C & D LANDFILL EXPANSION
HYDROGEOLOGICAL ASSESSMENT
C & D LANDFILL LTD

SUBMITTED TO:
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11 October 2013

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APPENDIX A - FIGURES
# INTRODUCTION

C & D Landfill Limited (C&DL) and Burrell Demolition have applied for consent to extend their Construction & Demolition (C&D) clean fill landfill operation at Happy Valley, Wellington (Figure 1 - Appendix A). Consent applications SR215490 with Wellington City Council (WCC) and WGN090036 with Greater Wellington Regional Council (GWRC) were submitted and a combined request for further information in relation to these applications has been coordinated through the GWRC.

**Figure 1. Location of C & D Landfill**

*(See Appendix A).*

The applications for the proposed expansion to the existing C&DL landfill was submitted by MWA solutions Ltd (MWA) in January 2012, followed by an updated submission by Opus International Limited (Opus), dated April 2013. The existing and proposed landfill expansion accepts only construction and demolition waste, and as such is regarded as a clean fill operation. The expansion of the C&DL landfill is expected to accommodate anticipated demolition waste volumes for the next 35 years.

In response to the updated application (Opus, 2013) the following requests for further information were made by Council and their reviewers:

- **Further Information Request under Section 92(1) of the Resource Management Act 1991, dated 23 September 2013 (referred to as the GWRC review, 2013); and**

- **Burrell Demolition – C & D Landfill Section 92 Request, dated 16 September 2013 by Pattle Delamore Partners Ltd (referred to as the PDP review, 2013).**

This report presents the findings of a hydrogeological assessment of the proposed expansion of the C&DL landfill operation and is intended to provide the additional information requested.

# SCOPE OF SERVICES

As outlined in our proposal 09870.000.000 dated 20 June 2013 and updated on 26 September 2013, Geoscience Consulting (NZ) Ltd (Geoscience) was requested by C&DL to complete the following scope of services that can be summarised as follows:

- Desktop review and reporting of relevant groundwater information provided by C&DL in addition to readily available public information;
- Construct a conceptual groundwater model of the proposed C&DL landfill expansion area based on the desktop review;
- Using the conceptual groundwater model, undertake an qualitative groundwater impact assessment of the likely impacts resulting from the proposed C&DL landfill expansion project, taking into consideration the likely leachate conditions arising from the C&DL landfill expansion.

This report summarises the findings from the above scope of services.
3 FURTHER INFORMATION REQUESTS

Items relevant to this hydrogeological assessment that were raised in the further information requests (GWRC review, 2013 and PDP review, 2013) and are summarised in Table 1 below, along with a summary of the findings of this hydrogeological assessment.

Table 1 Further Information Request Items

<table>
<thead>
<tr>
<th>Information Request Item</th>
<th>Report Section</th>
<th>Summary Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>GWRC Review, September 213</td>
<td>Section 7</td>
<td>Details of known and inferred groundwater conditions are summarised. There is limited site investigation data within the Western Gully. Observations made from a hydrogeological mapping have been used to corroborate data from other publically available sources. A summary of water quality monitoring is provided by others (Opus, 2013).</td>
</tr>
<tr>
<td>How groundwater conditions affect the proposed design/construction sequences to mitigate for adverse effects on groundwater</td>
<td>Section 4.3 &amp; 4.4</td>
<td>Groundwater conditions have influenced the staged design of the landfill as follows: • An underdrain that permits groundwater discharge to continue has been incorporated into the design at the base of the landfill; • Natural site hydraulic containment has resulted in the planned absence of a landfill liner; • High permeability drainage material (referred to as side taps) will be installed on the gully side walls where seepage is observed prior to landfilling to permit continued groundwater discharge and preferential conductance to the basal drainage system; and • Groundwater contribution to the leachate management system has been estimated and considered in the sizing of drainage pipes (Opus, 2013).</td>
</tr>
<tr>
<td>Details of monitoring bores (existing or proposed).</td>
<td>Section 7.1</td>
<td>There are a number of factors that contribute to the absence of onsite monitoring bores. These can be summarised as follows: • The risk to groundwater quality was deemed low given the activity is a clean fill operation. This has been demonstrated for the leachate management system monitoring for the existing C&amp;D landfill; • This risk to altering groundwater flow direction and discharge locations was deemed low, as groundwater flow is highly influenced by geologic structures that will not be altered by the presence of the C&amp;D landfill; and • The steep terrain of the Western Gully means the logistics associated with undertaking any site investigations would prove difficult and destructive to the regenerating bush. Extensive earthworks or specialised equipment would need to be flown in that is considered unjustified based on the sites risk profile.</td>
</tr>
</tbody>
</table>
### Information Request Item

