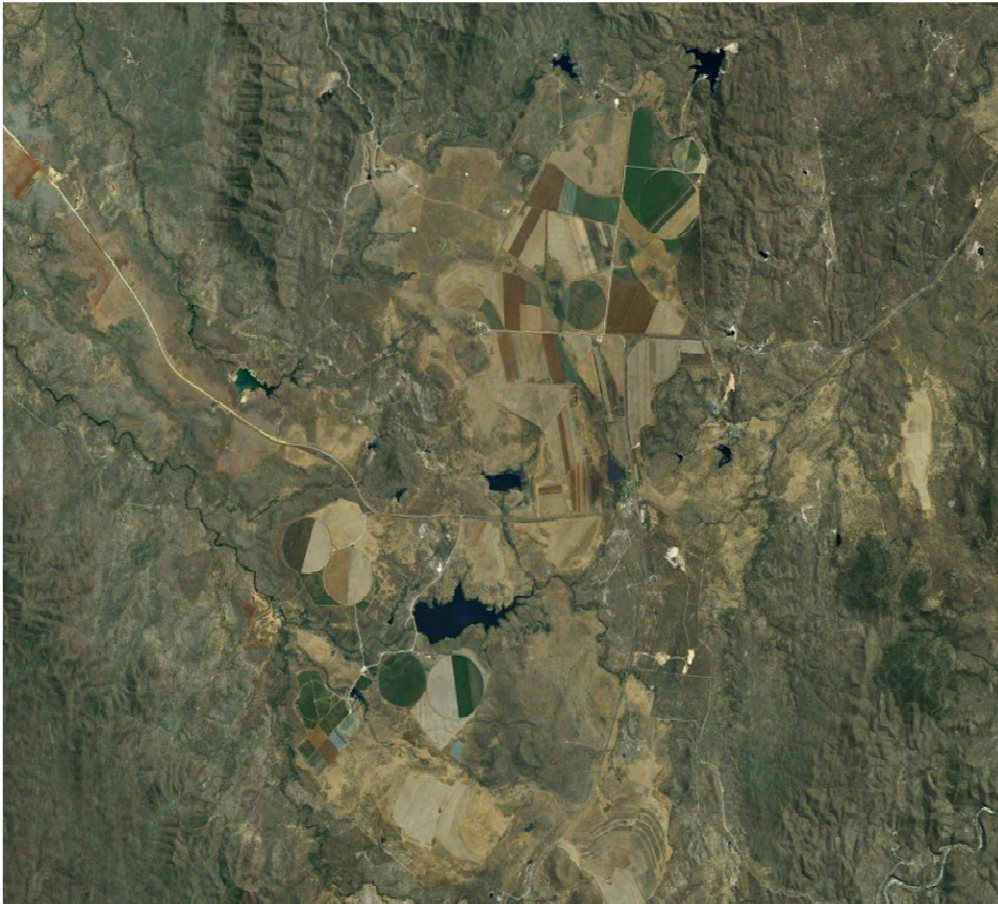


Lakeland Groundwater Review



February 2013

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Introduction

This report was undertaken by the Queensland Department of Natural Resources and Mines (DNRM) to support an update of the existing water management rules in the Lakeland Downs district, North Queensland. It aims to better define the extent of aquifers and groundwater storage capacity. The analysis consisted of examination of published reports, climatic variables, borehole logs, water level and water quality data and a reassessment of aquifer parameters including storage and transmissivity.

Most groundwater in the Lakeland Downs area is taken from aquifers in the McLean Basalt. The basalts cover an area of approximately 127 km². It is believed the McLean Basalt originated from 18 recognised vents of which at least 6 are represented within the study area. The basalts overlie steeply folded metamorphic rocks of the Hodgkinson Formation (Bain & Draper 1997) which provide limited supplies of groundwater.

The Lakeland study area (hereafter described as the Study area) roughly conforms to the major identified basalt outcrop in the Lakeland Downs area and occupies an area of approximately 101 km². For this report the Study area has been divided into two sectors, the northern sector (~52 km²) north of the Peninsula Development Road and a southern sector (~49 km²) south of the Peninsula Development Road.

A previous analysis was undertaken by AGE (2006). Since that report, further information has become available including the installation of additional bores in the area, and the construction by the Department of Natural Resources and Mines of two groundwater monitoring bores with continuous downhole data loggers, in the McLean Basalts. The loggers currently make only a limited contribution to this analysis. Although additional information has become available for the area, data is still limited. It is proposed to update and extend the scope of this report once more data becomes available.

Location

The Lakeland Downs district is located approximately 79 km southwest of Cooktown and 187 km north of Mareeba, within the Cape York Peninsula, Far North Queensland (Figure 1). It is positioned within the Normanby River basin, with the majority of local watercourses draining into the headwaters of the Laura River. The Normanby River Catchment is of high natural heritage value, encompassing both Lakefield National Park and Princess Charlotte Bay. It has been identified as containing vulnerable water dependent ecosystems and hydroecological processes (Cook *et al* 2011, Howley & Stephan 2005).

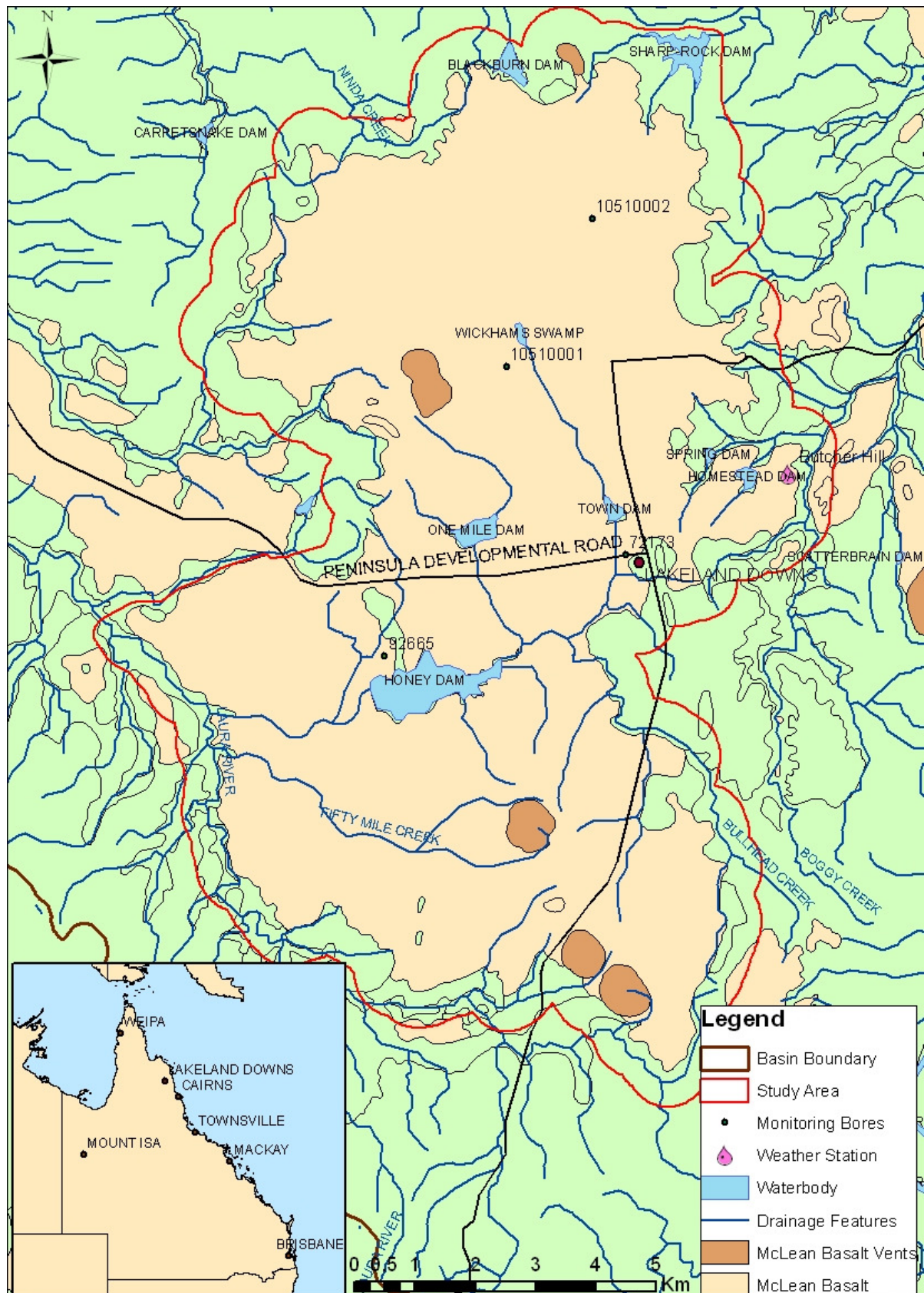


Figure 1 - Location map of Lakeland Downs, Far North Queensland

Topography and Drainage

The McLean Basalt has an elevation of between 200 and 300 m AHD. The basalt has infilled an old valley system, resulting in it being a small closed system. The topography of the Study area ranges from level to gently sloping plains (slope 0–4%) with elevated volcano remnants (Figure 2). There is a marked contrast between the McLean Basalt and the surrounding steep slopes of the Hodgkinson sediments. The surrounding land is hilly or mountainous, formed from sedimentary and granitic rocks.

The Study area is drained by two major watercourses, the Laura River to the west of the basalt flow and the Normanby River to the east. A large proportion of runoff diverts to the Laura River. There are no major drainage features located within the McLean Basalt, however smaller watercourses do exist. As can be seen in Figure 1, most of the watercourses that are located on the basalt flow have been dammed.

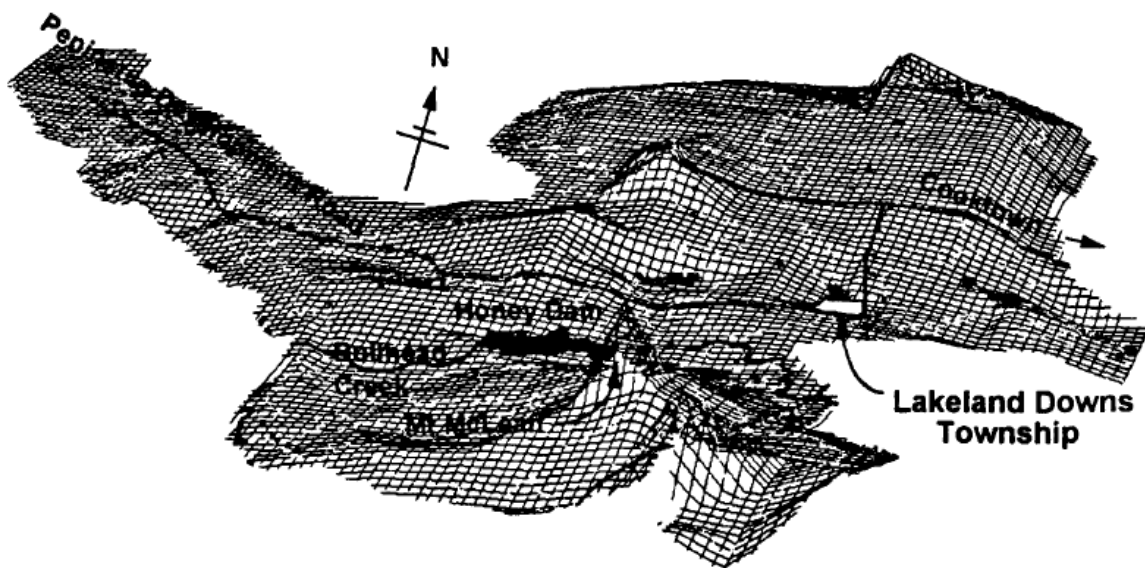


Figure 2 - Three dimensional representation of the landform of Lakeland Downs viewed from the southeast (Grundy & Heiner 1994)

Climate

Rainfall data has been examined for the Bureau of Meteorology's Butcher Hill (031009) and Maitland Downs (028013) weather stations. The Butcher Hill station is 9.3 km from the Lakeland township (Figure 1) and has a total of 23 years of complete annual rainfall data. Rainfall measurements at Butcher's Hill began to be collected in 1951 however data collection has been sporadic in recent years whereas Maitland Downs has a longer and more consistent dataset. Rainfall data at Maitland Downs began to be collected in 1965 and has a complete annual dataset for 41 years. As can be seen in Figure 3, mean monthly rainfall is similar at both weather stations. Mean annual rainfall at the Butcher Hill Station is 978.8 mm whilst median annual rainfall is 922.8 mm. Mean annual rainfall at the Maitland Downs Station is 937.1 mm and median annual rainfall is 922.1 mm. Collection of additional rainfall data may result in the rainfall statistics changing as both sites have limited data for calculating long term averages.

Rainfall in the Lakeland area is highly seasonal, with approximately 80% of rainfall occurring in the period from December to March. This is evident in [Figure 3](#). Highest rainfalls were experienced in 1971, 1976, 1981 and 1999 ([Figure 4](#)).

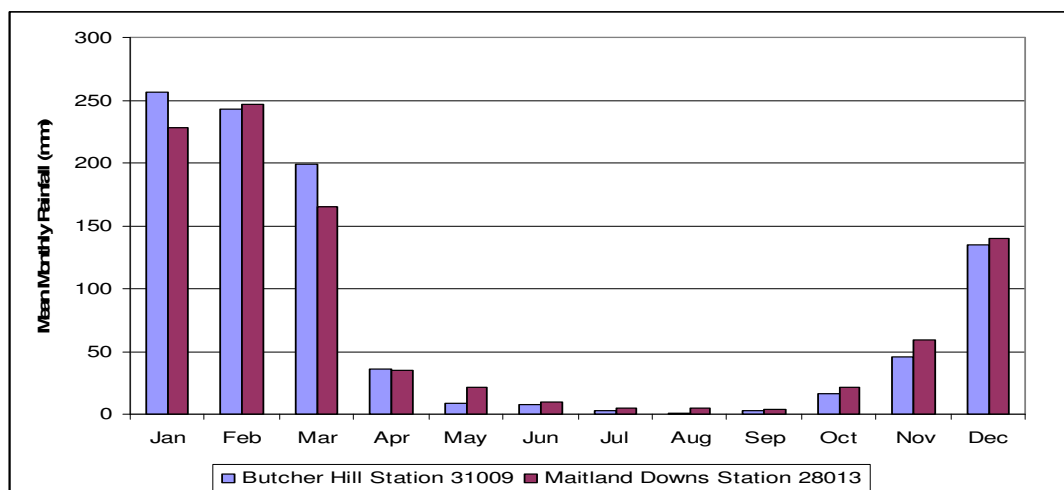


Figure 3 – Mean monthly rainfall at weather stations 031009 (Butcher Hill Station) and 028013 (Maitland Downs Station)

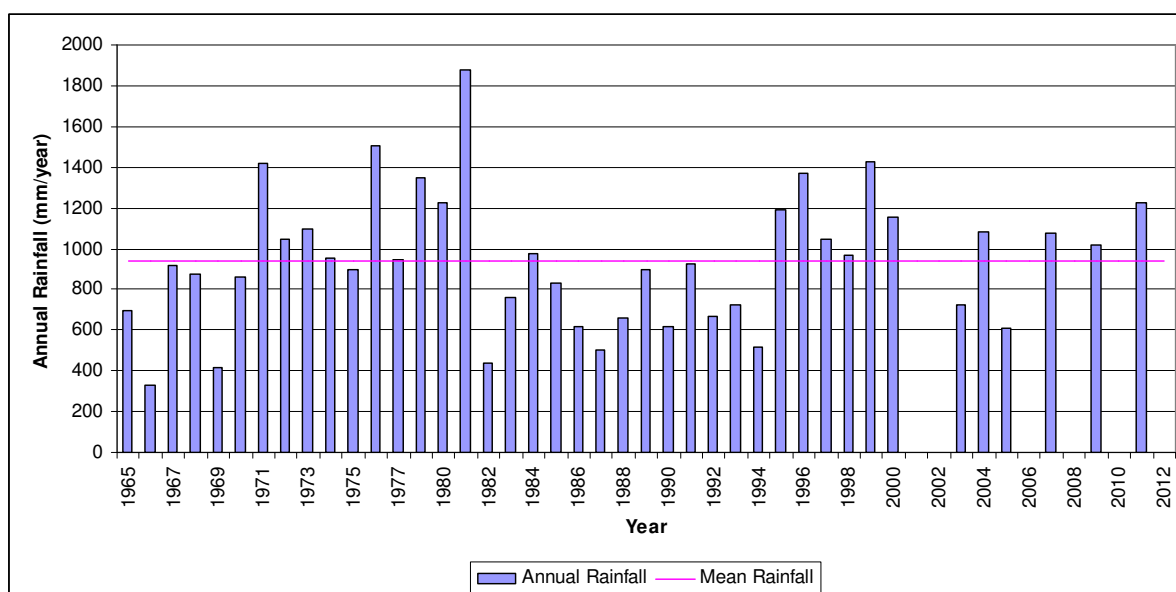


Figure 4 – Annual rainfall and annual mean rainfall at weather station 028013.
No data was available for 1978, 2001, 2002, 2006, 2008 and 2010.

A Cumulative Deviation from Mean Precipitation (CDMP) plot for monthly rainfall data in the Study area ([Figure 5](#)) shows that above average rainfall fell from 1970 to 1981 followed by a decline in rainfall from 1982 to 1996. This was followed by a period of average rainfall between 1996 and 2002 and a period of below average rainfall from 2002 to 2008. From 2008 until present, above average rainfall has fallen. The data used for this analysis is from the SILO database and is made up of modelled and actual data ([DSITIA 2012](#)).

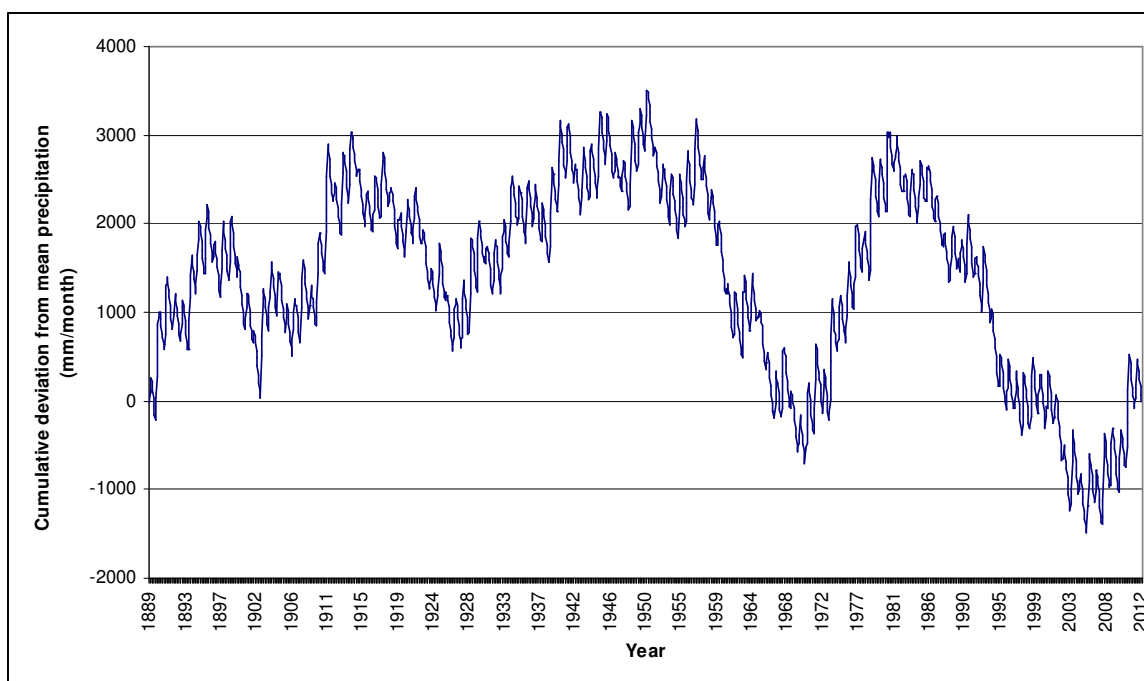


Figure 5 - Cumulative deviation from the mean plot for monthly rainfall at Butcher Hill. Data obtained from SILO and is based on long term averages i.e. it is not all measured data.

The closest Bureau of Meteorology evaporation pans are located in Cooktown (031017 and 031209) and Palmerville (028004). Cooktown has an annual average evaporation of between 1800 and 2000 mm, while Palmerville has an average annual evaporation of between 2400 and 2800 mm (Figure 6). There are no evaporation measurements for the Study area. Based on Cooktown and Palmerville data, average annual evaporation would range between 2000 and 2400 mm.

Mean daily evaporation from both the Cooktown Mission Strip station and the Palmerville station can be seen in Figure 7. Mean daily evaporation at the Palmerville station is consistently higher than the Cooktown Mission Strip station. This is particularly noticeable in the months from August to December when the mean daily evaporation at Palmerville is 1.8 mm to 3.4 mm higher than the Cooktown mean daily evaporation. This may be due to topographic differences. As average annual evaporation in the Lakeland area is modelled (BoM 2012a) to be between that of Palmerville and Cooktown (Figure 6). The average of the Palmerville and Cooktown mean daily evaporation will be used in this report.

Rainfall in the area of Lakeland is generally much less than monthly evaporation (Figure 8). This indicates that groundwater recharge through direct rainfall will mainly occur during the months January to March.

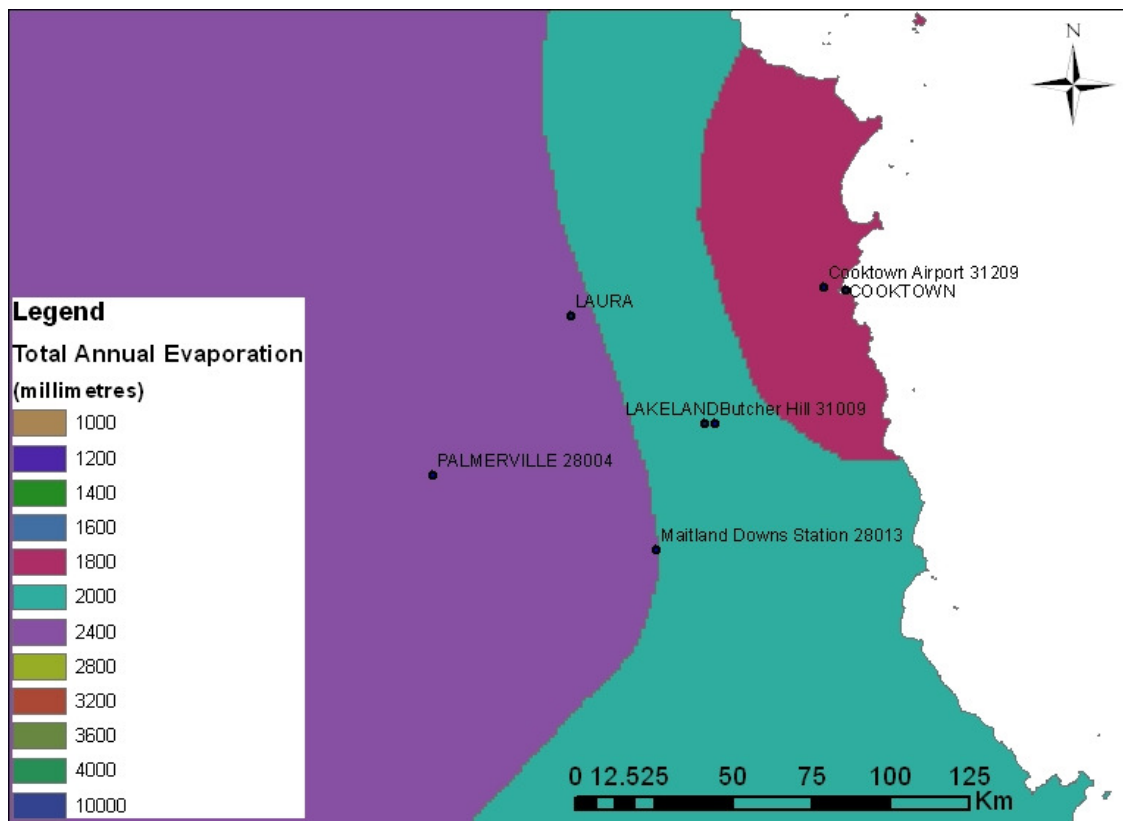


Figure 6 - Average annual evaporation and weather station locations. (Data supplied by the [Bureau of Meteorology, 2012a](#))

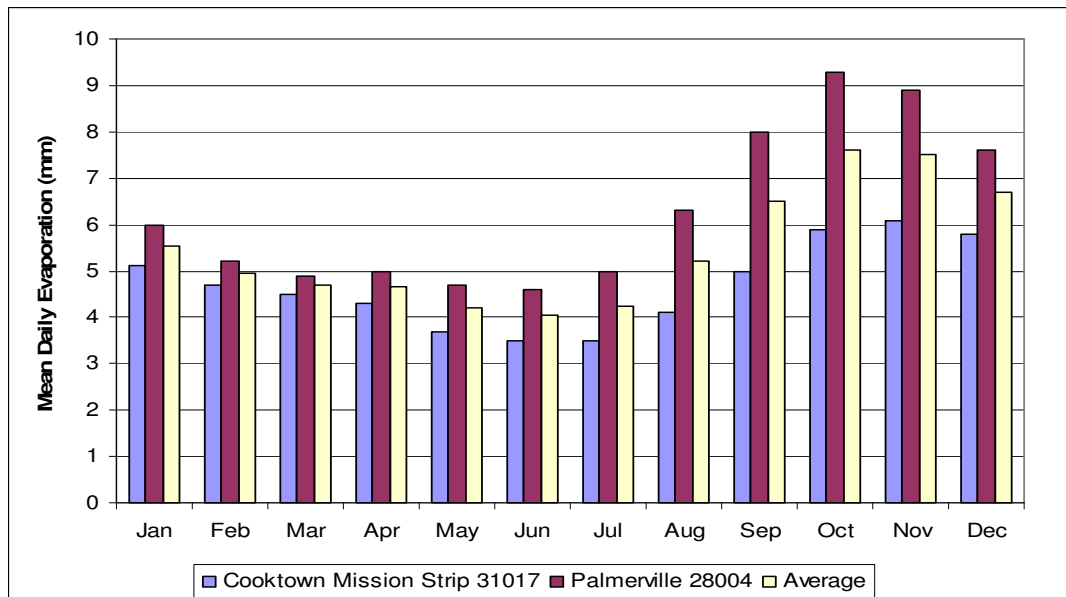


Figure 7 - Mean Daily Evaporation at the Cooktown Mission Strip station (031017) and the Palmerville station (028004)

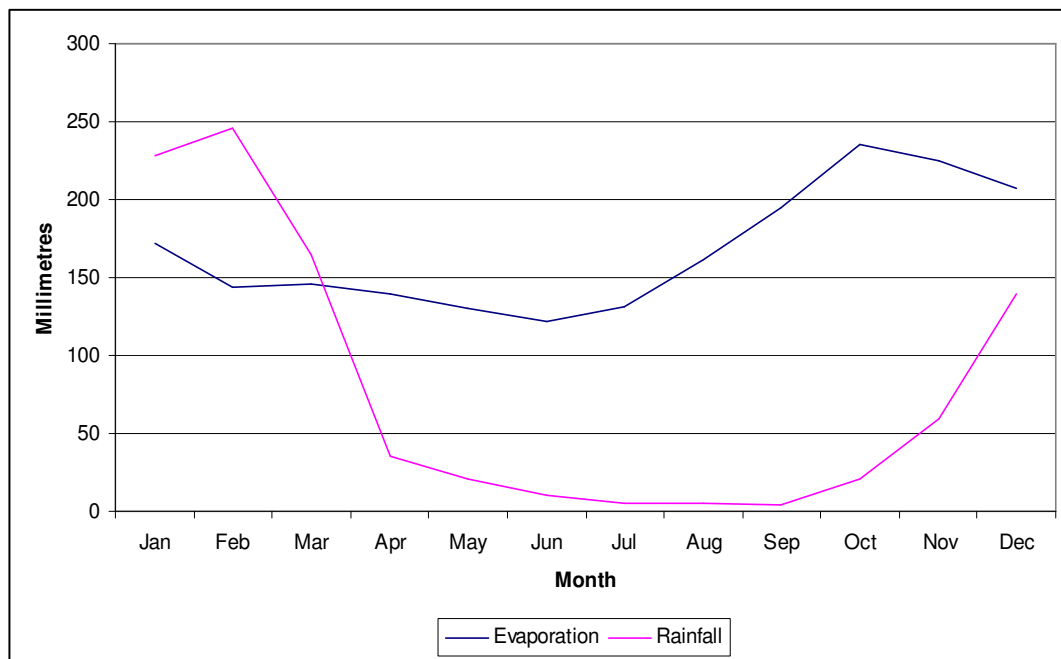


Figure 8 – Mean monthly rainfall at Maitland Downs Station (028013) and mean monthly evaporation calculated using Palmerville (28004) and Cooktown Mission Strip (031017) evaporation data

Geology

The underlying basement consists of the metamorphosed rocks of the Hodgkinson Formation which have undergone folding and faulting (de Keyser & Lucas 1968). Faulting in the area has a predominant northwest strike, parallel to the Palmerville fault and splinter faults are also present. Permo-Carboniferous igneous activity resulted in granitic plutons intruded within the pre-Carboniferous bedrock. The Bullhead and Mt Pike Granites of the Whypalla Supersuite outcrop to the southeast of the Study area and bore logs in the Study area show evidence of granite intrusion underlying basalt within the southern sector. During the Cenozoic, uplift occurred with faulting and basaltic volcanism (de Keyser & Lucas 1968). A generalised geological map of the Study area is presented in Figure 9.

Alluvium Sequences

The Quaternary age alluvium consists of surface sand and gravel layers underlain by alternating silty/sandy clay and clay. The clays are essentially isolated hill wash deposits that include bands of sand. The alluvium and colluvium overlie the Hodgkinson Formation and McLean Basalt. Only small alluvium deposits overlie the basalt flows within the Study area, although substantial deposits are present at the boundary of the Study area. Thick alluvial deposits are present to the south west of the Lakeland Downs township and associated with the present Laura River floodplain. Paleochannels have been identified in three bores and it is expected that where basalt flows have infilled or displaced watercourses there will be other channel deposits in the area.

McLean Basalt

The McLean Basalt is defined as vesicular, amygdaloidal and massive analcite, nepheline and olivine-bearing basalt lava flows locally with lherzolite inclusions, with minor coarse pyroclastics (vent and near-vent deposits). The McLean Basalt unconformably overlies the Hodgkinson Formation, Dalrymple Sandstone (GA 2012) and granitic intrusions. Volcanic activity occurred from the Tertiary to Quaternary period in the region associated with regional uplifting. Morgan (1968) identified eighteen vents within the McLean Basalt with several of the vents lying along faults. Volcanic vents are still discernible with at least six vents having directly influenced the Study area. Other vents may have been present but no longer have an obvious surface expression. AGE (2006) state that eruptions from The Brothers and Mt Mclean infilled valleys to the north-west of the cones and two unnamed vents infilled the northern sector of the valley overlapping older flows.

The various episodes of volcanism and faulting has led to complex basalt bedding sequences with at least three periods of volcanic inactivity as evidenced by the formation of weathered *in situ* basalt and clay layers. The basalt flows vary from massive to vesicular, with some fracturing having occurred. The thickness of the flows varies with the maximum known combined depth of 83 m close to the respective vent and reducing in thickness to the edges.

Soils derived from the basalt are predominantly brown-red clayey loams. Water is typically located within fractured rock, vesicular basalt (honeycomb) or at the highly weathered margins. The definition of the McLean Basalt includes amygdaloidal basalt indicating an infilling of the vesicles by secondary mineralisation reducing water storage capacity and transport.

In general the characteristics of basaltic aquifers vary locally due to flow type, thickness, age, weathering, fracturing and continuity of volcanic activity (Bean 1999) with porosity varying with void development. Primary water flow tends to be horizontal however weathering, fracturing and jointing creates secondary water flow pathways which can connect individual aquifer units. Peterson (1992) found that horizontal permeability typically exceeds vertical permeability and impermeable ash, weathered zones and massive basaltic layers can impede vertical recharge. In general transmissivity from fractured massive basalt is less than that of vesicular basalt (Bean 1999). Highly transmissive zones have been identified within the northern sector of the McLean Basalt and are associated with fractured vesicular basalt flows.

Colluvium

Colluvial deposition from surface wash is present as colluvial fans and footslopes at the edge of the basalt flows. Evidence of colluvium underlying basalt is present in one bore indicating a discontinuity between volcanic events and the underlying basement rocks.

Dalrymple Sandstone

The Dalrymple Sandstone is described as an early Cretaceous to mid Jurassic cross-bedded quartz and sublamine sandstone locally labile, conglomerate, minor shale; rare skolithos beds; non-marine, fluvial sedimentary sequence (GA 2012). Although there are no outcrops within the Study area there are outcrops north and west of the area. Sandstone with a clay layer was identified overlying the slate and shale of the Hodgkinson Formation in RN72307 and RN109715. The clay separating layer was not present in RN109715. This may be a remnant expression of the Dalrymple Sandstone or sandstone of the Hodgkinson Formation that has been eroded away and is not seen in other bores in the area. No samples were available for identification therefore this sandstone (at RN72307) has been included in the analysis as belonging to the Hodgkinson Formation.

Whypalla Supersuite Granite

Early Permian granite intrusions, described as extensively deformed, are present in the environment bounding the Hodgkinson Province including the Bullhead and MT Pike Granites of the Whypalla Supersuite (Marshallsea *et al* 2011). These are described (GA 2012) as white to pale pink—grey coarse to medium grained biotite granites. Granite intrusives have been identified in bore logs, underlying basalt and colluvium in the south west and to the west under the Mclean Basalt (RN126358) (outside the Study area). No identification is possible as there was no sampling of the drill chips at the time of drilling and there is no surface expression of the granites. Due to their location and overlying strata it is likely that they are also part of the Whypalla Supersuite.

Hodgkinson Formation

The AGE (2007) report states that the Hodgkinson Formation extends from Cooktown to Mission Beach and out to Chillagoe in the west. Rocks of the Hodgkinson Formation comprise of Silurian to Devonian marine siliciclastic rocks, dominated by deep water turbidite sequences. Subordinate chert layers and metabasalt lenses occur locally, and the unit includes low to medium graded metamorphic rocks with phyllite, slate, schist, quartzite, greywacke, chert, conglomerate and muddy sandstone (greywacke). The formation has experienced multiple deformations and intrusion by granites and basaltic volcanics. The dominant rock type is metamorphosed shale with a strong, near vertical cleavage. Cleavage generally dips towards the southwest and strikes in a north-westerly/south-easterly direction. There are numerous local cross-cutting faults. Silt and clay have been derived from in situ weathering of fine grained rocks of the Hodgkinson Formation on the valley floors and from mass wasting from elevated areas.

Geology Map

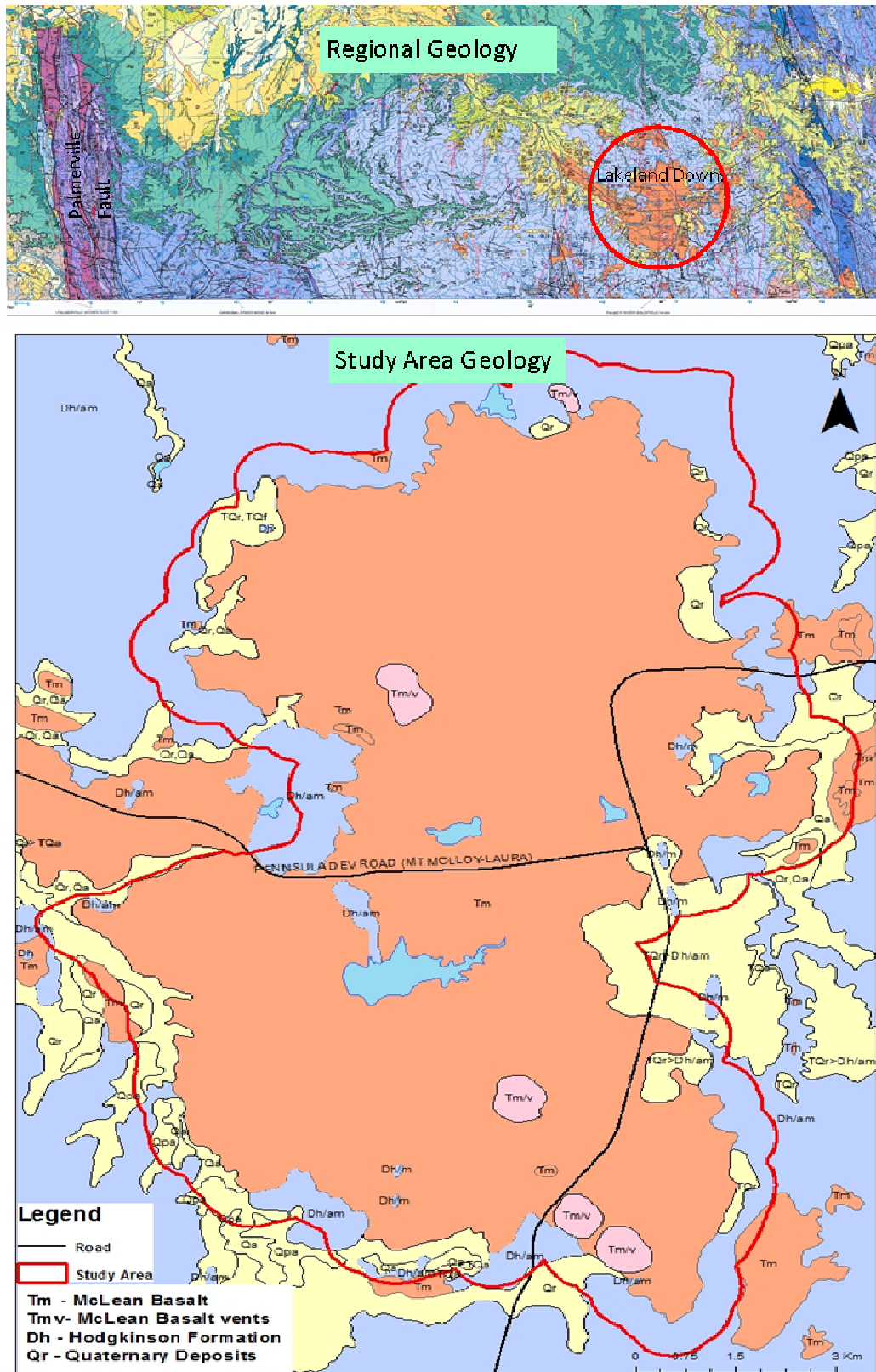


Figure 9 - Geology of the Lakeland Area

(Extract source for regional geology - Cooktown 250,000 geology map, Department of Mines and Energy 1997)

Methodology

Interpretation of underlying structures and strata have been undertaken in the assumption that the drilling logs and rates of supply provided by the drillers on completion of the bores are correct and still apply currently. Not all the bores known to be in the Study area have been used as their bore logs may not have sufficient information and in some cases no stratigraphy or bore depth is known. Where the drill logs strata description was incorrect the data description was adjusted accordingly by correlating to neighbouring bores. The drill log stratigraphy description is presented beside the logs, even where corrections have been made, to display the driller's strata interpretation.

The strata were differentiated into classes based on rock type and composition and subclasses depending on whether they contained water. The classes included alluvium and colluvium, basalt (massive, fractured, vesicular), metamorphic rocks and granitic rock types. Where possible the individual flow sequences have been identified by using unconformably overlying old soils, clays and weathered zones as marker beds (Pearce 2001).

Where the bore elevation is unknown the elevations have been determined by use of a digital elevation model of the area. This assumes that the bore position as listed in the record is correct which may not be the case for some of the older bores.

Bore drill log data was input into Strater3 (Golden Software 2012) to enable construction of borehole logs and cross sections (Appendix 1 & 2). In the construction of the cross sections correlation of adjacent bores and other cross sections was undertaken to attempt to build up a three dimensional conceptual model of the flow structure and basement contours. Pearce (2001) in the investigation of the Atherton Basalt flow sequences assumed that abrupt facies changes between adjacent bores were caused by faults, this concept was also applied to the analysis of the strata of the Study area. Cross sections were interpreted from individual bore logs and interpolated horizontally. Consideration was given to parallel and perpendicular cross sections and rock outcrops, to provide as accurately as possible an interpretation of the basement and bedding layers extent and topography. Figure 10 shows the locations of cross sections and fence diagrams.

Figure 11 provides a schematic of the basement contours based on extrapolated bore log data and current topography.

There are limited strata, water level and aquifer property analysis data available in the Study area. Where transmissivity testing has been undertaken the bores tended to intersect more than one aquifer. Insufficient data was available to determine the individual transmissivity and storativity of the aquifer units. Therefore the assumption that each unit has the same storage capacity and sustainable yield properties throughout has been adopted. In reality, this would be unlikely due to the anisotropic heterogeneous nature of the volcanic flows (differences in the properties of the aquifers both vertically and horizontally) and so the model would be expected to overestimate the availability of water within an aquifer.

Yield rates at time of drilling have been used to differentiate the aquifers although the original rates of supply may no longer be accurate due to weathering, aquifer changes and climatic variations. From analysis of the available data it was determined that there were many disjointed and interfingering aquifer units. Overall the analysis suggests:

- A limited extent high yielding basalt aquifer exists in the north sector,
- A shallower basalt aquifer that also had good yields of groundwater exists in the northern sector,
- Various smaller basalt aquifers with small to limited yields are present throughout the Study area, and
- Low yielding aquifers are present in the underlying basement material.

Due to the locations of the volcanic vents and subsequent flow sequences there is a discernible divide between the northern and the southern sectors of the Study area. For the analysis the area north of the Peninsula Development Road will be described as the northern sector and south of the road as the southern sector.

To simplify the analysis of the possible storage capacity of the aquifers, it was decided to consider the two higher yielding basalt aquifers (Figure 10) as separate units and to group the low yielding basalt aquifers together. The high yielding basalt aquifer will be referred to as Unit H and is only located in the northern sector. The medium yield basalt aquifer, also located in the northern sector will be referred to as Unit M. The other basalt aquifers are combined into one unit (Unit C) and differentiated by location as Unit C_{north} (northern sector) and Unit C_{south} (southern sector). The fractured rock aquifer of the basement Hodgkinson Formation (Unit B) is examined separately, as shown in the conceptual model in Figure 12. The limited supply from the fractured granite was not considered in the model. Water within weathered zones and clays near the ground surface were not included in water availability calculations as the water volumes outside of the wet season would be small and not allow extraction.

Due to the nature of volcanic flows, the various McLean Basalt flows are expected to have behaved typically, flowing from central vent/s down adjacent valleys and spreading across plains, infilling the valleys and depressions. The depth and properties of the flows would have depended on the viscosity of the material and speed of cooling. It was decided to use different methods to determine the volume of the rock for the aquifer units (Equations 1-3). The volume of saturated material is linked to the steepness of the bedrock contours and the spatial position of the groundwater table with respect to the basement contours. Determination of volume from the extrapolated basement contours was not undertaken as there is a scarcity of bore information and water level data and using the basement contour may induce further errors.

To overcome this lack of data it was assumed that the distribution of a basalt flow in an area of undulating topography was most likely to resemble either an infilled gully or prism. An area calculation would significantly overestimate the volume of basalt and therefore water contained, as the properties of a basalt flow vary with distance from the vent and is not of a constant depth throughout the area. The area method is the more accurate for the basement aquifers which are not contained to valleys. However from cross sections it can be seen that the basement aquifers do not appear to be continuous across the Study area due to metamorphic and intrusive processes and weathering, which will also lead to an overestimation. The determination of the volume of the McLean Basalt was an average of the infilled gully, area and prism shaped calculations. The underlying Hodgkinson Formation volume was determined by the area method only.

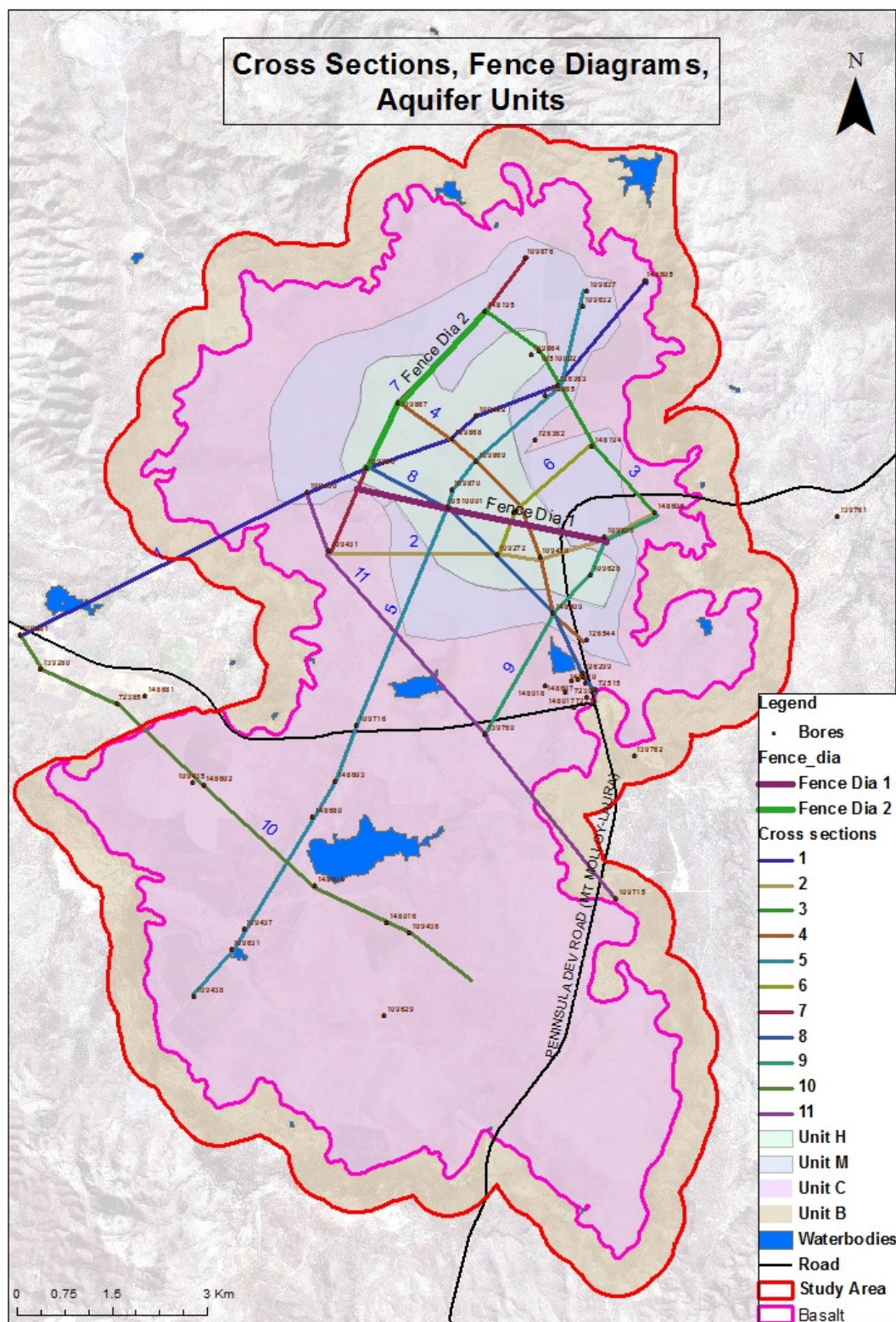


Figure 10 - Location of the cross sections and fence diagrams, including approximate coverage of the aquifer units.

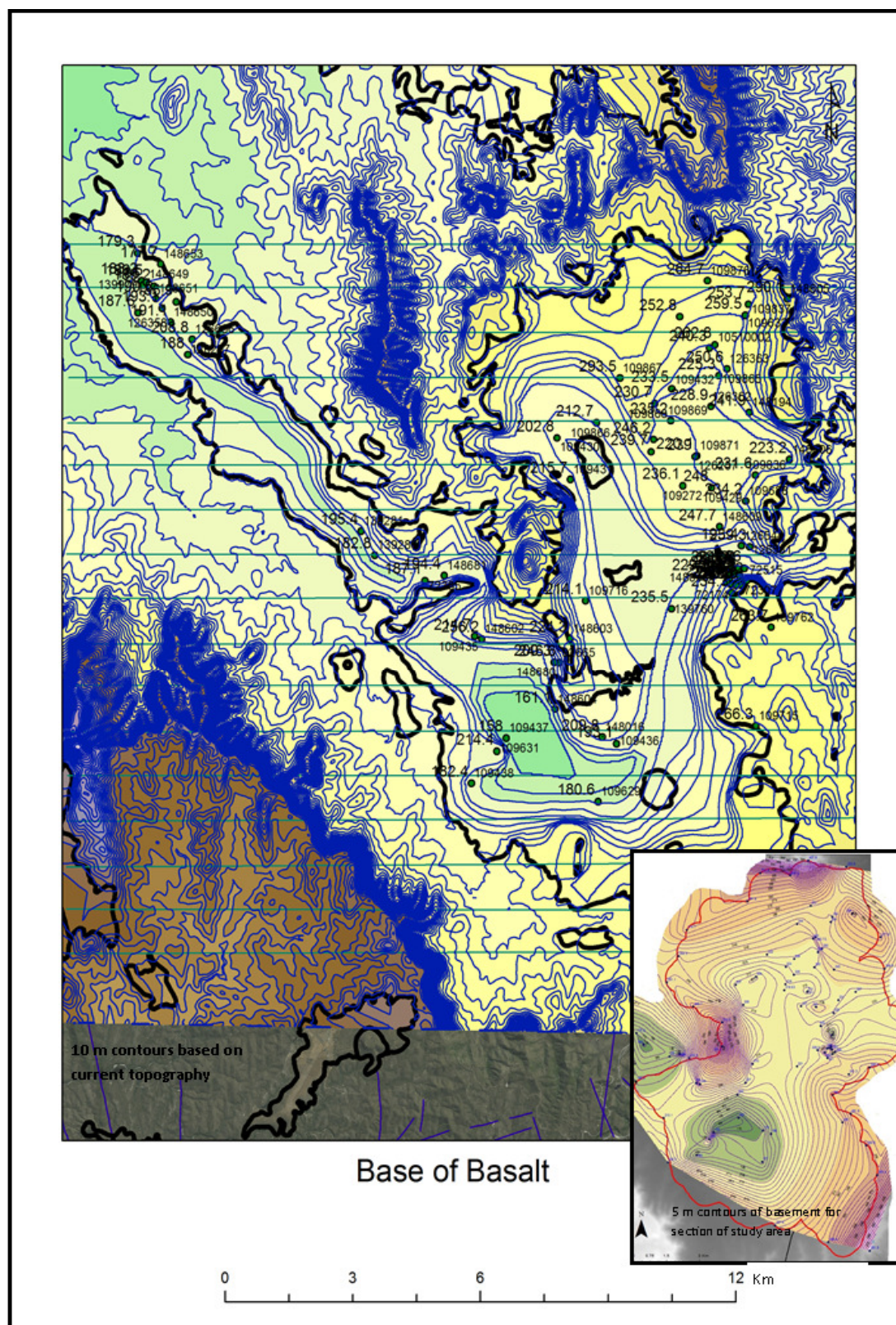


Figure 11 – Basement Contours

Contours based on current topography in 10 m elevation intervals. Horizontal lines (green) indicate locations of basement cross sections used to construct **Figure 17** and **Figure 18**. Insert section is schematic of 5 m contours for section of Study area based on bore log depth to basement.

