The GHD Assessment of Effects to Groundwater (Appendix 8) report has been reviewed by Mrs Sally Lochhead, Senior Hydrogeologist at T+T. Mrs Lochhead, has 20 years' experience in environmental geology and hydrogeology. Overall, there is limited description of the site hydrogeology and the development of the conceptual hydrogeological model lacks clarity. Further information is required to demonstrate the understanding of the two groundwater systems and how they are connected, and the interaction with the surface waters. We acknowledge that some of this information may be provided in the separate appendices, but this should be brought together and illustrated as a series of Figures which include the sections of the landfill, especially to show where areas of cut activities may or may not extend into the existing groundwater system.

	Item	Response post report update
5	**Appendix 8 - Groundwater Report**	**Response post report update**
5.2	**Section 3.0: Investigations findings and interpretation**	
5.3	**Section 3.2: Geology**	
a	Provide detail on the depths of the weathered Henley breccia and depth to unweathered bedrock to give a clearer understanding of the groundwater pathways.	As per Section 2.3.2 in Geotechnical interpretive report (GIR), joints, and other rock defects, were rare in both the sandstone/siltstone and breccia units of the Henley Breccia. Where boreholes did encounter defects, spacing was typically in excess of 10 m and too few were encountered to obtain any meaningful sense of predominant defect sets or trends. As per Section 3.2.7 of GIR, completely weathered - highly weathered rock was encountered at depths ranging from 0.7 - 4.4 mbgl, and was typically between 1 - 5 m thick (very stiff to hard soil and extremely weak to very weak rock). The remainder of the units encountered included moderately weathered - unweathered sandstone, siltstone, conglomerate and breccia. GIR Cross sections X-X', Y-Y' and Z-Z' indicate depth of MW-UW Henley Breccia across the site.
b	Advise whether the loess material exhibits any shrinkage cracks and other erosional features or fractures which could provide secondary groundwater flow paths.	As per Geotechnical Interpretive report (GIR) the loess soil typically comprised silt, with varying amounts of clay, sand and traces of fine gravel. These typically exhibited non-plastic to low plasticicity, however occasional layers had a higher clay content and displayed high plasticity. Bishop & Turnbull (1996) described columnar jointing and shrinkage cracks to be common in loess in the Dunedin area, however this was not observed at the site during investigations (Section 3.2.5 GIR). Section 6.2.1 of the GIR indicates that dispersion testing on samples of loess confirms that these materials are potentially dispersive when distured and prone to erosion. A number of shallow slope instability features were identified around the site, likely associated with the top few metres of loess and completely weathered rock.
c	Investigation bores; BH06, BH08, BH203 and BH209, and TP05 to TP12 are not shown on the investigation location plan Figure 6. Please provide an updated figure or reference an alternative figure.	This figure was intended to show the locations used for hydrogeological site investigation (with all investigation locations included in the geo report figures). All pertinent investigation locations have now been included in the revised figures.
5.4	**Section 3.3: Hydrogeology**	
5.4.1	**Section 3.3.1: Hydraulic conductivity**	
a	Provide a description of the geology, such as mention of any evidence of fractures or fissures within the bedrock that could increase the recorded hydraulic conductivities in order to assist with interpretation of the results of the hydraulic conductivity tests.	See response to 5.3 (a)
5.4.2	**Section 3.3.2: Hydraulic gradients, groundwater recharge and flow**	
Hydraulic gradients		
a	Reference is made to the brown siltstone layer: "retarding percolation of groundwater… resulted in the formation of a localised shallow groundwater system within the alluvium." Clarify how this conclusion is reached. Evidence provided in the report indicates it is not laterally extensive, e.g. the nested piezometers in BH03A and BH03B are shown to be installed above and below this siltstone layer, but both have a static water level at the same depth. The details of the potential presence identified in BH201, only refer to a colour change during the wash drilling of the BH201 (between 10.8 and 61 m), but no details are recorded on the bore logs.	Retardation of percolating groundwater is indicated by the difference in water levels installed above and below the fine-grained low permeability layer (Table 2 - BH02, BH03, BH04 and BH211), and the difference in water chemistry (Table A 5 - BH04 & BH211). A downwards hydraulic gradient at BH03 is recorded (Table A 2), however it is not as large as in other bore locations, potentially due to pinching out of the fine-grained low permeability layer in the base of the valley (BH01/BH02). As per Section 3.2, no approximate depth was provided for the reddish brown layer observed during wash drilling of BH201 - this was a verbal communication from the driller and therefore not included in the bore log. However, the groundwater level recorded in BH05B when compared with BH201 in July 2020 (Table A2) also indicates retardation of downwards percolating groundwater, with this likely due to the presence of this low permeability layer (which was also identified during drilling of BH05) and / or decreasing permeability of henley breccia with depth.