<table>
<thead>
<tr>
<th>GWRC Review, September 213</th>
<th>Section 7.0</th>
<th>Summary Response</th>
</tr>
</thead>
</table>
| Undertake a hydrogeological assessment which shall include but not be limited to the following:  
- The depth of groundwater  
- The location of recharge areas (seeps and springs)  
- Rate and direction of groundwater (gradient)  
- Baseline groundwater quality (note this should include an upstream control site for future monitoring)  
- The relationship between surface water and groundwater  
- Hydraulic conductivity | This hydrogeological assessment has been undertaken using the available data to establish groundwater levels, flow regime and recharge and discharge zones.  
The conceptual groundwater model identifies recharge zones at elevations near the ridge lines, creating a driving head to discharge zones that extend up from the base of the gully. Surface water flow in the gully is likely to have a baseflow component as a result of groundwater discharge through fracture zones.  
The ridge lines are interpreted to form groundwater divides limiting the size of the groundwater catchment area. Groundwater levels are expected to follow the catchment topography in a subdued manner until reaching discharges zones in the lower gully slopes. With respect to the groundwater system as a whole, the site is naturally hydraulically contained.  
Groundwater will flow preferentially along faults and fracture zones in the greywacke where rockmass permeability is higher. Hydraulic parameters in of the greywacke have been estimated from aquifer testing conducted in adjacent gullies that are in the same geologic units that are present in the Western Gully and on this basis it is reasonable to extrapolate these aquifer properties to this site. |

| Based on the hydrogeological assessment and the geological characteristics of the site, undertake an assessment on appropriate leachate management options. | Section 4.3 | The leachate system has been design by Opus (2013) and includes findings from this Hydrogeological assessment as well as the Geotechnical Assessment (Geoscience, 2013). |

| Please complete a risk assessment for leachate migration given the:  
- Materials to be landfill  
- Catchment  
- Geological setting  
- Hydro setting | Section 9.0 | A semi-quantitative risk assessment has been undertaken, the findings of which are presented in Section 9.0 of this report.  
It was concluded that the C&DL landfill would not result in any adverse impacts on groundwater flow, occurrence or quality. This was a result of the C&DL landfill design and existing and anticipated groundwater regime of the Western Gully. |

### PDP Review, September 2013

| A hydrogeological assessment of the site including detailed conceptual model and assess potential impacts that the proposed expansion may have on groundwater.  
State what groundwater monitoring is proposed. | Section 7.0 & 9.0 | This report present the finding of the hydrogeological assessment that have been used to develop the conceptual groundwater model for the site from which the potential for environmental effects have been assessed. The findings of all these are discussed throughout the report.  
It has been concluded that the risks presented by the proposed expansion to the existing C&DL landfill to groundwater flow or quality in the Western Gulley are minor or less than minor. |

Each item summarised in Table 1 is discussed in more detail in the following sections of this hydrogeological assessment report.
Geoscience note that the GWRC Review (2013) and PDP review (2013) include requests for items relating to issues not included in this hydrogeological assessment. Geoscience understands that these items have been investigated and responded to by others.

4 EXISTING AND PROPOSED LANDFILL ACTIVITY

Detailed information regarding the existing and proposed landfill activity at C&DL landfill has been described by others (MWA 2012 and Opus 2013). A brief summary of items relevant to groundwater effects have been summarised in the following sections.

4.1 Existing Landfill

As shown on Figure 1, the existing landfill is located in two small gullies towards the southern end of the lease area and to the west of Landfill Road. Geoscience understands from discussion with C&DL, that the landfill has been operating for approximately 25 years. Key features of the existing landfill are shown on Figure 2 (Appendix A).

Figure 2. Key Features of the Existing and Proposed C & D Landfill
(See Appendix A).

Key features are summarised as follows:

- The base of the fill immediately above Landfill Road is at an elevation of 130 masl (elevations given in metres above mean sea level [masl] in relation to New Zealand Geodetic Datum [2000]);
- As at September 2013 fill has been placed at elevations extending from 230 to 240 masl;
- Surface water flows from the Western Gully are directed into a 900 mm culvert which has an intake elevation of approximately 136 masl at the north-western edge of the existing landfill;
- To the east of the culvert intake is an approximately 15 m high fill slope which forms an embankment across the width of the gully. This structure is referred to as the ‘Landfill Bridge’. The width of the Landfill Bridge at its crest is approximately 25 m;
- Cut slopes into natural ground of up to 15m in height have been constructed at a number of locations around the perimeter of the landfill; and
- Depressions are left on the surface of each lift as required to contain low strength materials, and retain sediment laden water prior to evaporation or downward percolation.

Geoscience understand that approximately 70% of the volume of material being imported to the site comprises either demolition fill or is granular clean fill. The remaining 30% consists of soft, weak clean fill soil.

The net effect on the hydraulic properties of the materials placed during the operation at the conclusion of filling is expected to be as follows:

- The materials will have relatively uniform hydraulic properties with a degree of horizontal anisotropy present; and
- Isolated pockets of high and low hydraulic conductivity material may be present on a random basis throughout the landfill extents.

