AB Lime Limited Landfill Resource Consent Application

APP 20202200, APP 205862-01-V2 - s 92 Response to Environment Southland

IZ000400-LFC-NP-RPT-0006 | 1

2 September 2020

AB Lime Limited

AB Lime Limited Landfill Resource Consent Application

Project No: IZ000400
Document Title: APP 20202200, APP 205862-01-V2 - s 92 Response to Environment Southland
Document No.: IZ000400-LFC-NP-RPT-0006
Revision: 1
Date: 2 September 2020
Client Name: AB Lime Limited
Project Manager: Katrina Wilkinson
Author: Ryan McCone
File Name: AB Lime Limited Landfill Resource Consent Application - ES s 92

Jacobs New Zealand Limited

Level 2, Wynn Williams Building
47 Hereford Street
Christchurch Central
PO Box 1147, Christchurch 8140
New Zealand
T +64 3 940 4900
F +64 3 940 4901
www.jacobs.com

Document history and status

Revision	Date	Description	Author	Checked	Reviewed	Approved
A	27/07/2020	Draft for Internal Review	Ryan McCone	Ian Wiseman	Andrew Henderson	
0	28/08/2020	Draft for Client Comment/Legal Review	Ryan McCone	Ian Wiseman	Andrew Henderson	Vince Pace
1	2/09/2020	Final for Lodgement	Ryan McCone	Ian Wiseman	Andrew Henderson	Vince Pace

Contents

Important note about your report

The sole purpose of this report and the associated services performed by Jacobs (on behalf of AB Lime Limited) is to prepare a section 92 response to Environment Southland on the resource consent application for resource consents to operate a solid waste disposal facility and associated discharges at AB Lime Landfill at 10-20 Kings Bend, Winton, in accordance with the scope of services set out in the contract between Jacobs and AB Lime Limited (the Client).

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by the Client and/or from other sources. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and conclusions as expressed in this report may change.

Jacobs derived the data in this report from information sourced from the Client (if any) and/or available in the public domain at the time or times outlined in this report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report. Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

This report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by Jacobs for use of any part of this report in any other context. This report has been prepared on behalf of, and for the exclusive use of, Jacobs's Client, and is subject to, and issued in accordance with, the provisions of the contract between Jacobs and the Client. Jacobs accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report by any third party.

Introduction

This is a formal response to the request for further information for APP 20202200, APP 205862-01-V2 pursuant to section 92 of the Resource Management Act provided by Southland Regional Council to Jacobs New Zealand Limited on behalf of AB Lime Limited for resource consent to operate a solid waste disposal facility and associated discharges related to the change in activity at 10-20 Bend Road, Winton – received on 23 July 2020.

1. Further Information Requested – Air Quality and Odour

Please refer to the *Air Quality* section 92 response written by NZ Air and attached as Appendix A to this document.

2. Further Information Requested – Landfill Engineering, Leachate Collection and Management, and Landfill Gas Management

It is noted that RILEY consultants have made a number of points at the beginning of their peer review that require addressing prior to addressing the matters raised in the section 92 letter. The comments suggest the peer reviewer may have misunderstood the intent of the application and it is therefore important to address these to ensure that all parties are considering the application from the same starting point. RILEY's comments are as follows:

- *Several assumptions have been made by the applicant/applicant's consultant regarding the anticipated environmental effects of expanding the landfill and removing all incoming waste limits.*
- *Far a 'Class A' landfill (for all intents and purposes a Class 1 Landfill as per the 2018 WasteMINZ Technical Guidelines for Disposal to Land) these assumptions are considered too broad in nature and further explanation/justification is required in order to more effectively support the conclusions reached.*
- *Furthermore, the information currently provided is unlikely to be sufficiently robust in terms of its quality to support the application for the "removal of the current 100,000 tonne limit".*

The Applicant does not consider that the existing environment has been appropriately considered in the peer review by RILEY consultants. The relevance of the existing environment to the consideration of applications for resource consent is a well-established principle in resource management case law. Notably, the existing environment includes activities carried out under existing resource consents. The activities currently undertaken on the site by AB Lime are lawfully established under the suite of live resource consents granted in relation to the site and are therefore part of the existing environment.

This setting is extremely important for understanding the context of the application. We are concerned that without an appreciation of the historical context of the site, including existing resource consent conditions and an iterative development process undertaken with Independent Peer Reviewers for aspects of landfill operations, RILEY consultants has fundamentally misunderstood the nature of the application. We understand that the peer reviewer has not yet visited the site, which may also make it more difficult to fully understand the existing environment and site context.

Many of the Applicant's assumptions that the peer reviewer refers to are based on lawfully established design and management methodologies that have been previously approved through the independent peer review process.

Fundamentally, we wish to reiterate that the Applicant is not changing or expanding the landfill footprint. Because this is already consented it is not considered necessary to reinvestigate these matters The landfill has been operating for nearly two decades as the Southland Regional Landfill, with a good track record. The application is based on existing information and utilises the existing environment as the appropriate starting point from which to consider the effects of this activity.

The peer reviewer notes that there are several assumptions regarding the anticipated environmental effects of expanding the landfill. It is the rate of filling that is changing with this application. The landfill is not becoming larger or 'expanding' and this is fundamental to the assessment of effects in the resource consent application.

Furthermore, the peer reviewer has provided little comment on the proposed conditions of consent. In this regard the Applicant has concerns that the peer reviewer has misunderstood the hierarchy of the regulatory framework. The proposed conditions of consent provide clear performance and environmental standards that have been developed taking into consideration the uniqueness of the site. Importantly, any conditions of consent relating to the adaptive management framework are to be certified by an appropriately qualified and experienced person as being achieved. The key for successful adaptive management for the site is the collection of baseline knowledge upon which the management plans can build an ongoing process with the setting of clear objectives. This is provided for in the proposed conditions of consent, yet not commented on by RILEY consultants.

Lastly, the Applicant has concerns about the scope of the peer review, particularly in regard to site traffic. Traffic movements (both internal and external to site) are a consideration for Southland District Council and are undergoing assessment by the Southland District Council. The Applicant believes that RILEYS have gone beyond the scope of the consents required from Environment Southland resulting in unnecessary duplication of time and effort by all parties. The Applicant does recognise however that clarity has to be provided around operating procedures in regard to the 1000 m^2 working face, as this is a consideration relevant to the Southland Regional Council. Further detail regarding the 1000m^2 working face is provided within this s 92 response.

Lastly we note that RILEY consultants have made a comment on the disclaimer used by Jacobs New Zealand.

- *Additionally, and of equal or greater concern is the disclaimer by the applicant's consultant (refer to the "Important Note about this Report") prefacing the application and most of the technical memoranda which does not inspire confidence overall in the robustness of the application or in the conclusions that have been reached by the authors. The second paragraph of the disclaimer is of particular concern. The logical extension of this is that if the consultant has reservations then the regulators must have even greater reservations.*

Jacobs believe that the disclaimer used is entirely appropriate and it is standard procedure to include a disclaimer on all our work. Jacobs have relied on information provided to us that forms part of the historical context of the site (including the original resource consent application and associated reports). In Jacobs scope it is made clear that the consultant for the Applicant is relying on the assumption that this historical information is accurate.

This does not mean that Jacobs is not taking responsibility for our work. Jacobs are still responsible for the work produced, but not to the extent there are errors in the documents produced that are caused because there are errors in documents we have relied on.

This reflects the scope and obligations to Jacobs' client (AB Lime Limited). It is not intended to be a disclaimer to be relied upon by the regulatory authority, or their authorised agents.

Landfill Capacity and Lifespan

2.1 Please provide qualitative and quantitative information to confirm the derived tonnages per annum including consideration of population growth and per capita waste generation.

We consider that a request for such detailed information would be appropriate if consent was sought for a new, greenfields landfill. However, it is not. The landfill is lawfully established and has operated successfully for 15 years. The records held by the Applicant that have been maintained over the course of operating the landfill provide real data to help understand the waste stream.

We therefore do not consider that providing quantitative or qualitative analysis to confirm the derived tonnage, including consideration of population growth and per capita waste generation, will provide any additional benefits. The data gathered by AB Lime since the landfill commenced provides a real-life picture of the waste stream and annual trends. We therefore consider that requiring theoretical calculations is of no benefit.

In this regard it is important to note that the scenarios considered in the application provide benchmarks of waste volumes to enable potential effects to be assessed for the landfill under different scenarios and are not indicative of targets to be achieved. This information was provided for the purposes of providing context to the potential scale of waste acceptance in line with what was requested in a pre-application meeting with Environment Southland (provided to the Applicant on 9 April 2020) to show an indicative assessment of the shortest time to completely fill the landfill.

The derived tonnages for Scenario 2 provide the shortest lifespan possible for the landfill by accepting all waste from the lower South Island. It is important to reinstate that this scenario is indicative of a 'worst case' scenario and provides an upper limit that is highly improbable.

It is considered that the simple methodology adopted multiplying total waste acceptance in Class 1 landfills by the percentage of population currently identified in the lower South Island (south of and including Timaru) is adequate for the purpose this document serves to provide an indicative timeline for the lifespan of the landfill. Adding a layer of complexity to the model to include population growth and per capita waste generation is likely to only cause nominal changes to the 'worst case' scenario and provides no additional benefit to the assessment of effects to which this activity relates.

The landfill is consented, and the only change being sought in the present application is the removal of the existing annual waste acceptance cap to allow for higher volumes to be accepted at the site should the need arise or waste streams increase. Removal of the cap does not require an expansion in landfill footprint as no changes are sought to the originally consented landfill area or final contours.

2.2 As waste generated per annum is a function of population, population growth and per capita generation, please provide information on whether the effects of economic growth (upturn/downturn), the waste disposal levy and waste minimisation initiatives which directly impact per capita generation and hence resulting tonnages per annum have been considered.

Whilst we agree that these external factors have the ability to influence tonnage, we consider that these external factors are beyond the control of the Applicant for the purposes of this resource consent application.

We do not consider that the effects of economic growth, the waste disposal levy and waste minimisation initiatives (which directly impact per capita generation) are material considerations for the purposes of the Predicted Lifespan and Capacity Memo as it relates to the current AB Lime Landfill application. The landfill is consented and while the consent holder is committed to waste minimisation initiatives, these are matters that are more relevant to the creation of a new greenfield landfill and not one that has been operating lawfully under resource consents for over 15 years and has a further 18 years to run under the current consents.

The Applicant understands the importance of their role in waste minimisation and continues to undertake an active role in the education of the community to help understand the significance of effective waste management in the Southland region. As a solid waste disposal facility, the AB Lime landfill is the 'end of the line' for waste acceptance in the Southland region. The proposal identifies the need to future proof the landfill for the Southland region and beyond in a wide variety of circumstances.

We also reiterate that the scenarios included in the Application provide benchmarks for assessing the actual and potential effects of operating the landfill under different waste acceptance rates, and are not indicative of targets to be achieved. This information was provided for the purposes of providing context to the potential scale of waste acceptance in line with what was requested in a pre-application meeting with Environment Southland (provided to the Applicant on 9 April 2020) to show an indicative assessment of the shortest time to completely fill the landfill.

Furthermore, the Applicant believes that waste generation is not just a function of population, population growth and per capita generation. The Applicant has seen several scenarios of late that confirm that waste generation is also tied to external factors such as emergency and crisis events such as the Bonamia parasite infection at Big Glory Bay and Mycoplasma Bovis outbreak that resulted in a large number of cows being buried at the landfill. Experiences around the country also show that large demands can infrequently be placed on landfills as a result of other events, such as the Canterbury Earthquake Sequence. As such, proposed conditions of consent have been created as a means to manage emergency waste streams (please refer to Section 9 of the resource consent application) and there are corresponding management procedures under section 6 of the Landfill Operations Management Plan.

2.3 Please confirm what sensitivity analyses have been undertaken to confirm the robustness of the derived tonnages as well as the assumptions used in their derivation.

We do not consider that any sensitivity analyses are a material consideration for the purposes of the Predicted Lifespan and Capacity of the AB Lime Landfill Technical Memo.

Real data provides input for Scenarios 1 a) and b). Therefore, sensitivity analyses would only be relevant for Scenario 2.

Scenario 2 provides a benchmark for the landfill and is not a target to be achieved. This information was provided for the purposes of providing context to the potential scale of waste acceptance in line with what was requested in a pre-application meeting with Environment Southland (provided to the Applicant on 9 April 2020) to show an indicative assessment of the shortest time to completely fill the landfill.

Analysing the effects of certain variables to input into Scenario 2 are only likely to provide nominal changes to a hypothetical scenario. The benefits of sensitivity analysis for the purpose this information serves are considered negligible for this application.

2.4 Please advise how the expiry of the current consents in June 2038 and any new consents which are potentially acquired under the proposed removal of the tonnage limits on waste quantities for a maximum period of 35-years (hence potentially expiring circa 2055/56 if granted in 2020) have been considered in the analysis.

The landfill is currently operating under a suite of consents that expire in 2038. The consents establish the consented baseline for the site. Should the new consent be granted, the Applicant anticipates that the existing consents would be surrendered (apart from those recognised in the resource consent application that are not changing) at the time the new consents are given effect to.

For clarification, the Applicant proposes a change to Condition 1 under Schedule 1 General Conditions found under Section 9 of the resource consent application:

Table 1 Proposed Wording Change to Condition 1 Schedule 1 - General Conditions

Consent Number	Consent Condition	Proposed Change (deletions in ~~strikeout~~ and proposed changes or status in red)
Schedule 1 – General Conditions		
1.	The consent holder has 5 years from the granting of these consents to give effect to the consents in accordance with S.125 of the Act.	The consent holder has 5 years from the granting of these consents to give effect to the consents in accordance with S.125 of the Act. The surrender of existing consents will occur at the time these consents are given effect to.

The Predicted Lifespan and Capacity of the AB Lime Landfill Technical Memo identifies that projected waste acceptance based on data for a worst-case scenario is likely to exceed the consented limit in 2065, well after the existing 2038 expiry.

If new consents are granted, even in the 'worst-case' scenario, the lifespan of the landfill will extend beyond the expiry of these consents. It is the view of the Applicant that limiting the duration of the consent or placing a limit on tonnage is not the best way to address uncertainties about the adverse effects associated with this landfill.

Instead the range of adaptive management measures implemented through the management plan framework, as well as monitoring/reporting and conditions of consent are considered appropriate. Experience with the landfill has shown that there is not a linear relationship between waste acceptance levels and the creation of adverse effects. In the event that new consents are not granted post 2038 the Landfill Concept, Rehabilitation and Aftercare Plan would be the appropriate instrument that deals with the closure of the site and ongoing monitoring requirements.

2.5 Please provide validation of the derived 240,000t/yr using available data from all local authorities within the catchment identified in the LCLTM as the lower South Island.

It is considered that the simple methodology identified multiplying total waste acceptance in Class 1 landfills by the percentage of population currently identified in the lower South Island (south of and including Timaru) is adequate for the purpose of the Predicted Landfill and Capacity of the AB Lime Landfill Technical Memo. This memo serves to provide an indicative assessment of the shortest time to complete the landfill, to provide a 'worst-case scenario'.

2.6 Please provide comment whether the above is an accurate assessment of the data provided.

There are two scenarios that can be evaluated: maximum consented extraction of the limestone and the current average limestone extraction rate.

Table 2 Extrapolated Predicted Lifespan and Capacity Memo Data Calculations

	Maximum consented extraction rate	**Current average limestone extraction rate**
Extraction rate	350,000 t/year	209,179 t/year
Limestone density	2.5 t/m^3	
Extraction rate	$\frac{350{,}000\ \text{t/year}}{2.5\ \text{t/m}^3}$ = 140,000 m^3/year	$\frac{209{,}179\ \text{t/year}}{2.5\ \text{t/m}^3}$ = 83,672 m^3/year
Overburden ratio[A]	1.2	
Topo ratio[B]	2.72	
Total ratio	1.2 x 2.72 = 3.29 (after rounding)	
Excavated void volume	140,000 m^3/year x 3.29 = 461,211 m^3/year	83,672 m^3/year x 3.29 = 275,281 m^3/year
In-situ waste density	0.94 ton/m^3	
Incoming waste that can be accepted	461,211 m^3/year x 0.94 ton/m^3 = 430,000 t/year (after rounding)	275,281 m^3/year x 0.94 ton/m^3 = 259,000 t/year (after rounding)

A. Considers that the limestone over the weighbridge does not include the rock not suitable for limestone sales (i.e. knap rock)

B. Considers that there is space between the limestone surface before quarrying and the final capping surface that should be included in the volume to place waste once the limestone has been removed

Based on the current average extraction rate of the limestone, 259,000 t/year of waste can be accepted into the landfill. However, if the limestone was extracted at the maximum consented rate of 350,000 tonnes per annum over the weighbridge, the landfill could accept 430,000 t/year. This shows that there is sufficient room for this very high level of waste acceptance. Furthermore, the Applicant may apply to increase the extraction rate of quarrying if deemed necessary in the future.

Site Traffic

2.7 Please provide both qualitative and quantitative information to confirm the understanding stated including existing documented policies and procedures and independent verification of adherence to such policies and procedures.

2.8 Please provide information on existing practices (recommended traffic detours) under the removal of the tonnage limits on waste quantities and specific measures to manage any associated issues as a result of more waste from a larger waste catchment, multiple sources and non-local transporters.

2.9 Please provide a copy of the email referred to in the footnote.

Traffic matters are not relevant to the regional consent and therefore falls outside the scope of what should be considered by the peer reviewer. Traffic is a land use matter and therefore requires consideration by the Southland District Council as part of their assessment of the concurrent land use consent application. The proposed conditions of consent for traffic movements and the Site Traffic Technical Memo and Site Traffic Management Plan are relevant to the land use consent sought from the Southland District Council.

The Applicant is corresponding with the Southland District Council to respond to traffic queries related to external movements and has already provided further information in a section 92 request.

Traffic movements are a consideration for Southland District Council and are undergoing assessment by the Southland District Council. This RFI and the subsequent questions relating to traffic below do not relate to the actual and potential effects of the proposed activity on the environment that fall under the consideration of Environment Southland.

2.10 Please provide qualitative and quantitative information to reconcile the time frames stated in Table 15 for waste truck types (In: 30 to 40 seconds and Out: 3 to 4 minutes) with the activities required to be completed as per Section 7.2 of the Draft LOMP.

As set out above, traffic matters are not relevant to the regional consent and therefore falls outside the scope of what should be considered by the peer reviewer.

Any adverse effects arising from landfill traffic are managed through on-site management practices. Hours of operation for transportation in and out of the landfill site are already limited and are controlled to reduce effects such as noise and vibration when they could cause the most disturbance. Any constraints imposed on internal site movements should only be considered if necessary to reduce adverse effects on surrounding properties and the wider environment, taking into account the landfill's operation.

Dust emissions arising from traffic is a matter for consideration for the Regional Council and is addressed in the Landfill Air Quality Technical Memo and Landfill Air Quality Management Plan. How dust emissions are managed forms part of this section 92 response under Section 1.4.

The Applicant has deduced from the nature of these out of scope questions that the peer reviewer has likely concerns with operational management of the working face. Operation of the working face is related to the Regional Consents. This is examined in further detail in the response to question 2.15 below.

2.11 Please provide qualitative and quantitative information on the proportions of each vehicle type (waste, lime, fertiliser, blend) for the current operations and how this impacts the assessed/evaluated capacity.

Traffic matters are not relevant to the regional consent and therefore falls outside the scope of what should be considered by the peer reviewer. Traffic is a land use matter and therefore requires consideration the Southland District Council as part of their assessment of the concurrent land use consent application. The proposed conditions of consent for traffic movements and the Site Traffic Technical Memo and Site Traffic Management Plan are relevant to the land use consent sought from the Southland District Council.

2.12 Please provide qualitative and quantitative information on the proportions of each vehicle type for the proposed operations under the removal of the tonnage limits on waste quantities and specific measures to manage any associated issues.

Traffic matters are not relevant to the regional consent and therefore falls outside the scope of what should be considered by the peer reviewer. Traffic is a land use matter and therefore requires consideration the Southland District Council as part of their assessment of the concurrent land use consent application. The proposed conditions of consent for traffic movements and the Site Traffic Technical Memo and Site Traffic Management Plan are relevant to the land use consent sought from the Southland District Council.

2.13 Please provide qualitative and quantitative information to support or clarify the statement or amend the statement as the removal of the tonnage limits on waste quantities may lead to an acceleration of quarrying to create the necessary airspace in a timely manner and consequently need to be transported off site increasing the demand on the weighbridge from blend, fertiliser and blend truck type vehicle movements.

This is not relevant to the regional consent and falls outside the scope of what should be considered by the peer reviewer. Traffic is a matter that is under consideration of the Southland District Council.

The need to provide qualitative and quantitative information to support/clarify the statement that the removal of the annual tonnage limits on waste quantities may lead to an acceleration of quarrying is not applicable to this application. Land use consent 60/3/02/138/1 permits the extraction and processing of limestone up to 350,000 tonnes per annum. All traffic movements associated with quarrying activities are lawfully established under this operational land use consent.

The Applicant also contends that this is an operational consideration that is not relevant to this resource consent application. The Applicant has a number of levers to control the extraction rate of limestone including economic mechanisms such as the control of price to regulate supply and demand, as well as the potential to stockpile quarried material as currently consented under condition 1.11 of quarry land use consent 60/3/02/138/1.

2.14 Please provide qualitative and quantitative information on the following under the removal of the tonnage limits on waste quantities assuming that the landfill is operating to its full capacity (e.g. two weighbridges, fully available consented operating hours) and assist with further clarification around constraints:

- **Stockpiling – potential stockpiles (area/volume) for quarried materials, processed materials, landfill capping (intermediate and final cover materials).**
- **Waste Storage – if waste cannot be transported to the off-load area/working face for immediate disposal and management of the effects of waste storage (vermin, odour, etc.).**
- **Potential for on-site queueing – limits on queueing, impact on other on-site activities, on-site roads carriageway width.**
- **Potential for bin exchange area.**
- **Working face operation – failure of compactor/bulldozer.**
- **Time taken from when a waste truck enters the weighbridge to when it leaves the weighbridge including queueing, speed restrictions, travel to the point of unloading, unloading at the off-load area adjacent to the working face area, travel from the point of unloading to the weighbridge, queuing (if any before the weighbridge) when the landfill is operating fully to the limit of consented operational hours.**

a) Stockpiling

The Applicant contends that stockpiling of limestone extracted from the site is an operational consideration that is not relevant to this resource consent application. The Applicant has a number of levers to control the extraction rate of limestone including economic mechanisms such as the control of price to regulate supply and demand.

The Landfill Capacity and Lifespan memo indicates that stockpiling of quarrying material is not necessary prior to the expiry of the quarry land use consent. Even, if this worst case scenario was exceeded, the Applicant has the potential to stockpile quarried material as currently consented under condition 1.11 of quarry land use consent 60/3/02/138/1. Condition 1.11 of Land Use Consent 60/3/02/138/1 is reproduced below. This consent is set to expire in 2038, when the requirements for stockpiling lime can be appropriately reassessed:

Land Use Consent 60/3/02/138/1

1.11 That the location of stockpiles of quarried materials and overburden shall be within the area illustrated in green on Drawing Number 319-C-025.

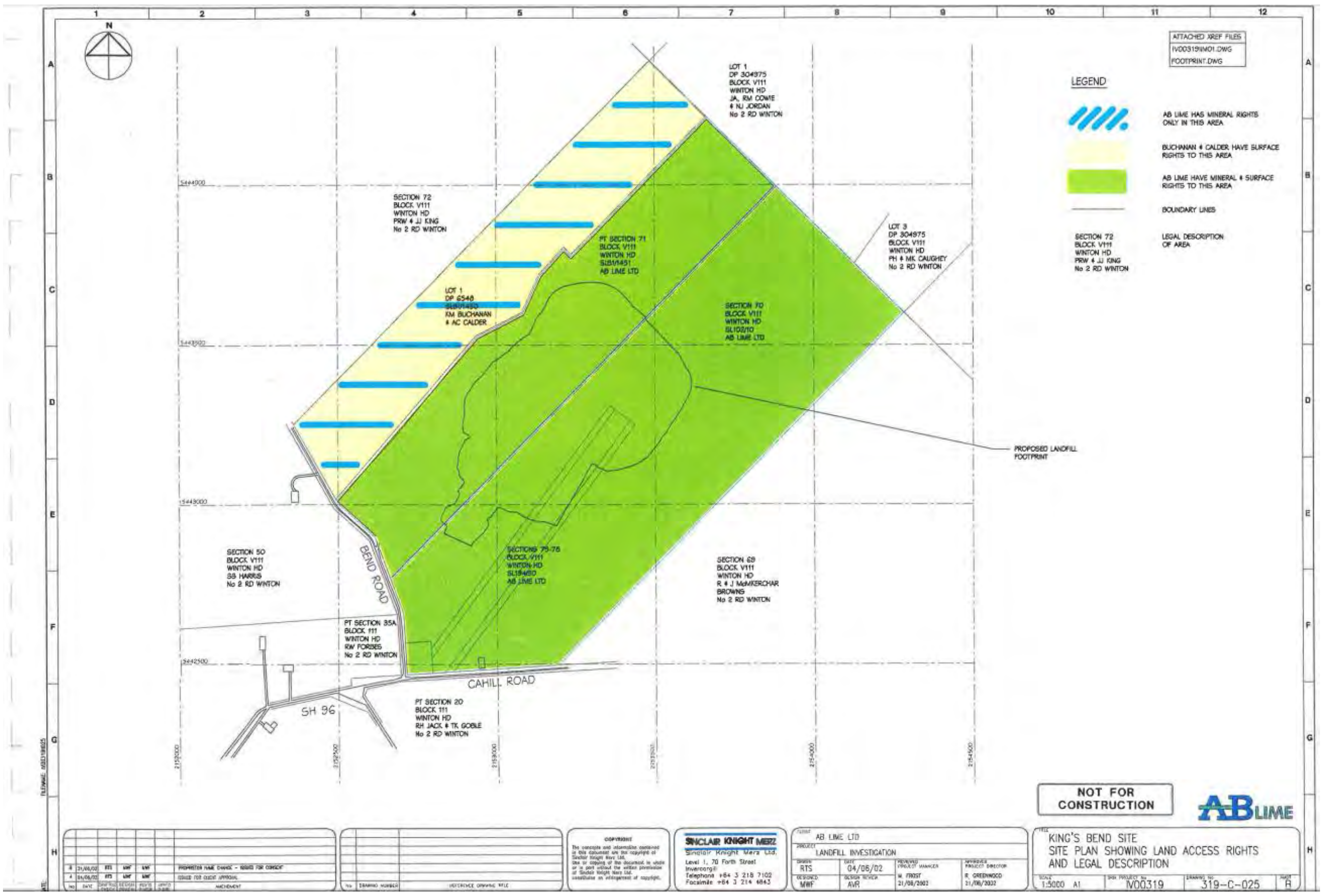


Figure 1 Drawing Number 319-C-025

The 300 mm intermediate cover/regulating layer and the 600 mm of compacted clay, overburden or soil material can consist of knap rock. The knap rock is sourced from the quarry and is readily available with an average yearly excavation rate of 83,672 m3.

b) Waste Storage

The answer to this is provided in the concept filling plan. Please refer to Section 14 of the updated Landfill Operations Management Plan.

c) Potential for on-site queuing

Traffic matters are not relevant to the regional consent and therefore falls outside the scope of what should be considered by the peer reviewer. Traffic is a land use matter and therefore requires consideration the Southland District Council as part of their assessment of the concurrent land use consent application. The proposed conditions of consent for traffic movements and the Site Traffic Technical Memo and Site Traffic Management Plan are relevant to the land use consent sought from the Southland District Council.

d) Potential for bin exchange area

Please see answer to b) "waste storage" above.

e) Working face operation – failure of compactor/bulldozer

If there is a failure of the compactor or bulldozer the Applicant has the ability to hire plant, while maintenance is carried out on the existing plant. Any replacement plant can be on site within 24 hours.

f) Time taken from when a waste truck enters the weighbridge to when it leaves the weighbridge

Internal site movements and manoeuvrability are not considered an operational constraint. The concept filing plan provides discussion on the movement of vehicles at the tipping face. Furthermore, AB Lime has a number of mechanisms to provide for better manoeuvrability including scheduling waste trucks and using all available consented hours for landfill operations (including weekends).

Landfill Operations

2.15 Please confirm that the LOMP will include a process for assessing new contaminants and for developing acceptance criteria and please provide a draft of the proposed process.

We confirm that the Landfill Operations Management Plan, see Section 4.5, has been updated to include a process for assessing new contaminants and for developing assessment criteria.

2.16 Please provide information on how materials and wastes containing persistent organic pollutants (POPs), including perfluorinated compounds (PFAS, PFOS and PFOA) are currently received, handled, disposed of and monitored at the landfill, in order to enable an assessment of how these compounds are being managed to ensure protection of human health and the environment.

AB Lime does not knowingly or deliberately accept POPs. POPs are categorised as a hazardous waste and all disposal companies have signed an agreement that they will not knowingly dispose of hazardous waste at the AB Lime Landfill.

Any POPs contained within municipal solid waste stream is considered incidental in nature and outside the control of AB Lime.

If in the future AB Lime would like to consider the acceptance of POPs including perfluorinated compounds (PFAS, PFOS and PFOA), then the process for assessing new contaminants and for developing acceptance criteria, as described in the LOMP, will be followed (see item 2.15).

2.17 Please provide information on how the landfill complies with the Hazardous Substances (Storage and Disposal of Persistent Organic Pollutants) Notice 2004.

We understand that there is no requirement for AB Lime to comply with the Hazardous Substances (Storage and Disposal of Persistent Organic Pollutants) Notice 2004 for the following reasons:

The Hazardous Substances (Storage and Disposal of Persistent Organic Pollutants) Notice 2004 is provided for the owner or collector of POPs. Clause 5 of the Notice provides several methods for the environmentally sound disposal of POPs. The one method that could be considered landfill disposal is where the POPs owner must treat the POP prior to disposal, *"the substance using a method that changes the characteristics of composition of the substance sot that the substance or any product of such treatment is no longer a persistent organic pollutant and is not a hazardous substance*". Therefore, the responsibility of compliance in terms of the notice lies with the POPs owner or collector.

Under Clause 5 the disposal of untreated POPs by a collector or owner is prohibited. AB Lime is not a collector or owner of POPs, under the definition of the Notice.

2.18 Please comment on and confirm the potential risks to human health from possible exposure to leachate and landfill gas contaminants.

The potential risks to human health from possible exposure to leachate and landfill gas contaminants are considered low since:

a) Landfill leachate is collected within the landfill, piped to an on-site leachate tank and the leachate removed off-site via trucks to an authorised facility;
b) There is a low risk of leachate adversely affecting groundwater users that are located hydraulically downgradient of the landfill as described in the hydrogeological report supporting the AEE in 2002, since:
    i. The distance of the closest bore to the landfill is more than 600 m; and

ii. Given the low permeability of the limestone and low groundwater seepage rates to the adjacent alluvium, the groundwater quantity and quality effects of quarrying and landfilling is anticipated to be limited to less than 500 m from the site.

c) Landfill gas is actively extracted via an engineered landfill gas extraction system and piped to a permanent principal flare. At the flare the is gas burned at a high temperature that destroys the contaminants contained within the landfill gas.

d) Landfill gas surface emissions and landfill gas off-site migration to nearby buildings is considered to be of negligible risk given the design and operation of the landfill. This pathway has been monitored in accordance with the consent conditions, which by nature are protective of human health to exposure of landfill gas.

2.19 Please provide an assessment of likelihood of Persistent Bio accumulative and Toxic (PBT) EmCoC within the leachate that could have a potential impact on human health receptors.

We consider that there is a low risk of Persistent Bio accumulative and Toxic (PBT) EmCoC within the leachate that could have a potential impact on human health receptors for the following reasons:

a) AB Lime does not knowingly or deliberately accept POPs, as previously described in item 2.16 above; and

b) Any POPs contained within municipal solid waste stream is considered incidental in nature, and likely to be in small quantities (if any).

2.20 Please also confirm how these compounds will be managed at the landfill in terms of waste acceptance criteria and site management practices.

Please see response under item 2.15.

2.21 Please provide comment on whether a weight (or volume) limit on waste acceptance may need to be imposed through the operational management plan should limestone extraction continue at the current rate, or a rate which does not accommodate all waste that may be generated within the proposed waste catchment area, assuming no on-site stockpiling of either quarried material or waste.

During the current lime quarry consent (until 2038) the filling of the landfill will not be constrained by the excavation of the limestone, even in the highly improbable 'worst case' scenario. After 2038 the consent for the 350,000 tonne excavation of lime can be revisited, as well as the need to revisit any operational requirements for stockpiling. This coincides with the renewal of the site stormwater consent that will also be revisited at this time and can be aligned to include any stormwater management for any potential impact of lime stockpiles.

To assume no on-site stockpiling of quarried material discards an already consented activity to stockpile quarried material as currently consented under condition 1.11 of the quarry land use consent 60/3/02/138/1.

Furthermore, the Applicant has a number of levers to control the extraction rate of limestone including economic mechanisms such as pricing.

Restricting the active working face to 1,000 m² serves to limit the number of trucks able to manoeuvre to dump waste at any one time. Internal site traffic manoeuvrability is not considered an issue for waste acceptance, nor is it an issue relevant to the scope of this application.

2.22 If quarried material or waste is to be stockpiled to allow additional waste acceptance, please provide information on how that is to be operationally managed.

There is to be no stockpiling of waste. Any waste that is dumped on site will form part of the 1000 m² working face. Please refer to the concept filling plan found in Section 14 of the updated Landfill Operations Management Plan.

The location of stockpiles of quarried materials and overburden is consented under land use consent 60/3//02/138/1.

Land Use Consent 60/3/02/138/1

1.11 That the location of stockpiles of quarried materials and overburden shall be within the area illustrated in green on Drawing Number 319-C-025.

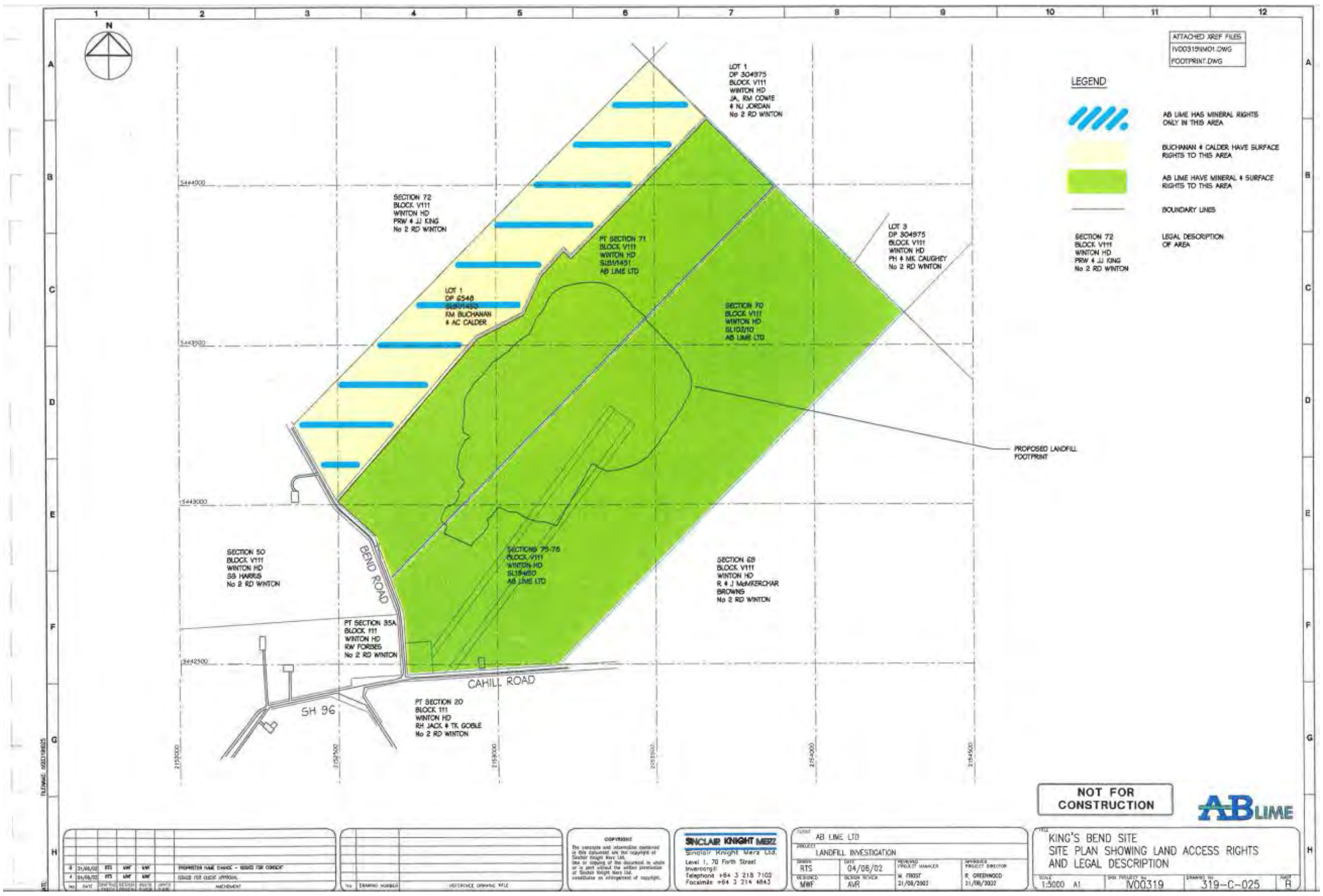


Figure 2 Drawing Number 319-C-025

This land use consent is operational until 2038 and this coincides with the expiry of the stormwater discharge consent.

Staged excavation of limestone and filling of waste under the Predicted Lifespan and Capacity of the AB Lime Landfill Memo indicates that excavation of each stage is completed prior to filling. This means that during the current lime quarry consented period (up to 2038), the filling of the landfill is not believed to be constrained by the excavation of the limestone.

Operational requirements for stockpiling of limestone will be managed as part of the new consenting process for stormwater discharge and quarry land use and are not a consideration for this resource consent application.

2.23 Please provide comment whether there is an action item within the LOMP and/or a variation on the proposed relevant conditions of consent that will encourage greater compliance by the landfill operator with the requirements following any increase in waste acceptance limits.

The following action items within the LOMP and/or a variation on the proposed relevant conditions of consent are considered to encourage greater compliance by the landfill operator with the requirements following any increase in waste acceptance limits:

a) Improving the temporary capping on the currently over-steep 'thinly capped' internal waste slopes, thereby reducing the potential for surface water infiltration (and thus reduce leachate generation) and reduce the potential for odour and landfill gas emissions;

b) A reduced working face (current 3625 m^2, proposed 1000 m^2) is anticipated to result in fewer landfill gas emissions.; and

c) A reduction in the current consent condition of <5% methane surface emission concentration to the proposed consent condition of <0.5%.

2.24 Please provide comment including qualitative and quantitative information on whether waste slopes steeper than recommended are acceptable.

The recommended maximum internal temporary waste slopes are 1(v):3(h), as described in Sections 9.2 and 9.3 of the LOMP. Steeper waste slopes are not acceptable since it is considered that intermediate cover on a temporary capping layer cannot be safely and appropriately placed and compacted on a slope steeper than 1(v):3(h).

2.25 Please provide comment whether removal of the waste acceptance limit, allowing a greater rate of waste placement, is expected to reduce the working face to be compliant with the LOMP.

The reduced working face area from 3625 m^2 to 1000 m^2 will be achieved by:

a) Preparing and adhering to a concept filling plan is identified in Section 14 of the revised Landfill Operational Management Plan, attached as Appendix E. The current area 15 filling plan is being created in alignment with the existing resource consent, however, the 1000 m^2 working face is set to be implemented as soon as practicable. This will provide AB Lime with the ability to give effect to the proposed consents applied for in this application and make this transition as efficient as possible.

b) Improved use of daily cover, intermediate cover and temporary capping as per Table 4 of the LOMP.

2.26 Will the recommended maximum working face in the LOMP be subject to revision?

It is the view of the applicant that the recommended working face is provided for in the Landfill Operations Management Plan. Maintaining the size of the working face within the management plan allows the applicant to strike a balance between certainty for the decision maker, and the need for flexibility for the Applicant. Importantly, any variation to the size of the working face must be approved by the independent peer reviewer(s) and certified by Environment Southland as the regional authority. Any approval on the size of the working face will be tied to adverse effects. It is expected that the independent peer reviewer(s) must be satisfied that any adverse effects are appropriately managed before agreeing to a change in size of the working face. Compliance and monitoring of the proposed consent conditions will provide an accurate indicator of whether a change in the size of the working face is justified.

Flexibility in the size of the working face may be required to manage fluctuations in waste acceptance, particularly if the landfill is faced with large volumes of waste in a short period of time, such as emergency waste acceptance scenarios. Adaptation of the filling plan for any variation to the working face can also be considered under the Landfill Operations Management Plan.

2.27 Is 1,000m2 workable for the proposed rate of filling?

Please refer to the response provided in 2.25 above.

2.28 Please provide information on the recommended maximum expected period for temporary capping and the reasons why this is considered appropriate for the proposed cap.

It is not considered necessary to recommend a maximum period for temporary capping as long as the temporary capping meets the proposed resource consent requirement in terms of <0.5% methane surface emission and to fulfil its function to reduce rainfall infiltration and stop windblown litter and to provide an effective barrier against sharp waste objects.

2.29 Please provide information on the target permeability for the temporary cap and commentary on whether this will be achieved?

It is not considered necessary to recommend a target permeability for the temporary capping. There is a proposed consent condition (also found in the NESAQ regulations) that stipulates that *'The concentration of methane measured at the surface of the landfill areas with temporary or permanent capping shall not exceed 0.5% by volume'*. If the temporary capping meets the proposed resource consent requirement in terms of <0.5% methane surface emission it is considered that the adverse effects of temporary capping are effectively managed and the temporary capping will concurrently will effectively fulfil its function to reduce rainfall infiltration, which will reduce leachate generation.

The Applicant considers that providing a target permeability for the temporary capping is not a material item for consideration in regard to the assessment of effects on the environment related to an increase in the rate of waste filling at the landfill.

2.30 Please provide clarification as to what is the maximum recommended angle for the final landfill surface and confirmation that the relevant documents and drawings have been updated to reflect the recommendations.

The maximum recommended angle for the final landfill surface is 1(V):4(H) for post-landfill settlement scenario, and 1(V):3(H) for the pre-settlement scenario. The drawings have been updated to reflect this in the Landfill Operations Management Plan under Attachment 1

2.31 Please provide information on an alternative proposal should the trial sample not achieve the target maximum permeability.

A study by Ouyang and Daemen (1992)[1] combined bentonite and crushed tuff to form a plug. They concluded that the permeability of the bentonite/crushed tuff plug decreased when the bentonite content increased. It is expected the same would occur when using the bentonite and knap rock to join the GCL to the original capping layer. Should the trial sample not achieve the target permeability, the bentonite content will be increased until it does.

2.32 Please provide information on what is proposed should the field trials not achieve the expected performance targets.

The inclusion of the GCL in the capping design is an improvement on the existing resource consent capping design, which forms part of the existing environment. The proposed design will reduce infiltration, which has a direct correlation to reducing leachate generation. Furthermore, the design will decrease the ability of landfill gas to escape through the surface.

[1] Ouyang, S., and Daemen, J.J.K., '*Sealing performance of bentonite and bentonite/crushed rock borehole plugs' (1992).*. Department of Mining and Geological Engineering, University of Arizona.

The primary aim of the trial pad is to observe the construction process of the proposed concept capping design. The observations from the construction trial pad may result in modifications, which will be included in the detailed design. However, AB Lime has experience on site placing the GCL on top of knap rock.

Therefore, the Applicant considers that there is a minor risk that the proposed concept design will not be effective. However, effective design improvements are suggested in Section 10.4.4 of the updated Landfill Operations Management Plan.

2.33 Please provide information about the original consented capping design including the availability and quantification of suitable soil available on site to form the cap?

The consented final cap design is found in the existing resource consent (consent condition 10 of discharge permit AUTH-201346-V3) and consists of:

- 300 millimetres intermediate cover/regulating layer of compacted quarry overburden;
- 600 millimetres of compacted clay, overburden or soil material, with a permeability coefficient (k) of not more than 1 x 10^{-7} metres per second; and
- 150 millimetres of growing medium.

The 300 mm intermediate cover/regulating layer and the 600 mm of compacted clay, overburden or soil material can consist of knap rock. The knap rock is sourced from the quarry and is readily available with an average yearly excavation rate of 83,672 m^3 and growing medium is available (please refer to calculations in 2.6).

2.34 Please provide information including any calculations on the permeability of the GCL at strains less than the ultimate value to assess whether longitudinal shear stress and/or strain in the GCL affect permeability at values less than ultimate.

Overall, the settlement process across the landfill will cause the GCL to experience compression. This compression will partially mitigate any elongation of the GCL associated with localised differential settlement.

We believe that in a worst-case scenario where 100 m depth of waste settles 12.5% in one location and 10 m away it settles 6.25%, the GCL will elongate approximately 18%. This amount of elongation is expected to have minimal impact on the permeability of the GCL.

We have been in contact with Geofabrics regarding the permeability of the GCL when elongated. Peter Finlay, Business Development Manager, from Geofabrics has directed the information to their laboratory and we are awaiting their reply. We will provide a response to this query once the information has been made available.

2.35 Please provide information on the methodology of extending and joining the GCL liner from cell to cell.

The methodology for joining the GCL can be seen in Section 10.4.1.4 of the updated Landfill Operations Management Plan.

Landfill Gas

2.36 Please provide further information on what risks that lithium batteries contained in waste pose to the landfill, on-site and off-site receptors and what control measures the applicant believes are appropriate to mitigate those risks.

Lithium batteries as a dedicated waste stream load would be considered a hazardous waste. AB Lime does not accept hazardous waste. Lithium batteries contained within the municipal solid waste stream are considered an incidental waste stream as it is reasonable to assume that they are present in minor quantities only.

Lowering the risk of lithium batteries entering the landfill would be 'to control at source', i.e. provide better information and/or education to people wanting to dispose of lithium batteries. This is considered a role for local and/or regional council. For example, once lithium-ion batteries have reached the end of their life, people may be encouraged to tape down the terminals (the points with a '-' and '+' sign on them) and get them to a drop off point or e-waste recycler.

The risks that lithium batteries contained in waste pose to the landfill, on-site and off-site receptors are landfill fires.

The control measures that AB Lime proposes to mitigate those risks are to maintain an appropriate Emergency Response Plan.

2.37 Please provide all landfill gas monitoring reports and copies of all AB Lime Gas Flare monitoring reports, as well as identifying what actions have been undertaken to correct any issues identified in these reports.

AB Lime have previously provided all relevant monitoring reports due to date to Environment Southland, in line with existing resource consent requirements and as such are available from Environment Southland

Any corrective actions have been in line with requirements necessitated as part of the compliance assessment undertaken by Environment Southland at the time.

2.38 Please provide an indication of the frequency and accumulative time that the ABL Gas Flare operated at temperature below 750°C. What was the reason for the low flare temperature and what corrective action has been undertaken to prevent this from re-occurring?

We consider that the operation of a minimum temperature in the gas flare is a resource consent compliance matter. The principal gas flare has been temperature-compliant since November 2017 as shown in the AB Lime annual monitoring reports to Environment Southland.

Historic gas flare temperature compliance is not considered to have a material impact in assessing the current resource consent application.

2.39 Please provide an assessment of the potential for dioxin and furan formation as well as other hazardous substances during low temperature operations of the gas flare and what were to potential risks to off-site receptors.

The principal gas flare has been temperature-compliant since November 2017 (see response to item 2.38 above).

In terms of the current resource consent application, i.e. to assess the environmental effects related to an increase the rate of waste filling at the landfill, we believe that providing an assessment of the potential for dioxin and furan formation as well as other hazardous substances during low temperature operations of the gas flare and to assess what were the potential risks to off-site receptors, is not a material item for consideration by the peer reviewer of the current consent application.

2.40 Please confirm that the distance of nearest receptors outlined in AEE Table 5 (Location of nearest receptors) from the nearest boundary of the landfill once all the filling has been completed.

Table 5 in the AEE identifies that the approximate distance of sensitive receptors from *current* landfill operations. The location of the nearest sensitive receptor (20 m from the façade of the closest residential dwelling not owned by the Applicant) from the *nearest boundary of the landfill* is identified as 1.2 km in Figure 4 Distance from Edge of Landfill Footprint to Nearest Sensitive Receptor (20 m from the Facade of the Closest Residential Dwelling not Owned by the Applicant) as of August 2020. below.

Landfill operations will extend further east as the landfill develops. There are no sensitive receptors in this direction closer to that identified below in Figure 4. The nearest sensitive receptor from the nearest boundary of the landfill once all the filling has been complete is at a distance of 1.2 km (as of August 2020).

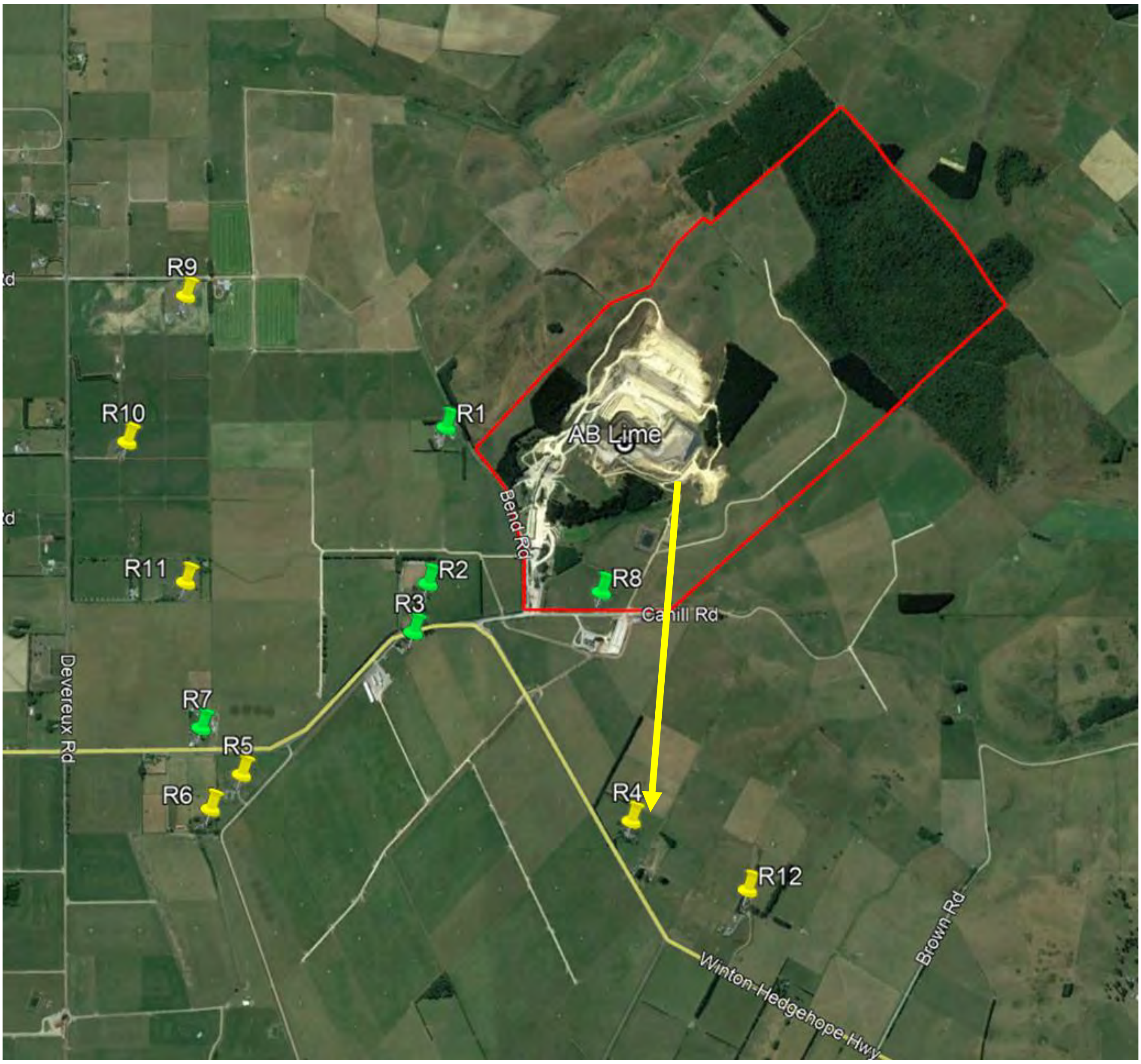


Figure 3 Nearest Sensitive Receptor not Owned by AB Lime as of August 2020 (note AB Lime now own R12)

Figure 4 Distance from Edge of Landfill Footprint to Nearest Sensitive Receptor (20 m from the Facade of the Closest Residential Dwelling not Owned by the Applicant) as of August 2020.

The nearest sensitive receptor (owned by the Applicant) is shown in Figure 5 below and is approximately 430 m from the edge of the landfill footprint:

Figure 5 Nearest Sensitive Receptor Owned by the Applicant

2.41 Please provide an assessment of the maximum probable distance that landfill gas could migrate from the landfill under worst case conditions.

We do not believe that it is possible to accurately provide an assessment of the maximum probable distance that landfill gas could migrate from the landfill under worst case conditions. However, we note the following mitigating circumstances at AB Lime:

a) The landfill has an engineered base and sidewall liner that prevents the lateral migration of landfill gas;

b) The landfill has an active landfill gas extraction system that limits the potential for lateral migration of landfill gas;

c) To monitor lateral landfill gas migration seven landfill gas perimeter monitoring probes were installed in July 2003. One of the 7 probes was located at the entrance of the current location of the stormwater pond (see Landfill Gas Management Plan) and the gas probe was destroyed during the construction of the pond. The remaining six probes have been monitored monthly for the past 17 years. In the past 10 years none of the six probes have exceeded the resource consent criteria of 1.25% methane, as shown in resource consent compliance monitoring reports sent by AB Lime to Environment Southland. Therefore, from the outset there is a low risk of landfill gas migration.

d) The soils outside the landfill have been described in the original AEE (2002) and have a permeability ranging from 1×10^{-6} m/s to 1×10^{-7} m/s and can be considered as relatively impermeable. Therefore, in the unlikely event of landfill gas migration through a hole/tear in the sidewall liner, the surrounding soil permeability is low enough for there to be a low risk of lateral gas migration.

e) Also as discussed in the original AEE Geological and Hydrogeological Report (attached as Appendix D) karstic features do not develop below the water table, further reducing the probability of this risk. Karstic features only occur in the limestone terrain adjacent to and above the landfill.

Overall, we believe the risk of landfill gas migration to an off-site receptor is very low.

2.42 Is it possible that landfill gas could migrate to any of the residential houses surrounding the landfill?

As identified in the answer to 2.41 we believe the risk of landfill gas migration to an off-site receptor is very low. Furthermore, as identified in the answer to 2.39, 20 m from the façade of the nearest sensitive receptor not owned by AB Lime is a considerable distance, at 1.2 km from the edge of the landfill footprint.

It is considered to be highly improbable that gas would migrate to these sensitive receptors and an assessment of the risk is unnecessary.

2.43 Does the geology surrounding the landfill (karst limestone) provide an opportunity for preferential pathway to exist and what investigations have been undertaken to identify any potential preferential gas pathway?

As discussed in the answer to question 2.42, karstic features do not develop below the water table therefore, these features are likely only occur in the limestone terrain adjacent and above the landfill. The closest off-site sensitive receptors (not owned by AB Lime) adjacent to and above the landfill are located greater than 1.2 km from the landfill (please see Figure 10 and Table 5 in Section 3 of the Resource Consent Application).

2.44 Please provide all landfill gas and surface walkover monitoring data for the existing landfill.

AB Lime have previously provided all relevant monitoring reports due to date to Environment Southland, in line with existing resource consent requirements.

2.45 Please provide further information for the landfill gas migration monitoring probes, including:

a) Depth of each monitoring probe.

b) Maximum and minimum depth of groundwater in each monitoring probe.

c) Screen interval of the probes.

d) Borehole logs for the probes.

e) Rationale for monitoring well spacing and whether the spacing meets or exceeds international best practice (i.e. Construction Industry Research and Information Association CIRIA C665).

Items a) to d) of the above query are covered in Attachment 1 of the Landfill Gas Management Plan.

In term of item e) we note that the existing landfill gas monitoring well spacing was approved under the existing resource consent.

If additional landfill gas migration monitoring probes are required, then this will be discussed and agreed with the Independent Peer Reviewer(s), including the locations for any additional wells, based on a risk assessment of off-site landfill gas migration. The risk assessment will include an evaluation of the applicability of the use of CIRIA C665 report.

2.46 Please provide further information on how the expected changes to landfill gas generation will impact on-site and off-site receptors?

We consider that the expected changes to landfill gas generation will have a positive impact, i.e. less impact, for on-site and off-site receptors since the LGTM and LOMP provided procedure that describe:

a) The current consent criteria of 5% methane surface emissions will be reduced to the proposed consent criteria of 0.5% methane, thus resulting in less landfill gas surface emissions and less impact for on-site and off-site receptors; and

b) Better quality landfill capping such as daily cover, intermediate cover and temporary capping will result in fewer fugitive landfill gas surface emissions, and better/higher landfill gas extraction, thereby have less impact for on-site and off-site receptors.

2.47 Please provide further information on how climate change may affect landfill gas generation rates given the LGTM (which discusses the predicted lifespan and capacity of the AB Lime Landfill) indicates that the landfill lifespan with the revised waste acceptance condition could run to 2065.

Qualitative: NIWA have conducted a Southland climate change impact assessment for the Southland region. It is considered that the projected changes in rainfall for 2040 and 2090 are relevant benchmarks for assessing the effects of climate change for leachate generation. By 2040, for most of the Southland region, annual rainfall is projected to increase by 0-5%[2]. At 2090, most of the region is projected to experience increases in annual rainfall of 5-10%[3]. The Applicant considers that a 5% increase in rainfall for the site is an accurate estimate of the effects of climate change for the site until 2065. This takes into account the mean of the projected increases and ties in with the expiry of the proposed consent term.

Quantitative: The rainfall intensity of the Winton area was examined and used to predict the intensity of rainfall with respect to climate change in the next 30 years. Using the climate change data produced by the Ministry for the Environment a calculation was carried out to assess the effects of a moderate increase in land-average temperature on the rainfall depth in the Winton area and corresponding leachate quantity produced. Rainfall was found to increase by 5.3% when assessing a scenario of a 2-year storm with a duration of 24 hours impacting by a temperature increase of 0.74 degrees Celsius as per emissions model RCP 4.5 between 2031 – 2050. Table 3 summarises and compares the results for rainfall volume collected at the current and proposed landfill working faces.

Table 3 Impact of Increased Rainfall on Leachate Production on the AB Lime Landfill

Landfill Working face	Area (m^2)	Current volume of rainfall (m^3 rainfall/2.33 ARI - 1 day duration)	2031-2050 volume of rainfall loading (m^3 rainfall/2.33 ARI - 1 day duration)
Current working face	3625	185	195
Proposed Working face	1000	51	54

Rainfall volume collected at the working face reduces by 344% when comparing the volume collected at the current working face and unmodified rainfall intensity and the proposed reduced working face in the modified rainfall scenario.

We consider that a 5% increase in rainfall will have no material impact on the estimated landfill gas generation rates since:

a) The modelled landfill gas generation is dependent on a several factors and rainfall is only one of those factors;

[2] *'Southland climate change impact assessment'* Prepared for Environment Southland, Invercargill City Council, Southland District Council and Gore Districted Council, (August 2018) at 59. Available at https://www.es.govt.nz/repository/libraries/id:26gi9ayo517q9stt81sd/hierarchy/environment/science/science-reports/science-reports-september-2018/Report%20-%20Southland%20climate%20change%20impact%20assessment%20-%20August%202018.pdf

[3] Ibid.

b) The k-value currently used (i.e. without considering climate change) in the modelled landfill gas generation is 0.1;

c) Assuming a 5% increase in rainfall could increase the k-value;

d) We have increased the k-value from 0.1 to 0.15 to allow for the 5% increase in rainfall;

e) We consider a k-value of 0.15 a conservative estimate since in New Zealand a k-value of 0.15 is typically used for relatively wet landfills, i.e. landfills with poor daily cover, intermediate cover, temporary capping and permanent capping;

f) We do not consider that the AB Lime landfill will have poor landfill capping as the landfill will need to comply with the proposed <0.5% methane surface emission criteria;

g) The table below shows how the increase in k-value from 0.1 to 0.15 has affected the landfill gas generation rate, assuming the same 75% collection efficiency as presented in the LGTM; and

h) The table shows that the increase in k-value results in a marginal increase in maximum landfill gas collected.

Table 4 Correlation between k-value and Maximum Landfill Gas Collected

Annual waste acceptance rate (tonnes/year)	k-value	Maximum landfill gas collected (m^3/hr)
100,000	0.1	606
	0.15	616
200,000	0.1	1202
	0.15	1229
300,000	0.1	1798

2.48 Please provide justification for parameters used in the landfill gas model, including:

a) LO - ultimate gas generation potential.

b) K- gas rate constant.

c) Total organic carbon.

<u>Lo-value</u>:

a) The Lo-value represents the potential methane generation capacity of the waste.

b) The Lo-value is dependent on the type and composition of the waste. The higher the cellulose content of the waste, the higher the Lo-value.

c) The composition of the waste for the period 2017-2018 is described in Attachment 7 and presented in the table below. We note that Attachment 7 identifies Organics as 29.2%. We have conservatively interpreted Organics as both kitchen (Food) waste and greenwaste (Garden), since Garden waste has a higher methane generation potential than Food, see column 4 of the table below.

Table 5 Based on SWAP Analysis 2017-2018 - See Attachment 7 of the Landfill Gas Technical Memorandum

First -order decay models parameters				LANDGEM USE	
Waste stream component	Default waste composition data (SWAP)	IPCC DOC	Equivalent methane generation potential Lo(m^3 CH_4/tonne)		CH4 potential (Lo) x Default waste composition
Food	0.0%	0.15	75		0.00
Garden	29.2%	0.20	100		29.20
Paper	11.0%	0.40	200		22.00
Wood	6.5%	0.43	215		13.98
Textile	5.9%	0.24	120		7.08
Nappies	6.7%	0.24	120		8.04
Sewage Sludge	3.0%	0.05	25		0.75
Other	37.7%	0.00	0		0.00
TOTAL	100.0%				81.05
			Values Used		*Lo*

d) DOC = the Degradable Organic Carbon value of each waste stream.

e) The DOC values in the Column 3 in the table above are obtained from Schedule 3 of the Climate Change (Unique Emissions Factors) Regulations 2009.

f) The AB Lime methane generation potential for each waste component in Column 5, is calculated by Column 2 x Column 4.

g) The AB Lime total Lo-value of 81.05 m3/tonne, is calculated by adding the individual waste stream L0-values in Column 5.

h) In the LGTM the L0-value of 81.05 m3/tonne has been rounded-up to 100 m3/tonne.

i) A higher Lo-value generates more landfill gas, therefore, selecting a higher Lo-value in the landfill gas modelling will over-estimate the landfill gas generated.

j) In terms of the impact the Lo-value has on the landfill gas modelling presented in the LGTM: The updated landfill gas modelling was carried out to provide a forecast of the likely landfill gas volumes generated per year for the three waste acceptance rates (100,000 tons/yr, 200,000 tons/yr and 300,000 tons/yr).

k) For the three waste acceptance rates the modelling produces an estimate of the collected volume of gas per hour (gas flow rate in m3/hr, at the principal flare).

l) The principle flare has been designed for a maximum gas flow rate of 1000 m3/hr.

m) The modelling then provides an early indication if and when the principal flare's capacity has been reached for each of the three waste acceptance rates:

   i. 100,000 tons/yr: the maximum gas flow rate is 606 m3/hr in 2055, thus the flare capacity of 1000 m3/hour will not be reached.

   ii. 200,000 tons/yr: A gas flow rate of 977 m3/hr in 2034.

   iii. 300,000 ton/yr: A gas flow rate of 995 m3/hr in 2027.

n) Therefore the modelling provides AB Lime with the opportunity to plan in advance for appropriately dealing with the collection and burning of the landfill gas, either via the installation of a second principal flare or using the landfill gas as a supplementary fuel source to coal, which is used to fire the limestone dryers (see Section 4.3.3 of the LGTM).

<u>k-value:</u>

a) The k-value is the methane generation rate and is largely dependent on the moisture content of the waste.

b) The higher the k-value, the faster the methane increases and then decays over time.

c) We have selected a k-value of 0.1 in the revised methane generation model in the LGTM. It is possible that a lower k-value would be applicable due to the proposed improved landfill capping of the landfill, i.e. better use of daily cover, intermediate cover and temporary capping.

d) We note that a change in k-value (e.g. lowering the k-value due to better use of capping) is unlikely the change the landfill gas generation model a lot, relative to a change of Lo-value.

Total Organic Carbon (TOC):

a) The TOC has been estimated in Attachment 7 of the LGTM.

b) Under the Lo-value response above, it has been discussed how the Degradable Organic Carbon is relevant to the methane generation potential/landfill gas modelling.

c) We note that changing the TOC in our landfill gas modelling is unlikely to affect the purpose of the landfill gas model, which is to comparatively show that an increase in waste acceptance rate increases the landfill gas generated, and that the existing landfill gas flare can cope with the actual and predicted landfill gas generated.

2.49 Please confirm if the backup flare has been installed in June 2020 as indicated by the report.

AB Lime has several candle-stick flares at a site nearby the AB Lime landfill. AB Lime is currently assessing the condition and suitability of using one of these candle-stick flares as the back-up flare.

2.50 Please provide an assessment on predicted landfill gas versus measured extracted gas at the flare time series from installation of the gas extraction system until present day.

An assessment of the future landfill gas flow rate at the flare has been presented in the LGTM. Better quality landfill capping such as Daily Cover, Intermediate Cover and Temporary Capping will result in fewer fugitive landfill gas surface emissions, and better/higher landfill gas extraction, thereby have less impact for on-site and off-site receptors.

In terms of the current resource consent application, i.e. to assess the environmental effects related to an increase the rate of waste filling at the landfill, we believe that providing an assessment on predicted landfill gas versus measured extracted gas at the flare time series from installation of the gas extraction system until present day is not a material item for consideration by the peer reviewer of the current consent application

2.51 Please provide information on what testing has been undertaken to identify the radius of influence for the gas wells and extraction efficiency of landfill gas extraction system.

Testing to identify the radius of influence for gas extraction wells is not common practice in New Zealand, it is relatively expensive to undertake and the outcome of the testing can be of limited value due to the heterogenous nature of the landfilled waste.

The AB Lime Landfill has adopted good industry practice by selecting an initial average well spacing of 50 m, as described in Table 2, Attachment 3 of the LGTM.

AB Lime has installed additional wells between the original 50 m well spacing to improve the landfill gas extraction efficiency, see also Attachment 3 of the LGTM.

Providing information on what testing has been undertaken to identify the radius of influence for the gas wells and extraction efficiency of landfill gas extraction system is not considered an issue relevant to this current consent application since:

a) Testing to identify the radius of influence for gas extraction wells is not common practice in New Zealand, relatively expensive to undertake and the outcome of the testing can be of limited value due to the heterogenous nature of the landfilled waste.

b) AB Lime landfill has adopted good industry practice by selecting an initial average well spacing of 50 m, as described in Table 2, Attachment 3 of the LGTM.

c) AB Lime has installed additional wells between the original 50 m well spacing to improve the landfill gas extraction efficiency, see also Attachment 3 of the LGTM.

2.52 Please provide further information on what investigations have been undertaken to identify the reasons for low landfill gas flow rate at the principal flare.

The likely reasons for the low landfill gas flow rates have been described in Section 4.1 of the LGTM.

We infer that the 'investigations' referenced in the s 92 query are in essence the implementation of the procedures proposed in the Landfill Gas Management Plan and Leachate Management Plan. For example, appropriate capping of the over steep faces, reducing the size of the working face, better quality landfill capping such as daily cover, intermediate cover and temporary capping.

2.53 Please provide an explanation of why the ratio of carbon dioxide is elevated within the extracted landfill gas, and whether there is a possibility this could pose a risk to off-site receptors.

We believe that there is no enrichment in CO2 in the landfill gas since the landfill gas CO2 concentration can range from to 16 % to 57%[4].

We consider that the risk of elevated CO2 adversely affecting nearby residential properties is very low since:

a) The majority of the CO2 within the landfill is collected and burned at the principal flare;

b) Therefore any CO2 migration off-site will be from an area source/diffuse source;

c) The closest AB Lime owned residential property is located 430 m away from the landfill footprint (and the nearest non-AB Lime owned residential property is located 1.2 km from the landfill footprint);

d) There is no ambient air quality guidelines under the NZAQG for CO2;

e) The NZ Workplace Exposure Standard, Time Weighted Average for CO2 is 9000 mg/m3, or around 5000 ppm, or 0.5%; and

f) The 430 m buffer distance between the landfill footprint and nearest residential property will adequately disperse any CO2 before it reaches a residential property at such a concentration where it could become a human health issue.

[4] Environment Agency, *"Guidance on the Management of Landfill Gas"*, (2004). Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/321606/LFTGN03.pdf

Landfill Gas System Design and Construction

2.54 Please provide further information regarding durability of design/material selection with regards to the landfill gas extraction system.

An assessment of the durability of design/material selection with regards to the landfill gas extraction system has been a matter of consideration for the landfill's current Independent Peer Reviewer. The landfill gas extraction system durability of design/material selection is currently consented and forms part of the existing environment.

The design/material selection is not changing with this application and is not considered a material matter for the assessment of effects on the environment related to this application.

2.55 Please provide information on the construction quality assurance programme associated with the landfill gas extraction system.

An assessment of the construction quality assurance programme associated with the landfill gas extraction system has been a matter of consideration for the landfill's current Independent Peer Reviewer. The construction of the landfill gas extraction system is currently consented and forms part of the existing environment.

The landfill gas extraction construction has already been completed and consented and is not changing with this application. Therefore, it is not considered a material matter for the assessment of effects on the environment related to this application.

2.56 Please provide information on how the design of the landfill gas collection system allows for differential settlement with respects to condensate management.

a) The pipework is located with a gradient/slope/fall so that condensate flows under gravity to a low point, where the condensate is collected.

b) AB Lime staff undertake weekly site walk-over inspections to observe if the above-ground landfill gas collection pipework has settled, is damaged or in any way adversely affects the condensate flow in the pipework.

2.57 Please provide details on how the design of the landfill gas extraction system will ensure proper sealing around the wellhead given the LGTM indicates that poor sealing around wellhead gas extraction may be occurring.

The design of the landfill gas extraction system around the wellhead is described in Section 10.4.2.2 of the Landfill Operations Management Plan.

2.58 Please provide detail calculations of pipe sizing (taking into account pressure drop) to verify proposed design and sizing of plant.

An assessment of calculations of pipe sizing (taking into account pressure drop) to verify proposed design and sizing of plant has been a matter of consideration for the landfill's current Independent Peer Reviewer. The pipe sizing is currently consented and forms part of the existing environment.

The landfill gas extraction construction has already been completed and consented and is not changing with this application. Therefore, it is not considered a material matter for the assessment of effects on the environment related to this application.

Landfill Leachate

2.59 Please provide qualitative and quantitative information of how climate change has been considered with respect to landfill leachate management (generation/production, treatment, and disposal).

Qualitative: NIWA have conducted a Southland climate change impact assessment for the Southland region. It is considered that the projected changes in rainfall for 2040 and 2090 are relevant benchmarks for assessing the effects of climate change for leachate generation. By 2040, for most of the Southland region, annual rainfall is projected to increase by 0-5%[5]. At 2090, most of the region is projected to experience increases in annual rainfall of 5-10%[6]. The Applicant considers that a 5% increase in rainfall for the site is an accurate estimate of the effects of climate change for the site until 2065. This takes into account the mean of the projected increases and ties in with the expiry of the proposed consent term.

Quantitative: The rainfall intensity of the Winton area was examined and used to predict the intensity of rainfall with respect to climate change in the next 30 years. Using the climate change data produced by the Ministry of Environment a calculation was carried out to assess the effects of a moderate increase in land-average temperature on the rainfall depth in the Winton area and corresponding leachate quantity produced. Rainfall was found to increase by 5.3% when assessing a scenario of a 2-year storm with a duration of 24 hours impacting by a temperature increase of 0.74 degrees Celsius as per emissions model RCP 4.5 between 2031 – 2050. Table 6summarises and compares the results for rainfall volume collected at the current and proposed landfill working faces.

Table 6 Impact of Increased Rainfall on Leachate Production on the AB Lime Landfill

Landfill Working face	Area (m^2)	Current volume of rainfall (m^3 rainfall/2.33 ARI - 1 day duration)	2031-2050 volume of rainfall loading (m^3 rainfall/2.33 ARI - 1 day duration)
Current working face	3625	185	195
Proposed Working face	1000	51	54

By difference, rainfall volume collected at the working face reduces by 344% when comparing the volume collected at the current working face and unmodified rainfall intensity and the proposed reduced working face in the modified rainfall scenario.

2.60 Please provide comment on how the current practice complies with existing consent conditions for monitoring, reporting, and measuring leachate levels.

Conditions for monitoring and reporting leachate levels are stated in conditions 24 – 38 of Discharge Permit AUTH-201346-V3 held with Environment Southland. The compliance monitoring reporting produced by Environment Southland addresses the performance of AB Lime and other industry partners in the region in regard to the conditions of the various discharge consent. Compliance monitoring reporting for previous years has noted no issues or non-compliances in relation to the monitoring, reporting and measurement of leachate levels between the 2016 – 2019 period. AB Lime have previously provided all relevant monitoring reports to

[5] *'Southland climate change impact assessment'* Prepared for Environment Southland, Invercargill City Council, Southland District Council and Gore Districted Council, (August 2018) at 59. Available at https://www.es.govt.nz/repository/libraries/id:26gi9ayo517q9stt81sd/hierarchy/environment/science/science-reports/science-reports-september-2018/Report%20-%20Southland%20climate%20change%20impact%20assessment%20-%20August%202018.pdf

[6] Ibid.

Environment Southland, in line with existing resource consent requirements. It is not the responsibility of the Applicant to provide these to the peer reviewer.

2.61 Please confirm the unit of measure for leachate quantities.

The unit of measure for leachate is tonnes/day. For simplicity, we have assumed landfill leachate has a density of 1000 kg/m^3 which is in the range commonly reported in literature.[7]

2.62 Please provide qualitative and quantitative information to explain the quantity of leachate in 2018.

Qualitative: According to the rainfall summary obtained from Environment Southland rainfall data at Winton shows rainfall for Winton being exceptionally high in 2018 compared to previous years. A graph of Winton rainfall data is provided in Figure 6 below. Higher levels of rainfall would contribute significantly to the levels of leachate produced.

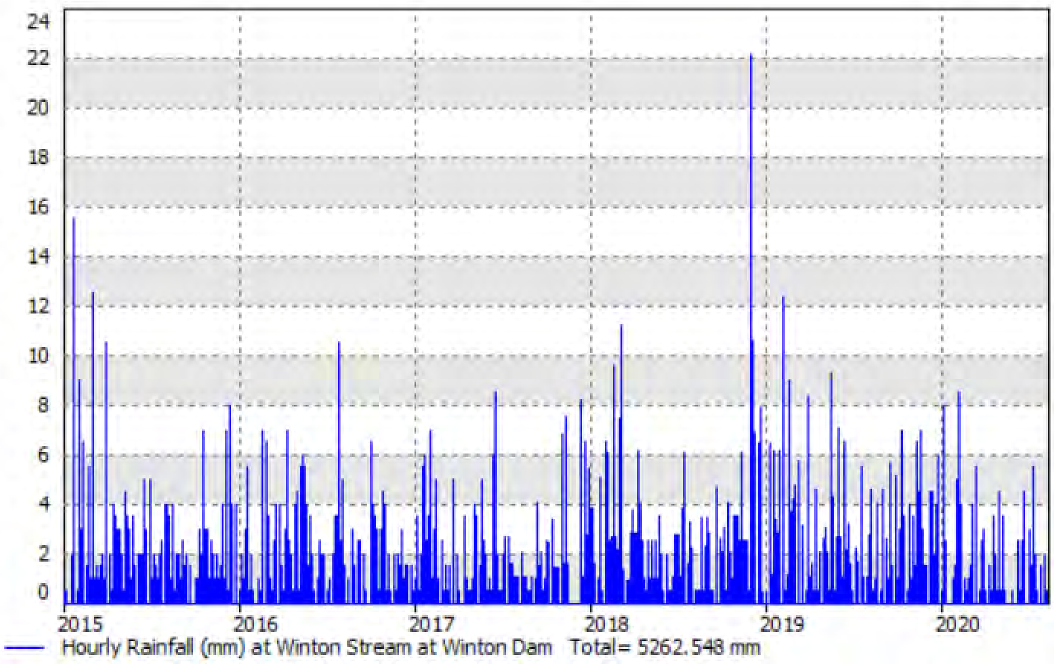


Figure 6 Rainfall in Winton from 2015-2020

Landfill acceptance volumes as seen in Figure 7 have displayed an upward trend with 2018 having a significantly higher quantity of waste being accepted in comparison to preceding years in particular 2016 and 2017.

Another contributor to the observed increase in landfill leachate in 2018 is the disposal of bovine carcasses in relation to the M.Bovis outbreak in 2018. Disposal of offal and carcasses is managed separately from other wastes received. The additional open face of the bovine disposal area created a larger area for water ingress, leading to a higher volume of leachate for that period.

Our assessment concluded that a combination of unusually high rainfall combined with the management of carcases as a result of the M/Bovis event resulted in higher leachate quantities being produced in 2018.

[7] Souze et al (2014). "*Analyze of the Density and Viscosity of Landfill Leachate in Different Temperatures*", American Journal of Environmental Engineering, 4(4):71-74, 2014

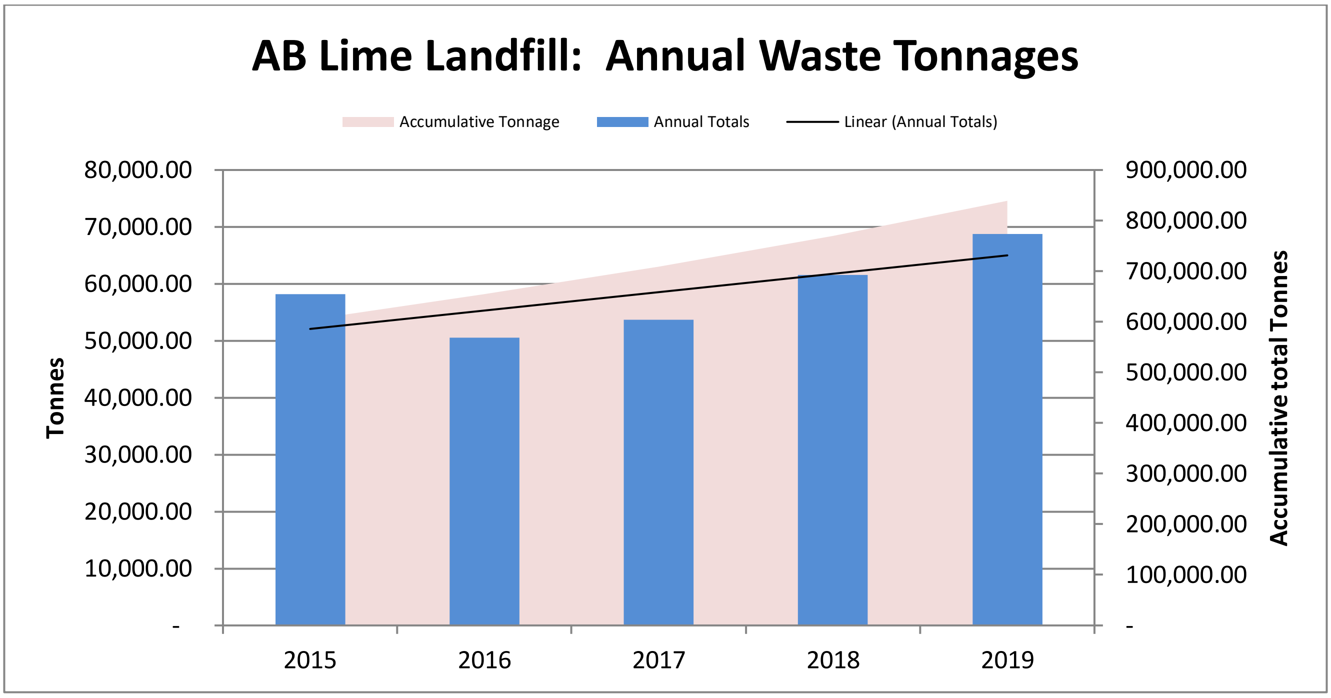


Figure 7 AB Lime Landfill Annual Waste Tonnages

<u>Quantitative</u>: Rainfall data was provided by Environment Southland for the Winton area. A table of the average rainfall per month can be seen in the Table 7 below. The average rainfall for a number of months reach a peak in 2018, with the maximum reported amount being 5.5 mm/hr. With a larger surface area being exposed at the landfill face during these periods, quantities of rainfall would contribute significantly to the quantities of leachate produced. The peak rainfall being produced in 2018 would therefore coincide with peak quantities of leachate being produced at the landfill in 2018.

Table 7 Average Rainfall per Month for Winton 2015-2020

	2015	2016	2017	2018	2019	2020
January	1.1	2.3	4.3	1.3	2.8	1.7
February	3.8	3.5	1.4	5.5	3.3	5.3
March	2.7	1.5	1.5	2.1	2.2	2.5
April	3.0	2.2	1.2	3.9	2.9	2.1
May	2.6	3.5	2.9	2.5	3.6	0.6
June	4.2	0.8	2.2	1.8	2.4	2.7
July	1.6	4.3	2.4	2.2	2.2	3.3
August	3.0	1.3	0.7	0.9	2.6	0.3
September	1.9	1.6	2.1	3.1	1.7	
October	3.3	2.8	0.9	3.1	3.4	

November	2.3	2.2	1.8	5.0	3.1	
December	2.5	1.2	3.2	4.2	3.2	

2.63 Please provide further information on the further investigations including any other potential contributing factors.

There is nothing more to add on this issue. All of the significant contributing factors relating to leachate production have been previously presented in the application.

2.64 Please provide information from any site records, monitoring reports and/or annual report for site stormwater management during 2017/2018 including breaches (if any) or malfunction of the stormwater system (e.g. diversion bund overtopping/breached).

AB Lime have previously provided all relevant monitoring reports due to date to Environment Southland, in line with existing resource consent requirements.

2.65 Please provide the full annual result of leachate production for 2019.

As can be seen in Figure 8 the leachate production in 2019 was 24,058 tonnes.

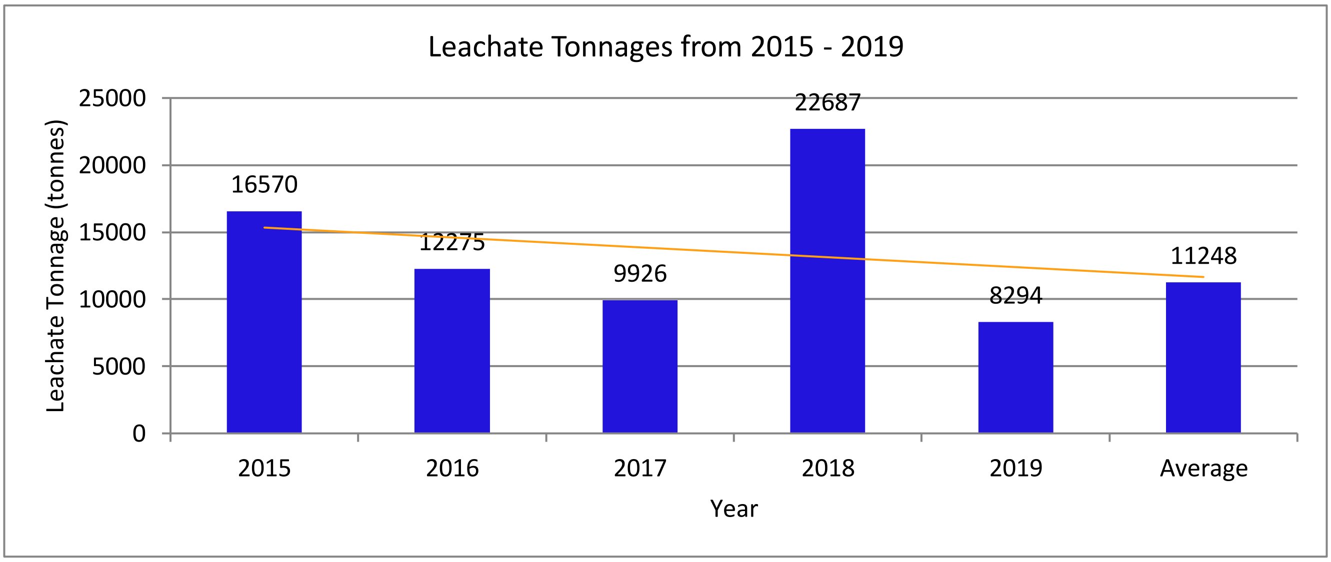


Figure 8 2015-2019 Leachate Tonnages

2.66 Please provide further evidence to support the conclusion that leachate production volumes at the landfill are decreasing.

With the new data identified in 2.65 the Applicant can no longer support the conclusion that leachate production volumes at the landfill are decreasing. However, the Applicant is minimising the working face as part of this application, which will impact future leachate generation. Landfill leachate production volumes are directly correlated to the open face surface area, and to a lesser extent to temporary cap. The larger the open surface, the greater the area across which rainfall can enter the landfill. The modified operation of the landfill will reduce the open face from currently 3625 m^2 to a maximum of 1000 m^2. Irrespective of previous leachate generation levels, the leachate generation after giving effect to this resource consent is expected to reduce accordingly.

2.67 Please provide a drawing/plan of the landfill base grades for the entire landfill footprint including proposed leachate collection pipe network. Also, please quantify the base area and sidewall area of the entire landfill.

The landfill base grades for the entire landfill footprint including the leachate collection network was consented as part of the original resource consent application and forms part of the existing environment. Please refer to drawings A02098.4-C-001 to -008 in Appendix F of the consent application for the original leachate drawings. It is not considered that this request for information is relevant for this application.

Site Stormwater

2.68 Please provide qualitative and quantitative information on consideration of the effects of climate change on site stormwater management (system design, treatment, and disposal).

The current stormwater system on site is authorised by the existing discharge permit 201347, which expires in 2038. No application has been made to change or replace this existing consent, as the change in incoming waste volumes are not considered likely to give rise to any change in stormwater management over that authorised by the existing consent. The system design, treatment approach and disposal methods are therefore consented through to 2038. Within the 18 years remaining of this consent it is not considered that changes in rainfall generation and intensity due to climate change are likely to materially modify site stormwater management practises.

2.69 Please provide information including calculations to confirm what Annual Exceedance Probability (AEP) event the existing pond has been designed to accommodate?

The original AEE in 2002 reported design calculations for the sizing of the stormwater pond. The pond was designed for a 2% AEP event with a spillway designed for a 1% AEP event. The following text is extracted from Section 3.2.8 Stormwater Design of the 2002 AEE:

Storm and Process Water Pond Design

Pond volume requirements are set based on the need to provide a volume for sediment build-up, process water use throughout a normal year, storage of the 1:50 year rainfall event and storage to allow the overflow of the 1:100 year rainfall event.

Other water that will enter the pond will come from the groundwater drainage system beneath the landfill, wheel wash and used process water. The rates of flow from these sources are insignificant in respect to peak flood flows and the design of stormwater attenuation.

The bottom 0.5m depth of the pond is available for sediment build-up. This equates to a volume of approximately 830 m^3.

The pond will be sized to store sufficient water for use in limestone processing. During normal daily operation the level in the pond will be refilled by rainfall and will lower during process water abstraction. A pumping station will be constructed adjacent to the pond to pump water to the plant. During normal processing, 216 m^3/day of water will be abstracted from the pond, and 132 m^3/day will be returned as used process water. The proposed net water usage from the pond is 84 m^3/day. The volume of water required to ensure that there is sufficient process water throughout a normal year is 3,000 m^3. In the past 35 years, there have been 3 occasions when this would have been insufficient.

Above the process water volume, there is a requirement to store the 1:50 year rainfall event. The volume of flow in a 30 minute 1:50 year rainfall event is estimated at 7,300 m^3.

An emergency spillway with invert set at the level of the 1:50 year pond water level is designed to carry flows in excess of the 1:50 year rainfall volumes. An additional 600 m^3 pond volume is required to provide a minimum of 300 mm freeboard during the emergency spilling of flows during a 1:100 year rainfall event.

The total volume of the pond used for treatment is approximately 11,130 m^3 (excluding flows over the emergency spillway). The total depth is 4.4 metres, made up of 0.5m sediment depth, 1.4m depth for process water, 1.95m for attenuating the 1:50 year event, 0.25m to overflow the emergency flows, and 0.3m freeboard.

The proposed stormwater pond volume of 11,300 m^3 compares with a volume of 9,900 m^3 required by Auckland Regional Council's TP90 for erosion and sediment control (during earthworks) and approximately 10,000 m^3 required by Auckland Regional Council's TP10 design manual for stormwater treatment devices designed to provide 75% sediment removal.

TP10 and TP90 are for Auckland weather that has approximately 30% more rainfall than Winton. Since many of the rainfall events will be stored below the pond outlet (due to level drop during process water take) the pond efficiency is likely to be significantly higher again. In addition we are proposing the use of a vegetated infiltration swale. Overall, it is likely that the proposed stormwater system will remove in excess of 90% of sediments entering the pond.

A dividing bund will be constructed partway along the pond to a height of 1 m above the floor to form a sediment forebay.

Wetland planting of the pond is not specifically proposed as the significantly varying water levels within the pond relating to process water take will not promote good plant growth. The pond levels and specific design will be confirmed at detailed design stage based on a more detailed site survey, geotechnical and groundwater survey.

An interceptor for wheelwash water is proposed to provide preliminary sedimentation and retention of oils and floatable materials prior to that water entering the stormwater pond:

A preliminary sediment pond is proposed for the process water return. The pond discharge will be via a weir and gravity pipe to the main stormwater pond.

Given no changes are proposed to the stormwater consent, no recalculation of pond sizing or design has been undertaken.

2.70 Please provide information including rationale or reasons for departure from the recommended criteria?

The current stormwater design was developed during the original engineering design and reported in the AEE submitted for the original landfill establishment and operation consents in 2002. The existing consent was then granted which authorised this design. This design was considered appropriate at the time of consenting. It allows for a stormwater pond that retains a 1:50 year event with an overflow that provides for a 1:100 year event.

Given that the existing system was designed and authorised prior to the 2018 guidelines existing and that the existing stormwater discharge consent is being retained and is not being modified through this application it is not considered that these guidelines are relevant for an established consented feature that will continue to operate as designed. In the future, when the stormwater consent is close to expiry, and is replaced, consideration will be made of the relevant guidelines at that time and whether the performance of the existing system requires modification to meet the guidelines existing at that time.

2.71 Please provide information including calculations which supports this statement and demonstrates the stormwater system has been specifically designed to accommodate these additional loads and is consistent with the relevant New Zealand recognised technical guideline (e.g. Auckland Council GD05 or equivalent)?

The stormwater system that exists on site was originally designed in accordance with the Auckland Regional Council TP10 guidelines and sized to provide for treatment of 75% of incoming TSS load. Given that the existing consent is not being modified and will continue to authorise the existing system and discharge until 2038, no consideration has been made of more relevant design guidelines, and neither is it required.

As noted in table 2 of section 4 of the Stormwater Management Technical Memo the change in operations may lead to changes in loads of existing contaminants compared to that at present. These relate to the flow off the capped areas, the flow from the quarry and that off roads. The system however was sized for all phases of the landfill site operation not just the operations that have occurred to date. Hence irrespective of the changes currently proposed to waste volumes, the loads from each area have varied and would continue to vary and change over time depending on the areas of capping, rates of quarry extraction and volume of vehicle traffic. Therefore, the stormwater system will already have variable loads over time generated by the same site material with large amounts of rock/quarry dust in it. The proposed changes to site operations will change loads slightly with some extra traffic tracking dirt on roads, and a potential for more quarry dust compared to the present day, the changes are not of a scale to mean that the existing pond systems are no longer functional.

As noted in the Stormwater Management Technical Memo the existing stormwater resource consent is being complied with in terms of discharge quality and the system that is currently authorised is treating the incoming contaminants to the level required by the consent, in accordance with the TP10 designs.

It was observed on site in 2020 that the forebay of the pond had a large build-up of deposited sediment within it. Therefore, it is trapping incoming suspended sediment material. It is considered that if flows of suspended sediments do increase from any of the identified sources (for example from extra traffic on the roads) compared to those that occur now then in order to maintain that performance the ponds forebays will need to be cleared more frequently to allow for ongoing capture of this material. The incoming loads may be higher than at present, but the material should be similar. This requirement for more frequent inspection and maintenance of the system, especially the forebay has therefore been proposed as a new action in the updated Site Stormwater Management Plan.

Given that the system was designed and sized to provide a specific level of treatment and that the overall catchment area is not changing, nor is a new consent being sought, it is therefore not considered that recalculating the design of the pond is required. Instead, it is an operational matter to manage the performance of the pond which may require more frequent inspection and maintenance to achieve the current level of treatment performance and compliance with relevant consent conditions.

2.72 Please provide information including identification of likely scenarios and quantification of stockpiling within the site under these scenarios, any likely constraints, and systems to manage the stormwater effects of this as a review of recent aerial images shows no obvious existing stockpile areas.

It is not considered that stockpiling of limestone will be required on site for the remaining duration of the stormwater or quarry consents, both of which expire in 2038. This is based on the calculations undertaken in the AEE appendix entitled “Predicted Lifespan and Capacity of the AB Lime Landfill, IZ000400-LFC-NG-RPT-0004/1”. Table 3 of Section 4 of the report calculates the number of years required for excavation of various stages of the quarry (stage 1,2 and 3) at the present-day limestone extraction rates. This then creates the volumes available for waste placement noted in Table 4. The amount of volume available for waste placement is greater than the amount of limestone extracted due to the ability to layer the landfill cells onto adjoining downslope ones as shown in the drawings attached to that report. These tables demonstrate that the extraction of lime from stage 1, which is expected to be complete by 2028 will create available room for waste placement in stage 1A till 2065. Tables 5 and 6 indicate that for higher waste acceptance rates for incoming waste volumes, quarried stages are completed ahead of the land filling, until 2037.. Therefore the excavation of limestone is not considered to be a constraint on the acceptance of waste, even in this unlikely projection.

It is not considered likely that stockpiles will be required during the remaining duration of the stormwater consent. Therefore, systems to manage stormwater from stockpiles are not required at this time.

Groundwater Quality

2.73 As relevant environmental quality criteria show some impact from landfill leachate on groundwater down-gradient, please confirm whether the statement in Section 8.7 of AEE stating no adverse effects is correct.

In section 8.7 of the AEE there is a statement '*at present the generation and disposal of leachate at the landfill goes not give rise to any adverse effects*.' The Groundwater Quality Technical Memo indicates that the effects on groundwater for this proposal are considered to be less than minor. At well SKM 108 there are leachate indicators present, but at levels at or below TL 1. Interestingly, when compared to the pre-landfill data, concentrations are very similar, suggesting these contaminants were already present in groundwater prior to the landfill being operational.

We agree that the statement in Section 8.7 should align with the statement in Section 8.6 and the effects of the generation and disposal of leachate at the landfill gives rise to effects that are less than minor.

Monitoring

2.74 Please provide the following consent compliance documents for leachate quality and water quality monitoring to date:

- **All six-monthly water quality monitoring reports (excepting July 2016, January 2017, and July 2017, which have already been made available by ES).**
- **All six-monthly leachate dissolved oxygen, quality, and recirculation reports (excepting June 2014 and December 2014 which have already been made available by ES).**
- **All independent peer review reports and minutes.**

AB Lime have previously provided all relevant monitoring reports due to date to Environment Southland, in line with existing resource consent requirements.

Furthermore, the independent peer reviewer is engaged by Environment Southland. It is expected that the regional authority provide any independent peer review reports and minutes to the peer reviewer for this application.

Landfill Rehabilitation and Aftercare

2.75 Please provide information on how the effect of climate change has been considered in the rehabilitation and aftercare of the landfill.

Qualitative: NIWA have conducted a Southland Climate Change Impact Assessment for the Southland region. It is considered that the projected changes in rainfall for 2040 and 2090 are relevant benchmarks for assessing the effects of climate change for leachate generation. By 2040, for most of the Southland region, annual rainfall is projected to increase by 0-5%[8]. At 2090, most of the region is projected to experience increases in annual rainfall of 5-10%[9]. The Applicant considers that a 5% increase in rainfall for the site is an accurate estimate of the effects of climate change for the site until 2065. This takes into account the mean of the projected increases and ties in with the expiry of the proposed consent term.

Quantitative: The rainfall intensity of the Winton area was examined and used to predict the intensity of rainfall with respect to climate change in the next 30 years. Using the climate change data produced by the Ministry of Environment a calculation was carried out to assess the effects of a moderate increase in land-average temperature on the rainfall depth in the Winton area and corresponding leachate quantity produced. Rainfall was found to increase by 5.3% when assessing a scenario of a 2-year storm with a duration of 24 hours impacting by a temperature increase of 0.74 degrees Celsius as per emissions model RCP 4.5 between 2031 – 2050.

Climate change could impact on rehabilitation and aftercare by creating a higher level of rainfall than anticipated. However, the levels of water infiltrating through the cap should be nominal so rainfall is unlikely to materially affect leachate generation.

Climate change could also increase rainfall intensity. Therefore it identifies the need to establish cap and drainage to cope with this, as well as providing the correct sizing of channels and any stormwater treatment system.

The following answers are considered to appropriately answer these climate change considerations:

- Landfill gas management during the rehabilitation and aftercare of the landfill is covered under item 2.47;
- Stormwater management during the rehabilitation and aftercare of the landfill is considered to be covered under item 2.68; and
- Leachate management during the rehabilitation and aftercare of the landfill is considered to be covered under item 2.59.

2.76 Please provide information on whether the implied surcharge loading of these mounds could induce differential settlement in the underlying landfill and possibly cause distress to the cap in the vicinity of the margins of the mound.

Mounds will only be required for stormwater control/cap erosion control, such as the landfill cap contour drains, these mounds are anticipated to be up to 1 m high and no deep rooting vegetation will be planted.

[8] *'Southland climate change impact assessment'* Prepared for Environment Southland, Invercargill City Council, Southland District Council and Gore Districted Council, (August 2018) at 59. Available at https://www.es.govt.nz/repository/libraries/id:26gi9ayo517q9stt81sd/hierarchy/environment/science/science-reports/science-reports-september-2018/Report%20-%20Southland%20climate%20change%20impact%20assessment%20-%20August%202018.pdf

[9] Ibid.

We believe the additional surcharge load is likely to cause negligible additional differential settlement to the already very difficult to calculate total and differential settlement that the thick waste underlying the 1m thick cap + 1 m thick bund will cause.

The Landfill Concept, Landscape, Rehabilitation and Aftercare Plan will have sufficient procedures to address differential settlement that may be induced in the vicinity of the margins of the mound.

2.77 Please provide information on whether monitoring of the cap surface and its condition is part of the aftercare plan and confirm if any triggers are assigned or to be assigned and what these triggers are.

Existing condition 12 of Schedule 1 to resource consent numbers 201346 to 201351 requires the consent holder:

a) *To submit a concept rehabilitation and aftercare plan to the Southland Regional Council, for acceptance in writing, within six months of the commencement of these consents*; and

b) *A revised plan a least twenty four months prior to planned landfill operations ceasing on this site*.

The revised aftercare and rehabilitation plan will provide information on monitoring of the cap surface and its condition and will address any triggers relevant to the monitoring of the cap surface.

Environmental Management / Others

2.78 Please provide comment whether the Draft EMP would benefit from stating a purpose of the EMP is to operate the landfill consistent with industry accepted best practice guidelines.

The draft Environmental Management Plan has been updated to incorporate best practice guidelines and is submitted as part of this Section 92 response as Appendix C. The changes are made under Section 1.1 of the draft Environmental Management Plan and are highlighted for ease of reference for the peer reviewer.

2.79 Please provide information including rational on whether there is a maximum angle upon which the liner can be safely placed.

The liner has been placed safely at a 1(V):2(H) on the side slopes since the landfill was consented. The liner on the side slope will continue to be placed on a 1(V):2(H) slope and it is not intended for the liner to be placed on a greater slope.

2.80 Please provide confirmation including revised drawings to clarify which of the liner options is proposed for the side slope.

The side slope liner option is the one shown in IZ000400-1000-NG-DRG-1017. It consists of:

- a geosynthetic clay liner, with a minimum thickness of 5 millimetres, a permeability coefficient (k) of not less than 5 x 10-11 metres per second and sufficient internal shear strength to maintain a stable configuration on slopes;
- a 2.0 mm HDPE flexible membrane liner;
- a geotextile
- a 300 mm minimum liner protection layer of soil or clay or granular material.

Drawings have been updated under Attachment 1 of the Landfill Operations Management Plan.

2.81 Please provide information on the expected normal force and the effect this may have on the proposed GCL and whether permeabilities in this range can be achieved in such a situation.

We agree the expected normal force will be approximate 8 kPa.

Mr Gates (SmecTech) has calculated that with 1 m of overburden, with complete Calcium for Sodium exchange in the GCL and groundwater of similar chemistry to site a hydraulic conductivity of 1.2 x 10-11 m/s will be achieved.

A study completed by Meer and Benson (2007) indicates that GCL used in a capping design that does not become desiccated, and is located in a wet environment, will maintain an appropriate permeability. GCL's with gravimetric water contents of greater than 100% have lower hydraulic conductivity (10-10 and 10-9 m/s). This study also indicated that there is no correlation between cover soil thickness and hydraulic conductivity.

The permeability of the GCL required for the consent application is 1 x 10-7 m/s. In the situation where there is a small thickness of knap rock (minimum of 300 mm) and topsoil (minimum of 150 mm), based on the above two examples it is anticipated that the GCL will achieve the permeability required for the consent.

2.82 Please provide a copy of the referred Landfill Capping Design Concept Design Memo to enable a review of the proposed capping.

Please see the Landfill Capping Concept Design Memo attached as Appendix G.

2.83 Please provide information regarding the solubility of this material near surface, where it will likely be exposed to alternate wetting and drying cycles.

The soluble nature of the limestone bedrock is identified by the karstic nature on site. However, as described in the Geological and Hydrogeological Report June 2002 these karstic features are developed by turbulent flow above the phreatic surface. Clearly, we do not have these conditions on the landfill cap. Therefore, we are not anticipating significant issues associated with the potential soluble nature of the knap rock.

As discussed in the Landfill Operations Management Plan there will also Cap inspections in line with Section 10.4.5.1.

2.84 Please provide information as to the robustness of the proposed alternative capping system to periods of little to no maintenance that may exceed recommended intervals. In such a situation, please confirm whether the capping layer will meet the recommended minimum requirements outlined in Table 5-8 of the WasteMINZ Guidelines 2018.

The robustness of the proposed capping design will be upheld by adaptive management measures such as regular walkover inspections of the area, as described in Section 10.4.5.1 of the updated Landfill Operations Management Plan. Walkovers will allow for potential defects in the capping to be identified and addressed. The capping is also expected to become more robust once vegetation has been established. Other adaptive management measures will be implemented should adjustments be required to the capping. It is expected that, with the above measures in place, the capping layer will meet the recommended minimum requirements outlined in Table 5-8 of the WasteMINZ Guidelines 2018.

2.85 Please provide information on the ability of the GCL in the capping layer to avoid or have acceptable cation exchange when the confining stress is less than that recommended for the liner.

Mr Gates (SmecTech) has calculated that with 1 m of overburden, with complete Calcium for Sodium exchange in the GCL and groundwater of similar chemistry to the site, a hydraulic conductivity of 1.2 x 10-11 m/s will be achieved.

A study completed by Meer and Benson (2007) indicates that GCL used in a capping design that does not become desiccated and is located in a wet environment will maintain an appropriate permeability. GCL's with gravimetric water contents of greater than 100 % have lower hydraulic conductivity (10-10 and 10-9 m/s). This study also indicated that there is no correlation between cover soil thickness and hydraulic conductivity.

The permeability of the GCL required for the consent application is 1 x 10-7 m/s. In the situation where there is a small thickness of knap rock (minimum of 300 mm) and topsoil (minimum of 150 mm), based on the above two examples it is anticipated that the GCL will achieve the permeability required for the consent.

2.86 Please provide a drawing(s) illustrating the relationship between the leachate recirculation plumbing and proposed GCL liner and comment whether the risk of this occurrence being repeated is reduced, increased or similar.

Leachate recirculation penetrations through the GCL will have a similar design to that in the ELCOSEAL Geosynthetic Clay Liner Installation Guide (provided in Question 2.35) Figure 13 would be used. However, the concrete pad/thrust block would not be included in the design. It is expected that the proposed capping design will reduce the risk of the leachate breaking through the final cap.

2.87 Please provide information on whether temporary and intermediate capping are also expected to increased in rate. If so, please provide confirmation of the availability of suitable material on site to form these caps.

The application of the intermediate and temporary capping layers will increase at a similar rate to the final capping. Both the intermediate and temporary capping layers are made up of knap rock. The knap rock is sourced from the quarrying operations and is readily available.

2.88 Please provide quantitative and qualitative evidence to support the statement that 1(V):4(H) will provide an adequate Factor of Safety for the waste and final capped layer. This should include the assessed and target Factors of Safety.

We do not believe that a slope stability analysis will be fruitful at this early stage of the design development for the capping improvements. The aim is to complete the construction trial prior to completing the next stage of development which is envisaged to include detailed design and slope stability analysis. Please note that a slope stability analysis has been included as a suggested effective design improvement, to be considered after the completion of the construction trial, in Section 10.4.4 of the updated Landfill Operations Management Plan.

2.89 Please also provide commentary on the potential effect of the GCL on stability, with respect to the thin cover possibly leading to breaking of the fabric bond and possible ooze through the fabric which could create a plane of weakness.

We have been in contact with Geofabrics regarding the permeability of the GCL when elongated. Peter Finlay, Business Development Manager, from Geofabrics has directed the information to their laboratory and we are awaiting their reply. We will provide a response to this query once the information has been made available.

2.90 Please provide information to support the variation from the WasteMINZ recommendation.

Figure 5-8 in the WasteMINZ Guidelines 2018 provides examples of the final cover designs. The final cover design 'Cap including membrane' in Figure 5-8 is not stated as a minimum requirement. Therefore, it is believed that the drainage layer is not required.

Furthermore, adaptive management measures such as walkover investigations, as described in Section 10.4.5.1, will be carried out across the capping. The walkovers will allow for potential defects in the capping to be identified and addressed. Other adaptive management measures will also be implemented should adjustments be required to the capping.

3. Further Information Requested - Geotechnical and Seismic Engineering

3.1 Please provide a groundwater recharge model post closure of the landfill and a discussion of how the groundwater flows through the limestone e.g. defect and bedding controlled, in order to establish the behaviour of groundwater in the limestone once the landfill is complete and to support an understanding of the need for side wall underdrainage.

Any drawdown effects on groundwater are the result of quarrying operations. Quarrying activities are consented through until 2038 and do not form a part of this application. The landfilling activity applied for as part of this application will not change the long-term impact on groundwater.

The original hydrogeological report from 2002 has been provided as Appendix D to provide context to support the answer above.

3.2 In view of the outcomes of query 1) above, please provide details of how groundwater underdrainage on the side walls will be addressed if it is shown that recharge will impact the side walls in order to ensure that there will be adverse impact on the liner.

Any drawdown effects on groundwater are the result of quarrying operations. Quarrying activities are consented through until 2038 and do not form a part of this application. The landfilling activity applied for as part of this application will not change the long-term impact on groundwater.

No adverse effects on the liner are expected to occur post-closure of the landfill as the height of the waste will be well above the groundwater table and will compensate for the uplift pressures from the groundwater. Please refer to drawings IZ000400-1000-NG-DRG-1009 to -1011.

3.3 Please provide an up to date ground water draw down zone of influence assessment and an assessment of effects related to this zone of influence in order to ensure that the drawdown zone of influence has no adverse effect outside of the property boundary.

This consent application will not change the currently consented effects of groundwater drawdown. If anything, by filling the quarry/landfill quicker, drawdown that has already occurred will start to reverse and tend toward pre-quarry levels.

3.4 Please provide a methodology on how the groundwater draw down zone of influence will be monitored over time, in order to ensure that the potential for adverse effects is being addressed.

This consent application will not change the currently consent effects of groundwater drawdown. If anything, by filling the quarry/landfill quicker, drawdown that has already occurred will start to reverse and tend toward pre-quarry levels.

The zone of influence as a result of historic quarrying activities is already monitored through the groundwater level monitoring undertaken in accordance with the Landfill Operations Management Plan.

The groundwater monitoring intervals are seen in Section 13.3.1 of the Landfill Operations Management Plan. Groundwater levels are measured and recorded at monthly intervals. Flow from the groundwater underdrainage system (site 13) is measured continuously with a flow meter. The groundwater levels can be seen in IZ000400-1000-NG-DRG-1009, -1010 and -1011.

3.5 Please provide the technical specification for area 15 in order for this reviewer to review the details of karst remediation specifics.

Area 15 is currently consented, and we believe it falls outside of the scope of what should be considered by the peer reviewer.

Karst remediation is described in the excerpt from the Area 15 Technical Specification below, in Section 10.1.3 of the Landfill Geotechnical Engineering Technical Memo and detailed in Drawing IZ000400-1000-NG-DRG-1019.

Site preparation includes clearance and disposal of vegetation, topsoil and any superficial obstructions, such as removal of any boulders in the footprint of the landfill. After site preparation, the landfill base shall be over-excavated to show a limestone surface. Any cracking, karsting, clay deposits or water inflows shall be inspected and mapped by an experienced Engineering Geologist or Geotechnical Engineer. The finished surface shall be inspected and signed off by the Engineer. A minimum of 50 mm blinding layer shall be placed over the excavated limestone surface and compacted to the requirements of structural fill (refer to **Section 5**).

This section of the technical specification presents the hold points identified in this project. Hold points refer to portions of work which, prior to proceeding with, the Contractor shall obtain the written consent of the Engineer. Any works carried out beyond a hold point without the approval of the Engineer will be entirely at the Contractor's risk. The Engineer may ask the Contractor to remove all or portions of such work or request for additional testing to verify its conformance to this specification. The hold points are listed in Table 5.

Table 5. Hold points for Area 15, Phase 4 of AB Lime Landfill

Item	Description of Work
1	Completion of subgrade preparation for landfill platform (geological mapping and photography of base)
3	Completion of groundwater collection trenches installation
4	Completion of geotextile separation layer installation
5	Completion of compacted knap rock for landfill liner
7	Completion of stormwater bunds
8	Completion of leachate collection layer installation
9	Installation and excavation of confining gravel layer
10	Installation of geogrid
11	Completion of the placement of select waste
12	Handover of all documentation, records and QA documentation

3.6 Please amend drawings 1017 and 1018 to consistently show the requirements of underdrainage for the side wall. In the event that a review of the recharge model and the likely groundwater impact of the side wall liner, please amend the drawings to consistently show any revised design.

Underdrainage is implemented when seepage is identified on the side slopes. No seepage has been encountered to date, so no underdrainage has been installed on the side slopes. However, if seepage was identified a design similar to that in Section B and Section 1 of drawing IZ000400-1000-NG-DRG-1019 would be envisaged for inflow cavities.

3.7 Please provide quantitative slope stability documentation, either from the original consent application or newly developed ground models for all required load cases and the changed ground water regime now and post closure in order to allow satisfactory review of landfill stability.

The side slopes on site consist of limestone, other than at Area 13. The original Assessment of Environmental Effects (2002) stated that the existing rock slopes were 1(V):1(H). There was no sign of visual instability and it was concluded that the final rock slopes would be stable at 1(V):1(H). The proposed side slopes are to be 1(V):2(H), less than the stated in the original assessment.

The side slope at Area 13 is soil constructed from structural fill. A stability analysis was carried out in 2013. It concluded that the slope was stable with safety factors of >1.0 for pseudo static and >1.5 for static scenarios (attached as Appendix F).

Considering that the proposed slopes are either remaining at the same slope or reducing in slope and the soil side slope was deemed stable, it is believed that a slope stability analysis is not required.

3.8 Please provide an identification methodology, risk assessment and mitigation for buried tomos under the floor of the landfill in order to understand the quantum of this potential risk on the landfill.

The hydrogeology report that formed part of the original consent submission (refer to Appendix D) indicated that the permeability of the rock over the site was reasonably low. The low permeability is more indicative of non-karst limestone than karst limestone. The report also concluded that solution features were practically non-existent beneath the groundwater table.

The floor of the landfill will be below the groundwater table, as seen in drawings IZ000400-1000-NG-DRG-1009, -1010, -1011 in the Landfill Geotechnical Engineering Technical Memo. To date no karstic features have been found on the floor of the landfill. From the conclusions of the hydrogeology report it is believed that there is low risk of buried tomos under the landfill floor.

3.9 Please provide a reason as to why engineering geological mapping is not a written requirement on the limestone side walls in order to understand if there is the potential for defect related ground water seepage.

As stated in the response to Question 3.6, there has been no seepage observed in the side slopes. Currently the consent conditions (consent condition 5, Schedule 1 – General Conditions) requires a geological map to be prepared for the base grade of the landfill. However, for the side slope Section 9.1.1 of the updated Landfill Operations Management Plan states that any features during the preparation of the subgrade will logged and shown on an as-built. Therefore, it is believed that engineering geological mapping is not required.

4. Conclusion

The Applicant has provided responses to this section 92 request to the level deemed necessary to address adverse effects on the environment related to the activities for which resource consent is applied for. As stated within this response, the Applicant has concerns regarding the relevance of some aspects of the section 92 request, particularly whether the RFIs are based on an understanding of the existing environment and the fact that the site has operated as a consented landfill since the early 2000's and the landfill footprint is not changing.

Furthermore, the Applicant believes that some of the requests for information RFI's goes beyond the scope of what is under the control of the Regional Authority for this application. This ultimately has led to a duplication in effort and costs, as matters are concurrently under consideration with the Southland District Council.

The Applicant welcomes a robust process, however, as bearer of the costs, sees the benefit in ensuring that the process is continued to run as efficiently and effectively as possible. Relevant technical experts are available if peer reviewers would prefer to discuss any of the items above to clarify any maters.

Appendix A. AB Lime Landfill Air Discharge Consent Application (APP 20202200, APP 205862-01-V2) – Air Quality Section 92 Response

Donovan Van Kekem
Air Quality Consultant
Ph: 021329970
www.nzair.nz

28 August 2020

Dear **Environment Southland**

Subject: AB Lime Landfill Air Discharge Consent Application (APP 20202200, APP 205862-01-V2) – Air Quality Section 92 Response.

Introduction

Jacobs New Zealand Limited (**Jacobs**) lodged an application for replacement air discharge consents on 29/5/2020 on behalf of AB Lime Limited (**AB Lime**).

In support of this application there was an air quality technical memo[1] (hereafter referred to as the 'technical memo') produced by NZ Air Limited (**NZ Air**).

Subsequent to the application being lodged NZ Air produced an addendum report[2] (hereafter referred to as the 'Addendum') with updated air dispersion modelling which was based on recent stack testing results undertaken on 3 June 2020.

Environment Southland commissioned Beca Limited to undertake a technical review of the air quality assessments associated with the consent application. Subsequent to this review and the review of the application as a whole, Environment Southland has requested further information[3] to support the application. Within this Section 92 request for further information are questions related to the air quality assessments, Questions 1.1 – 1.15.

Response

[1] NZ Air Report: AB lime Limited Landfill Resource Consent Application – Landfill Air Quality Technical Memo. Dated 29 May 2020.

[2] NZ Air Letter Report: AB Lime Landfill Air Discharge Consent Application (APP 20202200, APP 205862-01-V2) – Addendum to Air Dispersion Modelling Assessment. Dated 14 July 2020

[3] Environment Southland Letter: S92(1) Request for Further Information – AB Lime Limited – APP 20202200, APP 205862-01-V2. Dated 23 July 2020

Question 1.1

1.1 Section 6 of the NZAir Technical Memo and Section 10.5 of the AQMP refer to the current monitoring of hydrogen sulphide (H2S) on the boundary of the landfill and in the vicinity of the leachate tank. In order to gauge the extent of the current concentrations of H2S at these locations, please provide:

a. a summary of the results of the boundary and leachate tank H2S monitoring;

Currently there is no H_2S monitoring at the leachate tank or the landfill boundary. This is proposed as a future mitigation and monitoring As such, there is no current monitoring data available.

b. An explanation of the basis for the 20 ppb boundary trigger limit and the 1 ppm trigger limit for the leachate tank monitor; and

The 20 ppb H_2S concentration trigger at the boundary monitoring locations is based on the instrument level of detection, sensitivity, and the distance from the boundary to the nearest sensitive receptors. The proposed OdaLogg boundary monitors have a detection threshold of 10 ppb, thus, setting the trigger point at 20 ppb should not result in false alarms (which can occur at the threshold level of detection) and provide for meaningful data. Although the odour detection threshold (not recognition threshold) for H_2S can be as low as 5 ppb, because of the distance between the site boundary and the nearest sensitive receptors not owned by AB Lime (1.2 km from the edge of the landfill footprint) it is likely that with a boundary concentration of 20 ppb the resultant concentrations at off-site receptors will be well below the level of detection. The boundary monitors are designed to be an internal early warning trigger system for the Applicant before becoming a compliance issue.

The 1 ppm trigger at the leachate tank is set as an early warning trigger for worker health and safety. The Workplace Exposure Standard for H_2S has a TWA of 5 ppm. An added benefit of this monitoring is that elevated emissions of H_2S from this source, which may contribute to off-site nuisance effects, can be identified. Once an alarm is received, mitigation measures can be put into place to control these emissions (as stipulated in Table 1 of the AB Lime Landfill Air Quality Management Plan[4]

c. An indication of the frequency that these trigger limits have been exceeded.

As discussed above, this monitoring is not currently in place, but is proposed as a part of the future expanded operations.

Question 1.2

1.2 Section 6.1.2 of the NZAir Technical Memo notes that the area of the tip face and exposed waste area will be limited to 1,000 m2. In order to assess the potential impact on odour and dust emissions of limiting the area of the tip face to 1000m2 please provide:

a. An estimate of the current area of the tip face.

It is estimated that the current working face is approximately 3,625 m^2. However historically the working face may have been up to 5,000 m^2.

Question 1.3

[4] AB Lime Limited: *Ab Lime Landfill Air Quality Management Plan – Draft for consenting purposes.* Dated 29/5/2020

1.3 Section 6.5 of the NZAir Technical Memo describes the methods that will be used to mitigate the generation of dust at the landfill. Some of the mitigation methods rely on the use of water as a dust suppressant. Please provide:

a. Information on the source of water that will be used to suppress dust; and

Water is currently sourced from the stormwater pond, and AB Lime has a consented water take of 500 m^3/day (Consent No:201350). Currently, AB Lime only use approximately 600 m^3/month (well below the consented take) for dust suppression and other on-site water uses.

b. Evidence that there will be sufficient water available to control dust on the areas of the landfill that will be the major sources, including, haul roads, tip face, unvegetated and unconsolidated surfaces and stockpiles.

As discussed above, currently the volume of water used for dust control is well below the consented water take, which does not expire until 2038. The historic dust suppression on-site has been effective at controlling dust emissions to within the site boundary. There have been no dust complaints for more than 15 years. The water used for dust suppression is primarily used for the on-site quarry activities, which are not proposed to change and are outside the scope of this consent application. Additionally, as part of the improved Landfill Operations Management Plan, it is proposed that there will be smaller exposed areas, reducing the potential for odour and landfill gas emissions. Therefore, although there may be a slight increase in the overall length of the haul road to the tip face and an increase in traffic movements on this haul road, it is anticipated that the overall area which requires dust suppression by water is unlikely to be much larger than that already present on-site.

Notwithstanding the above, the conservative water application rate for dust suppression in the Ministry for the Environment Good Practice Guide for Managing and Assessing Dust (2016) is 1 l/m^2 per hour to unconsolidated exposed surfaces with dust emission potential. With the permitted water take of 500 m^3 per day AB Lime would have sufficient water resource for effective dust suppression of 50,000 m^2 (assuming a 10 hour working day). This is more than sufficient for the exposed surfaces at the site, which include the following factors:

- On any given working day AB Lime has approximately 2,500 m of active haul roads. At a typical haul road width of 4 m, this equates to 10,000 m^2 of exposed surface;
- The proposed open working face is 1,000 m^2. This is conservative as dust suppression by water is not required for the full extent of this area;
- It is unlikely that there will be more than 5,000 m^2 of temporary capped area or un-grassed area which contains unconsolidated surfaces;
- Stockpiles of capping/cover material are unlikely to have a surface area of more than 500 m^2; and
- There may also be some unconsolidated surfaces associated with active quarry operations, however it is anticipated that these will not be greater than 10,000 m^2.

Based on these conservative estimates, there may be a requirement for dust suppression on up to 26,500 m^2 of unconsolidated surfaces at any one time. This is well below the available water take which would enable dust suppression for up to 50,000 m^2. This is a worst case scenario. Based on current operations, AB Lime is able to effectively control dust emissions with a much lower volume of water than the current water take consent (or that calculated above).

Question 1.4

1.4 Sections 6.5.2 and 6.7.3 of the NZAir Technical Memo describe the mitigation and monitoring measures that will be used to minimise dust emissions. Section 6.1.2 notes that the onsite weather station will have automated alarms which will alert site staff of conditions which could blow emissions from the site towards the nearest neighbouring receptors but does not provide any details as to what those alerts will a. Please provide the following:

a. The temperature, wind speed and direction alert levels for warning staff of adverse weather conditions for odour discharges.

It is proposed that there will be automated weather station alerts when the wind direction is between 0 and 90 deg and the wind speed is either below 1 m/s or above 7 m/s. These wind directions cover the range of winds within which the nearest off-site receptors (identified as R1-R12 in the technical memo) are downwind. Wind speeds below 1 m/s are a trigger for reduced odour dispersion and an elevated risk of off-site odour effects. Wind speeds above 7 m/s are those at which dust from dry unconsolidated surfaces is likely to be entrained in the airstream.

At this stage there are no plans to introduce triggers for temperature. The above trigger points will be within the Landfill Air Quality Management Plan. As such, they can be amended over time to better respond to weather conditions which result in actual or potential off-site effects.

Question 1.5

1.5 Section 7 of the NZAir Technical Memo describes the atmospheric dispersion modelling methodology used to estimate the ambient concentrations of contaminants that will arise from the combustion of coal and landfill gas (LFG) in the lime kilns and the combustion of LFG in the landfill flare. The modelling is based on a set of emission values, the derivation of which, is only briefly described. Please provide the following information:

a. The calculations used for deriving the emissions of particulate matter (PM10), sulphur dioxide (SO2), nitrogen oxides (NOx) and carbon monoxide (CO) discharged from the lime kilns when burning only coal and when burning coal and LFG;

The NZ Air Addendum modelling replaced the modelling undertaken and presented in the Technical Memo. The calculations for Scenarios 1 and 4 as described in the Addendum are included in **Appendix A**.

Note that whilst reviewing these calculations, NZ Air has realised that a mistake has been made in the Scenario 1 model inputs. The total calculated emission rate for PM_{10}, NOx and CO for the coal combustion was applied to both kiln stacks, instead of being evenly divided between each stack. This effectively doubled the mass emissions from the kilns. Therefore, the modelling results for PM_{10}, NOx and CO presented in Table 2 of the Addendum are incorrect. Updated inputs and modelling results are included in Tables 1 and 2 below.

Table 1. – Updated Addendum Modelling Inputs

Modelling Inputs								
Source	Stack Height	Exit Diameter (m)	Exit Velocity (m/s)	Exit Temp (°C)	SO_2 Emission Rate (g/s)	NOx Emission Rate (g/s)	CO Emission Rate (g/s)	PM_{10} Emission Rate (g/s)
Scenario 1								
Kiln Stack 1	9	0.96	13	63	1.389	1.225	0.049	0.041
Kiln Stack 2	9	0.96	13	63	1.389	1.225	0.049	0.041
Flare	7	0.154	20	1000	0.043	0.066	1.212	0.027
Scenario 4								
Kiln Stack 1	9	0.96	13	63	0.278	[redacted]	[redacted]	[redacted]
Kiln Stack 2	9	0.96	13	63	0.278	[redacted]	[redacted]	[redacted]
Flare	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table 2. – Updated Addendum Scenario 1 Modelling Results

	PM_{10} µg/m^3		NO2 µg/m3		SO_2 µg/m^3		CO µg/m^3	
Averaging period	**24 hour**	**Annual**	**1 hour 99.9%ile**	**24 hour**	**1 hour 99.9%ile**	**24 hour**	**1 hour 99.9%ile**	**8 hour**
Max beyond site boundary	8.0	0.46	128	91	370	182	350	289
R9	0.43	0.01	97	76	23	11	14	8
R1	2.70	0.04	106	81	129	72	76	55
R2	0.10	0.00	96	75	14	3	5	2
R5	0.21	0.00	96	75	14	5	10	4
R4	0.35	0.05	98	76	33	8	24	17
Background	21	10	95	75	-	-	5000	2000
Max plus background	29	10	128	91	370	182	5350	2289
Criteria	**50**	**20**	**200**	**100**	**350**	**120**	**30000**	**10000**

For any further assessment of potential effects from the site's Scenario 1 combustion emissions, the results presented in Table 2 above should be used (rather than previous results).

The updated modelling results above do not result in a material change in the results, or conclusions, of the Addendum.

b. The calculations used for deriving the emissions of PM10, SO2, NOx and CO from the burning of LFG in the flare;

These calculations are also included in **Appendix A**.

c. An explanation of why the emission factors in Chapter 1.7 of the AP42 Compilation of Emission Factors for burning lignite in external combustion sources were used to estimate the emissions from coal burning in the lime kilns instead of the emission factors included in Chapter 11.7 of AP 42 which provides specific factors for lime manufacturing.

The lime kilns at AB Lime have a cyclonic separator followed by a wet scrubber prior to the stack discharge points.

In Table 11.7-5 of Chapter 11.17 of the USEPA AP42 Compilation of Emission Factors the most applicable factors for the AB Lime kilns would be those under 'coal fired rotary kiln with a wet scrubber'. However, there are no NOx or CO emission factors (listed as ND = no data) under this heading. For this reason, conservative emission rates of these pollutants from Chapter 1.7 have been used in the assessment.

The SO_2 emission rates were based on the actual and proposed consent mass emission limits and not derived from the USEPA AP42 emission factors.

It is expected that the particulate emissions from AB Lime's kilns will be very low due to the presence of the wet scrubber. As identified in the Beca peer review, NZ Air used an emission factor based on the coal combustion with a wet scrubber. This emission factor was 0.1051 kg/tonne of coal burnt. At peak coal consumption rates (2,800 kg/hr) this equated to 0.294 kg/hr.

The particulate emission factors in Table 11.17-1 of Chapter 11.17 are based on the rate of lime through the kiln (they are in kg of pollutant per tonne of lime). The combined peak lime throughput of both kilns is 120 tonnes per hour. The most appropriate USEPA AP42 particulate emission factor in Chapter 11.17 would be that for a 'coal fired rotary kiln with a venturi scrubber'. In Table 11.17-1, the combined filterable and condensable particulate mass emission rate is 0.86 kg/tonne of lime processed. For the AB Lime kilns this would equate to a particulate mass emission rate of 103 kg/hr. Approximately 16% of the particulate would be PM_{10} based on Table 11.17-7. The mass emission rate of PM_{10} would therefore be 16.48 kg/hr. In NZ Air's experience this is unrealistically high.

