



**ENVIRONMENTAL EARTH
SCIENCES**

CONTAMINATION RESOLVED

ANNUAL REPORT 2018 -
ENVIRONMENTAL MONITORING
AT THE DUNMORE RECYCLING
AND WASTE DEPOT, DUNMORE,
NEW SOUTH WALES
REPORT TO SHELLHARBOUR CITY
COUNCIL

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EXECUTIVE SUMMARY

Environmental Earth Sciences NSW have undertaken quarterly environmental monitoring of groundwater, surface water and leachate at the Dunmore Recycling and Waste Disposal Depot, Dunmore, New South Wales since 1992.

Surface water, groundwater, leachate, landfill gas and dust were collected/monitored on a quarterly basis between November 2016 and August 2017. The locations monitored include BH1c, BH2, BH3, BH4, BH5, BH13, BH14, BH15, BH16, BH19, BH20, BH20s, a leachate tank (LP1), four surface water ponds (SWP1, SWP2, SWP4 and SWP5) and four samples in Rocklow Creek; SWC_Up, SWC_Down, SWC_Down_2 and SWC2. This location is directly below current landfilling activities and the leachate ponds.

Inferred groundwater contours for the past four quarterly monitoring rounds, show a general groundwater direction to the south south-east towards Rocklow Creek. Groundwater velocity throughout the site varies between 1-16 m/yr and slows down in the downstream of the site due to low hydraulic gradients.

Over the 2017-2018 monitoring period, groundwater at boreholes BH1c, BH2, BH3, BH15, BH20 and BH20s exhibited strong signs of leachate influence, whereas bores BH4, BH13, BH14, BH16 and BH19 showed minor to no influence of leachate. This influence can be attributed to historical or current landfill leachate, and effluent leachate.

Annual organic, inorganic and microbial analysis of the water in the leachate tanks (LP1) continued to indicate that concentrations of leachate and contaminants in this water poses a risk to human health and any contact with this water should be avoided. Additional organic analysis that was undertaken in November 2017 at BH15 reported no detections and this analysis may be removed from the analytical schedule.

Results from surface water monitoring indicate possible site impacts are affecting locations SWP1, SWP2, SWP4 and SWP5. The connectivity between the surface water bodies and groundwater has not been specifically assessed however past chemical results indicate a potential interaction between the two.

There was no evidence of leachate impact detected at the down gradient Rocklow Creek site SWC2, SWC_Up, SWC_Down and SWC_Down_2. These locations had ammonium and nitrate levels over the last four sampling events between 0.1 and 1.4 mg/L. All constituents were below the ANZECC (2000) trigger values for marine waters (1.88 mg/L and 10.6 mg/L, respectively).

Ammonium in the groundwater generally exceeded the threshold values. Historically there has been an apparent decreasing trend in concentration in nitrogen species in the groundwater towards the south. However, between 2015-2017, elevated levels of ammonium were detected at BH20 which were higher than the upgradient bores. This more recent trend was not observed during the 2017-2018 monitoring period with ammonium concentrations decreasing south towards BH20. Results and previous review (Environmental Earth Sciences, 2017) suggest that the ammonia plume at BH20 was relatively stable and did not apparently impact Rocklow Creek.

No landfill cap deficiencies were noted during the 2017-2018 monitoring period. The current level of capping on the landfill is deemed sufficient. Furthermore, no gas was detected at site sheds, buildings, weighbridge, or offices. Ongoing monitoring should continue to occur on a quarterly basis to ensure no landfill gas related human health hazards are present at these locations.

The dust deposition gauge positioned at the north western site boundary contained slight levels of insoluble solids, ash and combustible matter. Calculated quarterly dust levels, were below the guideline value and are not considered a concern based on the appropriate Australian/New Zealand Standard AS/NZ 3580.10.1: (2003).

Results collected over the monitoring period for 2017-2018, suggest that the landfilling activities undertaken at Dunmore Recycling and Waste Disposal Depot, are not likely to be impacting offsite receptors.

Environmental Earth Sciences provides the following recommendations as part of the annual review in order to address concerns regarding leachate, gas and surface water impacts:

- continuation of the current monitoring program to meet EPL requirements and to ensure leachate plume, landfill gas migration and surface water conditions are monitored;
- removal of organic analysis at BH15 from the analytical schedule;
- commissioning of a new shallow groundwater sampling location in the area down-gradient of BH15 to monitor the mobile leachate plume detected in the scope of Environmental Earth Sciences' *Data review of environmental monitoring at Dunmore Waste & Recycling Facility (2017)*;
- repair or replacement of BH19 to ensure consistent monitoring of leachate plume migration towards Rocklow Creek;
- replacement of former bore BH18 to ensure detection of potential mobile leachate plumes that could be released from the eastern section of the landfill in the future; and
- the first sample collected from any new monitoring location is also recommended to be analysed for TRH. It is important to note that, due to the high potential for the presence of natural organic compounds in groundwater, any testing for TRH include a Silica Gel Cleanup (SGC) or Extractable Petroleum Hydrocarbons (EPH) scan to remove polar natural compounds prior to analysis.

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1 INTRODUCTION

Environmental Earth Sciences NSW have undertaken quarterly environmental monitoring of groundwater, surface water and leachate at the Dunmore Recycling and Waste Disposal Depot, Dunmore, New South Wales (the 'site') since 1992. This report discusses the monitoring results from groundwater monitoring locations in and around the Depot, as well as surface water samples collected from Rocklow Creek, surface water ponds and the site leachate collection pond.

In addition, landfill gas monitoring was carried out across the cap and within buildings located on the property, while dust monitoring was performed adjacent to the north-western boundary.

Results for the past 12-month monitoring period between November 2017 and August 2018 has been discussed within the report in conjunction with trends established by comparing monitoring data collected since November 1992.

Monitoring has been undertaken in accordance with Dunmore Recycling and Waste Depot's Environmental Protection License No.5984.

The data interpretation relies on professional judgement used to extrapolate between assessed areas. Actual conditions may vary from those inferred to exist. The actual interface between materials and variation of ground or surface water quality may be more abrupt or gradual than the report indicates.

This report should be read in conjunction with the limitations presented in Section **Error! Reference source not found.3**.

2 OBJECTIVES

The objective of this investigation is to assess the impacts of landfilling activities on surrounding land, adjacent watercourses and groundwater. All works have been undertaken in accordance with NSW EPA license No. 5984. It is noted that Council has commissioned works above and beyond the scope of the EPL to ensure that any potential environmental concerns are assessed, and a solution established as early as possible.

3 SCOPE OF WORK

The following scope of works was undertaken to achieve this objective:

- collect field measurements and sample water from selected boreholes, the leachate pond, the four surface water ponds and Rocklow Creek on a quarterly and biannual basis;
- analyse water from the boreholes for pH, total dissolved solids (TDS), total organic carbon (TOC), oxidation-reduction potential (ORP), temperature, soluble iron and manganese, total iron, biological oxygen demand (BOD) and an ionic balance for each quarterly sampling event (total recoverable hydrocarbons [TRH] to be analysed in one quarterly sampling event at BH15);
- analyse water from the leachate pond for turbidity, faecal coliforms and all borehole parameters on a quarterly basis;
- analyse water from the leachate pond for phenolic compounds, polycyclic aromatic hydrocarbons (PAH), total petroleum hydrocarbons (TPH), benzene, toluene, ethylbenzene and xylene (BTEX) and halogenated volatile compounds (HVC) annually;
- analyse water from Rocklow Creek (adjacent to the landfill) for nitrogen species, soluble iron, bicarbonate and turbidity quarterly;
- collect and analyse sample from a dust gauge bottle to the north of the site (DDG);
- undertake a gas walkover of all site buildings and the landfill cap with a flame ionisation detector (FID) or an Inspectra Laser Unit (ILU) and a Landfill Gas Analyser (GA2000 or GA5000);
- report on the physical and chemical characteristics of the groundwater and how the leachate produced from the Dunmore Waste Disposal Depot chemically and physically affects ground and surface water quality; and
- report on leachate plume movements (if any) and if necessary recommend action that may be required to prevent contamination of groundwater.

4 REGIONAL SETTING

The Dunmore Recycling and Waste Disposal Depot is located at Buckleys Road, Dunmore, New South Wales (Figure 1).

4.1 Regional Geology

The local geology has been described in the Kiama 1:50 000 *Geological series sheet* 9028-1 (Bowman, 1974) as being Quaternary aged (up to three million years old) alluvium, gravel, beach and dune sand. This sequence is underlain by early to late Permian aged (225-275

million years old) aphanitic (fine grained) to porphyritic (some large crystals) latite (the Bumbo Latite Member) which also forms the surrounding hills and is found outcropping to the north of the site. Swamp deposits consisting of sands, silts and clays are located in and around the area of Shellharbour.

4.2 Soil

A review of the Soil Landscapes of the Kiama 1:100 000 Sheet (Hazelton, 1992) indicates that the site falls within the Killalea (swamp) soil landscape. Soils are formed on coastal alluvial plains and swamps. Soil is described (Hazelton, 1992) as organic, black, massive sandy loam topsoil overlying loose bleached light grey sand with iron staining in the subsoil. The structure is generally apedal massive, with abundant roots and limited coarse material. Soils may also be sodic and strongly acid and have been characterised as Oxyaquic Hydrosols.

The Department of Land and Water Conservation (1997) Albion Park acid sulfate soil risk map indicates the site lies within the “Ap2” category, indicating a high probability of acid sulfate soils occurring within the soil profile. The potential acid sulfate soil material is within 1 metre of the ground surface, and severe environmental risk is considered likely if acid sulfate soil materials are disturbed by activities such as shallow drainage, excavation or clearing.

4.3 Topography and drainage

Steep hills (<15%) surround the site to the west, with Rocklow Creek located on the periphery of the site to the south and southwest.

Elevation across the Project Area is between approximately 3 and 5 m AHD, with the area of greatest elevation in the catchment being the artificial rise of the landfill to the east. The upper limit of the catchment alluvial soils is positioned at close to 10 m AHD. The catchment drains to Rocklow Creek, which flows south east into the estuary of Minamurra River, approximately 1,100 m south-east of the site. The lower catchment is subject to floods and has water-logging issues due to the permanently high water tables (Hazelton, 1992).

Surface water runoff from the old and the active landfill cell eventually drains into pond SWP4 (Figure 4). Given the shallow water table and sandy soil profile there is potential for surface runoff to infiltrate rapidly and contribute to groundwater flow in a general southward direction towards SWP4 (Figure 4).

4.4 Vegetation

The existing vegetation communities within the site include the following:

- exotic grass cover (pasture species);
- planted buffer zone: native Casuarina sp. trees with pasture grass understorey – 0.44 hectare; and
- native Swamp Oak Floodplain Forest (NSW Endangered Ecological Community) – 0.18 hectare.

The planted buffer zone of *Acacia* and *Casuarinaceae* species have the potential to affect the levels of nitrogen in the groundwater through atmospheric nitrogen fixation mechanisms occurring in and around the root zone.

4.5 Rainfall

Long term rainfall data has been sourced from the Bureau of Meteorology (2017) (www.bom.gov.au, verified 11 September 2018) Albion Park (Wollongong Airport) weather station, approximately 10 km from site. As this weather station has now been closed, monthly rainfall data from the Albion Park weather station has been compared to long term rainfall Data in Chart 1. The long term data consists of average rainfall data from 1897 to 2011.

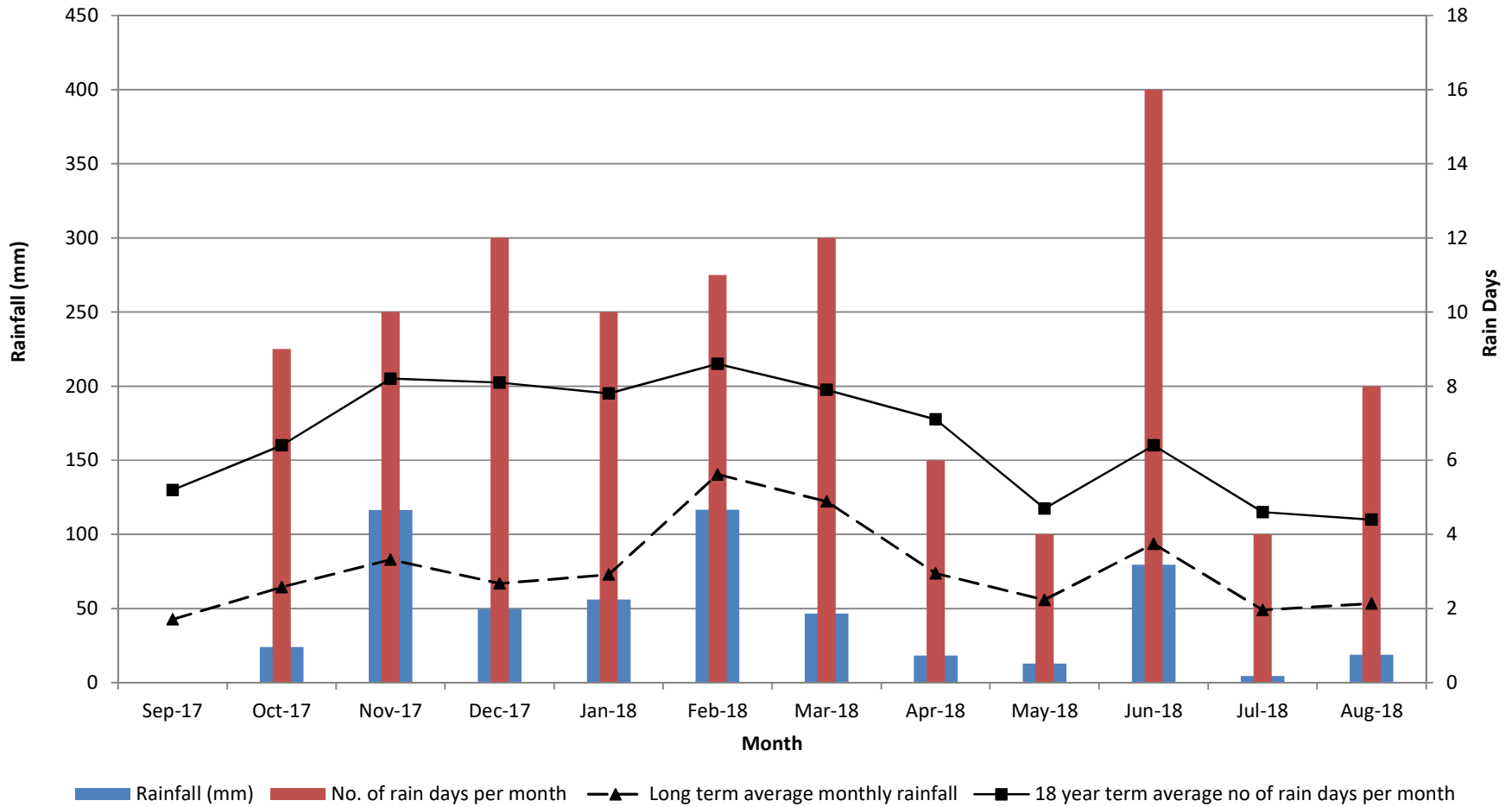


Chart 1. Rainfall and the number of rain days for the 2017/2018 monitoring period, Albion Park (Wollongong Airport) weather station.

5 SITE HISTORY AND LAND USE

Pertinent information relating to the site history and land use is described below:

- the Dunmore Recycling and Waste Disposal Depot is reported to have been established in 1945;
- Shellharbour City Council has managed the site since 1983;
- putrescible and non-putrescible waste generated in the Municipality of Shellharbour is deposited at the Dunmore Recycling and Waste Disposal Depot;
- before the mid 1980s there was no control on the disposal locations or the types of waste disposed of at the landfill. In the mid 1980s the landfill operations became more controlled and present filling is confined to the area depicted on Figure 1, adjacent to Buckleys Road;
- since Shellharbour City Council took over the operation of the Dunmore Recycling and Waste Disposal Depot, filling areas have been designated and regular night cover applied. A weighbridge and checkpoint station has been installed to inspect the type and amount of waste being disposed of, and a recycling collection area has been established;
- night soil and grease trap wastes were deposited in the vicinity of the former borehole BH1 and BH6 (Figure 1), until around 1985 where night soil disposal decreased;
- no night soil/effluent was disposed of in this area after 1989;
- it has been reported that ash material has been dumped at the landfill, supposedly spent dolomite from the Wollongong steel mill. The possibility that other industrial wastes may be present in the older parts of the landfill has not been discounted, due to the uncontrolled nature of dumping at the landfill up until the mid 1980s;
- current landfill disposal operations work on the principle of filling a cell with concrete, brick, tile and rock-fill wastes until the surface level is approximately one and a half metres above the groundwater table. A clay or geo-textile liner is then applied before putrescible wastes are disposed of in the cell. A clay/silt cap covers the cell at its final design surface. The cap was then top-soiled and re-vegetated with grass and shrubs;
- in 1983 an environmental impact statement (EIS) was prepared by Council for commencement of a sand dredging operation. This operation was put into effect in the latter half of 1993 and was located between boreholes BH1 and BH6 (Figure 1). Current sand mining operations are undertaken in the west of the site near SWP4;
- a landfill gas flare was installed to the north east section of the landfill. The landfill gas flare monitors the levels of gas within the landfill and safely vents the landfill gasses;
- the surface water pond SWP3 was filled with crushed rock and concrete during 2014, this is now an active landfill cell; and

- a surface water pond was constructed in the southern portion of the site near BH13. This surface water pond has been labelled as SWP5 and incorporated into the monitoring plan.
- two leachate ponds were present on the eastern side of the site before 2016. These former leachate ponds overflowed during 2003 with impacts notable on the surrounding groundwater chemistry;
- these two former leachate ponds were replaced in 2016 with four leachate tanks. Any water migrating through the landfill cells is intercepted by the leachate interception trenches. The leachate from the landfill cells is then directed towards the leachate tanks on site where it is stored and removed; and
- during 2016-2017 a new waste management facility was constructed in the eastern section of the site (the area around former BH5, BH6, BH12, and BH17). This construction caused the necessity of decommissioning of the boreholes located in this area.