Groundwater behaviour within the landfill material is typically difficult to predict, however it is reasonable to expect that the variations in hydraulic properties will result in localised perching of groundwater. This is in agreement with observations made by URS (2009) where it was noted that significant water losses have occurred while advancing boreholes through landfill materials at the existing C&D Landfill. It was interpreted by URS that the landfill was essentially free-draining, however, localised perched water levels may exist above areas of low permeability material.
4.2 Proposed Landfill

The proposed expansion to C&DL landfill is within a gully adjacent to the existing landfill operation and is referred to as the Western Gully. It has been assumed that the methodology that will be used to construct the landfill expansion will be the same as that used in the existing C&DL landfill.

The proposed landfill design is included on Figure 2 (Appendix C) and comprises three main stages, which are outlined below:

- **Stage 1** is subdivided into two sub stages:
  - **Stage 1S** includes raising the height of the existing landfill in the southern gully from 240 masl (the maximum height permitted under current Consent conditions) to 270 masl. Geoscience notes that Stage 1S does not form part of the current consented activity;
  - **Stage 1N** includes filling in the lowest part of the Western Gully adjacent to the existing Landfill Bridge at 135 masl to a level of 180 masl. The lowest part of the front face would be constructed from 150 masl; and
  - **Stage 1W** includes filling the upper part of the Western Gully between approximately 190 masl and 260 masl. The estimated solid volume of the Stage 1W fill is comprises 395,000 m$^3$.

- **Stage 2** includes filling above the Stage 1N fill from 180 masl to 220 masl. This filling will be wholly contained within the central part of the Western Gully and extend into the lower reaches of the secondary gullies located on the northern side of the main Western Gully; and

- **Stage 3** is the final stage of the landfill construction and includes filling above the Stage 2 level to a final level of no greater than 270 masl. The crest of the Stage 3 fill would be contoured as part of landscaping of the rehabilitation of the final fill profile. Refer Opus (2013) assessment for details of this aspect of the landfill construction.

As filling proceeds the working surface will be sloped at around 100H:1V upstream to direct water runoff to the upstream edges of the landfill. Blanket drains, adjacent to the pre-existing ground surface, will direct this flow down to the leachate collection system at the base of the gully (refer Opus, 2013 for details).

Preparation of the each stage of filling would involve the following activities prior to placement of landfill material:

- Stripping of vegetation from the base of the gully, removal of loose rock and soil;
- Extension of the culvert upstream with placement of pipe backfill above;
- Construction of debris control structures upstream of the culvert intake; and
- Construction of perimeter drains above the final height of the particular fill stage to intercept overland and stream flow.

It is difficult to accurately predict landfill filling rates, however, Geoscience, (2013) have estimated that the following date ranges of the various stages may generally apply: (note these timeframes do not include an allowance for filling in Stage 1S):

- **Stage 1N and Stage 1W**: 2014 to (2021 – 2023);
- **Stage 2**: (2021 – 2023) to (2026 – 2032); and
- **Stage 3**: (2026 – 2032) to (2034 – 2045).
4.3 Groundwater Seepage and Leachate Management System

Leachate management at the base of the C&DL landfill will be undertaken in a staged manner (Opus, 2013) as summarised below:

- Prior to the commencement of filling a groundwater/leachate collection system will be constructed in the gully base that will consist of a toe dam at the downstream end of each stage. This will assist in collecting groundwater and leachate flowing off the greywacke, forming the base and side slopes of the gully, that can then be directed into collection pipes;
- Running up the base of the main gully will be a highly permeable granular filled trench. This will collect groundwater seepage from below, as well as water infiltrating from above that has percolated through the fill surface and water inflows from the paleo-gullies in the sides;
- Side taps of high permeability material will be installed where seepages are observed in the gully side slope on an as needed basis;
- The combined groundwater/leachate flow will be directed into a lined retention pond at the head of Stage 2 that will include a flow measurement device and water quality monitoring point; and
- From the retention pond direct flow through a constructed wetland prior to discharge to the Western gully stream, subject to compliance with discharge conditions after reasonable mixing.

Surface water from upslope in the catchment will be managed in the following manner (Opus, 2013):

- Surface water will be collected using contour drains New Zealand Environmental Technologies Ltd (NZET, 2013) around the perimeter of the landfill to capture surface water from the upslope catchment before it can enter the fill.
- The landfill will be capped and grass cover sewn on completed areas as soon as feasible after filling is completed. Capping will also include the use of intermediate cover layers so that more surface water can be shed to the contour drains and clear of the fill while filling progresses.

Onsite water management will have a designed contingency system for discharge of groundwater and/or leachate to sewer as trade waste should a direct discharge not be in compliance. This will be subject to detailed design.