Reported particulate emissions from lime kilns in Europe[5] are lower. Typical particulate emission concentrations from lime kilns in Europe with wet scrubbers range from 20 – 100 mg/Nm^3. Based on the typical measured airflow in the Verum Stack testing (approximately 23,000 Nm^3/hr) this equates to a total particulate mass emission rate range of 0.46 – 2.3 kg/hr. Reported particulate size distribution of residual particulate emissions from wet scrubbers in Europe[6] indicate that less than 10% of the total particulate emitted post a wet scrubber is PM_{10}. Therefore, based on these European measured particulate emission rates and the measured airflow rates for the AB Lime kilns, the PM_{10} emission rate would be <0.046 – 0.23 kg/hr.

The particulate emission rates described above in the US EPA Chapter 11.17 are based on emissions testing undertaken in 1975 and 1986. The European emission factors are based on emission testing undertaken between 2001 and 2006. The more recent test results are considered more appropriate for emissions from the AB Lime kilns due to the advancements in both air discharge control equipment and emissions measurement techniques/accuracy from the 70's/80's to the 2000's.

---

[5] https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/CLM_Published_def_0.pdf

[6] EuLA (2006). "Database emissions from lime kilns".

The modelled PM_{10} mass emission rates used in the updated modelling inputs (**Table 1** above) equate to a mass emission rate of 0.29 kg/hr which is higher than the measured European PM_{10} emission rates for lime kilns with a wet scrubber. Therefore, if the more appropriate European PM_{10} lime kiln mass emission rates were to be used in the modelling, the peak off-site PM_{10} effects would be even lower than those presented in **Table 2** above. This would provide stronger support for the conclusions reached in the Addendum and the Technical Memo, that the proposed replacement of coal with LFG will result in a net reduction of PM_{10} off-site effects (due to the lower PM_{10} emissions that occur from LFG combust as compared to coal combustion).

d. The emission rates of PM10, NOx and CO from the lime kilns based on the emission factors included in Chapter 11.7 of AP 42.

As per answer above.

e. A copy of the calculations used to calculate the efflux velocities used in the revised modelling scenarios included in the NZAir Addendum, as measured values are not included in the Verum Group emission test reports appended to the document.

A copy of the measured exit velocities by Verum is attached as **Appendix B.**

Question 1.6

1.6 Section 7 of the NZAir Technical Memo describes the different scenarios that were modelled to assess the effects of the combustion discharges from the LFG flare and lime kilns. For scenarios 1 and 2, the report includes information on the quantities of LFG and coal that will be burnt in each of the combustion sources. However, for scenario 3 the report states that "even less coal" will be burnt but does not provide the quantity of coal to be burnt that was used as a basis for the modelling scenario. Neither does the description of the scenario identify the proportion of LFG that will be burnt in the landfill flare. There also appears to be some typographical errors associated with the units used for describing the quantities of LFG to be burnt as some quantities are referred to as kg/hr and others as m3/hr. Please provide the following:

a. The quantity of coal to be burnt that was used as the basis for scenario 3;

Scenario 3 in the Technical Memo was based on 1,798 m^3/hr of LFG being burnt in the kilns. This would replace 1,798 kg/hr of the peak 2,800 kg/hr of coal consumption (based on the assumption described in the Technical Memo that the energy provided by the combustion of 1 m^3 of LFG is approximately the same as burning 1 kg of coal). Therefore, the amount of coal burnt in this modelling Scenario is 1,002 kg/hr.

b. The quantity of LFG that will be burnt in the landfill flare in scenario 3;

There would not be any LFG burnt in the flare as it would all be ducted to the kilns. It is AB Lime's intention that available LFG will be used in the kilns, with the existing flare being available as a backup in the instance that the kilns are not running or the LFG kiln burners are undergoing maintenance or repairs.

c. Clarify the units that apply to the production rate of LFG.

All of the units for LFG produced by the landfill or combusted in kilns or flare should have been m^3/hr.

Question 1.7

1.7 Table 1 of the AQMP notes that the "fence line odour neutralising sprays are to be operational at all times during working hours". Please provide;

a. a description of the odour neutralising spray system including:

i. The chemical composition of the spray, and

ii. A general description of the design and operation of the spray system.

AB Lime currently operates an odour neutralising spray system that consists of a length of polythene pipe strung along the top of ~6 foot high posts with regularly spaced odour neutralising spray misting nozzles approximately 2.5 m apart. **Figure 1** shows a photo of the current fence spray line.

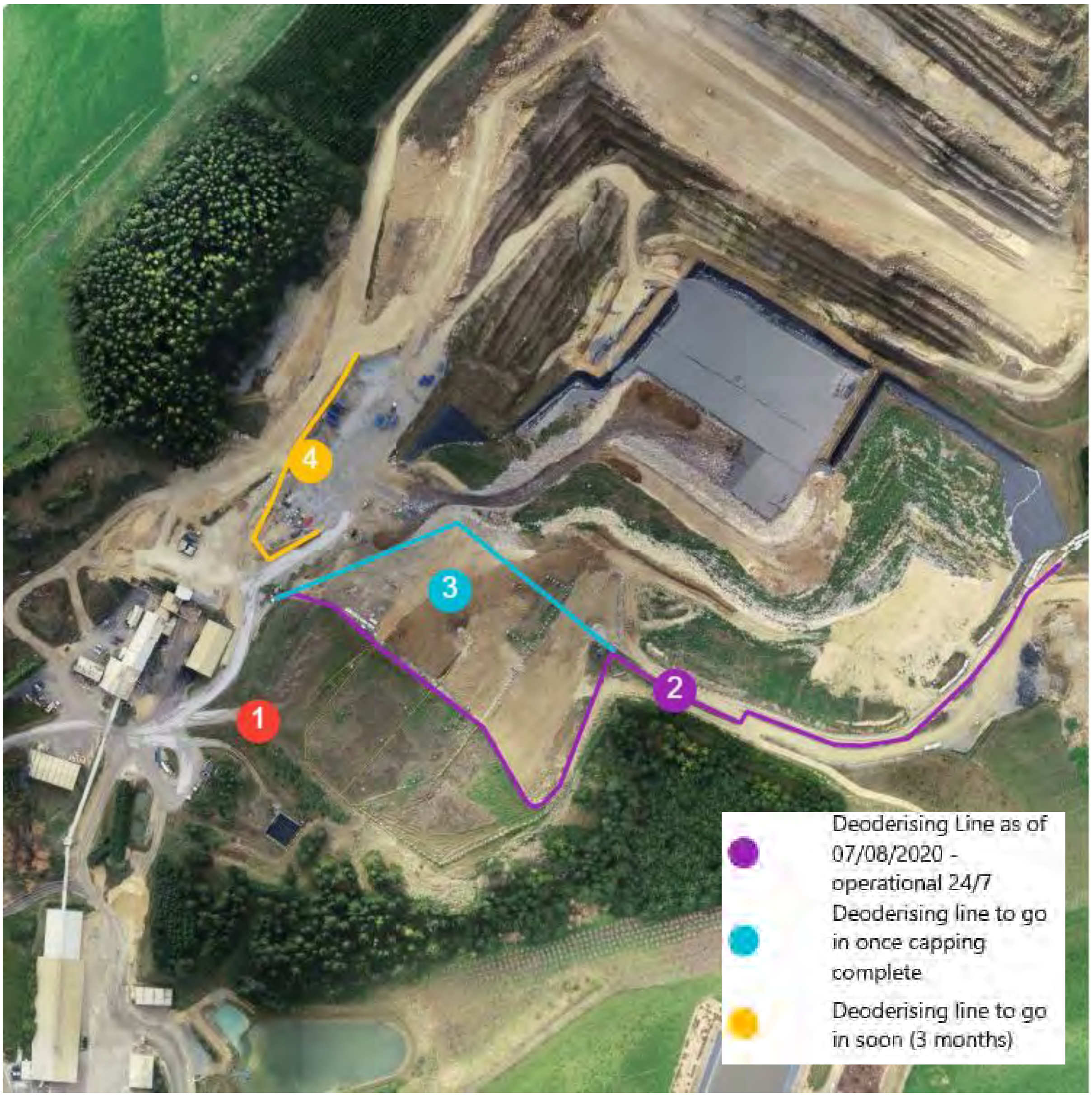
Figure 1. – Odour neutralising fence line spray system.

The deodorising agent is stored in a large tank on-site and pumped along the fence line 24 hours a day. Currently biOx PLUS40 is the deodorising agent used in the spray lines. A safety data sheet for this product which includes its chemical composition is attached as **Appendix C**.

Whilst the concentrated biOx PLUS40 contains substances that are toxic if inhaled, the solution is diluted at a ratio of ~1:200 prior to being used in the misting lines. Ambient air quality monitoring was undertaken at other worksites, which were using the same de-odorising agent at higher concentrations (see attached monitoring report in **Appendix D).** The results of this monitoring demonstrate that downwind concentrations of airborne chlorine dioxide are below 0.04 ppm within 10 m of the misting operation. The TWA for chlorine dioxide is 0.1 ppm. At these very low concentrations measured within 10 m of the source, and the substantial distance of the AB Lime misting lines from the site boundary (mostly greater than 300 m from the boundary), these odour neutralising sprays do not pose a risk to off-site ambient air quality.

Currently odour neutralising spray fence lines are situated between the active areas of the landfill and down valley sensitive receptors. A map of the current and proposed odour neutralising spray fence lines is included as **Figure 2** below.

Figure 2. – Odour neutralising fence line map.



There is also a mobile odour neutralising fog cannon (pictured in **Figure 3**) which also runs 24 hours a day. It is moved downwind of where daily waste is being placed and has its own independent supply of odour neutralising spray.

Figure 3. – Odour neutralising fog cannon.

Both these systems are checked daily to ensure correct operation and that there is sufficient odour neutralising chemical in the storage tanks.

AB Lime will continue to use these systems in the future as described in the Landfill Air Quality Technical Memo and the Landfill Air Quality Management Plan.

Question 1.8

1.8 Section 5 of the AQMP describes the hazardous waste streams that are consented to be received by AB Lime and the specific controls that are used to manage these wastes. The AQMP includes the potential discharges to air from aluminium dross but does not include any information on how this material is managed to minimise toxic fumes and dust. In order to assess the potential effects of disposing of aluminium dross in the landfill please supply:

a. information on how waste containing aluminium dross is and will be managed.

AB Lime has only received aluminium dross on one occasion and the existing resource consent was specifically altered to allow for this one event. AB Lime would like to retain the ability to dispose of this waste should at any point it be required to do so, however it is very unlikely that this will occur on a regular basis, if at all.

In terms of air discharge controls, due to the toxic nature of the waste, AB Lime propose to require the disposer to deliver the waste to the site in enclosed one tonne bags. These bags will be placed within a pre-prepared dedicated hazardous waste pit free of moisture (as the waste can react with water to form ammonia). As for other hazardous waste streams the enclosed bags of waste aluminium dross with then be immediately covered with capping material. Updates to the Landfill Air Quality Management Plan have been made to this effect.

By enclosing the aluminium dross within bags, minimising the handling of the waste, and preventing the waste from becoming wet, dust and toxic fume emissions will be avoided.

Question 1.9

1.9 Please provide copies of the relevant CALMET and CALPUFF inputs files used for the revised dispersion modelling assessment described in the NZAir Addendum.

The inputs for the revised modelling presented in this response are included in **Appendix E**.

Question 1.10

1.10 Please provide further details of the MM5 meteorological model predictions used as inputs to the CALMET model including whether the MM5 inputs were developed by NZAir or provided by a third party.

The one year (2019) MM5 prognostic meteorological dataset was developed by Lakes Environmental. The resolution was set to 4 km and the domain size was a 50 x 50 km centred on the site. There were 18 vertical levels included in the model, and Lakes Environmental provided NZ Air with CALMET ready 3D.dat files.

Question 1.11

1.11 Please provide further details as to how the modelled LFG flare discharge parameters (detailed in Table 1 of the NZAir Addendum) were derived.

The LFG flare model parameters in all the modelling scenarios were calculated using the CALPUFF 'flare tip' tool. The inputs used in this tool were as follows:

- Stack height – measured on-site as 7 m above ground level.
- LFG flow rate to flare – 0.1683 m^3/s (based on the Scenario 1 modelled LFG production rate of 606 m^3/hr).
- Components of the flare input gas were, 60% methane with a net heating value of 50,000 J/g-mol.
- Model default parameters for effective stack gas temperature, exit velocity, and inside diameter were used/calculated by the tool.

Question 1.12

1.12 A number of concerns are raised by the emission testing undertaken at the site and used to inform the NZAir Addendum assessment. The summary results presented in Appendix A of the addendum indicate that emission testing occurred when the lime feed rate to the kiln was between 1.76 – 3.31 t/hour. However, the current resource consent permits up to 120 t/hr of lime to be processed by the two kilns (or approximately 60t/hr per kiln). The testing appears to have occurred when the kiln was operating at only 3 -5.5% of the consented capacity. There is some uncertainty as to how well the testing represents emissions during normal and peak operating conditions. Please provide the following additional information:

a. An indication of how representative the testing of the lime kilns is to typical and peak operating conditions;

b. An assessment of how the SO2 emission rate and stack discharge parameters (i.e. stack discharge temperature and velocity) will vary from the emission test results when the kilns are operating at peak capacity.

In the first instance, the stack testing company was provided lime feed rates in the wrong units. The lime feed rate units should have been in tonnes per hour not kg/min. Amended stack testing reports with the correct units are attached as **Appendix F**.

The lime kiln tested were operating at close to 100% capacity (60 t/hr per kiln) during the testing for both the 'coal only' (average lime feed rate of 52 t/hr = 87% capacity) and 'coal and LFG' (average lime feed rate of 55 t/hr = 92% capacity) testing scenarios.

The lime feed rate was lower during the 'LFG only' testing scenario, average of 29 t/hr (approximately 50% capacity). This is due to the fact that there was not enough LFG available to run the burner at full capacity and thus not enough heat to dry lime at a peak lime feed rates.

It is important to note that the 'LFG only' stack testing scenario was undertaken more for the purposes of demonstrating that the combustion of LFG in the kilns will be equivalent to that in a flare, to meet the air quality NES Regulation 27 requirements for landfill gas destruction (VOC testing was also conducted during all of the testing rounds). It is not unlikely that there will be sufficient LFG produced by the landfill to run the kilns solely on LFG in the future.

AB Lime site staff have commented that the kilns are nearly always run at their peak production rates. As such, the discharge parameters for the 'coal only' and 'coal and LFG' testing scenarios are likely to be representative of actual conditions.

As the lime feed rates were close to the operating capacity of the kilns during testing, the SO_2 emission rates measured are considered to be representative of actual/likely emission rates in future operations. With regards to other stack parameters (exit temperature, exit velocity, etc) these are less related to the lime feed rate, and more dependent on the amount of fuel being burnt (see answer to Question 1.14 below for further discussion on this point).

Question 1.13

1.13 The emission test results also show that the percentage oxygen in the discharged kiln flue gas to be 20.7%. The observed oxygen content is close to the oxygen content of ambient air (approximately 21.0%). The testing suggests that the combustion gas produced by the burning of LFG at the point of discharge was highly diluted by the inflow air to the kiln. This is also highlighted by the *lower discharge temperature. To better understand kiln operating conditions during the LFG fired testing, please provide the following information:*

a. The maximum proposed LFG usage rate when the kiln is operating at peak capacity;

As is discussed in the Landfill Air Quality Technical Memo, the maximum LFG production rate is modelled to be 1,798 m^3/hr (under the 300,000 t/yr waste acceptance scenario).

b. Whether the operating conditions observed during the emission testing programme are representative of normal operating conditions when the kiln is fired with LFG;

Under the peak modelled LFG production rate (1,798 m^3/hr), it has been calculated by NZ Air that there will not be sufficient energy to operate the kilns solely on LFG. The operating parameters for the LFG and Coal testing scenarios are therefore more representative of actual peak operating conditions.

c. What the discharge conditions will be when the kilns are operating at peak capacity and fired with LFG.

It is difficult to predict the exact discharge parameters which will occur during 'peak capacity' as it is currently unknown how much LFG will be consistently produced by the landfill on any given day/month over the duration of the landfill life, its exact methane content (and hence calorific value), and what the combination of both LFG and coal will be used in the kilns to provide the required heat input.

As such the discharge parameters may be variable over time, however, NZ Air has attempted to be conservative with respect to the modelled discharge parameters. The exit temperature used for the kiln discharges was 63 deg C which was the lower of the most applicable testing scenarios, being the 'coal only' and 'coal and LFG' scenarios. The exit velocity (13 m/s) was also based conservatively on these two testing scenarios which had measured exit velocities of 13.05 and 13.25 m/s respectively.

Note that the fuel burning rates for both tests were not at their peak capacity so at peak fuel burning rates it is expected that there may be an increase in the discharge temperature and exit velocity. In this instance the modelled off-site concentrations are likely to decrease due to the increased dispersion which would occur under these discharge conditions.

1.14 The modelled kiln discharge parameters used in the NZAir Addendum dispersion modelling assessment appear to be based on the discharge parameters observed when the kiln was coal fired only, and the coal feed rate was approximately 1.14 t/hr (or 40% of the current consent limit of 2.8 t/hr). Please provide the following information:

a. How the kiln's discharge parameters will vary from those modelled if the kilns were operating at peak capacity;

b. The effect any changes to the kiln's discharge parameters will have on the predicted ground level concentrations, and the conclusions reached in the addendum.

The coal feed rate listed in the stack testing reports is only that for the kiln being tested, not the combined feed rate for both kilns. The coal feed rate for the two most relevant testing scenarios are as follows:

- Coal only – 1,140 kg/hr = 81% of capacity
- Coal and LFG – 1,122 kg/hr = 80% of capacity, based on the coal consumption only, excluding the LFG energy input. If we were to calculate the heat input for both fuels (based on the assumption of 1 m3 of LFG being equivalent to 1 kg of coal, as described in the Technical Memo), the kiln would have been operating at an equivalent fuel consumption rate of 1,222 kg of coal hour = 87% capacity.

If the coal/LFG consumption rates had been at 100% capacity then it is expected that there would be slightly higher exit temperatures and velocities, which would aid dispersion and lower off-site concentrations. As such, the modelling inputs are conservative and the conclusions reached in the Addendum remain valid.

1.15 It is noted that maximum SO2 emission rates were recorded when the kiln was LFG fired, but that the modelled discharge parameters are based on the coal fired test results. Given the low buoyancy of the emission plume, (i.e. discharge temperature of 29°C compared to the modelled 75°C), and therefore possibly poorer dispersion of the discharged emission plume, and the higher SO2 emission rate when the kiln was LFG fired, please provide the following information:

a. a. Why the modelled discharges parameters were based on coal fired emission test results and not the more conservative LFG fired emission test results;

b. b. The effect on predicted contaminant concentrations and conclusions of the assessment if the LFG fired emission parameters for the kilns operating at peak capacity were used in the modelling.

The SO_2 modelling in the Addendum was based on the proposed peak SO_2 emission rate of 2 kg/hr. This is far in excess of the measured SO_2 emission rates of any of the tests (peak single test emission rate was 0.3 kg/hr and peak average of any of the three tests was 0.1 kg/hr). Therefore, there is sufficient conservatism in the modelling and assessment approach to account for any variances in emissions that may occur through different operating conditions in the future.

As discussed above, the modelled discharge parameters are based on the ‘coal’ and ‘coal and LFG’ tests due to the fact that these are most representative of potential future operations. It is not anticipated that the exit temperature will be as low as the LFG only trial operation in the future, as the kilns almost always run at peak lime feed rates and therefore require an equivalent heat input. As is discussed above, the LFG production models predict that even if the landfill was to receive 300,000 t/yr then the peak LFG production (1,798 m^3/hr) would not be sufficient to solely operate the kilns (which are calculated to require 2,800 m^3/hr). Therefore, it is calculated that there is always going to be a requirement to use a combination of LFG and coal to achieve peak operating conditions.

Using the lower measured exit temperatures from the LFG testing, during which only 100 m^3/hr of LFG was being burnt, would not be representative of likely future operating conditions.

If for some reason the kilns were to run at below peak operating conditions (as occurred in the LFG only testing scenario) then the exit temperatures would be lower (similar to that measured), but the SO_2 mass emission rates would also be lower, as less H_2S would be being converted to SO_2 in the LFG burners and hence less SO_2 would be emitted. It is expected that in this instance it would be very unlikely that the SO_2 emission rate would be at 2 kg/hr (as is demonstrated by the emissions testing). If the maximum amount of LFG available under the 300,000 t/hr LFG model (1,798 m^3/hr) was combusted on its own, and this LFG had a concentration of 90 ppm H_2S (which is conservative) and all of the SO_2 produced from the combustion of this H_2S was emitted (without any being scrubbed out by the lime kiln and wet scrubber) then the peak SO_2 mass emission rate would be 0.46 kg/hr. This is well below the 2 kg/hr used. So even under this super conservative emission scenario, it is predicted that the peak off-site effects would be much lower than those modelled in the Addendum, primarily due to the much lower mass emission rates. Under this scenario the lower exit temperature is not predicted to result higher off-site effects.

Closure

If you have any questions about this work, please contact Donovan Van Kekem on 021 329 970.

Yours Sincerely,

Donovan Van Kekem

Managing Director

NZAIR

APPENDIX A – MODELLING INPUT CALCULATIONS

AB Lime Modelling Calculations

Kiln emission calculations: Scenario 1 - Coal only

Coal burn rate 2800 kg/hr

EF based on subpart D boiler with wet scrubber

USEPA emission factors (metic)

Nox from coal SN1		CO from coal SN1		PM from coal	
3.15	emission factor kg/tonne	0.125	emission factor kg/tonne	0.1051	emission factor kg/tonne
8.82	kg/hr	0.35	kg/hr	0.29428	kg/hr
2.45	g/s	0.0972	g/s	0.0817	g/s
1.225	g/s	0.0486	g/s	0.04087	g/s

Emission rate per kiln: 1.225 g/s (NOx); 0.0486 g/s (CO); 0.04087 g/s (PM)

Ash content 4.20%

Flare emission calculations: Scenario 1 - Coal Only

USEPA emission factors (metic)

Flare Nox SN1		Flare CO SN1		Flare PM SN1	
650	kg/10^6 m3 methane	12000	kg/10^6 m3 methane	270	kg/10^6 m3 methane
363.6	m3 methane/hr	363.6	m3 methane/hr	363.6	m3 methane/hr
0.000364	10^6 m3 methane/hr	0.0003636	10^6 m3 methane/hr	0.0003636	10^6 m3 methane/hr
0.23634	kg NOx/hr	4.3632	kg CO/hr	0.098172	kg PM/hr
0.06565	g/s	1.212	g/s	0.02727	g/s

Note: volume of methane/hr is calculated based on 60% methane in the 606 m3/hr of LFG produced under the 100,000 t/yr waste acceptance scenario

Scenario 1 SO2 Emission Rates

Kilns

Consented peak SO2 emission rate = 10 kg/hr

= 2.778 g/s

therefore each kiln = 1.389 g/s

16.48
16.3152
0.1648

Flare

Assumed peak H2S concentration in the flare = 90 ppm based on current peak measured on-site

The landfill gas flare converts 100% of the sulphur in the H2S to SO2

90 ppm = 135 mg/m3

Molar Mass H2S	34.1
Molar Mass SO2	64.066
factor	**1.878768**

SO2 ER 0.04269501 g/s

Scenario 4 SO2 Emission Rates

Kilns

Proposed Consent peak SO2 emission rate = 2 kg/hr

= 0.556 g/s

therefore each kiln = 0.278 g/s

Table 1.7-5. EMISSION FACTORS FOR FILTERABLE PM EMISSIONS FROM CONTROLLED LIGNITE COMBUSTION[a]

EMISSION FACTOR RATING: C (except as noted)

Firing Configuration	Control Device	Filterable PM Emission Factor (lb/ton)
Subpart D Boilers[b] (SCC 1-01-003-01/-02)	Baghouse Wet scrubber	0.08A 0.05A
Subpart Da Boilers[b] (SCC 1-01-003-01/-02)	Wet scrubber	0.01A
Atmospheric fluidized bed combustor (SCC 1-01-003-17/18)[b,c]	ESP	0.07A

[a] References 22-23. A = weight % ash content of lignite, wet basis. For example, if lignite is 2.3% ash, then A = 2.3. To convert from lb/ton to kg/Mg, multiply by 0.5. To convert from lb/ton to lb/MMBtu, multiply by 0.0625. SCC = Source Classification Code.
[b] Subpart D boilers are boilers constructed before August 17, 1971, and with a heat input rate greater than 250 million Btu per hour (MMBtu/hr). Subpart Da boilers are boilers constructed after September 18, 1978, and with a

Table 1.7-1. EMISSION FACTORS FOR SO_x, NO_x, CO, AND CO_2 FROM UNCONTROLLED LIGNITE COMBUSTION[a]

EMISSION FACTOR RATING: C (except as noted)

Firing Configuration	SO_x Emission Factor[b] (lb/ton)	NO_x Emission Factor[c] (lb/ton)	CO Emission Factor[d] (lb/ton)	CO_2 Emission Factor[g] (lb/ton)	TNMOC[j,k] Emission Factor (lb/ton)
Pulverized coal, dry bottom, tangential (SCC 1-01-003-02)	30S	7.1[i]	ND	72.6C	0.04
Pulverized coal, dry bottom, wall fired[e], Pre-NSPS[f] (SCC 1-01-003-01)	30S	13	0.25	72.6C	0.04
Pulverized coal, dry bottom, wall fired[e], NSPS[f] (SCC 1-01-003-01)	30S	6.3	0.25	72.6C	0.04
Cyclone (SCC 1-01-003-03)	30S	15	ND	72.6C	0.07
Spreader stoker (SCC 1-01-003-06)	30S	5.8	ND	72.6C	0.03
Traveling Grate Overfeed stoker (SCC 1-01-003-04)	30S	ND	ND	72.6C	0.03
Atmospheric fluidized bed combustor (SCC 1-01-003-17/18)	10S[j]	3.6	0.15[k]	72.6C	0.03

[a] To convert from lb/ton to kg/Mg, multiply by 0.5. To convert from lb/ton to lb/MMBtu, multiply by 0.0625. SCC = Source Classification Code. ND = no data.
[b] Reference 2. S = Weight % sulfur content of lignite, wet basis. For example, if the sulfur content equals 3.4%, then S = 3.4. For high sodium ash (Na_2O > 8%), use 22S. For low sodium ash (Na_2O < 2%), use 34S. If ash sodium content is unknown, use 30S.
[c] References 2-3, 8-9, 22-23.
[d] References 8, 23.
[e] Wall-fired includes front and rear all-fired units, as well as opposed wall-fired units.
[f] Pre-NSPS boilers are not subject to an NSPS. NSPS boilers are subject to Subpart D or Subpart Da. Subpart D boilers are boilers constructed after August 17, 1971 and with a heat input rate greater than 250 million Btu per hour (MMBtu/hr). Subpart Da boilers are boilers constructed after September 18, 1978 and with a heat input rate greater than 250 MMBtu/hr.

Table 2.4-4. (Metric Units) EMISSION FACTORS FOR SECONDARY COMPOUNDS EXITING CONTROL DEVICES[a]

Control Device	Pollutant[b]	$kg/10^6$ dscm Methane	Emission Factor Rating
Flare[c] (50100410) (50300601)	Nitrogen dioxide Carbon monoxide Particulate matter	650 12,000 270	C C D
IC Engine (50100421)	Nitrogen dioxide Carbon monoxide Particulate matter	4,000 7,500 770	D C E
Boiler/Steam Turbine[d] (50100423)	Nitrogen dioxide Carbon monoxide Particulate matter	530 90 130	D E D
Gas Turbine (50100420)	Nitrogen dioxide Carbon monoxide Particulate matter	1,400 3,600 350	D E E

[a] Source Classification Codes in parentheses. Divide $kg/10^6$ dscm by 16,700 to obtain kg/hr/dscmm.
[b] No data on PM size distributions were available, however for other gas-fired combustion sources, most of the particulate matter is less than 2.5 microns in diameter. Hence, this emission factor can be used to provide estimates of PM-10 or PM-2.5 emissions. See section 2.4.4.2 for methods to estimate CO_2, SO_2, and HCl.
[c] Where information on equipment was given in the reference, test data were taken from enclosed flares. Control efficiencies are assumed to be equally representative of open flares.
[d] All source tests were conducted on boilers, however emission factors should also be representative of steam turbines. Emission factors are representative of boilers equipped with low-NO_x burners and flue gas recirculation. No data were available for uncontrolled NO_x emissions.

APPENDIX B – VERUM MEASURED STACK VELOCITIES

Donovan Van Kekem

From: William Porter <w.porter@verumgroup.co.nz>
Sent: Wednesday, 8 July 2020 10:43 AM
To: Donovan Van Kekem
Subject: RE: Velocities

Follow Up Flag: Follow up
Flag Status: Completed

Average Stack Gas Velocity m/s

Gas only
T1= **14.7299**
T2= **12.9601**
T3= **12.3254**

Coal Only
T1= **12.5432**
T2= **13.2843**
T3= **13.3263**

Coal and Gas
T1= **13.0052**
T2= **13.1104**
T3= **13.6302**

From: Donovan Van Kekem <donovan@nzair.nz>
Sent: Tuesday, 7 July 2020 4:04 pm
To: William Porter <w.porter@verumgroup.co.nz>
Subject: RE: Velocities

Billy,

There is a 'velocity pressure' but I need the in stack velocity in m/s. Can you send me these?

Regards,

Donovan Van Kekem BSc, PG Dip FORS
Air Quality Consultant

Cell: 021 329970
Office: 03 420 1443
Email: donovan@nzair.nz
www.nzair.nz

APPENDIX C – ODOUR NEUTRALISING SPRAY SAFETY DATA SHEET

SAFETY DATA SHEET

Section 1. Identification of the material and the supplier

Product:	PLUS40
Product Code:	
Product Use:	Deodourising Agent
Restriction of Use:	Refer to Section 15
New Zealand Supplier:	biOx International Limited
Address:	38/38 Ashley Place Papamoa New Zealand
Telephone:	0800 NO DUST (663878)
Fax Number:	N/A
Emergency Telephone:	021815536
Date of SDS Preparation:	7 April 2020 version 5

Section 2. Hazards Identification

This substance is hazardous according to the EPA Hazardous Substances (Classification) Notice 2017

EPA Approval Code: HSR002530 Cleaning Products (Subsidiary Hazard) Group Standard

Pictograms:

Irritant

Chronic

Signal Word: DANGER

HSNO Classification	Hazard Code	Hazard Statement	GHS Category
6.3A	H315	Causes skin irritation.	Skin Irrit. 2
6.4A	H319	Causes serious eye irritation.	Eye Irrit. 2A
6.8A	H360	May damage fertility or the unborn child	Repr. 1A
9.1C	H412	Harmful to aquatic life with long lasting effects.	Aquatic Chronic 3
9.2C	H423	Harmful to the soil environment.	-

Prevention Code	Prevention Statement
P103	Read label before use.
P201	Obtain special instructions before use.
P202	Do not handle until all safety precautions have been read and understood.
P264	Wash hands thoroughly after handling.
P273	Avoid release to the environment.
P280	Wear protective gloves, protective clothing and eye protection.
P281	Use personal protective equipment as required.
Response code	Response Statement
P321	Specific treatment (see first aid instruction on product label).
P362	Take off contaminated clothing and wash before re-use.
P302 + P352	IF ON SKIN: Wash with plenty of soap and water.

P305 + P351+P338	IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
P308 + P313	IF exposed or concerned: Get medical advice/ attention.
P332 + P313	If skin irritation occurs: Get medical advice/ attention.
P337 + P313	If eye irritation persists: Get medical advice/attention.
Storage Code	Storage Statement
P405	Store locked up in original container in a cool well-ventilated area out of direct sunlight and away from strong acids oxidisers and reducing agents.
Disposal Code	Disposal Statement
P501	Triple rinse container and add rinsing's to mixing vessel. Puncture empty container before disposal to landfill. Unwanted material should be disposed of as a hazardous waste via a licensed waste disposal company.

Section 3. Composition / Information on Ingredients

Ingredients	Wt%	CAS NUMBER.
Sodium Chlorite	0-1%	7758-19-2
Potassium Persulphate	<0.1%	7727-21-1
Surfactant	<1.0%	1643-20-5
Other Non-Hazardous Components	Balance	N/A

Section 4. First Aid Measures

Recommended on site emergency facilities: Eye Wash, Emergency Shower

Routes of Exposure:

IF SWALLOWED: Rinse mouth. Do NOT induce vomiting. Give plenty of water to drink. Call a POISON CENTER or doctor/physician if you feel unwell (0800 764 766).

Specific Treatment:

IF ON SKIN (or hair): Remove/Take off immediately all contaminated clothing. Wash affected areas with soap and water. If skin irritation or rash occurs get medical advice/attention.

IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. If eye irritation persists: Get medical advice/attention.

Specific Measures:

IF INHALED: Remove to fresh air and keep at rest in a position comfortable for breathing. If breathing is difficult or if experiencing respiratory symptoms, remove to fresh air and keep at rest in a position comfortable for breathing. Immediately call a POISON CENTER (0800 764 766) or doctor/physician.

IF EXPOSED CONCERNED: Get medical advice/attention.

Most important symptoms and effects, both acute and delayed

Symptoms:

Ingestion : Not applicable.
Inhalation: Not applicable.
Skin: Causes skin irritation.
Eye: Caues eye irritation.
Chronic: May damage fertility or the unborn child.

Section 5. Fire Fighting Measures

Hazard Type	Eye and skin irritant, ecotoxic liquid.
Hazards from decomposition products	Chlorine and oxides of sodium.
Suitable Extinguishing media	All

Precautions for firefighters and special protective clothing	Evacuate unnecessary personnel. Wear chemically resistant clothing. Wear self-contained breathing apparatus, rubber boots and heavy rubber gloves. Dilute with water spray to avoid oxidative decomposition. Intensifies fires and releases heat on decomposition. Reaction with strong acids liberates toxic gas (chlorine dioxide). Contain run off. Toxic to the aquatic environment. Contact with combustible materials may cause fire after impregnation and drying out.
HAZCHEM CODE	NA

Section 6. Accidental Release Measures

Land Spill or Leaks

Large spills should only be handled by appropriately trained personnel or the emergency services. Wear suitable PPE (see section 8 of this SDS). Avoid contact with skin or eyes. If possible and safe to do so, stop/cut off the source of the leak. Contain any released substance with suitable inert spill media (e.g. zeolite, kitty litter, sand. Recover if possible by pumping into suitable containers (HDPE). Transfer all solid spill residues into labeled hazardous waste containers. Do not allow spill residues to dry out. Clean contaminated surfaces with an excess of water. Wash clothing and equipment after handling. Dispose of spill residues using a licensed hazardous waste company.

Section 7. Handling and Storage

Safe handling and storage of this substance must comply with the requirements of the site and storage conditions for ecotoxic substances (copies available from the NZ EPA website www.epa.govt.nz).

See section 15 of this SDS for all HSNO Trigger quantities.

Precautions for safe handling :

- Handle in accordance with good industrial hygiene and safety procedures.
- Reduce/avoid exposure and/or contact.
- Remove contaminated clothing immediately.
- Clean contaminated clothing.
- Keep container tightly closed.
- Keep away from: Heat sources, acids, food and feedstuffs.
- Collect spillages

Conditions for safe storage:

- Store in a cool well ventilated place out of direct sunlight.
- Avoid storing with acids, chlorine, hypochlorite and organic solvents.
- Keep containers closed when not in use.

Section 8 Exposure Controls / Personal Protection

WORKPLACE EXPOSURE STANDARDS (provided for guidance only)

Substance	CAS # (a)	TWA ppm(b)	TWA mg/m3(c)	STEL ppm(b)	STEL mg/m3(c)
Chlorine Dioxide	[10049-04-4]	0.1	0.28	-	-

Workplace Exposure Standard – Time Weighted Average (WES-TWA). The time-weighted average exposure standard designed to protect the worker from the effects of long-term exposure. Workplace Exposure Standard – Short-Term Exposure Limit (WESSTEL). The 15-minute average exposure standard. Applies to any 15- Minute period in the working day and is designed to protect the worker against adverse effects of irritation, chronic or irreversible tissue change, or narcosis that may increase the likelihood of accidents. The WES-STEL is not an alternative to the WES-TWA; both the short-term and time-weighted average exposures apply. Workplace Exposure Standards and Biological Exposure Indices NOV 2019 11TH EDITION.

Engineering Controls:

- Work under local exhaust/ventilation.

Personal Protective Equipment:

- Where exposure through inhalation may occur the use of approved respiratory protection equipment is recommended
- Use chemically resistant goggles or face shield with safety glasses.
- Protective gloves apron, boots, head and face protection should be worn.
- Emergency eye wash fountains and safety showers should be available in the immediate vicinity of any potential exposure.
- Avoid all unnecessary exposure.
- Ensure prompt removal from eyes, skin and clothing.

General:
Use of safe work practices are recommended to avoid eye or skin contact and inhalation. Observe good personal hygiene, including washing hands before eating. Prohibit eating, drinking and smoking in contaminated areas. Avoid all personal contact, including inhalation. Wear protective clothing.

Section 9 Physical and Chemical Properties

Appearance	Yellow Liquid
Odour	Characteristic mild chlorine-like odour
Odour Threshold	Not applicable
pH	8-9
Decomposition temperature	>170^{o}C
Melting Point	Not applicable
Freezing Point	Not applicable
Flash Point	Not applicable
Flammability	Not applicable
Upper and Lower Exposure Limits	Not applicable
Vapour Pressure	Not applicable
Vapour Density	Not applicable
Specific Gravity	1.05 g/cm^3
Solubilities	Completely soluble in water.
Partition Coefficient:	Not applicable
Auto-ignition Temperature	Not applicable
Decomposition Temperature	Not applicable
Kinematic Viscosity	Not applicable
Particle Characteristics	Not applicable

Section 10. Stability and Reactivity

Stability of Substance	This product is stable when stored under recommended normal temperature and pressures.
Conditions to Avoid	Keep away from strong acids.
Incompatible Materials	Acids, chlorine, hypochlorite, organic solvents and organic compounds. Will react with strong acids to liberate toxic gas (chlorine dioxide).
Hazardous Decomposition Products	On heating may release toxic and corrosive gases/vapours.
Packaging materials and containers	Recommended: Polyester, polyethylene, stainless steel, (small quantities: glass). Not recommended: Steel, Copper, Copper and its alloys, Aluminium and its alloys, rubber.

Section 11 Toxicological Information

Acute Effects:

Swallowed	Not applicable.
Dermal	Not applicable.
Inhalation	Not applicable.
Eye	Causes severe irritation to eyes
Skin	Causes skin irritation.

Chronic Effects:

Carcinogenicity	Not applicable.
Reproductive Toxicity	Suspected of damaging fertility or the unborn child.
Germ Cell Mutagenicity	Not applicable.
Aspiration	Not applicable.
STOT/SE	Not applicable.
STOT/RE	Not applicable.

Acute toxicity (calculated)

Oral	>5000mg/kg bw (Rat)
Dermal	>5000 mg/kg bw
Inhalation	>5 mg/l (mist)

Section 12. Ecotoxicological Information

HSNO Ecotoxicity Classifications: 9.1C = Harmful to aquatic life with harmful effects.
9.2C = Harmful to the soil environment.

Environmental hazards

This substance in its undiluted form is harmful to fish and harmful in the soil environment. Do not discharge effluent containing this product into lakes, streams, rivers, ponds, oceans or other natural waters unless in accordance with local bylaws or unless you have a permit to do so. Do not discharge effluent containing this product into sewer systems unless you have a permit to do so. For guidance contact your local authority.

Environmental Precautions: Avoid release to the environment.

Individual component toxicity data.

Sodium chlorite solution :

SPECIES: Daphnia magna (Water flea)
TYPE OF EXPOSURE: Static
DURATION: 48 hr
ENDPOINT: EC50 (Intoxiciation)
VALUE: 0.0146, 0.012 - 0.018 PPM (= 0.0146 mg/l)
Bioccumulative: ND
Rapidly Degradable: Yes

SPECIES: Selenastrum capricornutum (Green algae)
TYPE OF EXPOSURE: Static
DURATION: 96 hr
ENDPOINT: EC50 (Intoxication)
VALUE: 1.32, 1.18 - 1.47 ppm (= 1.32 mg/l)
Bioccumulative: ND
Rapidly Degradable: Yes

SPECIES: Cyprinodon variegatus (Sheepshead minnow)
TYPE OF EXPOSURE: Flow-through
DURATION: 96 hr
ENDPOINT: LC50 (Mortality)
VALUE: 75 PPM (= 75 mg/l)
Bioccumulative: ND
Rapidly Degradable: Yes

SPECIES: Activated sludge, domestic
ENDPOINT: EC50
VALUE: 2.2 mg/l
Soil DT 50 > 30 days: ND

SPECIES: Rat

ENDPOINT: LD50
VALUE: 165 mg/kg

Lauryl Dimethylamine oxide

9.1A (fish) REMARK: Refer to CAS # 112-18-5.

Bioccumulative: Yes
Rapidly Degradable: Yes

CAS #: 1643-20-5 N,N-DODECYLDIMETHYLAMINE OXIDE
Parameter Type : Screening Test Study Biodeg Eval: BF
Rate : 96 Units : %
DEGRADATION Oxygen Condition: AEROBIC
Incub Time (days): 19 Chem Conc (ppm): 5 Inoculum : SEWAGE Temp (deg C) : 25

Environmental Exposure Limits : No EEL's are set.

Section 13. Disposal Considerations

Waste information: Removal of residues: - Remove as a hazardous waste according to local and national regulations.

Polluted packaging: Remove as a waste according to local and national regulations.

Provisions relating to waste:

Disposal methods: Triple rinse container and add rinsing's to mixing vessel. Puncture empty container before disposal to landfill. Unwanted material should be disposed of as a hazardous waste via a licenced waste disposal company. Dispose of spills and residues as a hazardous

Precautions or methods to avoid: Avoid release to the environment.

Section 14 Transport Information

This product is not classified as a Dangerous Good for transport in NZ ; NZS 5433:2012

Section 15 Regulatory Information

EPA Approval Code: HSR002530 Cleaning Products (Subsidiary Hazard) Group Standard

HSNO Classification: 6.3A, 6.4A, 6.8A, 9.1C, 9.2C

HSW (HS) Regulations 2017 and EPA Notices	Trigger Quantity
Certified Handler	Not required
Location Certificate	Not required
Tracking Trigger Quantities	Not required
Signage Trigger Quantities	1000L (9.1C)
Emergency Response Plan	1000L (9.1C)
Secondary Containment	1000L (9.1C)
Restriction of Use	Only use for the intended purpose.

Section 16 Other Information

Glossary

EC_{50} Median effective concentration.
EEL Environmental Exposure Limit.
EPA Environmental Protection Authority
HSNO Hazardous Substances and New Organisms.
HSW Health and Safety at Work.

LC_{50}	Lethal concentration that will kill 50% of the test organisms	inhaling or ingesting it.
LD_{50}	Lethal dose to kill 50% of test animals/organisms.	
LEL	Lower explosive level.	
OSHA	American Occupational Safety and Health Administration.	
TEL	Tolerable Exposure Limit.	
TLV	Threshold Limit Value-an exposure limit set by responsible	authority.
UEL	Upper Explosive Level	
WES	Workplace Exposure Limit	

References:

1. EPA Hazardous Substances (Safety Data Sheets) Notice 2017
2. Workplace Exposure Standards and Biological Exposure Indices Nov 2017 edition.
3. Assigning a hazardous substance to a HSNO Approval (Aug 2013).
4. Transport of Dangerous goods on land NZS 5433:2012
5. HSW (Hazardous Substances) Regulations 2017

Issue Date: 7 April 2020 Review Date: 7 April 2025

Appendix D – Odour Neutralising ambient air quality tests

BIOX INTERNATIONAL LTD

AIR MATTERS REPORT 17048

Sampling for chlorine dioxide for Auckland City Rail Link – Enabling Works Contract 2

Victoria 2 shaft during dosing with chlorine dioxide mist.

Sampling dates:	21-24 March 2017
Report Date:	7/4/2017

Report prepared for Biox International Ltd by Air Matters Limited.

Report written by:

Carol McSweeney

Principal

Air Matters Report:	17048
Date:	7/04/2017
Status:	Final

Table of Contents

1. OBJECTIVES

1. To measure chlorine dioxide in air in two locations around the shaft at the Victoria Street works (Auckland City Rail Link – Enabling Works Contract 2)
   - At the base of the excavation works where operators work (in the breathing zone)
   - At ground level where operators are working around the top of the shaft
2. Report all findings. Compare data with occupational exposure and threshold limits set out by WorkSafe New Zealand and other international agencies if appropriate as part of the assessment of exposure risk.

2. INTRODUCTION

Biox International Ltd requested sampling within the Victoria No 2 shaft (Auckland City Rail Link – Enabling Works Contract 2) for chlorine dioxide. A misting system has been set up in this shaft to release a fine mist of chlorine dioxide. This is designed to act as an odour control in the shaft by oxidising any odours produced from work on the combined stormwater / sewer system at the base of the shaft. The system is set up around the shaft at approximately 10metres from the top. Ventilation in the shaft is designed to bring air from the bottom to the top of the shaft.

Chlorine dioxide has known health effects at certain doses and operators working at the base of the shaft raised concerns about the use of chlorine dioxide in the misting system. A request was made to obtain data on the concentration of chlorine dioxide in the air, particularly at the base of the shaft and carry out some risk assessment using this measured concentration.

Chlorine dioxide misting has not been approved for use during working shifts so sampling for the purpose of collecting data of chlorine dioxide concentrations during misting was conducted at night after the work shift was finished.

3. METHODOLOGY

Real time monitors were selected as an appropriate method to measure concentrations of chlorine dioxide. This method provides continuous monitoring and the monitors were set up overnight while the chlorine dioxide mist was applied. Two MX6 iBrid monitors fitted with chlorine dioxide electrochemical cells were used. The monitor has a range of 0-1ppm chlorine dioxide and a resolution of 0.01ppm. This is within the range of the workplace exposure standard, which is 0.1ppm. Chlorine gas is a known interference. Although the resolution is 0.01ppm, electrochemical cells are known to drift at the bottom of the range. Levels of 0.01ppm may not be accurate.

Two monitors were supplied by Entec New Plymouth (Sn13033MI-005 and 08111ek-011) and both were calibrated on 17/3/2017. (Calibration certificates are available on request)

4. WORKPLACE EXPOSURE STANDARDS

Workplace Exposure Standards (WES) can only be used as guidelines in making decisions regarding safe levels of exposure to various chemical agents found in the workplace. The standards are based on available information and suggest a level of exposure that the typical worker can experience without adverse health effects. There is no fine line between safe and dangerous exposures and the recommendation of agencies publishing these figures is that the concentrations should be kept as low as possible.

Compliance with the designated values does not guarantee protection from discomfort or possible ill health for workers. Individual susceptibility and exposure outside the workplace may lead to a varying response. More importantly there is an expectation in the legislation that employee exposure to hazardous substances will be controlled to a level as far below the relevant WES as practicable by applying the hierarchy of control required by the Health and Safety at Work Act 2015.

The results below are compared against the Workplace Exposure Standards (WES). For chlorine dioxide the WES is a time weighted average for an 8 hour shift. The method used for this study means that the results may not be directly compared against the standard as monitors were not set up on operators. However it is possible to calculate a WES TWA from real time monitors and an assessment of risk can be made using the WES as a guideline.

The 8 hr time weighted workplace exposure standard for chlorine dioxide is 0.1ppm.

The Workplace Exposure Standard should be viewed considering the comments above.

5. OPERATING CONDITIONS

Monitors were set up over 3 nights, one at the top of the shaft in the area of the ground level operators and one at the base of the shaft at approximately breathing height in the area where operators work during the day shift. There were no operators working over the misting and monitoring time as the exposure risk to the chlorine dioxide in the misting system had not been assessed.

The ventilation fan was operational during the time of sampling

Table 1 below summarises the sampling times and misting operation.

Table 1: Sampling programme

	Misting and sampling programme
21/3/2017 (PM)	Monitors on at 16:40 Misting turned on at 17:30
22/3/2017 (AM)	Misting off at 07:00 Monitor off at 08:10
22/3/2017 (PM)	Monitor on 14:30 Misting on 15:50
23/3/2017 (AM)	Misting not working at 06:30 Misting pump turned off 07:00 Monitors off
23/3/2007 (PM)	Monitors and misting system turned on at 16:30
24/3/2017	Monitors and misting system turned off at 07:00

6. RESULTS

The two figures below, Figure 1 and Figure 2, show the average chlorine dioxide concentrations over the misting period on the night of Tuesday 21-22 March 2017.

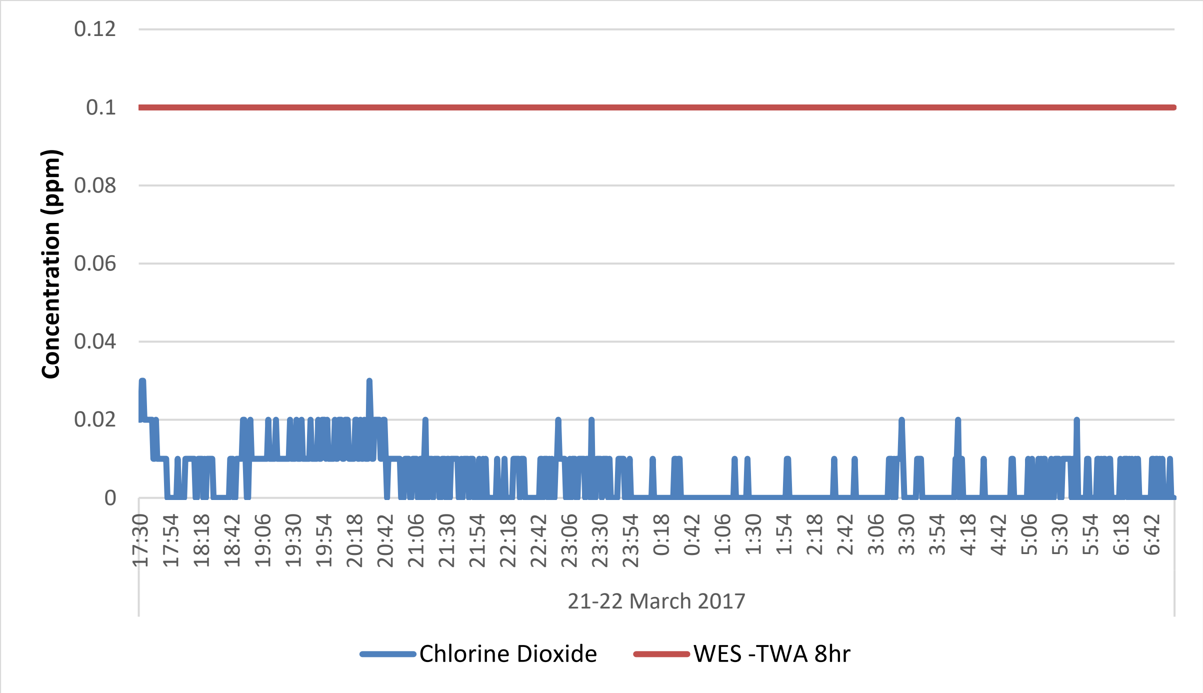


Figure 1: Chlorine dioxide concentrations on night of 21-22/3/2017 at the top of the shaft with comparison against the WES

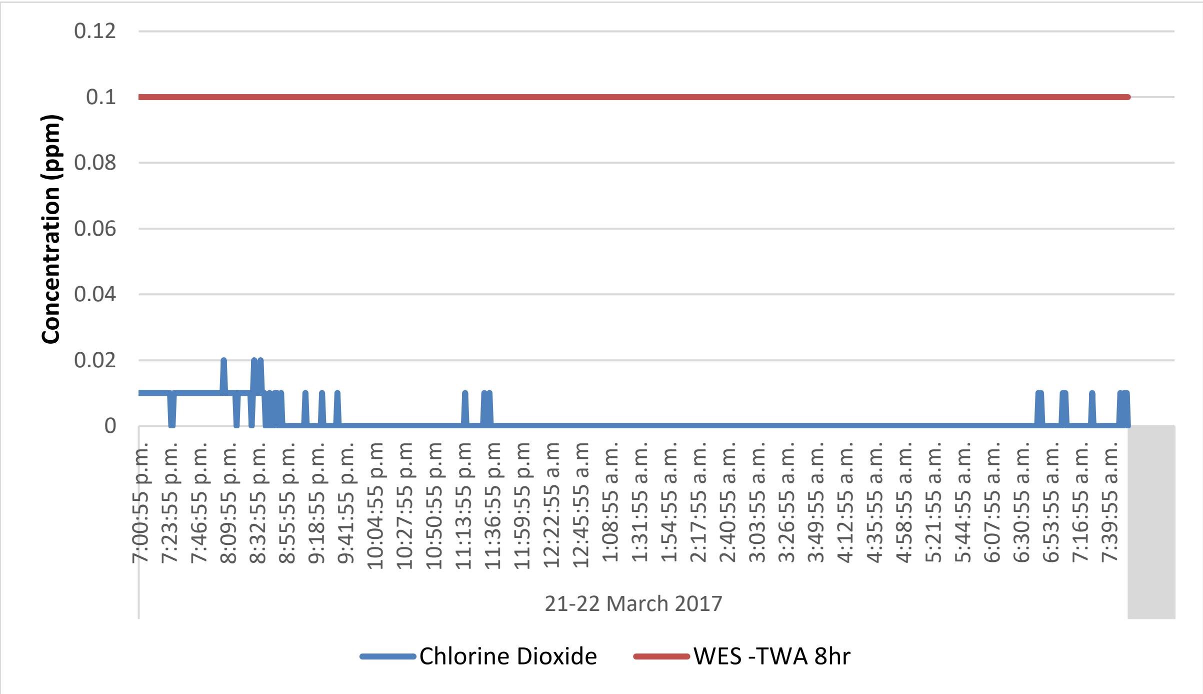


Figure 2: Chlorine dioxide concentrations on night of 21-22/3/2017 at the base of the shaft with comparison against the WES

The two figures below, Figure 3 and Figure 4, show the average chlorine dioxide concentrations over the misting period on the night of Wednesday 22-23 March2017.

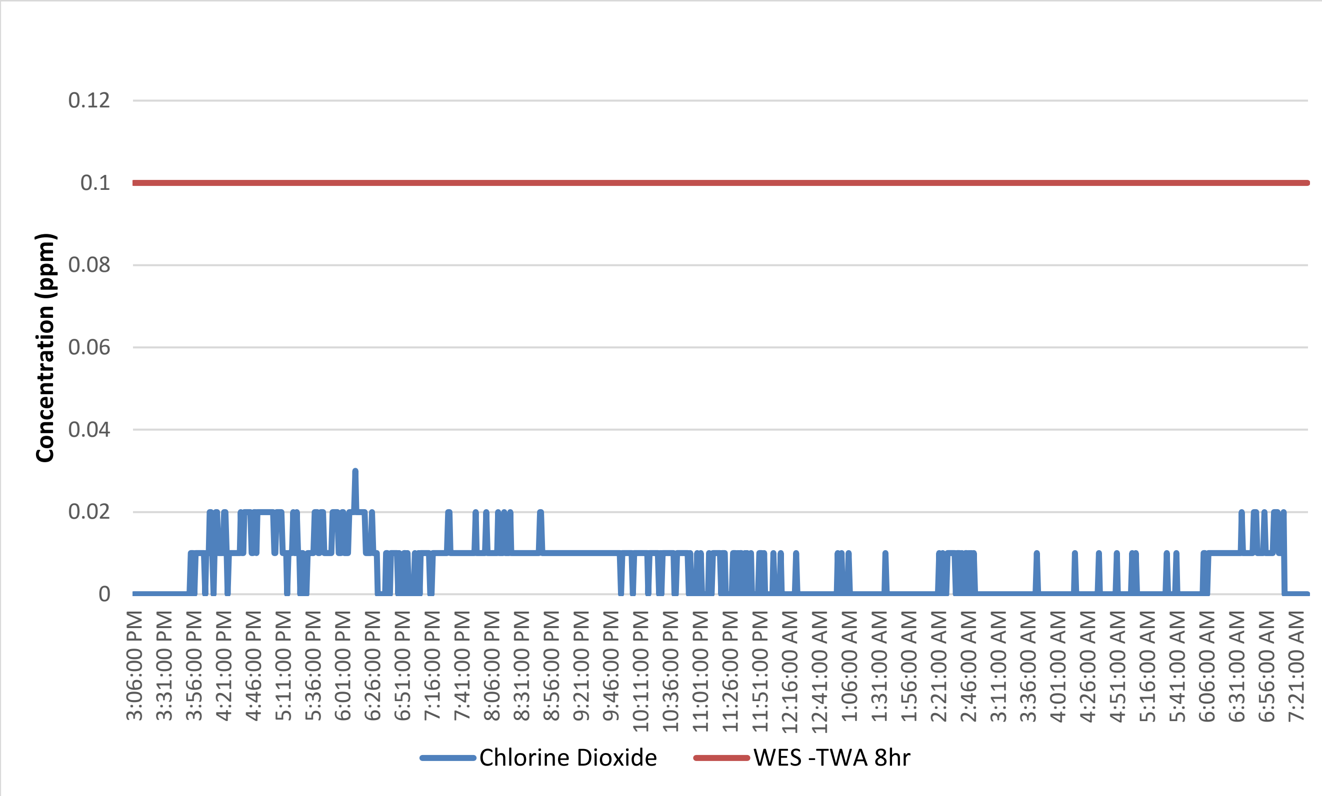


Figure 3: Chlorine dioxide concentrations on night of 22-23/3/2017 at the top of the shaft with comparison against the WES

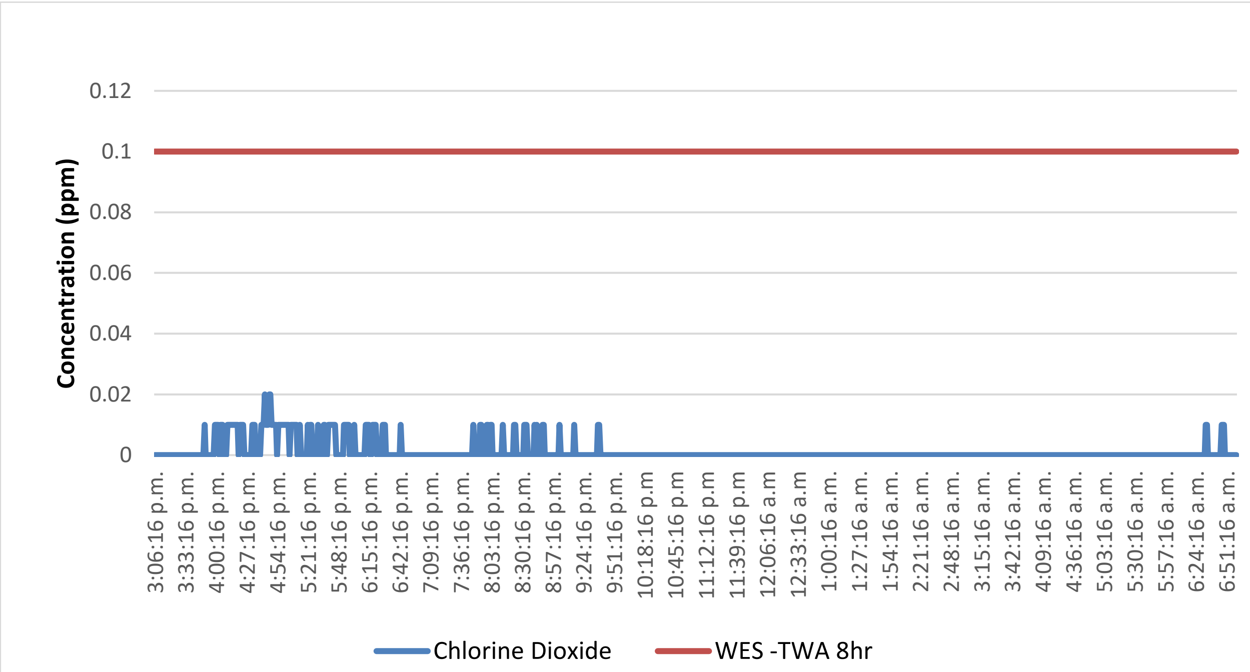


Figure 4: Chlorine dioxide concentrations on night of 22-23/3/2017 at the base of the shaft with comparison against the WES

The two figures below, Figure 5 and Figure 6, show the average chlorine dioxide concentrations over the misting period on the night of Wednesday 22-23 March2017.

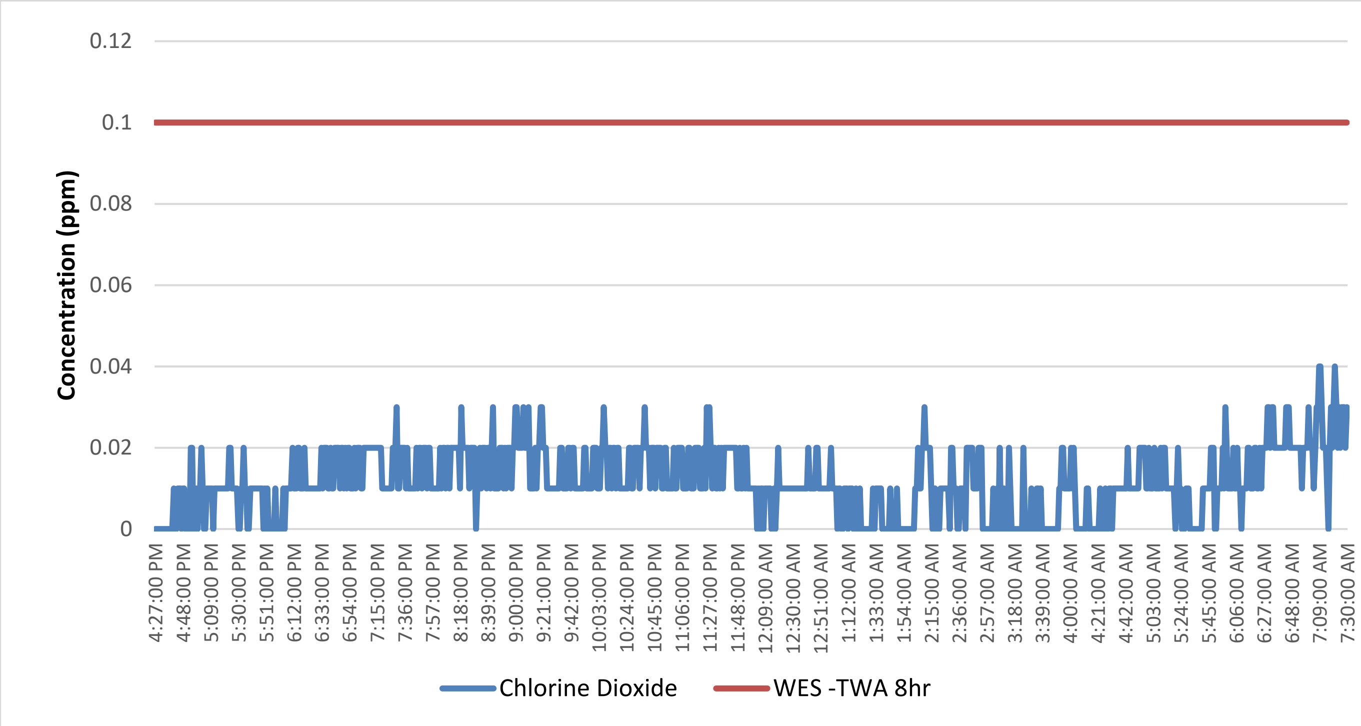


Figure 5: Chlorine dioxide concentrations on night of 23-24/3/2017 at the top of the shaft with comparison against the WES

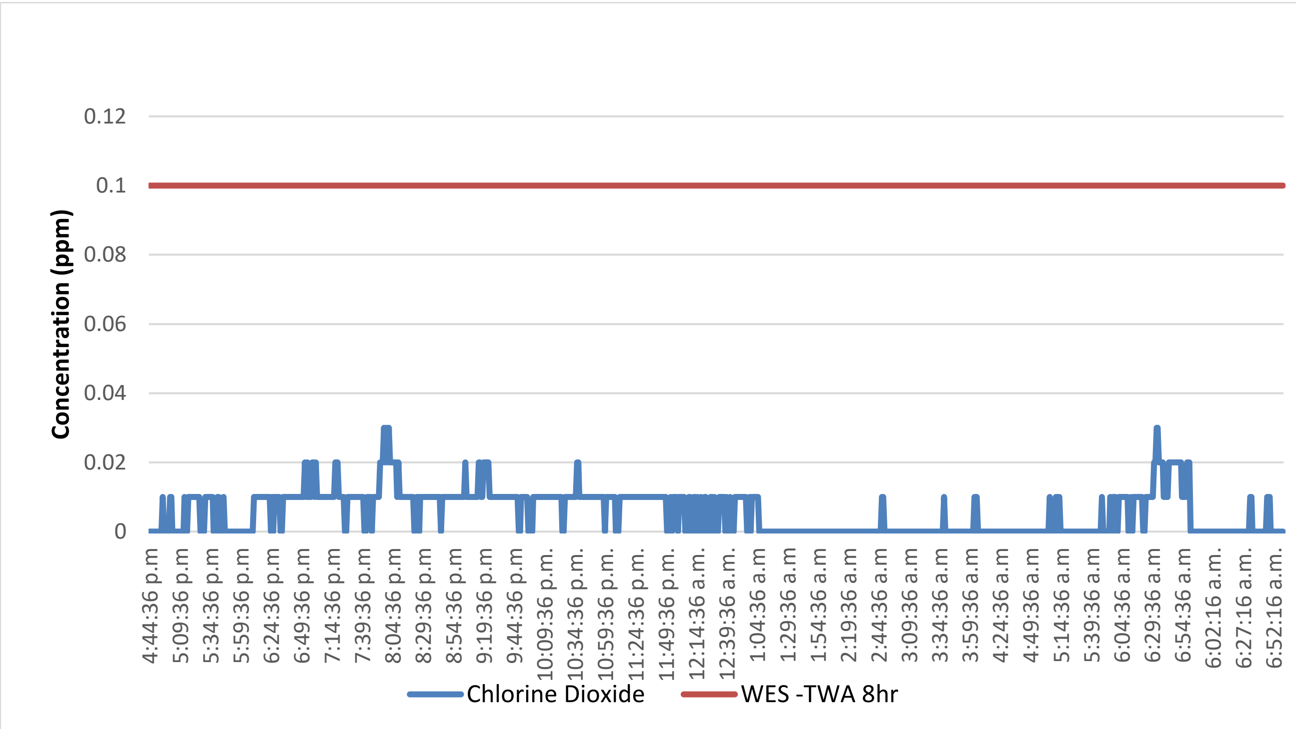


Figure 6: Chlorine dioxide concentrations on night of 23-24/3/2017 at the base of the shaft with comparison against the WES

Background levels of chlorine dioxide were measured when the monitors were operated across the three days of sampling before the chlorine dioxide misting as turned on (or after it was turned off). The background levels were 0ppm. During the background sampling the monitor occasionally read 0.1ppm for short periods. However, this is a factor of the electrochemical cell drifting at the low end of the range as has been discussed.

7. DISCUSSION

The three nights of sampling showed a similar pattern of chlorine dioxide concentrations in air. The monitors provided a 1 minute average across the sampling time. The 1 minute average concentrations overall were not detectable (less than 0.01ppm) for much or the time or low (less than 0.04ppm), with those at the top of the shaft being slightly higher (with short peaks of 0.03-0.04ppm) than the concentrations at the base of the shaft where there were occasional peaks of only 0.02ppm.

Electrochemical cells are not always accurate at the bottom of the range and measurements of 0.01ppm have a significant margin of error. For measurements of 0.02ppm and above, the margin of error is reduced.

8. CONCLUSION

The levels of chlorine dioxide measured at the site, both at ground level and at the base of the shaft, were low. The levels are well below the workplace exposure standard which is 0.1ppm averaged over an 8 hour. The calculated 8 hour average for all samples is well below 0.01ppm (more than 10 times lower than the workplace exposure standard).

The risk of exposure to chlorine dioxide at levels that is likely to cause health effects (with the use of the misting system set at the current dosing levels and with the ventilation fans in use) is very low both at ground level and at the base of the shaft.

9. REFERENCES

1. Health and Safety at Work Act, 2015.
1. Workplace Exposure Standards for New Zealand, 2016, WorkSafe New Zealand.
2. National Institute for Occupational Safety and Health (NIOSH), Manual of Analytical Methods (NMAM), Fourth Edition, August 1994.
3. Methods for the Determination of Hazardous Substances (MDHS) Health and Safety Executive. Third Edition 1999.

Appendix E - Section 92 response modelling inputs

CALPUFF Parameters

INPUT GROUP: 0 -- Input and Output File Names		
Parameter	**Description**	**Value**
PUFLST	CALPUFF output list file (CALPUFF.LST)	CALPUFF.LST
CONDAT	CALPUFF output concentration file (CONC.DAT)	CONC.DAT
DFDAT	CALPUFF output dry deposition flux file (DFLX.DAT)	DFLX.DAT
WFDAT	CALPUFF output wet deposition flux file (WFLX.DAT)	WFLX.DAT
LCFILES	Lower case file names (T = lower case, F = upper case)	F
NMETDOM	Number of CALMET.DAT domains	1
NMETDAT	Number of CALMET.DAT input files	12
NPTDAT	Number of PTEMARB.DAT input files	0
NARDAT	Number of BAEMARB.DAT input files	0
NVOLDAT	Number of VOLEMARB.DAT input files	0
NFLDAT	Number of FLEMARB.DAT input files	0
NRDDAT	Number of RDEMARB.DAT input files	0
NLNDAT	Number of LNEMARB.DAT input files	0
METDAT	CALMET gridded meteorological data file (CALMET.DAT)	CALMET_2019-01-01-00-0000-2019-01-31-00-0000.DAT
METDAT	CALMET gridded meteorological data file (CALMET.DAT)	CALMET_2019-01-31-00-0000-2019-03-03-00-0000.DAT
METDAT	CALMET gridded meteorological data file (CALMET.DAT)	CALMET_2019-03-03-00-0000-2019-04-02-00-0000.DAT
METDAT	CALMET gridded meteorological data file (CALMET.DAT)	CALMET_2019-04-02-00-0000-2019-05-03-00-0000.DAT
METDAT	CALMET gridded meteorological data file (CALMET.DAT)	CALMET_2019-05-03-00-0000-2019-06-02-00-0000.DAT
METDAT	CALMET gridded meteorological data file (CALMET.DAT)	CALMET_2019-06-02-00-0000-2019-07-02-00-0000.DAT
METDAT	CALMET gridded meteorological data file (CALMET.DAT)	CALMET_2019-07-02-00-0000-2019-08-02-00-0000.DAT
METDAT	CALMET gridded meteorological data file (CALMET.DAT)	CALMET_2019-08-02-00-0000-2019-09-01-00-0000.DAT
METDAT	CALMET gridded meteorological data file (CALMET.DAT)	CALMET_2019-09-01-00-0000-2019-10-02-00-0000.DAT

INPUT GROUP: 0 -- Input and Output File Names		
Parameter	**Description**	**Value**
METDAT	CALMET gridded meteorological data file (CALMET.DAT)	CALMET_2019-10-02-00-0000-2019-11-01-00-0000.DAT
METDAT	CALMET gridded meteorological data file (CALMET.DAT)	CALMET_2019-11-01-00-0000-2019-12-02-00-0000.DAT
METDAT	CALMET gridded meteorological data file (CALMET.DAT)	CALMET_2019-12-02-00-0000-2020-01-01-00-0000.DAT

INPUT GROUP: 1 -- General Run Control Parameters		
Parameter	**Description**	**Value**
METRUN	Run all periods in met data file? (0 = no, 1 = yes)	0
IBYR	Starting year	2019
IBMO	Starting month	1
IBDY	Starting day	1
IBHR	Starting hour	0
IBMIN	Starting minute	0
IBSEC	Starting second	0
IEYR	Ending year	2020
IEMO	Ending month	1
IEDY	Ending day	1
IEHR	Ending hour	0
IEMIN	Ending minute	0
IESEC	Ending second	0
ABTZ	Base time zone	UTC+1200
NSECDT	Length of modeling time-step (seconds)	3600
NSPEC	Number of chemical species modeled	4
NSE	Number of chemical species to be emitted	4
ITEST	Stop run after SETUP phase (1 = stop, 2 = run)	2
MRESTART	Control option to read and/or write model restart data	0
NRESPD	Number of periods in restart output cycle	0
METFM	Meteorological data format (1 = CALMET, 2 = ISC, 3 = AUSPLUME, 4 = CTDM, 5 = AERMET)	1
MPRFFM	Meteorological profile data format (1 = CTDM, 2 = AERMET)	1
AVET	Averaging time (minutes)	60
PGTIME	PG Averaging time (minutes)	60
IOUTU	Output units for binary output files (1 = mass, 2 = odour, 3 = radiation)	1

INPUT GROUP: 2 -- Technical Options		
Parameter	**Description**	**Value**

INPUT GROUP: 2 -- Technical Options		
Parameter	**Description**	**Value**
MGAUSS	Near field vertical distribution (0 = uniform, 1 = Gaussian)	1
MCTADJ	Terrain adjustment method (0 = none, 1 = ISC-type, 2 = CALPUFF-type, 3 = partial plume path)	3
MCTSG	Model subgrid-scale complex terrain? (0 = no, 1 = yes)	0
MSLUG	Near-field puffs modeled as elongated slugs? (0 = no, 1 = yes)	0
MTRANS	Model transitional plume rise? (0 = no, 1 = yes)	1
MTIP	Apply stack tip downwash to point sources? (0 = no, 1 = yes)	1
MRISE	Plume rise module for point sources (1 = Briggs, 2 = numerical)	1
MTIP_FL	Apply stack tip downwash to flare sources? (0 = no, 1 = yes)	0
MRISE_FL	Plume rise module for flare sources (1 = Briggs, 2 = numerical)	2
MBDW	Building downwash method (1 = ISC, 2 = PRIME)	2
MSHEAR	Treat vertical wind shear? (0 = no, 1 = yes)	0
MSPLIT	Puff splitting allowed? (0 = no, 1 = yes)	0
MCHEM	Chemical transformation method (0 = not modeled, 1 = MESOPUFF II, 2 = User-specified, 3 = RIVAD/ARM3, 4 = MESOPUFF II for OH, 5 = half-life, 6 = RIVAD w/ISORROPIA, 7 = RIVAD w/ISORROPIA CalTech SOA)	0
MAQCHEM	Model aqueous phase transformation? (0 = no, 1 = yes)	0
MLWC	Liquid water content flag	1
MWET	Model wet removal? (0 = no, 1 = yes)	0
MDRY	Model dry deposition? (0 = no, 1 = yes)	0
MTILT	Model gravitational settling (plume tilt)? (0 = no, 1 = yes)	0
MDISP	Dispersion coefficient calculation method (1= PROFILE.DAT, 2 = Internally, 3 = PG/MP, 4 = MESOPUFF II, 5 = CTDM)	2
MTURBVW	Turbulence characterization method (only if MDISP = 1 or 5)	3
MDISP2	Missing dispersion coefficients method (only if MDISP = 1 or 5)	3
MTAULY	Sigma-y Lagrangian timescale method	0
MTAUADV	Advective-decay timescale for turbulence (seconds)	0
MCTURB	Turbulence method (1 = CALPUFF, 2 = AERMOD)	1
MROUGH	PG sigma-y and sigma-z surface roughness adjustment? (0 = no, 1 = yes)	0
MPARTL	Model partial plume penetration for point sources? (0 = no, 1 = yes)	1
MPARTLBA	Model partial plume penetration for buoyant area sources? (0 = no, 1 = yes)	0
MTINV	Strength of temperature inversion provided in PROFILE.DAT? (0 = no - compute from default gradients, 1 = yes)	0
MPDF	PDF used for dispersion under convective conditions? (0 = no, 1 = yes)	1
MSGTIBL	Sub-grid TIBL module for shoreline? (0 = no, 1 = yes)	0
MBCON	Boundary conditions modeled? (0 = no, 1 = use BCON.DAT, 2 = use CONC.DAT)	0
MSOURCE	Save individual source contributions? (0 = no, 1 = yes)	0
MFOG	Enable FOG model output? (0 = no, 1 = yes - PLUME mode, 2 = yes - RECEPTOR mode)	0
MREG	Regulatory checks (0 = no checks, 1 = USE PA LRT checks)	0

INPUT GROUP: 3 -- Species List		
Parameter	**Description**	**Value**
CSPEC	Species included in model run	SO2
CSPEC	Species included in model run	NOX
CSPEC	Species included in model run	CO
CSPEC	Species included in model run	PM10

INPUT GROUP: 4 -- Map Projection and Grid Control Parameters		
Parameter	**Description**	**Value**
PMAP	Map projection system	UTM
FEAST	False easting at projection origin (km)	0.0
FNORTH	False northing at projection origin (km)	0.0
IUTMZN	UTM zone (1 to 60)	59
UTMHEM	Hemisphere (N = northern, S = southern)	S
RLAT0	Latitude of projection origin (decimal degrees)	0.00N
RLON0	Longitude of projection origin (decimal degrees)	0.00E
XLAT1	1st standard parallel latitude (decimal degrees)	30S
XLAT2	2nd standard parallel latitude (decimal degrees)	60S
DATUM	Datum-region for the coordinates	WGS-84
NX	Meteorological grid - number of X grid cells	30
NY	Meteorological grid - number of Y grid cells	30
NZ	Meteorological grid - number of vertical layers	10
DGRIDKM	Meteorological grid spacing (km)	0.2
ZFACE	Meteorological grid - vertical cell face heights (m)	0.0, 20.0, 40.0, 80.0, 160.0, 320.0, 640.0, 1200.0, 2000.0, 3000.0, 4000.0
XORIGKM	Meteorological grid - X coordinate for SW corner (km)	294.6796
YORIGKM	Meteorological grid - Y coordinate for SW corner (km)	4885.1506
IBCOMP	Computational grid - X index of lower left corner	1
JBCOMP	Computational grid - Y index of lower left corner	1
IECOMP	Computational grid - X index of upper right corner	30
JECOMP	Computational grid - Y index of upper right corner	30
LSAMP	Use sampling grid (gridded receptors) (T = true, F = false)	F
IBSAMP	Sampling grid - X index of lower left corner	1
JBSAMP	Sampling grid - Y index of lower left corner	1
IESAMP	Sampling grid - X index of upper right corner	2
JESAMP	Sampling grid - Y index of upper right corner	2
MESHDN	Sampling grid - nesting factor	1

INPUT GROUP: 5 -- Output Options		
Parameter	**Description**	**Value**

INPUT GROUP: 5 -- Output Options		
Parameter	**Description**	**Value**
ICON	Output concentrations to CONC.DAT? (0 = no, 1 = yes)	1
IDRY	Output dry deposition fluxes to DFLX.DAT? (0 = no, 1 = yes)	0
IWET	Output wet deposition fluxes to WFLX.DAT? (0 = no, 1 = yes)	0
IT2D	Output 2D temperature data? (0 = no, 1 = yes)	0
IRHO	Output 2D density data? (0 = no, 1 = yes)	0
IVIS	Output relative humidity data? (0 = no, 1 = yes)	0
LCOMPRS	Use data compression in output file (T = true, F = false)	T
IQAPLOT	Create QA output files suitable for plotting? (0 = no, 1 = yes)	1
IPFTRAK	Output puff tracking data? (0 = no, 1 = yes use timestep, 2 = yes use sampling step)	0
IMFLX	Output mass flux across specific boundaries? (0 = no, 1 = yes)	0
IMBAL	Output mass balance for each species? (0 = no, 1 = yes)	0
INRISE	Output plume rise data? (0 = no, 1 = yes)	0
ICPRT	Print concentrations? (0 = no, 1 = yes)	0
IDPRT	Print dry deposition fluxes? (0 = no, 1 = yes)	0
IWPRT	Print wet deposition fluxes? (0 = no, 1 = yes)	0
ICFRQ	Concentration print interval (timesteps)	1
IDFRQ	Dry deposition flux print interval (timesteps)	1
IWFRQ	Wet deposition flux print interval (timesteps)	1
IPRTU	Units for line printer output (e.g., 3 = ug/m**3 - ug/m**2/s, 5 = odor units)	3
IMESG	Message tracking run progress on screen (0 = no, 1 and 2 = yes)	2
LDEBUG	Enable debug output? (0 = no, 1 = yes)	F
IPFDEB	First puff to track in debug output	1
NPFDEB	Number of puffs to track in debug output	1000
NN1	Starting meteorological period in debug output	1
NN2	Ending meteorological period in debug output	10

INPUT GROUP: 6 -- Subgrid Scale Complex Terrain Inputs		
Parameter	**Description**	**Value**
NHILL	Number of terrain features	0
NCTREC	Number of special complex terrain receptors	0
MHILL	Terrain and CTSG receptor data format (1= CTDM, 2 = OPTHILL)	2
XHILL2M	Horizontal dimension conversion factor to meters	1.0
ZHILL2M	Vertical dimension conversion factor to meters	1.0
XCTDMKM	X origin of CTDM system relative to CALPUFF system (km)	0.0
YCTDMKM	Y origin of CTDM system relative to CALPUFF system (km)	0.0

INPUT GROUP: 9 -- Miscellaneous Dry Deposition Parameters		
Parameter	**Description**	**Value**

INPUT GROUP: 9 -- Miscellaneous Dry Deposition Parameters		
Parameter	**Description**	**Value**
RCUTR	Reference cuticle resistance (s/cm)	30
RGR	Reference ground resistance (s/cm)	10
REACTR	Reference pollutant reactivity	8
NINT	Number of particle size intervals for effective particle deposition velocity	9
IVEG	Vegetation state in unirrigated areas (1 = active and unstressed, 2 = active and stressed, 3 = inactive)	1

INPUT GROUP: 11 -- Chemistry Parameters		
Parameter	**Description**	**Value**
MOZ	Ozone background input option (0 = monthly, 1 = hourly from OZONE.DAT)	1
BCKO3	Monthly ozone concentrations (ppb)	80.00, 80.00, 80.00, 80.00, 80.00, 80.00, 80.00, 80.00, 80.00, 80.00, 80.00, 80.00
MNH3	Ammonia background input option (0 = monthly, 1 = from NH3Z.DAT)	0
MAVGNH3	Ammonia vertical averaging option (0 = no average, 1 = average over vertical extent of puff)	1
BCKNH3	Monthly ammonia concentrations (ppb)	10.00, 10.00, 10.00, 10.00, 10.00, 10.00, 10.00, 10.00, 10.00, 10.00, 10.00, 10.00
RNITE1	Nighttime SO2 loss rate (%/hr)	0.2
RNITE2	Nighttime NOx loss rate (%/hr)	2
RNITE3	Nighttime HNO3 loss rate (%/hr)	2
MH2O2	H2O2 background input option (0 = monthly, 1 = hourly from H2O2.DAT)	1
BCKH2O2	Monthly H2O2 concentrations (ppb)	1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00
RH_ISRP	Minimum relative humidity for ISORROPIA	50.0
SO4_ISRP	Minimum SO4 for ISORROPIA	0.4
BCKPMF	SOA background fine particulate (ug/m**3)	1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00
OFRAC	SOA organic fine particulate fraction	0.15, 0.15, 0.20, 0.20, 0.20, 0.20, 0.20, 0.20, 0.20, 0.20, 0.20, 0.15
VCNX	SOA VOC/NOX ratio	50.00, 50.00, 50.00, 50.00, 50.00, 50.00, 50.00, 50.00, 50.00, 50.00, 50.00, 50.00
NDECAY	Half-life decay blocks	0

INPUT GROUP: 12 -- Misc. Dispersion and Computational Parameters		
Parameter	**Description**	**Value**
SYTDEP	Horizontal puff size for time-dependent sigma equations (m)	550

INPUT GROUP: 12 -- Misc. Dispersion and Computational Parameters		
Parameter	**Description**	**Value**
MHFTSZ	Use Heffter equation for sigma-z? (0 = no, 1 = yes)	0
JSUP	PG stability class above mixed layer	5
CONK1	Vertical dispersion constant - stable conditions	0.01
CONK2	Vertical dispersion constant - neutral/unstable conditions	0.1
TBD	Downwash scheme transition point option (<0 = Huber-Snyder, 1.5 = Schulman-Scire, 0.5 = ISC)	0.5
IURB1	Beginning land use category for which urban dispersion is assumed	10
IURB2	Ending land use category for which urban dispersion is assumed	19
ILANDUIN	Land use category for modeling domain	20
Z0IN	Roughness length for modeling domain (m)	.25
XLAIIN	Leaf area index for modeling domain	3.0
ELEVIN	Elevation above sea level (m)	.0
XLATIN	Meteorological station latitude (deg)	-999.0
XLONIN	Meteorological station longitude (deg)	-999.0
ANEMHT	Anemometer height (m)	10.0
ISIGMAV	Lateral turbulence format (0 = read sigma-theta, 1 = read sigma-v)	1
IMIXCTDM	Mixing heights read option (0 = predicted, 1 = observed)	0
XMXLEN	Slug length (met grid units)	1
XSAMLEN	Maximum travel distance of a puff/slug (met grid units)	1
MXNEW	Maximum number of slugs/puffs release from one source during one time step	99
MXSAM	Maximum number of sampling steps for one puff/slug during one time step	99
NCOUNT	Number of iterations used when computing the transport wind for a sampling step that includes gradual rise	2
SYMIN	Minimum sigma-y for a new puff/slug (m)	1
SZMIN	Minimum sigma-z for a new puff/slug (m)	1
SZCAP_M	Maximum sigma-z allowed to avoid numerical problem in calculating virtual time or distance (m)	5000000
SVMIN	Minimum turbulence velocities sigma-v (m/s)	0.5, 0.5, 0.5, 0.5, 0.5, 0.5, 0.37, 0.37, 0.37, 0.37, 0.37, 0.37
SWMIN	Minimum turbulence velocities sigma-w (m/s)	0.2, 0.12, 0.08, 0.06, 0.03, 0.016, 0.2, 0.12, 0.08, 0.06, 0.03, 0.016
CDIV	Divergence criterion for dw/dz across puff (1/s)	0, 0
NLUTIBL	TIBL module search radius (met grid cells)	4
WSCALM	Minimum wind speed allowed for non-calm conditions (m/s)	0.5
XMAXZI	Maximum mixing height (m)	3000
XMINZI	Minimum mixing height (m)	50
TKCAT	Emissions scale-factors temperature categories (K)	265., 270., 275., 280., 285., 290., 295., 300., 305., 310., 315.

INPUT GROUP: 12 -- Misc. Dispersion and Computational Parameters		
Parameter	**Description**	**Value**
PLX0	Wind speed profile exponent for stability classes 1 to 6	0.07, 0.07, 0.1, 0.15, 0.35, 0.55
PTG0	Potential temperature gradient for stable classes E and F (deg K/m)	0.02, 0.035
PPC	Plume path coefficient for stability classes 1 to 6	0.5, 0.5, 0.5, 0.5, 0.35, 0.35
SL2PF	Slug-to-puff transition criterion factor (sigma-y/slug length)	10
FCLIP	Hard-clipping factor for slugs (0.0 = no extrapolation)	0
NSPLIT	Number of puffs created from vertical splitting	3
IRESPLIT	Hour for puff re-split	0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0
ZISPLIT	Minimum mixing height for splitting (m)	100
ROLDMAX	Mixing height ratio for splitting	0.25
NSPLITH	Number of puffs created from horizontal splitting	5
SYSPLITH	Minimum sigma-y (met grid cells)	1
SHSPLITH	Minimum puff elongation rate (SYSPLITH/hr)	2
CNSPLITH	Minimum concentration (g/m**3)	0
EPSSLUG	Fractional convergence criterion for numerical SLUG sampling integration	0.0001
EPSAREA	Fractional convergence criterion for numerical AREA source integration	1E-006
DSRISE	Trajectory step-length for numerical rise integration (m)	1.0
HTMINBC	Minimum boundary condition puff height (m)	500
RSAMPBC	Receptor search radius for boundary condition puffs (km)	10
MDEPBC	Near-surface depletion adjustment to concentration (0 = no, 1 = yes)	1

INPUT GROUP: 13 -- Point Source Parameters		
Parameter	**Description**	**Value**
NPT1	Number of point sources	3
IPTU	Units used for point source emissions (e.g., 1 = g/s)	1
NSPT1	Number of source-species combinations with variable emission scaling factors	0
NPT2	Number of point sources in PTEMARB.DAT file(s)	0

INPUT GROUP: 14 -- Area Source Parameters		
Parameter	**Description**	**Value**
NAR1	Number of polygon area sources	0
IARU	Units used for area source emissions (e.g., 1 = g/m**2/s)	1
NSAR1	Number of source-species combinations with variable emission scaling factors	0
NAR2	Number of buoyant polygon area sources in BAEMARB.DAT file(s)	0

INPUT GROUP: 15 -- Line Source Parameters		
Parameter	**Description**	**Value**
NLN2	Number of buoyant line sources in LNEMARB.DAT file	0
NLINES	Number of buoyant line sources	0
ILNU	Units used for line source emissions (e.g., 1 = g/s)	1
NSLN1	Number of source-species combinations with variable emission scaling factors	0
NLRISE	Number of distances at which transitional rise is computed	6

INPUT GROUP: 16 -- Volume Source Parameters		
Parameter	**Description**	**Value**
NVL1	Number of volume sources	0
IVLU	Units used for volume source emissions (e.g., 1 = g/s)	1
NSVL1	Number of source-species combinations with variable emission scaling factors	0
NVL2	Number of volume sources in VOLEMARB.DAT file(s)	0

INPUT GROUP: 17 -- FLARE Source Control Parameters (variable emissions file)		
Parameter	**Description**	**Value**
NFL2	Number of flare sources defined in FLEMARB.DAT file(s)	0

INPUT GROUP: 18 -- Road Emissions Parameters		
Parameter	**Description**	**Value**
NRD1	Number of road-links sources	0
NRD2	Number of road-links in RDEMARB.DAT file	0
NSFRDS	Number of road-links and species combinations with variable emission-rate scale-factors	0

INPUT GROUP: 19 -- Emission Rate Scale-Factor Tables		
Parameter	**Description**	**Value**
NSFTAB	Number of emission scale-factor tables	0

INPUT GROUP: 20 -- Non-gridded (Discrete) Receptor Information		
Parameter	**Description**	**Value**
NREC	Number of discrete receptors (non-gridded receptors)	1355
NRGRP	Number of receptor group names	0

APPENDIX F – AMENDED VERUM STACK TESTING REPORTS

Particulate Emission Report

Sulphur Dioxide Concentration

Coal and Gas - Kiln/Stack 1

Author(s): A.Duncan

Ref Number: I14-20-0008.1 V2

Client Name: AB Lime

Client Address: 10 Bend Road,
Browns, 9782
Winton

Date of Issue: 5 August 2020

Signature:
Name & Designation: Alex Duncan
Air Quality Analyst

Approved:
Name & Designation: Andy Englefield
Air Quality Analyst

Distribution: Nil
(other than client)

CHRISTCHURCH OFFICE
97 Nazareth Avenue
PO Box 29-415
Christchurch 8440
New Zealand
TEL +64 3 341 2120
www.verumgroup.co.nz

WELLINGTON OFFICE
68 Gracefield Road 5010
PO Box 31-244
Lower Hutt 5040
New Zealand
TEL +64 4 570 3700

HAMILTON OFFICE
C/- Ruakura Research Centre
Private Bag 3123
Hamilton 3240
New Zealand
TEL +64 7 929 4864

GREYMOUTH OFFICE
43 Arney Street
PO Box 290
Greymouth 7840
New Zealand
TEL +64 3 768 0586

Determination of Sulphur Dioxide (SO_2) Emissions from the 4 MW Rotary Kiln 1 at AB Lime

Introduction

Verum Group was engaged by AB Lime to perform SO_2 testing on the 4 MW Rotary Kiln 1 on 3 June 2020.

The requirement is that the SO_2 levels from the boiler be measured to an internationally accepted standard. In this case, USEPA Method 6 was applied. This is a wet chemical method in which an average SO_2 level is obtained for the sampling period.

Testing was carried out on 3 June 2020.

Methodology

USEPA Method 6: Determination of sulphur dioxide from stationary sources.
A gas sample is extracted from the sampling point in the stack using a Teflon-lined heated probe. Particulate material is captured by a filter at the inlet of the probe. The gas is then passed to an impinger containing a solution of 80% isopropanol. Any sulphuric acid mist (including sulphur trioxide) in the gas stream is captured at this point. The gas then passes through two further impingers both of which contain a 3% hydrogen peroxide solution for SO_2 capture. The gas passes through a fourth empty impinger to collect any overflow analyte, and finally, to a fifth impinger containing silica gel and from there to the dry gas flow measurement equipment. Sampling is conducted for 20 minutes at a flow rate of 1 litre/minute. Upon completion of sampling, the sampling train is purged for 15 minutes with clean air at the same flow rate (1 litre/minute).

The contents of the second, third and fourth impingers are combined and the amount of SO_2 captured is determined by barium-thorin titration. Blank solutions are also prepared and analysed.

The samples were sent to Verum Group's Lower Hutt laboratory, where the barium-thorin titrations were carried out on the 12 June 2020.

Sampling was carried out while the kilns were operating at a coal feed rate of 18-20 kg/min.

Fuels

A blend of New Vale coal, Ohai coal and landfill gas was used to fire the boiler during testing. Recent coal analyses put the sulphur content of the coal blend at approximately 0.35% (on an as received basis).

Results

Conditions during testing and results are presented in Table 1 below.

Table 1. Conditions and results from the Rotary Kiln, Stack 1

Parameter	Units	Test 1	Test 2	Test 3	Average
Start Time	hrs	12:44	1:50	15:10	n/a
Stop Time	hrs	13:04	2:10	15:30	n/a
Test Duration	hrs/mins	0:20	0:20	0:20	n/a
Coal Feed Rate	kg/min	20.0	18.0	18.0	18.7
Lime Feed Rate	tonnes/hr	53.6	55.8	56.2	55.2
Gas Feed Rate	m^3/hr	99.9	99.1	100.0	99.7
Stack Temperature	°C	75	75	75	75
Oxygen	%	14.9	15.0	14.7	14.8
Moisture Content	%	20.4	29.8	34.5	28.2
Stack Gas Volumetric Flow Rate	dsm^3/h	20703	18385	17802	18964
Actual Concentration of SO_2	mg/dsm^3	0	0	0	0
	ppm	0	0	0	0
Concentration of SO_2 at 12% CO_2	mg/dsm^3	0	0	0	0
	ppm	0	0	0	0
SO_2 Emission Rate	g/s	0.0	0.0	0.0	0.0
	kg/h	0.0	0.0	0.0	**0.0**

*All dsm^3 results are corrected to 273°K and 101.3 kPa - the conditions most commonly used in New Zealand.

This report must be quoted in full except with permission from Verum Group Ltd.

Particulate Emission Report

Sulphur Dioxide Concentration

Gas Only - Kiln/Stack 1

Author(s): A.Duncan

Ref Number: I14-20-0008.2 V2

Client Name: AB Lime

Client Address: 10 Bend Road,
Browns, 9782
Winton

Date of Issue: 5 August 2020

Signature:
Name & Designation: Alex Duncan
Air Quality Analyst

Approved:
Name & Designation: Andy Englefield
Air Quality Analyst

Distribution:
(other than client) Nil

CHRISTCHURCH OFFICE
97 Nazareth Avenue
PO Box 29-415
Christchurch 8440
New Zealand
TEL +64 3 341 2120
www.verumgroup.co.nz

WELLINGTON OFFICE
68 Gracefield Road 5010
PO Box 31-244
Lower Hutt 5040
New Zealand
TEL +64 4 570 3700

HAMILTON OFFICE
C/- Ruakura Research Centre
Private Bag 3123
Hamilton 3240
New Zealand
TEL +64 7 929 4864

GREYMOUTH OFFICE
43 Arney Street
PO Box 290
Greymouth 7840
New Zealand
TEL +64 3 768 0586

Determination of Sulphur Dioxide (SO_2) Emissions from the 4 MW Rotary Kiln 1 at AB Lime

Introduction

Verum Group was engaged by AB Lime to perform SO_2 testing on the 4 MW Rotary Kiln 1 on 3 June 2020.

The requirement is that the SO_2 levels from the boiler be measured to an internationally accepted standard. In this case, USEPA Method 6 was applied. This is a wet chemical method in which an average SO_2 level is obtained for the sampling period.

Testing was carried out on 3 June 2020.

Methodology

USEPA Method 6: Determination of sulphur dioxide from stationary sources.

A gas sample is extracted from the sampling point in the stack using a Teflon-lined heated probe. Particulate material is captured by a filter at the inlet of the probe. The gas is then passed to an impinger containing a solution of 80% isopropanol. Any sulphuric acid mist (including sulphur trioxide) in the gas stream is captured at this point. The gas then passes through two further impingers both of which contain a 3% hydrogen peroxide solution for SO_2 capture. The gas passes through a fourth empty impinger to collect any overflow analyte, and finally, to a fifth impinger containing silica gel and from there to the dry gas flow measurement equipment. Sampling is conducted for 20 minutes at a flow rate of 1 litre/minute. Upon completion of sampling, the sampling train is purged for 15 minutes with clean air at the same flow rate (1 litre/minute).

The contents of the second, third and fourth impingers are combined and the amount of SO_2 captured is determined by barium-thorin titration. Blank solutions are also prepared and analysed.

The samples were sent to Verum Group's Lower Hutt laboratory, where the barium-thorin titrations were carried out on the 12 June 2020.

Fuels

Testing was carried out while the kilns were running soley on landfill gas.

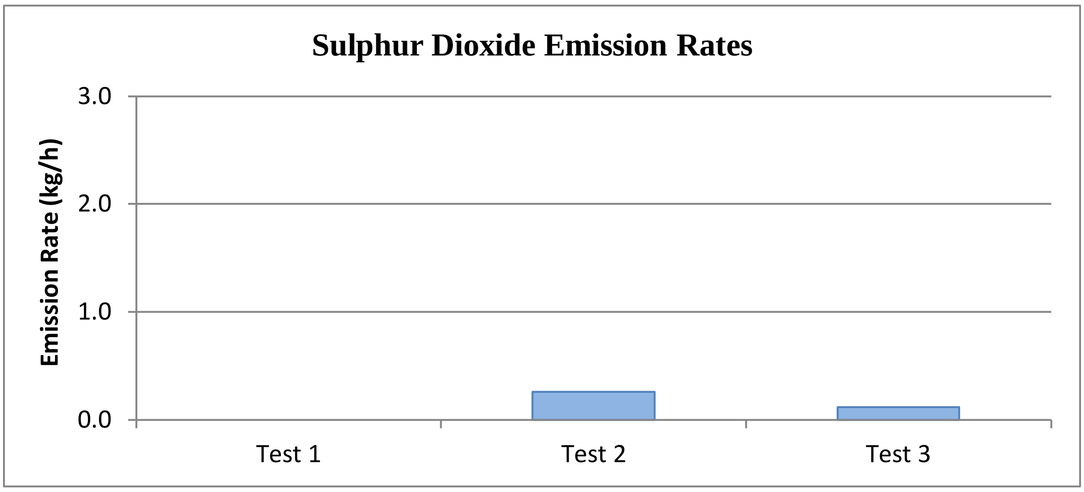
Results

Conditions during testing and results are presented in Table 1 below.

Table 1. Conditions and results from the Rotary Kiln, Stack 1

Parameter	Units	Test 1	Test 2	Test 3	Average
Start Time	hrs	17:12	18:12	19:30	n/a
Stop Time	hrs	17:32	18:32	19:50	n/a
Test Duration	hrs/mins	0:20	0:20	0:20	n/a
Coal Feed Rate	kg/min	0.0	0.0	0.0	0.0
Lime Feed Rate	tonnes/hr	28.6	30.2	29.1	29.3
Gas Feed Rate	m^3/hr	100.0	100.0	99.9	100.0
Stack Temperature	°C	35	26	25	29
Oxygen	%	20.8	20.6	20.8	20.7
Moisture Content	%	3.3	0.0	4.5	2.6
Stack Gas Volumetric Flow Rate	dsm^3/h	32039	30057	27368	29822
Actual Concentration of SO_2	mg/dsm^3	0	9	4	4
	ppm	0	3	2	2
Concentration of SO_2 at 12% CO_2	mg/dsm^3	0	656	688	448
	ppm	0	230	241	157
SO_2 Emission Rate	g/s	0.0	0.1	0.0	0.0
	kg/h	0.0	0.3	0.1	**0.1**

*All dsm^3 results are corrected to 273°K and 101.3 kPa - the conditions most commonly used in New Zealand.



This report must be quoted in full except with permission from Verum Group Ltd.

Particulate Emission Report

Sulphur Dioxide Concentration

Coal Only - Kiln/Stack 2

Author(s):	A.Duncan
Ref Number:	I14-20-0008.3 V2
Client Name:	AB Lime
Client Address:	10 Bend Road, Browns, 9782 Winton
Date of Issue:	5 August 2020
Signature: ***Name & Designation:***	Alex Duncan Air Quality Analyst
Approved: ***Name & Designation:***	Andy Englefield Air Quality Analyst
Distribution: ***(other than client)***	Nil

CHRISTCHURCH OFFICE
97 Nazareth Avenue
PO Box 29-415
Christchurch 8440
New Zealand
TEL +64 3 341 2120
www.verumgroup.co.nz

WELLINGTON OFFICE
68 Gracefield Road 5010
PO Box 31-244
Lower Hutt 5040
New Zealand
TEL +64 4 570 3700

HAMILTON OFFICE
C/- Ruakura Research Centre
Private Bag 3123
Hamilton 3240
New Zealand
TEL +64 7 929 4864

GREYMOUTH OFFICE
43 Arney Street
PO Box 290
Greymouth 7840
New Zealand
TEL +64 3 768 0586

Determination of Sulphur Dioxide (SO_2) Emissions from the 4 MW Rotary Kiln 2 at AB Lime

Introduction

Verum Group was engaged by AB Lime to perform SO_2 testing on the 4 MW Rotary Kiln 2 on 3 June 2020.

The requirement is that the SO_2 levels from the boiler be measured to an internationally accepted standard. In this case, USEPA Method 6 was applied. This is a wet chemical method in which an average SO_2 level is obtained for the sampling period.

Testing was carried out on 3 June 2020.

Methodology

USEPA Method 6: Determination of sulphur dioxide from stationary sources.
A gas sample is extracted from the sampling point in the stack using a Teflon-lined heated probe. Particulate material is captured by a filter at the inlet of the probe. The gas is then passed to an impinger containing a solution of 80% isopropanol. Any sulphuric acid mist (including sulphur trioxide) in the gas stream is captured at this point. The gas then passes through two further impingers both of which contain a 3% hydrogen peroxide solution for SO_2 capture. The gas passes through a fourth empty impinger to collect any overflow analyte, and finally, to a fifth impinger containing silica gel and from there to the dry gas flow measurement equipment. Sampling is conducted for 20 minutes at a flow rate of 1 litre/minute. Upon completion of sampling, the sampling train is purged for 15 minutes with clean air at the same flow rate (1 litre/minute).

The contents of the second, third and fourth impingers are combined and the amount of SO_2 captured is determined by barium-thorin titration. Blank solutions are also prepared and analysed.

The samples were sent to Verum Group's Lower Hutt laboratory, where the barium-thorin titrations were carried out on the 12 June 2020.

Sampling was carried out while the kiln was operating at a coal feed rate of 17-20 kg/min.

Fuels

A blend of New Vale and Ohai coal was used to fire the boiler during testing. Recent analyses put the sulphur content of the coal blend at approximately 0.35% (on an as received basis).

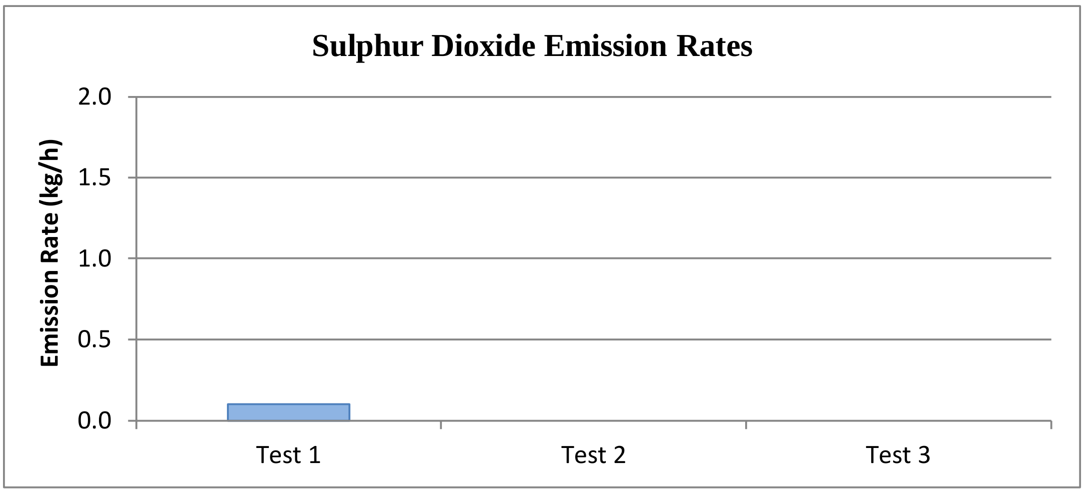
Results

Conditions during testing and results are presented in Table 1 below.

Table 1. Conditions and results from the Rotary Kiln, Stack 2

Parameter	Units	Test 1	Test 2	Test 3	Average
Start Time	hrs	20:17	21:14	10:06	n/a
Stop Time	hrs	20:37	21:34	10:26	n/a
Test Duration	hrs/mins	0:20	0:20	0:20	n/a
Coal Feed Rate	kg/min	17.0	20.0	20.0	19.0
Lime Feed Rate	tonnes/hr	56.1	51.7	48.2	52.0
Stack Temperature	°C	62	63	65	63
Oxygen	%	16.6	16.7	16.6	16.6
Moisture Content	%	9.2	22.0	10.2	13.8
Stack Gas Volumetric Flow Rate	dsm^3/h	23580	21386	24603	23189
Actual Concentration of SO_2	mg/dsm^3	4	0	0	1
	ppm	2	0	0	1
Concentration of SO_2 at 12% CO_2	mg/dsm^3	14	0	0	5
	ppm	5	0	0	2
SO_2 Emission Rate	g/s	0.0	0.0	0.0	0.0
	kg/h	0.1	0.0	0.0	**0.0**

*All dsm^3 results are corrected to 273°K and 101.3 kPa - the conditions most commonly used in New Zealand.



This report must be quoted in full except with permission from Verum Group Ltd.

Appendix B. Updated Landfill Air Quality Management Plan

AB Lime Limited

AB Lime Landfill Air Quality Management Plan

Landfill Air Quality Management Plan | 1

29 May 2020

AB Lime Ltd

Draft for Consenting Purposes

AB Lime Ltd

Project No:	IZ000400
Document Title:	AB Lime Landfill Air Quality Management Plan
Document No.:	Landfill Air Quality Management Plan
Revision:	1
Date:	29 May 2020
Client Name:	AB Lime Ltd
Project Manager:	Katrina Jensen
Author:	Donovan Van Kekem of NZ Air
File Name:	Landfill Air Quality Management Plan

Document history and status

Revision	Date	Description	Author	Checked	Reviewed	Approved
0	14/04/2020	Draft for Client Comment	Donovan Van Kekem			
1	29/05/2020	Final Draft for Consenting Purposes	Donovan Van Kekem			
2	28/08/2020	S 92 Response for Consenting Purposes	Donovan Van Kekem			

Contents

1. Introduction

1.1 Purpose/Objective of the Landfill Air Quality Management Plan

The purpose of this Landfill Air Quality Management Plan is to provide a framework for site operators and visiting contractors to minimise potential nuisance odour, dust, and toxic gas emissions from the site activities. These activities must be undertaken in a manner that will minimise the risk of adverse air quality effects beyond the boundary of the site during the hours of operation. Site personnel and contractors will be required to conform to the requirements of this Landfill Air Quality Management Plan. Specific controls are detailed to limit air discharges from each source on-site and are to be undertaken by designated site staff and checked by site management.

The goal is that by following the procedures outlined in this plan, the site-based activities will not result in the production of offensive or objectionable nuisance odour, dust, or toxic air quality effects beyond the boundary of the site.

It is intended that this document will be a 'living' document, which will be regularly referred to by site staff and management. It will also be updated to meet changing conditions on the site.

The Landfill Air Quality Management Plan is to manage the effects on landfill air quality in accordance with the corresponding legislative requirements outlined below in section 2. The Landfill Air Quality Management Plan covers the following matters:

- Odour Management;
- Hazardous Waste Handling;
- Crisis Waste Acceptance;
- Combustion Emissions;
- Dust Management;
- Maintenance Requirements;
- Monitoring Requirements; and
- Complaint Response.

The objectives of the Landfill Air Quality Management are as follows:

i. To control odours so that there shall be no odour that causes an objectionable effect beyond the boundary of the land owned by the consent holder.

ii. To ensure that the disposal of odorous loads only takes place when effective mitigation measures are in place.

iii. To ensure effective daily cover of at least 150 mm of soil or equivalent alternative material.

iv. To keep the working face as small as practicable.

v. To avoid excavation into old areas of refuse as far as practicable.

vi. To minimise water ingress to the working face.

vii. To control dust so that there shall be no dust that causes an objectionable effect beyond the boundary of the land owned by the Consent Holder.

viii. To minimise the extent of unvegetated areas.

ix. To enforce vehicle speed limits on site.

x. To keep unsealed road surfaces and working areas moist where potential for dust emissions beyond the boundary of the land owned by the Consent Holder exists.

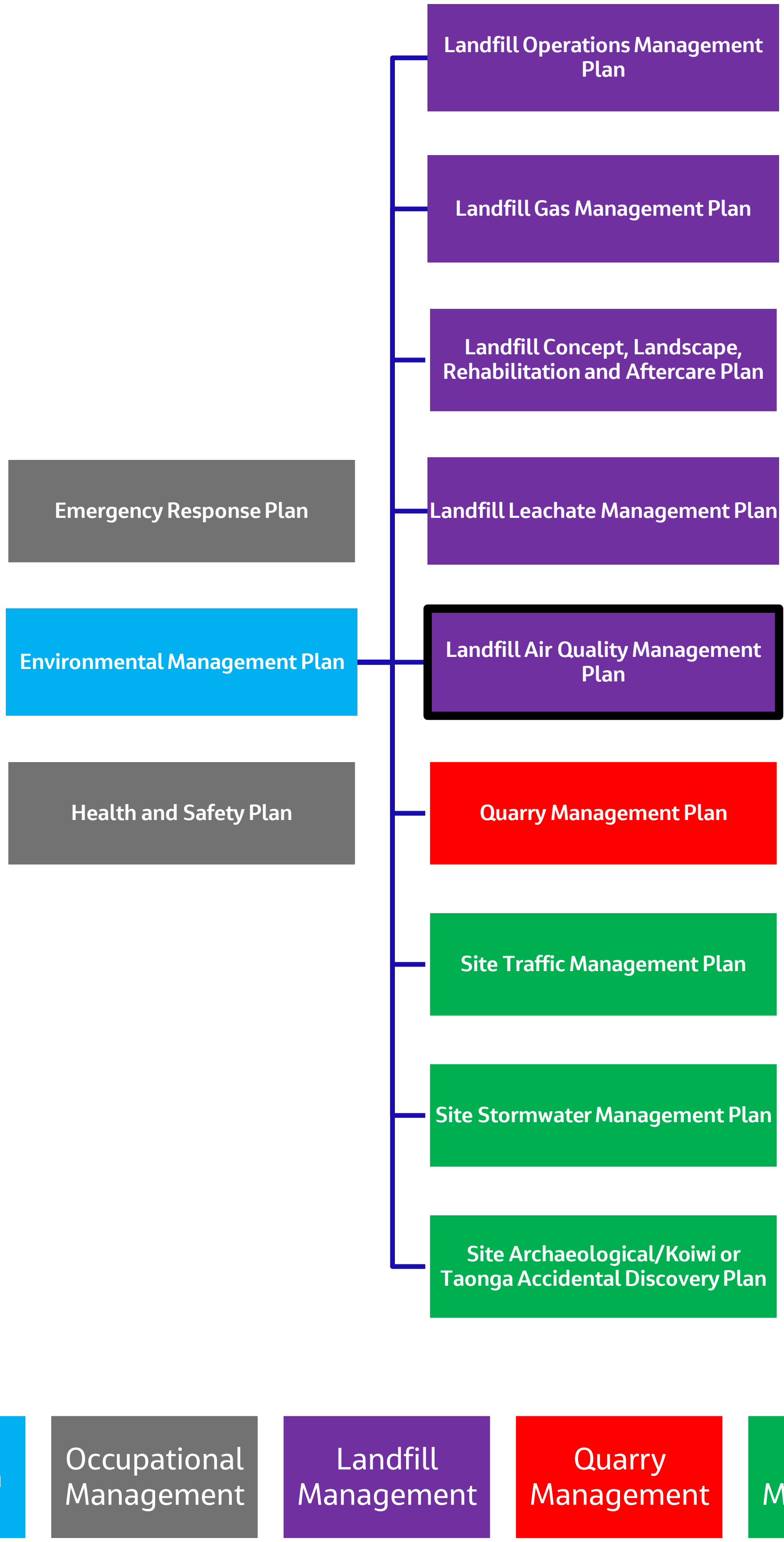
1.1.1 Management Plan Structure

The operation of AB Lime landfill and quarry requires a suite of environmental management and mitigation plans to ensure the successful operation of the entire site. The Environmental Management Plan sets the overall framework for the operation of the site and is supported by a series of sub management plans focusing on specialist environmental areas to effectively run the landfill and quarry.

The Landfill Air Quality Management Plan is a sub management plan under this framework that manages the effects of landfill air quality. Figure 1.1 below illustrates the relationship between the Landfill Air Quality Management Plan and the remainder of the AB Lime management plan framework.

This plan has been prepared in accordance with the certification and submission process outlined in section 1 of the AB Lime Environmental Management Plan.

Figure 1.1: AB Lime Limited Management Plan Structure



2. Legislative Requirements

The legislative requirements of this Landfill Air Quality Management Plan outline the consent conditions that this plan is designed to assist with implementing.

2.1 Resource Consent Requirements

Table 2.1: Relevant Conditions for Consents related to Landfill Air Quality Management Plan

Condition Number	Condition	Reference
Schedule 1 – General Conditions AUTH 201346, 201347, 201348, 201349, 201350, 201351		
26.	The consent holder shall prepare and maintain a Landfill Air Quality Management Plan (LAQMP). The LAQMP shall describe the air quality management for the landfill, including demonstrating how compliance with the relevant conditions of this consent will be achieved. The plan shall also achieve the following objectives:	
	i. To control odours so that there shall be no odour that causes an objectionable effect beyond the boundary of the land owned, or covenanted by the Consent Holder	Section 4
	ii. To manage the disposal of odorous loads to take place when effective mitigation measures are in place	Section 4
	iii. To manage effective daily cover of at least 150 mm of soil or equivalent alternative material;	Section 4
	iv. To keep the working face as small as practicable;	Section 4
	v. To limit excavation into old areas of refuse as far as practicable;	Section 4
	vi. To minimise water ingress to the working face;	Section 4
	Dust: i. To control particulate matter that causes an objectionable effect beyond the boundary of the land owned, or covenanted by the Consent Holder.	Section 8
	ii. To minimise the extent of unvegetated areas	Section 8.3
	iii. To enforce vehicle speed limits on site;	Section 8.3
	iv. To keep unsealed road surfaces and working areas moist where potential for dust emissions beyond the boundary of the land owned, or covenanted by the Consent Holder exists.	Section 8.3
Air Discharge Permit 201351		
2.	The discharge into air shall only be contaminants, including particulate matter, odour, combustion products and landfill gas, from a landfill as described in the application documents. The consent does not authorise the burning of solid waste at the site.	Section 3

Condition Number	Condition	Reference
3.	The discharges shall not cause odour or particulate matter that has an objectionable or offensive effect beyond the boundary of the land owned, or covenanted, by the Consent Holder, as determined by the Council (Manager of Compliance). The determination of an offensive or objectionable effect shall take into account the FIDOL factors and be made based on the guidance provided in Section 4.1.1 and Table 6 of the Ministry for the Environment Good Practice Guide for Assessing and Managing Odour (2016) or Section 4.2.1 and Table 8 of the Ministry for Environment Good Practice Guide for Assessing Dust (2016).	Section 4 and Section 8
4.	Where, during landfill operations, the Consent Holder is required to accept waste by a Government Agency as a crisis or emergency response, the following protocol shall apply: a) All crisis response waste acceptance shall trigger the protocol identified in the Crisis/Emergency Response chapter of the Landfill Operations Management Plan. b) The consent holder shall notify the Southland Regional Council Compliance Manager of this waste acceptance within 48 hours. c) A management response in line with the criteria identified within the Crisis/Emergency Response chapter of the Landfill Operations Management Plan shall be made available to the Southland Regional Council within 3 days of notification of condition (4)(b), above. d) All likely affected neighbours are to be notified of the crisis/emergency waste stream prior to acceptance on site, or as soon as practicable. e) Mitigation measures for crisis/emergency waste shall follow the guidelines identified in the Crisis/Emergency Response chapter of the Landfill Operations Management Plan. ***Advice Note:*** *There may be instances when the consent holder is required to accept waste under the direction of a Government Agency. Where this is the case, despite the conditions of consent that ordinarily apply to the landfill, it is accepted that there may be effects associated with the waste that are beyond the control of the consent holder. This shall be taken into consideration by the Southland Regional Council when discharging its duties to monitor the conditions of consent.*	Section 6
5.	To ensure compliance with Condition 3, odorous special wastes shall only be accepted by prior arrangement. The following mitigation measures shall be undertaken to minimise odorous emissions from these special wastes: (a) odorous wastes shall be covered immediately by at least 150mm of soil or overburden material; (b) highly odorous loads likely to cause a breach of Condition 3 shall only be accepted if the waste material has been pre-treated with odour suppressing chemicals or are received in air tight disposable containers; (c) the delivery of odorous loads shall be planned to occur during the typically windier period in the middle of the day, while allowing sufficient time for thorough covering prior to daily closure of the landfill; and	Section 4

Condition Number	Condition	Reference
	(d) odour suppressing chemicals and lime shall be applied, as required.	
8.	Where exposure of existing landfill material is necessary, this shall occur for the minimum practicable time and odour spray or lime shall be applied, as required by the Landfill Air Quality Management Plan.	Section 4
10.	The site entrance, roading to the lime storage areas and the truck access road shall be sealed as near as practical to the landfill. These sealed road surfaces shall be cleaned by mechanical sweeper, as necessary to minimise dust emissions.	Section 8
11.	A wheel wash shall be used by all vehicles leaving the landfill site that have travelled on unsealed or potentially dusty surfaces.	Section 8
12.	Water shall be applied to unsealed internal roads and other potentially dusty surfaces, as necessary to minimise dust emissions.	Section 8
13.	Exposed soil surfaces shall be planted in grass as soon as possible after construction. Soil stockpiles that are kept for longer than 6 months shall be planted in grass.	Section 8
14.	Maximum vehicle speed limits shall be set and enforced within the landfill site to minimise dust emissions.	Section 8
15.	Dusty special wastes shall only be accepted by prior arrangement. The following mitigation measures shall be undertaken to minimise dust emissions from these special wastes: (a) dusty wastes shall be dampened or enclosed in bags prior to delivery to the landfill, or controlled by water spray at the landfill; or (b) emissions from potentially dusty loads tipped at the workface shall be controlled by applying water or immediately covering the waste material.	Section 8

2.2 Monitoring and Reporting the performance of the Landfill Air Quality Management Plan

Table 2.2: Monitoring and Reporting Requirements Related to the Landfill Air Quality Management Plan

Condition	Requirement	Relevant Regulatory Authority	Frequency	Date	Responsibility
Schedule 1 – General Conditions AUTH 201346, 201347, 201348, 201349, 201350, 201351					
29.	The EMP and sub-management plans (where applicable) shall include monitoring with respect to surface water, groundwater, leachate, landfill gas and nuisance. Each monitoring element shall include: i. Monitoring locations; ii. Monitoring parameters;	Southland Regional Council	As deemed necessary in each management plan		Environmental Manager

Condition	Requirement	Relevant Regulatory Authority	Frequency	Date	Responsibility
	iii. Monitoring frequency; iv. Detection limits; v. Reporting; vi. Trigger levels (for each monitoring location) for implementing contingency/remedial actions				
Air Discharge Permit 201351					
26.	An on-site meteorological monitoring station shall be established and operated. The following parameters shall be measured and recorded at least once each hour: (a) Wind velocity and direction; (b) Barometric pressure; (c) Rainfall; and (d) Temperature.	Southland Regional Council	Continuous		Environmental Manager
28.	A record of any complaints relating to odour or dust shall be kept, and shall include: (a) the location where the effect was detected by the complainant; (b) the date and time when the effect was detected; (c) a description of the wind speed and wind direction when the effect was detected by the complainant; (d) the most likely cause of the effect detected; and (e) Advise the complainant of any corrective action undertaken by the consent holder in accordance with any relevant Management Plan or condition to avoid, remedy or mitigate the effect detected by the complainant within 10 working days. A record of all complaints received shall be kept by the consent holder in a complaint register, be available for inspection on request, and shall be provided to Environment Southland annually for the period 1 May to 30 April each year.	Southland Regional Council	As required		Environmental Manager

Condition	Requirement	Relevant Regulatory Authority	Frequency	Date	Responsibility
	Advice Note: *To help the Consent Holder in the management of complaints in accordance with this condition it is requested that all complaints received by the Southland Regional Council are passed on to the Consent Holder.*				
29.	The Consent Holder is to document a procedure for responding to a validated complaint or determination of a breach of Condition 3 by Environment Southland in the Air Quality Management Plan. ***Advice note:*** *Such procedures may include measures such as an odour diary survey and/or liaising with the established CLC.*	Southland Regional Council	As Required		Environmental Manager

2.2.1 Interaction Between Legislative Requirements and Landfill Air Quality Management Plan

If there is a conflict between the management plan and the corresponding legislative requirements, including consent conditions, then the legislative requirements must prevail.

3. Landfill Air Quality Management

3.1 Introduction

Discharges to air from the landfill operations include:

- **Nuisance odour and dust emissions** from the landfill operation which are mainly prevented through appropriate landfill operational practices. The primary control is through immediate effective compaction, daily cover, and minimisation of the working face, special handling of difficult waste and careful design and operation of leachate pond/gas system.
- **Landfill gas** (LFG) occurs as a result of decomposition of biodegradable material within a landfill, such as food, garden waste, paper, wood and cardboard. LFG consists of a mixture of carbon dioxide (CO_2, approximately 40%), methane (CH_4, approximately 60%), and trace gases including hydrogen sulphide (H_2S), ammonia (NH_3), hydrogen chloride (HCL), volatile organic compounds (VOC) and carbon monoxide (CO). H_2S, NH_4, HCL, CO and some VOC's are toxic gases which can result in adverse health effects if inhaled. CO_2, and CH_4 displace oxygen in the air and in high enough concentrations can lead to asphyxiation.

  LFG is often highly odorous and has a distinct 'rotten egg' odour due to the high concentrations of H_2S in the gas. The primary control measure for reducing odour emissions from the LFG emissions from the landfill mass is the use of a permanent landfill gas flare. Nearly all of the H_2S is converted to sulphur dioxide (SO_2) when combusted at high temperature in the flare.
- **Products of combustion** result from LFG being extracted and piped to the on-site LFG flare. This flare burns the LFG at high temperature (greater than 750 deg C) and the resulting products of combustion include particulate matter less than 10 microns in diameter (PM10), SO_2, nitrogen dioxide (NO_2) and CO. These gases are toxic to human beings and there are ambient air quality National Environmental Standards (NES) for these air pollutants. As such, emission of these pollutants needs to be minimised to a practical minimum to ensure compliance with the NES and health-based air quality criteria.

There is to be no burning of solid waste on-site.

3.2 Receiving Environment

It is important for all site staff to be aware of the surrounding environment, prevailing wind directions and site topography.

Site staff are to be aware of the extent of the site and land owned by AB Lime and the off-site locations where adverse air quality effects could be experienced by neighbouring receptors/landowners.

AB Lime's quarry and landfill are well separated from neighbouring properties/off-site dwellings. Figure 3.1 illustrates the location of off-site dwellings relative to the site. Green markers indicate dwellings owned by AB Lime, and the yellow markers are the nearest dwellings not owned by AB Lime. The nearest dwelling not owned by AB Lime (R4) is approximately 1,240 m from the landfill operations. Neighbouring dwellings are primarily situated west – south of the site, and the land northwest – south east is sparsely populated. As such winds blowing from the north, northeast and east have the highest potential to generate off-site air quality effects.

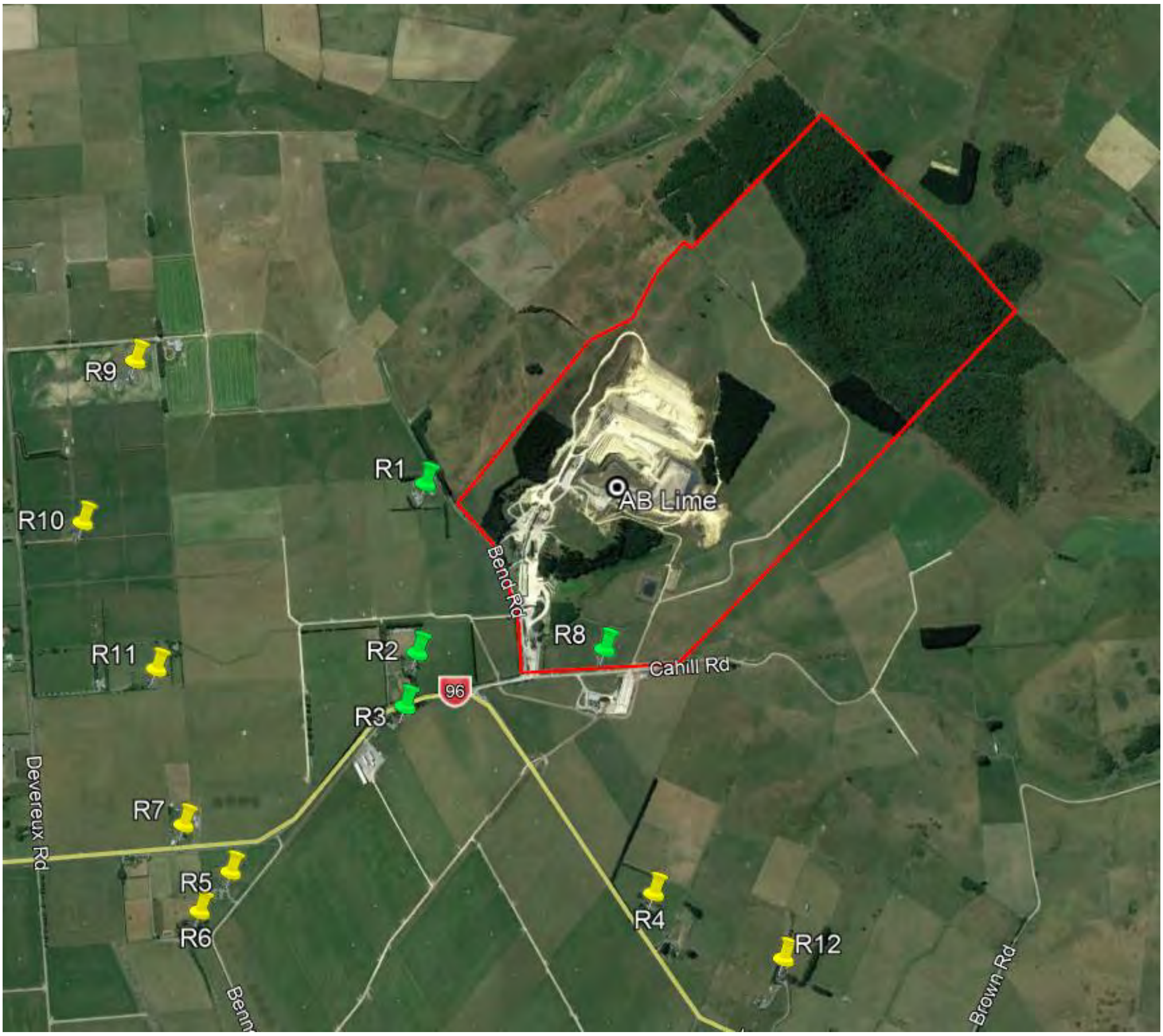


Figure 1 Neighbouring Receptors - As of April 2020

As shown in Figure 1 AB Lime also owns a large amount of the land surrounding the site. The land parcel to the north of the site is unoccupied and currently used for agricultural purposes. T

Whilst this management plan is focused on limiting the potential for adverse air quality effects at neighbouring dwellings, the proposed control measures will also limit the potential for adverse air quality effects at unoccupied land and adjacent public roads.

