Geotechnical Review of the Quarry Backfilling,

Kinley Estate, Lilydale

Prepared for:
Russell Kennedy
Level 12, 469 La Trobe Street, Melbourne 3000,

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Senversa Pty Ltd
ABN: 89 132 231 380
Level 6, 15 William Street, Melbourne, VIC 3000
tel: + 61 3 9606 0070; fax: + 61 3 9606 0074
www.senversa.com.au

Reviewer		Primary Author	
	Claire Howell Senior Associate		**John Piper** Senior Principal

Contents

List of Acronyms

Acronym	Definition
AHD	Australian Height Datum
AS	Australian Standard
BH	Borehole
CQAP	Construction quality assurance plan
FSL	Final Surface Level
Golder	Golder Associates
kPa	Kilo Pascal
K	H**ydraulic conductivity**
m	Metre
m^3	Cubic metres
m AHD	Metres Australian Height Datum
m bgl	Metres below ground level
mg/kg	Milligrams per kilogram
QA	Quality assurance
QC	Quality control
SOMC	Standard Optimum Moisture Content
S_y	Specific yield
SWL	Standing water level
T	Transmissivity
T & T	Tonkin and Taylor

1.0 Introduction and Objectives

In an email dated 6th August 2020, Senversa was requested to provide a proposal for the geotechnical review of the geotechnical framework for the backfilling of the Lilydale quarry to allow the site to be developed for commercial and residential purposes as part of an overall sub-division of the former Sibelco quarry and limestone treatment facility. Our proposal (M18268_PRP_Rev0 dated 18th August 2020) was accepted by Yarra Ranges City Council on the 4th September 2020.

1.1 Introduction

The former Lilydale Quarry redevelopment comprises 163 Ha of land for commercial, residential, retail and community purposes. The development is being carried out by Hume Lilydale Pty Ltd. and LBJ Corporation Pty Ltd. Our report only addresses the proposed structures, roads and features within the backfilled quarry that is located in Precinct 4. The former quarry is up to 120m deep. This quarry is to be backfilled and covers an area of about 25 ha at the surface. It is proposed that the central portion be developed as a neighbourhood centre with medium density town houses, commercial and retail buildings and possibly some higher density, multi-level apartments.

A new railway station may be constructed just west of the existing quarry. Part of the northern part of the quarry is to be transferred to Yarra Ranges Shire as public open space.

The proposed landform of the quarry surface is to allow for drainage under gravity from the south to the north. The planned finished surface level at the southern end of the quarry is to be at RL140m AHD with the surface sloping at 3% such that the northern edge of the quarry is be at about RL120m AHD and will drain further to the north of the quarry to about RL100m AHD. This will result in part of the existing quarry batters being retained at the northern face of the quarry. The volume of material required to fill the quarry to the level specified by the developer is approx. 9 million m^3. Only onsite fill is to be used to fill the quarry.

The proposed development plan with the quarry outlined has not been provided in any detail and it is understood that it is yet to be determined (Golder, March 2020).

1.2 Limitations of this Report

Senversa assessment is limited to the issues around the settlement of the backfill in the quarry and its suitability to support the proposed development. It does include an assessment of the framework for the handover proposal with respect to the period for onsite monitoring prior to transfer to the Council. Our limitations are further discussed in Section 8.0

Our assessment does not include any of the following:

- Landslip stability of the escarpment to be retained.
- A detailed assessment of the hydrogeological modelling of groundwater rebound, except where it affects the fill settlement.
- The backfilling process of the karst caves present in the sides of the quarry walls.
- Any landslip stability assessment of the quarry walls post construction.
- Geotechnical review of the site classification of the proposed buildings in accordance with AS 2870 *Residential Slabs and Footings*.
- Geotechnical review of the haul road widening.
- Any environmental investigation or assessment or importation or contamination management plan.
- Risk assessment of the slope stability of the faces of the current quarry condition.
- Detailed review of the proposed ground monitoring during filling.
- Road or building design nor criteria for acceptable settlement.

1.3 Documents reviewed

The following documents were provided and reviewed:

- Geotechnical Framework for the Kinley Development, Tonkin and Taylor, Version 8, Report No. 1000511.R6.v8, June 2020.
- Rehabilitation of Lilydale Quarry – Revised Comments Regarding Tonkin and Taylor documents provided December 2018, by Golder Associates, Ref No. 18101888-005-L_Rev0, dated 28th May 2019.
- Rehabilitation of Lilydale Quarry – Requirements for Geotechnical Documentation, Ref No. 18101888-004-L-Rev0, by Golder Associates, dated 7th June 2019.
- Former Lilydale Quarry – Revised Geotechnical Framework and S173 Documents, Ref No. 18101888-011-TM-rev0, by Golder Associates dated 3rd March 2020.
- Former Lilydale Quarry – Revised Geotechnical Framework, Ref: 18101888-012-TM-Rev0, by Golder Associates dated 20th March 2020.
- Development at 4 Melba Avenue, Lilydale and Hull Road, Mooroolbark, Geo-Tech Framework and 173 Agreement, Ref No. AJS115599-03816 by Russell Kennedy, dated 8th April 2020.

1.4 Objective

The objective of backfilling the quarry was to provide a ground surface for the proposed development at or close to the surface of the quarry. The crest of the quarry edge varies, between RL140m AHD at the southern edge to between RL116-120m AHD at the northern edge. The backfilling is expected to take place over a period of about 5 years. T & T indicate that the FSL will be vary from a high point of RL155m AHD to the south of the quarry to be about RL120m AHD at the northern edge of the quarry. Golder (March 2020) indicate that the fill in the quarry area may be as high as RL140m AHD, but T & T indicates that the FSL of 100m AHD may adopted. This confusion as to the final level may be due to iterations in the site development that the reader is not aware of.

The quarry has been dewatered for many decades and the current groundwater has been suppressed within the quarry by pumping to about RL0 m. The groundwater is expected to rebound to about RL88m AHD which is estimated to be the approximate natural groundwater level. T & T indicate that the groundwater rebound to RL88 AHD will provide between 28 and 42m cover over the water table depending on the final surface adopted. T & T indicate that it will be at least 12m if the FSL of 100m AHD is adopted as the final surface.

This report discusses and reviews:

- The methodology of the construction of the backfilling.
- The conceptual geotechnical model and methodology for settlement prediction.
- The proposed settlement.
- The proposed modelling of groundwater rebound.
- Proposed approach for the settlement monitoring.
- The implications for the expected total and differential settlement on the structures and the stability of the quarry walls.
- Period of monitoring required to ensure that the settlements can be reasonably predicted in light of what is proposed by T & T and Golder's comments.

1.5 Developer's Proposed Backfilling Approach

The quarry walls were stabilised and made safe to ensure that the filling could take place in a safe manner. Loose boulders in the walls and oversize rock has been separated and removed. Any uncontrolled fill and vegetation has been also removed. Any karst cavities have been or are being filled with flowable cementitious fill or concrete. We make no comment on the adequacy or otherwise of these works.

A drainage blanket has been placed across the entire floor to a thickness of 1m and constructed in two layers and compacted with 16 tonne vibrating roller. The drainage material is described as well graded between 50 and 300mm particle size. A 300mm thick filter layer was placed over this and a separation geotextile placed over this layer to prevent the ingress of fines. The function of the drainage layer is understood to control the rise of the water table within the quarry and will only have a function during backfilling.