6 SITE CHARACTERISTICS

6.1 Location of monitoring points

Table 1: Borehole locations

Bore	Date of installation	Location description	Former bores	Access to location
BH1a	May 2004 – May 2010	Immediately south and topographically down-gradient of the previous disposal area, and to the west of the currently operating fill area	BH1 - moved in 1995 due to the extension of the outer wall of the active landfill; destroyed during waste depot operations in February 2004	Decommissioned in 2010
BH1b	August 2010	As above	BH1a – required replacement due to damage.	Accessible
BH1c	August 2013	As above	BH1a and BH1b	Accessible
BH2	August 1991	South of the access road, down-gradient of land filling activities	-	Accessible

Bore	Date of installation	Location description	Former bores	Access to location
BH3	August 1991	Down-gradient of landfilling activities, between the landfill and Rocklow Creek	-	Accessible
BH4	August 1991	Down-gradient of land filling activities, between the landfill and Rocklow Creek	-	Accessible
BH5	August 1991	In a low-lying area on the verge of swamplands adjacent to Restoration Fill Services	-	Decommissioned in 2017
BH6b	February 2007	Down-hydraulic gradient of the HDPE lined leachate ponds	BH6 (August 1991) – situated east of the current landfill disposal site, inaccessible due the shallow sand mining; BH6a (August 2000) - south of the former leachate pond, damaged due to dredging related activities	Decommissioned in 2016 during construction works undertaken for new waste management facility.
BH7	August 1991	-	-	Destroyed by dredging activities
BH8	August 1991	Up-gradient of old landfill cell and land filling activities	-	Could not be located
BH9	August 1991	On edge of old landfill cell and up-gradient of current activities	-	Accessible

Bore	Date of installation	Location description	Former bores	Access to location
BH10	December 1992	North of site and up-gradient of the landfill, in a paddock adjacent to and down gradient of residential dwellings	-	Accessible
BH11	June 2002	Immediately east of the active landfill and south-east of the old capped landfill	Replaced by BH18	Decommissioned
BH12	November 2008	Down-hydraulic gradient of the HDPE lined leachate ponds and land filling operations	Previous BH12 moved south ~4 m to allow expansion of adjacent landfill cell	Decommissioned in 2017
BH13	June 2002	Down-hydraulic gradient of land filling operations on the southern side of the site - should detect impacts on groundwater from the controlled waste disposal areas	-	Accessible
BH14	June 2002	Down-hydraulic gradient of land filling operations on the southern side of the site - should detect impacts on groundwater from the controlled waste disposal areas	-	Accessible
BH15	June 2010	South of former borehole BH5 located within Killalea State park	-	Accessible

Bore	Date of installation	Location description	Former bores	Access to location
BH16	June 2010	East of former borehole BH5 located on adjacent property	-	Accessible
BH17	November 2012	North east corner of leachate pond	-	Decommissioned in 2016 during construction works undertaken for new waste management facility.
BH18	June 2010	north of former borehole BH11	-	Decommissioned in 2016 during construction works undertaken for new waste -- management facility.
BH19	July 2013	On the south west boundary of the site in close proximity to Rocklow creek	-	Accessible
BH20	July 2013	On the south boundary of the site in close proximity to Rocklow creek	-	Accessible
BH20s	September 2017	Nested well near BH20 (screened at 1.5-4.5 mBGL)	-	Accessible
SWC2	-	Rocklow creek south of the landfill	-	Accessible
SWC_UP	August 2013	Upper Rocklow creek south of the landfill	-	Accessible
SWC_Down	August 2013	South Rocklow creek south of the landfill	-	Accessible
SWC_Down_2	November 2017	South east of SWC_Down within Rocklow Creek	-	Accessible

Bore	Date of installation	Location description	Former bores	Access to location
LP1	-	Leachate tanks to the east of current active cell	-	Accessible
SWP1	-	West of the current active landfill and adjacent to the access road running around the site	-	Accessible

6.2 Stratigraphy

The stratigraphy is interpreted from geological logs of the bores presented in Appendix A.

Fill material was encountered to 1.5 m below ground level at borehole BH1a/b, and consisted of a grey, fine to medium grained sand matrix with metal, rock and household rubbish. Road base and a brown sandy loam with blue metal aggregate were encountered to 1 m below ground level (mbgl) at BH1, BH11 and BH18. Household waste was found at BH2 and BH3 to 1.5 m below ground level. BH6a had 0.9 m of clay fill while fill material was noted in BH8 down to 0.5 mbgl.

Natural alluvial material on site consisted of fine to medium grained sands (occasionally silty within the top 1 mbgl), yellow/orange/brown in colour sometimes grading to grey at 6 to 8 mbgl. Shell and gravel lenses were common throughout. A grey to green clay overlaid the latite bedrock encountered at 11 mbgl in borehole BH11 and 10 mbgl in borehole BH13. A sandy clay/clay horizon was encountered at boreholes BH7, BH8 and BH9 between 5 and 8 mbgl.

The stratigraphy at BH10 was different to the rest of the site. Brown sandy silts were intercepted to a depth of 2.0 mbgl. Underlying these sediments were brown silty clays and clayey silts, which overlies a weathered latite bedrock intercepted at 4.3 mbgl. It is understood that borehole BH10 has been constructed within a different aquifer to the bores located on the landfill site. As a result sampling of BH10 was excluded from the monitoring program.

Shallow water bearing zones were encountered between 0.39 and 0.98 mbgl at boreholes BH2, BH5, BH7, BH8 and BH9. For the remaining boreholes, groundwater was encountered between 2.43 and 6.00 mbgl during drilling.

Boreholes BH15 and BH16 were installed on the eastern boundary of the site into swampland environments where groundwater was encountered at or near surface level. Natural material encountered was light grey/ brown sand with grain size increasing with depth.

BH19 and BH20 were installed close to the Rocklow Creek to monitor the potential leachate movement towards the creek. No fill material was encountered at BH19 and all the layers

were composed of sand (silty sand was observed in the first ~30 cm). Water strike was noted at 3.5 m at this location. Approximately 1m of deep fill material was observed at BH20 containing plastic bags and other types of artificial material, before striking natural sand. Groundwater was encountered at around 2.5 m at BH20.

6.3 Groundwater physics

Inferred groundwater flow has been established in a south to south easterly direction (Environmental Earth Sciences, 2011, 2012a, 2013 and 2017) however influences on gradient include historical local sand-mining, the deep excavation of the landfill and subsequent overburden placement. There may also be minor tidal influences from Rocklow Creek (located to the south of the site). Changes in soil and bedrock stratigraphy across the site can also influence flow rates and pathways.

Groundwater recharge points include the upper catchment to the north and west, the site itself due to the high permeability of the soil and the large ponds created by sand mining/dredging. Recharge to the groundwater is expected to be rapid on the lower alluvial plains due to the high hydraulic conductivity of the alluvial based sandy soil. The expected discharge point for the local shallow groundwater is Rocklow Creek.

The groundwater monitoring wells are designed to collect water from the upper sand layers situated above the deep clay layer and latite bedrock (5-10 mbgl). Screens are positioned so that water from the unconfined Quaternary alluvium aquifer can be obtained. All boreholes except borehole BH10 are receiving water within the same groundwater flow path and aquifer. Borehole BH10 is located within a separate water bearing zone at the top of the local catchment (to the north of the site).

Groundwater velocity throughout the site varies between 1-16 m/yr (Environmental Earth Sciences NSW 2013). Groundwater levels are affected by the landfilling activities and calculated groundwater velocity and chemical groundwater results indicate (Environmental Earth Sciences NSW, 2013 and 2017) that movement of leachate is likely to be slower downgradient of the landfill near Rocklow Creek due to decreasing hydraulic gradients.

6.4 Tidal effects on groundwater

Environmental Earth Sciences NSW hydrogeological investigations on nearby sites in the same unconfined sand aquifer discharging to Rocklow Creek have determined that tidal influence from the creek results in a maximum observed tidal amplitude in the aquifer of 0.2 m (Environmental Earth Sciences, 2001). It was concluded that the tidal effect could extend as far west as between the landfill site and the Princes Highway (Environmental Earth Sciences, 2001).

Further work in 2005 (Environmental Earth Sciences, 2005) generally limited the tidal influence to between five and 50 m from the tidal creek, depending on soil permeability. Most of the groundwater monitoring wells (excluding BH3, 4, 19, 20 and 20s) are therefore unlikely to be significantly affected by tidal movements.

6.5 Groundwater inorganic chemistry interpretation

Groundwater chemical behaviour is controlled by its constituents that are determined by the initial source of water, the medium through which it travels and the quality and quantity of any infiltrating water (including leachate).

The identification of processes influencing groundwater is difficult when limited to comparing total ionic concentrations of different sources. This difficulty is enhanced by the variations in ionic concentrations resulting from localised dilution, dispersion, attenuation and infiltration. These influences include rainfall, open water bodies and tidal effects.

As an example, if potassium (K^+) concentrations in a water sample were originally 50 mg/L and are found to have reduced to 30 mg/L when the water is sampled three months later, we would generally draw the conclusion that the K^+ concentration is decreasing in the bore. However, it is also possible that the groundwater has been diluted by an external water source such as rainwater. This means that the relative K^+ concentrations compared to the other ions in the groundwater have not changed, instead they have been diluted for a short while by the influence of an external water source. The long-term data collected from this site has confirmed these effects.

The use of ratios between ionic concentrations simplifies the identification of changes in water quality and can highlight the dominant influences on groundwater chemistry. This method is useful when undertaking contamination investigations of groundwater, in order to identify the major controls on chemical behaviour. A particularly useful ratio is the leachate to non-leachate ratio (L/N ratio), which analyses the sum of leachate ions (potassium, ammonium and nitrate) over non leachate ions (sodium, calcium and magnesium), multiplied by 100, where ratios greater than 10 may indicate leachate influence.

Other influences on water quality and chemical behaviour and that can be used in the interpretation of chemical results include field measurements and observations such as oxidation/reduction potential, temperature, odour, colour, dissolved oxygen and pH. These are used in conjunction with ionic ratios and changes in ionic concentrations to determine the chemical behaviour of surface water and groundwater.

6.6 Groundwater relationships at the site

The nitrogen (N) content in the groundwater (existing as either ammonium (NH_4^+), nitrate (NO_3^-) or nitrite (NO_2^-)) at most bore locations is elevated and can be generally associated with landfill leachate. However given the natural setting of swamps and the presence of nitrogen fixing vegetation such as *Acacia* and *Casuarinaceae* species, contributions from naturally derived sources cannot be ignored.

Uncontrolled dumping was carried out on site before the mid 1980s and night soil and grease trap wastes were known to be located in the eastern portion of the site (near BH5). Household rubbish was noted in the logs of boreholes BH2 and BH3, but only to 1.5 mbgl. Furthermore, there might be several areas of land filling and night soil deposits, which were not identified in previous investigations and were possible sources of nutrients. These known and unknown sources may influence the nutrient detections at the groundwater monitoring points.

Many plant species such as *Leguminaceae*, *Casuarinaceae*, *Coriariaceae*, *Eleagnaceae* and *Mynacaceae* possess root nodules, which are capable of fixing N. Some of these species have been identified in the landfill and surrounding area. As many of these host plants are perennial growing, exact estimates of the amount of N fixed is difficult to ascertain.

Inputs of some nitrogen, usually as NH_4^+ , into the catchment can therefore be attributed to local vegetation. The inclusion of K^+ cannot be associated with these species and alternative contributions such as leachate and the night soil should be assessed.

Although K^+ is usually a useful parameter for identifying night soil and landfill leachate, the differing water chemistry and stratigraphy over the site makes it difficult to establish whether the K^+ levels are actually elevated or natural. $\text{Ca}^{2+}/\text{K}^+$ ratios are a useful indicator for the presence of influence from night soil or landfill leachate. Ratios less than three are an indication of these sources on this site.

In the absence of a carbonate source and under uniform pH conditions, bicarbonate (HCO_3^-) values on this site can be used as a proportional measure of microbial activity between bores. The record of shells in the logs indicates the presence of a carbonate (CO_3^{2-}) source; however, unlike microbial activity shells do not cause a rapid change in CO_3^{2-} concentration unless dissolved by acid. Hence, on the site, elevated HCO_3^- levels indicate elevated microbial activity which can assist in attenuating any leachate contamination.

7 FIELD INVESTIGATIONS

7.1 Sampling and field analyses

Monitoring has been on-going on a quarterly basis since November 1992. During this annual monitoring round surface and groundwater sampling was undertaken by Environmental Earth Sciences NSW on 22 November 2017, 13-14 February 2018, 29 March 2018 and 8-10 May 2018 and 14-15 August 2018.

Surface and groundwater samples were collected using submersible pumps or designated wattera tubing withdrawing the water straight from surface water bodies or boreholes into clean sampling containers. The sample is only taken after the wells have been purged of at least three standing volumes or water and redox potential (pe), EC (electrolytic conductance) and pH have stabilised. Sample containers are securely capped, stored in ice-filled coolers and transported to the laboratory for analysis. Cleaning and decontamination protocols have been provided in the QA/QC section in Appendix B.

Standing water level (SWL), temperature, pH, EC and ORP (oxidation-reduction potential in mV), colour, odour and flow characteristic measurements were collected in the field at each location.

BH19, located on the south west boundary of the site, was only sampled in November 2017 and February 2018 monitoring rounds due to damage to the well in May 2018 and August 2018 rounds.

Table 2 presents the water levels measured over the last year. Field measurements for the previous twelve months of sampling are reproduced in Table 7.

7.2 Groundwater flow

Table 2: Groundwater levels

Sampling location	SWL (mAHD)	SWL (mAHD)	SWL (mAHD)	SWL (mAHD)
	Nov-17	Feb-18	May-18	Aug-18
BH1c	0.675	0.454	0.414	0.536
BH2	1.035	0.683	0.667	0.752
BH3	0.807	0.529	0.539	0.614
BH4	0.059	0.514	0.509	0.569
BH9	1.085	0.987	0.745	0.885
BH10	3.646	3.616	3.791	3.841
BH13	1.175	0.8	0.72	0.855
BH14	1.206	0.765*	0.705	0.797
BH15	0.785	0.64	0.527	0.925
BH16	0.67	0.6	0.35	0.5
BH19	0.535	0.425	0.35	-
BH20	0.505	0.405	0.357	0.49
BH20s	0.491	0.392	0.35	0.46

Notes:

- * - BH14 sampled on 29 March 2018 after a sample was unable to be collected during February 2018 monitoring round due to damage to the well.

8 ADOPTED SITE CRITERIA

Adopted site criteria are taken from the guidelines for the protection of ecosystems we refer to the ANZECC (2000) — *Australian water quality guidelines* (ANZECC, 2000). The guidelines take into account trigger values for fresh and marine waters and provide level of protection percentages for specific analytes.

As previously discussed, groundwater flows vary over the site, but in general the pressure gradient is towards Rocklow Creek to the south of the site. The ANZECC (2000) guidelines

are therefore appropriate as the groundwater beneath the landfill will ultimately discharge into a marine environment. Values for a level of protection for 95% of species in a marine environment are considered relevant to this site and have been adopted as site criteria (Table 3).

It should also be recognised that these trigger values are conservative when used to assess groundwater at the point of discharge into a surface water body. Attenuation effects (e.g. dilution, dispersion and biological activity) could reduce contaminant levels substantially by the time the waters migrate and discharge to the river.

It should be noted a guideline value of 0.3 mg/L is used for soluble iron. This value is derived from interim indicative working level presented in *section 8.3.7* of ANZECC 2000 and is based on Canadian guidelines. Presently there are no Australian derived guidelines for dissolved iron in a marine environment.

Guidelines for the annual organic analysis of the leachate are presented in Table 4.

Table 3: Ecological investigation threshold levels

Analyte	Adopted criteria for groundwater (mg/L)	Adopted criteria for surface water (mg/L)
Ammonia ^D	2.09 ^A	1.88
Nitrate ^{J*}	10.6	10.6
pH	6.5-8.5	6.5-8.5
Dissolved iron [#]	300	300

Notes:

1. C = Figure may not protect key test species from chronic toxicity (this refers to experimental chronic figures or geometric mean for species) – check Section 8.3.7 for spread of data and its significance. Where grey shading and 'C' coincide, refer to text in Section 8.3.7.
2. D = Ammonia as TOTAL ammonia as [NH₃-N] at pH 7.5. For changes in trigger value with pH refer to Section 8.3.7.2 of ANZECC 2000
3. J = Figures protect against toxicity and don't relate to eutrophication. Refer to Section 3.3 if eutrophication is the issue.
4. * = Nitrate trigger value of 10600 µg/l used from Hickey (2013).
5. # = interim indicative working level presented in section 8.3.7 of ANZECC 2000, (Based on Canadian derived guidelines).
6. ^ = Ammonia-N value for 95% species protection for freshwater ecosystems adopted for groundwater.
7. Grey shading = adopted site criteria.

Table 4: Guidelines for organic analysis

Analyte	Adopted site criteria (µg/L)
Total petroleum hydrocarbons	10,000 [*]
Phenol	320 ^a
Benzene	950 ^a
Toluene	300 ^a
Ethyl benzene	140 ^b
Naphthalene	16 ^a

Notes:

- ^a – guideline levels from ANZECC (2000) Guidelines for protection of freshwater aquatic ecosystems; and
- ^b – guideline levels from NSW EPA (1994) Contaminated sites: Guidelines for assessing service station sites for protection of freshwater aquatic ecosystems
- * - Refer to Table 11.

9 LABORATORY ANALYSIS

NATA accredited laboratories were used for required analyses including:

- Sydney Analytical Laboratories (SAL) for inorganic analyses on water samples and ambient dusts concentrations;
- ALS Environmental (ALS) for organic analysis on groundwater at BH15 in November 2017;
- the National Measurement Institute (NMI) for organic analysis on the leachate sample (LP1) in November 2017; and
- Sonic Health for faecal coliforms and Escherichia coli on the leachate sample (LP1).

The following analyses were undertaken for site groundwater and surface water during the 2017-2018 monitoring events:

- groundwater – ionic balance (total dissolved salts (TDS), sodium, calcium, potassium, magnesium, fluoride, chloride, ammonium, sulfate, bicarbonate, phosphate and nitrate), total organic carbon (TOC), biological oxygen demand (BOD), total and soluble iron, and soluble manganese. Groundwater from BH15 was also analysed for TRH and BTEX during November 2017.
- surface water (SWC2, SWC_UP, SWC_DOWN and SWC_DOWN_2) – total and soluble iron, turbidity, nitrate, nitrite, ammonium and bicarbonate;

- SWP 1,2, 4 and 5, SWC_UP and SWC_DOWN – ionic balance, total and soluble iron and turbidity;
- additional analyses for SWP4, SWC_UP and SWC_Down include TOC and BOD; and
- leachate tanks – ionic balance, TOC, BOD, total and soluble iron, soluble manganese, turbidity, faecal coliforms and E.Coli. Additional sampling for total recoverable hydrocarbons (TRH), benzene, toluene, ethylbenzene, m/p xylene, o-xylene (BTEX), polycyclic aromatic hydrocarbons (PAHs) and halogenated aliphatic compounds (HACs) was undertaken on sample LP1 during the November 2017 monitoring round.

Over the 2017/2018 monitoring period surface water bodies continued to be monitored for most of the above constituents to assist in interpretation. Annual organic analysis was undertaken on a water sample collected from the leachate tanks and groundwater sample collected from BH15 in November 2017 round.

A discussion on quality assurance and quality control (QA/QC) sampling procedures is presented in Appendix B of this report, with results of field blind and laboratory duplicate analysis given as part of the laboratory transcripts in Appendix D.

10 RESULTS

All laboratory results are tabulated in Table 8 and Table 9 biological results are presented in Table 10 and organic lab results are presented in Table 11. Original laboratory transcripts for all analyses undertaken are presented in Appendix D.

11 DISCUSSION

11.1 Groundwater levels

Groundwater was determined to be flowing in a south by south easterly direction over the monitoring period (Figure 2), which was similar to previous years.

Standing water levels across the site have decreased steadily to an average of 0.87 mAHD following an extended period of below average monthly rainfall from March 2017 to August 2018. Groundwater levels across the site are highly correlated and historically show rapid recharge following months of average to above average rainfall (see Chart 2), with the site's sandy soils promoting percolation through the soil profile to groundwater.