3.2.1 Topography

Historic complaints have occurred down valley from the landfill during cold air drainage conditions. The local topography dictates the flow of air during these cold air drainage effects. Site staff need to be aware of the local topography and associated airflows.

The site is also situated in a semi-circular valley on the site of a hill (see Figure 2). As the land cools overnight the cold air drains down this valley towards the closest neighbouring receptors (see blue arrows on Figure 2). Due to this local topography and the cold air drainage directionality, during poor air dispersion conditions (low wind speeds, low temperature inversion layers, early mornings/late evenings), there is a much higher potential for adverse off-site air quality effects.

Particular care needs to be applied by all site staff during these meteorological conditions, particularly for odour emitting activities. Meteorological conditions such as those that relate to cold air drainage conditions are measured by the on-site weather station. In Section 10 below there are specific triggers for additional mitigation measures to be applied to the site. As part of the complaint response procedure (Section 11) the Environmental Manager is to record the meteorological conditions and any observed cold air drainage conditions that are resulting in adverse off-site air quality effects.

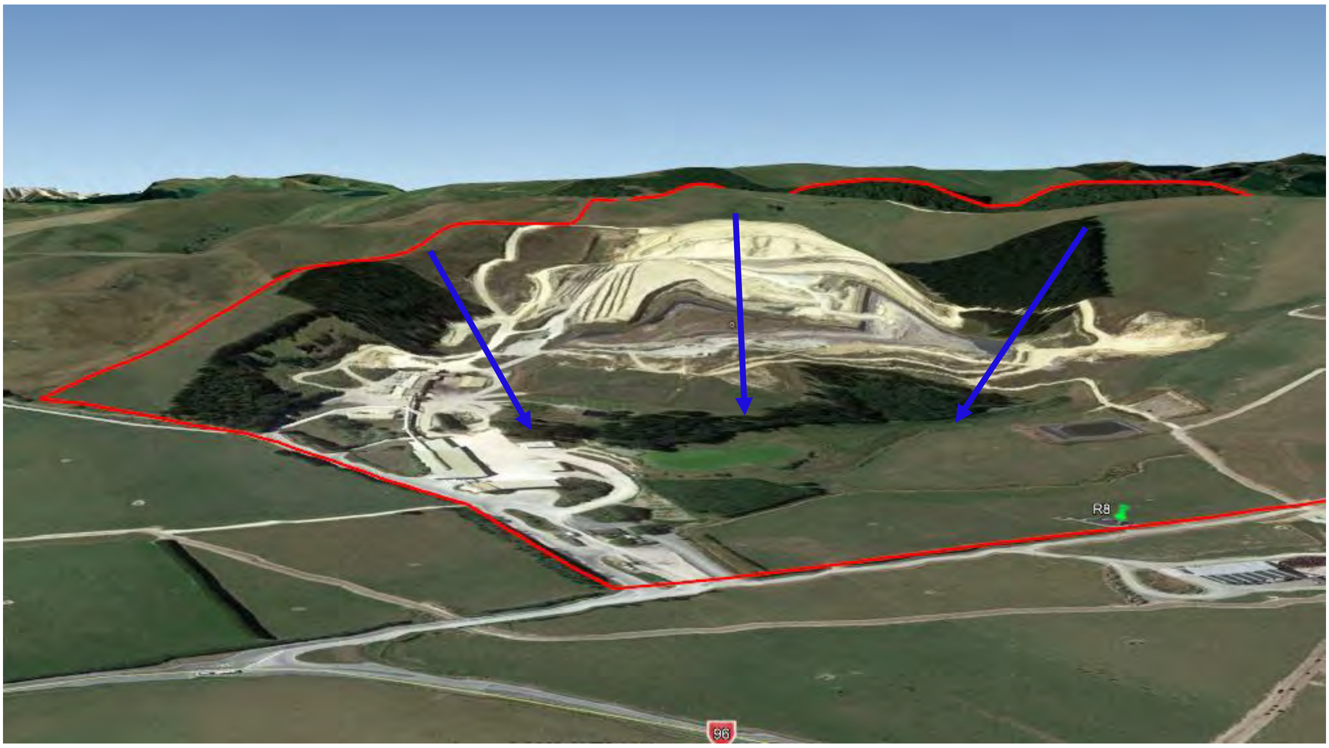


Figure 2 Topography - Cold Air Drainage

3.2.2 Local Meteorology

It is important for site staff to be aware of the weather conditions on-site as wind speed and wind direction play a very important part in the potential for adverse air quality effects off-site.

Predominantly winds measured on the site weather station blow from the west and the south (see windrose in Figure 3). These winds blow and air discharges on the site towards predominantly unoccupied land.

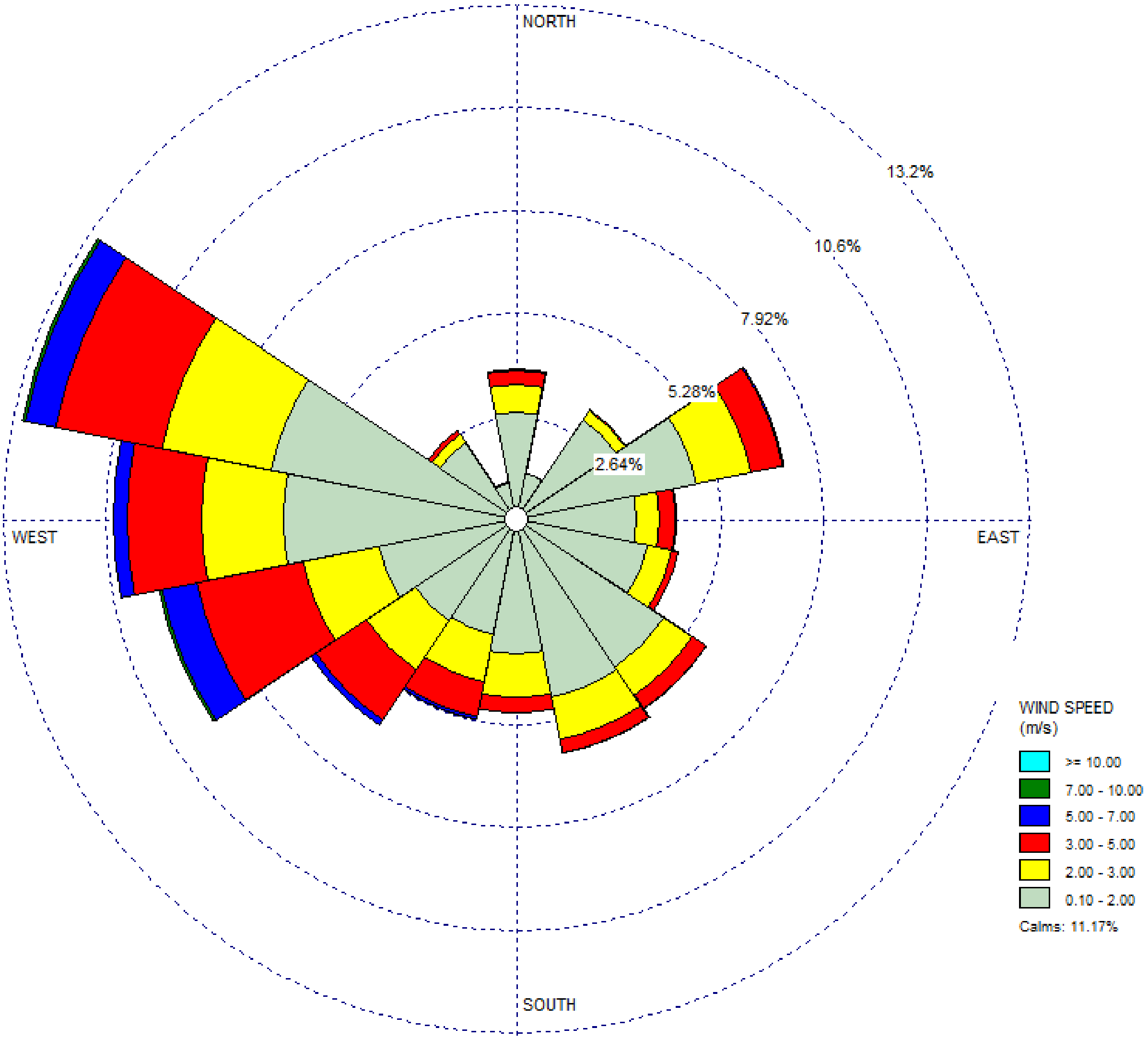


Figure 3 On-site Weather Station Windrose 2012-2014

Winds from the north – east (which would blow emissions from the site towards the nearest off-site dwellings) occur much less frequently.

Specific controls and activity restrictions with regard to site weather conditions are discussed further in Sections 4 and 10.

3.3 Air Quality Management Structure

Air discharges associated with the landfill operation can be discharged from a number of different sources/activities listed in the Sections 4, 5, 7 and 8 below. The proposed mitigation measures for each source are included under each potential source.

To provide for a high level of air discharge control from the landfill operation, this LAQMP includes a staged mitigation approach. This provides for multiple factors of safety. Mitigation/management procedures are broken down to three levels (Level1, Level 2, and Level 3). It is expected that Level 1 mitigation will be sufficient to mitigate the potential for off-site air quality effects during normal operating conditions. However, should Level 1 mitigation be insufficient to control air discharges from the source/activity, then Level 2 mitigation will be applied. If Level 1 and Level 2 controls are still not controlling air discharges from the site, Level 3 mitigation will be applied. Level 3 mitigation is a final resort and, in many instances, involves ceasing the emitting activity. This staged mitigation approach will ensure that the air discharges are controlled to a point that the site activities are not causing an adverse effect at dwellings or sensitive locations beyond the boundary of the site.

Note that in many cases not all the Level 2 or Level 3 mitigation measures will need to be applied when boundary monitoring/off-site feedback triggers the requirement to increase the level of mitigation. The mitigation measures are a toolbox of available mitigation measures to be applied at the site management's discretion, dependant on the severity of the actual or potential effect.

The trigger points which mandate the requirement to increase the mitigation/management practices to a higher level are based on boundary and off-site monitoring results and/or community/Council feedback. Where one of the following occurs during the course of exercising mitigation in line with the specified level for the offending emission source(s), AB Lime is to consider increasing mitigation to the next level:

- Boundary nuisance odour or dust assessments indicate that there is detectable odour at the boundary of the site or observable dust crossing the boundary of the site;
- An adverse/observable nuisance odour/dust or toxic air quality effect is observed by an on-site staff member/contractor;
- Boundary H_2S sensors exceed the trigger points in Section 10 below;
- An odour or dust observation has been called in from a neighbouring resident (as a part of the community engagement process);
- An air quality complaint has been made to the Regional Council or AB Lime has been called in from a neighbouring resident; and
- A Regional Council enforcement officer has observed nuisance odour or dust beyond the boundary of the site.

Ultimately the management plan structure is aimed at mitigating adverse effects before an off-site non-compliance occurs. This proactive management structure provides a buffer before non-compliance occurs.

This level of air quality management is considered to be consistent with or to exceed good practise air quality control for New Zealand landfill operations.

4. Odour

Nuisance odours generated from the landfill operations may cause offensive or objectionable effects beyond the boundary of the site if not managed carefully.

Based on current operations (as of April 2020) approximately 50% of the waste received on-site is organic waste. Organic waste has the potential to decompose and this decomposition process often releases offensive odours. Odour at the tip face and waste compaction zones is usually of a 'rotten cabbage' type odour. Site staff working in this environment will often become desensitised to the odour and therefore are less likely to notice odours associated with normal operations.

Currently, (as of April 2020) approximately 20% of the waste accepted at the landfill is 'special waste' which generally consists of highly odorous waste (Biosolids, animal hides, sump waste, dead animals, etc). Odour from these products is generally very offensive and as such a high level of odour mitigation is required for these products.

In short, the landfill receives waste that ranges from no odour emission potential to very odorous waste that is highly offensive.

Odour is also emitted from as a result of the anaerobic decomposition of the waste within the landfill. The principal odorous gas that is emitted from this process is H_2S which has a characteristic 'rotten egg' like smell. H_2S can be emitted from waste received at the tip face which has already begun to decompose anaerobically, from waste which is decomposing within the landfill cells (H_2S is often present in high concentrations in the LFG), and from the leachate. The control and management of H_2S emissions from a landfill is critical in managing off-site odour nuisance.

Essentially, landfill operations are inherently odorous and it is not possible to completely remove all odour emission from a landfill. Therefore, the control measures are critical to ensuring that nuisance effects do not occur beyond the boundary of the site.

4.1 Potential Odour Sources

The activities/processes which occur/will occur at the AB Lime landfill that have the potential to generate odour include:

- Transport of waste onto the site;
- Waste deposition, handling, and compaction at the tip face;
- Special waste handling;
- Landfill gas;
- Leachate collection and processing;
- Fugitive emissions from daily cover or final capping;
- Hazardous waste handling; and
- Combustion gases.

4.2 Site Wide Odour Mitigation

The following sitewide odour mitigation measures are to be applied by site staff. Additional activity specific measured are outlined in Table 1 below.

- Maintain planting and shelter trees around the landfill footprint. These trees help to encourage mixing of airflows and aid in plume dispersion.
- Where exposure of existing landfill material is necessary, this shall occur for the minimum practicable time and odour suppression spray or lime shall be applied.

- Highly odorous waste (special waste) is only to be accepted on-site under permit from AB Lime. The permit application and approval process are described in the Landfill Operations Management Plan.
- Boundary odour observations for informing odour management are to be made at least once a week during winds blowing from the north, northeast and east (winds blowing from 0 - 90 degrees azimuth), or during still (windspeeds below 1 m/s) cold air drainage conditions. Where practicable these odour observations are to be made during the first occurrence of these meteorological conditions during the working week. Where these meteorological conditions do not occur during the week, downwind odour observations are optional.
- These boundary odour observations are to be made in accordance with the procedures outlined in Attachment 1 (in general accordance with the Ministry for the Environment good practice guidance).
- Activities with a higher potential for odour emission are only to occur during favourable meteorological conditions (where practicable) and not during poor air dispersion conditions. Favourable meteorological conditions are winds which are not blowing from the north, northeast and east (winds blowing from 0 – 90 degrees azimuth). Poor dispersion conditions include inversion layers, low windspeeds, overcast conditions (where thermal convective cells are less likely), and cool temperatures.
- Automated weather station alerts (from the existing on-site weather station) are to be observable to all site staff during wind directions from north, northeast and east (winds blowing from 0 - 90 degrees azimuth) with windspeeds below 1m/s or above 7 m/s. These will be visualised by a wind sock and flashing light central to the site, and text message/e-mail alerts sent to site management/staff.
- Boundary H_2S sensors are to be installed on the site boundary as described in Section 10.5. Automated alerts from the boundary H_2S sensors are to be sent to site management so that additional mitigation can be implemented as soon as possible.
- The tip face and exposed waste area is to be limited to the smallest practicable size. The tip face is not to be greater than 1,000 m^2.
- All emission control equipment (landfill gas flare, odour suppressant sprays, leachate pond aerator, landfill gas monitoring equipment, boundary H_2S sensors, etc) is to be regularly inspected and maintained to ensure effective/consistent performance (see Section 9).
- The odour potential of any waste stream that a new client may propose to bring on to site needs to be assessed by AB Lime. AB Lime is to ensure that appropriate controls are in place for this client's waste stream and work with the client to ensure that these controls are maintained for the duration of the contract. Where required these controls can be revised in response to actual or potential odour emissions.
- All site staff, waste delivery drivers, and contractors are to know their responsibilities under this Plan. In particular, the requirements for special waste handling and odour mitigation procedures. Failure to follow the procedures in this Plan will result in consequences.

Table 1 Staged Odour Mitigation

Activity	Level 1	Level 2	Level 3
Transport of waste to site Odour or dust can be discharged to air during the transport of waste to the site. Odorous or dusty wastes are only accepted by prior arrangement.	- All waste acceptance on-site is to occur via the documented procedure in the Landfill Operations Management Plan. - AB Lime will only accept potentially odorous waste streams that are be delivered to site in covered trucks/containers. - All delivery drivers are to be aware of the composition of the waste they are carting. Records of the waste compositions and source are to be provided to AB Lime upon arrival at site. - AB Lime's weighbridge operators are to ensure that trucks carrying waste which is potentially odorous are fully enclosed. - Open trucks which contain odorous waste are to be rejected by AB Lime, and the number plate of the truck and client contact details are to be recorded. The client is to be warned that continued breaches of the AB Lime procedures will result in termination of the contract.	- Should fugitive odours still be escaping out of the truck covers and be detectable off-site, then AB Lime is to stipulate to delivery drivers that the offending waste materials are only to be transported to site in air tight sealed containers. An investigation is to be undertaken by AB Lime as to the products that are generating nuisance odour effects during transport. Where possible AB Lime is to provide education and limits to customers/contractors as to the required condition of waste prior to transport. - AB Lime is to advise clients delivering the waste to investigate pre-treating the waste to reduce its odour emission potential prior to delivering it to site. - Trucks delivering odorous waste are to consider utilising bin liners to prevent waste residue remaining in the truck after tipping.	- If waste transport is still generating offensive odour beyond the boundary of the site, consider moving the site access point and or truck transport route further from the nearest off-site receptors. - No raw materials which have produced detectable odour at off-site locations during transport to or through the site are allowed to be transported to site. - Customers/contractors whom have been supplying these materials are to be notified of the ban and should they continue to transport the offending products to site, be prohibited from transporting any material to site.
Waste deposition, handling and compaction at the tip face The tip face is a key odour emission point at the site. During operational hours odour is emitted constantly in varying degrees from this emission point. Waste spreading and compaction disturbs the waste profile and can result in elevated odour emissions from odorous waste. It can also enlarge the odour plume resulting in a higher potential for off-site effects.	- Waste placement, compaction and cover shall occur in accordance with the methodology stipulated in the Landfill Operations Management Plan. - Fence line odour neutralising sprays are to be operational at all times during working hours. This spray system is to be checked for correct and effective operation three times a day. - The tip face area is to be limited to the smallest area possible. It is not to be more than 1000 m^2 at any time. - Operational procedures adopted at the tipping face to aim to prevent surface ponding of water that which can potentially emit odours (refer to the Landfill Operations Management Plan). - No special waste is to be tipped or handled at the general tip face. - The weighbridge is to notify tip face staff of any special waste loads entering the pit. A description of the truck is to be provided such that tip face staff can direct the special waste loads to the designated special waste disposal area (refer to the Landfill Operations Management Plan). - Systematic compaction and cover is to occur in accordance with the Landfill Operations Management Plan. - Trucks delivering known odorous waste (that is not classified as special waste) are to be directed to a designated tipping bay where non-odorous waste or daily	- The size of tipping face is to be reduced. - Odorous waste loads being deposited at the tip face/special waste area are to be staggered such that cumulative odour emissions are reduced. - Odorous material is to be treated in situ with lime or odour suppressing chemicals. - Increase the thickness of cover material to inhibit odour emissions from previously tipped waste and continue to use cover on top of any subsequent odorous waste deposits. - Use less permeable cover material when covering odorous loads (i.e. ConCover Progaurd, clay, etc). No longer use porous non-odorous waste as cover material for odorous waste. - Increase boundary odour observations to hourly, to ensure that Level 2 mitigation is being effective. Level 2 mitigation measures can only cease when two consecutive hours of odour observations do not detect offensive odour at the downwind boundary of the site. - Restrict waste spreading and compaction activities to a smaller area. - Use localised odour neutralising fogging cannons at active areas of the tip face.	- Odorous waste deposition or waste spreading/compaction at the tip face is not to occur during wind directions which trigger the automated alarm system (see Section 10). Odorous waste deposition is only to recommence when these wind triggers cease, or other control measures become effective at managing odour emissions from the tip face. - Continue hourly boundary odour observations. - Consider redesigning tip face operations such that odour emissions can be further minimised.

Activity	Level 1	Level 2	Level 3
	cover is readily available to immediately cover the waste with at least 150 mm of cover material. - Ensure that there is a readily available stock pile of non-odorous cover material present at the tip face at all times for the purposes of covering any odorous waste tipped at the face. - All site staff are to be used as spotters, and where a highly odorous load is dumped on the active tip face (but not in the designated odorous waste tipping bay), the tip face manager is to be notified immediately and the material is to be covered with the available non-odorous waste/cover material. - Notify clients who are delivering known odorous waste to avoid scheduling waste deliveries in the early morning or late evening hours where air dispersion conditions are poorer. - Where waste spreading or compaction disturbs odorous waste resulting in a noticeably higher odour emission from the activity, immediately cover the source of the odour with non-odorous waste or cover material. - Avoid spreading odorous waste deposited at the tip face across a larger area. Where possible compact this waste in situ. - Ensure appropriate landfill gas extraction is occurring surrounding the tip face as detailed in the Landfill Gas Management Plan.		
Special waste Special Wastes are wastes that come in on permit and generally classified as Special Waste/ Difficult Waste/ Discretionary**.** These wastes include putrescible waste from commercial or industrial sources, such as produce, fish or animal waste; sludge, septage, mud trap and grease trap waste; odorous green waste and woody waste. Treated Hazardous Waste also becomes acceptable if it meets that Hazardous Waste criteria in the Landfill Operations Management Plan. Discretionary waste becomes acceptable waste with the issue of a Special Permit. Hazardous waste streams that are consented to be received by AB Lime are discussed in the Landfill Operations Management Plan. Special waste must be deposited in the landfill in accordance with the conditions and protocols outlined in the Landfill Operations Management Plan.	- All special waste is only to be accepted by special permit. Clients delivering the waste must notify AB Lime of the expected date and time which special waste will be delivered. - Special waste is only to be deposited in dedicated special waste pits, which are to be pre-prepared in advance of the delivery. - The GPS co-ordinates of the special waste pit, quantity and type of material being deposited are to be recorded and held on file. - Delivery truck drivers are to be directed to the dedicated special waste pit by the weigh bridge staff and the pointsman at the tipface. The road to the special waste pit is to be clearly sign posted. - The weighbridge is to radio the tip face staff at the time of arrival such that staff can be available to immediately cover/treat the load tipped. - The tip height of the load is to be limited to as low as practicable to minimise disturbance of the load. - There is to be no spreading, compaction, or disturbance of the waste prior to covering.	- Increase boundary odour observations to hourly, to ensure that Level 2 mitigation is being effective. Level 2 mitigation measures can only cease when two consecutive hours of odour observations do not detect offensive odour at the downwind boundary of the site. - Special waste deposition is not to occur during wind directions which trigger the automated alarm system (see Section 10). Special waste deposition is only to recommence when these wind triggers cease, or other control measures become effective at managing odour emissions from this activity. - Increase the amount of cover material to better capture odour being released from the waste deposited. - Use less permeable cover material when covering special waste (i.e. ConCover Progaurd, clay, etc). - Require a higher level of pre-treatment with odour suppressants of all odorous special waste prior to delivery to site. - Odorous waste loads being deposited at the tip face/special waste area are to occur concurrently	- Continue hourly boundary odour observations. - Require all odorous special waste delivered to site to be in air tight containers such that there is no or very limited potential for odour to be released when these sealed containers are placed in the special waste disposal pit.

Activity	Level 1	Level 2	Level 3
	- Special wastes are to be covered immediately by at least 150mm of non-porous soil, lime or overburden material. Sufficient quantities of cover material are to be stored directly adjacent to the special waste pit. - Highly odorous loads are only accepted if the material has been pre-treated with lime or odour supressing chemicals. - The delivery of odours loads is to be planned to occur during the typically windy period in the middle of the day, while allowing sufficient time for thorough covering prior to daily closure of the landfill. - Additional odour supressing materials or lime is applied to the waste as it is deposited as required. - Intermediate cover over special waste pits is to be prioritised over other areas of the landfill.	such that cumulative odour emissions are reduced. - To reduce migration of odour out the sides/bottom of the pit, partially or fully line the special waste pit with a nonporous material prior to special waste being deposited into the pit.	
Leachate Odour emissions from the leachate are most associated with the anaerobic state of the leachate when it drains out of the waste mass. The anaerobic decomposition of the organic material in the water results in the evolution of odorous gases, primarily H_2S. Leachate drains by gravity from the collection systems in the landfill to the concrete leachate storage tank. The tank is sized for average flows after 35 years of waste filling and for peak flow in the early phases of the landfill. The leachate tank has an aerator to maintain aerobic conditions within the leachate, reducing odours associated with any further anaerobic decomposition. For transport off-site, leachate is pumped from a sump in the concrete tank to a tanker loading point. The tanker loading bay has a drain back to the leachate tank. Leachate is occasionally recirculated into the landfill to make use of the absorptive capacity of the waste and enhance microbial degradation. The re-injection system is designed to allow leachate to be pumped from the leachate tank directly to the landfill. Dissolved oxygen (DO) levels are monitored continually within the leachate tank to ensure that oxygen levels are sufficient to avoid odours. The procedures for handling and managing leachate on-site are described in the Landfill Leachate Management Plan.	- Weekly checks to ensure that the aerator and dissolved oxygen meter are operating within the manufacturer's guidelines. - Leachate storage tank is to be routinely checked by site staff (weekly) for observable odour emissions. - Automated alarm on the DO meter to detect when DO levels fall below 1% to indicate that either the aerator is not working or there is some other malfunction in the system. - Continuous H_2S meter is to be installed within a low-lying area next to the leachate tank to indicate potentially dangerous working conditions and presence of strong odour. An alarm for this continuous monitor is to be set at 1 ppm. Notification of this alarm being triggered is to be visualised by a flashing light at the leachate pond and/or e-mail notification to site management. - Ensure spills are minimised during transfer to the tanker truck. - Monitor H_2S boundary sensor data. If boundary H_2S concentrations exceed 20 ppb investigate source (using portable H_2S sensor) and move to Level 2 controls for H_2S emitting activities. - Leachate infrastructure such as sumps, wells and vertical risers to be effectively sealed only retaining any necessary access for monitoring and maintenance. - Leachate irrigation and reinjection controls	- Increase frequency of leachate removal from the leachate tank (ideally empty it completely as frequent as possible). - Increase boundary odour observations to hourly, to ensure that Level 2 mitigation is being effective. Level 2 mitigation measures can only cease when two consecutive hours of odour observations do not detect offensive odour at the downwind boundary of the site. - Where DO levels are lower than 1%, increase aeration (either by increasing frequency of aerator operation or increasing airflow rates).	- Investigate installation of additional aerators. - Leachate collection and off-site transport is not to occur during wind directions which trigger the automated wind direction alarm system (see Section 10). Leachate collection and off-site transport is only to recommence when these wind triggers cease, or other control measures become effective at managing odour emissions. - Investigate installation of cover/roof for the leachate holding tank with extraction of the headspace gas to an odour treatment system (i.e. a biofilter).

Activity	Level 1	Level 2	Level 3
Capping A full description of the landfill cover/capping design and process is included in the Landfill Operations Management Plan. If the daily cover, intermediate cover, or final capping does not remain airtight then odour and/or landfill gas can be released from the waste mass below.	- Undertake landfill gas management in accordance with the Landfill Gas Management Plan. - Undertake weekly capping inspections as outlined above. - Measure any gas release from cracks using a portable gas detector. If more than 1 ppm of H_2S or 0.5% CH_4 is detected at ground level, immediately repair the crack. - Check the edges of the cells with the portable gas detector for gas leaks up the wall of the cell. - Calibrate/tune the landfill gas extraction system such that the highest percentage possible of landfill gas being produced by the waste mass is being captured and destroyed. - If fugitive gas emissions are passing through intermediate cover, apply an additional 200 mm of cover material. - If fugitive landfill gas emissions are occurring through the daily or intermediate cover, increase the thickness of the cover and calibrate the landfill gas extraction wells near the tip face. - If odour is being detected at or beyond the boundary as a result of breaking up the daily cover at the start of each day, use daily cover that does not need to be broken up at the start of the day (i.e. Cleanfill).	If the Level 1 mitigation is not sufficient to control off-site nuisance odour effects, identify the source of the odour emissions using portable gas sensors and odour scout monitoring. Then apply additional mitigation to the source of the emission points, such as: - Increase the amount of landfill gas extraction in the offending cell(s). - Investigate alternate daily, intermediate and/or final capping materials. - Investigate alternate crack repair methodology. - Add additional landfill gas extraction well(s). - Install a temporary candlestick flare to burn excess landfill gas at the source of emission.	- Reduce the area of intermediate cover by either applying final capping to the area or completing the cell as soon as possible. - Install a temporary biofilter blanket (~400 mm thick mature compost or similar) over the odour source. - Engage suitably qualified experts/consultants to review and if necessary re-design the capping and cover methodology.

5. Air Discharges from Hazardous Waste Handling

Hazardous waste streams that are consented to be received by AB Lime include:

- Medical waste – in accordance with "Healthcare Waste Management" standards;
- Asbestos – In accordance with NZ Health and Safety at Work (Asbestos) Regulations 2016;
- Methamphetamine contaminated furnishings; and
- Aluminium dross.

The procedures and process for receiving and depositing hazardous waste streams are outlined in the Landfill Operations Management Plan.

Potential discharges to air from this process include:

- Airborne pathogens from medical waste;
- Methamphetamine and toxic volatile organic compounds (**VOCs**) such as: acetone, benzene, isopropanol, from meth contaminated waste;
- Airborne asbestos fibres; and
- Toxic fumes and dust from aluminium dross.

Most asbestos and all medical waste-streams are delivered to site in appropriately labelled and sealed containers. Therefore, there is a very limited potential for discharges to air from these waste streams.

Asbestos contaminated soil/mixed fill material arrives in a double wrapped 'pillow'. The pillow can rupture during placement in the dedicated special waste pit. Specific controls for the handling and management of asbestos containing waste (including asbestos contaminated soil/mixed fill pillows) are detailed in the Landfill Operations Management Plan.

Methamphetamine waste can arrive at site in loads which are not fully enclosed. Most the meth/VOCs that are available to be aerosolised will have been released during removal/transport or are no longer unlikely to be aerosolised during waste placement, so there is a minimal potential for significant discharge of these air pollutants. Mitigation measures (including air discharge mitigation) associated with the handling and deposition of methamphetamine are outline in detail in the Landfill Operations Management Plan.

Aluminium dross can produce toxic dust and ammonia fumes if it comes into contact with water. AB Lime will require the disposer to deliver the waste to the site in enclosed one tonne bags. These bags are to be placed within a pre-prepared dedicated hazardous waste pit, free of moisture. As for other hazardous waste streams the enclosed bags of waste aluminium dross are to be immediately covered with capping material. By enclosing the aluminium dross within bags, minimising the handling of the waste, and preventing the waste from becoming wet, dust and toxic fume emissions will be avoided.

6. Air Discharges from Crisis Waste Acceptance

In the instance of a local, regional or national biosecurity emergency or disaster, AB Lime may be required to accept a substantial volume of waste over a relatively short period of time.

Due to the organic nature of some of these wastes, their acceptance at the landfill site is likely to cause a heightened loss of amenity or nuisance associated with odour.

A special procedure for the acceptance and management of this waste is included in the Landfill Operations Management Plan.

To control potential odour emissions from the receival and disposal of crisis waste, the existing odour mitigation measures and controls for acceptance of highly odorous waste described in Section 4 are to be applied, along with the following additional controls:

- AB Lime is to stipulate to the waste provider that wherever possible the waste is to be pre-treated or delivered in airtight disposable containers/bags. This will reduce odour emissions during disposal. Examples of pre-treatment include:
  - Mix with lime or an alternate chemical odour suppressant;
  - Mix the material in with a bulking agent – i.e. sawdust;
  - Slit stomachs of deceased animals to reduce the potential for bloat and gas production; and
  - Refrigerate the material prior to/during delivery to slow down the decomposition process.
- Crisis waste deliveries are to be made to site as early as possible such that any organic material is as 'fresh' as possible.
- AB Lime is to notify the community liaison group and/or neighbouring residents/landowners of the requirement to receive this emergency waste, the date and time when waste will be received, and the control measures that will be implemented to reduce the potential for nuisance odour emissions. AB Lime is to notify the neighbours that despite the additional odour controls, nuisance odour may still travel beyond the boundary of the site. As such the neighbours may wish to leave windows closed, not hang washing outside, or plan to be away from home during the times that the waste is proposed to be delivered.
- AB Lime is to provide neighbours with the contact phone number of the site Environmental Manager such that they can notify AB Lime if any offensive odour is observed off-site.
- AB Lime are to undertake hourly boundary odour observations during crisis waste deposition. Where applicable off-site odour scouting is to occur to identify the extent of any off-site odour plume. This information is to be retained and provided to Environment Southland on request.
- AB Lime are to invite an Environment Southland representative to be present during the crisis waste deposition to monitor any off-site nuisance effects and communicate with local residents/land owners.
- If any complaints are observed during the crisis waste acceptance, the complaint response procedures in the Environmental Management Plan are to be instigated.

7. Combustion Emissions

As discussed in Section 3, combustion emissions contain toxic air pollutants that are hazardous to human health and regulated by national environmental standards.

Products of combustion (CO, PM_{10}, NO_2 and SO_2) are emitted from the following sources on-site:

- Motor vehicle exhausts;
- The landfill gas flare;
- Portable temporary candlestick landfill gas flares; and
- The coal fired lime kilns (covered in a separate air discharge consent).

There are a limited number of site vehicles and delivery trucks on-site at any one time, as such exhaust emissions from these vehicles are minimal contributors to discharges of controlled pollutants from the site.

Air dispersion modelling has demonstrated that at peak operating conditions the combustion emissions from the operation of the gas flare and coal fired lime kilns result in low off-site concentrations of CO, PM_{10}, NO_2 and SO_2 beyond the boundary of the site. Nevertheless, the following good practise mitigation measures are to be implemented on-site.

7.1 Mitigation

The primary method for reducing the concentration of toxic products of combustion from the site is to ensure that the combustion equipment is well tuned and efficient combustion is occurring. Inefficient combustion results in higher emission rates of controlled pollutants.

The Landfill Gas Management Plan contains a full description of the landfill gas flare operations and associated mitigation and controls.

- The landfill gas flare is to be maintained and calibrated by an appropriately qualified technician at least annually to meet the requirement that at least 98% of non-methane organic compounds are destroyed. These procedures also ensure that effective efficient combustion of landfill gas occurs which minimises toxic products of combustion emission.
- The landfill site also contains a lime drying kiln which uses coal but can also utilise landfill gas – details associated with the operation of the drying kiln are covered in the Quarry Management Plan.

Contingency measures associated with reducing ground level concentrations of pollutants emitted from the flare/coal fired kilns include:

- Increasing the stack heights.
- Installing reducing cones on the stack tip to increase the exit velocity.
- Installing secondary scrubbers/after burners.
- Replacing the flare with a larger/more efficient flare.

8. Dust

AB Lime has a requirement to ensure the there is no offensive of objectionable dust discharged beyond the boundary of the site.

8.1 Emissions Sources

The main sources of nuisance dust emission at the landfill are:

- Disturbance of surface fines on access roads as a result of traffic movements;
- Earthworks and material handling activities - such as the placement of cover material during dry periods;
- Filling and compaction of dusty waste;
- Fugitive dust emissions from exposed surfaces;
- Material being tracked off-site onto Cahill Road by vehicle movements; and
- Dust from material stockpiles.

8.2 Factors Influencing Dust Generation

The major factors that influence dust emissions from surfaces are:

- Wind speeds across the site; increased pickup of dust from exposed surfaces occurs at windspeeds above 7 m/s;
- The percentage of fine particles in the material;
- Moisture content of the material;
- The area of exposed surfaces;
- Disturbances such as vehicle movements, materials handling activities, etc; and
- The height of the dust source above the surrounding ground level.

The separation distances between the primary dust generating activities and the site boundary are generally greater than 300 m. The main access road is sealed for a length of approximately 400 m reducing the potential for material to be tracked off-site. The nearest unsealed road is ~400 m from the nearest public road.

Given these large separation distances and the presence of mature planting mostly surrounding the operations, there is a limited potential for off-site nuisance dust effects. However, to ensure that the site remains compliant with its consent requirements the following dust mitigation measures are to be applied on-site.

8.3 Mitigation Measures

Two levels of mitigation measures for dust emissions are set out in Table 8.1. If the measures in level 1 are not sufficient to control dust emissions from the site, the level 2 contingency measures are to be considered by AB Lime management.

Table 8.1: Dust mitigation measures

Level 1	Level 2
• Dust control procedures and responsibilities are to be included in site induction training for all new staff/regular contractors on-site. • All site staff are to report any visible dust emissions (particularly those at or beyond the site boundary) to the site management so that additional mitigation can be applied to the source of the emission. • The main landfill entrance shall be permanently sealed. • Regular maintenance of unsealed haul roads with fresh coarse chip to ensure that the amount of surface fines on the road is limited. • Dust emissions from vehicle movements are directly related to vehicle speed. Control vehicle speeds (limit 30 km/hr on sealed roads and 15 km/hr on unsealed roads). Speed limits are to be signposted on all internal roads. • A water-cart will be used to reduce dust on both unsealed and sealed roads. Where required a sweeper truck is to be used to assist in cleaning sealed roads. • All vehicles/waste transporters leaving the site that have been off-road or at the working face shall use the wheel-wash facilities. • Dusty special wastes shall only be accepted by prior arrangement. The following mitigation measures shall be undertaken to minimise dust emissions from these special wastes: a) dusty wastes shall be dampened or enclosed in bags prior to delivery to the landfill, or controlled by water spray at the landfill. b) emissions from potentially dusty loads tipped at the workface shall be controlled by applying water or immediately covering the waste material. • Dust emissions from material disturbance activities are to be mitigated as follows: a) Ensure that there is a readily available source of water for dust mitigation measures within the active area of the landfill. b) Stockpiles of dusty/dry cover and capping material are to be limited to that which is needed for normal/immediate operations.	• Consider sealing more internal site roads. • Use a chemical dust suppressant on exposed unconsolidated surfaces. • Install fixed and or mobile sprinkler systems (i.e. k-line sprinklers) along/over dust emission points. • Increase the frequency of water cart operation or add a second water cart for dust control. • Further limit the size of unconsolidated surfaces and dusty stockpiles. • Grass or hydroseed stockpiles or unconsolidated surfaces which are not in active use.

Level 1	Level 2
c) Where required, during dry windy (windspeeds above 7 m/s) conditions, wet down cover and capping material prior to disturbance and/or during placement. d) Limit the drop height of all potentially dusty material placement, loading, and unloading activities to a practical minimum. e) Where required wet down dusty loads before and during tipping. • Dust from unconsolidated surfaces can be emitted during dry windy (windspeeds above 7 m/s) conditions. To mitigate the potential for these emissions, site staff are to apply the following mitigation measures: a) Keep the amount of open ground/unconsolidated surfaces to a practicable minimum. b) Traffic access to exposed areas is to be limited to a practical minimum. Where applicable isolation bunds are to be used to prevent vehicle access to exposed areas. Exposed areas with no or low traffic access will be watered to form a crust over the surface and limit the amount of fine particles on the surface. c) Progressive rehabilitation and re-grassing of capped areas of the site is to occur as soon as practically possible to limit the amount of exposed surface. d) Where dust emissions are not being controlled by the above measures, consider using additional controls such as hydroseeding, temporary covering with a course non-dusty material, or installing fixed/mobile sprinkler systems. • To limit dust emissions from material stockpiles, keep the volume of stockpiled material to a practical minimum. Where required water the sides of stockpiles to form a crust on the surface. • Grass large stockpiles that are not proposed to be used for long periods of time (>6 months) as soon as practicable. • Where practicable store fine/dusty material stockpiles below natural ground level.	

9. Maintenance

All critical air discharge control equipment and plant on-site is to be checked and maintained in accordance with the manufacturer's guidance and site procedures.

This includes:

- Daily pre-start checks are to be made on all site vehicles and the water cart. Vehicles are to be regularly serviced in accordance with the manufacturer's service and maintenance requirements.
- The fence line odour suppressant system and the portable odour fogging unit are to be checked/maintained at least monthly for correct and efficient operation.
- The on-site weather station and associated automatic alarm system is to be audited and calibrated annually.
- The boundary and onsite H_2S sensors are to be bump tested monthly and calibrated in accordance with the manufacturer's requirements.
- The landfill gas meter is to be bump tested at least monthly and calibrated in accordance with the manufacturer's requirements.
- The methane Flame Ionisation Detector (FID) is to be audited and calibrated in accordance with the manufacturer's requirements.
- The landfill gas flare(s) are to be maintained and monitored in accordance with the procedures outlined in the Landfill Gas Management Plan.
- The leachate tank aerator is to be monitored and maintained in accordance with the requirements in the Landfill Leachate Management Plan.

10. Monitoring

10.1 Landfill Gas Monitoring

Careful management and monitoring of the landfill gas system is required to minimise the potential for objectionable odours and the risk of explosion, combustion, asphyxiation, underground fires or vegetation damage within the landfill and beyond the site boundary. The landfill gas monitoring procedures are outlined in the Landfill Gas Management Plan.

10.2 Leachate Tank Monitoring

The Leachate Management Plan contains monitoring requirements for the DO levels in the leachate tank.

10.3 Site Weather Conditions

Currently AB Lime has a weather station located relatively central to the site. A backup station is located on the adjacent dairy farm (down valley of the farm).

Site weather conditions including rainfall, wind velocity and direction, barometric pressure and temperature are to continue to be monitored continuously (at least once every hour). The information will be used to assist investigations and response to any odour complaints and interpretation of gas monitoring results.

The weather station is to remain located in an area central to the site where the observations are representative of the site wind conditions. The height of the mast should be no less than 6 m above ground level, but ideally 10 m above ground level. The monitoring station is to not to be situated next to large structures or trees which would influence local airflows.

The weather station is to log measured parameters continuously. The weather station is to be connected to an automated alarm system that triggers an on-site flashing light and email/text message alerts to inform site staff of wind directions from the north, northeast and east (winds blowing from 0 - 90 degrees azimuth) and windspeeds below 1 m/s or above 7 m/s. At windspeeds below 1 m/s, there is a higher potential for nuisance odour effects, at windspeeds above 7 m/s there is a higher potential for dust emissions from unconsolidated surfaces.

10.4 Boundary Odour Observations

Boundary odour observations are to be made once a week during winds blowing from the north, northeast and east (winds blowing from 0 - 90 degrees azimuth), or during still (wind speeds below 1 m/s) cold air drainage conditions. Where practicable these odour observations are to be made during the first occurrence of these meteorological conditions during the working week. Where these meteorological conditions do not occur during the week, downwind odour observations are optional.

The monitoring frequency is to be increased if offensive odour emitted from the landfill is detected at the site boundary or an off-site complaint/observation is received as described in Section 4 and 11. The methodology for undertaking the boundary odour monitoring is explained in Attachment 1.

10.5 H_2S boundary monitoring

At least two low range continuous datalogging H_2S monitors are to be installed along the south western boundary of the site (for example, one at the site office and one near R8). The continuous monitors are to have a minimum H_2S detection limit of 10 ppb (i.e. an OdaLog Low Range H_2S Logger).

Data from these two monitors is to be logged and automated alarms are to be set at 20 ppb (0.02 ppm) such that additional mitigation measures discussed above can be implemented.

The monitors are to be installed as close to ground level as possible (without being at risk of flooding), as H_2S is heavier than air.

Where required, a low range H_2S sensor can be used in 'survey mode' to scan upwind and detect the source(s) of the H_2S emissions where an alarm has occurred.

11. Complaints

The process for managing complaints is detailed in the Environmental Management Plan. The following sections provide additional details when the complaints relate to air quality.

11.1 Response to Air Quality Complaints

The Environmental Manager will contact the complaint by telephone, or if this is not possible by sending a letter or email on the same day as the complaint is received.

To validate and investigate the source of the complaint undertake the following as appropriate:

- Correlate complaint with weather conditions.
- For a dust complaint, undertake off-site and on-site observations to determine the location and extent of the dust plume. Work upwind to identify the source(s) of the dust emissions.
- For an odour complaint, undertake odour scout survey to ascertain the extent, intensity, and character of the odour plume. Start at the area where the complaint was received and work upwind to identify the source of the odour. Where appropriate utilise an OdaLog low range H_2S sensor (or similar) to identify any measurable concentrations of H_2S within the plume/at the source.
- Check and record current tipping operations.
- Check and record any odorous/dusty load history (type, age, number, disposal method, timing).
- Check daily, intermediate and final cover.
- Check gas collection systems and flare for proper operation.
- Check leachate tank aerator unit for proper operation.
- Check leachate tank H_2S sensor readings.
- Record all odour scout and investigation observations in the AB Lime incident response forms.

If the cause of the complaint is identifiable, measures that have to/will be put in place to avoid a recurrence will be recorded and provided to external parties as required. If there is uncertainty as to the nature or cause of the complaint the Environmental Manager will seek clarification. A meeting may be required to discuss the complaint and if possible, will be arranged as soon as is practicable.

All complaints will be responded to in writing, and in some cases this may be after clarification.

Copies of the written responses will be filed in the complaints register.

All complaints will be reported to Environment Southland as soon as possible and no longer than one working day after the complaint is received.

11.2 Validated Complaints

Should investigation of odour/dust complaints indicate that discharges from the landfill are causing objectionable or offensive effects beyond the boundary, site staff are to instigate Level 2 or Level 3 mitigation measures for the source of the emission.

AB Lime will offer the complainant(s) and any other concerned neighbouring residents the opportunity to participate in an odour diary program. The design of the odour diary programme shall be in accordance with recognised good practice.

An odour diary record sheet is to be provided to all participants. The odour diary program is to continue for a minimum period of three weeks (pending participant approval). Contact details of the Environmental Manager are to be supplied to the participants of the odour diary program such that direct feedback can be provided to AB

Lime if and when landfill odour is detected beyond the boundary of the site. This feedback will used by AB Lime to further investigate odour sources on-site and implement additional controls where required.

Where appropriate, AB Lime shall notify Environment Southland of the odour diary program and provide a summary of the results on request.

11.3 Ongoing Air Quality Complaints

If a complainant is dissatisfied with a response to a complaint, every reasonable attempt is to be made to find a satisfactory solution. If all reasonable measures are rejected, the complainant will be referred to Environment Southland. Details of the measures offered will be sent to the regulatory authority at the same time as being offered to the complainant or if offered verbally as soon afterwards as is practical.

Attachment 1. Boundary Odour Monitoring

The methodology for the boundary odour scouting and monitoring are based on the current (2016) version of the Ministry for Environment Good Practice Guide for Assessing and Managing Odour (https://www.mfe.govt.nz/publications/air/good-practice-guide-assessing-and-managing-odour). Where an updated version of this guidance exists, AB Lime is to update this methodology accordingly.

Definitions

Objectionable **–** The term objectionable is used in AB Lime's consent conditions and is an ingredient of any subsequent enforcement action. It is a subjective term and is open to interpretation. There is guidance from case law which defines objectionable as: unpleasant or repugnant; open to objection or undesirable or disapproved, or; noxious or dangerous. A test will be applied by the court that the term objectionable will be as it applies to "the minds of a significant cross section of reasonable people in the community". The assessor must bear this test in mind when completing their assessment.

Intensity **–** The strength of the odour (e.g. 3 'distinct')

Character **–** What the odour smells like – describe the smell (e.g. fishy)

Hedonic tone **–** The degree to which an odour is perceived as pleasant or unpleasant (e.g. -4 'extremely unpleasant')

Methodology

The ambient odour monitoring is to be undertaken by someone that has not spent a significant amount of time in the active landfill just prior to the monitoring. For example, the person could be office staff or other staff prior to starting work on the site, or after leaving the site for some time. The purpose of this requirement is to avoid the effects of desensitisation affecting the effectiveness of the odour monitoring.

Field sheets for recording the odour observations are included in the 'field sheets' section below.

The assessor is to start by recording the meteorological parameters (ideally as measured by the on-site weather station(s)). Based on the measured and observed ground level wind direction, select a representative downwind assessment site on the boundary of the site. It may be appropriate to walk along the section of the downwind boundary to check if any initial odour is present on this boundary.

Record the location of the sampling site both on the field sheet and an aerial image.

Undertake the 10-minute assessment by recording an observation of the intensity and character of odour observed at the monitoring location every 10 seconds. Use the intensity and character descriptors listed on page two of the field sheets. Breath normally, don't sniff or breath only through the nose. Record your observations in the 60 boxes (one for each 10 second observation) on the first page of the field sheets.

Record all odour observations (i.e. earthy, or fresh cut grass), not just odours associated with the landfill.

Record the hedonic tone of any odour detected. Note that this may be variable over the course of the assessment.

Where landfill odour is detected undertake a 360-odour observation of the landfill to ensure that there are no off-site or upwind odour sources contributing to the observed odour. Also move through the odour plume to record the extent of the plume (i.e. how wide it is, and how far it is observable off-site).

If the odour character/hedonic tone is offensive and consistent with that from the landfill and has an intensity at or above 3 ‘distinct’, instigate the odour source. The investigation and associated response procedure outlined in Section 11 of the Plan. Immediately notify the Environmental Manager and Site Manager.

Appendix C. Updated Environmental Management Plan

AB Lime Ltd

AB Lime Ltd Environmental Management Plan

IZ000400-LFC-NP-RPT-0002 | 1

2 September 2020

AB Lime Ltd

Draft for Consenting Purposes

AB Lime Ltd

Project No: IZ000400
Document Title: AB Lime Ltd Environmental Management Plan
Document No.: IZ000400-LFC-NP-RPT-0002
Revision: 2
Date: 2 September 2020
Client Name: AB Lime Ltd
Project Manager: Katrina Jensen
Author: Ryan McCone
File Name: Environmental Management Plan - s 92

Jacobs New Zealand Limited

Level 2, Wynn Williams Building
47 Hereford Street
Christchurch Central
PO Box 1147, Christchurch 8140
New Zealand
T +64 3 940 4900
F +64 3 940 4901
www.jacobs.com

Document history and status

Revision	Date	Description	Author	Checked	Reviewed	Approved
0	22/05/2020	Draft for Comment	Ryan McCone	Craig Redmond	Andrew Henderson	
1	29/05/2020	Final Draft for Consenting Purposes	Craig Redmond	Ryan McCone	Andrew Henderson	Vince Pace
2	2/09/2020	Updated Draft for S 92 Response	Craig Redmond	Ryan McCone	Andrew Henderson	Vince Pace

Contents

Important note about this report

The sole purpose of this report and the associated services performed by Jacobs (on behalf of AB Lime Limited) is to provide a technical report for landfill management to assist with a resource consent application to increase the activities at AB Lime Landfill at 10-20 Kings Bend, Winton, in accordance with the scope of services set out in the contract between Jacobs and AB Lime (the Client).

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by the Client and/or from other sources. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and conclusions as expressed in this report may change.

Jacobs derived the data in this report from information sourced from the Client (if any) and/or available in the public domain at the time or times outlined in this report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report. Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

This report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by Jacobs for use of any part of this report in any other context. This report has been prepared on behalf of, and for the exclusive use of, Jacobs's Client, and is subject to, and issued in accordance with, the provisions of the contract between Jacobs and the Client. Jacobs accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report by any third party.

1. Background

1.1 Purpose/Objective of the Environmental Management Plan

This Environmental Management Plan is for the operation of the AB Lime Ltd landfill and quarry. The purpose of the Environmental Management Plan provides details of the practices and procedures to operate the landfill and quarry in compliance with the Resource Management Act.

The scope of the Environmental Management Plan is to:

- Capture and address the environmental and social effects generated by the operation of the landfill and quarry;
- Identify the compliance requirements for the operation of the entire site;
- Set a framework for the management of the environmental effects identified; and
- The scope of the draft EMP has been updated to include reference to the industry accepted best practice guidelines, while maintaining the focus on meeting the first order statutory requirements of environmental legislation. In particular, the Resource Management Act and conditions of consent provide clear performance or environmental standards that have been developed taking into consideration the uniqueness of the site, and they are to be certified by an appropriately qualified and experienced person as being achieved.

All activities on site will operate in accordance with this plan for the duration of the resource consents requiring it. The Environmental Management Plan is designed to achieve the following objectives:

- To operate in full compliance with the resource consent requirements and demonstrate this through reporting procedures to Consent Authorities;
- To liaise closely with neighbours and the local community, including iwi representatives, regarding landfill operational issues;
- To provide a safe working environment for people on the site;
- To maintain an independent review process for the design, construction, operation and aftercare of the landfill to confirm the work is undertaken by appropriately qualified personnel in accordance with good practice;
- To identify operational responsibilities, the management structure and staffing;
- To facilitate the effective training of staff;
- To facilitate accurate record keeping;
- To maintain community involvement including details of complaints procedures;
- To appropriately manage site access, fencing and security; and
- To manage site infrastructure and site amenities.

1.1.1 Description

AB Lime own and operate the Class A Southern Regional Landfill facility at Winton. It is the primary accepter of waste for the Southland region, as well as accepting waste from other regions in the lower half of the South Island. AB Lime also operate a lime quarry, cutting and processing limestone on site to produce high quality lime and fertiliser blends.

1.1.2 Location

The landfill is located on the eastern fringe of Winton, at 10-20 Bend Road, Kings Bend Figure 1 shows the location of the landfill and quarrying operations within the context of Winton, and Figure 2 shows a close up of the AB Lime Ltd landfill and quarry operations.

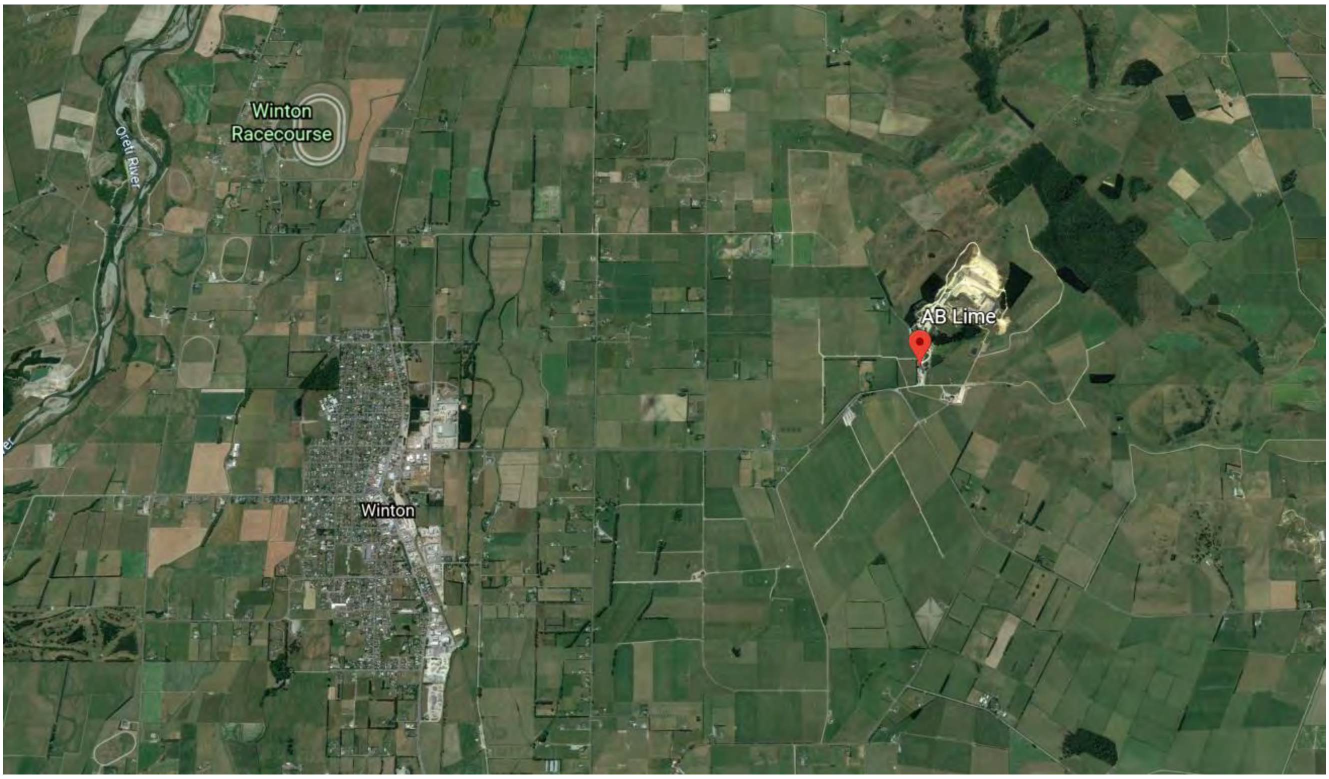


Figure 1 Local Context of AB Lime Landfill and Quarry

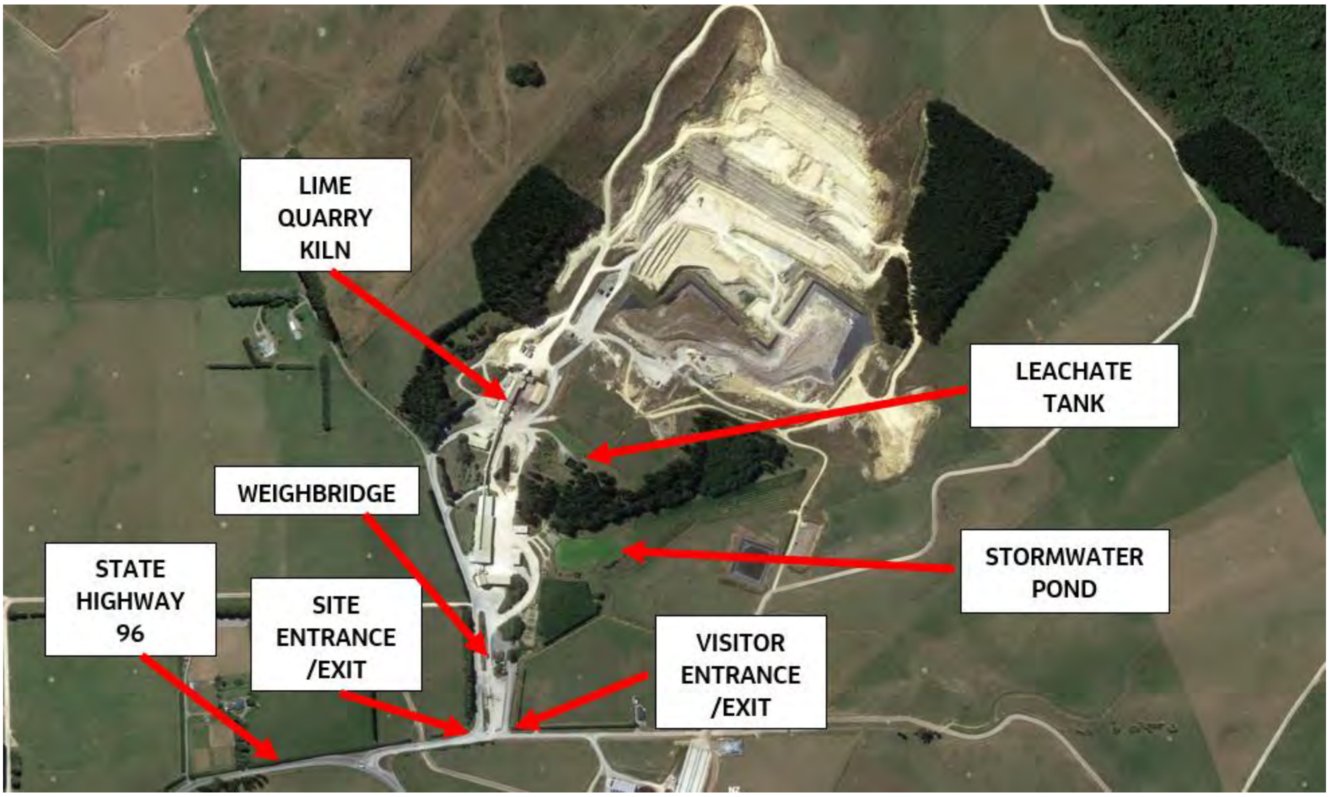


Figure 2 Close up of the AB Lime Landfill and Quarry

1.1.3 Management Plan Framework

The operation of AB Lime landfill and quarry requires a suite of environmental management and mitigation plans to operate the site. The Environmental Management Plan sets the overall framework for the operation of the site and is supported by a series of sub management plans focusing on specialist environmental areas to effectively run the landfill and quarry.

Figure 3 below illustrates the relationship between the Environmental Management Plan and the sub environmental management and mitigation plans.

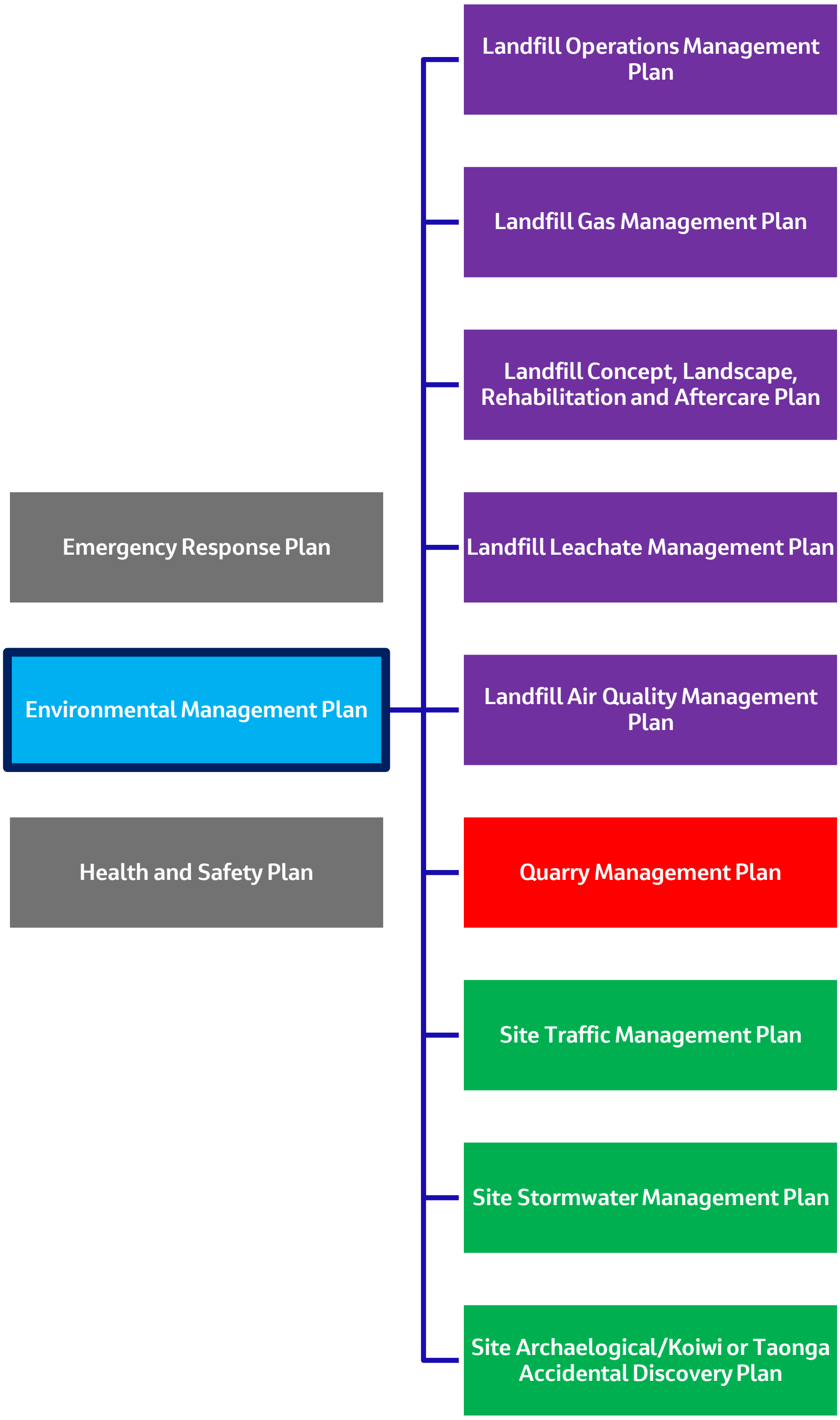


Figure 3 AB Lime Limited Management Plan Structure

Key:

1.2 Plan Preparation and Process

AB Lime have an environmental management plan framework to coordinate the efficient and effective environmental management of the landfill and quarry. This plan and all the sub plans are live documents that provide an adaptive management framework that will be updated as the site operations and industry guidance evolve. Updates and reviews to this plan will be carried out in accordance with section 4.6 of this plan.

1.2.1 Minimum Contents of Each Plan

Each management plan for the AB Lime landfill and quarry will specify:

- The purpose and objectives of the management plan;
- The legislative requirements and specific consent conditions the plan is designed to assist with implementing;
- How the site will give effect to the purpose, objectives and legislative requirements; and
- Monitoring and reporting the performance of the management plan in ensuring that conditions of consent are complied with.

1.2.2 Certification and Submission Process

All of the environmental management plans require certification and Environment Southland and/or Southland District Council require the following plans to be independently certified.

Table 1 List of Appointed Independent Reviewers/Certifier for Each Plan

Management Plan	Independent Reviewer/Certifier	Certifier
Environment Management Plan	To be appointed	Environment Southland/Southland District Council
Landfill Operations Management Plan	To be appointed	Environment Southland/Southland District Council
Landfill Gas Management Plan	To be appointed	Environment Southland
Landfill Concept, Landscape Rehabilitation and Aftercare Plan	To be appointed	Environment Southland/Southland District Council
Landfill Leachate Management Plan	To be appointed	Environment Southland
Landfill Air Quality Management Plan	To be appointed	Environment Southland
Quarry Management Plan	To be appointed	Southland District Council
Site Traffic Management Plan	To be appointed	Southland District Council
Site Stormwater Management Plan	To be appointed	Environment Southland
Site Archaeological/Koiwi or Taonga Accidental Discovery Plan	To be appointed	Environment Southland/Southland District Council

1.2.3 Certification Process

All AB Lime management plans that fit under the management plan structure identified in Table 1 are required to be independently certified. The EMP is required to be independently certified by the Southland Regional Council and the Southland District Council. The resource consent conditions in Land Use Consent

60/3/02/138/1 and Schedule 1 to the Environment Southland Consents for the AB Lime Landfill outline the process for certification and review for all management plans. The independent certification or reviewer process outlined in Figure 4 is used when first certifying the plans with the respective councils or when the plans are updated.

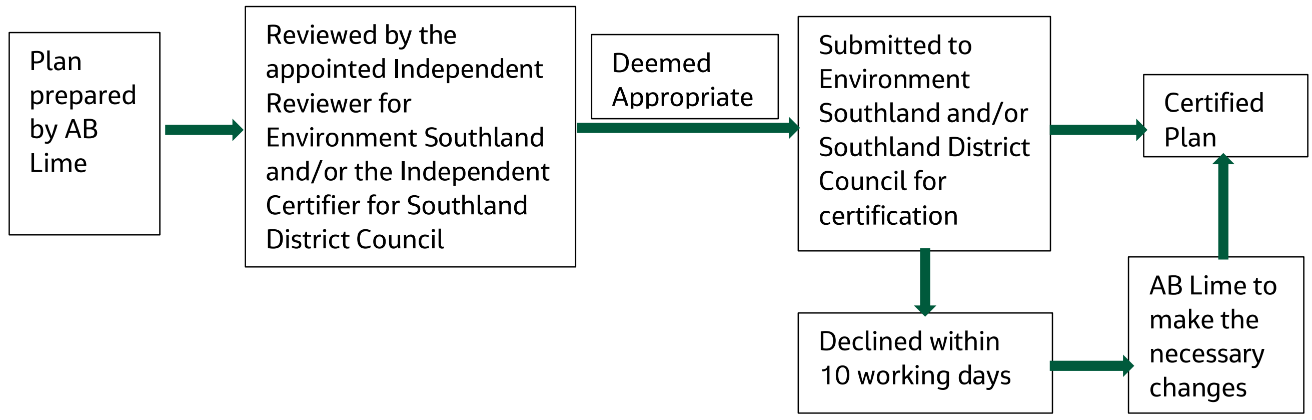


Figure 4 Management Plan Certification Process

1.3 Roles and Responsibilities

The listed site personnel in Table 2 will be required to ensure that the activities on-site are managed, and the management plans are given effect to in accordance with conditions of resource consents.

Roles and responsibilities for the implementation of this Plan are provided in Table 2 below. Everyone involved at AB Lime Ltd has a role in the implementation of the Environmental Management Plan. The roles listed are key proponents to ensuring the delivery of the Environmental Management Plan.

Table 2 Plan Implementation - Roles and Responsibilities

Name	Role	Contact Details	Key Responsibilities in Relation to this Plan
Steve Smith	AB Lime Landfill Manager and General Manager		▪ Implement appropriate training measures for all staff to familiarise with the EMP
Fiona Smith	AB Lime Environmental Manager		▪ Ensure that a copy of all consents and management plans are kept on site; ▪ Document control; ▪ Monitoring and reporting; and ▪ Liaison with regulatory authorities and Independent Peer Review Panel; ▪ Manage the entire disposal process associated with emergency waste
Craig Owen-Cooper	Landfill Supervisor		▪ Facilitate with landfill operators to ensure they are familiar with and apply all relevant components of the EMP in daily practise; ▪ Train and upskill new staff in landfill matters relating to the EMP;

Name	Role	Contact Details	Key Responsibilities in Relation to this Plan
			▪ Implement requirements that fall to the responsibility of the landfill supervisor under all relevant sub-management plans
TBC	Quarry Manager		▪ Facilitate with quarry maintenance and production staff to ensure they are familiar with and apply all relevant components of the EMP in daily practise; ▪ Train and upskill new staff in quarry matters relating to the EMP

1.4 Management Structure

The AB Lime organisational chart for the landfill and quarry is shown below in Figure 5.

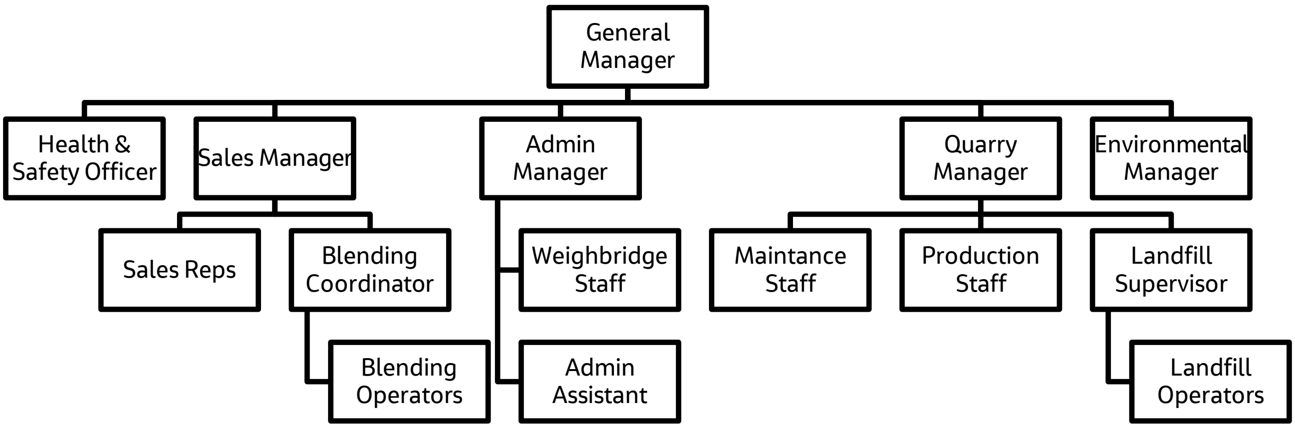


Figure 5 Organisational Chart - AB Lime Quarry and Landfill

2. Environmental and Social Management

2.1 Environmental and Social Impacts

2.1.1 Environmental Impacts

The potential environmental impacts for the operation of the landfill include:

- Noise;
- Litter;
- Vermin;
- Surface water;
- Groundwater;
- Leachate;
- Landfill gas;
- Air quality; and
- Ecology

The management plan framework created considers the sensitivity of the receiving environment to adverse effects. Landfill operations that utilise this management plan framework have minor impacts on the wider environment.

2.1.2 Social Impacts

The social impact of the operation of the landfill is considered to be substantially less when compared to the development of a new landfill at a new location. It is considered that any adjustment to property values in the vicinity of the landfill have already occurred as the landfill now forms an integrated part of the existing environment.

While there is acceptance of a continued need for a regional Class A landfill, it is considered to remain of concern to neighbours, who identify potential adverse effects that could impact on their current amenity. Issues that could affect current amenity of neighbours include:

- Odour;
- Landfill gas emissions;
- Noise;
- Traffic volumes;
- Road safety effects;
- Vermin and litter management;
- Dust; and
- Litter spread.

The perceptions of and stigma attached to landfills is an important matter requiring consideration. Whether or not all perceived effects actually materialise, recognition of these potential effects remains an important consideration as they can have a real effect on community wellbeing. AB Lime identify the need for continued open and transparent communication as a key mechanism to manage perceptions in the community.

The following mitigation measures are recommended to continue to ensure any perceived negative social effects are minimised:

- Ongoing consultation and interaction with the general public, local residents and local community groups through the Community Liaison Committee;
- AB Lime continue to play a role in the education of the waste minimisation and provide an understanding of the waste cycle;
- Provide improved management and mechanisms for neighbours and relevant authorities to manage complaints, particularly related to odour; and
- Remain accessible to neighbours and affected parties to maintain transparent and open communication channels .

2.2 Legislative Requirements

The legislative requirements of this Environmental Management Plan outline the consent conditions that this plan is designed to assist with implementing.

The Resource Management Act approvals listed in Table 3 apply to this site.

Table 3 Current Resource Management Act Approvals (to be completed once consent application is granted)

Granter	Authority number	Consent type	Purpose	Expiry

2.3 Resource Consent Requirements

The conditions relevant to the Environmental Management plan are compiled in Table 4.

Table 4 Relevant Conditions for Consents related to Environmental Management Plan

Condition Number	Condition	Reference
Land Use Consent 60/3/02/138/1		
Management Plans		
2.4	The solid waste disposal facility and associated operations shall operate in accordance with an Environmental Management Plan (EMP) for the duration of this consent.	Section 1.1

Condition Number	Condition	Reference
2.5	The EMP shall incorporate or refer to the following management plans, described in later conditions of this consent: a) Landfill Operations Management Plan; b) Landfill Gas Management Plan; c) Landfill Concept, Landscape, Rehabilitation and Aftercare Plan; d) Landfill Leachate Management Plan; e) Landfill Air Quality Management Plan; f) Quarry Management Plan g) Site Traffic Management Plan h) Site Stormwater Management Plan i) Site Archaeological/Koiwi or Taonga Accidental Discovery Plan In the event of an inconsistency between the management plans and a condition of this consent, these conditions shall prevail. ***Advice Note (i):*** *For completeness all sub-management plans are identified in condition (2.5). The sub-management plans relevant to this consent include the Landfill Operations Management Plan, the Landfill Concept, Landscape, Rehabilitation and Aftercare Plan, the Site Traffic Management Plan, and the Site Archaeological/Koiwi or Taonga Accidental Discovery Plan.* ***Advice Note (ii):*** *The objectives for each sub-management plan relevant to this consent are identified in consent conditions (2.12)-(2.16). There are also other objectives within these sub-management plans not relevant to this consent that are managed by the Regional Authority.*	Section 3.1
Appointment of Certifiers		
2.6	Within one month of giving effect to this resource consent the Consent Holder shall confirm the appointment of independent, suitably qualified and experienced person(s) to certify the management plans required by this consent, and provide information to the Southland District Council to demonstrate that the proposed certifier(s) is independent, suitably qualified and experienced. ***Advice Note:*** *If the Southland District Council does not approve the person(s) proposed by the Consent Holder, reasons must be provided in writing to indicate why the person(s) is not considered to be suitable.*	Section 1.5.1
2.7	Certification of the plans shall not proceed until the Southland District Council confirms in writing that the Certifier meets these requirements.	Section 1.5.1
2.8	The independent certifier may be changed at any stage during operations, however, the new certifier must be confirmed as being appropriate by the Southland District Council in accordance with condition (2.6)	Section 1.5.1
Certification Process		

Condition Number	Condition	Reference
2.9	If changes to the relevant plan are requested by the certifier, in alignment with conditions (2.11)-(2.14) these changes shall be made before the certification is confirmed by the Southland District Council.	Section 1.2
2.10	This resource consent and a copy of the Southland District Council certified versions of all the management plans required by this consent shall be kept on site at all times, and the consent holder shall ensure all personnel are made aware of each plan’s contents, where the plan relates to activities that those personnel are responsible for.	Section 1.2
Review Process		
2.11	The consent holder may make amendments to the final management plans that may change how any adverse effect is managed at any time subject to the certification of Southland District Council.	Section 1.2
2.12	All amendments shall be consistent with the objectives and performance requirements of the management plan and these consent conditions.	Section 1.2
2.13	a) In event of an amendment to a management plan under Condition (2.11), the consent holder must submit the amendment to Southland District Council for certification 10 working days before the commencement of the relevant works. Certification shall confirm that the amendment is in accordance with condition (2.3) and meets the objectives and performance requirements of the management plan. b) Southland District Council shall be requested, no later than 10 working days of the receipt of the amendment, to confirm to the consent holder that the amendment is either certified or declined. If no response is received, approval is deemed to have been given as set out in condition (2.14). c) Should Southland District Council decline to certify the amendment or request the incorporation of changes to the amendment the consent holder may then resubmit a revised amendment to the management plan(s) following the procedures set out in Condition 2.13(a)-(b)	Section 1.2
2.14	If no confirmation of the Plan’s suitability is received from Southland District Council within 10 working days of submission of any plan or other information provided for certification, the submitted information shall be deemed to have been approved.	Section 1.2
Environmental Management Plan		
2.15	The overall purpose of the EMP is to provide details of the practices and procedures to operate the landfill in compliance with the conditions of consent. The EMP shall comply with the relevant consent conditions and achieve the following objectives:	Section 1.1
	i. To operate in full compliance with the resource consent requirements and demonstrate this through reporting procedures to Consent Authorities.	Section 2.3
	ii. To liaise closely with neighbours and the local community, including iwi representatives, regarding landfill operational issues.	Section 3.2
	iii. To provide a safe working environment for people on the site.	Section 3.3.3

Condition Number	Condition	Reference
	iv. To maintain an independent review process for the design, construction, operation and aftercare of the landfill to confirm the work is undertaken by appropriately qualified personnel in accordance with good practice	Section 1.5
	v. To identify operational responsibilities, the management structure and staffing	Section 1.3 and Section 1.4
	vi. To facilitate the effective training of staff:	Section 4.2
	vii. To facilitate accurate record keeping	Section 4.6
	viii. To maintain community involvement including details of complaints procedures	Section 5.5
	ix. To appropriately manage site access, fencing and security	Section 3.3
	x. To manage site infrastructure and site amenities	Section 3.3
Operational Conditions		
2.20	That the solid waste disposal facility shall not accept any waste delivered to the site by the general public. Solid waste shall be delivered to the site only in vehicles which have been given prior authorisation to access the site by the consent holder.	Section 3.3
2.21	That the solid waste disposal facility shall be permitted to receive solid waste only between the hours of 8.00 am and 6.00 pm 7 days per week.	Section 3.3
2.23	Vehicles transporting refuse cover and/or construction material to and from the site shall not enter the site prior to 7.45 am or leave after 6.15 pm on any day. Other solid waste disposal operations (such as placing of cover and maintenance etc) may be undertaken between 7.00 am and 6.15 pm on any day.	Section 3.3
2.36	That the consent holder shall establish a “AB Lime Landfill Community Liaison Committee” (CLC) in accordance with the following requirements: d) The purpose of the CLC shall include, but no be limited to, the following: To engage on an ongoing and regular basis about matters associated with the operation of the landfill where those matters affect the community and are of mutual interest to the representative parties. To promote the free flow of information between the local community and the consent holder so as to, wherever possible, address any issues that may arise. a) The CLC shall initially comprise up to two representatives of the consent holder and the consent holder shall invite one representative from each of the following to be represented:: i. All adjoining landowners/occupiers whose properties bound on to the site of this consent and not owned by the consent holder. Te Ao Marama Incorporated. Southland District Council.	Section 3.2

Condition Number	Condition	Reference
	Environment Southland. Public Health South. Winton Community Board. ***Advice Note (i):*** *This condition only governs initial membership for the purposes of convening the first meeting of the CLC. Ongoing membership will be determined by the CLC.* e) The AB Lime CLC has the ability to set its own terms of engagement. ***Advice note (ii):*** *In the event that it is not possible to establish a CLC or convene meetings though lack of interest to participate from the local community, then such failure to do so shall not be deemed a breach of these conditions. Should the local community wish to re-establish meetings after a period of inactivity then the conditions above continue to apply.*	
2.37	That in all signage relating to the solid waste disposal facility, the facility shall be referred to as the "AB Lime Landfill" or the "AB Lime Solid Waste Disposal Facility" with no direct reference in the name of the facility to Kings Bend or Winton.	Section 3.3.6
Schedule 1 – General Conditions AUTH 201346, 201347, 201348, 201349, 201350, 201351		
Management Plans		
3.	The solid waste disposal facility and associated operations shall operate in accordance with an Environmental Management Plan (EMP) for the duration of this consent.	Section 1.1
4.	The EMP shall incorporate or refer to the following management plans, each of which is described in later conditions of this consent: a) Landfill Operations Management Plan; b) Landfill Gas Management Plan; c) Landfill Concept, Landscape, Rehabilitation and Aftercare Plan; d) Landfill Leachate Management Plan; e) Landfill Air Quality Management Plan; f) Quarry Management Plan g) Site Traffic Management Plan h) Site Stormwater Management Plan i) Site Archaeological/Koiwi or Taonga Accidental Discovery Plan In the event of an inconsistency between the management plans and a condition of this consent, these conditions shall prevail.	Section 3.1

Condition Number	Condition	Reference
	Advice Note (i): *For completeness all sub-management plans are identified in condition (4). The sub-management plans relevant to these consents include the Landfill Operations Management Plan, the Landfill Gas Management Plan, the Landfill Concept, Landscape, Rehabilitation and Aftercare Plan, the Landfill Leachate Management Plan, the Landfill Air Quality Plan, the Site Stormwater Management Plan and the Site Archaeological/Koiwi or Taonga Accidental Discovery Plan.* ***Advice Note (ii):*** *The objectives for each sub-management plan relevant to this consent are identified in consent conditions (21)-(28). There are also other objectives within these sub-management plans not relevant to these consents that are managed by the District Authority.*	
Appointment of Certifiers		
5.	Within one month of giving effect to this resource consent the Consent Holder shall confirm the appointment of independent, suitably qualified and experienced person(s) to certify the management plans required by this consent, and provide information to the Southland Regional Council to demonstrate that the proposed certifier(s) is independent, suitably qualified and experienced. ***Advice Note:*** *If the Southland Regional Council does not approve the person(s) proposed by the Consent Holder, reasons must be provided in writing to indicate why the person(s) is not considered to be suitable.*	Section 1.5.1
6.	Certification of the plans shall not proceed until the Southland Regional Council confirms in writing that the Certifier meets these requirements.	Section 1.5.1
7.	The independent certifier may be changed at any stage during operations, however, the new certifier must be confirmed as being appropriate by the Southland Regional Council in accordance with condition (5).	Section 1.5.1
Certification Process		
8.	Once the EMP and sub management plans have been reviewed and deemed appropriate by the independent reviewer(s), in accordance with conditions (16)-(20) the plan shall be provided to the Southland District Council for certification.	Section 1.5.1
9.	Southland Regional Council shall be requested, no later than 10 working days of the receipt of the management plan, to confirm to the consent holder that the plan is either certified or declined. If no response is received, approval is deemed to have been given as set out in condition (15)	Section 1.5.1
10.	If changes to the relevant plan are requested by the certifier, in alignment with conditions (12)-(15) these changes shall be made before the certification is confirmed by the Southland Regional Council.	Section 1.5.1
11.	This resource consent and a copy of the Southland Regional Council certified versions of all the management plans required by this consent shall be kept on site at all times, and the consent holder shall ensure all personnel are	Section 1.3

Condition Number	Condition	Reference
	made aware of each plan's contents, where the plan relates to activities that those personnel are responsible for.	
Review Process		
12.	The consent holder may make amendments to the final management plans that may change how any adverse effect is managed at any time subject to the certification of Southland Regional Council.	Section 1.2
13.	All amendments shall be consistent with the objectives and performance requirements of the management plan and these consent conditions.	Section 1.2
14.	a) In event of an amendment to a management plan under Condition (11), the consent holder must submit the amendment to Southland Regional Council for certification 10 working days before the commencement of the relevant works. Certification shall confirm that the amendment is in accordance with condition (2) and meets the objectives and performance requirements of the management plan. b) Southland Regional Council shall be requested, no later than 10 working days of the receipt of the amendment, to confirm to the consent holder that the amendment is either certified or declined. If no response is received, approval is deemed to have been given as set out in condition (14). Should Southland Regional Council decline to certify the amendment or request the incorporation of changes to the amendment the consent holder may then resubmit a revised amendment to the management plan(s) following the procedures set out in Condition (13)(a)-(b)	Section 1.2
15.	If no confirmation of the Plan's suitability is received from Southland Regional Council within 20 working days of submission of any plan or other information provided for certification, the submitted information shall be deemed to have been approved.	Section 1.2
Independent Peer Review Process		
16.	Within one month of giving effect to this resource consent the Consent Holder shall confirm the appointment of independent peer reviewer(s), suitably qualified and experienced person(s) to review conditions and the management plans required by this consent, and provide information to the Southland Regional Council to demonstrate that the proposed certifier(s) is independent, suitably qualified and experienced. ***Advice Note:*** *If the Southland Regional Council does not approve the person(s) proposed by the Consent Holder, reasons must be provided in writing to indicate why the person(s) is not considered to be suitable.*	Section 1.2
17.	The Independent Peer Review process shall not proceed until the Southland Regional Council confirms in writing that the Independent Peer Reviewer(s) meets these requirements.	Section 1.2
18.	The Independent Peer Reviewer(s) may be changed at any stage during operations, however, the new Independent Peer Reviewer(s) must be	Section 1.2

Condition Number	Condition	Reference
	confirmed as being appropriate by the Southland Regional Council in accordance with condition (15).	
19.	The consent holder shall engage, at its own cost, an Independent Peer Reviewer(s), to review the design, construction, operation, maintenance and monitoring of the landfill and to assess whether or not the work is undertaken by appropriately qualified personnel in accordance with good practice. The Independent Peer Reviewer(s) shall produce an annual report on the following matters by 1 May every year: ▪ site preparation, including hydrogeological and geotechnical issues; ▪ liner, leachate collection and stormwater system detailed design (including calculations), construction and quality control and use of on-site materials; ▪ landfill operations management; ▪ water control, including groundwater, stormwater and leachate management; ▪ compaction, including method and degree; ▪ waste acceptance; ▪ cover material used; ▪ landfill gas management; ▪ monitoring, modelling and records; ▪ site rehabilitation. Preparation of each annual report shall include at least one site inspection. In addition, the Independent Peer Reviewer may report, in writing, to the Southland Regional Council on any matter that he/she considers should be brought to the attention of the Council in respect of the landfill and its operation. Copies of all reports shall be sent to the consent holder and the Southland Regional Council. A Terms of Reference, to guide and direct the Independent Peer Reviewer, shall be established, in consultation with the Southland Regional Council.	Section 4.4.2
20.	Following independent peer review (as per condition 19 of this Schedule), detailed designs of all works, , shall be updated and included in the Environmental Management Plan and relevant sub management plan(s) and forwarded to the Southland Regional Council for acceptance in writing prior to works commencing. All works shall be carried out in accordance with the designs as accepted by the Southland Regional Council.	Section 4.4.2
Environmental Management Plan		
21.	The overall purpose of the EMP is to provide details of the practices and procedures to operate the landfill in compliance with the conditions of	Section 1.1

Condition Number	Condition	Reference
	consent. The EMP shall comply with the relevant consent conditions and achieve the following objectives:	
	i. To operate in full compliance with the resource consent requirements and demonstrate this through reporting procedures to Consent Authorities.	Section 2.3
	ii. To liaise closely with neighbours and the local community, including iwi representatives, regarding landfill operational issues.	Section 3.2
	iii. To provide a safe working environment for people on the site.	Section 3.3.3
	iv. To maintain an independent review process for the design, construction, operation and aftercare of the landfill to confirm the work is undertaken by appropriately qualified personnel in accordance with good practice	Section 1.2
	v. To identify operational responsibilities, the management structure and staffing	Section 1.3 and Section 1.4
	vi. To facilitate the effective training of staff:	Section 3.4
	vii. To facilitate accurate record keeping	Section 4.1
	viii. To maintain community involvement including details of complaints procedures	Section 4.3
	ix. To appropriately manage site access, fencing and security	Section 3.3
	x. To manage site infrastructure and site amenities	Section 3.3

2.4 Monitoring and Reporting the Performance of the Environmental Management Plan

Table 5 Monitoring and Reporting Requirements Related to the Environmental Management Plan

Condition	Requirement	Relevant Regulatory Authority	Frequency	Date	Responsibility	Reference
Land Use Consent 60/3/02/138/1						
2.28	The Southland District Council may, on 1 May each year, commence a review of the Environmental Management Plan to ensure that management practices continue to result in compliance with the conditions of this consent. Any costs inherent in this review shall be borne by the consent holder.	Southland District Council	Annually	1 May	Southland District Council Compliance Officer	N/A
Schedule 1 – General Conditions AUTH 201346, 201347, 201348, 201349, 201350, 201351						

Condition	Requirement	Relevant Regulatory Authority	Frequency	Date	Responsibility	Reference
29.	The EMP and sub-management plans (where applicable) shall include monitoring with respect to surface water, groundwater, leachate, landfill gas and nuisance. Each monitoring element shall include: ii. Monitoring locations; iii. Monitoring parameters; iv. Monitoring frequency; v. Detection limits; vi. Reporting; Trigger levels (for each monitoring location) for implementing contingency/remedial actions	Environment Southland	Refer to sub-management plans	Refer to sub-management plans	AB Lime Environmental Manager	Section 4

2.4.1 Interaction Between Legislative Requirements and Management Plans

If there is conflict between the management plan and the corresponding legislative requirements, including consent conditions, then the legislative requirements must prevail.

3. Implementation and Operation

This section of the plan outlines how the identified environmental and social requirements in section 2 will be managed to achieve the commitments outlined in section 1.1.

3.1 Environmental Management Plans

The conditions require a number of sub management plans to be developed and certified to support the Environmental Management Plan. The purpose of each plan is detailed in Table 6 and form the overall environmental management system for the site.

Table 6 Environmental Sub-Management Plans and Purpose

Plan	Purpose
Landfill Operations Management Plan	The Landfill Operations Management Plan sets out how operations of the landfill will be undertaken and managed to mitigate any adverse impact on sensitive receptors.
Landfill Gas Management Plan	The Landfill Gas Management Plan sets out how landfill gas systems will be designed and operated to appropriately manage the effects of landfill gas on the landfill site.
Landfill Concept, Landscape Rehabilitation and Aftercare Plan	The Landfill Concept, Landscape Rehabilitation and Aftercare Plan demonstrates how the effects of post-landfill management are mitigated or avoided for final contouring, landscaping activities, planting programmes and aftercare.
Landfill Leachate Management Plan	The Landfill Leachate Management Plan sets out how the effects of landfill leachate are managed, mitigated and avoided through leachate design, leachate treatment and disposal and leachate recirculation.
Landfill Air Quality Management Plan	The Landfill Air Quality Management Plan sets out how odour and emissions will be managed and treated at the landfill to mitigate and avoid any adverse effects on sensitive receptors and ensure compliance with consent conditions.
Quarry Management Plan	The Quarry Management Plan sets out how operations of the quarry will be undertaken and managed to mitigate any adverse impact on sensitive receptors.
Site Traffic Management Plan	The Site Traffic Management Plan sets out how traffic operations are designed and implemented on site.
Stormwater Management Plan	The Stormwater Management Plan sets out how to manage the effects of landfill and quarry stormwater in accordance with conditions of consent to manage and mitigate any adverse impact on the receiving environment
Site Archaeological/Koiwi or Taonga Accidental Discovery Plan	The Site Archaeological/Koiwi or Taonga Accidental Discovery Plan sets out how to manage Taonga and artefact discovery at the landfill and quarry.

3.2 AB Lime Landfill Community Liaison Committee

The following parties have been identified as important community pillars to remain involved in the operation of the landfill:

- All adjoining landowners/occupiers whose residential dwellings are in close proximity to the site of this consent and not owned by the consent holder;
- Te Ao Marama Incorporated;
- Southland District Council;
- Environment Southland;
- Public Health South; and
- Winton Community Board.

The objectives of the CLC are:

- To engage on an ongoing and regular basis about matters associated with the operation of the landfill, where those matters affect the community and are of mutual interest to the representative parties.
- To promote the free flow of information between the local community and the consent holder so as to, wherever possible, address any issues that may arise.

Importantly, given the fluid nature of the requirements to meet to discuss these issues it is recommended that the CLC have the ability to set their own terms of engagement. The condition of consent governs the initial membership of the purposes of convening the first meeting of the CLC and ongoing membership can be determined by the CLC.

In the event that it is not possible to establish or convene CLC meetings through lack of interest to participate from the local community, then such a failure to do so does not constitute a breach of the condition of consent. Should the local community wish to re-establish meetings after a period of inactivity then the conditions above continue to apply.

3.3 Site Provisions

3.3.1 Operating Hours

The landfill is normally open for waste acceptance during the following times:

- **Monday to Saturday 8am to 6pm**

Hours may be shortened over the winter period (May to October). Vehicles transporting refuse, cover and or construction material to and from the site do not enter the site prior to 7.45 am or leave after 6.15 pm on any day.

Other landfilling operations (such as placing cover, maintenance etc.) are undertaken during operating days between 7.00 am and 6.15 pm.

Gates are locked after hours.

3.3.2 Right of Access

There is no direct access to the landfill by the public and there are no recycling or composting facilities on site. A fence restricts vehicles from the site and there is a gate that is locked outside operating hours.

3.3.3 Safe Working Environment

The landfill operation complies with regulations under the Health and Safety at Work Act 2015.

A site Health and Safety Plan is in operation for landfill and quarrying activities (refer to section 1.1.3), and is adhered to by the site operator, contractors or any other persons entering the site. There is no direct public access to the landfill site.

Management, the workforce, contractors and visitors are made fully aware of the existence of the site safety regulations and know to observe them at all times. These regulations include instructions on:

- Speed limits;
- Personal protection clothing;
- The risk of overturning if vehicles attempt to discharge their loads on uneven surfaces;
- Fire hazards (no smoking or naked lights within the landfill area);
- No fires anywhere;
- Personal hygiene;
- Tetanus and hepatitis vaccination;
- Access to confined spaces;
- Reporting accidents and incidents;
- Personal noise exposure;
- Substances hazardous to health; and
- Emergency responses procedures

Access to leachate manholes or any underground chamber or trench is restricted to staff and contractors who are fully trained with appropriate health and safety procedures.

Prior to any work taking place in confined spaces, the work requires a Job Safety Analysis (JSA). All JSA must be signed off by the Quarry Manager before work can commence.

3.3.4 Fencing

- A fence is provided around the landfill site, and the gate to the landfill is locked outside normal operating hours;
- Security fences are erected around the gas flare compound.

3.3.5 Security

It is critical to control where and when people access the landfill. Unauthorised entry can lead to waste dumping, fires and vandalism of pollution control devices as well as loss of amenity. Salvaging / scavenging is prohibited as the practice is dangerous and interferes with the efficient operation of the landfill.

Site security includes controlling access onto the site and supervising the activities of all persons on-site.

Site security includes:

- Fencing of the perimeter of the site with one gate through which all vehicles and persons enter and leave
- The employment of appropriately trained staff to control access to the site by vehicular traffic
- Maintenance of physical access control
- Surveillance and control of visitors, users and employees

a) Inspection monitoring and maintenance

Site fence is to be inspected on a monthly basis by the Landfill Operations Manager and recorded in a monthly site inspection checklist. Illegal dumping, damage or vandalism either within the property or to perimeter fencing is to be reported.

b) Contingency Plan

Dependent on the nature of breach in site security, AB Lime has identified specific responses. Evidence of unauthorised disposal of waste will require the following actions:

Contingency triggering event	Response guidelines
Evidence of unauthorised disposal of waste	▪ Advise Site Management immediately ▪ Segregate wastes from approved wastes ▪ Notify Environment Southland ▪ Dispose of material in an approved location ▪ Breach to be recorded in incident register
Site security breach that results in damage to property	▪ Landfill Operations Manager to handle the breach work with the local police and property insurance company

3.3.6 Site Infrastructure and Amenities

The landfill shares the following facilities with the quarry:

- Weighbridge;
- Weighbridge office;
- Administration office;
- Parking;
- Wheel wash;
- Workshops; and
- Internal roading

The location of the landfill facilities is shown in Attachment 1.

3.3.6.1 Landfill Facilities

- The weighbridge office at the site entrance operates as a control office for acceptance of refuse and checking of documentation;
- A small portable office at the landfill is provided for record keeping, storage of monitoring equipment and may be used for staff training;
- Radio telephone contact is maintained between the weighbridge office and landfill operating area. The Landfill Supervisor is also contactable by cell phone; and
- The existing quarry workshop is used for maintenance of mobile plant and equipment.

3.3.6.2 Personnel Welfare Facilities

Welfare facilities include:

- Personal Effects Storage;
- Storage for safety equipment;
- Adequately heated and lighted staff room;
- Facilities for heating food and providing hot water;
- First aid equipment room;
- Washbasin with hot and cold water;

- Shower facilities; and
- Lavatories for both employees and visitors.

3.3.6.3 Hazardous Substances Storage

The following methodology is adopted for hazardous substances on site:

- A suitable storage area is provided for potentially harmful substances such as insecticides and weed killers in the AB Lime Dairy Farm Chemical Shed. This facility is clearly labelled and is locked with access only to authorised staff;
- For non-complying hazardous wastes delivered to site, contingency plans and temporary storage protocols are described in the appropriate sub-management plans; and
- Diesel fuel for mobile and static plant, operated on the landfill and quarry, is stored in a bunded tank. Fuel tanks are clearly labelled.

3.3.6.4 Wheel Wash

Vehicle wheel wash facilities are provided. The wheel wash facilities are used by all vehicles, as required, after depositing waste at the landfill to minimise the tracking of particulate matter off site. Waste water is drained to a settling pond before being recycled by the plant.

3.3.6.5 Signs and Lighting

A sign at the site entrance near the weighbridge displays that only authorised users may proceed to the weighbridge, and all other site visitors are to report to the office.

All signs are maintained during the operation of the landfill. All signs relevant to the naming of the landfill are required to have the title “AB Lime Landfill” or “AB Lime Solid Waste Disposal Facility’. There is to be no direct reference in any naming signage to Kings Bend or Winton.

A sign is located at the landfill which details the following:

- Prohibiting unauthorised vehicles;
- No smoking;
- Travel and tipping instructions;
- Safety Instructions; and
- Types of waste prohibited.

All exterior lighting is directed away from adjacent residence to minimise the potential for adverse effects from light spill in adjacent residents and to achieve compliance with Rule Rural.7(1) of the Operative Southland District Plan 2018.

3.4 Training

Part of the AB Lime Health and Safety Officers’ duties is the training and development of all landfill staff. All staff have the opportunity to attend external training courses to ensure best practice is maintained.

All site staff are required to have an understanding of the principles of landfill management and the requirements of the consent conditions and all management plans.

Training programs are prepared for site staff where appropriate to maintain their skills in the follow areas:

- Health and safety policy for contractors, visitors and transport operators;
- Emergency response procedures;
- Effective use of personal protection equipment;

- Hazardous waste identification;
- Waste acceptance procedures;
- Action plan, contingency and implementation for accidental hazardous waste acceptance;
- Hazard identification and reporting procedures;
- The effective use of litter fences;
- Rodent, cat and bird control;
- Entry into confined spaces;
- Refuelling procedures;
- Leachate management;
- Odour control;
- Plant and equipment maintenance and operation;
- Landfill gas risks and operational procedures;
- Dust control and suppression; and
- Wheel washing and general control of mud/dust.

All equipment and plant on-site will be operated and maintained by appropriately trained staff and in accordance with the manufacturer's instructions.

3.5 Emergency Contacts and Response

An Emergency Response Plan is in operation for landfill and quarrying activities. A current emergency contact list is displayed at the Landfill Office and Main Office as part of AB Lime Health and Safety policies.

Contact	Telephone Number
FIRE, AMBULANCE or POLICE EMERGENCY	111
Winton Medical Centre	(03) 236 7444
Regional Ambulance Centre	0800 100 776
Winton Police Station	(03) 236 6060
Winton Fire brigade (unattended)	(03) 236 7118
Browns Fire brigade (unattended)	(03) 236 4018
Power Net Ltd	(03) 217 1899
Power Services	(03) 236 9072
National Poison Centre	0800 764 766
Jodi Baylis – H & S Coordinator	027 531 3786
Steve Smith – General Manager	Home: (03) 236 9923 or Cell: 027 681 8881
Craig Owen-Cooper – Quarry Manager	Cell: 027 283 4585

4. Monitoring and Review

4.1 Record Keeping

All records are legible and stored either as paper copy in an appropriate file and/or as computer files. Records are maintained and backed up in accordance with AB Lime documented administrative procedures.

Monitoring information is compared to compliance requirements and trigger levels. Trends are monitored and explanations provided where possible.

The landfill operator maintains operational records including:

- Wastes accepted by type and weight;
- Waste inspections undertaken and any rejected loads;
- Daily record of areas used for waste disposal;
- Vehicle movements;
- 3-D disposal locations of treated hazardous wastes and special wastes;
- Any actions to control vermin;
- Complaints;
- Design and construction records, including as-built drawing; and
- Environmental Monitoring data as per the appropriate sub-management plans.

4.1.1 Onsite Documentation

The following information is documented and generated onto a computer system on the arrival of all waste consignments. Most of the data below is generated automatically:

- Date and time generated by computer;
- Container identification;
- Type of vehicle;
- Net weight;
- Vehicle registration number;
- Order number ;
- Truck ID;
- Client and source codes;
- Description of waste as per waste code and special permit numbers; and
- Drivers signature of waste docket book.

In the event that a consignment of waste that is considered unacceptable for disposal at the landfill due to hazardous content, procedures are followed as per the Landfill Operations Management Plan. Information recorded is documented on a waste inspection sheet and a copy sent to Environment Southland via email or fax. The original sheet is filed.

The results of one in fifty (50) random inspections are carried out every month and are recorded on Waste Inspection Sheets and transferred to an electronic spreadsheet. If during these random inspections hazardous waste is discovered, copies of the inspection sheets are sent to Environment Southland along with a description of the action taken.

Records of vehicle movements are supplied to Southland District Council every 6 months in accordance with the Site Traffic Management Plan.

4.2 Compliance Monitoring

The monitoring requirements and parameters are extrapolated under each relevant sub-management plan. For ease of reference and completeness all monitoring requirements related to the operation of the landfill are summarised in Table 7 below.

Table 7 Compliance Monitoring (table to be updated upon the consents being granted)

Environmental Aspect	Requirement	Relevant Regulatory Authority	Frequency	Management Plan with the Detailed Monitoring Requirements
Landfill Operations/ Groundwater	Annual noise monitoring survey	Southland District Council	Annually	Landfill Operations Management Plan
	Report of the waste types and quantities received	Environment Southland	Annually	
	Notification of any vehicles turned away for not meeting the waste acceptance criteria		As required	
	Report on the water level of each downgradient groundwater monitoring well		Monthly recording, quarterly reporting	
	Report on the groundwater composition for a range of parameters at each downgradient groundwater monitoring well		Quarterly and reduced to 6 Monthly	
	Report on the volatile organic compounds and semi-volatile organic compounds at each downgradient groundwater monitoring well		Annually - February	
	Report on the inspection of the landfill cap following storm events greater than 50% AEP or at least every 6 months.		As required post storm events or at least every 6 months	
	Report on the quantity of the groundwater taken from the groundwater underdrainage system		Continuous monthly recording, annual reporting	
	Report on daily water usage and pumping logs		Daily recording, annual reporting	
	Report produced by an appropriately experienced person on the operation of the landfill.		Annual report	
Landfill Gas	Record of weekly landfill inspection for evidence of possible gas leaks	Environment Southland	Weekly recording, remediation as required	Landfill Gas Management Plan

Environmental Aspect	Requirement	Relevant Regulatory Authority	Frequency	Management Plan with the Detailed Monitoring Requirements
	Record the methane concentrations at least once each month in at least 7 monitoring probes outside the landfill footprint		Monthly recording	
	Record for a range of parameters the landfill gas at each gas extraction well head		Monthly recording	
	Record continuously a range of parameters at the permanent landfill gas flare		Continuous recording	
	Record weekly the gas composition (ppm carbon monoxide) at the permanent landfill gas flare		Weekly recording	
	Record weekly the hydrogen sulphide concentration at the permanent landfill gas flare		Monthly recording	
	Record weekly the concentration of total non-methane organic compounds at the permanent landfill gas flare		Annual recording	
Landfill Landscape	Report on the progress and forward works relating to site rehabilitation	Southland District Council	5 Yearly	Landfill Concept, Landscape, Rehabilitation and Aftercare Plan
Landfill Leachate	Report the daily leachate volume withdrawn from the landfill, the leachate volumes discharged onto or into the landfill and the level of leachate in the landfill	Environment Southland	Daily recording, Annual reporting	Landfill Leachate Management Plan
	Report on the daily recorded dissolved oxygen levels leachate storage pond		Daily recording (2 readings between 8am and 10am each week), 6 monthly reporting	
	Report the inflow of the leachate composition for a range of parameters		6 monthly samples and reporting	
Landfill Air Quality	Record hourly wind velocity and direction, barometric pressure, rainfall and temperature.	Environment Southland	Hourly recording	Landfill Air Quality Management Plan
	Record boundary odour observations once a week during winds blowing from the north, northeast and east (winds		Weekly recording	

Environmental Aspect	Requirement	Relevant Regulatory Authority	Frequency	Management Plan with the Detailed Monitoring Requirements
	blowing from 0 - 90 degrees azimuth), or during still cold air drainage conditions.			
	Record H_2S continuously at two monitors along the south western boundary		Continuous monitoring	
Site Traffic	Report on the daily weigh bridge logs	Southland District Council	Daily recording, 6 monthly reporting	Site Traffic Management Plan and Environmental Management Plan
Stormwater	Report on the monthly rainfall at the rain gauge at Site 8	Environment Southland	Continuous monthly recording, annual reporting	Site Stormwater Management Plan
	Report on the continuous monitoring of stormwater discharge at Site 5 and 9		Continuous monthly recording, annual reporting	
	Report on the pH, conductivity, dissolved oxygen and turbidity in the stormwater discharge at Site 5 and 9		Continuous recording, quarterly reporting	
	Report on the stormwater composition for a range of parameters at Site 5 and 9		Quarterly reporting	
	Report on the volatile organic compounds and semi-volatile organic compounds in stormwater discharge at Site 5 and 9		Annual reporting	
	Report on stream sediments upstream and downstream of the site surface water discharge		2 yearly samples and reporting	
	Report on the flow and water quality of groundwater at Site 13.		Monthly recording, annual reporting	

4.3 Complaints and Feedback Procedure

A comprehensive analysis of complaints and mitigation measures is also provided in the Landfill Air Quality Management Plan.

4.3.1 Receiving Complaints and Feedback

If a complaint or feedback is received by post or fax or email, it is to be brought to the attention of the Environmental Manager as soon as possible and within 4 hours of receipt during normal working hours, dependant on the nature of the complaint.

If a complaint or feedback is received by phone, the call will be directed to the Environmental Manager, and if unavailable, to the General Manager. Failing that calls can be directed to the Quarry Manager.

The following details (when relevant) of all complaints or feedback are to be taken and recorded in the site register:

- Name, address and telephone number of complainant(s);
- Nature of complaint and effect detected;
- Time and day of occurrence that gave rise to the complaint;
- Location of the source of the effect;
- Weather, wind direction and rainfall at the time the effect was detected;
- Most likely cause of effect;
- Response made; and
- Corrective action taken or proposed to avoid, remedy or mitigate the effect

If the Environmental Manager is to be out of contact for more than 4 hours after receiving the complaint or feedback, with the General Manager or Quarry Manager will respond to the complaint or feedback.

4.3.2 Response to Complaints and Feedback

The Environmental Manager will contact the complainant by telephone, or if this is not possible by sending a letter, or email on the same day as the complaint or feedback is received.

If the cause of the complaint is identifiable, measures will be put in place to avoid a recurrence will be provided. If there is uncertainty as to the nature or cause of the complaint or feedback the Environmental Manager will seek clarification. A meeting may be required to discuss the complaint or feedback and if possible, will be arranged as soon as is practicable:

- All complaints and feedback will be responded to in writing, and in some cases this may be after clarification;
- Copies of the written responses will be filed with the complaints and feedback register;
- All complaints and feedback will be reported to Environment Southland as soon as possible and no longer than one working day after the complaint is received;
- Should investigation of odour complaints or feedback indicate that discharges from the landfill are causing objectionable or offensive effect beyond the boundary, a systematic odour diary will be instigated in accordance with the Air Quality Management Plan.

4.3.3 Ongoing Complaints

If a complainant is dissatisfied with a response to a complaint, every reasonable attempt is made to find a satisfactory solution. If all reasonable measures are rejected, the complainant will be referred to Environment Southland and Southland District Council. Details of the measures offered will be sent to the regulatory authority at the same time as being offered to the complainant or if offered verbally as soon afterwards as is practical.

4.3.4 Access to Complaints and Feedback Register

The register of complaints and feedback will be provided to Environment Southland annually and be available for inspection by Environment Southland and Southland District Council at all reasonable times.

4.4 Audits

4.4.1 Internal Audits

Internal audits will be undertaken periodically (at as a minimum annually) by the Environmental Manager with the objective to determine if the environmental management requirements are being implemented and maintained, assess the effectiveness of the environmental controls being applied, and identify areas of non-compliance or improvement opportunities so that corrective actions can be taken.

4.4.2 Independent Peer Reviewer Annual Report

Conditions 19 and 20 in Schedule 1 of the consents held with Environment Southland, which applies to all consents issued by Environment Southland and describes the process for review of the following:

- Management and Monitoring Plans;
- Site preparation;
- Liner design and construction;
- The use of on-site materials;
- Water control – including stormwater and leachate management;
- Compaction;
- Waste acceptance;
- Cover material used;
- Monitoring, modelling and records; and
- Rehabilitation.

Following Independent Peer Review detailed designs of all works shall be updated and included in the Environmental Management Plan and relevant sub management plan(s).

4.5 Corrective and Preventive Action

Corrective and preventative actions will be identified through compliance monitoring, audits, and complaints/feedback processes. The actions and response will be recorded in the Corrective and Preventive Action Register held by the Environmental Manager. The actions assessed and when relevant discussed with Environment Southland/Southland District Council. The Environmental Management Plan and the sub management and mitigation plans will be updated as required.

4.6 Management Review

Annually (or when any major changes to legislation or policy occurs), a management review of the Environmental Management Plan and the sub management plans will be undertaken. This review will be led by the General Manager and will include the Environmental Manager. The review will focus on how environmental compliance is being managed and achieved and identifying areas of improvement.

Attachment 1. Site Drawing

LEGEND

- CONSENTED LANDFILL FOOTPRINT
- CELL DEVELOPMENT OF LANDFILL
- CELL DEVELOPMENT OF FUTURE LANDFILL
- CADASTRAL BOUNDARY
- BUILDING
- TREE

NOTES

1. THE HORIZOTNAL COORDINATE SYSTEM FOR THE SITE IS NEW ZEALAND MAP GRID 1949.
2. THE LATEST SURVEY FOR THE SITE WAS PERFORMED BY DRONE SURVEY, FLOWN ON 12/03/2020.

SCALE 1:2000 (A1) 40 20 0 40 80 120 160 200m

CONSENT ISSUE

REV	DATE	APP'D	REVISION
A	29.05.20	VP	CONSENT ISSUE

SCALES AT A1

AB LIME

Jacobs

Level 2, Wynn Williams Building
47 Hereford Street
CHRISTCHURCH CENTRAL 8013
NEW ZEALAND
Tel: +64 3 940 4900
Fax: +64 3 940 4901
Web: www.jacobs.com

CLIENT AB LIME LTD.

PROJECT LANDFILL INVESTIGATION KING'S BEND SITE

DRAWN	DRAWING CHECK	REVIEWED	APPROVED
MH	JK	CW	VP
DESIGNED	DESIGN REVIEW	DATE 29.05.20	DATE 29.05.20
KJ	LJ		

TITLE LANDFILL FOOTPRINT AND SITE INFRASTRUCTURE

SCALE 1:10000 (A1) | DRAWING No IZ000400-1000-NG-DRG-1002 | REV A

A1

Appendix D. Original Geological and Hydrogeological AEE Report June 2002

A B Lime Ltd

Geological and Hydrogeological Report

June 2002

Appendix: E

SINCLAIR KNIGHT MERZ

Executive Summary

The executive summary of this report describes the background and objectives, and summarises the main findings of the study.

Background

The technical hydrogeological report forms an appendix to the main assessment of environmental effects (AEE) document, prepared for a resource consent application for construction and operation of a municipal landfill within decommissioned areas of the AB Lime quarry. The report presents the findings from desktop studies and investigations into the geology and hydrogeology at the quarry site and surrounding areas, and discusses the potential environmental effects on local groundwater resources resulting from the proposed landfill operation.

Objectives

The objectives of the hydrogeological investigations were as follows:

- To describe the existing geological and hydrogeological resources in the area of the quarry and surrounding areas.
- To determine the feasibility of a landfill with respect to the geological and hydrogeological properties of the site.
- To gain an understanding of the likely effects of quarrying on the groundwater resources in the area.
- To assess the potential environmental effects on local groundwater resources associated with the proposed landfill operations.

Regional Geology

There are four main geological formations of hydrogeological significance within and surrounding the study area.

Fluvio-Glacial Gravels

The geology surrounding Winton Hill consists of Quaternary age fluvio-glacial outwash gravels and glacial till deposited during the last glaciation. The alluvial gravel forms relatively undeformed higher terraces comprising a mixture of gravel, sand, silt and clay of greywacke-quartz-schist origin. In the study area the alluvium pinches out on the limestone and contains a high proportion of colluvium (slope-derived deposits) that is mostly clay weathered from the limestone hills.

Forest Hill Formation

Winton Hill forms part of the Mid-Tertiary age Forest Hill Limestone Formation. The Forest Hill Formation is a sandy-yellow-brown, thick bedded, moderately to highly indurated, bryozoan/brachiopod, calcirudite, biosparite and occasional biomicrite, with terrigenous detritus becoming more common towards the top. The limestone has a purity of 79-91%, making it suitable for agricultural and cement purposes.

Underlying the Forest Hill Formation at the site is the Chatton Formation.

Chatton Formation

The Chatton Formation is of Late Oligocene to Early Miocene age and comprises a shallow marine, often calcareous and glauconitic, fossiliferous, fine to coarse grained sandstone, siltstone and conglomerate.

Basement Rocks

Basement rocks of Triassic to Jurassic age underlie the former units. The basement rocks are composed of lithified, tuffaceous, feldspathic sandstones, siltstones and mudstones, with marine fossils, plant bed, thin bituminous seams, and granitic and volcanic conglomerates. The closest surface exposure of this formation is found in the Hokonui Hills, seven to ten kilometres to the northeast.

Regional Hydrogeology

Regional hydrogeological information for the Southland region and in particular the area surrounding the quarry is limited.

Occurrence of Groundwater

The highest yields of groundwater occur primarily within the gravel alluvium, with sustainable yields reported in the range of tens to hundreds of litres per hour. Downgradient of the study area, the gravels form a thin veneer over the basement rocks and tend to have less quartz, a smaller grain size sand and contain a higher proportion of silt. In the Quaternary gravels flow is towards the major surface water drainage features, which are located to the south and east of the site.

Groundwater Use

A recent groundwater quality survey conducted by the Southland Regional Council (1998) concluded that groundwater is used by over 50% of rural residents in Southland for potable, stock water, dairy shed washdown or irrigation purposes. In the absence of a bore or well, rainwater is the most common alternative to groundwater.

Groundwater Quality

A high proportion of Southland's groundwater resources is susceptible to contamination because much of the water is drawn from shallow unconfined highly permeable aquifers in areas of intensive land use. However, results from the Southland Regional Council survey indicated that:

- Nitrate levels were typically three to four times below the New Zealand drinking water standard of 11.3 mg/L (NO_3-N);
- No faecal coliforms were recorded in 60% of samples, while the remaining samples displayed faecal coliform concentrations above the New Zealand drinking water standard of 1 cfu/100 mL;
- Iron concentrations typically four times below the New Zealand drinking water standard of 0.2 mg/L; and
- Groundwater was generally only slightly acidic.

Karst Hydrogeology

A summary of Karst Hydrogeology is provided to place the hydrogeological significance of the limestone within this study area into perspective.

Karst is the name given to areas of limestone or marble characterised by landforms developed as a result of solution processes. Features of particular importance for the formation of karst include rock purity, porosity, fissuring, and formation thickness, depth to groundwater and rainfall characteristics of an area.

Sinkhole Development

The surface karst environment may develop topographically closed or pocked landforms that are characteristic of sinkholes.

Sinkholes form through the following processes:

- simple solution of the limestone;
- collapse of overlying sediments into solution voids (suffosion); or
- collapse of the limestone itself.

The development of solution sinkholes (the first two processes above) is a self-reinforcing process. An initial minor weakness in the rock produces higher hydraulic conductivity and preferential flow paths. The solution potential is increased along the conduit, further enlarging the conduit. The focussing of drainage from surface waters in the vicinity of the sinkhole increase the volume of water harvested, resulting in accelerated development and continual expansion of the sinkhole.

The presence of conduits where water can readily drain and where turbulent flow conditions can occur is a prerequisite for sinkhole development.

Hydraulic Characteristics

The hydrogeology of karst systems differ from standard groundwater systems in that:

- The hydraulic networks can consist of three types of spaces; pores (aquifer matrix), fracture and channel or conduit. For this reason, simple porous media or double porosity conceptual models of the system are not applicable.

- The circulation of water in a karst aquifer continually enhances the aquifer permeability. The hydraulic gradient will decrease through long periods of time, as the water table declines due to increases in storage and permeability.

- The piezometric surface geometry may not follow topographic lows and highs due to lowering of the water table through conduit drainage.

Most classifications of karst systems, show three primary hydraulic response zones:

i) ***Unsaturated (vadose) zone*** – comprising the soil, weathered subcutaneous (sub-surface) zone and free draining percolation zone;
ii) ***Intermittently saturated (epikarstic) zone*** – zone of water table fluctuation; and
iii) ***Saturated (phreatic zone)*** – zone beneath the true groundwater table.

Recharge

There are two broad types of recharge that occur in karst terrains:

i) ***Autogenic recharge*** – water that falls directly onto the Karst system, is dispersed relatively evenly and has a distinct chemistry, and
ii) ***Allogenic recharge*** – water that is sourced from external (non-carbonate) areas and flows onto the karst.

Karst springs

Karst springs usually represent the exsurgence (resurgence) of water from conduits in the limestone. The flow from karst springs is usually more reliable (often perennial) than karst surface water features, because they are supplied by matrix and fracture flow during periods of low rainfall.

Investigations in Karst

Investigations of karst aquifers are particularly challenging because complex networks of fractures and dissolution features can locally and regionally control groundwater flow. It is not realistic to expect to encounter conduits during drilling programs because of the infrequent and heterogenous nature of conduit distribution.

A single technique cannot fully characterise the porosity and permeability of a karst aquifer, because of their complexity. A multi-stranded approach is usually used to understand how permeability and porosity are distributed in the aquifer.

Hydrogeological Investigation

Overview

Hydrogeological investigations were undertaken within and surrounding the proposed landfill site to provide the factual data that forms the basis of the assessments of site feasibility and environmental effects with respect to groundwater.

The objectives of the site investigation were to determine or develop:

- the stratigraphic sequence of rocks within the proposed landfill site, including thickness of the limestone and underlying materials;
- the primary, secondary and tertiary structures developed trough sedimentary texture, local tectonism and dissolution, respectively.
- the rock matrix hydraulic conductivity of the unsaturated and saturated zones;
- the terrain geomorphology and nature of karst development;
- a conceptual hydrogeological model for the site.

The investigations conducted to date (May 2002) comprised a number of techniques to obtain the required data, including:

- aerial photograph analysis
- site walk over observing the geomorphology,
- borehole drilling (9 bores, 8 locations),
- excavation of soil testpits (10 testpits),
- hydraulic testing,

- groundwater level monitoring, and
- groundwater chemical sampling.

Drilling Methodology and Specifications

Nine bores were drilled using coring techniques at eight different locations, with a total of 421 m drilled and geologically logged. Groundwater monitoring piezometers were installed in each of the bores, with nested (dual) piezometers installed in the deeper bores to permit assessment of vertical hydraulic gradients.

Site Geology

From analysis of the geological logs, the site geology is summarised into three bulk units:

- Overburden Material
- Limestone of the Forest Hill Formation
- Siltstone of the Chatton Formation.

Overburden Material

The overburden material comprises topsoil, colluvium (silt and clay) and residual limestone clasts that are either remain *in-situ* or have been eroded from the slopes above. The thickness of the overburden is spatially variable, being thickest (2 to 7 m) on the lower slopes, and within valleys and sinkholes, and thinning on the upper slopes. The overburden material is absent in some places (predominantly on the steep sides of ridges) and limestone is exposed at the surface at these locations.

Limestone of Forest Hill Formation

The limestone located on site is of the Forest Hill Formation and is typically yellow brown or light greenish grey, thin to thickly bedded, highly indurated, and only slightly weathered. Thin, moderately weathered, soft clay/silt horizons occur occasionally nearer the top of the formation, becoming less frequent with depth.

Dissolution features were primarily encountered near the surface, as indicated by the loss of drilling fluid within the upper profile of the limestone during drilling. The occurrence of fractures and dissolution features (vertical fluting and cavities) decreases with depth and is limited to above the water table. This finding adheres to the standard conceptual model for karst hydrology, with groundwater becoming more saturated with calcium and bicarbonate, and losing its power to dissolve carbonate rocks as it migrates downward through the vadose zone.

Siltstone of Chatton Formation

Underlying the limestone is a siltstone of the Chatton Formation, which is comprised of dark grey to dark greenish grey, slightly calcareous, slightly to moderately sandy massive siltstone.

Sinkhole Development On-Site

The April 2002 aerial photo of the quarry site indicates that sinkholes are predominantly located along the limestone ridges. The relative lack of conduit development in the lower lying parts of the catchment is a function of the sinkhole development, which require turbulent flow conditions and undersaturated water with respect to calcium and bicarbonate to develop.

In lower lying areas where the water table is closer to the surface, sinkholes are less likely to develop than on the ridges because turbulent flow conditions do not have as much potential to develop and the water typically displays greater maturity (i.e., higher degree of saturation). Karstic development in the valleys is more juvenile than on the ridges.

Aquifer Hydraulic Testing

Hydraulic testing of the rock was undertaken to gain an understanding of the water transmission potential of the rock. The objective of the testing program was to quantify the permeability of both the unsaturated and saturated zones of the rock. Preliminary testing indicated the permeability below the water was too low to permit long duration test pumping, therefore only the following two approaches were employed:

- ***Packer Tests*** – provides indicative hydraulic conductivity values for the area immediate adjacent to the pneumatic packer assembly.

- ***Slug Testing*** – provides indicative hydraulic properties for the aquifer area immediately adjacent to the saturated extent of the testing bore.

Test results indicates hydraulic conductivity values for the:

- limestone of the Forest Hill Formation range from 1.24×10^{-8} to 2.94×10^{-6} m/s with an average of 3.30×10^{-7} m/s.
- the siltstone of the Chatton Formation range from 6.30×10^{-8} m/s to 1.3×10^{-7} m/s, with an average of 8.40×10^{-8} m/s.
- rock above the water table is generally greater than below, with averages of 8.61×10^{-7} m/s and 1.15×10^{-7} m/s, respectively.

The hydraulic conductivity values for the Forest Hill Formation are within the normal range of typical publicised values for non-karst limestone and lower than karst limestone. The hydraulic conductivity values for the Chatton Formation are comparable to typical published values for siltstones.

These findings indicate that the hydraulic properties of the limestone at this site are more indicative of non-karst than karst limestone.

Groundwater Level Monitoring

Groundwater monitoring was initiated during the drilling investigation phase, with groundwater levels recorded manually using a 100-m electronic water level dipper.

Depth to Groundwater

Groundwater is encountered at or near the surface in the quarry floor and in the valleys, and is deepest underneath the ridges in the upper parts of the catchment.

Vertical Pressure Gradients

Results to date (June 2002) support the standard conceptual hydrogeological model, with downward groundwater pressure gradients in higher altitude recharge areas and upward pressure gradients in the lower discharge areas. Positive groundwater gradients currently exist beneath the base of the quarry, with groundwater seepage towards the ground surface. This will provides a form of hydrogeological security to the landfill site against leachate leakage impacting on the local groundwater resource.

Groundwater Flow Direction

The local groundwater flow direction is predominantly to the southwest on the southern (quarry) side of the catchment divide and to the north and east on the northern side of the divide. The greatest flow velocity potential occurs where the groundwater contours are steepest, which generally coincides with the sides of incised valleys or ridges.

Groundwater Flow Rates

Water transmission through the saturated part of the aquifer, which at this site is primarily governed by flow through the matrix or porous media, conforms to Darcy's Law. Darcy's Law describes the velocity of flow and is a function of the hydraulic conductivity, effective porosity and hydraulic gradient within the aquifer.

An average linear flow velocity of 7.54×10^{-6} m/s was calculated for limestone aquifer, which equates to a travel time of approximately 4 years for a water particle to travel 100 m downgradient of the site.