The fill is to be sourced from the site stockpiles and is variable. The Earthworks Specification (Appendix M in the Geotechnical Framework) allows for a wide range of material to be placed as engineered fill varying from clayey gravels, silty gravel, low, medium and highly plastic clays and clayey sands. A maximum particle size of 300mm is being adopted and is being placed in a loose layer thickness of not greater than 400mm. The fill is being compacted to an average Standard dry density ratio of 101% with a minimum of 98%.The fill is to be placed at the field moisture content in the site stockpiles which is understood to be generally dry of the OMC. If compaction is completed at a moisture content less than the OMC, it is easier to achieve higher compaction but has other implications which are discussed in the following sections.

Monitoring of the fill during placement will take place, with particular reference to the settlement.

A concrete riser of 2m diameter is connected to a 4m x 4m concrete pit placed within the gravel drainage layer and contains the sump pump. The riser is extended as the fill is raised and maintains the groundwater below the current fill level to avoid construction issues. To reduce the very high down-drag forces, the sump riser is painted with a 10mm thick mm thick bitumen coating and is wrapped in a heavy duty polythene plastic layer surrounded with a 1m wide layer of uncompacted coarse ballast rock to allow surface water on the fill to drain to the base of the fill. The groundwater needs to be pumped at a rate of 2 ML/day. It is not clear if the sump pipes are to extend to the final ground surface or be stopped at the expected groundwater rebound level of RL88 m. Furthermore it is not clear if the developer intends to allow the groundwater to rise as the fill rises.

2.0 Fill Geomechanics

The settlement of the fill is expected to comprise a number of components:

- Immediate (elastic) settlement.
- Primary consolidation settlement which results in the porewater being expelled from the fill over time.
- Secondary consolidation or creep which occurs over a period of time.
- Hydro-consolidation also known as Collapse settlement occurs with increased stress from the filling but only as the fill becomes totally or partially saturated and subjected to stress.

Types of settlement, related to the ground improvement and development model, are described below.

2.1 Immediate settlement

The settlement is caused by the placement of a load. This typically occurs over a short timeframe, sometimes referred to as 'elastic' settlement. In the case of the filling of the quarry, immediate settlement occurs as the fill is placed continually then increase as further fill is placed to the full height. The placement of building, and other development features will increase this elastic settlement, but if the fill is well compacted, it is expected to be minor. Elastic rebound will occur if the fill is unloading.

2.2 Primary consolidation settlement

The settlement is caused by a load increasing the porewater pressure in the soil below. As this excess porewater pressure dissipates, the load transfers to the soil particles and the soil settles. This can vary between days and many years and depends on the hydraulic conductivity of the medium and the length of the flow path. The flow path for this site is considerable as it need to dissipate to the edges, the floor or the crest. However, the fill is proposed to be placed dry of the OMC, so that the pores will not be saturated, any porewater dissipation will be minor, except in the case where you have hydro-consolidation. However, once the fill is saturated, and additional load is applied by filling, primary consolidation will then re-commence, but the effective stress may reduce once the rising water table reaches equilibrium, thereby reducing the loads from self-weight.

Ground heave from increased moisture content can occur but only in the upper less loaded fill. Ground rebound can occur if the fill is unloaded but is typically much less than the initial consolidation and is not proposed for the quarry backfilled area. However, it will occur in the surrounding natural areas outside of the quarry as the surrounding stockpiles are removed and placed within the quarry. It is beyond the scope of this report to discuss the impacts.

2.3 Secondary compression settlement (creep)

Settlement that occurs when all excess pore pressures have dissipated, often known as creep settlement and can be a result of a number of causes such particle relocation. Secondary settlement is usually relatively small compared to primary settlement but, depending on soil types, can continue for decades as a reducing rate.

2.4 Hydro-consolidation Settlement

The reduction of the volume of fill soils inundated for the first time, can result in rapid settlement known as “collapse” settlement or hydro-consolidation. Hydro-consolidation can occur due to soil types, moisture at placement, increases mass loading until it equilibrates with the surrounding water level. This can be an issue if it occurs post development. The fill is to be placed well below optimum moisture content, which can potentially lead to volume change when infiltrated. The degree of ‘collapse’ is related to the void ratio so that even if the fill is compacted to high density, it can still have a significant air voids ratio if compacted well dry of the OMC. When the fill becomes moist or even saturated it can then ‘collapse’ and increase the porewater pressures which then need to dissipate to either the surrounding unsaturated soils or drainage points such as the perimeter, base of the fill or the sump riser perimeter gravels.

It is often not possible to distinguish between these latter settlement modes with monitoring alone.

2.5 Differential settlement

Uneven settlement of the fill surface can occur both during and post construction. Differential settlement may cause issues in the future and is discussed for completeness with respect to settlement types. Differential settlement could be caused by various issues at the site, including, but not limited to different fill types, compressibility, different moisture content and relative compaction, and difference in fill thickness i.e. benches within the quarry / edge of quarry and other factors.

Significant differential settlements during and post filling are expected. The differential settlements post filling are an important issue.

2.6 Discussion

The complexity of the various settlement issues makes it difficult to predict the post construction settlements with any accuracy due to many variable factors including geomechanics and hydrogeology. Consequently, and as proposed by all parties, the acceptance should be by monitoring of the fill settlements post filling.

No organic matter is proposed within the fill (AS3798 – Section 4.3) so landfill gases are expected to be minor.

The majority of the settlement will occur due to the self-weight of the fill with some minor settlement from the proposed buildings and site features and increased effective stress from the rise in the water table. Some settlement can also be a result of increased mass in the upper soils above the water table if the soils are placed dry of the OMC as proposed due to flooding, leaking pipes, and water migration to depth due to diffusion and hydraulic conductivity The majority of the stockpiled soils is reported to be clays but can be either gravelly clays, silty clays and sandy clays with some clayey gravels.

The immediate settlement will occur as the fill is placed. No unloading is proposed. Any settlement from low rise building loads is likely to be minor. Seasonal movement as a result of variable moisture contents in the upper soils can be expected and the amount will vary depending on the soil characteristics in the upper 2 – 3m

The fill is to be placed dry of the optimum moisture and potentially well dry of the OMC. Initially there will be minimal primary consolidation, but significant elastic settlement. However, as the water table rises, the clays will become saturated and the effective stress increases resulting in both hydro-compaction and primary consolidation. On-going settlement will occur consisting of both creep settlement and consolidation depending on the drainage pathways and distance. Once the water table has equilibrated, the effective stresses will decrease and once any excess porewater pressure has dissipated, the subsequent settlements will then decrease to on-going creep settlements. However, if the clays are placed wet of the OMC, primary consolidation may occur during the placement of the fill due to the increased stress but the rise in the water table will result in less settlement for the same dry density due to a lower void ratio and potentially less hydro-consolidation.