11.2 Groundwater chemistry

Groundwater chemistry across the site varies between those locations impacted by leachate and those not impacted. At locations of limited to no leachate impact, groundwater was characterised by K⁺/TDS ratio of <3 and Ca²⁺-Cl⁻ species dominance. Impacted groundwater locations generally displayed a high Cl⁻/SO₄²⁻ ratio with K⁺/TDS >3. Elevated HCO₃⁻ is also

observed at leachate impacted groundwater locations. Groundwater ionic ratios are presented in Table 12.

The comparison of ratios for groundwater between November 1992 and the last monitoring year generally indicates ongoing leachate plume movement across the site. A comparison of natural groundwater ion concentrations to those of the leachate pond shows that leachate water is chemically different to natural groundwater beneath the site. A detailed assessment on chemical status of groundwater at the site is included in the following sections. Individual borehole chemistry is discussed in Appendix E with accompanying Schoeller plots (Appendix F) to aid in interpretation.

11.2.1 Sample locations impacted by leachate

Over the past monitoring year, groundwater monitoring locations BH1c, BH2, BH3, BH15, BH20 and BH20s displayed chemistry indicative of groundwater dominated by non-native cations in one or more monitoring rounds (Appendix F – Schoeller Plots). This indicated that an external influence, such as leachate, is altering the groundwater chemistry. The sources of these non-native cations can potentially be from multiple sources including:

- landfill leachate associated with current land filling activities;
- residual landfill leachate associated with the shallow old landfill;
- residual impact from an overflow of the former leachate pond which occurred in 2003;
- stockpiles of organic waste;
- residual night soil deposits (referred to as aged or effluent contamination); and
- possibly nitrogen fixing vegetation and decomposition of organic matter under the forested area to the south (only minor influence).

The relative contribution of non-native ions is exhibited by elevated concentrations of potassium (K^+), ammonium (NH_4^+) and/or nitrate (NO_3^-) relative to sodium (Na^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}). The elevated non-native ion concentrations are expressed in a high (>10) or significantly high (>20) L/N ratio (Chart 2). Field measurements indicated possible leachate influence with elevated EC, leachate or H_2S odour, negative redox and a yellow and/or brown colour (Table 7).

Borehole BH1c is situated within the landfill cell and leachate was expected to be encountered at this location. The chemical signature of groundwater from this location was consistent with that of the sample collected from the leachate tank (e.g. elevated L/N and K/TDS ratios, reducing state [Appendix E]).

Borehole BH2 showed slight leachate influence, which can be attributed to being in close proximity to current landfilling activities and also being located in the shallow old landfill cells. No significant changes to chemical characteristics were notable at BH2 with the L/N ratio fluctuating between 13 and 16 (Table 8 and 12). NH_4-N levels were elevated at concentrations between 35 and 49 mg/L.

Groundwater from borehole BH3 has consistently shown leachate impact. During the last year, the L/N ratios at this location were recorded between 31 and 56%. The dominating nitrogen species at this location was NO_3^- . This indicated the occurrence of nitrification in this

area. Field observations at this location noted a black to clear color and no odour during 2017-2018 annual round.

Borehole BH15 displayed elevated L/N ratio, which was 54% in the August 2018 monitoring round. This is associated with high K^+ and NH_4^+ -N levels and a high K/TDS ratio >15 , (Table 12). Petroleum hydrocarbon analysis of groundwater at BH15 in the November 2017 monitoring round resulted in non-detections for all analytes. BH15 is located down-hydraulic gradient of the old unlined landfill cell and former leachate ponds and is also close to a drainage line with the groundwater bearing zones <0.5 m from the ground surface. A data review report issued in August 2017 (Environmental Earth Sciences, 2017) provided visual plots of a leachate plume, which was moving towards the south-south-east through bore BH15. The plume first appeared around 2006 to the north-west of bore BH5 (Environmental Earth Sciences, 2017). This plume may be associated with the leachate pond overflow incident that was recorded on 2003 or a potential leachate migration from the landfill. Over the course of the monitoring period (November 2017 – August 2018) there was a trend of decreasing L/N ratio from 109.33% recorded in November 2017 which occurred parallel to below average rainfall on site. It is important to note that bore BH15's location near the drainage line presents the potential for groundwater to be influenced by surface water flow and local onsite and offsite works. It is likely that high L/N values occur at BH15 from nutrient rich runoff that is transported through the drainage channel during times of rainfall.

BH20 is located directly down gradient of the landfill, leachate ponds and shallow old landfill. This borehole was positioned to assess the chemical characteristics on the boundary of the landfill site. The field observations of BH20 were found to have a negative redox with sulphuric odour and a colour fluctuating between light brown and clear between monitoring rounds. The L/N ratio steadily increased across the annual monitoring period from 18.60 to 35.23 % which gives the indication of a leachate impacted location (Table 12). However, as TDS at this location was low (<1000 mg/L) the L/N ratio may not be a reliable indicator of leachate influence. Significant K^+ levels and the presence of PO_4 and NH_4^+ suggests that a leachate influence was present.

Bore BH20s is located directly adjacent to BH20 but at a shallower depth. Screened intervals of BH20 and BH20s are 6.0-9.0 mBGL and 1.5-4.5 mBGL respectively. This bore was positioned to compare the chemical characteristics on the boundary of the landfill site in order to locate potential transport pathways to Rocklow Creek. In August 2018, field measurements at bore BH20s recorded a negative redox (-60.9 mV), clear colour of the groundwater and no odour was detected. The high levels of NO_3^- (39 mg/L) and increase in K^+ (110 mg/L) led to an elevated L/N ratio (73.69%), indicative of potentially high leachate impact at this site. TDS is relatively low (835 mg/L) making the L/N susceptible to natural variations or fluctuations in chemistry. Chemical characteristics of the bore show groundwater was low in Na^+ , with a moderate Ca/K and K/TDS ratio (Table 12). Ammonium levels (0.6 mg/L) have decreased slightly since May 2018 and remain lower than those seen at the deeper BH20 bore. It was previously thought that high nitrate levels in this shallower bore location was indicative of nitrification of the diluted ammonium plume present in the deeper aquifer throughout the soil profile, however, it is more likely that it is caused by the transport of nutrients from the up-gradient old shallow landfill. Continued monitoring at this location will be necessary to determine potential leachate transport to Rocklow Creek.

A detailed description of leachate impact at these locations is presented in Appendix E.

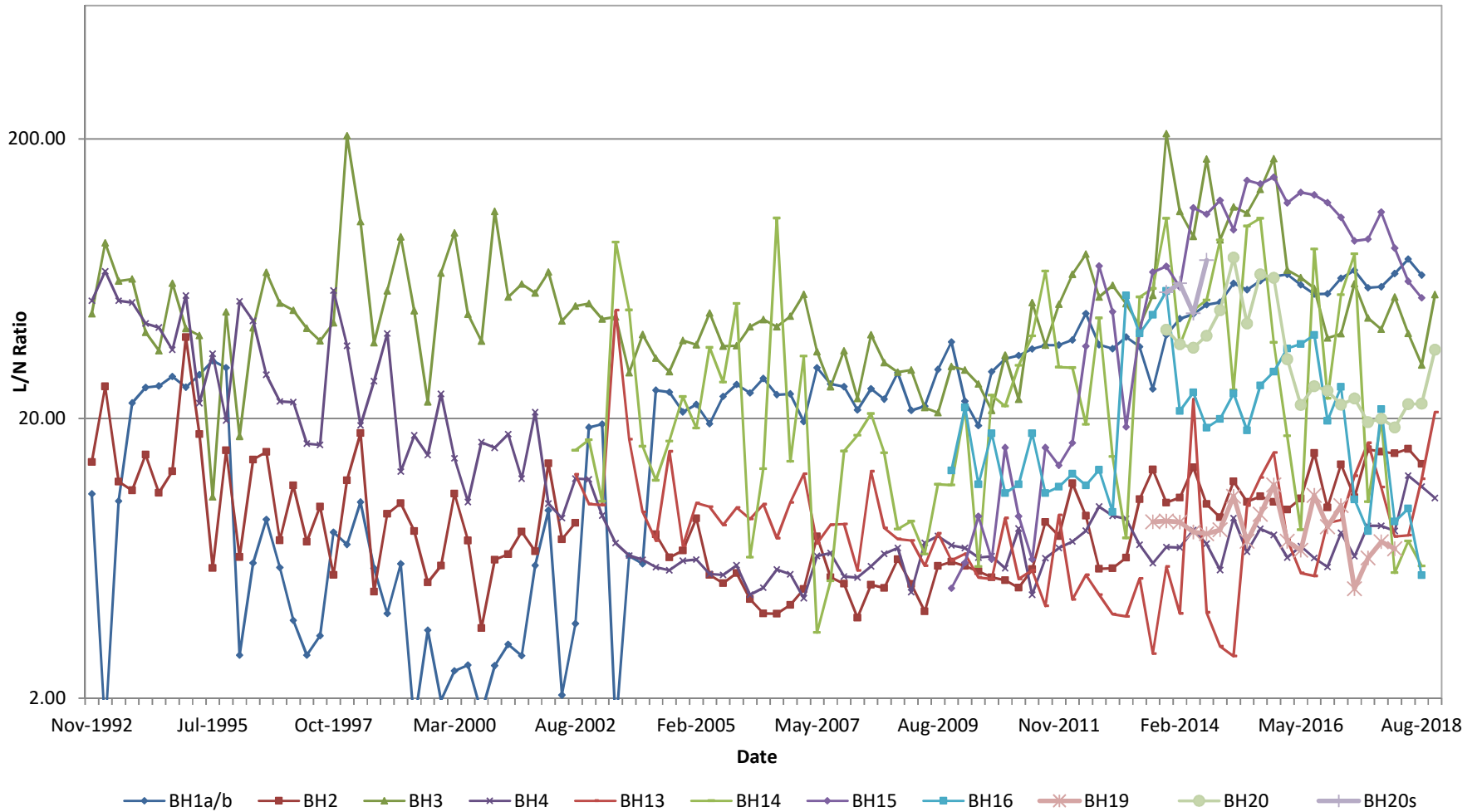


Chart 2. L/N ratio for all active groundwater boreholes from the beginning of monitoring in 1992.

11.2.2 Remaining bore locations

Boreholes BH4, BH13, BH14, BH16 and BH19 showed minimal leachate impact through the measurement of native ion dominance within groundwater.

Field observations show BH13 had a slight negative redox potential, no odour and a clear/brown colour. Similar to the previous year, nitrogen species were dominated by nitrate, which suggested redox conditions are slightly favouring oxygenated conditions. Ammonia concentrations have been elevated at this location since August 2017 (2.8 mg/L) where levels reached an historical peak. This location is strategically down gradient of the landfill and the ionic balance within borehole BH13 and chemical indicators measured across 2017-2018 may indicate a leachate plume has passed through the location over this time. This location will continue to be closely monitored as any future leachate front should be noticeable here.

The L/N ratio at Borehole BH14 decreased steadily from 19.76% in November 2017 to 5.94% in August 2018 over the past year (Table 12, Chart 2). Concentrations of K^+ have stabilised from the high levels measured in the previous 24 months of monitoring. NO_3^- was below typical concentrations at this location during the February, May and August 2018 (Table 8). It is possible that BH14 may have had a hydraulic connection with the former SWP3 which most likely collected run off from the former unlined landfill cell. The historical presence of nitrate as the dominant species within groundwater at BH14 is reflected by the typically positive historical ORP values. The oxygenation of the groundwater at BH14 was a relict effect of the former position of SWP3. The decrease in NO_3^- concentration and negative ORP values for the February, May and August 2018 monitoring rounds is evidence of the closure of the infiltration pathway for oxygenated water from SWP3 into BH14 following SWP3's infilling. Historically, fluctuation of NO_3^- has occurred at this location with very elevated levels occurring, peaking at 250 mg/L in May 2015. These fluctuations could be linked to rainfall events and the subsequent increase in groundwater flow, transporting nitrate from the shallow old landfill near this location and the main landfill mass up-gradient of this location (see Figure 1). Below average rainfall could explain the decrease in leachate impact over the 2017-2018 monitoring period.

Borehole BH16 is located on the neighboring site to the east and on the opposite side of the drainage line in a swampy area (Figure 2) with groundwater field observations recording a brown colour and a minor leachate / sulfuric odour. The sampled redox potential indicates a reducing environment, which may have an influence on the historical dominance of NH_4^+-N over NO_3^- . Groundwater sampling over the 2017-2018 monitoring period showed limited to no leachate impact at BH16 which was represented by an L/N ratio of <10% for the February, May and August 2018 monitoring rounds. Bores BH15 and BH16 are located close to a drainage channel where offsite impacts can readily influence the chemical characteristics of the shallow groundwater and should continue to be monitored for fluctuations.

Water from BH4 and BH19 showed limited influence from landfill activities as expressed by L/N ratios <10 (Table 12) in combination with other chemical and field observations. Groundwater chemistry at these two locations indicated that natural ions generally dominate. This is confirmed through field measurements including minor to no odour and minor staining or organic influence (Table 7). Field observations included a negative ORP, grey colour and no odour. A grey colour noted in the water can be attributed to fine sands being pumped out of the well.

Chemical characteristics of BH19 suggest limited to no leachate influence such as an L/N ratio < 10 and a relatively higher Ca/K ratio (> 20) (Table 12). BH19 is down gradient of

current sand dredging activities and unlined landfill cells. BH19 is in place to determine any potential leachate migration to the south west of site and will continue to be monitored.

11.3 Leachate chemistry

The chemistry of leachate water on this site was different to that of the groundwater and surface water. This is best illustrated through observation of leachate indicators for boreholes and the leachate tank presented in Table 8, 12, Chart 2 and Appendix F (Schoeller plot). Impacted bores generally displayed elevated total dissolved solids (TDS), biochemical oxygen demand (BOD), ammonium (NH_4^+) and potassium (K^+) concentrations compared to unaffected bores (Table 12 and Appendix F). Additionally, very low $\text{Ca}^{2+}/\text{K}^+$, and high $\text{Na}^+/\text{Ca}^{2+}$, $\text{Cl}^-/\text{SO}_4^{2-}$, total organic carbon (TOC) and L/N ratios are chemical signatures of landfill leachate (Schoeller Plot Appendix F).

During the annual monitoring period, laboratory analysis for faecal coliforms and *Escherichia coli* sampled at LP1 (Table 10) were low in comparison to historical values in all rounds except November 2017 (18,000 cfu/100 mL and 18,000 cfu/100 mL, respectively). Although low concentrations may indicate a reduced health risk, fluctuations occur regularly at LP1 and as such leachate waters must be treated as potential health risk and dermal contact should be kept to a minimum.

Organic analysis carried out during the November 2017 round measured the presence of petroleum hydrocarbons, BTEX, phenols, PAHs and HACs. Dermal contact with leachate should be avoided due to potential health hazards associated with detected contaminants.

11.4 Surface water monitoring

Results of surface water analysis (Table 9 and 13) for samples collected from Rocklow Creek (SWC2, SWC_Up, SWC_Down and SWC_Down_2) and four surface water ponds (SWP1, SWP2, SWP4 and SWP5) confirm that concentrations of ions in the waters continue to be similar to previous monitoring rounds (Schoeller Plots Appendix F).

Ponds SWP1, SWP2, SWP4 and SWP5 are intended to retain any surface water migrating towards Rocklow Creek. The results of the samples collected from these locations provide information about the potential leachate impact in the runoff water. The ionic balance results of the samples collected from these ponds were consistent with historical levels.

In the surface water ponds, in general, nitrate was the dominant nitrogen species indicating oxygenised conditions. Ammonium has dominated the nitrogen species at SWP1 and on one occasion at SWP2 over the past monitoring year.

SWP1 is located on the northern boundary (Figure 2) of the site and water at this site has very little impact from landfill activities. Surface water chemistry showed elevated ammonia concentrations in February (2.5 mg/L) and May 2018 (3.8 mg/L) which exceeded the adopted site criteria for surface water (1.88 mg/L) (Table 9 and Table 13). Ammonia presence at SWP1 is unlikely to be caused by leachate due to its up-gradient position from the landfill. This location generally has significant levels of organic matter floating on the surface and the presence of ammonia is likely as a result of the natural ammonification process of organic nitrogen to ammonia.

Surface water sampling location SWP2 was measured to have elevated nitrate in the November 2017 round (11 mg/L), exceeding the adopted site criteria of 10.8 mg/L. This surface water pond collects runoff from around the site and potential impacts from nutrient-transporting runoff are often observed. Chemical characteristics at SWP2 over the year were within historical levels.

Surface water samples from SWP4 may indicate leachate influence from the adjacent active cell and former unlined landfill cell with exceedances of the adopted site criteria for ammonia in May 2018 (2.6 mg/L) and for nitrate in November 2017 (15 mg/L) and February 2018 (12 mg/L). The retention ponds are able to buffer changes associated with leachate influence through biological activity. In the 2017/2018 annual round, the L/N ratio followed a decreasing trend, which may be correlated to the below average rainfall and the subsequent below average volume of surface runoff collected within surface water ponds on site.

Surface water pond SWP5 was sampled during one round (November 2017) in the last year as it was found to be dry in the other three quarterly monitoring rounds. Historical low TDS measurements (<1000 mg/L) at this location is evidence that water within this pond originates from surface water runoff and rainfall. Nitrate levels exceeded the adopted site criteria in November 2017 (60 mg/L) at this location after above average rainfall in that month.

Three surface water sites are sampled from Rocklow Creek (SWC_Up, SWC_Down and SWC2). SWC_Up, SWC_Down are positioned up and down gradient of the SWC2 site and aid in assessing leachate impacts within Rocklow Creek. This annual monitoring round was the first to include a new sampling location SWC_Down_2, located further downstream of SWC_Down (Figure 1). Rocklow Creek is an estuarine environment, represented by very high levels of EC and TDS, which fluctuate with the tide, and Na-Cl dominance with low calcium and low L/N ratio (<10%). These chemical characteristics are distinctly different to that of the onsite surface water ponds which is visually represented in Chart 4.

Low nutrient and L/N ratios at these locations indicated no leachate impact within Rocklow Creek. SWC2, SWC_Up, SWC_Down and SWC_Down_2 generally had low concentrations of ammonia and nitrate (<0.6 mg/L), despite slightly elevated ammonia at SWC2 in May 2018 (1.4 mg/L). These levels are within historical levels and do not exceed the adopted site criteria. Dissolved iron was within historical values at all locations within Rocklow Creek and below adopted site criteria (0.3 mg/L).