4.4 Completion of Final Fill Surface

At the completion of the Stage 3 filling, the upper surface of the fill will be capped with a low permeability material to reduce water infiltration to the fill. The fill surface will be bunded centrally to direct runoff to the perimeter drains that will bound the upper level of the fill surface.

Capping and grass cover of completed fill areas will be undertaken as soon as feasible, including using intermediate capping, so more surface water can be shed to the contour drains and clear of the fill.

Geoscience note that the following aspects of the design of the C&DL landfill expansion are outside of this scope and are being undertaken by others:

- Design of a stormwater management system for the western gully flow (NZET);
- Leachate collection design (Opus); and
- Landscaping and vegetation rehabilitation (Opus)

Geoscience have provided comment in relation to the hydrogeological aspects of each of these components where relevant to the conceptual groundwater model.
5 SITE SETTING AND TOPOGRAPHY

The C&D landfill is located on the western side of Landfill Road in Happy Valley, within the Carey’s Gully Catchment area. As shown on Figure 1 (appendix A), the existing consented landfill occupies a gully system on the southern side of the lease boundary. Photograph 1 below shows the extent of the landfill from its western edge.

The Western Gully (Figure 1, Appendix A) comprises the majority of the C&D landfill lease area and occupies an area of around 40 ha. The Western Gully system is bound on its northern and western sides by a prominent ridge system which reaches elevations of approximately 400 to 450 masl. A lower height ridge line on the south-eastern side of the site separates the Western Gully from the existing C&D Landfill. This ridge line ranges in elevation from 380 masl (towards the southwest) down to 280 masl (towards the northwest).

The flanks of the Western Gully are typically steeply inclined (Figure 1 and Photograph 2). Side slopes within the western gully have been measured up to 45°. Rock outcrops on the northern gully system have observed slope angles of over 60°.

Four prominent secondary gullies are noted on the northern flank of the main Western Gully system as shown on Figure 1. These secondary gullies drain towards the south.

The slopes of the Western Gully are covered with a mixture of regenerating native bush and introduced species (including gorse and broom: Photograph 2 below).
5.1 Climate

Wellington has a temperate climate with mild daytime temperatures and infrequent frosts. The area generally tends to receive high rainfall in winter and low rainfall in summer, but is prone to high intensity rainfall and wind that can occur at any time of the year (URS 2013). Annual rainfall is typically around 1,250 mm in the western hills area, west of Wellington.

6 GEOLOGICAL SETTING

The geological conditions at the site are discussed in the following sections and were sourced from published geological information as well as a site visit by Geoscience staff.

6.1 Geology

The geology of the Wellington area has been mapped by the Institute of Geological and Nuclear Sciences (Figure 1b after Begg & Mazengarb, 1996) and Figure 3 (Geoscience, 2013, Appendix A). Geological observations were also made during a site visit by two Engineering Geologists from Geoscience on 16 August 2013 and concentrated on establishing the geological conditions of the gully floor. These findings are discussed further in the Geoscience Geotechnical Assessment (Geoscience, 2013) with information relevant to the hydrogeology summarised in the following sections.

Figure 3. Geological Map of the C&D Landfill Area

(See Appendix A).

Begg & Mazengarb (1996) show the Western Gully to be underlain by Triassic age Torlesse Complex grey Sandstone and Siltstone/Mudstone (Argillite) sequences which have been repeatedly folded and faulted by a series of tectonic events. The Torlesse Complex rocks are more commonly referred to as “Greywacke”.

Overlying the Torlesse Greywacke in many areas around Wellington is a layer of relatively thin colluvial soil derived from the gravitational movement of soil and weathered rock downslope. Whilst in general the colluvium is typically less than a few metres in thickness, significantly larger soil thickness

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can occur in ‘Paleogully’ structures. These features comprise channels within the bedrock surface which have subsequently been infilled.

Geological conditions observed in the Western Gully are fairly uniform across the wider Carey’s Gully Catchment area and correlate strongly with geological conditions described in the Southern Landfill Section 96 resource consent application (URS, 2013). The Southern Landfill is located directly to the north of the existing C&DL landfill (Figure 1, Appendix A).

6.2 Geological Structures

The geological map of the area indicates that two faults, as shown on Figure 1 (Appendix A), transect the Western Gully. These comprise an unnamed fault towards the western (upstream) end of the gully system and the Parawhero Fault, which is located in the central part of the Western Gully. According to the New Zealand Active Faults Database, neither the unnamed fault nor the Parawhero Fault is thought to be active.

The Wellington Fault is located approximately 1.5 km northwest of the Western Gully.