Provided that the materials are compacted to a similar high dry density ratio (DDR), if the material is placed well dry of the OMC, it will have a higher void ratio and therefore more prone to hydro-consolidation as the water table rises, with the need to then dissipate any excess porewater pressures depending on the degree of saturation at the time. However very high levels of compaction can reduce the void ratio sufficiently to avoid significant hydro-consolidation. If on the other hand, the clays are placed wet of the OMC but at a similar DDR, the air void ratio will be less. Depending on the degree of compression due to the increased self-weight, consolidation can occur, taking time for the excess porewater pressure to dissipate. However, any hydro-consolidation will be less. Waddell and Wong (2005) recommend that to reduce the risk of hydro-consolidation settlement, the fill should be compacted to at least 98% Standard DDR with a moisture content near the OMC.

3.0 Hydrogeology

Understanding the hydrogeology within and external to the surrounding quarry is important as it affects the rate of saturation of the clay backfill, time for equilibration of the water table, the expected equilibrium water level and consequently the time for further consolidation and hydro-consolidation, both during and post filling.

The writer has been assisted in this review by Senversa Principal Hydrogeologist Barry Mann.

T & T conducted a preliminary hydrogeological assessment (Appendix I, Geotechnical Framework) with seepage modelling. T & T acknowledge that there is considerable uncertainty around the local hydrogeological regime and we would agree with the uncertainty raised. We consider that the hydrogeological assessment is of limited value, due mainly to the lack of assessment of site specific aquifer hydraulic properties, which is acknowledged in the modelling report. There are references to Geo-Eng (2000) and Sibelco reports (2016), but it is unclear how T & T related these to the adopted model inputs.

3.1 Aquifer Hydraulic Properties

The basis for the adopted Fill hydraulic conductivity (K) and anisotropy values are unclear. T & T refer to tests (test records not provided), but no reference as to why an anisotropy of 1 was adopted. Uniform permeability in the horizontal and vertical directions is considered unlikely for fill placed and compacted in lifts, based on experience in similar earthworks projects. No justification is provided for the adopted K values for Fill. The value of 1.9×10^{-4} m/s (or ~17 m/day) seems quite high for compacted fill with fines and is inconsistent with the laboratory results. The value is more consistent with coarser grained sediments (sands, gravels). Rocktest (2015) indicates that the limestone hydraulic conductivities may be > 1×10^{-4} m/s but does not provide any data to substantiate this. Published literature values (Domenico and Schwarz, 1990) cite K values for karst and reef limestone as ranging between 1×10^{-6} to 2×10^{-2} m/s, and for limestone and dolomite between 1×10^{-9} to 6×10^{-6} m/s. The wide range in values reflects the highly heterogenous nature of fractured rock aquifers and highlights the need for site specific hydraulic testing in support of modelling efforts.

There is also no justification for the adopted specific yield (S_y) for limestone and fill (0.02 and 0.08 respectively). Specific yield, also known as the drainable porosity, for an unconfined aquifer is typically analogous to effective porosity, and represents the volumetric fraction of water that an unconfined aquifer will yield, or drain, under the forces of gravity within a fixed aquifer volume (e.g cubic metre). Morris and Johnston (1967) and Rowe (2000) indicate that for clayey materials, S_y typically ranges between 0.02 to 0.05, averaging 0.03, which is lower than the adopted model value of 0.08.

The adopted S_y for the limestone (0.02) is considered low, as compared to published literature values (Heath, 1983; Morris and Johnston, 1967) which range between 0.14 to 0.18. When factoring in recharge, a higher S_y can translate to higher recharge rates, which may also significantly affect modelling results.

3.2 Model Calibration

Due to the lack of site specific hydrogeological data, it appears that the observed daily inflows at different depths (2 ML/day at 12 mAHD; 3.4 ML/day at 54 mAHD) were used as a basis for model calibration. If this assumption is correct, it would involve back-calculation of aquifer K and S values based on the known groundwater discharge (Q) to the quarry, using a derivation of the Theis (1935) equation. The Theis equation, however, is non-unique, in that numerous different combinations of K, and S can be used to yield a known Q. For modelling purposes, this requires operating within a reasonable envelope of values. However as noted above there can be a very wide range of values, resulting in considerable uncertainty in the absence of site specific data.

The model outputs, reported as steady state, show the predicted drawdown between the model boundary (1200 m distant, with fixed head of 100 mAHD) and the quarry. The modelled drawdown appears to extend out to the boundary, which suggests the model domain is too small and not accurately reflecting steady state conditions. The model should be extended out to say 2 km, or to a distance which fully contains the cone of depression.

3.3 Groundwater Rebound

Sibelco determined that the groundwater will rebound to about RL 88m AHD which is some 80m above the currently depressed groundwater level, and that this will take some 12 years for this to occur, as based on water balance calculations (Appendix Q, Geotechnical Framework contains T & T Preliminary Slope Instability Impact Assessment for Work Authority 199 Amendment, Appendix A Geo-Eng 2001 report, Appendix E)). This is based on groundwater recharge, precipitation, runoff and evaporation with an assumed natural final, equilibrated water level of RL 100m which is some 12m higher than that adopted in the T & T Geotechnical Framework report.

Rocktest (2015) reports that they expect the long term groundwater level to be about RL80m, based on a far field groundwater level reported to be between RL 90m and RL100m. They also point out the likelihood of a perched groundwater level within the upper Volcanic clays, which they assume forms an aquitard. The writer is not disputing the adopted RL 88m AHD for the equilibrated groundwater level, but does point out that there is considerable uncertainty around this estimate, as well as the potential impact of the aquitard on the saturation of the upper clays.

The Limestone K would be expected to control inflows to the pit, whether backfilled or not. The model run based on Fill K < Limestone K predicted 20+years to reach steady state recovery, while the model run with Fill K > Limestone K reached steady state recovery in 1.4 years. This highlights the need for a better understanding of the site specific hydrogeological properties.

3.4 Reporting Issues

Groundwater recharge is shown in the model output sections, but no values or justification of the adopted recharge is provided in the text. Groundwater models are typically sensitive to this parameter.

The model results summary does not include the high Fill K scenario.

3.5 Sump and Riser Design

The T & T report indicates that "*a drainage layer constructed of filter material shall be placed around the riser to allow surface water to drain down to the base of the riser and enter the sum*p".

Based on the design sketches, it appears that the filter pack around the riser is intended to provide direct hydraulic connection from surface of the backfill during filling to the sump, with the aim to drain surface water from the working ground surface and act as a type of surface water control mechanism. While this is a convenient approach to surface water runoff control, it will also work in reverse should pumping cease. Under non-pumping conditions, groundwater may preferentially enter and rise up the permeable riser filter pack, potentially to the expected equilibrium water level (~RL88m), and at a much higher rate than the overlying and surrounding compacted, low permeability fill. This may lead to differential saturation and differential settlement of fill during saturation, with higher hydro-consolidation rates closer to the riser pipe some years before all of the fill becomes saturated.

The reported perched water table in the Volcanics may also result in saturation of the clay backfill from the quarry perimeter inwards but is not discussed in the T & T report nor modelled.

The writer considers that the T & T prediction of the saturation of the quarry backfill has low reliability due to;

- The lack of any reliable, site specific hydraulic property (ie K, Sy) data for the surrounding limestone aquifer and fill material.
- The lack of any baseline groundwater level measurements in the limestone aquifer surrounding the quarry.
- The small model domain.
- The lack of assessment of the potential for the riser pipe filter pack to form a preferential pathway for groundwater rebound.
- The model does not consider the presence of the perched water table in the upper Volcanics.
- The model does not consider the presence of precipitation or runoff from the quarry sides during the filling process or post filling.