Groundwater Quality

Groundwater quality testing has been conducted on four bores to-date (May 2002) to characterise the groundwater body and to permit future comparisons if the landfill site becomes operational. Results from water quality analyses are summarised as follows:

- pH is typically around 7.4, with limited variation between the bores.
- The high bicarbonate and total hardness levels recorded in all bores are typical of limestone aquifers, and are of aesthetic significance only.
- Chemical concentrations of all parameters were below the ANZECC guidelines and the NZDWS, with the exception of:
  - dissolved lead in SKM104 (0.0282 mg/l) is less than the ANZECC guideline (0.0633 mg/l), but greater than NZDWS (0.01 mg/l); and
  - dissolved copper concentration in SKM104 (0.0101 mg/l) is marginally greater than the ANZECC guideline (0.0099 mg/l), but less that the NZDWS (2.0 mg/l).
  - Nitrate nitrogen is higher than the ANZECC guidelines (0.16 mg/l) in all groundwater samples obtained, but lower than NZDWS. Nitrate N is likely derived from stock effluent and fertilisers use.

Overall the water quality is reasonably good in comparison to guideline values. However the water quality does display naturally high calcium bicarbonate hardness, which is typical of limestone, and is effected by nitrate nitrogen, which would make it unpalatable. Metals are slightly elevated in one bore, although only one sampling round has been conducted to-date.

Conceptual Hydrogeological Model

The subterranean hydrology of the conceptual model has been simplified into two broad zones based on knowledge of karst hydrogeology and the hydraulic characteristics of the formation. These zones are described as follows:

- ***Karst (vadose) zone*** – water transmission zones comprising sinkholes, solution cavities and fractures within the upper 20 m and above the local groundwater table within the limestone of the Forest Hill Formation.
- ***Non-karst (saturated/phreatic) zone*** – aquifer zones beneath the local groundwater table consisting of massive low permeability limestone of the Forest Hill Formation and the underlying siltstone of the Chatton Formation. Flow characteristics of this zone conform to porous media flow governing equations.

Water may transit the system entirely within the karst zone, or may enter the deeper non-karst zone before exiting the system. The presence of sinkholes indicates that a connection exists between the recharge area and local karst springs. The exact nature of that connection is unknown at this stage. However, it is thought that the water from sinkholes travels laterally, discharging as karst springs on the valley sides and base at mid-level within the catchment. Further investigations are proposed over the coming twelve months to ascertain the flow pathways from the recharge area to the karst springs.

Water flow observed in testpits excavated into the valley floor to the east of the quarry indicates the possibility of high permeability conduits along the interface between the colluvium and underlying limestone. This interface drainage feature is possibly responsible for the recent development (in geological terms) of vertical shafts extending to the surface due to the dissolution and collapse of limestone at the colluvium contact.

Groundwater Numerical Modelling

Groundwater flow and contaminant transport models were developed for the non-karst limestone using the USGS MODFLOW and MT3DMS codes, respectively.
The objectives of the groundwater-modelling component of this study were as follows:

- To develop a model that accurately simulates groundwater flow and contaminant transport processes for the deeper non-karst limestone aquifer, where porous media flow governing equations are valid.
- To determine the effect on groundwater flow rates through quarrying and subsequent landfilling.
- To determine the groundwater level impact through quarrying and subsequent landfilling.
- To determine the groundwater seepage rates to the quarry and landfill underdrains.
- To evaluate potential contaminant plume distribution and movement from the landfill under worst case liner failure scenarios.

Simulation results are discussed in the following assessment of effects.

Assessment of Groundwater Effects

This chapter describes the anticipated effects of the quarry and landfill on the groundwater system beneath and downgradient of the landfill.

Effect of Quarrying

Groundwater Depressurisation

Quarry excavation will progressively impinge upon the groundwater table. However, based on historical observations within the quarry, the low hydraulic conductivity of the rock, small number of conduits in the phreatic zone and the progressive nature of the quarrying operation, groundwater seepage rates will be low and easily manageable.

The net effect of the quarry on the groundwater flow regime is a reduced hydraulic gradient, resulting in groundwater flow rates reduced by approximately 1.2% from the existing situation.

The reduced flow rates are unlikely to result in detectable changes in background groundwater chemistry, because the groundwater residence times will not be affected significantly.

Effect on Existing Springs

Continued lowering of the local water table by quarry excavation may inactivate a number of upper springs and seepages fed primarily by fracture flow in the epikarstic zone.

These springs only become active during wetter conditions, with a higher water table – therefore the effect also occurs naturally. The effect of the landfill is to increase the probability of this phenomenon occurring.

Effect of Landfilling

The hydrological effects of placing an impermeable barrier and landfill material in the quarry will be to reduce evaporation of near-surface groundwater; to reduce recharge in the quarry area; and potentially reduce the number of active karst springs.

Landfill Shadow Effect

Construction over the landfill footprint area will reduce rainfall recharge to the groundwater system. This would have the potential to lower groundwater levels to beneath the existing quarry floor.

The effect of reduced recharge is that the groundwater in the immediate area of the landfill will be depressurised. The extent of measurable impact (i.e., > 0.05 m) was modelled to be limited to within approximately 750 m of the site due to the low permeability of the aquifer. There is no significant effect on the position of the groundwater divide upgradient of the site.

The net effect on the groundwater flow regime is similar to that described in the previous section, with a reduced hydraulic gradient resulting in lower groundwater flow rates by approximately 12%.

Effect of Liner Leakage on Groundwater Quality

It is extremely unlikely that any significant leakage through the liner would occur because the proposed leachate collection and composite liner system provide a robust form of security against leakage.

There are two possible outcomes that could eventuate, should the worst case scenario materialise and significant leakage through the liner occurred:

i) under normal conditions the positive upward groundwater pressures from the underlying aquifer would prevent downward percolation of leachate to the underlying aquifer, resulting in leachate collection in the groundwater underdrains, and

ii) under prolonged dry conditions when the underlying groundwater pressures are likely to be less than normal, leachate may percolate through the unsaturated zone to the water table. This is considered unlikely because the path of least resistance for water flow beneath the liner system would be along the underdrain collection system, rather than entering the low permeability limestone. In the extreme case that leachate reached the aquifer system, groundwater modelling has demonstrated that plume movement would be extremely slow and limited in extent due to the low aquifer hydraulic conductivity and the natural process of advection, dispersion, sorption, and chemical decay.

Groundwater Underdrain System

There will be no additional groundwater dewatering effects on groundwater from the landfill underdrain system because they will effectively perform the same hydrological function as the quarry floor.

Effect on Bore Users

The distance to the closest bore is greater than 600 m. Given the low permeability of the limestone and low groundwater seepage rates to the adjacent alluvium, the groundwater quantity and quality effects of quarrying and landfilling is anticipated to be limited to less than 500 m from the site. This will not affect any bore users.

Conclusions

The main conclusions from the hydrogeological investigation of the site include:

- Positive (upward) groundwater pressures are evident in areas of lower ground elevation such as the existing quarry floor. Positive pressures provide a form of hydrogeological security because any leakage through the liner system is likely to be trapped against the landfill underdrain system and unlikely to migrate downwards through the aquifer.
- The limestone displays distinctly variable permeability with depth below the ground surface. Solution features and fractures become less prevalent with depth and are practically non-existent beneath the groundwater table.
- The lack of conduit features beneath the groundwater table indicates that the deeper limestone is non-karstic and groundwater flow is predominantly governed by porous media characteristics.

- Sinkholes are more prevalent on the ridges than in the valleys; mimicking the depth to groundwater pattern across the site, with groundwater being deeper on the ridges than in the valleys. The predominance of sinkholes on the ridges highlights that turbulent flow above the groundwater table is required for significant sinkhole development.
- The degree of karstification or sinkhole development decreases with depth because the ability of percolating rainwater to dissolve limestone is reduced with distance from the surface. This is due to the water becoming saturated in calcium and bicarbonate (i.e., by-product of the carbonation process), reducing its ability to dissolve limestone.
- Due to the morphological and hydrological features identified at the site, the nature of the karst terrain in terms of degree of karst development is considered juvenile.
- The likelihood of intersecting large solution conduits at the base of the quarry is low.
- The permeability of the rock is reasonably low with a site-wide average hydraulic conductivity value from aquifer testing of approximately 3.30×10^{-7} m/s, which is more indicative of non-karst than karst limestone.
- Due to the low hydraulic conductivity and natural attenuation process, the anticipated maximum extent of a conservative element contaminant plume has been estimated at approximately 2,300 m from site after 100 years of continuous discharge.

Contents

List of Figures

List of Tables

Document History and Status

Issue	Rev.	Issued To	Qty	Date	Reviewed	Approved
Working Draft	D	Internal	1	4 June 2002	Graham Wheeler	
Final Draft	A	Southland Regional Council	4	20 June 2002	Jon Williamson	

Printed: 21 June, 2002
Last Saved: 21 June, 2002
File Name: G:\DATA\PROJECT\Ivcl\Iv00319\Bore Holes\Hydrogeology Review.Doc
Authors: Jon Williamson, Stephen Swabey and Philip Jaggard
Project Manager: Jon Williamson
Name of Organisation: AB Lime Ltd.
Name of Project: Winton Landfill AEE
Name of Document: Hydrogeology Technical Report
Document Version: Final Draft
Project Number: IV00319.0

1. Introduction

1.1 Background

The technical report forms an appendix to the main resource consent application and assessment of environmental effects (AEE) document for construction and operation of a municipal landfill within decommissioned areas of the AB Lime quarry. The report presents the findings from desktop studies and investigations into the hydrogeology of the quarry site and surrounding areas (study area), and discusses the potential environmental effects on local groundwater resources resulting from the proposed landfill operation.

1.2 Objectives

The objectives of the hydrogeological investigations were as follows:

- To describe the existing geological and hydrogeological resources in the area of the quarry and surrounding areas.
- To determine the feasibility of a landfill with respect to the geological and hydrogeological properties of the site.
- To gain an understanding of the likely effects of quarrying on the groundwater resources in the area.
- To assess the potential environmental effects on local groundwater resources associated with the proposed landfill operations.

1.3 Report Structure

The structure of the report is as follows:

- Section 2 - Provides a description of the regional catchment characteristics, including the setting and existing landuse, topography and catchment watersheds and drainage.
- Section 3 – Provides a review of the regional geology from publicised references and previous reports, and includes sections on structural control and soils.
- Section 4 – Provides a review of regional hydrogeology including the occurrence of groundwater, groundwater regimes, groundwater use and groundwater quality.
- Section 5 - Provides a review of Karst hydrogeology, including descriptions of karst terrains, the karstification process, hydraulic and recharge characteristics of karst, karst springs and some of the issues to consider when investigating karst.
- Section 6 – Describes the hydrogeological investigations conducted at the site, including drilling, testpit excavating, aquifer hydraulic testing and groundwater level monitoring.
- Section 7 - Summarises the site hydrogeology as determined from all the available information including previous reports and data from the site investigation. This section includes a description of the site geology, aquifer hydraulic characteristics and groundwater quality and provides a geological structural model and a conceptual hydrogeological model for the site.
- Section 7 – Provides details of the numerical model developed and findings from an assessment of impacts on the groundwater flow regime and potential contaminant plume movement.
- Section 8 – Summarises independently the potential groundwater effects from quarrying and the proposed landfill.

- Section 9 – Summarises the findings of this report.

2. Regional Catchment Characteristics

A desktop review of available topography maps, aerial photos and previous reports for the study area was undertaken. The following sections summarise the main catchment characteristics of the regional environment.

2.1 Setting & Landuse

The quarry site is located within a prominent series of northwest to southeast orientated lime hills, approximately five kilometres east of Winton in the middle reaches of the Oreti River catchment, as shown in Figure 2-1.

The Oreti River catchment comprises an area of approximately 3,400 km^2 and traverses from high country tussock lands in the north to considerably flatter predominantly terraced fluvial-glacial alluvial plains in middle to lower sections of the catchment, to low-lying tidal reaches within the final twenty kilometres to the sea (Barry Robertson & Associates, 1992).

Prior to European settlement, most of the land in middle and lower reaches of Oreti River was wet and swampy, however this has been extensively drained and is now almost wholly pasture or cultivated land, heavily stocked with sheep, cattle and deer (Barry Robertson & Associates, 1992). A remnant stand of native bush is located above the quarry site, along the steeply incised gully down the northeastern side of the hills.

■ **Figure 2-1. Locality and topography plan.**

2.2 Topography

The topography and land surface gradients of the area are demonstrated in the contour maps shown in Figure 2-1 and Figure 2-2. The topography in the vicinity of the existing quarry can be broadly categorised into two topographical terrains as discussed below:

- ***Plains*** - relatively flat, gently sloping to undulating plains with land surface gradients less than 10%, or

- ***Lime Hills*** - prominent rolling lime hills, pock marked with sinkholes, and with incised drainage valleys. Land surface gradients typically reside between 10-33%, although flatter areas with gradients less than 10% occur on the ridges and steep-sided escarpments occur on the north-eastern side of the lime hills where surface gradients may be greater than 50%.

Figure 2-1 indicates that the plains downgradient of the quarry site have an average elevation of approximately 80 meters above mean sea level (mAMSL), while the lime hills vary between 80 m and 150 m above the surrounding plains, with a maximum elevation of approximately 230 mAMSL. Figure 2-2 indicates a propensity for steeper slopes on the northeastern margin of the lime hills with land surface gradients greater than 33%, which is related to the regional geology as discussed in subsequent sections.

- **Figure 2-2. Land surface gradient plan.**

2.3 Catchment Watersheds & Drainage

The drainage characteristics of an area are governed by the hydrological processes occurring in the catchment, which are dependent on a number of physical features of the land including topography, soils, geology, vegetation and climate.

There are a number of sub-catchments on Winton Hill, with drainage on the western side of the catchment divide to the plain and ultimately to Winton Stream and drainage on the eastern side ultimately to Otapiri Stream. Figure 2-3 shows the catchment watersheds within the study area and surrounding lands.

The surface drainage pathways on the lime hills predominantly comprise incised stream valleys orientated away from the northeast-southwest trending catchment divide along the ridges of the hills. These features were formed primarily through fluvial process, although secondary karstification in the valley bottoms may have accelerated valley development. The surface drainage networks of the lime hills comprise underfit streams (i.e., they have a greater flow capacity than is required for current catchment runoff potential). This has eventuated through the development of karstic landforms (sinkholes/dolines) predominantly on the ridges, resulting in the removal of runoff from the surface water system to subterranean karstic flow systems.

Several karstic springs flow from the lime hills. These springs feed lowland drains that traverse farmland downgradient of the site and discharge into larger streams that are tributaries of Winton Stream and eventually the Oreti River.

The surface drainage characteristics on the plains to the south of the lime hills differ significantly from that of the lime hills due to the change in geology and slope characteristics. Drainage on the plains comprises dendritic networks of shallow drains and natural streams flowing predominantly to the south-southwest. The drainage pathways of the land are highly modified with many of the drains regularly maintained for improving farm drainage and a high proportion of the minor streams straightened. The drainage system across the plains in this area displays a high proportion of straight reaches.

- **Figure 2-3. Catchment watershed plan.**

3. Regional Geology

The regional geological information for the study area is derived from three sources:

- New Zealand Geological Survey report by Isaac and Lindqvist (1990) entitled Geology and Lignite Resources of the East Southland Group;
- New Zealand Geological Survey 1:250,000 scale Geology Map for Invercargill (sheet 24); and
- the Southland Regional Council bore database.

A search of the Southland Regional Council bore database revealed approximately twenty bores within ten kilometres of the quarry site (Figure 3-1). No borelog details within the limestone formation were available, with bores typically drilled into the upper alluvial gravels surrounding Winton and Forest Hills.

The following sections describe the geological formations of hydrogeological and/or geotechnical significance to the quarry and surrounding areas. The geological formations are discussed in chronological order in the following sections from youngest to oldest. The following sections discus the soils of the lime hills, and regional structural control on geology and seismicity.

Figure 3-1 shows the geological formations described within this report and the location of boreholes within ten kilometres of the quarry site.

- **Figure 3-1. Surface geology map.**

3.1 Fluvio-Glacial Gravels

The geology surrounding Winton Hill consists of Quaternary age fluvio-glacial outwash gravels and glacial till deposited during the last glaciation. The alluvial gravel forms relatively undeformed higher terraces comprising a mixture of gravel, sand, silt and clay of greywacke-quartz-schist origin. The gravels underlie the most productive agriculture land and generally contain the highest yields of groundwater. In the study area the alluvium pinches out on the limestone and contains a high proportion of colluvium (slope-derived deposits) that is mostly clay weathered from the limestone hills.

3.2 Forest Hill Formation

Winton Hill forms part of the Mid-Tertiary age Forest Hill Limestone Formation[1] that outcrops as a series of prominent but discontinuous northeast-facing escarpment hills from Tussock Creek in the south to Kauana in the north. The alignment and geomorphology of these hills is governed by the regional structural control on geology, which comprises a northwest-southeast strike with beds dipping approximately 3 to 5° to the southwest, with gentle warping and variations in dip and strike.

[1] The quarry is situated entirely within the Forest Hill Formation.

The Forest Hill Formation is a sandy-yellow-brown, thick bedded, moderately to highly indurated, bryozoan/brachiopod[2], calcirudite[3], biosparite[4] and occasional biomicrite[5], with terrigenous detritus becoming more common towards the top. The limestone has a purity of 79-91%, making it suitable for agricultural and cement purposes.

The Forest Hill Formation was formed from inorganic precipitation of calcium carbonate minerals in a small geosynclinal shallow marine setting. The maximum preserved thickness of the formation is reported to be 78 m at Shark Tooth's Hill (five kilometres south of Forest Hill) although erosion has removed the upper contact of the formation at all locations (Isaac and Lindqvist, 1990).

The Forest Hill Formation is understood to be overlain and probably intercalated with Gore Lignite Measures, although this formation is thought to be absent in the Winton Hill area. Underlying the Forest Hill Formation is the Chatton Formation, the top of which forms an erosional discontinuity with the Forest Hill Formation (Isaac and Lindqvist 1990).

3.3 Chatton Formation

The Chatton Formation is of Late Oligocene to Early Miocene age and comprises a shallow marine, often calcareous and glauconitic, fossiliferous, fine to coarse grained sandstone, siltstone and conglomerate. Algal limestone is a common minor lithology and isolated outcrops of sandy limestone occur in some locations (Isaac and Lindqvist 1990).

The Chatton Formation is widespread but discontinuous, and demonstrates rapid lateral changes in facies and thickness. The thickness is spatially and vertically variable, ranging from 100-200 m to completely absent. Interfingering of the formation is likely (Isaac and Lindqvist 1990).

3.4 Basement Rocks

Basement rocks of Triassic to Jurassic age underlie the former units. The basement rocks are composed of lithified, tuffaceous, feldspathic sandstones, siltstones and mudstones, with marine fossils, plant bed, thin bituminous seams, and granitic and volcanic conglomerates.

The closest surface exposure of this formation is found in the Hokonui Hills, seven to ten kilometres to the northeast. The Hokonui Hills are part of the Southland Syncline – the main structural feature of the Southland region.

---

[2] Bryozoan – phylum of small aquatic colonial animal. Brachiopod – phylum of marine bivalve invertebrates.

[3] Calcirudite - coarse grained limestone.

[4] Biosparite - a limestone consisting of shell fragments within a sparry calcite cement. It is often the product of accumulation of clean washed, mud free shell debris, with diagenetic cement growth in pore spaces.

[5] Biomicrite - a limestone consisting of shell fragments set in a micrite of calcite matrix with a grain size less than 4 mm.

3.5 Soils

The soils of the limestone hills of Southland are brown earth soils that have developed over the calcareous parent material (rendzinas) and related soils. The soils have moderate natural fertility and are well to moderately well drained, but are generally shallow, due to the low mineral content of the limestone. Their profiles have friable very dark greyish brown silt loam topsoils with nut and granular structures, on yellowish brown or dark yellowish brown well-structured silt loam to clay loam, overlying sandy limestone or calcareous sandstone which outcrops on the surface in some places. Soils of this group have only slight or moderate limitations for pastoral use (Bruce, 1984).

3.6 Structural Control

Two main physiographic trends are evident in the Southland region:

1) The main north-easterly alignment of valleys and topographic divides is a product of Tertiary warping and faulting, and
2) The less obvious northwesterly alignment is a product of renewed movement of older structures formed during the late Mesozoic Rangitata Orogeny.

The main central structure of the district is the Southland Syncline trending northwest through the central area (Hokonui Hills). Pre-Tertiary rocks become older with increasing distance from the regional synclinal axis (Wood, 1966).

3.7 Seismicity

A detailed report on the seismicity of the Southland Region has been prepared, although is not included as part of this document. In summary, the findings from this report indicated that the potential for seismicity affecting the landfill was low.

4. Regional Hydrogeology

Regional hydrogeological information for the Southland region and in particular the area surrounding the quarry is limited to two main reports (AquaFirma 1994 and Southland Regional Council 1998); the New Zealand geological map sheet for Invercargill; and assessment of bore positions and lithologies from the Southland Regional Council bore database.

Much of the information presented in AquaFirma (1994) is derived from assessment of driller's diaries and borelogs, and is considered anecdotal rather than factual scientific information.

4.1 Occurrence of Groundwater

Groundwater of Southland is found in varying yields in the widespread Quaternary age fluvio-glacial gravels and the aquifers of the thick basement formations, which are of Tertiary age or older.

The highest yields of groundwater occur primarily within the gravel alluvium, with sustainable yields reputedly in the range of tens to hundreds of litres per hour (Woods, 1966). Younger, more recently worked lower alluvial terraces adjacent to the main rivers have greater water yields than the higher terraces, which typically display moderate to strong weathering of clasts, a higher proportion of clay materials and consequently lower porosity and permeability.

Downgradient of the study area, the gravels form a thin veneer over the basement rocks and tend to have less quartz, a smaller grain size sand and contain a higher proportion of silt compared to other alluvium in Southland (Southland Regional Council, 1998). Consequently the permeability of gravel alluvium downgradient of the quarry site is thought to be generally lower than what is typical for Southland.

Groundwater may be obtained from hard rock formations in the region, although yields are generally lower than the gravels due to lower porosity and smaller number of water bearing fractures and joints (Woods, 1966). For this reason deeper boreholes are required to obtain sufficient useable quantities of groundwater than in the gravels (i.e., > 100 m). The number of bores drilled in hard rock aquifers is limited by the significant costs involved in drilling to the required depths.

4.2 Groundwater Regime

Groundwater flow generally occurs from high head (or piezometric pressure) to low head. Consequently, groundwater flow patterns typically mimic land surface gradients and in the Quaternary gravels, flow is towards the major surface water drainage features. Flow direction in the rock aquifers is modified by the geological structures of the rock mass and hydraulic characteristics of the confining layers (aquitards) and aquifers.

The depth to groundwater at any point in the catchment is determined by the distance from main drainage features, the hydraulic characteristics of the aquifer and overlying materials, and groundwater recharge rates.

Groundwater is shallowest in the lower Quaternary gravel terraces of the main river valleys, typically encountered at depths of 0-6 m below ground level (mBGL), and deepest on the high terraces, with reported depths of >40 mBGL (Woods, 1966). Depth to groundwater in the hardrock aquifers will vary depending on the depth of the screened response zones; with deeper confined aquifers likely to display artesian levels.

Seasonal variation in groundwater levels is generally least in the younger gravels, rarely exceeding 3 m (Woods, 1966). This is due to the evenly distributed annual precipitation and high degree of connectivity to perennial drainage systems that mitigate the magnitude of groundwater fluctuation in the adjacent aquifer. In contrast, up to 12 m seasonal variation in water table position occurs in the older gravels (Woods, 1966). This is due to the increased distance from perennial rivers and lower storage (specific yield) characteristics of the aquifer. Seasonal groundwater oscillations are generally less in bores drilled in unfractured hardrock due to the buffering effect of the overburden rock mass, which provides a steady supply of groundwater recharge displaying attenuated and mitigated responses to climatic changes.

4.3 Groundwater Use

A recent survey conducted by the Southland Regional Council (1998) concluded that groundwater is used by over 50% of rural residents in Southland for potable, stock water, dairy shed washdown or irrigation purposes. In the absence of a bore or well, rainwater is the most common alternative to groundwater (Southland Regional Council, 1998). Due to water quality and quantity issues, it is likely that homes are supplied with rainwater and farms with groundwater if both supplies are available.

According to AquaFirma (1994) there have been no reports of groundwater level declines that can be attributed to bore interference effects or over utilisation of the groundwater resource. Land drainage is reported as the main cause of noticeable groundwater level decline. The level and density of groundwater use is such that over exploitation would only be anticipated in areas of intensive agricultural and industrial activities (AquaFirma, 1994).

4.4 Groundwater Quality

A high proportion of Southland's groundwater resources is susceptible to contamination because much of the water is drawn from shallow unconfined highly permeable aquifers in areas of intensive land use. However, results from the groundwater quality survey of 350 bores, wells and springs conducted by Southland Regional Council in 1998 for the unconfined aquifers indicated that:

- Nitrate levels were typically three to four times below the New Zealand drinking water standard of 11.3 mg/L (NO_3-N);
- No faecal coliforms were recorded in 60% of samples, while the remaining samples displayed faecal coliform concentrations above the New Zealand drinking water standard of 1 cfu/100 mL;
- Iron concentrations typically four times below the New Zealand drinking water standard of 0.2 mg/L; and
- Groundwater was generally only slightly acidic.

Poor well head protection was responsible for the majority of the high faecal coliform results, while a large number of the high nitrate results were accounted for by bores located in close proximity to septic tanks. Only six high nitrate concentrations in the 350 samples could not be attributed to localised sources of contamination (Southland Regional Council, 1998).

Woods (1966) states that the water quality in Southland is usually best in the younger gravels, with dissolved salts at a minimum, however such water is more vulnerable to pollution from surficial sources. Groundwater from the older weathered Quaternary deposits usually contains higher concentrations of dissolved iron. Of the many potential contaminants of groundwater, nitrates and faecal coliforms are the most widespread and problematic.

5. Karst Hydrogeology

This chapter on Karst Hydrogeology provides the necessary background information to place the hydrogeological significance of the limestone within this study area into perspective.

Karst is the name given to areas of limestone or marble (metamorphosed limestone) geology characterised by landforms developed as a result of solution processes.

The development of karst terrains occurs primarily when carbonate rocks[6] are hard and relatively free from impurities (less than approximately 20% terrigenous material). Some limestone, such as argillaceous limestone north of Auckland (e.g., at Redvale and Wellsford) are pure enough to be quarried for agricultural lime but are too impure for developed karst features to arise (Williams, 1992). Other rock characteristics of particular importance for the formation of karst include porosity, fissuring and thickness of the formation.

5.1 Karst Forming Processes

5.1.1 Carbonation

Carbonation is a chemical weathering process and is the fundamental chemistry of the karst forming solution process. Carbonation involves a reaction of dilute carbonic acid and a mineral (e.g., calcium carbonate) as summarised in the following equations:

Development of carbonic acid:

$$CO_2 + H_2O \rightarrow H_2CO_3$$

Dissociation of carbonic acid:

$$H_2CO_3 \rightarrow HCO_3^- + H^+$$

Acid reaction with calcite:

$$CaCO_3 + H^+ \rightarrow Ca^{2+} + HCO_3^-$$

In summary:

$$CO_2 + H_2O + CaCO_3 \rightarrow Ca^{2+} + 2HCO_3^-$$

[6] By definition carbonate rocks contain more than 50% carbonate minerals by weight, of which there are two end member: calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$). Limestone contains at least 90% calcite, with the remaining constituents comprising insoluble impurities such as clay and quartz. Carbonaceous rocks with more that 50% impurities are defined as, for example, calcareous sandstone or calcareous mudstone depending on the nature of the impurity.

Carbonic acid is formed where rainwater of low bicarbonate hardness percolates through soil absorbs CO_2 from air within the soil[7]. In the case of limestone, H^+ ions of the mildly acidic rainwater react with calcite producing calcium and bicarbonate ions. The acidic rainwater becomes progressively weaker through removal of H^+ ions as this process continues and the residual water becomes progressively saturated with respect to calcium and bicarbonate. As the degree of water saturation increases the ability of the water to dissolve limestone decreases. This typically relates to contact time, which generally correlates to depth below the ground surface.

5.1.2 Karstification

Karstification is the term used for the overall processes that increases the water bearing capacity of most carbonate rocks. Karstification is the result of the solution process that predominantly occurs in rock defects such as bedding planes, faults and joints. The defects are gradually enlarged and over time narrow fissures can develop into very large caves

The development of karst topography advances through stages, which may be identified as juvenile, maturity and old (Goodman, 1993). Figure 5-1 depicts some of these aspects of karst development.

It should be noted that different stages of karstic development may coexist, due to climatic variations and changes in local non-limestone geology. In hard, indurated limestone the progression through these stages may take a very long time, with the progression in stage unlikely to occur in a persons lifetime (Goodman, 1993).

The stages of karst landscape development have distinctive hydrological characteristics that form the basis of the karst landscape classification. These classifications and respective hydrological characteristics are discussed in the following sections.

5.1.3 Juvenile Karst Terrain

Juvenile karst terrain has not been lowered appreciably and retains relatively normal surface drainage, except that some stream discharge is lost to underground conduits and there are springs where these flows rejoin the surface (Goodman, 1993).

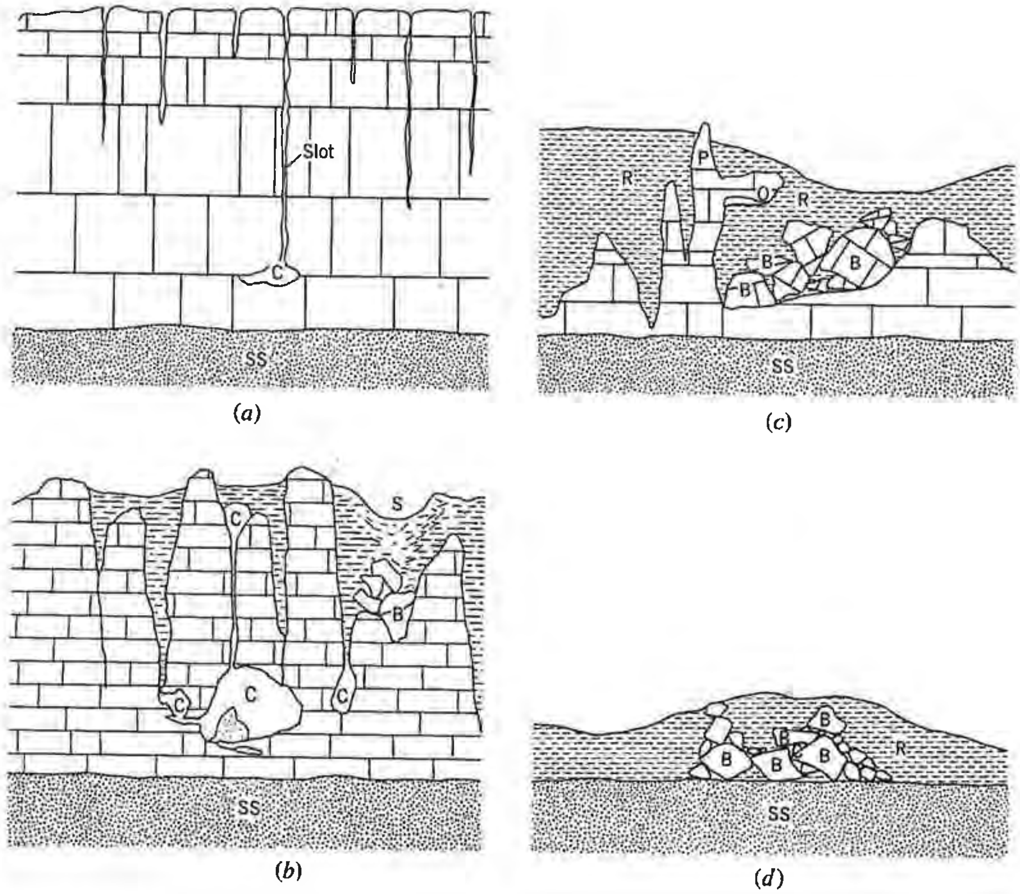
5.1.4 Mature Karst Terrain

In early maturity, vertical joints in the rock have been enlarged by solution to form pinnacles and narrow vertical caverns. Some shallow caves have formed, and the collapse of the roofs of some of these has created separate closed depressions (sinkholes).

In fully mature karst terrain, a well-developed and integrated underground runoff system modifies the hydrology of surface drainage in a complex manner. The land surface is irregular, with numerous small divides between sinkholes, the bottoms of which are at different elevations. Drainage is no longer dendritic, but focussed on sinkholes. The limestone is covered with an extremely variable thickness of residual clay through which rainfall readily infiltrates (Goodman, 1993).

---

[7] Soil CO_2 levels derived from the atmospheric are increased by plant respiration through their roots.



■ **Figure 5-1. Development of solution cavities and karst features:** (a) juvenile; b) early maturity; c) late maturity; d) old. C, cavity; S, sinkhole; SS, sandstone; B, block; R, residual soil; P, pinnacle; O, overhanging pinnacle (after Goodman, 1993).

5.1.5 Old Karst Terrain

The limestone is virtually levelled or completely removed in old karst terrain. It is replaced with a thick deposit of residual clay, consisting of the insoluble residue from calcite and dolomite solution. The topography is very irregular, with rugged knife-edge rock outcrops. There are no surface streams as all rainfall infiltrates the soil (Goodman, 1993).

5.2 Sinkhole Development

The surface karst environment may develop topographically closed landforms ('pocked') characterised by sinkholes[8] (Williams, 1992).

[8] The terminology for closed depressions in karst varies depending on regional/national location. 'Sinkhole' and 'doline' have been used interchangeably in other work to describe closed depressions with or without open shafts, respectively. In some literature, 'sinkhole' refers to the open shaft, and 'doline' to the surrounding closed depression. In this study we will follow common New Zealand usage of the terms (e.g., from NZMS topographic maps). Sinkhole will be used to describe closed depressions with or without an open shaft, whilst shafts are referred to separately.

Sinkholes form through the following processes:

- simple solution of the limestone;
- collapse of overlying sediments into solution voids (suffosion); or
- collapse of the limestone itself.

The development of solution sinkholes (the first two processes above) is a self-reinforcing process. An initial minor weakness in the rock produces higher hydraulic conductivity and preferential flow paths. The solution potential is increased along the conduit, further enlarging the conduit. The focussing of drainage from surface waters in the vicinity of the sinkhole increase the volume of water harvested, resulting in accelerated development and continual expansion of the sinkhole.

The presence of conduits where water can readily drain and where turbulent flow conditions can occur is a prerequisite for sinkhole development. If the subterranean conduit system has not developed sufficiently, sinkholes will not develop.

5.3 Hydraulic Characteristics

The hydrogeology of karst systems differ from standard groundwater systems in that:

- The hydraulic networks can consist of three types of spaces; pores (aquifer matrix), fracture and channel or conduit (Motyka, 1998). For this reason, simple porous media or double porosity conceptual models of the system are not applicable.

- The circulation of water in a karst aquifer continually enhances the aquifer permeability. The hydraulic gradient will decrease through long periods of time, as the water table declines due to increases in storage and permeability (Williams, 1992).

- The piezometric surface geometry may not follow topographic lows and highs due to lowering of the water table through conduit drainage.

According to Worthington *et al.* (2000) the rock matrix in karst accounts for almost all of the aquifer storage, while the channels transmit almost all the groundwater flow.

Temporary changes or cessations in rate and slight variations in material composition during sedimentary deposition produce the interstices that are the most significant pore spaces of the rock (i.e., the primary porosity).

Flexion from slight tectonic movements produces joints in the rock and stronger tectonic movements cause major dislocations (faults). These fissures provide potential pathways for the enhanced movement of groundwater and are classified as the secondary porosity.

The secondary porosity is transformed into significantly greater tertiary porosity by chemical enlargement of fissures (karstification). Circulation of water through the rock continually flushes the limestone with dilute acid, and the rock becomes progressively more and more riddled with interconnected voids of increasing size and complexity.

The distribution of rock defects is not regular, allowing the development of preferential flow paths for rapidly transporting percolating water downwards.

Percolating water becomes increasingly more saturated with bicarbonate (HCO_3) as it moves downwards, reducing its corrosiveness to carbonate rocks. For this reason, solution fissures are widest near the surface and gradually taper or close with depth and karst is usually more developed close to the surface.

Most classifications of karst systems (Motyka, 1998), show three primary hydraulic response zones:

iv) ***Unsaturated (vadose) zone*** – comprising the soil, weathered subcutaneous (sub-surface) zone and free draining percolation zone;

v) ***Intermittently saturated (epikarstic) zone*** – zone of water table fluctuation; and

vi) ***Saturated (phreatic zone)*** – zone beneath the true groundwater table (Williams, 1992).

The hydraulic characteristics of each of these zones depend largely on the degree of karst development. For example, flow changes from laminar to turbulent as the conduit diameter increases to approximately 10 mm[9]. This is a significant point for the application of Darcy's law, because the linear relationship assumed between flow velocity and hydraulic head no longer applies. However, Williams (1992) provides examples of karst in New Zealand and the Pacific Islands where laminar flow occurs in poorly developed or juvenile karst, and Darcy's law can be applied.

Where the aquifer is penetrated by under-saturated water (with respect to calcium and bicarbonate) and flows with sufficient turbulence to remove insoluble residues, the rate of conduit growth increases. The hydraulic behaviour of a cave stream in an enlarged conduit in vadose conditions is similar to that of open channel flow on the surface.

The coupling between conduit, fissure and matrix components of the aquifer permits a proportion of the epikarstic water to be removed more quickly from the system than might occur under simple matrix flow. The removal of water from the aquifer matrix via conduits leads to local depressions of the water table and a consequent reduction in recharge to the deeper groundwater system.

Information regarding the hydraulic behaviour of the karst system can be gained by assessing flow hydrographs and water quality time-series from karst springs. The spring hydrograph and chemograph respond rapidly to rainfall events when groundwater is dominated by channel flow and recharge is dominated by sinking streams. In contrast, the response can be lagged when flow is matrix dominated and recharge is dispersed.

The frequency distribution of electrical conductivity in karst springs is typically unimodal when rock matrix or fissures dominate flow and recharge is diffuse. This occurs because all water percolating slowly through an isotropic aquifer has similar residence and rock contact times. Where the aquifer experiences a significant

[9] Flow in karst may occur in several forms - laminar flow, turbulent flow with a laminar sublayer, and totally turbulent flow at high Reynolds number.

proportion of conduit flow, the frequency distribution of electrical conductivity is typically multi-modal – each mode representing the different residence periods in varying flow paths. This occurs in a well-karstified aquifers, where different flow routes and resident times result in contrasts in water quality (Williams, 1992).

5.4 Recharge

There are two broad types of recharge that occur in karst terrains:

iii) ***Autogenic recharge*** – water that falls directly onto the Karst system, is dispersed relatively evenly and has a distinct chemistry, and

iv) ***Allogenic recharge*** – water that is sourced from external (non-carbonate) areas and flows onto the karst.

As alluded to in the previous section, the water quality of the recharge waters will vary depending on the type of recharge, which has implications for the erosional capacity of the water and the chemical signature of the systems discharge water.

5.5 Karst springs

Karst springs usually represent the exsurgence (resurgence) of water from conduits in the limestone. The flow from karst springs is usually more reliable (often perennial) than karst surface water features, because they are supplied by matrix and fracture flow during periods of low rainfall.

5.6 Investigations in Karst

Investigations of karst aquifers are particularly challenging because complex networks of fractures and dissolution features can locally and regionally control groundwater flow. It is not realistic to expect to encounter conduits during drilling programs because of the infrequent and heterogenous nature of conduit distribution (Worthington *et al.,* 2000). Where drilling does penetrate conduits, it may result in aquifer hydraulic test results that are unrepresentative of the formation as a whole. Similarly, a near miss on a highly transmissive conduit may underestimate the aquifer characteristics in that location.

A single technique cannot fully characterise the porosity and permeability of a karst aquifer, because of their complexity. A multi-stranded approach is usually used to understand how permeability and porosity are distributed in the aquifer (Mace and Hovorka, 2000).

6. Hydrogeological Investigation

6.1 Overview

Hydrogeological investigations have been undertaken within and surrounding the proposed landfill site. The information gained from this investigation provides the factual data that will form the basis of the assessments of site feasibility and environmental effects with respect to groundwater.

The objectives of the site investigation were to determine or develop:

- the stratigraphic sequence of rocks within the proposed landfill site, including thickness of the limestone and underlying materials;
- the sedimentary texture of the materials encountered during drilling including, grain size, shape and fabric, which in turn govern bulk density, porosity and permeability of the rock matrix;
- the primary sedimentary structures of the materials encountered during drilling including bedforms, lamination, and bedding planes;
- the secondary sedimentary structures (defects) of the materials encountered during drilling including fracturing and faulting, which govern secondary porosity;
- the tertiary structures that have developed through the dissolution processes of carbonation that govern tertiary porosity and in this terrain have the biggest influence on preferential flow;
- the rock matrix hydraulic conductivity of the unsaturated and saturated zones;
- the terrain geomorphology and nature of karst development;
- a conceptual hydrogeological model for the site.

The investigations conducted to date (May 2002) comprised a number of techniques to obtain the required data, including:

- aerial photograph analysis
- site walk over observing the geomorphology,
- borehole drilling (9 bores, 8 locations),
- excavation of soil testpits (10 testpits),
- hydraulic testing,
- groundwater level monitoring, and
- groundwater chemical sampling.

The following sections document the field investigations and desktop analyses undertaken, describe the information gained, and summarise the results obtained.

6.2 Drilling Methodology and Specifications

McNeill Drilling Company Ltd. (Alexandra) was commissioned to install a series of 9 boreholes at 8 locations as shown in Figure 6-1, between 17 February and 9 March 2002. Drilling was conducted using the wire-line rotary continuous coring technique with a HQ size tungsten and diamond tipped core bit. The HQ coring drilling method produces a drilled-hole diameter of 96.1 mm and a rock core diameter of 63.5 mm, and permits detailed geological analysis of the recovered geological materials. The bores were drilled to depths between 9 and 77 mBGL, depending on the ground elevation at each site and the depth to base of limestone or water table.

■ **Figure 6-1. Borehole locations and topography of the site.**

6.2.1 Piezometer Completions

A nested piezometer configuration comprising two 20 to 32 mm PVC standpipes, or a single 50 mm PVC piezometer was installed in each borehole to facilitate groundwater monitoring and/or sampling. The aquifer response zones targeted in each piezometer were screened with either 3 m hand slotted or machine slotted screens varying from 6 to 12 m in length. The screens were surrounded by a gravel pack of 2-5 mm Walton Park quartz. A bentonite seal of a minimum thickness of 1 m was emplaced on top of the gravel pack, with the bore annulus backfilled and sealed near the surface with bentonite to prevent surface water ingress.

Bore logs detailing lithology and the details of the piezometer construction are given in Appendix A. Drilling, groundwater levels and survey details are summarised in Table 6-1 and a summary of the bore geology is presented in Table 6-3.

■ **Table 6-1. Bore Drilling, Survey and Monitoring Details.**

Bore	Easting	Northing	Piezometer Diameter (mm)	TOC (mAMSL)	Ground Elevation (mAMSL)	Drilled Depth (m)	Screened Interval (m)	SWL (mAMSL)
SKM101A	2152929.50	5443021.31	50	80.12	79.54	9	8.76 - 2.76	79.29
SKM101B	2152928.75	5443022.90	32	80.16	79.69	37.5	27.3 - 21.3	79.72
SKM101C	2152928.75	5443022.90	20	80.16	79.69	37.5	37.45 - 34.45	79.78
SKM102A	2153275.22	5443132.97	32	97.84	97.53	26.5	20 - 14	90.40
SKM102A	2153275.22	5443132.97	25	97.84	97.53	26.5	26.5 - 23.5	89.89
SKM103A	2152987.63	5443360.09	32	129.42	129.25	56.4	50 - 44	100.65
SKM103B	2152987.63	5443360.09	20	129.42	129.25	56.4	56.4 - 53.4	89.05
SKM104	2153261.85	5443788.63	50	187.68	187.42	77.0	67.7 - 55.7	137.03
SKM105A	2152673.21	5443117.23	20	123.57	123.09	58.0	44.5 - 41.5	83.77
SKM105B	2152673.21	5443117.23	32	123.57	123.09	58.0	58.9 - 55.9	82.83
SKM106	2153764.46	5443144.92	50	186.98	186.79	77.5	77.5 - 65.5	125.48
SKM107A	2153279.47	5442806.96	32	96.33	96.15	59.0	52.3 - 46.3	78.17
SKM107B	2153279.47	5442806.96	20	96.33	96.15	59.0	59.5 - 56.5	79.18
SKM108	2152768.01	5442563.30	50	66.32	66.19	20.5	20.5 - 14.5	65.39

Note: mAMSL is metres above mean sea level. TOC is top of casing. SWL is median groundwater level from piezometer completion date in either February or March 2002 to June 12 2002.

6.3 Testpits

On March 26 2002, a 12 ton excavator equipped with a 1 m diameter bucket was used for the excavation of ten testpits along a transect where small open sinkholes (shafts) were prevalent. The alignment of the shafts corresponds to a significantly incised drainage valley to the east of the existing quarry area, as shown in Figure 6-1.

Several testpits were excavated to examine the extent of shaft development and drainage characteristics. Soil profile characteristics, depth of the shafts and features indicative of surface water soakage were recorded.

The testpits were excavated to the maximum accessible depth of the excavator, or until impenetrable limestone was encountered. Testpit logs showing lithology, final depths and water levels where encountered are included in Appendix A. Table 6-2 summaries the excavation data and Table 6-3 summarises the geology of each testpit.

Data from the testpits indicates that free water was encountered above the limestone and near the base of the colluvium. This is likely to be an interface drainage feature between the two units.

- **Table 6-2. Summary of Testpit Details.**

Testpit	Excavation Depth (mBGL)	Depth to Limestone (mBGL)	Water Encountered (mBGL)
TP1	4.3	4	3.9
TP2	3.9	3.9	3.9
TP3	4.3	4.3	-
TP4	2.5	2.5	2.5
TP5	4.3	4.3	3.9
TP6	4.5	4	-
TP7	6		-
TP8	2.9	2.9	2.9
TP9	2	2	2
TP10	1.5	1.5	-

6.4 Site Geology

Table 6-3 provides a detailed summary of the geology encountered at each bore and testpit location.

- **Table 6-3. Summary of Geology.**

Location	Summary of Geology
SKM101	Limestone to a depth of 27.8 m. Predominantly yellowish brown with occasional horizons of greenish grey biomicrite and biosparite limestone occurring near the base of limestone. Occasional interbedded soft horizons and fractures, becoming less frequent with depth. Dark grey massive mudstone and siltstone from 27.8 m to end of hole at 37.5 m. Water table lies at 0.5 mBGL. Limestone fractures and conduits are found from the surface to 7.4 m.
SKM102	Brown colluvium to a depth of 2.4 m, overlying limestone. Predominantly greenish grey and yellowish brown biosparite limestone to a depth of 18.5 m with occasional horizons of greenish grey biomicrite limestone. Limestone is predominantly massive with occasional fractures. Dark grey massive siltstone from 20.9 m to end of hole at 26.5 m. Water table at 7.8 m, slightly above fractures found from 8 m to 16 m.
SKM103	Bore drilled in sinkhole. Brown colluvium to a depth of 7.2 m, overlying limestone. Predominantly yellowish brown biosparite limestone to a depth of 50.4 m with occasional horizons of greenish grey biomicrite and biosparite limestone occurring near the base of limestone. Heavily fractured and cavities present in the first 25 m of limestone, becoming massive with depth. Dark greenish grey massive siltstone and sandstone from 50.4 m to end of hole at 56.4 m. Two water table measurements give levels of 29 and 40.4 mBGL. Fractures and large cavities (conduits) are found in two zones, from 7.2 m to 26 m and also from 35.8 m to 46.2 m.
SKM104	Brown colluvium to a depth of 1.3 m, overlying limestone. Predominantly yellowish brown biosparite limestone to a depth of 68.8 m with occasional horizons of greenish grey biomicrite and biosparite limestone occurring near the base of limestone. Fractures and interbedded soft horizons occur in the initial 54 m of limestone, becoming less fractured and more massive with depth. Dark greenish grey massive siltstone from 68.8 m to end of hole at 77.5 m. Water table at 50.7 mBGL, with fractures occurring from 2.6 m to 53.6 m and also from 61.5 m to 64.3 m..
SKM105	Brown colluvium to a depth of 0.4 m, overlying limestone. Predominantly yellowish brown biosparite limestone with occasional horizons of greenish grey biomicrite and biosparite limestone. Fractures and interbedded soft horizons becoming less frequent with depth. Limestone to end of hole at 58 m. Water table at 40.9 mBGL, with numerous

Location	Summary of Geology
	fractures from 2.9 m to 46.2 m.
SKM106	Brown colluvium to a depth of 0.5 m, overlying limestone. Predominantly yellowish brown biosparite limestone to a depth of 76.1 m, with occasional horizons of greenish grey biomicrite and biosparite limestone occurring near base of limestone. Fractures and interbedded soft horizons occur in the initial 61 m of limestone, becoming less fractured and more massive with depth. Dark greenish grey massive siltstone from 76.1 m to end of hole at 77.5 m. Water table at 65 mBGL, fractures from 0.5 m to 59.9 m.
SKM107	Brown colluvium to a depth of 1.3 m, overlying limestone. Predominantly yellowish brown biosparite limestone to a depth 50.7 m with occasional horizons of greenish grey biomicrite and biosparite limestone occurring near base of limestone. Fractures and interbedded soft horizons occur in the initial 37 m of limestone becoming less frequent with depth. Large cavities were encountered in the initial 7 m of drilling. Dark greenish grey massive siltstone from 52 m to end of hole at 59 m. Water table at 18 mBGL. Fractures and large cavities (conduits) occur from 1.3 m to 34.3 m.
SKM108	Brown topsoil and alluvium to a depth of 3.4 m, overlying light greenish grey massive biosparite limestone. Limestone to end of hole at 20.5 m. Water table at 1.1 mBGL, with fractures occurring between 9.4 m and 13.6 m.
TP1	Dark tan/brown topsoil ~50-100 mm thick. Light tan clay to bottom at 4 m. Bluish grey clay in places where water seepage apparent. Becoming noticeably moist at ~2.5 m. Indurated limestone and positive spring flow encountered at 4 m. Water recovered about 200–400 mm and appeared to be bubbling in and flowing out at the same rate. Final depth 4.3 m. Water Table ~3.9 m.
TP2	Light tan brown clay to 3.7 m. Grey clay at base to 3.9 m. Hard, cream yellow, unweathered limestone at base of pit. Wet at bottom, although definitely no positive spring flow like that found in TP1.
TP3	Light tan clay to final depth of 4.3 m. Mottled (yellow/tan/grey) clay in places where water had seeped down the surface expression of sinkhole. Plastic grey moist clay at base and then into fresh yellow limestone, which seemed to be fractured at base. Water table ~ 200 milli below surface of limestone. Didn't bubble up like TP1.
TP4	Located on the western side of the valley. Old offal hole. Tan clay and offal (sheep bones) to final depth of 2.5 m. Hard limestone at base with water flowing from west of pit (i.e., from quarry side) to east towards middle of valley.
TP5	0.5 m brown topsoil. 0.5 – 3.9 m tan clay. 3.9 m brown grey clay with water gushing in. 4.3 m final depth, hard limestone.
TP6	Brown topsoil/regolith (valley wash) to ~2 m with variable base. Tan clay with numerous white specks of weathered Limestone/clay to ~3.5 m. 3.5 – 4 m very moist/plastic yellow tan grey tan mottled. 4 – 4.5 m green grey weathered and rubbly Limestone. No draining water, although moist.
TP7	200 milli brown topsoil/regolith wash. Tan brown clay to base of hole at 6 m. Speckled in places with weathered soft limestone inclusions (pebbly clay). Probably colluvium or regolith. Becoming more plastic near base. Too dangerous to progress further, but sense limestone getting close due to grey clay near base. Hole possibly excavated last summer for quarry water search. No groundwater.
TP8	Old spring, removed cylinder found field drains underneath. Grey black organic clay. Grey green weathered limestone at 2.9 m. Water flowing but then stopped to trickle.
TP9	Sinkhole 5 m further up from old spring. Uncovered channel on top of limestone on side with interface drainage yield of ~0.75 L/s. Flow seemed sustainable while at site (half an hour). Fresh hard cream yellow Limestone at 2 m.
TP10	Location was on valley to east of the spring line valley. 1.5 m of tan clay to yellow tan hard limestone. Dry. No photo.

From analysis of data provided in the above table and the regional geological summary provided in Chapter 3, the site geology may be summarised into three bulk formations, as indicated below and summarised in the following sections:

- Overburden Material
- Limestone of the Forest Hill Formation
- Siltstone of the Chatton Formation.

6.4.1 Overburden Material

The overburden material comprises topsoil, colluvium (silt and clay) and residual limestone clasts that are either remain *in-situ* or have been eroded from the slopes above. The thickness of the overburden is spatially variable, being thickest (2 to 7 m) on the lower slopes, and within valleys and sinkholes, and thinning on the upper slopes. Limestone is exposed at the surface in some places – predominantly on the steep sides of ridges.

6.4.2 Limestone of Forest Hill Formation

The limestone located on site is of the Forest Hill Formation and comprises yellow brown and light greenish grey, thin to thickly bedded, slightly weathered, bryozoan/brachiopod, biosparite that ranged in thickness between 18.4 m and 75.6 m. The formation is interbedded with moderately weathered, thin (generally <0.04 m), soft clay/silt horizons and occasional greenish grey biomicrite. The interbedding of thin soft clay/silt horizons generally occurs near the surface, becoming less frequent with depth. The light greenish grey biosparite limestone and greenish grey biomicrite limestone generally occur towards the base of the limestone.

The occurrence of fractures and dissolution features (vertical fluting and cavities) decreases with depth and is limited to above the water table. Cores recovered from the boreholes indicates that the fractures where occurring are near vertical, with a dip angle greater than 70°.

Dissolution features were primarily encountered near the surface, as indicated by the loss of drilling fluid within the upper profile of the limestone during drilling. This finding adheres to the standard conceptual model for karst hydrology and limestone dissolution theory (Section 5.3), with groundwater becoming more saturated with calcium and bicarbonate, and losing its power to dissolve carbonate rocks as it migrates downward through the vadose zone.

6.4.3 Siltstone of Chatton Formation

Underlying the limestone is a siltstone of the Chatton Formation, which is comprised of dark grey to dark greenish grey, slightly calcareous, slightly to moderately sandy siltstone. Occasional shell inclusions and mudstone and sandstone horizons also occur within the formation at the site. The interface between the Forest Hill Formation and the Chatton Formation is a sharp contact indicating the latter to be an erosional surface. Evidence of progressive coarsening towards the base of the limestone supports this.

6.5 Sinkhole Development

The April 2002 aerial photo of the quarry site shown in Figure 6-2 indicates two obvious areas of significant sinkhole development:

1) between altitude 110 m and 175 m along a northeast trending ridge east of the site between SKM107 and SKM106; and
2) predominantly along a ridgeline between SKM103 and SKM104 on the western and northern sides of the site.

■ **Figure 6-2. Aerial photograph of the quarry site (April, 2002).**

The distribution of sinkholes along the limestone ridges and relatively limited conduit development in the lower lying parts of the catchment, is a function of the sinkhole development process and indicates more advanced karstic development on the ridges. As indicated in Section 5.2, sinkholes require turbulent flow conditions and undersaturated water with respect to calcium and bicarbonate to develop. These conditions are more likely to occur in areas where the unsaturated zone above the water table is greatest.

In lower lying areas where the water table is closer to the surface, sinkholes are less likely to develop than on the ridges because turbulent flow conditions do not have as much potential to develop and the water typically displays greater maturity (i.e., higher degree of saturation). Karstic development in the valleys is thus more juvenile than on the ridges. A number of point collapses of overlying sediments into discrete conduits are evident and are likely to have occurred during very recent geological times. The surface appearance of these is a small hole in the ground. This may be a function of changing water tables, interface drainage between the limestone and colluvium in the bottoms of the valley, or may also be a function of changes in land-use practices.

The individual sinkholes identified in Figure 6-2 may be connected via a network of conduits that form a subterranean dendritic network, or more likely in juvenile karst are single input-output conduit system.

The connection to the output point may be at surface springs where abrupt changes in ground elevation occur or subterranean at the margin of the limestone.

Borehole SKM103 was drilled in a sinkhole (Figure 6-1), and reveals cavities in the top 25 m, probably representing the sinkhole conduit. However, boreholes SKM106 and SKM104 drilled along ridgelines in areas displaying numerous sinkholes, show no evidence of cavities (conduits). This indicates the discrete nature of the sinkholes and the spatial variability in rock hydraulic characteristics.

6.6 Aquifer Hydraulic Testing

Hydraulic testing of the rock was undertaken to gain an understanding of the water transmission potential of the rock. The objective of the testing program was to quantify the permeability of both the unsaturated and saturated zones of the rock.

Two approaches have been employed to characterise the aquifer hydraulic properties at this stage. Preliminary testing indicated the permeability below the water was too low to permit long duration test pumping. The techniques implemented include:

- ***Packer Tests*** – provides indicative hydraulic conductivity values for the area immediate adjacent to a pneumatic packer assembly that inflates and isolates a rock zone of interest. The packer assembly can be used to assess rock hydraulic properties above and below the water table.

- *Slug Testing* – provides indicative hydraulic properties for the aquifer area immediately adjacent to the saturated extent of the test bore (i.e., test the saturated rock zone or aquifer).

Appendix B provides commentary on the aquifer test methodologies and detailed analysis of each test. The following sections describe in summary the testing results.

6.6.1 Packer Tests

Between 27 February and 4 March 2002 a series of packer tests were conducted to determine the permeability of the limestone above and below the water table during the drilling of SKM104 and SKM105. Table 6-4 summarises the results of the packer tests.

Table 6-4. Summary of Hydraulic Testing Results from Packer Tests.

Bore	Formation	Test Interval m	Average K m/s	Remarks
SKM104	Limestone	5.5 – 7.0	2.94E-06	Above water table
SKM104	Limestone	14.5 – 16.0	8.81E-07	Above water table
SKM104	Limestone	29.8 – 32.9	3.28E-07	Above water table
SKM104	Limestone	41.5 – 44.5	9.95E-08	Above water table
SKM104	Limestone	53.5 – 56.5	1.24E-08	Below water table
SKM104	Limestone	65.5 – 68.5	2.70E-07	Below water table
SKM104	Chatton	71.5 – 74.5	6.30E-08	Below water table
SKM105	Limestone	11.5 – 14.5	5.41E-08	Above water table

6.6.2 Slug Tests

Between 11 and 14 March 2002 a number of slug tests were performed on the bores to determine the hydraulic conductivity of the Forest Hill and the Chatton Formation. Analysis of the slug test data was conducted using AquiferTest, a commercially available software package for graphical analysis and reporting of pump test and slug test data. Table 6-5 summarises the results of the slug tests.

Table 6-5. Summary of Hydraulic Testing Results from Slug Tests.

Bore	Test	Test Date	Analysis Method	Formation	Hydraulic Conductivity (m/s)
SKM101A	1	12/03/2002	Bouwer-Rice	Forest Hill	1.61E-07
SKM101A	1	12/03/2002	Hvorslev	Forest Hill	2.06E-07
SKM101A	2	12/03/2002	Bouwer-Rice	Forest Hill	2.08E-07
SKM101A	2	12/03/2002	Hvorslev	Forest Hill	2.66E-07
SKM101B	1	5/03/2002	Bouwer-Rice	Forest Hill	4.55E-08
SKM101B	1	5/03/2002	Hvorslev	Forest Hill	4.70E-08
SKM101B	2	7/03/2002	Bouwer-Rice	Forest Hill	3.89E-08
SKM101B	2	7/03/2002	Hvorslev	Forest Hill	4.02E-08
SKM101B	3	11/03/2002	Bouwer-Rice	Forest Hill	4.88E-08
SKM101B	3	11/03/2002	Hvorslev	Forest Hill	5.04E-08
SKM101C	1	11/03/2002	Bouwer-Rice	Chatton	1.30E-07
SKM101C	1	11/03/2002	Hvorslev	Chatton	1.16E-07
SKM102A	1	11/03/2002	Bouwer-Rice	Forest Hill	5.90E-08
SKM102A	1	11/03/2002	Hvorslev	Forest Hill	6.77E-08
SKM102A	2	11/03/2002	Bouwer-Rice	Forest Hill	5.48E-08
SKM102A	2	11/03/2002	Hvorslev	Forest Hill	6.29E-08
SKM103A	1	12/03/2002	Bouwer-Rice	Forest Hill	6.20E-08
SKM103A	1	12/03/2002	Hvorslev	Forest Hill	6.61E-08
SKM103A	2	13/03/2002	Bouwer-Rice	Forest Hill	6.38E-08
SKM103A	2	13/03/2002	Hvorslev	Forest Hill	6.80E-08

Bore	Test	Test Date	Analysis Method	Formation	Hydraulic Conductivity
SKM104	1	12/03/2002	Bouwer-Rice	Forest Hill	1.25E-08
SKM104	1	12/03/2002	Hvorslev	Forest Hill	1.50E-08
SKM104	2	13/03/2002	Bouwer-Rice	Forest Hill	2.20E-08
SKM104	2	13/03/2002	Hvorslev	Forest Hill	2.64E-08
SKM105B	1	12/03/2002	Bouwer-Rice	Forest Hill	5.74E-08
SKM105B	1	12/03/2002	Hvorslev	Forest Hill	5.58E-08
SKM105B	2	13/03/2002	Bouwer-Rice	Forest Hill	6.11E-08
SKM105B	2	13/03/2002	Hvorslev	Forest Hill	5.94E-08
SKM107A	1	12/03/2002	Bouwer-Rice	Forest Hill	1.20E-07
SKM107A	1	12/03/2002	Hvorslev	Forest Hill	1.20E-07
SKM107A	2	13/03/2002	Bouwer-Rice	Forest Hill	1.12E-07
SKM107A	2	13/03/2002	Hvorslev	Forest Hill	1.13E-07
SKM107B	1	12/03/2002	Bouwer-Rice	Chatton	1.23E-07
SKM107B	1	12/03/2002	Hvorslev	Chatton	1.07E-07
SKM107B	2	13/03/2002	Bouwer-Rice	Chatton	8.12E-08
SKM107B	2	13/03/2002	Hvorslev	Chatton	7.10E-08
SKM108	1	12/03/2002	Bouwer-Rice	Forest Hill	4.74E-07
SKM108	1	12/03/2002	Hvorslev	Forest Hill	5.11E-07
SKM108	2	12/03/2002	Bouwer-Rice	Forest Hill	4.76E-07
SKM108	2	12/03/2002	Hvorslev	Forest Hill	5.13E-07

6.6.3 Summary of Hydraulic Characteristics

Table 6-4 indicates hydraulic conductivity values for the limestone from packer tests range from 1.24×10^{-8} to 2.94×10^{-6} m/s with an average of 6.55×10^{-7} m/s. The only test conducted in the siltstone demonstrates a lower hydraulic conductivity than the average of 6.30×10^{-8} m/s. Hydraulic conductivity values are generally higher above the water table than below, with averages of 8.61×10^{-7} m/s and 1.15×10^{-7} m/s, respectively.

Table 6-5 indicates hydraulic conductivity values for the limestone from the slug tests range from 1.25×10^{-8} to 5.13×10^{-7} m/s with an average of 1.28×10^{-7} m/s. These values are within the normal range of typical publicised values for non-karst limestone, which range from 7×10^{-10} to 6×10^{-6} m/s and lower than karst limestone with a typical range of 1×10^{-6} to 2×10^{-2} (Figure 6-3) (Freeze and Cherry, 1979; Weight and Sonderegger, 2000).

Table 6-5 indicates hydraulic conductivity values for the Chatton Formation range from 7.10×10^{-8} to 1.3×10^{-7} m/s with an average of 1.05×10^{-7} m/s. The values are comparable to published values for siltstones, which range from 1×10^{-11} to 1.4×10^{-8} m/s (Figure 6-3) (Weight and Sonderegger, 2000).

An interesting point to note from analysis of the Figure 6-3, which compares the field testing results from this study with typical publicised data, is that the hydraulic properties of the limestone at this site are more indicative of non-karstic limestone that well developed karst.

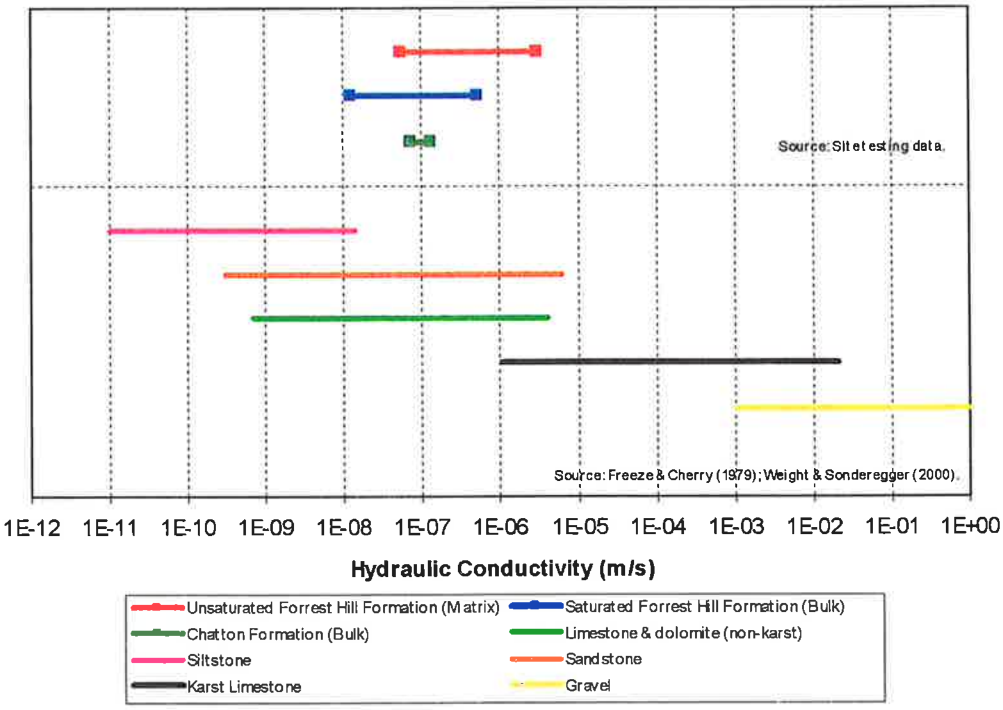


Figure 6-3. Comparison of hydraulic conductivity results to publicised data.

6.7 Groundwater Level Monitoring

Groundwater monitoring was initiated during the drilling investigation phase, following completion of each piezometer. Groundwater levels were recorded manually using a 100-m electronic water level meter. Automated groundwater pressure monitoring probes were installed in boreholes SKM101A and SKM102A on 26 March and 21 May 2002, respectively. Data will be collected continuously from the two probes and manually on a semi-regular basis (fortnightly) and over the following twelve months.

6.7.1 Bore Hydrographs

Hydrographs showing groundwater monitoring reduced levels (RL) to metres above mean sea level (mAMSL) from 22 February to 29 May 2002 are shown in Appendix C (Figures D1-D8).

At the time of this report (May 2002), detailed analysis of the hydrograph data is limited, due to the short timeframe of monitoring, low number of observations and the fact that some of the early time data reflects recovery following drilling. However, a number of temporal trends are evident, as summarised below for each location:

- *SKM101* – located within the quarry floor. Overall groundwater levels are increasing due to transition into winter and wetter conditions. During the initial period of monitoring from 22 March to 14 February 2002, groundwater levels are consistently higher with increasing depth of the piezometer screen, indicating upward groundwater flow at this location. Since this time, the groundwater levels in the deep and intermediate piezometers reverse, with the intermediate piezometer having higher head than the deeper. However, upward pressure is still maintained overall because the shallow piezometer has lower head than both of the deeper piezometers.

- *SKM102* – The deep piezometer displays higher head than the shallow piezometer indicating groundwater flow is downward at this location.
- *SKM103* – Shows a similar pattern to SKM102, indicating groundwater flow is downward at this location.
- *SKM104* –Shows a steady decline initially and recovering during May.
- *SKM105* – Shows a similar pattern to SKM102 and SKM103, indicating groundwater flow is downward at this location.
- *SKM106* – Shows a significant increase in groundwater level. The initial increase is probably recovery following drilling, while the later time increase is due to the onset of wet weather during May.
- *SKM107* – Shows a similar pattern to SKM101, indicating groundwater flow is upward at this location.
- *SKM108* – Shows a similar pattern to SKM106, with groundwater levels initially recovering following drilling, while the later time increase in groundwater levels is due to the onset of wet weather during May.

6.7.2 Vertical Pressure Gradients

Vertical pressure gradients were calculated for boreholes with nested piezometers installed (see Figures D1, D2, D3, D5, D7) as summarised in Table 6-6.

The methodology implemented for the vertical pressure gradient calculations followed that of Freeze and Cheery (1979). The head difference (Δh) between the shallowest piezometer at each location and the deeper piezometer was calculated (independently for each additional deep piezometer). The head difference was then normalised to a vertical pressure gradient; calculated from Δh over the elevation difference between the screen midpoints of the two piezometers. Positive values indicate upward pressure gradients, while negative values indicate downward pressure gradients.

Results presented in Table 6-6 indicate that as altitude increases the pressure gradient within the aquifer changes from positive to negative, however the correlation (R^2 0.47) is moderate but not conclusive[10].

There are a number of contributing factors to the only moderate correlation, including:

- small number of observation points;
- distance between the piezometer screens are variable; and
- aquifer hydraulic properties between the piezometer screens are variable.

---

[10] An R^2 of 1 is considered highly correlative, whilst an R^2 of 0 represents no correlation.

■ Table 6-6. Summary of Vertical Pressure Gradients.

Borehole	Location Elevation (mAMSL)	Shallow Piezo. Base (mBGL)	Deep Piezo. Base (mBGL)	Δh (m)	Press. Grad. (norm. Δh) (%)
SKM101b	80.2	8.76 (6 m)	27.3 (6 m)	0.01	0.02
SKM101c	80.2	8.76 (6 m)	37.5 (3 m)	0.43	0.01
SKM102	97.8	20.0 (3 m)	26.5 (6 m)	-0.44	-0.06
SKM103	129.4	50.0 (6 m)	56.4 (3 m)	-11.60	-1.60
SKM105	123.6	44.5 (3 m)	58.9 (3 m)	-1.08	-0.07
SKM107	96.3	52.3 (6 m)	59.5 (3 m)	0.88	0.12

Notes:

1. Calculations for SKM101 are based on the difference between the shallowest piezometer (SKM101a) and the piezometer nominated in the table.
2. Altitude refers to the ground elevation at each piezometer location.
3. Values in brackets refer to screen length.

Th data presented in Table 6-6 supports the standard conceptual model, which depicts downward pressure gradients in higher altitude recharge areas and upward pressure gradients in the lower discharge areas.

The cause of the extremely high negative pressure gradient at SKM103 is not clear. However, information from the borelogs shows that this piezometer is located on a sinkhole, which indicates that groundwater pressures in the shallowest piezometer may be higher due to the influence of preferential flows from within the overlying solution cavities associated with the sinkhole.

6.7.3 Piezometric Surface

The piezometric surface geometry is governed by the hydraulic and recharge characteristics of the aquifer and overlying materials, which are in-turn dependent on the geological and climate characteristics of the area. Analysis of piezometric surface geometry maps can thus provide important insights into these land characteristics, in addition to knowledge of groundwater flow direction and potential groundwater flow velocity.

The features of primary interest from the piezometric surface map include:

- elevation of the groundwater table and
- distribution of groundwater gradients (i.e., spacing of equipotential[11] lines).

The piezometric surface geometry interpolated from observed groundwater levels using Kriging geostatistical techniques, is shown in Figure 6-4.

This demonstrates that the groundwater table is encountered between 65-130 mAMSL across the site. Overall the piezometric surface demonstrates similar (although more smoothed) contour orientation and gradient trend to the topographic surface shown in Figure 2-1, with gradient flatter in the lower parts of the catchment and on the watershed divides (main ridges) and steeper in the mid to upper parts of the catchment.

Figure 6-4 also demonstrates a relatively steep hydraulic gradient averaging 5-10 %, in comparison to the ground surface, which is typically 10-33 % in this area. The

[11] Contour lines of equal groundwater head or pressure.

significantly flatter groundwater table compared to the topographic surface indicates that land geomorphology is controlling the maximum elevation of the groundwater table through valley drainage and/or subterranean channels of the shallow karst system, which effectively remove water from the deeper groundwater system. For example, the deeply incised gullies on the northeastern and northwestern sides of the quarry are likely to play an important role in controlling the height of the groundwater surface within the catchment.

The piezometric surface plot of Figure 6-4 also shows groundwater vectors that represent flow direction and potential flow magnitude. The groundwater vectors indicate that:

- local groundwater flow direction is predominantly to the southwest on the southern (quarry) side of the catchment divide and to the north and east on the other side of the divide; and
- the greatest flow velocity potential is where the groundwater contours are steepest, which generally coincides with the sides of incised valleys or ridges.

- **Figure 6-4. Interpolated piezometric surface.**

6.7.4 Depth To Groundwater

The depth to groundwater reflects the distance from ground surface to the piezometric surface. Plots of depth to groundwater plots are useful for:

- checking that piezometric surface plots are realistic (i.e., that groundwater levels are not above the ground surface in areas where they should not be),
- indicating areas of shallow or deep groundwater, and
- indicating areas where groundwater may pose a problem to land development (i.e., quarry or landfill activities).

Figure 6-5 provides a depth to groundwater plot for the study area and indicates that the groundwater is at or near the surface in the quarry floor, and elsewhere is generally shallowest in the valleys and deepest underneath the ridges in the upper parts of the catchment. The plot conforms to knowledge of the site, with no obvious discrepancies (i.e., groundwater levels above the ground in erroneous places).

Where the depth to groundwater is small and the ground surface is steep, it is likely that springs and seepage will be found at the surface. There is a small spring located in this valley immediately upgradient of SKM102, although anecdotal reports from the local farmer indicate it has not been active during the last year. However, recent heavy rain during May 2002 reactivated this spring with reported discharge volumes calculated by the quarry manager indicate flows in the order of 20 L/s.

- **Figure 6-5. Depth to groundwater at the site.**

6.7.5 Groundwater Flow Rates

Water transmission through the saturated part of the aquifer, which at this site is primarily governed by flow through the matrix or porous media, conforms to Darcy's Law. Darcy's Law describes the velocity of flow (v) as given in Equation 1.

Equation 1. $$v = -K\frac{dh}{dl}$$

Where K is hydraulic conductivity and dh and dl are change in groundwater pressure head and length over which this change occurs, respectively. dh/dl is the hydraulic gradient.

The porosity or pore space within the aquifer is the main mechanism through which water is transmitted. However, total porosity is not directly correlative with the water transmission potential, as not all pore spaces are connected meaning that water can fill these pore spaces but flow through them is restricted. The effective porosity (n) of the aquifer is the proportion of total porosity that permits water transmission. Thus, the true flow velocity within the aquifer, often referred to as the average linear velocity (lv), needs to account for effective porosity (Equation 2).

Equation 2. $$lv = \frac{v}{n}$$

Average linear groundwater flow velocities for the limestone have been calculated from:

- the average hydraulic gradient (0.099) across the site;
- the average bulk hydraulic conductivity (1.291×10^{-7} m/s) from the slug and packer tests results conducted below the water table within the limestone tests from Section 6.5; and
- the median effective porosity of 1.6% reported from a number of limestone studies by Bonacci (1987) as cited in Worthington *et. al.* (2000).

Table 6-7 indicates an average linear velocity of 7.54×10^{-6} m/s, which means that it would take approximately 4 years for a water particle to travel 100 m downgradient within the limestone aquifer.

■ Table 6-7. Calculation of groundwater flow rates.

Location	Hydraulic Gradient m/m	Hydraulic Conductivity m/s	Velocity m/s	Average Linear Velocity m/s
Whole site	0.099	1.291×10^{-7}	1.282×10^{-8}	8.01×10^{-7}

6.8 Groundwater Quality

Groundwater quality testing has been conducted on four bores to-date (May 2002) to characterise the groundwater body and to permit future comparisons if the landfill site becomes operational. Table 6-8 summarises the suites of parameter analyses that have been performed.

Table 6-8. Summary of Water Quality Analysis.

Suite	Parameters
Field Parameters	pH; Temperature; Electrical conductivity, Total Dissolved Solids
Nutrients	Total Ammoniacal-M, Total Kjeldahl Nitrogen (TKN), Total Organic Nitrogen, Nitrate-N, Nitrite-N, Dissolve Reactive Phosphorus
Heavy Metals	Boron, Iron, Manganese, Aluminium, Arsenic, Cadmium, Cobalt, Chromium, Copper, Nickel, Zinc
Major Anions & Cations	Alkalinity, Bicarbonate, Carbonate, Dissolved Calcium, Dissolve Magnesium, Total Hardness, Dissolved Sodium, Dissolved Potassium, Chloride, Sulphate.

Table 6-9 presents the data obtained to-date with values exceeding either the Australian and New Zealand Environment and Conservation Council (ANZEEC) 2000 guidelines for the protection of 95% of aquatic organisms or NZ Drinking Water Standards (NZDWS) 2000 guidelines highlighted. The following summarises these results:

- pH is typically around 7.4, with limited variation between the bores.
- The high bicarbonate and total hardness levels recorded in all bores is typical of limestone aquifers, and is of aesthetic significance only.
- Chemical concentrations of all parameters were below the ANZECC guidelines and the NZDWS, with the exception of:
  - dissolved lead in SKM104 (0.0282 mg/l) is less than the ANZECC guideline (0.0633 mg/l), but greater than NZDWS (0.01 mg/l); and
  - dissolved copper concentration in SKM104 (0.0101 mg/l) is marginally greater than the ANZECC guideline (0.0099 mg/l), but less that the NZDWS (2.0 mg/l).
  - Nitrate nitrogen is higher than the ANZECC guidelines (0.16 mg/l) in all groundwater samples obtained, but lower than NZDWS. Nitrate N is likely derived from stock effluent and fertilisers use.

■ **Table 6-9. Water quality results for samples obtained on 14th March, 2002.**

Parameter	SKM101A	SKM102A	SKM104	SKM108	ANZECC[1] (2000) Guideline	NZ Drinking Water Standards[5]
Water Level (mAMSL)	79.27	90.38	137.03	65.33	-	-
Temp (field)	12.1	10.8	11	12	-	-
pH (lab, pH units)	7.4	7.6	7.2	7.4	7.2-7.8	7.0-8.5[A]
Electrical Conductivity (mS/m, lab)	52.8	64.9	59.4	61.2	-	-
Total Dissolved Solids (ppm, field)	251	300	271	288	-	1000[A]
Alkalinity (as $CaCO_3$)	689	374	319	320	-	-
Aluminium (dissolved)	0.003	<0.003	<0.003	<0.003	0.055	0.15[A]
Arsenic (dissolved)	<0.001	<0.001	<0.001	0.006	0.024	0.01
Bicarbonate (at 25°C)	838	454	388	389	-	
Boron (dissolved)	0.025	0.043	0.01	0.03	0.37	1.4
Cadmium (dissolved)	<0.00005	<0.00005	<0.00005	<0.00005	0.0016[2]	0.003
Calcium (dissolved)	97.3	70.4	129	99.5	-	
Carbonate (at 25°C)	<1	<1	<1	<1	-	
Chloride (dissolved)	35.4	35.4	34.8	45.1	-	250[A]
Chromium (dissolved)	<0.0005	0.0007	<0.0005	<0.0005	0.0016[2]	0.05
Cobalt (dissolved)	<0.0002	<0.0002	<0.0002	0.0006	0.0014[4]	
Copper (dissolved)	0.002	0.0011	0.0101	0.0039	0.0099[2]	2.0
Iron (dissolved)	<0.02	<0.02	<0.02	<0.02	0.3[4]	0.2[A]
Lead (dissolved)	0.0002	<0.0001	0.0282	0.0012	0.0633[2]	0.01
Magnesium (dissolved)	5.5	12.4	3.13	15.9	-	
Manganese (dissolved)	0.0035	<0.0005	0.0041	0.0317	1.9	0.5
Nickel (dissolved)	0.0007	0.0006	0.0025	0.0029	0.078[2]	0.02
Nitrate N	1.71	0.27	1.2	0.41	0.16	11.3
Nitrite N	<0.05	<0.05	<0.05	0.05	-	0.91
Potassium (dissolved)	1.18	1.89	0.85	1.53	-	
Sodium (dissolved)	23.5	76.6	18.3	34.9	-	200[A]
Sulphate (dissolved)	16.9	34.3	4.9	18.9	-	250[A]
Total Ammoniacal-N	0.03	0.01	<0.01	0.09	2.33[3]	1.47
Total Hardness (as $CaCO_3$)	266	227	336	314	-	200[A]
Total Kjeldahl Nitrogen	0.6	1.1	0.4	0.4	-	
Total Organic Nitrogen	0.6	1	0.4	0.3	-	
Zinc (dissolved)	0.008	<0.001	0.026	0.017	0.057[2]	3.0

Notes:

All units are mg/L unless otherwise stated.

[1] ANZECC (2000) freshwater trigger values that suggest 95% of all species will be unaffected at these levels.

[2] Based on a hardness of 300 mg/L.

[3] Based on a pH of 6.8.

[4] Low reliability trigger value.

[5] Standards given are maximum acceptable values of health significance, or where these do not exist, guidelines of aesthetic significance (marked [A]).

Figure 6-6 shows a tri-linear chemical characterisation diagram (Piper diagram) for groundwater, which displays the chemical signature of the major groundwater constituents converted into per milli-equivalents (concentration/molecular weight). This plot is useful for comparing water characteristics from different areas and assessing the influence of geological materials on water chemistry.

For comparative purposes the average water quality from the downgradient stream (Tuthills Creek) is also included.

■ **Figure 6-6. Tri-linear chemical characterisation diagram (Piper Plot).**

Figure 6-6 clearly indicates the bores are proportionally high in bicarbonate and calcium as expected from a karst aquifer. Figure 6-7 is a water-type diagram for the purpose of hydrochemical classification and identifying hydrochemical processes which clearly shows a recharging water $Ca(HCO3)_2$-type.

- **Figure 6-7. Water type diagram.**

Over the coming months a groundwater monitoring program and trigger level compliance regime will be developed.

7. Conceptual Hydrogeological Model

A conceptual model of the geology and hydrologic functionality of a site develops during the analysis of field investigation data from drilling and hydraulic testing. Conceptual hydrogeological models aid in the understanding of the hydrogeological regime of the site and are presented as written summaries and/or schematic drawings. The conceptual model reflects is a necessary simplification of the system, which rationalises the spatially variable physical characteristics of the sites geological and hydrological regimes.

The conceptual hydrogeological model of this site has been developed in two phases of model development, including:

a) geological structural model, and
b) hydrological model.

7.1 Geological Structure Model

To demonstrate the geological structure of the site, a three-dimensional geological model of the study area was constructed using topographic and borehole data. This data was spatially interpolated using kriging geostatistical techniques to generate two-dimensional surfaces, which combined form the basis of the three-dimensional solid model. The cross sections along which the model was developed are displayed on Figure 6-2.

Figure 7-1 indicates that the geological model comprises three units incorporating overburden material (red), limestone (yellow) and siltstone (green). It can be seen that the contact between the Forest Hill and Chatton Formation dips in a southwest direction with a gradient of approximately 4%. Colluvium overlies the limestone in the valleys or foot of the hills, pinching out further up slope. The position of the existing quarry is indicated by the basin shaped depression on the lowermost NW-SE orientated section.

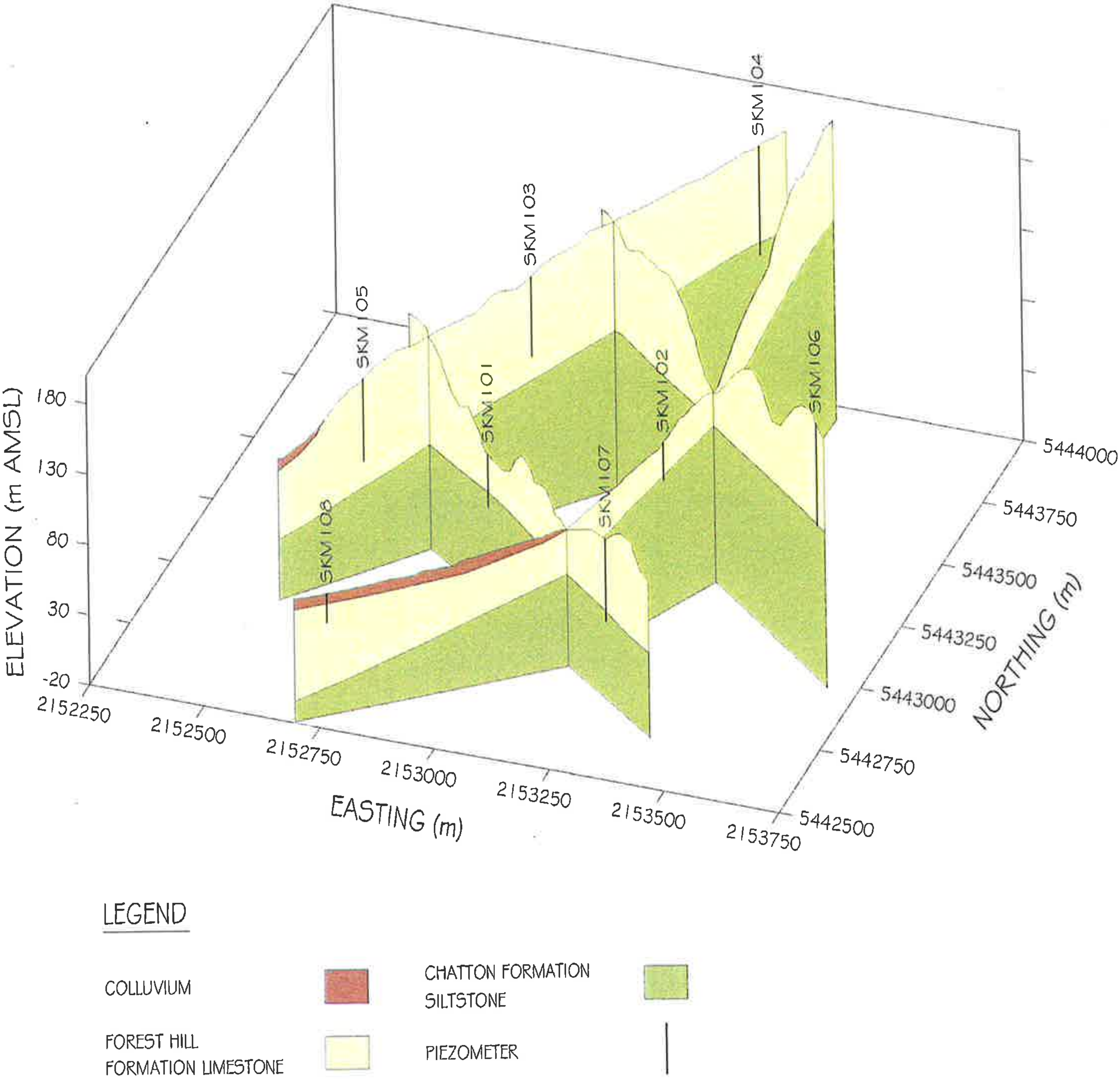


Figure 7-1. Geological model of the site

7.2 Hydrological Model

The subterranean hydrology of the conceptual model has been simplified into two broad zones based on knowledge of karst hydrogeology (Chapter 5) and the hydraulic characteristics of the formation (Chapter 6). These zones are described as follows:

- ***Karst (vadose) zone*** – water transmission zones comprising sinkholes, solution cavities and fractures within the upper 20 m of the Forest Hill Formation limestone above the local groundwater table.
- ***Non-karst (saturated/phreatic) zone*** – aquifer zones beneath the local groundwater table consisting of massive low permeability limestone of the Forest Hill Formation and the underlying siltstone of the Chatton Formation.

The hydrology of the conceptual model was developed through an understanding of the model inputs, model throughflow and model outputs for the various hydrological zones of the underlying rock formations. The three processes are examined independently for each zone within system in the following sections.

7.2.1 Model Inputs

Recharge to the karst components (shallow) of the Forest Hill Formation occurs via[12]:

a) autogenic recharge from diffuse percolation through the overlying soils to the limestone; and
b) autogenic recharge via discrete points in sinkholes developed in the limestone.

Recharge to the deeper non-karst components of the Forest Hill Formation occurs via:

a) autogenic recharge from diffuse percolation through the overlying limestone matrix; and
b) allogenic recharge of mature groundwater from the underlying Chatton Formation in lower parts of the catchment.

Proportionally, the main input to both components of the system is through diffuse recharge, although the large number of nested sinkholes on the ridges suggests 10-15% of the surface area may experience point recharge. The main implications of point recharge are that the majority of recharge waters derived from this source are likely to be removed from the system through the output processes of the karst (discussed in Section 7.2.3), effectively reducing recharge to the deeper non-karst component of the system.

7.2.2 Model Throughflow

Throughflow within the limestone occurs via:

a) matrix flow in the massive beds of the Forest Hill limestone (primary porosity);
b) fracture flow in fractures (secondary porosity); and
c) conduit flow from sinkholes to springs (tertiary porosity).

Throughflow in the karst (vadose) zone occurs via matrix, fracture and conduit flows. The proportion of flow due to each component has not been assessed at this stage,

[12] See Section 5.5 for terminology.

although matrix flow occurs across the entire catchment, while conduit flow is localised to areas where sinkholes are prevalent. However, conduits have the potential to convey significantly greater volumes of water per unit area than the matrix and they may also act as subterranean drains, attracting drainage from the rock matrix within the unsaturated zone. For these reasons, subsurface flow in the vadose (unsaturated) zone is likely to be more rapid than in the phreatic zone. This has been demonstrated by the vertical hydraulic gradient at borehole SKM103, which is significantly stronger than areas less influenced by sinkhole development.

The non-karst or phreatic zone hydraulic conductivity is dominated by primary porosity and is similar to other non-karst limestone, but significantly lower than karst limestone (Figure 6-3). The hydraulic conductivity due to secondary or tertiary porosity is expected to be almost non-existent or a minor proportion of total groundwater flow in this zone given the low density of fractures and conduits.

7.2.3 Model Outputs

Outputs from the karst limestone are via:

- matrix, fracture and conduit flow to the alluvial gravels on the downgradient plains; and
- matrix percolation to the deeper non-karst limestone.

Conduit flow from the karst zone may appear at the surface as springs, whilst fracture and matrix flow may appear as diffuse seepages. This water may be subsequently returned to subterranean flow paths through shafts in the colluvium along the valleys.

Outputs from the non-karst limestone are via predominantly matrix seepage to the downgradient plains, although spring seepage may also occur in drains that intersect the water table in low lying parts of the catchment.

Further work is planned over the next twelve months to:

- confirm the depth extent of sinkholes;
- investigate the subterranean flow characteristics in the karst within the upper parts of the catchment; and
- confirm the hydrologic functionality with respect to discharge locations.

7.3 Summary

The limestone of the Forest Hill Formation at this site is considered to have distinctly variable hydraulic characteristics with depth. Above the groundwater table and within approximately 20 m of the ground surface, there is evidence of high secondary permeability through solution cavities and sinkholes. Below the water table, permeability is low and dominated by the matrix properties of the rock mass. The hydraulic characteristics of the underlying siltstone of the Chatton Siltstone Formation are considered to be similar to that of the overlying non-karst (deep) limestone.

Water may transit the system entirely within the karst zone, or may enter the deeper non-karst zone before exiting.

Larger older sinkholes are present on the recharge area (ridges), with numerous smaller shafts found in lower areas (valleys) (Figure 6-2).

The presence of sinkholes indicates a connection between the recharge area and local karst springs exists. The exact nature of that connection is unknown at this stage. However, based on the lack of solution cavities at depth within the limestone and the position of karst springs at mid-level within the catchment, it is thought that the water from sinkholes travels laterally, discharging as karst springs on the valley sides and base at mid-level within the catchment (Figure 7-2). This water effectively becomes part of the surface water system or a perched interface drainage system (above the deeper groundwater table). Further investigations are proposed over the coming twelve months to ascertain the flow pathways from the recharge area to the karst springs.

Water flow observed in testpits excavated into the valley floor to the east of the quarry indicates the possibility of high permeability conduits along the interface between the colluvium and underlying limestone. This interface drainage feature is possibly responsible for the recent development (in geological terms) of vertical shafts extending to the surface (Figure 7-1) due to the dissolution and collapse of limestone at the colluvium contact.

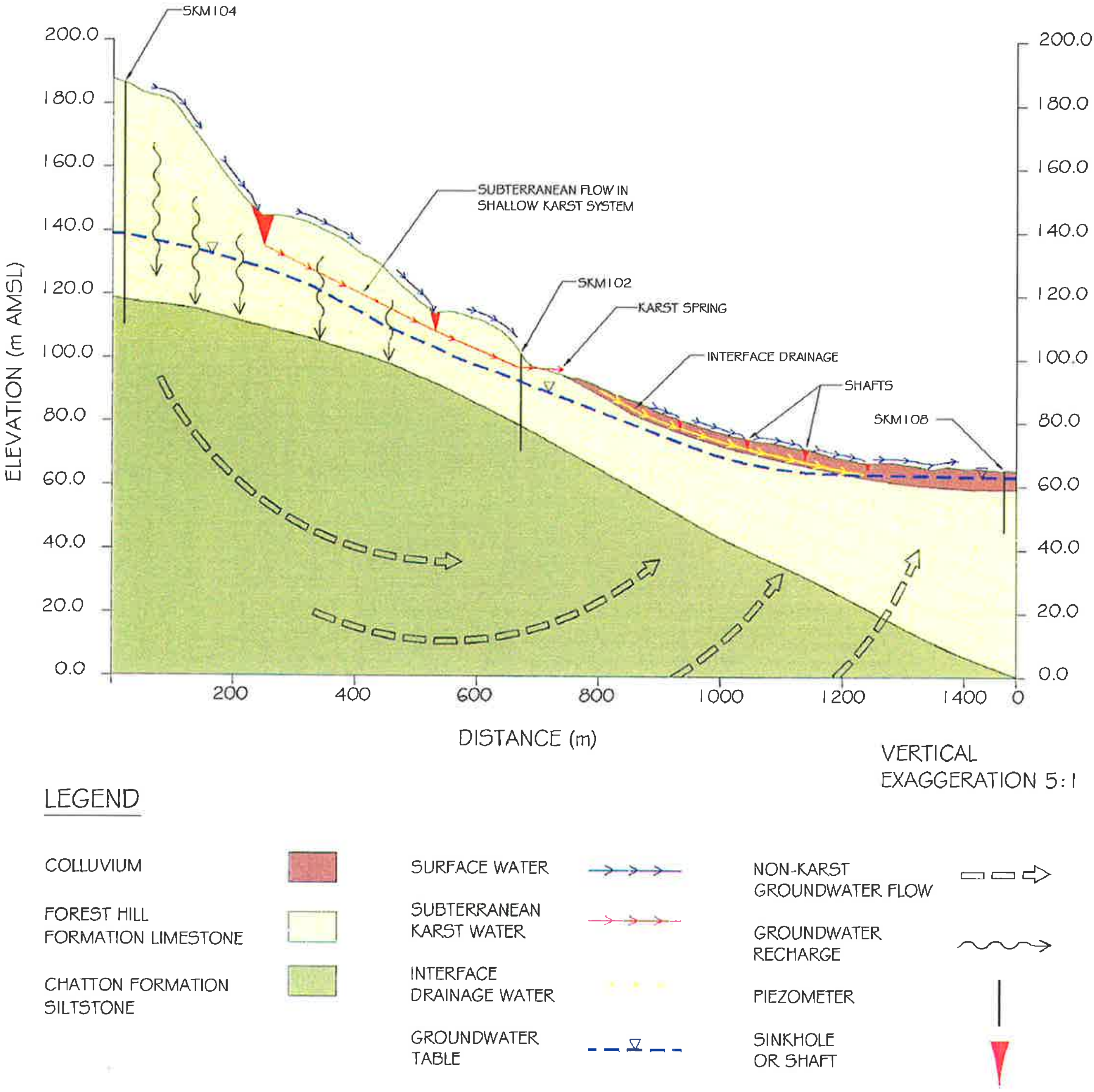


Figure 7-2. Hydrogeological conceptual model (section).

8. Groundwater Numerical Modelling

8.1 Introduction

The application of computer based numerical modelling to problem solving in groundwater engineering, provides a powerful tool for the rationalisation of spatially and temporally varying field conditions. The groundwater modelling process is a technique for simulating aquifer flow using a system of mathematical equations based on Darcy's law for water flow through porous media. This is achieved through discretisation of the area of interest into a number of blocks or cells, which are independently solved for head using conditions in neighbouring cells.

Groundwater modelling overcomes many of the difficulties and restrictions inherent with analytical methods of groundwater analysis, which assume regular aquifer geometry, homogeneity, uniform recharge and other simplified conditions.

The modelling process requires conceptualisation of the aquifer system in respect of the following:

- aquifer geometry including lateral and depth extent;
- aquifer hydraulic property distributions (e.g., hydraulic conductivity and specific yield for an unconfined aquifer and specific storage for a confined aquifer);
- regional groundwater pressure distributions (e.g., groundwater mass, flow directions and boundary fluxes); and
- groundwater recharge processes.

8.2 Modelling Objectives

The objectives of the groundwater-modelling component of this study were as follows:

- To develop a model that accurately simulates groundwater flow and contaminant transport processes for the deeper non-karst limestone aquifer, where porous media flow governing equations are valid.
- To determine the effect on groundwater flow rates through quarrying and subsequent landfilling.
- To determine the groundwater level impact through quarrying and subsequent landfilling.
- To determine the groundwater seepage rates to the quarry and landfill underdrains.
- To evaluate potential contaminant plume distribution and movement from the landfill under worst case liner failure scenarios.

8.3 Model Descriptions

8.3.1 Flow Model - MODFLOW

Several numerical modelling strategies are available for groundwater flow modelling. In this study, MODFLOW - the modular finite difference groundwater flow model developed by the United States Geological Survey was selected. MODFLOW is the industry standard model for groundwater flow simulation.

MODFLOW simulates three-dimensional flow of constant density groundwater through porous aquifer materials using the finite difference method, which provides an approximate solution to the partial-differential equation describing the three-dimensional flow of groundwater[13].

The finite difference method requires the modelled area to be divided into a grid of rectangular cells defined by numbered columns and rows. The number of cells within the model is determined by the spatial variations occurring in aquifer properties and the anticipated hydraulic gradients developed by imposed stresses (e.g., groundwater dewatering through quarrying). A compromise between accuracy and computing efficiency results in different sized cells. Small cells are used in areas where steep gradients or complex flow patterns are expected, while larger cells are employed in areas where shallow gradients occur or localities distant from the main areas of interest.

A local model was developed using the aquifer geometry and hydraulic properties determined during the field investigation phase of this study.

8.3.2 Solute Transport Model – MT3DMS

Several modelling codes are also available for three-dimensional simulations of solute transport within the aquifer. For the contaminant transport model, the industry standard MT3DMS modelling code was selected, as it is well tested internationally, extremely robust, and utilises the cell to cell flow data output from MODFLOW.

MT3DMS is capable of simulating contaminant transport in groundwater considering the processes of advection, dispersion/diffusion, chemical decay, and mixing using various boundary condition inputs (wells, drains and rivers).

8.4 MODFLOW Configuration

8.4.1 Model Domain

The model developed consists of a single-layer 6,850 m long by 3,500 m wide, comprising 4,218 active cells representing an area of approximately 1940 hectares. Cell dimensions vary from about 10 m in the area of interest (the quarry) to approximately 200 m in the extremities of the model.

Additional details of the model configuration has not been documented to date and will be included over the following weeks.

8.5 Model Simulation Results Summary

Full documentation of the modelling simulations conducted has not been prepared at this stage, however a summary of the results from the simulations conducted are provided within the assessment of groundwater effects in the following chapter.

[13] For a full description of the MODFLOW code refer to M^{c}Donald and Harbaugh (1988).

9. Assessment of Groundwater Effects

There will be two discrete systems or phases of groundwater control related respectively to initially the quarry and then the landfill. This chapter describes the anticipated effects of the quarry and landfill on the groundwater system beneath and downgradient of the landfill.

9.1 Effect of Quarrying

9.1.1 Groundwater Depressurisation

Quarry excavation will progressively impinge upon the groundwater table and when this occurs, groundwater seepage at the quarry face will be enhanced until effective dewatering of the rock face has been achieved and the water table has lowered to the toe elevation of the quarry.

Based on historical observations within the quarry, the low hydraulic conductivity of the rock, small number of conduits in the phreatic zone and the progressive nature of the quarrying operation, groundwater seepage rates will be low and easily manageable. Nevertheless, groundwater seepage rates are anticipated to reach their maximum during the quarrying phase. By the time the quarry floor is ready for use as a landfill, groundwater seepage will have reached an equilibrium and be at a new, lower imposed steady state.

The net effect of the quarry on the groundwater flow regime is a reduced hydraulic gradient, resulting in slightly reduced groundwater flow rates. The groundwater model predicts a reduction in groundwater flow through a 500 m wide transect downgradient of the quarry site from 15.27 m^3/day under the existing conditions (May 2002) to 15.08 m^3/day for quarrying up to chainage 400. These flow rates are equivalent to seepages per linear metre of approximately 3.47×10^{-4} L/s and 3.42×10^{-4} L/s, respectively.

The reduced flow rates are unlikely to result in detectable changes in background groundwater chemistry, because the groundwater residence times will not be affected significantly.

9.1.2 Effect on Existing Springs

Continued lowering of the local water table by quarry excavation may inactivate a number of upper springs and seepages fed primarily by fracture flow in the epikarstic zone.

These springs only become active during wetter conditions, with a higher water table – therefore the effect also occurs naturally. The effect of the landfill is to increase the probability of this phenomenon occurring. Further investigation of the nature of secondary and tertiary karst hydrological development is required to assess the extent of this potential effect.

9.2 Effect of Landfilling

The hydrological effects of placing an impermeable barrier and landfill material in the quarry will be to reduce evaporation of near-surface groundwater; to reduce recharge in the quarry area; and potentially reduce the number of active karst springs.

9.2.1 Landfill Shadow Effect

Construction over the landfill footprint area will reduce rainfall recharge to the groundwater system. The combination of an engineered groundwater under drain system, a low permeability basal liner, a leachate collection system and the permanent landfill cap will reduce the existing rainfall infiltration rates compared to undisturbed areas. This would have the potential to lower groundwater levels to beneath the existing quarry floor.

The effect of reduced recharge is that the groundwater levels in the immediate area of the landfill will be depressurised. The extent of measurable impact (i.e., > 0.05 m) is limited to within approximately 750 m of the site due to the low permeability of the aquifer. There is no significant effect on the position of the groundwater divide that exists along the ridgeline upgradient of the site.

The net effect on the groundwater flow regime is similar to that described in the previous section, with a reduced hydraulic gradient resulting in slightly lower groundwater flow rates. The groundwater model predicts a reduction in groundwater flow through a 500 m wide transect downgradient of the potential landfill from 15.27 m^3/day to 13.41 m^3/day due to the combined effect from loss of recharge and quarry dewatering. This is equivalent to a flow rate per linear metre of approximately 3.04×10^{-4} L/s, which is a 12% reduction in flow.

9.2.2 Effect of Liner Leakage on Groundwater Quality

It is extremely unlikely that any significant leakage through the liner would occur because the proposed leachate collection and composite liner system provide a robust form of security against leakage.

There are two possible outcomes that could eventuate, should the worst case scenario materialise and significant leakage through the liner occurred:

i) under normal conditions the positive upward groundwater pressures from the underlying aquifer would stop downward percolation of leachate to the underlying aquifer, resulting in leachate collection in the groundwater underdrains, and

ii) under prolonged dry conditions when the underlying groundwater pressures are likely to be less than normal, leachate may percolate through the unsaturated zone to the water table. This is considered unlikely because the path of least resistance for water flow beneath the liner system would be along the underdrain collection system, rather than entering the low permeability limestone. In the extreme case that leachate reached the aquifer system, it would become part of the groundwater flow regime, resulting in migration of potential contaminants downgradient. Due to the low aquifer hydraulic conductivity and the natural process of advection, dispersion, sorption, and chemical decay, migration of contaminants is likely to be extremely slow. Preliminary groundwater modelling results indicate that movement of a potential contaminant plume would be extremely slow and would be naturally remediated to near background levels within close proximity to the site[14]. Table 9-1 shows the configuration of the contaminant plume at various stages from a highly conservative model configuration, including a continuous contaminant source and a highly persistent contaminant parameter (chloride).

■ **Table 9-1. Summary of potential contaminant plume dimensions with time.**

Time (years)	Length (m)	Width (m)
10	145	230
25	265	310
50	580	350
75	1,400	400
100	2,300	460

9.2.3 Groundwater Underdrain System

The groundwater underdrains of the landfill will act to relieve pressure from the underside of the landfill. Without the underdrains groundwater would have the potential to recover with the landfill in place, due to the loss of the open evaporative area of the open quarry pit and pond system controlling groundwater levels. The groundwater underdrain system will provide an engineered system to effectively perform the same groundwater control function as that of the quarry. There will be no additional groundwater dewatering effects on groundwater from the landfill underdrain system.

9.3 Effect on Bore Users

The distance to the closest bore is greater than 600 m. Given the low permeability of the limestone and low groundwater seepage rates to the adjacent alluvium, the groundwater quantity and quality effects of quarrying and landfilling is anticipated to be limited to less than 500 m of the site. This will not effect any bore users.

---

[14] The contaminant plume simulated utilised chloride (Cl) as the contaminant. Cl can be considered an environmental tracer because it is a highly conservative element, meaning that it has an extremely long radioactive half-life, and thus degrades slowly. Cl concentrations of 5,000 mg/L were assigned to the landfill as a continuous input (rather than a single event) over the duration of the simulation (100 years). The extent of the contaminant plume was taken as the 100 mg/L concentration isopleth.

10. Conclusions

The main conclusions from the hydrogeological investigation of the site include:

- Positive (upward) groundwater pressures are evident in areas of lower ground elevation such as the existing quarry floor. Positive pressures provide a form of hydrogeological security because any leakage through the liner system is likely to be trapped against the landfill underdrain system and unlikely to migrate downwards through the aquifer.
- The limestone displays distinctly variable permeability with depth below the ground surface. Solution features and fractures become less prevalent with depth and are practically non-existent beneath the groundwater table.
- The lack of conduit features beneath the groundwater table indicates that the deeper limestone is non-karstic and groundwater flow is predominantly governed by porous media characteristics.
- Sinkholes are more prevalent on the ridges than in the valleys; mimicking the depth to groundwater pattern across the site, with groundwater being deeper on the ridges than in the valleys. The predominance of sinkholes on the ridges highlights that turbulent flow above the groundwater table is required for significant sinkhole development.
- The degree of karstification or sinkhole development decreases with depth because the ability of percolating rainwater to dissolve limestone is reduced with distance from the surface. This is due to the water becoming saturated in calcium and bicarbonate (i.e., by-product of the carbonation process), reducing its ability to dissolve limestone.
- Due to the morphological and hydrological features identified at the site, the nature of the karst terrain in terms of degree of karst development is considered juvenile.
- The likelihood of intersecting large solution conduits at the base of the quarry is low.
- The permeability of the rock is reasonably low with a site-wide average hydraulic conductivity value from aquifer testing of approximately 3.30×10^{-7} m/s.
- Due to the low hydraulic conductivity and natural attenuation process, the anticipated maximum extent of a conservative element contaminant plume has been estimated at approximately 2,300 m from site after 100 years of continuous discharge.

11. References

AquaFirma Ltd., 1994. Southland Region Groundwater Resource; Scoping study. Report prepared for Southland Regional Council.

Barry Robertson & Associates, 1992. Oreti – New River Estuary; Review of Existing Water Quality. Report prepared for Southland Regional Council.

Bonacci, O., 1987. Karst hydrology, with special reference to the Dinaric Karst. Springer-Verlag, Heidelberg.

Bruce, J.G., 1984. Soil Resources of Southland Region, New Zealand. New Zealand Soil Survey Report 76, New Zealand Soil Bureau, Lower Hutt.

Freeze, R.A. and Cherry, J., 1979. Groundwater. Prentice Hall, New Jersey.

Goodman, R.E., 1993. Engineering Geology: Rock in Engineering Construction. John Wiley & Sons, Inc.

Isaac, M.J., and Lindqvist, J.K., 1990. Geology and lignite resources of the East Southland Group, New Zealand. New Zealand Geological Survey Bulletin 101. Department of Science and Industrial Research.

Motyka, J., 1998. A conceptual model of hydraulic networks in carbonate rocks, illustrated by examples from Poland. Hydrogeology Journal (1998) 6:469-482.

Mace, R.E., Hovorka, S.D., 2000. Estimating porosity and permeability in a karstic aquifer using core plugs, well tests, and outcrop measurements, in Sasowsky, I. D., and Wicks, C.M (eds) Groundwater Flow and Contaminant Transport in Carbonate Aquifers. A.A. Balkema.

Southland Regional Council, 1998. Groundwater Quality in Southland: A Regional Overview. Southland Regional Council Publication No 96.

Todd, D.K., 1980. Groundwater Hydrology. Second Edition. John Wiley & Sons, Inc, Toronto.

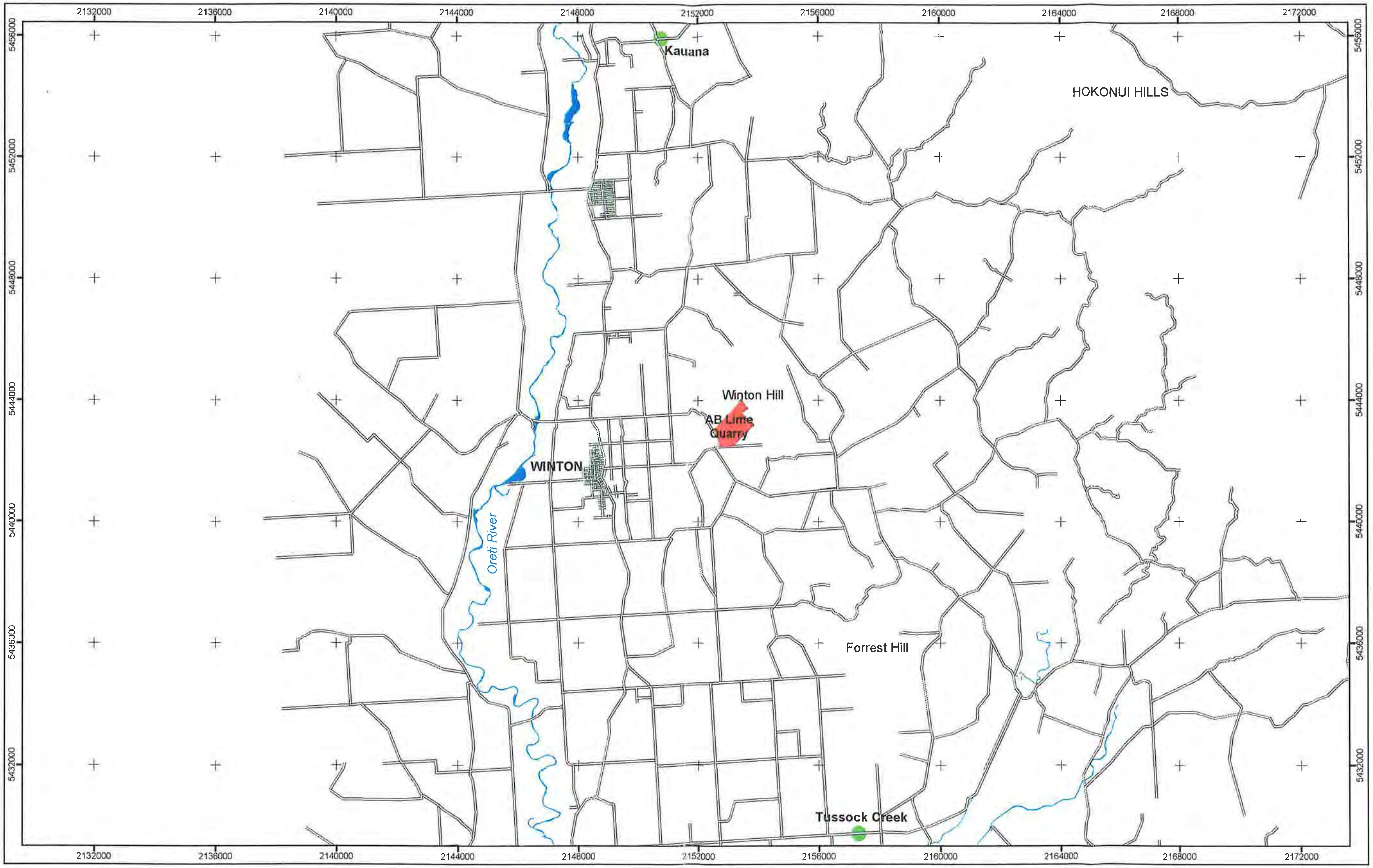
Weight, W.D. and Sonderegger, H.L., 2001. Manual of Applied Field Hydrogeology, Mc Graw-Hill.

Williams, P.W., 1992. Karst Hydrology, in Mosley, M.P. (ed.), Waters of New Zealand. NZ Hydrological Society Publication.

Wood, B.L., 1966. Sheet 24 Invercargill (1st Ed.) Geological Map of New Zealand 1:250,000. Department of Science and Industrial Research, Wellington New Zealand.

Worthington, R.H., and Ford, D.C., 2000. Matrix, fracture and channel components of storage and flow in a Paleozoic limestone aquifer, in Sasowsky, I. D., and Wicks, C.M (eds) Groundwater Flow and Contaminant Transport in Carbonate Aquifers. A.A. Balkema.

Worthington, S.R.H., Ford, D.C. and Beddows, P.A. 2000. Porosity and Permeability Enhancement in Unconfined Carbonate Aquifers as a Result of Solution; in Klimchouk, A.B., Ford, D.C., Palmer, A.N. and Dreybrodt, W. (Eds.) 2000. Speleogenesis - Evolution of Karst Aquifers. National Speleological Society: Huntsville, Alabama.



LEGEND

- AB Lime Quarry
- Roads
- Towns
- Regional Topography
- Rivers

Document Status:
SKM-AUCK I:\vcl\lv00319\Drawings\Gis

	Name	Date
Locality.mxd	PTJ	6/6/02

Data Notes:
Topographic data derived from Land Information New Zealand.
Crown copyright reserved.
Currency of source data:
Topographic data 1999.
Topographic contour interval 20 metres

1:120,000

Meters
0 1,000 2,000 3,000 4,000 5,000

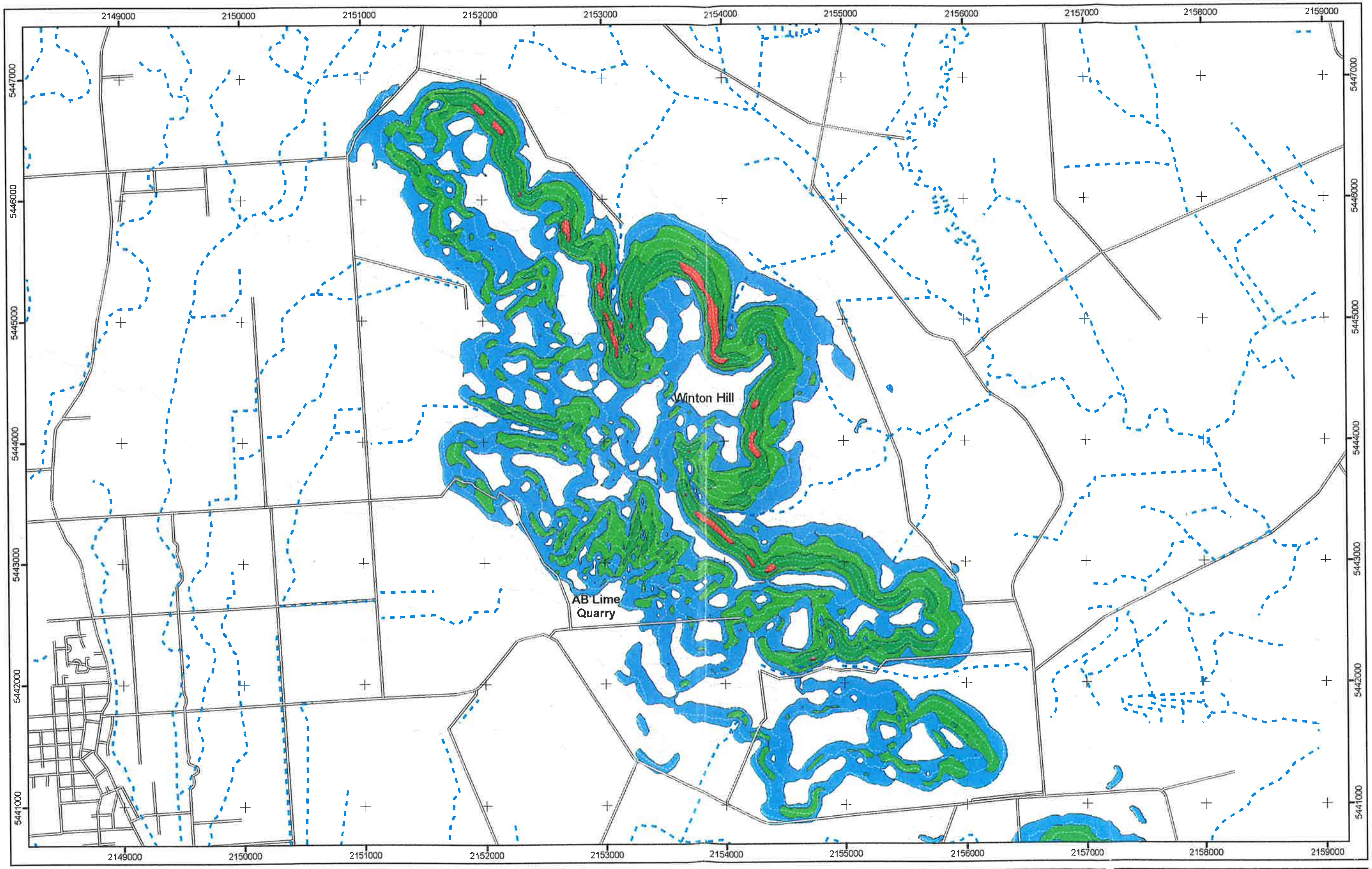
N

AB LIME

SINCLAIR KNIGHT MERZ

LOCALITY AND TOPOGRAPHY PLAN

FIGURE 2-1.



LEGEND

- Streams
- Roads
- Regional Topography

Ground surface gradient

- >50%
- 33-50%
- 20-33%
- 10-20%
- 0

Document Status:

SKM-AUCK I:\vc\iv00319\Drawings\Gis

	Name	Date
Slope.mxd	PTJ	6/6/02

Data Notes:

Topographic data derived from Land Information New Zealand. Crown copyright reserved.
Currency of source data:
Topographic data 1999 .
Topographic contour interval 20m.
Spatial data interpolated using kriging geostatistical technique.

1:30,000

Meters

0 500 1,000 1,500

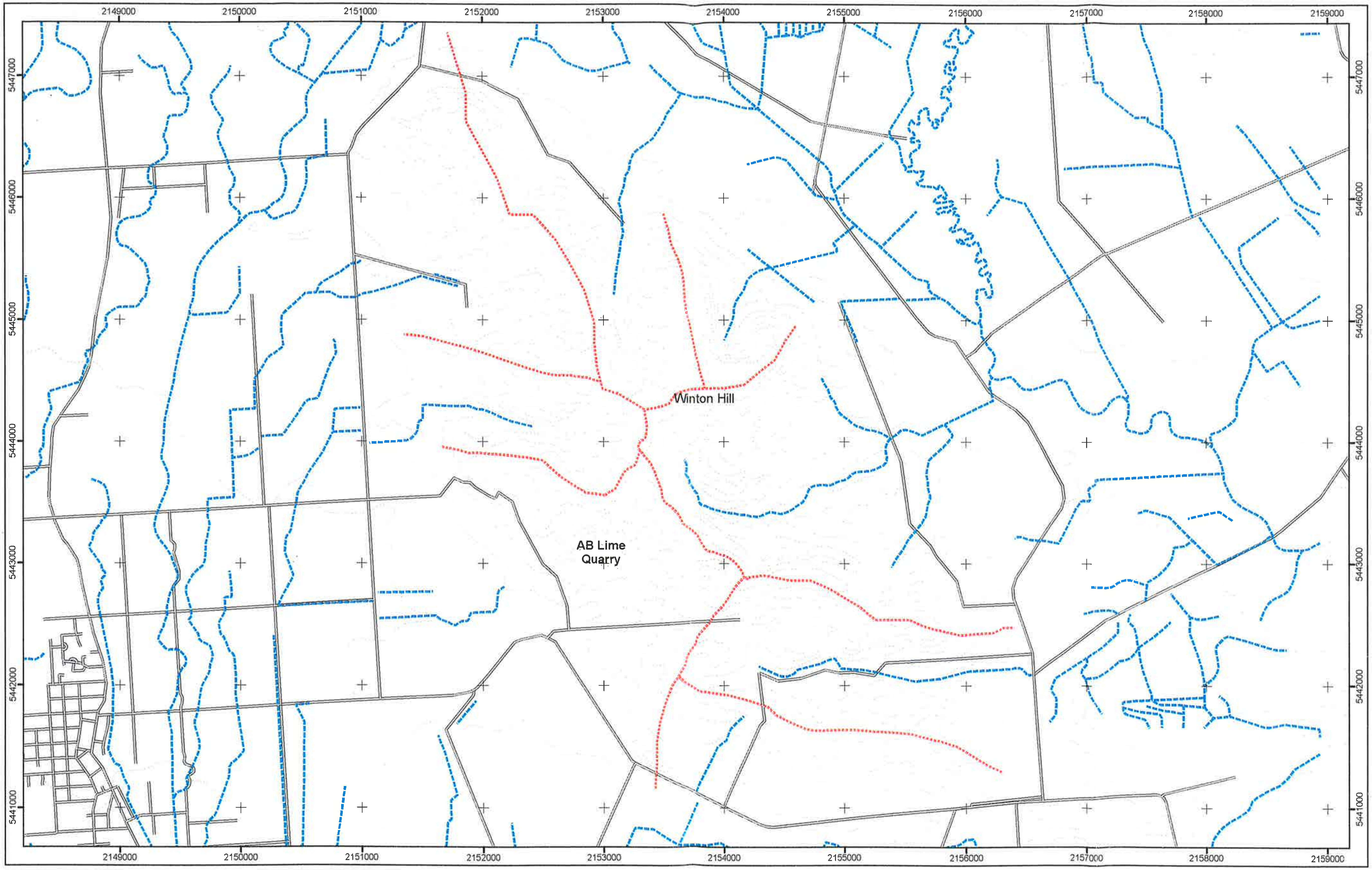
N

AB LIME

SINCLAIR KNIGHT MERZ

LAND SURFACE GRADIENT PLAN

FIGURE 2-2.



LEGEND
- Catchment Divides
- Streams
- Roads
- Regional Topography

Document Status:
SKM-AUCK I:\vcl\lv00319\Drawings\Gis

	Name	Date
Catchment.mxd	PTJ	6/6/02

Data Notes:
Topographic data derived from Land Information New Zealand.
Crown copyright reserved.
Currency of source data:
Topographic data 1999.
Topographic contour interval 20m.

1:30,000

Meters
0 500 1,000 1,500

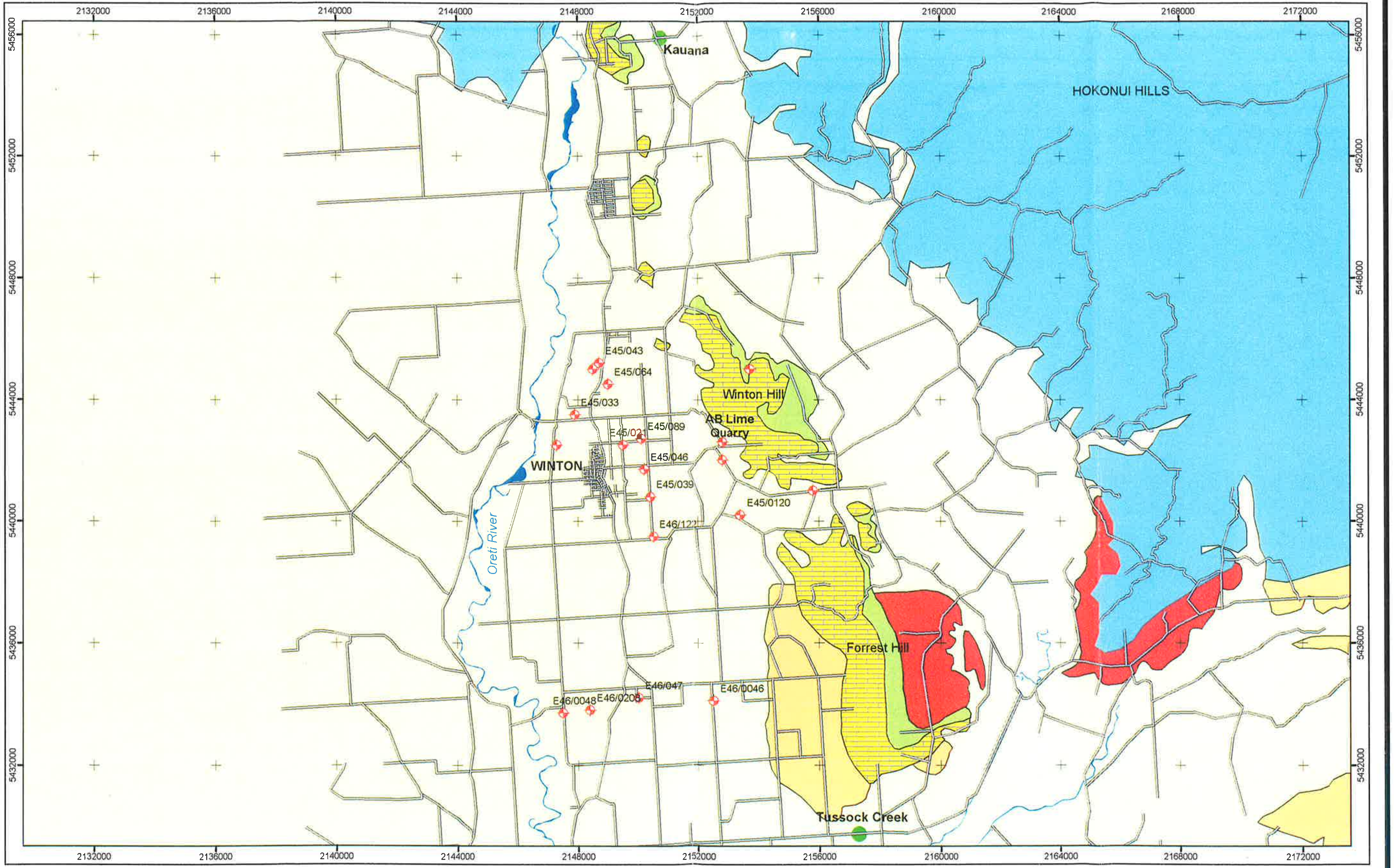
N

AB LIME

SINCLAIR KNIGHT MERZ

CATCHMENT WATERSHED PLAN

FIGURE 2-3.