6.3 Surface Hydrology

Based on topographical data (LIDAR, provided by C&DL) the total land area of the C&DL landfill site which contributes stormwater to the catchment of the Carey’s Gully Stream is approximately 73 Ha. Physical characteristics of the stream can be summarised as follows:

- In the central part of the gully system above about 200 masl, relatively small extents of alluvial material were observed. In general, the alluvium comprises free-draining sand to coarse gravel material; and
- In general, the hill slopes of the gully are covered with a thin and discontinuous colluvial soil horizon. However, significant thicknesses of material (over 2 m) could be observed in some areas on the slopes immediately above the base of the gully. The exposures of colluvial soil typically comprised angular to subangular boulders at the base, fining upwards to sandy gravel.

Surface water flows in the Western Gully were observed by Geoscience (August 2013) in the lower part of the gully in the main stream channel. The channel was dry above approximately 220 masl. Above 220 masl, shallow groundwater flow was observed within the alluvium at the base of the gully. This is in broad agreement with the NZET (2013) analysis in that:

- Surface water passing down the steeper faces of the gullies are predominantly flowing through the colluvium filled areas;
- The fill material adjacent to the culvert inlet also appears to be relatively permeable; and
- Flows received at the culvert inlet are much lower than those predicted from standard catchment yield formulae (suggesting significant lateral flow through the colluvium).

Connectivity between surface water and shallow groundwater was noted in the Southern Landfill resource consent application (URS, 2013) in that:

- Groundwater contributes baseflow to the steam allowing for perennial stream flow conditions; and
- There is an upward vertical hydraulic gradient in groundwater at the base of the gully.

Surface water flows in the culvert exiting the C&DL site were recorded on multiple occasions in 2013 by NZET following moderate rainfall events. Average flows of approximately 50 litres/second were recorded.

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7 HYDROGEOLOGICAL SETTING

Factors controlling groundwater flow and occurrence in the Western Gully are summarised in the following sections, along with the source of the information.

7.1 Groundwater Investigations

No data relating to site specific groundwater levels has been obtained from monitoring wells in the preparation of this report. Information contributing to the conceptual groundwater model (Section 7.5) has been made from desktop study, investigations in the immediate vicinity of the site and other site observations. Anecdotal information from changes in seasonal vegetation type does, however, provide an indication of groundwater discharge elevations (Photographs 3a and 3b).

There is an absence of existing groundwater monitoring wells at the site which reflects the absence of any real risk to groundwater associated with the existing landfill operation. Clearly groundwater monitoring was not considered a requirement under any condition of the existing consents. As discussed in Section 9.0, groundwater impacts are expected to be less than minor and on this basis monitoring is not considered necessary.

Access to the Western Gully is difficult at best and site investigation are not considered justified at this time given the logistics involved. Steep and uneven terrain as well as dense bush significantly restricts access. Extensive clearance of regenerating bush would be required to gain access, particularly to the upper slopes of the ridges.

The Southern Landfill has nine monitoring wells installed in four locations across the site (URS, 2013) in a directly analogous geological and hydrological setting, being in the adjacent gully approximately 1 km to the north of C&DL landfill (Figure 1, Appendix A). Investigations there have included:

- The installation of multilevel piezometers four sites to investigate lateral and vertical groundwater gradients;
- Groundwater level observations made in March and June of 2011 and
- A pumping well was constructed for hydraulic testing of the greywacke rock that was undertaken in June 2011.

The URS (2013) monitoring bores were installed to depths ranging from 10 to 104.5 m at selected locations near the ridgelines and in the gully floor.

URS (2013) noted from aquifer testing that conductivity appeared greater where relaxation of the rock mass was likely to have occurred, such as near the surface of the ridges and side slopes. Here, hydraulic conductivity decreased with depth as the degree of relaxation decreases and fracture
aperture or extent reduces. It was also noted that the inverse relationship is evident at the gully floor, which may be explained by compression being greatest near the surface.

These features will result in anisotropy due to differences in hydraulic conductivity within the greywacke rockmass and therefore zones of preferential flow and discharge.

Connectivity via fracture flow was demonstrated during aquifer testing undertaken by URS (2013) where a rapid drawdown response to abstraction was observed in some monitoring wells. Calculated hydraulic conductivity values for the greywacke rock were in the order of 1.0x10^-7 to 2.0x10^-6 m/s (metres per second). These hydraulic conductivity values are likely to be at the higher end of the range as they were calculated from drawdown data in monitoring wells that were likely to be located in a hydraulically connected shear zone.

Analysis of the recovery data at the cessation of pumping suggested poor recharge in the greywacke aquifer and limited connectivity with the larger groundwater system through the geologic structures. This is has been interpreted from the absence of full groundwater level recovery after 4 days of observations.

Soil infiltration tests were carried out by NZET (2013) in the Western Gully (using AS/NZS 1547:2000). Four locations were tested at depth ranges of 150 to 300 mm below ground level (bgl) and 300 to 450 mm bgl. The range of saturated infiltration rates (essentially equivalent to hydraulic conductivity) was 4.6x10^-7 m/s to 3.0 x10^-5 m/s with a mean of 1.3x10^-5 m/s. These data indicate that the surface soils have a greater capacity to accept and conduct water than the deeper rockmass. Further the surface soils will store water (due to higher porosity) that will act as an ongoing source of recharge for the deeper aquifer system at certain times of the year.

