00
Bore Hole 6	1.30	1.30
Bore Hole 7	0.90	0.80
Leachate dam 1 Pt 9	dry	0.30
Sed Pond dam 2 Pt 8	2.10	0.60
Tharbogang Swamp	dry	dry
Chloride (mg/L)	**Mar-19**	**Aug-19**
Bore Hole 1	1,850.0	1,720.0
Bore Hole 3	452.0	438.0
Bore Hole 4	3,830.0	3,290.0
Bore Hole 5	1,360.0	1,480.0
Bore Hole 6	1,710.0	1,740.0
Bore Hole 7	1370.00	1350.00
Leachate dam 1 Pt 9	dry	6010.00
Sed Pond dam 2 Pt 8	688.00	73.00
Tharbogang Swamp	dry	dry
Sulphate (mg/L) SO4	**Mar-19**	**Aug-19**
Bore Hole 1	404.00	512.00
Bore Hole 3	6.00	25.00
Bore Hole 4	444.00	378.00
Bore Hole 5	128.00	158.00
Bore Hole 6	236.00	268.00
Bore Hole 7	391.00	356.00
Leachate dam 1 Pt 9	dry	816.00
Sed Pond dam 2 Pt 8	72.00	46.00
Tharbogang Swamp	dry	dry
Sp. Conductance (µS/cm)	**Mar-19**	**Aug-19**

Bore Hole 1	7060.00	7250.00
Bore Hole 3	2110.00	1810.00
Bore Hole 4	11800.00	11000.00
Bore Hole 5	5440.00	6110.00
Bore Hole 6	6720.00	7010.00
Bore Hole 7	8910.00	9110.00
Leachate dam 1 Pt 9	dry	19500.00
Sed Pond dam 2 Pt 8	2740.00	672.00
Tharbogang Swamp	dry	dry
Suspended.Solid (mg/L)	**Mar-19**	**Aug-19**
Bore Hole 1	9.00	5.00
Bore Hole 3	58.00	30.00
Bore Hole 4	29.00	62.00
Bore Hole 5	19.00	35.00
Bore Hole 6	31.00	511.00
Bore Hole 7	91.00	49.00
Leachate dam 1 Pt 9	dry	132.00
Sed Pond dam 2 Pt 8	1280.00	5.00
Tharbogang Swamp	dry	dry
Total Org Carbon-felt (mg/L)	Mar-19	Aug-19
Bore Hole 1	37.00	7.00
Bore Hole 3	15.00	3.00
Bore Hole 4	53.00	9.00
Bore Hole 5	69.00	21.00
Bore Hole 6	32.00	1.00
Bore Hole 7	46.00	31.00
Leachate dam 1 Pt 9	dry	250.00
Sed Pond dam 2 Pt 8	164.00	28.00
Tharbogang Swamp	dry	dry
Total Phenol (mg/L)	**Mar-19**	**Aug-19**
Bore Hole 1	1.00	1.00
Bore Hole 3	1.00	1.00
Bore Hole 4	1.00	1.00
Bore Hole 5	1.00	1.00
Bore Hole 6	1.00	1.00
Bore Hole 7	1.00	1.00
Leachate dam 1 Pt 9	dry	1.00
Sed Pond dam 2 Pt 8	1.00	1.00
Tharbogang Swamp	dry	dry
Dissolved Iron (mg/L)	**Mar-19**	**Aug-19**
Bore Hole 1	0.12	0.39
Bore Hole 3	6.56	1.36
Bore Hole 4	2.13	0.85
Bore Hole 5	1.12	3.27
Bore Hole 6	0.58	1.3
Bore Hole 7	0.81	1.42
Leachate dam 1 Pt 9	dry	0.74
Sed Pond dam 2 Pt 8	14	1.27
Tharbogang Swamp	dry	dry
Dissolved Manganese (mg/L)	**Mar-19**	**Aug-19**
Bore Hole 1	0.018	0.013
Bore Hole 3	0.120	0.065