LEGEND

- Boreholes
- Un-named Sandy Mudstone
- Fluvio-Glacial Gravels
- Forest Hill Formation
- Chatton Formation
- Gore Lignite Measures
- Mesozoic Basement

Document Status:
SKM-AUCK I:\vc\\v00319\Drawings\Gis

	Name	Date
Geology.mxd	PTJ	6/6/02

Data Notes:

1:120,000

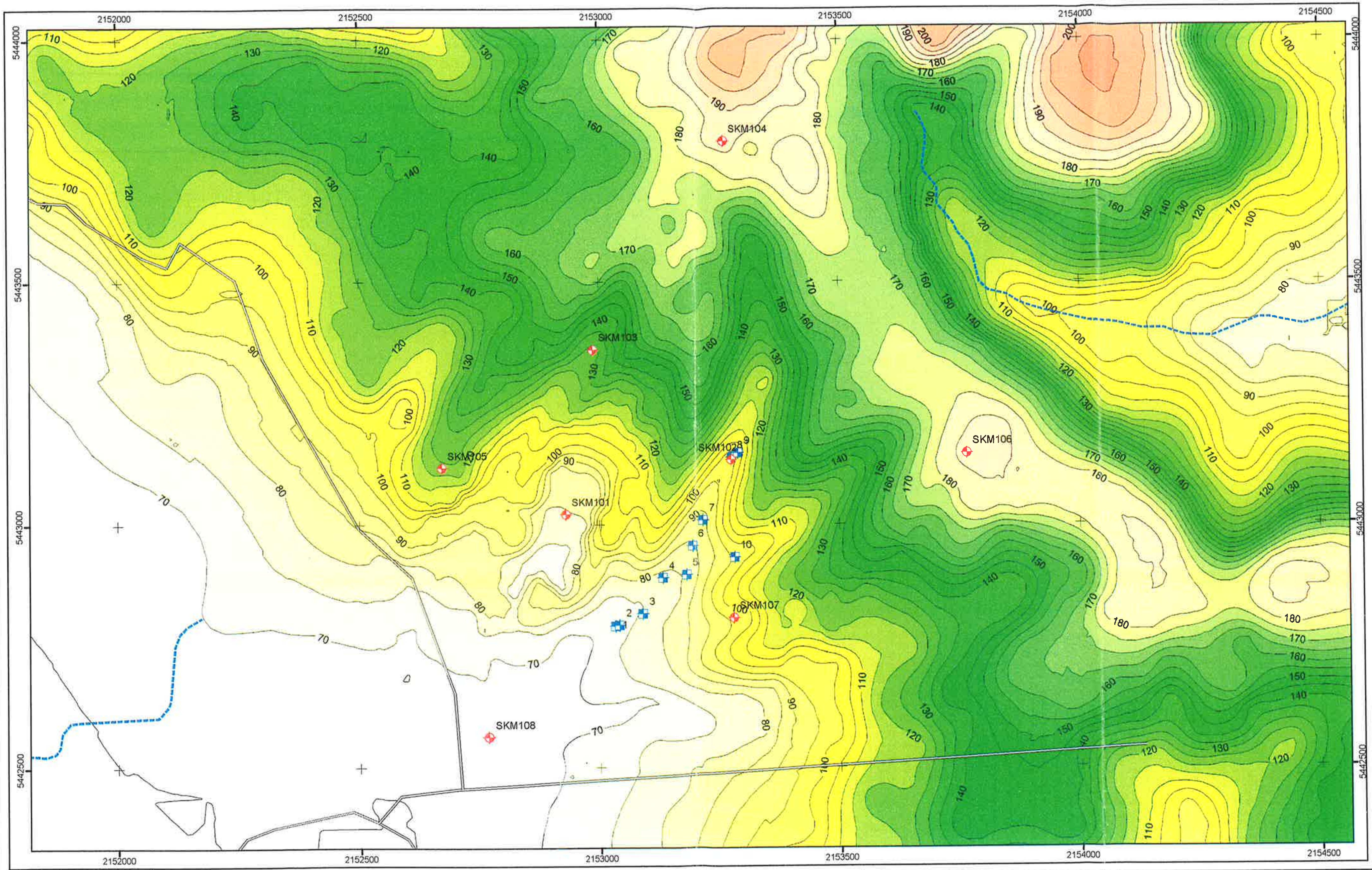
Meters
0 1,000 2,000 3,000 4,000 5,000

AB LIME

SINCLAIR KNIGHT MERZ

SURFACE GEOLOGY MAP

FIGURE 3-1.



LEGEND

- Boreholes
- Testpits
- Streams
- Roads

Document Status:

SKM-AUCK I:\vcl\v00319\Drawings\Gis

	Name	Date
Boreholes.mxd	PTJ	6/6/02

Data Notes:

Topographic data derived from Land Information New Zealand and site survey.
Crown copyright reserved.
Currency of source data:
Topographic data 1999.
Survey data 2002.
Spatial data interpolated using kriging geostatistical technique.
Topographic contour interval 5 metres.

1:7,500

Meters

0 100 200 300 400

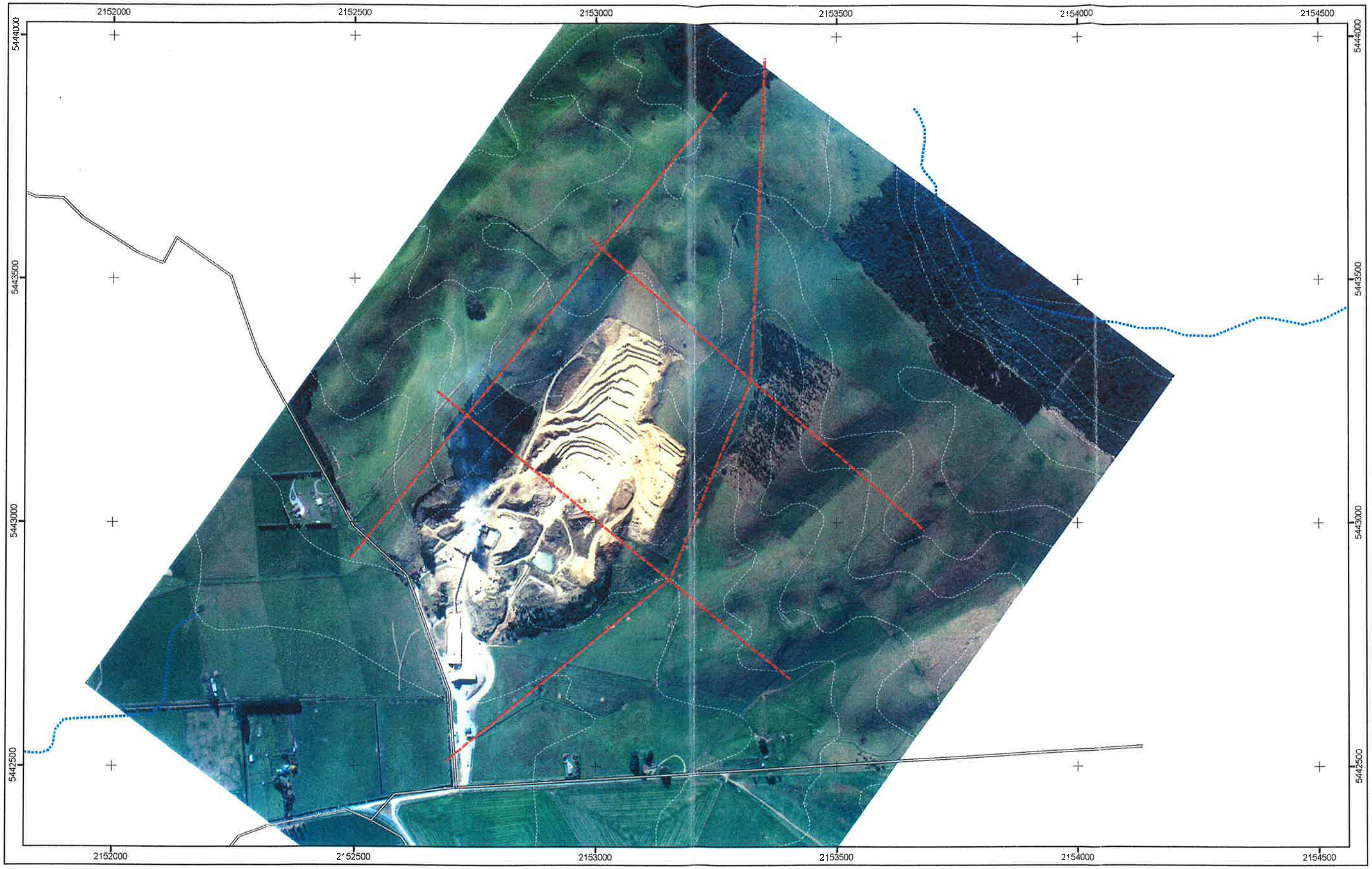
N

ABLIME

SINCLAIR KNIGHT MERZ

BOREHOLE LOCATIONS AND SITE TOPOGRAPHY

FIGURE 6-1.



LEGEND

- Cross Sections
- Streams
- Roads
- Regional Topography

Document Status:
SKM-AUCK I:\vcl\v00319\Drawings\Gis

	Name	Date
Aerial.mxd	PTJ	6/6/02

Data Notes:
Topographic data derived from Land Information New Zealand.

Currency of source data:
Topographic data 1999.
Topographic contour interval 20 metres.

1:7,500

Meters
0 100 200 300 400

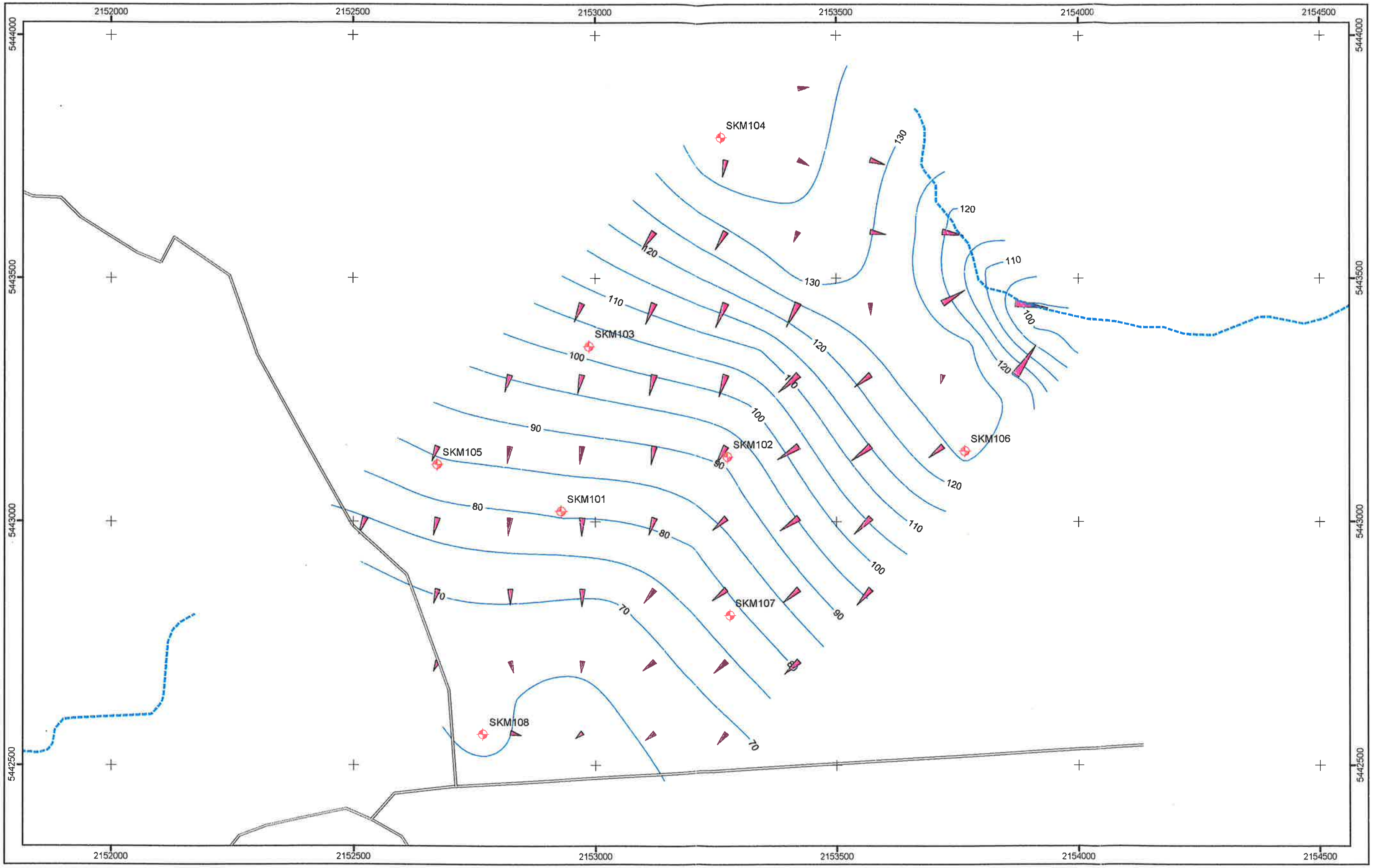
N

AB LIME

SINCLAIR KNIGHT MERZ

AERIAL PHOTOGRAPH OF THE QUARRY SITE (APRIL, 2002)

FIGURE 6-2.



LEGEND

- Boreholes
- Streams
- Roads
- Regional Topography

Document Status:
SKM-AUCK I:\Ivcl\Iv00319\Drawings\Gis

	Name	Date
GWL.mxd	PTJ	6/6/02

Data Notes:
Topographic data derived from Land Information New Zealand.
Crown copyright reserved.
Currency of source data:
Topographic data 1999.
Topographic contour interval 20 metres.
Spatial data interpolated using kriging geostatistical technique.
Only bores shown used in interpolation

1:7,500

Meters
0 100 200 300 400

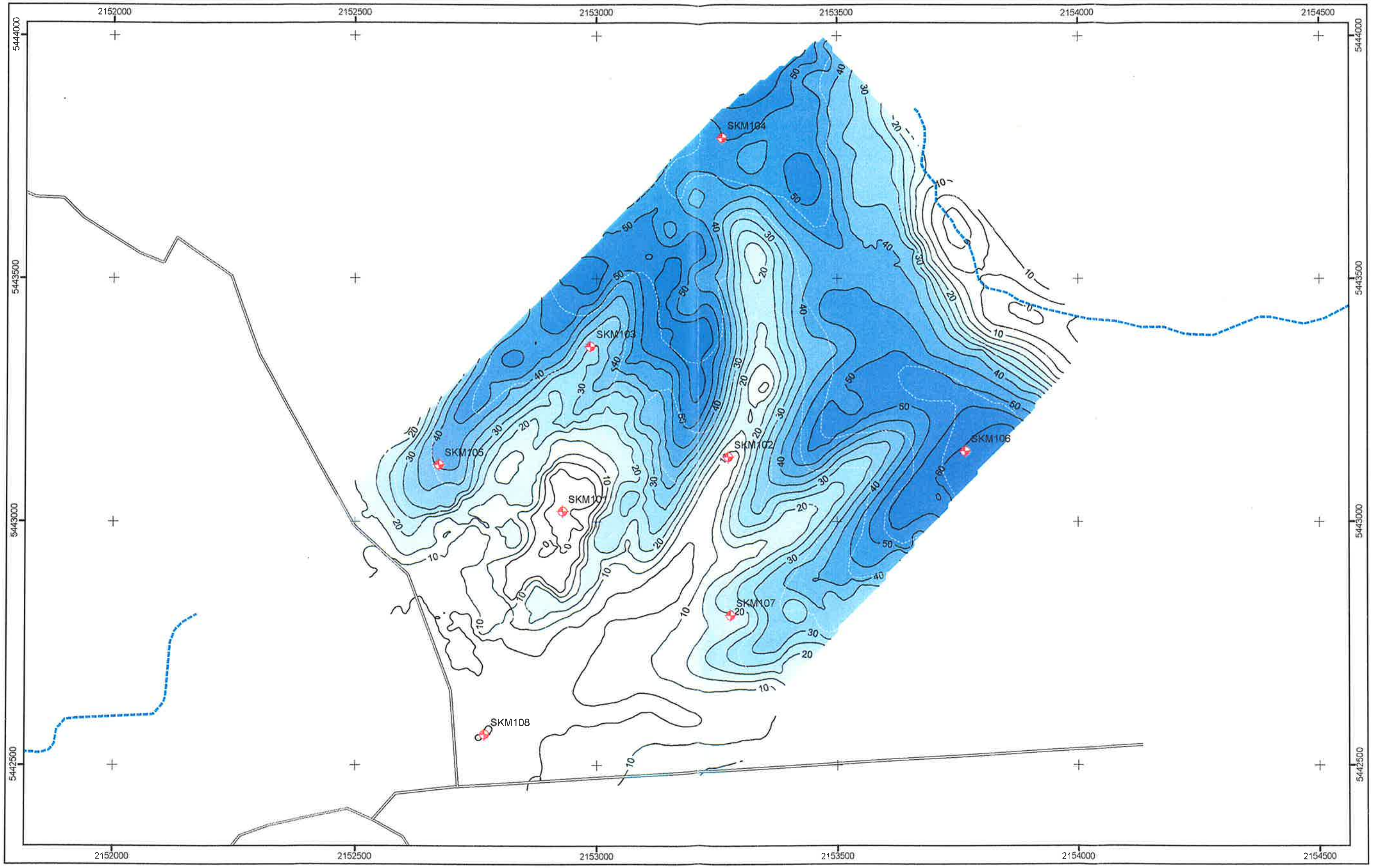
N

ABLIME

SINCLAIR KNIGHT MERZ

INTERPOLATED PIEZOMETRIC SURFACE

FIGURE 6-4.



LEGEND
- Boreholes
- Streams
- Roads
- Regional Topography

Document Status:
SKM-AUCK I:\vcl\iv00319\Drawings\Gis

	Name	Date
Depth to GW.mxd	PTJ	6/6/02

Data Notes:
Topographic data derived
from Land Information New Zealand.
Crown copyright reserved.
Currency of source data:
Topographic data 1999
Spatial data interpolated using kriging
geostatistical technique.
Only bores shown used in interpolation

1:7,500

Meters

0 100 200 300 400

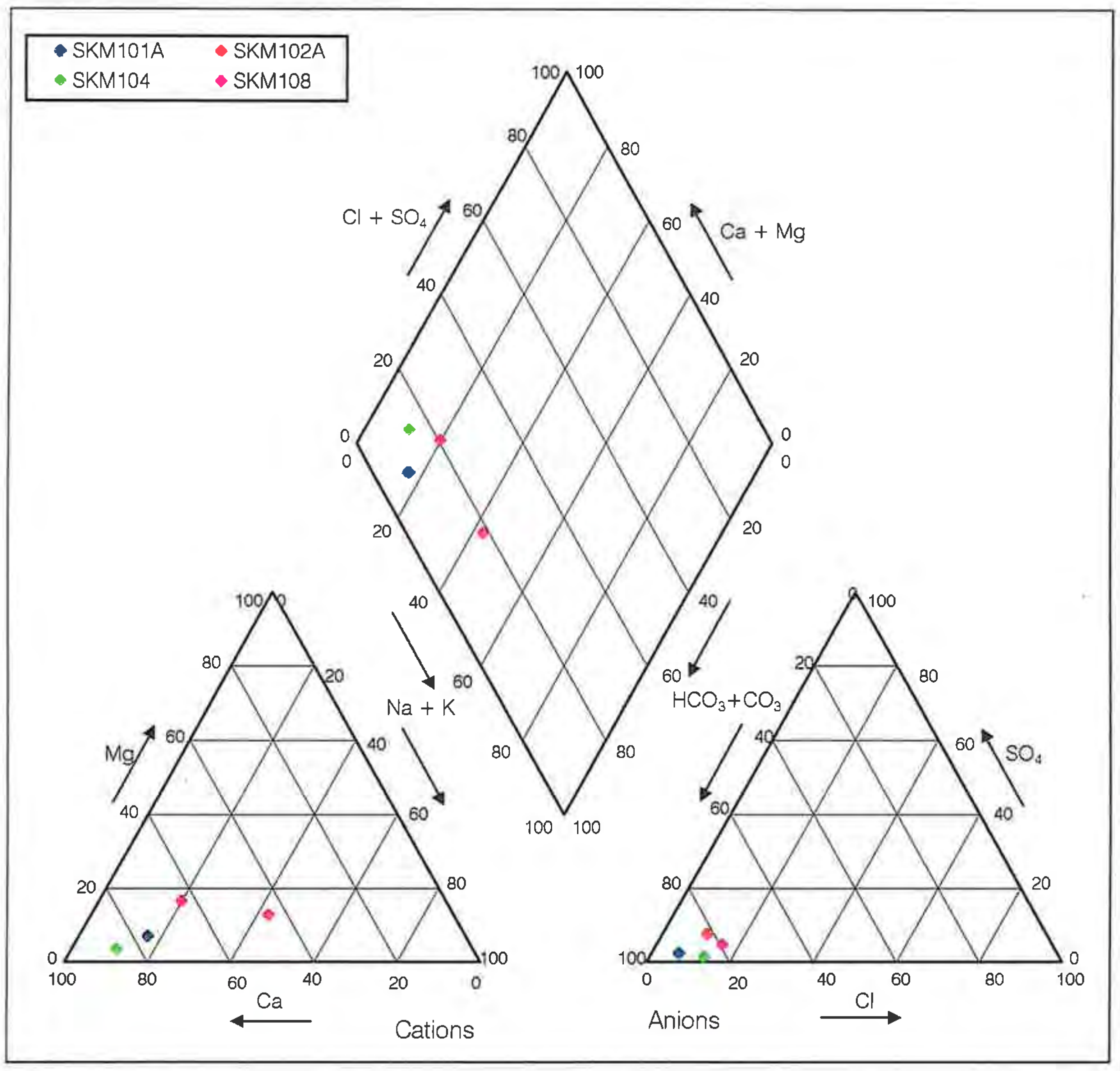
N

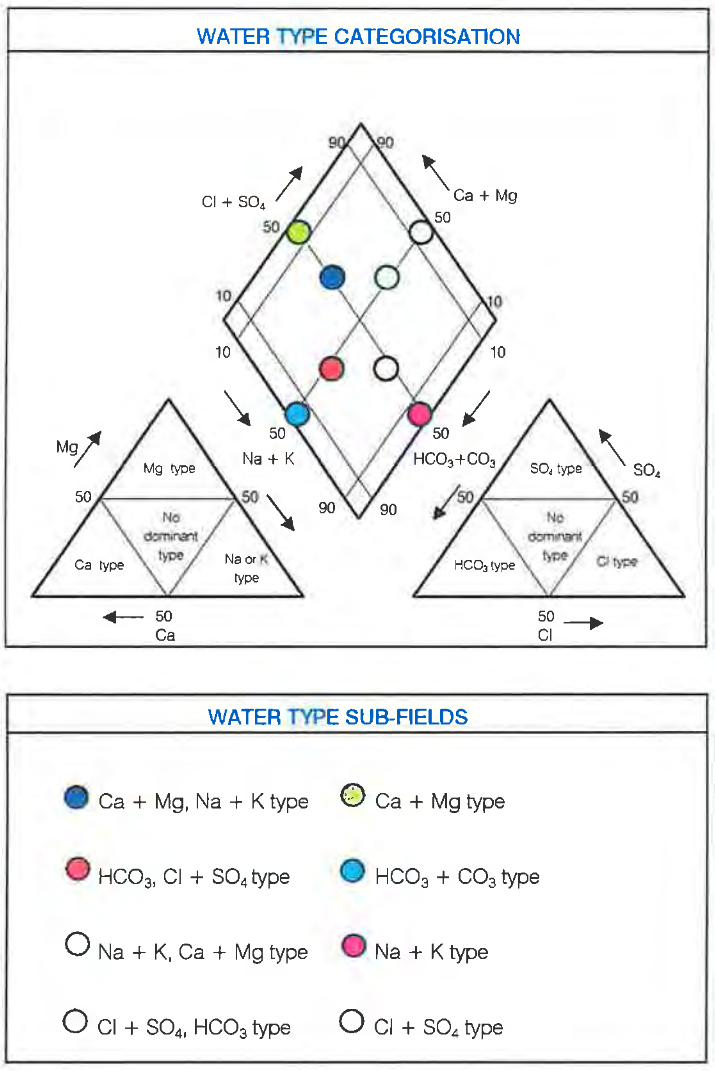
AB LIME

SINCLAIR KNIGHT MERZ

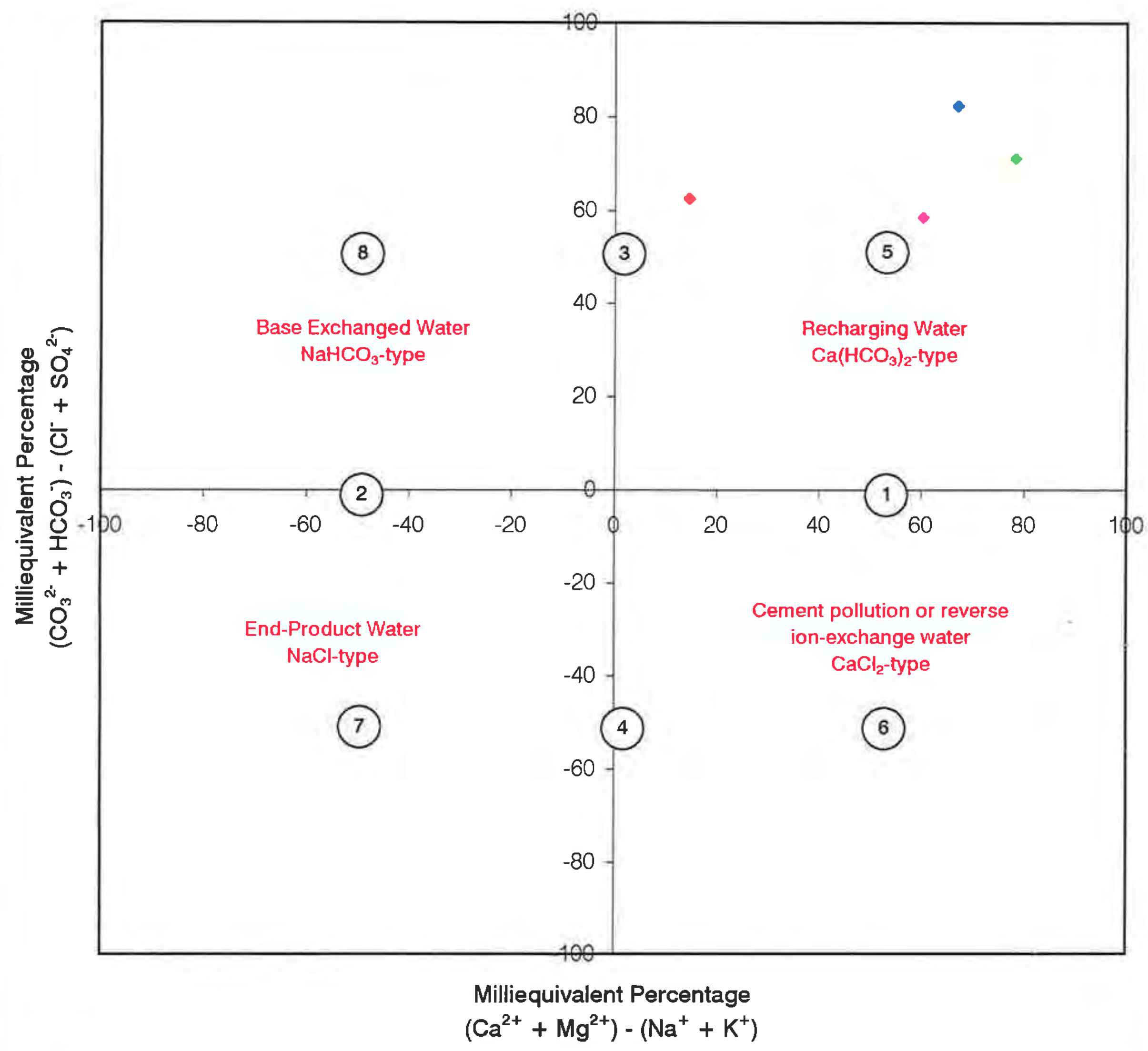
DEPTH TO GROUNDWATER

FIGURE 6-5.





SINCLAIR KNIGHT MERZ	Piper Diagram				Figure 6-6
Date: 20/06/2002	Project:	AB Lime	Description	Sampled 14/3/2002	HydroCHEM 1.0
PATH: I:\IVCL\iv00319\Data\Gw\[WQ_Piper.xls]PIPER	Project No:	IV00319.0	Client:	AB Lime Ltd	



WATER TYPE SUB-FIELDS

1. Alkaline earths exceed alkali metals
2. Alkali metals exceed alkaline earths
3. Weak acidic anions exceed strong acidic anions
4. Strong acidic anions exceed weak acidic anions
5. Alkaline earths and weak acidic anions exceed both alkali metals and strong acidic anions respectively (water with temporary hardness)
6. Alkaline earths exceed alkali metals and strong acidic anions exceed weak acidic anions (water with permanent hardness)
7. Alkali metals exceed alkaline earths and strong acidic anions exceed weak acidic anions (water generally creates salinity problems)
8. Alkali metals exceed alkaline earthsand weak acidic anions exceed strong acidic anions (water deposits residual sodium carbonate in irrigation use and cause foaming problems)

SINCLAIR KNIGHT MERZ	Water Type Diagram			Figure 6-7
Date: 20/06/2002	Project: AB Lime		Description: Sampled 14/3/2002	HydroCHEM 1.0
PATH: I:\VCL\iv00319\Data\Gw\[WQ_Piper.xls]WATER TYPE	Project No: IV00319.0		Client: AB Lime Ltd	

Appendix A Testpit and Borelogs

BOREHOLE SKM101

SINCLAIR KNIGHT MERZ

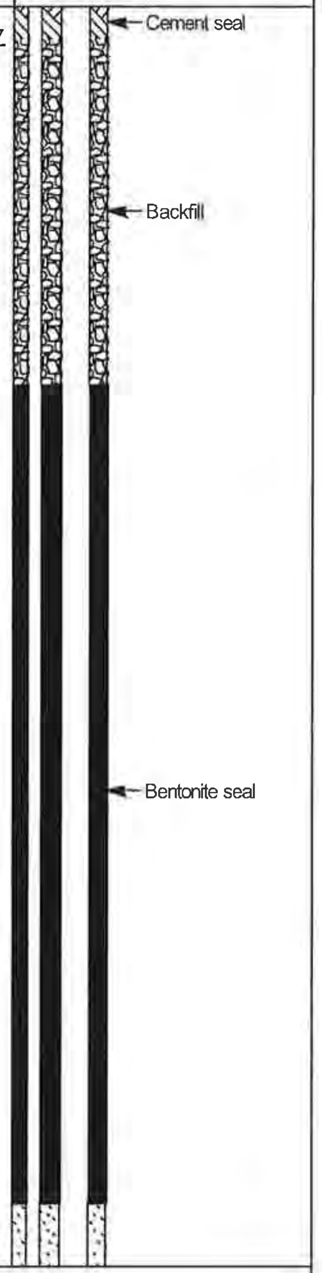
Sinclair Knight Merz Ltd.
25 Teed St, Newmarket
Auckland
Phone:
Fax:

Project:	AB LIME	**Ground Elevation:**	79.69 mAMSL
Job Number:	IV00319.04	**Top of Casing Elev.:**	80.16 mAMSL
Location:	AB LIME QUARRY, WINTON, NEW ZEALAND	**Drilling Method:**	HQ Coring
Coordinates:	E 2152929.5 N 5443021.3	**Sampling Method:**	Core

Depth (mBGL)	LITHOLOGICAL DESCRIPTION	Elevation (mAMSL)
0–1	LIMESTONE - yellowish brown, unweathered to sl. weathered, mod. strong to strong, biosparite LIMESTONE, mod. thick to thickly bedded with interbedded thin (generally <0.04m) soft horizons, skeletal particles, occ. black specks (pyrite), occ. near vertical tight and undulated rough fractures. [FORREST HILL FORMATION]	78.7
2	- 0.34m core loss from 0 to 1.5 m - possible cavity at ~1m (0.15m thick). - soft horizons at 2.5, 2.65 and 4.8m. - fractures at 2.8 (0.3m), 3.75 (0.4m) and 4.6m (0.08m).	77.7
3		76.7
4		75.7
5	- soft horizons at 7.8, 9, 9.3, and 9.6m. - fractures at 6.4 and 7.4m. - occasional thin (0.003m thick) calcite veins.	74.7
6		73.7
7		72.7
8		71.7
9	- gradually becoming lighter in colour.	70.7
10	- soft horizons at 11.6 and 16.1m.	69.7
11	- numerous skeletal particles (0.2m thick).	68.7
12		67.7
13	- sl. porous texture (0.25m thick), occ. orange brown staining.	66.7
14	- greenish brown and brown speckled horizon (0.5m thick), finer matrix. - lt. yellow brown, massive, occ. porous texture with red brown staining.	65.7
15		64.7
16		63.7
17	LIMESTONE - lt. greenish grey, unweathered, massive, mod. strong to strong, biosparite LIMESTONE, skeletal particles, occasional black specks (pyrite) and green inclusions (glauconite). [FORREST HILL FORMATION]	62.7
18		61.7
19		60.7

Groundwater Level

Piezometer Construction Details



DRILLING DETAILS

Drilled Depth:	37.50 mBGL
Bore Diameter:	96 mm
Date Borehole Started:	18/03/02
Date Borehole Completed:	20/03/02
Logged By:	PTJ
Drilling Company:	McNeill Drilling Co. Ltd

COMMENTS

1. SKM101B & C

The stratification lines represent approximate boundaries. The transition may be gradual.

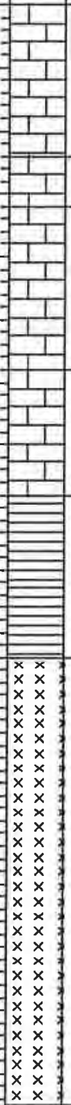
SKMHYDRO_1 LIME.GPJ SKM2.GDT 21/06/02

BOREHOLE SKM101

SINCLAIR KNIGHT MERZ

Sinclair Knight Merz Ltd.
25 Teed St, Newmarket
Auckland
Phone:
Fax:

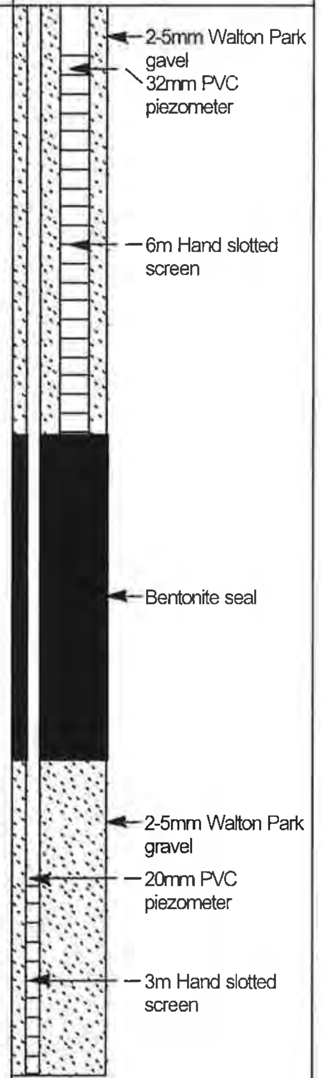
Project:	AB LIME	**Ground Elevation:**	79.69 mAMSL
Job Number:	IV00319.04	**Top of Casing Elev.:**	80.16 mAMSL
Location:	AB LIME QUARRY, WINTON, NEW ZEALAND	**Drilling Method:**	HQ Coring
Coordinates:	E 2152929.5 N 5443021.3	**Sampling Method:**	Core



Depth (mBGL)	LITHOLOGICAL DESCRIPTION	Elevation (mAMSL)
21		58.7
22		57.7
23	LIMESTONE - yellow brown, unweathered, massive, mod. strong to strong, biosparite LIMESTONE, skeletal particles. [FORREST HILL FORMATION]	56.7
24	LIMESTONE - dk. greenish grey, unweathered, massive, weak to mod. strong, biomicrite LIMESTONE, skeletal particles, calcareous. [FORREST HILL FORMATION]	55.7
25		54.7
26	LIMESTONE - yellow brown, unweathered to sl. weathered, massive, mod. strong to strong, biosparite LIMESTONE, skeletal particles. [FORREST HILL FORMATION] - gritty shell horizon (0.4m thick).	53.7
27	- greenish brown horizon, finer matrix (0.2m thick).	52.7
28	MUDSTONE - dk. grey, unweathered, massive, weak to mod. strong MUDSTONE, sl. calcareous. [CHATTON FORMATION]	51.7
29		50.7
30		49.7
31	SILTSTONE - dk. grey, unweathered, massive, strong SILTSTONE, sl. to mod. sandy (very fine grained), sl. calcareous. [CHATTON FORMATION]	48.7
32		47.7
33		46.7
34		45.7
35	- very strong calcareous horizon (0.05m thick), white veins. - sand horizons at 35.2 (0.03m thick) and 35.4 m (0.01m thick).	44.7
36		43.7
37		42.7
38	EOH @ 37.5m	41.7
39		40.7

Groundwater Level

Piezometer Construction Details



DRILLING DETAILS	
Drilled Depth:	37.50 mBGL
Bore Diameter:	96 mm
Date Borehole Started:	18/03/02
Date Borehole Completed:	20/03/02
Logged By:	PTJ
Drilling Company:	McNeill Drilling Co. Ltd

COMMENTS

1. SKM101B & C

The stratification lines represent approximate boundaries. The transition may be gradual.

SKMHYDRO_1 LIME.GPJ SKM2.GDT 21/06/02

SINCLAIR KNIGHT MERZ

BOREHOLE SKM101A

Sinclair Knight Merz Ltd.
25 Teed St, Newmarket
Auckland
Phone:
Fax:

Project:	AB LIME	**Ground Elevation:**	79.54 mAMSL
Job Number:	IV00319.04	**Top of Casing Elev.:**	80.12 mAMSL
Location:	AB LIME QUARRY, WINTON, NEW ZEALAND	**Drilling Method:**	HQ Coring
Coordinates:	E 2152928.8 N 5443022.9	**Sampling Method:**	Core

LITHOLOGICAL DESCRIPTION

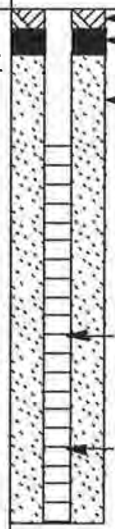
LIMESTONE - yellowish brown, unweathered to sl. weathered, mod. strong to strong, biosparite LIMESTONE, mod. thick to thickly bedded with interbedded thin (generally <0.04m) soft horizons, skeletal particles, occ. black specks (pyrite), occ. near vertical tight and undulated rough fractures. [FORREST HILL FORMATION]
- 0.34m core loss from 0 to 1.5 m
- possible cavity at ~1m (0.15m thick).
- soft horizons at 2.5, 2.65 and 4.8m.
- fractures at 2.8 (0.3m), 3.75 (0.4m) and 4.6m (0.08m).
- soft horizons at 7.8, 9, 9.3, and 9.6m.
- fractures at 6.4 and 7.4m.
- occasional thin (0.003m thick) calcite veins.
- gradually becoming lighter in colour.

EOH @ 9.0m

Depth (mBGL)	Elevation (mAMSL)
1	78.5
2	77.5
3	76.5
4	75.5
5	74.5
6	73.5
7	72.5
8	71.5
9	70.5
10	69.5
11	68.5
12	67.5
13	66.5
14	65.5
15	64.5
16	63.5
17	62.5
18	61.5
19	60.5

Graphic Log | Groundwater Level

Piezometer Construction Details



DRILLING DETAILS

Drilled Depth:	9.00 mBGL
Bore Diameter:	96 mm
Date Borehole Started:	20/03/02
Date Borehole Completed:	20/03/02
Logged By:	PTJ
Drilling Company:	McNeill Drilling Co. Ltd

COMMENTS

The stratification lines represent approximate boundaries. The transition may be gradual.

SINCLAIR KNIGHT MERZ

BOREHOLE SKM102

Sinclair Knight Merz Ltd.
25 Teed St, Newmarket
Auckland
Phone:
Fax:

Project:	AB LIME	**Ground Elevation:**	97.53 mAMSL
Job Number:	IV00319.04	**Top of Casing Elev.:**	97.84 mAMSL
Location:	AB LIME QUARRY, WINTON, NEW ZEALAND	**Drilling Method:**	HQ Coring
Coordinates:	E 2153275.2 N 5443133.0	**Sampling Method:**	Core

Depth (mBGL)	LITHOLOGICAL DESCRIPTION	Elevation (mAMSL)
0	TOPSOIL - dk. brown sl. clayey ORGANIC SILT.	
1	SILT - brown, mod. clayey SILT, plastic, firm to stiff, black specks. [COLLUVIUM] - 0 to 1.5m, 0.35m loss of core.	96.5
2	- lt. greenish brown horizon (0.2m thick), increase clay, plastic, occ. orange brown streaks	95.5
3	LIMESTONE - lt. green, unweathered to sl. weathered, massive, mod. strong to strong, biosparite LIMESTONE, skeletal particles. [FORREST HILL FORMATION] - silt horizon (0.2m thick). - very gritty horizons at 2.8, 3.05, 4.25, 4.7, 5m. - large shells at 4.7 and 5m.	94.5
4		93.5
5		92.5
6	LIMESTONE - greenish grey, unweathered, massive, weak to mod. strong, biomicrite LIMESTONE, skeletal particles. [FORREST HILL FORMATION] LIMESTONE - greenish grey and orange brown mottles, sl. weathered, massive, mod. strong, biomicrite - biosparite LIMESTONE, skeletal particles, silty/clayey matrix. [FORREST HILL FORMATION]	91.5
7	LIMESTONE - yellow brown, unweathered, mod. strong to strong, biosparite LIMESTONE, thickly bedded with interbedded thin (generally <0.04m thick) soft horizons, skeletal particles, occ. black specks (pyrite). [FORREST HILL FORMATION] - soft horizons at 9.3 and 9.9m. - fracture at 8.05m.	90.5
8		89.5
9		88.5
10	- soft horizons at 11.5,12.1,13.1 and 13.8m - fractures at 11.4 and 16m (0.25m long), sl. orange brown staining.	87.5
11		86.5
12		85.5
13		84.5
14		83.5
15		82.5
16	- sl. porous texture with orange brown staining, numerous skeletal particles.	81.5
17		80.5
18	LIMESTONE - greenish grey, yellow brown and brown mottles, sl. weathered, mod. strong, biomicrite-biosparite LIMESTONE, skeletal particles, orange brown staining in horizontal bands. [FORREST HILL FORMATION]	79.5
19	LIMESTONE - greenish grey, unweathered, massive, weak to mod. strong, biomicrite LIMESTONE, numerous skeletal particles. [FORREST HILL FORMATION]	78.5

Piezometer Construction Details:
- Cement seal
- Backfill
- Bentonite seal
- 2-5mm Walton Park gravel
- 32mm PVC piezometer
- 6m Hand slotted screen

DRILLING DETAILS

Drilled Depth:	26.50 mBGL
Bore Diameter:	96 mm
Date Borehole Started:	21/03/02
Date Borehole Completed:	21/03/02
Logged By:	PTJ
Drilling Company:	McNeill Drilling Co. Ltd

COMMENTS

1. SKM102A & B

The stratification lines represent approximate boundaries. The transition may be gradual.

SINCLAIR KNIGHT MERZ

BOREHOLE SKM102

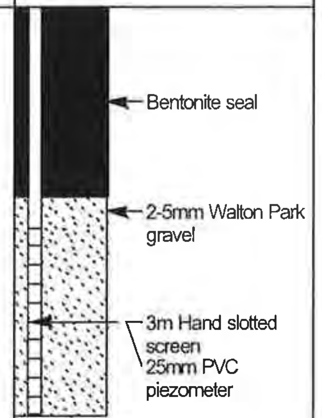
Sinclair Knight Merz Ltd.
25 Teed St, Newmarket
Auckland
Phone:
Fax:

Project:	AB LIME	**Ground Elevation:**	97.53 mAMSL
Job Number:	IV00319.04	**Top of Casing Elev.:**	97.84 mAMSL
Location:	AB LIME QUARRY, WINTON, NEW ZEALAND	**Drilling Method:**	HQ Coring
Coordinates:	E 2153275.2 N 5443133.0	**Sampling Method:**	Core

Depth (mBGL)	LITHOLOGICAL DESCRIPTION	Elevation (mAMSL)
20.5–21.0	LIMESTONE - yellow brown, unweathered, massive, moderately strong to strong, biosparite LIMESTONE, skeletal particles, fractured, small cavities and large vesicles. [FORREST HILL FORMATION]	
21	SILTSTONE - dk. grey, unweathered, massive, strong SILTSTONE, sl. to mod. sandy (very fine grained), occ. shell fragments, black specks, sl. calcareous, occ. sandy/gritty inclusions (possible bioturbation). [CHATTON FORMATION]	76.5
22		75.5
23		74.5
24		73.5
25	- decrease in sand.	72.5
26		71.5
27	EOH @ 26.5m	70.5
28		69.5
29		68.5
30		67.5
31		66.5
32		65.5
33		64.5
34		63.5
35		62.5
36		61.5
37		60.5
38		59.5
39		58.5

Groundwater Level

Piezometer Construction Details



DRILLING DETAILS

Drilled Depth:	26.50 mBGL
Bore Diameter:	96 mm
Date Borehole Started:	21/03/02
Date Borehole Completed:	21/03/02
Logged By:	PTJ
Drilling Company:	McNeill Drilling Co. Ltd

COMMENTS

1. SKM102A & B

The stratification lines represent approximate boundaries. The transition may be gradual.

SINCLAIR KNIGHT MERZ

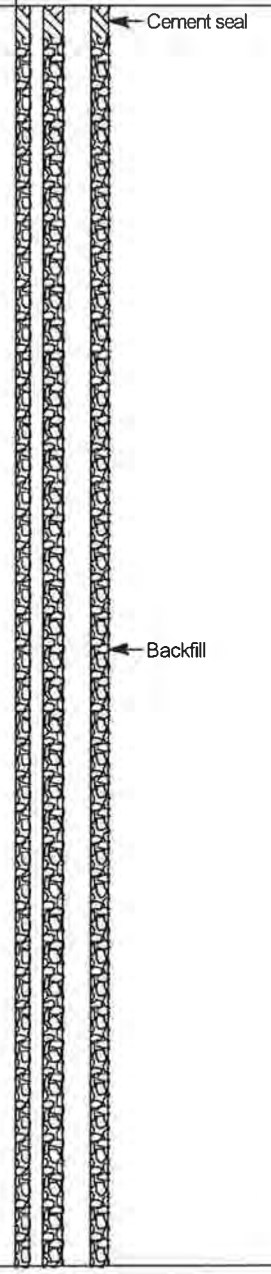
BOREHOLE SKM103

Sinclair Knight Merz Ltd.
25 Teed St, Newmarket
Auckland
Phone:
Fax:

Project:	AB LIME	**Ground Elevation:**	129.25 mAMSL
Job Number:	IV00319.04	**Top of Casing Elev.:**	129.42 mAMSL
Location:	AB LIME QUARRY, WINTON, NEW ZEALAND	**Drilling Method:**	HQ Coring
Coordinates:	E 2152987.6 N 5443360.1	**Sampling Method:**	Core

Depth (mBGL)	LITHOLOGICAL DESCRIPTION	Elevation (mAMSL)
0	TOPSOIL - dk. brown sl. clayey ORGANIC SILT.	
	SILT - brown, mod. clayey SILT, plastic, firm to stiff, black specks. [COLLUVIUM]	
1		128.3
2		127.3
	- sl. sandy (coarse), occ. red brown staining.	
3		126.3
	- 2.4 to 3.9m, 0.5m loss of core, possible cavity, loss of drilling fluids.	
4		125.3
5		124.3
	- 3.9 to 5.9m, no recovery.	
6		123.3
7	- 5.4 to 6.9m, 0.8m loss of core.	122.3
	- cavity (approx. 0.5m thick from 7.2m)	
8	LIMESTONE - yellowish brown, unweathered to sl. weathered, mod. strong to strong, biosparite LIMESTONE, mod. thick to thickly bedded with interbedded thin (generally <0.04m) soft horizons, skeletal particles, occ. black specks (pyrite), occ. near vertical tight undulated rough fractures. [FORREST HILL FORMATION]	121.3
9	- soft horizons at 8.2 and 9.7m.	120.3
	- fractures at 8, 8.55 (0.2m), 9 (0.9m), and 9.61m (0.5m).	
10	- calcite precipitation at 9.8m.	119.3
	- cavity (~0.1m thick).	
	- soft horizons at 11, 13.3,13.8,13.9 and 14m.	
11		118.3
12		117.3
13		116.3
	- cavity (~0.4m thick).	
14		115.3
15	- soft horizons at 15.5, 15.8, 16.25, 16.5, 16.75, 17, 17.1,17.8, 18.1, 18.55 and 19.3m.	114.3
	- fracture at 15.2m.	
16	- cavity (~0.1m thick).	113.3
17		112.3
	- heavily fractured from 17.4 to 18.1m.	
18		111.3
19	- heavily fractured	110.3

Piezometer Construction Details



DRILLING DETAILS

Drilled Depth:	56.40 mBGL
Bore Diameter:	96 mm
Date Borehole Started:	22/03/02
Date Borehole Completed:	26/03/02
Logged By:	PTJ
Drilling Company:	McNeill Drilling Co. Ltd

COMMENTS

1. SKM103A & B

The stratification lines represent approximate boundaries The transition may be gradual

SINCLAIR KNIGHT MERZ

BOREHOLE SKM103

Sinclair Knight Merz Ltd.
25 Teed St, Newmarket
Auckland
Phone:
Fax:

Project:	AB LIME	**Ground Elevation:**	129.25 mAMSL
Job Number:	IV00319.04	**Top of Casing Elev.:**	129.42 mAMSL
Location:	AB LIME QUARRY, WINTON, NEW ZEALAND	**Drilling Method:**	HQ Coring
Coordinates:	E 2152987.6 N 5443360.1	**Sampling Method:**	Core

Depth (mBGL)	LITHOLOGICAL DESCRIPTION	Elevation (mAMSL)	Groundwater Level	Piezometer Construction Details
	- soft horizons at 20.4, 20.65, 21, 21.4, 21.55, 21.75, 23.8,23.9, 24.1, 24.6, and 24.85m.			
21	- heavily fractured from 21.4 to 21.55m, 21.9 to 23m.	108.3		
22	- 1.18m core loss from 21.9 to 23.4m.	107.3		
23		106.3		
24	- fractured from 24.1 to 25.55 sl. weathered, 26.65 (0.15m) and 27.5m (0.15m).	105.3		
25	- soft horizons at 25.05, 25.15, 25.6 (0.1m thick), 26, 26.4, 26.5, 26.8, 27.1, 27.4, 28.2, 28.45, 28.75, 28.75, 29.1, 29.5, 29.6 and 29.8m.	104.3		Bentonite seal
26	- cavity (approx. 0.2m thick).	103.3		
27		102.3		
28		101.3		
29		100.3	∇	
30	- soft horizons at 30.9 (0.2m thick), 31.2, 32.4, 32.7, and 33.65m	99.3		
31		98.3		
32		97.3		
33		96.3		
34	LIMESTONE - greenish grey, unweathered, massive, weak to mod. strong, biomicrite LIMESTONE, skeletal particles. [FORREST HILL FORMATION]	95.3		
35		94.3		
36	LIMESTONE - yellow brown, unweathered, mod. strong LIMESTONE, thickly bedded with interbedded thin (generally <0.04m) soft horizons, skeletal particles, occ. blacks specks (pyrite). [FORREST HILL FORMATION]	93.3		
37	- soft horizons at 36.55, 38.1, 38.7, 38.8 and 39.7m. - fractured at 35.8 (0.1m), sl orange brown staining.	92.3		2-5mm Walton Park gravel
38	- sl. porous texture and numerous skeletal particles from 36.9 to 37.6m.	91.3		
39		90.3		

DRILLING DETAILS

Drilled Depth:	56.40 mBGL
Bore Diameter:	96 mm
Date Borehole Started:	22/03/02
Date Borehole Completed:	26/03/02
Logged By:	PTJ
Drilling Company:	McNeill Drilling Co. Ltd

COMMENTS

1. SKM103A & B

The stratification lines represent approximate boundaries. The transition may be gradual

SKMHYDRO_1 LIME.GPJ SKM2.GDT 21/06/02

SINCLAIR KNIGHT MERZ

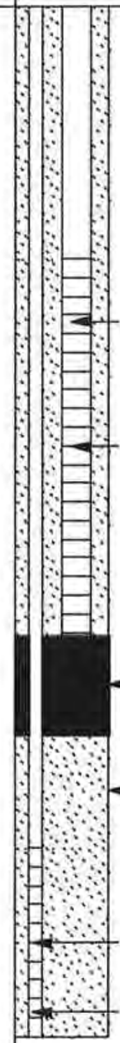
BOREHOLE SKM103

Sinclair Knight Merz Ltd.
25 Teed St, Newmarket
Auckland
Phone:
Fax:

Project:	AB LIME	**Ground Elevation:**	129.25 mAMSL
Job Number:	IV00319.04	**Top of Casing Elev.:**	129.42 mAMSL
Location:	AB LIME QUARRY, WINTON, NEW ZEALAND	**Drilling Method:**	HQ Coring
Coordinates:	E 2152987.6 N 5443360.1	**Sampling Method:**	Core

Depth (mBGL)	LITHOLOGICAL DESCRIPTION	Elevation (mAMSL)
	- soft horizons at 40.15, 40.35, 40.55, 41.35, 41.5,41.65, 41.9, 41.95, 42.35, 42.75, 42.65, 43, 43.1,43.7 and 44.15m.	
41	- fractures at 44.6 (0.08m), 44.95 (0.4m) and 46.2m, sl. orange brown staining.	88.3
42		87.3
43		86.3
	- sl. porous from 43.4 to 43.85m.	
44		85.3
45		84.3
46	- large amount of bivalves from 45.8 to 45.9m.	83.3
47	LIMESTONE - greenish grey, yellow brown and brown mottles, sl. weathered, massive, mod. strong biomicrite-biosparite LIMESTONE, skeletal particles. [FORREST HILL FORMATION]	82.3
48	LIMESTONE - greenish grey, unweathered, massive, weak to mod. strong, biomicrite LIMESTONE, skeletal particles. [FORREST HILL FORMATION]	81.3
49	LIMESTONE - lt. greenish grey, unweathered, massive, mod. strong to strong LIMESTONE, skeletal particles, black specks. [FORREST HILL FORMATION] - dk. green fine grained horizon from 50.1 to 50.3m, white calcite crystals.	80.3
50	SILTSTONE - dk. greenish grey, unweathered, massive, strong SILTSTONE, sl. to mod. sandy (very fine grained), occ. shell fragments, black specks, sl. calcareous, occ. sandy/gritty inclusions (possible bioturbation). [CHATTON FORMATION]	79.3
51		78.3
52		77.3
53	SANDSTONE - dk. greenish grey, unweathered, massive, strong SANDSTONE (fine to medium grained), black specks (coarse grained). [CHATTON FORMATION]	76.3
54	SILTSTONE - dk. greenish grey, unweathered, massive, strong SILTSTONE, sl. to mod. sandy (very fine grained), occ. shell fragments, black specks, brown inclusions (shell remnants?), sl. calcareous, occ. sandy/gritty inclusions (possible bioturbation). [CHATTON FORMATION]	75.3
55		74.3
56	SANDSTONE - dk. greenish grey, unweathered, massive, strong SANDSTONE (fine to medium grained), black specks (coarse grained). [CHATTON FORMATION]	73.3
57	EOH @ 56.4m	72.3
58		71.3
59		70.3

Piezometer Construction Details



DRILLING DETAILS	
Drilled Depth:	56.40 mBGL
Bore Diameter:	96 mm
Date Borehole Started:	22/03/02
Date Borehole Completed:	26/03/02
Logged By:	PTJ
Drilling Company:	McNeill Drilling Co. Ltd

COMMENTS

1. SKM103A & B

The stratification lines represent approximate boundaries. The transition may be gradual.

SKMHYDRO_1 LIME.GPJ SKM2.GDT 21/06/02

SINCLAIR KNIGHT MERZ

BOREHOLE SKM104

Sinclair Knight Merz Ltd.
25 Teed St, Newmarket
Auckland
Phone:
Fax:

Project:	AB LIME	**Ground Elevation:**	187.42 mAMSL
Job Number:	IV00319.04	**Top of Casing Elev.:**	187.68 mAMSL
Location:	AB LIME QUARRY, WINTON, NEW ZEALAND	**Drilling Method:**	HQ Coring
Coordinates:	E 2153261.9 N 5443788.6	**Sampling Method:**	Core

Depth (mBGL)	Graphic Log	LITHOLOGICAL DESCRIPTION	Elevation (mAMSL)	Groundwater Level	Piezometer Construction Details
		SILT - brown, mod. clayey SILT, plastic, firm to stiff. [COLLUVIUM]			Cement seal
1			186.4		
		LIMESTONE - yellowish brown, unweathered to sl. weathered, mod. strong to strong LIMESTONE, mod. thick to thickly bedded with interbedded thin (generally <0.04m) soft horizons, skeletal particles, occ. black specks (pyrite), occ. near vertical tight and undulated rough fractures. [FORREST HILL FORMATION]			
2			185.4		
3		- soft horizons at 3.45, 3.65 and 4.08m. - fractured at 2.6 (0.25m), 3.15 (0.05m) and 4.85m (0.2m).	184.4		
4			183.4		
5		- soft horizons at 5.05, 7.15, 8.4, 8.75, 8.9, 9.35 and 9.5m. - fractured at 5.25 (0.1m), 5.4 (0.1m), 6 (0.3) sl. weathering, 7.2 (0.15m), 7.45 (0.08m), 8 (0.05m) and 8.65m, sl. red brown staining.	182.4		
6			181.4		
7		- 5.5 to 7m, 0.45m core loss.	180.4		
8			179.4		
9			178.4		
10		- soft horizons at 10.4, 10.5, 10.7, 12.8, 13.3, 13.5, 14.3 and 14.8m. - fractured at 10.2 (0.1m), sl. orange brown weathering, 11.8 (0.4m) and 14 5m (0.2m). - cracks at 13.8 (0.04m) and 14.3m (0.2m).	177.4		Backfilled
11			176.4		
12			175.4		
13			174.4		
14			173.4		
15		- soft horizons at 15, 16.6, 17.3, 18.3, 19.25, 19.3, 19.45, 19.75 and 19.9m. - fractured at 15.35 (0.03m), sl. orange brown staining, 15.5 (0.3m), sl. orange brown staining, 16 (0.25m), 17.3 (0.15m), 18.2 (0.1m), 19.35 (0.05m), sl. orange brown staining and 19.45m (0.1m).	172.4		
16			171.4		
17			170.4		
18			169.4		
19			168.4		

DRILLING DETAILS

Drilled Depth:	77.50 mBGL
Bore Diameter:	96 mm
Date Borehole Started:	27/03/02
Date Borehole Completed:	27/03/02
Logged By:	PTJ
Drilling Company:	McNeill Drilling Co. Ltd

COMMENTS

The stratification lines represent approximate boundaries. The transition may be gradual

BOREHOLE SKM104

SINCLAIR KNIGHT MERZ

Sinclair Knight Merz Ltd.
25 Teed St, Newmarket
Auckland
Phone:
Fax:

Project:	AB LIME	**Ground Elevation:**	187.42 mAMSL
Job Number:	IV00319.04	**Top of Casing Elev.:**	187.68 mAMSL
Location:	AB LIME QUARRY, WINTON, NEW ZEALAND	**Drilling Method:**	HQ Coring
Coordinates:	E 2153261.9 N 5443788.6	**Sampling Method:**	Core

Depth (mBGL)	Graphic Log	LITHOLOGICAL DESCRIPTION	Elevation (mAMSL)	Groundwater Level	Piezometer Construction Details
		- soft horizons at 20.4, 20.8, 21.15, 21.4, 22.3, 23.2, 23.5, 24.3, 24.7 and 24.9m. - fractured at 21 (0.1m), 21.7 (0.1m), 22.3 (0.2m), 23.2, sl. orange brown staining, 23.7 (0.25m) and 24.5 (0.2m). - cracks at 20.3 (0.04m) and 20.75 (0.2m), sl. orange brown staining.			
21			166.4		
22			165.4		
23			164.4		
24			163.4		Bentonite seal
25		- soft horizons at 25.2, 25.7, 26 (0.1m thick), 26.2, 26.5, 26.8, 27, 27.1, 27.2, 28, 28.15, 28.35, 29.3 and 29.7m. - fractured at 27.2, 27.75 (0.25m) and 28.85m (0.25).	162.4		
26			161.4		
27			160.4		
28			159.4		
29			158.4		
30		- soft horizons at 30.05, 30.55, 31.35, 31.7, 32.3, 33.2 and 34.4m. - fractured at 33.3 (0.3m), sl. discolouration, 34.1 (0.1m), sl. orange brown staining and 34.9m (horizontal) orange brown staining.	157.4		
31			156.4		
32			155.4		
33			154.4		
34			153.4		
35		- soft horizons at 35.1, 36.1, 36.65, 37.5, 37.75, 38, 38.15, 39 and 39.85m. - fractured at 36.35 (0.2m), 37.35 (0.05m), 38.1 (0.05) and 38.85m (0.1m).	152.4		
36			151.4		
37			150.4		
38			149.4		
39			148.4		

DRILLING DETAILS

Drilled Depth:	77.50 mBGL
Bore Diameter:	96 mm
Date Borehole Started:	27/03/02
Date Borehole Completed:	27/03/02
Logged By:	PTJ
Drilling Company:	McNeill Drilling Co. Ltd

COMMENTS

The stratification lines represent approximate boundaries. The transition may be gradual

BOREHOLE SKM104

SINCLAIR KNIGHT MERZ

Sinclair Knight Merz Ltd.
25 Teed St, Newmarket
Auckland
Phone:
Fax:

Project:	AB LIME	**Ground Elevation:**	187.42 mAMSL
Job Number:	IV00319.04	**Top of Casing Elev.:**	187.68 mAMSL
Location:	AB LIME QUARRY, WINTON, NEW ZEALAND	**Drilling Method:**	HQ Coring
Coordinates:	E 2153261.9 N 5443788.6	**Sampling Method:**	Core

Depth (mBGL)	LITHOLOGICAL DESCRIPTION	Elevation (mAMSL)	Groundwater Level	Piezometer Construction Details
	- soft horizons at 40.3, 41.2, 41.8, 43.15, 44.15m. - fractured at 40.4m (0.25m), sl. orange brown staining.			
41		146.4		2-5mm Walton Park gravel
42		145.4		
43		144.4		
44		143.4		
45	- soft horizons at 45, 45.5, 47.75, 47.95, 49.7 and 49.75m. - fractured at 48.35m (0.15m). - crack at 47.3m (0.15m).	142.4		50mm Class D PVC piezometer
46		141.4		
47		140.4		
48		139.4		
49		138.4		
50	- soft horizon at 50.7m	137.4	∇	
51		136.4		
52	LIMESTONE - greenish grey, orange brown, mottles, sl. weathered, massive, mod. strong, biomicrite/biosparite LIMESTONE, skeletal particles. [FORREST HILL FORMATION]	135.4		
53	LIMESTONE - yellowish brown, unweathered to sl. weathered, mod. strong to strong, biosparite LIMESTONE, mod. thick to thickly bedded with interbedded thin (generally <0.04m thick) soft horizons, skeletal particles, occ. black specks (pyrite), occ. near vertical, tight and undulated rough fractures. [FORREST HILL FORMATION] - soft horizons at 53.75m. - fractured at 53.6m (0.15m)	134.4		
54		133.4		
55		132.4		
56	LIMESTONE - greenish grey and orange brown mottles, sl. weathered, massive, mod. strong, biomicrite/biosparite LIMESTONE, skeletal particles. [FORREST HILL FORMATION]	131.4		
57	LIMESTONE - greenish grey, unweathered, massive, weak to mod. strong, biomicrite LIMESTONE, skeletal particles. [FORREST HILL FORMATION] LIMESTONE - lt. greenish grey, unweathered, mod. strong to strong, biosparite LIMESTONE, massive, skeletal particles. [FORREST HILL FORMATION]	130.4		
58	LIMESTONE - greenish grey, unweathered, massive, weak to mod. strong, biomicrite LIMESTONE, skeletal particles. [FORREST HILL FORMATION]	129.4		
59	LIMESTONE - yellowish brown, unweathered to sl. weathered, mod. strong to strong, biosparite LIMESTONE, mod. thick to thickly bedded with interbedded thin (generally <0.04m) soft horizons, skeletal particles, occ. black specks (pyrite),	128.4		

DRILLING DETAILS		**COMMENTS**
Drilled Depth:	77.50 mBGL	
Bore Diameter:	96 mm	
Date Borehole Started:	27/03/02	
Date Borehole Completed:	27/03/02	
Logged By:	PTJ	
Drilling Company:	McNeill Drilling Co. Ltd	

The stratification lines represent approximate boundaries. The transition may be gradual.

SINCLAIR KNIGHT MERZ

BOREHOLE SKM104

Sinclair Knight Merz Ltd.
25 Teed St, Newmarket
Auckland
Phone:
Fax:

Project:	AB LIME	**Ground Elevation:**	187.42 mAMSL
Job Number:	IV00319.04	**Top of Casing Elev.:**	187.68 mAMSL
Location:	AB LIME QUARRY, WINTON, NEW ZEALAND	**Drilling Method:**	HQ Coring
Coordinates:	E 2153261.9 N 5443788.6	**Sampling Method:**	Core

Depth (mBGL)	LITHOLOGICAL DESCRIPTION	Elevation (mAMSL)	Piezometer Construction Details
	occ. near vertical, tight and undulated rough fractures. [FORREST HILL FORMATION]		
61	- soft horizons at 58, 58.1, 58.45, 58.6, 59.05, 59.3 and 59.9m. - crack at 58.3m. - greenish brown mottled horizon from 57.4 to 57.7m	126.4	12m Machine slotted screen
62	- soft horizons at 60.1, 60.5, 60.7, 60.95, 61.3, 62.15, 62.45, 62.7, 63.2, 63.8, 64.8 and 64.9m. - fractured at 61.45 (0.8m), orange brown staining, 62.3 (0.15m) and 64.3m (0.5m),	125.4	
63		124.4	
64		123.4	
65	- soft horizons at 65.2 and 65.3m.	122.4	
66	LIMESTONE - greenish grey, orange brown, mottles, sl. weathered, massive, mod. strong, biomicrite/biosparite LIMESTONE, skeletal particles. [FORREST HILL FORMATION]	121.4	
67	LIMESTONE - dk. greenish grey, unweathered, mod. strong to strong, massive, biosparite LIMESTONE, skeletal particles. [FORREST HILL FORMATION]	120.4	
68	- numerous fossils and shells from 67.6m.	119.4	
69	SILTSTONE - dk. greenish grey, unweathered, massive, strong SILTSTONE, sl. to mod. sandy (very fine grained), occ. shell fragments, black specks, sl. calcareous, occ. sandy gritty texture (possible bioturbation). [CHATTON FORMATION]	118.4	
70		117.4	
71		116.4	
72	- dk. grey.	115.4	Backfill
73	- decrease in sand at 72.5m	114.4	
74		113.4	
75		112.4	
76		111.4	
77	- occ. sandy inclusions (bioturbation)	110.4	
78	EOH @ 77.5m	109.4	
79		108.4	

Graphic Log | Groundwater Level

DRILLING DETAILS

Drilled Depth:	77.50 mBGL
Bore Diameter:	96 mm
Date Borehole Started:	27/03/02
Date Borehole Completed:	27/03/02
Logged By:	PTJ
Drilling Company:	McNeill Drilling Co. Ltd

COMMENTS

The stratification lines represent approximate boundaries. The transition may be gradual

SKM^YDRO_1 LIME.GPJ SKM2.GDT 21/06/02

BOREHOLE SKM105

SINCLAIR KNIGHT MERZ

Sinclair Knight Merz Ltd.
25 Teed St, Newmarket
Auckland
Phone:
Fax:

Project:	AB LIME	**Ground Elevation:**	123.09 mAMSL
Job Number:	IV00319.04	**Top of Casing Elev.:**	123.57 mAMSL
Location:	AB LIME QUARRY, WINTON, NEW ZEALAND	**Drilling Method:**	HQ Coring
Coordinates:	E 2152673.2 N 5443117.2	**Sampling Method:**	Core

Depth (mBGL)	Graphic Log	LITHOLOGICAL DESCRIPTION	Elevation (mAMSL)	Groundwater Level	Piezometer Construction Details
		TOPSOIL - dk. brown sl. clayey ORGANIC SILT.			Cement seal
		SILT - brown, mod. clayey SILT, plastic, firm to stiff. [COLLUVIUM]			
		LIMESTONE - yellowish brown, unweathered to sl. weathered, mod. strong to strong LIMESTONE, mod. thick to thickly bedded with interbedded thin (generally <0.04m) soft horizons, skeletal particles, occ. black specks (pyrite), occ. near vertical, tight and undulated rough fractures. [FORREST HILL FORMATION]			
1			122.1		
2		- soft horizons at 2.6, 6.25 and 6.5 (0.15m thick). - fractured at 2.9 (0.08m), calcite precipitation. - crack at 18.35m (0.25m).	121.1		
3			120.1		
4			119.1		
5		- soft horizons at 6.25 and 6.5m (0.15m thick).	118.1		
6			117.1		
7			116.1		
8			115.1		
9			114.1		
10		- soft horizon at 13.5m	113.1		Backfill
11			112.1		
12			111.1		
13			110.1		
14			109.1		
15		- soft horizons at 15.05, 15.3, 15.4, 16.5, 17.6, 17.7, 17.9, 18.35 and 18.85m - fractured at 19.7m (0.2m) calcite precipitation. - crack at 18.35m (0.25m).	108.1		
16			107.1		
17			106.1		
18			105.1		
19			104.1		

DRILLING DETAILS

Drilled Depth:	58.00 mBGL
Bore Diameter:	96 mm
Date Borehole Started:	04/03/02
Date Borehole Completed:	05/03/02
Logged By:	PTJ
Drilling Company:	McNeill Drilling Co. Ltd

COMMENTS

1. SKM105A & B

The stratification lines represent approximate boundaries. The transition may be gradual.

SINCLAIR KNIGHT MERZ

BOREHOLE SKM105

Sinclair Knight Merz Ltd.
25 Teed St, Newmarket
Auckland
Phone:
Fax:

Project:	AB LIME	**Ground Elevation:**	123.09 mAMSL
Job Number:	IV00319.04	**Top of Casing Elev.:**	123.57 mAMSL
Location:	AB LIME QUARRY, WINTON, NEW ZEALAND	**Drilling Method:**	HQ Coring
Coordinates:	E 2152673.2 N 5443117.2	**Sampling Method:**	Core

Depth (mBGL)	LITHOLOGICAL DESCRIPTION	Elevation (mAMSL)	Piezometer Construction Details
	- soft horizons at 20.5, 20.65, 20.9, 21.1m.		
21	LIMESTONE - greenish grey and orange brown, mottles, sl. weathered, massive, mod. strong, biomicrite-biosparite LIMESTONE, skeletal particles. [FORREST HILL FORMATION]	102.1	
22	LIMESTONE - yellowish brown, unweathered to sl. weathered, mod. strong to strong, massive, biosparite LIMESTONE, skeletal particles, occ. near vertical, tight and undulated rough fractures. [FORREST HILL FORMATION]	101.1	
23	- fractured at 23.1 (0.2m) sl. discolouration.	100.1	
24	LIMESTONE - greenish grey and orange brown, mottles, sl. weathered, massive, mod. strong, biomicrite-biosparite LIMESTONE, skeletal particles. [FORREST HILL FORMATION]	99.1	
25	LIMESTONE - yellowish brown, unweathered to sl. weathered, mod. strong to strong LIMESTONE, mod. thick to thickly bedded with interbedded thin (generally <0.04m) soft horizons, skeletal particles, occ. black specks (pyrite), occ. near vertical, tight and undulated rough fractures. [FORREST HILL FORMATION]	98.1	Bentonite seal
26	- soft horizons at 25.25, 25.7, 26.1, 26.3, 27.4 and 28.6m.	97.1	
27	- fractured at 25 (0.55m), sl. discolouration, 26.1 (0.2m), orange brown staining, 26.7 (0.2m), sl. calcite precipitation, 27.2 sl. discolouration, 28.8 (0.15m), 29.1 (0.1m), sl. orange brown staining and 29.5m.	96.1	
28		95.1	
29		94.1	
30	- soft horizons at 30, 30.2, 32.5, 31.15, 31.55, 32.1, 33.6 and 33.8m.	93.1	
31	- fractured at 31.75 (0.15m), 33.1 (0.2m), 34.3 (0.3m) and 35m (0.3m). - crack at 32.7m (0.05m).	92.1	
32		91.1	20mm PVC piezometer
33		90.1	
34		89.1	
35	- soft horizons at 35 (0.3m), 35.8, 38, 38.1, 38.9, 39.8 and 39.6m.	88.1	
36	- fractured at 35 (0.3m), 36.9 (0.6m), 36.9 (0.1m), 37.1 (0.1m), 38.55 (0.08m) and 39.3m (0.7m).	87.1	2-5mm Walton Park gravel
37		86.1	
38		85.1	
39		84.1	

DRILLING DETAILS

Drilled Depth:	58.00 mBGL
Bore Diameter:	96 mm
Date Borehole Started:	04/03/02
Date Borehole Completed:	05/03/02
Logged By:	PTJ
Drilling Company:	McNeill Drilling Co. Ltd

COMMENTS

1. SKM105A & B

The stratification lines represent approximate boundaries. The transition may be gradual

SINCLAIR KNIGHT MERZ

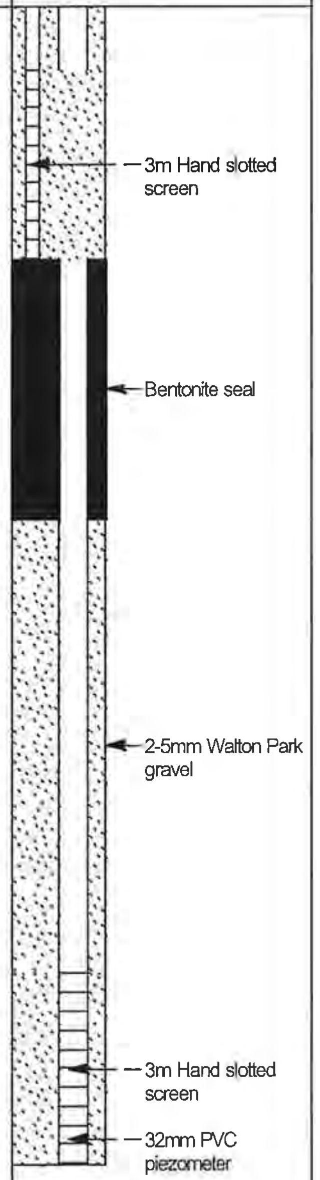
BOREHOLE SKM105

Sinclair Knight Merz Ltd.
25 Teed St, Newmarket
Auckland
Phone:
Fax:

Project:	AB LIME	**Ground Elevation:**	123.09 mAMSL
Job Number:	IV00319.04	**Top of Casing Elev.:**	123.57 mAMSL
Location:	AB LIME QUARRY, WINTON, NEW ZEALAND	**Drilling Method:**	HQ Coring
Coordinates:	E 2152673.2 N 5443117.2	**Sampling Method:**	Core

Depth (mBGL)	LITHOLOGICAL DESCRIPTION	Elevation (mAMSL)	Groundwater Level
	- soft horizon at 40.9, 41.7, 42.1, 42.3, 42.75, 43, 43.3, 44.4 and 44.65m. - fractured at 40.5 (0.15m), dk. orange brown staining and 44.7m (0.1m).		▼
41		82.1	
42		81.1	
43		80.1	
44		79.1	
45	- soft horizon at 45.85, 46.15, 46.6 and 47m - fractured at 46.15m (0.35m).	78.1	
46		77.1	
47		76.1	
48	LIMESTONE - greenish grey, orange brown, mottles, sl. weathered, massive, mod. strong, biomicrite-biosparite LIMESTONE, skeletal particles, silty/clayey matrix. [FORREST HILL FORMATION]	75.1	
49	LIMESTONE - yellowish brown, unweathered to sl. weathered, mod. strong to strong LIMESTONE, mod. thick to thickly bedded with interbedded thin (generally <0.04m) soft horizons, skeletal particles, occ. black specks (pyrite). [FORREST HILL FORMATION]	74.1	
50	- soft horizons at 48.95, 49.15, 49.25, 49.75, 49.95, 50.75 (0.25m), 51.25 and 54.5m.	73.1	
51	- shell horizon (0.2m).	72.1	
52	- increase in shells.	71.1	
53		70.1	
54		69.1	
55	- soft horizons at 55.05, 55.25 and 55.8m.	68.1	
56		67.1	
57		66.1	
58	EOH @ 58m	65.1	
59		64.1	

Piezometer Construction Details



DRILLING DETAILS

Drilled Depth:	58.00 mBGL
Bore Diameter:	96 mm
Date Borehole Started:	04/03/02
Date Borehole Completed:	05/03/02
Logged By:	PTJ
Drilling Company:	McNeill Drilling Co. Ltd

COMMENTS

1. SKM105A & B

The stratification lines represent approximate boundaries. The transition may be gradual

SKM HYDRO_1 LIME.GPJ SKM2.GDT 21/06/02

SINCLAIR KNIGHT MERZ

BOREHOLE SKM106

Sinclair Knight Merz Ltd.
25 Teed St, Newmarket
Auckland
Phone:
Fax:

Project:	AB LIME	**Ground Elevation:**	186.79 mAMSL
Job Number:	IV00319.04	**Top of Casing Elev.:**	186.98 mAMSL
Location:	AB LIME QUARRY, WINTON, NEW ZEALAND	**Drilling Method:**	HQ Coring
Coordinates:	E 2153764.5 N 5443144.9	**Sampling Method:**	Core

Depth (mBGL)	LITHOLOGICAL DESCRIPTION	Elevation (mAMSL)	Piezometer Construction Details
	TOPSOIL - dk. brown sl. clayey ORGANIC SILT.		Cement seal
	SILT - brown, mod. clayey SILT, plastic, firm to stiff. [COLLUVIUM]		
1	LIMESTONE - yellowish brown, unweathered to sl. weathered, mod. strong to strong LIMESTONE, mod. thick to thickly bedded with interbedded thin (generally <0.04m) soft horizons, skeletal particles, occ. black specks (pyrite), occ. near vertical, tight and undulated rough fractures. [FORREST HILL FORMATION]	185.8	
2	- 0.25 core loss from 0 to 1m, 0.65m core loss from 1 to 2.5m, 0.43 core loss from 2.5 to 4m.	184.8	
3	- 0.5 to 4m, very fractured with occasional soft horizons. - soft horizon at 4.9m.	183.8	
4		182.8	
5	- soft horizons at 5.05, 5.4, 6, 6.2, 8.9, 9.2 and 9.9m. - cracks at 6.7 (0.1m) and 9.1m (0.1m).	181.8	
6		180.8	
7		179.8	
8		178.8	
9		177.8	
10	- soft horizon at 10.9, 11.1, 11.3, 11.8, 12.2, 12.9, 13.8, 14.2 (0.1m), 14.5 and 14.8 (0.1m). - fractured at 10.2 (0.2m), 11.7 (0.5m), 12.75 (0.25m), 13.2 (0.1m) and 13.4 (0.25m). - crack at 10.8 (0.1m). - crush zone (0.4m thick).	176.8	Backfill
11		175.8	
12		174.8	
13		173.8	
14		172.8	
15	- soft horizon at 15.35, 15.5, 15.85, 16.6 (0.08m), 17 and 18.7m. - fractured at 17.1 (0.04m),17.6 (0.1m), 18.4 (0.15m) and 18.8 (0.2m). - cracks at 15.7 (0.15m) and 16.3 (0.1m).	171.8	
16		170.8	
17		169.8	
18		168.8	
19		167.8	

DRILLING DETAILS

Drilled Depth:	77.50 mBGL
Bore Diameter:	96 mm
Date Borehole Started:	07/03/02
Date Borehole Completed:	08/03/02
Logged By:	PTJ
Drilling Company:	McNeill Drilling Co. Ltd

COMMENTS

The stratification lines represent approximate boundaries. The transition may be gradual.

BOREHOLE SKM106

SINCLAIR KNIGHT MERZ

Sinclair Knight Merz Ltd.
25 Teed St, Newmarket
Auckland
Phone:
Fax:

Project:	AB LIME	**Ground Elevation:**	186.79 mAMSL
Job Number:	IV00319.04	**Top of Casing Elev.:**	186.98 mAMSL
Location:	AB LIME QUARRY, WINTON, NEW ZEALAND	**Drilling Method:**	HQ Coring
Coordinates:	E 2153764.5 N 5443144.9	**Sampling Method:**	Core

Depth (mBGL)	LITHOLOGICAL DESCRIPTION	Elevation (mAMSL)
	- soft horizons at 20, 20.35, 20.45, 23, 23.45, 23.65, 23.9, 24.15, 24.65, 25.1, 25.2, 25.4, 26.4 and 26.8m. - fractured at 22m (0.2m).	
21		165.8
22		164.8
23		163.8
24		162.8
25		161.8
26	- increase of clay in matrix from 25.7 to 26m and 26.2 to 26.4m.	160.8
27		159.8
28	LIMESTONE - greenish grey and orange brown mottles, sl. weathered, massive, mod. strong, biomicrite/biosparite LIMESTONE, skeletal particles, silty/clayey matrix. [FORREST HILL FORMATION]	158.8
29	LIMESTONE - yellowish brown, unweathered to sl. weathered, mod. strong to strong LIMESTONE, mod. thick to thickly bedded with interbedded thin (generally <0.04m) soft horizons, skeletal particles, occ. black specks (pyrite), occ. near vertical, tight and undulated rough fractures. [FORREST HILL FORMATION]	157.8
30	- soft horizons at 29.8, 30.05, 30.1, 30.5, 31.05, 31.85, 32.15, 32.9, 33.7, 33.8, 34.05 and 34.5m. - fractured at 29.5 (0.15m) dk. red brown staining, 30.35 (0.1m), 31.9 (0.25m), 32.3 (0.1), 32.55 (0.1m), 33 (0.1m) and 34.95m (0.55m).	156.8
31		155.8
32		154.8
33		153.8
34		152.8
35	- soft horizons at 35.3, 36.25, 36.45, 36.7, 37.1, 37.6, 38.15, 38.35, 38.65, 39, 39.1 and 39.7m. - fractured at 35.9 (0.3m), 37.3 (0.1m) and 38.6m (0.2m).	151.8
36		150.8
37		149.8
38		148.8
39		147.8

Groundwater Level

Piezometer Construction Details: Bentonite seal

DRILLING DETAILS

Drilled Depth:	77.50 mBGL
Bore Diameter:	96 mm
Date Borehole Started:	07/03/02
Date Borehole Completed:	08/03/02
Logged By:	PTJ
Drilling Company:	McNeill Drilling Co. Ltd

COMMENTS

The stratification lines represent approximate boundaries. The transition may be gradual.

SINCLAIR KNIGHT MERZ

BOREHOLE SKM106

Sinclair Knight Merz Ltd.
25 Teed St, Newmarket
Auckland
Phone:
Fax:

Project:	AB LIME	**Ground Elevation:**	186.79 mAMSL
Job Number:	IV00319.04	**Top of Casing Elev.:**	186.98 mAMSL
Location:	AB LIME QUARRY, WINTON, NEW ZEALAND	**Drilling Method:**	HQ Coring
Coordinates:	E 2153764.5 N 5443144.9	**Sampling Method:**	Core

Depth (mBGL)	LITHOLOGICAL DESCRIPTION	Elevation (mAMSL)	Piezometer Construction Details
	- soft horizons at 40.4, 41, 41.2, 42.2, 42.4, 42.55, 42.6, 43.4, 43.7 and 44.1m. - fractured at 42.4m (0.15m). - crack at 44.3m (0.07m) n shaped.		
41		145.8	
42		144.8	
43		143.8	
44		142.8	
45	- soft horizons at 45.8, 45.55, 45.3, 46.15, 46.8, 46.95, 47.15, 47.4, 47.7 and 48m.	141.8	
46		140.8	
47		139.8	
48		138.8	
49	- increase clay in matrix 49.5 to 50.1m.	137.8	
50	- soft horizons at 50.95, 51.1, 51.85, 52.2, 52.5 and 54.6m. - crack at 54.9m (0.07m).	136.8	
51		135.8	
52		134.8	2-5mm Walton Park gravel
53		133.8	
54		132.8	
55	- soft horizons at 56.4 and 57.3m. - fracture at 59.25m. - crack at 59.9m (0.15m).	131.8	50mm Class D PVC piezometer
56		130.8	
57		129.8	
58		128.8	
59		127.8	

DRILLING DETAILS

Drilled Depth:	77.50 mBGL
Bore Diameter:	96 mm
Date Borehole Started:	07/03/02
Date Borehole Completed:	08/03/02
Logged By:	PTJ
Drilling Company:	McNeill Drilling Co. Ltd

COMMENTS

The stratification lines represent approximate boundaries. The transition may be gradual.

SINCLAIR KNIGHT MERZ

BOREHOLE SKM106

Sinclair Knight Merz Ltd.
25 Teed St, Newmarket
Auckland
Phone:
Fax:

Project:	AB LIME	**Ground Elevation:**	186.79 mAMSL
Job Number:	IV00319.04	**Top of Casing Elev.:**	186.98 mAMSL
Location:	AB LIME QUARRY, WINTON, NEW ZEALAND	**Drilling Method:**	HQ Coring
Coordinates:	E 2153764.5 N 5443144.9	**Sampling Method:**	Core

Depth (mBGL)	LITHOLOGICAL DESCRIPTION	Elevation (mAMSL)	Groundwater Level	Piezometer Construction Details
	- soft horizons at 60.1, 60.6 and 60.95m.			
61		125.8		
62	LIMESTONE - greenish grey and orange brown, mottles, sl. weathered, massive, mod. strong, biomicrite/biosparite LIMESTONE, skeletal particles. [FORREST HILL FORMATION]	124.8		
63	LIMESTONE - yellowish brown, unweathered to sl. weathered, mod. strong to strong LIMESTONE, massive, skeletal particles, occ. black specks (pyrite), occ. near vertical, tight and undulated rough fractures. [FORREST HILL FORMATION]	123.8		
64	LIMESTONE - greenish grey and orange brown mottles, sl. weathered, massive, mod. strong, biomicrite/biosparite LIMESTONE, skeletal particles. [FORREST HILL FORMATION]	122.8		
65	LIMESTONE - greenish grey, unweathered, massive, weak to mod. strong, biomicrite LIMESTONE, skeletal particles. [FORREST HILL FORMATION]	121.8	∇	
66	LIMESTONE - lt. greenish grey, unweathered, massive, mod. strong to strong, biosparite LIMESTONE, skeletal particles. [FORREST HILL FORMATION] - yellowish brown.	120.8		
67	LIMESTONE - greenish grey and orange brown, mottles, sl. weathered, massive, mod. strong LIMESTONE, skeletal particles. [FORREST HILL FORMATION]	119.8		
68	LIMESTONE - yellowish brown, unweathered to sl. weathered, mod. strong to strong LIMESTONE, mod. thick to thickly bedded with interbedded thin (generally <0.04m thick) soft horizons, skeletal particles, occ. black specks (pyrite). [FORREST HILL FORMATION] - soft horizon at 66.7, 66.8, 67.2, 67.4 (0.11m), 67.8 (0.15m), 68.05, 68.4 (0.25m), 69, 69.1, 69.4, 69.7, 70.1m.	118.8		
69		117.8		
70		116.8		
71		115.8		12m Machine slotted screen
72		114.8		
73	- soft shelly horizon from 72.35 to 72.9m.	113.8		
74	LIMESTONE - greenish grey and orange brown, mottles, sl. weathered, massive, mod. strong LIMESTONE, skeletal particles. [FORREST HILL FORMATION]	112.8		
75	LIMESTONE - greenish grey, unweathered, massive, weak to mod. strong, biomicrite LIMESTONE, skeletal particles. [FORREST HILL FORMATION]	111.8		
76		110.8		
77	SILTSTONE - dk. greenish grey, unweathered, massive, strong SILTSTONE, sl. to mod. sandy (very fine grained), occ. shell fragments, black specks, sl. calcareous, occ. sandy/gritty inclusions (possible bioturbation). [CHATTON FORMATION]	109.8		
78	EOH @ 77.5m	108.8		
79		107.8		

DRILLING DETAILS

Drilled Depth:	77.50 mBGL
Bore Diameter:	96 mm
Date Borehole Started:	07/03/02
Date Borehole Completed:	08/03/02
Logged By:	PTJ
Drilling Company:	McNeill Drilling Co. Ltd

COMMENTS

The stratification lines represent approximate boundaries. The transition may be gradual

SINCLAIR KNIGHT MERZ

BOREHOLE SKM107

Sinclair Knight Merz Ltd.
25 Teed St, Newmarket
Auckland
Phone:
Fax:

Project:	AB LIME	**Ground Elevation:**	96.15 mAMSL
Job Number:	IV00319.04	**Top of Casing Elev.:**	96.33 mAMSL
Location:	AB LIME QUARRY, WINTON, NEW ZEALAND	**Drilling Method:**	HQ Coring
Coordinates:	E 2153279.5 N 5442807.0	**Sampling Method:**	Core

Depth (mBGL)	LITHOLOGICAL DESCRIPTION	Elevation (mAMSL)	Piezometer Construction Details
0	TOPSOIL - dk. brown sl. clayey ORGANIC SILT.		Cement seal
	SILT - brown, mod. clayey SILT, plastic, firm to stiff. [COLLUVIUM]		
1		95.2	
	LIMESTONE - yellowish brown, unweathered to sl. weathered, mod. strong to strong, biosparite LIMESTONE, mod. thick to thickly bedded with interbedded thin (generally <0.04m) soft horizons, skeletal particles, occ. black specks (pyrite), occ. near vertical, tight and undulated rough fractures. [FORREST HILL FORMATION] - cavities at 1.35 to 1.6m. - 0.3 core loss from 4 to 4.5m, 1m core loss from 5.5 to 7m, 1.2m core loss from 7 to 8.5m, 0.8m core loss from 8.5 to 10m. - fractured from 1.3m to 13.6m and 14.3 to 25m.		
2		94.2	
3		93.2	
4		92.2	
5		91.2	Backfill
	- cavity at 5.2 to 5.9m.		
6		90.2	
	- cavity at 6.1 to 6.4m.		
7		89.2	
8		88.2	
9		87.2	
10		86.2	
11		85.2	
12		84.2	
13		83.2	
14		82.2	
15	- soft horizons at 15.8, 17, 18, 18.3, 19, 19.6, 19.8m.	81.2	
16		80.2	
17		79.2	
18		78.2	Bentonite seal
19		77.2	

DRILLING DETAILS	
Drilled Depth:	59.00 mBGL
Bore Diameter:	96 mm
Date Borehole Started:	08/03/02
Date Borehole Completed:	09/03/02
Logged By:	PTJ
Drilling Company:	McNeill Drilling Co. Ltd

COMMENTS

1. SKM107A & B

The stratification lines represent approximate boundaries. The transition may be gradual.

SINCLAIR KNIGHT MERZ

BOREHOLE SKM107

Sinclair Knight Merz Ltd.
25 Teed St, Newmarket
Auckland
Phone:
Fax:

Project:	AB LIME	**Ground Elevation:**	96.15 mAMSL
Job Number:	IV00319.04	**Top of Casing Elev.:**	96.33 mAMSL
Location:	AB LIME QUARRY, WINTON, NEW ZEALAND	**Drilling Method:**	HQ Coring
Coordinates:	E 2153279.5 N 5442807.0	**Sampling Method:**	Core

Depth (mBGL)	LITHOLOGICAL DESCRIPTION	Elevation (mAMSL)
	- soft horizons at 21.5, 21.8, 23 and 24.2m. - fractured from 20 to 26.1m.	
21		75.2
22		74.2
23		73.2
24		72.2
25	- soft horizons at 25.05, 25.5, 25.6, 29.1m - crack at 28.8m (0.2m)	71.2
26		70.2
27		69.2
28		68.2
29		67.2
30	- soft horizons at 33.7 (0.3m thick) and 36.6m. - fractured at 34.3m (0.1m).	66.2
31		65.2
32		64.2
33	- sl. darker in colour from 32.8 to 33.5m.	63.2
34		62.2
35		61.2
36		60.2
37	LIMESTONE - greenish grey and orange brown mottles, sl. weathered, massive, mod. strong, biomicrite-biosparite LIMESTONE, skeletal particles. [FORREST HILL FORMATION]	59.2
38	LIMESTONE - lt. greenish grey, unweathered, massive, mod. strong to strong, biosparite LIMESTONE, skeletal particles. [FORREST HILL FORMATION]	58.2
39	LIMESTONE - greenish grey, unweathered, massive, weak to mod. strong, biomicrite LIMESTONE, skeletal particles. [FORREST HILL FORMATION]	57.2

Groundwater Level

Piezometer Construction Details: 2-5mm Walton Park gravel

DRILLING DETAILS

Drilled Depth:	59.00 mBGL
Bore Diameter:	96 mm
Date Borehole Started:	08/03/02
Date Borehole Completed:	09/03/02
Logged By:	PTJ
Drilling Company:	McNeill Drilling Co. Ltd

COMMENTS

1. SKM107A & B

The stratification lines represent approximate boundaries. The transition may be gradual.

SINCLAIR KNIGHT MERZ

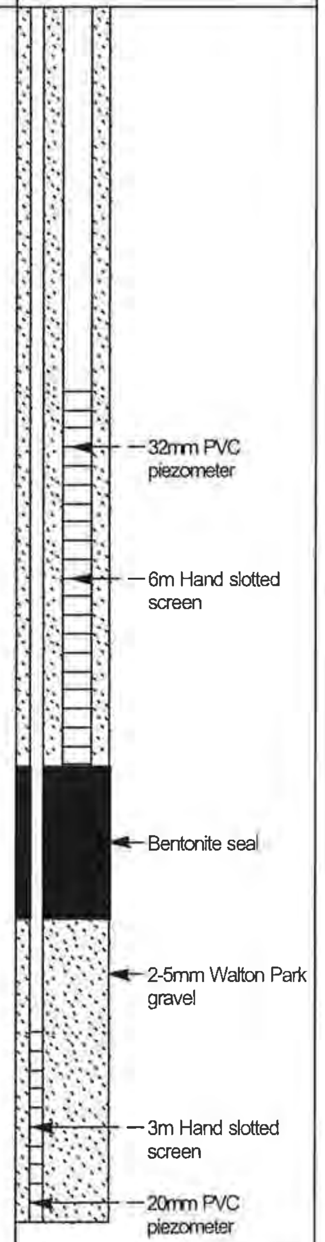
BOREHOLE SKM107

Sinclair Knight Merz Ltd.
25 Teed St, Newmarket
Auckland
Phone:
Fax:

Project:	AB LIME	**Ground Elevation:**	96.15 mAMSL
Job Number:	IV00319.04	**Top of Casing Elev.:**	96.33 mAMSL
Location:	AB LIME QUARRY, WINTON, NEW ZEALAND	**Drilling Method:**	HQ Coring
Coordinates:	E 2153279.5 N 5442807.0	**Sampling Method:**	Core

Depth (mBGL)	LITHOLOGICAL DESCRIPTION	Elevation (mAMSL)
	LIMESTONE - lt. greenish grey, unweathered, massive, mod. strong to strong, biosparite LIMESTONE, skeletal particles. [FORREST HILL FORMATION]	
41	LIMESTONE - greenish grey, unweathered, massive, weak to mod. strong, biomicrite LIMESTONE, skeletal particles. [FORREST HILL FORMATION]	55.2
42	LIMESTONE - lt. greenish grey, unweathered, massive, mod. strong to strong, biosparite LIMESTONE, skeletal particles. [FORREST HILL FORMATION] - fractured at 40.3 (0.1m), C shaped, sl. fractured at 42m.	54.2
43		53.2
44		52.2
45		51.2
46		50.2
47		49.2
48	- large amount of shell material from 48.1 to 48.6m	48.2
49	- dk. greenish grey inclusions at 49.1m.	47.2
50		46.2
51	- very gritty texture and large amount of shells from 51.2 to 52m.	45.2
52	SILTSTONE - dk. greenish grey, unweathered, massive, strong SILTSTONE, sl. to mod. sandy (very fine grained), occ. shell fragments, black specks, sl. calcareous, occ. sandy/gritty inclusions (possible bioturbation). [CHATTON FORMATION]	44.2
53		43.2
54		42.2
55		41.2
56		40.2
57		39.2
58		38.2
59	EOH @ 59m.	37.2

Graphic Log | Groundwater Level | Piezometer Construction Details



DRILLING DETAILS

Drilled Depth:	59.00 mBGL
Bore Diameter:	96 mm
Date Borehole Started:	08/03/02
Date Borehole Completed:	09/03/02
Logged By:	PTJ
Drilling Company:	McNeill Drilling Co. Ltd

COMMENTS

1. SKM107A & B

The stratification lines represent approximate boundaries. The transition may be gradual.

SKMHYDRO_1 LIME.GPJ SKM2.GDT 21/06/02

SINCLAIR KNIGHT MERZ

BOREHOLE SKM108

Sinclair Knight Merz Ltd.
25 Teed St, Newmarket
Auckland
Phone:
Fax:

Project:	AB LIME	**Ground Elevation:**	66.19 mAMSL
Job Number:	IV00319.04	**Top of Casing Elev.:**	66.32 mAMSL
Location:	AB LIME QUARRY, WINTON, NEW ZEALAND	**Drilling Method:**	HQ Coring
Coordinates:	E 2152768.0 N 5442563.3	**Sampling Method:**	Core

Depth (mBGL)	LITHOLOGICAL DESCRIPTION	Elevation (mAMSL)
0	TOPSOIL - dk. brown sl. clayey ORGANIC SILT, soft, plastic, occ. orange brown streaks, occ. hard small nodules.	
1	SILT - brownish grey, mod. clayey SILT, plastic, stiff, non plastic, occ. limonitic nodules, occ. orange brown streaks. [ALLUVIUM] - 0 to 1.4m, 0.8m loss of core.	65.2
2	- blue grey , green mottles, orange brown streaks.	64.2
3	- very soft, loss of core from 3m.	63.2
3.4	LIMESTONE - lt. greenish grey, unweathered, massive, mod. strong to strong, biosparite LIMESTONE, skeletal particles. [FORREST HILL FORMATION]	
4		62.2
5		61.2
6		60.2
7	- sl. darker greenish grey 6.8 to 8.8m, gritty texture.	59.2
8	- sl. porous.	58.2
9	- occ. small cracks with orange brown staining. - less gritty. - fracture (0.08m), sl. orange brown staining.	57.2
10		56.2
11		55.2
12		54.2
13		53.2
14	- slickensided fracture at 13.6m (0.1m), sl. discolouration (dk green) on fracture	52.2
15	- sl .vesicular from 14.7m and grittier.	51.2
16		50.2
17		49.2
18		48.2
19		47.2

Groundwater Level: ▽ at approx. 1 m

Piezometer Construction Details
- Cement seal
- Bentonite seal
- 2-5mm Walton Park gravel
- 50mm Class D PVC piezometer
- 6m Machine slotted screen

DRILLING DETAILS	
Drilled Depth:	20.50 mBGL
Bore Diameter:	96 mm
Date Borehole Started:	06/03/02
Date Borehole Completed:	06/03/02
Logged By:	PTJ
Drilling Company:	McNeill Drilling Co. Ltd

COMMENTS

The stratification lines represent approximate boundaries. The transition may be gradual.

SKMHYDRO_1 LIME.GPJ SKM2.GDT 21/06/02

SINCLAIR KNIGHT MERZ

BOREHOLE SKM108

Sinclair Knight Merz Ltd.
25 Teed St, Newmarket
Auckland
Phone:
Fax:

Project:	AB LIME	**Ground Elevation:**	66.19 mAMSL
Job Number:	IV00319.04	**Top of Casing Elev.:**	66.32 mAMSL
Location:	AB LIME QUARRY, WINTON, NEW ZEALAND	**Drilling Method:**	HQ Coring
Coordinates:	E 2152768.0 N 5442563.3	**Sampling Method:**	Core

Depth (mBGL)	Graphic Log	LITHOLOGICAL DESCRIPTION	Elevation (mAMSL)	Groundwater Level	Piezometer Construction Details
		EOH @ 20.5m			
21			45.2		
22			44.2		
23			43.2		
24			42.2		
25			41.2		
26			40.2		
27			39.2		
28			38.2		
29			37.2		
30			36.2		
31			35.2		
32			34.2		
33			33.2		
34			32.2		
35			31.2		
36			30.2		
37			29.2		
38			28.2		
39			27.2		

DRILLING DETAILS

Drilled Depth:	20.50 mBGL
Bore Diameter:	96 mm
Date Borehole Started:	06/03/02
Date Borehole Completed:	06/03/02
Logged By:	PTJ
Drilling Company:	McNeill Drilling Co. Ltd

COMMENTS

The stratification lines represent approximate boundaries. The transition may be gradual.

Appendix B Rock Hydraulic Testing

B.1 Packer Tests

Packer testing of open hole sections within SKM104 and SKM105 was conducted using a single Longyear wireline pneumatic packer, which permitted sealing and testing of the bottom one to three metre intervals during drilling. The packer was inflated and testing was conducted over a range of pressures (50-150 kPa). Eight separate intervals were isolated and tested in this manner. Figures C1 to C3 provides comparison of flow rate to pressure for each test interval.

Hydraulic conductivity for a constant pressure test using packers is given by the formula:

- **Equation 3** $$K = \frac{Q}{2\pi LH} \text{Log}_e \frac{L}{r}$$

Where:
K is hydraulic conductivity in m/day;
Q is rate of flow;
L is the length of test zone;
H is the pressure head at mid-test zone (after gravity and friction corrections);
r is the test zone radius.

Table 6-3 of the report summarises the results from this analysis.

B.2 Slug Tests

Slug tests were conducted on boreholes SKM101A, SKM101B, SKM101C, SKM102A, SKM102B, SKM103A, SKM104, SKM105B, SKM107A, SKM107B and SKM108. Data analysis results from the field-testing are presented in the following figures.

B.2.1 Field Procedure

The following outlines the steps implemented during the field testing procedure:

- Groundwater levels in all the bores were measured and recorded prior to the slug test.
- An instantaneous injection of between half a litre and one and a half litres of water was inserted into the bore.
- The recovering water level in the bore was measured and recorded at appropriate intervals until groundwater levels had reached a quasi steady state.

B.2.2 Analysis Methodology and Test Results

Data from the field-testing were analysed using Aquifer Test, a software package developed for graphical analysis and reporting of pumping test and slug test data. Analysis of the slug test data was performed using the Bouwer-Rice Method (Equation 1) and Hvorslev Method (Equation 2), which are applicable to unconfined aquifers and single well tests. Two methods of analysis are employed to provide an independent check or verification of the other method. The mathematical equations for each method are summarised below:

Bouwer-Rice Method

- **Equation 1** $$K = \frac{r_c^2 \ln(R_e / r_w)}{2d} \frac{1}{t} \frac{h_o}{h_t}$$

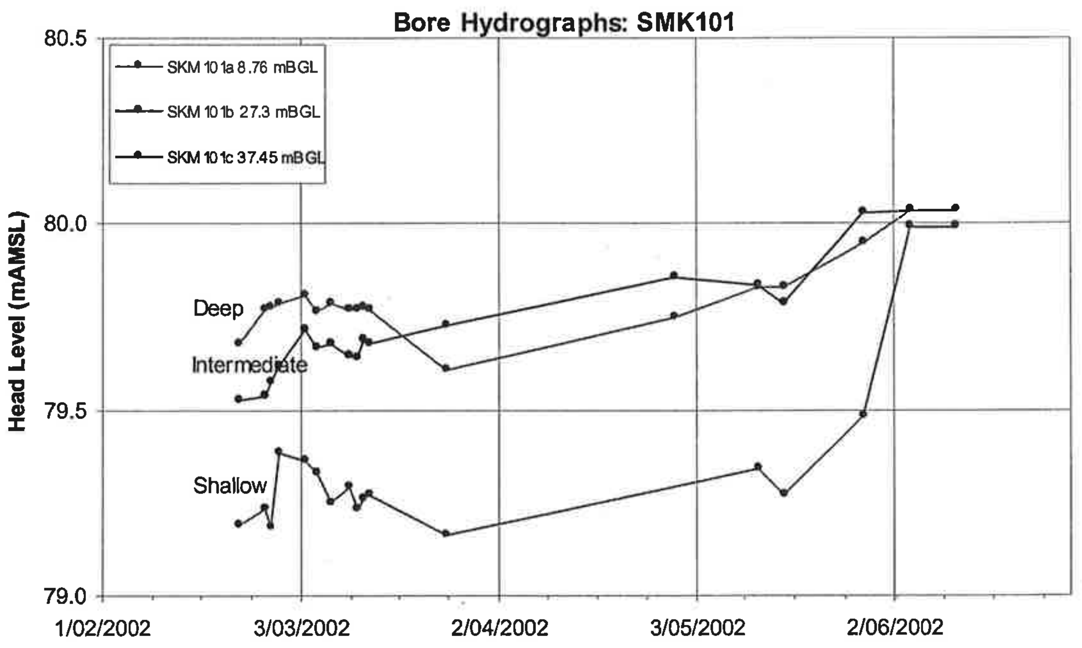
Where:
K is hydraulic conductivity in m/day;
r_c is the bore casing radius or the radius of the unscreened portion of the bore where the head is rising;
R_e is radial distance over which the difference in head is dissipated in the flow system of the aquifer. R_e cis rarely know and is obtained from empirical curves using d/r_w;
r_w is horizontal distance from well centre to undisturbed aquifer;
t is time since the test started;
h_o is head in well at time t_o=0;
h_t is head in well at time $t > t_o$; and
d is length of screen or open section of bore.

Hvorslev Method

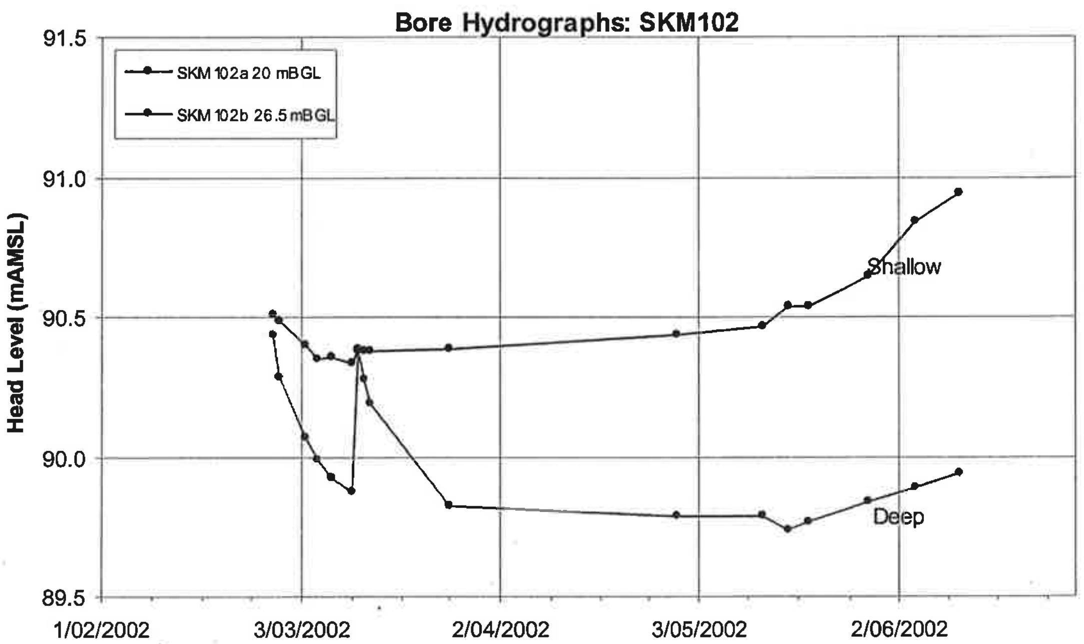
- **Equation 2** $$K = \frac{r^2 \ln(L / R)}{2LT_o}$$

Where:
r is the radius of well casing;
L is length of well screen plus filter packing; if it extends above the top of screen;
R is radius of screen plus packing (effective radius);
T_o is time to reach 37% of H_o.

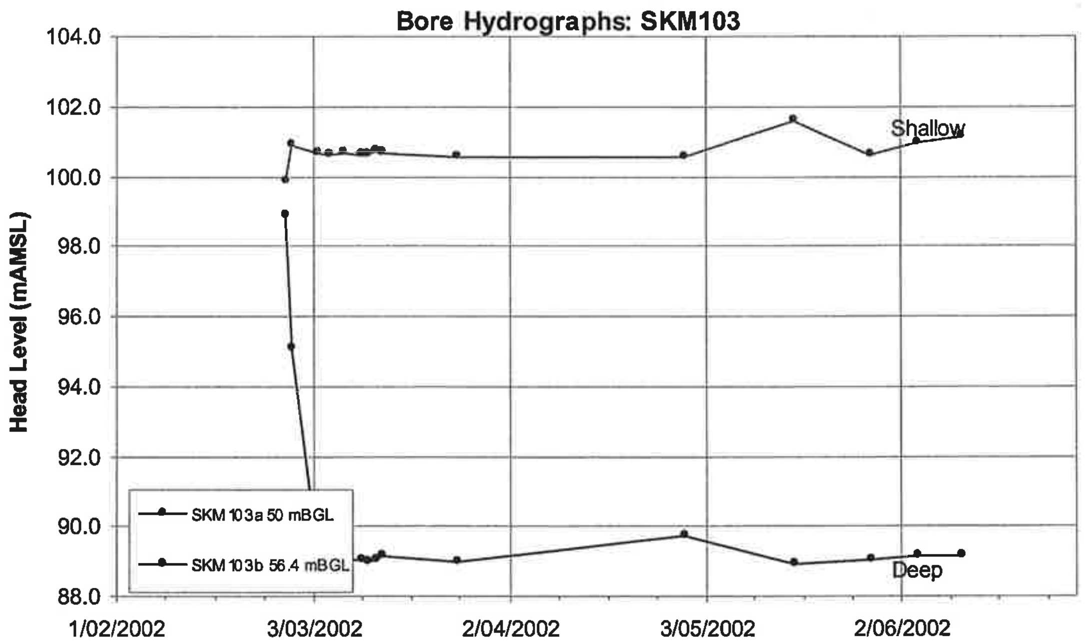
Appendix C Groundwater Monitoring Results



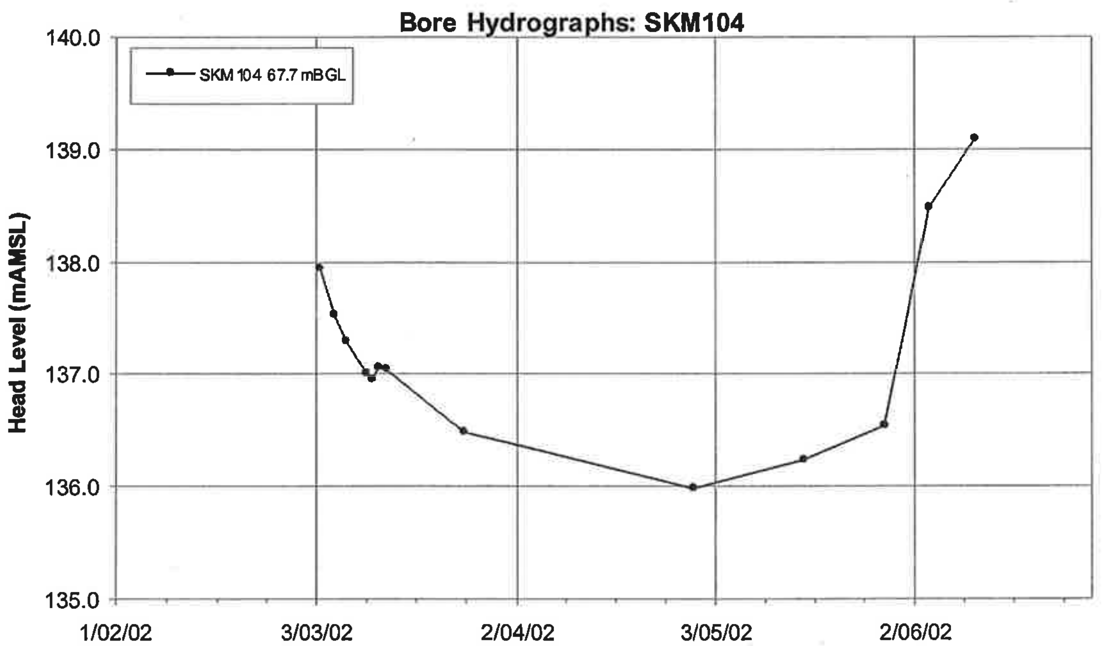
■ **Figure C-1 Bore hydrographs for SKM101**



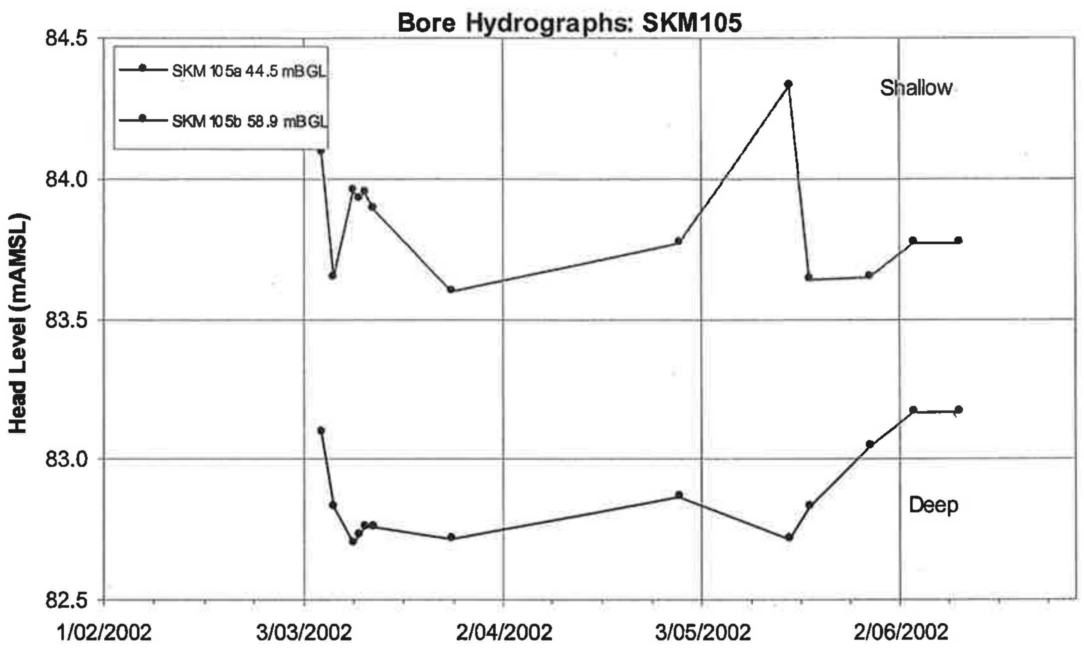
■ **Figure C-2 Bore hydrographs for SKM102**



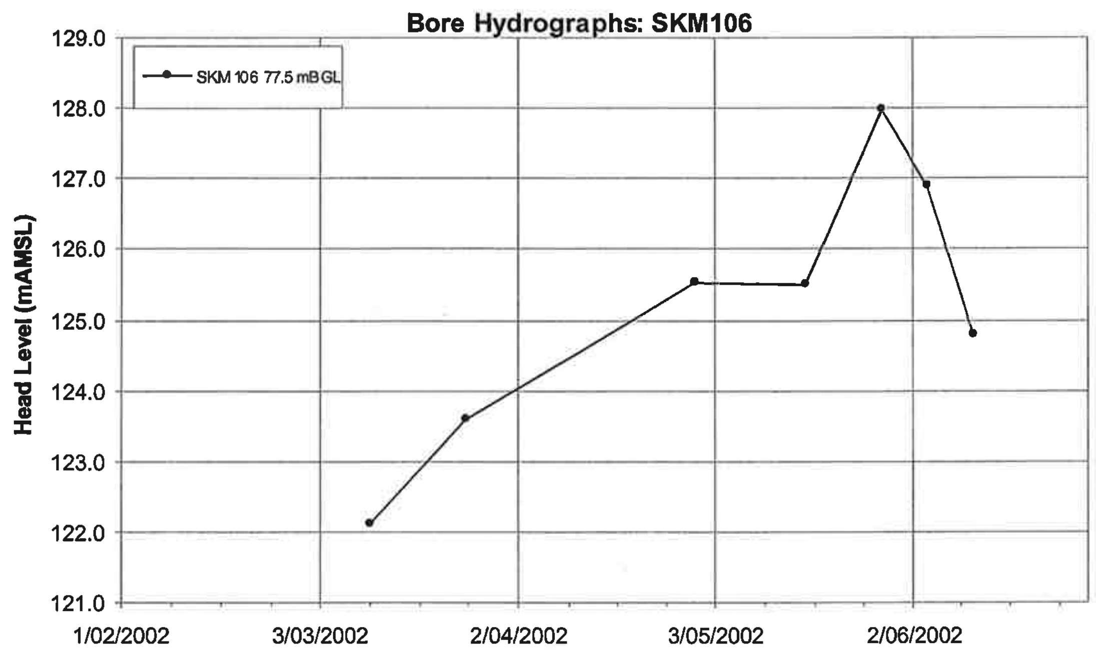
■ **Figure C-3 Bore hydrographs for SKM103**



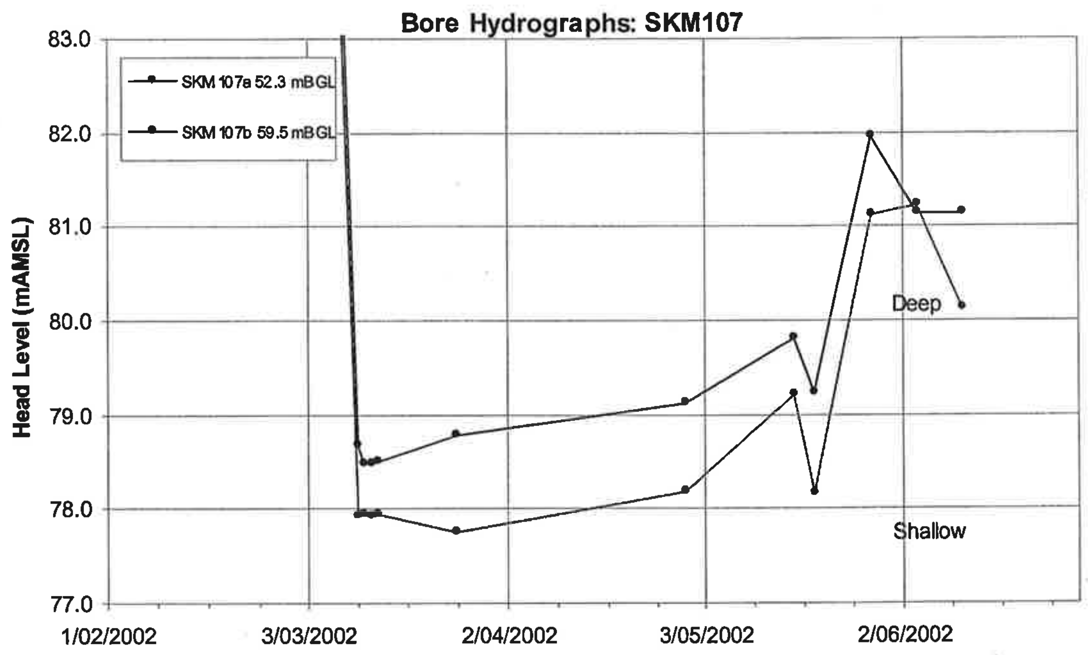
■ **Figure C-3 Bore hydrographs for SKM104**



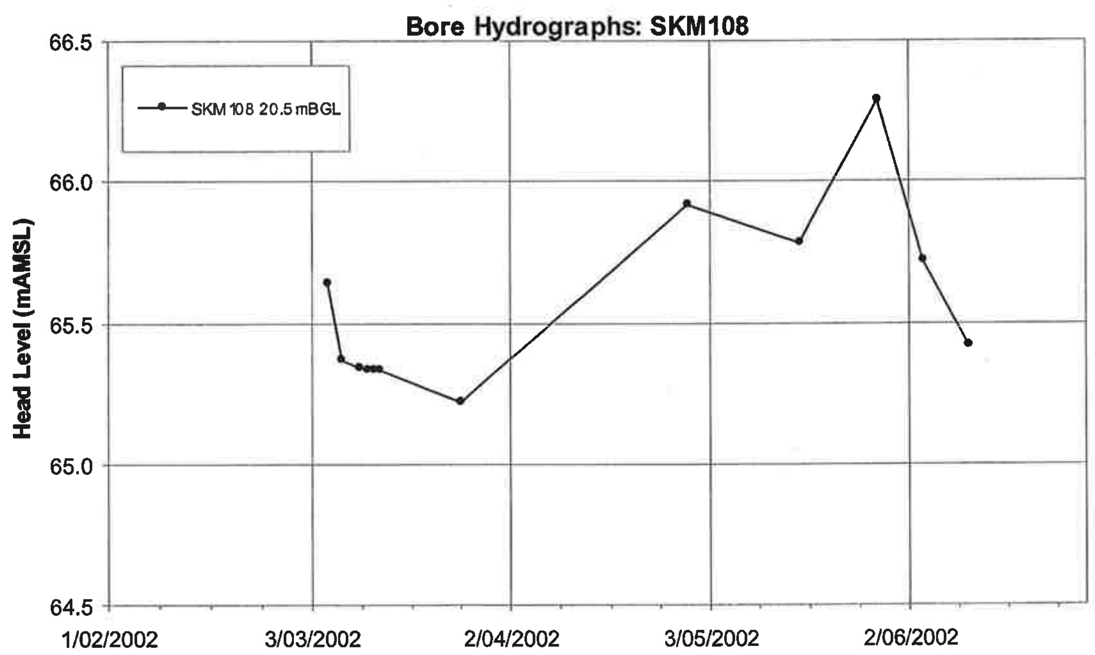
■ **Figure C-4 Bore hydrographs for SKM105**



■ **Figure C-5 Bore hydrograph for SKM106**



■ **Figure C-6 Bore hydrographs for SKM107**



■ **Figure C-7 Bore hydrograph for SKM108**

Appendix E. Updated Landfill Operations Management Plan

AB Lime Limited

AB Lime Ltd Landfill Operations Management Plan

IZ000400-LFC-NG-RPT-0003 | 2

2 September 2020

AB Lime Ltd

Draft for Consenting Purposes

AB Lime Limited

Project No:	IZ000400
Document Title:	AB Lime Ltd Landfill Operations Management Plan
Document No.:	IZ000400-LFC-NG-RPT-0003
Revision:	2
Date:	2 September 2020
Client Name:	AB Lime Ltd
Project Manager:	Katrina Jensen
Author:	Walter Starke
File Name:	Landfill Operations Management Plan - Environment Southland s 92 Version

Jacobs New Zealand Limited

Level 2, Wynn Williams Building
47 Hereford Street
Christchurch Central
PO Box 1147, Christchurch 8140
New Zealand
T +64 3 940 4900
F +64 3 940 4901
www.jacobs.com

Document history and status

Revision	Date	Description	Author	Checked	Reviewed	Approved
1	29/05/2020	Final Draft for Consenting Purposes	Walter Starke	Craig Redmond	Andrew Henderson	Vince Pace
2	2/09/2020	Environment Southland s 92 Version	Walter Starke/Katrina Wilkinson	Ryan McCone	Andrew Henderson	Vince Pace

Contents

Abbreviations

- AB Lime: AB Lime Limited
- ADW: Aluminium Dross Waste
- ANZECC: Australian and New Zealand Environment and Conservation Council
- cm^2: centimetre squared
- COD: Chemical Oxygen Demand
- ELVs: End-of-Live Vehicles (shredding of waste from ELVs may be auto shredder residue)
- EMP: Environmental Management Plan
- EPA: Environmental Protection Agency
- ES: Environment Southland, i.e. Southland Regional Council
- GCL: Geocomposite Clay Liner
- g/m^3: grams per cubic metre
- h: horizontal
- HDPE: High Density Polyethylene
- HSNO: Hazardous Substances and New Organisms Act 1996
- H&S: Health and Safety
- IPR: Independent Peer Reviewer
- Jacobs: Jacobs New Zealand Limited
- k: permeability
- LOMP: Landfill Operations Management Plan
- MPI: Ministry for Primary Industries
- m^3: cubic metre
- NESCS: Resource Management (National Environmental Standard for Assessing and Managing Contaminants in Soil to Protect Human Health) Regulations 2011
- NZS: New Zealand Standard
- PCBU: Person Conducting a Business or Undertaking
- PCBs: Polychlorinated biphenyls
- POPs: Persistent organic pollutants
- PPE: Personal Protective Equipment
- ppm: parts per million
- SDC: Southland District Council
- SKM: Sinclair Knight Merz Limited, now part of Jacobs
- SRC: Southland Regional Council, i.e. Environment Southland
- SVOCs: Semi Volatile Organic Compounds
- TBC: To be confirmed
- TCLP: Toxic Characteristic Leaching Procedure
- USEPA: United States Environmental Protection Agency

- v: vertical
- VOCs: Volatile Organic Compounds
- µg: micro gram, i.e. 0.000001 gram

Important note about this report

This report has been prepared by Jacobs New Zealand Limited (Jacobs)for AB Lime Limited (the Client) for the purposes of a Landfill Operations Management Plan guiding the operations of the AB Lime landfill. Jacobs accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report (or any part of it) for any other purpose.

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by the Client and/or from other sources. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and conclusions as expressed in this report may change.

Jacobs derived the data in this report from information sourced from the Client (if any) and/or available in the public domain at the time or times outlined in this report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report.

Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

This report may also describe specific limitations and/or uncertainties which qualify its findings. Accordingly, this report should be read in full and no excerpts are to be taken as representative of the findings unless any such excerpt and the context in which it is intended to be used have been approved by Jacobs in writing.

1. Introduction

1.1 Purpose/Objective of the Landfill Operations Management Plan

The purpose of the AB Lime Ltd Landfill Operations Management Plan is to manage key operational aspects of the landfill in accordance with the corresponding legislative requirements outlined below in Section 2, in particular the resource consents granted by Environment Southland, and Southland District Council, and in accordance the New Zealand good practice landfill guidelines; such as the Technical Guidelines for Disposal to Land prepared by WasteMINZ (2018).

The Landfill Operations Management Plan has the following objectives relevant to resource consents held with the Southland District Council:

Nuisance Control:

i. To maintain a clean and tidy site

ii. To maintain screen and litter fences and ensure litter does not accumulate on the screens and litter fences

iii. To minimise wind-blown litter outside the site boundaries

Noise:

iv. To operate the landfill within the notional boundary noise limits

v. To keep all site machinery well maintained and hold all necessary compliance certification

Facilities and Maintenance:

vi. To minimise the establishment of vermin, insect and bird populations through effective management of the refuse disposal and process area

vii. To implement pest management strategies as required

Contaminated Land Procedures:

viii. To appropriately assess and manage contaminants in the soil to protect human health

ix. To appropriately identify procedures for asbestos management on site.