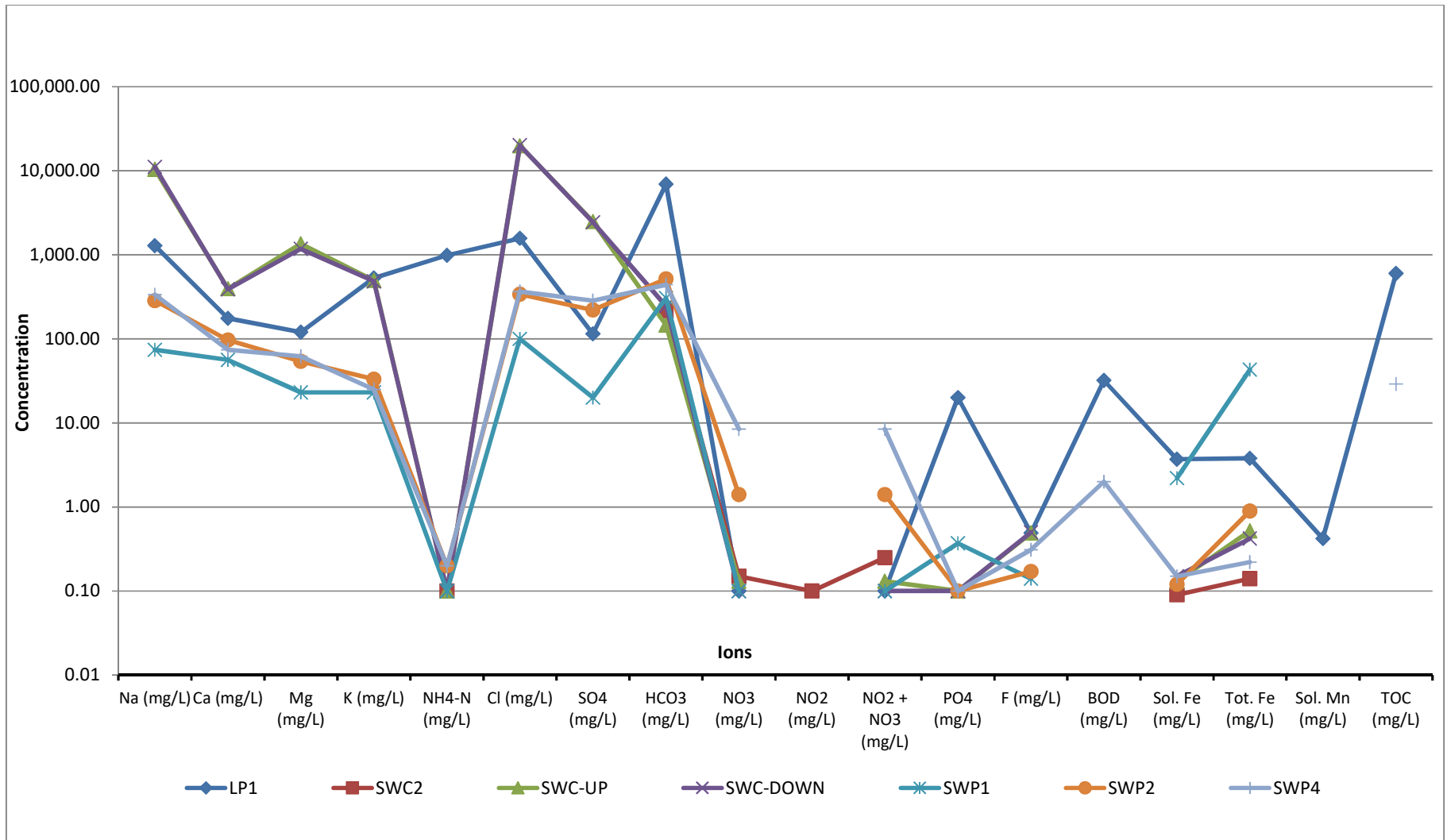


Chart 3. Chemical composition of surface water sites for the August 2018 sampling period.

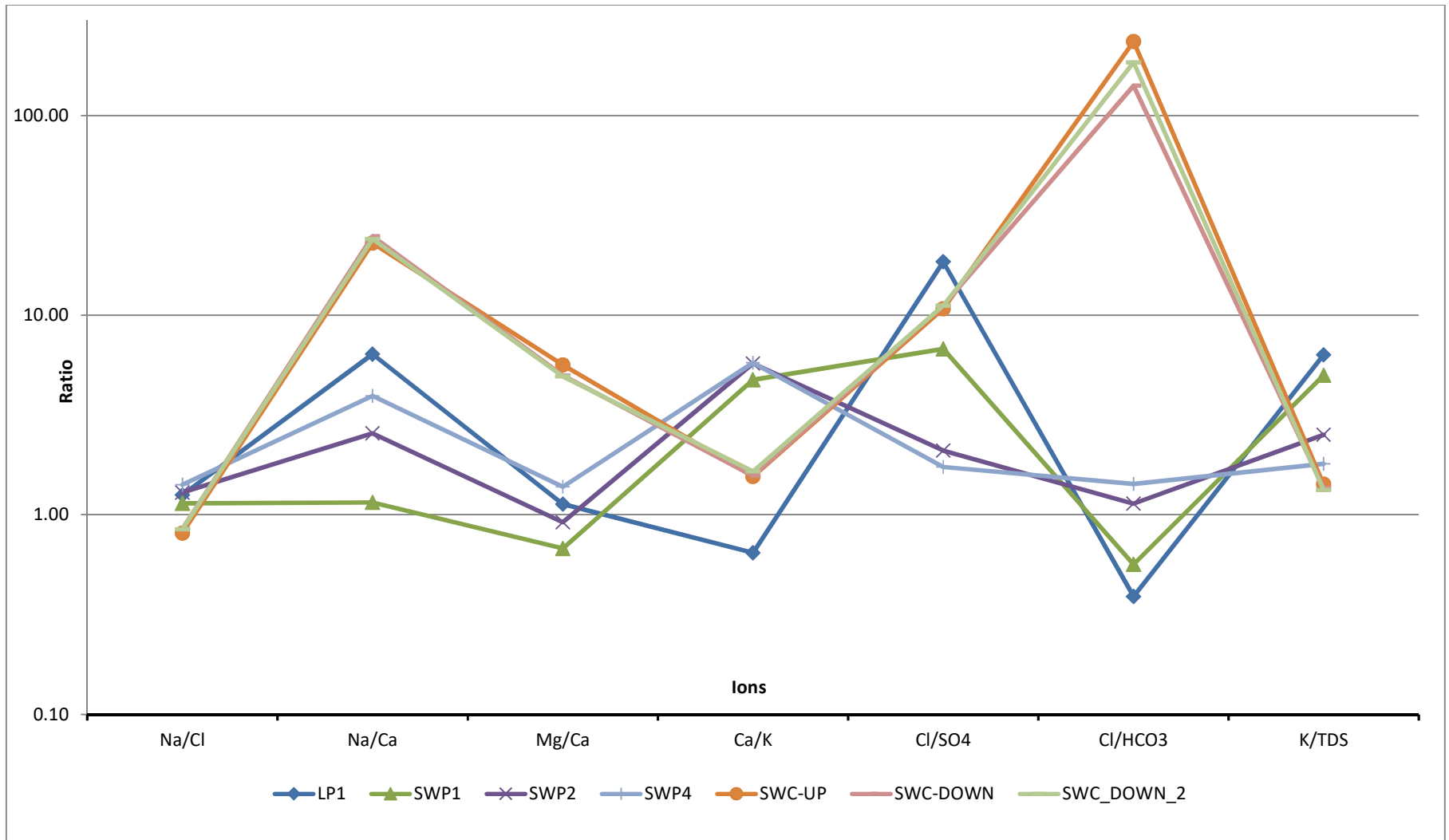


Chart 4. Surface water ratios for the August 2018 sampling period.

11.5 Gas monitoring

Landfill gas was measured in the field using a Flame Ionisation Detector (FID)/ Intra spectre Laser Unit (ILU) and a GA5000 Landfill Gas Analyser (a GFM430 was used during the August 2018 monitoring round). Measurements were taken within and around all buildings in a 250 m radius from the current landfill cell as well as across the landfill cap and active landfilling face for the four monitoring periods. A summary of these results is presented in Table 5. Sampling across the relevant locations consisted of walking a grid pattern and taking readings every minute (see Figure 3 for the gas walkover grids).

A deficiency in the landfill cap is indicated by the presence of methane at levels greater than 500 ppm (NSW EPA, 2016). No landfill deficiencies were noted over the period from November 2017 to August 2018. Ongoing monitoring will occur on a quarterly basis to ensure any future deficiencies are detected.

Table 5: Summary of gas analysis for 2017-2018

Location	Nov-17		Feb-18		May-18		Aug-18	
	GA 5000 V/V%	ILU V/V%	GA 5000 V/V%	ILU V/V%	GA 5000 V/V%	ILU V/V%	GA 5000 V/V%	ILU V/V%
Landfill cap	0	0.00019	0	0.00001	0	0.00646	0	0
Main weigh bridge, weigh bridge office and landfill office sheds	0	0.0002	0	0.0001	0	0.00027	0	0
Dunmore Resource & Recycling Services	0	0.0002	0	0.00036	0	0.00036	0	0.00002
GUIDELINES	1.00% v/v and 0.05% v/v							

Notes:

1. results and guidelines are expressed in V/V %.
2. Guidelines are as per the NSW EPA (2016):
3. reporting threshold of 1.00 % v/v CH₄ within onsite buildings;
4. the threshold level for further investigation and corrective action is 500 parts per million (volume/volume) of methane at any point on the landfill surface for intermediate and finally-capped areas.
5. CH₄ = methane; VOCs = volatile organic compounds (total);
6. - not analysed; and
7. values above the guidelines are **bolded**.

11.6 Dust monitoring

Dust monitoring and analysis is carried out to comply with the requirements of Australian Standards AS 3580.10.1. The annual average limit for fallout of dust (derived for coal mining areas of NSW) is 4 g/m²/month annual average of total solids. The location of the dust deposition gauge is placed at the northern boundary of the site, adjacent to the closest residences, along Shellharbour Road (Figure 1).

The average total solids for dust deposition measured from November 2017 to August 2018 was 0.7 g/m²/month (annual average), below the average limit of 4 g/m²/month for fallout of dust. Hence, dust generation from the landfill towards the nearest residences does not

appear to be significant and as such is not a concern. Results of dust analysis are presented as part of Table 14 and Appendix D.

11.7 Comparison to adopted site criteria

Groundwater and surface water samples were compared to the adopted site criteria listed in Section 8 to assess the impact of leachate on and offsite.

Exceedances of the adopted site criteria are summarised below and in Table 6:

- No exceedances of pH.
- 33 exceedances of the ammonium adopted site criteria at nine groundwater locations and two surface water ponds. No exceedances were recorded in Rocklow Creek.
- 11 exceedances of the nitrate adopted site criteria at four groundwater locations and three surface water ponds. No exceedances were recorded in Rocklow Creek.
- 23 exceedances of the dissolved iron adopted site criteria at four groundwater locations, one surface water pond and one location within Rocklow Creek.

Groundwater locations with high ammonium levels were generally in close proximity to or directly beneath known areas of waste such as at BH1c, BH2, BH3 and BH4. BH20 is located down-hydraulic gradient of the landfill mass and has a screened interval of 6 to 9 mBGL which intercepts the ammonium plume that is transported through the deeper aquifer. Elevated levels of ammonium at BH15 are caused by a mobile leachate plume that was discussed in the data review of environmental monitoring data conducted by Environmental Earth Sciences (2017). BH15 is the furthest down-gradient location in the south-eastern area of the site and the fate of the leachate plume is currently unable to be assessed due to no groundwater sampling location between BH15 and Rocklow Creek.

Relatively high exceedances for nitrate in groundwater (>20 mg/L) were observed at BH3, BH13, BH14 and BH20s. BH3 accounted for three of the seven exceedances at groundwater locations and down-hydraulic gradient BH20s accounted for two exceedances. Levels of nitrate measured at BH3 were on average 55% higher than at BH20s indicating dispersion and dilution of the nitrate plume towards Rocklow Creek.

Table 6: Sample locations exceeding adopted site criteria

Analyte	Number of exceedances	Exceedance location	Exceedance date	Value (mg/L)
pH (6.5 – 8.5)	0	-	-	-
Ammonium (NH ₄ ⁺ -N) (1.88 mg/L for surface water and 2.09 mg/l for groundwater)	33	BH1c	November 2017	320
			February 2018	380
			May 2018	360
			August 2018	340
		BH2	November 2017	49
			February 2018	35
			May 2018	42
			August 2018	43
		BH3	November 2017	11
			February 2018	44
			May 2018	24
			August 2018	26
		BH4	November 2017	7.2
			February 2018	8.9
			May 2018	70
			August 2018	7.7
		BH13	November 2017	2.7
			February 2018	2.6
			May 2018	2.2
		BH15	November 2017	110
February 2018	135			
May 2018	4			
August 2018	115			
BH16	November 2017	6.9		

Analyte	Number of exceedances	Exceedance location	Exceedance date	Value (mg/L)
		BH19	November 2017	6.3
			February 2018	6.9
		BH20	November 2017	12
			February 2018	16
			May 2018	19
			August 2018	21
		SWP1	February 2018	2.5
			May 2018	3.8
		SWP4	May 2018	2.6
Nitrate (NO ₃ ⁻) (10.6 mg/L)	11	BH3	November 2017	66
			February 2018	23
			August 2018	78
		BH13	August 2018	26
		BH14	November 2017	30
		BH20s	November 2017	42
			August 2018	39
		SWP2	November 2017	11
		SWP4	November 2017	15
			February 2018	12
		SWP5	November 2017	60
Soluble Iron (Fe) (0.3 mg/L)	23	BH1c	November 2017	2.5
			February 2018	3.2
			May 2018	1.9
			August 2018	2.2
		BH2	November 2017	2.8

Analyte	Number of exceedances	Exceedance location	Exceedance date	Value (mg/L)
			February 2018	4.1
			May 2018	0.85
			August 2018	0.73
		BH4	November 2017	0.47
			February 2018	0.75
			May 2018	0.42
		BH15	November 2017	19
			February 2018	18
			May 2018	13
			August 2018	11
		BH16	November 2017	0.35
			February 2018	0.37
			May 2018	0.75
			August 2018	1.2
		SWP1	February 2018	4.5
			May 2018	2.7
August 2018	2.2			
SWC2	November 2017	0.34		

Notes: SWP = surface water pond, BH = borehole.

12 RECOMMENDATIONS AND CONCLUSION

Inferred groundwater contours for the past four quarterly monitoring rounds, show a general groundwater direction to the south south-east towards Rocklow Creek. Groundwater velocity throughout the site varies between 1-16 m/yr and slows down in the downstream of the site due to low hydraulic gradients.

Over the 2017-2018 monitoring period, groundwater at boreholes BH1c, BH2, BH3, BH15, BH20 and BH20s exhibited strong signs of leachate influence, whereas bores BH4, BH13, BH14, BH16 and BH19 showed minor to no influence of leachate. This influence can be attributed to historical or current landfill leachate, and effluent leachate. Groundwater from the remaining sampling locations did not appear influenced by leachate.

Annual organic, inorganic and microbial analysis of the water in the leachate tanks (LP1) continued to indicate that concentrations of leachate and contaminants in this water poses a risk to human health and any contact with this water should be avoided.

Results from surface water monitoring indicate possible site impacts are affecting locations SWP1, SWP2, SWP4 and SWP5. The connectivity between the surface water bodies and groundwater has not been specifically assessed however past chemical results indicate a potential interaction between the two.

There was no evidence of leachate impact detected at the down gradient Rocklow Creek site SWC2, SWC_Up, SWC_Down and SWC_Down_2. These locations had low ammonium and nitrate levels over the last four sampling events between November 2017 and August 2018 (between 0.1 and 1.4 mg/L). All constituents were below the ANZECC (2000) trigger values for marine waters (1.88 mg/L and 10.6 mg/L, respectively).

Ammonium in the groundwater generally exceeded the threshold values. Historically there has been an apparent decreasing trend in concentration in nitrogen species in the groundwater towards the south. However, between 2015-2017, elevated levels of ammonium were detected at BH20 which were higher than the upgradient bores. This more recent trend was not observed during the 2017-2018 monitoring period with ammonium concentrations decreasing south towards BH20. Results and previous review (Environmental Earth Sciences, 2017) suggest that the ammonia plume at BH20 was relatively stable and did not impact Rocklow Creek.

No landfill cap deficiencies were noted during the 2017-2018 monitoring period. The current level of capping on the landfill is deemed sufficient. Furthermore, no gas was detected at site sheds, buildings, weighbridge, or offices. Ongoing monitoring should continue to occur on a quarterly basis to ensure no landfill gas related human health hazards are present at these locations.

The dust deposition gauge positioned at the north western site boundary contained slight levels of insoluble solids, ash and combustible matter. Calculated quarterly dust levels, were below the guideline value and are not considered a concern based on the appropriate Australian/New Zealand Standard AS/NZ 3580.10.1: (2003).

All results collected over the monitoring period for 2017-2018, suggest that the landfilling activities undertaken at Dunmore Recycling and Waste Disposal Depot, are not significantly impacting offsite receptors.

The following recommendations should be considered by Shellharbour City Council:

- continue the current monitoring program to meet EPL requirements and to ensure leachate plume, landfill gas migration and surface water conditions are monitored;
- a shallow groundwater sampling location is recommended to be established in the area toward down-gradient of BH15 to monitor the mobile leachate plume detected in the scope of Environmental Earth Sciences' *Data review of environmental monitoring at Dunmore Waste & Recycling Facility (2017)*;
- former bore BH18 is recommended to be replaced to ensure detection of potential mobile leachate plumes that could be released from the eastern section of the landfill in the future; and
- The first sample collected from any new monitoring location is also recommended to be analysed for TRH. It is important to note that, due to the high potential for the presence of natural organic compounds in groundwater, any testing for TRH include a Silica Gel Cleanup (SGC) or Extractable Petroleum Hydrocarbons (EPH) scan to remove polar natural compounds prior to analysis.

13 LIMITATIONS

This report has been prepared by Environmental Earth Sciences NSW ACN 109 404 006 in response to and subject to the following limitations:

1. The specific instructions received from Shellharbour City Council;
2. The specific scope of works set out in PO112168 issued by Environmental Earth Sciences NSW for and on behalf of Shellharbour City Council;
3. May not be relied upon by any third party not named in this report for any purpose except with the prior written consent of Environmental Earth Sciences NSW (which consent may or may not be given at the discretion of Environmental Earth Sciences NSW);
4. This report comprises the formal report, documentation sections, tables, figures and appendices as referred to in the index to this report and must not be released to any third party or copied in part without all the material included in this report for any reason;
5. The report only relates to the site referred to in the scope of works being located at Dunmore Recycling and Waste Depot, Buckleys Road, Dunmore, NSW ("the site");
6. The report relates to the site as at the date of the report as conditions may change thereafter due to natural processes and/or site activities;

7. No warranty or guarantee is made in regard to any other use than as specified in the scope of works and only applies to the depth tested and reported in this report;
8. Fill, soil, groundwater and rock to the depth tested on the site may be fit for the use specified in this report. Unless it is expressly stated in this report, the fill, soil and/or rock may not be suitable for classification as clean fill, excavated natural material (ENM) or virgin excavated natural material (VENM) if deposited off site;
9. This report is not a geotechnical or planning report suitable for planning or zoning purposes; and
10. Our General Limitations set out at the back of the body of this report.