b	Reference to "dipping of layers of the Henley Breccia is expected to promote some horizontal movement". Provide further detail clarifying how this has been established, e.g. records of bedding, direction of dip etc from the site investigation data and published information (where available). This information will support the identification of the potential groundwater flow paths and the inferred direction of groundwater flows within the deeper aquifer.	As per Section 2.3.2 of GIR - Literature reports dipping of Henley Breccia to the west or northwest at 15-30 degrees (Bishop, 1994). Observed unit contacts in boreholes generally confirmed the bedding dip angle where it could be discerned (between 10 - 80 degrees), however dip direction could not be confirmed as the boreholes were not oriented. No outcrops were present at site to confirm bedding orientation. Given the very long travel times, and lack of nearby receivers within the deep groundwater system, direction of deep groundwater flow is not considered a risk, as it would take >8,000 years to reach either the Pacific Ocean or Taieri Basin, with discharge rates considered to be very low due to the low permeabiilty.

c	The description of groundwater movement is not clear. Further development of the hydrogeological conceptual site model and annotated sections is required to clarify the groundwater regime. This will help to show how groundwater is inferred to be recharged in the two identified groundwater systems.	As described in Section 3.5 - the deep groundwater system is located within the Henley Breccia and is subject to vertical downwards hydraulic gradients, with very low rates of rainfall recharge through the overlying low permeability loess/siltstone/henley breccia. Horizontal groundwater gradients are relatively flat, however infer a flow direction towards the south east. The shallow groundwater system is considered to be relatively localised within the base of the valley predominantly within permeable alluvium and colluvium, with high rates of recharge from rainfall and runoff, and groundwater flow directions following topography. Its also likely that some groundwater within the shallower, more permeable units of Henley Breccia discharges to this system at the base of the valley (upwards hydraulic gradients at BH01, and groundwater gradients towards the Otokia Creek in piezometers installed above the fine-grained low permeability layer where present).
Groundwater recharge and flow		
d	Clarify conceptually how recharge is received to the underlying aquifers, given the extent of the alluvium and colluvium shown on Figure 7 is limited to the valley floor within the gullies at the site.	Recharge to the localised shallow groundwater system is considered to predominantly be from direct rainfall recharge and runoff to the permeable alluvium and colluvium units. Additional recharge to the shallow groundwater system is likely to come from shallow groundwater within the adjacent more permeable Henley Breccia units. The deep groundwater system is likely to receive only a small volume of recharge directly through vertical percolation of rainfall that manages to recharge through the loess, and migrate vertically through the henley breccia and fine-grained low permeability layer. Recharge from the shallow system to the deep system is considered to occur (elevated concentrations of nitrate-N and ammonia as N (BH201)), however this recharge may be impeded to some degree by the fine-grained low permeability layer where present. No recharge from the shallow groundwater sytem is inferred where upwards hydraulic gradients are present in the base of the valley (BH01) where alluvium and colluvium are present.
e	Based on the input parameters in Table 3, it appears that the extent of the aquifer is 250 m wide and possibly represents the alluvium, although this is not established. Provide a figure (in plan and section view) as part of the hydrogeological conceptual site model showing the extent of the shallow groundwater system.	The extent of the shallow groundwater system cannot be well defined at the site as groundwater is flowing both vertically and horizontally. Table 3 adopts a conservatively large saturated aquifer thickness at the location of BH03 along the central ridge, however the thickness is anticipated to be less than this in the adjacent valleys and closer to BH01. While the discharge quantified by the Darcy's law calculation goes some way to attempting to understand the existing site conditions, ultimately the outcome of the assessment will not fundamentally change if the actual discharge is significantly higher or lower. This is because although a reduction in groundwater levels is considered likely due to placement of the landfill, this is considered to be than offset by the Stormwater retention ponds and attenuation basin, which will provide flow attenuation and stormwater soakage to ground through the valley floor.