It is acknowledged that T & T have indicated that there is considerable uncertainty in the model and we concur with that view.

4.0 Fill Settlement Performance

4.1 Required Fill Performance

The fill performance criteria is discussed in a draft T & T report (December 2017) for handover of assets is discussed in Appendix P.

The settlement performance criteria for commercial and residential buildings is not discussed. There should be a discussion of the acceptable total and differential settlements for various building types, heights and foundations.

The transfer of land including development for public open space will only be handed over to the Council subject to the following:

1. The predicted maximum total settlement from post 5 years after completion of the filling in next 45 years is equal to or less than 500mm.
2. Less than 55mm of settlement in the year prior to handover to the Council.
3. Less than 450mm of settlement per log cycle of time (base 10) in the years prior to transfer.

We understand that these areas may contain sporting complexes including ovals, hockey pitches or other sporting complexes inclusion basketball courts as well as stadiums and pavilions. The details of what is to be constructed where has not been provided to us but we understand that in the public open space, any buildings will not exceed one storey, apart from a pavilion that may be two stories.

The transfer of land to the Council for Council reserves including road reserves will only be handed to the Council where:

1. The predicted maximum total settlement from post 5 years after completion in next 45 years is equal to or less than 300mm.
2. Less than 37mm of settlement in the year prior to transfer.
3. Less than 300mm per log cycle of time (base 10) in the years prior to transfer.

Again the acceptable total and differential settlements for these structures, drainage, features and roads should be determined.

4.2 Differential Settlements

While differential settlements are discussed, no criteria for the differential settlements is proposed and will be left until the land is transferred to the Council.

It is our opinion that a criteria for the acceptable differential settlements with respect to the proposed land use needs to be determined now such that the differential settlements are measured over the period prior to transfer and predicted settlements are acceptable for the proposed land use including ovals, buildings, roads and below ground services. We understand that the developer wishes to leave the determination of what buildings and less flexible structures such as netball, basketball and hockey can be constructed and where these are to be located until the expected settlement can be determined. While this approach could be adopted, considerable discussion will be required at the later time in the development, particularly if the post fill settlements are significant and either required additional foundation measures or at worse, cannot be constructed in the proposed location. The developer may wish to delay handing sections of the site to the Council for these facilities that may not be agreeable to the Council's time frame. This is not an approach that we would recommend to the Council and the criteria for total and differential settlement for each type of structure and feature such as roads should be determined now and a cost formula calculated for increased foundation costs or reduced design life.

We understand that the Council's preferred position is to locate these facilities and buildings outside the quarry area.

Considerable differential settlement can be expected if say the asset traverses the quarry boundary or is close to the quarry boundary. In this circumstance, the total and differential settlement could be similar and likely to pose more of an issue for the development than the total settlements alone. In this situation near the quarry edges, it may be necessary to pile buildings and provide special treatment for below ground services and roads. It is recognised that where the filling is deep, piling will become impractical and will only be practical where near the quarry edge. Piling construction issues can also occur with piling on steep quarry edges. The situation with the pile toe 'sliding down' the quarry face and not socketing into the rock face can sometime occur.

In certain circumstances, significant differential settlement could occur above and around the riser pipe, although the developer proposes to avoid buildings or structures sensitive to differential movement in the riser location.

The proposed maximum total settlement of 300mm could result in a maximum of differential settlement between the quarry edge and the deepest fill zone and may be acceptable for conventional shallow foundations for buildings, but is going to depend greatly on the horizontal distance over which this differential settlement can occur. The differential settlement is important. For domestic dwellings as specified in AS2870 Table 4.1 and depending on the type of superstructure, the maximum differential settlement that can be tolerated varies between 10mm and 40mm. It is acknowledged that suitably designed foundations can accommodate greater differential settlements.

Therefore for a clad framed building, the total settlement of 300mm may result in a differential settlement of between 100 and 150mm across the building located well within the quarry area, which will require special consideration of foundations, such as an adjustable foundation or a screening slab. Either will incur additional foundations costs. A structural engineer should be consulted for further details. It may not be practical to construct solid masonry or brick veneer structures.

The differential settlement could also be aggravated by proximity of the sump location depending on the rate of saturation of the fill. The rate of saturation from the base of the quarry, from the perimeter perched groundwater table, and saturation of the upper fill from either flooding or rainfall will all contribute to the differing settlement rates along the different materials used in backfill, varying from a clay to a gravel, although it is understood that most of the engineered fill is to be a clay, of some type.

We have not been provided the proposed latest development plan but T & T Dwg No 1000511-06 dated Sep 2019 (preliminary draft) shows what appears to be a hockey pitch over the site boundary and a school between sump and the quarry boundary. Increased maintenance and special design considerations will be required to address the expected total and differential settlement issues.

4.3 Ground Settlement Impacts Adjacent to the Quarry

There does not appear to be any consideration of the impacts of the settlement on the ground adjacent to the quarry edge. Providing that the fill is backfilled to a high level of compaction as proposed up to the edge of the quarry, any movement of the adjacent ground is limited and is defined by:

- Vertical movement (settlement) of the fill.
- Lateral movement of the fill.
- The passive pressure from the placement of the engineered fill.
- The compressibility of the adjacent natural ground.

Any such movement is likely to be limited to a small confined area adjacent to but beyond the quarry edge. Any laterally moving landslips or tension cracks are likely to be limited in movement or width to the lateral movement of the fill and the passive pressure from fill. This does not apply to any landslips with a rupture surface day-lighting at the toe of the slope or quarry face at or near the top of the fill. However this is not part of consideration in this report and will only apply where there is a slope or quarry face rising away from the edge of the fill.

This is not likely to be a major issue, except for conventional shallow foundations for structures immediately adjacent to the quarry edge.

4.4 Monitoring Methods

It is proposed to monitor the performance of the fill and groundwater during the 5 years of filling.

4.4.1 VW piezometers

The vibrating wire piezometers within the fill are proposed to monitor the pore water pressures and transmit the information to a control box with a data logger. Care needs to be taken to ensure that the piezometers measures pore water pressure and not a combination of the porewater and air pressure.

4.4.2 Groundwater Response

It is proposed to install water pressure instruments to measure the groundwater response but the details of where this is to be undertaken is not provided.

4.4.3 Shape array

The shape array is fitted with accelerometers to measure the differential settlement with time relative to a quarry bench. These will be installed at first or second bench and then at a bench about RL40 – 50 m AHD. Few details have been provided. The settlement will be monitored as the settlement progress.

4.4.4 Surface Settlement Monitoring Points

Surveyors are to measure the rate of settlement of the surface at the top of the filled area post filling. The plates are to be surveyed to AHD from a remote TBM using precise surveying techniques and recorded to 1mm accuracy.

4.4.5 Settlement points within the Backfill

Six vertical extensometers are proposed between the horizontal arrays and the surface to measure the settlement.

4.5 Monitoring Frequency

It is proposed to monitor the instrumentation once per day except for the extensometers which will be less frequent.