On the assumption that the McLean Basalt behaves in a comparable manner to other similarly structured basalt systems that have been investigated, where aquifer properties are unknown, applicable researched values have been used. Basalt systems that are similar include the Atherton Basalt and Deccan Basalt amongst others. The Atherton Basalt, a tectonic interplate Tertiary olivine basalt, has a similar complex sequence of flows, strata variability, multiple vents, and aquifers. These features are compartmentalised by underlying bedrock topography providing perched, semi- confined and confined aquifer units. Secondary porosity is present due to faulting and weathering and provides regional recharge opportunities. The Atherton igneous activity occurred over a significantly larger area and some of the sub areas within the Atherton basalt have differing climatology to the McLean Basalt area.

Total rock volume calculations for the aquifers were based depending on the aquifer type as either:

- Area $V_r = A * D$ Equation 1
- Prism $V_r = (((L_b + W_b) + (L_t * W_t) + ((L_b + L_t) * (W_b + W_t))) * D) / 6$ Equation 2
- Gully $V_r = 0.22 * W_{max} * D_{max} * G$ Equation 3

Where V_r = volume of rock (m^3); A = area (m^2); D = average depth of aquifer unit in metres (m); D_{max} = maximum depth of aquifer (m); W_{max} = maximum width; L_b = length at bottom (m); L_t = length at top (m); W_b = width at bottom (m); W_t = width at top (m); $G = 1.2$ represents gully shape; and $1 m^3 = 1000 L$ (litres).

Each method used results in a different volume of rock, for example the volume of rock in the Unit H aquifer of the northern sector is $133 \times 10^6 m^3$ (area); $65.2 \times 10^6 m^3$ (prism); $80.8 \times 10^6 m^3$ (gully).

Water that is available from the storage (working storage W_s) was calculated using the following equations:

- From Storativity $W_s = V_r * S * 0.2 * 0.001$ megalitres (ML) Equation 4

- From Specific Yield $W_s = V_s * S_y * 0.001$ (ML) Equation 5

$$\text{where } V_s = V_r * n_1 \text{ (ML)} \quad \text{Equation 6}$$

Where V_s = saturated rock volume (m^3); S = storativity coefficient; n_1 is saturated porosity; S_y = specific yield; 0.2 represents retained water; W_s = water available from the aquifer (ML); and 0.001 is the conversion to ML.

Conceptual Model Schematic

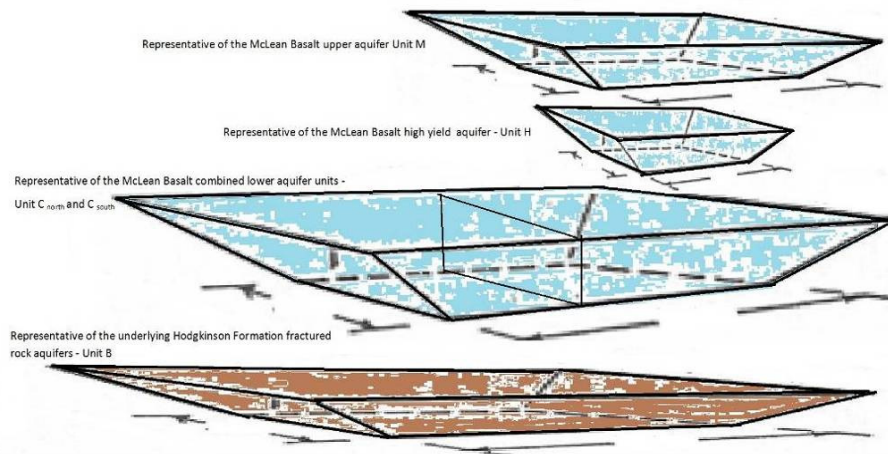


Figure 12 - Prism based conceptual model of the aquifer system

Bore locations and Loggers

There are 78 bores in the Lakeland Downs area with 73 bores having strata details (Figure 13). Not all of these bores are located within the Study area. Appendix 1 contains logs of these bores. Cross-sections constructed from bore data shows that not all beds are continuous across the basin and that they conform to the underlying basement topography (Figure 14 & Appendix 2).

There are 38 bores with known stratigraphy in the northern sector and 14 in the southern sector. The majority intercept more than one aquifer unit and five bores intercept both basaltic and basement rock types. There are six bores that target only the metamorphic sequences and one that is only in surface alluvium/colluvium near the town centre (RN72173). Granite, underlying basalt, is intercepted in one bore (RN109631) in the southern sector with water found within fractured quartz layers. The medium and high yielding basalt aquifers have only been identified in the northern sector (to the north and north east of the two unnamed vents) and have 23 bores intersecting them with nine bores intersecting both aquifers. Of the 23 bores, 14 also tap other low-yielding basalt aquifer units.

In the southern sector RN139760 intersects five vesicular and fractured basalt aquifer units within 32 m of the surface, although the combined supply rate is unknown. To the west of the Study area the majority of bores (13 of 18) access water from the metamorphic sequences. One bore intersects water from seven different thin broken slate units but the combined supply rate is only 20 L/s. There are five bores obtaining water from alluvial/colluvial sequences with two exclusively accessing water from the paleochannel sequences. To the east of the Study area the three bore logs indicate that there is limited basalt flow with only one bore intercepting basalt (RN109721) and the majority of the water coming from fractured siltstone and shale.

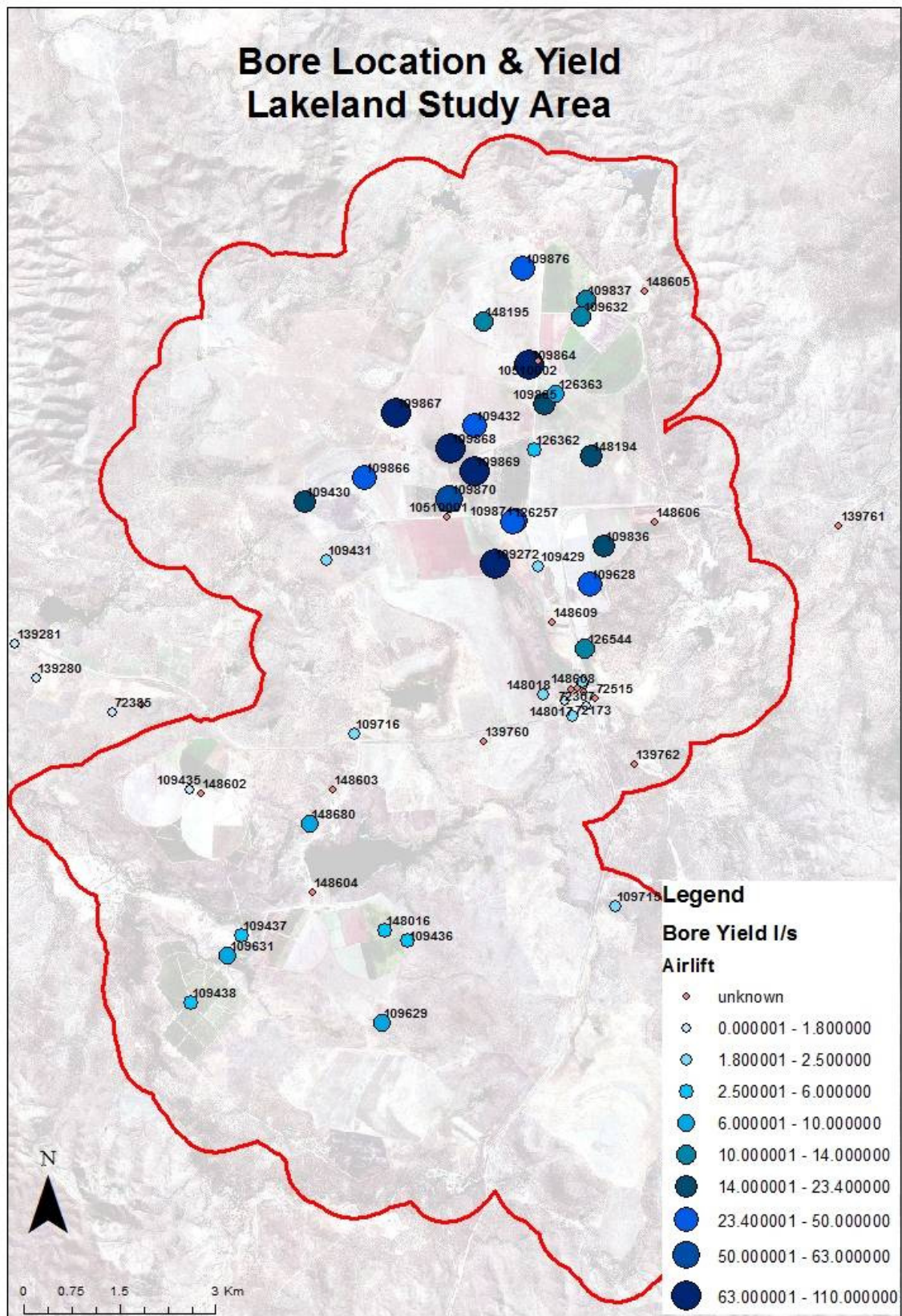
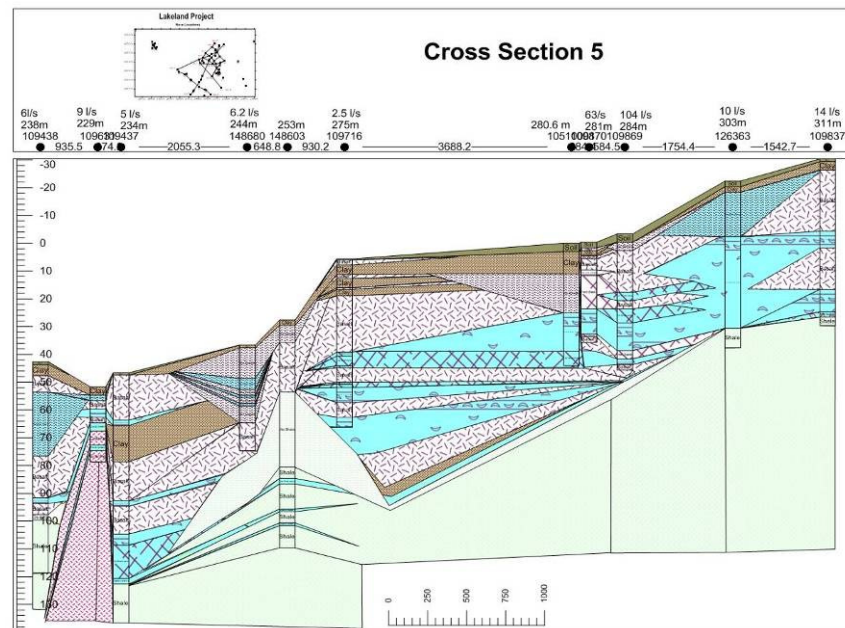
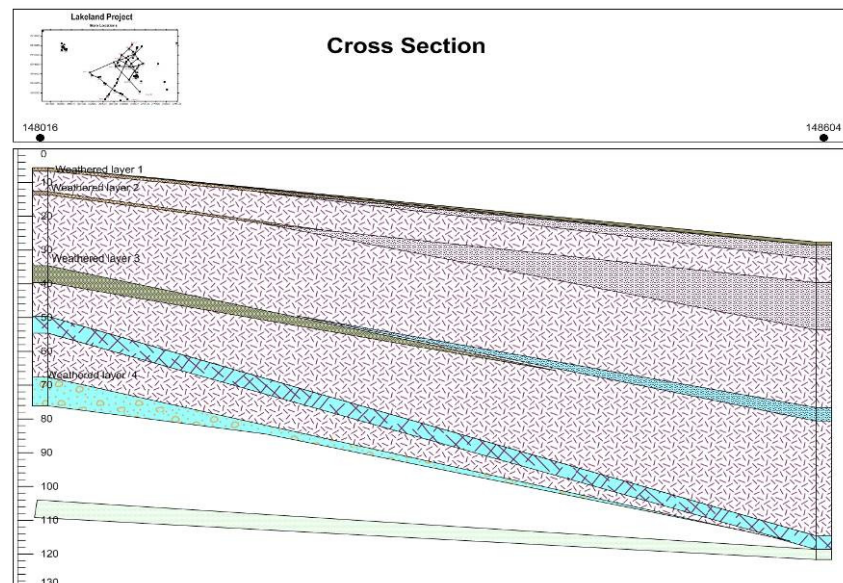


Figure 13 – Bore locations and known yields in L/s (litres per second)

During 2010, the Queensland Government installed two groundwater monitoring bores in the northern sector of the management area to gather data to assist in determination of aquifer sustainable yield. RN10510001 is located within Unit H and RN10510002 within the Unit M.



A



B

Figure 14 - Cross section samples

A: cross section 5 running from south to north through the Study area

B: cross section showing the weathered zones and unconformities within the basalt sequence

Key: colour represents different stratigraphy (i.e. Turquoise = contains water, brown = clay, maroon= basalt, green = shale, red = granite) and patterns depict differences in condition (i.e. weathered, fractured, vesicular), for example maroon cross hatching on turquoise is a fractured basalt aquifer. Further cross sections are located in [Appendix 2](#). A legend for the bore logs ([Appendix 1](#)) and cross sections ([Appendix 2](#)) is located in [Appendix 1](#).

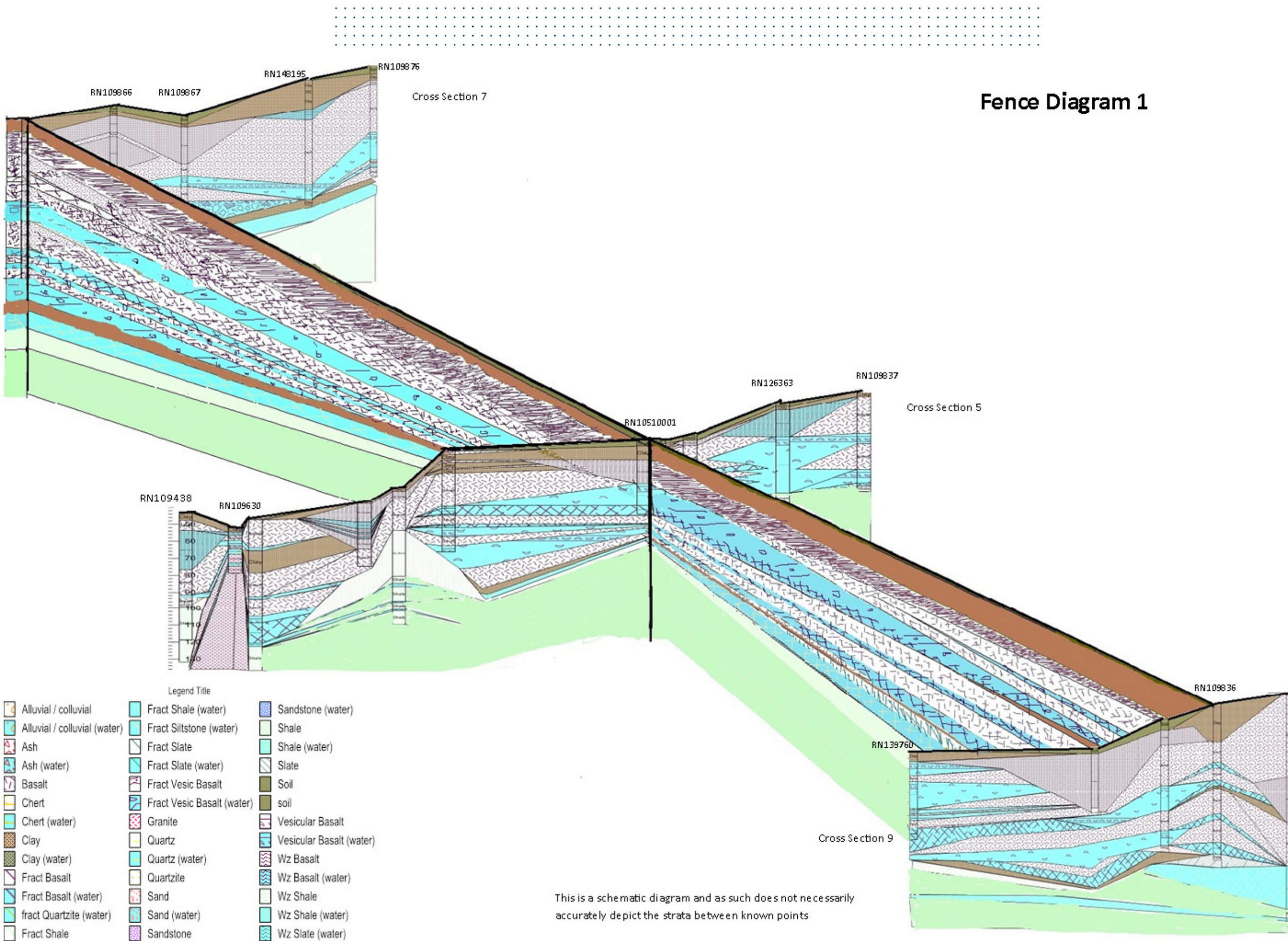


Figure 15 - Fence diagram 1

Fence Diagram 2

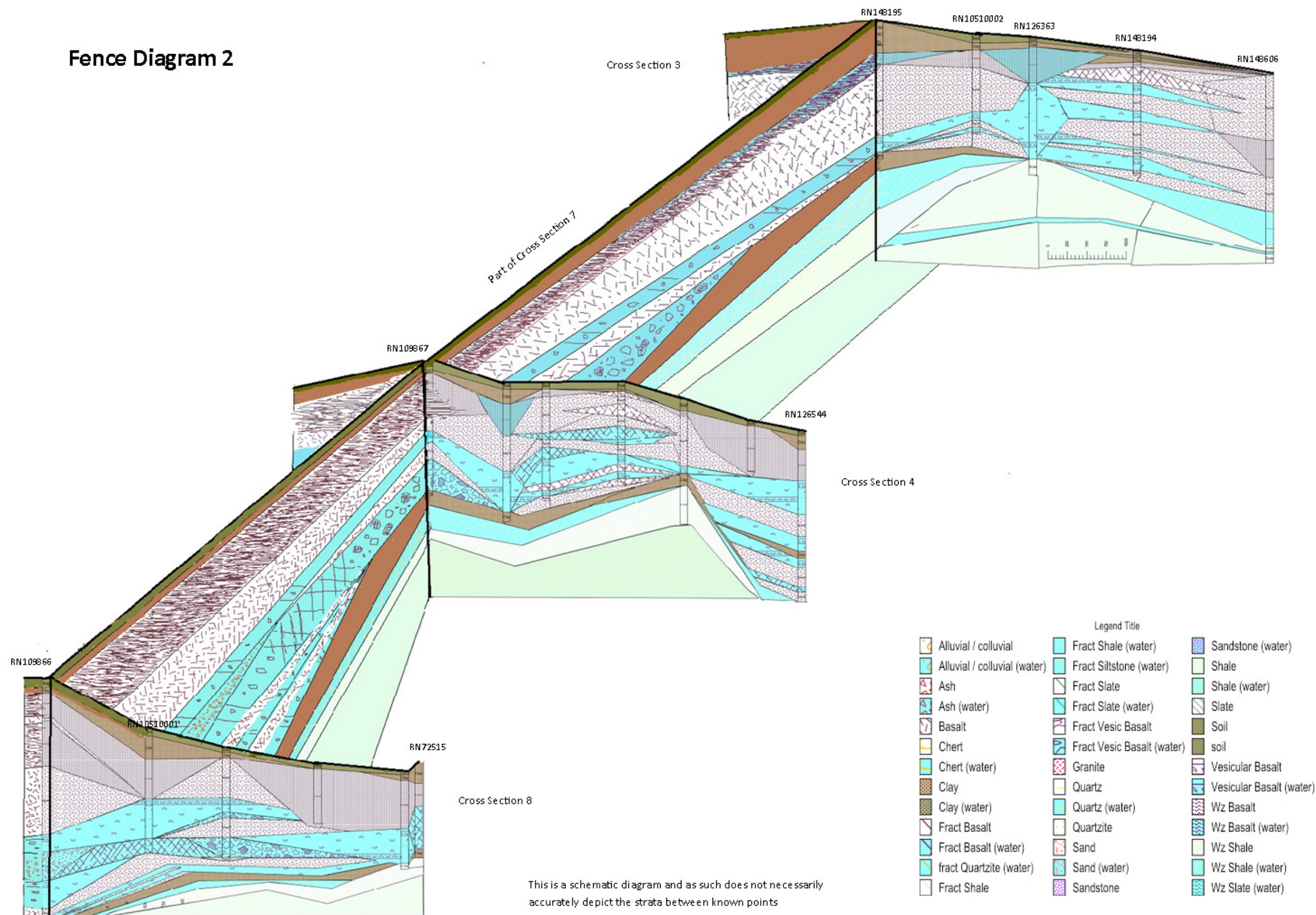


Figure 16 - Fence diagram 2

Aquifer characteristics

Aquifer Description

Globally, basalt aquifer systems commonly occur as interbedded lava flows with weathered and pyroclastic materials. There are three main structures for water movement and storage—vesicles, fractures/joints and interflow, the lateral movement of water through the vadose zone. Basalt aquifers frequently have secondary porosity associated with weathered zones, fractures, shear zones, joints and other discontinuities especially in tropical environments (Singhal & Gupta 1999). Weathered basalt, palaeosols and alluvial or colluvial sediments are also observed between lava flows (Bean 1999), as seen in Figure 14B. Groundwater can occur under perched, unconfined, semi-confined and confined conditions within basalt aquifer systems due to the occurrence of impervious formations such as dense basalt and ash beds, however regional hydraulic conductivity may also be present due to reactivation of pre-existing basement structures and localised recharge (Bean 1999).

Horizontal hydraulic conductivity is generally significantly larger than vertical hydraulic conductivity (Singhal & Gupta 1999) as seen in the Atherton Basalt where the basalt is very anisotropic with vertical flow considerably less than horizontal flow (Buck 1999). Interaction between the mineralogy of the basalt, overlying weathered zone, bedrock composition, porosity, permeability, thickness, bedrock composition, climate and topography determines the hydrogeochemistry of the groundwater (Locsey 2004).

There are numerous basalt aquifer units within the Study area most of limited extent both vertically and horizontally due to the underlying basement topography (Figure 14, Figure 15 and Figure 16). Aquifers within the Hodgkinson Formation and Whypalla Supersuite Granite tend to be thin fractured rock aquifers that have limited connectivity through fracture zones and surface expression.

Alluvium and Colluvium

The associated soils are predominantly grey-brown clayey loams. The thickness of the alluvial sequence decreases upstream and maximum depth varies depending on the extent of the watercourse. Sequences up to 20 m are present (RN72173). Water is typically found in sand and gravel sequences and can vary in quantity depending on the porosity, permeability and extent of the host material. Annual recharge is expected to occur in all the surface floodplains. Paleochannels present may contain trapped water or be in connection to other overlying aquifer units.

There are seven bores that penetrate water bearing alluvial/colluvial sequences at depth within the Lakeland Downs area. In two bores that contain sand and basalt aquifers, the total combined flow rates were 1.8 and 1.25 L/s indicating that there is little available water in the sequence. Only one bore (RN109871) to the west of the Study area indicates any significant supply rate from sand (20 L/s) and it is likely to be a limited extent paleochannel associated with the Laura River. Colluvial deposits intercepted in the bore logs contained less than 2 L/s on average. Surface alluvium was present in three bores; RN72173 had a supply rate of 2.2

L/s. The other two bores intersecting these deposits appear to contain no significant water (RN148017, RN72385).

McLean Basalt

The soils derived from the McLean Basalts tend to be red - brown structured clay soils. The thickness of the McLean Basalt sequence varies with the maximum depth registered in bore logs as 83 m. The actual thickness varies locally depending on the basement topography and proximity to individual volcanic vents (Figure 17 and Figure 18). Analysis of the different flows, based on the methodology for the development of a bedding conceptual model of Pearce (2001), indicates that the northern sector basalts appear to have originated from at least three unnamed vents, to the south-west (two vents) and north-west of the sector (one vent). Interfingering of the flow events has occurred and it is in this sector that the higher-yielding aquifers occur. Two higher-yielding aquifers overlap in places and are representative of different flow events. These consist of a shallower vesicular basalt (Unit M) and a deeper fractured vesicular basalt layer (Unit H) with the highest transmissivity observed in the deeper of these two aquifers (Figure 10 & Figure 16).

The basalts of the southern sector appear to have originated from Mt McLean and The Brothers to the south of the sector and the water bearing layers tend to be thin with low yields. Combined the low yield basalt aquifers have an average thickness of 15 m with individual unit thickness varying from <1 m to 21 m with the majority of beds <4 m.

Bean (1999) estimated the typical supply rate on the Atherton Tablelands for massive basalt as <2 L/s, vesicular basalt < 20-40 L/s and highly fractured vesicular basalt > 40 L/s, similar rates have been seen within the McLean Basalt. Based on bore airlift supply rates at time of construction, the highest yielding aquifer (Unit H) has a supply rate ranging from 5–100 L/s and averaging 42 L/s, the shallower medium yield aquifer (unit M) ranges from 4–50 L/s averaging 17 L/s and the combined low yield aquifer units (Unit C) have flow rates ranging from 0.06–10 L/s averaging 2.7 L/s.

Granite

Various granites and granodiorites are present in the region, frequently intruding the Hodgkinson Formation. Soils derived from the granites tend to be red and grey clay and loams. Water is contained within weathered margins and fractured rock bands. The quantity of water varies significantly depending on the medium, but tends to be poor. Granite was seen in two bores (RN109436, RN109631) in the southern sector and is expected to be associated with the same intrusive process. RN109436 is located near the edge of the intrusion and RN109631 is closer to the surface being intersected at 85 m and 16 m respectively. RN148016 located between these bores contains a colluvial layer containing quartz, granite and basalt material at 64 m supporting the conclusion that the intrusion is underlying the area. Water was only intersected in one of these bores within fractured quartz veins that had an airlift rate at construction of <3 L/s (RN109631). The limited lateral extent of the aquifer units within the granite intrusion reduces the availability of water within the aquifers and it is unlikely to have much potential for further extraction. As there is no surface expression of this intrusion and there is massive basalt with limited porosity overlying the

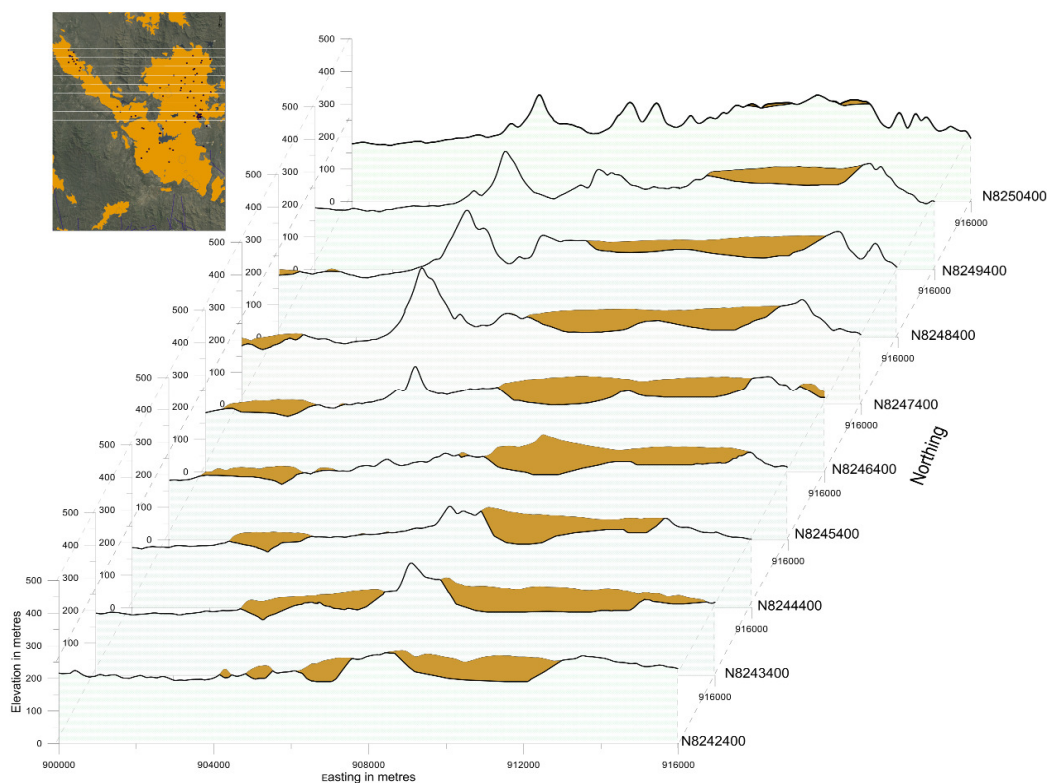


Figure 17 - West to east natural surface profiles showing simplified extent of Basalt within the Northern Section of the Study Area

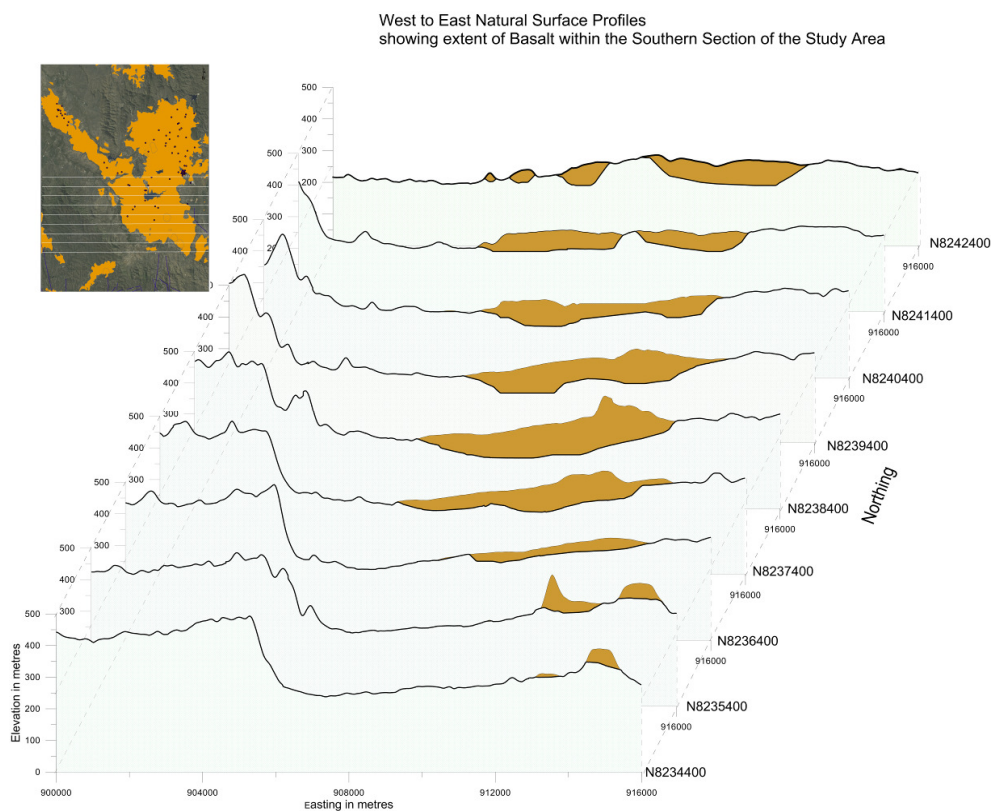


Figure 18 - West to east natural surface profiles showing simplified extent of basalt within the southern section of the study area

granite then recharge must be due to hydraulic connectivity to overlying/adjacent strata or the water contained within these beds is old and of limited life.

Hodgkinson Formation

Soils derived from this formation include brown-reddish brown friable loam and grey, yellow and white clayey loams. Aquifers within the Hodgkinson Formation tend to occur within fractured rock and can be an important source of rural residential and stock groundwater supplies. The fractured rock aquifers generally have secondary porosity, may be hydraulically disjointed and can be difficult to analyse. The fault breccia can be porous and permeable and groundwater can accumulate within it. The mechanism for recharge is by direct infiltration of rainfall. Recharge to fractured zones in the Hodgkinson Formation will be rapid in areas where open cleavage partings persist to depth with the maximum opportunity for recharge to these aquifers occurring where cleavage partings are exposed in ephemeral streams that flow during the wet season. Significant groundwater supplies are usually obtained from the Hodgkinson Formation at relatively shallow depths. Below about 60 m bedding surfaces and cleavage partings are usually closed and there is a marked reduction in porosity and permeability. Bores drilled to depths of approximately 50 m deliver supplies of 4 L/s to 7 L/s. While chemically suitable for all purposes, the groundwater from the Hodgkinson Formation sometimes has higher than the recommended levels of dissolved iron. Exceptional bores drilled into the Hodgkinson Formation obtain supplies in excess of 20 L/s. These bores are located at the intersections of geological fractures (AGE 2007).

Supply rates from the Hodgkinson Formation along the east coast tend to be <10 L/s. Overall the rate averaged 2.7 L/s with the majority of known water bearing beds yielding <1 L/s within the Study area. It is considered that there is limited opportunity for further development of this aquifer sequence within the Study area.

Unit Descriptions

For the analysis the main basalt aquifers have been identified by examination of the bore data in particular the yield rate at time of construction, depth and known properties. It was determined that there were two main water bearing layers within the northern sector (Figure 10). Additionally up to 6 water bearing layers with low yields are also present in bore logs. These have been grouped together into one unit. The units are defined as:

Unit H

Unit H is the highest yielding aquifer with supply rates between 5–100 L/s. The average thickness of the Unit H, as determined from bore logs, is 12.5 m with a maximum thickness of 17 m. Unit H is only found in a limited area of the northern sector (Figure 10) to the north and north west of the unnamed vents.

Unit M

The Unit M has an average thickness of 12.6 m with a maximum thickness of 34 m. The yield at bore construction ranges from 4–50 L/s averaging 17 L/s. Unit M is the shallower of the two main aquifers in the northern sector (Figure 10) and overlies Unit H in a restricted area.

Unit C

Consists of the low yielding basalt aquifers contained within the study area and is bisected by the Peninsula Development Road into two sub-units depending on sector (C_{north} and C_{south}) (Figure 10).

Unit C_{north}

The low yielding basalt aquifers in the northern sector have been combined into this unit. Individually the thickness of the beds range from 0.6-17 m with a combined thickness seen in bore logs of 2-24 m. Up to 3 separate beds are present at some locations.

Unit C_{south}

The low yielding basalt aquifers in the southern sector have been combined into this unit. Individually the thickness of the beds range from 1-23 m with a combined thickness seen in bore logs of 2-35 m. Up to 6 separate beds are present at some locations.

Unit B

This unit consists of the combined water bearing beds of the basement rocks of the Hodgkinson Formation.

Figure 11 shows the derived contours of the basement unit. The thickness of the combined bed ranges from 2–54 m with an average of 16 m. To the north the combined thickness of the beds ranges from 8-54 m and in the south from 2-36 m. Individually the majority of the beds are < 8 m with one bed located in the north having a thickness of 50 m and in the south 30 m. Supply rates tend to be <2.7 L/s, with the majority of beds yielding <1 L/s.

Aquifer Properties

The succession of volcanic activity that initiated the McLean Basalt is likely to have created changes in landscape evolution with ponding in basement depressions creating massive flows, and thinner flows associated with intermittent activity. Further complicating the flow layering is the presence of multiple vents all interacting within the same basin over time causing interfingering of flows where they intersect drainage features and depressions. The underlying topography has caused a compartmenting of some of the deeper basalt aquifer units. The number and nature of the volcanic events has created a complex basalt aquifer sequence in the Study area. The fence diagrams (Figure 15 and Figure 16) modelling the northern aspect of the Study area from two different directions intersecting near RN109866, indicate the complexity of the issue where Unit H is seen to taper off prior to cross-section three (Figure 16). The presence of multiple aquifers within the basalt of various consistency, extent and yield indicates a high level of heterogeneity. This heterogeneity complicates the assessment of the aquifers. Significant differences in supply rates across the different aquifers indicate that the aquifers are anisotropic.

A lack of water level and pump test data throughout the Study area hampers the determination of connectivity and storativity for the different aquifer units. Pump tests undertaken were mainly from multi-slotted bores intersecting at least two aquifers reducing

the usefulness of the data for interpreting properties of individual beds. Water level and pump test data are located in [Appendix 4](#).

Faulting associated with the Palmer Fault and splinter faults are also expected to have changed flow pathways within the basalts and underlying basement material. Evidence of faulting can be seen in [Figure 9](#). Fracturing can also be due to localised pressure on existing bedding during eruptive phases or pressure from overburden. The fracturing could result in zones of increased secondary porosity through the strata. The faulting/fracturing provides an opportunity for hydraulic connection and localised recharge within the infilled basement depressions. Fracturing of the vesicular basalt is likely to contribute to the high transmissivity in Unit H.

Cross sections through Bore logs indicate that some of the fractured beds described were isolated to one layer only, reducing possibility of secondary porosity increasing vertically ([Figure 15 and Figure 16](#)). Water movement through some beds may be due to water pooling in cooling joints rather than fault or pressure induced fracturing.

A consequence of the differences between boundary conditions of the various basalt aquifer units would mean that in localised areas (compartments) there will be from high to low hydraulic connection between the aquifers. Some aquifers act as a single unit, while other more confined aquifers present little chance of recharge. The Unit M is seen to be more continuous across the northern sector and the lower yielding aquifers (Unit C) of various thicknesses are located within dips in the basement topography. Bed thickness also varies as does composition and associated porosity of the flows, changing water storage capacity within an aquifer. There appears to be limited hydraulic interconnection of water bearing beds. Aquifers are frequently separated by thick massive basalt and clay layers which would limit water movement between aquifers except in fracture zones and edges of underlying and exposed basement.

Hydraulic connectivity between the basement aquifers and lower basalt aquifer layers is seen to be present in bore logs but the extent of the interconnectivity cannot be measured at this time ([Cross sections 1, 4, 5, 8 in Appendix 2](#)). Locally, the complexity of the inferred stratigraphy could indicate that there could be confined, semi-confined and unconfined aquifer units present in the Study area, with the majority probably semi-confined.

Groundwater is also found in alluvium and colluvium sequences at the basement interface and within the basalt sequences as paleochannels; within the weathered basement layer; in fractured intrusives (granite); and fractured basement rock layers.

While environmental tracers can be used to determine aquifer recharge no data were available for the McLean Basalts. The complexity of the aquifer system, high spatial variability of transmissivity and intermittency of the seasonal rainfall has limited the ability to identify the recharge for individual aquifer units. Typically infiltration through basalt derived soils is high and this could readily recharge the unsaturated zones and have a delayed infiltration to the lower aquifers.

Water level data

Two department owned monitoring bores (RN10510001 and RN10510002) exist in the McLean Basalt. These bores were constructed in November 2010 and have limited manual water level data.

A logger was installed in RN10510001 which is located in Unit H during December 2010. Data obtained shows the influence of a nearby pump (Figure 19). The overall trend is a decrease in water level during the dry season (May 2011 to December 2011), followed by a period of limited recharge (or a decrease in pumping) from January 2012 to May 2012 when water levels remained static. This is followed by a decrease in water levels from May 2012 to September 2012. It is likely that pumping increased during the dry periods. It is difficult to draw any conclusions from this as the 2011/2012 wet season was below average in the Lakeland area so little lateral recharge would have been available.

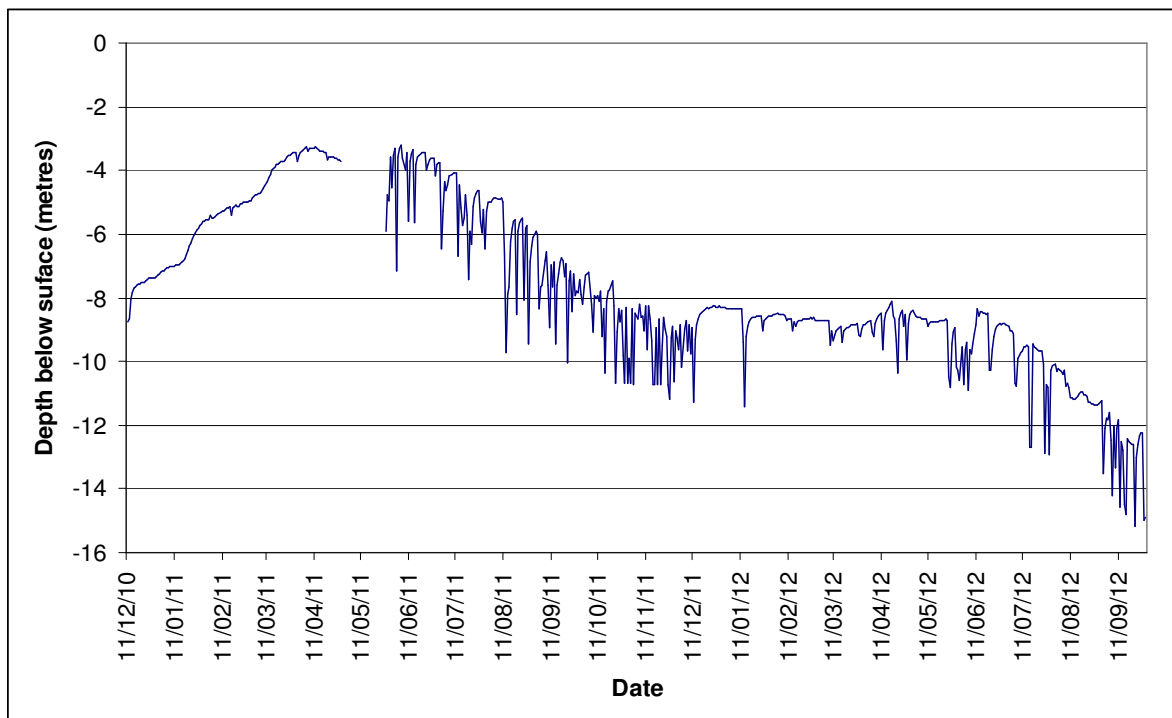


Figure 19 – Logged water level data for RN10510001

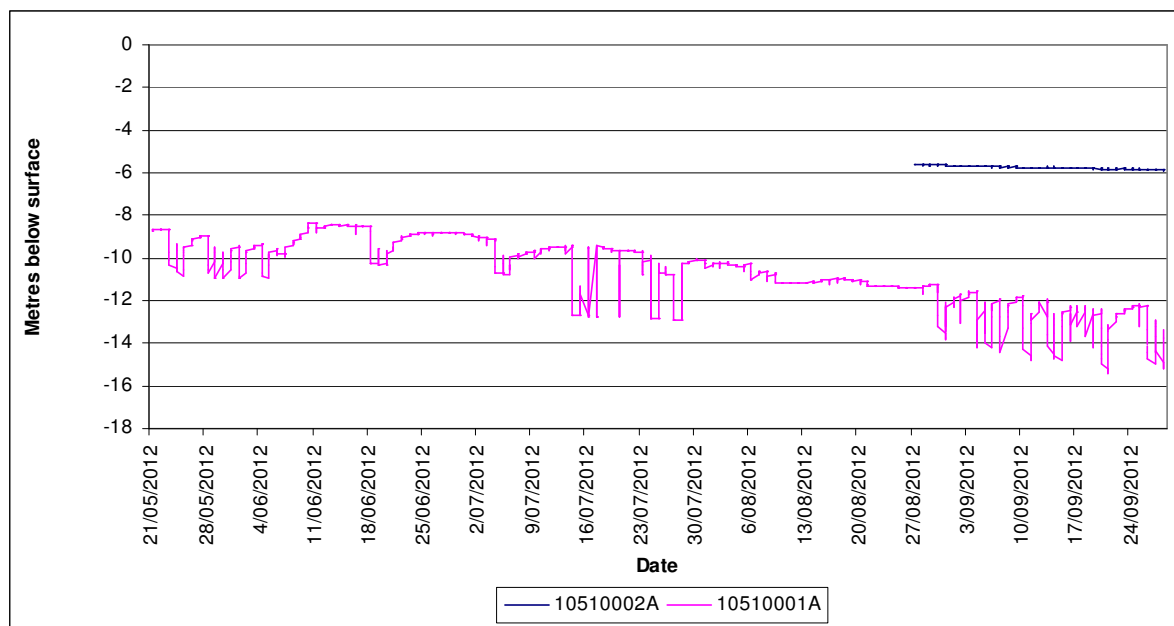


Figure 20 – Logged groundwater levels for monitoring bores RN1051001A and RN10510002A from May 2012 to September 2012

A logger was installed in RN10510002 (Figure 20) located within Unit M during August 2012. From Figure 20 it can be seen that the water level in RN10510002A behaves very differently to that of RN10510001A. Water levels in RN10510002A showed a steady decline over the period of measurement, but showed minimal daily variation. Whereas the water level in RN10510001A also showed an overall decline, but up to 2 metres variation in water level was observed on some days. The variation in water level does not occur on a daily basis, therefore it is likely that the significant drop in water level is due to nearby pumping. The two monitoring bores are located approximately 3 km apart and are likely to be located in different unconnected aquifer units.

A bore with water level data (RN 72173) also targets the Hodgkinson Formation in the Study area (Figure 21). Water levels recorded between November 1988 and February 1991 show a general trend to recharge during the wet season and drawdown of the aquifer during the dry season.

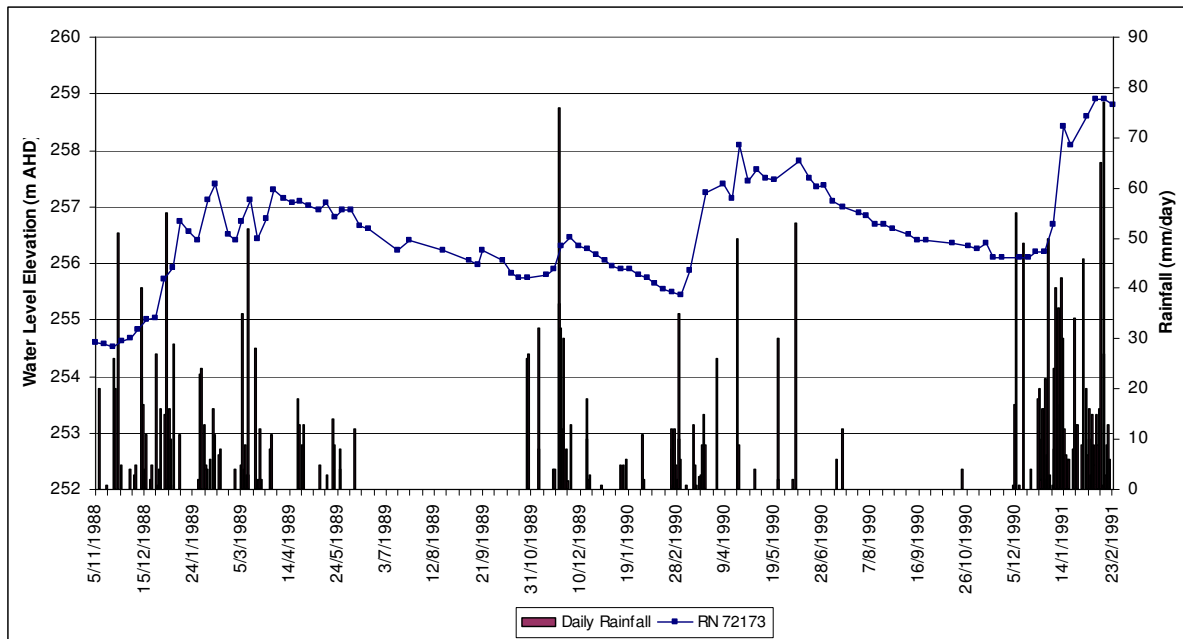


Figure 21 - Groundwater levels for RN72173 from 1988–1991

Standing water level was also measured in 63 production bores at the time of drilling. These water level measurements were taken between 1987 and 2010. As can be seen in [Figure 22](#), in the north eastern area, water levels range from 1 to 5 m below the surface. One of the bores located in this area, RN 109272, was subartesian at the time of drilling in 2003, but became artesian at an estimated flow rate of 2 to 5 L/s in approximately 2008. This coincides with above average rainfall as can be seen in [Figure 5](#). The bore was capped in June 2009 ([Plate 1](#)). This bore intercepted both Unit M and Unit H therefore it is difficult to determine the contribution of each aquifer.