f	Further detail is required on the water balance. If the shallow groundwater system is to receive less than 1% of total rainfall, this indicates that the surface water system (excluding evapotranspiration) receives the remaining and most of the rainfall. Given that the streams have been identified as ephemeral streams within the landfill footprint and the perennial flows of the Otokia Creek are identified approximately 1 km downstream of the site, the report does not clearly show what happens to all of the rainfall recharge.	As per Section 2.3 Rainfall in the vicinity of Dunedin has been recorded to vary between 652 mm (Airport) - 968 mm (Botanical Gardens). Evapotranspiration is 856 mm/year (Penman method). This indicates that evapotranspiration at the site is likely to be significant, which is likely why the stream remains ephemeral in the vicinity of the site.
g	Clarify the amount of recharge to the groundwater system. Data in Table 3 reports on groundwater discharge rather than flows, since no velocities are provided. The size (area and depth) of the shallow aquifer in Table 3 is small and information on the deeper groundwater system should be provided for the remainder of the site area.	As discussed in the response to 5.4.2 (e) the discharge from (and hence recharge to) the shallow groundwater system does not impact the outcome of the assessment due to the mitigation provided by the SRPs and attenuation basin. Quantification of recharge or flow within the deep groundwater system is not considered to be necessary as travel times are in excess of 8,000 years and discharge to the Pacific Ocean is considered to be negligible.
h	The report states that "Flow has not been estimated in the deeper groundwater system", although a flow rate of 4 m3/d is provided later in the report. Accordingly, clarify how this has been calculated?	The sub-soil drain discharge calculations have been updated for the revised design. See section 4.4.3 of report. Flow has not been estimated for the deep groundwater system (as discussed in (g) above)
5.4.3	**Section 3.3.3: Groundwater and surface water quality**	
a	A reasonable amount of detail has been provided on existing nitrate-N concentrations in the groundwater samples and fertiliser application. Further clarification is required as to whether fertiliser has been applied at this site to validate these discussion points. Are there any other potential sources for the elevated nitrate-N concentrations?	There are no other potential sources of elevated nitrate concentrations at the site. It is standard practice for forestry operations to use fertiliser.
b	Only one groundwater sample from each of the selected bore locations have been obtained during November 2019. Further groundwater samples need to be collected.	Additional sampling undertaken and reported in revised design report.
5.5	**Section 3.4: Surface water interactions**	
a	Provide further detail on the flow rates in the Otokia Creek, with stream monitoring and more detailed assessment of the location of where stream flows become perennial in relation to the proposed landfill to support the water balance.	*See Surface Water report*

b	Provide further information to support the conclusions of how no leachate will enter the Open Stream surface water catchment at the south end of the proposed landfill. Since the deeper groundwater flows have been identified to flow into this surface water catchment.	Leachate is not anticipated to impact surface water catchments (away from Otokia Creek) as a result of migration within the deep groundwater system. Each valley is considered to host it's own localised shallow groundwater system similar to that present in the upper stretches of the Otokia Creek, with limited to no interaction with deep groundwater. The rates of deep groundwater flow are also so low that potential impacts to receptors would be negligible.
5.6	**Section 3.5: Conceptual hydrological and hydrogeological model**	
5.6.1	**Section 3.5.1: Deep groundwater system**	
a	Further detail of the hydrogeological conceptual site model is required on the deeper groundwater system and the extent of the deeper groundwater system across the site. Information on groundwater flows, areas of recharge and discharge need to be included.	See responses 5.4.2 (d) and (g)
b	Describe how groundwater is recharged at the southern edge of the site (i.e. within the Open Stream surface water catchment) and clarify if this forms part of the deeper groundwater system.	No longer applicable - updated landfill design does not extend into Open Stream catchment.