14 REFERENCES

- Australian & New Zealand Environment & Conservation Council/Agriculture and Resource Management Council of Australia and New Zealand, 2000, *Australian and New Zealand guidelines for fresh and marine water quality*.
- Australian/New Zealand Standard, AS 3580.10.1:2003. *Methods for sampling and analysis of ambient air; Method 10.1: Determination of particulate matter – Deposited matter – gravimetric method*
- Bowman, H N, 1974, Kiama 1:50 000 geological sheet 9028-1. *Geological Survey of NSW, Sydney*.
- DLWC (1997), *Albion Park acid sulfate soil risk map (9028N1)*. Edition two
- Environmental & Earth Sciences Pty Ltd, 1999, *Background water chemistry at Dunmore Waste Disposal Depot, Dunmore, New South Wales*. Report number 199175 to Shellharbour City Council.
- Environmental & Earth Sciences Pty Ltd, 2000, — *Background water chemistry at Dunmore Waste Disposal Depot, Dunmore, New South Wales*. Report number 100138 to Shellharbour City Council.
- Environmental & Earth Sciences Pty Ltd, 2001 *Hydrogeological and hydrological investigation, Dunmore Lakes – Stage 2, Dunmore, New South Wales*. Report number 101025 to Dunmore Sand & Soil Pty Ltd dated 23 July 2001.
- Environmental & Earth Sciences Pty Ltd, 2002, *Background water chemistry at Dunmore Waste Disposal Depot, Dunmore, New South Wales*. Report number 102004 to Shellharbour City Council.
- Environmental & Earth Sciences Pty Ltd, 2003, *Background water chemistry at Dunmore Waste Disposal Depot, Dunmore, New South Wales*. Report number 103011 to Shellharbour City Council.
- Environmental & Earth Sciences NSW, 2004, *Background water chemistry at Dunmore Waste Disposal Depot, Dunmore, New South Wales*. Report number 104010 to Shellharbour City Council.
- Environmental & Earth Sciences NSW, 2005, *Water Chemistry Monitoring at Dunmore Recycling & Waste Disposal Depot, Dunmore, NSW*. Annual Report 2004 to 2005. Report no. 105010 to Shellharbour City Council,

- Environmental & Earth Sciences Pty Ltd, 2009, *Soil, gas and groundwater sampling manual*. 2009.
- Environmental & Earth Sciences NSW, 2011, *Environmental Monitoring at the Dunmore Waste and recycling disposal depot, Dunmore, NSW*. Annual Report September 2010 to August 2011. Report number 110031_Annual_2011 to Shellharbour City Council
- Environmental Earth Sciences NSW, 2012a, *Environmental Monitoring at the Dunmore Waste and recycling disposal depot, Dunmore, NSW*. Annual Report September 2011 to August 2012. Report number 110031_Annual_2012 to Shellharbour City Council
- Environmental Earth Sciences NSW, 2012b. *Interim gas management plan for buildings surrounding the weighbridge at the Dunmore Recycling and Waste Disposal Depot, Buckley's Road, Dunmore, NSW*. Report number 112059_LMP to Shellharbour City Council
- Environmental Earth Sciences NSW, 2013. *Hydrogeological assessment for Lot 21 DP 653009, Dunmore Recycling and Waste Disposal Depot, Dunmore, NSW, 113057_Hydrogeology*
- Environmental Earth Sciences NSW, 2017. *Data review of environmental monitoring at Dunmore Waste and Recycling Facility, 31 August 2017, New South Wales; report number 117061_V1*.
- Hazelton, P A and Tille, P J, 1990, *Soil landscapes of the Wollongong–Port Hacking 1:100 000 series sheet*, Soil conservation Service of NSW, Sydney.
- Hazelton, P A, 1993, *Kiama soil landscape 1:100 000 series sheet*, Department of Conservation and Land Management of NSW, Sydney.
- Hickey, C W, 2013. *Updating nitrate toxicity effects on freshwater aquatic species*. National Institute of Water & Atmospheric Research Ltd (NIWA), Hamilton, NZ, January 2013
- National Environment Protection Council (NEPC), 1999, *National environment protection (assessment of site contamination) measure 1999*.
- NSW Environmental Protection Authority, 2016, *Environmental Guidelines – Solid waste landfills*, Second edition, www.epa.nsw.gov.au
- Sherwin, L and Holmes, G (eds.) 1982 *Geology of the Wollongong and Port Hacking 1:100 000 sheet (9029, 9129)*, New South Wales Geological Survey, Sydney.

15 GLOSSARY OF TERMS

The following descriptions are of terms used in the text of this report.

Acid Sulfate Soil (ASS). A soil containing iron sulfides deposited during either the Pleistocene or Holocene geological epochs (Quaternary aged) as sea levels rose and fell.

Alluvial. Describes material deposited by, or in transit in, flowing water.

Anaerobic. Reducing or without oxygen.

Aquifer. A rock or sediment in a formation, group of formations, or part of a formation which is saturated and sufficiently permeable to transmit economic quantities of water to wells and springs.

Aquifer, confined. An aquifer that is overlain by a confining bed with significantly lower hydraulic conductivity than the aquifer.

Aquifer, perched. A region in the unsaturated zone where the soil is locally saturated because it overlies soil or rock of low permeability.

Background. The natural level of a property.

Baseline. An initial value of a measure.

Biodegradation. A biochemical process of microbial oxidation of complex organic compounds, to simpler chemical products. Micro-organisms derive the energy and cell carbon for growth from oxidation of organic compounds.

Bore. A hydraulic structure that facilitates the monitoring of groundwater level, collection of groundwater samples, or the extraction (or injection) of groundwater. Also known as a well, monitoring well or piezometer, although piezometers are typically of small diameter and only used for measuring the groundwater elevation or potentiometric surface.

Borehole. An uncased well drill hole.

Cation Exchange Capacity (CEC). The maximum positive charge required to balance the negative charge on colloids (clays and other charged particles). The units are milli-equivalents per 100 grams of material or centimoles of charge per kilogram of exchanger.

Clay. A soil material composed of particles finer than 0.002 mm. When used as a soil texture group such soils contain at least 35% clay.

Colluvial. Unconsolidated soil and rock material moved down-slope by gravity.

Confined Aquifer. An aquifer that is confined between two low-permeability aquitards. The groundwater in these aquifers is usually under hydraulic pressure, i.e. its hydraulic head is above the top of the aquifer.

Confining layer. A layer with low vertical hydraulic conductivity that is stratigraphically adjacent to one or more aquifers. A confining layer is an aquitard. It may lie above or below the aquifer.

Contaminant. Generally, any chemical species introduced into the soil or water. More particularly relates to those species that render soil or water unfit for beneficial use.

Contamination. Is considered to have occurred when the concentration of a specific element or compound is established as being greater than the normally expected (or actually quantified) background concentration.

Diffusion. A process by which species in solution move, driven by concentration gradients (from high to low).

Dilution. The mixing of a small volume of contaminated leachate with a large volume of uncontaminated water. The concentration of contaminants is reduced by the volume of the lower concentrated water. However the physical process of dilution often causes chemical disequilibria resulting in the destruction of ligand bonds, the alteration of solubility products and the alteration of water pH. This usually causes precipitation by different chemical means of various species.

Discrete sample. Samples collected from different locations and depths that will not be composited but analysed individually.

Dispersion. A process by which species in solution mix with a second solution, thus reducing in concentration. In particular, relates to the reduction in concentration resulting from the movement of flowing groundwater.

Dissolved Oxygen (DO). Oxygen in the gaseous phase dissolved in water. Measured either as a concentration in mg/L or as a percentage of the theoretical saturation point, which is inversely related to temperature. At 19, 20 and 21 degrees Celsius, the oxygen concentrations in mg/L corresponding to 100% saturation are 9.4, 9.2 and 9.0 respectively.

Electrical Conductivity (EC). The EC of water is a measure of its ability to conduct an electric current. This property is related to the ionic content of the sample, which is in turn a function of the total dissolved (ionisable) solids (TDS) concentration. An estimate of TDS in fresh water can be obtained by multiplying EC by 0.65.

Flow path. The direction in which groundwater is moving.

Fluvial. A material deposited by, or in transit, in streams or watercourses.

Fracture. A break in the geological formation, e.g. a shear or a fault.

Gradational. The lower boundary between soil layers (horizons) has a gradual transition to the next layer. The solum (soil horizon) becomes gradually more clayey with depth.

Gradient. The rate of inclination of a slope. The degree of deviation from the horizontal; also refers to pressure.

Groundwater. The water held in the pores in the ground below the water table.

Groundwater Elevation. The elevation of the groundwater surface measured relative to a specified datum such as the Australian Height Datum (mAHD) or an arbitrary survey datum onsite, or “reduced level” (mRL).

Head space. The air space at the top of a soil or water sample.

Heavy Metals. All metallic elements whose atomic mass exceeds that of calcium (20) and includes lead (Pb), copper (Cu), Zinc (Zn), cadmium (Cd), and tin (Sn).

Heterogeneous. A condition of having different characteristics in proximate locations. Non-uniform. (Opposite of homogeneous).

Horizon. An individual soil layer, based on texture and colour, which differs from those above and below.

Hydraulic Conductivity (K). A coefficient describing the rate at which water can move through a permeable medium. It has units of length per time. The units for hydraulic conductivity are typically m³/day/m² or m/day.

Hydraulic Gradient (i). The rate of change in total head per unit of distance of flow in a given direction – the direction is that which yields a maximum rate of decrease in head. Hydraulic Gradient is unit less.

Hydraulic Head (h). The sum of the elevation head and the pressure head at a point in an aquifer. This is typically reported as an elevation above a fixed datum, such as sea level.

Hydrocarbon. A molecule consisting of carbon and hydrogen atoms only, such as found in petroleum.

Hydrocarbon, volatile. A hydrocarbon with a low boiling point (high vapour pressure). Normally taken to mean those with ten (or less) carbon atoms per molecule.

Infiltration. The passage of water, under the influence of gravity, from the land surface into the subsurface.

Ionic Exchange. Adsorption occurs when a particle with a charge imbalance, neutralises this charge by the attraction (and subsequent adherence of) ions of opposite charge from solution. There are two types of such a charge: pH dependent; and pH independent or crystalline charge. Metal hydroxides and oxy-hydroxides represent examples of the former type, whilst clay minerals are representative of the latter and are normally associated with cation exchange.

Ions. An ion is a charged element or compound as a result of an excess or deficit of electrons. Positively charged ions are called cations, whilst negatively charged ions are called anions. Cations are written with superscript +, whilst anions use - as the superscript. The major aqueous ions are those that dominate total dissolved solids (TDS). These ions include: Cl⁻, SO₄²⁻, HCO₃⁻, Na⁺, Ca²⁺, Mg²⁺, K⁺, NH₄⁺, NO₃⁻, NO₂⁻, F⁻, PO₄³⁻ and the heavy metals.

Lithic. Containing large amounts of fragments derived from previously formed rocks.

Mottled. Masses, blobs or blotches of sub-dominant, varying colours in the soil matrix.

Nodulation. Are hard, usually small, accumulation of precipitated iron and/or manganese in the soil profile, usually a result of past alternating periods of oxidation/reduction.

Nodule. A small, concretionary (hard) deposit, usually of iron and/or manganese.

Organics. Chemical compounds comprising atoms of carbon, hydrogen and others (commonly oxygen, nitrogen, phosphorous, sulfur). Opposite is inorganic, referring to chemical species not containing carbon.

Oxidation. Was originally referred only to the addition of oxygen to elements. However oxidation now encompasses the broader concept of the loss of electrons by electron transfer to other ions.

Perched Groundwater. Unconfined groundwater separated from an underlying main body of groundwater by an unsaturated zone. Perched groundwater typically occurs in discontinuous, often ephemeral, lenses, with unsaturated conditions both above and below.

Permeability (k). Property of porous medium relating to its ability to transmit or conduct liquid (usually water) under the influence of a driving force. Where water is the fluid, this is effectively the hydraulic conductivity. A function of the connectivity of pore spaces.

Piezometric or Potentiometric Surface. A surface that represents the level to which water will rise in cased bores. The water table is the potentiometric surface in an unconfined aquifer.

pH. A logarithmic index for the concentration of hydrogen ions in an aqueous solution, which is used as a measure of acidity.

Polycyclic aromatic Hydrocarbons (PAHs). Complex organic molecules which originate typically in the combustion of organic compounds.

Potential Acid Sulfate Soil (PASS). A soil that has the potential to become acidic if it is exposed to the atmosphere.

Porosity (n). The ratio of the volume of void spaces in a rock or sediment to the total volume of the rock or sediment. Typically given as a percentage.

Porosity, effective (ne). The volume of the void spaces through which water or other fluids can travel in a rock or sediment divided by the total volume of the rock or sediment.

Precipitation (chemical). There are two types of precipitation, pH dependent precipitation and solubility controlled precipitation. As the pH is raised beyond a threshold level the precipitation of metal cations such as oxy-hydroxides and hydroxides occur. As the pH is raised further precipitation continues until there are very few metal cations remaining in solution. This reaction is entirely reversible. Solubility controlled precipitation occurs between two ions when, at a given temperature and pressure, the concentration of one of the ions exceeds a certain level.

Profile. The solum. This includes the soil A and B horizons and is basically the depth of soil to weathered rock.

Purge (wells). The pumping out of well water to remove drilling debris or impurities; also conducted to bring fresh groundwater into the casing for sample collection. The later ensures that a more representative sample of an aquifer is taken.

QA/QC. Quality Assurance / Quality Control.

Recharge Area. Location of the replenishment of an aquifer by a natural process such as addition of water at the ground surface, or by an artificial system such as addition through a well

Recovery. The rate at which a water level in a well rises after pumping ceases.

Redox. REDuction-OXidation state of a chemical or solution.

Redox potential (Eh). The oxidation/reduction potential of the soil or water measured as milli-volt.

Reducing Conditions. Can be simply expressed as the absence of oxygen, though chemically the meaning is more complex. For more details refer to OXIDATION.

Remediation. The restoration of land or groundwater contaminated by pollutants, to a state suitable for other, beneficial uses.

Representative Sample. Assumed not to be significantly different than the population of samples available. In many investigations samples are often collected to represent the worst case situation.

Saturated Zone. A zone in which the rock or soil pores are filled (saturated) with water.

Shale. Fine-grained sedimentary rock formed by the compaction of silt, clay, or sand that accumulates in deltas and on lake and ocean bottoms. It is the most abundant of all sedimentary rocks.

Standing Water Level (SWL). The depth to the groundwater surface in a well or bore measured below a specific reference point – usually recorded as metres below the top of the well casing or below the ground surface.

Stratigraphy. A vertical sequence of geological units.

Subsoil. Subsurface material comprising the B and C horizons of soils with distinct profiles. They often have brighter colours and higher clay content than topsoils.

Texture. The size of particles in the soil. Texture is divided into six groups, depending on the amount of coarse sand, fine sand, silt and clay in the soil.

Topsoil. Part of the soil profile, typically the A1 horizon, containing material which is usually darker, more fertile and better structured than the underlying layers.

Total Dissolved Salts (TDS). The total dissolved salts comprise dissociated compounds and undissociated compounds, but not suspended material, colloids or dissolved gases.

Toxicity. The inherent potential or capacity of a material to cause adverse effects in a living organism.

Unsaturated Zone. The zone between the land surface and the water table, in which the rock or soil pores contain both air and water (water in the unsaturated zone is present at less than atmospheric pressure). It includes the root zone, intermediate zone and capillary fringe. Saturated bodies such as perched groundwater may exist in the unsaturated zone. Also referred to as the Vadose Zone.

Volatile. Having a low boiling or subliming pressure (a high vapour pressure).

Water table. Interface between the saturated zone and unsaturated zones. The surface in an aquifer at which pore water pressure is equal to atmospheric pressure.

Well. A hydraulic structure that facilitates the monitoring of groundwater level, collection of groundwater samples, or the extraction (or injection) of groundwater. Also known as a Bore.

ENVIRONMENTAL EARTH SCIENCES GENERAL LIMITATIONS

Scope of services

The work presented in this report is Environmental Earth Sciences response to the specific scope of works requested by, planned with and approved by the client. It cannot be relied on by any other third party for any purpose except with our prior written consent. Client may distribute this report to other parties and in doing so warrants that the report is suitable for the purpose it was intended for. However, any party wishing to rely on this report should contact us to determine the suitability of this report for their specific purpose.

Data should not be separated from the report

A report is provided inclusive of all documentation sections, limitations, tables, figures and appendices and should not be provided or copied in part without all supporting documentation for any reason, because misinterpretation may occur.

Subsurface conditions change

Understanding an environmental study will reduce exposure to the risk of the presence of contaminated soil and or groundwater. However, contaminants may be present in areas that were not investigated, or may migrate to other areas. Analysis cannot cover every type of contaminant that could possibly be present. When combined with field observations, field measurements and professional judgement, this approach increases the probability of identifying contaminated soil and or groundwater. Under no circumstances can it be considered that these findings represent the actual condition of the site at all points.

Environmental studies identify actual sub-surface conditions only at those points where samples are taken, when they are taken. Actual conditions between sampling locations differ from those inferred because no professional, no matter how qualified, and no sub-surface exploration program, no matter how comprehensive, can reveal what is hidden below the ground surface. The actual interface between materials may be far more gradual or abrupt than an assessment indicates. Actual conditions in areas not sampled may differ from that predicted. Nothing can be done to prevent the unanticipated. However, steps can be taken to help minimize the impact. For this reason, site owners should retain our services.

Problems with interpretation by others

Advice and interpretation is provided on the basis that subsequent work will be undertaken by Environmental Earth Sciences NSW. This will identify variances, maintain consistency in how data is interpreted, conduct additional tests that may be necessary and recommend solutions to problems encountered on site. Other parties may misinterpret our work and we cannot be responsible for how the information in this report is used. If further data is collected or comes to light we reserve the right to alter their conclusions.

Obtain regulatory approval

The investigation and remediation of contaminated sites is a field in which legislation and interpretation of legislation is changing rapidly. Our interpretation of the investigation findings should not be taken to be that of any other party. When approval from a statutory authority is required for a project, that approval should be directly sought by the client.