Limited water level data is available for the north western area, but in general, water levels are much deeper ranging from 12 to 24.5 m below the surface. In the southern area, limited water level data has also been collected. Water levels in this area range from 0.1 to 26 metres below the surface.

Based on these water level measurements, the regional flow of groundwater runs generally in a southerly direction. A more detailed analysis could not be undertaken as the water levels were measured at different times and are from different aquifers.

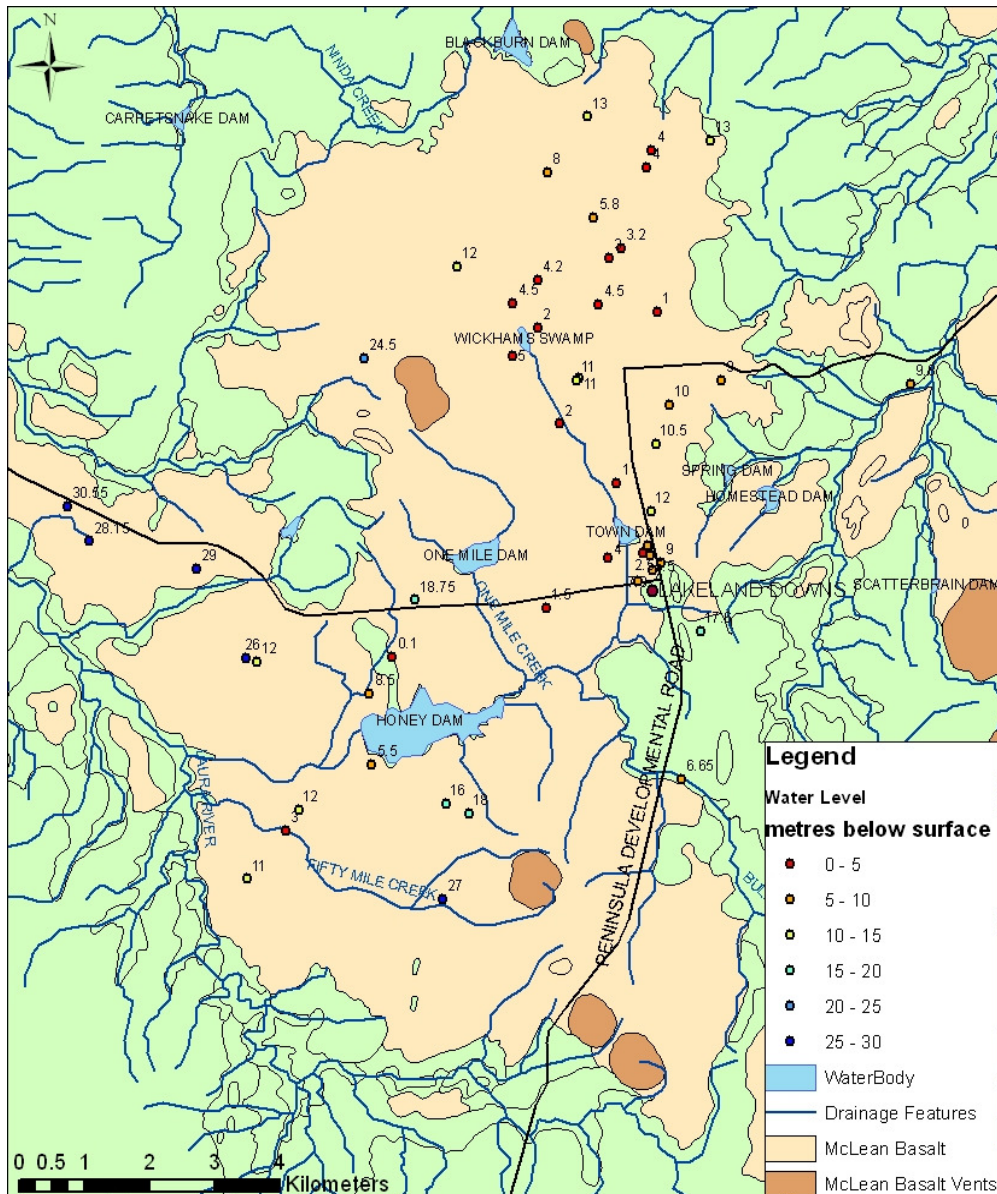


Plate 1 -RN109272, June 2009

Water Quality

Four water samples have been collected in the Lakeland area and analysed for major ions. These monitoring bores are identified as RN72173, RN92665, RN10510001 and RN10510002. The location of these monitoring bores can be seen in [Figure 1](#). The water quality analysis data was checked for accuracy using the following equation:

$$\text{Electrical Balance (E.B., \%)} = \frac{(\text{Sum of cations} + \text{Sum of anions})}{(\text{Sum of cations} - \text{Sum of anions})} \times 100 \quad \text{Equation 7}$$

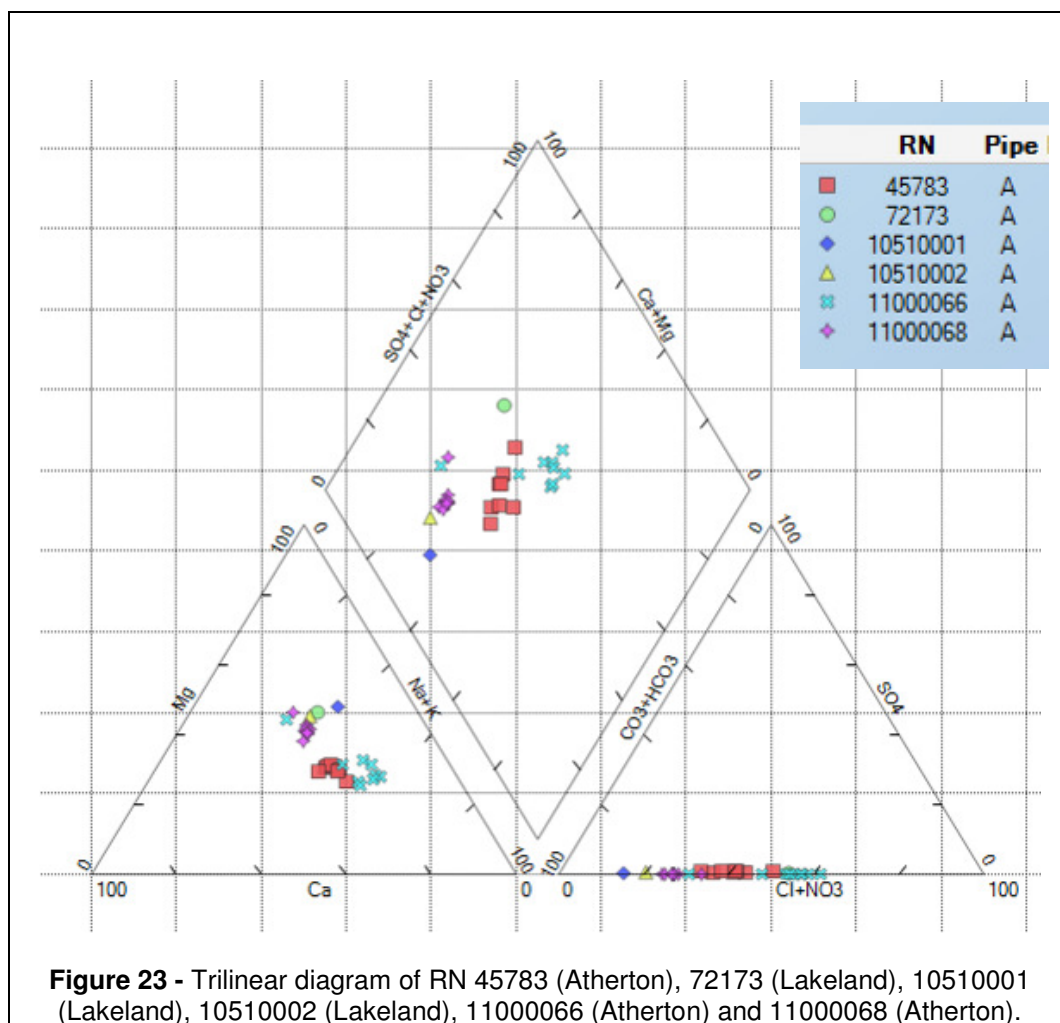
An analysis collected from spring water at RN92665 has an electrical balance of 3% and was therefore discarded. All of the other samples have an electrical balance of less than 1%. Electrical balance percentages can be found in [Appendix 3](#) along with the parameters measured as part of the monitoring program.

Water sampled from RN72173 is approximately 30 mg/L higher in sodium and 260 mg/L higher in chloride than other water sampled in the Lakeland area. The drill log for this bore states that the bore takes water from shale underlying basalt. Typically in this area, underlying metamorphic rocks are of marine origin which can result in groundwater's with elevated sodium and chloride levels compared to those in basalts.

The drill log of RN10510001, indicates that samples collected from this piezometer are located in honeycomb basalt and fractured basalt, whereas RN10510002 is located in honeycomb basalt and basalt. As can be seen in [Figure 23](#), samples analysed from these two piezometers in the Study area have a similar chemical composition to RN1100068 which is also located in honeycomb basalt on the Atherton Tablelands.

For the Atherton Tablelands basalt, [Locsey and Cox \(2000\)](#) developed a rating-based classification scheme to identify 'upper-', 'mid-' and 'lower-flow' position groundwater. The results of this hydrochemical classification scheme correspond well with water level response to recharge events. This classification scheme is based on five key indicators of the chemical evolution of basalt-hosted groundwater (i.e. $\text{Mg}^{2+}/\text{Cl}^-$, $\text{HCO}_3^- + \text{CO}_3^{2-}/\text{Sum Cations}$, $\text{HCO}_3^-/\text{Cl}^-$, H_4SiO_4 concentration and the percentage of $\text{HCO}_3^- + \text{CO}_3^{2-}$ of major anions). The final 'Class' equals the sum of the five weighted ratings within a range of 0–3. The lower end of this range represents an 'upper-flow' position and a shorter residence time, while the upper end of this range represents a 'lower-flow' position and a longer residence time. [Locsey and Cox \(2000\)](#) state that the findings of this research project are applicable to other basalt groundwater systems, particularly those in high rainfall areas, therefore this classification scheme was used to estimate residence time for groundwater in the Lakeland area.

Water samples collected from RN10510001 and RN10510002 in the Mclean Basalt were not analysed for silicic acid (H_4SiO_4), therefore the samples were classified using the 'Method B weighting' as outlined in [Locsey and Cox \(2000\)](#). The sample taken from RN10510001 falls into the class 2 – 2.58 and the sample taken from 10510002 falls into class 1.38 – 2.



It is likely that water sampled from the Mclean Basalt in the Lakeland area has a medium to long residence time, with groundwater in RN10510002 having a lesser residence time than groundwater in RN10510001. Groundwater in RN10510001 may be older than RN10510002 due to RN10510001 taking water from honeycomb basalt and fractured basalt. It is probable that water in the fractured basalt is older than that in the honeycomb basalt due to the fractured basalt having a lower transmissivity.

The chemical composition of both samples from Lakeland (RN10510001 and RN10510002) is very similar to that of RN11000068 (Figure 23) which was classified by [Locsey and Cox \(2000\)](#) to be a mid-level flow in Atherton. RN45783 and RN11000066 were classified by [Locsey and Cox \(2000\)](#) as being in an upper-flow position and therefore having a lower residence time. Figure 23 shows how the chemical composition of these two piezometers differs from that in Lakeland.

The actual age of the groundwater in the McLean Basalt is unknown. The age of the groundwater in the Atherton Basalt was estimated by the use of chemistry ([Locsey and Cox 2000](#); [Herczeg 2001](#); [Cook et al. 2001](#)) and ranged from 5 to 120 years. The current lack of data makes it difficult to quantify the age of groundwater in Lakeland based on these studies.

Aquifer Recharge

Recharge is defined as the net volume of water that infiltrates to the saturated groundwater system from surface sources (e.g. rainfall, streamflow) and sources in the unsaturated soil zone (e.g. reticulation, leakage etc.). Factors influencing groundwater recharge include topography, land use and vegetation cover, existing soil moisture and the ability of the recharge beds and aquifer materials to capture and transmit water. Estimating recharge in irrigated areas is difficult due to the numerous land and water management decisions that take place at the paddock scale such as irrigation technology, irrigation timing and application of soil ameliorants to change infiltration characteristics.

In Lakeland, potential recharge sources include streamflow infiltration, irrigation, lateral inflow and rainfall. Of these, rainfall is the largest potential recharge source. Recharge is likely to occur when there is an excess of rainfall over evapotranspiration and there is no soil moisture deficit. As can be seen in [Figure 8](#), this is likely to occur in the months of January to March. This is supported by [Figure 24](#), however additional data is needed to confirm that the rise in water level is due to recharge resulting from rainfall and not due to a lack of pumping or the lateral flow of groundwater.

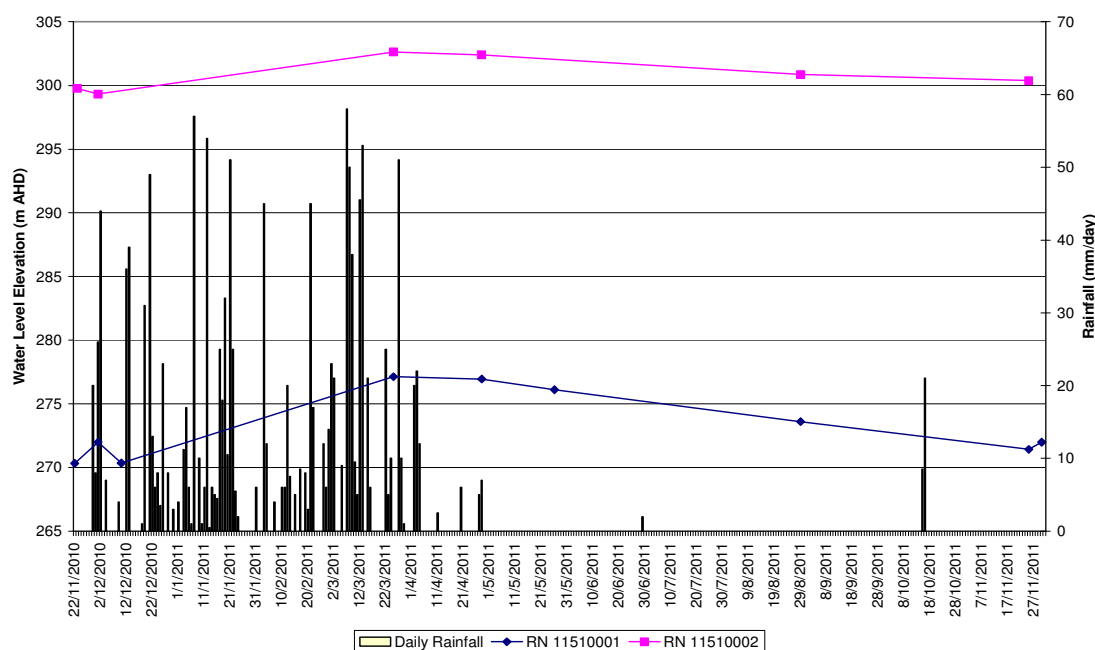


Figure 24 – Manually measured water level elevation at RN 11510001 and 11510002 and daily rainfall at Maitland Downs Station

A detailed investigation of recharge has not been undertaken in the Study area. [AGE \(2006\)](#) estimated that the primary basalt flow, would receive approximately 2000 ML of recharge for median wet season rainfall. This figure was calculated using an infiltration rate of 5% and a median rainfall of 697 mm. As of September 2012 the median annual rainfall at the Maitland Downs weather station is 922 mm/year. Therefore, using an infiltration rate of 5% and a median rainfall of 922 mm/year, estimated median annual recharge north of the Peninsula Road is 2380 ML/year (based on an area of 51.7 km²), while south of the Peninsula Road (based on an area of 49 km²), estimated median annual recharge equates to 2250 ML/year.

Chloride mass balance

The mean annual recharge rate can be estimated from the mass balance of chloride using:

$$C_P (P - S) = C_R R \quad \text{Equation 8}$$

Where C_P and C_R are the chloride concentrations of precipitation and groundwater respectively, and P , S and R are the mean annual rates of precipitation, surface runoff and recharge (Eriksson & Khunakasem, 1969). The assumptions associated with this method include:

1. The chloride in the groundwater originates from precipitation (not rock weathering or halite dissolution).
2. The chloride imported or exported via runoff or runoff can be accounted for.
3. The chloride is conservative in the system.
4. The chloride deposition rate has not changed over time (Leaney *et al.* 2011).

Weathering of basaltic minerals produces negligible chloride because of the absence of chloride bearing salts, and the very low chloride concentrations in rock forming minerals (~150 ppm for basalts) (Cook *et al* 2001). It is assumed that the groundwater chloride concentration originates solely from precipitation.

In the Atherton Tablelands Cook *et al* (2001) estimated the mean annual surface runoff to be 150 mm. This is similar to that estimated by North Australian Water Strategies (2010) (NAWS) for the catchment area of Honey Dam. Therefore, 150 mm will be used as the mean annual surface water runoff in the chloride mass balance calculation.

Vegetation is generally very efficient at excluding chloride from water up take from the soil and so any loss through vegetation is negligible. In most cases chloride does not interact geochemically with the soil, and there are usually no sources or sinks within the soil (Leaney *et al* 2011). It can be assumed that chloride is a conservative tracer.

Chloride deposition has not been directly measured in the Lakeland area. However, Davies (2011) interpolated observational chloride in rainfall data to form a gridded data set for Australia. The mean chloride concentration in precipitation in the Lakeland area is estimated to be 2.2 mg/L based on the gridded data set. This is compared to the mean chloride concentration of groundwater in the basalt aquifer which is 28.5 mg/L (calculated from RN 10510002 and 10510001).

Assuming a mean annual rainfall of 937 mm, results in a mean annual recharge of 61 mm/year. This equates to an estimate of 3150 ML/year of recharge in the area north of the Peninsula Road and 2990 ML/year of recharge in the area south of the Peninsula Road. However, it should be noted that only two groundwater samples have been analysed for chloride in the Lakeland area, therefore they may not be representative for the entire aquifer system. Chloride deposition has also been interpolated from a sparse dataset and could range from 1.6 mg/L to 3 mg/L.

Comparison with other recharge estimates

Crosbie *et al* (2009) estimated recharge in a non-irrigated area of Laura to be 35 mm/year using the steady-state chloride mass balance of groundwater method. Laura is located approximately 55 km north west of Lakeland and has a mean annual rainfall of 959 mm which is similar to that of Lakeland, rainfall distribution and other climate factors are also similar, however soil type and land use differs. It is likely that recharge in the Lakeland area is higher than that of Laura due to it being an irrigated area. Other estimates made by Crosbie *et al* (2009) in non-irrigated, inland Cape York Peninsula, range from 7 mm/year to 47 mm/year. However, Crosbie *et al* (2009) states that there is very little quality control on all of these estimates.

Recharge was also measured in the irrigated area of the Atherton Tablelands basalt by Cook *et al* (2001). This study used a combination of tracer techniques, chlorofluorocarbon-11, chlorofluorocarbon-12, ^{14}C , $\delta^{18}\text{O}$ (oxygen-18), $\delta^2\text{H}$ (deuterium), temperature and major ion analyses. It was found that recharge rates decrease towards the north from approximately 440–660 mm/year (22–33% of rainfall) near Malanda, to 300–450 mm/year (15–23% of rainfall) south of Atherton, and 150–225 mm/year (11–16% rainfall) in the Atherton/Tolga/Kairi area. Although both Lakeland and Atherton are basalt aquifers located in north Queensland, these recharge estimates may not be indicative for Lakeland as it has a more distinct ‘wet season’ compared to that of Atherton. It is likely that recharge at Lakeland is less than recharge in Atherton.

Therefore, a potential annual recharge rate of about 60 mm/year, or 6–7% of average annual rainfall seems plausible for the McLean Basalt. It is important to note that actual groundwater recharge will vary spatially and temporally with soils, climate, vegetation and aquifer properties. For example, recharge to deeper basalt aquifers may be limited by the capacity of the overlying aquifers to capture and transmit water.

Recharge to the Hodgkinson Formation

Owing to its geological structure, the fractures within the Hodgkinson Formation are capable of receiving leakage from the overlying basalt aquifer where hydraulic connectivity and hydraulic gradients exists. Recharge from the Hodgkinson Formation to the overlying/adjacent basalt units may also occur where connectivity of aquifer units and hydraulic gradients are present.

Discharge

Evapotranspiration

Evapotranspiration (ET) is the loss of water through evaporation or vegetative use (transpiration) in the near surface environment. In some catchments in Australia, which are often relatively flat and with very low hydraulic gradient, the water table may come relatively close to the ground surface at many locations throughout the catchment (Evans 2007).

Evans (2007) states that ET from the groundwater table is approximately 5–10% of the actual ET as described in the Climatic Atlas of Australia — Evapotranspiration. The actual ET includes ET from the land surface and the unsaturated zone. Areal actual ET is defined

by the [Bureau of Meteorology \(2012a\)](#) as the ET that actually takes place, under the condition of existing water supply, from an area so large that the effects of any upwind boundary transitions are negligible and local variations are integrated to an areal average.

The annual average areal actual ET for the Lakeland area ranges between 800 mm and 900 mm ([Bureau of Meteorology 2012a](#)). Therefore, evapotranspiration in the northern area may range from 21–46 ML, and 20–44 ML in the southern area.

Groundwater Extraction

Groundwater extraction refers to groundwater removed from the aquifer by the pumping of bores and wells. The Lakeland area is located within the Cook Subartesian Area in which licences for groundwater are required for all purposes other than stock and domestic. As of October 2012, 2438 ML of groundwater had been allocated from the Study area. The majority of the licences are within the northern sector.

Additional water may be taken from the McLean Basalt for stock and domestic purposes. Assuming a total of fifteen households who have installed a bore and are using groundwater, equates to a total of 30 ML (based on 2 ML/household). Therefore, an estimate of groundwater extraction from the study area equates to around 2468 ML per year. A more precise estimate of groundwater extraction is unable to be made as there are no meters with long term data.

Spring Discharge and Baseflow

Spring and discharge areas have been identified in the study area by aerial photography and examination of standing water level and topography intersections ([Figure 25](#)). Springs are known to be associated with various dams in the Study area and some of the springs are known to flow all year round ([Plate 2 and 3](#)). Baseflow in the watercourses outside of the wet season is expected to be from groundwater and interflow discharge with the majority of the smaller watercourses being ephemeral. However, limited gauging of baseflow has been undertaken and it is expected that some springs will dry up during the later stages of the dry season as the water table drops. A ground truth exercise was not undertaken as part of this assessment, and there may be additional springs to those shown of [Figure 25](#).



Plate 2 – Spring at Lakeland

4/4/2005



Plate 3 – Spring fed dam

4/4/2005

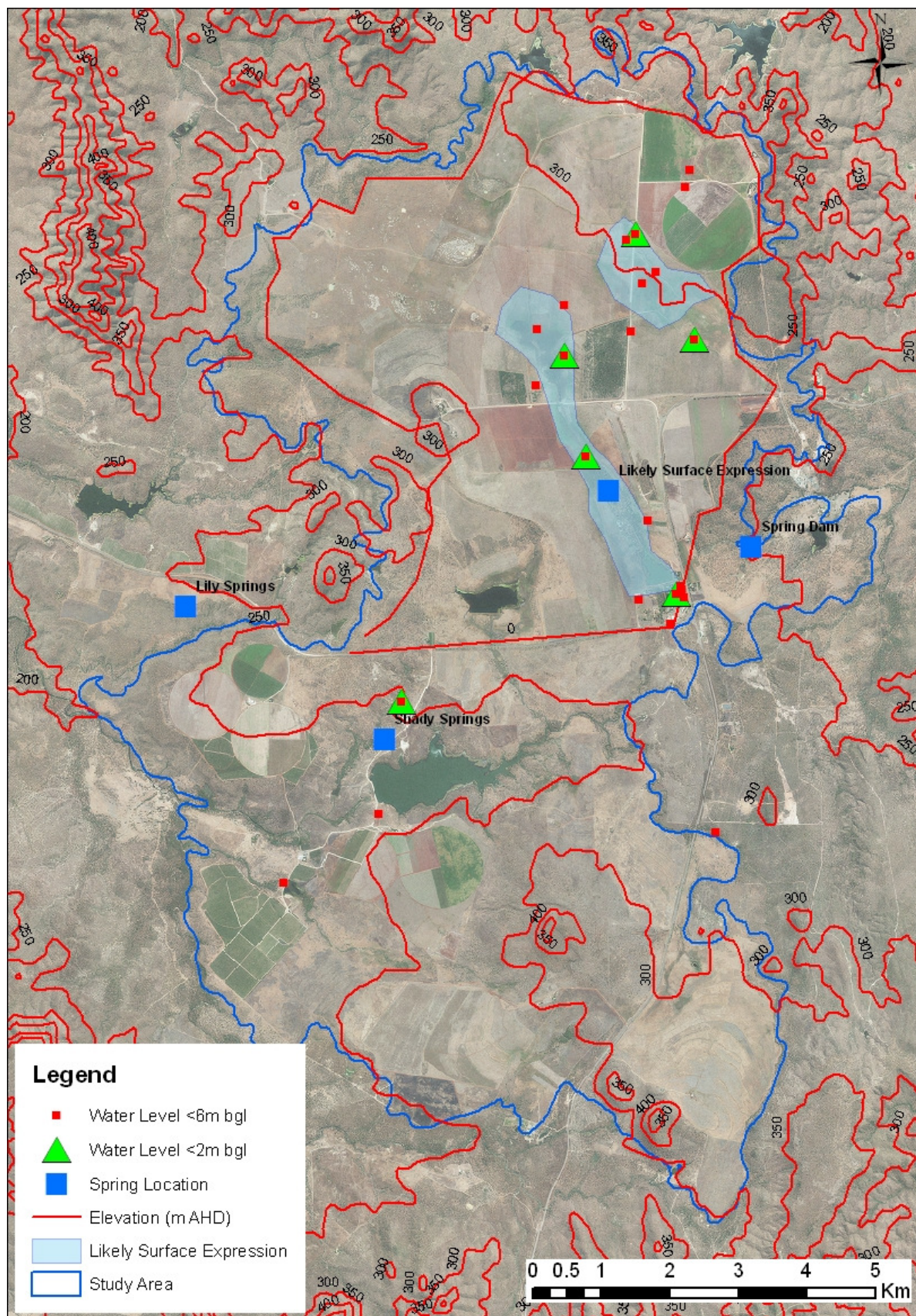


Figure 25 - Likely surface expression and spring location

According to North Australia Water Services (NAWS) the Bullhead Creek catchment drains almost the entire area of the Lakeland Plateau (NAWS, 2010). A stream gauging monitoring program was undertaken by the department (DNRM 2012) of the baseflow of Perfume Gully (Wickham's Swamp watercourse), Bullhead Creek, 50 Mile Creek, an unnamed drain and One Mile Creek upstream of Perfume Gully. This program commenced in 2009 and concluded in 2011. It was part of an investigation into water storage and reliability in Honey Dam and 50 Mile Dam. Estimates of flows were made for ungauged months to fit a recession curve. The origin of water within a watercourse is often a combination of quick flow and groundwater fed baseflow. The proportion of each can vary spatially and temporally. The origin of the groundwater is therefore difficult to identify without chemical analysis as aquifer extent does not often comply with surface water catchments.

Estimates of flows based on the stream gauging measurements were averaged and an additional groundwater discharge of 25% of the flow of the major tributaries into Honey Dam was calculated. Table 1 provides the average flow rates and approximated monthly volumes based on those flow rates. The results indicate a combined dry season groundwater discharge of approximately 444 ML for Perfume Gully and Bullhead Creek, 457 ML for One Mile Creek and 671 ML for the unnamed drain and Fifty Mile Creek. It should be noted that above average rainfall fell in 2009 and 2011 (2010 has an incomplete data set) and while some of the springs are known to flow all year round, it is expected that the majority of springs will dry up during the later stages of the dry season as the water table drops. This decrease in groundwater level can be seen in Figure 19, Figure 20 and Figure 21. Indications are that groundwater discharge into these watercourses may be from upper aquifers including perched aquifers, the vadose zone and saturated weathered material not included in the aquifer water volume analysis due to the low volume and inaccessibility of the water for extractive uses.

NAWS (2010) states there is significant inflow into Honey Dam from groundwater discharge into Perfume Gully, One Mile and Bullhead Creeks. NAWS estimated an additional groundwater discharge into Honey Dam from other groundwater sources would equate to 25% of total flow of the major watercourses. NAWS (2010) estimated a total groundwater baseflow input of 467 ML into Honey Dam from all tributaries including Wickham's Swamp (Perfume Gully), One Mile and Bullhead Creeks.

This compares to an analysis of the groundwater component of Honey Dam completed by DNRM which estimated the groundwater component for Honey Dam as averaging 1675 ML/year (DNRM 2012). Groundwater discharge has also been estimated for other watercourses in the Lakeland area including, 303-400 ML into Sharprock Dam (NAWS 2009, DNRM 2012), 79-125 ML into Dump Gully Dam (NAWS 2011, DNRM 2012), 61 ML into the proposed Cooktown Road Dam no. 1 (NAWS 2012a) and 61 ML into the proposed Cooktown Dam no. 2 (NAWS 2012b). It is assumed that the majority of the groundwater discharge into watercourses comes from the basalt aquifers and not the Hodgkinson Formation.

Table 1- Stream gauging flow rates averaged over time for the major groundwater distributaries

Averaged stream gauging flow rates for main watercourses within the Study area											
		Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Perfume Gully	L/s	45.8	29.7	22.2	10.7	8.5	7.0	6.1	5.6	2.8	138.4
	ML/mth	118.7	79.5	57.5	28.7	22.8	18.2	16.3	14.5	7.5	363.8
Bullhead Creek	L/s	7.6	5.5	3.3	3.5	2.8	1.0	1.0	0.0	0.0	24.7
	ML/mth	19.7	14.7	8.6	9.4	7.5	18.2	2.7	0.0	0.0	80.7
One Mile Ck	L/s	45.0	31.8	28.0	22.6	23.5	13.0	6.8	5.7	3.0	179.4
	ML/mth	116.6	85.2	72.6	60.5	62.9	18.2	18.2	14.8	8.0	457.1
Additional watercourses at 25%	L/s										85.6
	ML/mth	63.8	44.9	34.7	24.6	23.3	13.7	9.3	7.3	3.9	225.4
Sub-total	L/s	98.4	67.0	53.5	36.8	34.8	21.0	13.9	11.3	5.8	342.5
Sub-total	ML/mth	318.8	224.3	173.3	123.2	116.5	68.3	46.5	36.6	19.4	1126.9
Drain	L/s	37.7	38.2	25.4	21.2	10.0	6.7	4.2	0.6		144.0
	ML/mth	97.7	102.3	65.8	56.8	26.8	18.2	11.2	1.6		380.4
50 Mile Ck	L/s	47.5	27.8	14.0	8.3	5.2	3.2	0.8	0.0		106.8
	ML/mth	123.1	74.4	36.3	22.2	13.9	18.2	2.1	0.0		290.4
Sub-total	L/s	85.2	66.0	39.4	29.5	15.2	9.9	5.0	0.6		250.8
Sub-total	ML/mth	220.8	176.7	102.1	79.0	40.7	36.4	13.4	1.6	0.0	670.8

To determine an approximation for average annual groundwater discharge to watercourses it has been assumed that, as the 50 Mile Creek catchment is totally within the southern sector, the groundwater component would come from aquifers and interflow associated with this section. Inflows into Sharprock Dam and the proposed Cooktown Road Dams 1 and 2 would come from the northern sector. The other watercourses are likely to include groundwater discharge from both sectors, proportionally more from the northern sector for Perfume Gully and One Mile Creek. If we take the averaged stream gauging derived values and the maximum values provided for other watercourses as an estimate of saturated zone discharge during the dry season then discharge from the northern sector would be approximately 1332 ML (= 400 ML + (457.1 ML * 0.95) + (363.8 ML * 0.95) + (80.7 ML * 0.1) + 61 + 61 + (225.4 * 0.1)). Correspondingly the southern sector discharge was estimated at 1112 ML (= 670.8 ML + (80.7 ML * 0.9) + (457.1 * 0.05) + (363.8 * 0.05) + 125 ML + (225.4 * 0.9 ML)) during the dry season.

Transmissivity

Transmissivity (T) is defined as the amount of water that can be transmitted horizontally through a unit width of aquifer multiplied by the full saturated thickness of the aquifer, under a hydraulic gradient of 1. It is calculated using the following formula:

$$T = k b$$

Equation 9

Where k = hydraulic conductivity (m/day), and b = saturated aquifer thickness (m). An average transmissivity value is typically used for an aquifer (Heath 1983).

Of the 37 bores drilled in the McLean Basalt to the north of the Peninsula Developmental Road (northern sector), 12 have been pump tested. The pump tests indicate that transmissivity ranges from 16–2668 m²/d. Five of the bores pump tested have a transmissivity of <500 m²/d, while seven have a transmissivity >500 m²/d. It is unlikely that low yielding bores are pump tested, therefore available transmissivity data is likely to be above average. It is also likely that there is error associated with the maximum transmissivity of 2668 m²/d as minimal drawdown was obtained during this pump test. Transmissivity values in excess of 500 m²/d are believed to be associated with vesicular or honeycomb basalt, while lower values are likely to be associated with jointed or unweathered vesicular basalt (Cook *et al.* 2001).

Higher transmissivity aquifer material appears to be restricted to the central area of the northern basalt flow, however, large portions of the aquifer remain untested. A majority of the bores tested intercept more than one basalt aquifer unit, therefore it is difficult to identify the contribution of the individual units. However from bores that only intercepted the Unit M, transmissivity ranged from 16–780 m²/d depending on proximity to the vent.

A trend to higher transmissivity closer to the vents was also evident in bores tested that intercept multiple aquifer units. In these formations transmissivity ranged from 56–2668 m²/d with the lower value associated with a bore located in the northern edge of the basalt flow area.

The pump test from this bore (RN109876) indicates that bores near the edge of the basalt formation may dewater with continued pumping. The 2668 m²/d value is associated with a bore that intersected both Unit H and Unit M in a fractured zone along the primary flow pathway. The transmissivity values are similar to those recorded in other Australian vesicular and fractured basalt flows such as the Atherton Basalt. Within the Atherton Basalt, transmissivity ranges from 4 to 3500 m²/d depending on location, with the upper aquifers being more dominant resulting in the system being modelled as two units (Leach 1986). Transmissivity rates >1000 m²/d in the Atherton Basalt were associated with bores that had yields >20 L/s (Leach 1986) which is also consistent with the bores pump tested in the McLean Basalts. It is expected that Unit H and Unit M bore yields are likely to be similar to the lower extremes of the Atherton Basalt measured values.

To the south of the Peninsula Developmental Road, approximately 10 bores have been drilled in the McLean Basalt with none of these being pump tested. However, rates of supply are significantly lower than that of the northern area indicating that transmissivity is also likely to be low and the aquifer material is likely to be jointed or unweathered vesicular basalt.

A pump test has also been undertaken in the Hodgkinson formation indicating a transmissivity value of 65 m²/d.

Hydraulic Conductivity

Hydraulic conductivities vary horizontally and vertically in basalt (anisotropic) depending on the heterogeneity, with estimates of hydraulic conductivity obtained by dividing transmissivity of an aquifer with saturated aquifer thickness. Typical horizontal conductivity values, which is

a measure of permeability, for basalt range from 2×10^{-6} – 2×10^{-3} m/s and shale from 10×10^{-13} – 10×10^{-9} m/s. Hydraulic conductivity measurements ranging from 1.8×10^{-9} – 3.2×10^{-6} m/s were identified for the Lismore Basalt (New South Wales) (Golder Associates 2008) near Tintenbar. While horizontal conductivity values for the Columbia River Basalt system in the United States ranged from 1×10^{-12} – 1×10^{-2} m/s for simple vesicular flows and 1×10^{-15} – 1×10^{-8} m/s for blocky jointed basalt (Tolan *et al* 2009).

To put this in perspective, although there is a potential for recharge in the northern sector of 3150 ML and southern sectors of 2250 ML in average conditions, not all this water will penetrate as far as the aquifer units due to the presence of impermeable layers and varying hydraulic conductivities of the aquifers and confining layers. The time it takes for water to move from the ground surface (recharge area) to a groundwater discharge area can take from days to thousands of years (Heath 1983) as indicated in Figure 26. In basalt systems vertical conductivity is significantly smaller than horizontal conductivity. In complex systems as occurs in the Study area multiple boundary conditions occur in addition to zones of high and low transmissivity with different flow conditions (heterogeneity) (Rhia 1979).

No actual hydraulic conductivity measurements have been done for the Mclean basalt. Transmissivity readings are available for the Unit M and this would provide estimated horizontal hydraulic conductivity readings ranging from 7×10^{-4} – 4×10^{-2} m/s.

According to the bore logs the majority of the Study area has on average 10 m of clay and weathered material below the ground surface which may or may not contain water but would allow the passage of water at varying velocities. Between this weathered zone and the first aquifer (on average), is 14 m of massive basalt which has limited to no permeability except through fractured zones. Separating water bearing beds on average is a further 9 m of massive basalt.

In the high transmissivity aquifer of the Atherton Basalts the active flow zone was approximately 30 m thick, with horizontal groundwater flow rates of tens of metres per year (ranging from 0.2–4 m/d). The water aged by use of chlorofluorocarbons indicated most of the aquifers in the Atherton Basalts contain water that is <30 years old with groundwater velocities calculated at between 2–6 m/year (Cook *et al* 2001).

The Mclean Basalts are more compartmentalised and limited in extent with lower rainfall and infiltration in relation to the highly transmissive aquifer of the Atherton basalt and therefore horizontal movement is expected to be less and indications are that the age of water in some of the more confined aquifers is older.

Cook *et al* 2001 found vertical hydraulic conductivities of 100–300 mm/year in the Atherton Basalt where mean porosity was approximately 0.05%, this would equate to the time for water movement from the surface to the upper McLean Basalt aquifer unit of 47–140 years (assuming that there is some permeability of the overlying bed averaging 14 m).

The presence of fractures and faults at the surface obviously significantly changes this timeframe and some confined aquifers may not recharge at all. Previously isolated aquifers may now be in hydraulic connection through infrastructure (bores). The impact of these multi-slotted bores on recharge from the upper to the lower aquifers is expected to be minimal due to extraction and hydraulic pressure. Until further data is collected from monitoring bores the lag time and rates of recharge cannot be accurately determined.

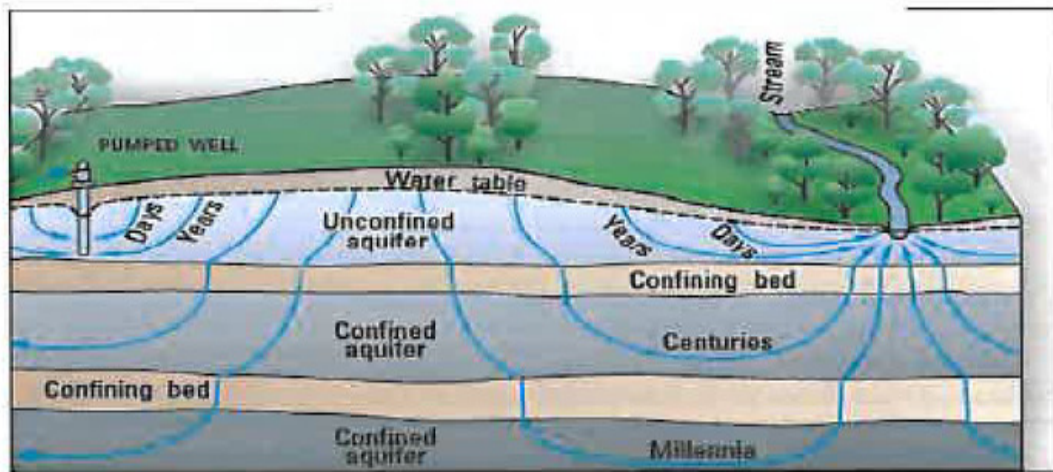


Figure 26-Groundwater recharge discharge and flow representation (sourced Winter et al 1998)

Storativity

Storativity of a confined aquifer is defined as the volume of water released from storage per unit of surface area per unit decline in hydraulic head. Typically confined aquifer storativity ranges from 5×10^{-5} to 5×10^{-3} and for unconfined aquifers from 0.1–0.3 (Heath 1983).

$$S = S_s b \quad \text{Equation 10}$$

Where S = storativity (storage coefficient), S_s = specific storage (L^{-1}) and b = aquifer thickness (L).

In an unconfined aquifer storativity is:

$$S = S_y + S_s b \quad \text{Equation 11}$$

Where S_y = specific yield. As $S_s b$ is often very small then S approximates to S_y .

No actual storativity investigations have been undertaken for the McLean Basalt.

AGE (2006) reviewed storativity of Australian fractured rock basalt aquifers and found ranges from 5.0×10^{-2} to 1.0×10^{-4} from which they used the median value (1.0×10^{-3}) for their calculation of storage volume.

The Newer Volcanics Tertiary basalt located in Victoria, are highly variable with hydraulic conductivity and storativity values ranging from 0.1–20 m/d and 1.0×10^{-6} –0.1 respectively (ANRA 2012; SKM 2010). SKM (2010) used a transmissivity 7.5 m²/d and storativity of 3.0×10^{-2} –0.1 (for the highly fractured vesicular zone) as representative values for modelling the Newer Volcanics. Storativity values obtained by field testing of the Werrie Basalt (New South Wales) found values of 2.0×10^{-3} –0.133 with an average effective porosity of 0.1% and permeability of 2.0×10^{-5} (RW Corkey & Co 2010). Pump testing of bores in the Leslie Creek area of the Atherton Tablelands (Queensland) obtained mean storativity values of 5.7×10^{-4} – 6.8×10^{-3} for semi confined to confined aquifers (Prendergast & Walsh 2006). The Toowoomba Basalt Aquifer Sustainability Assessment (KCB 2007) used 5–10% aquifer

storage in areas outside of a 500m buffer around watercourses and 1×10^{-5} – 1×10^{-3} aquifer storativity within 500 m of watercourses.

For this study three different storativity coefficients were used for the basalt aquifer units (3.0×10^{-2} , 1.0×10^{-2} , and 1.0×10^{-3}) on the assumption that the highly transmissive Unit H would have a higher storage capacity than the less transmissive units. This may lead to an overestimation of water storage within the basalt aquifer units especially in the Unit C_{north} and Unit C_{south} where the value may be as low as 1.0×10^{-4} .

For the analysis of storativity for the Hodgkinson Formation a value of 1.0×10^{-4} was obtained from pump testing undertaken in the Cooktown region (Leach 1983). As the strata is the same as Cooktown this value was utilised in the calculations for the known aquifer units. Storage volumes calculated using these storativity coefficients are located in Table 2.

Specific Yield and Porosity

Specific yield is defined as the volume of water released from storage by an unconfined aquifer per unit surface area of aquifer per unit decline of the water table (Heath 1983).

$$n = S_y + S_r \quad S_y = V_d/V_t \quad S_r = V_{rt}/V_t \quad \text{Equations 12-14}$$

Where n = total porosity, S_y = specific yield, S_r = specific retention (amount of water retained by capillary forces), V_d = volume of water that drains from a total volume of V_t , V_{rt} = volume of water retained (m^3).

No actual specific yield or porosity investigations have been undertaken for the Study area. Heath (1983) lists young basalt porosity as 11%, specific yield as 8% and specific retention as 3%. Durick (2001) when calibrating the modelling of the Atherton Basalt found a specific yield of 6.36% and 9% matched the water level profile of the bores, which is a lower value than that identified by Cook *et al* (2001) (value of 0.2 for the higher yielding aquifer). The Department of Natural Resources and Water (2006) used a range of specific yield values to examine the storage in the Atherton Basalt water resource plan sub areas from 3-15%. The differences in the specific yield within the Atherton Basalt studies can be attributed to the heterogeneity of the different aquifers, methods used and the varying locations of the studies.

Laboratory testing of the Deccan basalts of the Bombay region found porosity to be 10–34% in weathered basalt, 5–15% in fractured to jointed basalt, 0-3% in fresh amygdaloidal basalt and massive basalt was found to be non-porous. Pump testing in Maharashtra determined the specific yields of weathered basalt, vesicular basalt and fractured-jointed basalts ranging from 2–7%, 1–4% and 0.8–1% respectively, with corresponding transmissivity ranging from 90–200 m^2/d , 50–100 m^2/d and 20–40 m^2/d (Deolankar 1980). The Deccan basalt study has shown that although porosity can be up to 34% the specific yield may be only 7% resulting from higher retention due to the presence of clay minerals. The porosity of 15% and 40% in fractures and vesicular basalts respectively have only 1 and 4% specific yields indicating that there is poor interconnection between the fractures, joints and vesicles (Deolankar 1980). Effective porosity values for the Columbia River Basalt system in the U.S.A found values ranging from 3 to 6% for simple vesicular flows and 0 to <1% for blocky jointed basalt (Tolan *et al* 2009).

The Lakeland area is more likely to conform to the areas that have lower values as the Study area is a small basin with multiple vents and variations in flow type, thickness, secondary mineralisation and weathering. Rainfall and therefore recharge is also likely to be significantly lower than most of the areas studied.

The specific yield used to determine a working storage were: 6 % for Unit H, 4% for the Unit M, 3% for Unit C_n and Unit C_s and 1% for Unit B. The results of this calculation based on the different methods for determining the area are located in [Table 2](#).

Working Storage

Depending on the method used, the saturated storage of the various aquifers differ, the averaged values (as ML of water) for Unit H, Unit M, Unit C_{north}, Unit C_{south} and Unit B are 2000, 1850, 1450, 1750 and 200 ML respectively.

The available groundwater can be defined as the volume of saturated material multiplied by the specific yield; or storativity less retained or unobtainable water. Separate methods were used to determine available water volumes for rock volumes based on prism, gully infill and outcrop surface area:

1. Volumes were calculated based on porosity and specific yield values of the Deccan Basalt ([Deolankar 1980](#)); and
2. Volumes were calculated using storativity coefficients 3.0×10^{-2} , 1.0×10^{-2} and 1.0×10^{-3} , for the aquifer unit volumes with 20% retention ([AGE 2006](#)).

The values were then averaged to give working storage volumes for each unit ([Table 2](#)). No account was taken for losses from the system by evapotranspiration or discharge to surface water at this stage and the effect of extraction is considered in a later section. As these are calculated values based on data from other areas and formations there are errors that are likely to be included in the results which could be +/- approximately 20%.

Analysis of the calculated working storage data indicates that there is likely to be 4115 ML and 1084 ML of water available from basalt in the northern and southern sectors if the aquifers are fully saturated, based on available data and calculations. There is a significant difference in working storage volumes between the northern and southern sectors due to the origin, nature and distribution of the basalt flow sequences. Full saturation will not occur in all years and within years due to fluctuations in recharge with climate variations and drawdown by pumping.

As there appears to be large volumes of water being extracted from the Unit H aquifer (as confirmed by logger data in RN10510001, [Figure 19](#)) the storage levels are likely to be below full capacity in most years.

Table 2- Estimated Working storage (Ws) within the aquifer units

	Unit H	Unit M	Unit C _{north}	Unit C _{south}	Unit B
Prism S	1006	1214	1283	1410	84
Gully S	1710	1422	888	1082	129
Area S	2052	1744	1241	1660	129
Prism Sy	1454	1720	962	982	186
Gully Sy	1710	1422	444	541	323
Area S	2052	1744	620	830	323
Average Ws	1664	1544	906	1084	196
North Basalt Total	4115		South Basalt	1084	
Averaged Saturated Rock Volume (ML)	2000	1850	1450	1750	200
Saturated Volume (ML)	North	5402	South	1848	

*The exact accumulative error associated with these calculations could not be determined but it is expected that they would be <20%

Sustainability

The *Water Act 2000*, when determining sustainable water availability for allocation, requires consideration that extraction will not detrimentally affect existing entitlement holders and that groundwater dependent ecosystems (GDE's) and other environmental and social requirements are taken into account. Additionally, should an aquifer be drained of water below a certain point, the pressure from overburden can cause compression leading to structural collapse, fracturing and land surface subsidence (Heath 1983). No groundwater dependant ecosystem studies have been undertaken within the Study area however the potential for GDE's have been identified in the area (Figure 27). Various studies undertaken in close proximity to the Study area have also identified GDE's.

Historically allocation of groundwater in the Lakeland Downs area was based on a fractured rock system approximating to 1 ML/ha/year over the entire property or 3 ML/ha/year over a lesser cropped area. Table 3 shows that this rate of allocation is actually higher than what is available from any individual aquifer when distributing the working storage of available water over an even distribution, except from the Unit H.

Table 3 – Distributed annual volume (W_s) per hectare per year*

	Unit H	Unit M	Unit C _{north}	Unit C _{south}	Unit B
W_s	1664	1544	906	1084	196
Surface Area (ha)	950	2422	5170	4939	10 109
Equivalent ML/ ha/year	1.75	0.64	0.18	0.22	0.02

*no evapotranspiration losses or discharge to surface water systems have been accounted for.

Table 4 provides an indication of the system water demand based on a fixed scenario where the saturated storage starts at full capacity, full allocated extraction and other discharge occurs and then the system is recharged assuming that all recharge goes into the storage. All the values are based on calculated values and as such are an estimate of the system. The residual column provides an indication of the proportion of water left in the system after extraction and natural discharge. Not all water within the saturated zone is available for extraction with water being retained within isolated pores and weathered zones. It can be seen that at a full extraction, with the estimated discharge and recharge for the northern sector there is an overall deficit of 469 ML. Due to the climatic variability of the area, recharge rates and age of the water contained within the lower aquifer units, to reduce the storage any further would significantly affect the aquifers ability to fully recharge. This would potentially reduce reliability for existing entitlement holders and have a detrimental effect on the environment. The residual water provides a buffer in the aquifer for below average recharge years and protects the security and reliability of existing entitlements.