Bore Hole 4	0.170	0.089
Bore Hole 5	0.360	0.346
Bore Hole 6	0.044	0.031
Bore Hole 7	0.253	0.209
Leachate dam 1 Pt 9	dry	0.114
Sed Pond dam 2 Pt 8	0.446	0.149
Tharbogang Swamp	dry	dry
Dissolved Calcium (mg/L)	**Mar-19**	**Aug-19**
Bore Hole 1	26.00	39.00
Bore Hole 3	10.00	9.00
Bore Hole 4	56.00	63.00
Bore Hole 5	77.00	89.00
Bore Hole 6	38.00	44.00
Bore Hole 7	269.00	239.00
Leachate dam 1 Pt 9	dry	16.00
Sed Pond dam 2 Pt 8	23.00	26.00
Tharbogang Swamp	dry	dry
Dissolved Magnesium (mg/L)	**Mar-19**	**Aug-19**
Bore Hole 1	155.00	180.00
Bore Hole 3	21.00	18.00
Bore Hole 4	140.00	141.00
Bore Hole 5	139.00	167.00
Bore Hole 6	102.00	108.00
Bore Hole 7	472.00	418.00
Leachate dam 1 Pt 9	dry	257.00
Sed Pond dam 2 Pt 8	21.00	17.00
Tharbogang Swamp	dry	dry
Dissolved Potassium (mg/L)	**Mar-19**	**Aug-19**
Bore Hole 1	96.00	74.00
Bore Hole 3	18.00	12.00
Bore Hole 4	161.00	129.00
Bore Hole 5	66.00	63.00
Bore Hole 6	80.00	68.00
Bore Hole 7	188.00	158.00
Leachate dam 1 Pt 9	dry	1100.00
Sed Pond dam 2 Pt 8	59.00	26.00
Tharbogang Swamp	dry	dry
Dissolved Sodium (mg/L)	**Mar-19**	**Aug-19**
Bore Hole 1	1310.00	1190.00
Bore Hole 3	398.00	323.00
Bore Hole 4	2470.00	2040.00
Bore Hole 5	920.00	924.00
Bore Hole 6	1350.00	1270.00
Bore Hole 7	1150.00	1040.00
Leachate dam 1 Pt 9	dry	3320.00
Sed Pond dam 2 Pt 8	438.00	72.00
Tharbogang Swamp	dry	dry
Ammonia (as N) (mg/L) N	**Mar-19**	**Aug-19**
Bore Hole 1	0.12	0.0
Bore Hole 3	9.95	5.9

Bore Hole 4	0.85	0.4
Bore Hole 5	2.87	2.01
Bore Hole 6	0.35	0.44
Bore Hole 7	23.80	15.30
Leachate dam 1 Pt 9	dry	5.21
Sed Pond dam 2 Pt 8	0.26	0.63
Tharbogang Swamp	dry	dry
Total Oxidised Nitrogen (as N) (mg/L)	**Mar-19**	**Aug-19**
Bore Hole 1	20.90	7.17
Bore Hole 3	0.29	0.24
Bore Hole 4	0.28	0.62
Bore Hole 5	0.81	0.55
Bore Hole 6	1.23	0.60
Bore Hole 7	378.00	447.00
Leachate dam 1 Pt 9	dry	0.56
Sed Pond dam 2 Pt 8	0.15	0.69
Tharbogang Swamp	dry	dry
Volatile Organics (ug/L)	**Mar-19**	**Aug-19**
Bore Hole 1	50	50
Bore Hole 3	50	50
Bore Hole 4	50	50
Bore Hole 5	50	50
Bore Hole 6	50	50
Bore Hole 7	50	50
Leachate dam 1 Pt 9	dry	50
Sed Pond dam 2 Pt 8	50	50
Tharbogang Swamp	dry	dry