Geoscience geologists observed the following features during the site visit:

- Where exposed in the lower reaches of the gully system (below about 200 masl), the rock mass was typically slightly weathered, strong and closely jointed;
- The orientation of bedding appears to be very steeply inclined to the west (i.e. upstream);
- The rock mass conditions typically deteriorate with distance upstream. Above approximately 270 masl, the rock mass is highly weathered and weak to moderately strong. Bedding was not observed in the upper areas of the gully system;
- Groundwater flows within the Western Gully are interpreted to be controlled by the presence of large scale structures (faults and shear zones) which tend to influence the groundwater flow direction locally; and
- There was no observed groundwater seepage in areas other than the floor of the gully, however it is expected that seepage does exist in a number of areas along the lower flanks of the gully system.

Geoscience observation from the site walk over tends to corroborate the URS (2013) data in that:

- Groundwater is likely to be controlled by the presence and orientation of structures within the rockmass and seepage occurs predominantly from these features that contribute to baseflow in the gully streams (based on observed shear zones);
- The degree of weathered and relaxation of the rock increases upstream, towards the upper reaches and on higher ground along the ridges and reduces in the base of the gully (based on the weathered profile); and
- Groundwater is closer to the surface at the base of the gully than higher up the ridges (based on the presence and distribution of the seepage locations).

These common features suggest direct analogy between the Southern Landfill and the C&DL landfill in Western Gully.
7.2 Groundwater Quality

Water quality monitoring in the leachate management system for the existing C&DL landfill has been undertaken by others (Opus, 2013, NZET, 2013). Historical monitoring indicates no long term trend of deteriorating water quality as a result of leachate seeping from the existing C&DL landfill.

7.3 Groundwater Levels

Groundwater level data was available from the Gully floor from site observations undertaken by Geoscience (2013). It was noted that groundwater is hydraulically connected with the surface water in the colluvium of the Western Gully. This is in agreement with groundwater measurements taken in the Southern Landfill (URS, 2013).

Furthermore, URS (2013) undertook the following groundwater level measurements that are consistent with observations from the Western Gully and typically seen in catchments of the type seen at the Southern Landfill and Western Gully, as follows:

- Groundwater elevations were found to be highest in the vicinity of the ridgelines and lowest at the base of the gully;
- Groundwater level fluctuations were greatest nearer the ridgelines and least (or no change) in the gully floor between observations in March and July 2011;
- Groundwater was nearer or at ground level in the base of the gully and up to 16 m bgl near the ridgelines; and
- Vertical hydraulic gradients were evident at each location with strongly downward gradients at the ridgelines and vertically upward in the gully floor. Observed horizontal gradients ranged from 0.2 to 0.4. Observed vertical hydraulic gradients were in the order of 0.2.

The above observations from the Southern Landfill (by URS, 2013) are consistent with Western Gully observations in terms of baseflow contribution from shallow groundwater in the gully floor.

7.4 Hydrostratigraphy and Groundwater Flow

Groundwater flow in the Western Gully is likely to be heavily influenced by the weathering of the rock mass, defect orientation and the presence and orientation of major geologic structures (faults, fracture zones and shear zones) within the rock.

Major structures may act as preferential paths for groundwater flow due to increased secondary permeability sub-parallel to the orientation of the structure. Photograph 4 shows a surface expression of a shear zone, observed by Geoscience (2013).
Photograph 4: Fault or fracture zone exposed in the base of the Western Gully, sub parallel to the local gully orientation.

Preferential discharge may occur along the interface between the residual soil and unweathered rock below (contact springs). NZET (2013) observed on 26 September in the cut faces at the western edge of the stage 1S area a clear interface between soil and rock where modest groundwater seepage was discharging.

URS (2013) also noted groundwater discharging from a fracture zone during a site visit in the same manner as that observed by NZET (2013) and Geoscience (2013).

This observed stratigraphically controlled groundwater flow in the Western Gully was consistent with URS’s (2013) observations of seepage locations and aquifer test results from the Southern Landfill.

7.5 Groundwater and Surface Water Hydrology

Surface water flow has been monitored in the existing culvert exiting the Western Gully, by NZET (2013) for stormwater design. Observed flows average approximately 0.05 m$^3$/s (cubic metres per second), (or 50 litres per second [L/s]) typically observed after rainfall events. Anecdotally, the highest flow in the existing culvert is reported to be approximately to 0.39 m$^3$/s (or 390 L/s). This range does not represent low flow conditions in the stream.

NZET (2013) calculated a total catchment area for the C&DL landfill to be 59 ha (hectares). This value was verified with Geoscience’s own assessment of the combined surface water subcatchments draining to the perimeter drain of the proposed C&DL landfill extension (Figure 4).