In the southern sector the basalt and metamorphic aquifers have a lower yield and overall storage capacity. The saturated storage capacity of the southern aquifer units is calculated to be 1848 ML. Of this 1311 ML is lost annually due to extraction, ET and discharge to watercourse baseflow. This leaves a residual of only 537 ML (**Table 4**). Not all of this residual water would be available for extraction. The residual water provides a buffer in the aquifer for below average recharge years and protects the security and reliability of existing entitlements. Full recharge is expected to occur in years where rainfall duration and intensity meet the required criteria. While it is expected that the aquifers would recharge fully over time assuming connectivity, the climatic variability of the area, recharge rates and probable age of the water contained within the lower aquifer units indicates that this may not be a suitable resource for further allocation.

If the sustainability of the aquifer and environmental requirements were disregarded the amount available per hectare (**Table 3**) of <0.2 ML/ha/year (based on working storage) would make it unlikely to benefit entitlement holders. Typical yields for the southern aquifers are low and to further utilise the resource, multiple bores may be required over a small area. This could result in drawdown interference due to the cone of depression, which would also reduce the volumes available for pumping from any bore.

Table 4 – Estimates of available water (from saturated storage) after extraction and discharge with recharge.

	Saturated Storage [^] (ML)	Extraction* (ML)	Full Discharge (ML)	ET (ML)	Residual (ML)	Max Pot. Recharge (ML)	Balance (ML)	Storage Difference (ML)
Northern Sector[#]	5402	2266	1332	21	1783	3150	4933	-469
Southern Sector⁺	1848	179	1112	20	537	2250	Full	939 ^Ω
Total	7250	2445	2445	41	2319	5400	7719	469 ^Ω

includes water entitlement from alluvium

+ includes water entitlement from granite

*extraction does not include the water permit but does include a stock and domestic component

[^] full storage volume includes water not able to be extracted

^Ω water held in weathered zone, within isolated pores and as interflow

The National Water Initiative 2004 (COAG 2004) defined sustainable yield as: *'the level of water extraction from a particular system that, if exceeded, would compromise key environmental assets, or ecosystem functions and the productive base of the resource'*. The ratio of extraction to sustainable yield (E/SY) is a measure of the extent of development within a groundwater system relative to an estimate of the sustainable yield. A high E/SY ratio indicates that extraction is operating near its estimated sustainable limit, while a low E/SY indicator indicates a low level stress due to extraction on an overall per unit area basis (SKM 2012). Sinclair Knight Merz (2012) describe the limitations in applying this indicator, which include:

- data on extraction volumes is limited, particularly for stock and domestic use;
- there is no consistent method to calculate sustainable yield;
- estimates of sustainable yield vary in accuracy depending on the method adopted and data available; and
- a high E/SY ratio may not necessarily mean that ecosystems in the management unit are stressed, as the level of stress is a function of the degree of drawdown induced by pumping, so knowledge of the spatial relationship between pumping centres and GDEs is crucial. Conversely, where the E/SY ratio is low, GDEs may be stressed by virtue of the same spatial relationship between the GDE and the pumping centre.

Based on the specific yield of the basalt minus discharge as an indication of sustainable yield on a 1 km² unit area basis, the ratio of extraction to sustainable yield would be 0.8 for the northern sector and 0.9 for the southern sector. This would indicate that the aquifers are already operating near their sustainable limit. Additionally there are restrictions on access to the water due to the distribution of the aquifers.

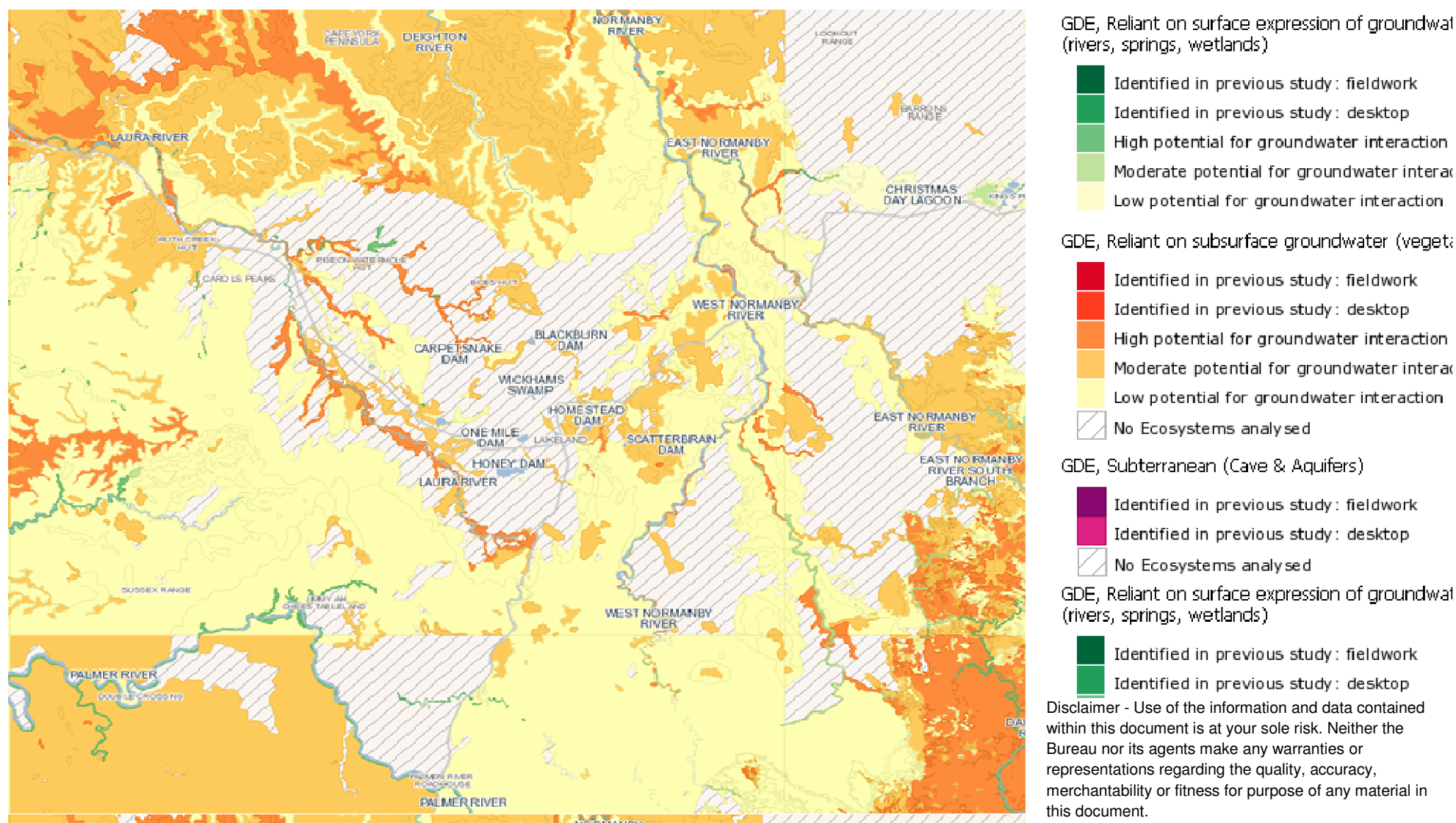


Figure 27 - Groundwater dependant ecosystems (Sourced BoM 2012b)

Conclusions

This study was undertaken to examine the extent and availability of groundwater in the Lakeland Downs area. The McLean Basalt is the major water bearing strata in the study area. There are limited data available in the Study area and this investigation has been based on the assumption that the data that is available is accurate and that the McLean Basalts behave in a comparable manner to other similar basalts. In determining the volume of groundwater that may be available for extraction the upper clay and unsaturated weathered zone was not included in the calculations.

The McLean Basalt overlies the metamorphic Hodgkinson Formation over most of the Study area. The basalt appears to consist of a sequence of lava flows originating from different vents, with secondary porosity and mineralisation. The flows have followed and infilled depressions and valleys in the underlying topography of the basement rocks.

The basalt aquifers can be seen to be compartmentalised, heterogeneous and anisotropic therefore the water is not evenly distributed over the surface area but is concentrated in zones within the aquifer where for example the fractured vesicular basalt flow is thickest. It would appear that confined, semi-confined and unconfined aquifers are present. Hydraulic connectivity exists between some of the basalt aquifer units and between the lower basalt aquifer units and the underlying fractured rock aquifers but the extent cannot be determined at this time

There are two main water bearing aquifers present Unit H and Unit M, located only in the northern sector. Of the remaining basalt aquifers (Unit C_{north} and Unit C_{south}), the aquifers tend to be thinner with lower yields. The Hodgkinson Formation and granite fractured rock aquifers have low yield and specific yield potential.

Groundwater is discharging to springs and watercourses in the Study area. Based on available pump test data transmissivity differences are seen to occur between the Unit H and Unit M.

No actual estimates of groundwater age can be made for the Study area. Based on a similar approach used in other basalt areas it would appear that there is a difference in time to recharge between Unit H and Unit B. Recharge could range from days to surface saturated weathered zones to hundreds of years for the deeper aquifers. Recharge is very dependent on climatic variability.

Actual lag time between infiltration and recharge where it occurs is not known. The indications are that there are small confined aquifers within the Unit C_{north} and Unit C_{south}. If this is the case then recharge of these is unlikely to occur and any withdrawal of water from these sources will deplete the aquifer.

Although based on limited sampling, the different chemical compositions of the Unit H and Unit M groundwater indicates they are likely to behave differently. Correlating these chemical composition differences with age the groundwater in Unit H would appear to be older than Unit M and this would imply that recharge to Unit H is slower than recharge of Unit M.

The preliminary estimates of water availability indicate the aquifers appear to be near their sustainable yield capacity with the current level of licensed extraction. Any further allocation would not be sustainable and will adversely affect entitlement reliability. Should Unit H be unable to recharge fully or only recharge very slowly then current rates of extraction could rapidly dewater the aquifer. Further investigation is required to identify water availability once there is more data available. Water requirements for groundwater dependent ecosystems and any streamflow dependent ecology should also be determined.

Recommendations

Recommendations are:

- Additional monitoring be undertaken and at least 5 additional monitoring bores be installed;
- Further analysis should be undertaken once sufficient data is available from monitoring bores and loggers;
- Existing bores and springs should be identified and their coordinates updated by GPS;
- Further hydrologic and hydro-chemical studies should be undertaken to identify recharge rates and pathways;
- Further studies should be undertaken to determine the age of groundwater. (Isotopic analyses would be most definitive);
- Pump testing of the Unit H and Unit M should occur to determine actual storativity values for the two main aquifer units;
- A pluviometer should be installed at a logged monitoring site to provide rainfall data;
- Water requirements for groundwater dependent ecosystems and any streamflow dependent ecology should be determined;
- Further discharge studies should be undertaken;
- Investigations to obtain aquifer characteristics should be undertaken: and
- A framework for water management of the area should be instituted.



Disclaimer

The above report has been produced on the assumption that strata and aquifer properties as represented in bore logs are correct. Cross sections produced are conceptual interpolated representations of the strata that is likely to be present between bores and may not accurately represent the underlying strata. Various assumptions have been made within the context of the analysis based on work completed on similar strata outside the area due to the lack of data available and this will affect the reliability of the calculations. Quantity of water has been determined using averaged or estimated values and while an attempt has been made to use values or methodology that would most likely approximate the Study area there will be variation and an expected tendency towards overestimation of storage capacity. As further data becomes available the report should be revisited and the analysis reviewed.

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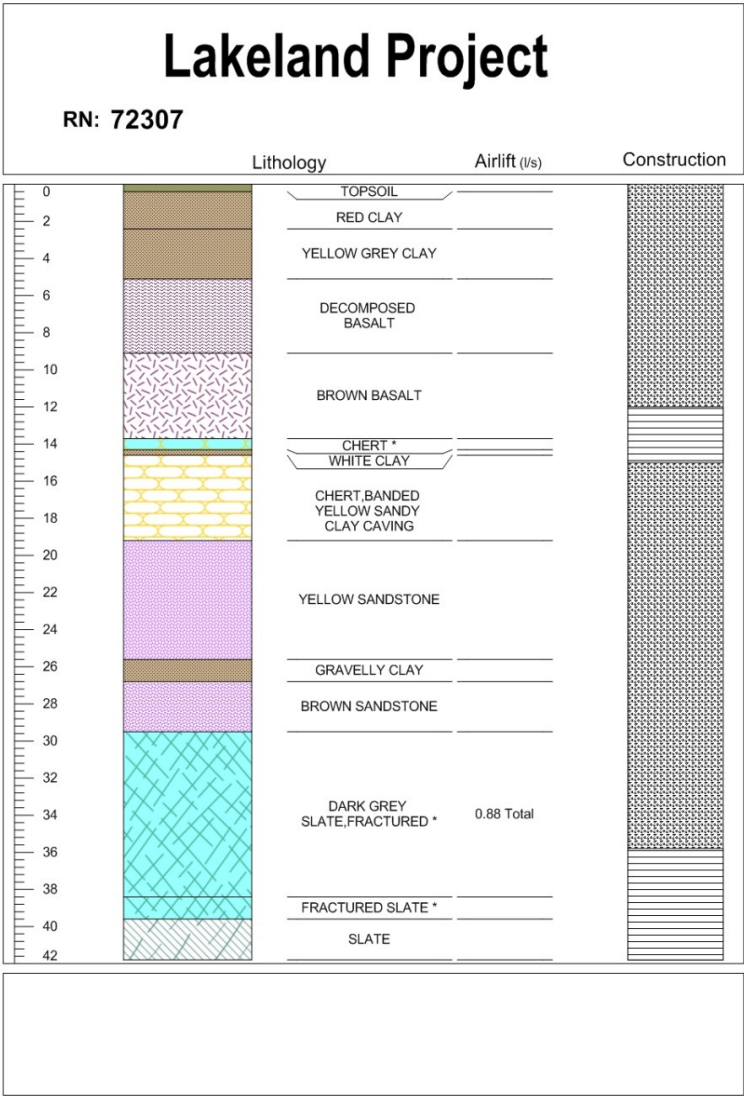
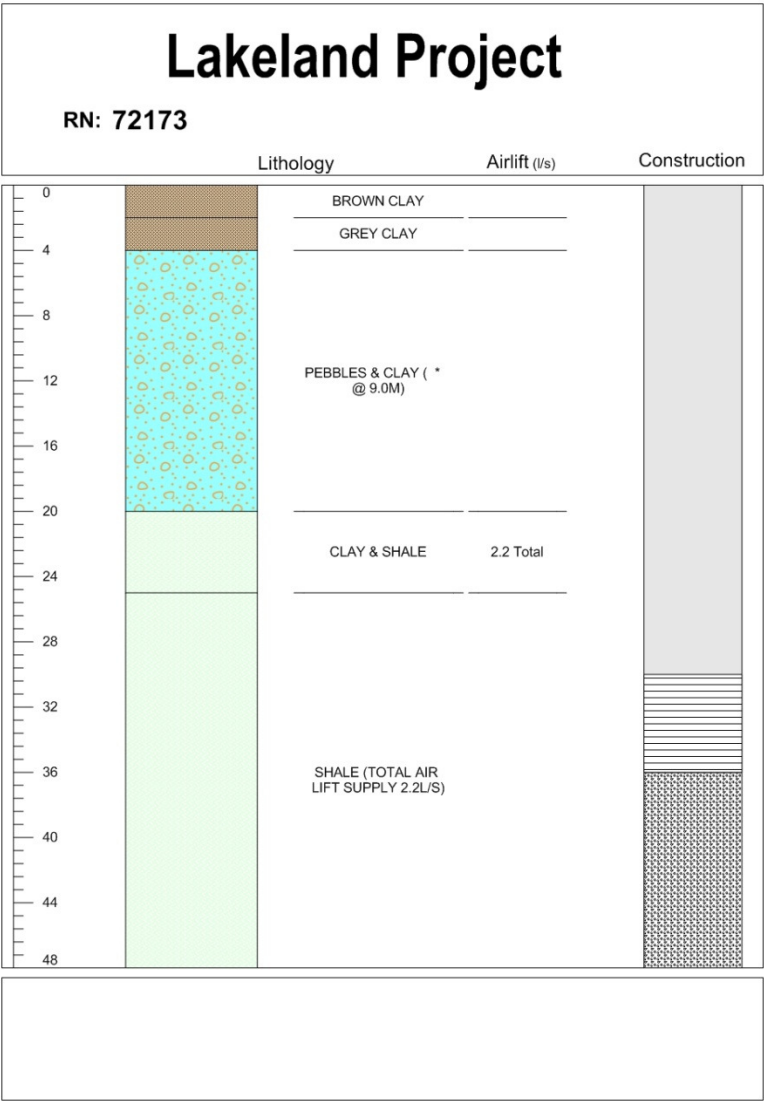
APPENDICES

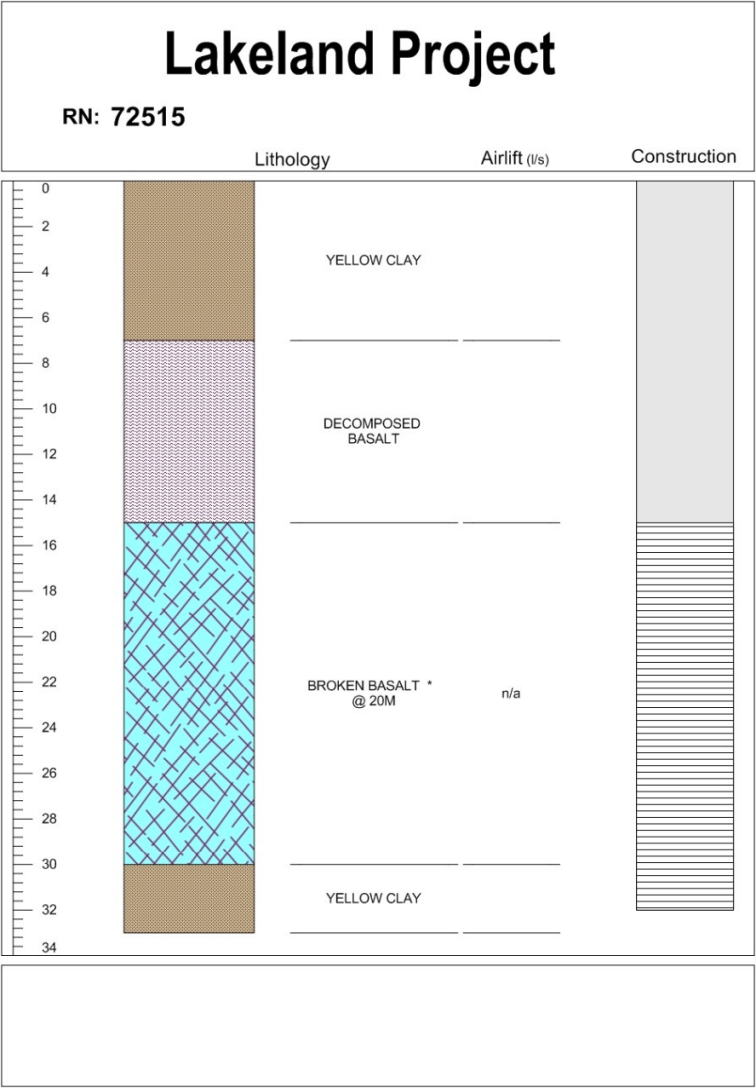
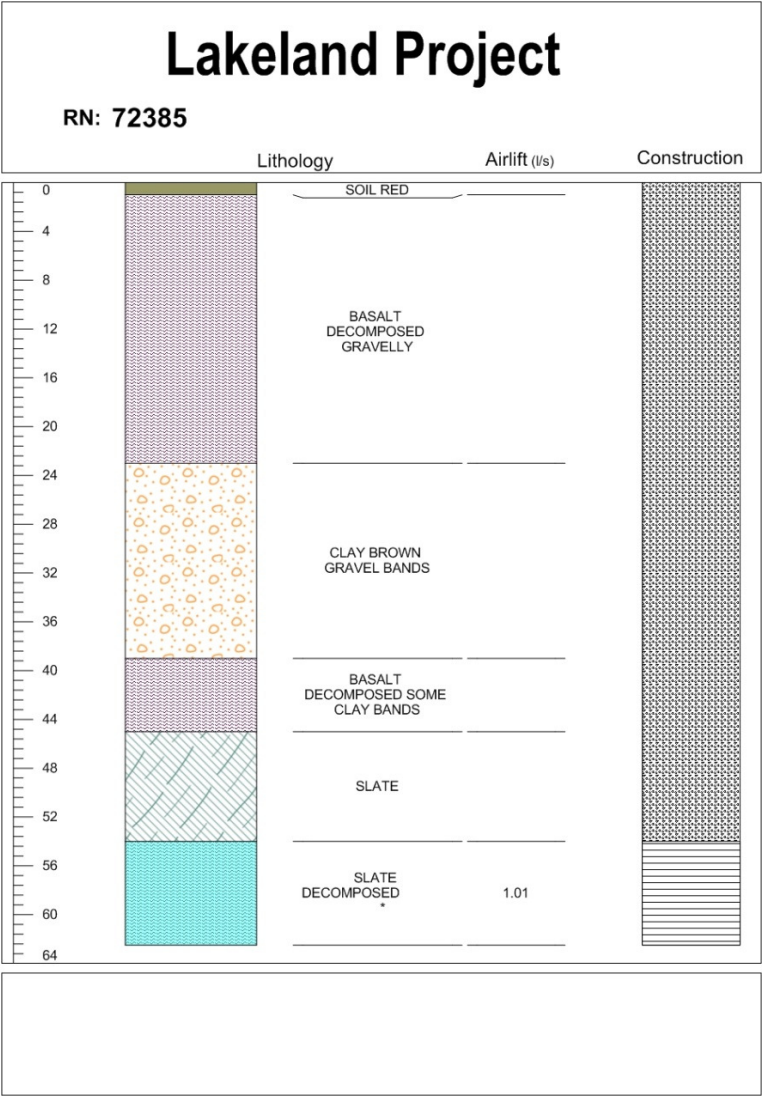
APPENDIX 1- Bore logs

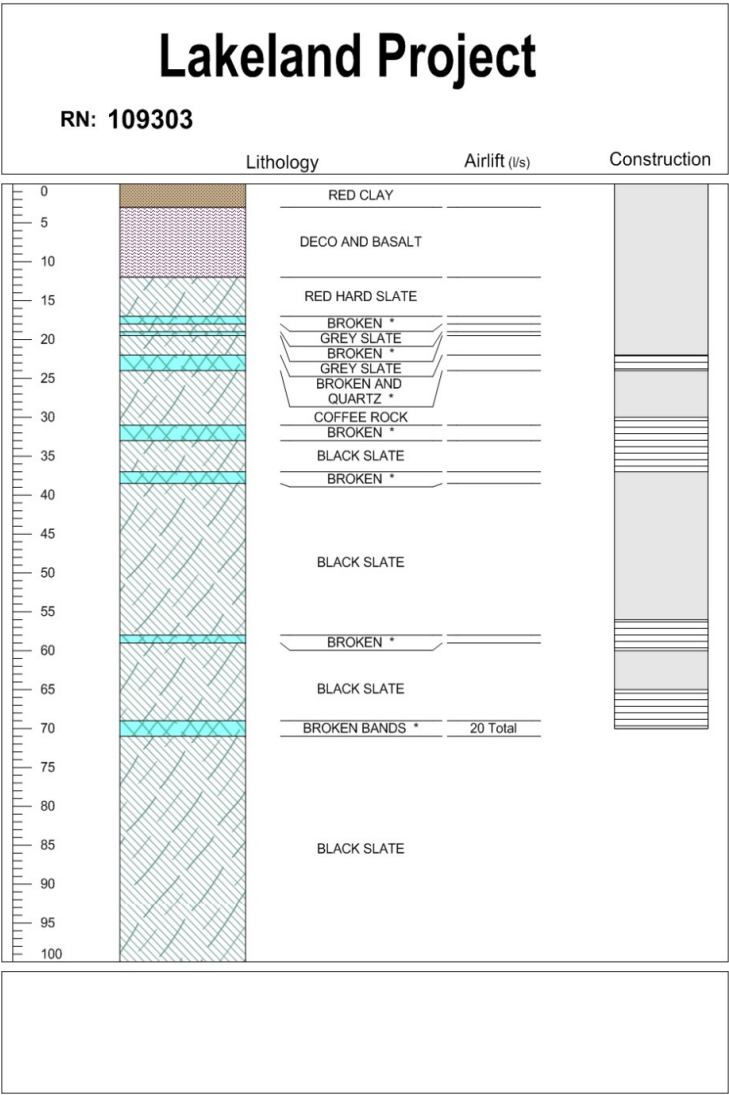
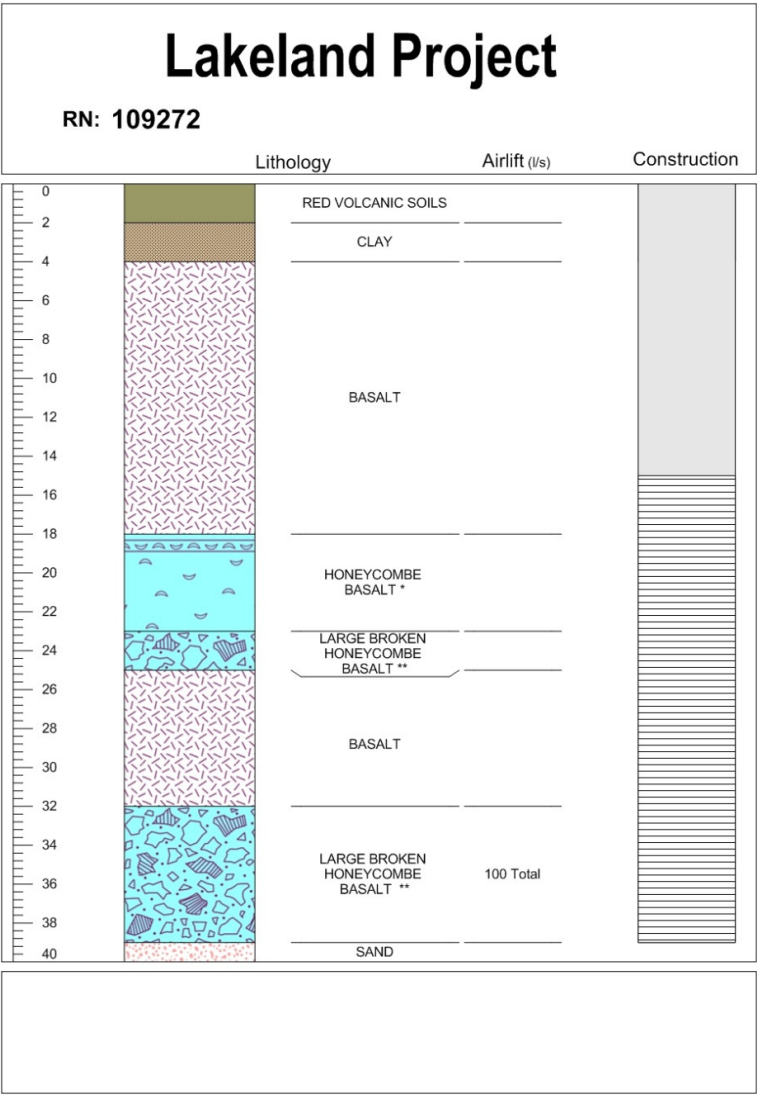
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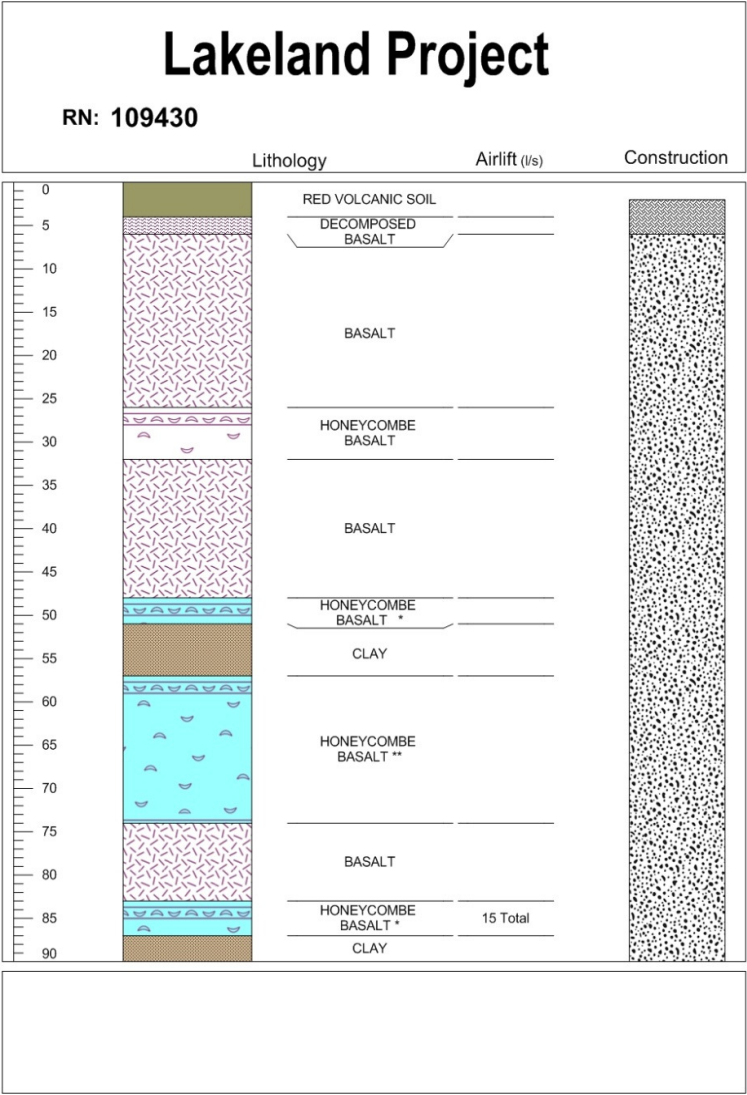
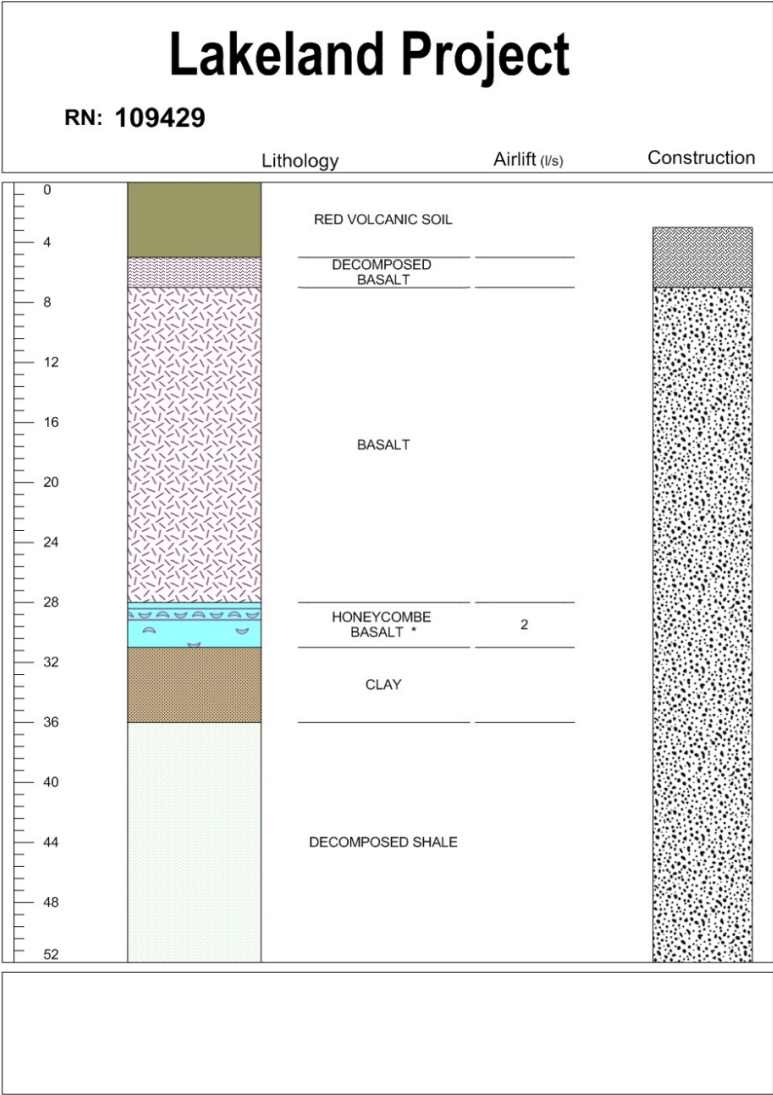
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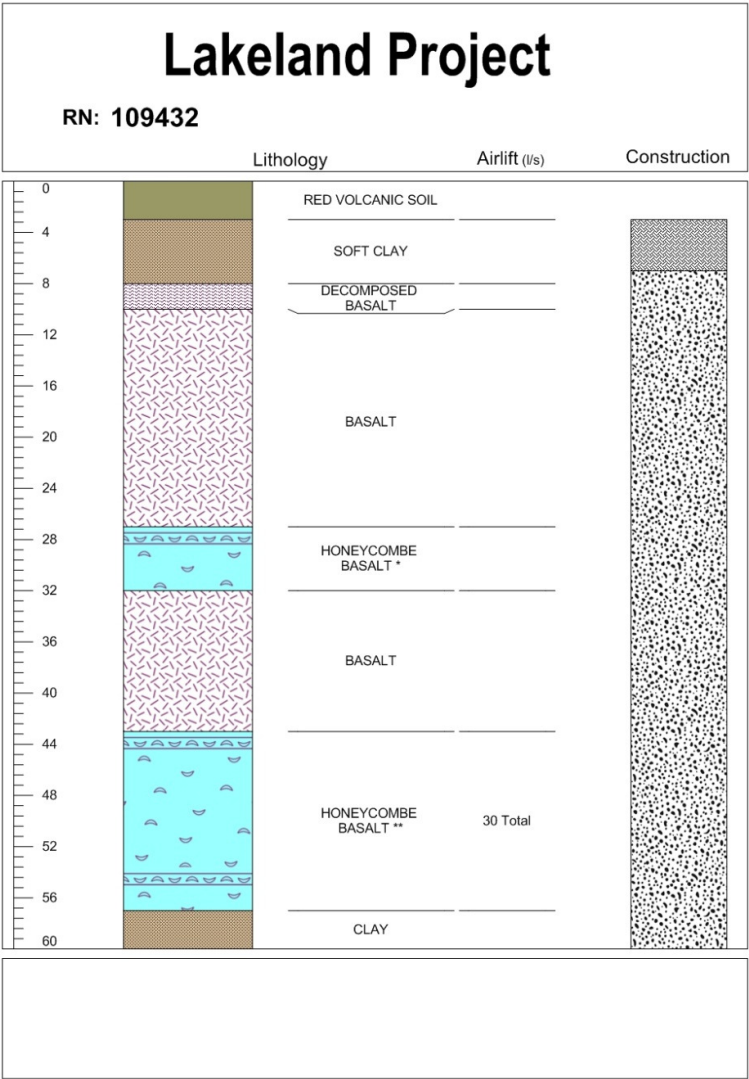
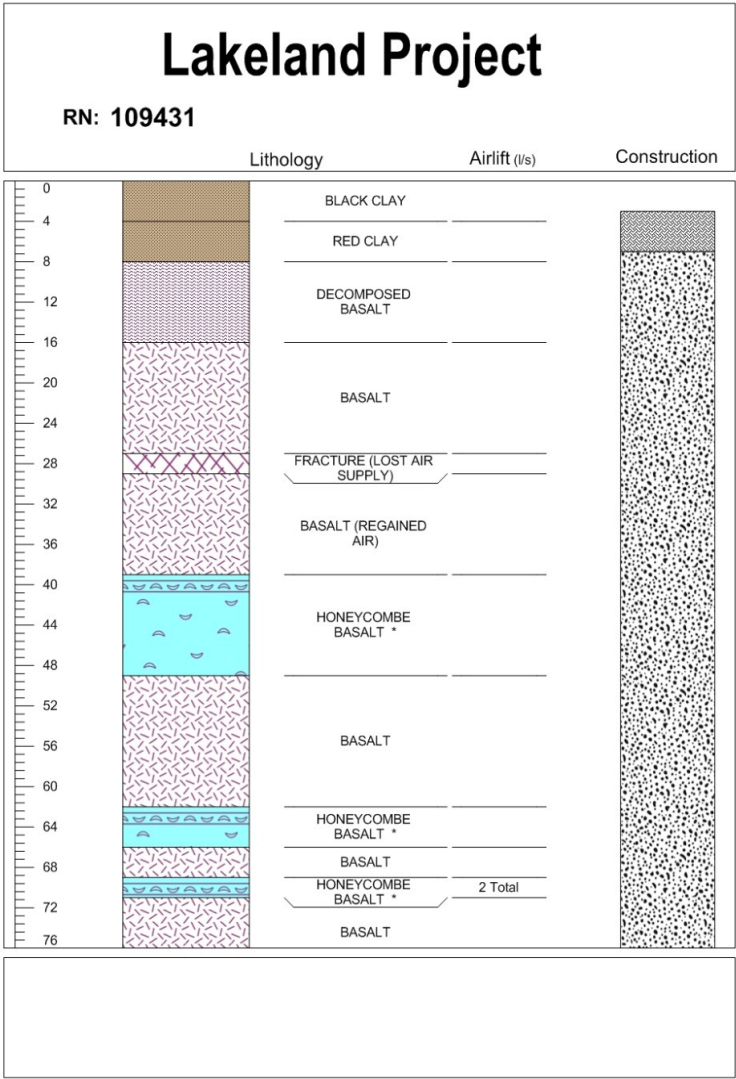
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	Alluvial / colluvial (water)		Fract Siltstone (water)		Shale
	Ash		Fract Slate		Shale (water)
	Ash (water)		Fract Slate (water)		Slate
	Basalt		Fract Vesic Basalt		Soil
	Chert		Fract Vesic Basalt (water)		soil
	Chert (water)		Granite		Vesicular Basalt
	Clay		Quartz		Vesicular Basalt (water)
	Clay (water)		Quartz (water)		Wz Basalt
	Fract Basalt		Quartzite		Wz Basalt (water)
	Fract Basalt (water)		Sand		Wz Shale
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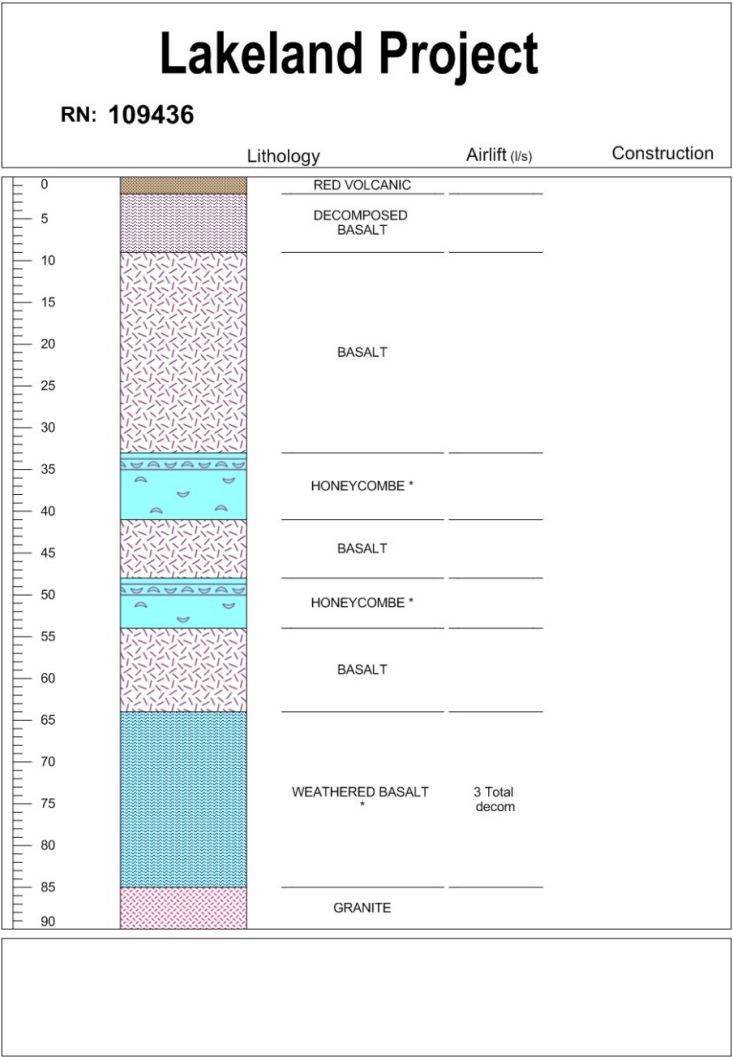
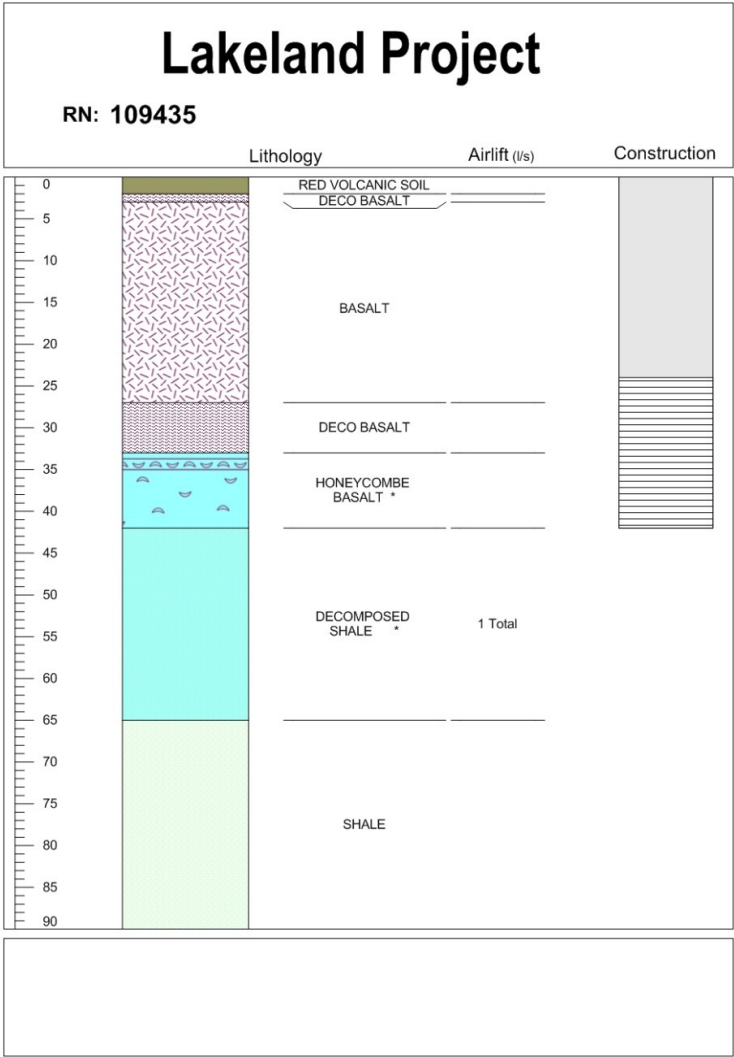


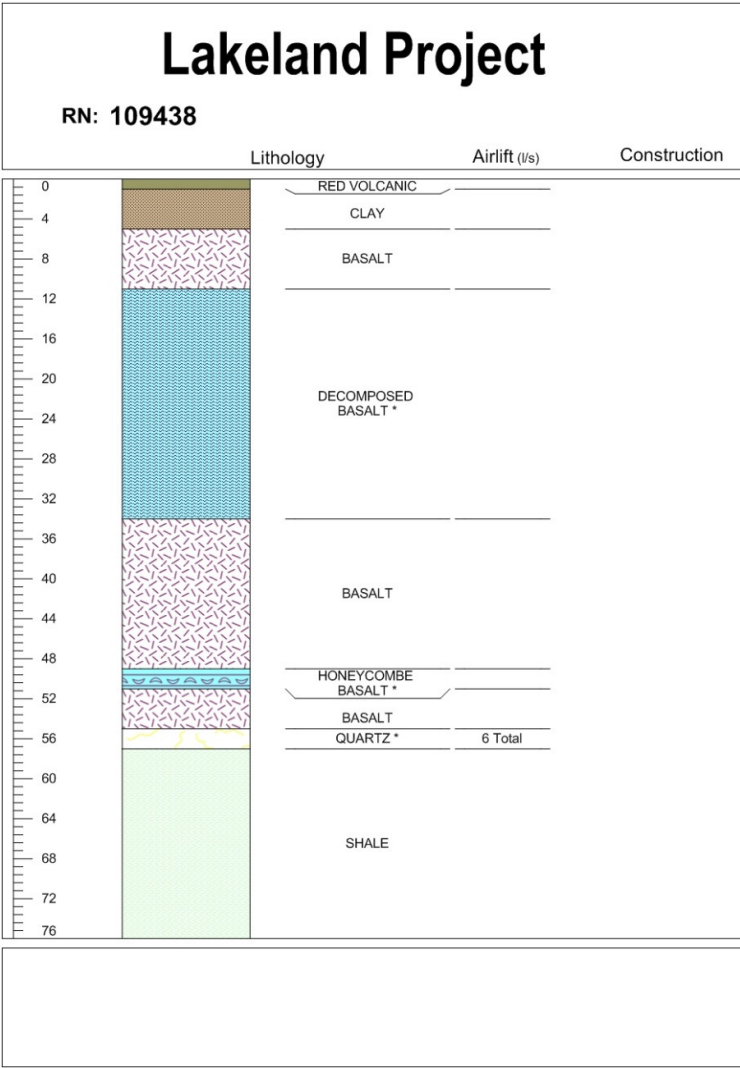
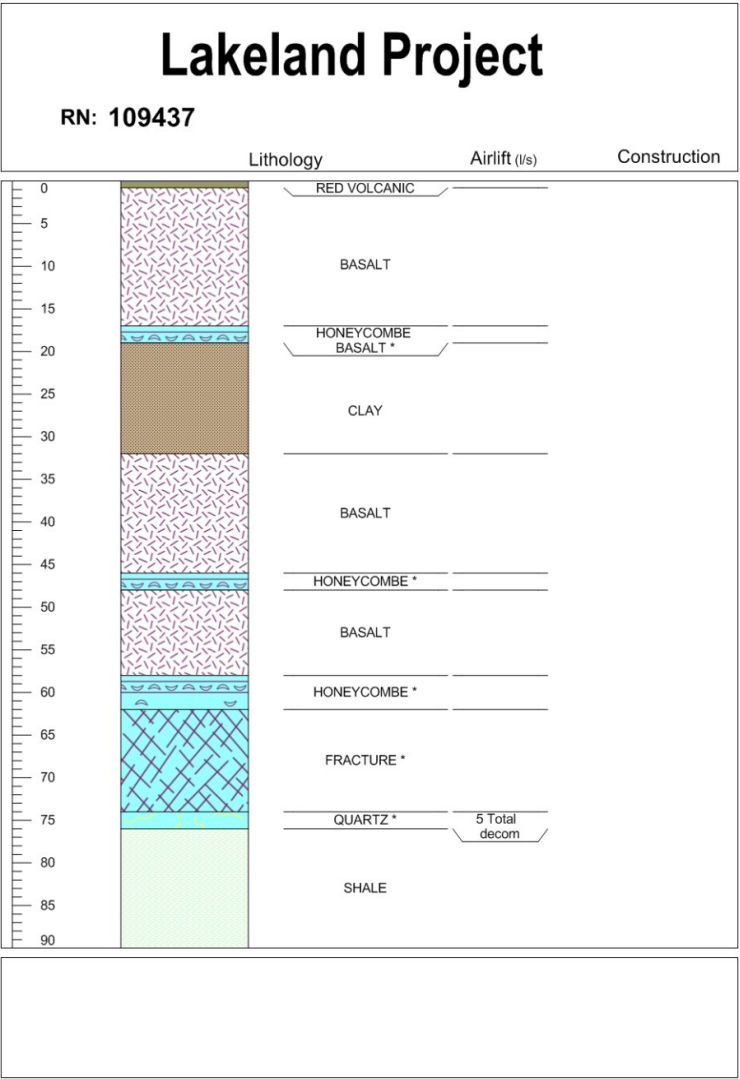