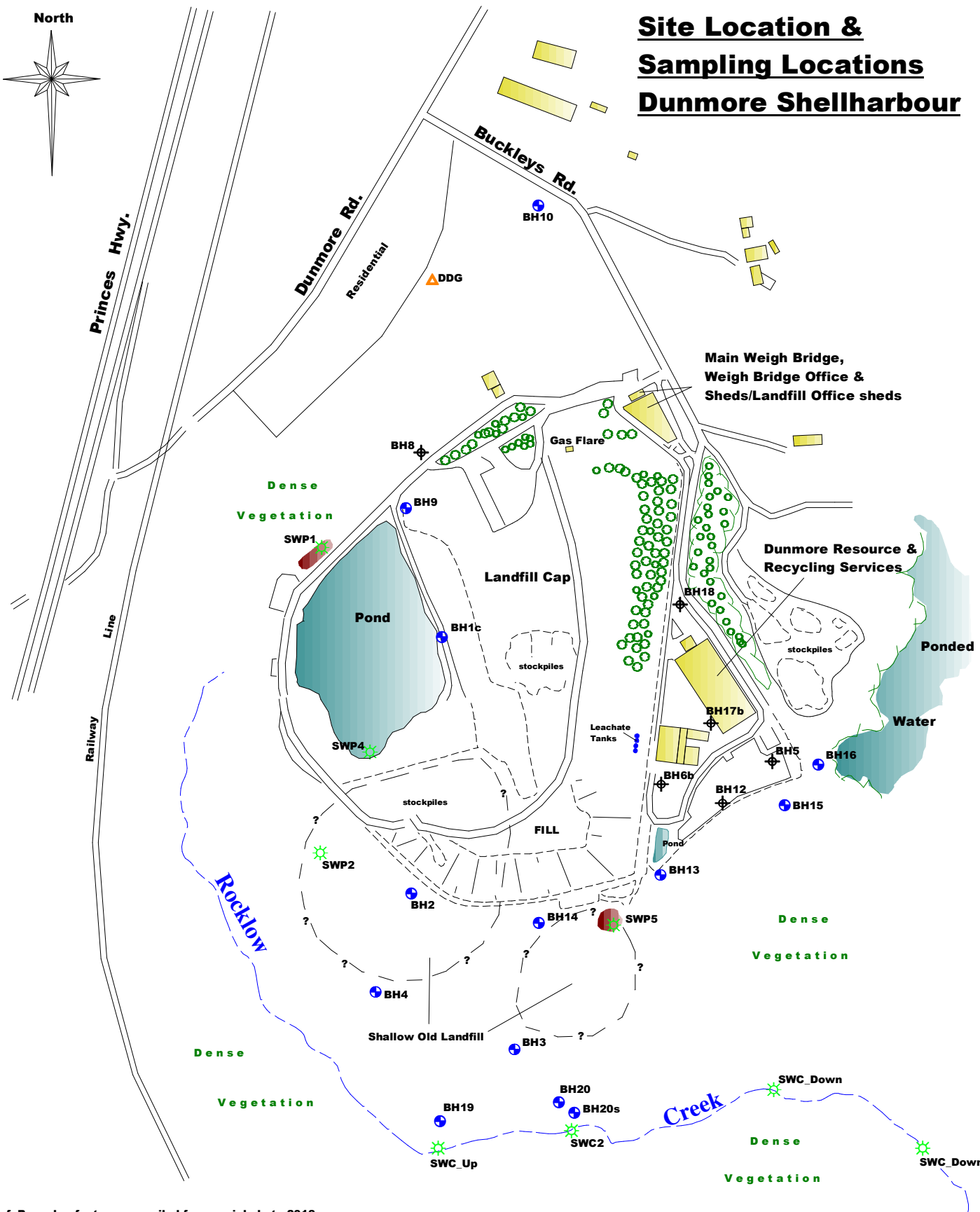
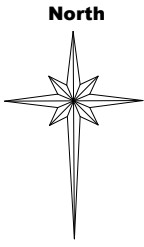
Limit of liability

This study has been carried out to a particular scope of works at a specified site and should not be used for any other purpose. This report is provided on the condition that Environmental Earth Sciences NSW disclaims all liability to any person or entity other than the client in respect of anything done or omitted to be done and of the consequence of anything done or omitted to be done by any such person in reliance, whether in whole or in part, on the contents of this report. Furthermore, Environmental Earth Sciences NSW disclaims all liability in respect of anything done or omitted to be done and of the consequence of anything done or omitted to be done by the client, or any such person in reliance, whether in whole or any part of the contents of this report of all matters not stated in the brief outlined in Environmental Earth Sciences NSW's proposal number and according to Environmental Earth Sciences general terms and conditions and special terms and conditions for contaminated sites.

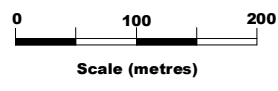
To the maximum extent permitted by law, we exclude all liability of whatever nature, whether in contract, tort or otherwise, for the acts, omissions or default, whether negligent or otherwise for any loss or damage whatsoever that may arise in any way in connection with the supply of services. Under circumstances where liability cannot be excluded, such liability is limited to the value of the purchased service.

FIGURES

Site Location & Sampling Locations Dunmore Shellharbour




Ref. Baseplan features compiled from aerial photo 2018.

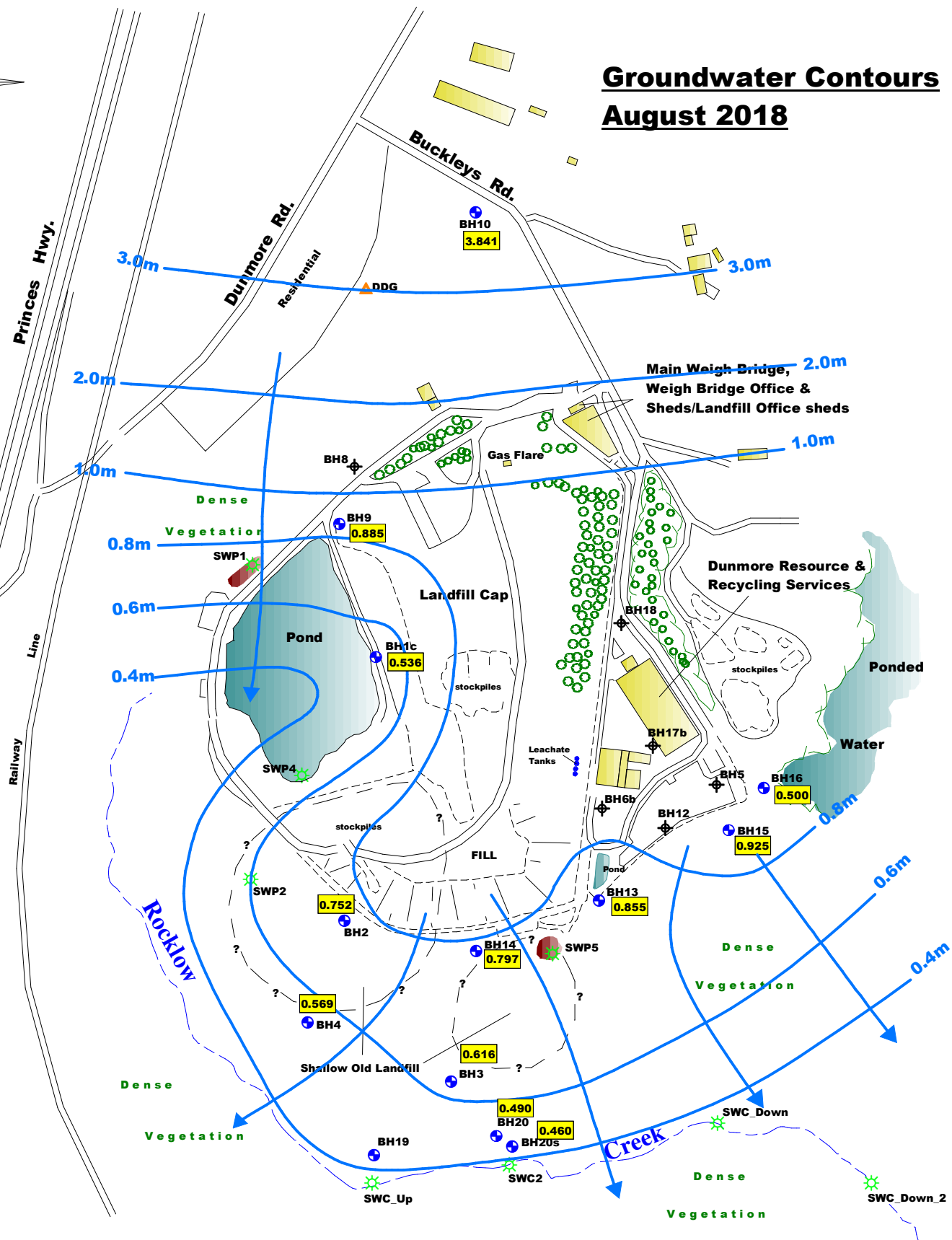
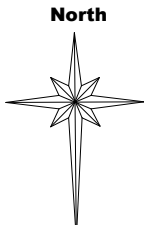


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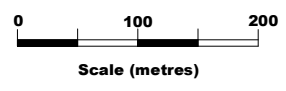
- ⊕ Bore locations
- △ Dust gauge locations
- ⊛ Surface water locations
- ⊕ Decommissioned bores

 ENVIRONMENTAL EARTH SCIENCES CONTAMINATION RESOLVED	Title: Site Plan & Sampling Locations		
	Location: Buckleys Road, Dunmore, Shellharbour, NSW		
Client: Shellharbour City Council	Job No. 118077	Date: August 2018	Figure 1
	Drawn by: TRJ	Proj. Man. LV	

Groundwater Contours August 2018



Ref. Baseplan features compiled from aerial photo 2018.

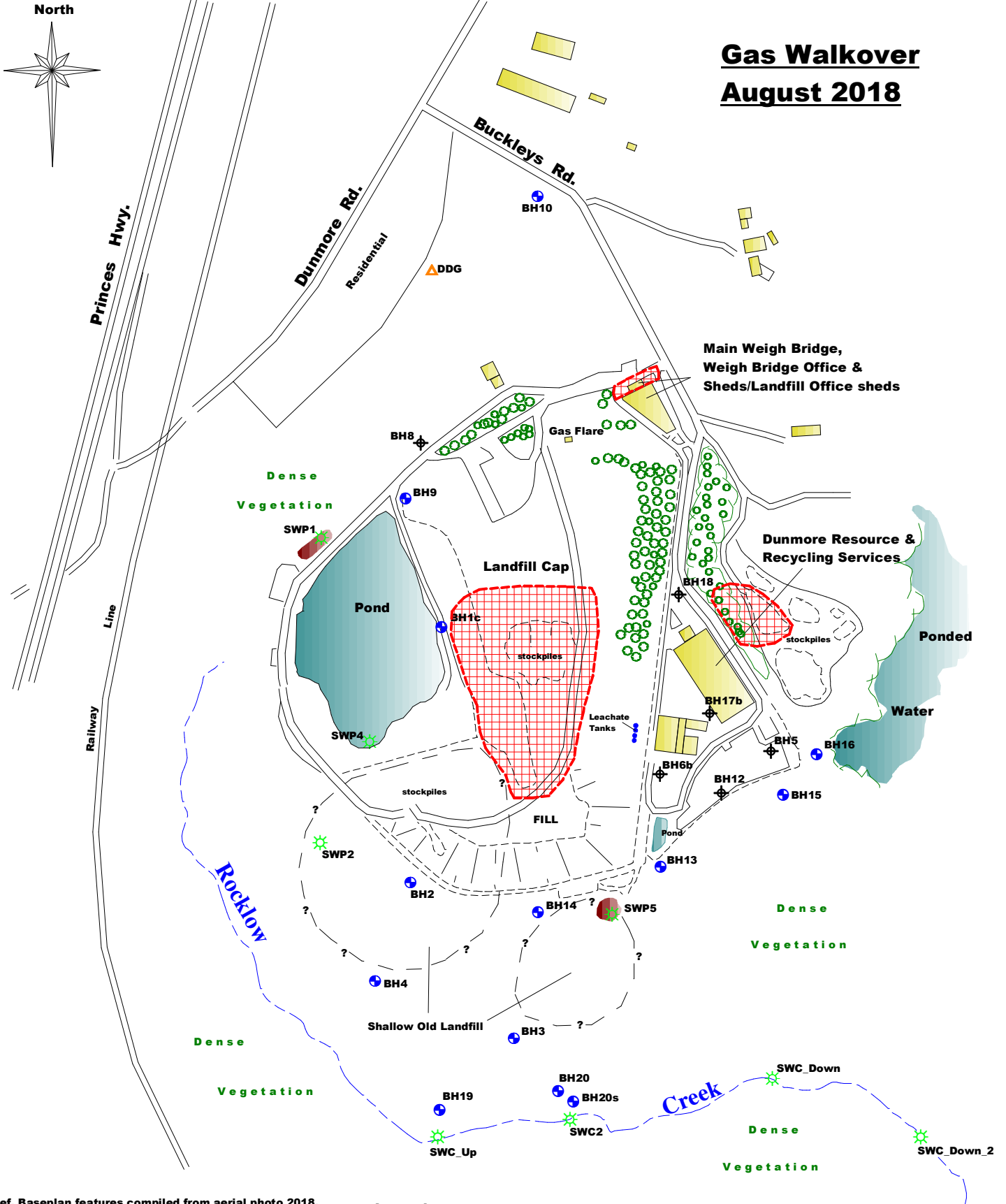


Legend:

- Bore locations
- ▲ Dust gauge locations
- ☼ Surface water locations
- ⊕ Decommissioned bores
- 3.0m Inferred groundwater contour (m AHD)
- Inferred flow direction
- 0.490 SWL (standing water level m AHD)

<p>ENVIRONMENTAL EARTH SCIENCES CONTAMINATION RESOLVED</p>	Title: Groundwater Contours - August 2018		
	Location: Buckleys Road, Dunmore, Shellharbour, NSW		
	Client: Shellharbour City Council	Job No. 118077	Date: August 2018
		Drawn by: TRJ	Proj. Man.: LV
		Scale: As shown	Figure 2

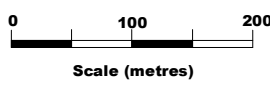
Gas Walkover August 2018



Ref. Baseplan features compiled from aerial photo 2018.

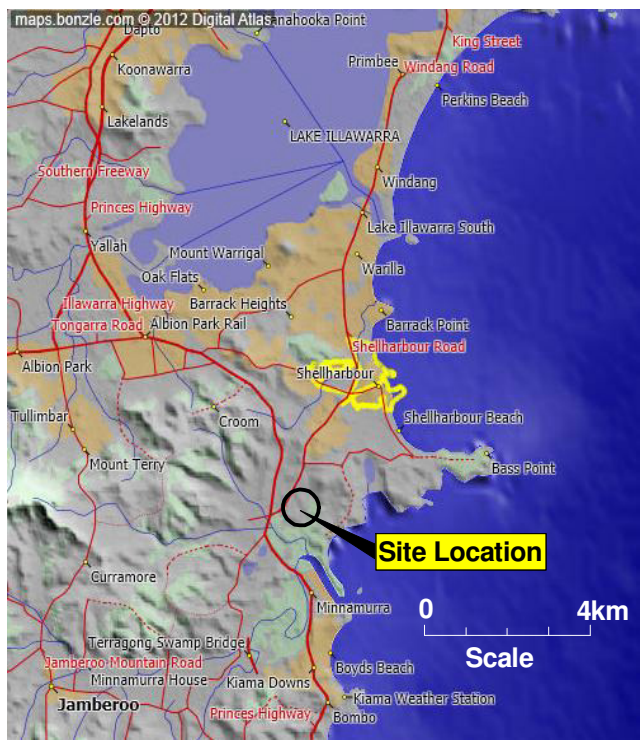
Legend:

- ⊕ Bore locations
- △ Dust gauge locations
- ⊗ Surface water locations
- ⊕ Decommissioned bores
- Gas walkover

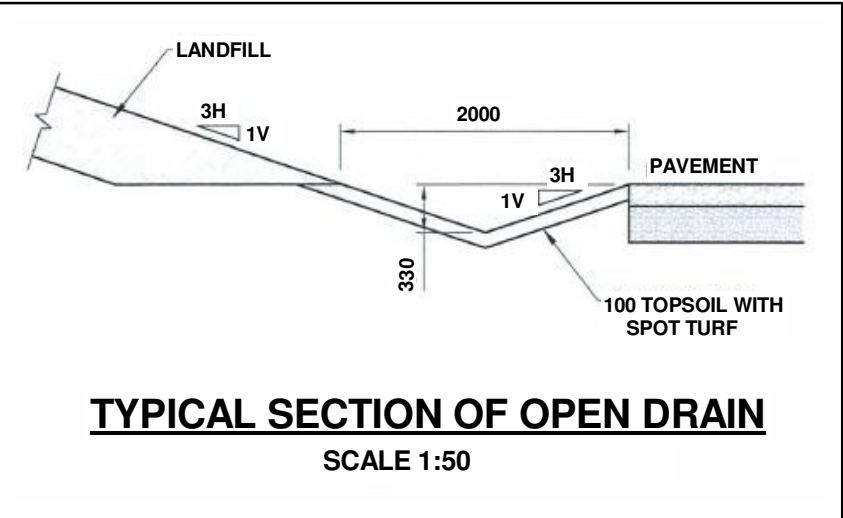
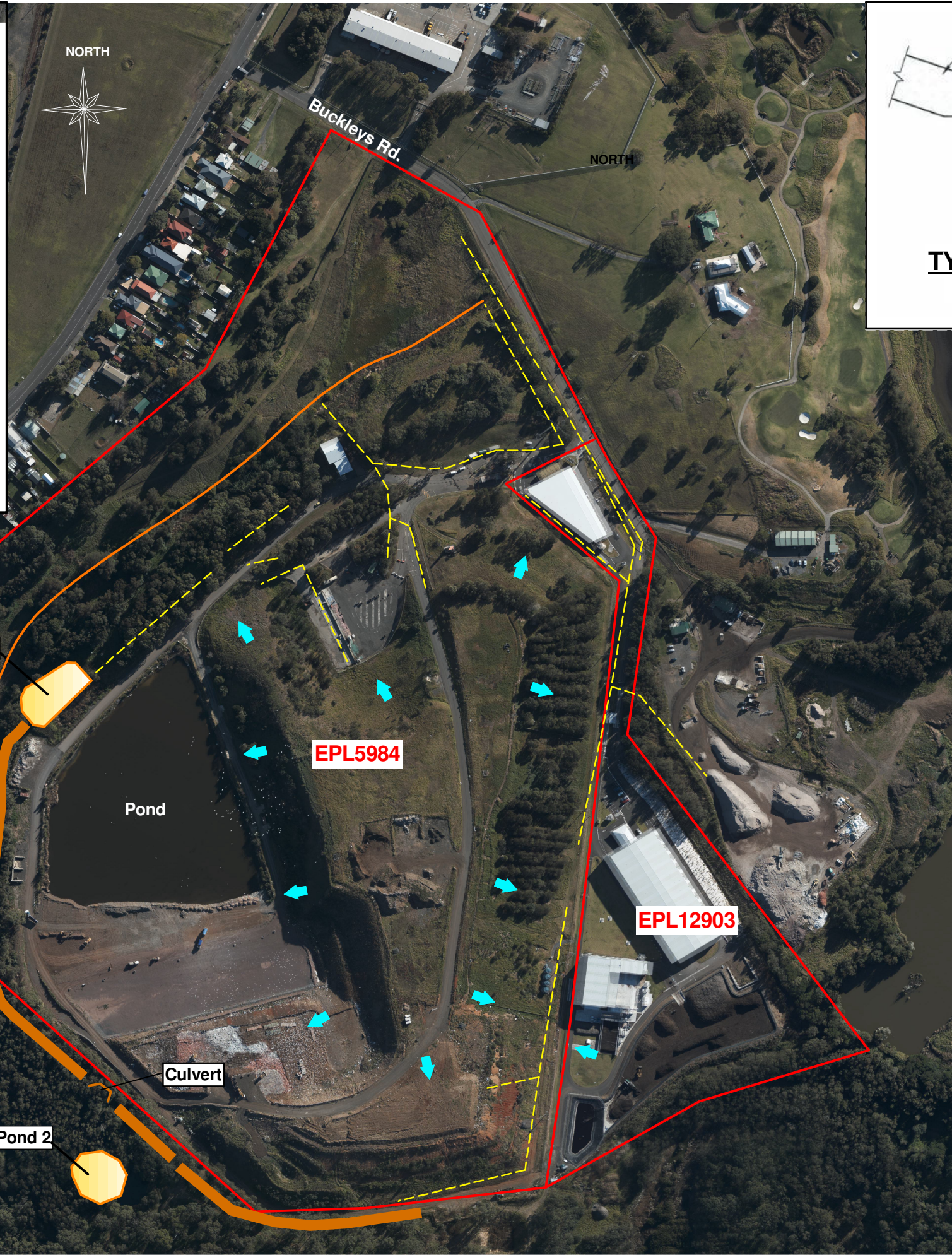


ENVIRONMENTAL EARTH SCIENCES CONTAMINATION RESOLVED	Title: Gas Walkover		
	Location: Buckleys Road, Dunmore, Shellharbour, NSW		
	Client: Shellharbour City Council	Job No. 118077	Date: August 2018
	Drawn by: TRJ	Proj. Man.: LV	Scale: As shown

Figure 3



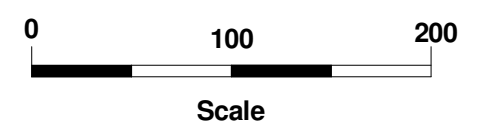
Regional Locality Map



TYPICAL SECTION OF OPEN DRAIN
SCALE 1:50

Legend:

- licence boundary
- levee bank
- drainage layout
- approx. stormwater diversion drain
- ▶ - approx. stormwater flow direction



Ref. Based on updated aerial photograph 2018.