Figure 4. Surface Water Subcatchments of the Western Gully

(See Appendix A).

NZET’s (2013) estimation of flows from the catchment is approximately 30% of the annual average rainfall, or a unitary catchment contribution of 1.5x10^-8 m$^3$/s/m$^2$.

Opus (2013) calculated the groundwater and leachate contribution to the stream flow as averaging 0.003 m$^3$/s (or 3 L/s) for a catchment above Eastern Landfill, calculated as being 3.68 ha, based on 30% of the annual rainfall of 1,450 mm contributing directly to stream flow. This gives a catchment contribution of 2.1x10^-9 m$^3$/s/m$^2$. 
The unitary values of catchment contribution calculated by NZET (2013) and Opus (2013) are in good agreement with the URS estimate unitised discharge of between $2.1 \times 10^{-9}$ to $3.5 \times 10^{-9} \text{ m}^3/\text{s/m}^2$.

### 7.6 Conceptual Groundwater Model

Site specific hydrogeological observations made in the Western Gully has served to verify the nature of the groundwater system between the proposed fill area and the existing Eastern Landfill site. Further, the observations made in the Western Gully and Eastern Landfill sites concur with the more detailed assessment made by other in the adjacent catchment that is host to the GWRC municipal landfill. On the basis of this assessment it is reasonable to summarise the C&DL landfill site conceptual groundwater model as follows:

- Structural features and fault systems also influence the geomorphology of the gully and also the groundwater system;
- The site is hydraulically contained and internally draining;
- The primary rockmass permeability of the greywacke is very low;
- The greywacke aquifer exhibits preferential flow from secondary permeability along fracture zones within geologic structures resulting in anisotropy with an orientation parallel to these features;
- Groundwater flow is expected to be greatest where faults and fracture zones are more extensive, open and interconnected;
- Hydraulic conductivity will decrease with depth as faults become less open and are subject to greater compressive forces (i.e. less relaxation than near the surface and at elevation near the ridges);
- Whilst secondary permeability enhances aquifer hydraulic conductivity, the degree to which this occurs is limited by relatively few faults and fracture zones and small or infilled defect apertures;
- Groundwater storage in the aquifer is low the majority occurring in the fault and fracture zones;
- The water table typically follows the site topography in a subdued manner, with the water table intercepting the basal slopes near the gully floor, where groundwater discharges surface water via contact springs; and
- Groundwater recharge is limited to direct rainfall infiltration that is concentrated on the ridges within the groundwater catchment area.
- Steep vertical and horizontal hydraulic gradients are likely to exist that drive groundwater flow directions. Lower hydraulic gradients may exist where higher rockmass permeability occurs due to fault and fracture zones.

The conceptual groundwater model is illustrated in Figure 5 (Appendix A).

**Figure 5. Conceptual Groundwater Model of Western Gully**

(See Appendix A).

The conceptual groundwater model demonstrates the groundwater system within the catchment area is hydraulic contained; created by the groundwater divide along the ridgelines, the driving hydraulic gradients from the steeply elevated ridges that form recharge zones and the seepage and discharge zones in the lower gully slopes that ultimately report into the surface water system. The potential for groundwater to discharge into another catchment from the C&DL landfill site is considered to be almost non-existent.
8 LANDFILL LEACHATE AND WATER MANAGEMENT

The leachate and stormwater management system has been described by others (Opus, 2013, NZET, 2013). The items considered relevant from the leachate and stormwater management system design that assist in managing any potential risks to groundwater are as follows:

- Perimeter cut off drains constructed in the gully sides will act both as cut off drains for stormwater down from the slopes above and also as final surface drains for the completed landfill once capping has been applied (once initial settlement has occurred); and
- A leachate collection and treatment system will be constructed on the gully floor;
- Seepages from isolated areas in the gully sides are expected and, where encountered, would be controlled by the construction of blanket drains immediately above the natural ground surface;
- Mounding and sloping of the landfill surface will be undertaken to reduce infiltration from direct precipitation.

The volume of leachate generated is, therefore, anticipated to be small given the above proposed design features. This has been demonstrated already from the existing C&DL landfill water quality monitoring (NZET, 2013).