4.6 Conclusions

The proposed monitoring and frequency appears to be sufficient although the number of surface monitoring points needs to be sufficient to determine not just the total settlement but also the differential settlement at the surface as well. The measurements of differential settlements should be concentrated particularly in areas where structures or features will be impacted by differential settlements or there is variability in the ground properties such as zones of more compressible soils or increased groundwater saturation. Due to the variability of the soils and compaction, differing fill depths over benches, differing saturation and different toleration of structures or roads and other features, the settlements of the fill surface are likely to vary across the filled area and the total and differential settlements need to be considered in the acceptance.

5.0 Comparison of the T & T and Golder Comments

Golder Associates Comment No		Senversa Comments (relating to filling only)
Page No	Technical Memo Ref: 18101888-011-TM-Rev0 dated 3rd March 2020	
2	Geotechnical Framework	We have reviewed section of Version 8 dated June 2020. It is a long document with multiple appendix levels. We agree with Golder that rationalising the appendix numbering would be helpful to avoid confusion
2 & 3	Lack of definitive development plan	A development plan is important so know where the more sensitive structures, public open space and other areas are located. We agree with Golder's request.
3	Accepted settlement criteria	We agree with Golder's view that the settlement criteria need to be reviewed, enhanced and determined at this time. The suitability of the total and differential settlements and the accuracy of the predictions will depend on many factors and not just on previous settlement results. For instance, hydro-consolidation in the future may still occur if the saturation of the engineered fill is only partially completed and make future logarithmic extrapolations problematic. It is not recommended that the Council accept settlements based on time but on reasonable expectation of future settlements. Issues such as differential settlement from differing fill depths over benches, and riser pipes need to be considered. If the Council accepts the proposed settlement criteria, there may be a need for additional foundation costs due to adjustable foundations. Hockey pitches and roads will require additional maintenance over their design life. It is acknowledged that the settlement is primarily proportional to the fill depth, provided the relative compaction, moisture condition, the fill type and saturation is all similar. Battering the upper slopes back to reduce the change in fill depth can increase the distance over which the total settlement increase or in other words, reduce the differential settlement over a fixed distance. There are some advantages with this approach for roads and some features such as basketball courts etc in these areas. However, Senversa's view is that the criteria for the building and site features be determined now, with the a series of increasing design measures or decreased design life to be incorporated with associated costs if the agreed predicted differential settlement cannot be achieved with agreement now on compensation in the unlikely event that the differential settlement suitable for the buildings and structures cannot be achieved.
3	Engineered fill in quarry area is unlikely to be satisfactory founding stratum for higher density residential apartments and potential commercial and retail facilities.	Golder comment that the buildings can be founded on piles in natural ground is not practical in our view, except around the perimeter. Piling of the buildings on the perimeter of the quarry edge will be required due to potential differential settlements but can be problematic where the quarry face is in hard rock and very steep and will need to be able to accommodate the future down drag (negative skin friction) forces as well as the building loads. We agree with Golder that the engineered fill within the quarry is not likely to be a satisfactory founding stratum for higher density multi-storey apartment buildings (unless piled). However other low-rise residential or commercial building types could be considered, but will be dependent on the acceptability of the future total and differential settlements for shallow foundations. As discussed earlier in this report, additional foundation requirements will be required with associated increased foundation costs.
3	Zoning of highly plastic clays from Precinct 2 into areas that can accommodate more settlement.	We consider this approach problematic and may increase the differential settlements across the filling. If this zoning is proposed, it requires careful consideration but may be better to spread as a thin layer over the entire filled quarry area and be placed in the upper fill layer but below any seasonal moisture fluctuations, say below 2.5m.

Golder Associates Comment No		Senversa Comments (relating to filling only)
4	Sump Riser, Golder point out the potential for significant differential settlement if the sump riser extends to the FFL. If the riser is finished well below the FFL, the differential settlement will be less.	We agree with the Golder comment generally that it is better to stop the riser well below FSL. However, the Golder comment does not appear to consider the frictionless coating on the riser. If the riser extends to the proposed surface level and provided that the frictionless coating is effective, the ground around the riser should not 'hang up' on the riser, and the localised differential settlement will be only on the surface of the riser to the surrounding ground. If on the other hand if you stop the riser below the surface, and the surrounding interface is frictionless or close to it, the soil above riser will sit above the riser and the extent will depend on the shear angle of the soil. In addition, the saturation of the surrounding clays from water from the gravel surrounding the riser will saturate the clays closer to the riser and increase settlements in this area relative to soil above the riser which will not settle. Either way, there is the potential for significant differential settlements in this area, but we agree that on balance it will be better to stop the riser some 12m or more below the surface to reduce the rate of differential settlement over distance, but details of the proposed completion of the sump riser should be provided.
5	Upper Fill material	It is desirable to have low reactive material in the upper 2.5m or so of the fill material to reduce soil reactivity. It is recommended that low reactive suitable soils of not greater than 75mm in diameter in the upper 2.5m of fill be adopted.
5	Fill Suitability	We agree with all parties that organic matter, topsoil, pure silt, acid sulfate soils, contaminated soils and foreign matter are not suitable. The environmental suitability of the soils is not part of this assessment but could be provided if required. While the max particle size is limited to 300mm, limits on the % of oversized material and any gap grading must be undertaken to avoid voids occurring between boulders, not just a limit on size, and a visual assessment is recommended by Golder and we agree with the recommendation that the specification should contain a limit of coarse rock per m^3.
5	Moisture Conditioning and Relative compaction	T & T argues that limits on the moisture placement is not required based on their testing. T & T propose to compact the fill materials, presumably at the field moisture content that is well dry of the OMC. We understand that this will make higher levels of relative compaction possible but considerable effort may be required by the contractor. The test results show that the level of compaction is the more important factor in reducing the hydro-consolidation than the moisture content, but the air void ratio is a combination of both of these factors. Using the results of the consolidation tests undertaken by T & T and not withstanding some of the anomalies in the test data, the test results indicate a clear relationship between the initial void ratio (or relative compaction) with % collapse for a particular stress. If the initial void ratio is below 0.6, the % hydro- consolidation is below 1%.