The Landfill Operations Management Plan has the following objectives relevant to resource consents held with Environment Southland:

i. To utilise an effective cover system to maintain quality site rehabilitation, while minimising long term leachate generation

ii. To limit face access, thus enabling the size of the active area to be minimised.

iii. To minimise stockpiling, both within and outside the footprint.

iv. To outline Waste Acceptance Criteria and Procedures:
   - To protect the receiving environment;
   - To protect the health and safety of people;
   - To maintain that all waste received is compatible with the land filling operation;
   - To maintain that all waste landfilled complies with 'Waste Acceptance Criteria' outlined in the relevant consent conditions.

v. To outline crisis response and emergency waste acceptance procedures:
   - To manage the identification of all special waste;
   - To pre-arrange the disposal of special waste;

- To have in place measures and appropriate provisions for disposal of each special waste load are in place before the waste arrives at the landfill.

vi. The placing of refuse and daily cover:

- To achieve a minimum in-situ refuse density of 0.8;
- To maintain a working face that is as small as possible;
- To cover all refuse daily;
- To manage special waste planning;
- To record the location of special waste by survey;

vii. The effective capping of the landfill:

- To minimise ingress of rainwater into the landfill;
- To minimise erosion and cracking of the cap through design, planting and maintenance

1.1.1 Management Plan Structure

The operation of AB Lime landfill and quarry requires a suite of environmental management and mitigation plans to operate the site. The Environmental Management Plan (EMP) sets the overall framework for the operation of the site and is supported by a series of sub management plans focusing on specialist environmental areas to effectively run the landfill and quarry. The Landfill Operations Management Plan is a sub management plan under this framework that manages key day to day operations and processes of the landfill. Figure 1 below illustrates the relationship between the Landfill Operations Management Plan and the remainder of the AB Lime management plan framework.

This plan has been prepared in accordance with the certification and submission process outlined in section 1 of the AB Lime Environmental Management Plan.

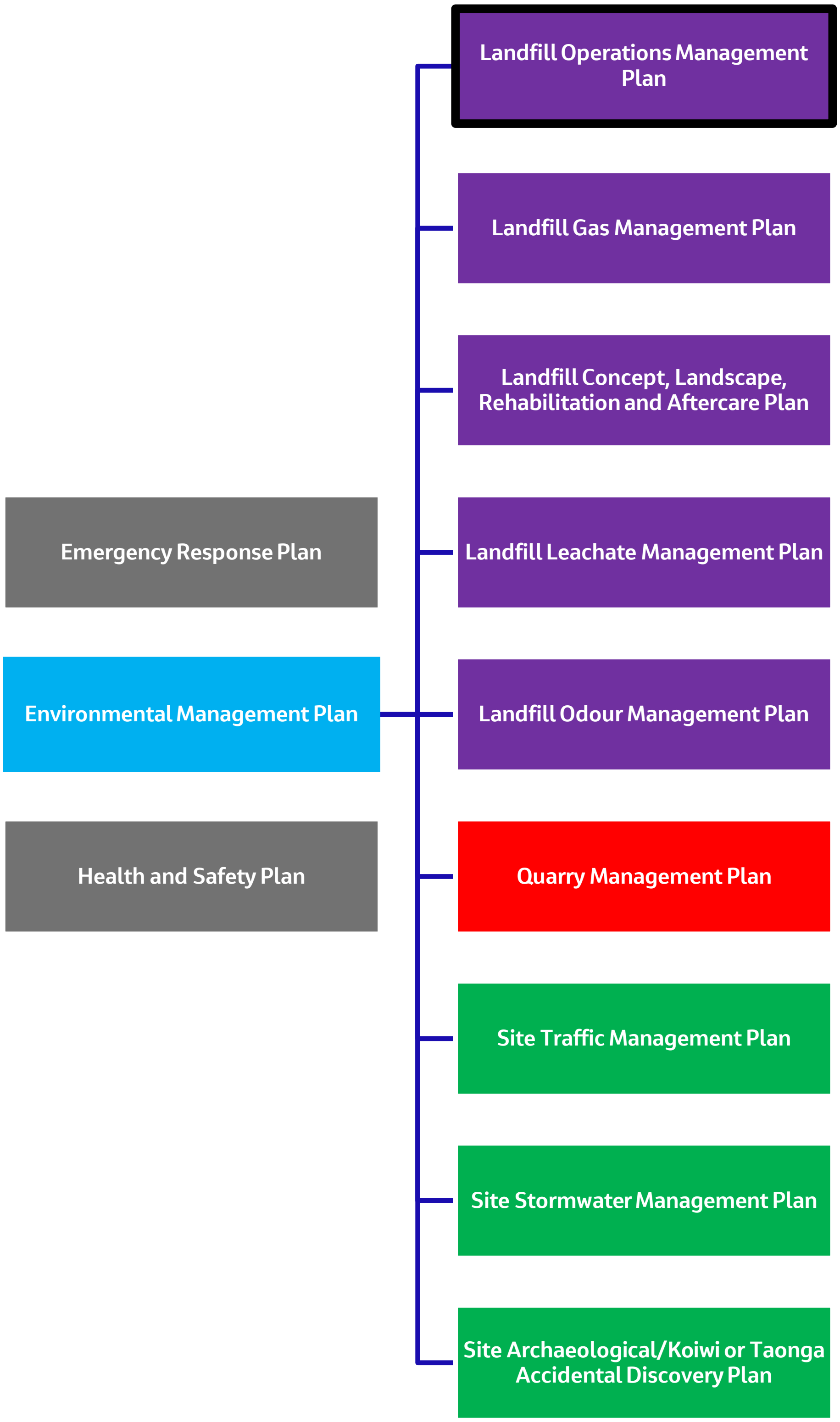


Figure 1 AB Lime Limited Management Plan Structure

Key:

2. Legislative Requirements

The legislative requirements of this Landfill Operations Management Plan outline the consent conditions that this plan is designed to assist with implementing.

2.1 Resource Consent Requirements

Table 1 Relevant Conditions for Consents related to the Landfill Operations Management Plan

Condition Number	Condition	Reference
Land Use Consent 60/3/02/138/1		
2.16	The consent holder shall prepare and maintain a Landfill Operations Management Plan (LOMP) for certification by the Council. The LOMP shall describe the operations of the landfill, including demonstrating how compliance with the relevant conditions of this consent will be achieved. The plan shall also achieve the following objectives:	
	Nuisance Control: i. To maintain a clean and tidy site	Section 8
	ii. To maintain screen and litter fences and ensure litter does not accumulate on the screens and litter fences	Section 8
	iii. To avoid wind-blown litter outside the site boundaries	Section 8
	Noise: iv. To operate the landfill within the site boundary noise limits	Section 8.3
	v. To ensure all site machinery is well maintained and hold all necessary compliance certification	Section 8.3
	Facilities and Maintenance: vi. To avoid the establishment of vermin, insect and bird populations through effective management of the refuse disposal and process area	Section 8.5
	vii. To implement pest management strategies as required	Section 8.5
	Contaminated Land Procedures: viii. To appropriately assess and manage contaminants in the soil to protect human health:	Section 12
	ix. To appropriately identify procedures for asbestos management on site	Section 5.5.4
2.22	Noise: That all activities associated with the construction and operation of the solid waste disposal facility and associated operations including, but not limited to any recontouring and earthworks associated with solid waste disposal activity shall comply with the following:	Section 8.3

Condition Number	Condition	Reference
	The consent holder shall ensure that all activities on the site to which this consent applies are managed and carried out so that the rating level measured at the notional boundary of any residential, hospitality, tourist, educational or health activity excluding property owned, or covenanted by the consent holder does not exceed the following levels: Monday - Saturday, 7.00 am - 10.00 pm 50 dBA Leq All other times including public holidays 40 dBA Leq Daily, 10.00 pm - 7.00 am the following day 70 dBA Lmax "Notional boundary" means a line 20 metres from the façade of the building in question of the nearest residential boundary, excluding property owned, or covenanted by the consent holder, or this legal boundary on which the building is located where the boundary is closer to the building than 20 metres. Sound levels shall be measured in accordance with the provisions of NZS 6801:2008 Acoustics - Measurement of Environmental Sound, and assessed in accordance with the provisions of NZS 6802:2008 Acoustics - Assessment of Environmental Noise.	
2.25	That all exterior lighting shall be directed away from adjacent residences not owned or covenanted by the consent holder, so as to minimise the potential for adverse effects from light spill on adjacent residents, and so as to achieve compliance with Rule Rural.7 of the Operative Southland District Plan 2018.	Section 8.7
2.26	That the consent holder shall take all practicable steps to minimise the potential for litter spillage on to roads and adjacent properties not owned, or covenanted by the consent holder. The consent holder shall be responsible for the removal, as soon as practicable, of any litter spillage resulting from the site operations on to public roads, and wind-blown litter on to adjacent properties not owned, or covenanted by the consent holder at the request of any such adjacent landowner(s), to the satisfaction of the Southland District Council.	Section 8.4
Schedule 1 – General Conditions 201346, 201347, 201348, 201349, 201350 and 201351		
22.	The consent holder shall prepare and maintain a Landfill Operations Management Plan (LOMP). The LOMP shall describe the operations of the landfill, including demonstrating how compliance with the relevant conditions of this consent will be achieved. The plan shall also achieve the following objectives:	
	i. To utilise an effective cover system to maintain quality site rehabilitation, while minimising long term leachate generation	Section 10
	ii. To limit face access, thus enabling the size of the active area to be minimised.	Section 7.4.3

	i. To minimise stockpiling, both within and outside the footprint.	Section 8.5
	ii. To outline Waste Acceptance Criteria and Procedures: ▪ To protect the receiving environment; ▪ To protect the health and safety of people; ▪ To maintain that all waste received is compatible with the land filling operation; ▪ To maintain that all waste landfilled complies with 'Waste Acceptance Criteria' outlined in the relevant consent conditions.	Section 4
	iii. To outline crisis response and emergency waste acceptance procedures: ▪ To manage the identification of all special waste; ▪ To pre-arrange the disposal of special waste; ▪ To have in place measures and appropriate provisions for disposal of each special waste load are in place before the waste arrives at the landfill.	Section 6
	iv. The placing of refuse and daily cover: ▪ To achieve a minimum in-situ refuse density of 0.8; ▪ To maintain a working face that is as small as possible; ▪ To cover all refuse daily; ▪ To manage special waste planning; ▪ To record the location of special waste by survey;	Section 10.1
	v. The effective capping of the landfill: ▪ To minimise ingress of rainwater into the landfill ▪ To minimise erosion and cracking of the cap through design, planting and maintenance	Section 10.4
30.	A geological map of the base grade of the landfill shall be prepared and upgraded from time to time as the base grade is exposed. The geological mapping shall include detailed logging of the location, extent and nature of fractures, fracture zones, Karst features and other defects.	Section 11
31.	As-built drawings shall be forwarded to the Southland Regional Council following completion of works and structures, for acceptance in writing, prior to the disposal of refuse in each newly constructed stage. These drawings shall include 0.25 metre contours for the liner base, final elevations of the HDPE or compacted clay liner prior to placement of the leachate drainage layer sufficient to monitor future movement of the base.	Section 11

32.	All investigations, design, supervision of construction, operation, monitoring and after-care shall be undertaken by suitably qualified personnel experienced in such works, or works of a similar nature, and to the satisfaction of the Southland Regional Council.	Section 12
36.	All water quality sample analyses required shall be undertaken using standard methods as detailed in the "Standard Methods For The Examination Of Water And Waste Water, 1998" 20th edition by A.P.H.A. and A.W.W.A. and W.E.F or by some other method approved in advance in writing by the Southland Regional Council.	Section 13
Discharge Permit AUTH-201346-V3		
2.	The discharge of waste is authorised only on the areas of the site identified as the landfill footprint, as shown on drawing number IZ000400-1000-NG-DRG-1002 attached to this consent.	Section 3 Attachment 1
6.	a) The leachate containment and leachate collection system for the base of the landfill, and any side slopes with a slope less than 2H:1V, shall consist of the following as a minimum, from bottom to top: ▪ a groundwater underdrainage system; ▪ a minimum of 600 millimetres of compacted soil with a permeability coefficient (k) not exceeding 1 x 10^{-9} metres per second; ▪ a 1.5 millimetre high density polyethylene (HDPE) flexible membrane liner; ▪ a 300 millimetre minimum liner protection/leachate collection layer of granular material. or ▪ a groundwater underdrainage system; ▪ a minimum of 300 millimetres of compacted soil with a permeability coefficient (k) not exceeding1 x 10^{-9} metres per second; ▪ a geosynthetic clay liner (GCL), with a minimum thickness of 5 millimetres, a permeability coefficient (k) not exceeding 5 x 10^{-11} metres per second; ▪ a 1.5 millimetre high density polyethylene (HDPE) flexible membrane liner; ▪ a 300 millimetre minimum liner protection/leachate collection layer of granular material. or ▪ a groundwater underdrainage system; ▪ a minimum of 600 millimetres of compacted soil with a permeability coefficient (k) not exceeding1 x 10^{-8} metres per second; ▪ a geosynthetic clay liner (GCL), with a minimum thickness of 5 millimetres, a permeability coefficient (k) not exceeding 5 x 10^{-11} metres per second; ▪ a 1.5 millimetre high density polyethylene (HDPE) flexible membrane liner;	Section 11.9

	▪ a 300 millimetre minimum liner protection/leachate collection layer of granular material. b) An alternative to the above minimum specifications may be proposed and included in the Landfill Operations Management Plan subject to Independent Peer Review approval and subsequent council certification.	
7.	a) The leachate containment system for the side slopes of the landfill, with a slope of 2H:1V or greater, shall consist of the following as a minimum, from bottom to top: ▪ a groundwater underdrainage system where required; ▪ a geosynthetic clay liner, with a minimum thickness of 5 millimetres, a permeability coefficient (k) not exceeding 5 x 10^{-11} metres per second and sufficient internal shear strength to maintain a stable configuration on slopes; ▪ a 2.0 millimetre HDPE flexible membrane liner; and ▪ a 300 millimetre minimum liner protection layer of soil or clay or granular material. b) An alternative to the above minimum specifications may be proposed and included in the Landfill Operations Management Plan subject to Independent Peer Review approval and subsequent council certification.	Section 11.9
8.	The consent holder shall prepare landfill side slopes, to ensure a smooth surface appropriate for the placement of geosynthetic liner materials. This shall include the smoothing of rough surfaces, sealing of solution features or compaction of slopes to an appropriate bearing capacity.	Section 11
9.	The leachate collection system shall be designed to maintain a leachate head of less than 300 millimetres on the base liner and side liner, as demonstrated by design calculations, to the satisfaction of the Southland Regional Council, based on the expected leachate impingement rate due to rainfall and any leachate recirculation and expected clogging of the leachate collection system.	Section 11.9
12.	The HDPE component of composite lining systems may be replaced with an alternative material, following acceptance in writing by the Southland Regional Council, where an alternative material is demonstrated to provide equivalent, or superior, performance in terms of ▪ puncture resistance ▪ resistance to chemical degradation; ▪ hydraulic containment; ▪ physical strength and deformation characteristics under service and seismic loads; ▪ welding and general installation;	Section 11.7

	expected service life.	
13.	Liner components comprising synthetic or geo-synthetic materials shall be constructed in accordance with the manufacturer's recommended quality assurance/quality control procedures.	Section 11
14.	The landfill gas collection and leachate recirculation systems shall be designed to prevent puncture of the landfill liner by system components. In particular, any vertical wells or pipes installed for the collection of landfill gas, or re-injection of leachate into the landfill, shall terminate at a height above the base or side liner that will ensure that pipes, or wells, will not puncture the liner as a result of refuse settlement, or incorporate other appropriate design features that allow for expected settlement, to the satisfaction of the Southland Regional Council.	Section 11
16.	No bulk liquid waste shall be accepted for disposal. The definition of liquid waste shall be any waste that contains free liquid on arrival at the landfill, or has a solids content of less than 20 percent, except such waste that passes the USEPA Paint Filter Liquids Test (EPA Method 9095A).	Section 4.4.1
17.	Medical wastes shall be accepted only in accordance with NZS 4304:2002 " Health Care Waste Management" or subsequent amendments.	Section 5.5.4
18.	Asbestos wastes shall be accepted only in accordance with the Health and Safety at Work (Asbestos) Regulations 2016, or subsequent amendments.	Section 5.5.4
19.	Where, during landfill operations, the Consent Holder is required to accept waste by a Government Agency as a crisis or emergency response, the following protocol shall apply: a) All crisis response waste acceptance shall trigger the protocol identified in the Crisis/Emergency Response chapter of the Landfill Operations Management Plan b) The consent holder shall notify the Southland Regional Council Compliance Manager of this waste acceptance within 24 hours. c) A management response in line with the criteria identified within the Crisis/Emergency Response chapter of the Landfill Operations Management Plan shall be made available to the Southland Regional Council within 3 days of notification of condition (xx)(b), above. d) All likely affected neighbours are to be notified of the crisis/emergency waste stream prior to acceptance on site, or as soon as practicable. Mitigation measures for crisis/emergency waste shall follow the guidelines identified in the Crisis/Emergency Response chapter of the Landfill Operations Management Plan. ***Advice Note:*** *There may be instances when the consent holder is required to accept waste under the direction of a Government Agency. Where this is the case, despite the conditions of consent that ordinarily apply to the landfill, it is accepted that there may be effects associated with the waste that are beyond the control of the consent holder. This shall be taken into consideration by the Southland Regional Council when discharging its duties to monitor the conditions of consent.*	Section 6

20.	For other than minor amounts of offal, the consent holder shall: ▪ require all offal to be disposed of to be pre-booked by the waste generator or transporter, and only be accepted in discrete loads; ▪ record information on the source of the offal, including the origin of the animals; ▪ record information on the cause of death of the animals from which the offal is sourced; ▪ dispose of the offal in pits specifically excavated in the landfill for each discrete load of offal; ▪ cover each load of offal immediately following deposition; and record the location of each pit used for the disposal of offal.	Sections 4.3 & 5.2.1
21.	Material contaminated with methamphetamine and/or chemicals associated with the manufacture of methamphetamine may be accepted into the landfill provided that the level of contamination does not exceed 100 μgm/cm^2, based on an average by weight per individual household lot. The material that may be accepted includes wall linings (including gib board), soft furnishing (e.g. Curtains, carpets), furniture, bedding, clothing and whiteware. Actual stocks of chemicals used in, or leftover from, methamphetamine manufacture are also excluded from this condition. The consent holder shall: i. Record the date, source, volume and nature of the material received; ii. Keep a record of monitoring data that confirms the contamination level of the material; and iii. Record the location where the material is placed within the landfill in 3 dimensions.	Sections 4.2 and 5.2.2
22.	Aluminium dross waste (AWD) and material contaminated with this waste may be accepted into the landfill provided that the concentrations of aluminium and fluoride do not exceed the leachability limits or screening concentrations set out in Table 1 of "Module 2: Hazardous Waste Guidelines, Landfill Waste Acceptance Criteria and Landfill classification , May 2004". The leachability limits shall be established using SPLP testing, with concentrations not to exceed a SPLP test result of 40g/m^3 of Aluminium and 200 g/m^3 of Fluoride. The material that may be accepted includes gravels and soils that have been contaminated with dross. The consent holder shall: i. Record the date, source, volume and nature of the material received; ii. Notify the Southland Regional Council within 7 days of the material being accepted, and provide details of the source and volume of the material; iii. Keep a record of monitoring data that confirms the contamination level of the material; and	Sections 4.2 and 5.2.3

	iv. Record the location where the material is placed within the landfill. The information recorded shall be made available to the consent authority or its representative on request.	
23.	With the exception of medical wastes and asbestos wastes, no hazardous waste shall be accepted for disposal at the landfill. The definition of "hazardous waste" shall be: i. Wastes which are defined as either radioactive, explosive, flammable, oxidising, or corrosive, in terms of the HSNO regulations, or capable, by any means after disposal, of yielding another material, for example, leachate, which possesses any of the above characteristics; ii. Wastes which exhibit the characteristics of toxicity and eco-toxicity which following testing using the USEPA Toxicity Characteristic Leaching Procedure (TCLP) result in leachable concentrations of contaminants in excess of the leachable concentration limits listed in Schedule 2; and iii. Wastes which exhibit the characteristics of toxicity and eco-toxicity with total concentrations in excess of the total concentration limits listed in Schedule 2. Where leachable concentration or total concentration limits do not exist in Schedule 2 for a substance for which a disposal request is made, the leachable limit, following testing using the USEPA TCLP shall be set at the lesser of: ▪ NZS 9201 Trade Waste Bylaw limits; or ▪ 100 times the New Zealand drinking water standard water quality standards to which all drinking-water supplies must comply as per the Drinking-water Standards for New Zealand 2005 (revised 2018); or ▪ 1000 times the Default Guideline Values in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality, August 2018. The definition of "hazardous waste" shall not include small quantities of waste products containing potentially hazardous components that are not likely to have adverse effects on the environment, such as can reasonably be expected to be contained in the municipal waste stream. To minimise the potential for hazardous waste to be disposed of at the landfill the following measures shall be taken: ▪ use of a waste manifest/disposal agreement system to authorise landfill loads/users and document waste acceptance; ▪ notice shall be clearly positioned at the landfill entrance to identify the hazardous wastes which are unacceptable at the landfill; and	Section 5.3.1 Section 5.3.3 Section 4.1 Section 4.1 Section 4.5

	▪ random inspections of incoming loads, for the presence of hazardous waste, shall be undertaken, at the average rate of at least one inspection per 50 loads.	
28.	The consent holder shall install new downgradient groundwater monitoring wells, if deemed necessary by the consent holder. The final locations shall be agreed in writing by the Southland Regional Council.	Section 13
34.	If any groundwater monitoring well is destroyed the consent holder shall replace it with a new well, in the same general location, to the satisfaction of the Southland Regional Council.	Section 13
Water Permit 201348		
2.	The taking of groundwater is authorised only from the groundwater underdrainage systems beneath the landfill footprint and leachate storage pond, as shown on drawing IZ000400-1000-NG-DRG-1008 attached to this consent.	Section 13 Attachment 1
Air Discharge Permit 201351		
6.	The lateral extent of the landfill working face shall be kept to a practical minimum. The extent of the area between load tipping and load spreading shall be minimised at all times.	Sections 7.4.3, and 7.4.6
7.	All refuse placed in the working face area shall be covered with soil or equivalent material. Cover shall be applied at the end of each day to a depth of approximately 150 millimetres in accordance with the Landfill Operations Management Plan.	Section 7.5

2.2 Monitoring and Reporting the performance of the Landfill Operations Management Plan

Table 2 Monitoring and Reporting Requirements Related to the Landfill Operations Management Plan

Condition	Requirement	Relevant Regulatory Authority	Frequency	Date	Responsibility
Land Use Consent 60/3/02/138/1					
2.33	An annual noise monitoring survey shall be carried out for the duration of the consent in order to ensure that the consent holder is operating in compliance with Condition 2.23.	Southland District Council	Annual Recording		
Schedule 1 – General Conditions 201346, 201347, 201348, 201349, 201350 and 201351					
29.	The EMP and sub-management plans (where applicable) shall include monitoring with respect to surface water, groundwater, leachate, landfill gas and nuisance. Each monitoring element shall include:	Southland Regional Council	All Monitoring parameters are referred to in various	N/A	Environmental Manager

Condition	Requirement	Relevant Regulatory Authority	Frequency	Date	Responsibility
	i. Monitoring locations; ii. Monitoring parameters; iii. Monitoring frequency; iv. Detection limits; v. Reporting; vi. Trigger levels (for each monitoring location) for implementing contingency/remedial actions		consent conditions		
34.	The consent holder shall retain an appropriately experienced person to supervise the operation of the landfill. That person shall compile an annual report on the operation of the landfill, including: ▪ the status of landfilling operations on the site and work completed during the preceding year; ▪ the results of environmental monitoring; ▪ any difficulties which have arisen in the preceding year and measures taken to address those difficulties; and ▪ activities proposed for the next year of the landfill operation. This report shall be forwarded to the Southland Regional Council by 1 May, unless otherwise agreed in writing with the Southland Regional Council.	Southland Regional Council	Annually	1 May	Environmental Manager
Discharge Permit AUTH-201346-V3					
24.	The consent holder shall maintain, to the satisfaction of the Southland Regional Council, a record of the quantities and types of waste accepted at the landfill, including the location (in three dimensions) of: ▪ treated hazardous wastes; and	Southland Regional Council	Annually	1 May	Environmental Manager

Condition	Requirement	Relevant Regulatory Authority	Frequency	Date	Responsibility
	▪ specials wastes (as listed in the landfill management plan). A copy of this record shall be forwarded to the Southland Regional Council by 1 August 1 May each year, unless otherwise agreed in writing by the Southland Regional Council.				
25.	The consent holder shall immediately notify the Southland Regional Council if any vehicle(s) is turned away from the landfill with waste that does not comply with the waste acceptance criteria detailed in conditions 18, 19, 20, 21 and 22. This notification shall include the vehicle registration number and source of the waste (if known).	Southland Regional Council	As required	N/A	Environmental Manager
29.	The consent holder shall conduct a rising head test, or other test(s) as agreed in writing by the Southland Regional Council (within 3 months), to demonstrate that any new groundwater monitoring well is working and assess the hydraulic conductivity of the in-situ ground. A water sample shall be taken from the well and tested for turbidity to determine whether the well is clean enough to provide samples of dissolved constituents. The results of these tests shall be forwarded to the Southland Regional Council with the first set of monitoring results from the well.	Southland Regional Council	Within 3 months of any new well	N/A	Environmental Manager
30.	The consent holder shall monitor water quality in existing downgradient groundwater monitoring wells SKM104, SKM201, SKM202, SKM203 and SKM204, as indicated on drawing number IZ000400-1000-NG-DRG-1008 attached to this consent, to the satisfaction of the Southland Regional Council. To this end the consent holder shall monitor water level every month, and water quality for the following parameters four times a year:	Southland Regional Council	Existing groundwater wells - monthly		Environmental Manager

Condition	Requirement	Relevant Regulatory Authority	Frequency	Date	Responsibility
	pH (field and laboratory) Conductivity (field and laboratory) Turbidity Chloride Total Ammoniacal Nitrogen COD Soluble Iron Soluble Manganese Soluble Aluminium Soluble Arsenic Soluble Cadmium Soluble Chromium Soluble Copper Soluble Nickel Soluble Lead Soluble Zinc Total hardness Alkalinity Potassium Sulphate Sodium Magnesium Calcium Bicarbonate Total Phenols Volatile Acids Dissolved Reactive Phosphorus Total Organic Carbon Total Kjeldahl Nitrogen Nitrate Nitrogen The consent holder shall monitor for the following parameters once every year, to coincide with summer groundwater minimum: Volatile Organic Compounds Semi-volatile Organic Compounds Sampling shall be undertaken under protocols approved in writing by the		Water quality – quarterly Specialist compounds -annually		

Condition	Requirement	Relevant Regulatory Authority	Frequency	Date	Responsibility
	Southland Regional Council, including on site filtration and preservation of samples for soluble metals analysis. An ion balance to APHA criteria shall be provided for the anions and cations. The results of such monitoring shall be reported in writing to the Southland Regional Council within two months of sampling.				
31.	The consent holder shall establish baseline groundwater quality for each new groundwater monitoring well, monitored in accordance with condition 28 and condition 31 of this consent, after a minimum of four groundwater sampling events. Following the establishment of baseline groundwater quality, to the satisfaction of the Southland Regional Council, the consent holder may reduce the frequency of monitoring for those parameters requiring monitoring from four times a year to twice a year, (to coincide with expected groundwater level maximum and minimum).	Southland Regional Council	Quarterly reduced to biannually		Environmental Manager
32.	The consent holder shall, monitor water quality in any new downgradient groundwater monitoring well(s), installed in accordance with condition 30 of this consent, to the satisfaction of the Southland Regional Council. To this end the consent holder shall monitor water level every month, and water quality for the following parameters four times a year: pH (field and laboratory) Conductivity (field and laboratory) Turbidity Chloride Total Ammoniacal Nitrogen COD Soluble Iron	Southland Regional Council	Water Quality – quarterly Water level - monthly Specialist compounds - biannually		Environmental Manager

Condition	Requirement	Relevant Regulatory Authority	Frequency	Date	Responsibility
	Soluble Manganese Soluble Aluminium Soluble Arsenic Soluble Cadmium Soluble Chromium Soluble Copper Soluble Nickel Soluble Lead Soluble Zinc Total hardness Alkalinity Potassium Sulphate Sodium Magnesium Calcium Bicarbonate Total Phenols Volatile Acids Dissolved Reactive Phosphorus Total Organic Carbon Total Kjeldahl Nitrogen Nitrate Nitrogen The consent holder shall monitor for the following parameters once every year, to coincide with summer groundwater minimum: Volatile Organic Compounds Semi-volatile Organic Compounds Sampling shall be undertaken under protocols approved in writing by the Southland Regional Council, including on site filtration and preservation of samples for soluble metals analysis. An ion balance to APHA criteria shall be provided for the anions and cations. The results of such monitoring shall be reported in writing to the Southland				

Condition	Requirement	Relevant Regulatory Authority	Frequency	Date	Responsibility
	Regional Council within two months of sampling.				
33.	The consent holder shall develop trigger levels for each parameter within each new groundwater monitoring well downgradient of the landfill, to identify, to the satisfaction of the Southland Regional Council, any significant change in background groundwater quality for these wells. The consent holder shall within six months of the completion of each such well submit interim trigger levels to the Southland Regional Council. Trigger levels shall be finalised after a minimum of four sampling rounds over at least one year. The consent holder shall notify the Southland Regional Council in writing within one month of the identification of any significant change in groundwater quality.	Southland Regional Council	Within 6 months of completion of each well		Environmental Manager
35.	The consent holder shall undertake a formal inspection of the landfill cap following significant storm events (greater than 50 percent AEP at a duration of less than one day), but at least every six months. The inspection shall check for: Vegetation die-off; Cracking of the cap surface; Subsidence and erosion; Leachate break-out through the cap; Refuse protruding through the cap. Any defects noticed during the inspection shall be remedied immediately. A report on the inspection, and details of any remedial actions undertaken as a result, shall be forwarded to the Southland Regional Council within two months of each inspection.	Southland Regional Council	As required but at least bi-annually		Environmental Manager
Water Permit 201348					

Condition	Requirement	Relevant Regulatory Authority	Frequency	Date	Responsibility
3.	The consent holder shall monitor the quantity of groundwater taken from the groundwater underdrainage system to the satisfaction of the Southland Regional Council. The volume of groundwater taken shall be recorded at monthly intervals. The volume of groundwater taken shall be reported in writing to the Southland Regional Council by 1 May every year.	Southland Regional Council	Monthly recording, Annual reporting	1 May	Environmental Manager
Water Permit 201350					
2.	The consent holder shall maintain a record of the daily pumping hours (the actual number and period of hours over which water was taken) and daily water usage (total daily volume), which shall be made available to the Southland Regional Council at all reasonable times. These records shall be forwarded to the Southland Regional Council by 1 May each year.	Southland Regional Council	Daily recording Annual reporting NB: Information always available on request of SRC	1 May	Environmental Manager

2.2.1 Interaction Between Legislative Requirements and the Landfill Operations Management Plan

If there is a conflict between the management plan and the corresponding legislative requirements, including consent conditions, then the legislative requirements must prevail.

3. Landfill Facilities and Site Development

3.1 Landfill Area and Void Volume

The total landfill area is 37.15 ha and the total approximate void volume is 20 million m^3 (Mm^3).

Refuse deposition commenced in 2004 in the lowest part of the quarry (i.e. southern part of the quarry) and has been gradually progressing to the north.

In the period 2004 to March 2020 the total amount of waste accepted at the landfill is approximately 855,000 tonnes.

The final contours are shown on drawing IZ000400-1000-NG-DRG-1003 in Attachment 1.

3.2 Site Development

The landfill is being developed in a series of cells/areas as shown on drawing IZ000400-1000-NG-DRG-1003 in Attachment 1.

In April 2020 waste is being placed in Area 14 and Area 15 is being developed to accept refuse from mid-2020.

The layout and phases are developed to fit into the quarry development plans. This allows the detailed planning and design to progress logically and achieve the following:

- Progressive use of the landfill area such that some parts of the site are capped, or being capped, an area is being prepared to received waste and a small area is being actively filled with waste;
- Effective planning for and the use of materials for liner, cover and cap;
- Enable progressive restoration;
- Minimise leachate production by keeping the active area to a minimum;
- Coordinate haul and access roads; and
- Segregate clean surface water runoff.

Each area is developed in the construction season (late summer) prior to placement of waste in that area. The liner is in place for up to 6 to 12 months prior to waste placement. Each area will be bought up to as close to finished contours that access will allow, before starting in the next area. Where the area can be bought up to final levels, capping is progressively carried out. The detailed design for each area will be undertaken and approved progressively. The concept designs for all future phases are considered many years before they are needed.

3.3 Design Principles

Principal components of the landfill site development are:

- Access facilities, site office and access road development;
- Landfill formation;
- Leachate management system;
- Surface water management system;
- Landfill gas management system;
- Groundwater underdrain management system;
- Landscaping and screen planting; and

- Site fencing.

The design principles are:

- To place waste within the landfill footprint using modern landfill techniques and good industry practice;
- To generally maintain surface water run-off paths within the AB Lime property by realigning these around the landfill footprint in stages during the course of the landfill development;
- To collect and divert clean stormwater within the landfill footprint via a 1200 mm diameter stormwater pipe discharging the stormwater to an on-site stormwater pond;
- To collect and contain leachate by maintaining a leachate collection system discharging to the landfill leachate tank;
- To dispose of collected leachate off-site to the Wastewater Treatment Plant in Clifton that is operated by Invercargill City Council;
- To control the ingress of precipitation by a staged placement of landfill cover (daily, temporary, intermediate and final) and landfill capping;
- To manage the uncontrolled release of landfill gas via active gas extraction wells connected via a gas header pipe system to a principal flare that treats the gas prior to discharge to the atmosphere; and
- To collect any groundwater below the landfill base liner in a groundwater underdrainage system prior to discharge to the site stormwater pond.

3.4 Construction Activities

Construction activities will include the construction and establishment works as follows:

- Excavation and general earthworks;
- Subgrade preparation;
- Stormwater system construction and maintenance including maintenance of stormwater pond;
- Managed wetland maintenance;
- Groundwater underdrainage construction;
- Landfill base and sidewall liner construction;
- Leachate collection disposal system construction and maintenance of leachate tank;
- Construction of vertical and horizontal gas wells, reticulation gas header pipes and gas condensate traps;
- Placement of intermediate cover;
- Placement of temporary and final capping; and
- Remediation works.

Construction activities do not include operation works. Operational works are defined as works directly related to the placement of refuse and include the following:

- Removal of daily cover at the start of each working day;
- Tipping refuse or Special Waste;
- Placing and compacting refuse; and
- Placing daily cover at the end of each working day on the active tipping face.

4. Waste Acceptance Criteria

4.1 General

This section sets out the procedures relating to waste acceptance criteria and includes an application and approval processes described as the Landfill Users Access Agreement.

All landfill users and waste carriers are required to complete a formal application form for waste acceptance and sign a Landfill Users access agreement to authorise landfill loads/users and document waste acceptance.

Waste is only delivered to the site in vehicles dedicated specifically for the transport of solid waste, and which have been given prior authorisation to access the site by AB Lime.

A notice is clearly positioned at the landfill entrance to identify the hazardous wastes which are unacceptable at the landfill.

The landfill is NOT open to the general public for the disposal of waste.

An additional approval process applies to waste types that cannot be freely accepted for disposal and are restricted because of their nature, properties or composition. These wastes are referred to as "Special Waste" and are discussed in Section 5.

4.2 Acceptable Waste Types

Solid wastes will be accepted for disposal provided it complies with the acceptance criteria set out in this plan.

The types of waste that can be accepted at the AB Lime landfill include:

- Domestic;
- Industrial;
- Commercial;
- Clean fill;
- Medical waste only in accordance with NZS 4304:2002 "Health Care Waste Management";
- Special Waste subject to the criteria set out in Section 5;
- Asbestos in accordance with the Health and Safety at Work (Asbestos) Regulations 2016 (see also Section 5.5.4);
- Methamphetamine contaminated household wastes that have an average contamination of below $100ug/100cm^2$ (see Section 5.2.2);
- Difficult wastes that require special handling e.g. cess pit sludge, offal, bulky items in minor quantities; and
- Acceptable Aluminium Dross Waste (see Section 5.2.3).

Staff working at the tip face are trained in the waste acceptance procedures and in identifying non-conforming loads. Disposal at the working face is always supervised to ensure that unacceptable wastes are not being placed.

4.3 Acceptable Offal Waste

Acceptable offal waste is discussed in Section 5.2.1.

4.4 Waste Types Not Accepted

Wastes that are excluded from the landfill include:

- Bulk liquid waste;
- Hazardous medical wastes;
- Hazardous wastes; and
- Sludges.

A notice is clearly positioned at the landfill entrance that identifies the wastes that are not accepted at the landfill.

4.4.1 Bulk Liquid Waste

Liquid waste is defined as being any waste that contains free liquid on arrival at the landfill or has a solids content of less than 20% except such waste that passes the USEPA Paint Filter Liquids Test (USEPA Method 90905A).

Liquids in small containers forming part of domestic waste that are impractical to be emptied and that do not contain hazardous characteristics are considered acceptable waste.

4.4.2 Sludges

Sludges have a consistency of a viscous liquid and pour and behave like a liquid. Sludges will be defined as having have less than 20% solids (as sewage sludge typically has a higher content and may be accepted under the Special Waste Category).

Sludges will not be accepted unless the sludge can be, or has been, treated/stabilised in such a way that it does not behave like a liquid.

4.4.3 Hazardous Waste

Except for asbestos waste, medical waste and Aluminium Dross Waste (ADW) (see Section 5.2), no hazardous waste is accepted for disposal at the landfill.

The definition of “hazardous waste” is:

- Wastes which are defined as either radioactive, explosive, flammable, oxidising, or corrosive in terms of the HSNO Classification regulations, or capable, by any means after disposal, of yielding another material, for example leachate which possess any of the above characteristics.
- Wastes which exhibit the characteristics of toxicity and eco-toxicity, which following testing using the USEPA Toxicity Characteristic Leaching Procedure (TCLP) result in leachable concentrations of contaminants in excess of the leachable concentration limits listed in Schedule 2 (see Consent 210346, Attachment 2).
- Waste that exhibit the characteristics of toxicity and eco-toxicity with total concentrations in excess of the total concentration limits listed in Schedule 2 (see Attachment 2).

The definition of ‘hazardous waste’ does not include small quantities of waste products containing potentially hazardous components that are likely to have adverse effects on the environment, such as can be expected to be contained in the municipal waste stream.

4.5 New Contaminants

The process for assessing and developing assessment criteria for new contaminants is seen below:

4.5.1 Emerging Contaminants

It is possible within the lifetime of the consent, that a contaminant or group of contaminants may become a concern typically due to improvements over time in scientific knowledge about its effects and distribution. Additional Waste Acceptance Criteria may be needed in due course and is to be reviewed using the following methodology:

review of the Waste Acceptance Criteria will be conducted every 10 years during the lifetime of the landfill. The aim of the review will be to consider amendment to any existing Waste Acceptance Criteria

The objectives of the review are as follows:

1) To consider the addition of any new Waste Acceptance Criteria to manage potential environmental harm or human health risk associated with emerging contaminants;
2) With regard to any contaminant that does not already have Waste Acceptance criteria within this management plan, the characteristics that may trigger its inclusion in a review are:
   i. Evidence of greater potential harm presented in recent publications;
   ii. Known presence in a regional context; and
   iii. More frequent instances of special waste disposal applications requiring assessment on a case-by-case basis.
3) The review steps for emerging contaminants will be:
   a) Identify the contaminant and review the reasons for it to be a candidate for imposition of special waste acceptance criteria;
   b) Review New Zealand and international regulations and good practice guidelines to look for any existing WAC for the contaminant at other landfills within New Zealand;
   c) If there are existing waste acceptance criteria, then compare the management of these emerging contaminants against the AB Lime landfill context and determine whether existing criteria can be adopted for the AB Lime site;
   d) If there are no existing waste acceptance criteria, or if the existing criteria are not site specific, then AB Lime develop landfill specific criteria;
   e) In developing site-specific criteria for a contaminant AB Lime shall have regard to tits mobility, persistence, degradation products, pathway to any receptor and published evidence of harm;
   f) Measure or estimate the concentration and total mass of the contaminant in raw leachate, raw landfill gas, treated leachate, treated landfill gas and waste mass wherever relevant;
   g) Consider the potential discharges from the landfill in the longterm;
   h) Recommend whether or not new waste acceptance criteria are justified (and if so, then reasonable prarameter limits;
   i) Recommend any worthwhile additional and/or alternative related monitoring;
   j) Summarise the assumptions and findings of the review; and
   k) If new waste acceptance or monitoring parameters are proposed, then follow the procedure for revision of the Landfill Operations Management Plan.

4.6 Random Load Inspections of Incoming Waste

Random inspections of incoming loads for the presence of not accepted wastes are undertaken at the average rate of at least one inspection per 50 loads (approximately once a week) at the site entrance.

The results of these inspections are recorded on the Waste Inspection Sheets.

If, during random inspections, waste that is not accepted at the landfill is discovered, the material is reloaded onto the delivery vehicle for return and a copy of the Inspection Sheet is sent to Environment Southland within 48 hours, along with a description of the action taken, including:

- The date and time at which the vehicle was turned away;
- The registration number of the vehicle;
- The identity of the carrier;
- The size and type of the load;
- The source of the load; and
- The category of the hazard.

In the event that not accepted waste is discovered during tipping the following contingency responses will apply:

- Safety first;
- Notify the Landfill Site Supervisor and co-workers;
- Cordon off the hazardous waste;
- Track down the customer who delivered it;
- Refuse any further deliveries from that customer until satisfactory resolution;
- Instruct the customer to remove the not accepted waste;
- If removal will occur promptly, then assist the customer with removal;
- If the response from the customer is slow, then consult with a specialist advisor and the regulator about alternative methods to address the hazardous waste;
- Remove and/or treat as required;
- Contact hazardous waste/not accepted waste removal contractor for removal to their hazardous/ not accepted waste treatment facility if required;
- Survey any burials;
- Review the pre-acceptance process, the customer's systems, and the source before recommencing deliveries;
- Ensure that the clean-up is satisfactory for worker safety and environmental containment; and
- The incident is to be recorded in accordance with incident reporting.

5. Special Waste Acceptance

5.1 Special Waste Application Form

The generator of special waste or the cartage contractor will be required to make an application for the disposal and supply the following details:

- Nature and source of the waste stream;
- Details of the process generating the waste;
- Estimates of the quantities and expected frequency of disposal;
- Substances (i.e. 'contaminants') present in the waste including contaminant testing and TCLP results; and
- Relevant supporting analytical information.

An application form is provided in Attachment 3.

If the special waste does not contain contaminants then the only restriction on the waste is its physical nature (e.g. large objects such as wire rope, bulky objectives or demolition waste), then in these cases, arrangements for disposal can be made with the Environmental Manager.

5.2 Special Waste Application Appraisal

Information on the special waste will be appraised for completeness.

The appraisal process will consider the protection of human health and safety, protection of the environment and compatibility with the operation of the landfill. This can only be done by either:

- using the listed waste acceptance criteria, or
- considering a disposal application as special waste.

5.2.1 Acceptable Offal Waste

For other than minor amounts of offal, AB Lime requires that Offal Waste is classified as a Special Waste subject to the following procedures:

- All offal to be disposed of is to be pre-booked by the waste generator or transporter, and will be only be accepted in discrete loads;
- Information on the source of the offal, including the origin of the animals is recorded;
- Information on the cause of death of the animal from which the offal is sourced is recorded;
- Age of the offal and any treatment applied to stabilise offal (note: old offal may be odorous and will be assessed as described in the Landfill Odour Management Plan;
- Disposal of the offal into pits specifically excavated in the landfill for each discreet load of offal;
- Each load of offal is immediately covered following deposition; and
- The location of each pit used for the disposal of offal is record.

5.2.2 Acceptable Methamphetamine Contaminated Waste

Material contaminated with methamphetamine and/or chemicals associated with the manufacture of methamphetamine may be accepted into the landfill provided that the level of contamination does not exceed 100 μgm/cm^2, based on an average by weight per individual household lot.

The material that may be accepted includes wall linings (including gib board), soft furnishing (e.g. curtains, carpets), furniture, bedding, clothing and whiteware. Actual stocks of chemicals used in, or leftover from, methamphetamine manufacture is excluded from this condition.

For Methamphetamine Contaminated Waste AB Lime will:

- Record the date, source, volume and nature of the material received;
- Keep a record of monitoring data that confirms the contamination level of the material; and
- Record the location where the material is placed within the landfill in 3 dimensions.

5.2.3 Acceptable Aluminium Dross Waste

Aluminium dross waste and material contaminated with this waste may be accepted into the landfill provided that the concentrations of aluminium and fluoride do not exceed the leachability limits or screening concentrations set out in Table 1 of "Module 2: Hazardous Waste Guidelines, Landfill Waste Acceptance Criteria and Landfill Classification, May 2004".

The leachability limits shall be established using Synthetic Precipitation Leaching Procedure (SPLP) testing, with concentrations not to exceed a SPLP test result of:

- 40 g/m^3 of Aluminium and
- 200 g/m^3 of Fluoride.

The material that may be accepted includes gravels and soils that have been contaminated with dross.

For aluminium dross waste AB Lime will:

- Record the date, source, volume and nature of the material received;
- Notify the SRC within 7 days of the material being accepted, and provide details of the source and volume of the material;
- Keep a record of monitoring data that confirms the contamination level of the material; and
- Record the location where the material is placed within the landfill.

The information recorded will be made available to Environment Southland or its representative on request.

5.3 Special Waste Acceptance Criteria

The criteria outlined below and defined in 2 indicate whether a special waste is acceptable for disposal in the landfill.

As wastes are usually mixtures of a range of substances the most stringent criteria that relates to a component applies. As such a waste may be treated to remove its prohibited properties so that it can be accepted as a special waste.

If no criteria is listed then the waste is accepted for disposal unless the waste is defined as a hazardous substance in terms of the HSNO regulations (Hazardous Substances and New Organisms (HSNO) Act 1996).

If it is defined as a hazardous substance then the waste is only accepted if a risk assessment (see Section 5.5.4) shows that it is able to be landfilled without adverse effects on human health or safety, the environment and it is compatible with the operations of the landfill.

5.3.1 Hazardous Characteristics

Any waste with a characteristic defined in Table A in Attachment 4 is not acceptable for disposal. If there is any doubt in the interpretation of this list, then reference is made to the HSNO definition.

5.3.2 Nature and Composition of Waste

Criteria relation to the nature and composition of wastes are listed in Attachment 2.

These tables include:

- elutriation criteria;
- maximum allowable concentrations acceptable with the requirement to undertake an elutriation test; and
- maximum concentrations.

5.3.3 Elutriation Criteria

The elutriation criteria are based on the USEPA Toxicity Characteristic Leaching Procedure (TCLP), USEPA Method 1311. The TCLP is designed to determine the mobility of both organic and inorganic analytes present in the liquid, solids and multiphase wastes.

The criteria are the lesser of:

- The trade waste consent limit (NZS 9201), or
- 100 times the drinking water standard, or
- 1000 times the guidelines for the protection of local aquatic ecosystems, or
- 1000 times the LD50 for the most sensitive local aquatic species, or
- a specific value calculated for that substance.

<u>Total Concentration of contaminants in a waste without Elutriation Tests</u>

Wastes with total concentrations of all chemical parameters less than those listed are accepted without the need for a TCLP test.

The listed value is 20 times the TCLP criteria, because the TCLP test included a 20 times dilution.

<u>Maximum Concentration</u>

This is the maximum concentration at which disposal is allowed. If no value is included, then the waste is able to be landfilled regardless of the concentration provided the other criteria are satisfied.

5.3.4 Physical Nature

Criteria relating to the physical characteristics of a waste a listed in Table B in Attachment 4. The only restriction on these wastes is their physical nature. In these cases, special arrangements for disposal are made with the Environmental Manager.

5.4 Special Case Procedure- Special Waste Acceptance

An alternative to using the criteria outlined in Section 5.3 is to assess an application as a Special Case- Special Waste Acceptance. This involves the use of a risk assessment process and may allow the disposal of wastes that exceed the listed criteria.

This approach is not available for all substances. Those for which this option is not available are marked with an asterisk in the lists and must comply with the listed values.

An inventory of the individual Special Case- Special Waste Acceptance documentation will be kept on file for reference by the Environmental Manager.

5.4.1 Risk Assessment Process- Special Case Procedure- Special Waste Acceptance

The leachate generated by a waste can be estimate on a pro-rata basis. The potential increase of a substance in the leachate discharge can be estimated by:

(Daily tonnes of a special waste/daily total tonnage) x TCLP concentration = substance increase in leachate conc.

This approach does not allow for attenuation and assumes that the waste will be in contract with extreme acidic conditions, i.e. TCLP concentration will be achieved in the leachate out of the specific waste. For example, for metallic analyte determinations the sample must be acidified with nitric acid to a pH < 2, and such a low pH-value is rarely observed in municipal solid waste landfills.

An example would be 10 tonnes/day of copper foundry waste with a TCLP concentration of 20 mg/L. If the total refuse tonnage were 1000 tonnes, then the maximum increase in leachate concentration would be:

(10/1010) x 20 mg/L = 0.2 mg/L is possible increase in copper concentration.

With comparison of the leachate copper concentration and trade waste limits (10 g/m^3 = 10 mg/L), acceptance of this waste stream would be acceptable.

On the other hand, for the disposal of 200 tonnes/day of the same waste, the copper concentration would be:

(200/1200) x 20 mg/L = 3.3 mg/L is possible increase in copper concentration.

Then if the existing leachate copper concentration is 5 mg/L, then the additional 3.3 mg/L would be very close to the trade waste limit of 10 mg/L, and in that instance, it would not be recommended to accept the special waste.

5.5 Disposal Method for Special Waste

5.5.1 Location of Special Waste Disposal

Special waste approved for disposal under Sections 5.1-5.4 will be disposed of as follows;

a) Either at the working face where it will be covered with refuse prior to compaction, or

b) Placed into pits/excavations in mature refuse to minimise exposure to acidic conditions such as arise in leachate generated in the early stages of refuse decomposition.

Waste approved for disposal under Section 5.4 (Special Case Waste) must be only be disposed of under item b) above.

5.5.2 Special Holes for Special Waste Disposal

Waste that is potentially a health hazard or visually distressful or landfill staff such as fine dust, autoclaved medical waste and sewage effluent screenings will be deposited into a special hole in a mature area of the landfill where practicable.

A minimum of Temporary Capping (see Section 12.3) shall be applied immediately to the Special Waste requiring disposal under Section 5.5.1-b), and the cover application operation must be supervised by the Landfill Supervisor.

5.5.3 Buffer Distance to Liner System for Special Waste Disposal

A 3 m buffer to the liner system is required to ensure that the excavation of special holes in the landfill do not compromise the base and sidewall liner system and are separate from the leachate collection system, no special wastes requiring special disposal will be accepted for disposal until the Environmental Manager has certified that sufficient waste has been placed to allow construction of special holes whereby the distance between the base of the special hole and the liner will be greater than 3 metres.

5.5.4 Disposal of Asbestos Waste and Medical Waste

Asbestos and medical related waste will be handled in accordance with AB Lime's document 4.30 Policy & Procedure Name: Approved Hazardous Waste 4.30. A copy of this document in contained in Attachment 5.

5.5.5 Surveying Location of Special Waste Disposal

The Landfill Supervisor is responsible for setting out and surveying the special holes.

5.6 Special Waste Tracking

If AB Lime decides, using the acceptance criteria of this plan, that the Special Waste can be disposed of at the landfill, then a permit will be issued to the special waste generator and/or contractor transporting the special waste. A copy of an example permit is contained in Attachment 6.

The permit must be carried by the transporter of the Special Waste and presented to the weighbridge operator to gain entry into the landfill.

The permit will have details of:

- A description of the approved special waste;
- The estimate of quantities to be disposed of;
- Customer details and permit expiry date;
- A permit number;
- The waste classification code; and
- The area for disposal.

The Weighbridge Operator will enter the permit number and waste classification code from the permit into the computer, together with the weigh details when the transporter leaves the landfill again, via the weighbridge.

All details associated with the waste will be able to be accessed by reference to the permit number.

5.7 Record Keeping- Special Waste

A full record will be kept for all Special Waste accepted at the landfill. For wastes approved under the category Special Case Procedure- Special Waste Acceptance a database of specific substances will be maintained to track any possible cumulative effect of that substance on leachate quality.

6. Crisis/Emergency Response Waste Acceptance

6.1 Waste Acceptance Criteria in Response to an Emergency and Government Agency Instruction

In the instance of a local, regional or national biosecurity emergency or disaster, AB Lime may be required to accept a substantial volume of waste over a relatively short period of time.

Due to the organic nature of some of these wastes, their acceptance at the landfill site is likely to cause a heightened loss of amenity or increased nuisance associated with odour.

A relaxation of the consent conditions with regards to the nuisance to neighbours and the general public associated with the acceptance of this waste is possible on condition of the following:

- Environment Southland are notified within 24 hours prior to the acceptance of the waste. The notification is to include the following:
  - A copy of the disposal authorisation/directive from the relevant Government Agency;
  - Proof of notification to neighbours;
  - The nature of the waste;
  - The volume of the waste;
  - Expected number of loads and the duration over which they will be accepted;
  - The generator or source of the waste;
  - The potential impacts associated with accepting the waste;
  - The conditions of the consent that will potentially be breached;
  - The request that a Council Officer be made available to oversee the disposal; and
  - A waste treatment or disposal procedure outlining the management controls and mitigation measures that will be employed.

AB Lime will require acknowledgement of receipt of the notification and authorisation from Environment Southland before they are permitted to accept the waste.

6.2 Mitigation Measures when Accepting Crisis/Emergency Response Waste

In these circumstances, the following provisions and management measures are to be employed to mitigate the potential impacts associated with the acceptance and handling of the waste:

a) The Environmental Manager will manage the entire disposal process associated with the emergency waste.

b) Trained operational staff are to be briefed on the procedure, advised of the health and safety risks and provided with the respective PPE.

c) A special area is to be designated and available to accept emergency waste.

d) An Environment Southland officer is to be present on site for the duration of the disposal procedure to ensure the management controls and mitigation measures are implemented as far as is possible.

e) The existing controls for odorous loads as per Landfill Odour Management Plan are to be employed along with the following additional controls:

- All waste to be disposed of under full-time supervision of the Environmental Manager;

- Waste is to be treated with additional lime at a ratio of 2:1, where it is considered safe to do so;
- Deep burial to a minimum of 2 metres;
- Application of lime with the biosecurity waste being disposed of; and
- Trench and cover immediately to Temporary Capping criteria (see Section 12.3).

f) Before exiting the landfill, all vehicles are to be disinfected as follows:

- Vehicle to first be water blasted in the washbay;
- Vehicle is then to be disinfected using a Ministry of Primary Industries approved disinfectant that is to be applied as per the manufacturer's instructions; and
- The disinfectant may need to be left on for 10-20 minutes to have full effect.

Upon completion of disposal but within 1 month, AB Lime are to provide Environment Southland with a report outlining the following:

- Confirmation of volume of waste received;
- Confirmation of number of loads received;
- Confirmation of duration of disposal process;
- Number of complaints received over the duration of the disposal process and how they were handled; and
- Lessons learnt and recommendations on how the process could be better managed in future.

7. Landfilling Operations

7.1 Site Control and Management

7.1.1 General Operations

All processes on site shall be undertaken in accordance with the Environmental Management Plan so that odours, noise, litter and other effects from the site operations are minimised.

7.1.2 Emergency Operating Hours

In an emergency, refuse may be delivered to the landfill outside the operating hours, provided that:

- Environment Southland are informed within 24 hours of the AB Lime Landfill being notified of the upcoming emergency waste acceptance event in terms of:
  a) The nature of the emergency; and
  b) The time/times of delivery and number of vehicles involved.
- The emergency is no more than one truck-load.

The information of the emergency event shall be made available to the Community Liaison Ground upon request.

For emergency waste that involves more than one truckload the procedures under Section 6 must be followed.

7.2 Weighbridge: Incoming Waste

All loads of waste will be weighed and inspected prior to entering the site and on leaving the site. The Weighbridge Operator:

- Will be present at the weighbridge office at all times the landfill is open to accept waste. The Weighbridge Operator duties will be shared with other qualified staff during breaks;
- Ensures that all vehicles entering the site will go over the weighbridge and be weighed on entry (gross weight- tonnes) and again on exit from the site (net weight- tonnes);
- Will check that any customer/transporter disposing of Special Waste has a valid Disposal Permit and that all Permit conditions have been complied with;
- Checks that waste transporters arriving at the landfill have their loads securely covered with no loose litter, dust or liquid leaking from the vehicle. Loads that do not meet these criteria will be refused entry;
- Will instruct a Pointsman to conduct the load inspection to ensure compliance with the Waste Acceptance Criteria for the landfill;
- Will provide the waste transporter with the location and directions to safely travel to the working face;
- Manages the weighbridge computer system that automatically records weights;
- Collects all forms required to be accompanied with the waste; and
- Records waste classifications and vehicle/transporters numbers.

7.3 Offloading Waste

The Pointsman:

- Will direct vehicles/transporters of waste to the appropriate location to offload;

- Instruct the vehicles to reverse to the offloading area where it is safe to do so, and discharge their load;
- Visually inspect load as they are offloaded to ensure compliance with Waste Acceptance Criteria; and
- Check for odorous loads and if found to be odours during tipping, the load shall be covered immediately with other waste or clean soil reserved for daily cover.

Any load that is found to contain waste that is not accepted at the landfill under the full-time supervision of the Landfill Supervisor will be pushed to one side for immediate reloading, on the waste transporter/vehicle and removed from the landfill.

The Landfill Supervisor will inform the Environmental Manager of the incident who will discuss with the transporter and/or transporter's client and/or generator of the waste, the reason for the waste being removed from the landfill.

A record will be kept by the Environmental Manager of all incidences related to waste not accepted at the landfill entering the landfill. This information will be reported to Environment Southland.

7.4 Placement & Compaction of Waste

7.4.1 Filling Programme

The landfill will be filled in a series of areas, i.e. cells. In April 2020 fifteen (15) areas have been filled as shown on drawing IZ000400-1000-NG-DRG-1003 in Attachment 1.

The future filling programme for areas 15 to Area 20 and Future Area's 1, 2 and 3 is shown on drawing IZ0004000-1000-NG-DRG-1002 in Attachment 1.

The design of the filling programme has been carried out in collaboration between AB Lime and Jacobs, so as to safely manage leachate, stormwater and landfill gas management associated with the landfilling operations and to accommodate the quarry operations that occur in close proximity to the landfilling operations. Please refer to landfill design documents for more detail.

7.4.2 First Placement of Refuse

- Loosely placed a 1 m minimum thick protection layer (selected waste) over the geogrid covering the leachate drainage material.
- The 1 m thick selected waste layer may consist of bagged domestic, selected refuse or other appropriate waste. The 1 m thick layer must not include any sawdust, sludge, bulky steel and other material which may damage the flexible membrane liner and reduce disturbance or cause clogging of the leachate collection blanket and pipework.
- No sludges or Special Waste pits will be disposed of within a 3 m zone above the drainage layer.
- The 1 m thick layer will be lightly compacted by a bulldozer or similar size and weight equipment, i.e. not a landfill compactor.
- The loose refuse on the perimeter of the lightly compacted refuse is tamped with the excavator bucket and covered with soil.
- Once sufficient area of the liner has been covered with the 1 m protection layer, refuse may be placed in 300 mm thick layers and subject to the usual refuse compaction by the landfill compactor to achieve a minimum compaction rate of 0.8 ton/m^3.

7.4.3 Working Face

The working face, also known as the open face or operating face, is the area where the waste is tipped, spread and compacted.

The area of the working face, i.e. exposed refuse, shall be kept to a practical minimum having given consideration to the quantity of waste entering the site, maintenance of optimum compaction and health & safety requirements.

The working face will not exceed 1000 m^2.

A schematic diagram showing the placement and compaction of waste at the working face, using the "face tipping" method or the "onion skin tipping" method is presented in Figure 2.

The Pointsman, Refuse Bulldozer Operator and Refuse Compactor Operator must maintain continuous contact via radio and/or visual contact, to assess the placement of each load on the working face.

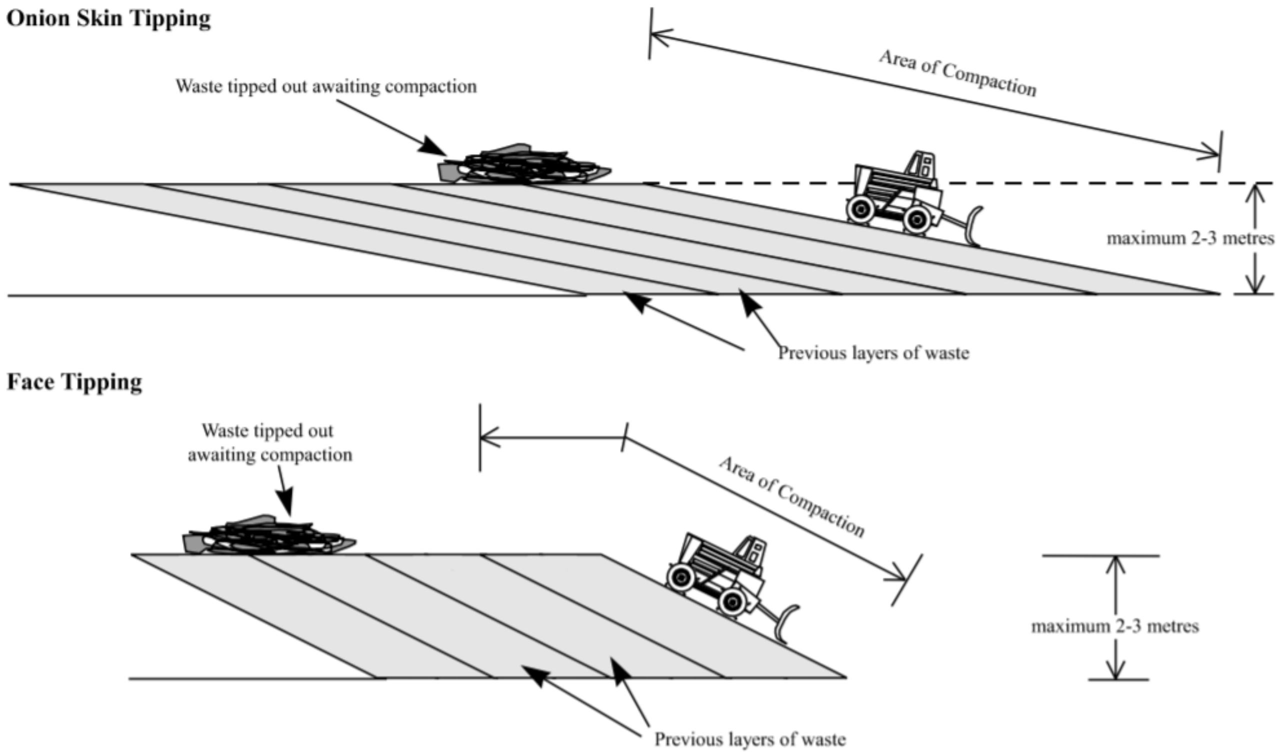


Figure 2 Two options for Working Face Refuse Tipping Methods (source; Fig 4 of EPA, Landfill Manuals, Landfill Operational Practices, Ireland, 1997)

7.4.4 Refuse Bulldozer Operator

The Refuse Bulldozer Operator:

- Will strip/blade the daily cover and stockpile it along the perimeter of the working area for re-use at the commencement of each working day;
- Ensure that sufficient daily cover is removed, to enable free drainage of leachate to the leachate collection system;
- Carry out the stripping of daily cover in tandem with the placement of fresh refuse to minimise the discharge of odour;
- Blade the waste from the off-load area to the working face area;
- Spread the waste in a 300 mm to 500 mm thick layer at the working face area as indicated by the Refuse Compactor Operator; and
- Track-roll the waste prior to the placement of daily cover at the end of each working day.

7.4.5 Refuse Compactor Operator

The Refuse Compactor Operator:

- Compacts the waste by a minimum of three to five passes (one pass is 'there-and-back');
- Instructs the Refuse Bulldozer Operator where each layer of waste is placed; and
- Liaises with the Refuse Bulldozer Operator that the waste is spread in 300 mm to 500 mm thick layers.

The compactor used at AB Lime is a BOMAG BC 772 RB-2 which is a 36-ton compactor.

It is envisaged that a minimum target refuse density of 0.8 tonnes/m^3 will be achieved if the refuse is placed in 300-500 mm loose lift layers and compacted using a minimum of 3-5 passes.

7.4.6 Temporary Access Road to Working Face

A temporary all-weather access road for the transporter of waste to travel to or near the working face (<50 m) and allow for the unloading of the waste, is essential for efficient operation of the landfill.

The temporary roads should allow for an approximate area of 4 m width per truck for unloading of waste, and for sufficient room for trucks to turn around.

This temporary access road is by its nature is always formed on waste. Forward planning by the Environmental Manager and Landfill Supervisor of operational areas will be carried out so that maximum use and minimum maintenance of these temporary access roads is achieved.

The temporary access roads and unloading areas will be constructed as to provide adequate traction for vehicles accessing the working face in all weather conditions.

7.4.7 Special Waste Disposal

The special waste disposal is described in Section 5.5.

The construction of special holes, limitations where special holes shot not be dug (with 3 m of base and sidewall landfill liner) and surveying of special holes is also presented in Section 5.5.

7.5 Daily Covering of Waste

7.5.1 Daily Cover

The main objectives of daily cover at the landfill include:

- Reduction of odour and landfill gas emissions;
- Prevention of wind-blown litter;
- Deterrence of scavenging by birds or other animals;
- Prevention of fly infestations;
- Reduction of dust nuisance;
- Deterrence of vermin such as rats;
- Reduction of the risk of fire; and
- Improvement of the visual appearance.

At the end of each working day the waste will be covered by a 'daily cover' layer that may comprise:

- A minimum 150 mm thick cover of suitable soil such as quarry overburden.

a) Note, this is a 150 mm thick layer after compaction so the loose lift layer thickness should be around 200 mm to 250 mm, to achieve a minimum 150 mm compacted thickness of daily cover soil.

b) The reason for a 200 mm to 250 mm loose lift layer thickness is that soil may drop into open spaces of the compacted waste.

c) For this reason, proper compaction of the refuse at the end of each working day is recommended as this reduces the risk of 'losing' soil in the underlying waste and thus, minimises the loose lift layer thickness of daily cover soil.

Alternative daily covers that can be used include:

- Sludge (lime dust and coal ash slurry) from the mill/kiln scrubbers;
- ConCover ProGaurd 11B (pulp and paper spray); and
- Other suitable alternatives that may be present in the waste stream.

7.5.2 Unsuitable Daily Cover

Unsuitable daily cover includes auto-shredder residue, also referred to as fragmentised waste, frag or fluff, or car-flock. The waste is generated from the shredding of end-of-life vehicles (ELVs) after the removal of hazardous and certain recyclable materials. The shredder residue is now not considered to be suitable as daily or intermediate cover at landfills.

The shredder residue has the potential to contain high levels of contaminants such as heavy metals, oils, and persistent organic pollutants (POPs) including certain brominated flame retardants and polychlorinated biphenyls (PCBs). It also presents a fire hazard, can be visually unattractive and can cause dust and litter concerns, depending on the composition of the material.

7.5.3 Daily Cover Odour Mitigation

If there is odour at the working face the alternative daily cover should not be used. Instead a soil cover of at least 150 mm thick should be used.

7.5.4 Removal of Daily Cover

- The next working day the daily cover will be removed as much as reasonably practical to allow leachate to migrate downwards rather than sideways, before it is covered with waste
- Any remaining daily cover will be scarified to facilitate vertical drainage
- During wet periods when it is difficult to remove daily cover material, trenches will be dug in the daily cover to expose the underlying refuse to facilitate leachate migration into the landfill

Further details about daily cover, intermediate cover, temporary capping and permanent capping are presented in Section 12.

7.5.5 Supply of Daily Cover

7.5.5.1 Excavated Cover

Excavation of soil for daily cover such as quarry overburden should be made available from areas of the site identified with agreement from both Landfill Supervisor and the Quarry Manager.

The Landfill Supervisor shall ensure that:

- The daily cover soil/material should be placed in reasonably close and practical proximity to working face, so that there is no risk of the daily cover not being applied at the end of each working day due to limited day-light hours to apply the daily cover, or because 'the working shift is over'; and
- All personnel and equipment required to apply the daily cover are available to apply the daily cover.

7.5.5.2 Imported Cover

Imported cover is soil or other approved alternative cover material that has been brought to the landfill. Material such as clean fill, dirt and small pieces of rubble may be used as cover for refuse.

Imported materials such as asphalt grindings and broken concrete should be used for building roads and for surfacing wet weather areas (e.g. waste transporter access to unloading area near working face).

Various types of imported fill material may be stockpiled in areas designated by the Landfill Supervisor.

7.5.6 Placement of Daily Cover

The placement of daily cover is by a combination of bulldozer and compactor (see Section 7.4) for soil-type daily covers.

7.5.7 Special Waste Cover including Asbestos Waste

Where it is deemed necessary to excavate pits to bury Special Waste, the type of cover must comprise at least Temporary Capping (see Section 5.5).

AB Lime has special procedures for handling and disposal of Asbestos Waste, and these are contained in Attachment 5.

7.5.8 Bulky Waste Items

The Landfill Supervisor will ensure that all bulky items (with a solid dimension in excess of 1 m) are NOT placed within 3 m of the base or sidewall of the landfill, or within 3 m of the final landfill cap.

7.5.9 Placement of Intermediate Cover, Temporary Capping and Final Capping

For placement of Intermediate Cover, Temporary Capping and Final/Permanent Capping, see Section 11.

7.6 Cleanfill

The AB Lime Landfill is consented to take cleanfill but under the agreement that is in place with Wastenet all Southland cleanfill is to be taken to other cleanfill sites.

Cleanfill is material that when discharged to the environment will have no adverse effect on people of the environment, and includes natural materials such as clay, soil and rock, and other materials, such as concert, brick or demolition products, that are free of:

- Combustible, putrescible, degradable or leachable components;
- Hazardous substances or materials (such as municipal solid waste) likely to create leachate by means of biological breakdown;
- Any products or materials derived from hazardous waste treatment, hazardous waste stabilisation or hazardous waste disposal practices;
- Materials such as medical and veterinary waste, asbestos;
- Radioactive substances that may present a risk to human health; and

- Contaminated soil and other contaminated materials.

Suitable cleanfill material that arrives at the landfill in discreet loads can be used for:

- Access routes within the landfill (hardfill);
- Temporary drainage systems within the landfill, for example leachate recirculation entry points (hardfill);
- Soil/subsoil as daily cover and screening bunds on landfill; and
- Topsoil restoration work.

All other material that may be considered suitable for a cleanfill activity is placed within the landfill containment area.

8. Nuisance Control

8.1 Odour Control

Please refer to Landfill Odour Management Plan.

8.2 Dust Control

Please refer to the Landfill Air Quality Management Plan.

8.3 Noise Control

All activities on the site are managed and carried out so that the rating level measured at the notional boundary of any neighbouring property does not exceed the following levels.

Table 3 Noise Limits

Monday – Saturday, 7.00 am – 10.00 pm	50 dBA L_{eq}
All other times including public holidays	40 dBA L_{eq}
Daily, 10.00 pm – 7.00 am the following day	70 dBA L_{max}

"Notional boundary" means a line 20 metre from the façade of the building in question or the legal boundary of the site on which the building is located where the boundary is closer to the building than 20 metres.

Sound levels are those as measured in accordance with the provision of NZS 6801:2008 Acoustics – Measurement of Environment Sound and assessed in accordance with the provision of NZS 6802:2008 Acoustics – Assessment of Environmental Noise.

Measurement of Environment Sound and assessed in accordance with the provision of NZS 6802:2008 Acoustics – Assessment of Environmental Noise.

An annual noise monitoring survey shall be carried out for the duration of the consent in order to ensure that the consent holder is operating in compliance with condition 2.22.

8.4 Litter Control

Uncontrolled litter can contribute significantly to the loss of amenity experienced at a landfill site. The location of AB Lime is in a general rural area with many trees around the landfill boundary providing a degree of screening.

AB Lime will implement the following controls to prevent and manage nuisance from wind-blown litter.

8.4.1 Secure Loads

A condition of entry is that all trucks/transporters of waste must have secured loads to prevent the escape of litter.

The covers are not to be removed until the trucks reach the off-loading area near the working face. The Weighbridge Operator will remind the drivers of the trucks of this requirement when they enter the landfill.

Should the waste transporter experience litter falling or blowing from the truck when driving to the working face, the driver must inform the Pointsman immediately who in turn will advise the Landfill Supervisor who will be responsible for arranging a clean-up of litter as soon as reasonably practical.

8.4.2 Tipping Areas

Ensure that vehicles are only unloaded within the active cell and in the vicinity of the working face.

Ensure adequate plant is available on site for the placement, compaction and covering of waste.

Ensure an adequate supply of daily cover materials is available on site and that cover is placed over the waste as soon as practical but no later than the end of the day.

During dry and windy conditions, the active working face is to be kept damp by watering. In high winds it may be necessary to suspend disposal activities for a short period.

8.4.3 Litter Nets

Litter control nets will be erected around the perimeter of the operational area which will be an appropriate set back from the working face in order for the bulldozer and compactor to work safely and efficiently.

The litter nets will be generally 6 m high constructed of tantalised timber poles from which 75 mm mesh netting is hung.

Additional relocatable litter nets will be placed immediately adjacent to the working face on an as-required basis as determined by the Landfill Supervisor.

8.4.4 On-Site Litter Checks

The Landfill Supervisor shall ensure that checks of the site for litter including all litter nets and areas outside the landfill footprint are undertaken. Any litter found must be removed the same day.

8.4.5 Litter on Adjacent Properties

If any complaints are received from adjacent landowners in relation to windblown litter from the landfill, the Landfill Supervisor shall inform the Environmental Manager, who will carry out an investigation into the origin of the litter immediately and ensure that the litter is collected as soon as practicable. If the nuisance is of an on-going nature as deemed from the receipt of repeated valid complaints, take steps to ensure any identified impacts are addressed.

Litter complaint reporting is to be undertaken in accordance with the Environmental Management Plan Complaints Register.

8.5 Vermin Control

Vermin can spread disease, cause property destruction or contaminate food; however, vermin are generally not present at a properly operated and maintained sanitary landfill.

Rat and cat populations occur because they are brought to the site in incoming waste loads or migrate to the landfill. Effective site management is the best way to counter rat or cat infestation.

Local feral cats can cause a wild cat population problem in the landfill and surrounding area. Regular trapping of cats in humane cages is undertaken during autumn and spring. Captured cats are humanely shot, neutered/spayed or in the case of kittens rehomed if possible.

The Landfill Supervisor is responsible that the following vermin controls are undertaken:

- Ensuring that the waste arriving on site is promptly unloaded and compacted, i.e. no stockpiling of waste unless an emergency;
- Applying cover on the working face daily (delegate responsibility to Landfill Supervisor and Pointsman);

- Check that there is sufficient thickness and appropriate daily cover in those areas that will require re-filling with refuse within one month;
- Check that there is sufficient intermediate cover in those areas that will not require re-filling with waste within one month;
- Regular mowing of grassed areas to prevent nest establishment and seeding;
- Keeping equipment, storage and leisure/office areas free of debris and food waste to prevent vermin from establishing residence in or near areas where employees or support personnel work, eat and drink;
- Arranging poisoning by a pest controller, if appropriate; and
- Reject incoming loads if vermin is present.

8.5.1 Vermin Surveys

An independent pest controller, such as Allpests Southland Pest Control, is engaged to carry out a vermin survey on a monthly basis. They report to AB Lime monthly on rodent activity and bait placement. These reports are available for Environment Southland, upon request.

If increased vermin levels are detected the Landfill Supervisor shall take immediate action to reduce the vermin numbers.

8.5.2 Fly Control

Flies may become a problem over the summer months and are capable of transmitting diseases such as salmonella and other food-borne diseases.

The Landfill Supervisor is responsible for undertaking the following controls:

- Ensure that all the waste arriving on-site is promptly compacted;
- Daily covering of the working face;
- Burying odorous loads inadvertently accepted immediately;
- Rejecting maggot infested load; and
- Arranging the application of insecticide by a pest controller if required.

8.6 Bird Control

Bird control at the site will focus on ensuring that minimal numbers of gulls are attracted to the landfill and the bird nuisance effects are minimised. Bird control practices to be used on site are outlined below.

8.6.1 Covering the Refuse and Controlling the Tipping

The methods described in this section are used to limit the access to food and will have the greatest effect on controlling the likelihood of a bird problem occurring on site. The techniques here include:

- No public access;
- All refuse loads arriving at the site will be covered;
- The working face will be kept to a practical minimum (<1000 m^2);
- Continuous movement of machinery over the working face; and
- Daily covering of exposed refuse.

8.6.2 Bird Dispersal Techniques

Bird dispersal involves harassing or frightening birds away from the refuse so that they ultimately leave. Methods of bird dispersal include auditory or visual scaring devices and chemical repellents.

A gas cannon (gas operated scare-gun) will be used on-site if required, and uses a loud noise to scare the birds. These cannons can be effective until birds become 'habituated' to the device. To prevent habituation the location of the gas cannon will be regularly moved, and it will fire at irregular intervals with varying number of shots together.

8.6.3 Bird Obstruction/Shooting/Poison Techniques

Wires with metallic flagging tape will be placed randomly near the working face to assist in preventing birds gaining access to the working face.

The culling of birds, only those listed in Schedule 5 of the Wildlife Act 1953, by shooting shall be done under the instruction of the Environmental Manager. Only persons with a firearms licence issued by the New Zealand Police shall operate a firearm on the landfill.

Earmuffs and safety glasses shall be worn at all times when shooting. A clear unobstructed line of sight is required before any shot is taken. A normal firearms safety procedure must be adhered to. The firearm shall be discharged at an angle not exceeding 20 degrees from the vertical. At no stage shall a firearm be discharged horizontally on the landfill.

Poisoning birds with alpha chloralosed paste is a last resort method. This poison is best used in cold conditions and works by slowing the metabolism of the birds down. Non-target species can be revived by warming them up. If it were deemed necessary to use poison a suitably qualified contractor would be engaged by AB Lime. Prior to implementing the programme, the contractor would need to develop a plan to be approved by the Environmental Manager to ensure the effective use of the poison, that only target species are killed and no birds die off-site from the landfill.

The number of birds culled will be recorded by the Environmental Manager. All carcasses will be removed to the working face and buried under the direction of the Landfill Supervisor.

8.7 Exterior Lighting Control

All activities on the site are managed so that all exterior lighting shall be directed away from adjacent residences not owned by the consent holder, so as to minimise the potential for adverse effects from light spill on adjacent residents, and so as to achieve compliance with Rule Rural.7 of the Operative Southland District Plan 2018.

9. Slope Stability

9.1 Soil or Rock Landfill Side Slopes (Pre-Landfilling)

The side slopes of the landfill are either limestone or soil side slopes. Limestone side slopes are excavated from the existing limestone rock and the soil side slopes are constructed from structural fill. It is recommended that any karst features are identified and removed during the limestone quarrying.

The side slope liner design is specified for slopes of 2H:1V or greater in proposed consent conditions and is shown in drawing IZ000400-1000-NG-DRG-1018 in Attachment 1. The side slope liner includes the following components:

- A groundwater underdrainage system where required;
- 5 mm GCL with a maximum permeability of 5×10^{-11} m/s;
- 2.0 mm HDPE;
- A liner protection layer of geotextile;
- A 300 mm of granular material; and
- A 1 m select waste layer.

Further details on the side slope liner design and construction are provided in the Technical Specification and Quality Assurance & Quality Control Standard documents, the latest of which are for Area 15. The GCL, HDPE and select waste layer are discussed in Section 12.

9.1.1 Subgrade Preparation

The proposed consent conditions state that the landfill side slopes will be prepared to ensure a smooth surface appropriate for the placement of geosynthetic liner materials. This shall include the smoothing of rough surfaces, sealing of karstic solution features or compaction of slopes to an appropriate bearing capacity. During this process, especially the sealing of solution features, observations will be noted, and any features will be logged and shown on an as-built.

9.1.2 Groundwater Underdrainage System

For the side slope liner, a groundwater underdrainage system is only constructed where groundwater is observed on the exposed limestone surface. This varies from the base liner design, where the groundwater underdrainage layer is continued across the entire landfill base. The limestone side slope surface is clearly exposed, and superficial obstructions are disposed of and the face is checked for the presence of groundwater and karstic features. There is no requirement for a groundwater underdrainage system for soil side slopes if no groundwater or karstic features are identified.

The groundwater underdrainage system for the limestone side slopes involves a separate design for outflow and inflow karstic cavities. Outflow cavities (i.e. cavities orientated approximately downslope) are backfilled and sealed to form a smooth surface. There are several sealing techniques, such as grouting or using a flexible filler. Inflow cavities (i.e. cavities orientated approximately upslope) are drained using a drainage strip, such as CORDRAIN, which is connected to the groundwater underdrainage system under the base liner. This side slope groundwater underdrainage system is described in the Technical Specification, the most recent of which is Area 15 Technical Specification.

9.1.3 Anchor Trenches

At the top of the slope the GCL and the HDPE is placed in an anchor trench on all edges as shown in drawing IZ000400-1000-NG-DRG-1018. Structural fill is backfilled and compacted in the anchor trench to provide resistance against pull out. Further details are provided in the ELCOSEAL Installation Guidelines.

9.1.4 Slope Stability

The soil or rock landfill side slopes have been designed with a typical slope of 1(v):2(h), since:

- AB Lime has quarried the site for many years and has a significant amount of slope stability experience from the quarrying operations
- The quarrying operations are relatively steep slopes with a height of 5 m and 5 m wide benches
- In the past 15 years the landfill design has successfully used a typical slope of 1(v):2(h) as this is considered a maximum slope where specialist contractors can safely carry out the in-situ welding operations of the HDPE liner.
- The landfill footprint and cell/area layout shows that a 1(v):2(h) provides a good compromise between maximising landfill airspace (which favours a steep slope) and the practicality of installing the HDPE liner system.
- Geotechnical observations have proven that the slope of 1(v):2(h) contains an appropriate factor of safety against slope instability
- The slope of 1(v):2(h) has been allowed for in the resource consent conditions.

9.2 Waste Slopes- Working Face

The refuse filling operations are typically carried out in 300 mm to 500 mm thick lift on a near horizontal surface (in the longitudinal direction) with a shallow lateral slope into the waste.

The shallow slope into the waste will be no greater than a slope of 1(v):3(h), although the slope may be a lot shallower if the 'onion skin tipping' method is used Section 7.4.3).

The height of the working face slope will be no greater than 2-3 m so there is no risk of working face slope instability (Section 7.4.3).

9.3 Internal Temporary Slope

For the internal temporary slopes, the design criteria are a slope of 1(v):4(h), and this slope should provide the Landfill Bulldozer Operator and Landfill Compactor Operator will a reasonable slope angle to place and compact the intermediate cover or temporary capping (see Sections 12.2 and 12.3).

At the discretion of the Environmental Manager, after consultation and agreement with the Landfill Supervisor, Landfill Dozer Operator and Landfill Compactor Operator, the internal temporary slope of 1(v):4(h) may be increased to a slope of 1(v):3(h), provided that the intermediate cover or temporary capping layer can be safely and appropriately compacted on the 1(v):3(h) slope.

A diagram of the internal temporary slope of 1(v):3(h) is presented in Figure 3 for 'overlaying phases' and in Figure 4 for a 'typical filling sequence'.

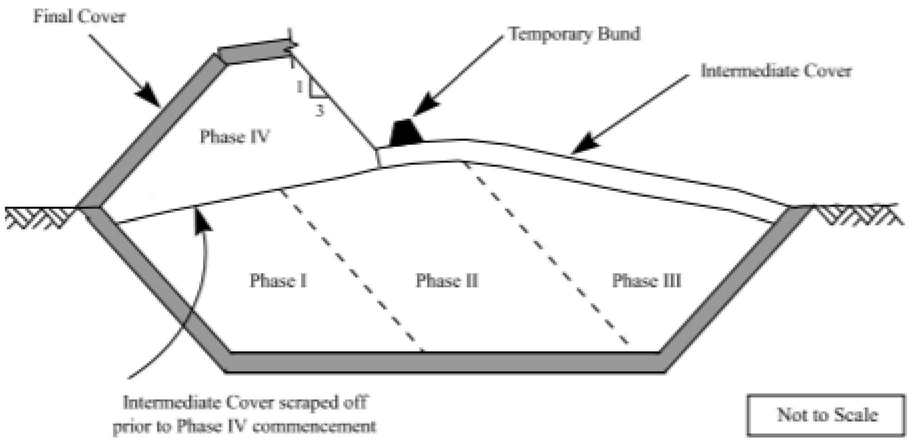


Figure 3 Internal Temporary Slope of 1(v):3(h) for Overlaying Phases (source; Fig 8 of EPA, Landfill Manuals, Landfill Operational Practices, Ireland, 1997)

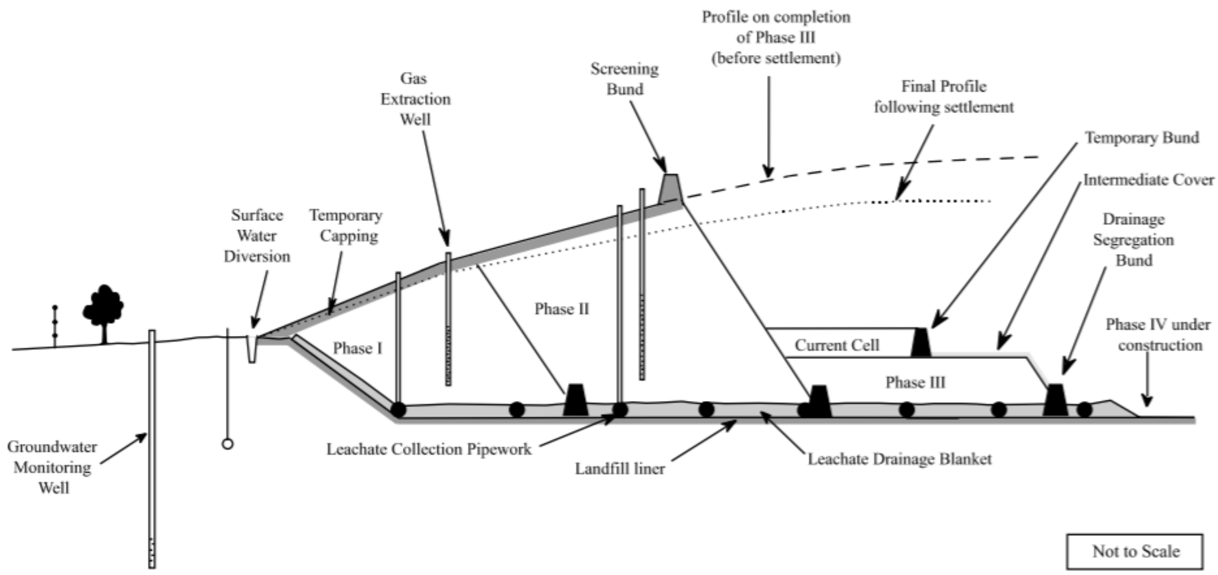


Figure 4 Internal Temporary Slope of 1(v):3(h) for Typical Landfill Filling Sequence (source; Fig 7 of EPA, Landfill Manuals, Landfill Operational Practices, Ireland, 1997)

9.4 Improvement of Existing Temporary Capping on Steep Slopes

There are currently several relatively large steep temporary slopes at the landfill where the thickness and type capping soil does not meet the temporary capping criteria (see Section 10.3).

Since these relatively large steep slopes do not have appropriate capping there are potential hazards for:

- Odour and landfill gas emissions, due to the relatively thin and not-compacted capping layer;
- Air ingress through the thin capping layer into the gas extraction wells, resulting in a lower than optimal vacuum that otherwise could be applied to the gas wells, thus not maximising gas extraction and inefficient use of the gas plant;
- Oxygen infiltration through the temporary cap also increases the risk of underground fires;
- Leachate generation, due to rainfall and surface water infiltration through the thin cover layer; and
- Slope in-stability, due to a combination of the size and steepness of the slopes and potential for water/leachate to build up within the steep slopes.

It is proposed to mitigate these potential hazards by providing an improved temporary capping layer covering the top/flat area of the steep slope and the slope itself. The improved temporary capping layer will be a minimum thickness of 600 mm and meeting the Temporary Capping criteria.

The mitigation measures to improve the temporary capping on the steep slopes are shown diagrammatically on an east-west trending ground profile cross section covering Area 14 and Area 15, see drawing IZ000400-1000-NG-DRG-1014 in Attachment 1.

The ground profile cross section shows the following sequence of construction events (see cross section in drawing IZ000400-1000-NG-DRG-1014 in Attachment 1:

- Construct a 600 mm minimum thickness intermediate cover on the relatively flat area on Area 14;
- The cover should be placed in no less than four layers, each layer comprising a loose lift layer thickness of no less than 200 mm so that the compacted total cover thickness is at least 600 mm thick;
- The slope of the newly place cover should be placed so that the surface water run-off is guided away from the Area14/15 steep slope;
- Install a leachate collection pipe, leachate gravel surrounding the pipe covered with a geotextile in the existing buffer zone between the base of the existing Area14-15 stormwater bund and the base of the existing Area 14 slope. Connect the leachate pipe to the existing leachate system;
- Place and compact waste between the Area 14/15 bund and the base of the existing slope Area 14 slope to a height 0.5 m below the existing height of the existing Area 14/15 bund;
- Construct a low permeability soil bund on top of the recently placed waste but off-set to the east from the existing Area 14/15 bund;
- The new bund dimensions will be approximately as follows: crest 2 m, height 3 m, side slopes 1(v):1(h), base 8 m wide;
- Place and compact waste as per item d) above;
- Construct another bund as per item e) above;
- Repeat process until the top of the existing slope at Area 14 has been reached; and
- At the top of the Area 14 slope provide an additional bunded area to guide stormwater away from the newly constructed benched bunds between Area 14/15.

The low permeability soil bund can be progressively stripped back when waste placement occurs in Area 15, where it is considered safe to do so by the Environmental Manager.

Area 15 will be filled using the maximum slope criteria described in Sections 11.2 and 11.3, so that future large steep slope faces are avoided.

9.5 External Permanent Slope- Landfill Permanent Capping Slope

The external permanent landfill capping slope will be 1(v):4(h) (post-settlement). This is further discussed in Section 12 below.

10. Landfill Cover and Capping

The terms landfill cover and landfill capping can be distinguished by the material type and when they are applied during the landfill operation, see Table 4 below.

A site plan showing the part of the landfill that have permanent capping, temporary capping, intermediate cover and the working face (as of April 2020) is presented in drawing IZ000400-1000-NG-DRG-1012 in Attachment 1.

Table 4 Summary of Cover and Capping Types for the AB Lime Landfill, Thickness and Material Type

Cover/Capping Type	When used	Material type (typical) and thickness	Section of LOMP
Daily cover	Each day	150 mm minimum thick soil	Section 7.5.1
Intermediate cover	>7 days	300 mm minimum thick low permeability soil	10.2
Temporary capping	>3 months	600 mm minimum thick low permeability soil	10.3
Permanent capping	As required	See consent conditions	10.4

10.1 Daily Cover

The objectives and types of daily cover are presented in Section 7.5.1

10.2 Intermediate Cover

Intermediate cover refers to the placement of suitable, adequate and stable material (minimum 300 mm if soil is used) over deposited waste for a period of time prior to temporary capping or prior to further disposal of waste in that area.

The 300 mm minimum compacted thickness should be applied in at least two loose lift layer thicknesses of no more than 200 mm to 250 mm per layer.

Daily cover should generally be replaced by intermediate cover in any area of an active cell where a new covering lift of waste is not planned within the next seven days, although the precise timeframe may vary according to prevailing conditions.

Intermediate cover has the same objectives as daily cover, i.e. to control nuisances such as litter, odour and vermin, but in addition, intermediate cover should reduce the infiltration of rainfall, help prevent the escape of leachate and landfill gas, and be functional over a prolonged period of time (e.g. weeks or months).

Where odour control is an issue and/or active landfill gas extraction is warranted, the intermediate cover may need to be replaced by a temporary capping (see Section 12.3).

Not all materials used as daily cover may be suitable for use as intermediate cover. Intermediate cover needs to be robust and to provide greater long-term protection to the landfill surface until such time as capping takes place or waste placement in that area recommences.

Soils that are not free-draining are more suitable for use as intermediate cover than daily cover, because they will help prevent the ingress of rain and lessen fugitive landfill gas emissions and leachate break-outs. Areas with intermediate cover should be regularly inspected by site staff, and any eroded cover materials should be replenished.

10.3 Temporary Capping

Temporary capping will be used for all parts of the landfill where the intermediate capping has been in place for more than 3 months.

Temporary capping at the AB Lime landfill may be present for months to years and as such, the soil thickness and soil type should be compatible with minimising landfill gas surface emissions, minimising rainfall/surface water infiltration, and maximising landfill gas extraction from the gas extraction wells.

The AB Lime temporary capping will be constructed of low permeability soil with a minimum compacted thickness of 600 mm, constructed in a minimum of four layers where each layer has a minimum loose lift layer thickness of 200 mm to 250 mm.

Alternatives to the low permeability soil layer such as a Geocomposite Clay Liner (GCL), in conjunction with another soil layers (e.g. AB Lime knaprock or quarry overburden), may be considered but only with prior discussion and approval from the Independent Peer Reviewer.

Temporary capping will be used in all areas of the landfill where increased landfill gas extraction from vertical wells is required (e.g. for odour control and/or to minimise landfill gas surface emissions).

10.4 Final Capping

The objectives of the final cover and capping applied to landfills are outlined by the Technical Guidelines for the Disposal to Land by Waste Management Institute New Zealand (WasteMINZ, 2018) as follows:

- Provide a barrier to surface water infiltration into the waste;
- Control discharges of landfill gas and leachate; and
- Rehabilitate the site surface.

The Technical Guidelines for Disposal to Land (WasteMINZ, 2018) states that a simple final cover system should include the following elements from bottom to top:

- Intermediate soil cover;
- A low permeability layer; and
- A topsoil layer.

Final capping that was constructed prior to April 2020 adhered to Condition 10 of Consent AUTH-201346-V3, which is presented below:

"Final cover and capping shall be constructed to the following minimum specification, from bottom to top, as each stage of the landfill is completed:

- *300 millimetres intermediate cover/regulating layer of compacted quarry overburden;*
- *600 millimetres of compacted clay, overburden or soil material, with a permeability coefficient (k) of not more than 1 x 10-7 metres per second;*

- *150 millimetres of growing medium."*

Final capping that is constructed post April 2020 will adhere to the proposed consent conditions. The updated consent condition includes two capping design options, which both adhere to WasteMINZ guidelines.

10.4.1 Final Capping Design

AB Lime's landfill final capping design details of the edge extent of the final capping layer is shown in drawing IZ000400-1000-NG-DRG-1017 in Attachment 1. It meets the minimum specification of Option Two of the proposed consent conditions. The final capping design also includes additional layers to improve its effectiveness in managing effects. The components of the final capping system, from bottom to top, are as follows:

- The first three layers meet consent requirement for a minimum 300 mm thick intermediate cover/regulating layer:
  - ~~100 to~~ 200 mm thick intermediate layer (knap rock);
  - 200 ~~to 300 mm~~ of quarry rock;
  - 600 mm of compacted knap rock;
- A geosynthetic clay liner (GCL) with a permeability coefficient (k) not exceeding 1×10^{-7} metres per second;
- 300 mm of compacted knap rock (growth layer); and
- 150 mm of topsoil.

The final capping surface cover has a minimum gradient requirement of 1(V):20(H) to promote effective shedding of surface water. The WasteMINZ guidelines recommend a maximum gradient of 1(V):3(H) for capping (WasteMINZ, 2018). The current maximum gradient for AB Lime Landfill's final surface is 1(V):3(H). This provides an acceptable factor of safety for waste stability and aids to minimise erosion and post-closure care issues; it is also appropriate for after use as it can be traversed by agricultural machinery.

Permanent stakes, or similar are installed in the ground at existing ground level and immediately outside the anchor trench, at 20 m centres, to clearly mark the lateral extent of the landfill capping layer. The stakes protect the capping layer from unnecessary plant and equipment driving over it.

Further details on the components of the proposed final capping layer, from bottom to top, are presented from Section 10.4.1.1 to 10.4.1.6.

10.4.1.1 Intermediate Layer

On top of the landfill waste a ~~100 –~~ 200 mm thick intermediate layer is placed. The intermediate layer is constructed from knap rock material and is deposited in one lift. The intermediate layer is compacted to hold waste in place, minimise odour, and to provide a uniform platform for the remaining capping material to be built upon. There are no specific compaction requirements associated with the intermediate layer.

10.4.1.2 Quarry Rock

A 200 ~~– 300 mm~~ quarry rock layer is placed on top of the intermediate layer and is deposited in one lift. The quarry rock is compacted to provide a firm base to allow ease of compaction of the lower knap rock layer. The quarry rock layer has the following specifications:

- The maximum particle size is a diameter of 150 mm;
- Compaction plant will be managed so that during spreading, compaction and subsequent trafficking, weaving and rutting of the compacted fill surface is avoided; and

- During compaction the maximum tolerable temporary weave will be a temporary deflection of 50 mm and a permanent deflection of 20 mm under the passage of a fully laden earthmoving plant or compactor, measured from the surface level of the compacted layer.

10.4.1.3 Lower Knap Rock

The lower knap rock is deposited on top of the quarry rock in ~~one~~ two lifts. The minimum thickness of the compacted knap rock layer is 600 mm. The knap rock is compacted to provide a smooth surface for the GCL to be laid on and acts as an additional contaminant barrier. The lower knap rock layer has the following specifications:

- It will contain only screened, well graded sands and gravels with a maximum particle size of 32 mm diameter. In addition, d_{60} will be less than 5 mm and d_{20} will be less than 0.15 mm (as per manufactures recommendations). These materials should bind and have good bearing capacity when compacted/rolled;
- The lower knap rock layer shall have a minimum relative compaction of 90%, where minimum relative compaction refers to the Maximum Dry Density (MDD) Ratio at Standard Compaction. The testing requirements for the lower knap rock layer are outlined in Table 5 and Table 6.;
- The lower knap rock layer will be proof rolled with a smooth drum roller immediately prior to deployments of the GCL to ensure a smooth, flat surface with no visible rutting or deformation; and
- The finished surface of the knap rock will be free of foreign matter, free standing water or loose stones. To protect the GCL layer from damage, no stones protruding out of the subgrade by more than 10 mm will be allowed (as per manufactures recommendations).

10.4.1.4 GCL

The GCL layer provides a hydraulic and gas barrier and is the main component of the final capping system that reduces infiltration into the waste material. The GCL is from the EnviroFix X1000-X2000 range, which have a permeability between 1.8 to 2.6 x 10^{-11} m/s. Therefore, all options meet the consent requirement to have a maximum permeability of 1×10^{-7}m/s. The recommended system is the X2000 GCL.

The principal advantage of using a GCL is the ease of the construction and quality assurance process of the capping construction. In addition, this capping arrangement is superior to the previous capping design (pre-March 2020) due to the lower permeability of the GCL and its ability to handle 15%-50% (product dependant) of elongation that will allow for differential settlement. The GCL will be joined from cell to cell using the methodology for longitudinal and transverse overlaps as described in Attachment 9.

Further details of this recommendation are discussed in the Landfill Capping Concept Design Memo. The attachments from the Landfill Capping Concept Design Memo should be referred to for further information regarding the construction requirements and installation guidelines.

10.4.1.5 Upper Knap Rock (Growth Layer)

The upper knap rock layer is placed immediately above the GCL in one lift. It provides a buffer layer between the vegetation and the GCL, which protects the GCL from root growth. The minimum thickness of the compacted knap rock layer is 300 mm. The upper knap rock layer has the following specifications:

- It will contain only screened, well graded material with a maximum particle size of 32 mm diameter and a uniformity coefficient greater than 5 (as per manufactures recommendations);
- The upper knap rock layer will be track rolled but does not need to be rolled smooth. The knap rock receives minimal compaction, which assists with its stability, but avoids creating a hard, low permeability layer beneath the topsoil; and
- Prior to placing the topsoil, the surface of the knap rock layer is scarified to increase its permeability and roughen the surface to assist with retention of topsoil.

10.4.1.6 Topsoil

A topsoil layer of 150 mm thickness is placed over the upper knap rock layer. The growing season is taken into consideration when timing the placement of the topsoil. Therefore, topsoil placement might be delayed until autumn or spring. Vegetation is limited to grasses; no large trees or deep rooting shrubbery.

10.4.2 Final Capping Connection Details

10.4.2.1 Clay and GCL Capping Layers Connection

The GCL is partially inserted into the clay capping layer. To achieve this 300 mm of the compacted clay layer is excavated from the clay capping layer for a minimum length of 1 m adjacent to the GCL capping layer. The GCL is then laid atop of the compacted clay, and backfilled with 65% knap rock and 35% bentonite (further details provided in Section 11.4.2.3). Between the clay and GCL capping design, the GCL shall be placed vertically and then laid on top of the lower knap rock layer of the GCL capping layer. The horizontal connection detail to tie the GCL capping layer (new design) into the clay capping layer (original design) is shown in drawing IZ000400-1000-NG-DRG-1016 in Attachment 1.

10.4.2.2 Gas Well and Capping Layer Connection

Within a 1 m radius around the gas well a bentonite and knap rock seal (further details provided in Section 11.4.2.3) is placed, that extends from the bottom of the intermediate layer to the top of the upper knap rock layer. The GCL is partially inserted into the gas well seal. The bentonite and knap rock mixture allows for settlement of the waste and capping layer surrounding the gas well, while still maintaining a tight seal. The connection detail for gas wells that penetrate through the GCL capping layer is shown in drawing IZ000400-1000-NG-DRG-1015 in Attachment 1.

10.4.2.3 Bentonite and Knap Rock Mixture

The backfill mixture for the capping connection details shall be composed of 65% knap rock and 35% bentonite by weight. The bentonite and knap rock shall be mechanically blended with the appropriate amount of water to form a homogenous mix with suitable consistency. It is also necessary to ensure that the knap rock is well graded. Based on findings in literature, the 65% knap rock and 35% bentonite mixture is expected to have a permeability lower than $1x10^{-7}$ m/s. However, one permeability test will need to be performed in order to confirm that it meets requirements.

10.4.3 Final Capping Quality Control

The lower knap rock layer is the only layer within the final capping system that requires testing. Testing requirements to confirm the achieved compaction of the lower knap rock layer is summarised in Table 10.2.

Table 5 Testing Requirements for Lower Knap Rock Layer

Parameter	Test	Standard	Capping
Minimum Relative Compaction[1]	Nuclear Densometer (NDM)	NZS 4407:2015 Test 4.2	90%
Notes: 1. Minimum relative compaction refers to the Maximum Dry Density (MDD) Ratio at Standard Compaction.			

The minimum frequency of testing required is summarised in Table 10.3. The actual amount of testing carried out will depend on the size and shape of areas being worked and the consistency of operations and materials on site.

Table 6 Frequency of Testing Required for Lower Knap Rock Layer

Parameter	Test	Standard	Frequency
MDD and OMC	Standard Compaction Test (5-point laboratory test)	NZS 4402:1986 Test 4.1.2	1 test per 10,000 m^3 sampled from each stockpile. Additional tests shall be performed if the stockpile is visually variable.
Relative Compaction (% of MDD) and Moisture Content	Nuclear Densometer (field test)	NZS 4407:2015 Test 4.2	1 set (1 NDM test and 1 moisture content test) per 500 m^2 of compacted material for each layer for the first 1,000 m^3; thereafter 1 set per 1,000 m^2 of compacted material for each layer. A minimum of 2 sets per day shall be taken during knap rock placement.

10.4.4 Final Capping Trial Pad

A trial pad is to be constructed to observe whether the GCL capping design and construction methodology is suitable. The trial pad will be a minimum size of 20 m by 20 m and will be constructed adjacent to the current capping layer. The trial pad will be constructed atop of the landfill waste and shall tie-in with the slope of the current capping layer at 1(V):4(H).

The gas well connection detail and the clay and GCL horizontal capping connection detail as described in Section 10.4.2 and shown in drawing IZ000400-1000-NG-DRG-1015 and drawing IZ0004000-1000-NG-DRG-1016 respectively, found in Attachment 1 and will both be constructed as part of the trial pad.

Upon the completion of the capping trial pad, testing for landfill gas surface emissions will be carried out. This should be completed once a week for the first month and then monthly for up to 6 months. The testing should be carried out when the wind speed is less than 5 km/hr and at least two rounds of testing should be completed during falling and low (<1000 mbar) barometric pressure. An Internal Trigger Level (TL-1) of 0.05%, as specified in the Landfill Gas Management Plan, will be applied.

Following completion of the capping trial pad the final capping design will be finalised and the Final Capping Specification and Quality Control Standard will be issued for approval to the Independent Peer Reviewer and Environment Southland. The Landfill Operations Management Plan will then be updated to refer to the Final Capping Specification and Quality Control Standard document for design and construction details.

Effective design improvements to the capping design are suggested below:

- The requirement of the knap rock below the GCL capping liner to meet a required permeability;
- Drainage layer above the GCL;
- Slope stability analysis
- Anchor trench detail improvements; and
- GCL penetration detail

10.4.5 Final Capping Management

10.4.5.1 Inspections of Final and Temporary Capping Areas

Inspections of the permanent and temporary capping areas are carried out at least once every six months and following significant storm events (greater than 50% AEP at a duration of less than one day). This formal inspection requirement is outlined in Condition 36 of Consent AUTH-201346-V3.

The inspection criteria are listed below:

- Vegetation die-off;
- Cracking of the cap surface;
- Subsidence and erosion;
- Leachate break-out through the cap; and
- Refuse protruding through the cap.

AB Lime typically carries out weekly landfill cap inspections, and a summary of the inspections are provided annually in the Environmental Monitoring Report. Any defects that are noticed are remedied immediately and a report of the inspection and actions taken are forwarded to SRC within two months of each inspection, or as agreed with Environment Southland.

10.4.5.2 Management of Final Cap Settlement

There is a requirement for long term management of the landfill cap and its settlement to ensure it remains effective at managing effects. Differential settlement can cause cracking of the capping layer and issues with drainage, which results in landfill gas discharging to the atmosphere, ponding of water and increased quantities of leachate.

Technical Guidelines for Disposal to Land Appendices (WasteMINZ, 2018) state that waste will typically undergo total settlement of approximately 25% of the waste depth. About half of settlement occurs during waste placement and, following completion of waste filling, it is expected that 10 to 12.5% long-term settlement will occur due to secondary compression and waste degradation. It should be noted that the settlement rate may increase at leachate recirculation injection points due to accelerated breakdown of wastes in these areas. However, currently AB Lime does not utilise leachate recirculation.

As of March 2020, the capping inspections have indicated no major cracks in the final capping layer. However, if in the future, severe settlement and cracking of the clay capping layer occurs then the following steps will be taken:

- The topsoil and knap rock growth layer will be removed (scrape from the surface and temporarily stockpiled);
- The clay layer will then either be excavated, reworked, and compacted back into place, or
- If cracking is well defined, cracks will be locally filled with bentonite pellets;
- Finally, the knap rock and topsoil layer will be reinstated.

Care will be taken to overlay the in-situ clay with the re-compacted clay to create a smooth transition between the existing cap and reworked areas. This is to reduce the tendency for cracks to reappear at the boundaries of the reworked areas. Clay will be placed back up to the original level before settlement, resulting in a localised thickening in the area of settlement.

There are minimal concerns regarding detrimental effects on the GCL when subject to total and differential settlements. The X800/X1000 GCL product is able to elongate in excess of 15% prior to failure, and the X2000

GCL product is able to elongate in excess of 50% before failure. However, if, severe settlement and cracking of the GCL capping layer occurs then the following steps will be taken:

- The topsoil and upper knap rock layer will be removed (scrape from the surface and temporarily stockpiled);
- Place another layer of GCL over the defective area and glue to the original GCL following installation guidelines; and
- Finally, the knap rock and topsoil layer will be reinstated.

If settlement is minor and does not affect the integrity of clay or GCL capping layers, then it will be sufficient to remove the topsoil layer and top up settled areas with compacted knap rock to maintain drainage gradients of the cap and prevent ponding of surface water. Topsoil will then be replaced over the knap rock. Further details on management of the final cap settlement are included in the Landfill Concept, Landscape, Rehabilitation and Aftercare Plan.

11. Base Liner System

11.1 Introduction

The objectives of the base liner system are outlined by the Technical Guidelines for the Disposal to Land by Waste Management Institute New Zealand (WasteMINZ, 2018) as follows:

- Contain leachate; and
- Control the ingress of groundwater.

Area 1 to Area 15 of the landfill have base liner systems that adhere to, or have been approved as being equivalent to, Condition 6 of Consent AUTH-201346-V3, which are presented in Table 7.

Table 7 Description of Base Liner Systems Allowed for in Consent AUTH-201346-V3.

Type	Base Liner System Description (from bottom to top)
1	▪ a groundwater underdrainage system; ▪ a minimum of 1000 millimetres of compacted clay with a permeability coefficient (k) of not more than 1 x 10^{-9} metres per second; ▪ a 300 millimetre minimum liner protection/leachate collection layer of granular material with a permeability coefficient (k) of not less than 1 x 10^{-3} metres per second;
2	▪ a groundwater underdrainage system; ▪ a minimum of 600 millimetres of compacted clay with a permeability coefficient (k) of not more than 1 x 10^{-9} metres per second; ▪ a 1.5 millimetre HDPE flexible membrane liner; ▪ a 300 millimetre minimum liner protection/leachate collection layer of granular material with a permeability coefficient (k) of not less than 1 x 10^{-3} metres per second;
3	▪ a groundwater underdrainage system; ▪ a minimum of 300 millimetres of compacted clay with a permeability coefficient (k) of not more than 1 x 10^{-9} metres per second; ▪ a geosynthetic clay liner, with a minimum thickness of 5 millimetres, a permeability coefficient (k) of not less than 5 x 10^{-11} metres per second and sufficient internal shear strength to maintain a stable configuration on slopes; ▪ a 1.5 millimetre HDPE flexible membrane liner; ▪ a 300 millimetre minimum liner protection/leachate collection layer of granular material with a permeability coefficient (k) of not less than 1 x 10^{-3} metres per second."
4 (approved as equivalent to Type 1)	▪ a groundwater underdrainage system; ▪ a minimum of 300 millimetre of compacted knap rock with a permeability coefficient (k) of not more than 1 x 10^{-8} metres per second; ▪ a geosynthetic clay liner, with a minimum thickness of 5 millimetres, a permeability coefficient (k) of not less than 5 x 10^{-11} metres per second and sufficient internal shear strength to maintain a stable configuration on slopes ▪ a 1.5 millimetre thick HDPE flexible membrane liner; ▪ a 300 millimetre minimum liner protection/leachate collection layer of granular material with a permeability coefficient (k) of not less than 1 x 10^{-3} metres per second."

New Zealand's landfill guidelines have been updated since AB Lime's consent (Consent AUTH-201346) was granted, and therefore, the original consented base liner systems are no longer all recommended systems.

The base liner system for Area 16 and future areas will adhere to proposed consent conditions, which has been updated to reflect the latest Technical Guidelines for the Disposal to Land (WasteMINZ, 2018). It includes the three base liner system options recommended by WasteMINZ, including a groundwater underdrainage system underneath, and a leachate collection system on top. The three options for minimum base liner designs are detailed in Table 8.

Table 8 Description of Base Liner Systems Recommended by WasteMINZ (2018) and Allowed for in the Proposed Consent Conditions.

Type	Base Liner System Description (from bottom to top)
1	▪ a groundwater underdrainage system; ▪ a minimum of 600 mm of compacted soil with a permeability coefficient (k) not exceeding 1 x 10^{-9} m/s; ▪ a 1.5 mm high density polyethylene (HDPE) flexible membrane liner; ▪ a 300 mm minimum liner protection/leachate collection layer of granular material.
2	▪ a groundwater underdrainage system; ▪ a minimum of 300 mm of compacted soil with a permeability coefficient (k) not exceeding 1 x 10^{-9} m/s; ▪ a GCL, with a minimum thickness of 5 mm, a permeability coefficient (k) not exceeding 5 x 10^{-11} m/s; ▪ a 1.5 mm HDPE flexible membrane liner; ▪ a 300 mm minimum liner protection/leachate collection layer of granular material.
3	▪ a groundwater underdrainage system; ▪ a minimum of 600 mm of compacted soil with a permeability coefficient (k) not exceeding 1 x 10^{-8} m/s ▪ a GCL, with a minimum thickness of 5 mm, a permeability coefficient (k) not exceeding 5 x 10^{-11} m/s; ▪ a 1.5 mm HDPE flexible membrane liner; ▪ a 300 mm minimum liner protection/leachate collection layer of granular material.

11.2 Base Liner System Design

A Type 3 Base Liner System is the approach AB Lime will take for Area 16 and future areas, with some additional elements included to improve the performance of the base liner. Overall, the base liner system is comprised of the following, from bottom to top:

- Groundwater underdrainage system composed of:
  - Groundwater collection trenches;
  - Geotextile; and
  - Blinding layer;
- 600 mm compacted knap rock layer with a maximum permeability of 1 x 10^{-8} m/s;
- A 5 mm GCL with a maximum permeability of 5 x 10^{-11} m/s;
- A 1.5 mm HDPE;
- Geotextile;
- 300 mm leachate collection layer; and
- Confining stress layer.

Further details on each component of the base liner system is provided in the Technical Specification and Quality Assurance & Quality Control (QA/QC) documents, the latest of which is for Area 15.

11.3 Subgrade Preparation

Site preparation includes clearance and disposal of vegetation, topsoil and any superficial obstructions, such as removal of any boulders in the footprint of the landfill. After site preparation, the landfill base shall be over-excavated to show a limestone surface. The consent conditions require a geological map of the base grade of the landfill to be prepared and upgraded from time to time as the base grade is exposed. The geological mapping shall include detailed logging of the location, extent and nature of fractures, fracture zones, Karst features and other defects. In addition, it shall be confirmed that the landfill base has a minimum slope of 2% gradient.

11.4 Groundwater Underdrainage System

11.4.1 Groundwater Collection Trenches

The groundwater underdrainage system comprises of minimum 300 mm by 300 mm trenches filled with gravel with a minimum permeability of 1×10^{-3} m/s. The trenches are excavated at 20 m centres and are laid perpendicular to the fall of the landfill floor. Laid in the gravel trench is a 110 mm diameter Marley Drainflo, or similar approved perforated pipes wrapped in a filter sock.

11.4.2 Geotextile

A geotextile separation layer is placed over the gravel layer. The geotextile is a A19 Bidim, or similar as approved by the engineer and as meets the requirements of Type B, Class 3 as defined in Transit NZ Specification for Geotextiles, TNZ F/7, 2003.

11.4.3 Blinding Layer

A minimum of 50 mm of knap rock is laid and compacted over the excavated limestone surface. This forms the blinding layer. The maximum particle size shall be 75% of the loose layer thickness. This will form the blinding layer for the landfill liner system and will extend over the full width and length of the liner. The blinding layer shall be compacted to the requirements of structural fill.

The finished groundwater collection trenches shall be completed free of potholes, gullies and depressions where water may accumulate. In addition, haul trucks and earth moving plant will not operate or drive on top of the geotextile separation layer without a minimum of 150 mm cover being placed above.

The groundwater collection trench design is shown in drawing IZ000400-1000-NG-DRG-1019 found in Attachment 1. Further details on the material specification and construction methodology are provided in the Technical Specification documents, the latest of which is Area 15 Technical Specification.

11.5 Compacted Knap Rock Layer

Knap rock is weathered limestone and is classified as a sandy GRAVEL with some silt and minor clay. The knap rock is mined from the in-situ limestone and is screened to produce a well graded material with a maximum particle size of 40 mm. As the knap rock is mined it is placed in temporary stock piles, which are constructed to be free draining and shaped to prevent ponding and erosion of the material.

In order to assess the compaction, water content and permeability properties of the knap rock a field trial and laboratory testing of the knap rock material was undertaken in 2014. The methodology and results of the field and laboratory testing are presented in the Proposed Alternative Basal Liner Report (AE03541.16-E SG-RP-001). Since the report was issued in August 2014, further compaction, water content and permeability testing of the knap rock material has been completed. Based on all the testing that has been completed on the knap rock material, a relationship between permeability, relative compaction and water content was found.

It is a consent requirement that the knap rock has a permeability no greater than 1×10^{-8} m/s. Since an undisturbed knap rock sample cannot be collected, relative compaction and water content parameters of knap rock are used to determine permeability. Therefore, it is anticipated that the permeability requirement is achieved if the criteria in Table 9 is achieved.

Table 9 Relative Compaction & Water Content Requirements

Scenario	Relative Compaction (measured as minimum % of MDD)	Water Content
1	95%	+3% to +6% wet of OWC
2	98%	+0% to +3% wet of OWC
Where: MDD is the maximum dry density and OWC is the optimum water content as determined from a Heavy Compaction Test (NZS 4402 - Test 4.1.2).		

Based on the above findings the following testing methodology was established:

- A knap rock sample is taken from the temporary stockpile and undergoes a laboratory heavy compaction test. This determines the material's maximum dry density (MDD) and optimum water content (OWC) parameters;
- Another knap rock sample is taken from the temporary stockpile and undergoes a laboratory permeability test targeting either of the scenarios in Table 9, using the heavy compaction test results from Step 1 as the reference;
- The proposed consent conditions require the knap rock to have a permeability no greater than 1×10^{-8} m/s. If the permeability test results are $\leq 1 \times 10^{-8}$ m/s, and the target relative compaction and water content are achieved then the stockpile is appropriate to use for the compacted knap rock layer;
- The knap rock is laid and compacted in 150 mm layers until the minimum thickness of 600 mm is constructed.
- Once a 300 mm knap rock layer has been laid and compacted, then nuclear densometer (NDM) and water content laboratory testing is completed. This determines the knap rock's in-situ relative compaction and water content;
- If the NDM and water content test results meet the requirements shown in Table 9, of either scenario one or two, the compacted knap rock layer has achieved the permeability consent requirement.

The compacted knap rock layer has a minimum thickness of 600 mm. The Technical Guidelines for the Disposal to Land recommend that the knap rock material is deposited and compacted in layers a maximum of 150 mm thick (WasteMINZ, 2018). Testing is required twice, firstly after 300 mm has been placed and compacted, and secondly after 600 mm has been placed and compacted. The testing type and frequency required for the compacted knap rock layer is outlined in Table 10. AB Lime is to provide Jacobs with all test results on the compacted knap rock layer.

Table 10 Testing Type and Frequency for the Compacted Knap Rock Layer.

Parameter	Test	Standard	Test Frequency
Relative Compaction[1]	Nuclear Densometer - NDM (Field)	NZS 4407:2015 Test 4.2	1 set (1 NDM test and 1 moisture content test) per 500 m^2 of compacted material on each layer for the first 1,000 m^3; thereafter 1 set per 1,000 m^2 of compacted material on each layer. A minimum of 2 sets per day shall be taken during knap rock placement.
MDD & OMC	Heavy Compaction Test (Laboratory)	NZS 4402:1986 Test 4.1.2	1 test per 10,000 m^3 sampled from each stockpile. Additional tests shall be performed if the stockpile is visually variable.
Minimum Clegg Impact Value	Clegg Impact Hammer - 4.5 kg (Field)	ASTM D5874-16 2016	1 set per 500 m^2 of compacted material on each layer. No Clegg impact hammer tests needed if NDM tests are undertaken.
Maximum Permeability	Constant Head (Laboratory)	BS 1377 1990	1 test per 3,000 m^2 of compacted material or 1 test per week (whichever is the greater number of tests).
Water Content[2]	Water Content (Laboratory)	NZS 4402:1986 Test 2.1	1 test per NDM test.

Notes:

1. Relative compaction refers to the MDD ratio at heavy compaction.
2. Moisture content refers to the percentage variation from the OMC as determined from the heavy compaction test.

There are two hold points for construction of the compacted knap rock layer that require input and approval by Jacobs, and there are as follows:

- Approval of the knap rock stockpile – needs to meet the permeability requirement; and
- Approval of the compacted knap rock layer – needs to meet relative compaction and water content requirements.

11.6 GCL

The installation of the GCL shall only commence once the compacted knap rock layer is approved by the Engineer. The construction of the GCL shall only be started if the HDPE, leachate collection layer, and 500 mm confining gravel layer can be deployed within the working day. This is to ensure that the confining stress requirements of the GCL are met.

The GCL shall be stored and installed in accordance with ELCOSEAL Installation Guidelines, unless stated otherwise in this specification or by the Engineer in writing. An X1000 or equivalent GCL should be used with a minimum bentonite mass of 4 kg/m^2.

There are several points that should be taken into consideration to ensure best management practices are adhered to during placement of the GCL panels:

- Vehicles of any kind are not to drive or operate on the GCL;
- The GCL is not damaged by handling, movement of vehicles or other site activities;

- GCL shall be deployed only if it can be covered at the end of the working day with a minimum cover of 300 mm of soil, a geomembrane or a temporary waterproof tarpaulin (as per the ELCOSEAL Installation Guidelines);
- The completed GCL panel shall be protected from wind by putting temporary load on the GCL;
- The GCL shall not be left uncovered overnight;
- If partial hydration of the GCL occurs, the operating considerations outlined in the ELCOSEAL Installation Guidelines shall be adhered to.

At the top of the slope the GCL shall be placed in an anchor trench on all edges. The backfill should be placed in the anchor trench to provide resistance against pull out.

11.7 HDPE

The installation of the 1.5 mm High Density Polyethylene (HDPE) will commence within the same working day following placement of the GCL.

The HDPE shall be stored and installed in accordance with manufacturer's requirements. There are several points that should be taken into consideration to ensure best management practices are adhered to during placement of the HDPE panels:

- The HDPE shall not be installed when the ambient air temperature is below 0°C or above 40°C, during precipitation, heavy fog conditions, high humidity, in areas of ponded water, or in windy conditions;
- Vehicles of any kind are not to drive or operate on the HDPE liner;
- The HDPE is not damaged by handling, movement of vehicles or other site activities; and
- The completed HDPE panel is suitably protected from damage and wind by putting a temporary load on the HDPE.

At the top of the slope the HDPE shall be placed in an anchor trench on all edges. The backfill should be placed in the anchor trench to provide resistance against pull out. The details of the anchor trenches are indicated on the drawings and further details are provided in the ELCOSEAL Installation Guidelines.

11.8 Geotextile

Geotextile is placed over the HDPE in order to protect the liner from damage during placement of the leachate drainage layer. The geotextile is A14 Bidim or a similar product approved by the Engineer that is nonwoven and needle punched and that meets the requirements of Type A, Class 3 as defined in Transit NZ Specification for Geotextiles, TNZ F/7, 2003. In addition, the geotextile shall be installed in accordance with this Transit NZ specification.

11.9 Leachate Collection Layer

The leachate collection system is a 300 mm gravel layer and an array of 150 mm diameter perforated pipes at 20 m spacing, which drain to 300 mm diameter solid pipes at 80 m spacing. The leachate collection layer should be at a minimum slope of 2% gradient.

The leachate collection layer is placed over the HDPE liner without damaging the HDPE or creating squeezing within the GCL. General construction traffic is not be permitted on the installed leachate collection layer at any time. End tipping of gravel directly on to the HDPE liner is not permitted.

Leachate collection pipes for the future stages shall be completely sealed, non-perforated, within the cell boundary and shall be laid at the same level or above the leachate collection pipes for this stage of the landfill development.

The leachate collection system has been designed such that the direction of flow is towards the leachate collection tank and the maximum drainage path is 20 m to reach a collection pipe. A minimum of 1.5% fall will be maintained for all the pipes.

A biaxial geogrid shall be placed over the leachate collection layer and the confining gravel layer to avoid 'thinning-out' of the gravel layer during placement of the confining stress layer.

11.10 Confining Stress Layer

The GCL needs to be covered after installation to provide the necessary confining stress to avoid cation exchange. Once the leachate collection system is constructed, a 500 mm thick layer of gravel is placed over the leachate collection layer (a total thickness of 800 mm) in order to meet the confining requirements of the GCL. This confining gravel layer extends across the entire area. When waste is ready to be placed in the area then the 500 mm of gravel is excavated, and geogrid is placed over the leachate collection layer. A 1 m thick layer of select waste is then be placed over the geogrid. The excavation of the gravel can be completed in parts as the waste placement in the area progresses.

The select waste (fluff layer) shall preclude items such as angular rock fragments, sharp objects or other deleterious material which could adversely affect the performance of the leachate collection layer or any of the underlying layers. Where it is not possible to source such fill, shredded tyres or similar material shall be used.

11.11 Hold Points

The proposed consent conditions state that as-built drawings shall be forwarded to SRC following completion of works and structures, for acceptance in writing, prior to the disposal of refuse in each newly constructed stage. These drawings shall include 0.25 metre contours for the liner base, and final elevations of the HDPE liner.

The hold points indicate the portions of work which, prior to proceeding, need approval from the Engineer. These are listed in Table 11.

Table 11 Hold Points for AB Lime Landfill Area Construction

Item	Description of Work
1	Completion of subgrade preparation for landfill platform (geological mapping and photography of base)
2	Confirm that the landfill floor has a minimum gradient of 2%
3	Completion of groundwater collection trenches installation
4	Completion of geotextile separation layer installation
5	Completion of compacted knap rock for landfill liner
7	Completion of stormwater bunds
8	Completion of GCL, HDPE & geotextile installation
9	Completion of leachate collection layer installation
10	Installation and excavation of confining gravel layer
11	Installation of geogrid
12	Completion of the placement of select waste

12. Contaminated Land Procedures

The contaminated land procedures to appropriately assess and manage contaminants in the soil to protect human health are as follows.

- Contaminated soil will be assessed as a Special Waste and disposed of following the Special Waste Acceptance procedures (see Section 5)
- Random load inspections of incoming waste will be carried out (see Section 4.5)
- At the working face the Pointsman is responsible for managing odorous waste including contaminated soil (see Section 7.2.2)
- Odorous contaminated soil procedures are covered in the Landfill Air Quality Management Plan.

12.1 NESCS

The objective of the Resource Management (National Environmental Standard for Assessing and Managing Contaminants in Soil to Protect Human Health) Regulations 2011 (NESCS) is to ensure that land affected/potentially affected by contaminants in soil which may have an adverse effect on human health, is appropriately identified and assessed when soil disturbance and/or a change in land use occurs. This includes, where appropriate, the requirement that contaminants are contained, or the land remediated to make the land safe for human use.

The NESCS applies to specific activities on HAIL sites including sampling, investigating, remediating or disturbing a *piece of land* and changing the use of a *piece of land*.

12.1.1 Pre-Landfilling Areas

Preliminary Site Investigations, undertaken in general accordance with the most recent version of the MfE Contaminated Land Management Guidelines (CLMG) No. 1 – Reporting on Contaminated Sites in New Zealand and CLMG No.5 - Site Investigation and Analysis of Soils, are required prior to the development of future Areas of the landfill to determine whether the *piece of land* for development has been subject to an activity or industry that could result in soil contamination and whether resource consent under the NESCS is required.

12.1.2 Post-Landfilling Areas

Once a cell has been filled with refuse and once the whole landfill is complete, the NESCS does apply, under HAIL Category G3 *"Landfill sites"*.