5.6.2	**Section 3.5.2: Shallow groundwater and surface water system**	
a	The assessment of effects needs to include the Open Stream surface water catchment. Whilst placement of clean engineered fill is reported to be the only fill material placed in this catchment, since deeper groundwater flows are reported to flow toward the southeast, there is the potential for contaminated groundwater from the leakage of leachate through the liner to enter into this catchment. These potential effects need to be assessed.	Updated landfill design does not extend into Open Stream catchment. Impact from deep groundwater responded to in 5.5 (b)
5.7	**Section 4.1: Landfill activity**	
5.7.1	**Section 4.1.2: Landfill design**	
a	The recent groundwater levels recorded over a 6 month duration in the shallow valley bores generally record groundwater levels at depths of between near surface and 5 m depth. Provide annotated figures of the hydrogeological conceptual site model to show the amount of excavation in these areas.	Discussed in Groundwater Report
b	It is uncertain whether the design of the attenuation basin is sufficient to provide capacity for the stormwater and groundwater flows, in particular associated with the predicted changes (reductions) to the groundwater levels. Further detail is required to support the design.	See Surface Water Report for Attenuation basin design parameters
5.7.2	**Section 4.1.4: Leachate management**	
a	It is well known/reported that landfill liner systems are not free of leakage. Further clarification should be provided and/or reference made to the other reports which supports the statement that "leakage is mitigated" for the Type 2 liner system or alternatively clarify whether it is the expectation that there be contact between the HDPE and GCL.	Use of the word 'mitigation' refers to 'minimising' leachate. The assessment does not infer that the liner system will be free of leakage. As discussed in Section 4.1.4 and Tech appendix C Section 2.2.2, the assessment has assumed that imperfections in the liner quality or liner placement will occur (pin hole density 2/hectare. Instalation defects 25/hectare. Installation quality: poor). The liner modelled assumes a clay layer overlain by GCL and FML (HDPE) - as discussed, an intimate contact bewteen the HDPE and GCL is intended to minimise leachate leakage.
b	Show how the monitoring will ensure that there are no significant effects from leachate leakage on the groundwater, attenuation basin and Otokia Creek.	Monitoring will not prevent effects, however will provide the ability to monitor landfill performance and provide advance warning of potential impacts to surface water quality (wording revised within report).
c	Appendix D (Monitoring Plan) provides very limited information. Upgradient groundwater monitoring locations need to be included. Monitoring bore locations in relation to the inferred deeper groundwater flows being toward the southeast of the site need to be considered.	Further information to be provided in the Landfill Management Plan
d	Demonstrate how discharges from the landfill reach the groundwater i.e. source-pathway- receptor detail and the detail of how the groundwater will be protected from the proposed landfill activities.	This is described in the Groundwater Report in terms of the liner design and receptors. The Design Report provides more details on this issue
5.8	**Section 4.2: Landfill water balance and leachate**	
a	Further details are required on the volumes of rainfall predicted to report to the attenuation basin.	Provided in Surface Water Report
5.8.1	**Section 4.2.3: Leachate generation and leakage**	
a	A leachate leakage rate of 3 m3/year at Stage 5 is reported. It is not clear whether this is an average year or a peak year. If it is for an average year, please provide expected leakage for a peak rainfall year and provide an assessment for that leakage rate. Please provide HELP output data to support the information provided in Appendix C.	The leachate leakage for each landfill stage is calculated using annual average leachate rates for different landfill areas and conditions (cover/slope etc.). Worst case leachate leakage is 0.3 m3/year when using annual average rates. The peak daily values after closure of the landfill are 0.000043 mm/day (through 4% grade 'base') and 0.00001 mm/day (through 20% grade slopes). Leachate leakage using the peak daily values would equate to 1.35 m3/year.
b	Leachate quality has been obtained from published data (CAE, 2000). Assessment should be considered against recorded leachate quality for other landfill sites in the region (particularly Green Island) for a comparison of the data.	Please refer to Green Island concentration comparison (image snippped to the right). Leachate quality at Green Island has been compared to the upper quartile concentrations from published data used in the assessment (CAE, 2000). The published data provides a more conservative assessment for all parameters, with the exception of chloride and sodium. Although the maximum recorded concentration from Green Island is greater than the values used in the assessment for magnesium and nitrate, the adopted assessment value was greater than the average concentration from Green Island. Further, the adopted assessment value for total inorganic nitrogen (NH4N & NO3N) concentration is much more conservative than the Green Island leachate.