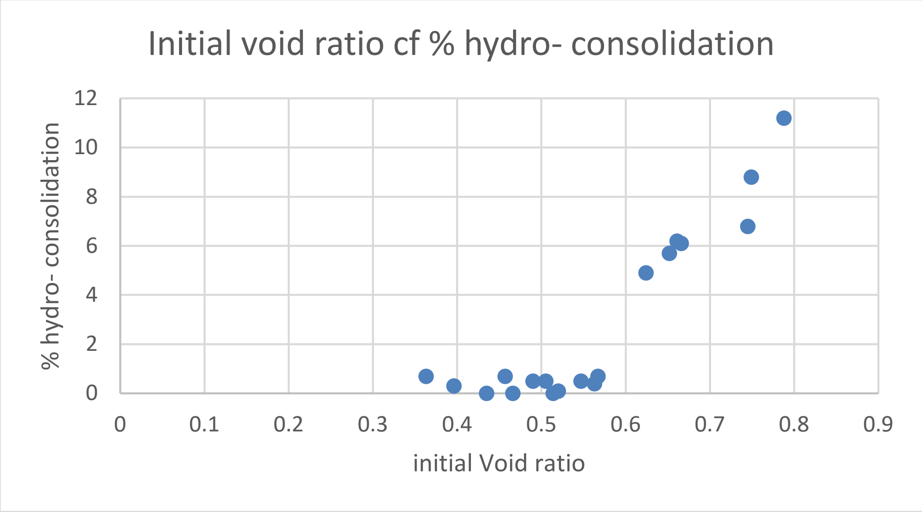
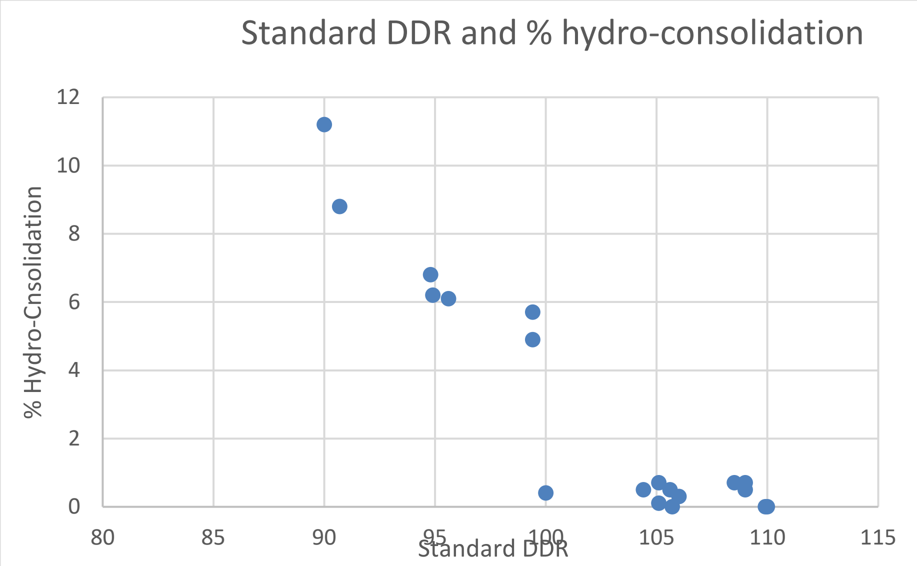


Figure 5-1: % Hydro-consolidation and initial void ratio

Golder Associates Comment No		Senversa Comments (relating to filling only)
		 **Figure 5-2: Dry Density ratio compared with % hydro-consolidation** Expressed in another way, if the Standard DDR is equal to or greater than 101%, the collapse consolidation is less than 1% as the void ratio has been sufficient reduced. It is noted that a minimum average Standard DDR of 101% is specified for the filing of the quarry, but the minimum of 98% SDDR could undergo some greater hydro-consolidation. Based on the T & T data, there is no direct relationship between moisture content alone dry of the OMC and the % collapse consolidation. A change in the density of the soil will have a bigger effect than a change in the moisture content. For example, a 10% change in the density will have a much bigger effect than a 10% change in the moisture content in reducing the void ratio. However, the literature indicates that % hydro- consolidation is expected to become greater as the moisture content becomes more dry of the OMC for the same DDR. (Waddell & Wong, 2005). On the other hand, if the soils are compacted wet of the OMC or even at OMC, the specified DDR will be more difficult to achieve. With increased load as the fill is placed, there is the potential for positive porewater pressures which may dissipate slowly, slowing the rate of settlement. To a certain extent this may happen anyway, as at least partial saturation will need to occur, to initiate hydro-consolidation We agree with Golder comments about the need to avoid placing the material too dry of the OMC as it will create a higher air void ratio for the same DDR and the potential for greater future hydro-consolidation settlement. We also note that the placement of material too wet may mean that the DDR cannot be achieved and lead to saturation of the compacted clays. Porewater pressure dissipation is then occur as the fill becomes more loaded. However, it is noted that the higher compaction even if dry of the OMC can also reduce the air void ratio to an acceptable level. As recommended by Golder, a target moisture limit should be specified for the specified DDR but can be fairly broad and it is acknowledged that the DDR is the more important factor.
6	Monitoring	Further details of the monitoring with plans should be provided including surface monuments to measure both total and differential settlements, particularly if the shape arrays fail.
6	Approval post construction	Golder indicate that the Geotechnical Framework still has information gaps that need to be addressed. The Council concern is not only for the public open space land and the road reserves, but also for the future privately owned properties. It is reasonable for the Council to insist on the details of total and differential settlement monitoring in all areas including roads.
6	Performance criteria	See Section 6.

6.0 Conclusions

Senversa was asked to consider whether the period for monitoring of the settlement can be reduced from the period of 5 years post construction before the site is handed over to the Council. Golder (March 2020) provided a commentary on this issue.

This section involves a discussion of the following:

- The establishment of criteria for acceptable total and differential settlements across the proposed area or building for the design life of the building.
- The expected future settlement from the handover of the site to the Council for the expected design life of the building, structure and features.

6.1 Settlement Performance Criteria

It is recommended that the Council specify what they consider acceptable total and differential settlements over the life of the proposed structure or proposed use of the site. For example, in public open space which is only park land, a larger settlement could be tolerated than for say buildings. However, tennis and basketball courts and synthetic or hybrid pitches (hockey, soccer) cannot tolerate significant differential settlement without impacting their performance. For some structures, adjustable foundations can be incorporated into the design to allow for increased differential settlements, but this results in significant additional foundation costs.

We agree with the Council approach that the criteria for the backfill should be ‘performance based’ This approach appears to be agreed by all parties and the method to achieve this performance is up to the developer. However, we are of the view that the acceptable performance criteria should be specified at this time, with a sliding scale of compensation to the Council if these cannot be achieved.

T & T Fill Performance Criteria report (2017), within Appendix P of Geotechnical Framework, indicates that the construction of assets on land to be handed over the Council could be conducted over a staggered period of not more than 10 years. It is unclear whether this approach is acceptable to the Council as residents may expect these facilities in a lesser period. For public open space the settlement is not to exceed 500mm in the next 45 years after handover to the Council. They indicate the example of public open space with an oval that can tolerate greater total and differential settlements than say a pavilion. While this approach could be considered, it does raise the issue of what are acceptable total and differential settlements for these buildings and ovals. If the predicted future total and differential settlements do not decrease sufficiently within 10 years to allow the pavilion to be constructed, what is the proposed action in that event? It may be as simple as an agreement or formula that the developer provide compensation to the Council for increased oval maintenance and increased foundation building costs. It is recommended that these possible issues be resolved sooner rather than later.