The requirement for resource consent under the NESCS to carry out an activity such as "soil disturbance" on those existing landfilled areas will be discussed and agreed with Environment Southland, on a case by case basis.

13. Groundwater Monitoring

Groundwater monitoring is required as part of a range of environmental monitoring activities that are conducted to assess how the landfill is performing with the design, operational practices and regulatory requirements.

Trigger levels are a set of standards used to gauge the effects on the environment from the operation of the landfill. The Environmental Manager will compare all monitoring data with the trigger levels for groundwater monitoring. Exceedance of a trigger level requires investigation and reporting and may require immediate remedial action.

Trigger levels are set at two levels, namely Trigger Level 1 (a lower response limit / warning level) and Trigger Level 2 (upper response limit / alarm level).

Exceedance of TL1 warns of potential adverse effects, and potential future non-compliance with the resource consent conditions and results in a review of landfill management practices to identify and remedy the cause of the exceedance.

Exceedance of a TL2 is a strong indication that significant adverse effects and breaches of consent conditions may already be occurring, or could have occurred, or are about to occur. Exceedance of TL2 will necessitate one or more of the following actions:

- Urgent mitigative actions;
- Notifications of the authorities - Environment Southland;
- Calling of a specialist adviser (a qualified person or consultancy with experience in environmental management;
- Prompt instigation of investigations; and
- Remedies.

Extreme exceedance of TL2 might require reference to the site Emergency Response Plan.

13.1 Groundwater Trigger Levels

TL1 levels are based on probable worst-case statistics (median plus or minus two times the standard deviation value) of background water quality data for each site. The median has been implemented rather than the mean as it places less emphasis on extreme values.

TL2 levels are based primarily on ANZECC (2000) or USEPA (1999) guidelines where available, with a focus on the protection of aquatic life. Drinking water guidelines are not considered relevant as there are no downgradient users of the water for potable supply purposes. Where no regulatory standards are defined for a parameter or where background levels exceed regulatory standards, the TL2 is defined as the median background concentration plus or minus three standard deviations.

The ANZECC (2000) and USEPA (1999) water quality guidelines for metals are based on analysis of the dissolved metal fraction (i.e. metals occurring naturally in solution) and as such dissolved metals will be specified to the laboratory. Dissolved metal concentrations are hardness dependant. The guideline for dissolved metals will be corrected to the median background hardness obtained from baseline monitoring. The methodology for this calculation is detailed in the ANZECC (2000) Guidelines.

The following approaches will be used to assess compliance of groundwater quality trigger levels:

- For continuous monitoring (i.e. 2.5-minute measurements) compliance with trigger levels will be assessed using running means calculated over 6 successive measurements (i.e. 15-minute averages). Only the running means will be stored to the datalogger.

- For grab samples or monthly, quarterly or annual monitoring, compliance with trigger levels will be assessed using individual data points.

13.2 Groundwater Monitoring Parameters

For groundwater the following parameters in Table 12 will be monitored at the landfill.

Table 12 Groundwater Monitoring Parameters

Parameter	Details
Major Elements	Major elements including calcium, magnesium, sodium and chloride are common constituents of surface water and groundwater. By monitoring these parameters prior to landfill development, a distinction can be made between the effects of the landfill activities and background levels.
Electrical Conductivity	Conductivity is the ability of the water to conduct electricity and is based on the quantity of charged ions (i.e. sodium, potassium, calcium, chloride and carbonates) in the water. Conductivity measurements can be used as a quick indicator of potential water quality problems associated with increased ion concentrations.
Suspended Solids and Turbidity	Suspended solids and turbidity are measures of the amount of particulate suspended matter in a water body. High sediment concentrations can inhibit plant growth by reducing the amount of light in the water column and smothering organisms. Suspended solids in surface water may be of concern particularly where earthworks are an essential part of operation, as in the case of a landfill. Suspended solid and turbidity concentrations can change rapidly over time, particularly during storm events when surface runoff from the catchment may be high. Turbidity will be monitored continuously in surface water at the landfill as it is a quicker method than measuring total suspended solids, which is usually determined by filtering and drying a water sample. An empirical relationship between turbidity and suspended solids will be developed in order to estimate suspended solid concentrations from turbidity levels.
Dissolved Oxygen	Fish and other aquatic organism require dissolved oxygen for respiration. The amount of dissolved oxygen is dependent on the water temperature, quantity of sediment, presence of decaying and respiring organisms, stream flow and aeration. Depletion of dissolved oxygen can encourage the microbial reduction of nitrate to nitrite and sulphate to sulphide, giving rise to odour problems. Maintenance of high dissolved oxygen levels in the leachate pond is an effective method of odour control at the landfill.
Nutrients and Bacteria	The presence of excessive nutrients (e.g. nitrogen and phosphorus) and microorganisms (bacteria) in surface water can indicate possible contamination from the landfill or other sources.
Organic compounds, COD, TOC	Leachate contains a wide variety of organic compounds that are typically associated with organic decomposition processes. They can provide a measure of the strength and age of the leachate Total organic carbon (TOC) and chemical oxygen demand (COD) are measured to provide an indication of contamination by organic compounds. Individual species such as volatile acids and total phenols are also often measured as indicator species. A more comprehensive organic compound analysis including volatile and semi-volatile compounds may be conducted at less frequent intervals.
Trace Metals	Leachate contains a variety of trace metals (i.e. lead, cadmium etc.) many of which are toxic at low concentrations.

13.3 Monitoring Network

Drawing IZ000400-1000-NG-DRG-1008 (Attachment 1), Figure 5 and Table 13.2 outline the groundwater monitoring network. Attachment 7 contains copies of the construction logs for all bores.

Groundwater abstraction and quality is monitored at Site 13 (landfill underdrainage system). Groundwater quality from Site 17 (leachate pond underdrainage system) is also monitored.

Site 17 is a manhole with an open grate. It is located at a low point in the topography into which surface water from around the leachate pond will drain. This means that the manhole will gradually fill up with sediment and the collected water will comprise of both surface water and groundwater. The manhole will be regularly pumped clean of sediments to allow fresh groundwater to flow in for sampling. The contingency plan for site 17 (see section 13.3.2.1) refers to the action.

Table 13 Groundwater Monitoring Network

Site	Parameter	Location
SKM104	Groundwater level, water quality	Along ridge line up-gradient of the landfill
SKM106	Groundwater level, water quality	Along ridge line up-gradient of the landfill
SKM108	Groundwater level, water quality	Down gradient of the landfill near site boundary
SKM201	Groundwater level, water quality	Along the southern boundary of the landfill footprint
SKM202	Groundwater level, water quality	Along the southern boundary of the landfill footprint
SKM203	Groundwater level, water quality	Along the southern boundary of the landfill footprint
SKM204	Groundwater level, water quality	Along the southern boundary of the landfill footprint
Site 13	Flow/abstraction, water quality	Landfill underdrainage pipe manhole
Site 17	Water quality	Leachate pond underdrainage pipe manhole

13.3.1 Groundwater Levels

Groundwater levels are measured and recorded at monthly intervals as outlined in Table 14. The water levels are measured from the top of the casing and recorded to the nearest 0.01m in accordance with appropriate sampling and analysis procedures (see Attachment 8.). Flow from the groundwater underdrainage system (site 13) is measured continuously with a flow meter.

Table 14 Groundwater Level Monitoring Plan

Site	Parameter	Detection Limit	Trigger Level		Monitoring Frequency	Report
			TL1	TL2		
All Bores	Groundwater Level	0.01 mAMSL	Variable	N/A	Monthly	Report 1 & 3
Site 13	Flow/abstraction		N/A	40 m^3/day	Monthly	Report 1 & 3

13.3.1.1 Contingency Plan

The following contingency measures in Table 15 shall be used as appropriate.

Table 15 Contingency Measures for Groundwater Levels

Contingency Triggering Event	Contingency Action
Abstraction from Site 13 exceeds the maximum levels specified in the resource consent	Operational records to be reviewed to determine the reason for the exceedance

13.3.2 Groundwater Quality

Groundwater sampling from the monitoring bores are undertaken at biannual intervals as agreed by Environment Southland in 2012. Table 16 shows the range of parameters that are analysed. Volatile and semi-volatile organic compounds are sampled annually.

Groundwater quality monitoring from the groundwater underdrainage systems (Site 13 & 17) comprises sampling for a small suite of leachate indicator parameters at monthly intervals. If it is detected that leachate is present a more comprehensive sampling round will be conducted. Baseline water quality is to be established at Site 13 and Site 17 prior to each stage of landfill development by monitoring for the list of parameters given in Table 16. An ion balance to APHA criteria will be achieved and a quality control program is to be implemented for each sampling round.

Groundwater Monitoring Bores are monitored biannually and reported on in Reports 1 & 3.

Table 16 Groundwater Monitoring Plan

Parameter	Detection Limit	T2 Levels	Upper T1 Trigger Levels for Each Bore						
			104	106	108	201	202	203	204
Alkalinity	1 mg/L	20	337	515	320	643	403	337	310
Bicarbonate	1 mg/L		419	620	399	791	482	416	377
Calcium	0.05 mg/L		141.5	173	115	245	211	126	125
Chloride	0.5 mg/L	230	31.1	37	71.2	47	46	34	27.7
COD	6 mg/L		170.1	9	6	4.1-9.2	8	6	6
Conductivity (field & laboratory)	0.1 m/Sm		73.4	70.2	77.6	124.3	105.0	66.5	60.6
Dissolved Aluminium	0.003 mg/L	0.055	0.003	0.003	0.003	0.003	0.008	0.003	0.004
Dissolved Arsenic	0.001 mg/L	0.024	0.001	0.001	0.0053	0.001	0.0011	0.001	0.001
Dissolved Boron	0.005 mg/L		0.005						
Dissolved Cadmium	0.00005 mg/L	0.00155	0.00005	0.0004	0.00005	0.00005	0.00005	0.00005	0.00005
Dissolved Chromium	0.0005 mg/L	0.0218	0.006	0.002	0.0005	0.00554	0.0006	0.0005	0.0005
Dissolved Copper	0.0005 mg/L	0.0099	0.0034	0.002	0.0020	0.00560	0.0012	0.0012	0.0012
Dissolved Iron	0.02 mg/L	0.3	0.25	0.02	0.51	0.67	0.02	0.02	0.02
Dissolved Lead	0.0001 mg/L	0.0633	0.002	0.001	0.0001	0.0001	0.00011	0.00023	0.0002
Dissolved Manganese	0.0005 mg/L	1.7	0.0142	0.0016	21.7	1.225	0.0005	0.0005	0.0005
Dissolved Nickel	0.0005 mg/L	0.0779	0.0012	0.002	0.0005	0.006	0.0089	0.0005	0.0005
Dissolved Reactive Phosphorus	0.004 mg/L	0.01	0.004	0.051	0.022	0.01	0.035	0.035	0.01
Dissolved Zinc	0.001 mg/L	0.057	0.0391	0.051	0.0244	0.0185	0.0116	0.015	0.0181
Magnesium	0.02 mg/L		3.3	4.5	21.7	14.9	8.2	3.9	3.9
Nitrate-Nitrogen	0.002 mg/L	0.16	2.2	3	0.064	2.04	3.54	3.8	3.7
pH (field & laboratory)	0.1 pH units	7.2-7.8	7.6	6.5-8.2	7.1-7.8	6.7-7.3	6.9-7.3	7.1-7.5	7.1-7.6
Potassium	0.05 mg/L		1.6	2.38	2.4	1.52	1.58	1.04	0.92
Sodium	0.02 mg/L		19.2	23.4	41.3	37.2	25	19.4	19.4
Sulphate	0.5 mg/L		14.4	10.4	7.7	84	152	6.3	7.6
Total Ammoniacal Nitrogen	0.01 mg/L		3.7	0.018	0.023	0.431	1.18	0.025	0.01
Total Hardness	1 mg/L		372	447	382	668	561	332	330
Total Kjeldahl Nitrogen	0.1 mg/L		3.3	0.84	0.2	0.85	0.30	0.19	0.37
NPOC (Organic Carbon)	0.5 mg/L		20.8	1.8	1.6	5.47	2.9	1.3	1.7
Total Phenols	0.002 mg/L	0.32	0.0143	0.024	0.003	0.0036	0.005	0.00	0.004
Turbidity	0.05 NTU		26.7	29.4	28.8	12.17	20.3	62	5.0
Volatile Acids	5 mg/L	5	5	5	5	5	5	5	5
Semi-volatile Organic Compounds	0.003 mg/L								
Volatile Organic Compounds	0.004 mg/L								

Underdrainage groundwater is monitored monthly and reported in Reports 1 and 3 as per Table 17.

Table 17 Groundwater Monitoring Plan

Site	Parameter	Detection Limit	Trigger Level		Monitoring frequency	Reporting Frequency
			TL1	TL2		
13	Conductivity (field & laboratory) Total Ammoniacal Nitrogen pH (field & laboratory) Chloride	0.1 mS/m 0.01 mg/L 0.1 pH units 0.5 mg/L	13.2-126.1 0.00-0.11 6.8-8.2 4.4-77.5		Monthly Monthly Monthly Monthly	Reports 1 & 3 Reports 1 & 3 Reports 1 & 3 Reports 1 & 3
17	Conductivity (field & laboratory) Total Ammoniacal Nitrogen pH (field & laboratory) Chloride	0.1 mS/m 0.01 mg/L 0.1 pH units 0.5 mg/L			Monthly Monthly Monthly Monthly	Reports 1 & 3 Reports 1 & 3 Reports 1 & 3 Reports 1 & 3

13.3.2.1 Contingency Plan

Site 13

Figure 5 shows a schematic outline of the contingency plan for the monthly monitoring at Site 13. The contingency measures in Table 18 will be used as appropriate for site 13.

Table 18 Site 13 Monitoring Contingency Measures

Contingency Triggering Event	Contingency Action
Indicator parameters at Site 13 exceed their respective TL1 trigger levels	▪ A grab sample will be taken from the site as soon as practical and analysed for the parameters specified in Table 13.8. ▪ A preliminary review of operations will be undertaken. ▪ Both the results of the preliminary review and the analytical results from the grab samples are to be reviewed by the Environmental Manager.
Water quality parameters measured in the grab sample exceed the respective TL2 trigger level	▪ The groundwater is to be treated and/or disposed of as leachate and Environment Southland will be advised within one month of sampling. ▪ If identified as necessary by Environment Southland, further monitoring and/or mitigation measures will be undertaken.

Table 19 Groundwater Quality Grab Sample Parameter List

Parameter	Detection Limit
pH (field & laboratory) Conductivity (field & laboratory) Alkalinity Chloride Potassium Suspended Solids Total Ammoniacal Nitrogen Total Boron Total Iron Total Organic Carbon Total Zinc	0.1 pH units 0.1 mS/m 1 mg/L 0.5 mg/L 0.05 mg/L 3 mg/L 0.01 mg/L 0.005 mg/L 0.02 mg/L 0.5 mg/L 0.001 mg/L

Site 17

The following contingency measures in Table 20 will be followed for Site 17.

Table 20 Site 17 Monitoring Contingency Measures

Contingency Triggering Event	Contingency Action
	▪ The leachate pond underdrainage manhole is to be pumped out regularly (approximately **every 6 months**). This is to remove accumulated sediments and allow fresh groundwater to flow into the manhole.
The indicator parameter exceeds the respective TL1 trigger levels	▪ The manhole is to be pumped out again as soon as practical and a grab sample taken for analysis. ▪ The grab sample parameters to be analysed are the same as Site 13 as specified ▪ A review of operations is to be undertaken. The **Environmental Manager** is to evaluate both the results of the sampling and the operational review.
TL2 trigger levels are not required by consent condition for Site 17. However, if grab sample parameters indicate that groundwater from the leachate pond underdrainage system is contaminated	▪ The groundwater shall be treated and/or disposed of as leachate. ▪ The grab sample results will be compared against the TL2's for Site 13. ▪ Contingency process is similar to that described for Site 13 except that the manhole is required to be pumped immediately prior to taking a grab sample and there are no specified trigger levels in the resource consent conditions.

All Sites

The following contingency measures in Table 21will be followed for all sites.

Table 21 Contingency Measures to be Followed at all Sites

Contingency Triggering Event	Contingency Action
Baseline monitoring confirms that SKM108 is not the most appropriate downgradient position	▪ An appropriately constructed groundwater monitoring bore is to be installed in a better location and added to the monitoring schedule.
A bore is destroyed	▪ A new bore is to be drilled in the same general location ▪ A rising head test is to be conducted on any new bore to demonstrate that the bore is working and assess the hydraulic conductivity of the *in-situ* ground
Parameters from quarterly or annual monitoring exceed their respective TL1	▪ the Environmental Manager is to conduct a preliminary review of operations. ▪ If the parameter exceeds the TL1 on a regular basis, changes to the landfill management practice are to be implemented to remedy the cause of the exceedance.
Parameters exceed their respective TL2	▪ Environment Southland will be notified. Immediate steps will be taken to prevent further leachate contamination.

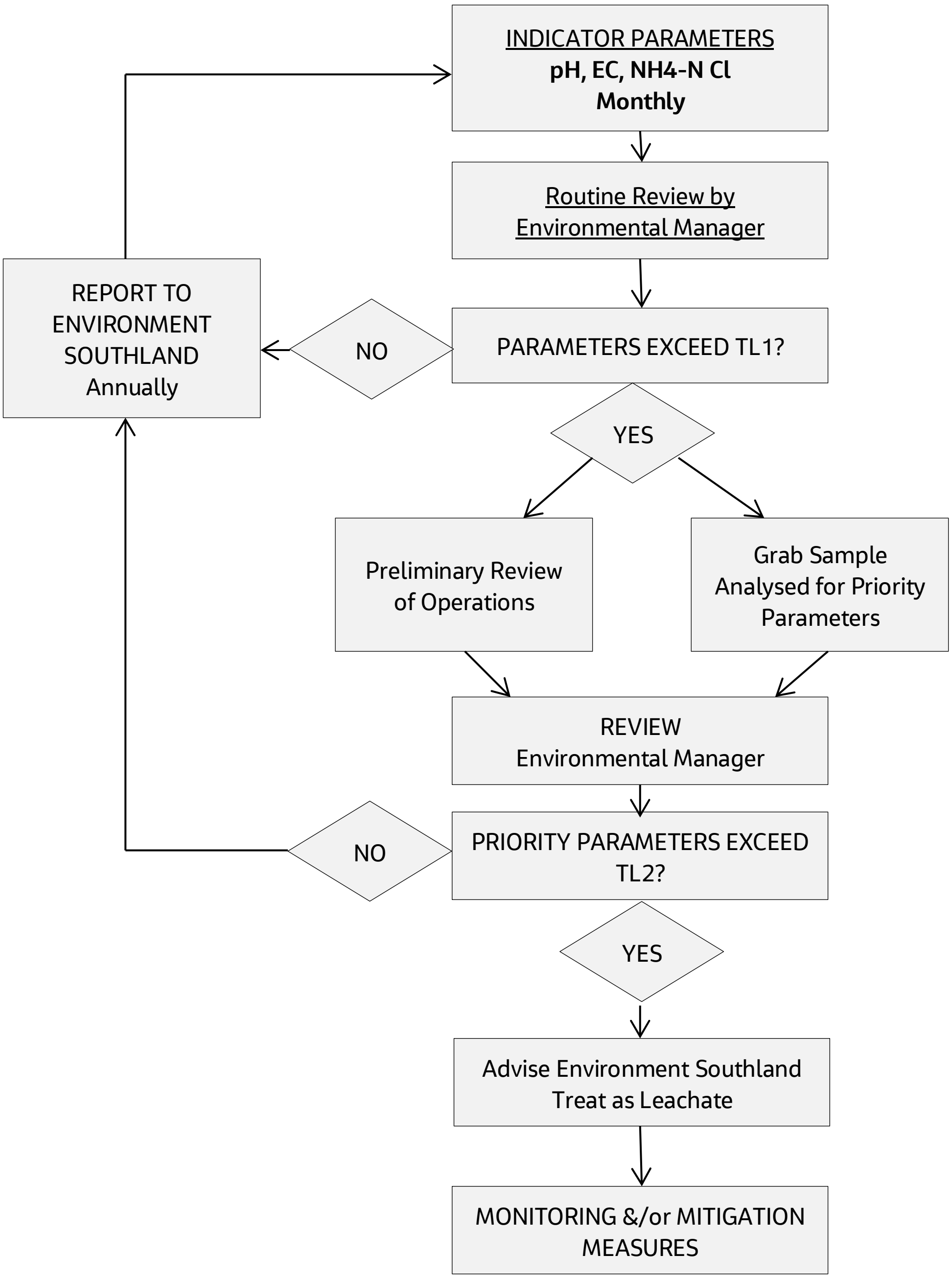


Figure 5 Groundwater Monitoring Contingency Plan: Site 13

13.3.3 Groundwater Contamination Remediation Plan

Contamination remediation plans are to be developed on an individual basis dependent on the nature and degree of contamination detected.

- The general approach to a remediation plan would be as follows:
- Identification of the type of contamination;
- Assessment of the potential environmental impact;
- Isolation of the source of the contamination and redirection of the flow of leachate storage ponds if possible;
- Assessment and implementation of appropriate treatment for the contamination;
- Further monitoring to identify the source of the contaminations this may include the expansion of the existing monitoring programme to include more locations, more parameters and more often; and
- Implement corrective measures to rectify the source of contamination.

Specific contingency plans and reporting activities are not necessary until the uncontrolled release of pollutants have been identified. Reporting will be necessary to demonstrate to Environment Southland that the situation is under control. Additionally, management plans may require amending.

Potential Corrective Measures for contamination are as follows:

Landfill

- Cease placing waste and re-circulating leachate in the area of concern;
- Assess whether liner repairs can be undertaken, providing it will not risk further damage to the intact lining system;
- Isolate and cap the area of concern to prevent further water ingress;
- Increase the leachate extraction from the cell; and
- Re-assess the risks with Environment Southland and discuss specific remediation measures of the monitored natural attenuation is considered inappropriate i.e. pump and treat.

Leachate Tank

- Empty the leachate pond by pumping leachate back to the landfill or tankering all leachate off-site;
- Repair / replace the liner system in accordance with the adopted specification;
- Confirm the installation / repair of the lining system with a leak location survey; and
- Re-assess the risks with Environment Southland and discuss any further remediation measures required.

13.4 Installation of Groundwater Monitoring Wells

The consent holder shall install new downgradient groundwater monitoring wells, if deemed necessary by the consent holder. The final locations shall be agreed in writing by the Southland Regional Council. If any groundwater monitoring well is destroyed AB Lime will discuss the requirement for replacing the well with Environment Southland, and where required by Environment Southland to do so, replace it with a new well, in the same general location, to the satisfaction of Environment Southland.

13.5 Taking of Groundwater

AB Lime will only take groundwater from the groundwater underdrainage systems beneath the landfill footprint and leachate storage pond, as shown on drawing IZ0004000-1000-NG-DRG-1008 found in Attachment 1.

13.6 Maximum Allowable Surface Water Take

AB Lime will not take more surface water than 500 cubic metres in any 24-hour period.

14. Area 15 Concept Filling Plan

14.1 Location

Area 15 is located west of Area 14 and north of Areas 11 and 12, see Drawing IZ000400-1000-NG-DRG-6000.

In plan-view the Area 15 base-liner footprint is approximately 150 m long (east-west) and 100 m wide (north-south).

14.2 Phased Filling of Area 15

Area 15 will be filled in three phases as shown conceptually on the recent aerial photographs (taken Aug 2020) contained in Attachment 10.

For the concept filling plan for Area 15 we have assumed a base-liner footprint filling of 120 m long (east-west) and 90 m wide. This allows for sufficient room for the construction of the temporary access track to each of the three phases. The location of the temporary access track is located in the western part of Area 15, see Attachment 10.

It is envisaged that the remaining area of the base-liner footprint of Area 15 (i.e. 30 m east-west and 10 m north-south), will be filled during the Area 16 filling.

The three filling phases can be summarised as follows:

a) Phase 1: the southern part of Area 15, approximately 120 m long 30 m wide. The aerial photograph shows that the selected waste layer (fluff layer) is being placed.

b) Phase 2: the middle part of Area 15, approximately 120 m long and 30 m wide. This area has an additional 500 mm confining gravel layer placed on top of the leachate collection layer and geogrid. The 500 mm gravel layer will be removed and 1 m of select waste will be placed once Phase 1 has been filled.

c) Phase 3: the northern part of Area 15, approximately 120 m long and 30 m wide. This area has an additional 500 mm confining gravel layer placed on top of the leachate collection layer and geogrid.

14.3 Filling via Cells and Typical Working Face Area

Each phase will be filled via a series of cells that constitute the Working Face. Each cell has a plan-view area of up to 30 m long and 25 m wide, so that the average Working Face area is 750 m^2.

The average 750 m^2 Working Face is below the maximum 1000 m^2 Working Face area (see Section 7.4.3), thereby allowing AB Lime to operate a second Working Face of up to 250 m^2 elsewhere within Area 15 as a contingency.

14.4 Cell Filling Sequence within each Phase

A concept filling sequence for each of the three phases is presented on two cross sections contained within Attachment 10:

a) Cross Section 1: this is a North-South cross section showing the filling sequence against the oversteep northern slopes of Areas 11 and 12. The North-South cross-section shows that during and after Area 15 filling the northern waste slopes have reduced from approximately 1(v):2(h) to 1(v):3(h).

b) Cross Section 2: this is an East-West cross section showing the filling sequence against the oversteep western slope of Area 14. The East-West section also shows that during and after Area 15 filling the western waste slopes have reduced from approximately 1(v):2(h) to 1(v):3(h).

Based on 5 m filling height per cell the concept filling sequence will be as follows:

a) Phase 1: 19 cells, start: Cell 15-1A, finish: Cell 15-1S.

b) Phase 2: 27 cells, start: Cell 15-2A, finish: Cell 15-2AA.

c) Phase 3: 27 cells, start: Cell 15-3A, finish: Cell 15-3AA.

The 5 m filling height is considered the maximum filling height per cell. The 5 m height may be reduced to 2 m or 3 m if AB Lime considers a lower filling height more practical.

14.5 Airspace Volume of Area 15

An estimate of the airspace volume of Area 15 has been based on filling sequence shown on the North-South and East-West cross sections contained in Attachment 10.

A summary of the estimated airspace volume for each of the three phases of filling Area 15 is presented in Table 14.1 below.

Table 14.1: Summary of Estimated Airspace Volume for each of the Three Phases of Filling Area 15

Phase	Number of cells (1)	Identification of cells (1)	Airspace Volume, estimate (m^3) (2)
1	19	15-1A - 15-1S	25,000
2	27	15-2A - 15-2AA	70,000
3	27	15-3A - 15-3AA	88,000
TOTAL	73		183,000

Notes:

1) Number of cells and location of cells based on North-South and East-West cross sections contained in Attachment 10.

2) Both North-South and East-West cross sections show that the waste filling occurs to a height of approximately '30 m', i.e. level with the assumed existing (Aug 2020) waste level of Areas 11, 12 and 14. This is a conservative fill height since additional fill can be placed in Area 15 with a slope of 1(v):3(h) to the east (i.e. towards Area 14) and the same slope to the south (i.e. towards Areas 11 and 12).

   Similarly, the waste truck access located on the western part of Area 15 has not been included as it is conservatively assumed that this access track will be required during the construction of Area 16, which is located west and adjacent to Area 15, see Drawing IZ000400-1000-NG-DRG-6000, rev. A.

14.6 Time Estimate to fill Area 15

A broad time estimate to fill Area 15 is presented in Table 14.2 below and is based on the following assumptions:

a) Waste acceptance rate of 100,000 tons/year.

b) Landfill operating 52 weeks/year, 6 days/week, i.e. waste acceptance rate is 321 ton/day.

c) Assume compacted waste density is 0.85 ton/m^3, i.e. waste acceptance rate is 273 m^3/day.

d) Allow for 15% of Daily Cover, Temporary Cover and Intermediate Capping, i.e. 0.15 x 273 = 41 m^3/day.

e) Volume of waste + Daily Cover, etc = 273 + 41 = 314 m^3/day.

f) Use 314 m^3/day for each of the airspace volumes in Table 14.1.

Table 14.2: Summary of Time Estimate to Fill Area 15

Phase	Airspace Volume, estimate (m^3) (1)	Broad Time Estimate (2)		
		days	weeks	years
1	25,000	80	13	
2	70,000	223	37	
3	88,000	280	47	
TOTAL	183,000		97	1.9

Notes:

1) See Table 14.1.

2) These are broad time estimates only, and should not be relied upon for detailed planning of Area 15 filling duration.

14.7 Waste Truck Access to Area 15

Access to Area 15 will be via a temporary road on the western side of Area 11, see location on background of recent aerial photograph in Attachment 10.

The aerial photographs shows that there is an existing access road to Area 15. The existing access road is used by the AB Lime to transport waste from the top of the slope, down the access track, to Area 15.

The existing access road is will be upgraded with gravel/hardfill. This will enable AB Lime waste trucks (Huka Trucks) to bring the waste in bins from the top of the slope to Area 15.

14.8 Waste Drop-Off Areas for Incoming Waste Trucks

For the filling of Area 15 waste truck entering the landfill via the weighbridge will transport the waste to one of the three areas as shown on the aerial photograph contained in Attachment 10.

The AB Lime Huka Truck will transport the waste to the Working Face.

Attachment 1. Drawings

LEGEND

- CONSENTED LANDFILL FOOTPRINT
- CELL DEVELOPMENT OF LANDFILL
- CELL DEVELOPMENT OF FUTURE LANDFILL
- CADASTRAL BOUNDARY
- BUILDING
- TREE

NOTES

1. THE HORIZOTNAL COORDINATE SYSTEM FOR THE SITE IS NEW ZEALAND MAP GRID 1949.
2. THE LATEST SURVEY FOR THE SITE WAS PERFORMED BY DRONE SURVEY, FLOWN ON 12/03/2020.

SCALE 1:2000 (A1) 40 20 0 40 80 120 160 200m

CONSENT ISSUE

REV	DATE	APP'D	REVISION
A	29.05.20	VP	CONSENT ISSUE

SCALES AT A1

AB LIME

Jacobs

Level 2, Wynn Williams Building
47 Hereford Street
CHRISTCHURCH CENTRAL 8013
NEW ZEALAND

Tel: +64 3 940 4900
Fax: +64 3 940 4901
Web: www.jacobs.com

CLIENT: AB LIME LTD.

PROJECT: LANDFILL INVESTIGATION KING'S BEND SITE

DRAWN	DRAWING CHECK	REVIEWED	APPROVED
MH	JK	CW	VP
DESIGNED	DESIGN REVIEW	DATE 29.05.20	DATE 29.05.20
KJ	LJ		

TITLE: LANDFILL FOOTPRINT AND SITE INFRASTRUCTURE

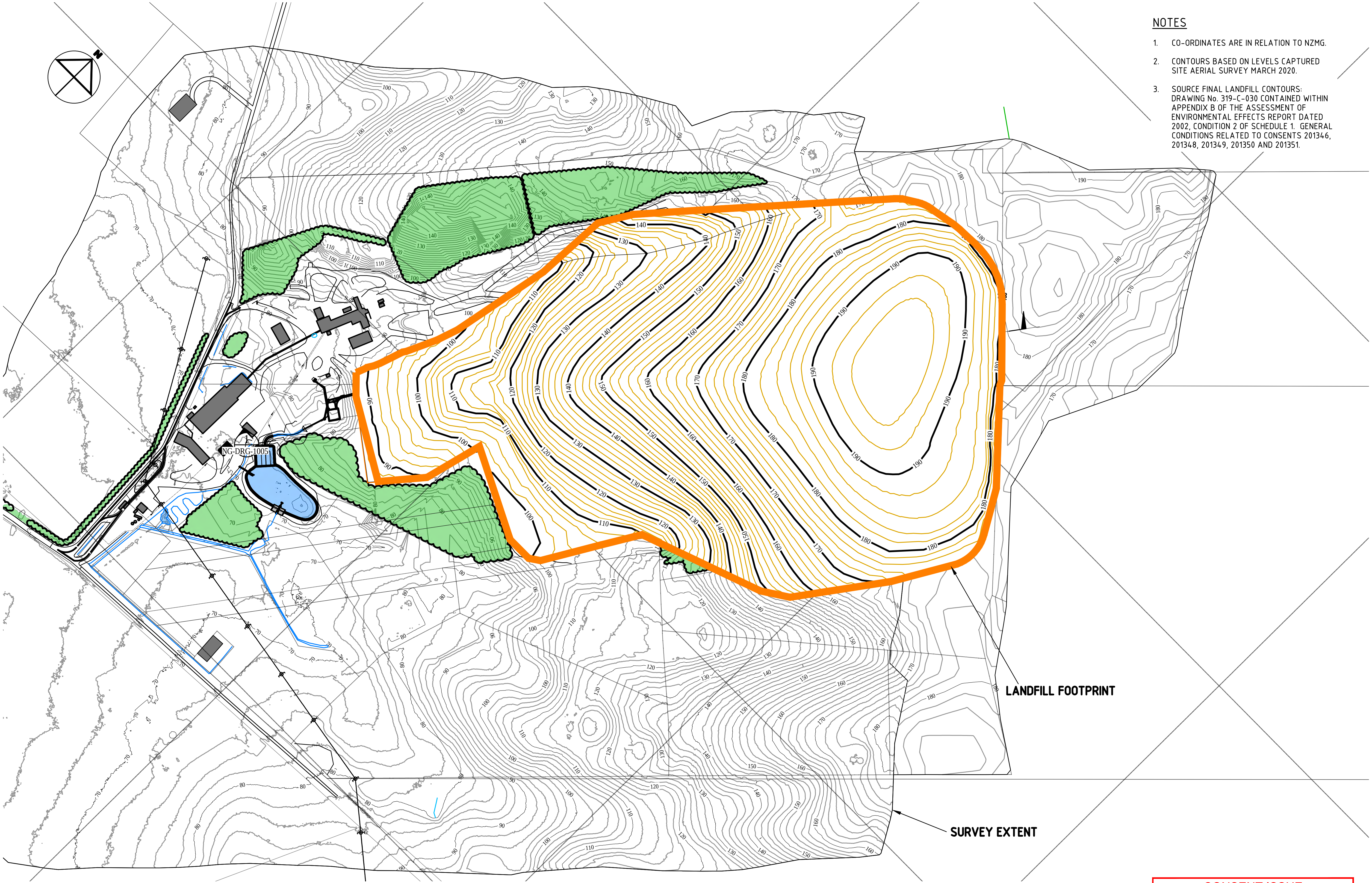
SCALE: 1:10000 (A1)

DRAWING No: IZ000400-1000-NG-DRG-1002

REV: A

A1

DATE: 29/05/2020 2:22:48 PM NAME: HOBDAY, MAI
LOCATION: C:\users\hobdaym\appdata\local\projectwise\jacobs_anz_ie\d0213192\IZ000400-1000-NG-DRG-1003.dwg



NOTES

1. CO-ORDINATES ARE IN RELATION TO NZMG.
2. CONTOURS BASED ON LEVELS CAPTURED SITE AERIAL SURVEY MARCH 2020.
3. SOURCE FINAL LANDFILL CONTOURS: DRAWING No. 319-C-030 CONTAINED WITHIN APPENDIX B OF THE ASSESSMENT OF ENVIRONMENTAL EFFECTS REPORT DATED 2002, CONDITION 2 OF SCHEDULE 1. GENERAL CONDITIONS RELATED TO CONSENTS 201346, 201348, 201349, 201350 AND 201351.

CONSENT ISSUE

REV	DATE	APP'D	REVISION
A	29.05.20	VP	CONSENT ISSUE

SCALES AT A1

AB LIME

Jacobs
Level 2, Wynn Williams Building
47 Hereford Street
CHRISTCHURCH CENTRAL 8013
NEW ZEALAND
Tel: +64 3 940 4900
Fax: +64 3 940 4901
Web: www.jacobs.com

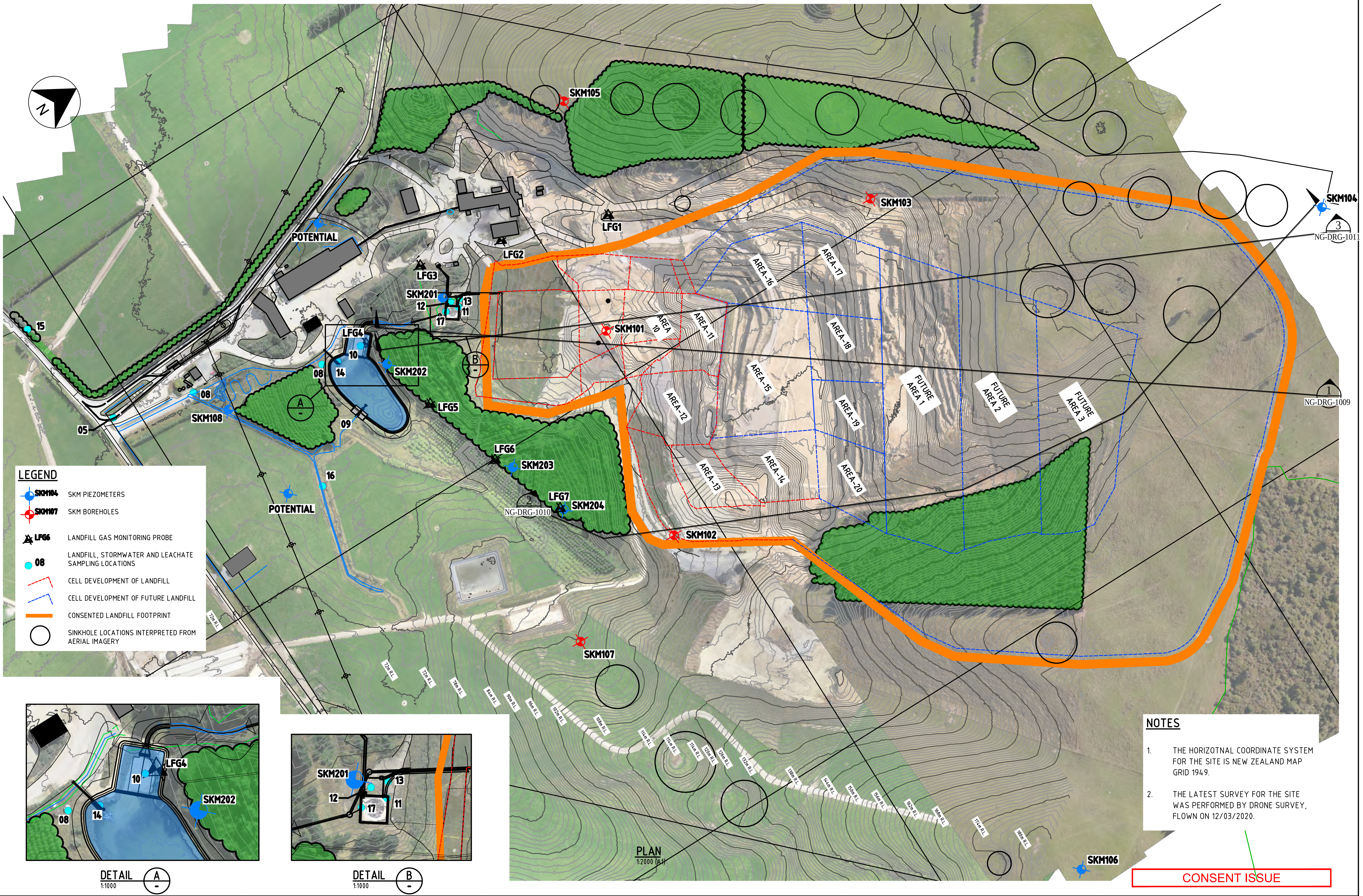
CLIENT: AB LIME LTD.
PROJECT: LANDFILL INVESTIGATION

DRAWN	DRAWING CHECK	REVIEWED	APPROVED
MH	JK	CW	VP
DESIGNED: KJ	DESIGN REVIEW: LJ	DATE 29.05.20	DATE 29.05.20

TITLE: PROPOSED LANDFILL FINAL CONTOURS

SCALE: 1:2500 (A1)
DRAWING No: IZ000400-1000-NG-DRG-1003
REV: A

A1



LOCATION: C:\users\kimj\appdata\local\projectwise\jacobs_anz_ie\d0213192\IZ000400-1000-NG-DRG-1008.dwg DATE: 29/05/2020 12:17:57 PM NAME: KIM, JOHN

REV	DATE	APP'D	REVISION
A	29.05.20	VP	CONSENT ISSUE

SCALES AT A1

AB LIME

Jacobs

Level 2, Wynn Williams Building
47 Hereford Street
CHRISTCHURCH CENTRAL 8013
NEW ZEALAND
Tel: +64 3 940 4900
Fax: +64 3 940 4901
Web: www.jacobs.com

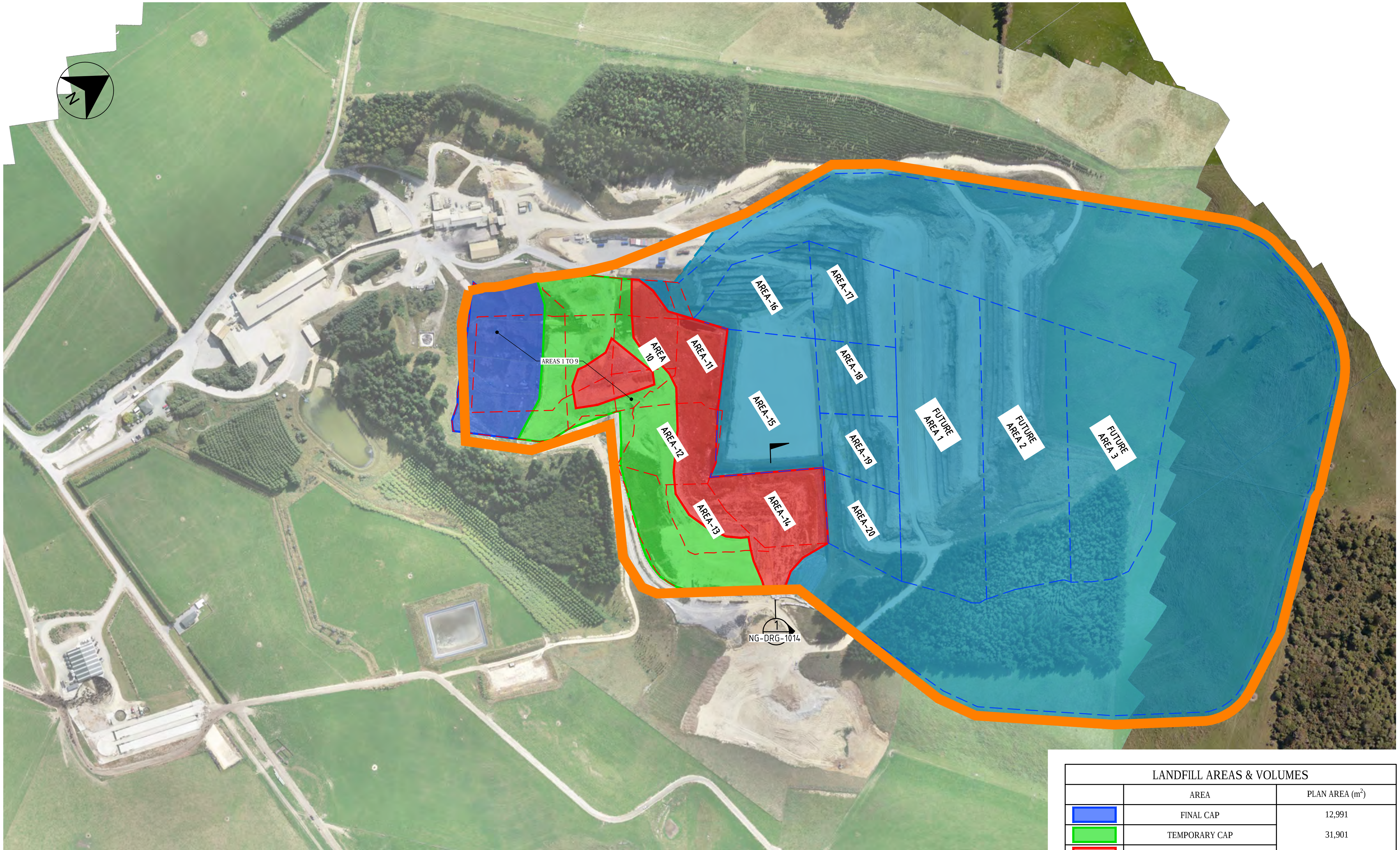
CLIENT: AB LIME LTD.
PROJECT: LANDFILL INVESTIGATION

DRAWN	DRAWING CHECK	REVIEWED	APPROVED
NBL	KJ	CW	VP
DESIGNED	DESIGN REVIEW	DATE 29.05.20	DATE 29.05.20
LJ	CW		

TITLE: GROUNDWATER, STORMWATER & GAS BOREHOLE LOCATIONS PLAN

SCALE: AS SHOWN
DRAWING No: IZ000400-1000-NG-DRG-1008
REV: A

A1



LANDFILL AREAS & VOLUMES

	AREA	PLAN AREA (m^2)
(blue)	FINAL CAP	12,991
(green)	TEMPORARY CAP	31,901
(red)	WORKING AREA \ DAILY COVER	27,060
(light blue, dashed)	AREA 15 TO FUTURE LANDFILL	310,654

CONSENT ISSUE

REV	DATE	APP'D	REVISION
A	29.05.20	VP	CONSENT ISSUE

SCALES AT A1

AB LIME

Jacobs

Level 2, Wynn Williams Building
47 Hereford Street
CHRISTCHURCH CENTRAL 8013
NEW ZEALAND
Tel: +64 3 940 4900
Fax: +64 3 940 4901
Web: www.jacobs.com

CLIENT: AB LIME LTD.
PROJECT: LANDFILL INVESTIGATION

DRAWN	DRAWING CHECK	REVIEWED	APPROVED
NBL	KJ	CW	VP
DESIGNED: WS	DESIGN REVIEW: BC	DATE 29.05.20	DATE 29.05.20

TITLE: LANDFILL CAPPING STATUS
AS OF APRIL 2020
PLAN

SCALE: 1:2000 (A1)
DRAWING No: IZ000400-1000-NG-DRG-1012
REV: A
A1

BUND INSTALLATION NOTES

0 INSTALL TEMPORARY COVER 0.6m THICK COMPACTED LOW PERMEABILITY SOIL, MINIMISE RAINFALL INFILTRATION AND REDUCE LANDFILL GAS EMISSIONS THROUGH CAP

1 PLACE WASTE 0.5m THICK LAYER LOOSE LIFT THICKNESS, COMPACT WITH MINIMUM 3 PASSES (1 PASS = THERE AND BACK), COMPACT REFUSE TO 3m HEIGHT

2 CONSTRUCT KNAP ROCK BUND, 3m HEIGHT, 1(V):1(H) SLOPE, 2m CREST, 8m BUND, OFFSET FROM EXISTING SW BUND

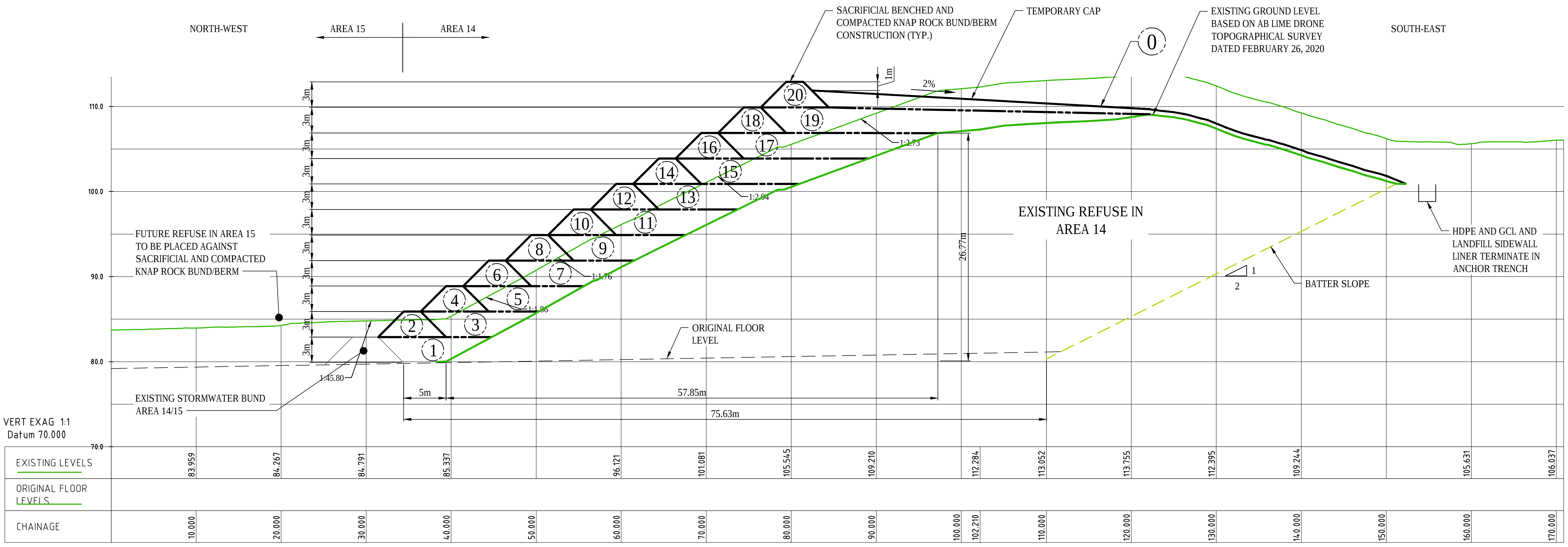
3 REPEAT STEP 1

4 REPEAT STEP 2

5 REPEAT STEP 3

6 REPEAT STEP 4

ETC.



SECTION 1
SCALE 1:250 IZ000400-1000-NG-DRG-1002

NOTE

1 CONSTRUCT A SERIES OF COMPACTED LOW-PERMEABILITY SOIL BUNDS, MEETING THE TEMPORARY COVER CRITERIA

CONSENT ISSUE

REV	DATE	APP'D	REVISION
A	29.05.20	VP	CONSENT ISSUE

SCALES AT A1

Jacobs
Level 2, Wynn Williams Building
47 Hereford Street
CHRISTCHURCH CENTRAL 8013
NEW ZEALAND
Tel: +64 3 940 4900
Fax: +64 3 940 4901
Web: www.jacobs.com

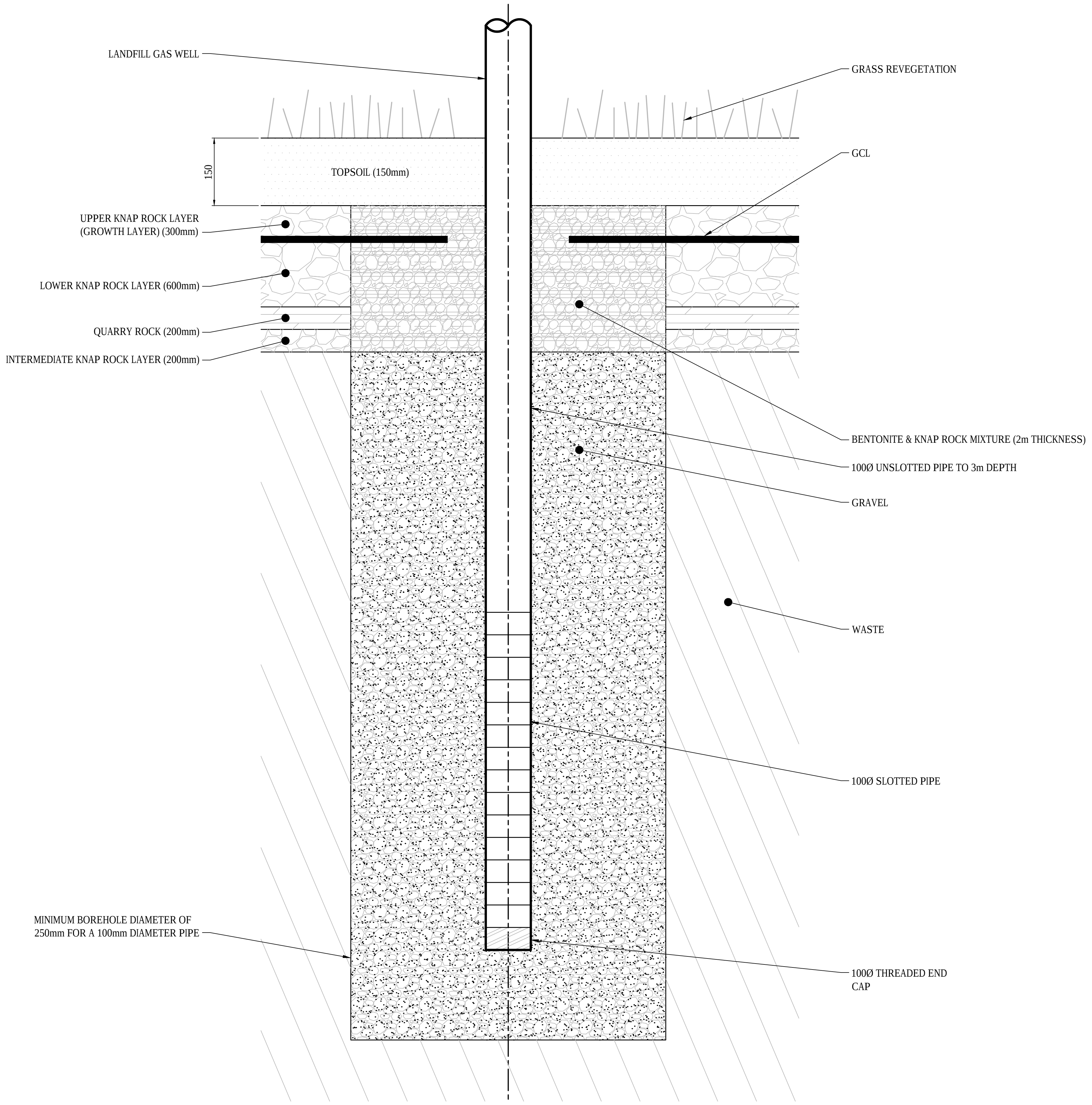
CLIENT AB LIME LTD.
PROJECT LANDFILL INVESTIGATION

DRAWN	DRAWING CHECK	REVIEWED	APPROVED
NBL	KJ	CW	VP
DESIGNED WS	DESIGN REVIEW BC	DATE 29.05.20	DATE 29.05.20

TITLE
AREA 14 & 15
PROPOSED REMEDIAL WORKS FOR
THE EXISTING STEEP REFUSE SLOPE

SCALE AS SHOWN
DRAWING No IZ000400-1000-NG-DRG-1014
REV A

A1



CONSENT ISSUE

REV	DATE	APP'D	REVISION
A	29.05.20	VP	CONSENT ISSUE

SCALES AT A1

Jacobs
Level 2, Wynn Williams Building
47 Hereford Street
CHRISTCHURCH CENTRAL 8013
NEW ZEALAND
Tel: +64 3 940 4900
Fax: +64 3 940 4901
Web: www.jacobs.com

CLIENT: AB LIME LTD.
PROJECT: LANDFILL INVESTIGATION

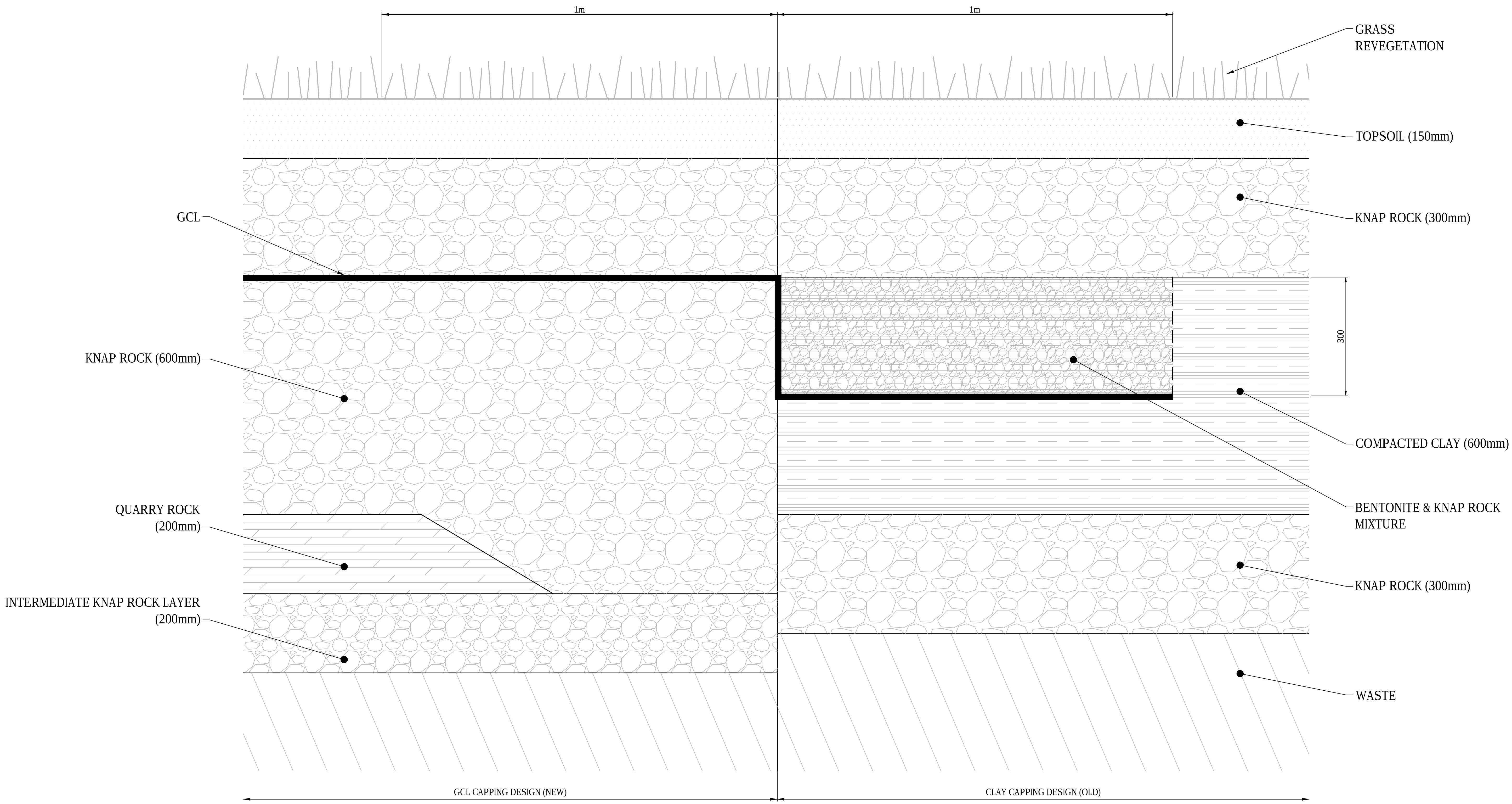
DRAWN	DRAWING CHECK	REVIEWED	APPROVED
NBL	KJ	CW	VP
DESIGNED	DESIGN REVIEW		
WS	BC	DATE 29.05.20	DATE 29.05.20

TITLE
LANDFILL FINAL CAPPINIG DESIGN
GAS WELL CAPPING DETAIL

SCALE	DRAWING No	REV
1:5 (A1)	IZ000400-1000-NG-DRG-1015	A

A1

DATE: 28/08/2020 10:09:59 AM NAME: HOBDAY, MAI
LOCATION: C:\users\hobdaym\appdata\local\projectwise\jacobs_anz_ie\d0213192\IZ000400-1000-NG-DRG-1015.dwg



CONSENT ISSUE

REV	DATE	APP'D	REVISION
A	29.05.20	VP	CONSENT ISSUE

SCALES AT A1

AB LIME

Jacobs

Level 2, Wynn Williams Building
47 Hereford Street
CHRISTCHURCH CENTRAL 8013
NEW ZEALAND
Tel: +64 3 940 4900
Fax: +64 3 940 4901
Web: www.jacobs.com

CLIENT: AB LIME LTD.

PROJECT: LANDFILL INVESTIGATION

DRAWN	DRAWING CHECK	REVIEWED	APPROVED
NBL	KJ	CW	VP
DESIGNED: KJ	DESIGN REVIEW: CW	DATE 29.05.20	DATE 29.05.20

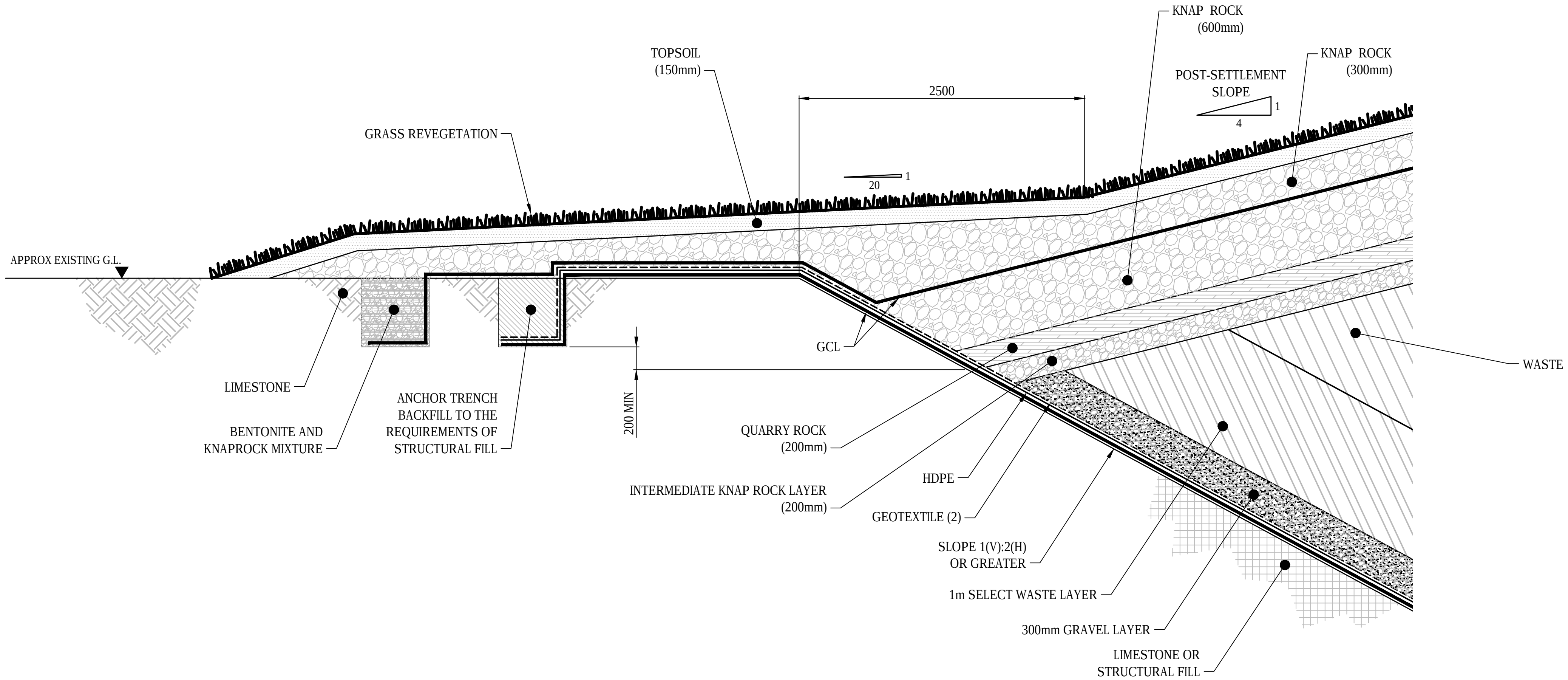
TITLE: LANDFILL FINAL CAPPING DESIGN HORIZONTAL CONNECTION DETAIL

SCALE: 1:5 (A1)

DRAWING No: IZ000400-1000-NG-DRG-1016

REV: A

A1



CONSENT ISSUE

REV	DATE	APP'D	REVISION
A	29.05.20	VP	CONSENT ISSUE

SCALES AT A1

AB LIME

Jacobs

Level 2, Wynn Williams Building
47 Hereford Street
CHRISTCHURCH CENTRAL 8013
NEW ZEALAND

Tel: +64 3 940 4900
Fax: +64 3 940 4901
Web: www.jacobs.com

CLIENT AB LIME LTD.

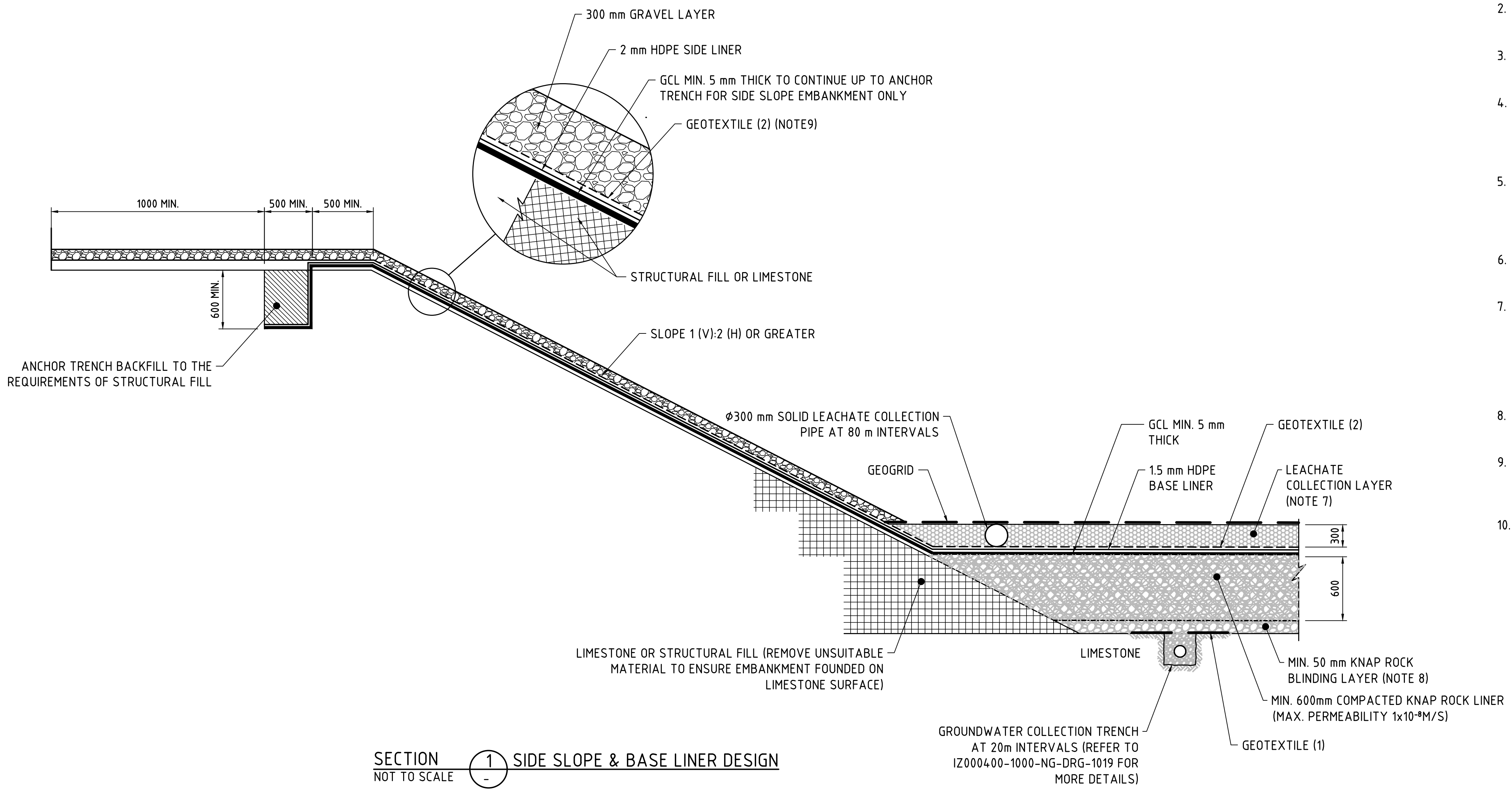
PROJECT LANDFILL INVESTIGATION

DRAWN	DRAWING CHECK	REVIEWED	APPROVED
NBL	KJ	CW	VP
DESIGNED	DESIGN REVIEW	DATE 29.05.20	DATE 29.05.20
KJ	CW		

TITLE
LANDFILL FINAL CAPPING LAYER & SIDE SLOPE SECTION

SCALE	DRAWING No	REV
AS SHOWN	IZ000400-1000-NG-DRG-1017	A

A1



SECTION 1 – SIDE SLOPE & BASE LINER DESIGN
NOT TO SCALE

NOTES:

1. EARTHWORKS, STRUCTURAL FILL AND LINER INSTALLATION TO BE CARRIED OUT IN ACCORDANCE WITH THE SPECIFICATION & QA QC STANDARD (LATEST VERSION).
2. CONTROL OF EARTHWORKS AND TESTING OF LINER TO BE CARRIED OUT IN ACCORDANCE WITH THE QA QC STANDARD (LATEST VERSION).
3. HDPE SIDE LINER ON SIDE SLOPE EMBANKMENT SHALL BE 2.0 mm AND SINGLE SIDE TEXTURED WITH THE TEXTURED SIDE FACING THE GCL.
4. GEOTEXTILE (1) IS A SEPARATION LAYER AND SHALL MEET REQUIREMENTS OF TYPE B, CLASS 3 AS DEFINED IN TNZ F/7, 2003 (SPECIFICATION ITEM 3.3). BIDIM A19 IS AN ACCEPTABLE SEPARATION LAYER.
5. GEOTEXTILE (2) IS A HDPE PROTECTION LAYER AND SHALL MEET REQUIREMENTS OF TYPE A, CLASS 3 AS DEFINED IN TNZ F/7, 2003 (SPECIFICATION ITEM 7.3.2). BIDIM A29 IS AN ACCEPTABLE PROTECTION LAYER.
6. GEOGRID SHALL BE BIAXIAL, POLYPROPYLENE WITH NOMINAL APERTURE SIZE OF 30 mm.
7. INITIALLY, A 500mm GRAVEL LAYER WILL BE PLACED OVER THE 300mm LEACHATE COLLECTION LAYER TO MEET THE CONFINING REQUIREMENTS OF THE GCL. WHEN WASTE IS READY TO BE PLACED THEN THE 500mm GRAVEL LAYER WILL BE EXCAVATED, AND THE GEOGRID AND 1m SELECT WASTE LAYER WILL BE PLACED. REFER TO THE LATEST TECHNICAL SPECIFICATION FOR FURTHER DETAILS.
8. THE BLINDING LAYER SHALL MEET THE REQUIREMENTS OF STRUCTURAL FILL.
9. AS PLACEMENT OF WASTE PROGRESSES WITHIN THE AREA, A 300mm GRAVEL LAYER AND 1m SELECT WASTE LAYER WILL BE PLACED ON TOP OF GEOTEXTILE (2) ON THE SIDE SLOPE.
10. ALL DIMENSIONS ARE IN MILLIMETRES UNLESS STATED OTHERWISE.

CONSENT ISSUE

REV	DATE	APP'D	REVISION
A	29.05.20	VP	CONSENT ISSUE

SCALES AT A1

Jacobs
Level 2, Wynn Williams Building
47 Hereford Street
CHRISTCHURCH CENTRAL 8013
NEW ZEALAND
Tel: +64 3 940 4900
Fax: +64 3 940 4901
Web: www.jacobs.com

CLIENT: AB LIME LTD.
PROJECT: LANDFILL INVESTIGATION

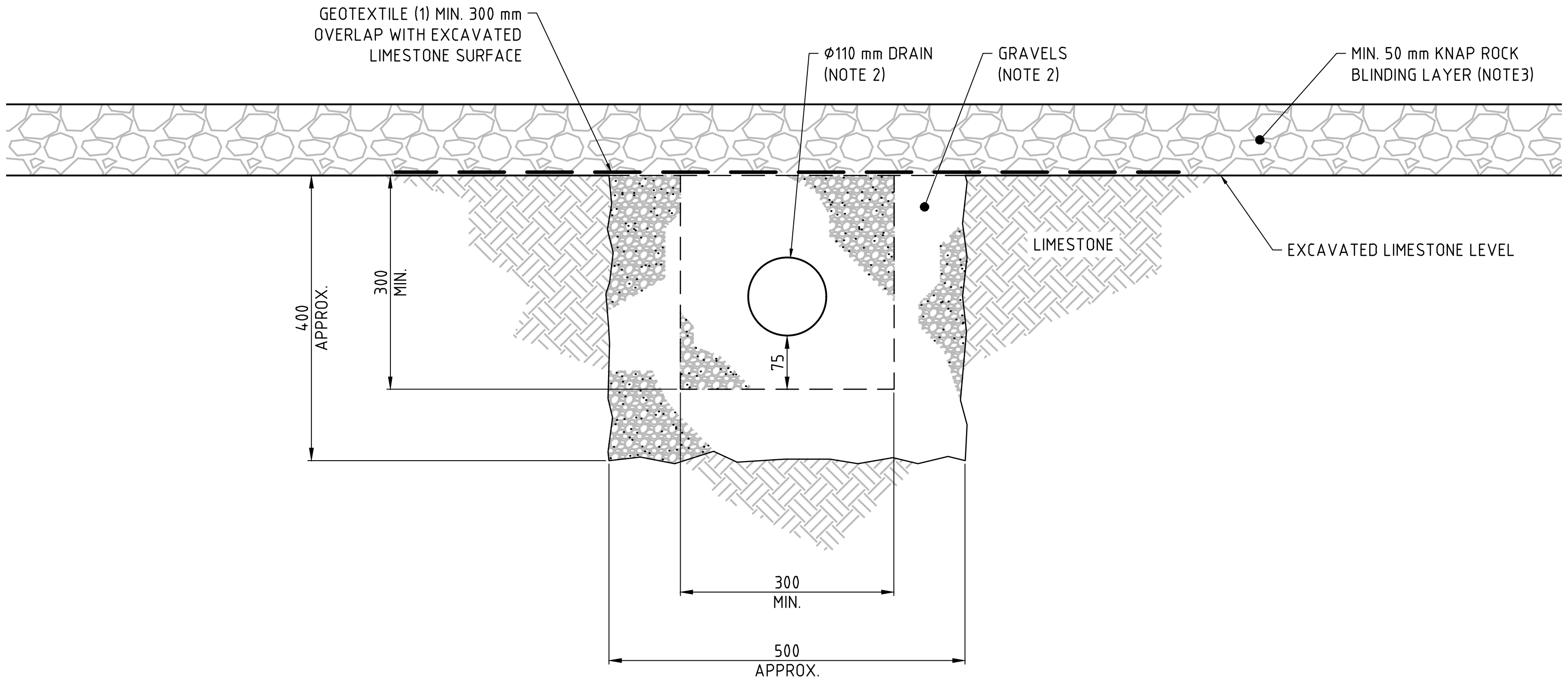
DRAWN	DRAWING CHECK	REVIEWED	APPROVED
NBL	KJ	CW	VP
DESIGNED: KJ	DESIGN REVIEW: CW	DATE 29.05.20	DATE 29.05.20

TITLE: SIDE SLOPE & BASE LINER DESIGN SECTION

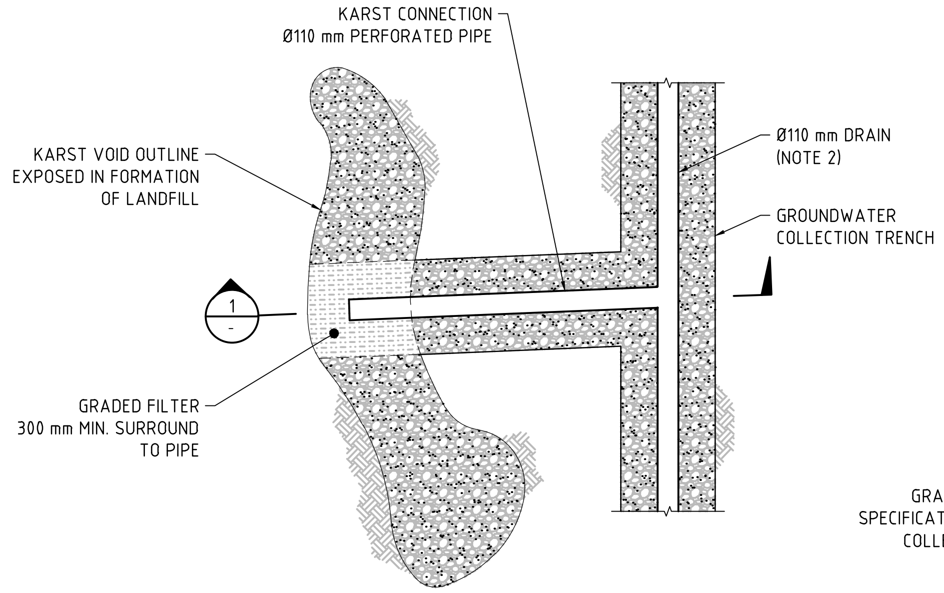
SCALE	DRAWING No	REV
AS SHOWN	IZ000400-1000-NG-DRG-1018	A

A1

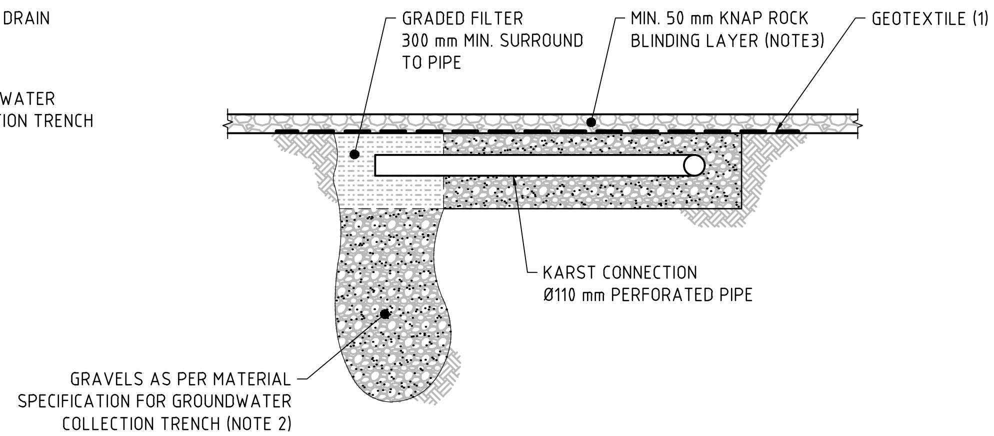
DATE: 29/05/2020 2:04:11 PM NAME: KIM, JOHN
LOCATION: C:\users\kimj\appdata\local\projectwise\jacobs_anz_ie\d0213192\IZ000400-1000-NG-DRG-1019.dwg



DETAIL (A) GROUNDWATER COLLECTION TRENCH
SCALE 1:5 (A1)



DETAIL (B) KARST VOID TREATMENT PLAN
SCALE NTS



SECTION (1) KARST VOID TREATMENT CROSS SECTION
SCALE NTS

NOTE:

1. GEOTEXTILE (1) IS A SEPARATION LAYER AND SHALL MEET THE REQUIREMENTS OF TYPE B, CLASS 3 AS DEFINED IN TNZ F/77, 2003 (SPECIFICATION ITEM 3.3). BIDIM A19 IS AN ACCEPTABLE SEPARATION LAYER.
2. REFER TO LATEST TECHNICAL SPECIFICATION FOR FURTHER DETAILS.
3. THE BLINDING LAYER SHALL MEET THE REQUIREMENTS OF STRUCTURAL FILL.
4. ALL DIMENSIONS ARE IN MILLIMETRES UNLESS STATED OTHERWISE.

CONSENT ISSUE

REV	DATE	APP'D	REVISION
A	29.05.20	VP	CONSENT ISSUE

SCALES AT A1

AB LIME

Jacobs
Level 2, Wynn Williams Building
47 Hereford Street
CHRISTCHURCH CENTRAL 8013
NEW ZEALAND
Tel: +64 3 940 4900
Fax: +64 3 940 4901
Web: www.jacobs.com

CLIENT: AB LIME LTD.
PROJECT: LANDFILL INVESTIGATION

DRAWN	DRAWING CHECK	REVIEWED	APPROVED
NBL	KJ	CW	VP
DESIGNED: KJ	DESIGN REVIEW: CW	DATE 29.05.20	DATE 29.05.20

TITLE: GROUNDWATER COLLECTION TRENCH DESIGN SECTION & DETAILS

SCALE: AS SHOWN | DRAWING No: IZ000400-1000-NG-DRG-1019 | REV: A

A1

Attachment 2. Schedule 2 to AUTH-201346-V3

Schedule 2
Waste Acceptance Criteria
Leachable and Total Concentration Limits

Contaminant threshold is the maximum allowable concentration if a TCLP test is not carried out.

Contaminant	Contaminant Threshold (mg per litre)	Leachable Concentration (mg per litre)	Total Concentration (mg per litre)
Arsenic	100	5.0	
Benzene	10	0.5	
Benzo(a)pyrene	0.8	0.04	
Beryllium	20	1.0	
Cadmium	20	1.0	
Carbon Tetrachloride	10	0.5	
Chlorobenzene	2000	100	
Chloroform	120	6	
Chromium (VI)	100	5	
Chlorpyrifos	4	0.2	
m-Cresol	4000	200	
o-Cresol	4000	200	
p-Cresol	4000	200	
Cresol (total)	4000	200	
Cyanide (amenable)	70	3.5	
Cyanide (total)	320	16	
2,4-D	200	10	
1,2-Dichlorobenzene	86	4.3	
1,4-Dichlorobenzene	150	7.5	
1,2-Dichloroethane	10	0.5	
1,1-Dichloroethylene	14	0.7	
Dichloromethane	172	8.6	
2,4-Dinitrotoluene	2.6	0.13	
Ethylbenzene	600	30	
Fluoride	3000	150	
Fluroxypyr	40	2	
Halogenated compounds			1000
Lead	100	5	
Mercury	4	0.2	
Methyl ethyl ketone	4000	200	
Molybdenum	100	5	
Nickel	40	2	
Nitrobenzene	40	2	
C6-C9 petroleum hydrocarbons	N/A	N/A	650
C10-C36 petroleum hydrocarbons	N/A	N/A	10000
Phenol (non-halogenated)	288	14.4	

Attachment 3. Special Waste Application Form

Special Waste Permit Application

Print | Log out

User Profile | Your Permits | New Permit Application

PERMIT #:

COMPANY:		NAME:	
PHONE NUMBER:		MOBILE:	
EMAIL:	FSmith@ablime.co.nz		
BILLING ADDRESS:			

TYPE: For example: Asbestos, sump cleanings, animal carcasses, soil

DESCRIPTION: For example: Asbestos roofing tiles, dead cattle, backfill soil from fuel tank, expired pastry packaged in lined cardboard boxes.

ATTACH LAB RESULTS (IF AVAILABLE): Choose File No file chosen

SOURCE: Physical address of where waste came from

TOTAL QUANTITY:		LOAD SIZE:	
NO. DELIVERIES:		FREQUENCY:	--Please select--

PACKAGING / CONTAINMENT METHOD: How will it be delivered i.e. loose load, palletised, drums, triple bagged

SELECT COMPANY: --Please select--

APPLICATION CONDITIONS:

1. Only the legal owner of the waste may apply to hold a permit
2. Each permit will only be valid for a maximum of twelve months
3. Two days notice of special waste disposal must be given
4. AB Lime Ltd have the right to refuse waste at any stage

DECLARATION

I declare that the above waste is accurately described

NAME: ______ DATE (DD/MM/YYYY): 13/05/2020

☐ Accept these terms and conditions

Send Application

Attachment 4. Special Wastes Characteristics Tables

Hazardous Characteristic	General Description	HSNO definition (summary)
Explosives	An explosive substance or waste is a solid or liquid substance or waste (or mixture of substances or wastes) that is, in itself, capable by chemical reaction of producing gas at such a temperature and pressure, and at such a speed, as to cause damage to the surroundings.	See document.
Flammable	Solids, or waste solids, other than those classed as explosives, which are readily combustible, or may cause or contribute to fire through friction.	See document. A liquid is flammable if it: gives off a flammable vapour which ignites in a closed cup flash point test at a temperature <=93˚C;
Oxidising	Substances or wastes which, in themselves are not necessarily combustible, but may, generally by yielding oxygen, cause or contribute to the combustion of other materials.	Oxidising substances not organic peroxides, being substances which while in themselves not necessarily combustible may, generally by yielding oxygen, chlorine or fl uorine, cause or contribute to the combustion of other material. Organic peroxides, being substances which contain the bivalent oxygen [-0-0-] structure and may be considered as derivatives of hydrogen perovide where one or both of the hydrogen atoms has been replaced by an organic radical.
Corrosive	Substances or wastes which, by chemical action, will cause severe damage when in contact with living tissue, or in the case of leakage, will materially damage, or even destroy other goods. An aqueous waste with pH less than 2 or greater than 12.5 is defined as corrosive.	See document.
Toxic	This characteristic is defined in terms of landfill waste acceptance for many substances under this heading in Tables 2 to 7.	Acute toxicity including oral, dermal, and inhalation effects. Skin irritation (including corrosive effects) Eye irritation Sensitisation Reproductive/Developmental/Teratogenic effects or Chronic Toxicity Other statistically signifi cant biological effects
Ecotoxic	This characteristic is defined in terms of landfill waste acceptance for many substances under this heading in Tables 2 to 7.	Aquatic toxicity Effects on the soil environment Effects on terrestrial vertebrates Effects on terrestrial benefi cial invetebrates Biocidal action

Type of material		**Criteria**
Asbestos		see AB Lime- Procedure 4.30
Aesthetically disturbing		
Odourous		
Dusts		
Demolition material		
Overlengths		
Wire rope		
Bulky objects		

Attachment 5. Approved Hazardous Waste 4.30

4.30 Policy & Procedure Name: Approved Hazardous Waste

Positions responsible for implementing	Health & Safety Coordinator, Quarry Manager, Environmental Manager, Landfill Supervisor
Purpose of the Policy	To ensure approved hazardous waste is accepted and disposed of appropriately.
Reporting lines	Health & Safety Coordinator, Quarry Manager , Area Supervisor, Staff

Personal Protective Equipment (PPE):					
					

Policy & Procedure	Picture	Training Required
Policy: General		
Asbestos, medical waste and methamphetamine contaminated waste are consented hazardous wastes that can be accepted in the AB Lime Landfill.		

Policy & Procedure	Picture	Training Required

Policy: Accepting Approves Hazardous Wastes – Asbestos 1. Discrete Loads		
Asbestos must be disposed of in accordance with Health and Safety at Work (Asbestos) Regulations 2016. A copy of these regulations can be found at the main office and at the Landfill office.		
It must be double wrapped		
It must be on pallets		
It must be identified with Asbestos stickers		
It must come in on an approved carrier		
It must have a Special Permit		

We require 48 hours' notice to prepare a burial site before the waste arrives		
Disposal follows standard special waste disposal procedures.		

Policy & Procedure	Picture	Training Required
Policy: Accepting Approves Hazardous Wastes – 2. Bulk Rubble		
Delivery Method to Site: • Truck and Trailer bins to be lined with plastic sheeting • Plastic Sheeting to be folded over top of loads and appropriated labelled with Asbestos Stickers.		
Delivery expectations: • That the rubble will be dampened down at the point of loading • The product will have been dampened down prior to travel		

Policy & Procedure	Picture	Training Required
Policy: Accepting Approves Hazardous Wastes – Disposal		
Disposal site will be recorded via GPS. Elevations will be done at the end of each day.		
The trucks will deposit the rubble via a tip-face prepared for this waste only		

At the tip-face a spray boom will operate to eliminate any dust during disposal.		
A hand operated spray will also be used for dust suppression as the product moves down into the deposition hole and settles.		
A sheet of liner will be in position allow the rubble move freely into the designated burial site		
A digger will move each load into position after deposition to allow the layers to build in a space effective manner		
After each load is deposited 1m of fresh municipal waste will be immediately compacted over the top of it		
At final height, geo grid will be placed over the entire deposition site with Asbestos labels secured to it		

Policy & Procedure	Picture	Training Required
Policy: Accepting Approves Hazardous Wastes – Personal Safety Equipment		
Truck Drivers will not be permitted to leave their trucks at the tip face except to open the bin. Masks must be used.		
AB Lime staff will wear disposal overalls, with hoods, that will be disposed of into the landfill prior to leaving the Landfill footprint (including toilet, meal and coffee breaks)		

A new suit is required for each load if there is a break between receiving loads.		
AB Lime staff will wear appropriate face masks to eliminate inhalation of dust		
AB Lime staff will wear gloves and company approved footwear		
AB Lime staff will shower prior to leaving the AB Lime workplace. AB Lime will provide wash and towels.		

Policy & Procedure	Picture	Training Required
Policy: Accepting Approves Hazardous Wastes – Medical Waste		
It must come in on an approved carrier		
It must have a Special Permit		
48 hours' notice to prepare a burial site before the waste arrives		

Disposal follows standard special waste disposal procedures.		

Policy & Procedure	Picture	Training Required
Policy: Accepting Approves Hazardous Wastes – Contaminated Waste		
It must come in on an approved carrier		
It must have a Special Permit		
48 hours' notice to prepare a burial site before the waste arrives		
Disposal follows standard special waste disposal procedures.		

Attachment 6. Example of Special Waste Permit

APPROVED/~~DECLINED~~

Permit No: OR 00023

Special Waste Permit: Difficult/Discretionary Waste

Date: 23-May-18

Company:	**S J Allen Holdings Ltd**	**Name:**	Reon McPherson
Phone Number:		**Mobile Number:**	0210 2954 276
Billing Address:	**P O Box 55** **Arrowtown**	**Email:**	reon@sjallenholdings.co.nz
Waste Type:		**Source:**	Central Otago
Description:		**Load Size:**	
		Frequency:	
		Total Quantity:	
		No Deliveries:	

Packaging/Containment Method

Carrier Company:

Application Conditions:

1. Only the legal owner of the waste may apply to hold a permit

2. Each permit will only be valid for a maximum of twelve months

3. Two days notice of special waste disposal must be given

4. ABLime Ltd have the right to rfuse waste at any stage

Declaration and Acceptance:

I delcare that the above waste is accurately described and accept these terms and conditions.

Name: **Date:**

AB Lime Ltd Use Only:

Status: ACCEPTED / ~~DECLINED~~

Decline Comments if applicable:

Waste Codes:	***L-Code***	20 03 06		***Standing Special Permit***	NEW
	W-Code	W8			
	D/R Code	D1			
Pricing:	***Cost per tonne***	$263.83	ex GST	***Application Fee***	N/A
Permit Expiry Date:		31/12/2018		***Delivery Date***	From 23 May 2018

Special Permit Application Continued……….

Special Waste Permit: Difficult/Discretionary Waste

Conditions of Permit

1. AB Lime ltd reserve the right to refuse waste at any stage

2. This permit will ony be valid for up to a maximum of twelve months

3. This permit shall be read together with the Special Waste Permit Application (above)

4. Only the special waste described in the application (as modified in the Disposal Conditions) of the specified quantity may be disposed under this permit

5. The specified waste can only be delivered to the landfill on the date specified and between the hours specified

6. The landfill operator will not accept the specified Special Waste where:

a. It does not conform to the description, quantity or codes

b. It is not delivered when specified on this permit

c. It is not delivered as specified by any Disposal Conditions

d. It is not suitably contained

Disposal Conditions

1. One days notice must be given prior to waste being delivered and only between the hours of 8.30am - 4.30pm, Monday to Saturday

2. All loads must be covered and delivery to landfill securely contained

3. Offensively odourous waste will not be accepted. Please take all steps to desodorise waste.

4. All Waste must be greater than 20% solid. Liquid waste is not accpeted at the AB Lime Landfill.

Additional Conditions if applicable: N/A

Signed on behalf of AB Lime Ltd: Fiona Smith **Date:** 23-May-18

Applicant Acceptance

The Undersigned declares that:

- ***The waste which accompanies this permit is as described by this permit***
- ***It will meet all costs associated with the disposal of this waste***
- ***It accpets the above terms and condtions***

Name ____________ **Date** ____________

Title ____________

Special Waste Permit Application Difficult/Discretionary Waste

Approved Applicant Permit #:2295

Company:
Blue Sky Meats

Name:
Christian Harvey

Phone Number:
03 2313 421

Mobile:
0276666876

Email:
christian@bluesky.co.nz

Billing Address:
729 Woodlands-Morton Mains Road

Type:
Animal (ovine) wool on pelts

Description:
Raw animal wool on pelts

Source:
729 Woodlands-Morton Mains Road, Morton Mains, RD1, Invercargill

Total Quantity:
max 80,000 kg

Load Size:
10,000-20,000 kg

No. Deliveries:
up to 4

Frequency:
Weekly

Packaging / Containment Method:
Loose load

Select Company:
Freight Haulage

Application Conditions:

1. Only the legal owner of the waste may apply to hold a permit
2. Each permit will only be valid for a maximum of twelve months
3. Two days notice of special waste disposal must be given
4. AB Lime Ltd have the right to refuse waste at any stage

Declaration

I declare that the above waste is accurately described

Name:
Christian Harvey

Date (dd/mm/yyyy):
02/03/2020

√ Accept these terms and conditions

AB Lime Use Only

Status:
CONFIRMED

Decline Comments:

Waste Code

L-Code:
02 01 02

W-Code:
W14

D/R-Code:
D1

Standing Permit:
2251

Conditions of Permit:

1. AB Lime reserve the right to refuse waste at any stage
2. This permit will only be valid for up to a maximum of twelve months
3. This permit shall be read together with the Special Waste Permit Application
4. Only the special waste described in the application (as modified in the Special Disposal Conditions) of the specified quantity may be disposed under this permit
5. The specified waste can only be delivered to the landfill on the date specified and between the hours specified
6. The landfill operator will not accept the specified Special Waste where:
   - It does not conform to the description, quantity or codes
   - It is not delivered when specified on this permit
   - It is not delivered as specified by any Special Disposal Conditions
   - It is not suitably contained

Disposal Conditions

1. Two days notice must be given prior to waste being delivered and only between the hours of 10 am – 4 pm, Monday to Saturday
2. All loads must be covered and delivery to landfill securely contained.

Additional conditions:
REPLACES 2251

Expiry Date:
16/03/2021

Delivery Date:
16/03/2020

Signed on Behalf of AB Lime Ltd

Name:
Fiona Smith

Date:
16/03/2020

WasteNet Council Use Only

Status:
CONFIRMED

Decline Comments:

Cost per Tonne:
$238.75 excluding GST

Application Fee:
$25.00 ex GST

Issue Date:
18/03/2020

Signed on behalf of WasteNet Southland

Name:
Donna Peterson

Date:
18/03/2020

Applicant Acceptance

The Undersigned declares that:

- The waste which accompanies this permit is as described by this permit
- It will meet all costs associated with disposal of this waste

Name:
Christian Harvey

Date (dd/mm/yyyy):
18/03/2020

Title:
Technical Compliance Manager

√ Confirmation of terms and conditions

Attachment 7. Bore Logs

Groundwater Monitoring Bore Specifications

Bore ID	Easting	Northing	TOC Elevation (mAMSL)	Ground Elevation (mAMSL)	Piezometer diameter (mm)	Bore Depth (mBGL)	Casing Depth (mBGL)
SKM104	2153261.85	5443788.63	187.68	187.42	50	67.7	55.7
SKM106	2153764.46	5443144.92	186.98	186.79	50	77.5	65.5
SKM108	2152768.01	5442563.30	66.31	66.19	50	20.5	14.5
SKM201	2152809.80	5442869.24	74.55	73.69	50	10.2	1.7
SKM202	2152840.95	5442773.92	75.01	74.33	50	10.1	1.6
SKM203	2153019.64	5442834.00	74.66	73.99	50	10	1.5
SKM204	2153092.44	5442858.04	77.01	76.28	50	10	1.5

Attachment 8. Sampling Protocols

The sampling procedures outlined below should be followed at all times. Any variations from the procedures and the reasons for the variation should be noted at the time of sampling. Reviews of the procedures will need to be made should further clarification of the sampling protocol be required or changes to equipment and subsequent methodology occur. Details of specific equipment purchased by the landfill operators will be added when added when information is available.

B.1 Sample Control

- The appropriate sample bottles for each sampling round should be ordered from the analytical laboratory. The laboratory should also be phoned if there is any change from the normal schedule to advise when the samples will be dropped off to them.
- Using labels provided by the laboratory label each bottle. Prepare a chain of custody form and fill out the field sheets with sample numbers and relevant details
- Do not open sample containers until immediately before the sample is to be taken, then fill as quickly as possible. Do not touch the inside of the lid or container with fingers or other objects. Reject a bottle if the lid has fallen off.
- A chilly bin or waterproof bad with "Slikka" pads must be used to keep the samples chilled.
- All equipment should be maintained and operated in accordance with the manufacturer's specifications. Records of services and calibrations intervals should be kept.

B.2 Safety

- Treat all samples and sampling locations as toxic. Wear protective gloves at all time and change at each location. Try not to unduly splash or breathe waters. Be careful around all waterways.
- Follow AB Lime H&S procedures for all sampling activities

B.5 Groundwater

Pre-fieldwork procedures checklist	Equipment checklist	Field procedures
▪ Review Sampling Procedures ▪ Organise equipment & documentation ▪ Check equipment is in good working condition (i.e. calibrated) & properly decontaminated	▪ Site map ▪ Keys for well locks ▪ Field recording sheets ▪ Chain of Custody form ▪ Camera/phone	▪ Sampling should be carried out from the least contaminated to the most contaminated site
		<u>Measure static water level</u> ▪ Measure the static water level before purging ▪ Read water level measurement to the nearest 0.01m from the top of casing ▪ Decontaminate the dipper using Deacon 90 between each well. Thoroughly rinse with distilled water.
	<u>Purging Equipment</u> ▪ Groundwater Dipper ▪ Air compressor ▪ Red and Blue hoses ▪ Micro purge	<u>Purging (this is for bailing)</u> ▪ Calculate the volume of groundwater requires to remove 3 bore volumes (based on volume of

	▪ Clear curly cord ▪ Black extension tubing ▪ Portable Sonde ▪ Calibrated bucket ▪ Calculator	standing water as measured above and bore dimensions) ▪ Purge water from the borehole into the bucket. Using the portable sonde, record the DO, conductivity, pH, TDS, temperature. Note odour, colour & clarity of the water. ▪ Once the field parameters have stabilised or 3 bore volumes of water have been removed, the sample bottles can be filled.
	<u>Sampling Equipment</u> ▪ Sample Bottles ▪ Distilled water ▪ Residue free detergent (Deacon 90) ▪ Disposable Gloves ▪ Chilly bin ▪ Ice	<u>Sampling</u> ▪ Fill sample bottles ▪ Store samples on ice ▪ Decontaminate all equipment with the Deacon 90 between sites. Rinse thoroughly with distilled water.

Attachment 9. ELCOSEAL Installation Guide

GEOFABRICS®
Smarter Infrastructure

ELCOSEAL®

Geosynthetic Clay Liner Installation Guide

ABOUT ELCOSEAL

ELCOSEAL is a needle-punched Geosynthetic Clay Liner (or GCL) produced in Australia in accordance with the ISO 9001:2015 Quality Management System.

ELCOSEAL consists of premium grade sodium bentonite powder, which acts as the swelling and sealing component, embedded and sandwiched between two or more geotextiles. The composite is then needle-punched through all layers and thermally-locked developing high connection strength. Thus, ELCOSEAL is a shear strength transmitting GCL.

ELCOSEAL is generally fast and easy to install, however the performance of the GCL is dependent on the quality of its installation. It is the installer's responsibility to follow these guidelines and the project specifications and drawings whenever possible. It is the engineer's and owner's responsibility to provide construction quality assurance (CQA) for the installation to ensure that the installation has been executed properly. Variance from this guideline is at the engineer's discretion.

Recommended further reading:

- ASTM D 5888 - *Standard Guide for Storage and Handling of GCLs*
- ASTM D 6102 - *Standard Guide for Installation of GCLs*
- ASTM D 5889 - *Standard Practice for Quality Control of GCLs*
- ASTM D 6072 - *Standard Guide for Obtaining Samples of GCLs*

BEFORE YOU BEGIN

Prior to delivery of ElcoSeal on-site ensure the project team has:

- Read these guidelines;
- Raise any questions not answered by these guidelines with Geofabrics;
- Read the ElcoSeal Safety Data Sheet and Bentonite Material Safety Datasheet (available on the Geofabrics website);
- All the required equipment to unload, store and install ElcoSeal on site;
- All the required PPE for safe handling and installation of ElcoSeal.

Personal Protective Equipment

The use of respiratory, eye, hand and body protection is recommended when handling ElcoSeal Geosynthetic Clay Liners. Please refer to the ElcoSeal Safety Data Sheet for more information prior to any commencement of work. ElcoSeal contains powdered sodium bentonite which contains quartz/cristobalite which is classified as hazardous according to the Globally Harmonised System of Classification and Labelling of Chemicals (GHS).

A respirator with a removable dust mask should be used

Safety glasses with side shields should be worn

Wear gloves of impervious material

Wear suitable protective workwear. Overalls are recommended.

GHS Classified as hazardous

PACKAGING, TRANSPORTATION, UNLOADING & STORAGE

Packaging

ELCOSEAL rolls are packed in moisture tight plastic wrapping. The standard roll dimensions and weights are listed in Table 1 below.

Every ELCOSEAL roll has a unique roll number on the wrapping label and on the panel itself. This information allows for matching of manufacturing quality assurance (MQA) records.

! *After transportation and unloading the plastic wrapping should be checked. Minor damage should be repaired with weather-resistant adhesive tape. Wrapping should only be removed immediately before use.*

Table 1: ELCOSEAL Roll Dimensions & Freight Capacities

Grade	Width (m)	Length (m)	Diameter (m)	Roll Mass (kg)	Rolls per B Double	Rolls per 20ft Container	Rolls per 40ft Container
X800	4.7	45	~0.56	~1,035	20	15	22
X1000	4.7	35	~0.52	~915	23	15	24
X2000	4.7	30	~0.56	~890	23	15	25
X3000	4.7	30	~0.57	~940	23	16	23

Transportation

ELCOSEAL rolls are usually delivered to site in closed containers or covered trailers on flatbed trucks. At the point of unloading, the rolls need to be accessible either from the top of the trailer or the container opening. Please see the table above for average freight capacities for B Double and 20ft and 40ft containers.

Should any damage to rolls occur in transit it must be immediately brought to the attention of Geofabrics, who will advise on the required course of action.

Unloading

A flat, hard, dry and free draining surface must be provided for unloading and storage. Offloading on site will require heavy equipment: an excavator (tracked or wheeled); front-end loader; or a forklift. Heavy equipment must be correctly rated for the expected load (see Table 1 on the previous page). Rolls may be offloaded using:

A A Spreader Bar with steel tube insert through the core of the rolls. Refer to the *ELCOSEAL Spreader Bar Safe Usage Guideline* from the Geofabrics website for detailed information; **OR**

B A 'carpet prong', rated to 1,200 kg and matched to the forklift, protruding from the front end of the forklift (>4.5 tonne) or other equipment. The prong should be at least ¾ the length of the ELCOSEAL core and also must be capable of supporting the full weight of ELCOSEAL without significant bending; **OR**

C The two slings provided by the Geofabrics (upon request) wrapped around the ELCOSEAL roll at third (⅓) points along the roll, fixed to an excavator bucket or a front-end loader. Slings should not be used for general lifting and transportation around the site. If excessive deformation or bending of the roll occurs the integrity of the geocomposite may be affected. A steel tube or similar reinforcement can be inserted into the core of the roll to prevent excessive deformation across the roll during off-

Storage

ELCOSEAL rolls should be stored in their original, unopened packaging in a location away from construction traffic but sufficiently close to the active work area to minimise handling.

The designated storage area should be level, dry, well-drained, stable, and should protect the product from:

- Precipitation;
- Chemicals;
- Standing water;
- Excessive heat;
- Ultraviolet radiation;
- Vandalism and animals.

ELCOSEAL rolls should always be stored lying flat, continuously supported, and should never be stored standing on one end. Enclosed indoor storage such as shipping containers or a warehouse environment is preferred if ELCOSEAL® is to be stored for long periods.

The maximum storage height is four rolls.

! *ELCOSEAL rolls should not exposed to moisture prior to installation. Damaged wrappers should immediately be repaired with weather resistant tape. Wrapping should only be removed from ELCOSEAL rolls immediately prior to installation.*

INSTALLATION

What You'll Need On Site

Prior to commencement of installation the following equipment will be required:

- Excavator (tracked or wheeled) or a front-end loader. Equipment should be rated for the expected load. Please see Table 1 on page 2 of this document for roll masses;
- Spreader bar/loading frame;
- HP Paste;
- Trowel;
- Carpet knife or safety knife;
- Felt pens or chalk;
- Measuring tape;
- Broom;
- PPE including dust mask, goggles, gloves and protective workwear.

Weather Conditions for Installation

Light rainfall (defined as <5mm/hour intensity) should not affect the installation of ELCOSEAL provided deployed panels are covered and confined by 300 mm of cover soil (or equivalent) within 2 hours of first exposure to the light rain. Heavy direct raindrop impact should be avoided. The ELCOSEAL panels can be covered during heavy rainfall events with a tarpaulin or plastic sheet if there is not enough time to complete soil cover placement.

Avoid placing ELCOSEAL in areas where water is ponding unless panels can be confined immediately (with 300 mm cover soil or equivalent).

! *ELCOSEAL rolls should not be exposed to moisture prior to installation. During installation ELCOSEAL panels should be covered with a tarpaulin or plastic sheet during heavy rain events.*

Subgrade Preparation

The preparation of the subgrade before placement of any lining material is critical to the system's performance. The surface(s) upon which ELCOSEAL is to be laid should be suitable for the intended application and function.

ELCOSEAL will generally be placed on either an earthen e.g. compacted clay, or geosynthetic e.g. geotextile or geocomposite) subgrade.

Earthen Subgrades

The surface upon which ELCOSEAL® will be deployed should conform to the following:

- The subgrade should be firm and unyielding (typically compacted to >90% density), without abrupt elevation changes, and be proof rolled with a smooth drum roller immediately prior to deployment of the ELCOSEAL panels. The subgrade should not be disturbed or rutted by the equipment deploying the rolls or other traffic. No foreign matter or stones loose on the surface or penetrating out of the subgrade >10 mm should be allowed. The engineer's approval of the subgrade needs to be obtained immediately prior to roll deployment;
- In applications where ELCOSEAL is the sole or primary barrier, and will be subjected to constant or long-term hydraulic heads exceeding 300 mm (1 ft), subgrade surfaces consisting of gravel or granular soils may not be appropriate due to their large void contents and puncture potential. In these applications, the top 150 mm of the subgrade should possess a particle size distribution where at least 80% of the soil is finer than 0.25 mm (or #60 sieve) - unless the ELCOSEAL grades X2000 or X3000 are being used (see below);
- For X2000 and X3000 grades (with a composite woven/nonwoven carrier geotextile) in high hydraulic head applications:

  Subgrade materials recommended without further investigation are:

  » Clays or clay-based mixes;

  » Sandy clays (with > 20% fines);

  » Silty or loamy clays (with > 20% fines)
  [fine grained soils should be placed at suitable moisture contents for construction operations and roll deployment - that provide adequate bearing capacity to deploy the rolls without disturbance of the subgrade - i.e no rutting or large deflections];

  » Well graded sands and gravels (max < 32 mm, d60 < 5 mm, d20 < 0.15 mm).
  [these materials should bind and have good bearing capacity when compacted/rolled].

  Subgrade materials not recommended without further investigation:

  » Single-sized and gap-graded sands and gravels of any size or description;

  » Sands or soils that have low bearing capacity at the moisture contents during the construction/deployment operations i.e. materials that do not bind when rolled; will heave/shove under equipment or foot traffic during or after deployment);

  » Subgrades that have a bony or porous appearance after compaction and rolling.

Geosynthetic Subgrades

When deploying ELCOSEAL over a geosynthetic material such as a geomembrane or geotextile, the surface should be firm and unyielding as per the requirements for earthen subgrades. The equipment used to deploy ELCOSEAL should be approved for use by the Design Engineer and/or the Supplier of the underlying geosynthetic material. Generally, the underlying geosynthetic and ELCOSEAL® rolls will be deployed consecutively such that each layer is side-cast from equipment tracking over the earthen subgrade - unless specialised light rubber tyred dispensers are available and approved by the Design Engineer that allow direct trafficking over the geosynthetics.

GCL Placement

The ELCOSEAL roll wrapping should only be removed immediately prior to installation. On site, ELCOSEAL is unrolled along the prepared subgrade using the Spreader Bar assembly as shown in Figures 1 and 2 (overleaf).

! *ELCOSEAL should only be trafficked by light, low tyre pressure vehicles (no tracked vehicles).*

Rolls must be laid without folds on the subgrade with a standard overlap of 300 mm in both the longitudinal and transverse direction as detailed in Figures 3, 4 and 5. For longitudinal or edge overlaps, the blue coloured line on the underside of the panels can be used to ensure the correct overlap width. The edge of deployed or previously placed panels needs to coincide or match with the visible blue line on the roll being deployed.

The transverse or end overlaps need to be sealed using bentonite paste. The treatment of end (transverse) overlaps is detailed in Figures 6 and 7.

Rolls can be cut to length with a carpet/Stanley knife. When overlapping cut panels, bentonite paste will need to be applied as per the requirements for end (transverse) overlaps on the following page under *ELCOSEAL Panel Overlaps*.

No trafficking or walking should occur over the overlap region during installation. The overlap must also be free from folds and foreign matter e.g. soil. Any soil particles on the laps must be swept away carefully.

Overlaps should occur in the direction of ground slope in a similar manner to roof tiles.

Damage to ELCOSEAL During Installation

Where ELCOSEAL has been damaged during installation, covering with an overlapping piece of ELCOSEAL can repair such areas. The overlap should be at least 500 mm and should be completed in accordance with the ELOSEAL Panel Overlaps section.

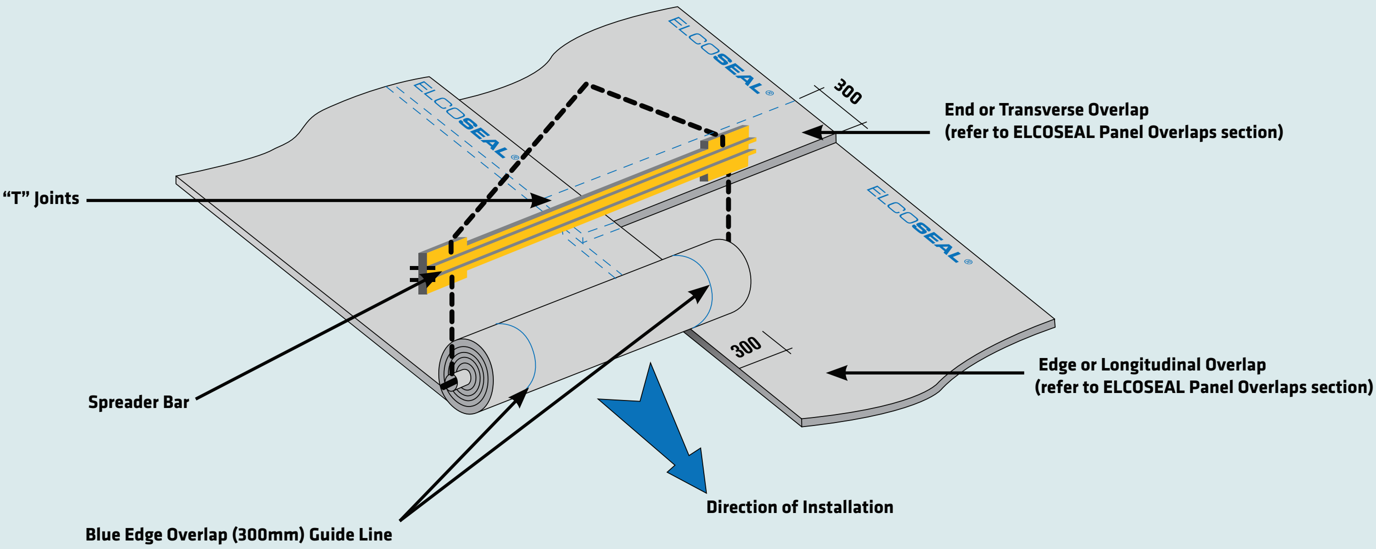


Figure 1 ELCOSEAL deployment using the standard ELCOSEAL Spreader Bar

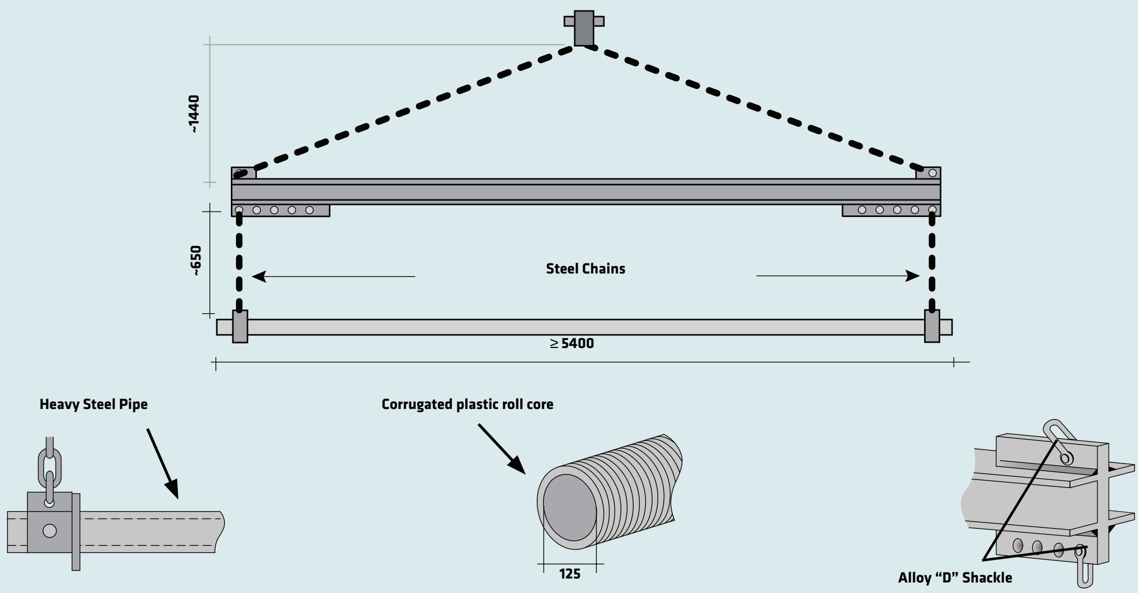


Figure 2 ELCOSEAL typical Spreader Bar assembly

! *Refer to the ELCOSEAL Spreader Bar Safe Use Guide prior to using the lifting equipment and ensure that occupational health and safety requirements have been met and potential hazards eliminated.*

ELCOSEAL Panel Overlaps

Logitudinal Overlaps

The longitudinal overlap is where GCL rolls overlap along their length. The installation of a longitudinal overlap can be seen in Figure 1. The width of this overlap shall be a minimum of 300 mm which is indicated by a blue marker line printed on the bottom of the roll. The overlapping area has bentonite powder impregnated into the top nonwoven fibres of the GCL as seen in Figure 3 for grades X800 and X1000 and in Figure 4 for grades X2000 and X3000. When hydrated, the impregnated bentonite will swell into the fibre porespace to provide a sealed hydraulic barrier. An installed cross section can be seen in Figure 5.

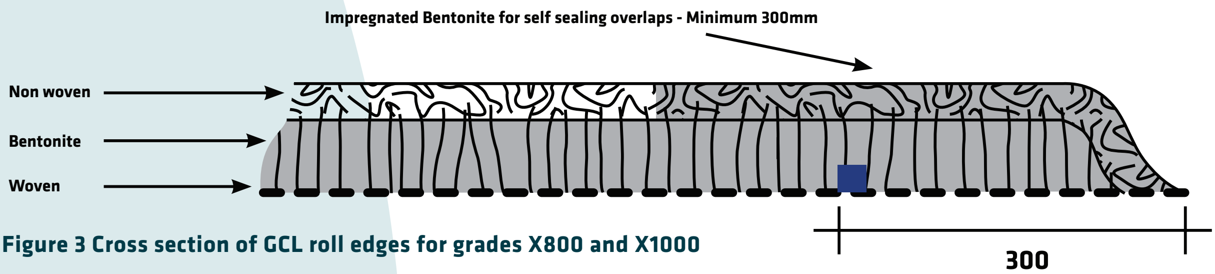


Figure 3 Cross section of GCL roll edges for grades X800 and X1000

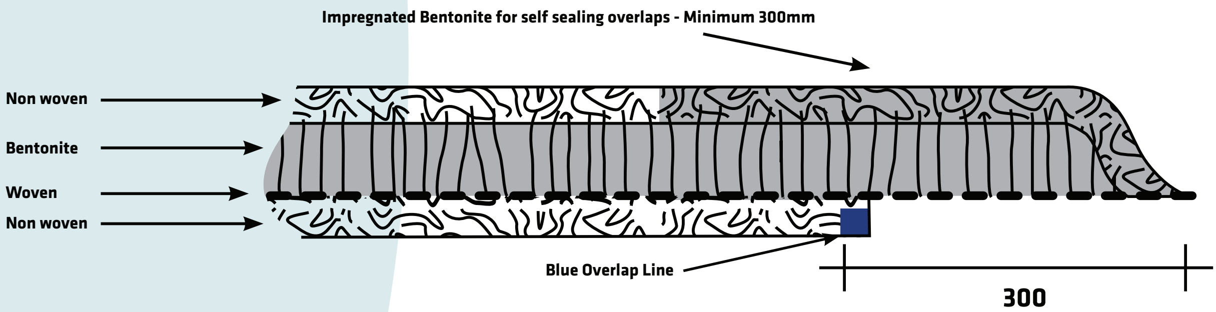


Figure 4 Cross section of GCL roll edges for grades X2000 and X3000

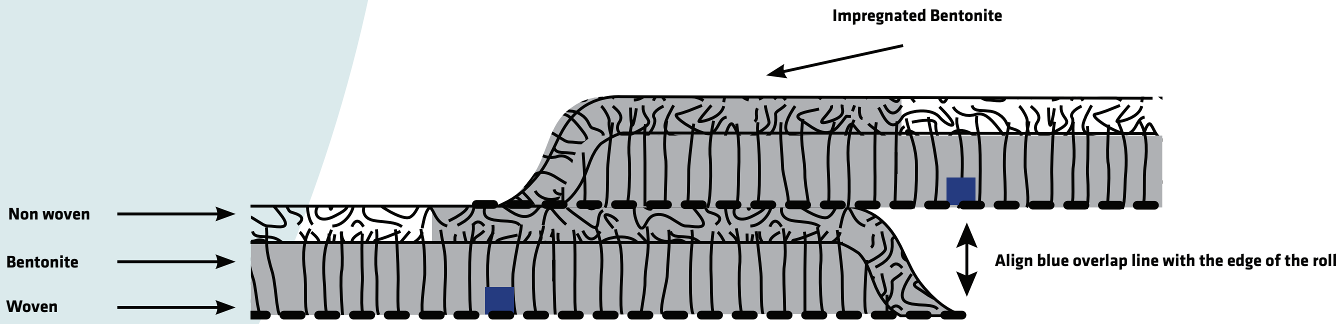


Figure 5 Longitudinal (or edge) overlap with self-sealing impregnated bentonite (X1000 shown)

Transverse Overlaps

Transverse overlaps occur at the end of rolls. The width of the GCL transverse overlap shall be a minimum of 300 mm. It is recommended that the topside of the underlying ELCOSEAL panel be marked as per Figure 6, as a reference point for paste placement. The top ELCOSEAL panel is then pulled back after marking.

All transverse/roll end overlaps should be sealed with bentonite paste. Geofabrics supplies HP paste which is an extensively tested sealing solution available in 20 L containers. As indicated in Figure 6, HP paste should be placed within the 300 mm overlap with a minimum width of 200 mm and a nominal thickness of 10 mm. The paste can be easily poured from the 20 L container and spread into place using a trowel or broom. Approximately 10L or ½ of a container is used for each roll width at the transverse overlap. Once the paste is applied, the top panel is then rolled back into place and pressed down (Figure 6). Care should be taken to prevent folds or creases. The end overlap cross section for X1000 is shown in Figure 7. If an alternative method of end of roll overlap sealing is required, please consult your local Geofabrics office.

To ensure the integrity of the ELCOSEAL® lining system it is essential that the treatment of end overlaps be carefully supervised. End overlaps in sumps or inverts are to be avoided.

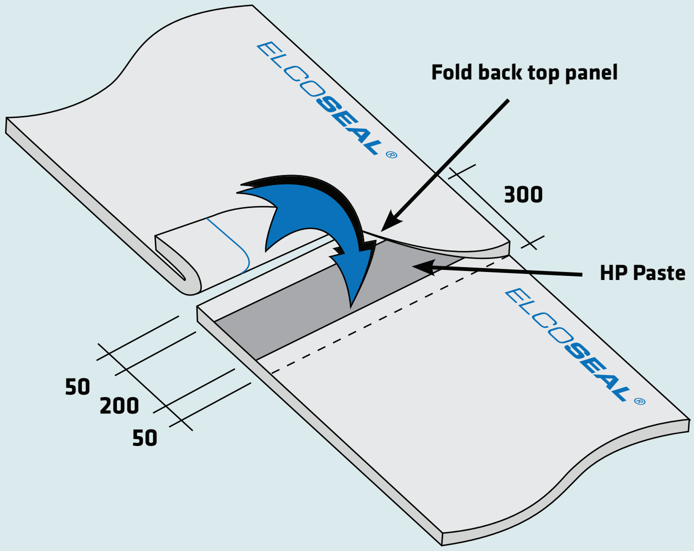


Figure 6 Transverse (end) overlap installation with applied HP Paste of minimum 200 mm width

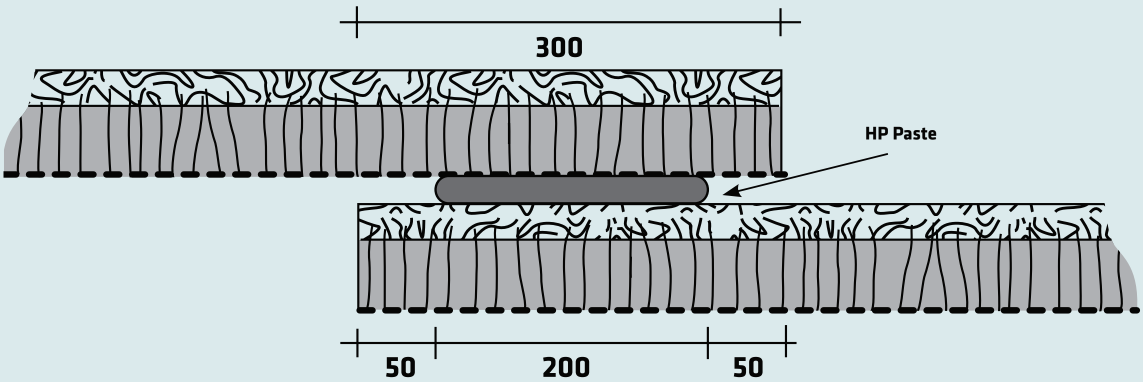


Figure 7 Transverse (end) overlap cross section (X1000 shown)

Installation on Slopes

The stability of lining system components on slopes should be assessed on a case-by-case basis. Geofabrics can assist in this respect upon request.

ELCOSEAL panels should be deployed in the direction of the slope as per Figure 8 and anchored at the crest of the slope (Figure 9). End (or transverse) overlaps on steep slopes should be avoided. If overlaps on slopes are unavoidable, please consult your local Geofabrics branch for information on custom extra-long GCL rolls.

Cover soil should be placed up the slope (starting at the toe). It must not be installed down the slope unless stability for this approach has been carefully investigated.

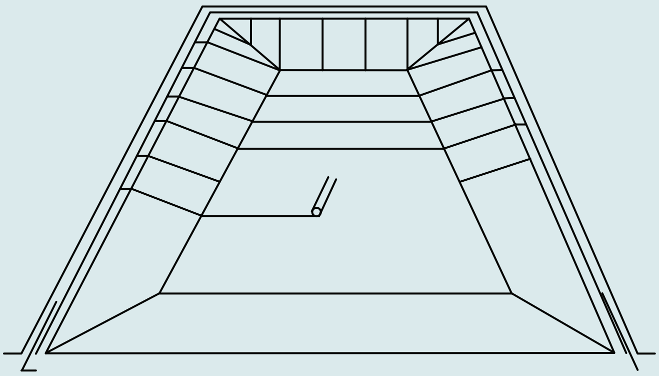


Figure 8 Recommended panel layout for sloping sites

Anchor Trenches

Anchor trench and slope stability considerations should be assessed by the Design Engineer.

As a general guide:

- An anchor trench should be used at the top of slopes steeper than 7H: 1V. (see Figure 9 for a typical anchor trench detail);
- The anchor trench should be constructed free of sharp edges or corners and maintained in a dry condition. The ELCOSEAL panels should be placed down the front face and along the base of the anchor trench. The base of the anchor trench should not contain large gravel or loose material and the trench backfill material should be compacted.

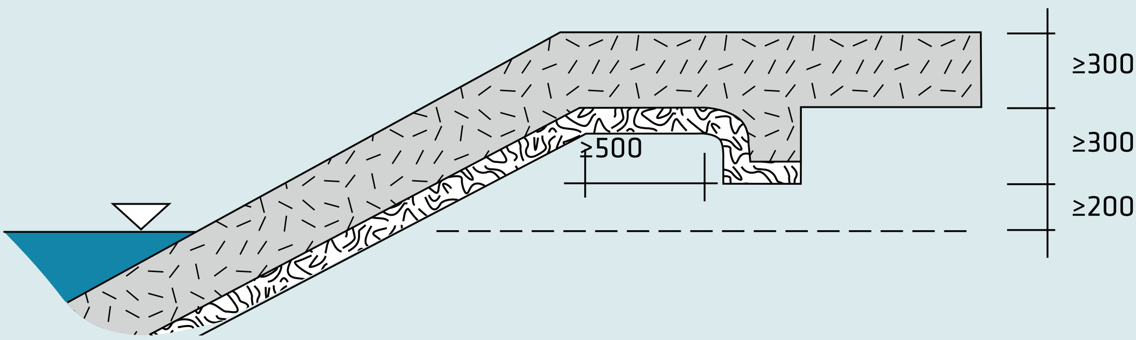


Figure 9 Typical anchor trench (all dimensions shown are typical values only)

Connections & Penetrations

Overlaps around connections, penetrations, and where panels have been cut should be carried out according to the principles outlined in Figures 5, 6 and 7. Most situations require site specific design input, however some commonly used details are shown below:

- Integration with thick compacted clay liners is shown in Figure 10;
- Cut-off trenches using ELCOSEAL GCL in cohesive soil are typically constructed as shown in Figure 11;
- Attachment and sealing against concrete structures, can be achieved according to Figures 12a and 12b. These typical connections are appropriate where the structure needs to be waterproofed to a height above and below the maximum containment level. Temporary fixing of the vertical ELCOSEAL panel to the structure (as shown) is required to allow the backfill placement;
- Penetrations such as pipe ducts are typically carried out according to Figure 13;
- Further connection methods and penetrations details can be discussed with Geofabrics.