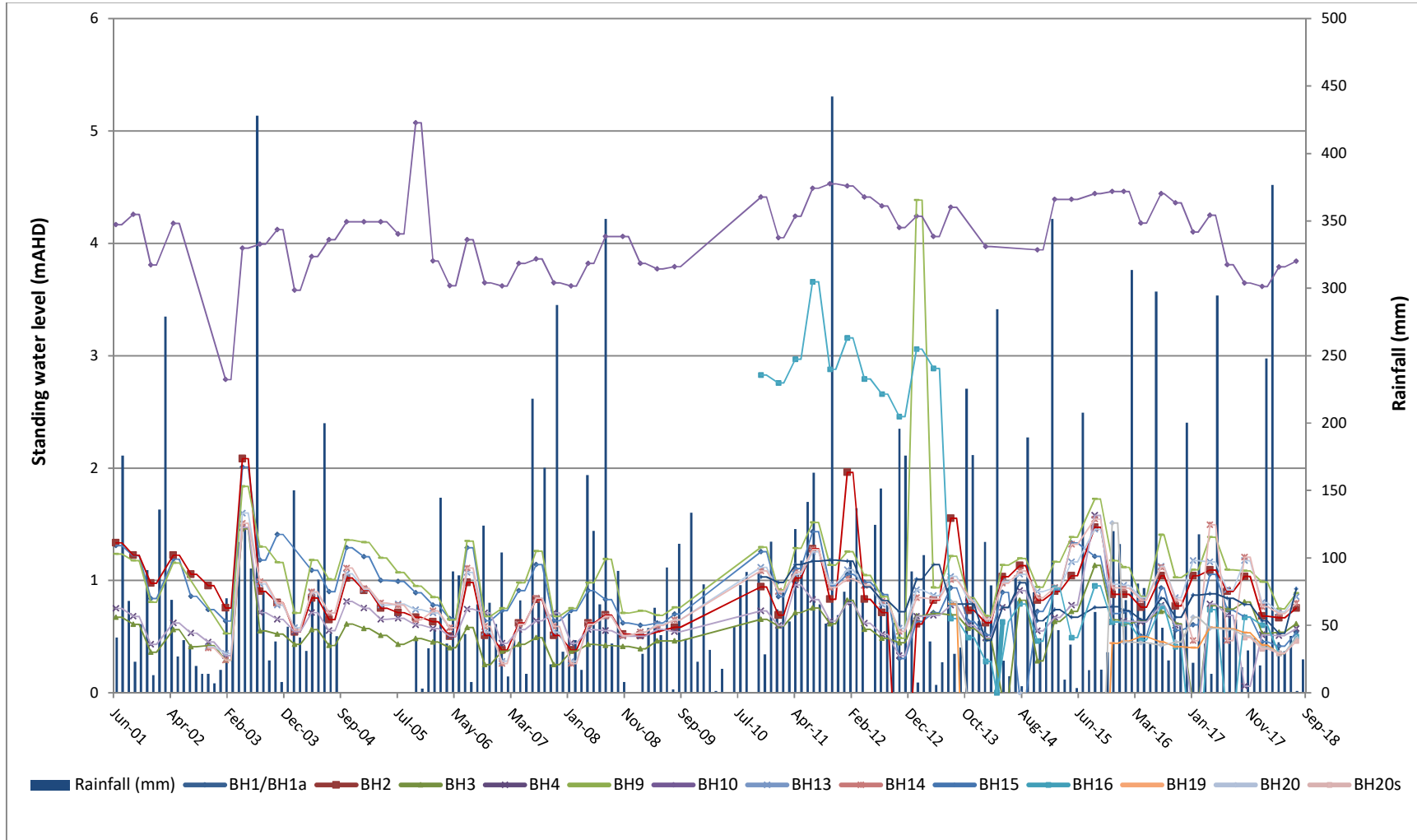
	Title: Surface Water Runoff	
	Location: Dunmore Recycling & Waste Disposal Depot, Shellharbour	
Client: Shellharbour City Council	Job number: 118077	
Drawn by: TRJ	Scale: As shown	Source: See Ref.
Proj Man: LV	Date: June 2018	Figure 4

Figure 5: Groundwater levels and rainfall since January 2001



TABLES

Table 7: Groundwater field measurements

Location	Date	SWL (mAHD)	pH	EC (mS/cm)	Temp. (°C)	DO (mg/L)	ORP (mV)	Colour	Odour	TDS (mg/L)	Comments
BH1c	Nov-17	3.279	7.09	6.73	26.5	1.5	-43.6	light brown	Leachate	-	
BH1c	Feb-18	3.5	7.05	6.34	28.1	1.44	-99	Light brown	Leachate	4,008	
BH1c	May-18	3.54	6.51	7.02	25.1	0.05	-127	Light brown	Leachate	4,620	
BH1c	Aug-18	3.418	6.78	6.241	25.3	0.49	-118.4	Brown tinge	Leachate	-	
BH2	Nov-17	3.757	6.99	3.25	22.6	1.11	-105	slight brown	Leachate	-	
BH2	Feb-18	4.109	7.14	2.746	23.3	1.22	-111	Clear	Leachate	1,782	
BH2	May-18	4.125	6.4	3.30	21.1	0.53	-83	Light brown	Leachate	2,170	
BH2	Aug-18	4.04	6.85	3.498	22.7	1.67	-111.3	Light brown	Leachate	-	FD1
BH3	Nov-17	2.957	7.45	1.13	18.9	6.27	47.3	black	no odour	-	BD1/SD1
BH3	Feb-18	3.235	7.5	1.88	20.4	2.9	-111	Clear with black floaties	None	1,226	
BH3	May-18	3.225	6.67	1.61	18.9	3.86	-98	Grey	None	1,050	
BH3	Aug-18	3.15	7.61	1.973	19	3.42	-78.5	Clear	None	-	
BH4	Nov-17	4.96	7.31	1.34	19.1	3.81	-106	clear	no odour	-	
BH4	Feb-18	4.505	7.11	1.51	21	0.23	-98	Clear	None	992	
BH4	May-18	4.51	6.26	1.69	20	0.2	-73	Clear	None	1,105	
BH4	Aug-18	4.45	7.46	1.852	19	2.38	-100	Very light brown	None	-	
BH13	Nov-17	4.12	6.64	1.60	21	0	-56	clear	no odour	-	
BH13	Feb-18	4.495	7.13	1.72	22.6	0.63	-64	Clear	None	1,050	FD1 + FD2
BH13	May-18	4.575	6.45	1.64	21.5	1.66	-43	Light brown	None	1,118	
BH13	Aug-18	4.44	6.85	1.556	20.9	0.03	-13.6	Very light brown	None	-	
BH14	Nov-17	4.509	7.01	1.969	21.2	2.14	5			-	
BH14	Feb-18	4.95	6.57	2.12	21.9	0.47	7	Clear	None	-	Obstruction cleared
BH14	May-18	5.01	5.64	2.34	21.5	0.41	-30	Light brown	None	1,520	
BH14	Aug-18	4.918	6.81	2416	21.5	3.07	-37.8	Clear	None	-	
BH15	Nov-17	0.625	6.95	5.78	17.1	3.18	-114.4	brown	leachate	-	
BH15	Feb-18	0.77	6.72	7.79	23.1	0.97	-79	Light brown	Yes	5,250	
BH15	May-18	0.883	6.18	10.25	18.2	0.68	-13	Light brown	Egg/leachate	6,560	
BH15	Aug-18	0.485	6.69	6.087	13.9	0.92	-95.8	Brown	Leachate	-	

Location	Date	SWL (mAHD)	pH	EC (mS/cm)	Temp. (°C)	DO (mg/L)	ORP (mV)	Colour	Odour	TDS (mg/L)	Comments
BH16	Nov-17	0.71	7.22	2.224	18.2	0.44	-145	brown/black	H2S	-	
BH16	Feb-18	0.78	6.69	3.71	21	1.84	-151	Light brown	Yes	-	
BH16	May-18	1.03	6.71	3.32	18.1	2.04	-137	Dark brown	Egg	2,180	
BH16	Aug-18	0.88	7.76	0.477	14.9	2.14	-177.2	Brown	Minor leachate	-	
BH19	Nov-17	4.655	7.6	1.74	18.8	3.72	-73	grey	no odour	-	
BH19	Feb-18	4.765	7.14	0.92	20.7	0.22	-66	Milky	None	595	
BH19	May-18	4.84	-	-	-	-	-	-	-	-	Well blocked
BH19	Aug-18	-	-	-	-	-	-	-	-	-	Damaged well
BH20	Nov-17	2.265	6.28	1.34	18.8	6.02	-86	light brown	reducing	-	
BH20	Feb-18	2.365	7.55	1.46	20.7	0.05	-140	Clear	H2S	815	
BH20	May-18	2.265	6.28	1.34	18.8	6.02	-86	light brown	reducing	-	
BH20	Aug-18	2.28	7.42	1.393	18.7	0	-131	Clear	None	-	
BH20s	Nov-17	2.279	7.08	1.09	18.7	1.52	7.9	light brown	no odour	-	
BH20s	Feb-18	2.378	7.49	1.158	21.5	0.07	-24	Clear	Yes	770	
BH20s	May-18	2.42	2.42	1.404	20	0.45	-29	Clear	None	914	
BH20s	Aug-18	2.31	7.26	1.065	17.7	0	-60.9	Clear	None	-	

Notes:

- DO = dissolved oxygen;
- ORP = Oxygen/reduction potential recorded in mV; and
- * = Uncertainty in field results associated with instrument malfunction.

Table 8: Groundwater inorganic laboratory results

Sample	Date	pH	TDS	Na	Ca	K	Mg	NH4-N	Cl	F	NO3	NO2	SO4	HCO3	PO4	TOC	BOD	Sol. Mn	Sol. Fe	Tot. Fe	Alkalinity (as CaCO ₃)
			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BH1c	Nov-17	7.3	4010	650	160	230	120	320	895	0.2	0.1		12	3050	0.31	200	6	0.12	2.5	18	2505
BH1c	Feb-18	7.2	3910	665	130	210	100	380	805	0.1	0.1		14	3170	0.92	195	8	0.09	3.2	15	2603
BH1c	May-18	7.1	3940	660	110	290	105	360	835	<0.1	<0.1		18	3110	0.43	195	12	0.11	1.9	16	2553
BH1c	Aug-18	7.1	3920	665	130	250	110	340	820	0.23	0.1		14	3100	0.49	180	14	0.11	2.2	17	2545
BH2	Nov-17	7.2	1910	310	240	46	74	49	480	0.17	0.1		93	1310	0.1	71	2	0.49	2.8	14	1076
BH2	Feb-18	7.2	1730	300	195	49	69	35	430	0.1	0.62		160	985	0.1	60	2	0.44	4.1	13	809
BH2	May-18	7	1880	350	185	53	76	42	470	<0.1	<0.1		105	1160	<0.1	59	2	0.44	0.85	12	952
BH2	Aug-18	7	1910	360	195	44	78	43	475	0.31	0.1		120	1190	0.1	66	4	0.4	0.73	12	977
BH3	Nov-17	7.3	700	35	150	34	19	11	99	0.1	66		72	410	0.1	12	7	0.03	0.07	1.1	337
BH3	Feb-18	7.3	950	110	125	39	28	44	230	0.1	23		83	530	0.1	19	4	0.22	0.08	7.4	435
BH3	May-18	7.3	810	77	130	41	26	24	170	<0.1	7.5		97	470	<0.1	20	3	0.16	0.03	2.9	386
BH3	Aug-18	7.2	930	91	140	41	30	26	190	0.13	78		86	475	0.1	13	3	0.14	0.04	3.5	390
BH4	Nov-17	7.4	885	94	170	16	30	7.2	125	0.1	0.1	0.1	94	655	0.1	16	2	0.16	0.47	4.3	538
BH4	Feb-18	7.2	810	95	145	25	32	8.9	155	0.1	0.1	0.1	110	510	0.1	19	2	0.17	0.75	4.6	419
BH4	May-18	7.2	895	125	160	29	31	70	180	<0.1	<0.1	<0.1	105	585	<0.1	15	<2	0.18	0.42	4.1	480
BH4	Aug-18	7.1	965	130	170	27	35	7.7	185	0.1	0.1	0.1	120	625	0.1	19	2	0.17	0.27	4.6	513
BH13	Nov-17	7.4	1080	120	205	21	44	2.7	170	0.22	4.2		120	745	0.1	27	2	0.23	0.26	3.4	612
BH13	Feb-18	7.2	1060	110	215	25	42	2.6	135	0.1	0.49		170	730	0.1	23	2	0.27	0.26	2	599
BH13	May-18	7.1	1030	87	185	36	44	2.2	73	<0.1	0.22		335	515	<0.1	19	<2	0.3	0.17	4	423
BH13	Aug-18	7	1000	75	195	38	39	1.1	64	0.24	26		290	560	0.1	17	3	0.21	0.13	2	460
BH14	Nov-17	7	1070	200	135	44	43	0.6	245	0.52	30	0.1	190	565	0.34	48	2	0.26	0.2	1.8	464
BH14	Feb-18	6.9	1390	100	320	26	58	0.7	250	0.14	0.13		120	975	0.28	38	2	0.25	0.06	1.8	800
BH14	May-18	6.9	1360	195	220	33	50	0.8	230	0.13	<0.1		140	925	0.12	22	<2	0.38	0.2	3.7	759
BH14	Aug-18	6.8	1370	210	225	28	48	0.6	245	0.45	0.1		135	910	0.1	31	2	0.35	0.26	3.3	747
BH15	Nov-17	7	3970	525	170	735	78	110	1500	0.18	0.13	0.1	190	1150	1.5	205	2	0.4	19	21	944
BH15	Feb-18	6.8	4520	740	215	715	89	135	1920	0.1	0.1	0.26	245	1110	1.1	200	2	0.52	18	25	911
BH15	May-18	6.8	4880	850	270	660	125	4	2110	<0.1	<0.1	<0.1	320	1060	1.1	200	2	0.67	13	24	870
BH15	Aug-18	6.7	5850	1090	300	710	135	115	2590	0.17	0.1	0.1	350	1080	0.49	170	4	0.74	11	24	886
BH16	Nov-17	7	1410	235	120	83	62	6.9	455	0.17	0.1		380	235	0.15	59	2	0.11	0.35	17	193
BH16	Feb-18	6.8	2150	580	105	61	50	1.8	1070	0.1	0.1		145	160	0.18	28	2	0.08	0.37	5.1	131
BH16	May-18	7	1640	440	52	50	41	0.7	770	<0.1	<0.1		125	150	0.34	63	2	0.05	0.75	4.2	123
BH16	Aug-18	7.3	265	90	5.8	5.1	2.3	0.2	49	0.94	0.1		67	110	0.64	33	3	0.03	1.2	9	90
BH19	Nov-17	7.4	1000	86	200	17	37	6.3	175	0.1	0.13		140	610	0.1	19	2	0.07	0.26	32	501
BH19	Feb-18	7.3	970	88	190	15	39	6.6	180	0.1	0.1		170	520	0.1	16	2	0.08	0.13	68	427
BH20	Nov-17	7.7	730	49	135	29	37	12	125	0.12	0.1		170	385	0.18	21	2	0.06	0.09	3	317

Sample	Date	pH	TDS	Na	Ca	K	Mg	NH4-N	Cl	F	NO3	NO2	SO4	HCO3	PO4	TOC	BOD	Sol. Mn	Sol. Fe	Tot. Fe	Alkalinity (as CaCO ₃)
			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BH20	Feb-18	7.5	785	66	125	35	36	16	155	0.1	0.1		210	320	0.28	24	2	0.08	0.03	1.8	263
BH20	May-18	7.6	850	75	125	36	44	19	135	<0.1	<0.1		205	420	0.28	16	<2	0.07	0.05	1.5	346
BH20	Aug-18	7.4	850	60	115	55	41	21	110	0.16	0.1		250	380	0.34	19	2	0.08	0.07	6.4	312
BH20s	Nov-17	7.5	770	32	145	76	32	0.2	31	0.12	42		130	540	0.1	35	2	0.02	0.12	31	444
BH20s	Feb-18	7.5	790	50	100	110	38	1.3	55	0.1	3.1		190	460	0.1	20	2	0.07	0.12	7.1	378
BH20s	May-18	7.6	835	64	120	100	35	1	76	<0.1	3.1		220	465	<0.1	10	<2	0.08	0.06	1.2	383
BH20s	Aug-18	7.4	860	40	125	110	38	0.6	76	0.11	39		200	435	0.1	16	2	0.08	0.07	0.25	357
ANZECC 2000	-	6.5-8.5	-	-	-	-	-	2.09*	-	-	10.6#	-	-	-	-	-	-	-	0.3	-	

Notes:

1. results are in mg/L;
2. – not tested;
3. # guideline from trigger values for slightly disturbed ecosystems in lakes and reservoirs – Hickey (2013);
4. * guideline from freshwater trigger values as total NH4-N at different pH values - Table 8.3.7 of ANZECC (2000) - based on average laboratory measured pH of 7.1 from pH values from all quarters;
5. ** interim indicative working level presented in section 8.3.7 of ANZECC 2000 (based on Canadian derived guidelines);
6. # - based on the recalculated trigger value for freshwater, Hickey 2013; and
7. values above or below the guidelines are bolded.