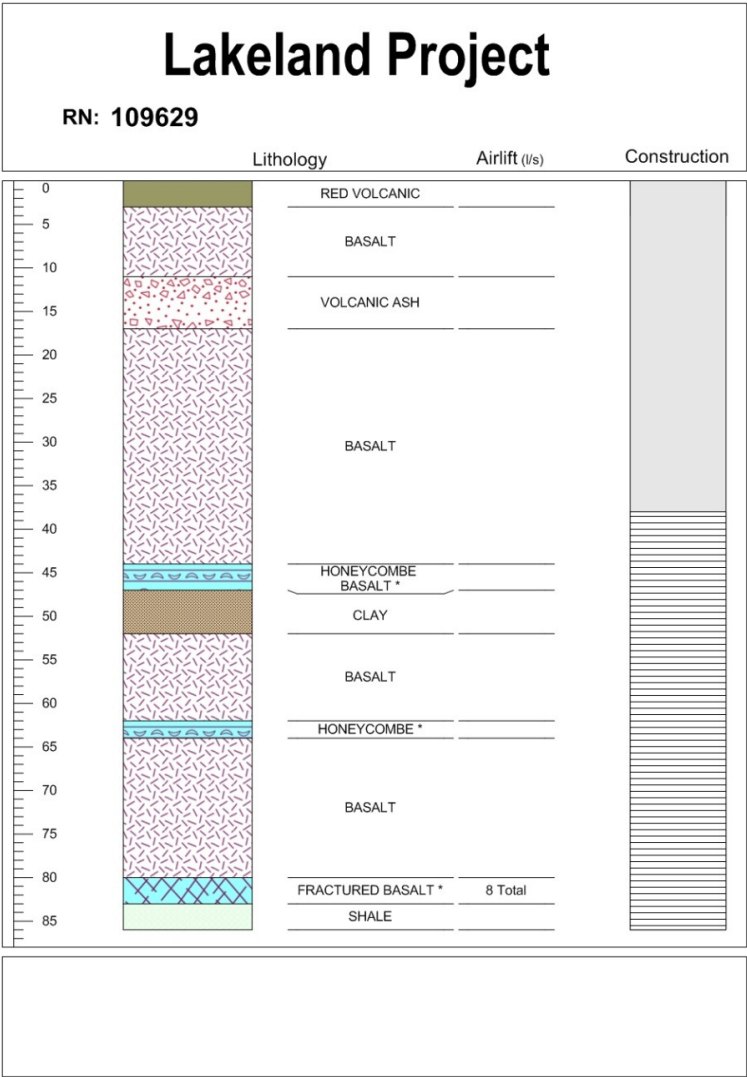
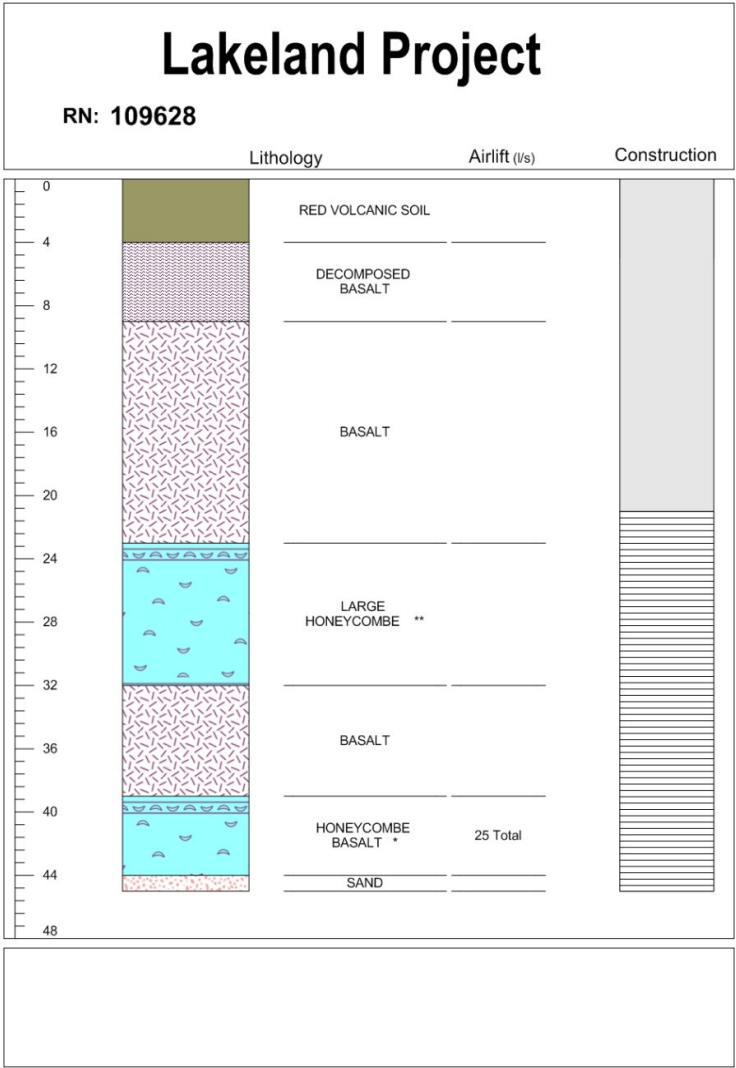


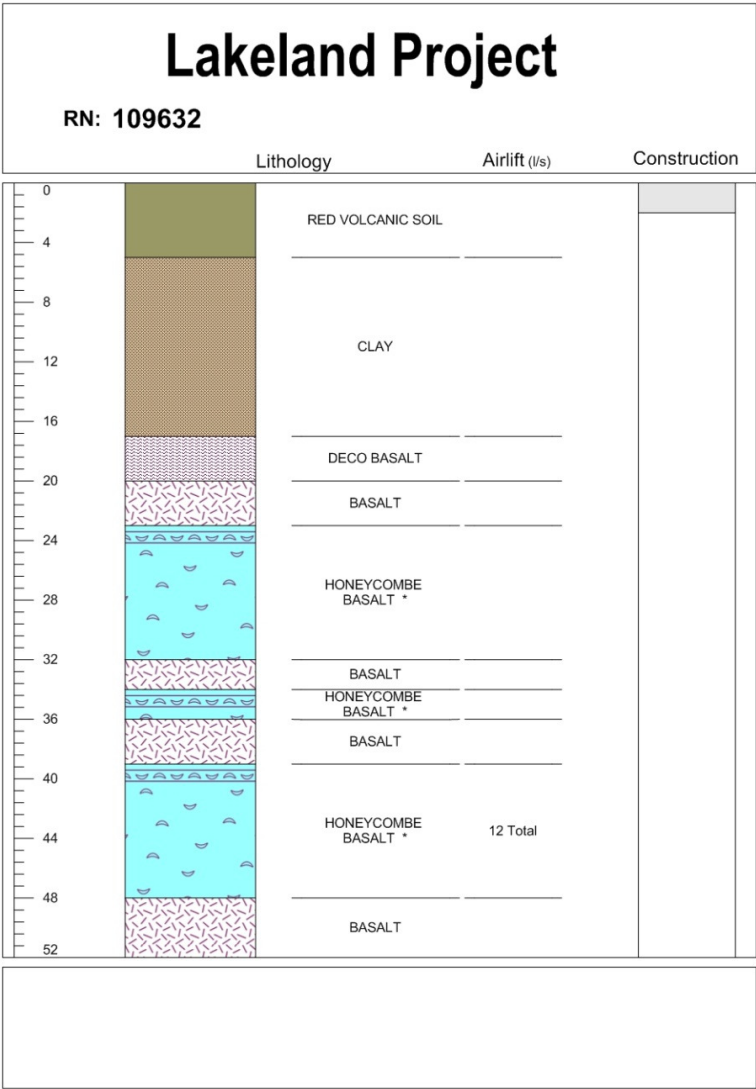
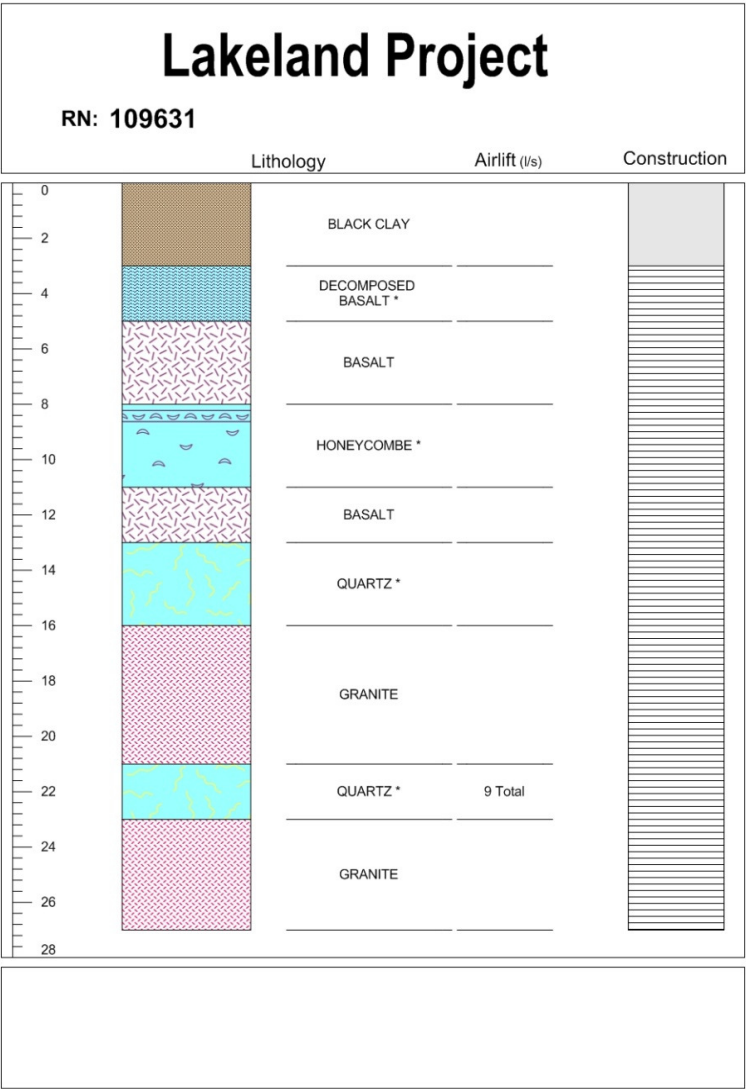


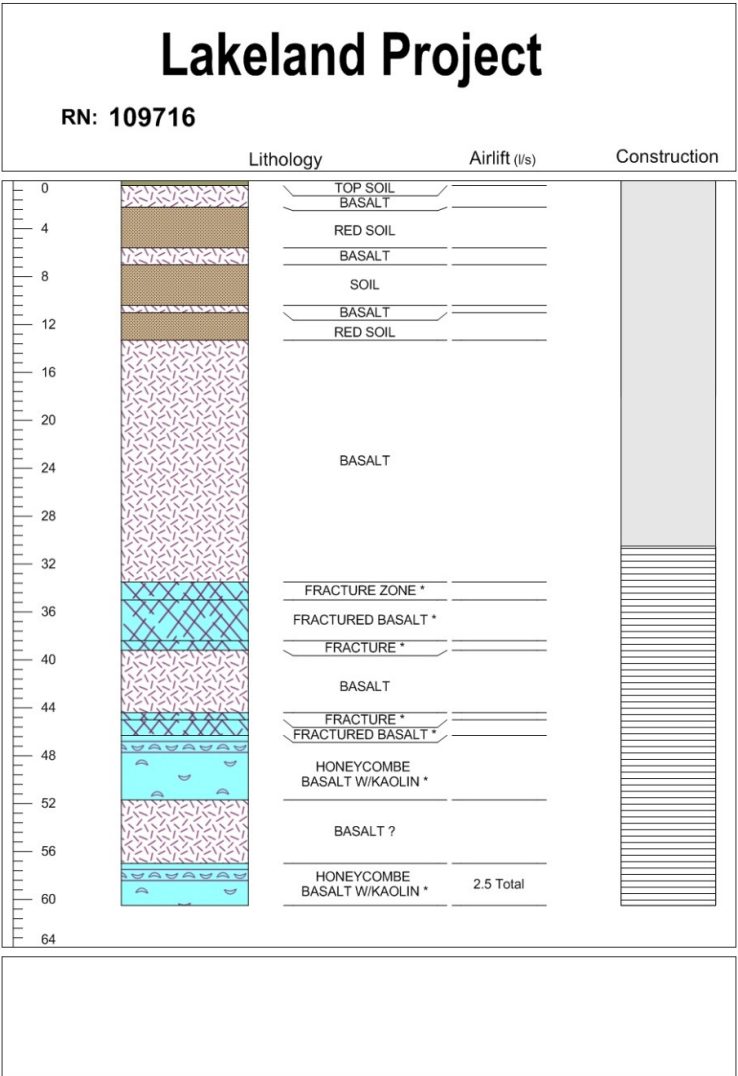
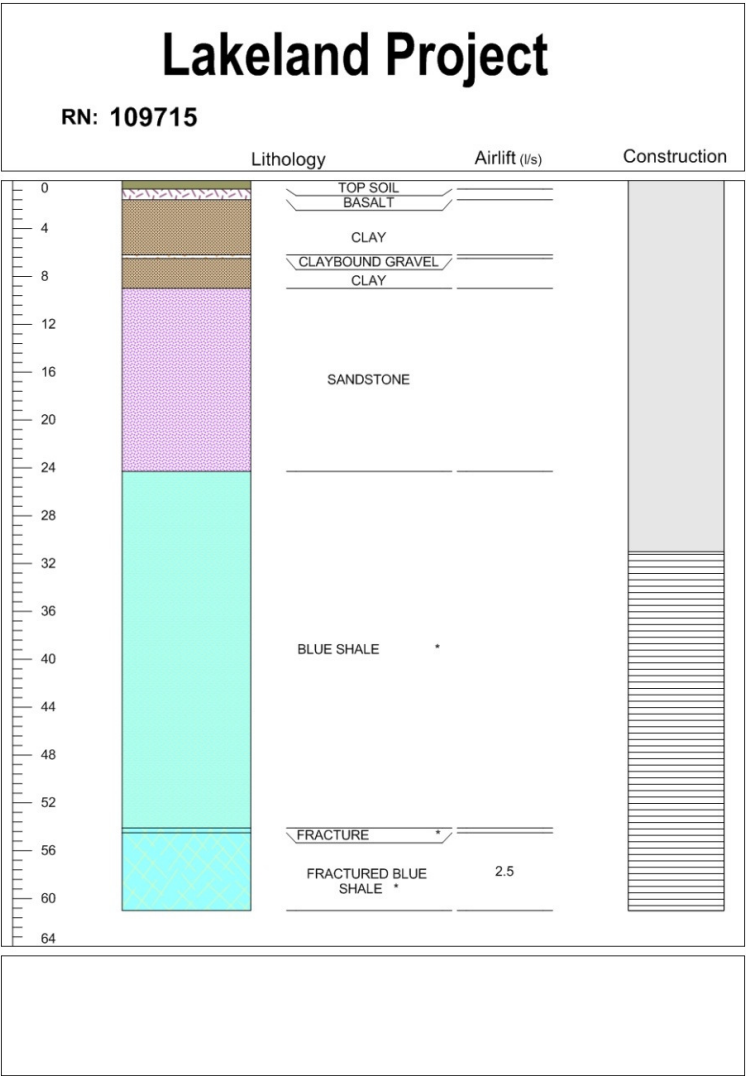


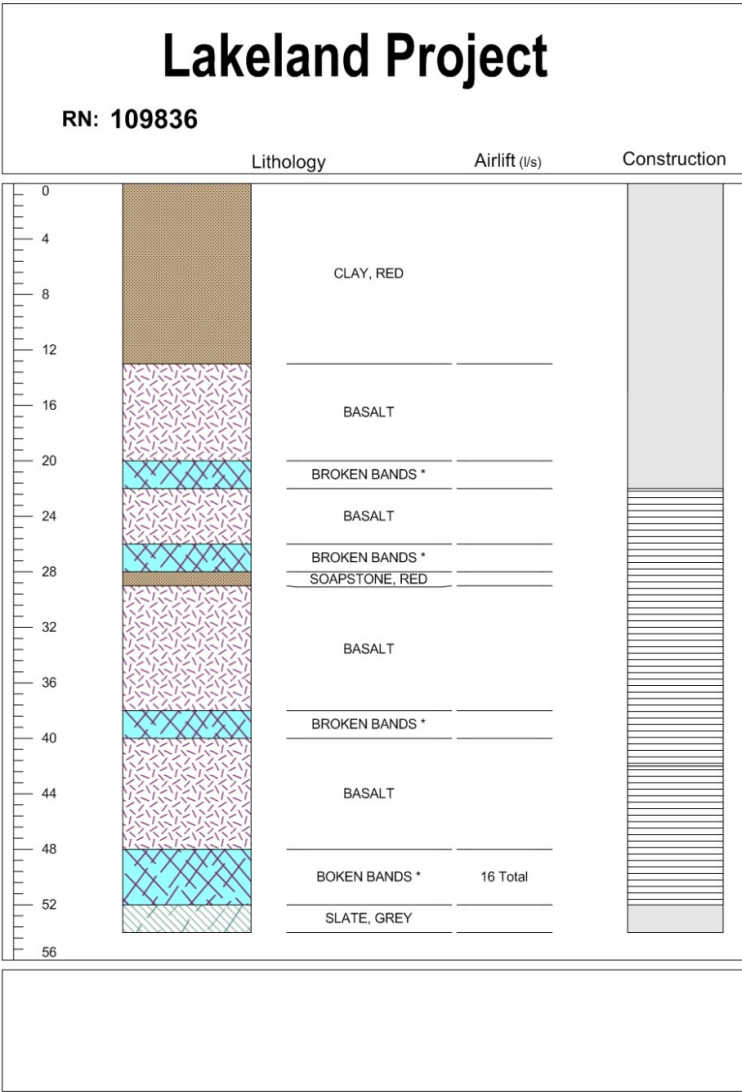
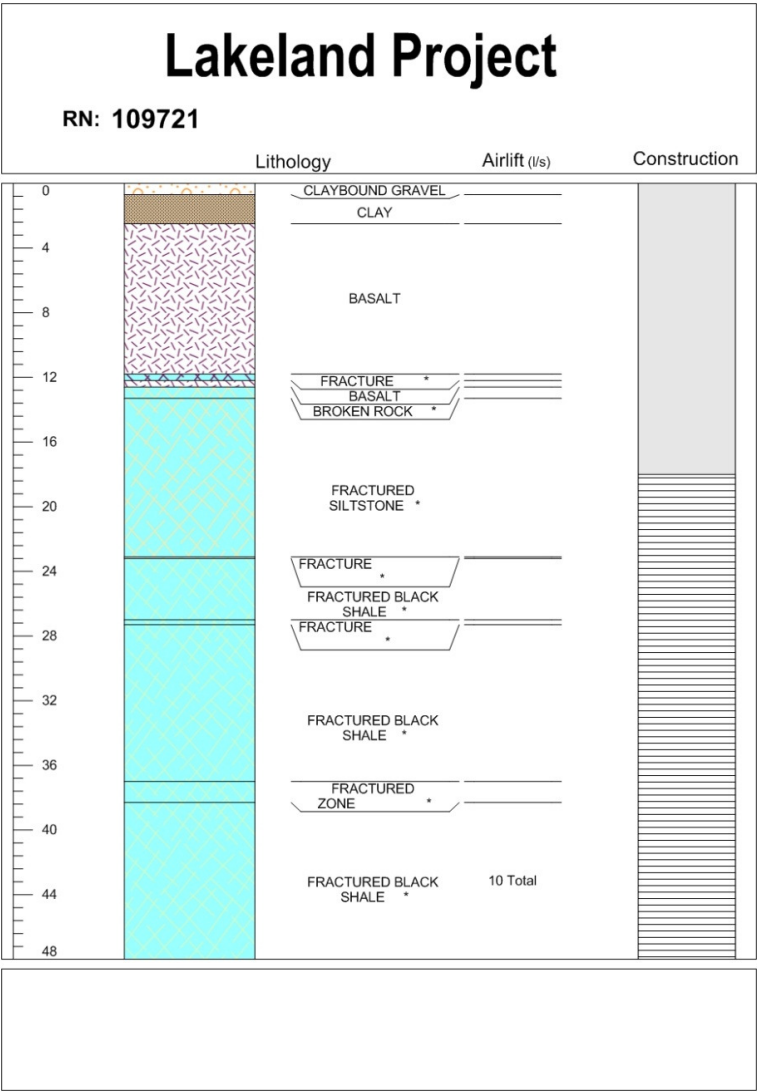


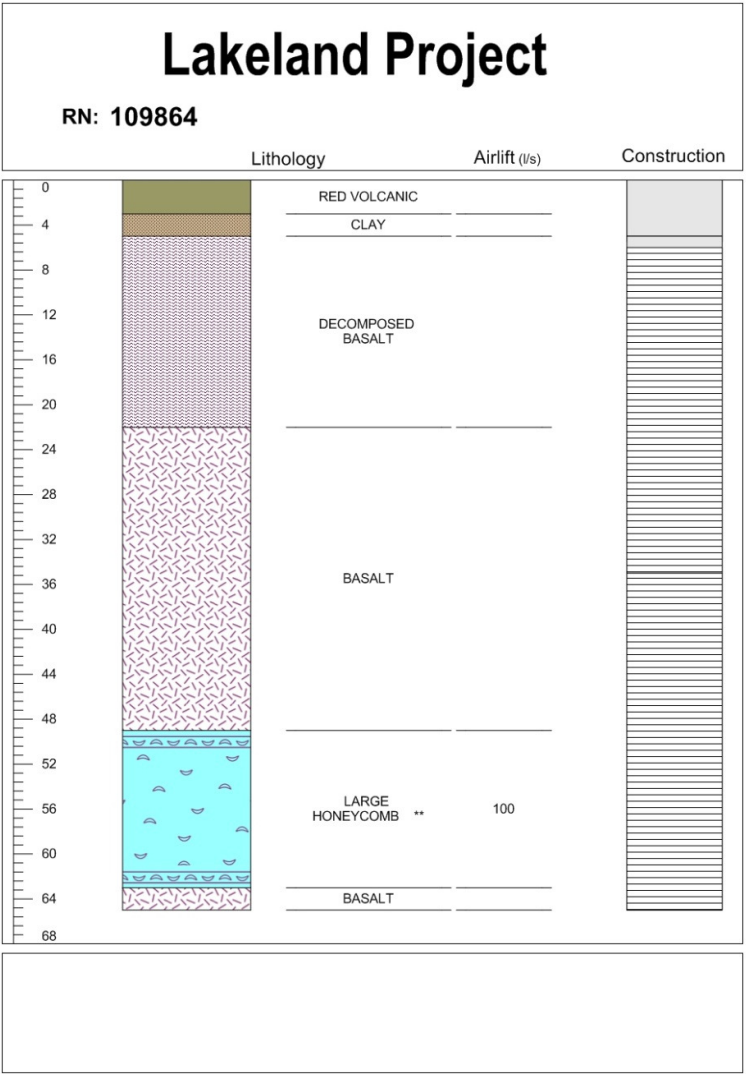
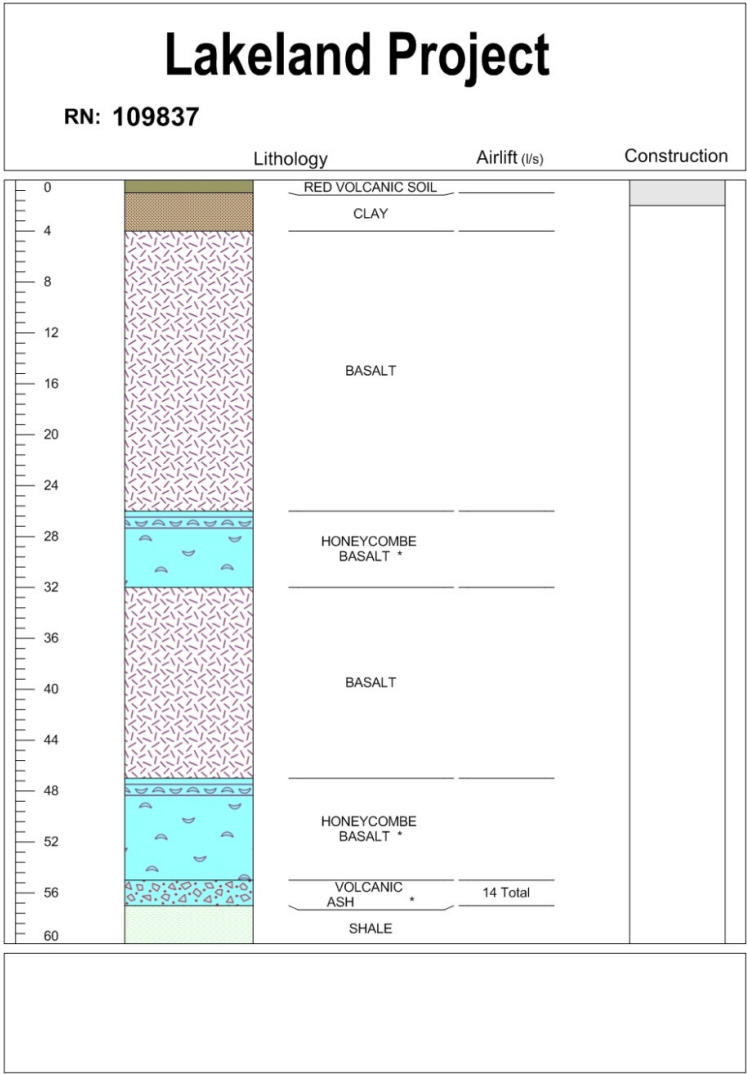


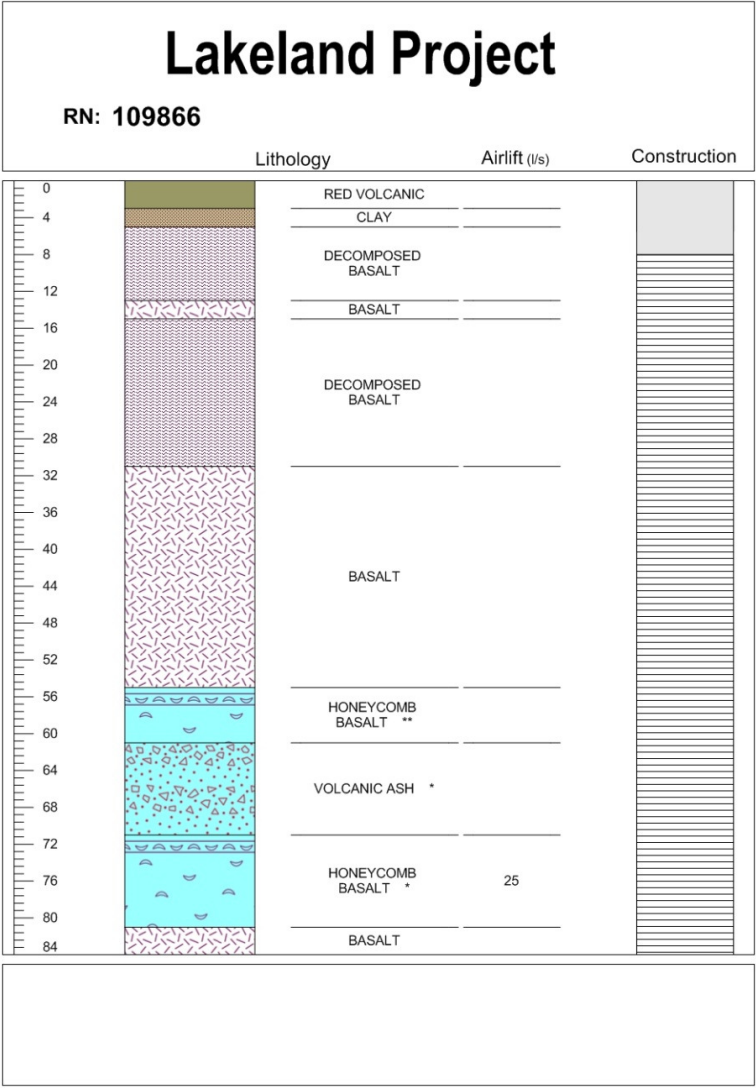
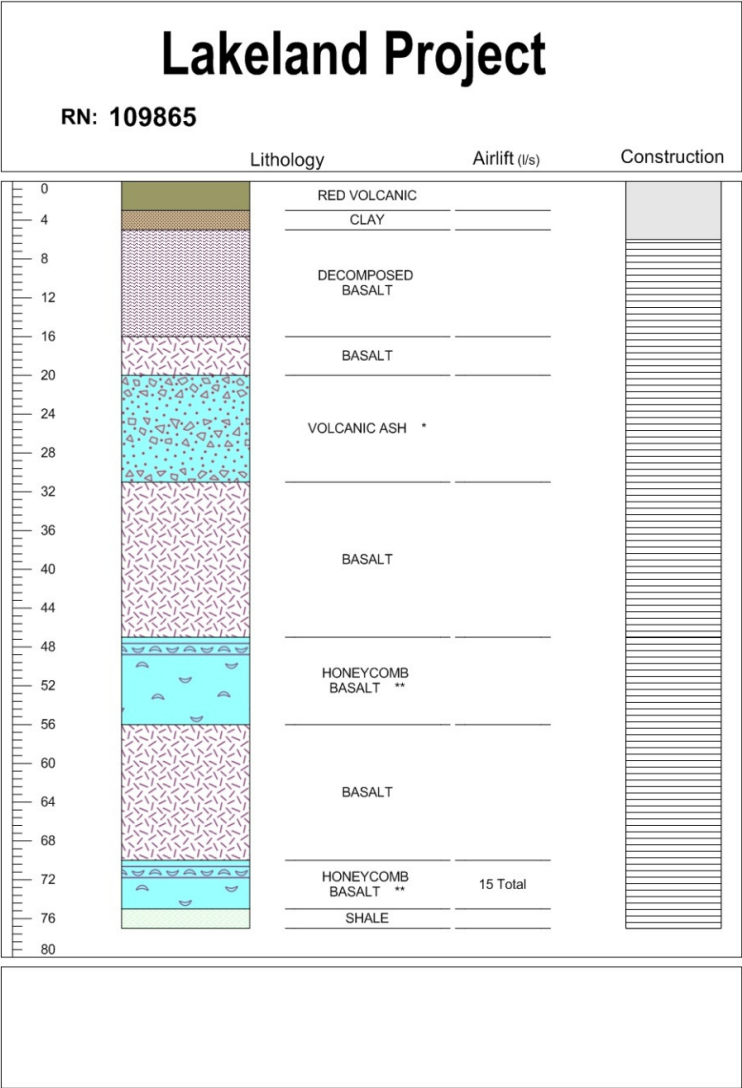


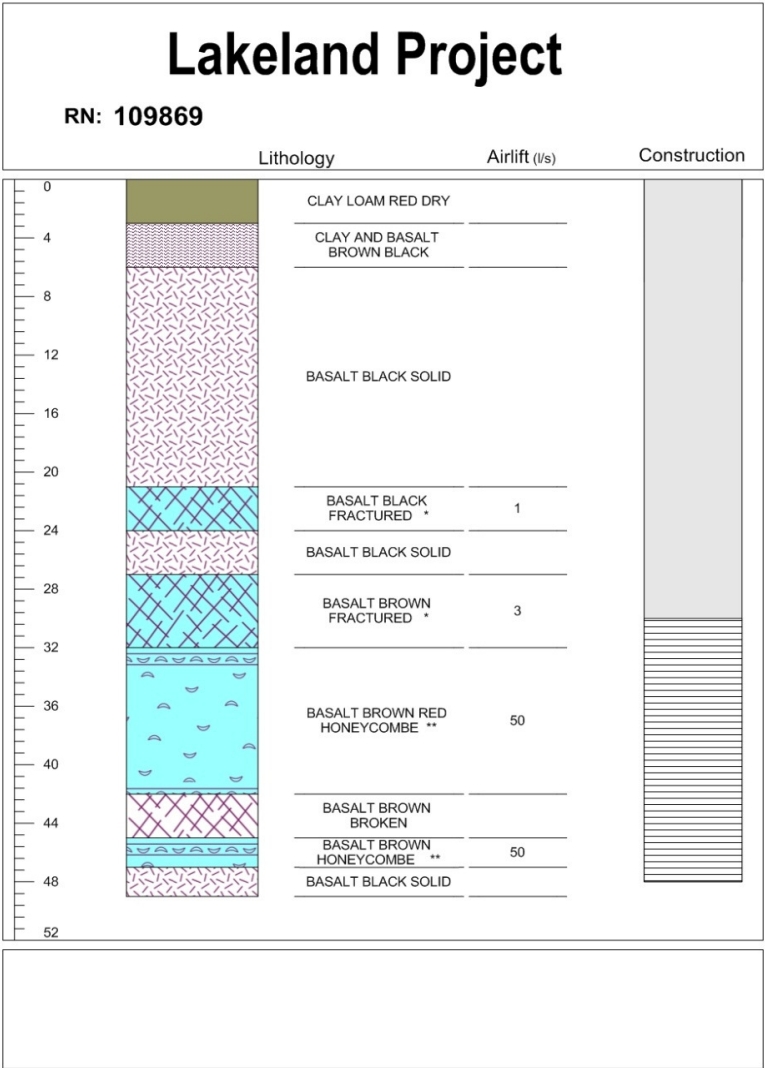
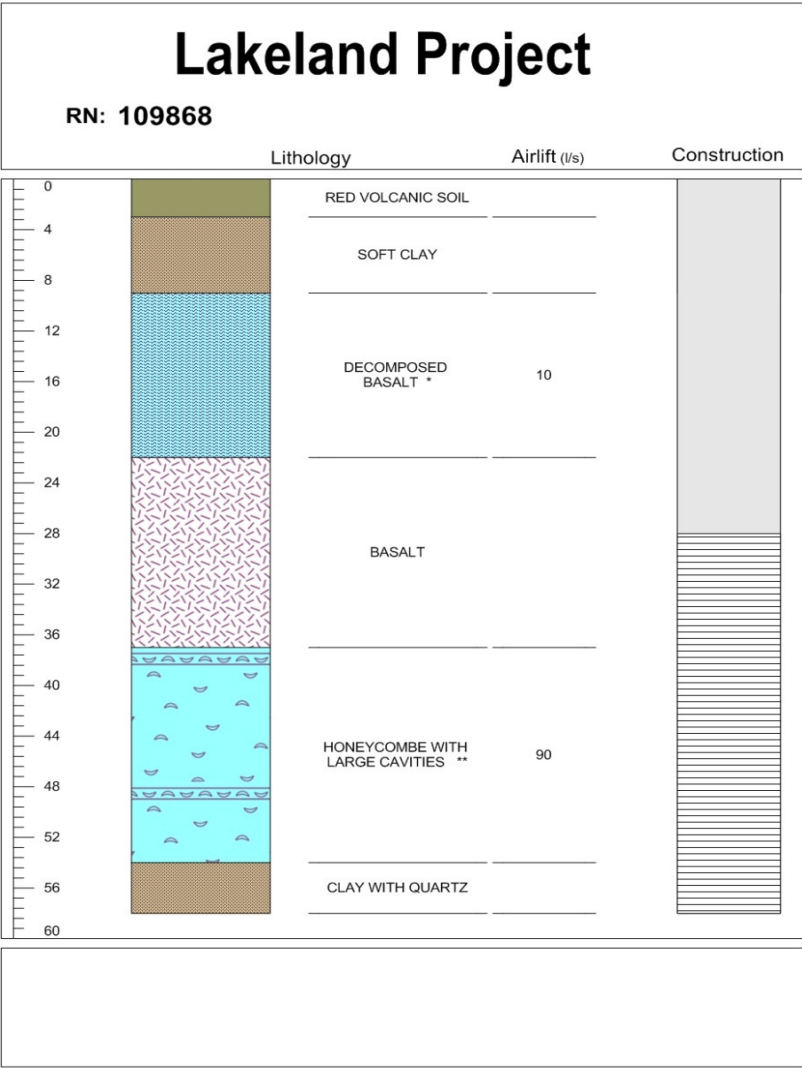


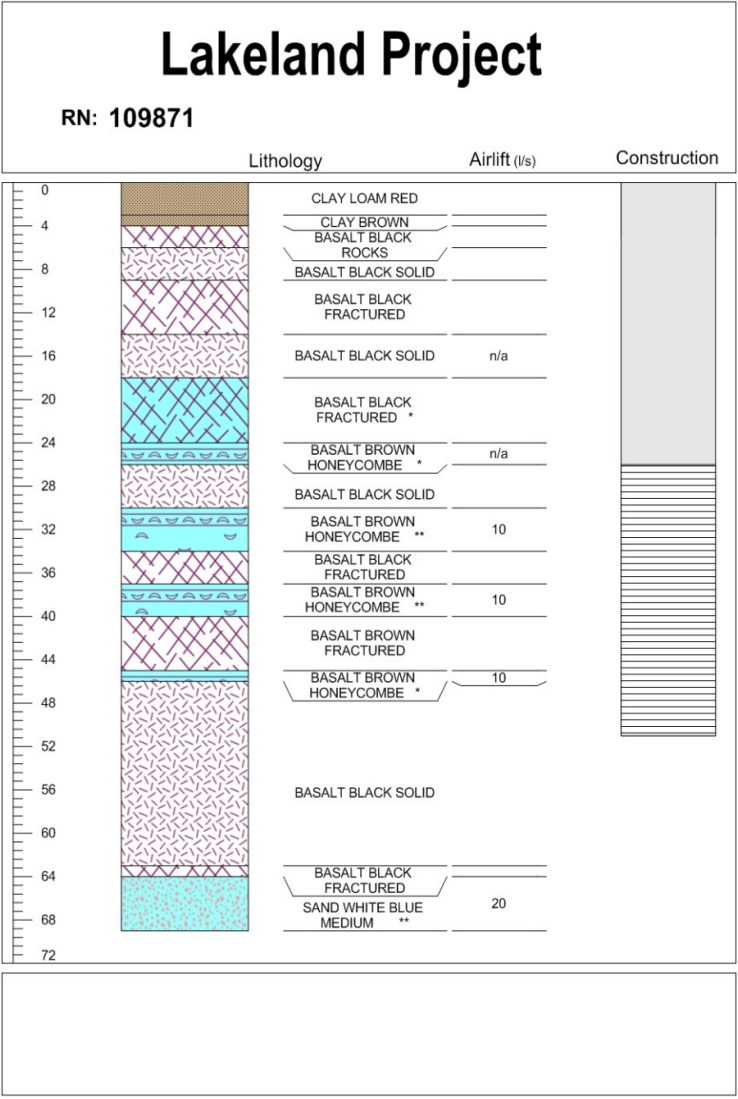
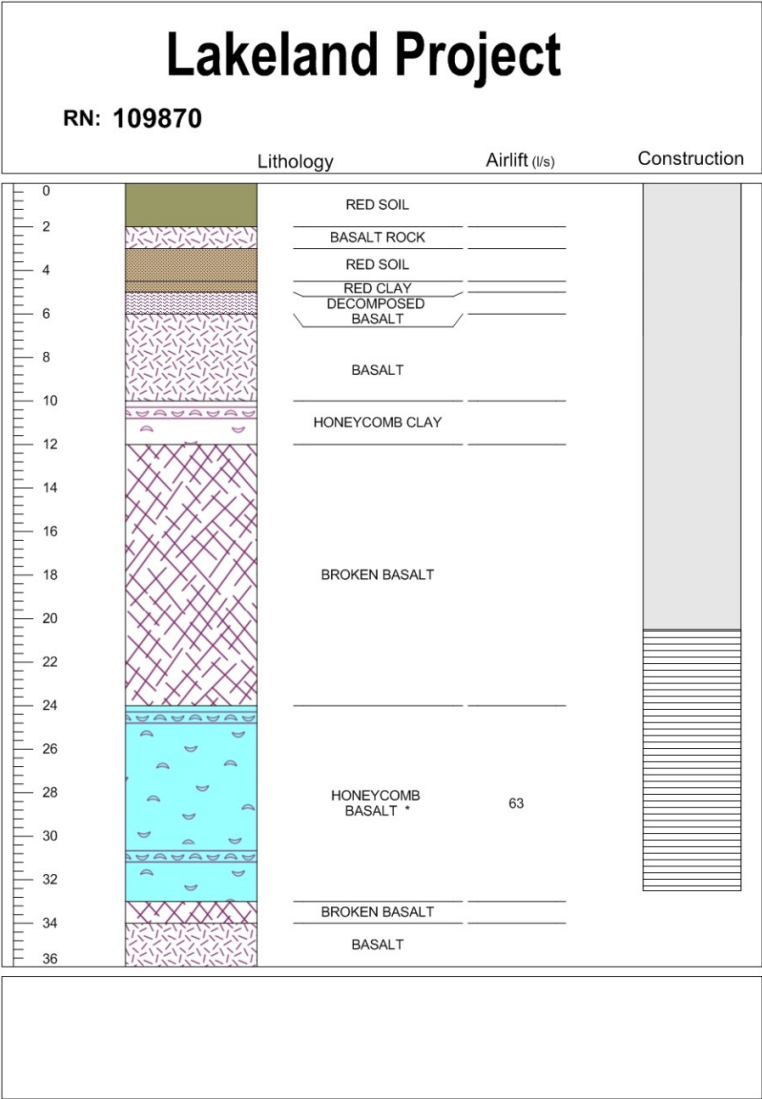


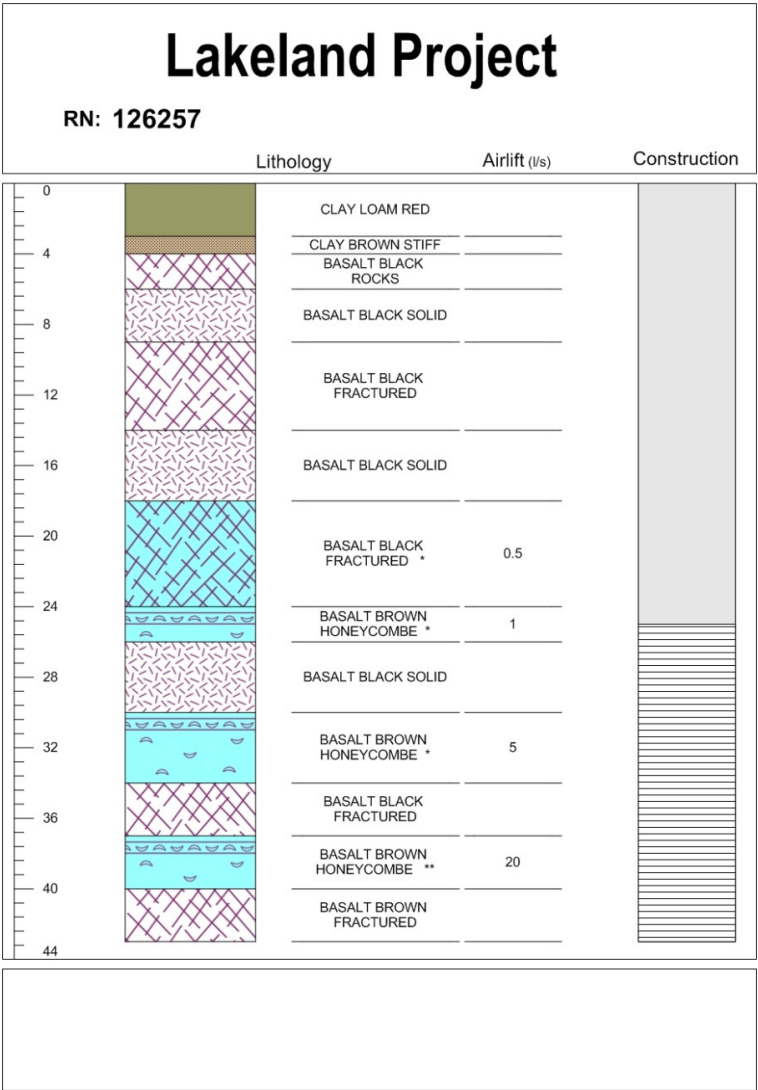
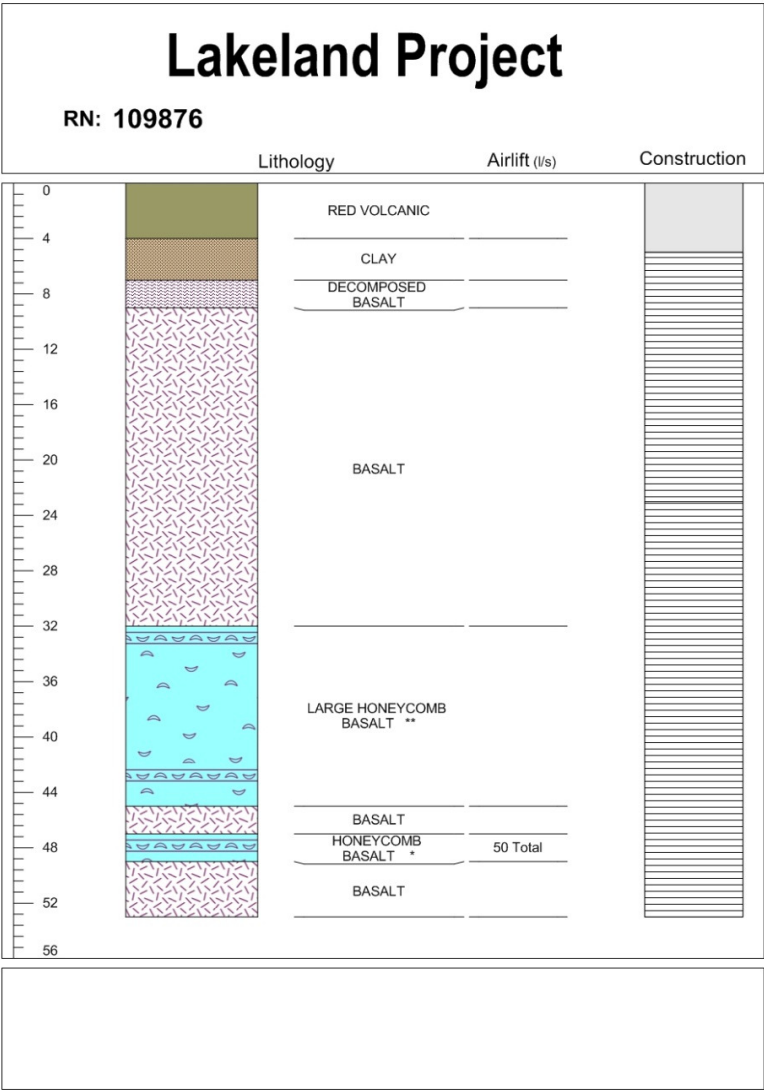


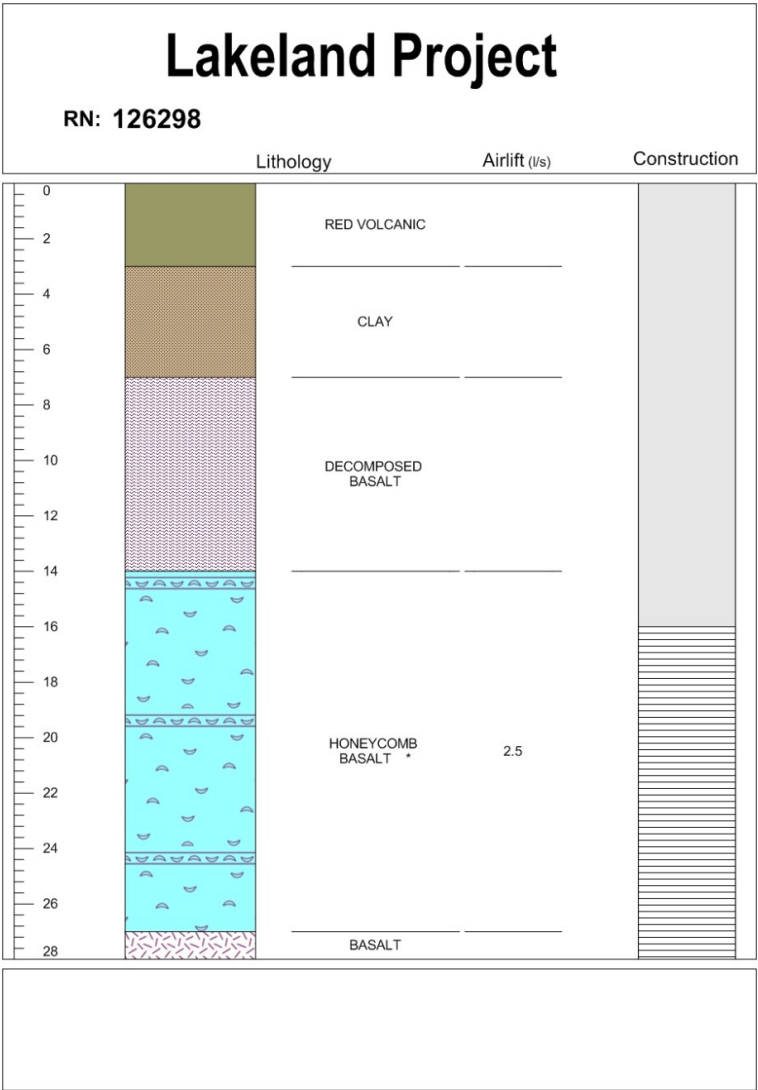
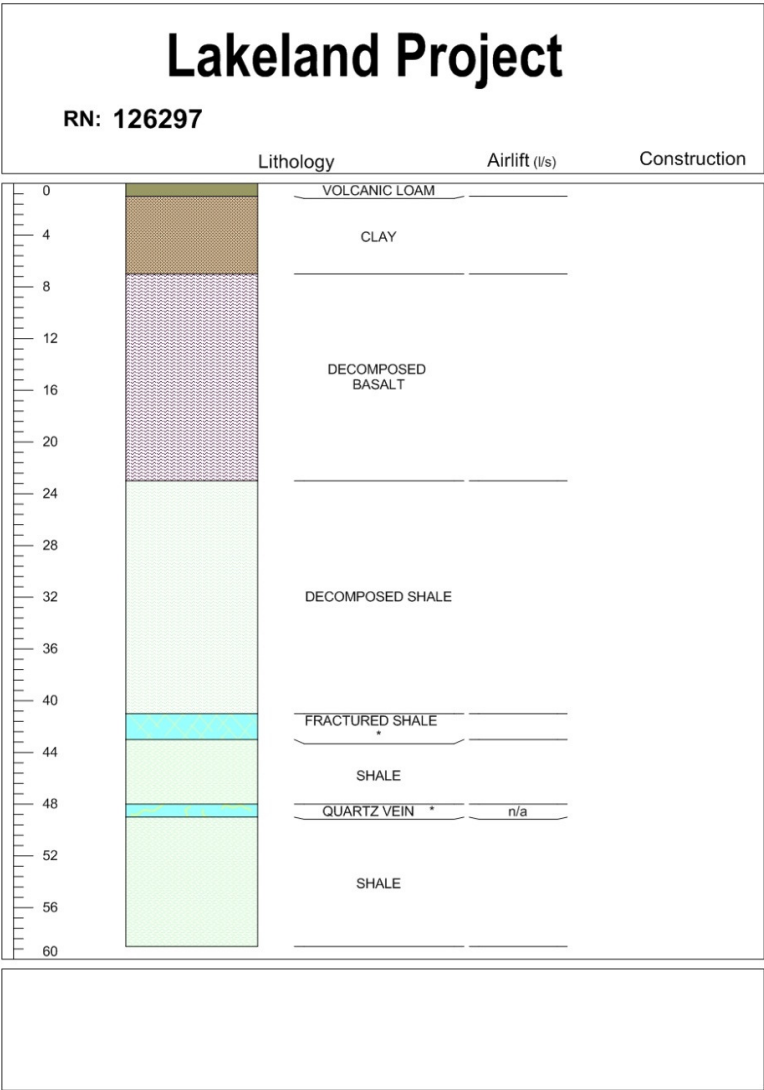