c	Appendix C Section 2.2.1 describes a landfill profile with a municipal waste thickness of 100 mm for open waste and a municipal waste thickness of 1400 mm for the final cap phase. These seem strange thicknesses and are not consistent with later information. Please confirm the descriptions provided in this section of the report for the modelling undertaken.	As per Table A1 in Appendix C, Municipal waste thickness was 100 cm for open waste/daily cover and intermediate cover, and 1400 cm for final cap. The units reported for these materials in the text of Section 2.2.1 of Appendix C were incorrect and have been revised.
5.9	**Section 4.3: Catchment water balance**	
a	Clarify how the outputs of the catchment water balance are derived, in particular evapotranspiration and the shallow and deeper groundwater system. It appears that shallow and deep groundwater has been modelled as one unit in this assessment. It is not clear how the amount of evapotranspiration can be increased during the landfill operation with a reduction in plant cover.	The water balance makes use of HELP calculations of actual evapotranspiration, runoff, leachate collection and leakage. In addition to the landfill scenarios, a scenario was also undertaken for the existing environment (details now included in appendix C). The shallow and deep groundwater components are derived as per Table 3 and the discussion in Section 3.3.2 of the report. The recharge is assumed to come from the runoff component of the water balance, with the runoff value from the HELP model adjusted to represent this. As discussed in Section 4.3, evapotranspiration increased during landfill operation due to an increase in water infiltration and soil moisture retention within the surface soils (existing environment modelled as silt loam (1x10-8 m/s), which has lower permeability and lower field capacity than modelled landfill soil cover materials).
b	Describe how the calculation of up to 4 m3/d of groundwater is predicted to be collected and intercepted from the subsoil drains.	Sub-soil drains assessment has been updated in Section 4.4.2
c	How has the long-term effects as a result of the groundwater diversion through the sub- surface drains been calculated.	while Section 4.4.2 discusses the initial rate of discharge anticipated, there will be no long term effect as the lack of recharge due to landfill placement will cause a reduction in groundwater levels and groundwater gradients within the shallow groundwater system and is anticipated to reduce groundwater levels below the level of the subsoil drains.
5.1	**Section 4.4: Effects to shallow groundwater and surface water**	
5.10.1	**Section 4.4.2: Scenario 1 - Potential upper bound for effects to shallow groundwater**	
a	More detailed assessment on the effects on groundwater is required. The effects on the shallow groundwater appears to be based on the entire landfill area covering the shallow groundwater system, whereas other parts of the report indicate that the shallow groundwater system is within the lower gullies.	Assessment updated for updated design.
b	The predicted effects to shallow groundwater have been assessed and identify a reduction in groundwater levels during the landfill development of 2-3 m beneath the landfill footprint. This lowering of the groundwater levels has been taken into account for the design of the soakage of stormwater from the attenuation basin. No calculations on this design have been provided and the back calculation using Darcy's Law is not clear. Accordingly, provide detail on the duration of these predicted changes.	The revised assessment indicates that groundwater levels will reduce by approximately 1 m down gradinet of the landfill in response to the lack of recharge across the landfill footprint - this is considered to be a permanent change that will persist as long as the landfill is in place.
5.10.2	**Section 4.4.4: Effects to surface water level flow**	
a	Further detail is required on the potential effects on surface water flows in Otokia Creek based on the reported decrease in baseflows and the estimated regression of the perennial reach of this surface water. In particular, how the measurement of 50 m regression has been calculated and whether the reported stream flows of 10 L/s will be maintained. Stream flow monitoring needs to be completed to support these assessments.	Discussed extensively in Section 5 of the Surface Water Report
5.11	**Section 4.5: Effects to deep groundwater**	
a	How has the horizontal permeability value been obtained in the deep groundwater system to support the groundwater velocities toward the Pacific Ocean?. Clarification on if these flows are separate to the 4 m3/d estimated to be "flowing" to the north beneath the landfill is required.	The 4 m3/day was anticipated to be shallow groundwater (updated calcuation now provided in Section 4.4.2). The deep groundwater system horizontal permeability (average of 1x10-8 m/s) is the geomean of the adopted from test results for BH201, BH202 and BH211B presented in Appendix A Table A 3.