Table 9: Surface water laboratory results

Sample	Date	pH	TDS mg/L	Na mg/L	Ca mg/L	K mg/L	Mg mg/L	NH4-N mg/L	Cl mg/L	F mg/L	NO3 mg/L	NO2 mg/L	SO4 mg/L	HCO3 mg/L	PO4 mg/L	TOC mg/L	BOD mg/L	Sol. Mn mg/L	Sol. Fe mg/L	Tot. Fe mg/L	Alkalini ty (as CaCO ₃) mg/L
LP1	Nov-17	6.8	8650	1160	810	345	230	590	1380	0.17	0.1		1290	5590	6.8	470	1590	7.8	57	60	4587
LP1	Feb-18	7.8	7080	1190	200	390	110	810	1530	0.19	1.2		120	5600	19	800	240	0.43	1.5	100	4617
LP1	May-18	7.7	8490	1360	180	520	100	1010	1770	0.14	<0.1		125	6800	21	730	110	0.4	22	26	5600
LP1	Aug-18	8.1	8370	1280	175	530	120	990	1570	0.49	0.1		115	6930	20	600	32	0.42	3.7	3.8	5743
SWC2	Nov-17							0.6			0.84	0.13		125					0.34	1.4	
SWC2	Feb-18							0.3			0.1	0.1		255					0.06	0.21	
SWC2	May-18							1.4			<0.1	<0.1		225					0.06	0.25	
SWC2	Aug-18							0.1			0.15	0.1		215					0.09	0.14	
SWC-UP	Nov-17	7.2	6380	1710	135	130	240	0.6	3400	0.26	0.75		495	125	0.12				0.13	1.4	123
SWC-UP	Feb-18	7.3	36200	11100	425	455	1170	0.1	20000	0.2	0.1		2450	185	0.1				0.07	0.18	312
SWC-UP	May-18	7.3	29000	8700	375	520	980	0.5	15600	0.1	0.53		2070	335	<0.1				0.07	0.19	333
SWC-UP	Aug-18	7.8	35600	11100	390	485	1180	0.1	20100	0.5	0.1		2440	245	0.1				0.15	0.42	120
SWC-DOWN	Nov-17	7.4	19600	5490	280	370	820	0.3	10800	0.38	0.58		1350	215	0.1				0.04	0.65	103
SWC-DOWN	Feb-18	7.2	35900	10800	440	470	1220	0.1	19200	0.18	0.1		2560	245	0.1				0.1	0.17	152
SWC-DOWN	May-18	7.4	29700	9130	400	550	1060	0.4	16900	<0.1	0.18		2230	840	<0.1				0.05	0.17	275
SWC-DOWN	Aug-18	7.9	36000	11200	405	480	1210	0.1	20400	0.5	0.1		2480	190	0.1				0.11	0.19	202
SWC-DOWN-2	Nov-17	7.2	12000	3580	190	205	440	0.6	6770	0.33	0.58		880	150	0.1				0.11	1.1	177
SWC-DOWN-2	Feb-18	7.2	36600	10900	440	460	1170	0.2	20200	0.19	0.1		2530	380	0.1				0.04	0.25	201
SWC-DOWN-2	May-18	7.2	29200	8850	390	520	1030	0.5	15900	0.11	0.18		2120	405	<0.1				0.05	0.18	690
SWC-DOWN-2	Aug-18	7.8	34800	10400	395	495	1350	0.1	19800	0.49	0.13		2490	145	0.1				0.13	0.52	157
SWP1	Nov-17	7	330	44	45	16	15	0.1	50	0.12	0.1		57	205	0.31				0.25	4.4	168
SWP1	Feb-18	6.9	595	115	60	18	24	2.5	100	0.1	0.1		15	480	0.1				4.5	110	394
SWP1	May-18	6.9	660	105	76	33	38	3.8	125	<0.1	<0.1		41	515	0.22				2.7	93	423
SWP1	Aug-18	6.9	460	74	56	23	23	0.1	100	0.14	0.1		20	305	0.37				2.2	43	250
SWP2	Nov-17	8.1	1070	215	83	29	48	0.1	280	0.17	11		210	405	0.1				0.07	0.82	336
SWP2	Feb-18	7.8	1290	275	100	32	56	0.2	325	0.1	0.18		195	545	0.1				0.12	0.18	449
SWP2	May-18	8	1370	275	110	38	55	1.8	330	<0.1	0.18		230	570	0.18				0.05	0.22	471

Sample	Date	pH	TDS mg/L	Na mg/L	Ca mg/L	K mg/L	Mg mg/L	NH ₄ -N mg/L	Cl mg/L	F mg/L	NO ₃ mg/L	NO ₂ mg/L	SO ₄ mg/L	HCO ₃ mg/L	PO ₄ mg/L	TOC mg/L	BOD mg/L	Sol. Mn mg/L	Sol. Fe mg/L	Tot. Fe mg/L	Alkalini ty (as CaCO ₃) mg/L
SWP2	Aug-18	7.8	1310	285	97	33	54	0.2	340	0.17	1.4		220	515	0.1				0.12	0.89	425
SWP4	Nov-17	8.3	1210	265	67	28	50	1.1	325	0.33	15		205	410	0.1	31	2		0.03	0.17	342
SWP4	Feb-18	8.3	1340	340	61	27	57	1.5	360	0.13	12		280	380	0.1	34	2		0.02	0.12	317
SWP4	May-18	7.7	1330	295	78	29	54	2.6	360	<0.1	2.1		260	430	<0.1	16	<2		0.22	0.35	354
SWP4	Aug-18	8	1390	335	74	25	62	0.2	365	0.31	8.4		285	440	0.1	29	2		0.15	0.22	364
SWP5	Nov-17	7.6	320	47	36	18	12	0.5	66	0.13	60		80	42	0.12	10	2		0.13	3.8	35
Adopted guidelines		6.5-8.5	-	-	-	-	-	1.88*	-	-	10.6[#]	-	-	-	-	-	-	-	0.3	-	

Notes:

1. results are in mg/L;
2. – not tested;
3. [#] guideline from trigger values for slightly disturbed ecosystems in lakes and reservoirs – Hickey (2013);
4. * guideline from marine trigger values as total NH₄-N at different pH values - Table 8.3.7 of ANZECC (2000) - based on average laboratory field measured pH of 7.5 from pH values from all quarters;
5. ** interim indicative working level presented in section 8.3.7 of ANZECC 2000 (based on Canadian derived guidelines); and
6. values above or below the guidelines are **bolded**.

Table 10: Leachate pit - biological laboratory results

Date	E. coli	Faecal Coliforms
	cfu/100 mL	cfu/100 mL
26/11/2008	1300	1300
26/02/2009	80	80
27/05/2009	5400	>16000
27/08/2009	330	330
26/11/2009	>160000	>160000
24/02/2010	>12000	>16000
25/05/2010	1700*	1700*
31/08/2010	>16000	>16000
25/11/2010	1700	1700
24/02/2011	>16000	>16000
23/05/2011	>16000	>16000
23/05/2011	>16000	>16000
21/11/2011	1700	1700
22/02/2012	1300	1300
22/05/2012	790	790
23/08/2012	230	330
5/12/2013	790	790
26/02/2013	34000	17000
28/05/2013	9200	9200
28/08/2013	2400*	2400*
13/11/2013	9200	>16000
26/02/2013	>16000	>16000
28/05/2013	4000	4000

Date	E. coli	Faecal Coliforms
	cfu/100 mL	cfu/100 mL
26/08/2014	1,600,000	1,600,000
21/11/2014	16,000	16,000
24/02/2015	160,000	160,000
27/05/2015	10,000	8,000
4/09/2015	92,000	5,400
3/12/2015	54,000	54,000
9/02/2016	490	490
19/05/2016	260	260
17/08/2016	<10	<10
10/11/2016	< 20	< 20
16/02/2017	1700	1300
9/05/2017	330	330
21/08/2017	400	400
22/11/2017	18000	18000
13/02/2018	<20	<20
10/05/2018	50	80
14/08/2018	<20	20

Table 11: Organic laboratory analysis at LP/LP1 – 2008 - 2018

Analyte	Leachate Pond Waters										Guideline
	Nov-08	Nov-09	Nov-10	Nov-11	Nov-12	Nov-13	Nov-14	Nov-15	Feb-17	Nov-17	
Phenol	8.1 [#]	7 [#]	352.3 [#]	ND	180 [#]	ND	84 [#]	ND	20.1 [#]	1,200	320 ^a
BTEXN											
Benzene	<40	<1	<1	<1	<1	<1	<1	<1	<1	2.9	950 ^a
Toluene	<40	1.5	<1	<1	<1	<1	<1	<1	<1	36	300 ^a
Ethylbenzene	<40	1.3	<1	<1	<1	<1	<1	<1	<1	7.8	140 ^b
Naphthalene	<16 [^]	1.7 [^]	1.7 [^]	ND	ND	ND	1 [^]	ND	ND	1.4	16 ^a
Petroleum hydrocarbons											
C ₆ -C ₉	<250	<25	<25	<25	<25	<25	<25	<25	160	2,700	-
C ₁₀ -C ₁₄	900	1,900	1,300	1100	750	<25	1,900	420	1,500	1,400	-
C ₁₅ -C ₂₈	3,400	5,500	6,000	4,800	2,800	<100	8,500	1,700	4,900	720	-
C ₂₉ -C ₃₆	560	630	1,200	450	390	<100	3,000	180	<100	<100	-
Total petroleum hydrocarbons	4,860	8,030	8,500	5,350	3,940	<100	13,400	2,300	6,560	4,820	10,000*

Notes:

1. results are expressed in µg/L;
2. ^a - guideline levels from ANZECC (2000) Guidelines for protection of freshwater ecosystems;
3. ^b - guideline levels from NSW EPA (1994) Contaminated sites: Guidelines for assessing service station sites for protection of freshwater aquatic ecosystems;
4. * - Information needed to select threshold concentrations is incomplete. The NSW Clean Waters Act 1970 and Clean Waters Regulations 1972 prohibit the pollution of waters by unlicensed contaminated discharges and require licensed discharges to be visually free of oil and grease. Experience has demonstrated that the latter criterion is equivalent to an oil and grease concentration of approximately 10mg/L;
5. [#] - Values given are for *Total Phenols* which were previously used as per ANZECC 1992;
6. [^] - Values given are for *Total PAHs* which were previously used as per ANZECC 1992.
7. PAH – polycyclic aromatic hydrocarbons; HACs – halogenated aliphatic compounds; PHs –petroleum hydrocarbons.

Table 12: Groundwater ionic ratios for 2017-2018

Location	Sample Date	Na/Cl	Na/Ca	Mg/Ca	Ca/K	Cl/SO4	Cl/HCO3	K/TDS	L/N
BH1c	Nov-17	0.73	4.06	0.75	0.70	74.58	0.29	5.74	59.15
BH1c	Feb-18	1.27	4.46	1.27	1.21	77.91	0.44	5.37	65.93
BH1c	May-18	1.22	5.23	1.57	0.74	62.85	0.46	7.36	74.30
BH1c	Aug-18	1.25	4.46	1.40	1.01	79.36	0.46	6.38	65.20
BH2	Nov-17	0.65	1.29	0.31	5.22	5.16	0.37	2.41	15.24
BH2	Feb-18	1.08	1.34	0.58	7.76	3.64	0.75	2.83	15.00
BH2	May-18	1.15	1.65	0.68	6.81	6.07	0.70	2.82	15.56
BH2	Aug-18	1.17	1.61	0.66	8.65	5.36	0.69	2.30	13.76
BH3	Nov-17	0.35	0.23	0.13	4.41	1.38	0.24	4.86	54.41
BH3	Feb-18	0.74	0.77	0.37	6.25	3.75	0.75	4.11	40.30
BH3	May-18	0.70	0.52	0.33	6.19	2.37	0.62	5.06	31.12
BH3	Aug-18	0.74	0.57	0.35	6.66	2.99	0.69	4.41	55.56
BH4	Nov-17	0.75	0.55	0.18	10.63	1.33	0.19	1.81	7.96
BH4	Feb-18	0.95	0.57	0.36	11.31	1.91	0.52	3.09	12.54
BH4	May-18	1.07	0.68	0.32	10.76	2.32	0.53	3.24	31.39
BH4	Aug-18	1.08	0.67	0.34	12.28	2.09	0.51	2.80	10.42
BH13	Nov-17	0.71	0.59	0.21	9.76	1.42	0.23	1.94	7.56
BH13	Feb-18	1.26	0.45	0.32	16.78	1.08	0.32	2.36	7.65
BH13	May-18	1.84	0.41	0.39	10.02	0.30	0.24	3.50	12.16
BH13	Aug-18	1.81	0.34	0.33	10.01	0.30	0.20	3.80	21.07
BH14	Nov-17	0.82	1.48	0.32	3.07	1.29	0.43	4.11	19.76
BH14	Feb-18	0.62	0.27	0.30	24.01	2.82	0.44	1.87	5.61
BH14	May-18	1.31	0.77	0.37	13.00	2.23	0.43	2.43	7.29
BH14	Aug-18	1.32	0.81	0.35	15.68	2.46	0.46	2.04	5.94

Location	Sample Date	Na/Cl	Na/Ca	Mg/Ca	Ca/K	Cl/SO4	Cl/HCO3	K/TDS	L/N
BH15	Nov-17	0.35	3.09	0.46	0.23	7.89	1.30	18.51	109.34
BH15	Feb-18	0.59	3.00	0.68	0.59	10.62	2.98	15.82	81.45
BH15	May-18	0.62	2.74	0.76	0.80	8.93	3.43	13.52	53.35
BH15	Aug-18	0.65	3.17	0.74	0.82	10.03	4.13	12.14	54.11
BH16	Nov-17	0.52	1.96	0.52	1.45	1.20	1.94	5.89	21.58
BH16	Feb-18	0.84	4.82	0.79	3.36	10.00	11.51	2.84	8.56
BH16	May-18	0.88	7.38	1.30	2.03	8.35	8.84	3.05	9.53
BH16	Aug-18	2.83	13.53	0.65	2.22	0.99	0.77	1.92	5.50
BH19	Nov-17	0.49	0.43	0.19	11.76	1.25	0.29	1.70	7.25
BH19	Feb-18	0.75	0.40	0.34	24.71	1.43	0.60	1.55	6.85
BH20	Nov-17	0.39	0.36	0.27	4.66	0.74	0.32	3.97	18.60
BH20	Feb-18	0.66	0.46	0.47	6.97	1.00	0.83	4.46	22.51
BH20	May-18	0.86	0.52	0.58	6.77	0.89	0.55	4.24	22.58
BH20	Aug-18	0.84	0.45	0.59	4.08	0.60	0.50	6.47	35.23
BH20s	Nov-17	1.03	0.22	0.22	1.91	0.24	0.06	9.87	56.56
BH20s	Feb-18	1.40	0.44	0.63	1.77	0.39	0.21	13.92	60.85
BH20s	May-18	1.30	0.46	0.48	2.34	0.47	0.28	11.98	47.53
BH20s	Aug-18	0.81	0.28	0.50	2.22	0.51	0.30	12.79	73.69

Notes:

1. Bolded values indicate L/N ratio above the threshold level of 20.

Table 13: Surface water ionic ratios for 2017-2018

Location	Sample Date	Na/Cl	Na/Ca	Mg/Ca	Ca/K	Cl/SO4	Cl/HCO3	K/TDS	L/N
LP1	Nov-17	0.84	1.43	0.28	2.35	1.07	0.25	3.99	42.50
LP1	Feb-18	1.20	5.19	0.91	1.00	17.28	0.47	5.51	80.08
LP1	May-18	1.18	6.59	0.92	0.68	19.19	0.45	6.12	93.30
LP1	Aug-18	1.26	6.38	1.13	0.64	18.50	0.39	6.33	96.51
SWC-Up	Nov-17	0.53	18.84	2.32	0.93	7.69	45.13	1.71	4.90
SWC-Up	Feb-18	0.83	21.60	4.39	1.87	10.82	91.49	1.26	3.68
SWC-Up	May-18	0.86	19.78	4.36	1.46	10.16	67.57	1.78	5.07
SWC-Up	Aug-18	0.81	22.95	5.64	1.56	10.77	235.03	1.42	4.08
SWC-Down	Nov-17	0.50	12.67	1.78	1.04	6.87	27.20	2.04	6.30
SWC-Down	Feb-18	0.86	22.77	4.54	1.82	11.06	186.07	1.26	3.59
SWC-Down	May-18	0.86	20.22	4.31	1.41	10.21	80.15	1.79	5.18
SWC-Down	Aug-18	0.85	24.81	4.99	1.57	11.16	141.21	1.36	3.83
SWC-Down-2	Nov-17	0.51	19.61	2.93	0.76	8.00	50.23	1.89	5.63
SWC-Down-2	Feb-18	0.87	21.40	4.57	1.83	10.16	134.88	1.31	3.77
SWC-Down-2	May-18	0.83	19.90	4.37	1.42	10.27	34.63	1.85	5.20
SWC-Down-2	Aug-18	0.85	24.11	4.93	1.65	11.15	184.80	1.33	3.75
SWP1	Nov-17	0.88	0.98	0.33	2.81	0.88	0.24	4.85	15.58
SWP1	Feb-18	1.77	1.67	0.66	6.50	9.03	0.36	3.03	10.35
SWP1	May-18	1.30	1.20	0.82	4.49	4.13	0.42	5.00	16.85
SWP2	Nov-17	1.14	1.15	0.68	4.75	6.77	0.56	5.00	15.16
SWP2	Feb-18	0.77	2.59	0.58	2.86	1.33	0.69	2.71	11.59
SWP2	May-18	1.30	2.40	0.92	6.10	2.26	1.03	2.48	7.51
SWP2	Aug-18	1.29	2.18	0.82	5.65	1.94	1.00	2.77	9.09
SWP4	Nov-17	1.29	2.56	0.92	5.73	2.09	1.14	2.52	7.94
SWP4	Feb-18	0.82	3.96	0.75	2.39	1.59	0.79	2.31	11.54
SWP4	May-18	1.46	4.86	1.54	4.41	1.74	1.63	2.01	8.84
SWP4	Aug-18	1.26	3.30	1.14	5.25	1.88	1.44	2.18	7.89
SWP5	Nov-17	1.42	3.95	1.38	5.77	1.74	1.43	1.80	7.13

Notes:

1. **Bolded** values indicate L/N ratio above the threshold level of 20.

Table 14: Dust gauge results for 2017-2018

Analyte	Dust Gauge Analysis					Guidelines g/m ² /month
	Nov-17	Feb-18	May-18	Aug-18	Annual Average	
Ash	0.6	0.1	0.2	0.6	0.4	-
Combustibles	0.4	0.1	0.2	0.3	0.3	-
Insolubles	1	0.2	0.4	0.9	0.6	-
Solubles	0.2	<0.1	0.1	0.1	0.1	-
Total Solids	1.2	0.2	0.5	1	0.7	4
Particulates	<0.1	<0.1	<0.1	<0.1	<0.1	-
Total Exposure (days)	91	84	86	92	88.3	-

Notes:

1. Australian Standards AS 3580.10.1. The annual average limit for fallout of dust (derived for coal mining areas of NSW) is 4 g/m²/month annual average of total solids;
2. Values in Bold indicate exceedances; and
3. Not calculated.