The settlement criteria for roads and drainage of 300mm per log cycle of time is specified by T & T (2017). For a 20 year design life with the road construction completed 5 years after filling, the expected settlement is approximately 210mm. The differential settlement could be between typically 105mm in the centre of the quarry and up to 210mm near the quarry edge, depending on the steepness of the quarry face, presence of berms and other features on the quarry edge. In our experience, differential settlements can be greater than those predicted with computer modelling, even though total settlements can be less. There is no discussion over the increased maintenance and impacts on the roads and drainage within the quarry area. The differential settlements between the roads traversing the edge of the quarry and the quarry backfill need to be considered. The distance over which the differential settlements occur will depend on many factors, but the most important factor is the increasing depth of fill provided all other factors discussed earlier are similar. While greater than normal differential settlements may be able to be accommodated in the design of roads and services by increasing the number of side entry pits, increased grades, measures to reduce reflective cracking in the roads by reinforcement of the asphalt layer with geotextiles or geogrids and/or accepting a reduced road life. These costs will need to be considered by the Council with increased maintenance and/or reduced life. Near the edge of the quarry, the differential settlement over time will be a similar value to the total settlement, although the distance over which the differential settlement will occur could vary. Other measures will need to be considered in this area and the Council should be specifying acceptable future differential settlement limits for all of the scenarios and assets they are taking over. T & T (2017) indicates that the settlement of well compacted fill will settle uniformly with a constant settlement with a logarithm of time for the nominated design life of 50 years. While we would generally agree with that comment, it is only applicable if the material and compaction are relatively uniform, the depth of the fill is similar and the groundwater and moisture conditions within the fill have achieved equilibrium. It has been suggested that the groundwater within the quarry may take some 20 years to achieve equilibrium but may occur quicker in different parts of the quarry. Furthermore, it is proposed to have few controls on the location or thicknesses of various soil material to be backfilled within the pit. We consider that the rates and amount of settlement will vary with associated differential settlement occurring.

In conclusion, the performance criteria for each area or asset to be taken over by the Council needs to be specified now, such that at the time of handover, there is an agreement of the acceptable criteria for the expected future total and differential settlements at the time of construction of these assets that will be eventually handed to the Council. It will vary for different assets. There also should be an agreement now of the approach to determine the future total and differential settlement predictions at any time post filling and if these are not achieved within the time period acceptable to Council, the methodology for compensation to the Council for increased foundation costs and maintenance.

We understand that the Council will not be liable for any privately owned assets or buildings. However, the Council has expressed interest in the assessment for these assets. Moreover, we note and agree with Golder that it is unlikely that the deep fill will provide a satisfactory foundation for higher density, multi-level residential dwellings or offices. It is possible even low density, one and two storey residential dwellings or commercial buildings may require additional foundation costs or possibly reduced performance over their design life. It is, however, considered that over a number of years from that time, as the confidence in the future predicted settlement increases, and the groundwater equilibrates, the development potential for the backfilled quarry areas may increase.

6.2 Predicted Future Settlement

The predicted future settlement needs to demonstrate compliance with the settlement criteria. Whilst the proposed methodology for the prediction of settlements is a reasonable approach, it is at best an estimate only and could vary considerably. A time period of monitoring to provide justification for handover to the Council alone is not appropriate. The period of monitoring of the settlement to demonstrate compliance with the criteria, should be either less or more based on the data and method of prediction, rather than just a time period. We note that T & T are proposing a settlement criteria for the design life of the proposed area.

It is our opinion that the prediction of future settlement cannot be made with a high level of confidence until the groundwater is at, or is close to, the final expected level, such that any hydro-consolidation has occurred. Once it can be assured that this has occurred, the prediction of future settlement will have a greater level of confidence. The time and the amount of the hydro-consolidation settlement that will occur, will depend on when the fill is loaded & saturated and also depends on the void ratio. If at the time of the hydro-consolidation, the soil is close to or saturated, excess pore water pressure will need to dissipate.

The T & T prediction of the time period for saturation of the fill by the groundwater to occur has a low reliance (as acknowledged by T & T). However, there does not appear to be any firm discussion if the groundwater will be allowed rise during the backfilling of the quarry so saturation will occur during filling nor any assessment of the saturation of the backfill around the riser, the final height of the riser nor the impacts on the total and differential settlements due to the riser remaining in place post backfilling. The impacts of the surrounding natural ground becoming saturated earlier or a perched water table occurring in the upper horizons does not appear to have been considered. If saturation of the fill is allowed to occur during filling or more quickly, it may help reduce the time for ongoing monitoring. As the filling is to be placed dry, there does not appear to be an assessment of the increased mass in upper soils over time from rainfall and diffusion to the lower layers (say 2 – 5m below the surface). This increased moisture content will result in swelling of the upper soils but also settlement of the deeper fill due to the increased mass and weight of the upper soils along with the proposed structures over time. Although it is acknowledged that at depth within the fill, the % of increased load is likely to be minor.

For all of the reasons discussed above, it is likely that there will be significant differential settlements across the site and in particular near the edges of the quarry. We agree with Golder that there needs to be sufficient settlement monitoring points across the final surface level to monitor the settlements over time to allow for an assessment of the expected future total and differential settlements for the site overall and for individual assets or land that will be transferred to the Council. This is likely to necessitate multiple settlement points for each area for the Council asset. The number and location of the proposed surface monitoring points is not known at this time.

The methodology and hold points that need to be achieved before the land is handed over to the Council need to be clearly determined now due to different interpretations by different organisations at a later stage. This data should drive the handover rather than any fixed time period. However, it is our view that the monitoring period must occur until at least the saturation of the backfill has occurred. VW piezometers will measure the groundwater at depths, but these have not been specified, apart from one elevation of RL40m.

It is important to understand the impacts on time period for monitoring settlement and the impacts that the longer period of monitoring has in increasing the confidence in the predicted final settlement over the 50 year design life. For example if the settlement is monitored for 5 years, the settlement from the end of the 50 years will increase by log(55/5) by 1.04 per log cycle of time. For 300mm per log cycle of time, this equates to settlement of the order of 312mm . However, if you only allow the monitoring for 2 years, the future settlement for the next 50 years can be expected to increase by 1.41 times the settlement per log cycle of time. i.e. ~424mm of settlement. If you allow the monitoring to occur for 10 years, the future settlement is only expected to 0.78 the settlement per log cycle of time i.e. of the order of 233mm of settlement. The greater the potential of extrapolation of the settlement, the lesser the potential accuracy of any future prediction. We are not suggesting that the accuracy of any prediction will be as precise as indicated above but the numbers determined here are to illustrate the issue. The longer you undertake monitoring prior to development, the more accurate the prediction of future settlement and the less settlement that will occur over the design life of the structure. Furthermore, the longer you wait prior to commencing the development, the considerably less settlement over the 50 year design life (between 233 and 424mm of settlement if development commences 10 years after development compared with 2 years, respectively). Note that these settlements are slightly greater if you adopt 50 year design life of the building rather than 50 years from completion of the filling as proposed by T & T (T & T, 2017).

Therefore the period to predict the future settlement is dependent on the following and therefore the period for monitoring. The period for monitoring should be determined by consideration of the following:

1. The consistency of the settlement plots with logarithm of time within defined areas of the development.
2. The consistency in the differential settlement across or along road reserves and other future Council land.
3. The groundwater located within and across the entire quarry back fill has equilibrated and is verified by monitoring.
4. The acceptability of the predicted total and differential settlements of the proposed Council structures and features including, pavilions, ovals, synthetic pitches, roads and drainage.
5. The longer the period allowed after construction prior to the commencement of the building or asset, the lesser the settlement over the design life of the structure.

Unless the total and differential settlements are much less than the specified criteria and equilibrium of the water table has occurred, in our opinion, it is unlikely that a settlement monitoring period of less than 5 years will be acceptable.

6.3 Monitoring

We agree with Golder (March 2020) that the details of the monitoring plan need to be provided and the monitoring plan needs to be sufficient with adequate surface survey monitoring points. The monitoring points need to be sufficient to determine the total and differential settlement for both Council and private assets. There also need to be sufficient measurements of porewater pressures within the quarry backfill to establish that the water table within the fill has reached the long term equilibrium. These monitoring points need to be protected from damage and vandalism.