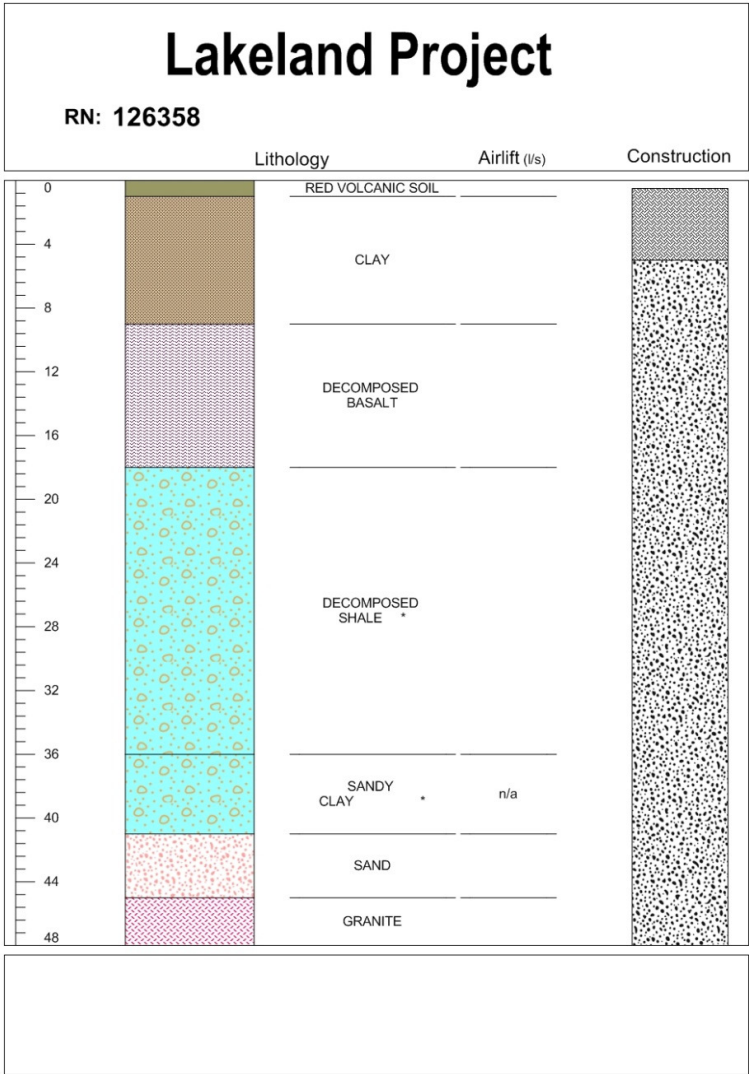
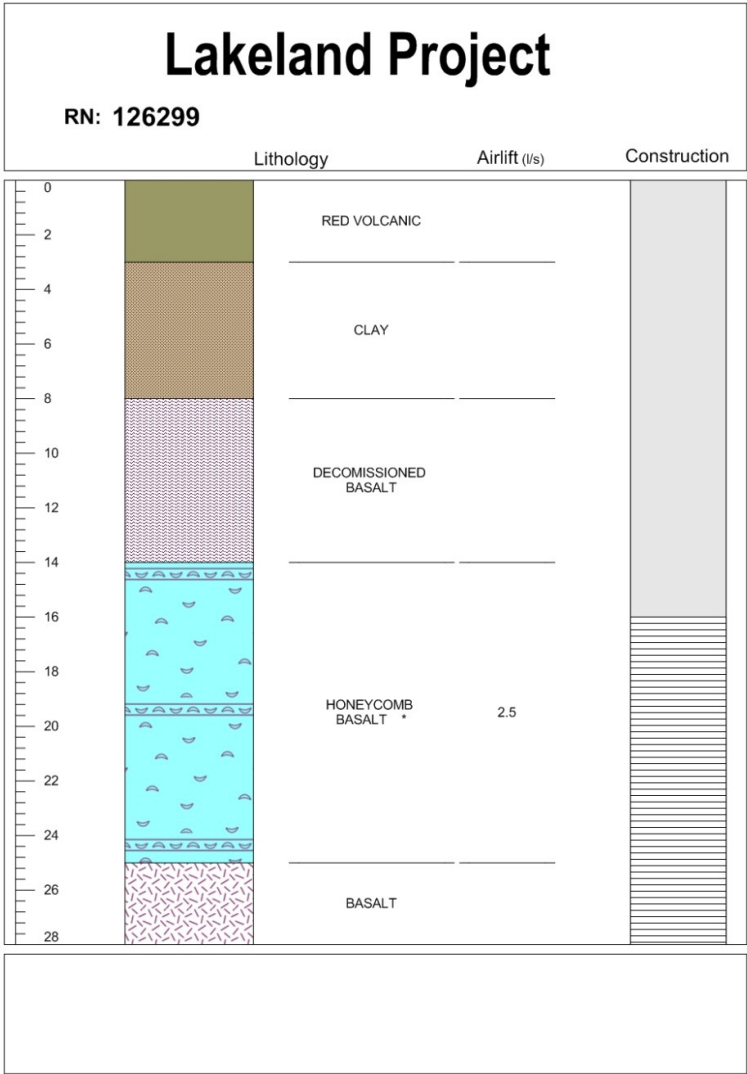


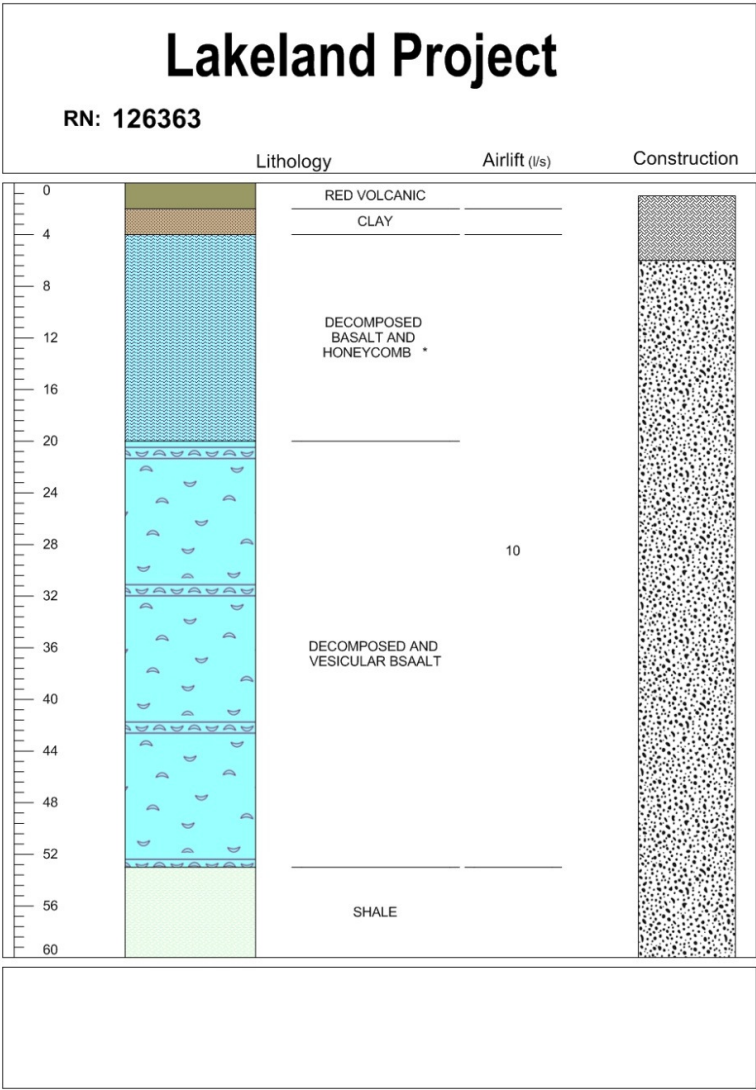
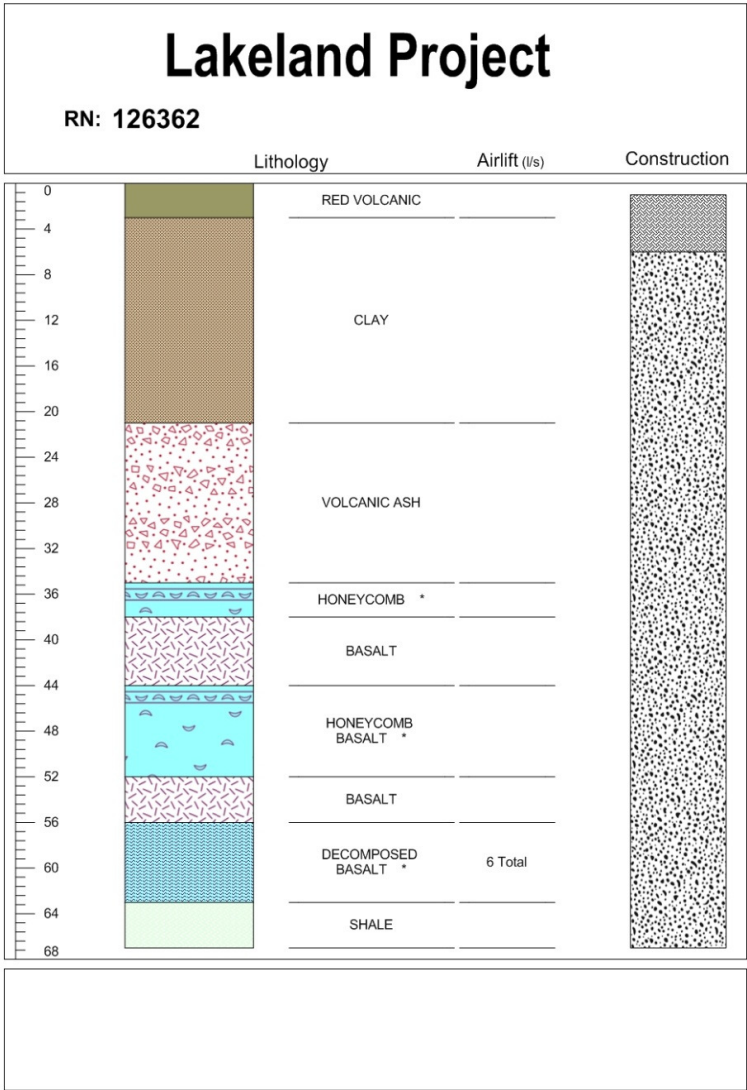


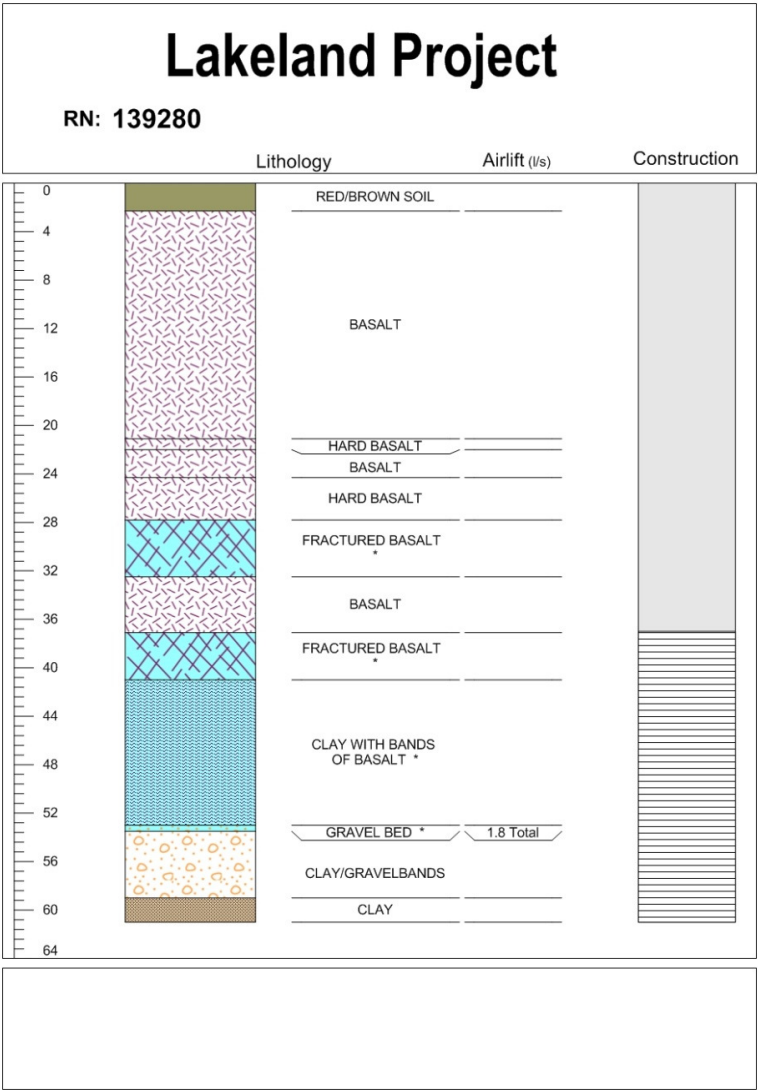
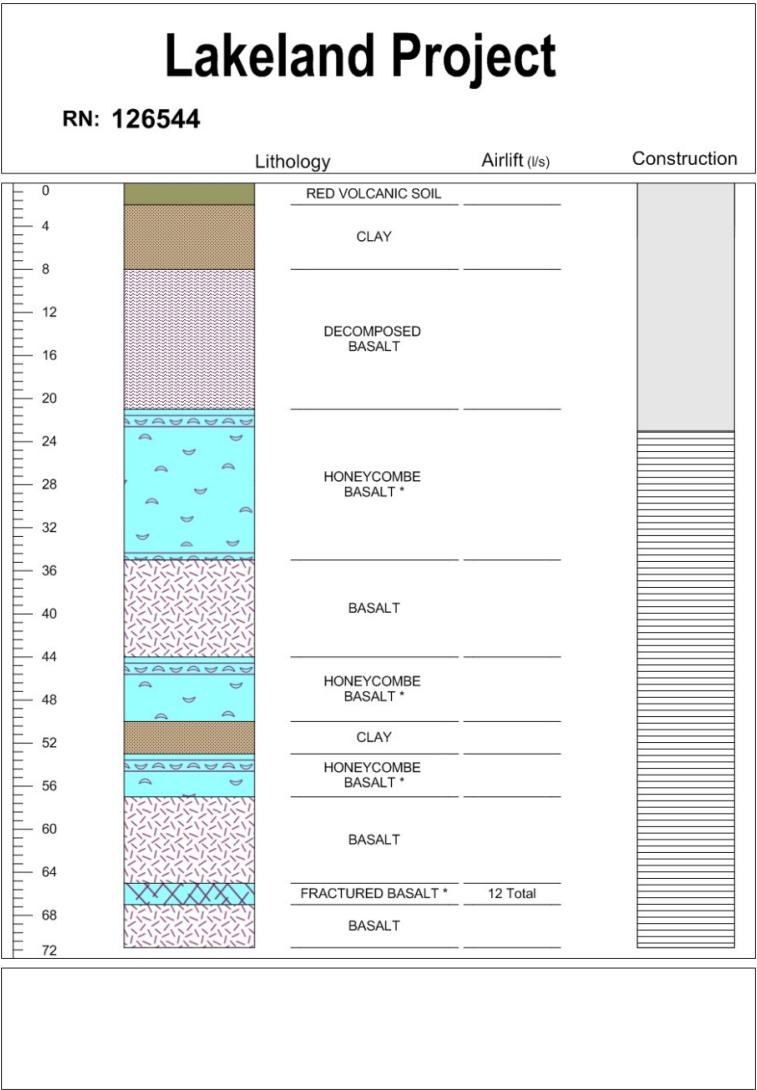


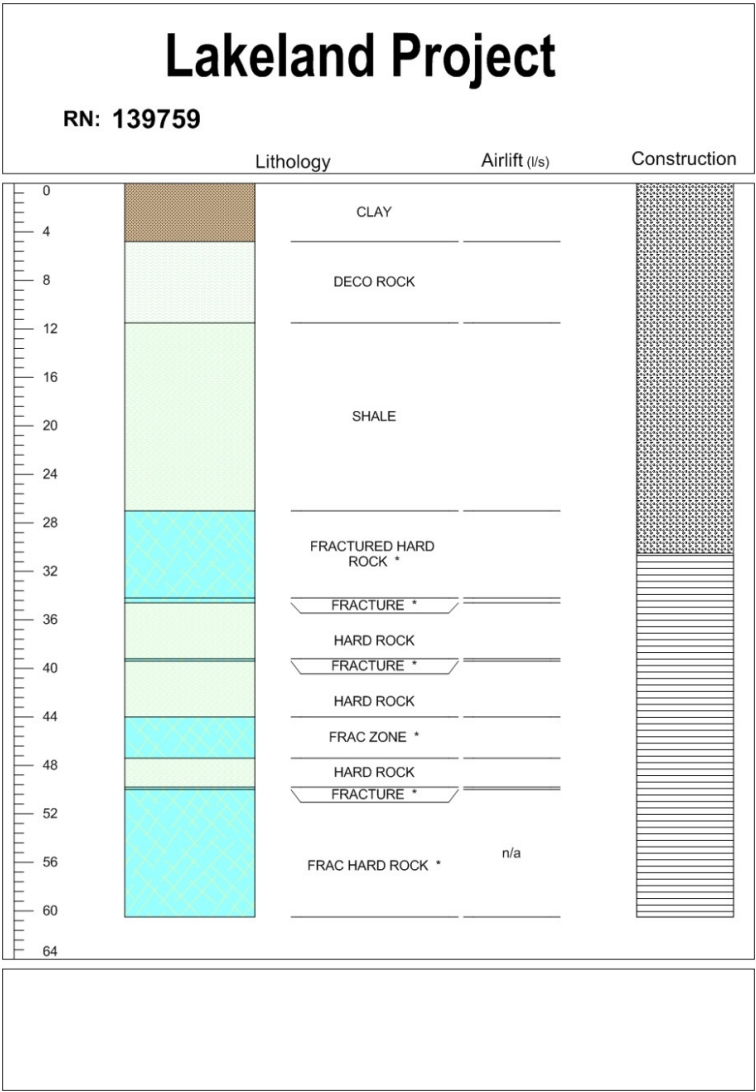
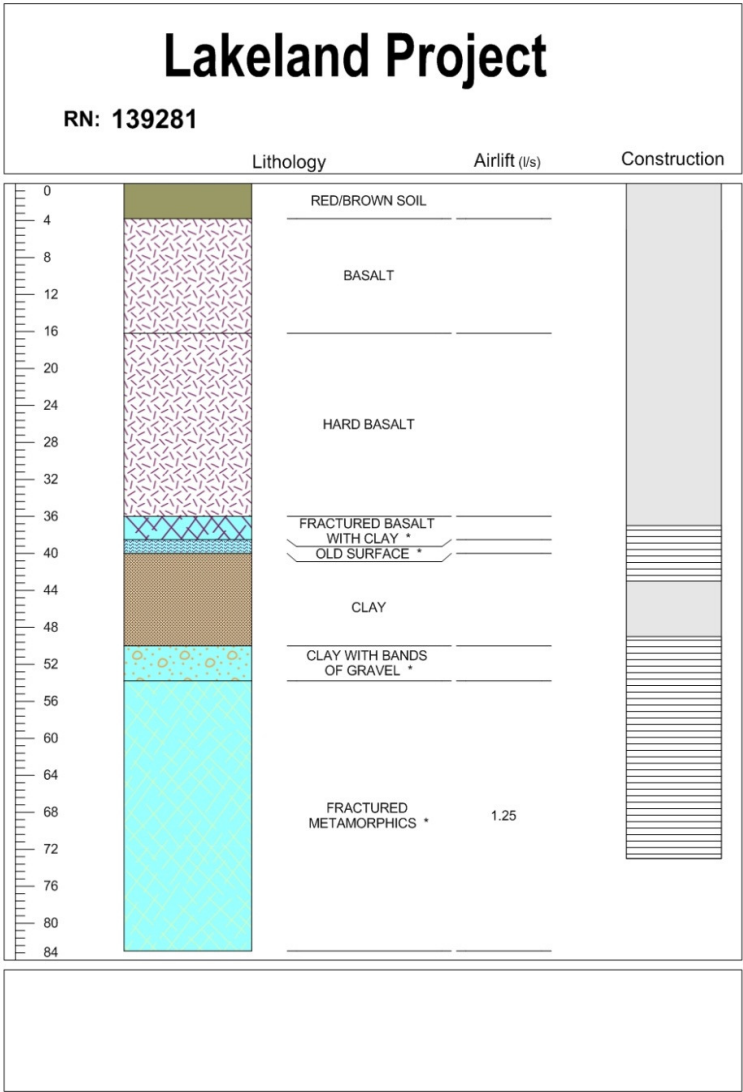


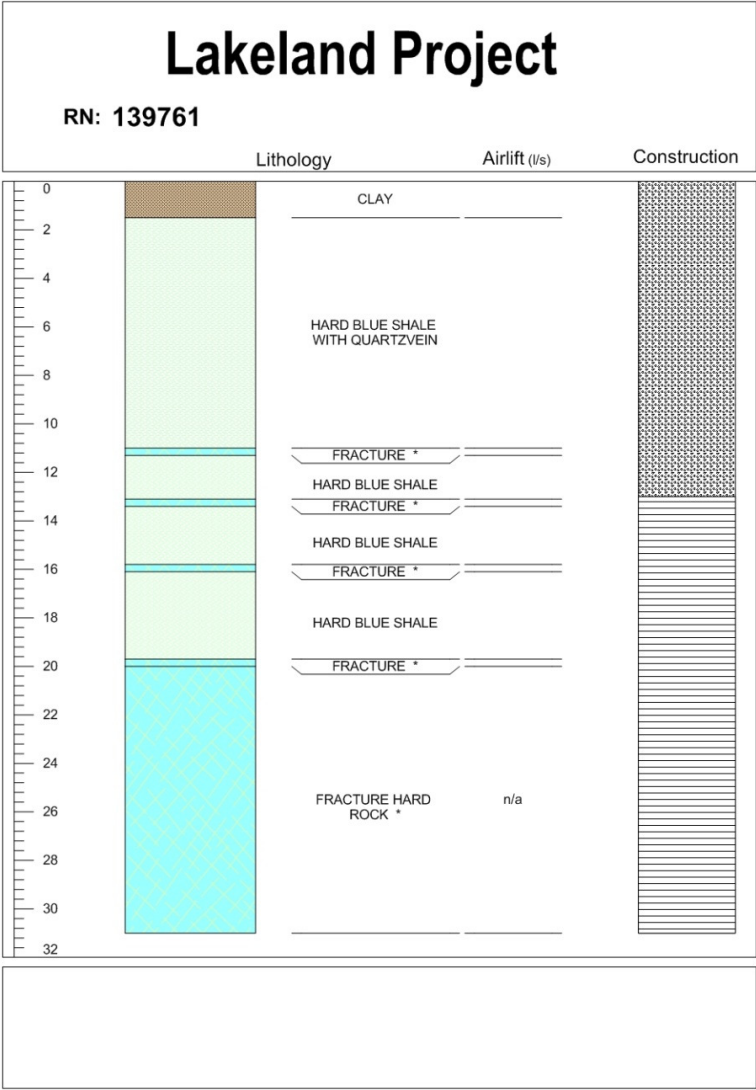
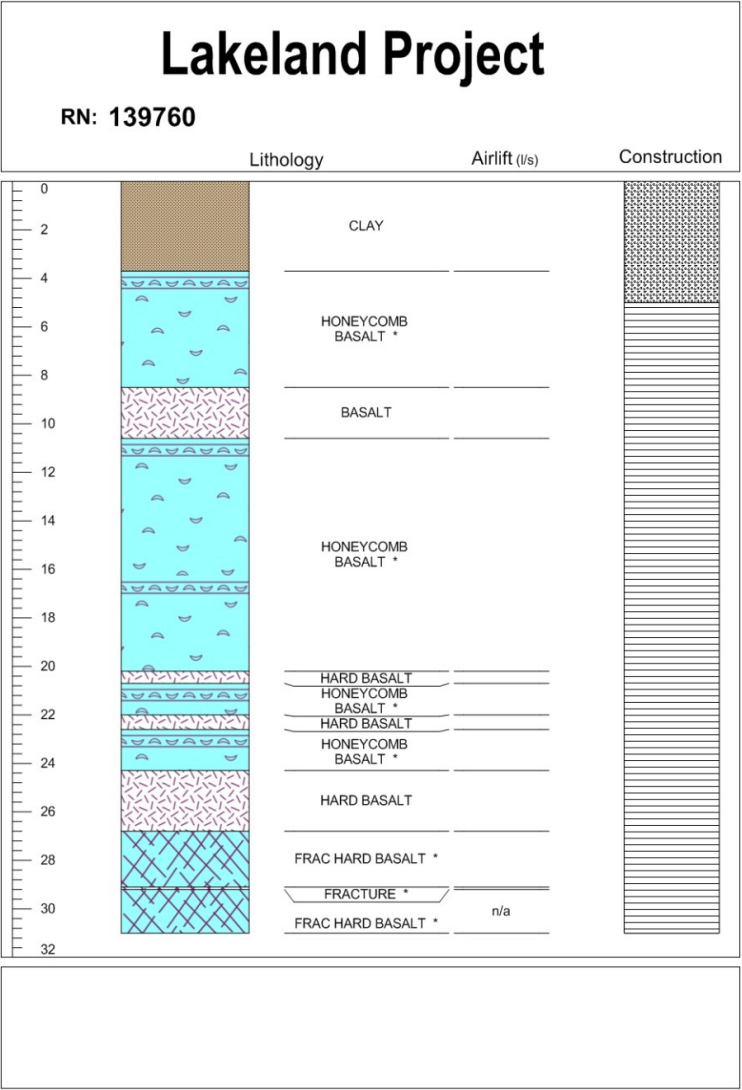


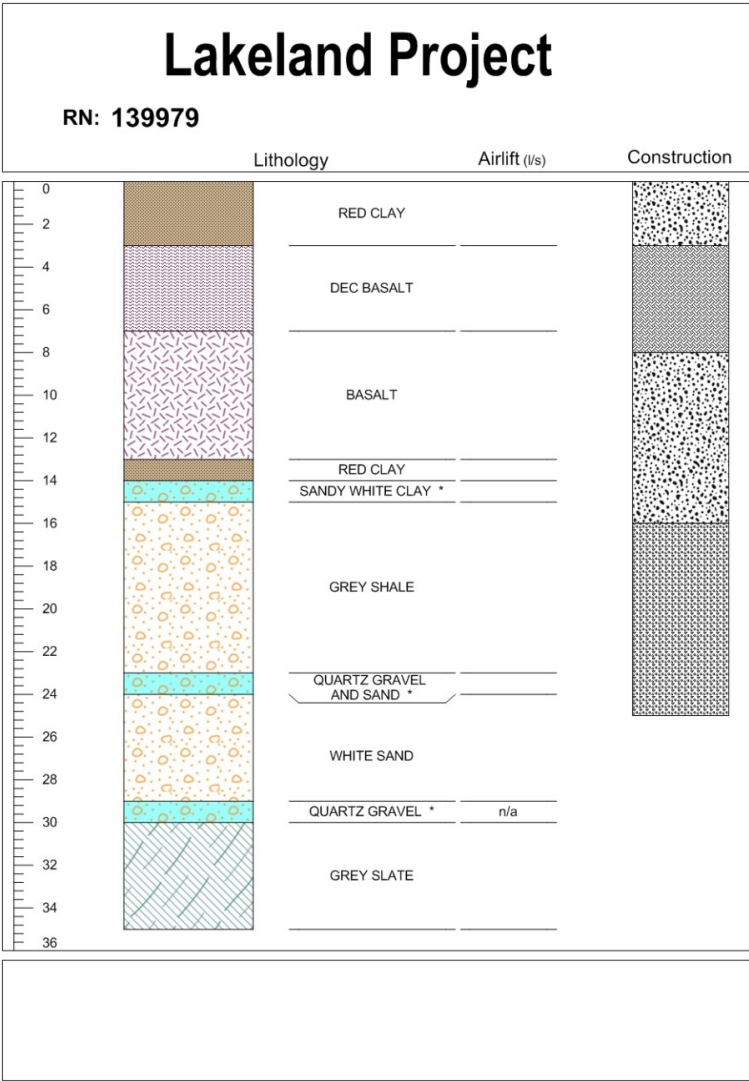
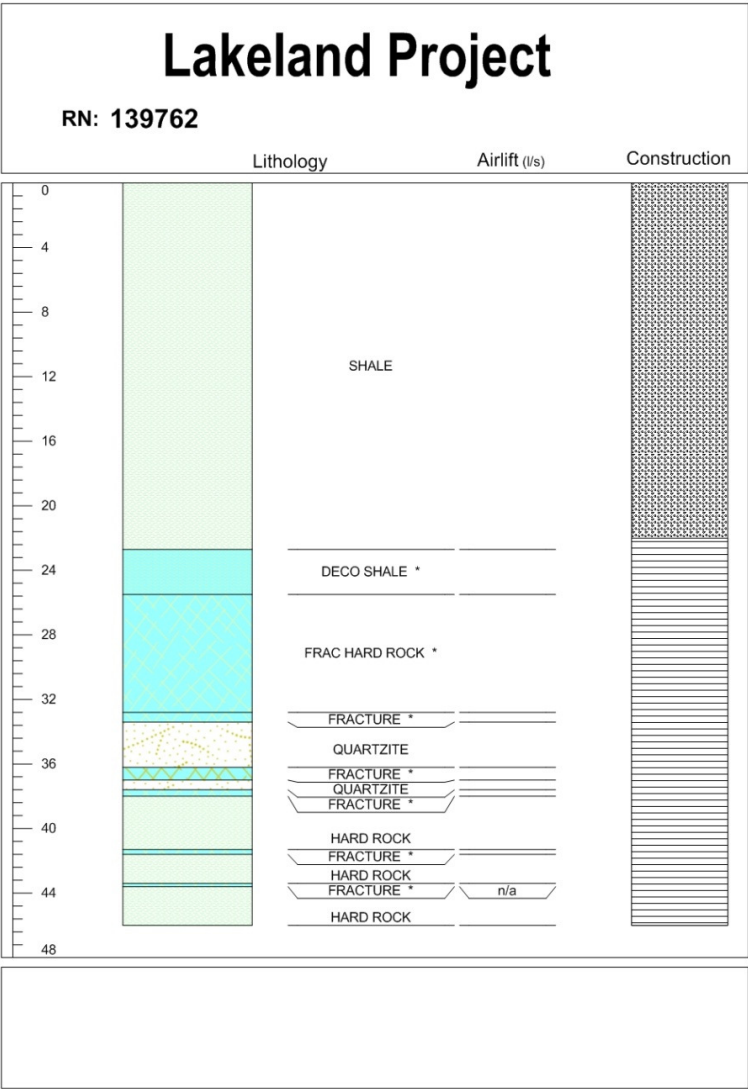


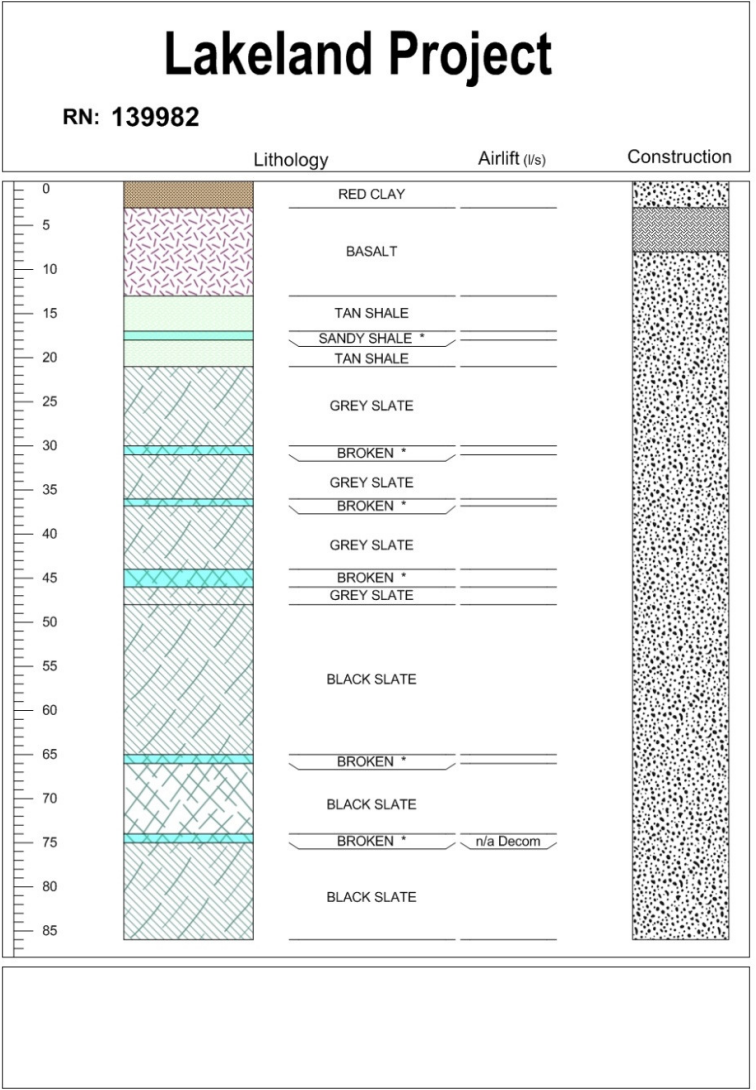
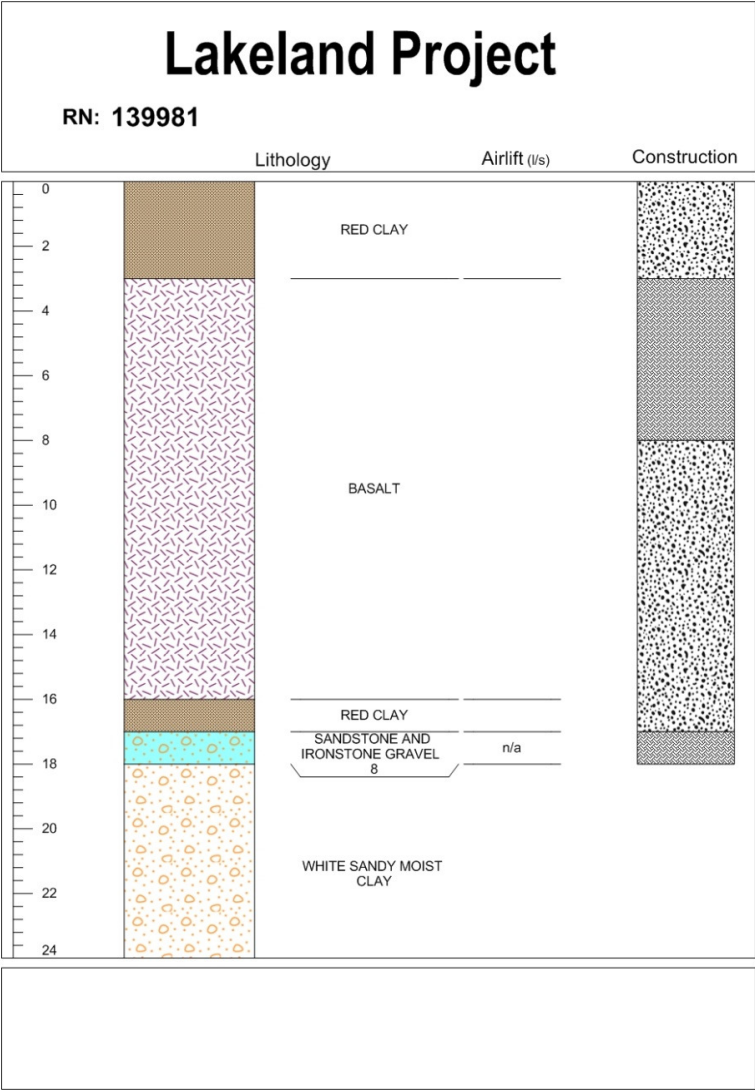


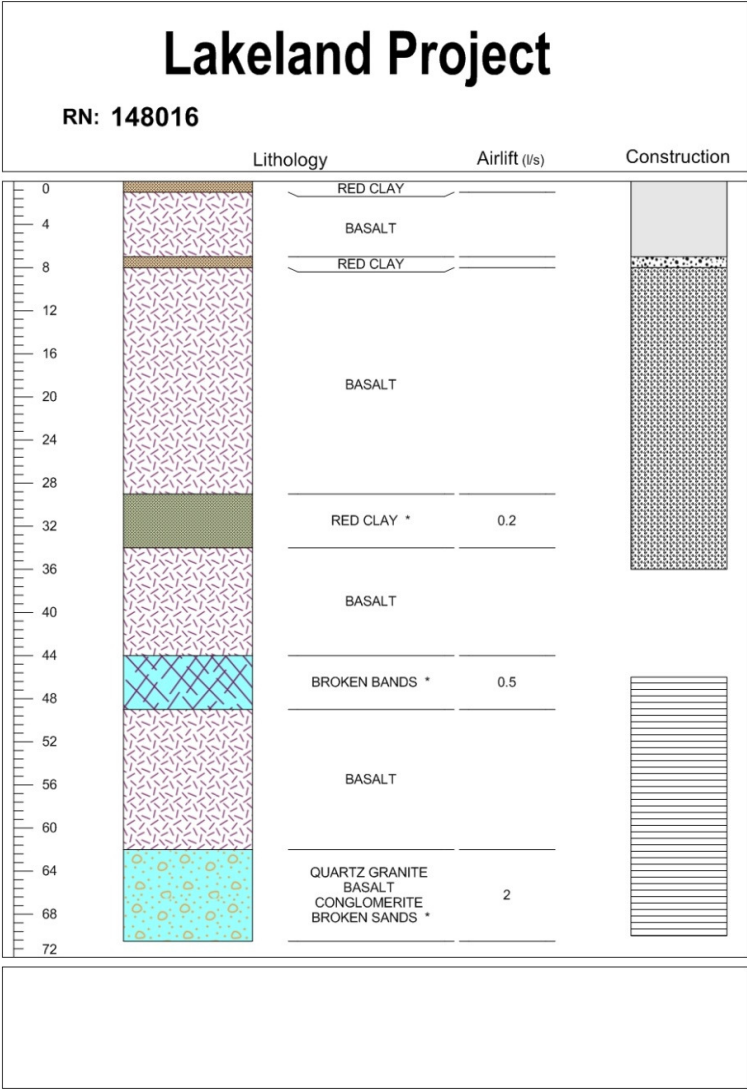
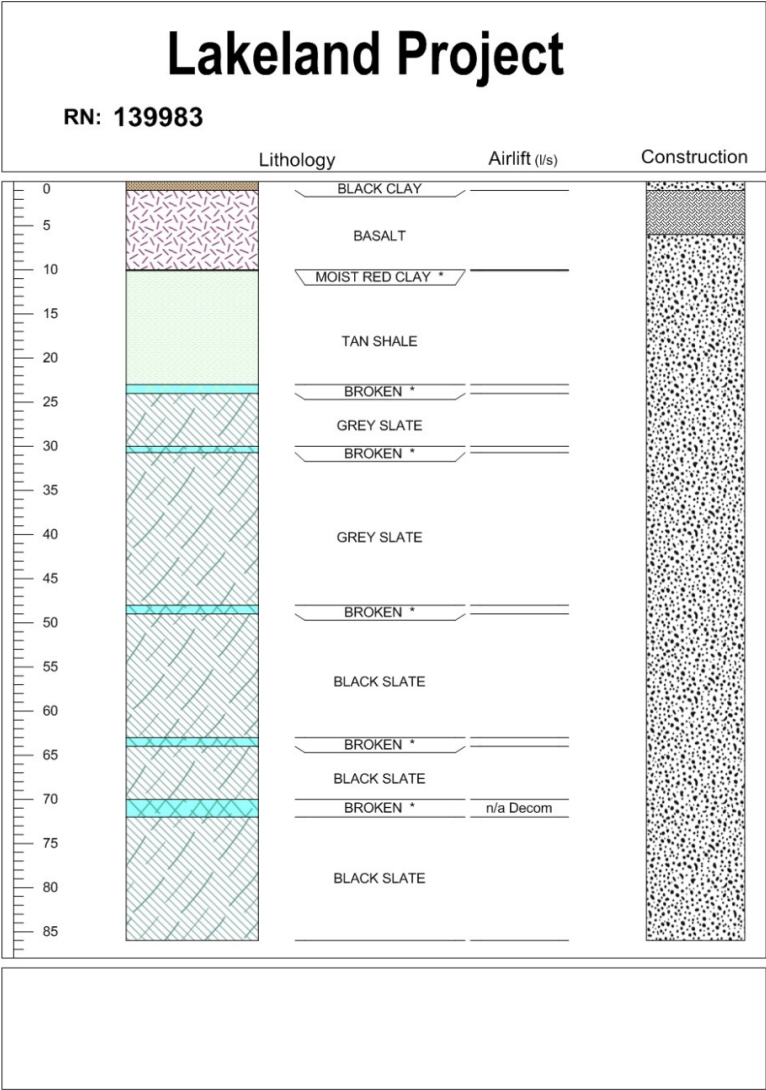


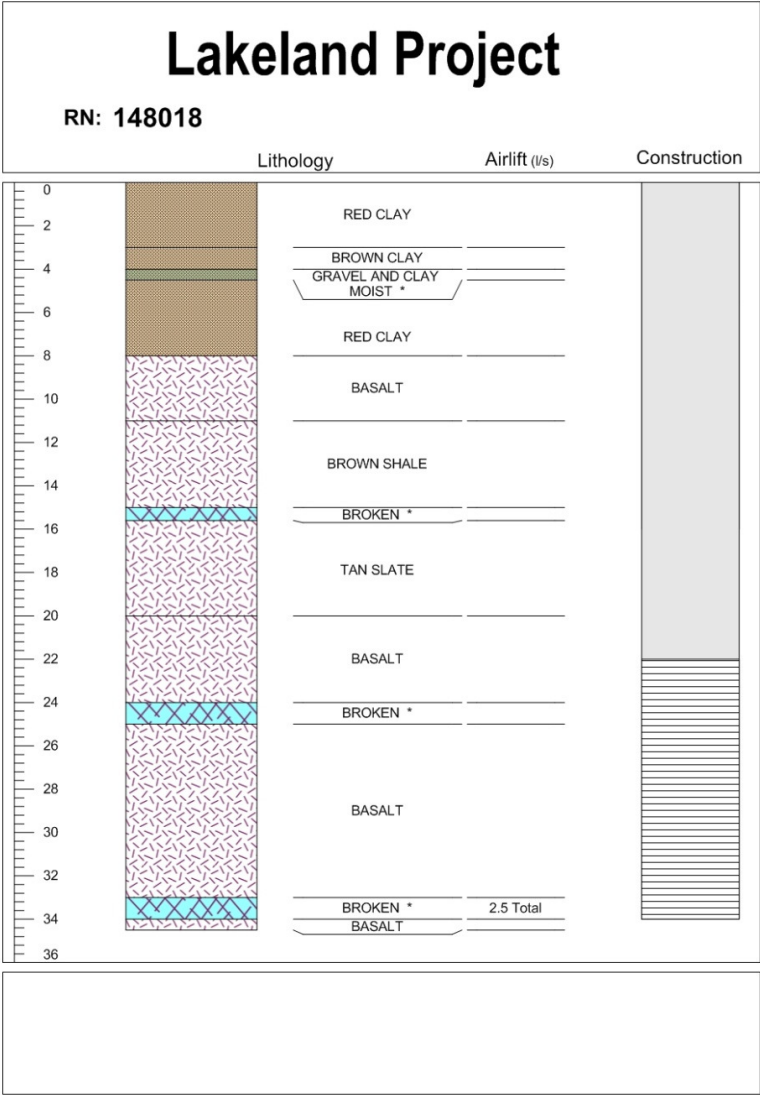
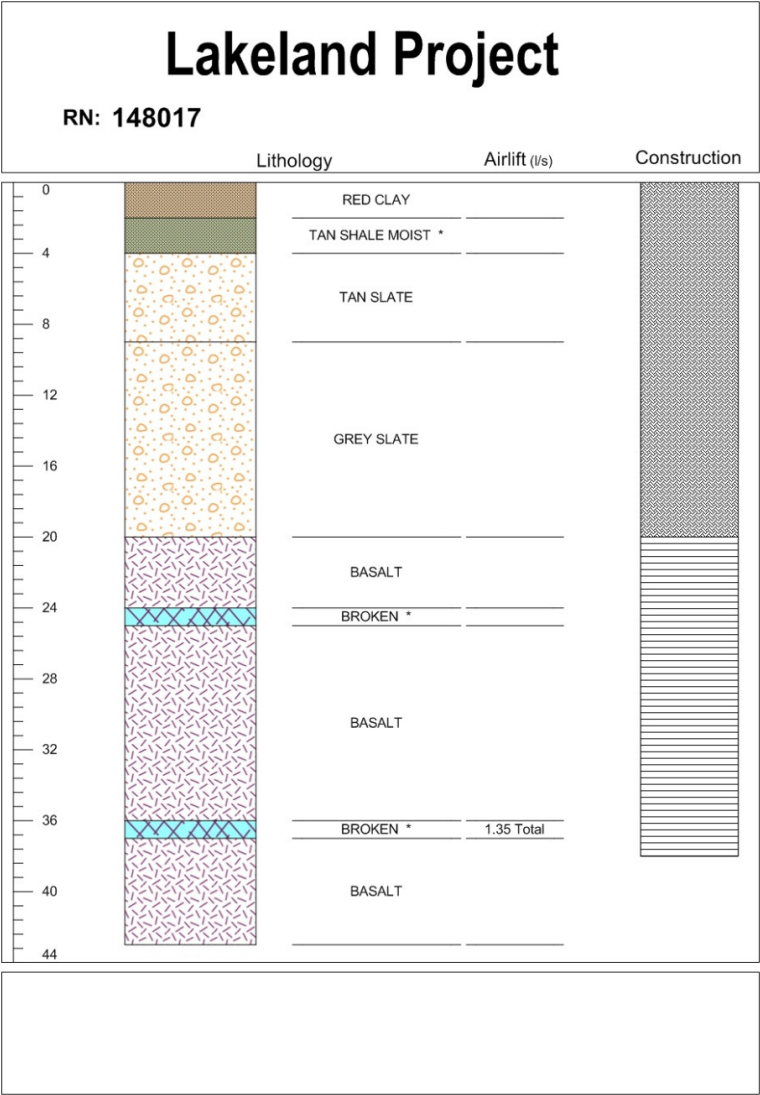