5.12	**Section 4.6: Effects to water quality**	
5.12.1	**Section4.6.1: Assessment methodology**	
a	The existing contaminant flux from the shallow groundwater system to the Otokia Creek can be measured by water samples supported by information on the conceptual site model. Water quality samples from the Otokia Creek need to be collected to support this report.	The surface water samples collected for the assessment do not adequately characterise the shallow groundwater contaminant flux, as they were collected after a period of rainfall (see section 3.3.3). As discussed in the Surface Water Report, collection of surface water sampls at this site and downstream of the site has been extremel;y challenging over the past 12 months. No surface flow in gullies has been identified at least as far downstream as the culvert beneath McLaren Gully Road. Surface water has retreated to a series of disconnected wetlands.
b	The modelled rate of leachate leakage reflects the closed landfill scenario and considers the operational scenarios to be temporary in nature. Given that the indicative operation durations may be ongoing for up to 55 years, show the assessments of the contaminant flux, in particular ammoniacal nitrogen, when the calculated peak rates of leachate generation are predicted.	Revised assessment indicates worst case leachate leakage during closure scenario (0.26 m3/year), with this value used within assessement of effects.

c	Predicted changes in contaminant flux show an increase in improvement of water quality compared with the existing water quality following completion of the landfilling activities with the exception of ammoniacal nitrogen. Provide justification of this assessment and provision of the output data to support that.	This assessment has been updated for the updated design - contaminant flux for existing environment comprises geomean concentrations for alluvium (BH01A) and shallow breccia (BH01B, BH02A, BH02B, BH03A, BH04A and BH211A), and a total discharge rate as per the sub-catchment calc in Table 3 . Where results were less than the detection limit, 0.5x the LOD was used within the geomean calculations.
d	Provided detail on how the travel times have been established for the migration of groundwater through the shallow aquifer.	Shallow groundwater flow calculations provided in table 3.
5.12.2	**Section 4.6.4: Surface water quality limits - Regional Plan**	
a	Provide further information on the potential contaminant flux in the deeper groundwater system, since the groundwater quality monitoring identified similar water chemistry in samples collected.	Assessment of contaminant flux within the deep groundwater system is not considered to be necessary as travel times are in excess of 8,000 years and discharge to the Pacific Ocean is considered to be negligible.
5.13	**Section 5.4: Monitoring recommendations**	
a	Provide further details in Appendix D (Monitoring Plan) to show bore locations, depth and which groundwater system they are monitoring.	Details provided in Landfill Managenet Plan and shown on Drawing C308
5.14	**Other comments**	
a	We understand the physical constraints of the monitoring bore installations and the preference for drilling along the ridgeline where access tracks provide access to the site. The cross sections provided in the report reflect the ridgeline data (Figure 7) and the large depths to groundwater. Further information needs to be provided regarding potential changes to groundwater levels at the valley sides and whether changes to the depth of groundwater would be expected. Another section, shown as a figure, should be provided east-west across the proposed landfill footprint in the southern part of the site to show the groundwater levels.	See Updated landfill design and GIR
b	Figures 7 and 8 geological sections need to include an overlay of the landfill footprint including areas of cut and fill for greater clarity and to show areas where excavations may extend into the groundwater level.	See updated Report.
c	Groundwater seepages have been identified at the site and within the proposed landfill footprint. Further details need to be provided on their location, elevation and estimates on the volume of seepage to support the engineering design.	Landfill design updated
d	There is no reference to the impacts on the hydrogeology regime during the construction of the proposed landfill and the resultant cut and fill activities. This information needs to be provided.	See section 4.4.2 of the revised assessment