7.0 Recommendations

The following recommendations are made with respect to the filling of the quarry:

1. It is our opinion, that on balance, the period to assess compliance with the performance criteria should be at least 5 years. As discussed in this report, the longer the period of monitoring prior to the development or handover to the Council, the greater the confidence in the predicted settlement over the next 50 years and the lesser settlement over this period. Notwithstanding these recommendations:
    a. If the developer can demonstrate that the predicted total and differential settlements are much better than the accepted performance criteria over a period of 3 years after filling and prior to any construction, equilibrium in the groundwater within the quarry has occurred and the settlement points are showing consistent values with minimal differential settlement, the period for monitoring may be able to be reduced.
    b. On the other hand, if the predicted settlements are marginal; there is considerable difference in settlement between settlement locations and the transition to achieve equilibrium of the groundwater within the pit backfill is still on-going, the monitoring period may need to be extended to beyond the 5 years after the completion of the fill, prior to construction.
2. It has been suggested that the poorer highly plastic clays or other compressible soils should be zoned into areas that can accept greater total and differential settlements. We consider this approach to be problematic due to the following:
    a. It will exacerbate the differential settlements across the overall site.
    b. The quantity of these materials is largely unknown with any accuracy at this time and the layer of this thickness is unknown at this time.
3. It is recommended that the zoned materials be placed across the entire backfilled areas in layers with a similar thickness of a particular soil or rock material across the quarry area and the thickness of these layers and soil type be recorded.
4. No details are provided on how the developer proposes to address the significant differential settlement between the edge of the quarry and the deeper section of quarry and how it will impact on roads and other structures in this area.
5. As discussed in this report, the performance acceptance criteria for each of the Council or other assets within the quarry backfill should be determined now, even if the location is not known, with an associated cost compensation formula if the predicted total and/or differential settlements are greater than normal, resulting in increased foundation costs or reduced design life.
6. The period for the settlement prediction for most structures for their effective design period, whether it be 20 years or 50 years, should commence from the commencement of construction and not from the completion of filling. There appears to some difference in interpretation between T & T and Golder.
7. Moisture content limits should be specified to achieve the required air void ratio to reduce the potential for larger hydro-consolidation settlements.
8. More details on the monitoring locations and elevations and frequency of readings needs to be provided.
9. The details of the decommissioning of the sump riser and the proposed final level of the riser need to be provided and how any differential settlement if the riser is to be retained will be accommodated or determine if it is not an issue.

10. A better, more robust 3 – dimensional computer groundwater model of the expected rate of saturation of the backfill taking into account the impacts of the riser surrounding ballast, the surrounding perched water table, rainfall and drainage surface water impacts on the backfill during the monitoring period and better determination of the final groundwater level is recommended. This will require a hydrogeological investigation with appropriate pumping testing and monitoring to derive the onsite hydrogeological parameters. A 3 – dimensional settlement model which includes the berms and any more compressible layers and include information gained during the backfilling to date.
11. Provide information if the groundwater levels will be allowed to rise during the quarrying backfilling and include this impact in the hydrogeological and settlement models.

8.0 Principles and Limitations of Investigation

This report has been prepared by Senversa with all reasonable skill, care and diligence in agreement with the Client. Information reported herein is based on the interpretation of data collected and has been accepted in good faith as being accurate and valid.

Area	Uncertainties and Limitations
Site Specific	Specific uncertainties and limitations noted for this investigation are as follows: • The assessment is based on a review of the reports provided of the site at the time of assessment. Senversa's conclusions presented in this report are therefore based on the information available in these reports. • At the time of this report, detail of the proposed development is not known. • This geotechnical report should not be used for detailed design. No environmental assessment has been undertaken nor is implied in this report.
Scope of Services	This geotechnical report has been prepared in accordance with the scope of services set out in the proposal, or as otherwise agreed, between the Client and Senversa. In some circumstances the scope of services may have been limited by a range of factors such as time, budget, access and/or site disturbance constraints.
Reliance on Data	In preparing the report, Senversa has relied upon data, surveys, analyses, designs, plans and other information provided by the Client and other individuals and organisations. Senversa will not be liable in relation to incorrect conclusions should any data, information or condition be incorrect or have been concealed, withheld, misrepresented or otherwise not fully disclosed to Senversa.
Purpose and Use of Geotechnical Investigation Report	Geotechnical engineering reports are prepared to meet the specific needs of the agreed scope. This report was prepared expressly for the Client for purposes identified in the scope of works and as indicated by the Client or its representative. The report should not be use by any other persons for any purpose, or by the Client for a different purpose. The Client should not use this report for anything other than its intended purpose without seeking additional geotechnical advice. This report should only be reproduced in its entirety.
Limitations of Site Investigation	The comments and conclusions are based on the information provided and there is the possibility that other information or further assessment may alter the conclusions and recommendations. Site exploration identifies specific subsurface conditions only at those points from which samples have been taken. The risk that variations will not be detected can be reduced by increasing the frequency of test locations; nonetheless, even a rigorous assessment may fail to detect all of the geotechnical conditions on a site. Site variations may be present in areas not investigated or sampled. The data derived from the site investigation works and subsequent laboratory testing are extrapolated across the site to form an inferred geological model and an engineering opinion about overall subsurface conditions and their likely behaviour with regard to the proposed development.
Subsurface Conditions are Time Dependant	Site assessments are limited by time, and natural processes such as erosion, or mankind altering the ground conditions, including the site levels or filled areas, may affect the condition of the site, and subsequently, the findings of this site assessment. This geotechnical report should not be used when the nature of the proposed site usage changes, when the size, layout, or location of the development is modified, when the site ownership changes nor should it be applied to a nearby area. No environmental assessment has been undertaken nor is implied.
Avoid Misinterpretation	Costly problems can occur if the report is misinterpreted. To avoid these problems, Senversa should be retained to work with the appropriate design professionals and to review the adequacy of their plans and specifications relative to the geotechnical matters.

9.0 References

AS2870 – 2011 Australian Standard 2870 – Residential Slabs and Footings.

CIRIA (2002): PUB C572 Treated ground: engineering properties and performance. ISBN 0860175723.

Heath, R.C. (1983). Basic ground-water hydrology, U.S. Geological Survey Water-Supply Paper 2220, 86p.

Morris, D.A. and Johnston, A.I. (1967): Specific yield — compilation of specific yields for various materials. U.S. Geological Survey Water Supply Paper 1662-D. 74 p.

Rowe, R.K., Geotechnical and Geoenvironmental Engineering Handbook, 2001.

Theis, C.V. (1935): The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage, Am. Geophys. Union Trans., vol. 16, pp. 519-524.

Waddell P.J and Wong P.K. (2005): Settlement Characteristics of Deep Engineered Fills, Australian Geomechanics, Vol 40, No 4., 2005.

tel: + 61 3 9606 0070
fax: + 61 3 9606 0074
enquiries@senversa.com.au
www.senversa.com.au
Level 6, 15 William Street, Melbourne, VIC 3000
Senversa Pty Ltd ABN 89 132 231 380