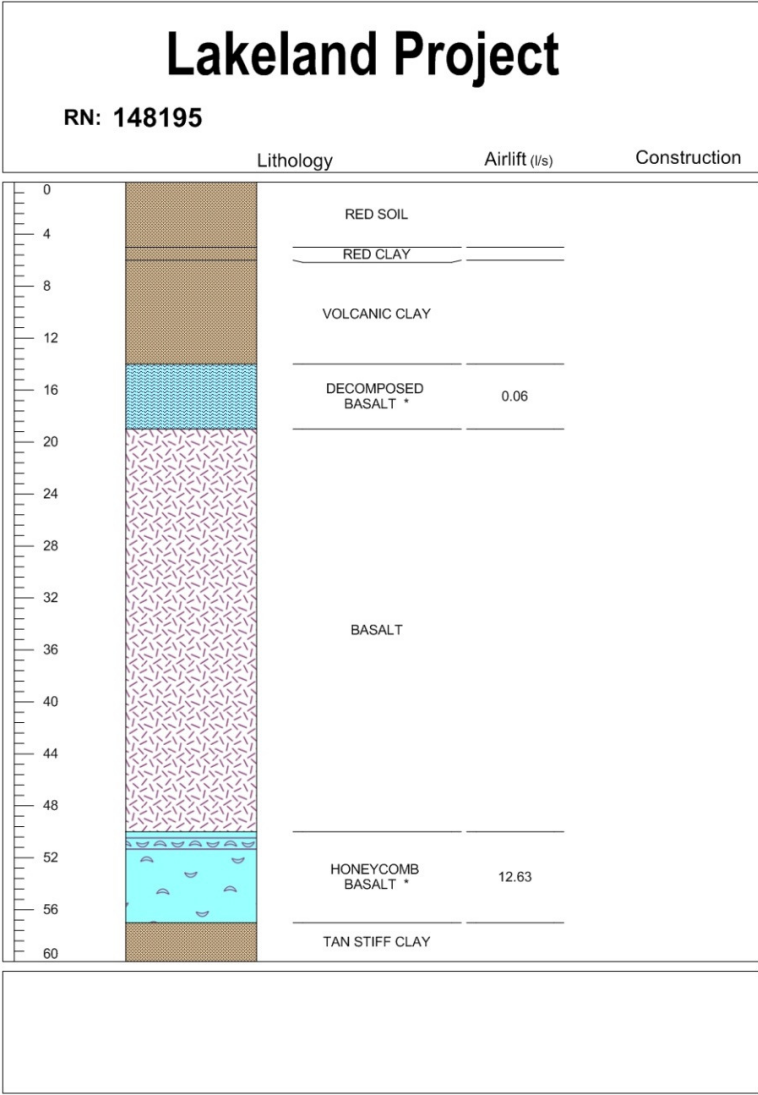
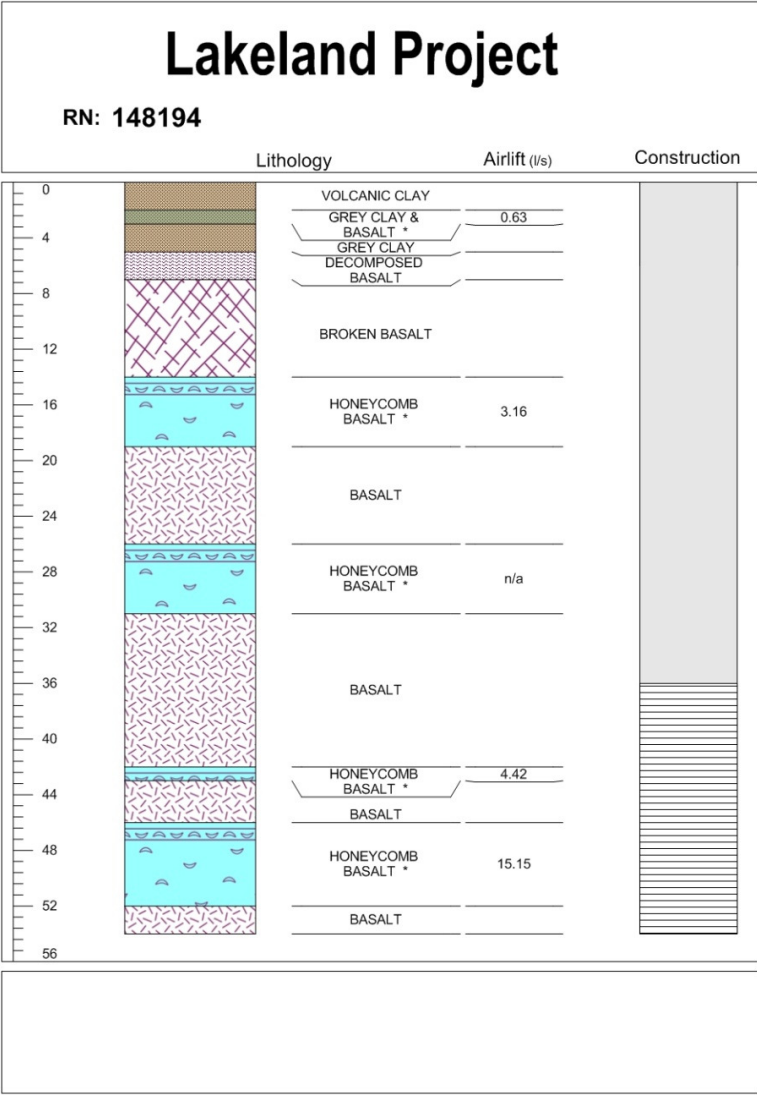


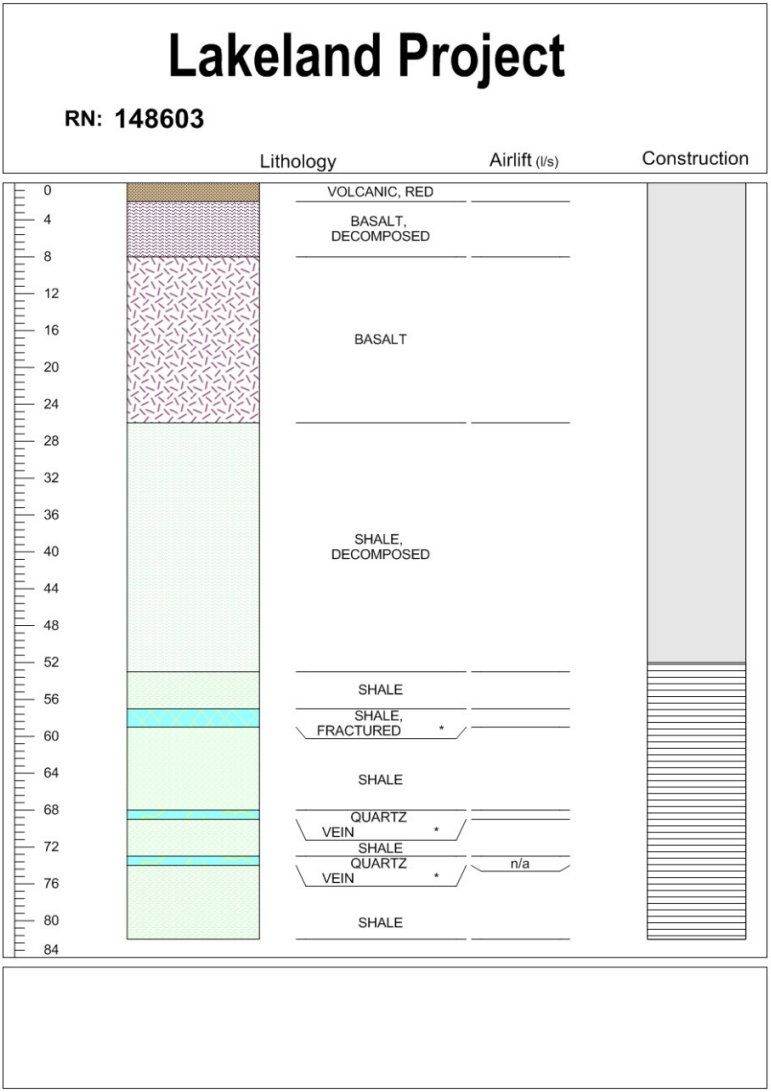
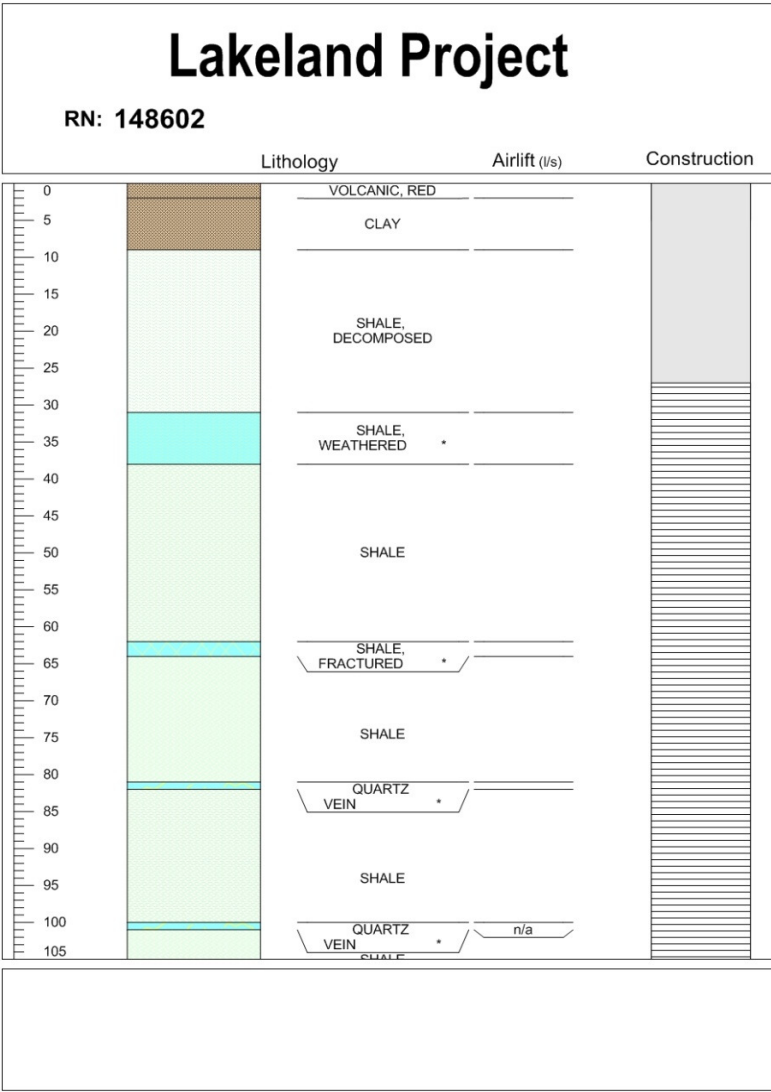


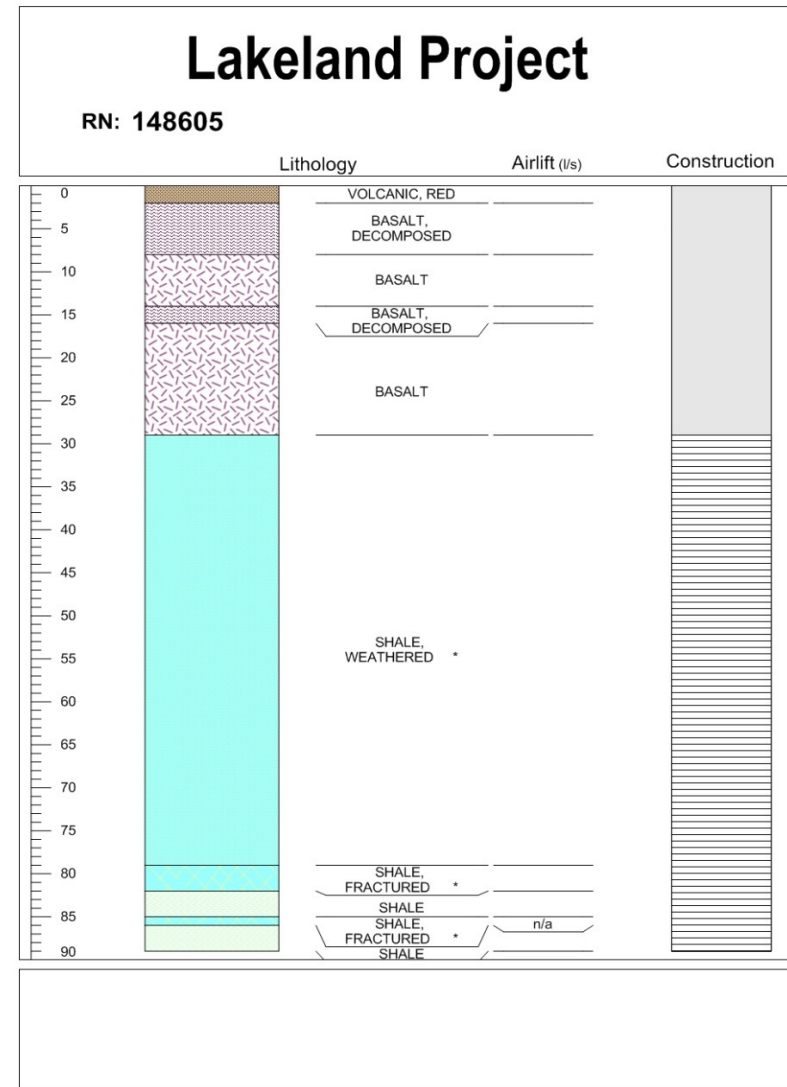


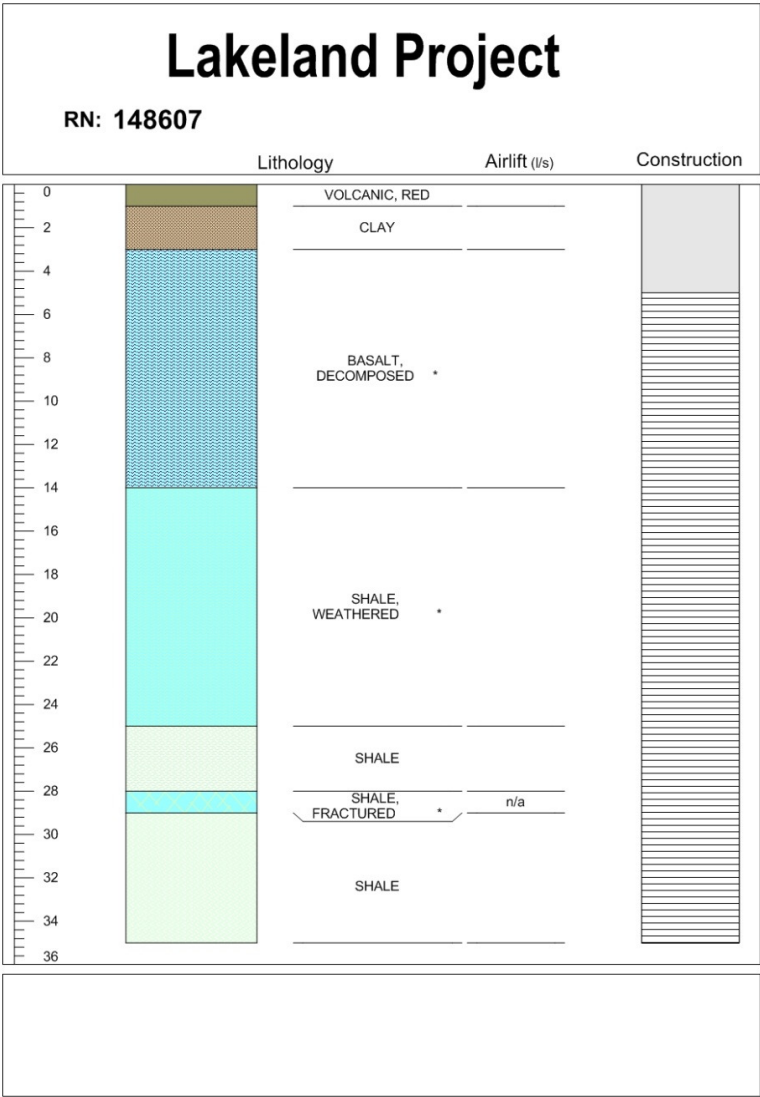
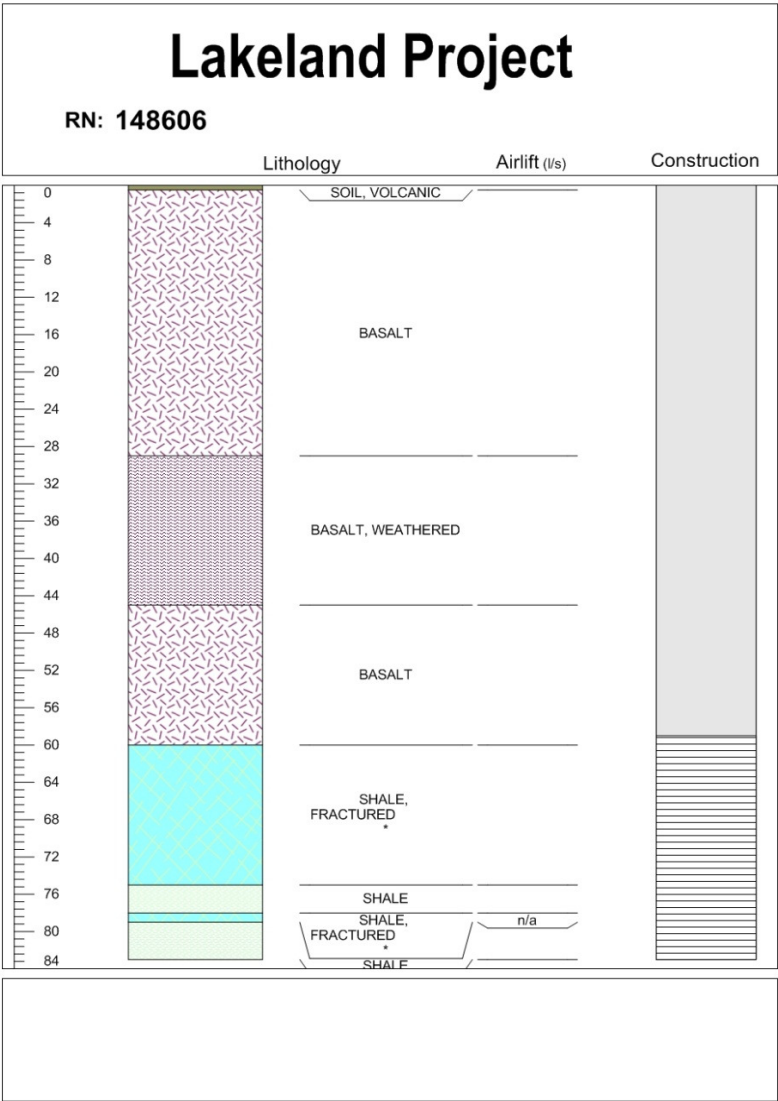


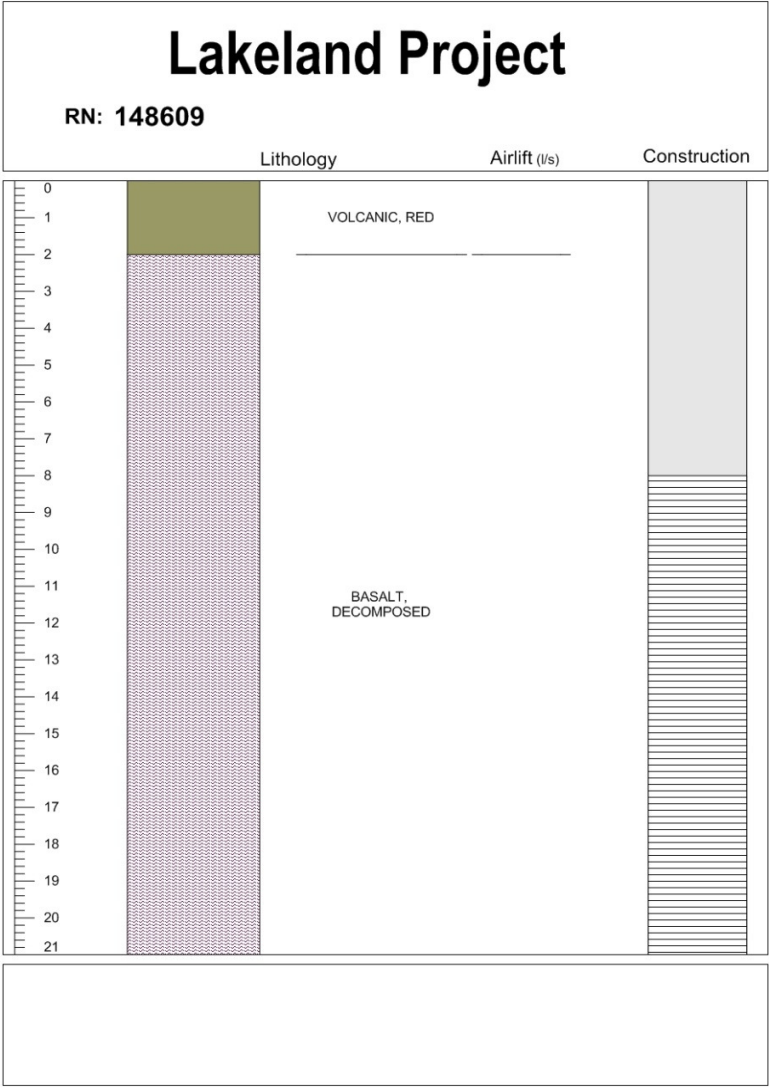
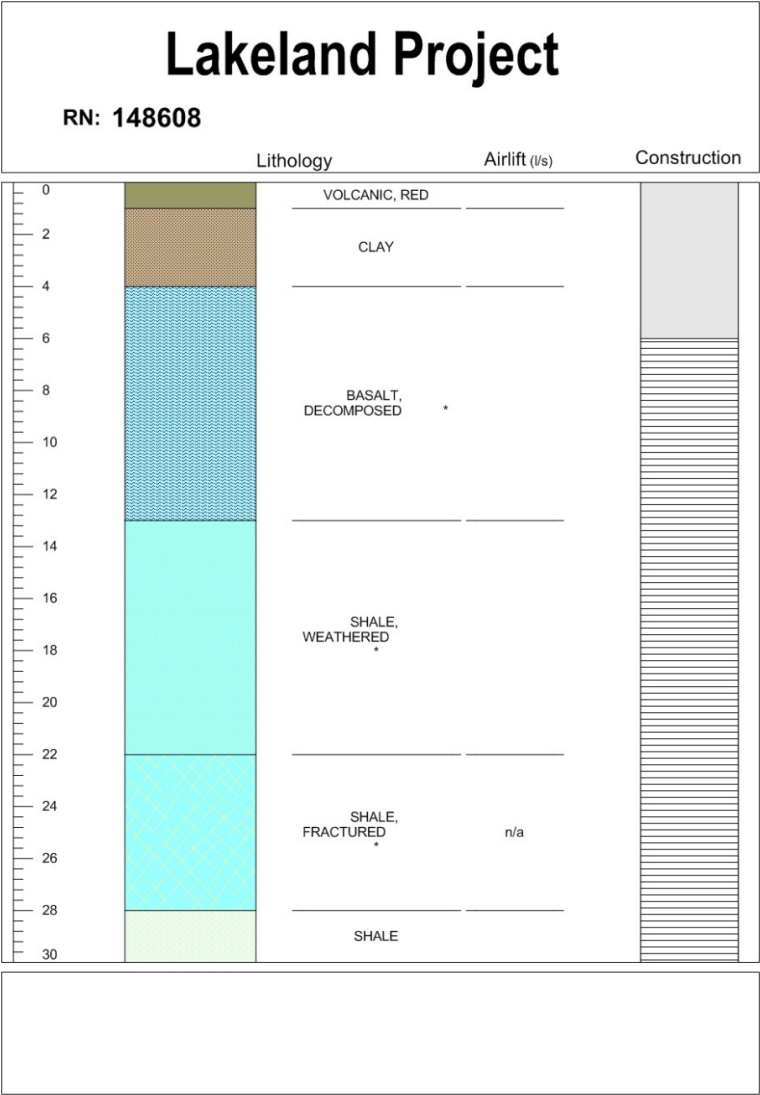


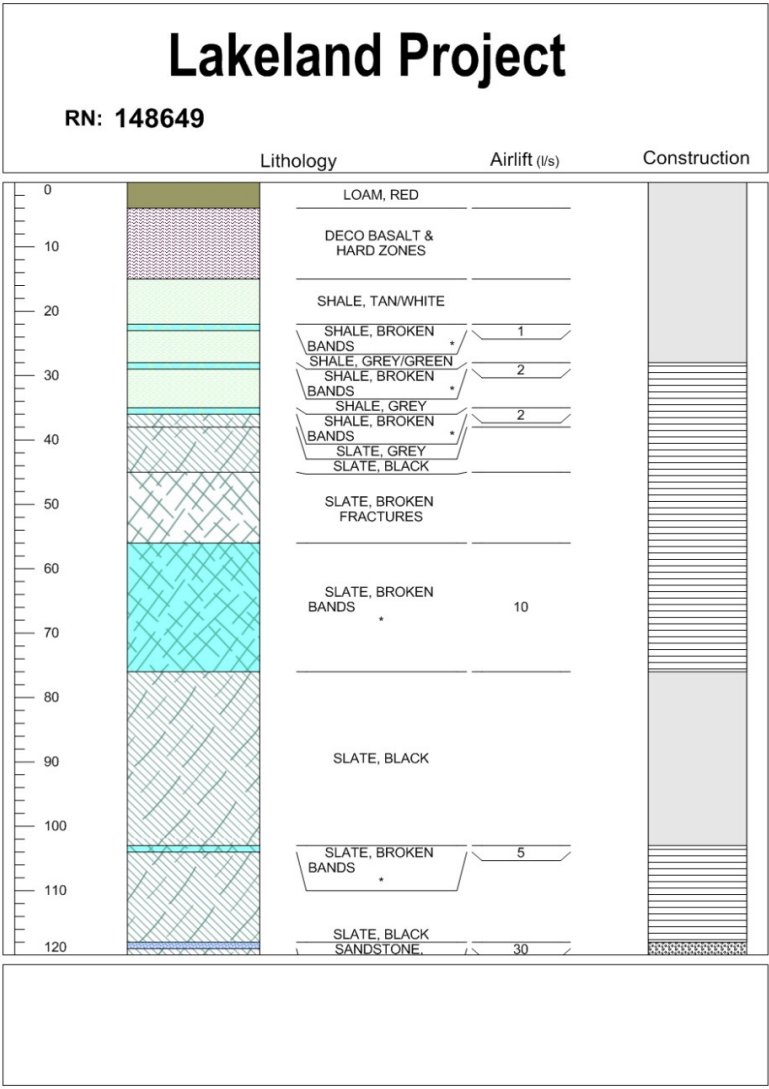
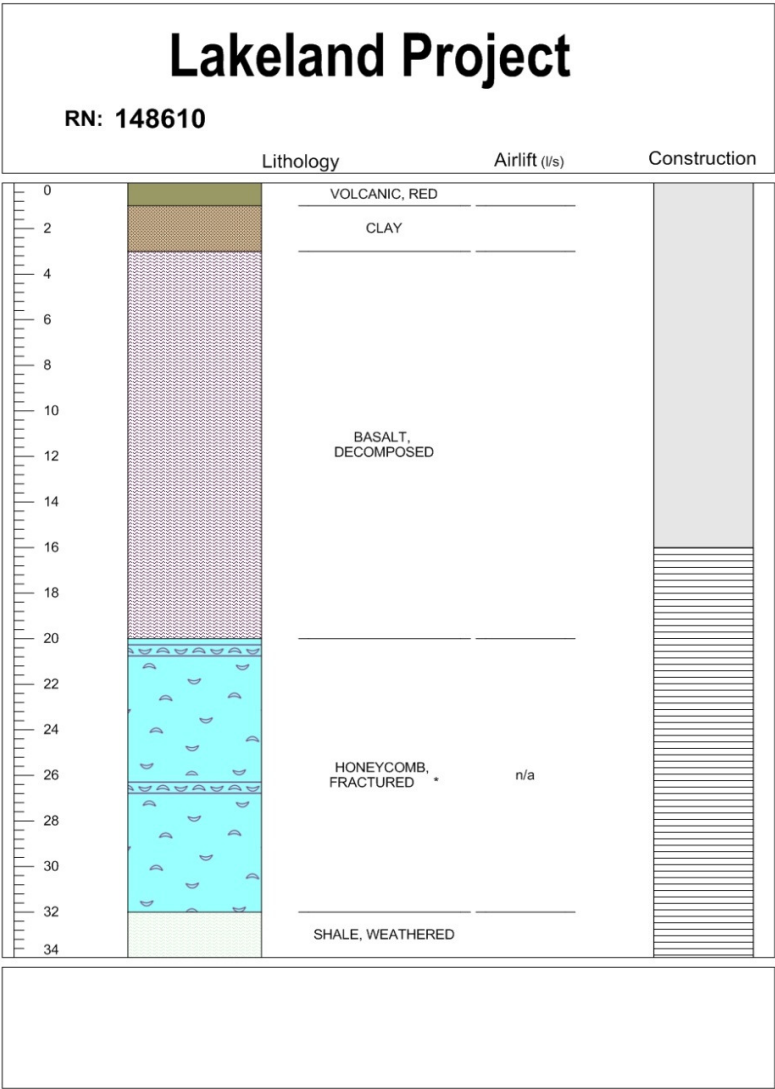


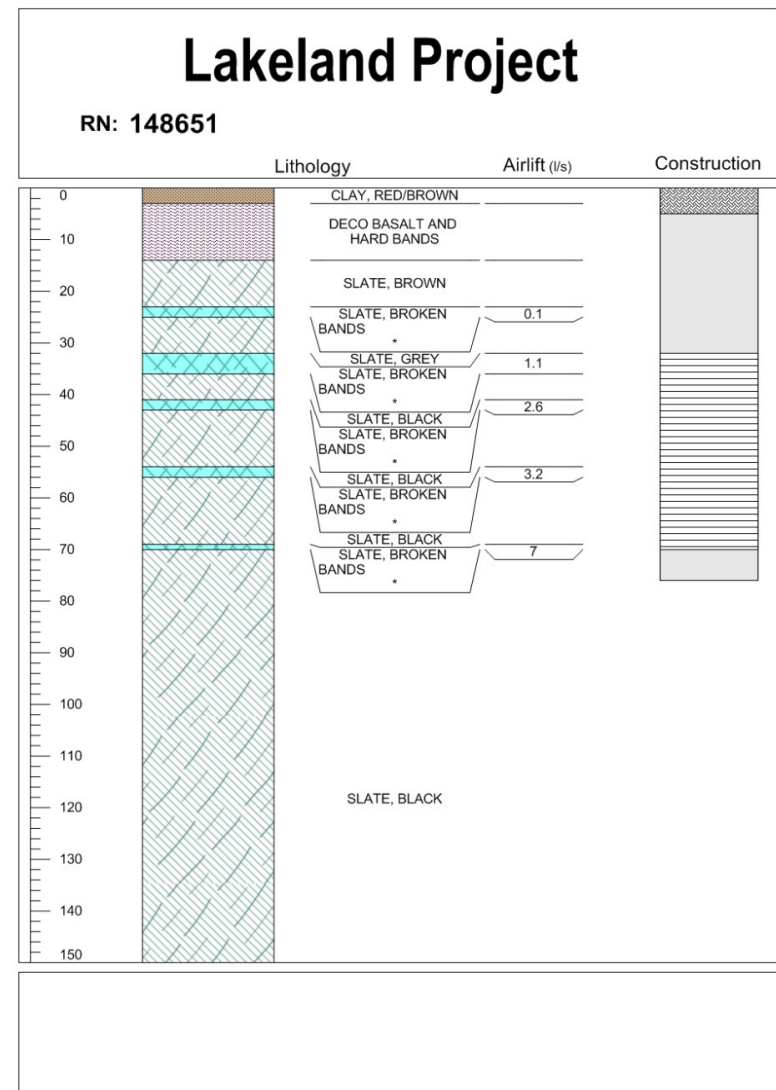


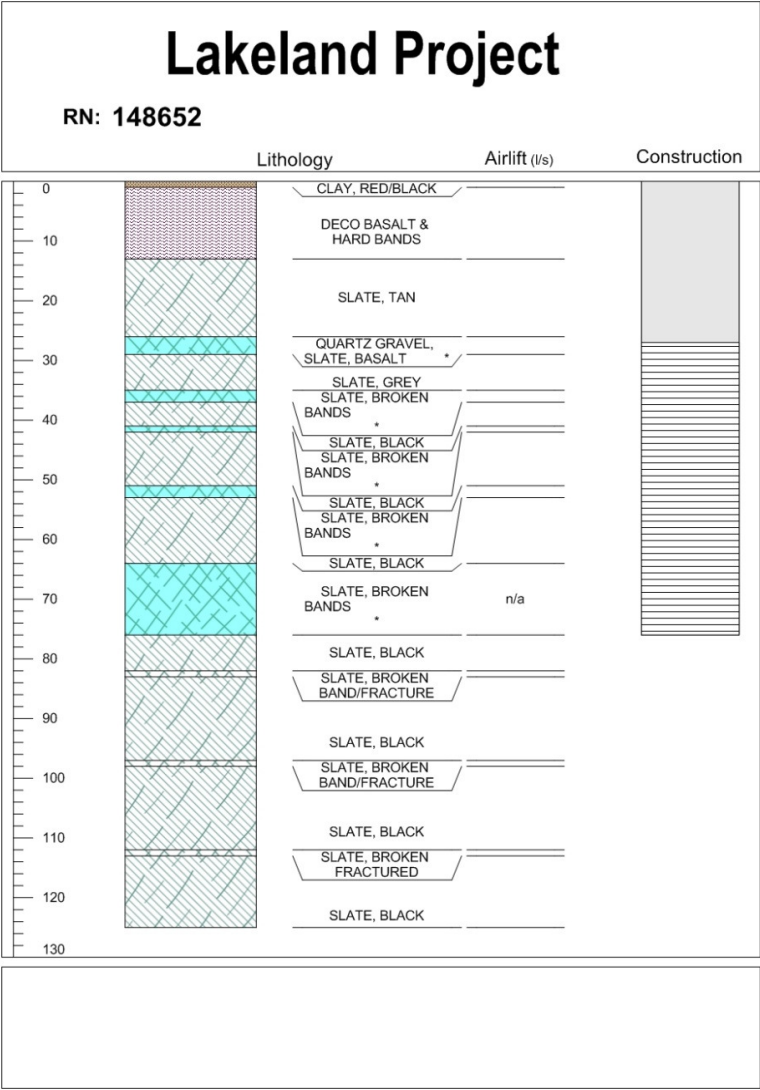


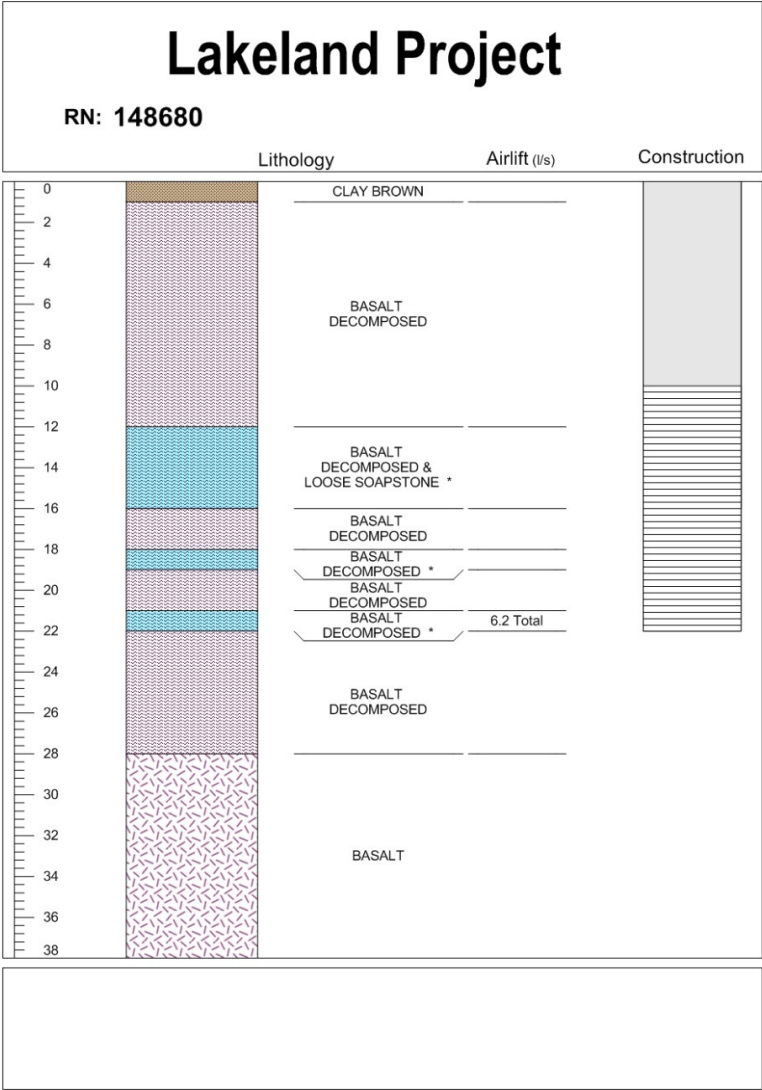
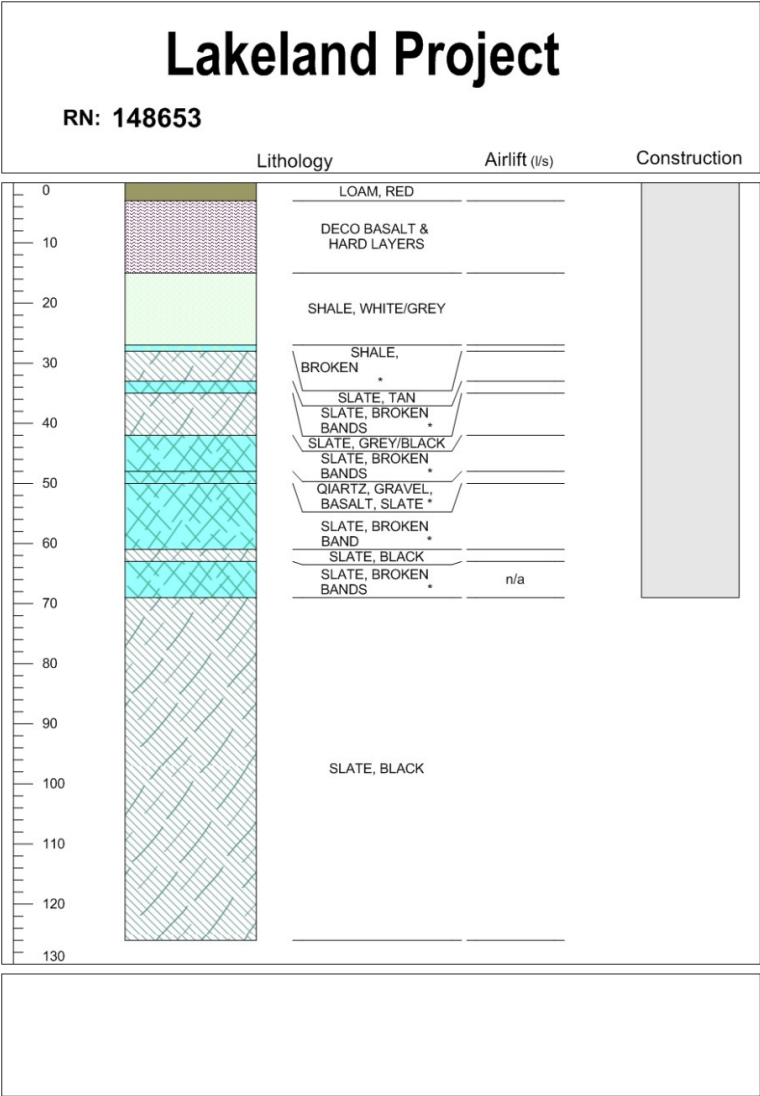


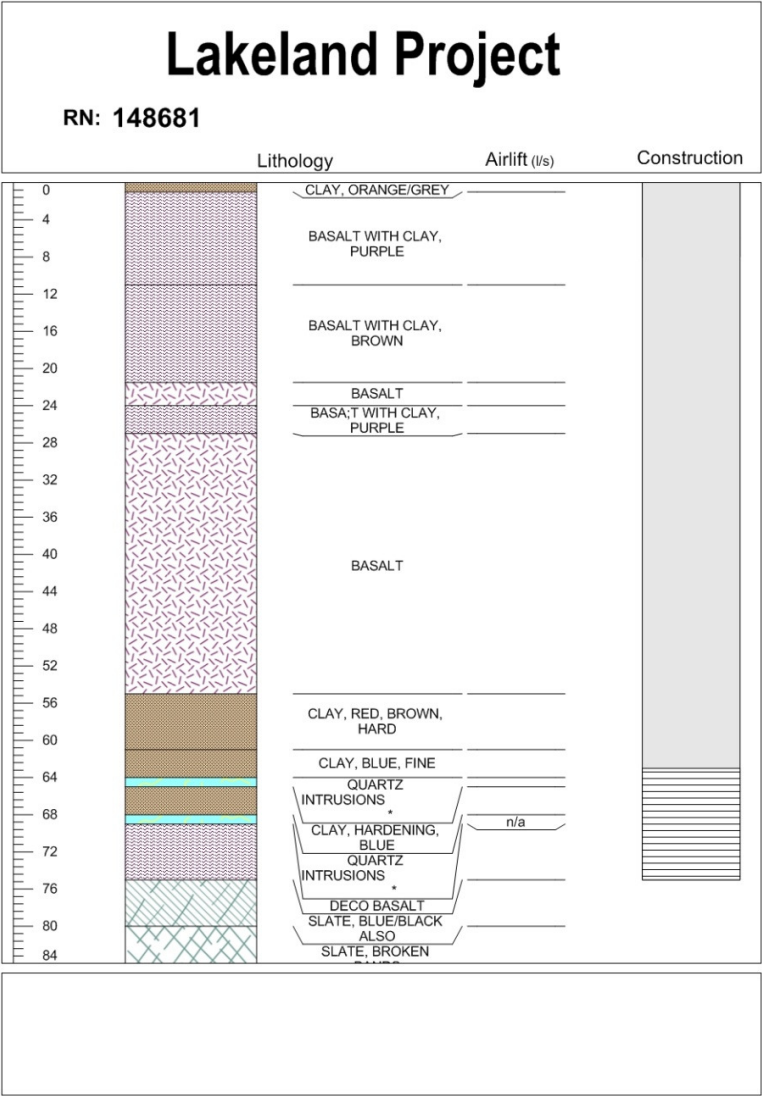


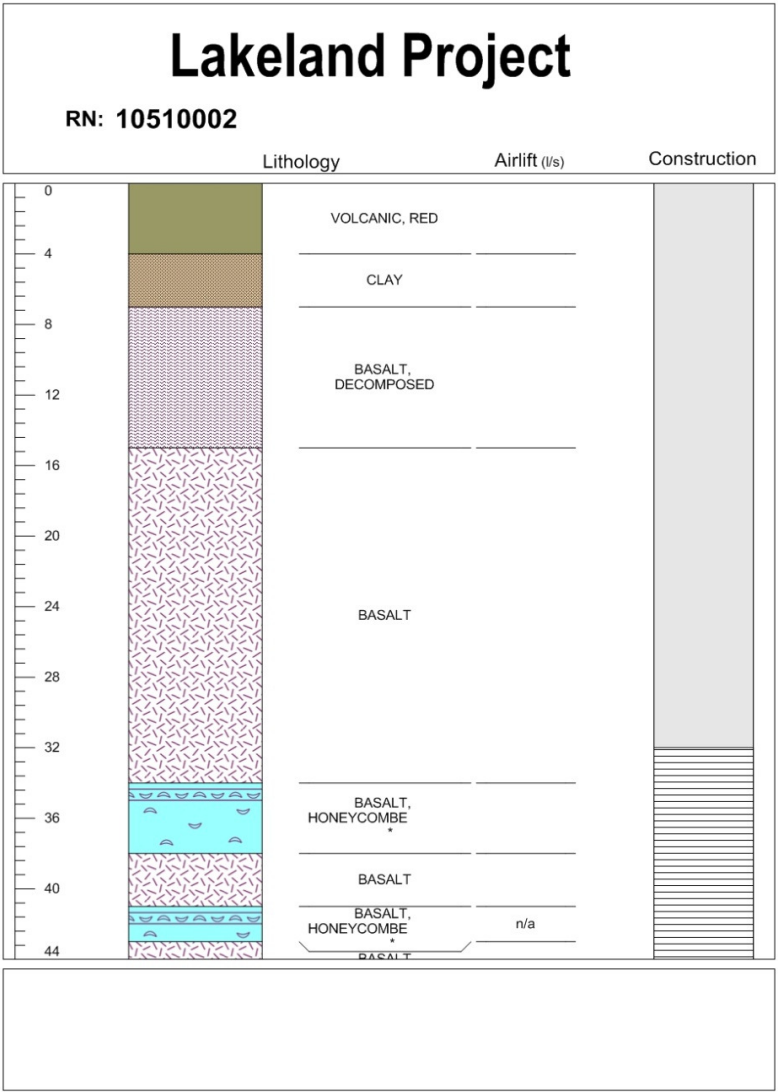
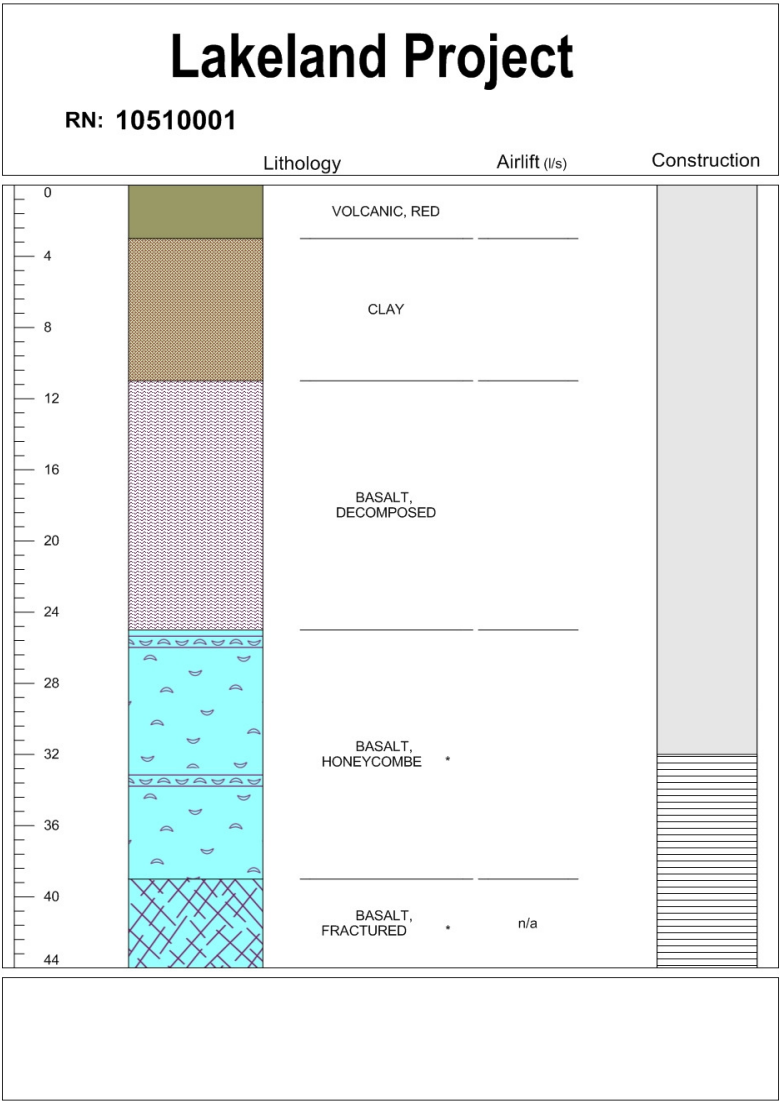










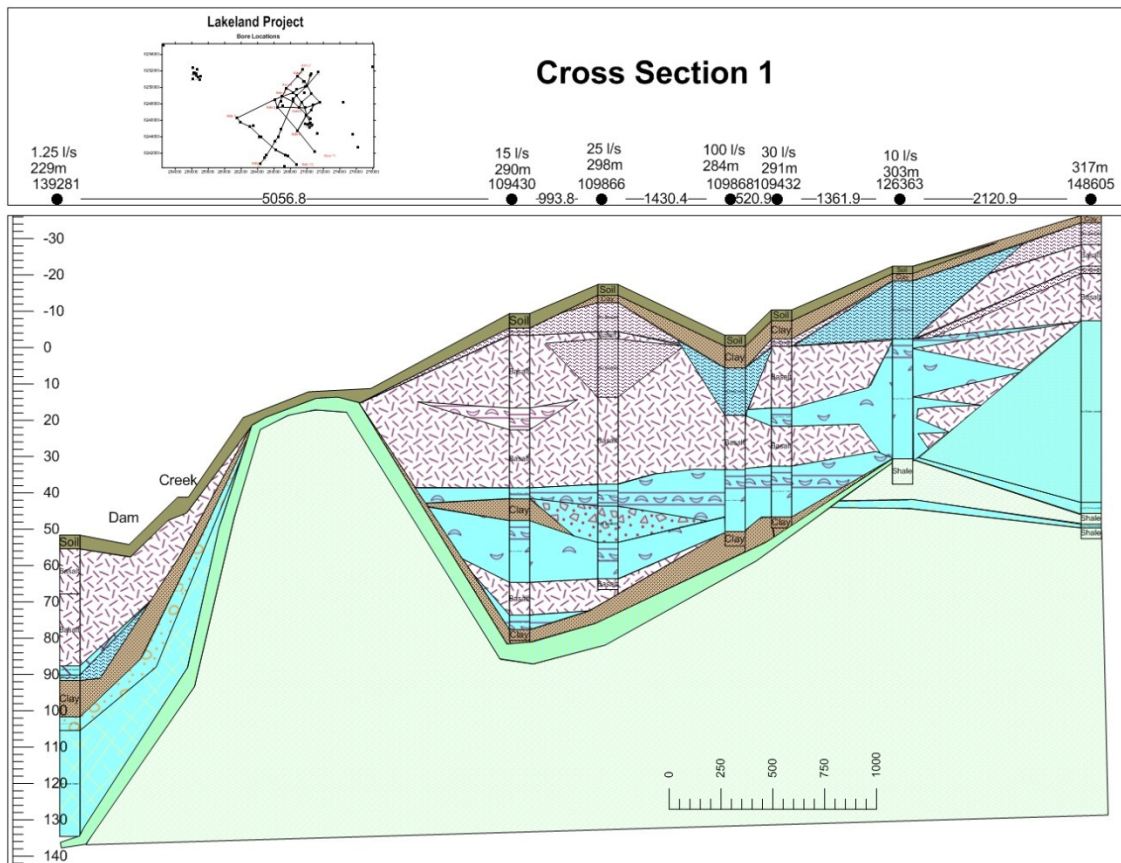
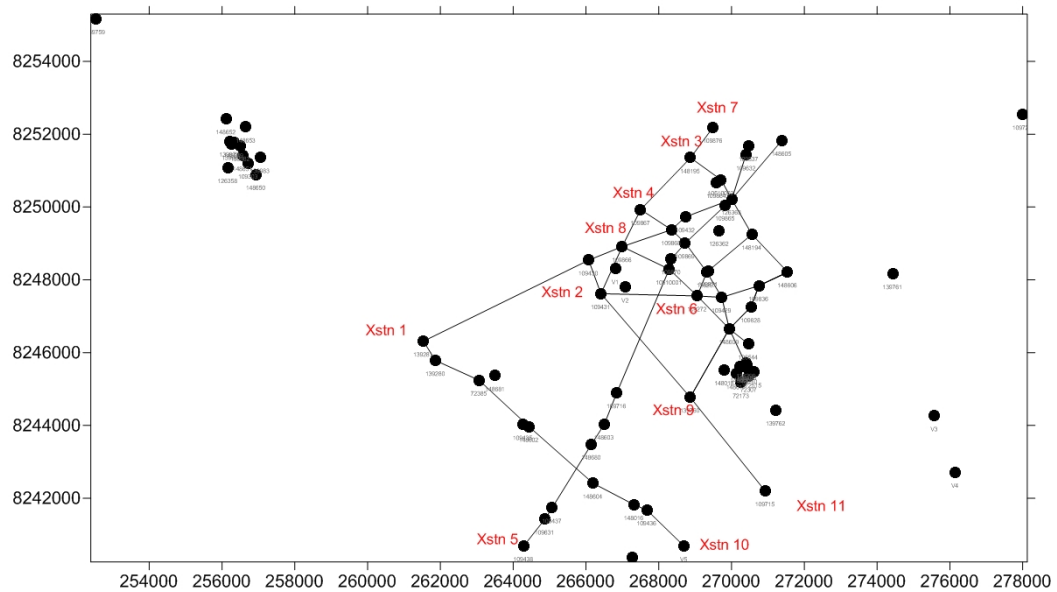