9 ASSESSMENT OF ENVIRONMENTAL EFFECTS

The proposed Western Gully C&DL landfill expansion has the theoretical potential to influence groundwater levels, flow and quality that could result in adverse effects to the environment. These potential effects and mitigating features are summarised as follows:

1. **C&DL landfill acting as a physical barrier to groundwater recharge**;
   - As the landfill is not proposed to be located within the groundwater recharge zone, (i.e. near the ridges and upper portions of the gully slopes), there is unlikely to be a significant reduction in recharge.
2. **C&DL landfill acting as a physical barrier to groundwater discharge**;
   - To mitigate against the barrier effect of the landfill on groundwater discharge, an underdrain system has been proposed beneath the landfill at approximately the same level as the existing gully stream. This will allow groundwater discharge to continue, maintaining existing groundwater levels and contribution to baseflow in the stream. This should result in an impact on groundwater levels and flow to be negligible.
   - Where preferential groundwater discharge zones are noted to occur (ie. fault and fracture zones), permeable side taps will be constructed that hydraulically connect the springs to the underdrainage system.
3. **Unacceptable change to groundwater flow direction**;
   - Groundwater recharge and discharge zones are not anticipated to be significantly altered due to the C&DL landfill expansion. Therefore the existing groundwater flow regime should be maintained within the gully. This is considered likely as the adjacent ridges constrain groundwater movement due to higher heads along bounding and head build up or reversal is mitigated against in the landfill design.
4. **Leachate generation at the base of the C&DL landfill**;
   - Natural hydraulic containment exists in the catchment and this anticipated to continue after construction of the C&DL landfill due to the vertically upward groundwater flow direction and discharge to the base of the gully. This means leachate will be contained to the immediate vicinity of the C&DL landfill footprint resulting in it reporting to the leachate collection and management system.
5. **Leachate generation at the sidewalls of the C&DL landfill; and**
o The steepness of the gully walls are likely to strongly influence the flow of leachate within the landfill. The relative high permeability of the fill compared with the sidewalls of the gully will result in leachate migrating to the base of the gully and reporting to the C&DL landfill leachate collection and management system.

o Interception of surface water from the sidetap drainage will minimize surface water inflow and therefore leachate generation potential.

6. **Migration of leachate along preferential flow paths:**

   o The low permeability of the greywacke rockmass will assist in containing leachate in the direct vicinity of the C&DL landfill;

   o However the presence of faults and shear zones can act as preferential flow paths, enabling leachate to migrate away from the site. This is considered unlikely, given the known hydraulic containment created by adjacent gullies and the potentially limited interconnectivity between fault systems, demonstrated in the aquifer testing in the Eastern Landfill (URS, 2013); and

   o Groundwater head buildup will be mitigated against in areas of preferential discharge by the construction of side tap drains, thereby maintaining existing hydraulic gradients and preventing gradient reversal that could result in the off site migration of leachate.

   o Water quality monitoring of the existing C&DL landfill leachate management system has shown no adverse impacts on water quality. This suggests the C&DL landfill clean fill poses a minor risk to water quality assuming the same clean fill practices are continued in the expansion project.

### 9.1 Summary of Assessment on Effects to Groundwater

Potential impacts on groundwater by the proposed C&DL landfill expansion are considered to be strongly mitigated against by a number of factors that are summarised below:

- Maintaining the existing hydraulic containment of the groundwater catchment created naturally by the steep sided gullies that exist in the area;
- The low primary permeability of the greywacke rock forming the sides and base of the C&DL landfill;
- The upward hydraulic gradient that exists in the base of the Western Gully causes discharge into the gully stream, meaning leachate will be contained within a small mixing zone and within the area of influence of the underdrain;
- Steeply inclined and low primary permeability gully sidewalls and side tap drains that limit the potential for water infiltration and leachate generation;
- A proposed leachate collection and management system that will reduce leachate levels at the base of the C&DL landfill;
- An underdrainage system beneath the landfill that will maintain groundwater flows to within the greywacke and limit the potential for uncontrolled groundwater discharges.

These factors have carefully considered and have influenced the design of the existing C&DL landfill as well as that of the adjacent municipal Southern Landfill operated by GWRC.

It is considered that these mitigating factors should result in the proposed C&DL landfill expansion having an effect on groundwater that is minor or less than minor.

### 10 LIMITATIONS

i. We have prepared this report in accordance with the brief as provided. This report has been prepared for the use of our client, C & D Landfill, their professional advisers and the relevant Territorial Authorities in relation to the specified project brief described in this report. No liability is
accepted for the use of any part of the report for any other purpose or by any other person or entity.

ii. The recommendations in this report are based on the ground conditions indicated from published sources and site inspections described in this report based on accepted normal methods of site investigations. Only a limited amount of information has been collected to meet the specific financial and technical requirements of the Client’s brief and this report does not purport to completely describe all the site characteristics and properties. The nature and continuity of the ground between test locations has been inferred using experience and judgment and it must be appreciated that actual conditions could vary from the assumed model.

iii. This Limitation should be read in conjunction with the IPENZ/ACENZ Standard Terms of Engagement.

iv. This report is not to be reproduced either wholly or in part without our prior written permission.

We trust that this information meets your current requirements. Please do not hesitate to contact the undersigned if you require any further information.

For and on behalf of Geoscience Consulting (NZ) Ltd

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Appendix A – Figures
Figure 1A. Site Location
source image: Google Earth

Figure 1B. Geological Setting
genological plan from Begg & Mazengarb (1996)

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