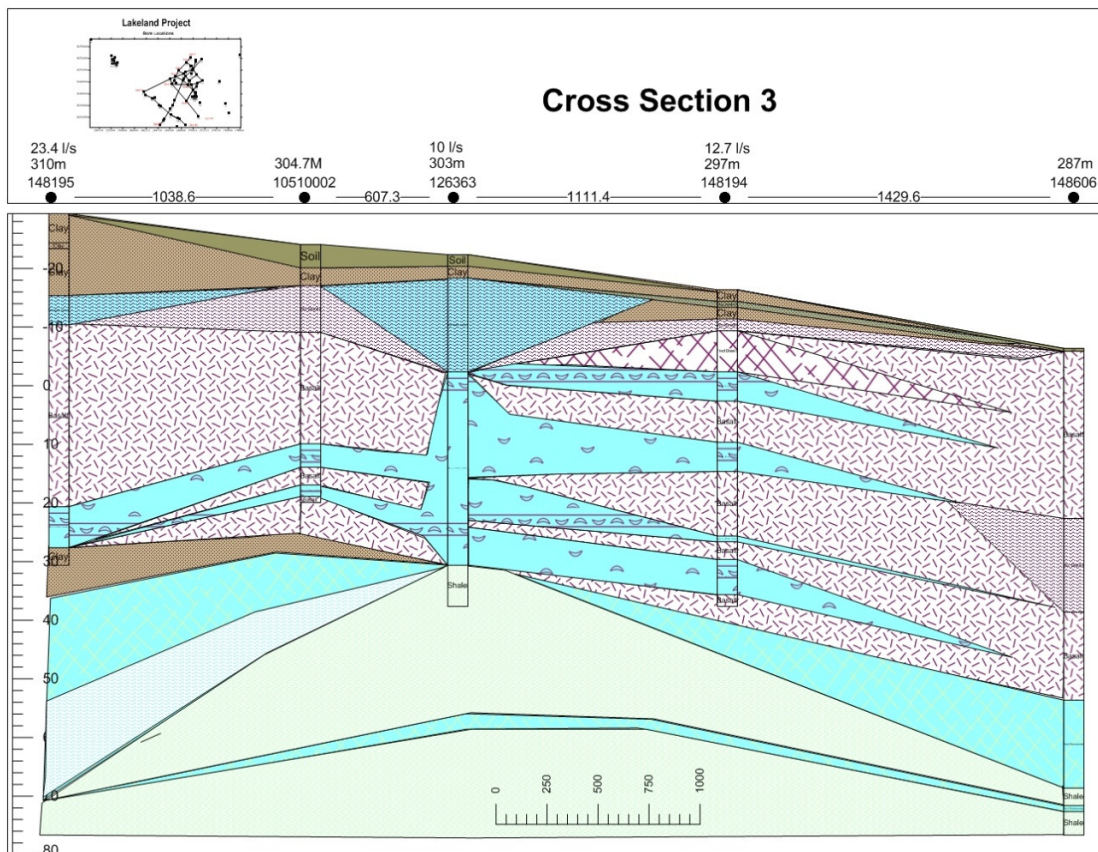
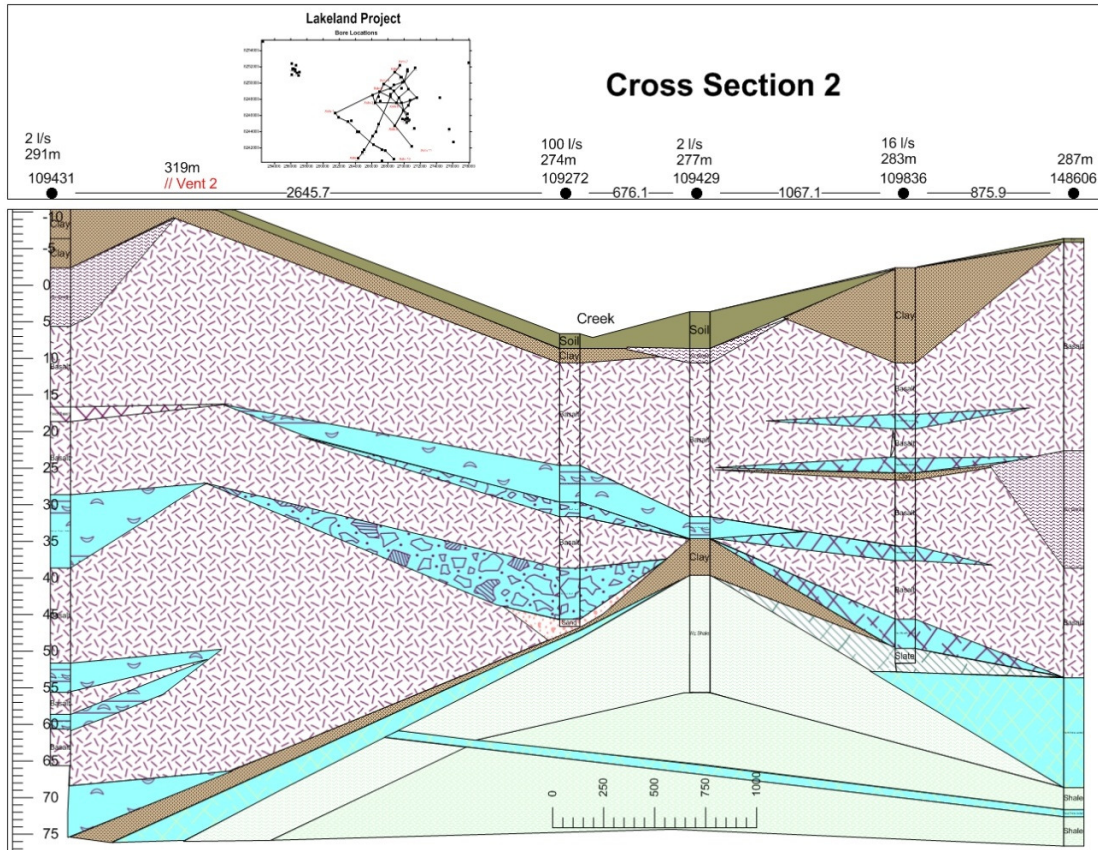
APPENDIX 2 – Cross sections

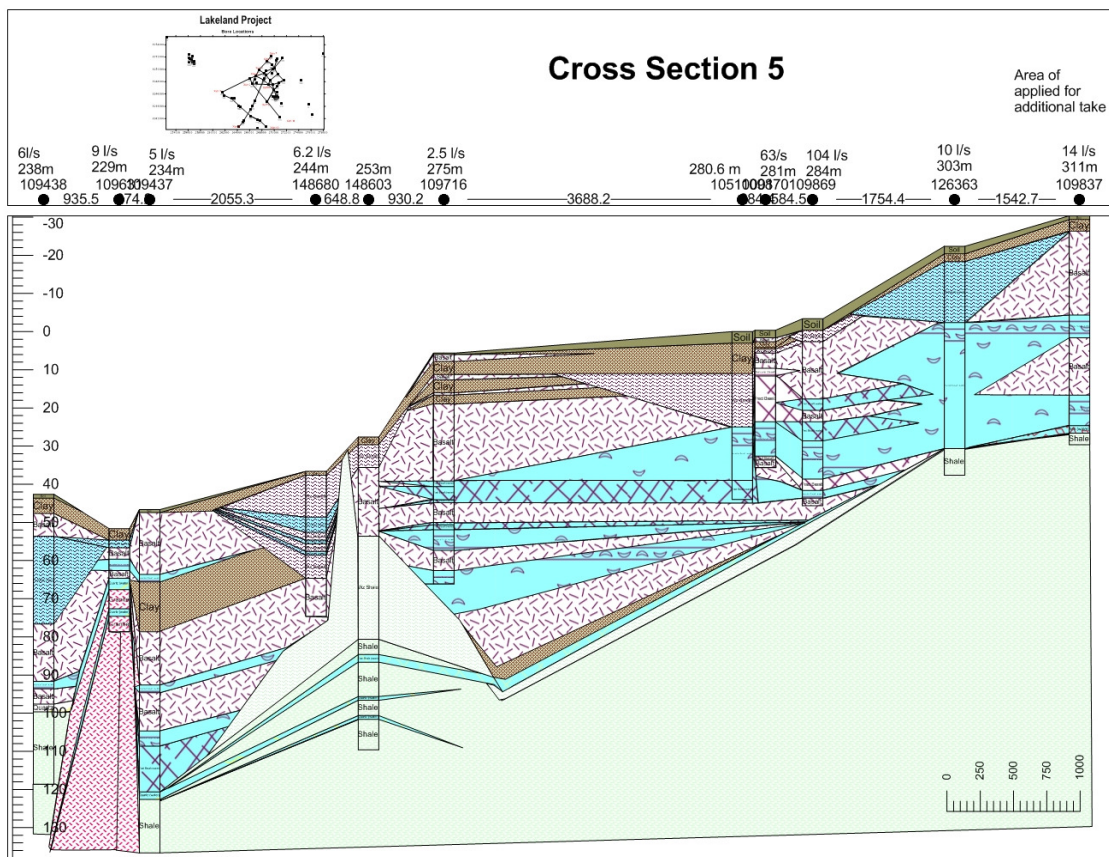
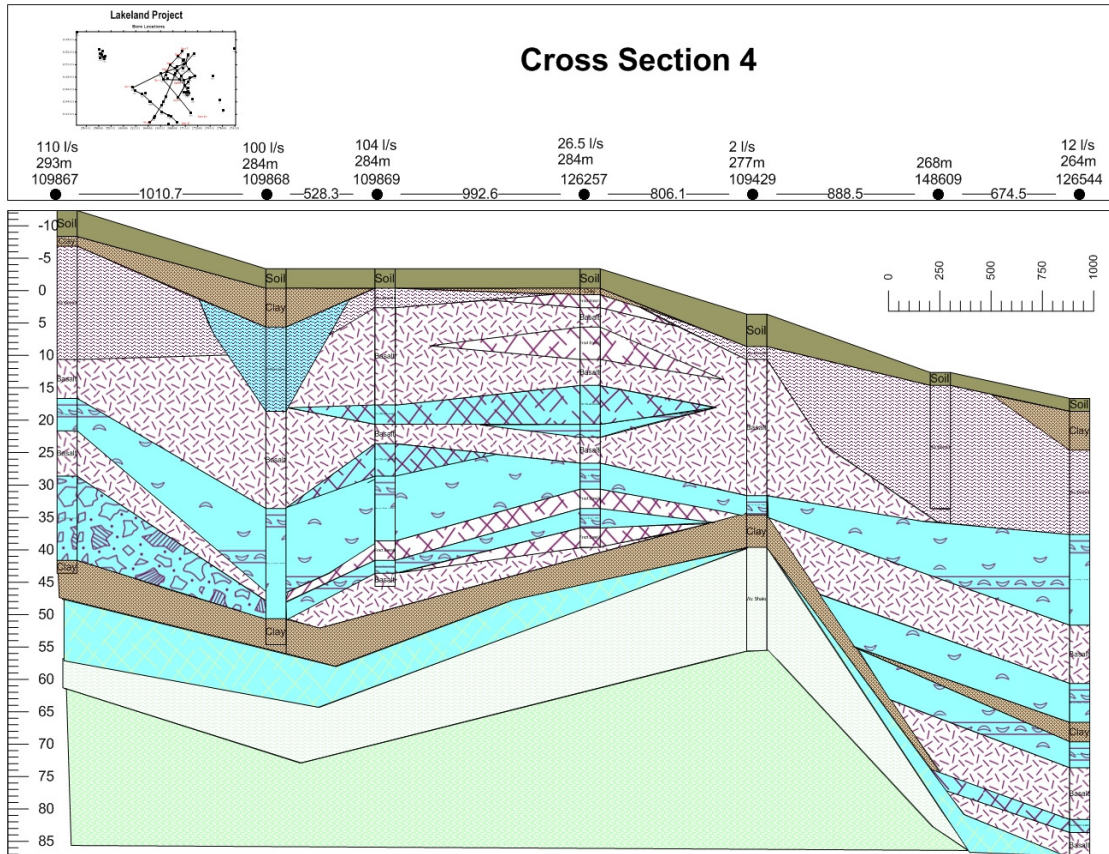
Schematic cross section diagrams

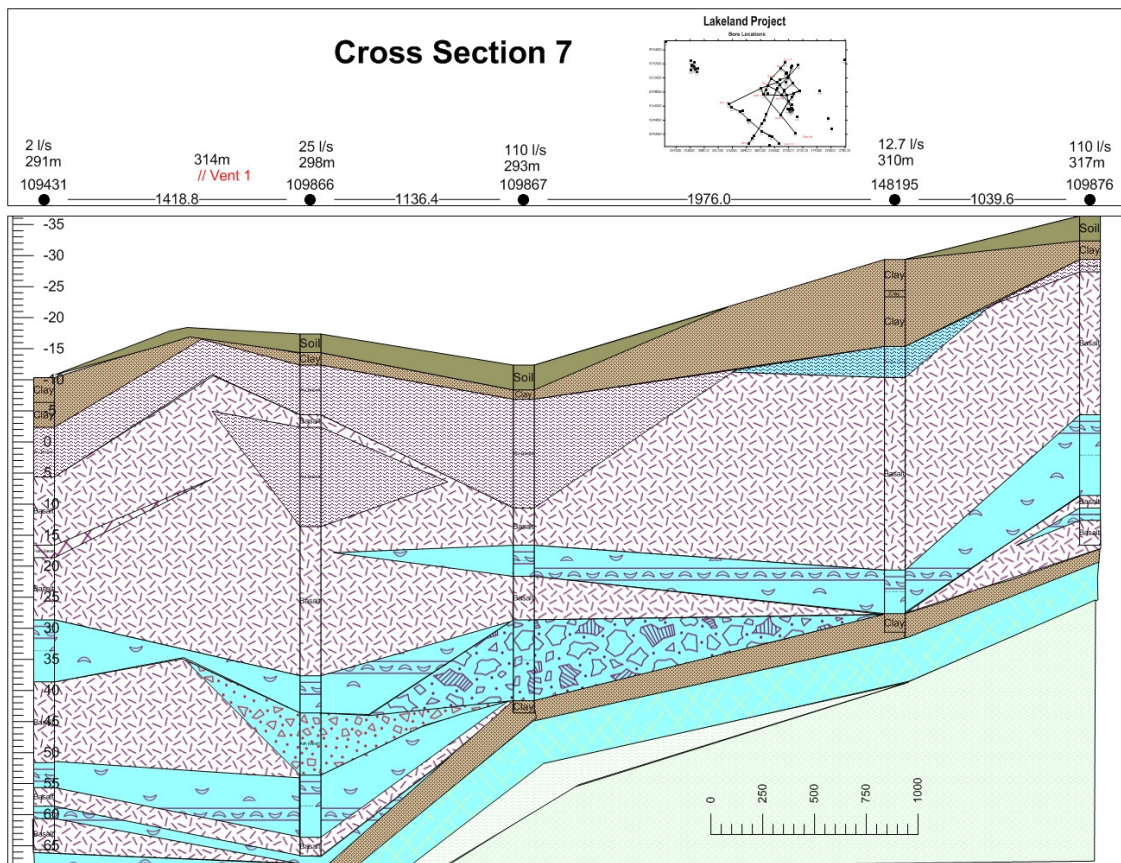
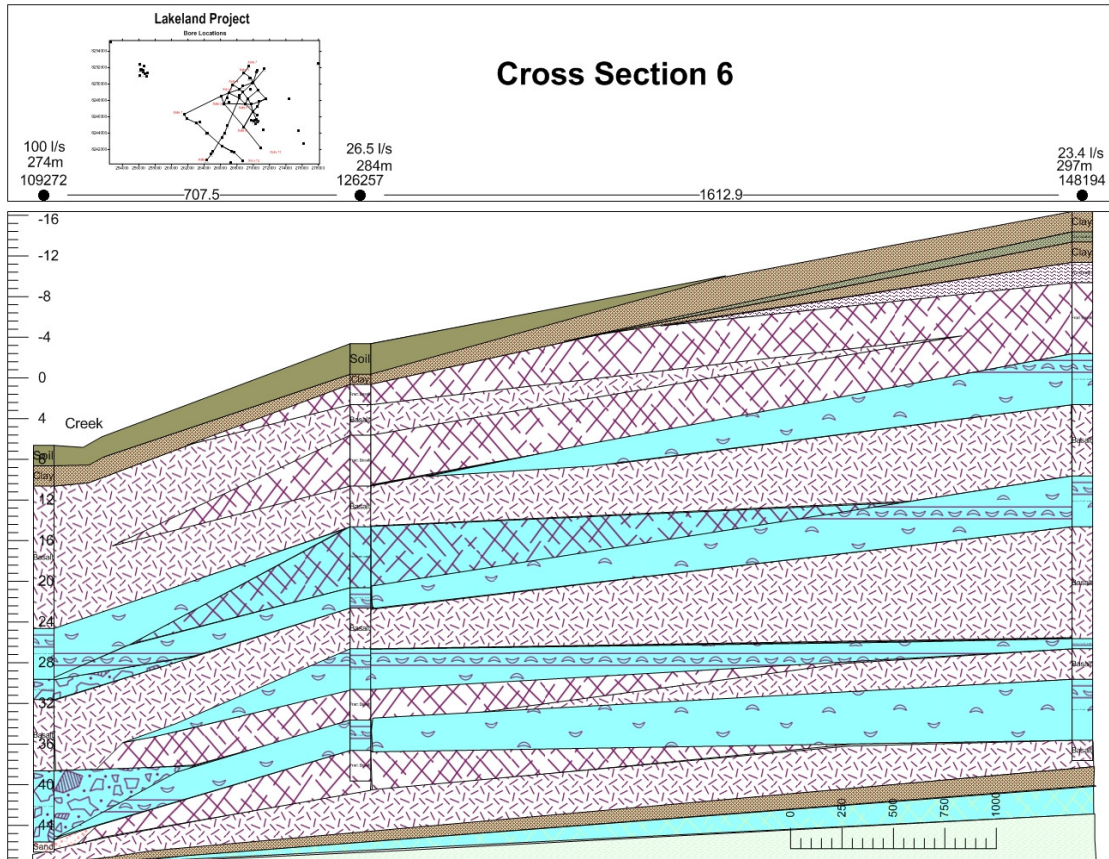
Lakeland Project

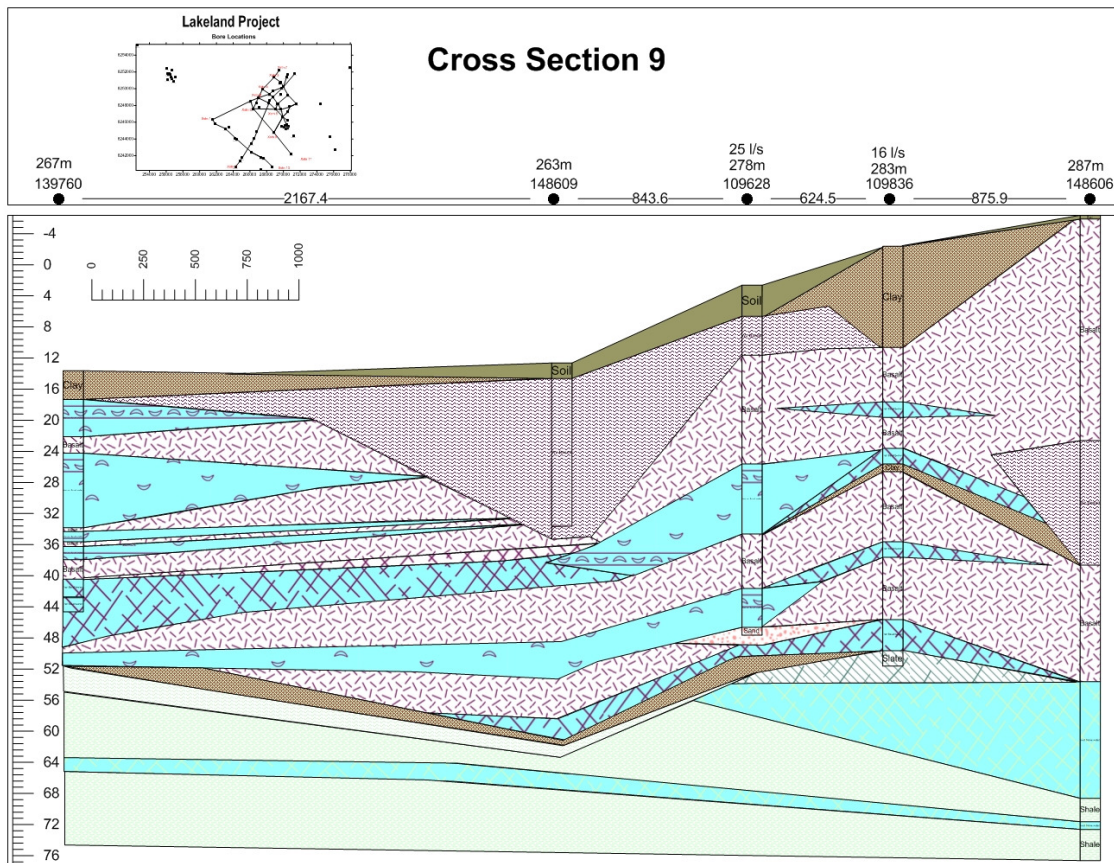
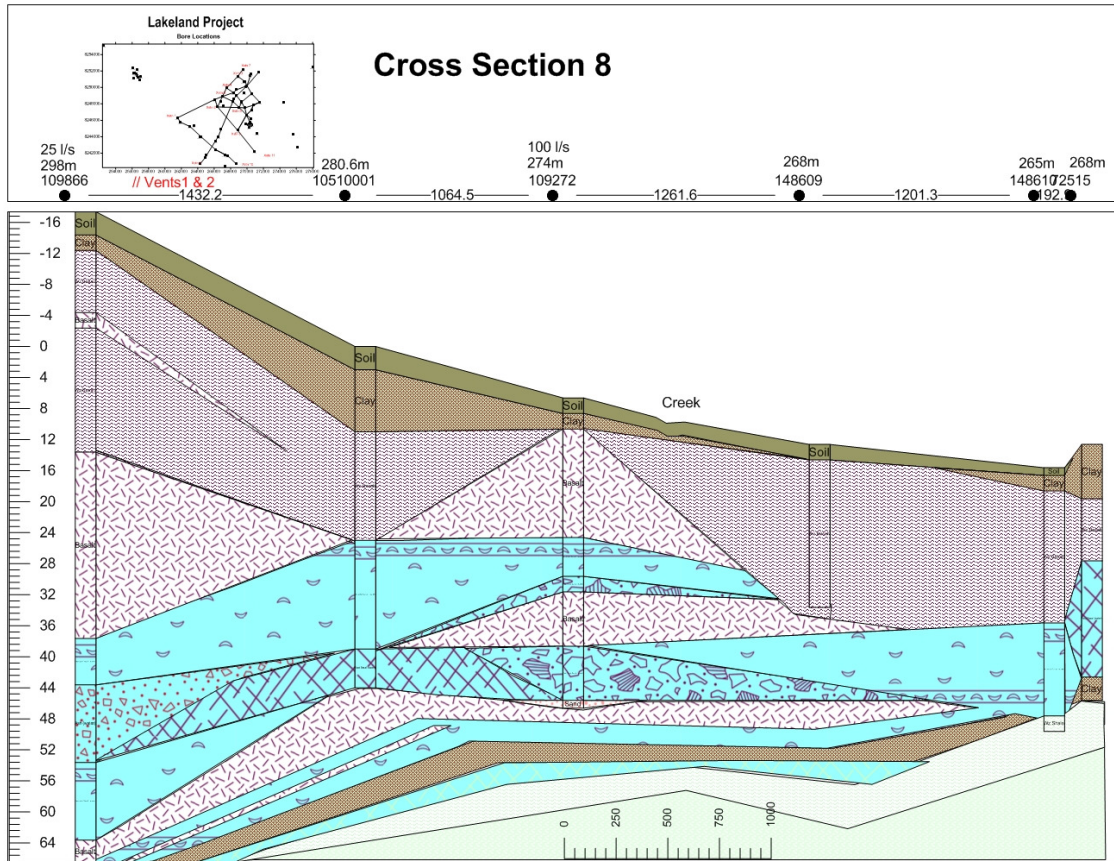
Bore Locations

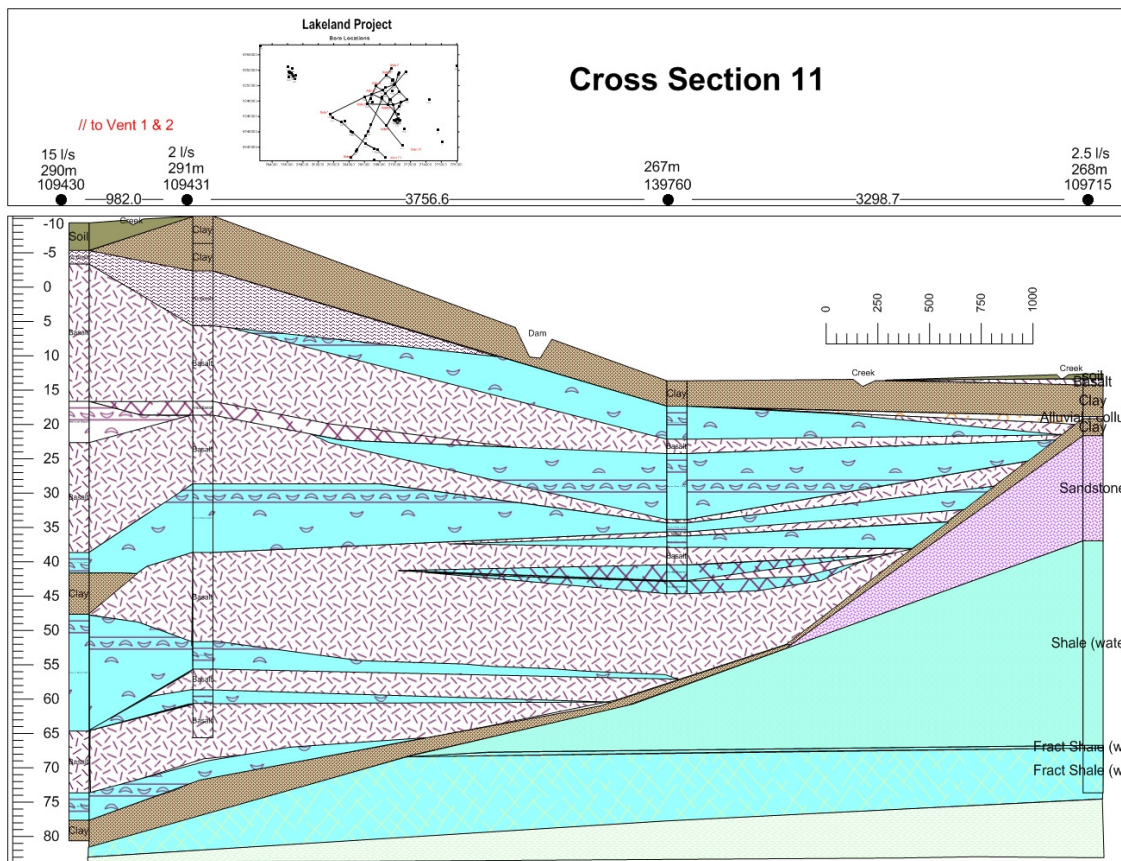
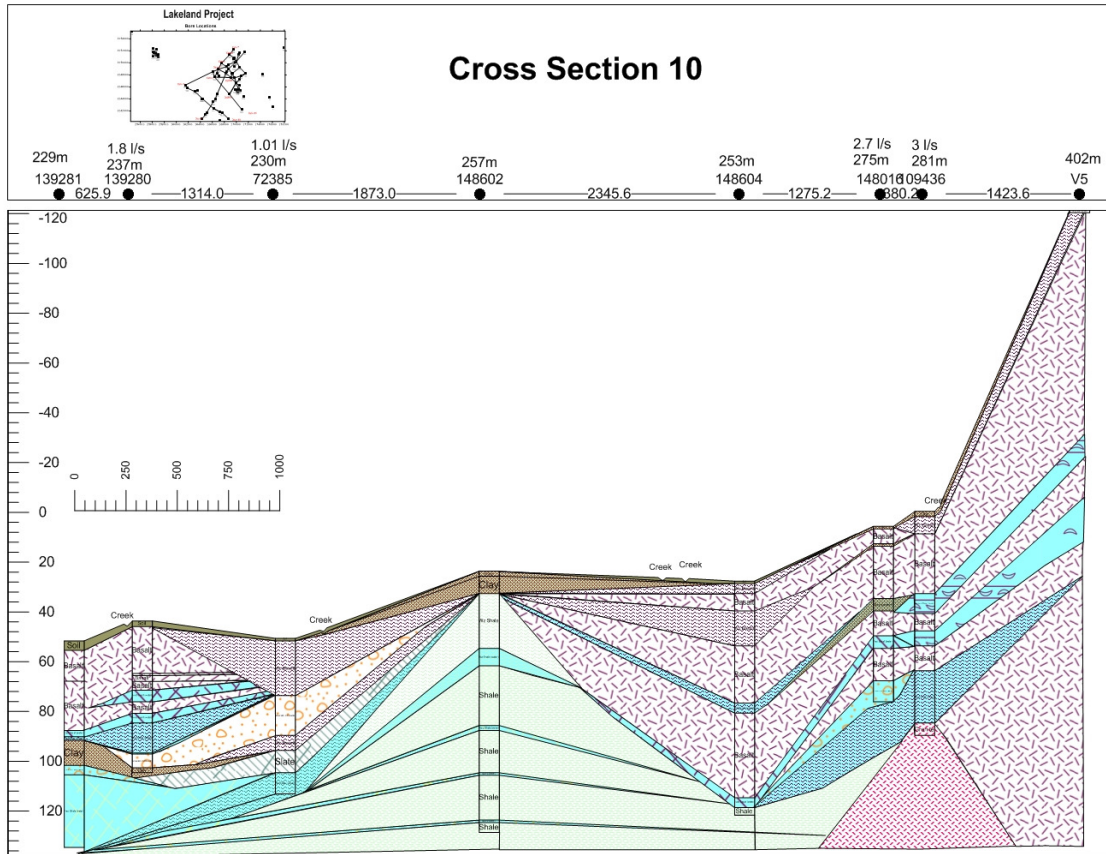












APPENDIX 3 - Electrical Balance Calculations

RN	RDATE	NA_ meq_L	K_ meq/L	CA_ meq/L	MG_ meq/L	FE_ meq/L	MN_ meq/L	HCO3_ meq/L	CO3_ meq/L	CL_ meq/L	F_ meq/L	NO3_ meq/L	Electrical Balance %
72173	5/11/1987	4.00	0.06	3.19	6.25	0.00	0.00	-6.23	-0.06	-7.33	-0.01	-0.07	-0.75
92665	1/10/1997	4.12	0.16	7.45	4.82	0.00	0.30	-15.32	-0.09	-2.17	-0.02	0.00	-3.06
10510002	29/04/2011	1.00	0.05	0.95	1.65	0.00	0.00	-2.90	-0.01	-0.65	-0.01	-0.09	-0.25
10510001	29/04/2011	2.48	0.15	1.40	3.70	0.00	0.00	-6.34	-0.11	-0.96	0.00	-0.19	0.76
45783	25/02/1999	0.6	0.05	0.54	0.49	0	0	-0.82	0	-0.43	0	-0.4	1.03
11000066	24/02/1999	0.37	0.02	0.14	0.25	0	0	-0.29	0	-0.4	0	-0.06	2.01
11000068	12/12/1998	0.34	0.06	0.38	0.53	0	0	57.6	0	-0.32	0	-0.02	0.48

APPENDIX 4- Water Level and Pump Test Data

RN		SWL	Top (m)	Bottom (m)	Test Dur (mins)	SWL (m)	Recov Time (mins)	Resid DD (m)	Max DD (m)	Q at max DD (l/s)	Time to max DD (min)	Q (l/s)	Calc Stat HD (m)	Design Yield (l/s)	Design BP (m)	Suct. Set (m)	TMSY (m ² /day)
72173	5/11/1987	-1.7															
72307	4/06/1988	-7.8															
72385																	
72515	12/11/1990	-9															
109272	26/08/2003	-2															
	3/07/2005		18	39	1440	-2	10	1	14046	93.2	1380	93.2					735
109303	28/11/2008	-14															
109429																	
109430	8/08/2003	-24.5															
109431																	
109432	31/07/2003	-4.2															
109435	29/07/2003	-26															
109436	22/07/2003	-18															
109437	16/07/2003	-12															
109438	17/07/2003	-11															
109628	18/05/2005	-10.5															
	25/05/2005		23	44	1440	-10.5	240	0.5	28.5	24.56	1440	29.65	-10.5	22.85	41.5	41.5	90
109629	22/07/2003	-27															
109631	28/07/2003	-3															
109632	5/05/2005	-4															
109715	9/09/2003	-6.65															
109716	15/05/1998	-18.75															
109721	11/09/2003	-2.3															
109836	12/01/2010	-10															
109837	30/04/2005	-4															
109864	9/06/2005	-5.8															
	11/07/2005		49	63	1440	-5.8	60	0	9.7	84.86	1260	84.86					778
109865	31/05/2005	-3															
	9/08/2005		20	75	1440	-3	180	0	47.5	6.75	660	8.71					16
109866	8/06/2005																
	19/09/2005		55	81	1440		150	0	25	19.97	720						2668
109867	21/08/2003	-12															
	15/05/2005		29	54	1440	-24	6	0	5	84.86	960	84.86					
109868	20/08/2003	-4.5															
	28/06/2005		22	54	1440	-4.5	10	4.9	84.86	1440	84.86						1450
109869	21/11/2002	-2															
	25/06/2002		21	47	2880	-7	300	0	11.2	39.91	2880	41.23					760
109870	20/12/2001	-5															

	30/01/2003				2880	-3.95	300	0	3.25	41.8	2880	41.9	-4.95	82			580
109871	28/11/2002	-11															
	30/01/2004		30	69	2880	-16.4	300	0.35	10.6	48.76	1860	48.76					56
109876	10/06/2005	-13															
	16/07/2005		32	49	1440	-13	300	0.2	34	48.1	840	71.2					
126257	19/11/2002	-11															
126297	25/05/2005																
126298	24/05/2005	-6.5															
126299	24/05/2005	-6.5															
126358																	
126362	31/05/2005	-4.5															
126363	1/06/2005	-3.2															
126544	30/07/2003	-12															
139280	10/10/1992	-28.15															
139281	7/10/1999	-30.55															
139759	2/10/1999	-11.7															
139760	6/10/1992	-1.5															
139761	8/10/1992	-9.8															
139762	8/10/1992	-17.6															
139979	20/11/2008	-14															
139981	20/11/2008	-14															
139982	20/11/2008	-16															
139983	20/11/2008	-11															
148016	16/01/2009	-16															
148017	18/01/2009	0															
148018	19/01/2009	-4															
148194	18/12/2001	-1															
148195	19/12/2001	-8															
148602	31/05/2011	-12															
148603	1/06/2011	-0.1															
148604	2/06/2011	-5.5															
148605	3/06/2011	-13															
148606	3/06/2011	-9															
148607																	
148608	7/06/2011	-2.5															
148609	7/06/2011	-1															
148610	9/06/2011	-5.5															
148649	9/08/2011	-10															
148650	20/08/2011	-8															
148651	22/08/2011	-11															
148652	24/08/2011	-3															
148653	13/08/2011	-10															
148680	14/09/2011	-8.5															
148681	23/09/2011	-29															

RN		SWL	Type
10510001*	22/11/2010	-9.8	M
	01/12/2010	-8.64	M
	10/12/2010	-10.27	M
	11/12/2010	-8.768	L
	12/12/2010	-8.674	L
	13/12/2010	-8.017	L
	14/12/2010	-7.824	L
	15/12/2010	-7.709	L
	16/12/2010	-7.644	L
	17/12/2010	-7.602	L
	18/12/2010	-7.572	L
	19/12/2010	-7.545	L
	20/12/2010	-7.517	L
	21/12/2010	-7.512	L
	22/12/2010	-7.5	L
	23/12/2010	-7.465	L
	24/12/2010	-7.447	L
	25/12/2010	-7.397	L
	26/12/2010	-7.379	L
	27/12/2010	-7.402	L
	28/12/2010	-7.382	L
	29/12/2010	-7.375	L
	30/12/2010	-7.329	L
	31/12/2010	-7.276	L
	1/01/2011	-7.221	L
	2/01/2011	-7.175	L
	3/01/2011	-7.153	L
	4/01/2011	-7.13	L
	5/01/2011	-7.093	L
	6/01/2011	-7.066	L
	7/01/2011	-7.059	L
	8/01/2011	-7.03	L
	9/01/2011	-7.014	L
	10/01/2011	-6.998	L
	11/01/2011	-6.972	L
	12/01/2011	-6.969	L
	13/01/2011	-6.966	L
	14/01/2011	-6.937	L
	15/01/2011	-6.893	L
	16/01/2011	-6.837	L
	17/01/2011	-6.766	L
	18/01/2011	-6.663	L
	19/01/2011	-6.53	L
	20/01/2011	-6.391	L

	21/01/2011	-6.277	L
	22/01/2011	-6.157	L
	23/01/2011	-6.043	L
	24/01/2011	-5.962	L
	25/01/2011	-5.884	L
	26/01/2011	-5.808	L
	27/01/2011	-5.724	L
	28/01/2011	-5.679	L
	29/01/2011	-5.616	L
	30/01/2011	-5.582	L
	31/01/2011	-5.55	L
	1/02/2011	-5.549	L
	2/02/2011	-5.528	L
	3/02/2011	-5.404	L
	4/02/2011	-5.497	L
	5/02/2011	-5.49	L
	6/02/2011	-5.449	L
	7/02/2011	-5.417	L
	8/02/2011	-5.342	L
	9/02/2011	-5.296	L
	10/02/2011	-5.284	L
	11/02/2011	-5.266	L
	12/02/2011	-5.233	L
	13/02/2011	-5.181	L
	14/02/2011	-5.16	L
	15/02/2011	-5.155	L
	16/02/2011	-5.431	L
	17/02/2011	-5.201	L
	18/02/2011	-5.148	L
	19/02/2011	-5.111	L
	20/02/2011	-5.119	L
	21/02/2011	-5.121	L
	22/02/2011	-5.053	L
	23/02/2011	-5.025	L
	24/02/2011	-5.006	L
	25/02/2011	-4.998	L
	26/02/2011	-5.002	L
	27/02/2011	-4.976	L
	28/02/2011	-4.958	L
	1/03/2011	-4.932	L
	2/03/2011	-4.881	L
	3/03/2011	-4.824	L
	4/03/2011	-4.78	L
	5/03/2011	-4.764	L
	6/03/2011	-4.717	L

	7/03/2011	-4.701	L
	8/03/2011	-4.673	L
	9/03/2011	-4.594	L
	10/03/2011	-4.475	L
	11/03/2011	-4.356	L
	12/03/2011	-4.238	L
	13/03/2011	-4.13	L
	14/03/2011	-4.009	L
	15/03/2011	-3.933	L
	16/03/2011	-3.877	L
	17/03/2011	-3.823	L
	18/03/2011	-3.79	L
	19/03/2011	-3.747	L
	20/03/2011	-3.719	L
	21/03/2011	-3.702	L
	22/03/2011	-3.692	L
	23/03/2011	-3.675	L
	24/03/2011	-3.598	L
	25/03/2011	-3.551	L (-3.5 M)
	26/03/2011	-3.52	L
	27/03/2011	-3.494	L
	28/03/2011	-3.449	L
	29/03/2011	-3.433	L
	30/03/2011	-3.421	L
	31/03/2011	-3.733	L
	1/04/2011	-3.513	L
	2/04/2011	-3.424	L
	3/04/2011	-3.377	L
	4/04/2011	-3.331	L
	5/04/2011	-3.288	L
	6/04/2011	-3.265	L
	7/04/2011	-3.376	L
	8/04/2011	-3.285	L
	9/04/2011	-3.278	L
	10/04/2011	-3.279	L
	11/04/2011	-3.272	L
	12/04/2011	-3.295	L
	13/04/2011	-3.339	L
	14/04/2011	-3.373	L
	15/04/2011	-3.373	L
	16/04/2011	-3.405	L
	17/04/2011	-3.444	L
	18/04/2011	-3.453	L
	19/04/2011	-3.681	L
	20/04/2011	-3.584	L

	21/04/2011	-3.567	L
	22/04/2011	-3.572	L
	23/04/2011	-3.597	L
	24/04/2011	-3.617	L
	25/04/2011	-3.637	L
	26/04/2011	-3.658	L
	27/04/2011	-3.664	L
	28/04/2011	-3.692	L (-3.69 M)
	29/04/2011		
	30/04/2011		
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	21/05/2011		
	22/05/2011		
	23/05/2011		
	24/05/2011		
	25/05/2011		
	26/05/2011	-4.52	M
	27/05/2011	-5.897	L
	28/05/2011	-4.75	L
	29/05/2011	-4.941	L
	30/05/2011	-3.564	L
	31/05/2011	-4.549	L
	1/06/2011	-3.535	L
	2/06/2011	-3.28	L
	3/06/2011	-7.163	L
	4/06/2011	-3.598	L

	5/06/2011	-3.315	L
	6/06/2011	-3.197	L
	7/06/2011	-3.637	L
	8/06/2011	-3.989	L
	9/06/2011	-3.434	L
	10/06/2011	-5.607	L
	11/06/2011	-3.722	L
	12/06/2011	-3.471	L
	13/06/2011	-3.367	L
	14/06/2011	-5.636	L
	15/06/2011	-3.792	L
	16/06/2011	-3.578	L
	17/06/2011	-3.511	L
	18/06/2011	-3.463	L
	19/06/2011	-3.446	L
	20/06/2011	-3.453	L
	21/06/2011	-3.46	L
	22/06/2011	-3.968	L
	23/06/2011	-3.808	L
	24/06/2011	-3.658	L
	25/06/2011	-3.635	L
	26/06/2011	-3.622	L
	27/06/2011	-3.614	L
	28/06/2011	-4.163	L
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	30/06/2011	-3.78	L
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	3/07/2011	-5.284	L
	4/07/2011	-4.373	L
	5/07/2011	-4.618	L
	6/07/2011	-4.466	L
	7/07/2011	-4.178	L
	8/07/2011	-4.112	L
	9/07/2011	-4.085	L
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	15/07/2011	-5.742	L
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	17/07/2011	-4.784	L
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	19/07/2011	-7.421	L

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	21/07/2011	-6.312	L
	22/07/2011	-5.131	L
	23/07/2011	-4.839	L
	24/07/2011	-4.707	L
	25/07/2011	-4.649	L
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	30/08/2011	-6.086	L
	31/08/2011	-5.996	L
	1/09/2011	-5.898	L
	2/09/2011	-6.008	L

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	4/09/2011	-7.662	L
	5/09/2011	-7.596	L
	6/09/2011	-6.817	L
	7/09/2011	-6.539	L
	8/09/2011	-7.597	L
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	10/09/2011	-6.982	L
	11/09/2011	-7.664	L
	12/09/2011	-6.894	L
	13/09/2011	-9.444	L
	14/09/2011	-7.599	L
	15/09/2011	-7.252	L
	16/09/2011	-6.888	L
	17/09/2011	-6.749	L
	18/09/2011	-6.82	L
	19/09/2011	-7.313	L
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	23/09/2011	-7.134	L
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	7/10/2011	-9.096	L
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	13/10/2011	-9.227	L
	14/10/2011	-8.333	L
	15/10/2011	-10.349	L
	16/10/2011	-8.121	L
	17/10/2011	-7.778	L

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	19/10/2011	-7.594	L
	20/10/2011	-7.493	L
	21/10/2011	-8.262	L
	22/10/2011	-10.66	L
	23/10/2011	-9.081	L
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	5/11/2011	-8.681	L
	6/11/2011	-8.213	L
	7/11/2011	-8.628	L
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	22/11/2011	-8.64	L
	23/11/2011	-9.005	L
	24/11/2011	-9.207	L
	25/11/2011	-10.743	L (-9.2 M)
	26/11/2011	-11.205	L
	27/11/2011	-9.262	L
	28/11/2011	-8.914	L
	29/11/2011	-10.646	L
	30/11/2011	-9.05	L (-8.64 M)
	1/12/2011	-9.262	L

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	3/12/2011	-8.861	L
	4/12/2011	-10.183	L
	5/12/2011	-8.996	L
	6/12/2011	-8.709	L
	7/12/2011	-9.651	L
	8/12/2011	-8.852	L
	9/12/2011	-9.768	L
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	13/12/2011	-8.846	L
	14/12/2011	-8.652	L
	15/12/2011	-8.547	L
	16/12/2011	-8.471	L
	17/12/2011	-8.422	L
	18/12/2011	-8.386	L
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	5/01/2012	-8.326	L
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	7/01/2012	-8.341	L
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	9/01/2012	-8.355	L
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	11/01/2012	-8.365	L
	12/01/2012	-9.383	L
	13/01/2012	-11.4	L
	14/01/2012	-9.235	L
	15/01/2012	-8.877	L

	16/01/2012	-8.734	L
	17/01/2012	-8.668	L
	18/01/2012	-8.63	L
	19/01/2012	-8.607	L
	20/01/2012	-8.596	L
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	25/02/2012	-8.636	L
	26/02/2012	-8.644	L
	27/02/2012	-8.64	L
	28/02/2012	-8.701	L
	29/02/2012	-8.695	L

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	3/03/2012	-8.7	L
	4/03/2012	-8.722	L
	5/03/2012	-8.721	L
	6/03/2012	-8.715	L
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	10/04/2012	-8.488	L
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	13/04/2012	-8.5	L
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	18/04/2012	-8.552	L
	19/04/2012	-8.652	L
	20/04/2012	-9.373	L
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	28/04/2012	-8.783	L
	29/04/2012	-8.511	L
	30/04/2012	-8.446	L
	1/05/2012	-8.403	L
	2/05/2012	-8.571	L
	3/05/2012	-8.6	L
	4/05/2012	-8.624	L (-8.47 M)
	5/05/2012	-8.616	L
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	16/05/2012	-8.735	L
	17/05/2012	-8.735	L
	18/05/2012	-8.703	L
	19/05/2012	-8.714	L
	20/05/2012	-8.714	L
	21/05/2012	-8.725	L (-8.56 M)
	22/05/2012	-8.667	L
	23/05/2012	-8.689	L
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	25/05/2012	-10.834	L
	26/05/2012	-9.449	L
	27/05/2012	-9.058	L
	28/05/2012	-8.955	L
	29/05/2012	-10.196	L

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	31/05/2012	-10.573	L
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	3/06/2012	-9.606	L
	4/06/2012	-9.392	L
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	9/07/2012	-9.713	L
	10/07/2012	-9.696	L
	11/07/2012	-9.556	L
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	13/07/2012	-9.473	L

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	23/08/2012	-11.293	L
	24/08/2012	-11.329	L
	25/08/2012	-11.338	L
	26/08/2012	-11.368	L
	27/08/2012	-11.385	L

	28/08/2012	-11.368	L
	29/08/2012	-11.31	L
	30/08/2012	-11.227	L
	31/08/2012	-13.519	L
	1/09/2012	-12.085	L
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	24/09/2012	-12.343	L
	25/09/2012	-12.237	L
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	27/09/2012	-14.987	L
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	01/12/2010	-5.4	M
	25/3/2011	-2.09	M
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	25/11/2011	-4.35	M
	04/05/2012	-4.73	M
	21/05/2012	-4.85	M
	28/08/2012	-5.633	L
	29/08/2012	-5.656	L
	30/08/2012	-5.656	L
	31/08/2012	-5.653	L
	1/09/2012	-5.688	L

	2/09/2012	-5.693	L
	3/09/2012	-5.703	L
	4/09/2012	-5.707	L
	5/09/2012	-5.713	L
	6/09/2012	-5.721	L
	7/09/2012	-5.729	L
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	14/09/2012	-5.751	L
	15/09/2012	-5.77	L
	16/09/2012	-5.791	L
	17/09/2012	-5.789	L
	18/09/2012	-5.793	L
	19/09/2012	-5.805	L
	20/09/2012	-5.811	L
	21/09/2012	-5.825	L
	22/09/2012	-5.824	L
	23/09/2012	-5.81	L
	24/09/2012	-5.814	L
	25/09/2012	-5.828	L
	26/09/2012	-5.838	L
	27/09/2012	-5.857	L
	28/09/2012	-5.872	L

*Data from loggers based on daily average. L = logger reading, M = manual reading



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