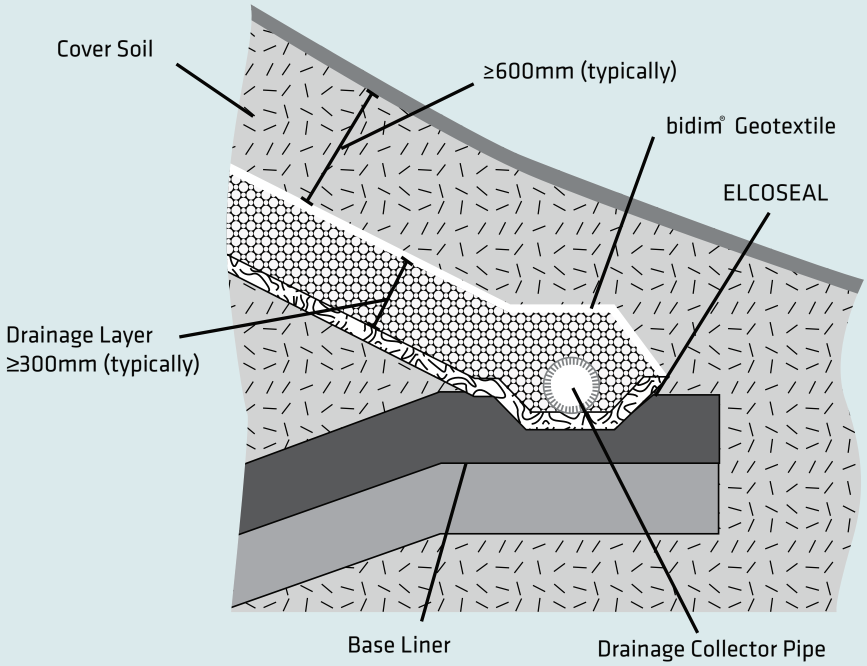


Figure 10 ELCOSEAL cap connection with base liner

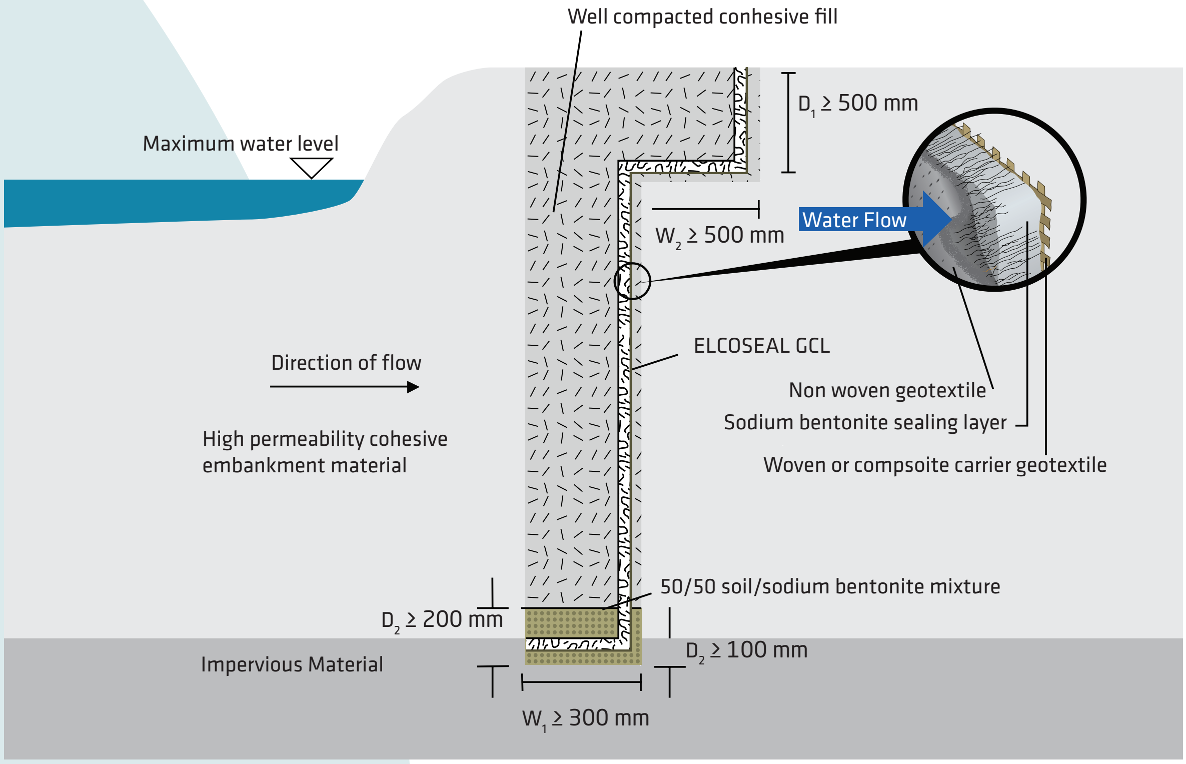


Figure 11 ELCOSEAL cut off trench detail for cohesive soils

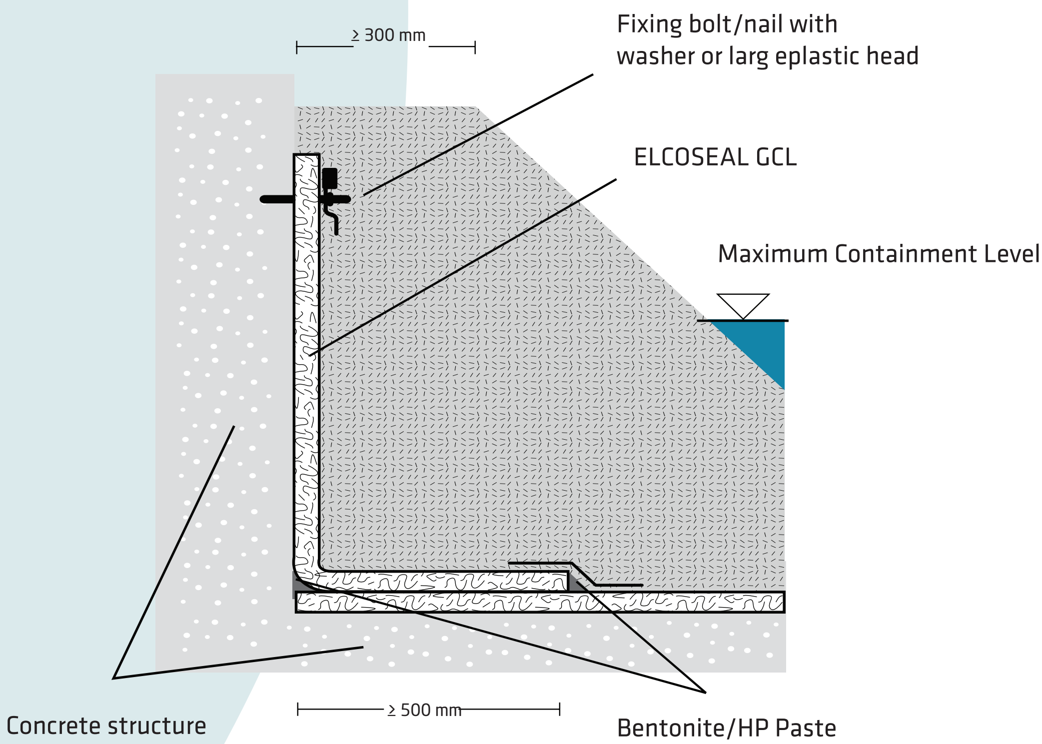


Figure 12a Typical connection to a concrete structure where the ELCOSEAL panel if required to extend above the maximum containment level

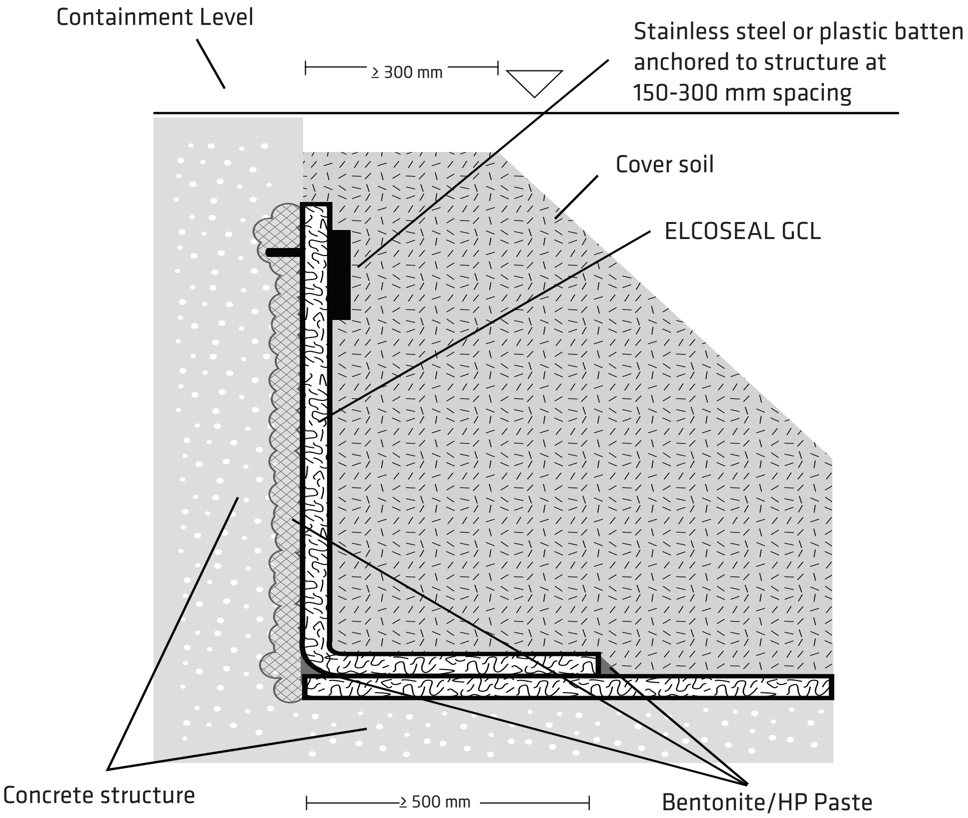


Figure 12b Typical connection to a concrete structure where the ELCOSEAL panel if required to extend below the maximum containment level

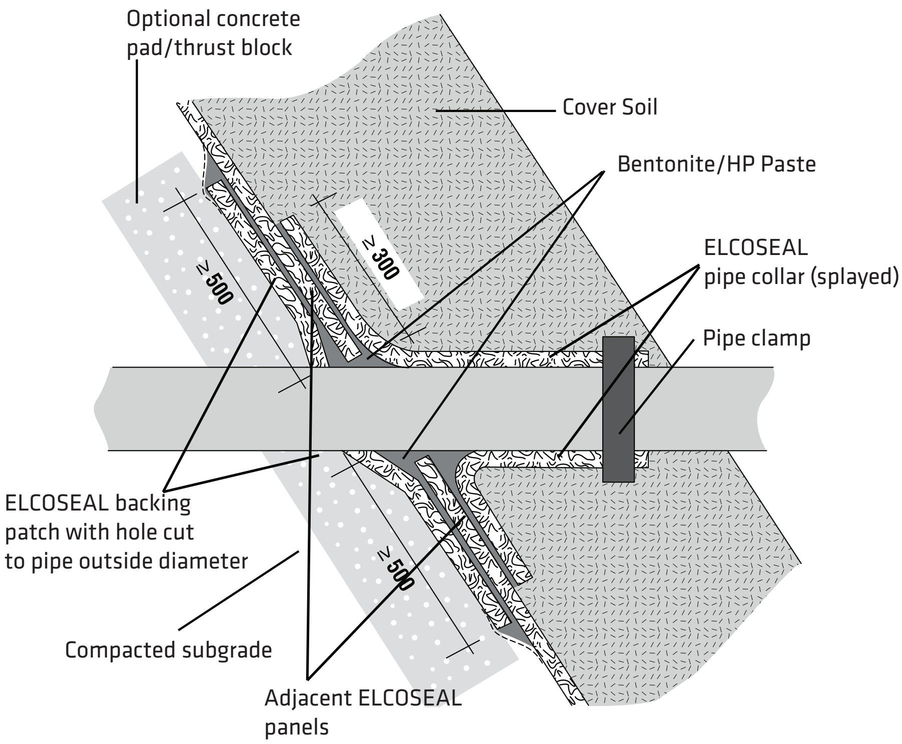


Figure 13 Typical pipe penetration detail

Preparation for Placing Soil Cover

Where the ELCOSEAL is not confined by the cover soil the same working day as deployment, a temporary layer of plastic should be laid to protect ELCOSEAL from prematurely hydrating (Figure 14).

If the deployed ELCOSEAL panels have hydrated (for example during a rainfall event) without confinement, special operating conditions may need to be imposed during cover soil placement. For example:

- If ELCOSEAL m.c.[1] <50% — No special considerations;
- If ELCOSEAL 50% <m.c. <100% — Avoid direct traffic (including foot traffic) on panels;
- If ELCOSEAL m.c. >100% — Contact Geofabrics for advice.

1. m.c. = moisture content of the bentonite, % by weight

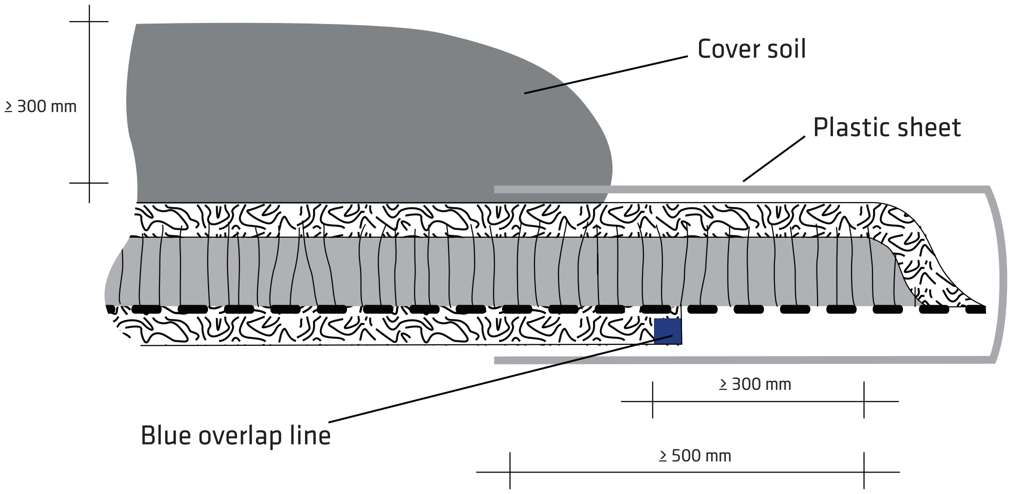


Figure 14 Covering ELCOSEAL with plastic sheet overnight or during wet weather

Soil Cover Placement

A cover soil layer of at least 300 mm thick (approx. 6 kN/m² confining stress) should be placed and compacted over ELCOSEAL each working day immediately after the deployed panels have been inspected. In general, fine-grained cohesive material is recommended, although stones up to 32 mm are acceptable if the material is well graded (Cμ >5) or stones up to 16 mm if single sized. Silty soils or organic material are not recommended without further stability analysis. Calcareous or limestone based cover soils should be evaluated prior to use.

Disturbance of the overlap area during placement (by means of vehicles spreading cover soil) must be avoided. It may be necessary to place the cover soil in this area manually or carefully using vertical placement by an excavator. The cover should not be pushed or graded in a direction that may cause the overlap to move (Figure 15).

ELCOSEAL may not be trafficked directly. The cover material should be pushed in front of the construction equipment thus creating a safe working platform. Overlaps should not be moved or squeezed during this process. In the case of an expected repeated dynamic load on ELCOSEAL, a sand layer of at least 300 mm should be laid first on the ELCOSEAL.

Generally, temporary access roads should not go over deployed panels. These areas should be sealed last to minimise traffic volume over deployed material. Where site traffic cannot be avoided e.g. the delivery of cover material by lorries) additional protection measures will be required. For temporary roads, a minimum roadbase thickness over ELCOSEAL of 600 mm is acceptable without any further analysis. Shallower coverage or alternative cover materials may be allowed after further analysis or field trials to assess the damage potential.

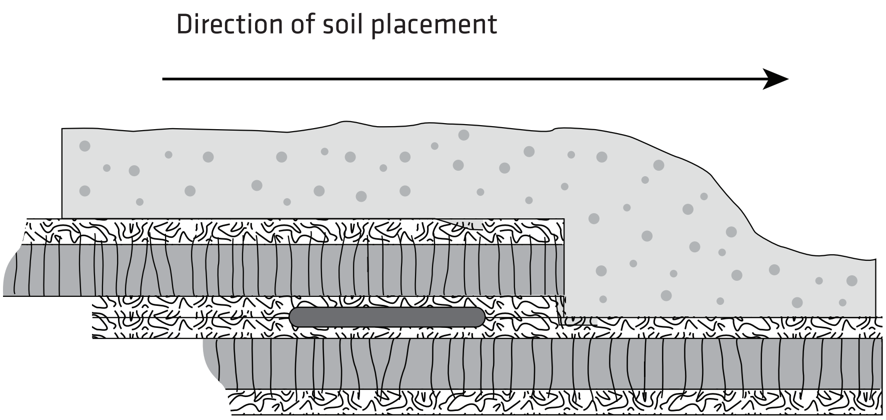


Figure 15 Cover soil placement

Attachment 10. Phased Filling of Area 15

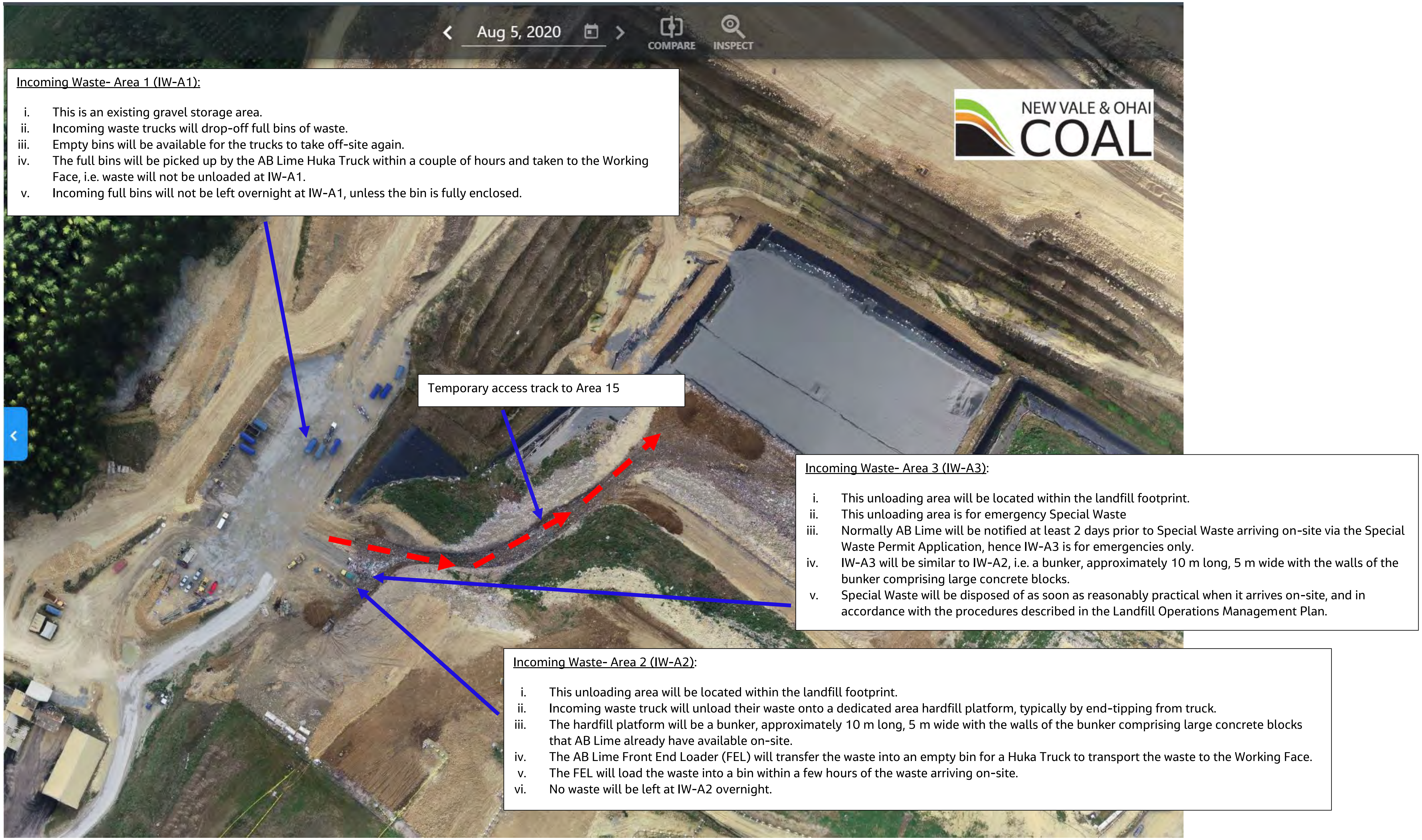


Figure 1: Incoming Waste and Access Track Temporary Locations

Phase 1 Filling

Volume Airspace = 25,000 m^3

Phase 1 consists of 19 cells

Filling sequence: 1, 2, 3 and 4 as follows (see concept cross sections):

1: Cell 15-1A to 15-1E

2: Cell 15-1F to 15-1J

3: Cell 15-1K to 15-1O

4: Cell 15-1P to 15-1S

AR= Temporary access road to Working Faces of Phase 1

Figure 2: Phase 1 – Concept Filling Plan for Area 15

Phase 2 Filling

Volume Airspace = 70,000 m^3

Phase 2 consists of 27 cells

Filling sequence: 1, 2, 3, 4, 5, 6 as follows (see concept cross sections):

1: Cell 15-2A to 15-2E

2: Cell 15-2F to 15-2J

3: Cell 15-2K to 15-2O

4: Cell 15-2P to 15-2S

5: Cell 15-2T to 15-2W

6: Cell 15-2X to 15-2AA

AR= Temporary access road to Working Faces of Phase 2

Figure 3: Phase 2 – Concept Filling Plan for Area 15

Phase 3 Filling

Volume Airspace = 88,000 m^3

Phase 3 consists of 27 cells

Filling sequence: 1, 2, 3, 4, 5, 6 as follows (see concept cross sections):

1: Cell 15-3A to 15-3E

2: Cell 15-3F to 15-3J

3: Cell 15-3K to 15-3O

4: Cell 15-23 to 15-3S

5: Cell 15-3T to 15-3W

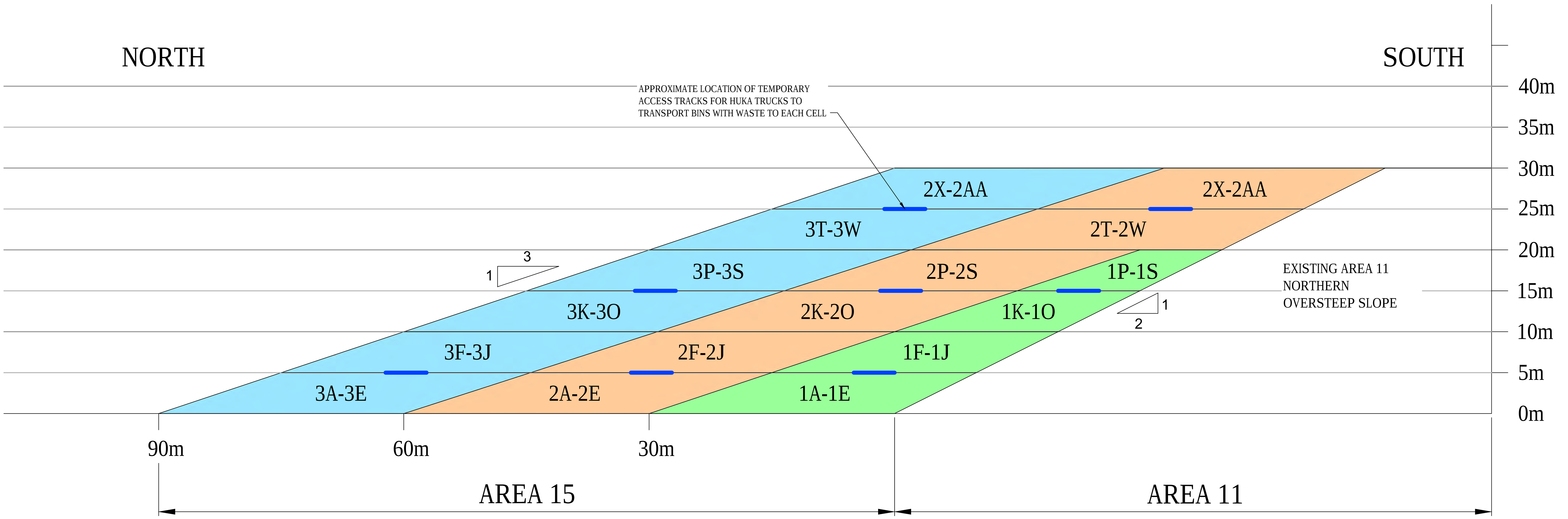
6: Cell 15-3X to 15-3AA

AR= Temporary access road to Working Faces of Phase 3

Figure 4: Phase 3 – Concept Filling Plan for Area 15

NOTE

1. NOTE: 1A-1E = CELLS 15-1A +15-1B + 15-1C + 15-1D + 15-1E, SEE ALSO CROSS SECTIONS EAST-WEST FOR PHASES 1-3



PRELIMINARY ISSUE

REV	DATE	APP'D	REVISION
0	02/09/2020	VP	PRELIMINARY ISSUE

SCALES AT A1

Jacobs
Level 2, Wynn Williams Building
47 Hereford Street
CHRISTCHURCH CENTRAL 8013
NEW ZEALAND
Tel: +64 3 940 4900
Fax: +64 3 940 4901
Web: www.jacobs.com

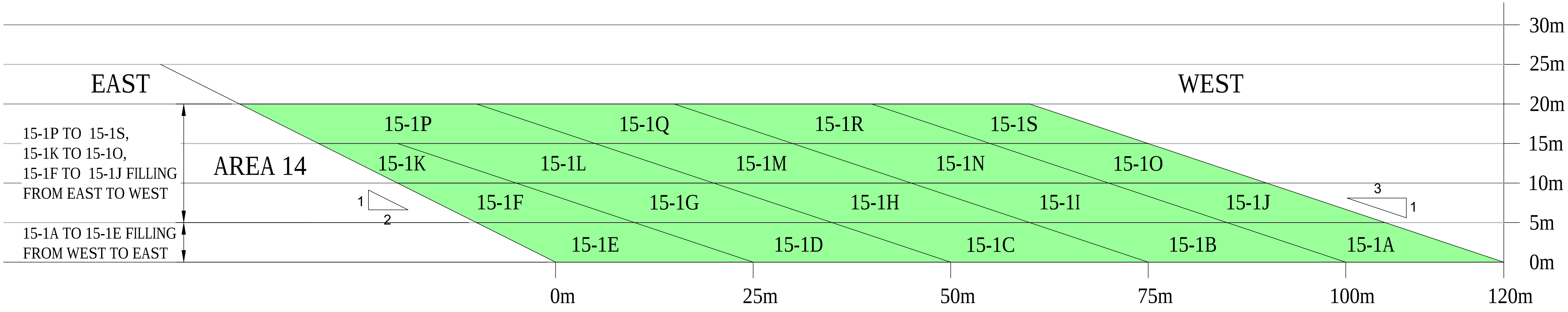
CLIENT: AB LIME LTD.
PROJECT: LANDFILL INVESTIGATION

DRAWN	DRAWING CHECK	REVIEWED	APPROVED
MH	KJ	WS	VP
DESIGNED	DESIGN REVIEW	DATE 02/09/2020	DATE 01/09/2020
KJ	CW		

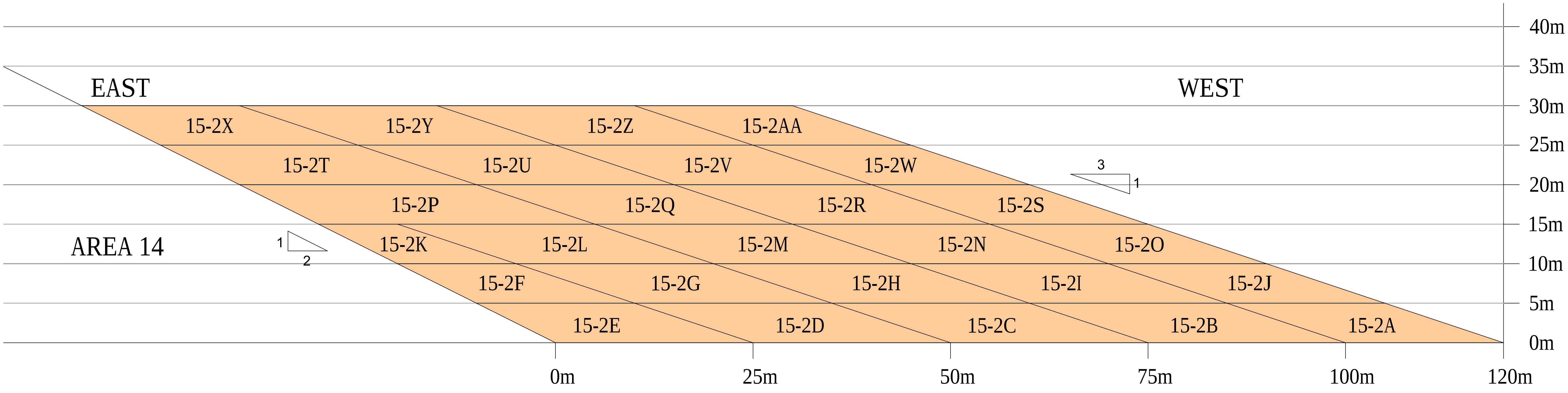
TITLE: AREA 15 FILLING PLAN ADJACENT TO AREA 11

SCALE	DRAWING No	REV
1:5 (A1)	IZ000400-OA-NG-DRG-0003	0

A1



PHASE 1 FILLING - AREA15



PHASE 2 FILLING - AREA15

PRELIMINARY ISSUE

REV	DATE	APP'D	REVISION
A	02/09/2020	VP	PRELIMINARY ISSUE

SCALES AT A1

AB LIME

Jacobs
Level 2, Wynn Williams Building
47 Hereford Street
CHRISTCHURCH CENTRAL 8013
NEW ZEALAND
Tel: +64 3 940 4900
Fax: +64 3 940 4901
Web: www.jacobs.com

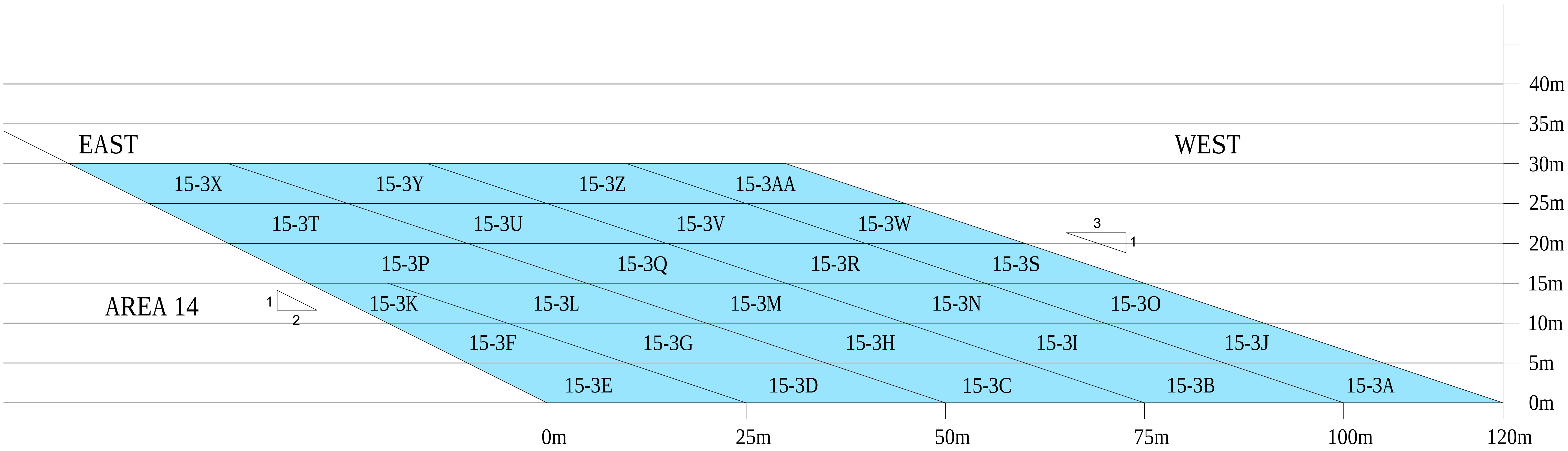
CLIENT: AB LIME LTD.
PROJECT: LANDFILL INVESTIGATION

DRAWN	DRAWING CHECK	REVIEWED	APPROVED
MH	KJ	WS	VP
DESIGNED: KJ	DESIGN REVIEW: CW	DATE 02/09/2020	DATE 02/09/2020

TITLE: AREA 15 FILLING PLAN
PHASE 1 & 2

SCALE	DRAWING No	REV
1:5 (A1)	IZ000400-OA-NG-DRG-0004	0

A1



PHASE 3 FILLING - AREA15

PRELIMINARY ISSUE

REV	DATE	APP'D	REVISION
A	02/09/2020	VP	PRELIMINARY ISSUE

SCALES AT A1

AB LIME

Jacobs

Level 2, Wynn Williams Building
47 Hereford Street
CHRISTCHURCH CENTRAL 8013
NEW ZEALAND
Tel: +64 3 940 4900
Fax: +64 3 940 4901
Web: www.jacobs.com

CLIENT: AB LIME LTD.
PROJECT: LANDFILL INVESTIGATION

DRAWN	DRAWING CHECK	REVIEWED	APPROVED
MH	KJ	WS	VP
DESIGNED	DESIGN REVIEW	DATE 02/09/2020	DATE 02/09/2020
KJ	CW		

TITLE: AREA 15 FILLING PLAN ADJACENT TO AREA 14

SCALE	DRAWING No	REV
1:5 (A1)	IZ000400-OA-NG-DRG-0005	0

A1

Appendix F. Area 13 Stability Memo

Memo

To	Leah Bateman, Fiona Smith	Date	9 July 2013
From	Tim Gillon	Project No	AE03541
Copy	Grant Murray, Charlie Watts, Matt Engel		
Subject	**AB Lime: Area 13 Embankment Stability Analysis**		

Leah,

Revised stability analysis of the Area 13 embankment was undertaken as per your request. AB Lime have recently indicated they are in position to construct a buttress (if required). This memo summarises the revised stability analysis and its implications for buttressing.

1.0 Background

1.1 2012 Geotechnical Assessment Report (GAR)

Previous stability results[1] indicated deep seated, circular embankment slope failures with safety factors below unity, under seismic conditions.

The GAR recommended:

1) topographic survey of the AB Lime site and the adjacent gully.
2) refine the stability analysis following completion of survey.
3) preliminary design of improvement works to enhance embankment stability.

1.2 Peer review of GAR

The URS peer review[2] of the GAR included the following statements:

"SKM have reported that excavation work in this previously constructed embankment indicated that a significant amount of lime sludge was discovered within the embankment structure. As a result, AB Lime has taken the decision to remove this embankment and replace it with structural fill. The previous stability report is therefore no longer relevant."
[Section 1, page 2]

"The designer needs to further address the external bund seismic stability in light of the geometry presented in the drawings and revised ground conditions. In, addition the global stability of the bund and any slope below should be checked by the designer and results provided to the peer reviewer."
[Section 5, page 4]

1.3 Developments at AB Lime landfill

During April 2012 an aerial survey was undertaken via drone aircraft. Drawing AE03541-ESG-DG-0002 (Figure 1 in Appendix A) includes contours from the aerial survey.

2.0 2013 stability analysis update

Subsections 2.1 to 2.4 describe the revised stability analysis, ascertained from Slide modelling.

2.1 New cross section alignment and embankment profile

The aerial survey contours indicated the embankment slope gradients are steeper than what had previously been analysed. Subsequently a new cross section alignment X-X' was selected, as shown on Figure 1.

Borelog data for BH02 represents the ground profile at the cross section location. The limestone depth was extrapolated from BH01 data.

---

[1] SKM. April 2012. *Area 13 Embankment Design – Geotechnical Assessment Report (reissue).*

[2] URS. December 2012. *AB Lime Landfill – Area 13 Design Peer Review Comments*.

2.2 Ground model

As part of the revised stability analysis the ground model was reviewed. Consequently:

- alluvium/colluvium was remodelled as a 2m deep bed, underlying the southern portion of the embankment.
- depth of fill was increased by 3 metres.

The justification for revising the ground model was the presence of organic material, as per the BH01 borelog.

Groundwater records from the BH007, BH008 and BH011 borelogs were used to develop the regional groundwater profile. Figure 2 (Appendix A) is a Google Earth Professional aerial photo of SKM's available borehole data. Appendix B contains relevant borehole records.

2.3 Other notes regarding the 2013 stability analysis

The material properties were consistent with the properties in the GAR report.

The GAR report highlights:

- peak ground acceleration is 0.35g.
- horizontal seismic coefficient (K_h) is 0.23g.

0.23g was applied for the pseudo static stability analysis of the embankment. 0.35g was used within the Makdisi/Seed check

All safety factors for analysis of the southeast slope were obtained using the Simplified Bishop method of analysis. Deep seated, circular slope failure planes which encroach the embankment crest centreline were obtained. These failure planes were re-analysed for the pseudo-static loading scenario.

2.4 Results

Outputs of the revised slide models are attached to this memo in Appendix C and are summarised in Table 1. The results from the 2012 GAR report are re-presented in Table 2, for comparison.

- **Table 1: Safety factor results from July 2013 stability analysis**

Slope analysed	Southeast slope	
Loading scenario	Static	Seismic
Present embankment	1.77 (shallow)	1.35 (deep)
Embankment with adjacent Area 13 infill	2.00 (deep)	1.30 (deep)

- **Table 2: Safety factor results from 2012 GAR stability analysis**

Slope analysed	Southeast slope	
Loading scenario	Static	Seismic
Present embankment	1.13 (shallow)	0.85 (deep)
Embankment with adjacent Area 13 infill	1.71 (deep)	0.97 (deep)

3.0 Revised Makdisi / Seed analysis

The Makdisi / Seed analysis was updated and revised calculations are included in Appendix D. Slide was used to determine the critical yield acceleration k_y that produces a safety factor of 1. The critical yield acceleration (= 0.39) is greater than the design PGA = 0.35.

Under normal circumstances this would suggest that the ultimate limit state earthquake event will not induce any deformation. However, we do note that some technical papers discuss the relationship between embankment crest and base acceleration and suggest including an allowance for some amplification effects for large embankments / dams.

For the purposes of our analysis we have considered a conservative approach and if we assume the crest acceleration is 3.5 times higher than the base acceleration we still only estimate a horizontal displacement of 10mm using Makdisi / Seed procedure.

4.0 Discussion of stability and Makdisi / Seed analysis

Safety factors increased for both the static and pseudo-static (seismic) scenarios. These increases are due to two revisions comprising:

- the reduction in the steepness and depth of the gully to the southeast of the embankment.
- the selection appropriate / realistic slope failure mechanisms for pseudo-static analysis.

The impact on the embankment from a 10mm horizontal displacement would be negligible. It is expected the landfill liner and the proposed anchor trenches would be undamaged. Minor surface repairs or regrading may be necessary near the embankment crest centreline and/or on part(s) of the southeast slope. However these repairs could be undertaken without compromising the embankment, landfill or the liner.

It is noted the results presented in this memo rely on the accuracy of the aerial survey results. It is unlikely that the margin of error in the interpretation of ground contours from the aerial survey will have a significant impact on the stability assessment but it would be prudent to correlate the aerial survey with some ground proving topographical surveys in the area.

5.0 Conclusions and recommendations

- The embankment model has been revised to reflect current embankment conditions.
- The embankment surface profile has been revised following aerial survey results.
- Material parameters are unchanged from previous analysis. Seismic inputs are unchanged from previous analysis.
- The assumed ground conditions and underlying material are based upon available, interpolated borehole data.
- Safety factors for the embankment are >1.0 for pseudo static and >1.5 for static scenarios respectively
- AB Lime have indicated material is available for buttressing. However safety factors indicate the embankment is stable under static and seismic load conditions.
- The estimated 10mm horizontal displacement is considered an acceptable deformation. The effect on the liner, anchor trench and GCL layers would be inconsequential. Minor, surface repairs may be required on the embankment however these could be undertaken without compromising landfill operations.

We trust this memo is satisfactory however please do not hesitate to contact should you need any further clarification or information.

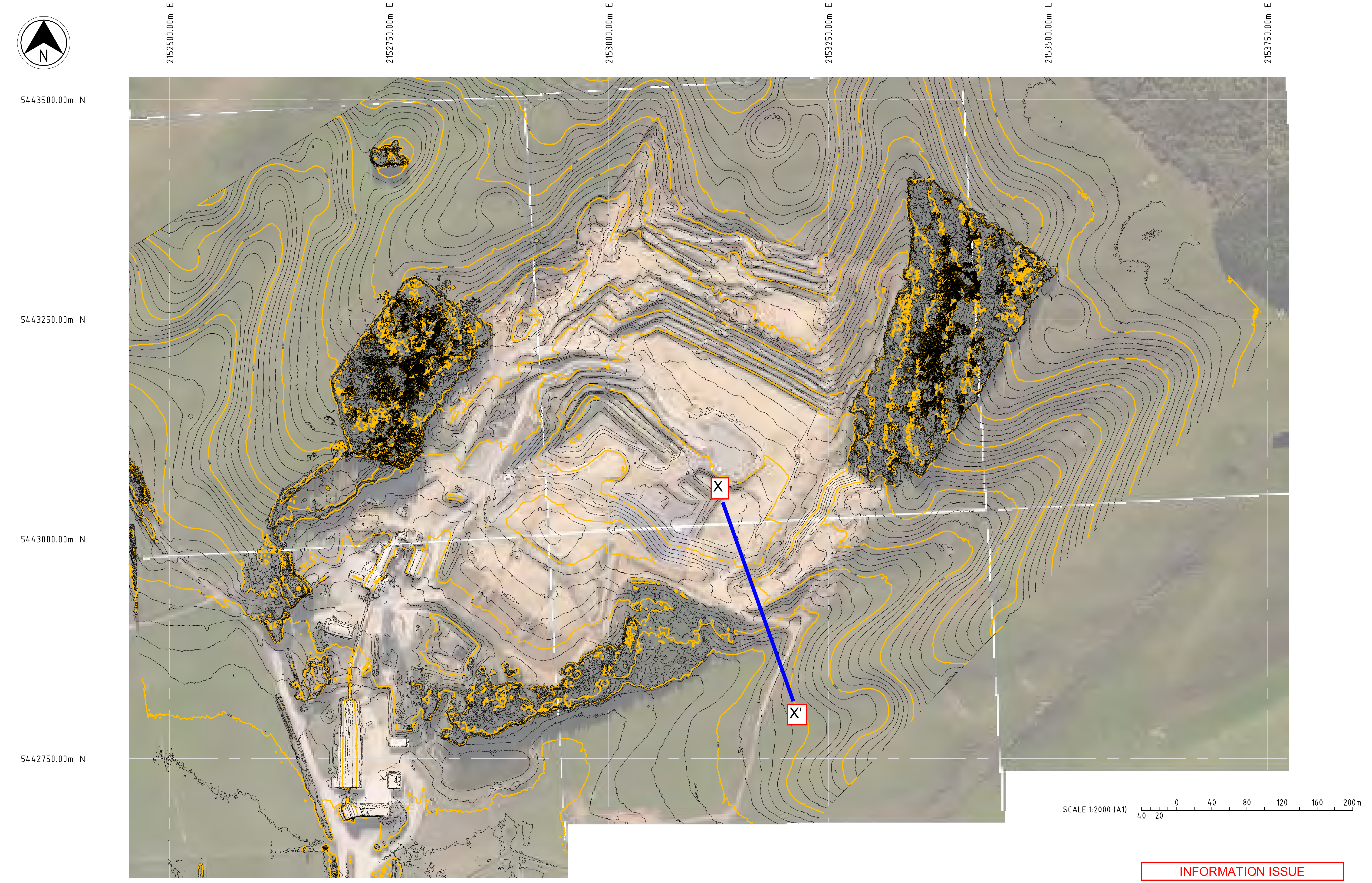
Yours sincerely

Tim Gillon
Geotechnical Engineer
Phone: 09 928 5815
Fax: 09 928 5501
E-mail: tgillon@globalskm.com

Attachments

1) Appendix A – Figures 1 and 2
2) Appendix B – Borehole records
3) Appendix C – Slide models as shown in Figures C1 to C5
4) Appendix D – Makdisi Seed analysis

Figure 1



INFORMATION ISSUE

REV	DATE	DRAWN	REV'D	APP'D	REVISION
A	06/06/13	RM			ISSUED FOR INFORMATION

DRAWING NUMBER	REFERENCE DRAWING TITLE

AB LIME

SKM

Sinclair Knight Merz
142 Sherborne Street
Saint Albans
CHRISTCHURCH 8014
NEW ZEALAND

Tel: +64 3 940 4900
Fax: +64 3 940 4901
Web: www.globalskm.com

CLIENT: AB LIME LTD

PROJECT: AB LIME LANDFILL
SOUTHLAND

DRAWN	DRAWING CHECK	REVIEWED	APPROVED
RM			
DESIGNED	DESIGN REVIEW	DATE	DATE
TG			

TITLE: KING'S BEND SITE
CONTOUR MAP

SCALE	DRAWING No.	REV
1:2000 (A1)	AE03541-ESG-DG-0002	A

A1

DATE: 6/06/2013 3:13:04 PM LOGIN NAME: MARTIN, MERCI (SKM)
LOCATION: I:\AENVA\Projects\AE03541-ESG-DG-0001.dwg

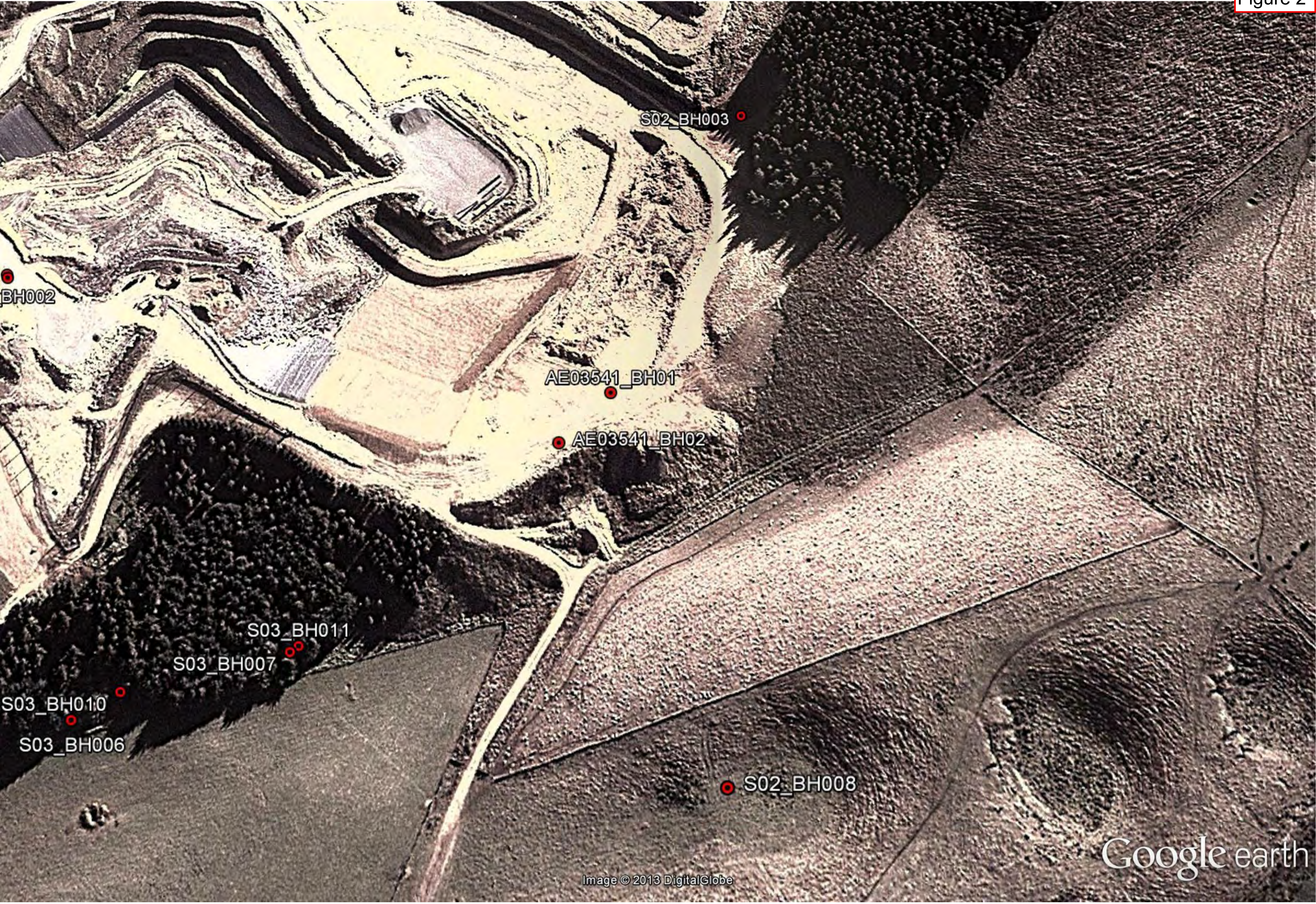

S02_BH003
BH002
AE03541_BH01
AE03541_BH02
S03_BH011
S03_BH007
S03_BH010
S03_BH006
S02_BH008
Image © 2013 DigitalGlobe
Google earth

Figure 2

SKM

Draft Log of Investigation

Borehole

Project: **AB Lime - Area 12 Design**

Location: **Upslope from BH02** | Project No: **AE03541**

Hole ID: **BH01**

Client: **AB Lime**

Date: **1/11/2011**

R.L. (m): 110.0, 109.0, 108.0, 107.0, 106.0, 105.0, 104.0

Depth (m): 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0

Drilling Method (Shift Details / Casing Diameter (mm))	TCR (%) (SCR (%))	RQD	In-Situ Testing	Sampling
HQ3	100	N/A		
SPT	100	N/A	I_{vp}34/I_{vr}23 ^{c} SPT$_s$=2,10,11 N=21	
HQ3	67	N/A		
SPT	100	N/A	SPT$_s$=17,18,11 N=29	
HQ3	62	N/A		
SPT	100	N/A	SPT$_s$=7,10,7 N=17	
HQ3	95	N/A		
SPT	100	N/A	SPT$_s$=2,3,3 N=6	

Description of Strata

Slightly weathered, brownish white LIMESTONE; weak. Core recovered as cobbles. [FILL]

Coarse sandy SILT with trace of gravel; light brown. Firm, moist, low to medium plasticity. Gravel is coarse, uniformly graded, subangular limestone. [FILL]

0.75m: Grades to fine sandy SILT with trace of medium, limestone gravel; greyish brown.

CLAY with trace of gravel; brown. Soft, moist, highly plastic. Gravel is medium, uniformly graded, subangular limestone. [FILL]

2.20m: Grades to gravelly CLAY. Very soft, wet.

No core recovery.

Slightly weathered, brownish white LIMESTONE; weak, closely spaced joints. Core recovered as cobbles. [FILL]

No core recovery.

SILT; brown. Very soft, wet, low plasticity. [FILL]

Slightly weathered, brownish white LIMESTONE; weak, closely spaced joints. Core recovered as cobbles. [FILL]

Silty coarse SAND with minor gravel; light brown. Medium dense, moist, non plastic. Gravel is coarse, uniformly graded, subangular limestone. [FILL]

Silty CLAY with trace of gravel; greyish brown. Soft, moist, moderately plastic. Gravel is fine to coarse, well graded, subangular limestone. [FILL]

Gravelly SILT; light brown. Soft, wet, moderately plastic. Gravel is fine to coarse, well graded, subangular limestone. [FILL]

Comments | Backfill / Installation

Started: 1/11/2011
Finished: 1/11/2011
Driller: Perry
Plant: Morooka MST800
Logged: TG
Checked: RGK

Groundwater Observations

No.	Struck (m)	Date	Observations	Standing (m)
1	9.5	2/11/2011	> 12 hours post drilling	

Remarks

Co-ordinates and ground elevation captured using Garmin eTrex GPS. Co-ordinates are in NZTM format. Shear vane used was calibrated (serial # 218) and owned by Perry Drilling. Some shear vane readings unavailable due to core material or stability in barrel.

Co-ordinates:
4881023.72mN
1243396.18mE
Elevation: 110.34mRL
Inclination: -90°

See key sheet for an explanation of symbols and abbreviations. Material descriptions as per NZGS Guidelines - December 2005.

Draft Log of Investigation

Borehole

Project: **AB Lime - Area 12 Design**

Location: **Upslope from BH02** Project No: **AE03541**

Hole ID: **BH01**

Client: **AB Lime**

Date: **1/11/2011**

R.L. (m)	Depth (m)	Drilling Method	TCR (%) (SCR (%))	RQD	In-Situ Testing
103.0		HQ3	100	N/A	
		SPT	100	N/A	SPT_s=8,5,7 N=12
102.0	8.0	HQ3	81	N/A	
101.0	9.0	SPT	100	N/A	I_{vp}5/I_{vr}0 c SPT_s=10,5,7 N=12
	10.0	HQ3	81	N/A	
100.0		SPT	100	N/A	I_{vp}19/I_{vr}0 c SPT_s=3,6,4 N=10
99.0	11.0	HQ3	100	N/A	
98.0	12.0	SPT	100	N/A	I_{vp}56/I_{vr}43 c SPT_s=6,6,7 N=13
97.0	13.0	HQ3	86	N/A	
	14.0	SPT	100	N/A	SPT_s=0,3,3 N=6

GroundWater: 1 (at approx. 9.5 m)

Description of Strata

Slightly weathered, light brown LIMESTONE; weak. Core recovered as cobbles. [FILL]

Gravelly SILT; light brown. Soft, wet, moderate plasticity. Gravel is fine to coarse, well graded, subangular limestone. [FILL]

Silty GRAVEL; light brown. Wet, medium dense. Gravel is subangular, well graded, limestone cobbles. [FILL]

Gravelly SILT; light brown. Very soft, wet, low plasticity. Gravel is fine to medium, well graded, subangular limestone. [FILL]

No core recovery.

Gravelly SILT; light brown. Very soft, moist, low plasticity. Gravel is fine to medium, well graded, subangular limestone. [FILL]

No core recovery.

Gravelly SILT; light brown. Soft, moist, low plasticity. Gravel is fine to medium, subangular limestone. [FILL]

9.95m to 10.30m: Core is wet.

Clayey SILT with trace of gravel; greyish brown. Stiff, moist, moderately plastic. Gravel is coarse, uniformly graded, subangular limestone. [ALLUVIAL AND COLLUVIAL DEPOSITS]

No core recovery.

Clayey SILT with trace of gravel; greyish brown. Stiff, moist, moderately plastic. Gravel is coarse, uniformly graded, subangular limestone. [ALLUVIAL AND COLLUVIAL DEPOSITS]

12.85m to 13.50m: Core is wet.

Started: 1/11/2011

Finished: 1/11/2011

Driller: Perry

Plant: Morooka MST800

Logged: TG

Checked: RGK

Groundwater Observations

No.	Struck (m)	Date	Observations	Standing (m)
1	9.5	2/11/2011	> 12 hours post drilling	

Remarks

Co-ordinates and ground elevation captured using Garmin eTrex GPS. Co-ordinates are in NZTM format. Shear vane used was calibrated (serial # 218) and owned by Perry Drilling. Some shear vane readings unavailable due to core material or stability in barrel.

Co-ordinates:
4881023.72mN
1243396.18mE

Elevation: 110.34mRL

Inclination: -90°

See key sheet for an explanation of symbols and abbreviations. Material descriptions as per NZGS Guidelines - December 2005.

Draft Log of Investigation

Project: **AB Lime - Area 12 Design**	**Borehole**
Location: **Upslope from BH02** Project No: **AE03541**	Hole ID: **BH01**
Client: **AB Lime**	Date: **1/11/2011**

R.L. (m): 96.0, 95.0, 94.0, 93.0, 92.0, 91.0
Depth (m): 15.0, 16.0, 17.0, 18.0, 19.0

Drilling Method	TCR (%) (SCR (%))	RQD	In-Situ Testing
HQ3	100	N/A	
SPT	100	N/A	SPT_s=3,7,10 N=17
HQ3	100	N/A	
SPT	100	N/A	SPT_s=2,4,4 N=8
HQ3	100	N/A	
HQ3	33	100	
HQ3	100	100	
SPT	100	N/A	SPT_s=50 N=50/50
HQ3	100	59	

Description of Strata

Silty CLAY with trace of gravel; brownish grey. Firm, moist, highly plastic. Gravel is coarse, uniformly graded, subangular limestone. [ALLUVIAL AND COLLUVIAL DEPOSITS]

14.95m to 15.00m: Bed of coarse LIMESTONE gravel.

15.80m to 15.81m: Organic material (rootlets) present.
15.90m to 15.91m: Organic silt present; black. Fibrous, soft.
15.95m to 15.96m: Organic material (rootlets) present.

16.45m to 16.50m: Bed of coarse sandy SILT.

16.95m to 17.20m: Bed of CLAY.

Slightly weathered, brownish white LIMESTONE; weak, closely spaced joints. [FOREST HILL FORMATION]
17.30m: Moderately inclined joint (20°), rough, undulating.
17.39m: Sub-horizontal joint (5°), rough, undulating.

No core recovery.

Slightly weathered, brownish white LIMESTONE; weak, closely spaced joints. [FOREST HILL FORMATION]
17.80m: Sub-horizontal joint (5°), rough, undulating.
18.05m to 18.20m: Core recovered as cobbles.
18.20m to 18.45m: Joints very closely spaced (every 50mm), sub-horizontally (5°) inclined, rough, undulating, silt covered.
18.45m to 19.00m: Joints closely spaced (every 100mm), sub-horizontally (5°) inclined, rough, undulating.

19.00m to 19.20m: Core recovered as cobbles.

19.20m to 19.50m: Joints closely spaced (every 100mm), sub-horizontally (5°) inclined, rough, undulating.

BH01 terminated at 19.50m. Target Depth

Started: 1/11/2011
Finished: 1/11/2011
Driller: Perry
Plant: Morooka MST800
Logged: TG
Checked: RGK

Groundwater Observations

No.	Struck (m)	Date	Observations	Standing (m)
1	9.5	2/11/2011	> 12 hours post drilling	

Remarks
Co-ordinates and ground elevation captured using Garmin eTrex GPS. Co-ordinates are in NZTM format. Shear vane used was calibrated (serial # 218) and owned by Perry Drilling. Some shear vane readings unavailable due to core material or stability in barrel.

Co-ordinates:
4881023.72mN
1243396.18mE
Elevation: 110.34mRL
Inclination: -90°

Data Template: DATA TEMPLATE.GDT Output Form: COMPILATION - NO DEFECTS Project File Name: AE03541 LOGS.GPJ 12/12/11

Version 1.6 28/08/2006 - S.Humphreys

See key sheet for an explanation of symbols and abbreviations. Material descriptions as per NZGS Guidelines - December 2005.

Draft Log of Investigation

Project: AB Lime - Area 12 Design

Borehole

Location: Downslope from BH01 | **Project No:** AE03541

Hole ID: BH02

Client: AB Lime

Date: 2/11/2011

R.L. (m)	Depth (m)	Shift Details / Drilling Method / Casing Diameter (mm)	TCR (%) (SCR (%))	RQD	In-Situ Testing	Sampling	Geology Legend	GroundWater
108.0		HQ3	100	N/A				
107.0	1.0							
		SPT	100	N/A	SPT_s=1,2,12 N=14			
106.0	2.0	HQ3	100	N/A				
105.0	3.0	SPT	33	N/A	SPT_s=6,6,3 N=9			
104.0	4.0	HQ3	76	N/A				
		SPT	44	N/A	SPT_s=3,3,6 N=9			
103.0	5.0	HQ3	81	N/A				1 ▽
102.0	6.0	SPT	89	N/A	SPT_s=1,2,4 N=6			
	7.0							

Description of Strata

Gravelly SILT; light brown. Soft, wet, low plasticity. Gravel is coarse, uniformly graded, subangular limestone. [FILL]

Slightly weathered, light brown LIMESTONE; weak. Core recovered as cobbles. [FILL]

SILT with minor gravel; light brown. Soft, wet, moderately plastic. Gravel is coarse, uniformly graded, subangular limestone. [FILL]

Gravelly SILT; light brown. Soft, wet, moderately plastic. Gravel consists of cobbles, uniformly graded, subangular limestone. [FILL]

2.40m to 2.50m: Core sample is very soft, saturated.

3.75m to 3.85m: Core sample is very soft, saturated.

No core recovery.

Clayey SILT with minor gravel; brown. Soft, wet, moderately plastic. Gravel is coarse, uniformly graded, subangular limestone. [FILL]

No core recovery.

Gravelly SILT; greyish brown. Soft, wet, low plasticity. Gravel is fine to coarse, well graded, subangular limestone. [FILL]

Comments

Backfill / Installation

Started: 2/11/2011

Finished: 2/11/2011

Driller: Perry

Plant: Morooka MST800

Logged: TG

Checked: RGK

Groundwater Observations

No.	Struck (m)	Date	Observations	Standing (m)
1	5.6	2/11/2011	> 40 mins post drilling	

Remarks

Co-ordinates and ground elevation captured using Garmin eTrex GPS. Co-ordinates are in NZTM format. Shear vane used was calibrated (serial # 218) and owned by Perry Drilling. Some shear vane readings unavailable due to core material or stability in barrel.

Co-ordinates:
4880998.30mN
1243374.41mE

Elevation: 108.20mRL

Inclination: -90°

See key sheet for an explanation of symbols and abbreviations. Material descriptions as per NZGS Guidelines - December 2005.

SKM

Draft Log of Investigation

Project: AB Lime - Area 12 Design

Borehole

Location: Downslope from BH01 | **Project No:** AE03541

Hole ID: BH02

Client: AB Lime

Date: 2/11/2011

R.L. (m) markers: 101.0, 100.0, 99.0, 98.0, 97.0, 96.0, 95.0

Depth (m) markers: 8.0, 9.0, 10.0, 11.0, 12.0, 13.0, 14.0

Drilling Method (Shift Details, Casing Diameter (mm))	TCR (%) (SCR (%))	RQD	In-Situ Testing
HQ3	71	N/A	
SPT	100	N/A	SPT_s=2,3,4 N=7
HQ3	100	N/A	I_{vp}90/I_{vr}37 c
SPT	11	N/A	SPT_s=6,6,6 N=12
HQ3	100	N/A	
SPT	67	N/A	SPT_s=8,8,9 N=17
HQ3	100	N/A	
HQ3	0	N/A	
HQ3	100	0	
SPT	44	N/A	SPT_s=8,25,16 N=41
HQ3	48	0	
SPT	33	N/A	SPT_s=60 N=60/150

Description of Strata

Description of Strata
No core recovery.
Silty CLAY with minor gravel. Soft, moist, moderately plastic. Gravel is coarse, uniformly graded, subangular limestone. [FILL] *7.45m: 10mm sub-horizontal bed of black organic material (decomposed wood fragments).* *7.95m: 10mm sub-horizontal bed of black organic material (decomposed wood fragments).*
Gravelly SILT; brown. Stiff, moderately plastic, wet. Gravel is coarse, uniformly graded, subangular limestone. [FILL]
Silty CLAY with trace of gravel; greyish brown. Soft, wet, moderately to highly plastic. Gravel is coarse, uniformly graded, subangular limestone. [FILL] *10.95m to 11.00m: Core sample is very soft, saturated.* *11.00m: Grades to brown CLAY; brown. Wet, soft, moderately to highly plastic.* *11.10m to 11.20m: Core sample is very soft, saturated.*
No core recovery.
Core recovered as slightly weathered, light brownish white LIMESTONE cobbles; weak. Very closely spaced discontinuities. [FILL]
No core recovery.
Core recovered as slightly weathered, light brownish white LIMESTONE cobbles; weak. Very closely spaced discontinuities. [FILL] *13.05m to 13.35m: Bed of gravelly SILT; brown. Soft, wet, moderately plastic. Gravel is medium, uniformly graded, subangular limestone.*

Columns also printed: Sampling, Geology Legend, GroundWater, Comments, Backfill / Installation

Started: 2/11/2011

Finished: 2/11/2011

Driller: Perry

Plant: Morooka MST800

Logged: TG

Checked: RGK

Groundwater Observations

No.	Struck (m)	Date	Observations	Standing (m)
1	5.6	2/11/2011	> 40 mins post drilling	

Remarks

Co-ordinates and ground elevation captured using Garmin eTrex GPS. Co-ordinates are in NZTM format. Shear vane used was calibrated (serial # 218) and owned by Perry Drilling. Some shear vane readings unavailable due to core material or stability in barrel.

Co-ordinates:
4880998.30mN
1243374.41mE
Elevation: 108.20mRL
Inclination: -90°

See key sheet for an explanation of symbols and abbreviations. Material descriptions as per NZGS Guidelines - December 2005.

Draft Log of Investigation

SKM

Project: **AB Lime - Area 12 Design** | **Borehole**

Location: **Downslope from BH01** Project No: **AE03541** | Hole ID: **BH02**

Client: **AB Lime** | Date: **2/11/2011**

R.L. (m) scale: 94.0, 93.0, 92.0, 91.0, 90.0, 89.0

Depth (m) scale: 15.0, 16.0, 17.0, 18.0, 19.0

Drilling Method	TCR (%) (SCR (%))	RQD	In-Situ Testing
HQ3	52	0	
SPT	11	N/A	SPT$_s$=5,7,3 N=10
HQ3	76	N/A	
SPT	78	N/A	SPT$_s$=3,5,9 N=14
HQ3	86	N/A	
SPT	0	N/A	SPT$_s$=3,5,4 N=9
HQ3	100	N/A	
SPT	0	N/A	SPT$_s$=5,7,5 N=12

Description of Strata

No core recovery.

Core recovered as slightly weathered, light brownish white LIMESTONE cobbles; weak. Very closely spaced discontinuities. [FILL]

14.80m to 14.90m: Bed of gravelly SILT; greyish brown. Soft, wet, low plasticity. Gravel is fine, uniformly graded, subangular limestone.

Clayey SILT with trace of gravel; brownish grey. Firm, moist, moderately plastic. Gravel consists of cobbles, uniformly graded, subangular limestone. [ALLUVIAL AND COLLUVIAL DEPOSITS]

16.40m to 16.50m: Bed of SILT; brownish grey. Firm, moist, moderately plastic.

17.15m to 17.25m: Bed of organic SILT; black. Soft, moist, moderately plastic.

No core recovery.

BH02 terminated at 19.95m. Target Depth

Started: 2/11/2011
Finished: 2/11/2011
Driller: Perry
Plant: Morooka MST800
Logged: TG
Checked: RGK

Groundwater Observations

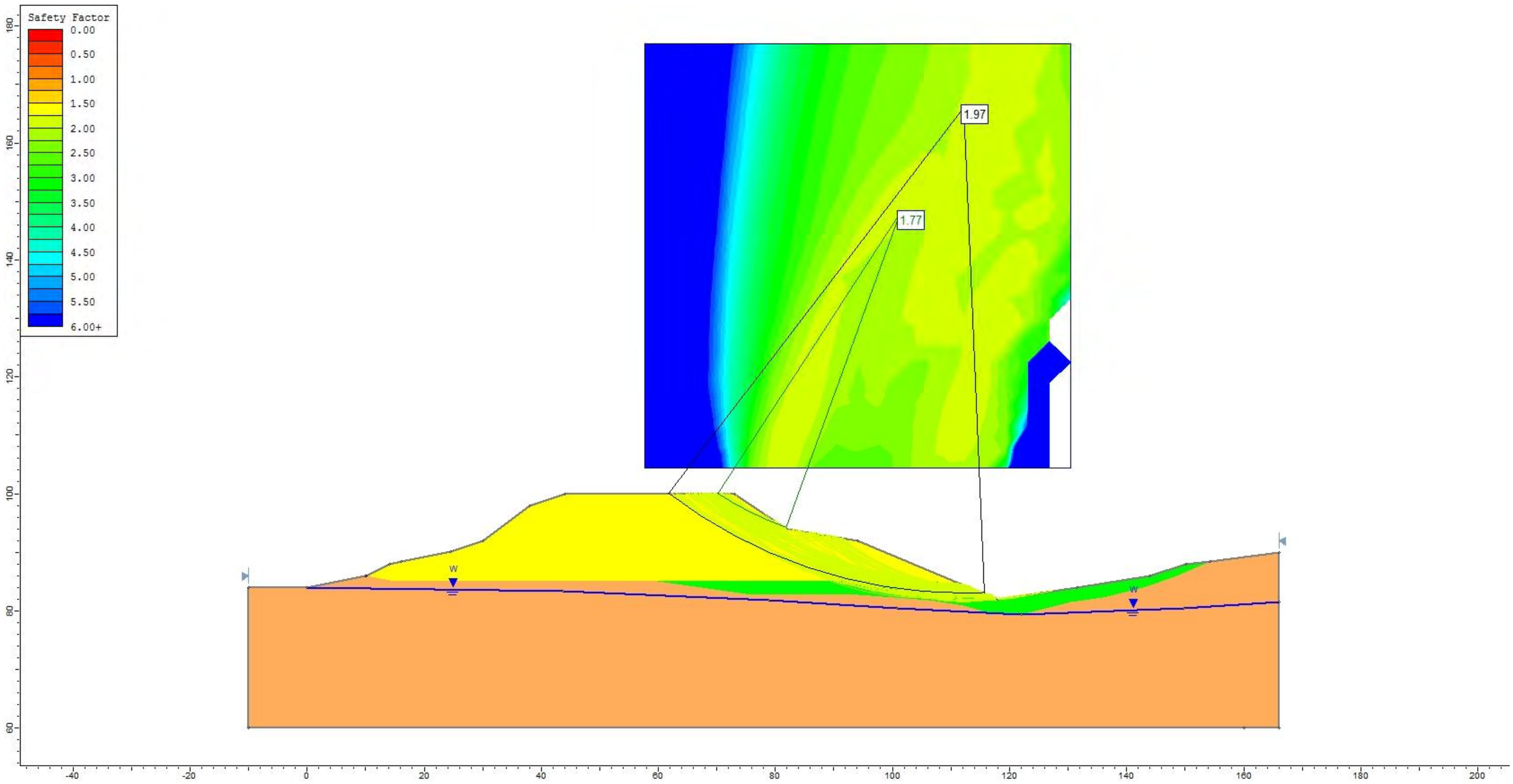
No.	Struck (m)	Date	Observations	Standing (m)
1	5.6	2/11/2011	> 40 mins post drilling	

Remarks
Co-ordinates and ground elevation captured using Garmin eTrex GPS. Co-ordinates are in NZTM format. Shear vane used was calibrated (serial # 218) and owned by Perry Drilling. Some shear vane readings unavailable due to core material or stability in barrel.

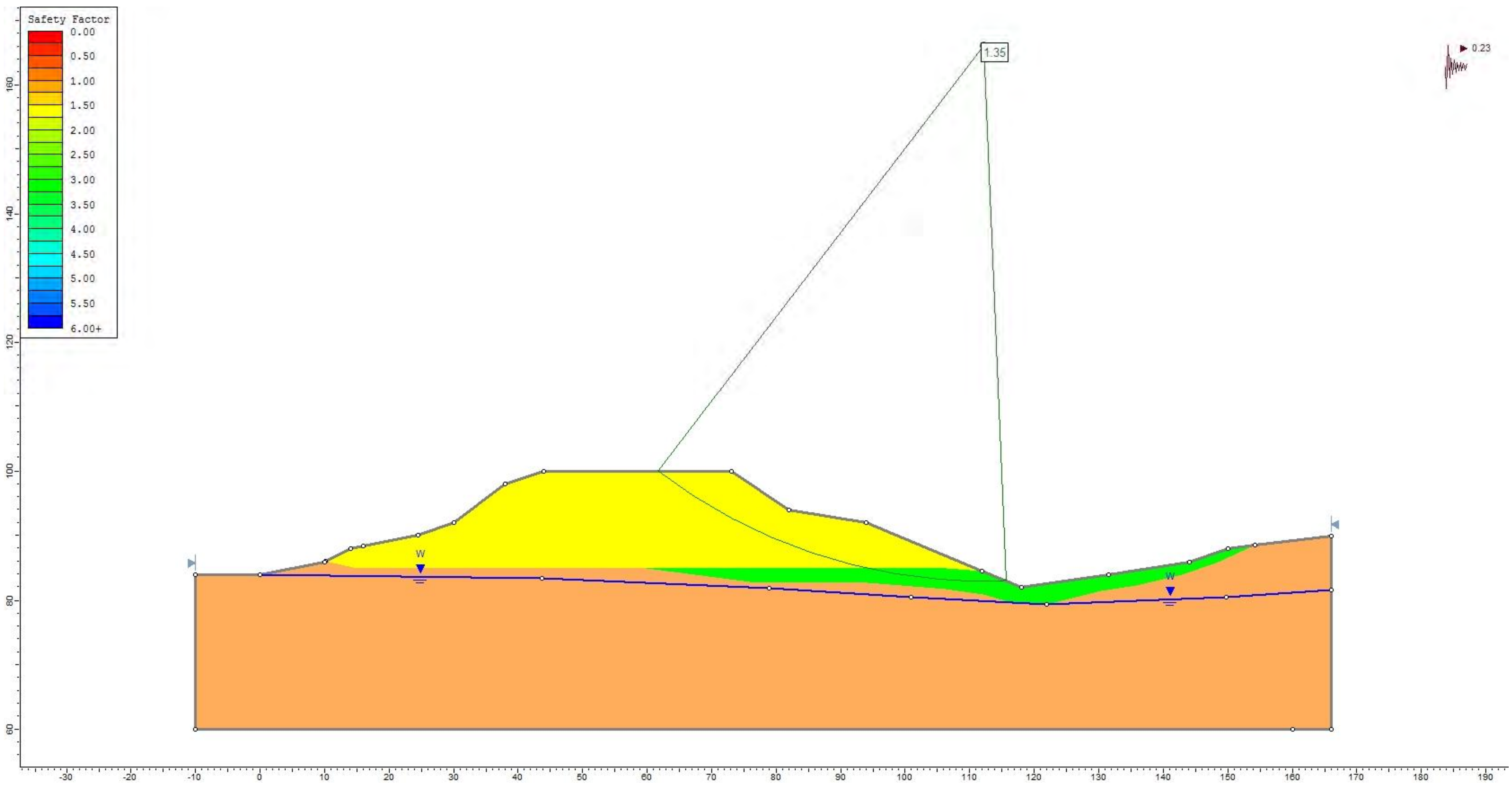
Co-ordinates:
4880998.30mN
1243374.41mE
Elevation: 108.20mRL
Inclination: -90°

See key sheet for an explanation of symbols and abbreviations. Material descriptions as per NZGS Guidelines - December 2005.

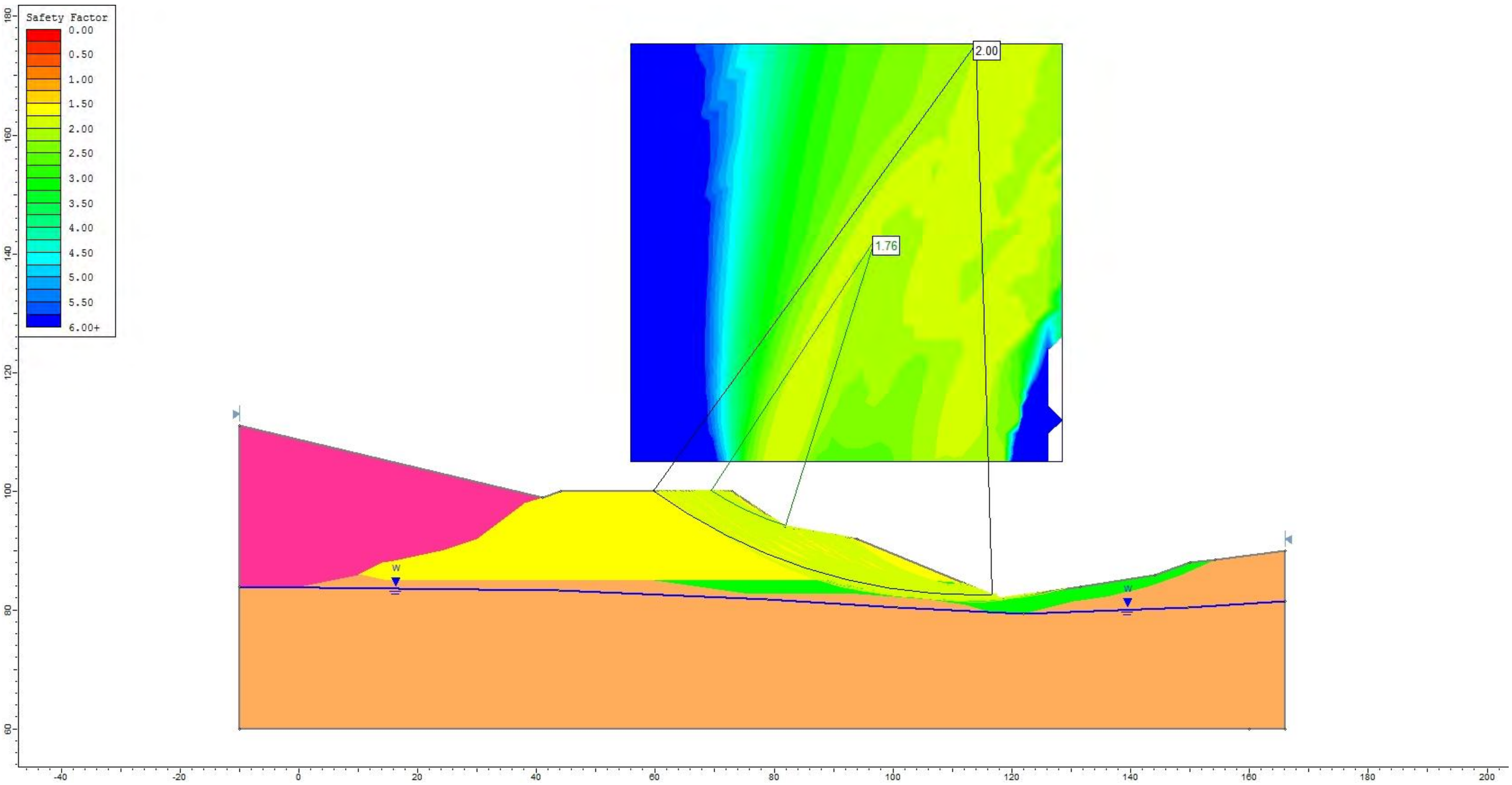
▪ **Figure C1: Static analysis of the Area 13 Embankment southeast slope.**



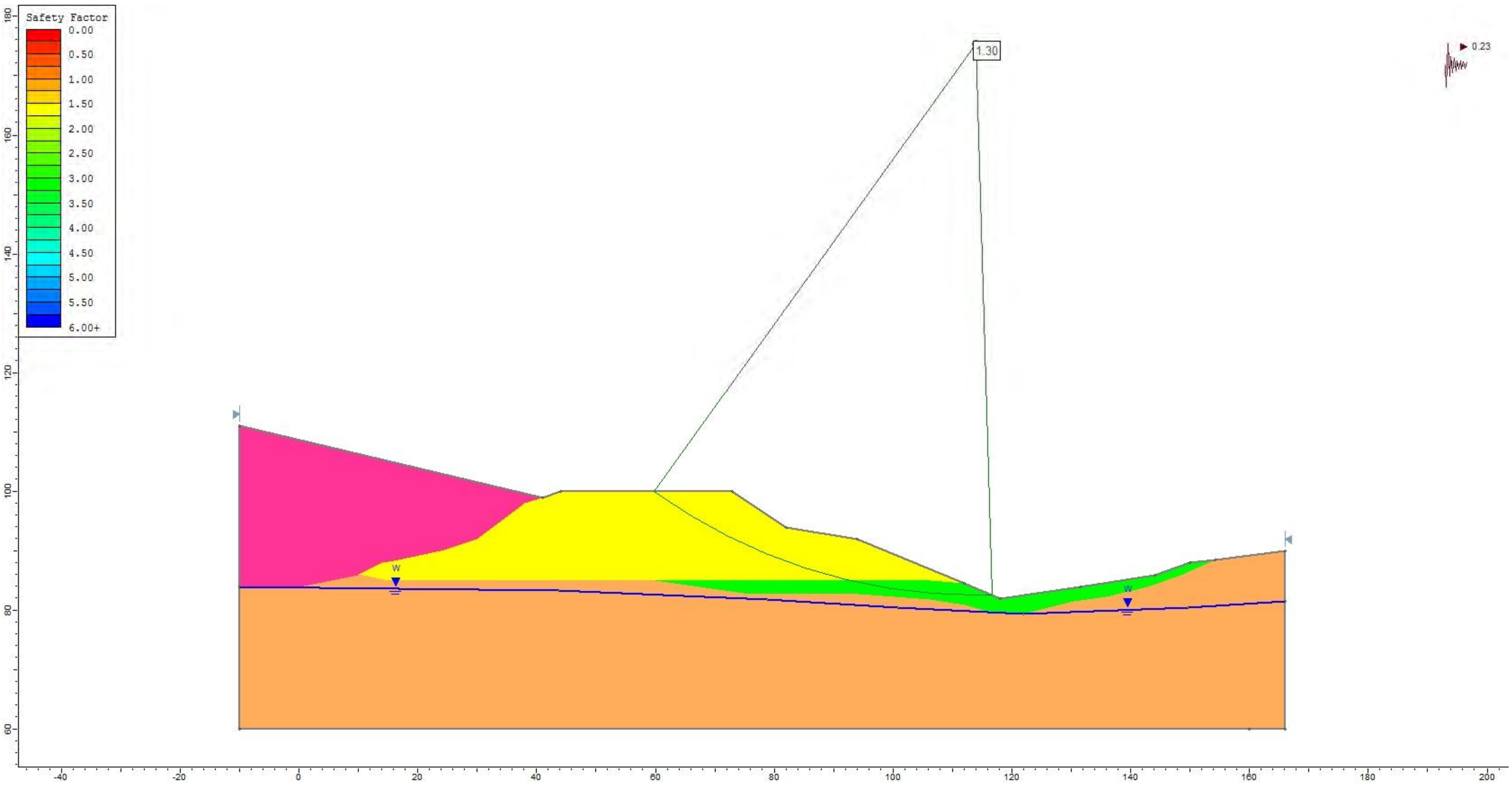
▪ **Figure C2: Seismic analysis of the Area 13 Embankment southeast slope.**



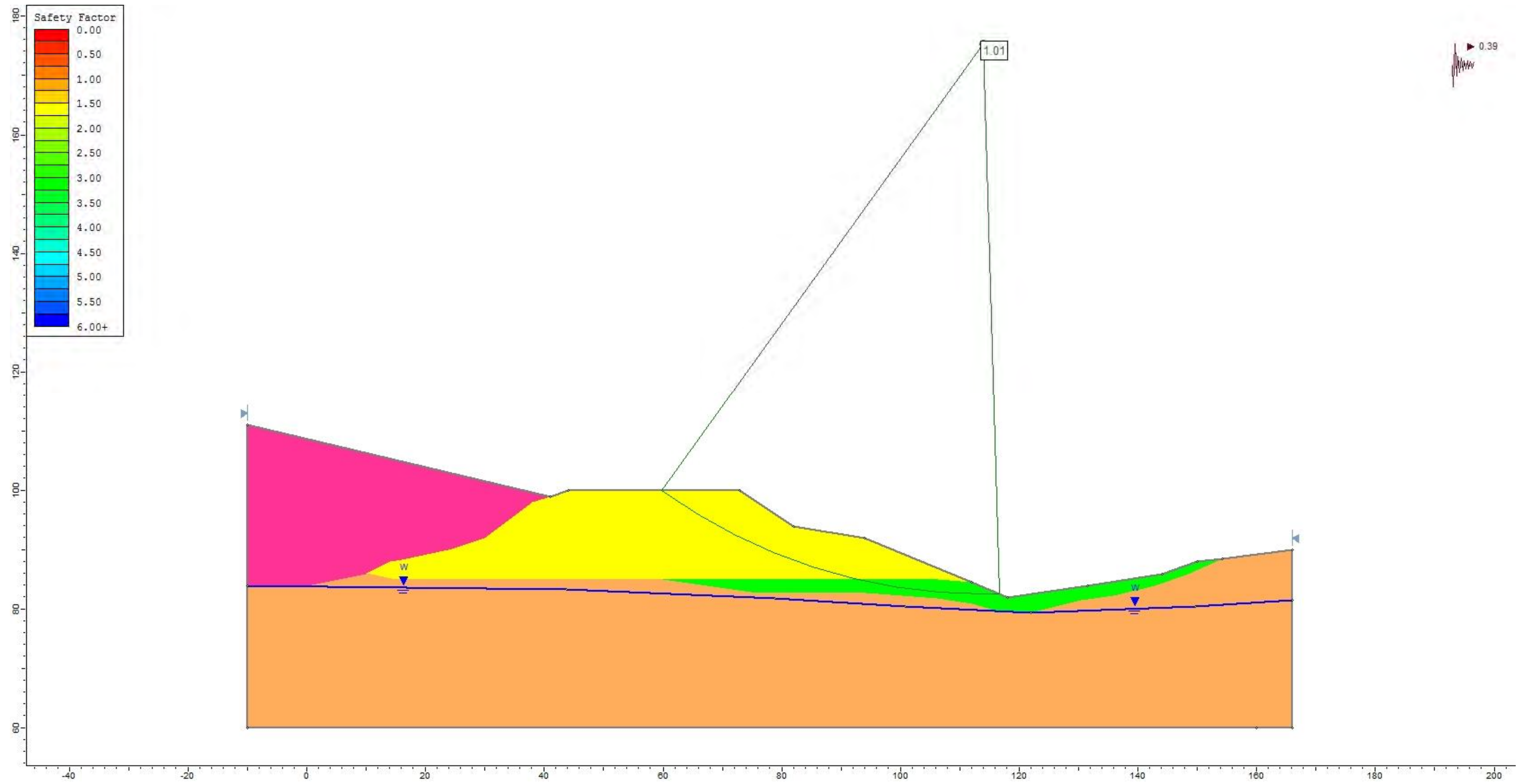
▪ **Figure C3: Static analysis of the Area 13 Embankment southeast slope with waste.**



▪ **Figure C4: Seismic analysis of the Area 13 Embankment southeast slope with waste.**



▪ **Figure C5: Makdisi analysis of the Area 13 Embankment southeast slope with waste.**



SKM

Job No. AE03541.11

Calc. Series

Client AB Lime

Page 1

Job Name Cell 13 Embankment Design - RevB

By T Gillon

Calcs Title Displacement due to seismic effect

Date 5/7/2013

Aim: To calculate permanent displacement of Area 13 embankment due to seismic loading

▸ Reference: "Geotechnical Engineering of Dams" 2005 (R Fell et al) subsection 12.6.3.4 details basic steps of Makdisi/Seed analysis procedure. Attached as |Appendix A|

Step 1/ Determine y/h ratio where: y = depth to base of sliding mass

h = embankment height

Failure is through the base of the alluvium/colluvium layer. From slide analysis the failure circle skims the top of the limestone. Essentially y=h from slide figure in |Appendix C|.

Step 2/ Determine the yield acceleration (k_y) for the potential sliding mass.

Doing back analysis on Slide I adjusted the seismic loading that would produce a deep seated failure with safety factor of unity.

$k_y = 0.39g$

Step 3/ Determine crest acceleration $\ddot{u}_{max}$ & period of the embankment T_o.

The site specific pga was previously calculated to be 0.35g. This will represent the PGA at the embankment base.

Makdisi & Seed proposed the relationship $T_o = 2.62 * H$ whereby: T_o = natural embankment period
H = dam/embankment height
V_s = approximate value of shear wave velocity

Refer |Appendix B|

Let $H = (106-87)$ metres $* 3.2808$
$= 62.34$ feet   convert metres to feet

From Appendix B use $V_s = 700$ feet/sec

$\therefore T_0 = (2.62 * 62.34)/700 = 0.23$ seconds

Figure 5 of Makdisi/Seed, Figure 14.5 of J D Bray & Figure 6 of Shahrour et al ... all suggest ground acceleration at the crest can amplify approx 2.5 to 3.45 times the base acceleration.

For this analysis we will assume 3.5 times the base amplification

Thus $\ddot{u}_{max} = 3.5 * 0.35g$
$= 1.23$

crest acceleration

Step 4/ Calculate maximum value of acceleration history using Figure 7 of Makdisi Seed

we know $y/h = 1.0$ which gives $k_{max}/\ddot{u}_{max} = 0.35$ (using the "average of all data" trendline from figure 7)

If we already know $\ddot{u}_{max}$ then $k_{max} = 0.35 * \ddot{u}_{max}$
$= 0.35 * 1.23$
$= 0.43$

Step 5/ Using figure 10b of Makdisi Seed & with calculated values of k_y & k_{max} determine horizontal component of seismic induced permanent displacement.

$k_y = 0.39$ $k_{max} = 0.43$ $\therefore k_y/k_{max} = 0.91$

Using figure 10b this gives displacement of 1cm = 10mm

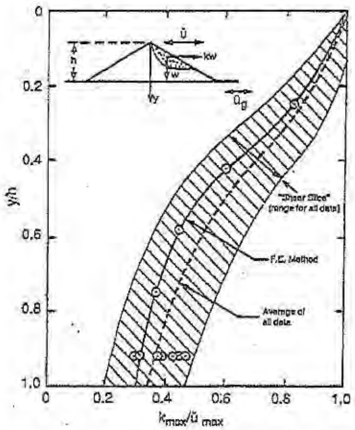


Figure 12.37. Variation of seismic coefficient k_{max} with depth of the base of the potential sliding (Makdisi and Seed, 1978, reproduced with permission of ASCE).

and Makdisi and Seed (1978)). It is generally found that, provided the yield acceleration is accurately evaluated, the approach can estimate the permanent displacement of a soil mass in reasonably good agreement with those observed during past earthquakes.

It is also stressed that Newmark's approach is limited in application to compacted clayey embankments and dry or dense cohesionless soils that experience very little reduction in strength due to cyclic loading. The approach should not be applied where embankments or their foundations are susceptible to liquefaction or strain weakening because it will significantly underestimate displacements.

12.6.3.4 *Makdisi and Seed (1978) analysis*

The Makdisi and Seed (1978) approach is based on Newmark's method, but modified to allow for the dynamic response of the embankment as proposed by Seed and Martin (1966). The approach was developed from a series of deformation analyses performed on a large number of embankments subjected to earthquake loading.
The approach involves the following main steps:

(a) Determine y/h ratio for the potential sliding mass, where y is the depth to the base of the sliding mass and h is the embankment height;
(b) Calculate the yield acceleration k_y for the potential sliding mass;
(c) Determine the maximum crest acceleration $\ddot{u}_{max}$ and the predominant period of the embankment T_o (in seconds);
(d) Determine the maximum value of the acceleration history k_{max} using the normalized relationship given in Figure 12.37 and the values calculated in steps (a) and (c);
(e) Enter Figure 12.38 with the calculated values of k_{max} and T_o to determine the horizontal component of earthquake induced permanent displacement, U, in the potential sliding mass;

Appendix A

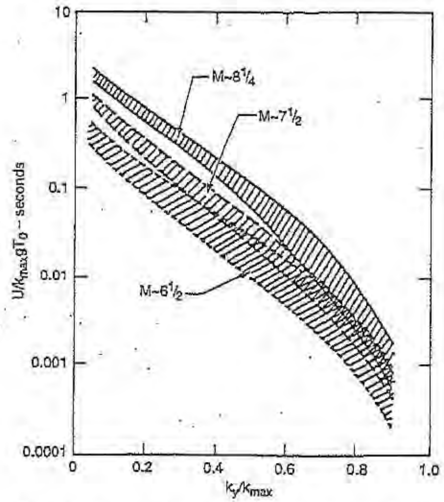


Figure 12.38. Variation of yield acceleration with normalized permanent displacement (Makdisi and Seed, 1978, reproduced with permission of ASCE).

It should be noted that an important step in determination of k_{max} in step (d) is to establish the dynamic properties of the material forming the embankment and the foundation. This can be achieved by:

- Triaxial compression tests, simple shear tests or torsional shear tests conducted under cyclic loading conditions;
- Resonant column testing;
- Field measurement of shear wave velocities, either by downhole or crosshole techniques;
- Back calculation using finite element techniques, modelling measured responses to earthquake events;
- Empirical relationships, such as those given by Hardin and Drenerich (1972) and Seed et al. (1986).

Given that the laboratory and field based methods are expensive, it is recommended that the values of k_{max} be initially calculated using a range of G_{max} values obtained from the empirical relationships. Should the results of the analysis be marginal then a more elaborate program of laboratory and/or field testing may be warranted.

It should be noted that relating satisfactory dam performance to earthquake induced deformation is very subjective and generally depends on dam specific criteria about the allowable loss of freeboard or the tolerable extent of horizontal displacements.

The Makdisi and Seed approach is widely used and accepted among practicing engineers. However, like Newmark's approach, it is limited in application to dams not susceptible to liquefaction or strain weakening in the embankment or its foundations.

The process was repeated for every time step to calculate the entire time history of the average acceleration. This acceleration is also called "effective peak acceleration" of the overall sliding mass.

Step III – Calculation of Seismically-Induced Permanent Displacements

Computation of accumulated permanent displacement along the direction of a potential sliding surface (for the initial development of these simplified design charts) was based on simple double-integration procedures (of average sliding mass acceleration-time history, where it exceeds the yield acceleration).

Based on the simplified design charts developed by Makdisi and Seed (based on previous detailed dynamic analysis for several earthfill slopes and earthquake loading conditions), accumulated permanent displacements were simply calculated based on the yield acceleration, the maximum value of acceleration of a potential sliding mass (or effective peak acceleration), and the magnitude of the earthquake for which the earthfill/landfill response is being evaluated.

PROCEDURE

The procedure involves the determination of:

Slope Geometry, Shear Wave Velocity and Natural Period

Calculation of maximum height of earthfill or refuse fill (H) at the section being considered. Section to be considered for seismic response analyses should be those resulting in the lowest static factor of safety. Evaluation would typically be made of the approximate value of shear wave velocity for the earthfill and/or refuse fill (V_s). For compacted earthfill materials, V_s is on the order of 1,000 feet per second (ft/s), and approximately 700 ft/s for refuse fill near surface, increasing with depth to approximately 900 ft/s at approximately 50 feet of depth. A simplified procedure for computing maximum crest acceleration and natural period for embankments was proposed by Makdisi and Seed (1977). The fundamental natural period of an embankment is approximated by 2.62 H/V_s.

For the RFETS project, the anticipated maximum height and thickness of the earthfill was approximately 45 feet, which based on an estimated shear wave velocity of the refuse soil mixture of 700 feet/second, resulted in a maximum first natural period of the earthfill/landfill of approximately 0.17 seconds.

Peak Horizontal Acceleration at the Base of the Embankment/Landfill

This step requires identification of primary seismic sources (faults, area sources) which are in the proximity of the site, and determine the Richter magnitude of the maximum event that could be generated at that source, and the distance from source to the project site, and calculate peak horizontal ground acceleration using a suitable ground motion attenuation relationship. If other site geologic conditions exist, namely near surface materials consisting of soil sediments instead or rock, the peak ground surface horizontal acceleration can be estimated based on simple correlations with peak rock acceleration developed by Seed and Idriss (1982) available for various typical soil profile types of stiff soil, soft soil, deep soil.

For the RFETS project, the anticipated peak horizontal acceleration in bedrock corresponding the an earthquake event with an acceleration exceedance probability of 2 percent in 50 years, as estimated by Risk Engineering (RE, 1994) and from the 2002 USGS database, are approximately 0.10g and 0.12g (gravity), respectively.

The corresponding RFETS peak horizontal acceleration in soil (at the ground surface, at the base of the earthfill), was estimated by RE at approximately 0.15g for the same probability of exceedance. Similarly, and based on approximate correlations between peak rock acceleration and peak horizontal ground acceleration developed for a stiff soil profile (as shown on Figure F7 per Seed and Idriss, 1982), the later would be on the order of 0.12g to 0.13g, which is consistent with the RE (1995) assessment. A site-specific response spectra may also be performed using the program "shake" in place of the above two spectral relationships.

Peak Horizontal Acceleration at the Crest

The crest acceleration is approximately determined based on the spectral acceleration of the embankment/landfill. For the first mode of vibration displacement, the spectral response acceleration is approximately the peak crest acceleration of the embankment/landfill. This

CHAPTER 14
SIMPLIFIED SEISMIC SLOPE DISPLACEMENT PROCEDURES

Jonathan D. Bray[1]
Dept. Civil & Environ. Engineering, Univ. of California, Berkeley, USA

Abstract. Simplified seismic slope displacement procedures are useful tools in the evaluation of the likely seismic performance of earth dams, natural slopes, and solid-waste landfills. Seismically induced permanent displacements resulting from earthquake-induced deviatoric deformations in earth and waste structures are typically calculated using the Newmark sliding block analogy. Some commonly used procedures are critiqued, and a recently proposed simplified procedure is recommended for use in engineering practice. The primary source of uncertainty in assessing the likely performance of an earth/waste structure during an earthquake is the input ground motion, so the proposed method is based on the response of several realistic nonlinear fully coupled stick-slip sliding block models undergoing hundreds of recorded ground motions. The calculated seismic displacement depends primarily on the ground motion's spectral acceleration at the degraded period of the structure and the structure's yield coefficient and fundamental period. Predictive equations are provided for estimating potential seismic displacements for earth and waste structures.

1. Introduction

The failure of an earth dam, solid-waste landfill, or natural slope during an earthquake can produce significant losses. Additionally, major damage without failure can have severe economic consequences. Hence, the potential seismic performance of earth and waste structures requires sound evaluation during design. Seismic evaluations of slope stability range from using relatively simple pseudostatic procedures to advanced nonlinear finite element analyses. Performance is best evaluated through an assessment of the potential for seismically induced permanent displacements. Following largely from the landmark paper of Newmark (1965) sliding block analyses are utilized as part of the seismic evaluation of the likely performance of earth and waste structures. Simplified Newmark-type procedures such as Makdisi and Seed (1978) are routinely used to provide a rough assessment of a system's seismic stability. Some of these procedures are critiqued in this paper, and a recently proposed simplified method for estimating earthquake-induced deviatoric deformations in earth and waste structures is summarized and recommended for use in practice.

K.D. Pitilakis (ed.), Earthquake Geotechnical Engineering, 327–353.

4.3. MAKDISI AND SEED (1978) SIMPLIFIED SEISMIC DISPLACEMENT METHOD

The first step in the widely used Makdisi and Seed (1978) approach is the evaluation of the material's strength loss potential. They recommend not using their procedure if the loss of material strength could be significant. If only a minor amount of strength loss is likely, a slightly reduced shear strength, which often incorporates a 10% to 20% strength reduction from peak undrained shear strength, is recommended. The strength reduction is applied because of the use of a rigid, perfectly plastic sliding block model, wherein if peak strength was used the accumulation of nonlinear elasto-plastic strains for cyclic loads below peak would be significantly underestimated (i.e., zero vs. some nominal amount). Based on these slightly reduced best estimates of calibrated dynamic strengths and slope geometry and weight, k_y is then calculated in the second step.

In step three, the *PGA* that occurs at the crest of the earth structure is estimated. This is one of the greatest limitations of this method. As shown in Figure 14.5, which presents results of 1D SHAKE analyses of columns of waste placed atop a firm foundation for a number of ground motions, the *PGA* (or maximum horizontal acceleration, *MHA*) at the top of the landfill varies significantly. There is great uncertainty regarding what value of *PGA* to use. This is critical, because in the next step, the maximum seismic coefficient (k_{max}) is estimated as a function of the *PGA* at the crest and the depth of sliding below the crest. Thus, the uncertainty in the estimate of k_{max} is high, because the uncertainty

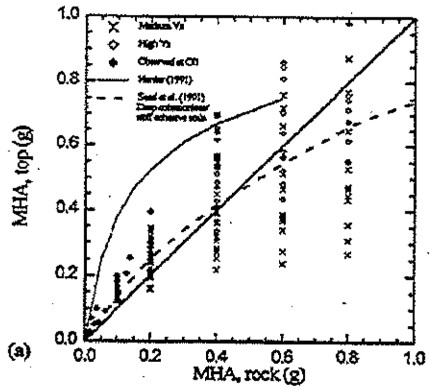
(a)


Fig. 14.5. Maximum horizontal acceleration at top of waste fill vs. *MHA* of rock base (Bray and Rathje, 1998)

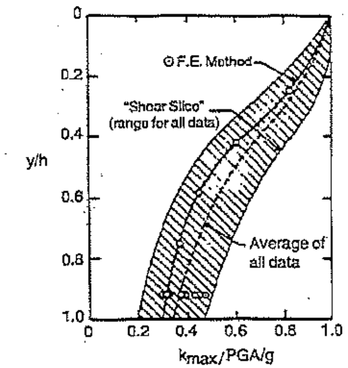


Fig. 14.6. Estimating seismic coefficient as a function of the peak acceleration at the crest and the depth of sliding (Makdisi and Seed, 1978)

in estimating the crest *PGA* is high. Even with advanced analyses, estimating the crest *PGA* is difficult, and the need to perform any level of dynamic analysis to estimate the crest *PGA* conflicts with the intent of a simplified method that should not require more advanced analysis.

Moreover, the bounds shown on the Makdisi and Seed (1978) plot of k_{max}/PGA vs. y/h (Figure 14.6) are not true upper or lower bounds. Stiff earth structures undergoing ground motions with mean periods near the degraded period of the earth structure can have k_{max} values exceeding 50% of the crest *PGA* for the base sliding case (i.e., $y/h = 1.0$), and flexible earth structures undergoing ground motions with low mean periods can have k_{max} values less than 20% of the crest *PGA* for base sliding.

When typically used in practice, the final step is to estimate seismic displacement as a function of the ratio of k_y/k_{max} and earthquake magnitude. Again the range shown in Figure 14.7 does not constitute the true upper and lower bounds of the possible seismic displacement, as only a limited number of earth structures were analyzed with a very limited number of input ground motions. As recommended by Makdisi and Seed (1978): "*It must be noted that the design curves presented are based on averages of a range of results that exhibit some degree of scatter and are derived from a limited number of cases. These curves should be updated and refined as analytical results for more embankments are obtained.*" Similar to how the Seed and Idriss (1971) simplified liquefaction triggering procedure was updated through Seed et al. (1985) and then Youd et al. (2001), it is time to update and move beyond the Makdisi and Seed (1978) design curves.

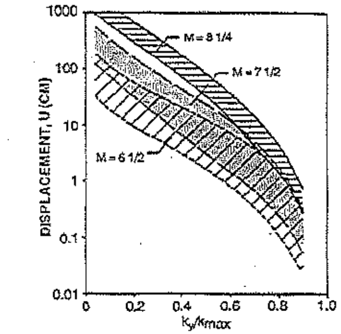


Fig. 14.7. Seismic displacement vs. *ky/kmax* and magnitude (Makdisi and Seed, 1978)

The Makdisi and Seed (1978) simplified seismic displacement method is one of the most significant contributions to geotechnical earthquake engineering over the past few decades. But as they recommended, their design curves should be updated as the profession advances. Since 1989, the number of recorded ground motions has increased dramatically. Thousands of well recorded ground motions are now available. The Makdisi and Seed (1978) work is based on a limited number of recorded and modified ground motions. Moreover, the important earthquake ground motion at a site is characterized by the *PGA* at the crest of the slope and earthquake magnitude. The *PGA* at the crest of the slope is highly variable and important frequency content aspects of the ground motion are not captured. The analytical method employed was relatively simple (e.g., primarily the shear slice method and a few equivalent-linear 2D finite element analyses). The decoupled approximation was employed, there is no estimate of uncertainty, and the bounds shown in the design curves are not true upper and lower bounds.

4.4. BRAY ET AL. (1998) SIMPLIFIED SEISMIC DISPLACEMENT APPROACH

The Bray et al. (1998) method is largely based on the work of Bray and Rathje (1998) which in turn follows on the works of Seed and Martin (1966), Makdisi and Seed (1978), and Bray et al. (1995). The methodology is based on the results of fully nonlinear decoupled one-dimensional D-MOD (Matasovic and Vucetic, 1995) dynamic analyses combined with the Newmark rigid sliding block procedure. To address the importance of the dynamic response characteristics of the sliding mass, six fill heights with three shear wave velocity profiles each with multiple unit weight profiles and two sets of strain-dependent shear modulus reduction and material damping relationships were used.

4.3. MAKDISI AND SEED (1978) SIMPLIFIED SEISMIC DISPLACEMENT METHOD

The first step in the widely used Makdisi and Seed (1978) approach is the evaluation of the material's strength loss potential. They recommend not using their procedure if the loss of material strength could be significant. If only a minor amount of strength loss is likely, a slightly reduced shear strength, which often incorporates a 10% to 20% strength reduction from peak undrained shear strength, is recommended. The strength reduction is applied because of the use of a rigid, perfectly plastic sliding block model, wherein if peak strength was used the accumulation of nonlinear elasto-plastic strains for cyclic loads below peak would be significantly underestimated (i.e., zero vs. some nominal amount). Based on these slightly reduced best estimates of calibrated dynamic strengths and slope geometry and weight, k_y is then calculated in the second step.

In step three, the *PGA* that occurs at the crest of the earth structure is estimated. This is one of the greatest limitations of this method. As shown in Figure 14.5, which presents results of 1D SHAKE analyses of columns of waste placed atop a firm foundation for a number of ground motions, the *PGA* (or maximum horizontal acceleration, *MHA*) at the top of the landfill varies significantly. There is great uncertainty regarding what value of *PGA* to use. This is critical, because in the next step, the maximum seismic coefficient (k_{max}) is estimated as a function of the *PGA* at the crest and the depth of sliding below the crest. Thus, the uncertainty in the estimate of k_{max} is high, because the uncertainty

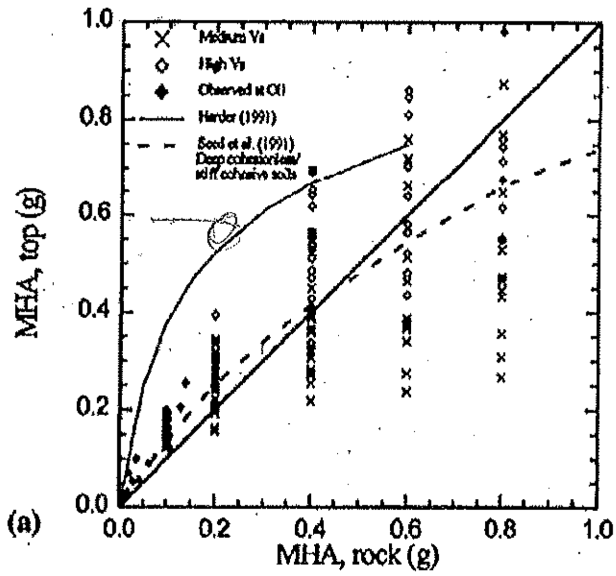


Fig. 14.5. Maximum horizontal acceleration at top of waste fill vs. *MHA* of rock base (Bray and Rathje, 1998)

Nat. Hazards Earth Syst. Sci., 9, 451–458, 2009
www.nat-hazards-earth-syst-sci.net/9/451/2009/

Natural Hazards and Earth System Sciences

Review Article: Numerical analysis of the seismic behaviour of earth dam

Y. Parish, M. Sadek, and I. Shahrour

Laboratory of Mechanics of Lille, University of Science and Technology of Lille, 59 650 Villeneuve d'Ascq, France

Received: 24 July 2008 – Revised: 5 February 2009 – Accepted: 16 March 2009 – Published: 23 March 2009

Abstract. The present study concerns analysis of the seismic response of earth dams. The behaviour of both the shell and core of the dam is described using the simple and popular non associated Mohr-Coulomb criterion. The use of this constitutive model is justified by the difficulty to obtain constitutive parameters for more advanced constitutive relations including isotropic and kinematic hardening. Analyses with real earthquake records show that the seismic loading induces plasticity in a large part of the shell and in the lower part of the core. Analysis shows that plasticity should be considered in the analysis of the seismic response of the dam, because it leads to a decrease in the natural frequencies of the dam together to energy dissipation, which could significantly affect the seismic response of the dam. Plastic analysis constitutes also a good tool for the verification of the stability of the dam under seismic loading.

1 Introduction

Seed et al. (1978, 1979) reported that the seismic performance of embankment dams has been good in general, except when liquefaction or unusual circumstances have been involved. They noted that a well-built compacted embankment dam can withstand moderate earthquake shaking, with peak accelerations of 0.2 g and more, with no detrimental effects. The efficiency of modern compacted embankment dams was further demonstrated in 1994 when the Los Angeles Reservoir was severely shaken by the Northridge Earthquake (Davis and Sakado, 1994). The seismic performance of embankment dams has been closely related to the nature and state of compaction of the fill material USCOLD (1992, 2000). Well-compacted modern dams can withstand substantial earthquake shaking with no detrimental effects.

The pseudo static approach is largely used in engineering practice to assess the seismic stability of earth fill dams. In this approach, the earthquake effect on a potential soil mass is represented by means of equivalent static horizontal force equal to the soil mass multiplied by a seismic coefficient. This approach is quite simplistic since it attempts to represent complex dynamic behaviour in terms of static forces. Stability is expressed in terms of an overall factor of safety. The implicit assumption is that the soil is rigid-perfectly plastic behaving as an undeformable block.

Since the 1971 San Fernando earthquake in California (Ming and Li, 2003), major progress has been achieved in the understanding of the earthquake action on dams. Gazetas (1987) discussed the historical developments of theoretical methods for estimating the dynamic response of earth dams to earthquakes ground excitation. He outlined their important features, their advantages and limitations. Progress in the area of geotechnical computation and numerical modeling offers interesting facilities for the analysis of the dam response in considering complex issues such as the soil non linearity, the evolution of the pore pressure during the dam construction procedure and real earthquake records. Detailed analysis techniques include equivalent linear (decoupled) solutions, and non linear finite element and finite difference coupled or decoupled formulations (Lin and Chao, 1990; Abouseeda and Dakoulas, 1998; Cascone and Rampello, 2003).

Wood (1973) showed that where the frequency at which the principal energy of the input motions approaches the fundamental frequency of the unrestrained backfill, dynamic amplification becomes an important factor, which is not considered in engineering approaches that assess the earth fill dam stability. The paper presents a numerical study of the seismic behaviour of earthfill dams. It will mainly focus on

Correspondence to: M. Sadek
(marwan.sadek@polytech-lille.fr)

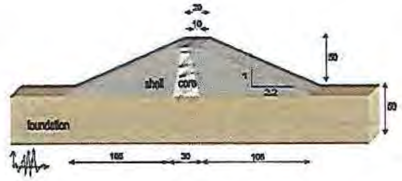


Fig. 1. Geometry of dam and the shape of zones (units in meter).

Table 1. Properties of foundation and earth dam soils.

	Units	Foundation 1	Earth dam Core	Shell
Dry density (ρ)	(kg/m^3)	2200	1800	2000
Young's modulus (E)	(MPa)	1000	40	60
Poisson's ratio (ν)		0.25	0.30	0.30
Elastic shear modulus (G)	(MPa)	400	15.38	23.08
Bulk modulus (K)	(MPa)	666.67	33.33	50.00
Cohesion (C)	*(kPa)*	–	*100*	*0.10*
Plasticity Friction angle (φ)	*(Degree)*	–	*15*	*35*
Dilation angle (ψ)	*(Degree)*	–	*3*	*10*

seismic amplification at the dam crest under real earthquake records with frequency content close to the natural frequency of the dam. In the present study, analysis is conducted using a 3-D finite difference modeling. It corresponds to the response of the dam before water impoundment. Results are presented first considering linear visco-elastic behaviour for the dam material; then analyses are conducted within the framework of plasticity in order on investigate the influence of plasticity on the seismic response of the dam. Indeed, plasticity could affect both the material damping and the dominant frequencies of the dam.

The elastoplastic analysis constitutes an efficient tool for the investigation of the stability of dams under seismic loading. The seismic induced displacement could be used for the evaluation of the stability of the dam. Since the displacement is dependant on the geometric and mechanical properties of the dams as well as the frequency and amplitude of the input loading, a specific study could be conducted for the analysis of the influence of the major input parameters on the stability of the dam. This analysis is not presented in this paper.

This paper does not consider the fluid-skeleton interaction, which could have a significant influence on the seismic response of the dam. This issue was recently investigated by the authors (Parish et al., 2008).

2 Problem under consideration

The selected example is a simplified representation of typical earth dam geometry. The dam section assumed in the present survey is a symmetric zone section with clay core and foundation as shown in Fig. 1. Geotechnical properties used in the analyses are presented in Table 1 for foundation soil and earth dam materials. The materials properties are chosen more close to reality. The foundation is assumed to be stiff with a Young's Modulus E=1000 MPa. The Young's modulus of the shell is equal to 60 MPa, while that of the core is equal to 40 MPa

2.1 Numerical model

Numerical analyses are conducted using the finite difference program FLAC3D based on a continuum finite difference discretization using the Langrangian approach (FLAC3D, 2005).

This program is based on a continuum finite difference discretization using the Langrangian approach. Every derivative in the set of governing equations is replaced directly by an algebraic expression written in terms of the field variables (e.g. stress or displacement) at discrete point in space. For dynamic analysis, it uses an explicit finite difference scheme to solve the full equation of motion using lumped grid point masses derived from the real density surrounding zone. The calculation sequence first invokes the equations of motion to derive new velocities and displacements from stresses and forces. Then, strain rates are derived from velocities, and new stresses from strain rates. Every cycle around the loop correspond to one time step. Each box updates all of its grid variables from known values that remain fixed over the time step being executed.

Dynamic loading is applied at the base of the foundation layer as a velocity excitation. Kuhlemeyer and Lysmer (1973) showed that for an accurate representation of the wave transmission through the soil model, the spatial element size, Δl, must be smaller than approximately one-tenth to one-eighth of the wavelength associated with the highest frequency component of the input wave i.e.,

$$\Delta l \leq \lambda/10 \quad (1)$$

λ is the wave length associated with the highest frequency component that contains appreciable energy. The consequence is that reasonable analyses may be time and memory consuming. In such cases, it may be possible to adjust the input by recognizing that most of the power for the input history is contained in lower frequency components.

The procedure of Free-Field Boundaries used in FLAC3D aims absorbing outward waves originating from the structure. The method involves the execution of free-field calculations in parallel with the main-grid analysis. The lateral boundaries of the main grid are coupled to the free-field grid by viscous dashpots to simulate a quiet boundary.

Rayleigh damping R_d=5% is used in the analyses to compensate for the energy dissipation through the medium (Paolucci, 2002; Lokmer et al., 2002). The behaviour of the

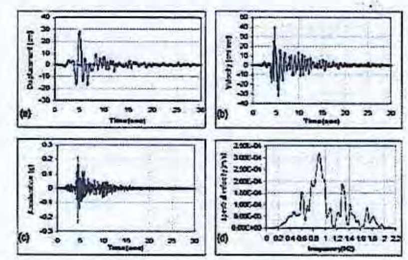


Fig. 2. Kocaeli earthquake record, 1999 (Ambarli Station, Record ID P1086) (a) Displacement,(b) Velocity, (c) Acceleration, (d) Fourier Spectra of Velocity Component.

shell and core of the dam is described using the non associated Mohr Coulomb criterion (Table 1); in this case the hysteretic damping is considered using Rayleigh damping R_d=2%. The use of this model is justified by the difficulty to obtain constitutive parameters for more advanced constitutive relations including both isotropic and kinematic hardening.

2.2 Input loading

Dynamic loading is applied at the base of the foundation layer as a velocity excitation. The earth dam is subjected to earthquake loading representative of the 1999 Kocaeli earthquake in Turkey (Mw=7.4, Chen and Scawthorn 2003). The estimated peak velocity is approximately 40 cm/s (peak acceleration 0.247 g), and the duration is approximately 30 s. The record for base acceleration, velocity, and displacement waves are shown in Fig. 2a, b and c (records at Ambarli Station). Fourier analysis of the earthquake velocity record results in a power spectrum depicted in Fig. 2d. The velocity spectrum reveals a dominant frequency of about 0.9 Hz (the second peak is observed at 1.3 Hz). Also note that most of the power for the input history is contained in low frequencies. From the other hand, the natural frequencies of the foundation-dam system were determined by a Fourier analysis of the free vibration response of the dam (Fig. 3). It shows a fundamental frequency f_1=0.7 Hz which is close to dominant frequency of seismic loading (f=0.9 Hz); the second frequency is close to f_2=1.4 Hz (close to the second peak 1.3 Hz)

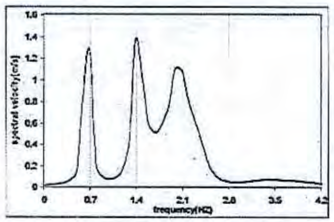


Fig. 3. Response spectra of free horizontal motion at the dam crest.

Fig. 4. Dam deformation at the maximum of excitation (Kocaeli earthquake record) (U_{max}=0.30 m at the dam crest).

3 Analysis of the seismically induced response in the dam

3.1 Elastic response

The response of the dam at the maximum excitation is presented in Fig. 4. It shows an increase in the horizontal amplification at the upper part of the dam. Figure 5 shows the velocity amplification in the axis of the dam. It can be observed that the amplification increases with the distance from the foundation; it attains 3.45 at the top of the dam. Figure 6 shows the variation of the lateral amplification in the horizontal direction at the middle height of the dam and the crest. In the first section, we observe a variation in the dynamic amplification between 2 and 2.5. At the crest, we observe a uniform distribution of the amplification (close to 3.45).

3.2 Influence of Plasticity

Figure 7 shows the location of the zones concerned by plastic deformation at the peak of the seismic excitation. It can be observed that plasticity is induced in a large part of the shell and in the lower part of the core. The upper part of the core remains in the elastic domain. Figure 8 shows the displacement pattern in the axis and the middle height of the dam at the maximum of seismic excitation. It can be observed that the displacement in the axis of the dam is close to the first mode of the dam; the variation of the displacement at the middle height shows a sharp increase at the extremities,

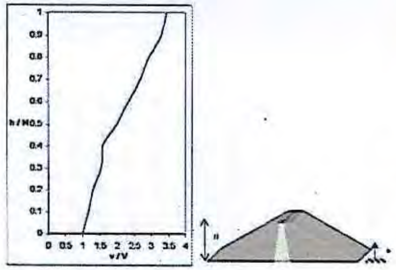


Fig. 5. Velocity amplification in the dam axis (Kocaeli earthquake record) (V: velocity at the base for h=0).

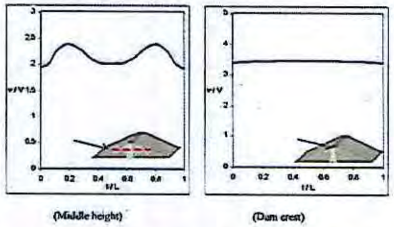


Fig. 6. Variation of the amplification in the horizontal direction.

which could indicate the imminence of soil instability in this area. The residual (permanent) displacement is presented in the Fig. 9 that shows the seismic induced residual displacement in the upper part of the dam and the extremities. As seen from this figure, whereas the residual displacement almost unvarying in the lower two-thirds of the crest, it displays significant increase in the upper one-third of the dam. In fact, previous research works indicated this behaviour (Ohmachi and Kuwano, 1994; Ozkan et al., 2006). That's why in the design of embankment dams, due to the stronger shaking at the upper parts, special attention should be given to the crest to avoid undesirable deformations.

Figure 10 shows a comparison between the elastic and elastoplastic analyses at the maximum of velocity. It can be observed that the plastic deformation leads to a decrease in the velocity amplification, in particular in the upper part. This reduction attains about 50%. This result could be attributed to the energy dissipation by plastic deformation and to the influence of plasticity on the reduction of the fundamental frequencies of the dam as illustrated Fig. 11, which shows the influence of plasticity on the spectral response at the crest of the dam.

Fig. 7. Reference example: Distribution of plasticity in the dam (at maximum excitation).
(-n: the zone is at active failure now; -p: the zone has failed in the past; shear: yield criterion -shear failure).

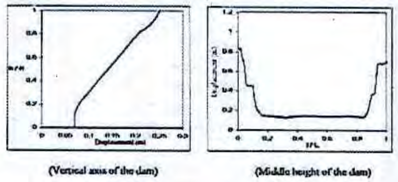


Fig. 8. Displacement pattern at maximum of velocity.

3.3 Influence of the input loading

This section presents an analysis of the influence of both the frequency content and the loading amplitude on the seismic response of the dam.

3.3.1 Frequency content of seismic excitation

The seismic performance of the dam is analysed through time-history analysis using the 1978 Tabas earthquake record that has been adjusted to have a maximum amplitude velocity of 0.4 m/s in order to compare it with the response under Kocaeli earthquake. The time history of this record is illustrated in Fig. 12 (9101 Tabas Station). Note that the dominant frequency of this record is about 0.5 Hz.

Figure 13 shows a comparison between the dynamic amplification profiles obtained with the elastoplastic analyses of the dam subjected the Kocaeli and Tabas earthquake records. We observe an agreement between these profiles. The maximum velocity due to the Tabas earthquake record is equal to 1.26 m/s (v/V=2.97); this value is higher than that obtained with the Kocaeli earthquake record (V_{max}=0.95 m/s, v/V=2.59).

Figure 14a and b depict the response spectra obtained with the Kocaeli and Tabas earthquake records together with the input motions respectively for elastic and elastoplastic modeling. For elastic analysis, it can be observed that maximum peak of the response to Tabas earthquake (respectively Kocaeli) occurs at the first frequency of the dam $f_{1\,dam}$=0.7 Hz (respectively at $f_{2\,dam}$=1.4 Hz) while the second peak is

JOURNAL OF THE GEOTECHNICAL ENGINEERING DIVISION

Simplified Procedure for Estimating Dam and Embankment Earthquake-Induced Deformations

By Faiz I. Makdisi,[1] A. M. ASCE and H. Bolton Seed,[2] F. ASCE

Introduction

In the past decade major advances have been achieved in analyzing the stability of dams and embankments during earthquake loading. Newmark (13) and Seed (18) proposed methods of analysis for predicting the permanent displacements of dams subjected to earthquake shaking and suggested this as a criterion of performance as opposed to the concept of a factor of safety based on limit equilibrium principles. Seed and Martin (26) used the shear beam analysis to study the dynamic response of embankments to seismic loads and presented a rational method for the calculation of dynamic seismic coefficients for earth dams. Ambraseys and Sarma (1) adopted the same procedure to study the response of embankments to a variety of earthquake motions.

Later the finite element method was introduced to study the two-dimensional response of embankments (5,7) and the equivalent linear method (21) was used successfully to represent the strain-dependent nonlinear behavior of soils. In addition the nature of the behavior of soils during cyclic loading has been the subject of extensive research (10,20,23,29). Both the improvement in the analytical tools to study the response of embankments and the knowledge of material behavior during cyclic loading led to the development of a more rational approach to the study of stability of embankments during seismic loading. Such an approach was used successfully to analyze the Sheffield Dam failure during the 1925 Santa Barbara earthquake (24) and the behavior of the San Fernando Dams during the 1971 earthquake (25). This method has since been used extensively in the design and analysis of many large dams in the State of California and elsewhere.

Note.—Discussion open until December 1, 1978. To extend the closing date one month, a written request must be filed with the Editor of Technical Publications, ASCE. This paper is part of the copyrighted Journal of the Geotechnical Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 104, No. GT7, July, 1978. Manuscript was submitted for review for possible publication on August 30, 1977.

[1] Project Engr., Woodward-Clyde Consultants, San Francisco, Calif.

[2] Prof. of Civ. Engrg., Univ. of California, Berkeley, Calif.

From the study of the performance of embankments during strong earthquakes, two distinct types of behavior may be discerned: (1) That associated with loose to medium dense sandy embankments, susceptible to rapid increases in pore pressure due to cyclic loading resulting in the development of pore pressures equal to the overburden pressure in large portions of the embankment, associated reductions in shear strength, and potentially large movements leading to almost complete failure; and (2) the behavior associated with compacted cohesive clays, dry sands, and some dense sands; here the potential for buildup of pore pressures is much less than that associated with loose to medium dense sands, the resulting cyclic strains are usually quite small, and the material retains most of its static undrained shearing resistance so that the resulting post-earthquake behavior is a limited permanent deformation of the embankment.

The dynamic analysis procedure proposed by Seed, et al. (25) has been used to predict adequately both types of embankment behavior using the "Strain Potential" concept. Procedures for integrating strain potentials to obtain the overall deformation of an embankment have been proposed by Seed, et al. (25), Lee (9), and Serff, et al. (27).

The dynamic analysis approach has been recommended by the Committee on Earthquakes of the International Commission on Large Dams (3): "high embankment dams whose failure may cause loss-of-life or major damage should be designed by the conventional method at first, followed by a dynamic analysis in order to investigate any deficiencies which may exist in the pseudo-statical design of the dam." For low dams in remote areas the Committee recommended the use of conventional pseudostatic methods using a constant horizontal seismic coefficient selected on the basis of the seismicity of the area. However, the inadequacy of the pseudostatic approach to predict the behavior of embankments during earthquakes has been clearly recognized and demonstrated (19,24,25,26, 28). Furthermore in the same report (3) the Commission refers to the conventional method as follows: "There is a need for early revision of the conventional method since the results of dynamic analyses, model tests and observations of existing dams show that the horizontal acceleration due to earthquake forces varies throughout the height of the dam . . . in several instances, this method predicts a safe condition for dams which are known to have had major slides."

It is this need for a simple yet rational approach to the seismic design of small embankments that prompted the development of the simplified procedure described herein.

This approximate method uses the concept originally proposed by Newmark (13) for calculating permanent deformations but it is based on an evaluation of the dynamic response of the embankment as proposed by Seed and Martin (26) rather than rigid body behavior. It assumes that failure occurs on a well-defined slip surface and that the material behaves elastically at stress levels below failure but develops a perfectly plastic behavior above yield. The method involves the following steps:

1. A yield acceleration, i.e., an acceleration at which a potential sliding surface would develop a factor of safety of unity is determined. Values of yield acceleration are a function of the embankment geometry, the undrained strength of the material (or the reduced strength due to shaking), and the location of the potential sliding mass.

2. Earthquake induced accelerations in the embankment are determined using dynamic response analyses. Finite element procedures using strain-dependent soil properties can be used for calculating time histories of acceleration, or simpler one-dimensional techniques might be used for the same purpose. From these analyses, time histories of average accelerations for various potential sliding masses can be determined.

3. For a given potential sliding mass, when the induced acceleration exceeds the calculated yield acceleration, movements are assumed to occur along the direction of the failure plane and the magnitude of the displacement is evaluated by a simple double integration procedure.

The method has been applied to dams with heights in the range of 100 ft–200 ft (30 m–60 m), and constructed of compacted cohesive soils or very dense cohesionless soils, but may be applicable to higher embankments. A similar approach has been proposed by Sarma (16) using the assumption of a rigid block on an inclined plane rather than a deformable earth structure that responds with differential motions to the imposed base excitation.

In the following sections the steps involved in the analyses will be described in detail and design curves prepared on the basis of analyzed cases will be presented, together with an example problem to illustrate the use of the method. Note, however, that the method is an approximate one and involves simplifying assumptions. The design curves are averages based on a limited number of cases analyzed and should be updated as more data become available and more cases are studied.

Determination of Yield Acceleration

The yield acceleration, k_y, is defined as that average acceleration producing a horizontal inertia force on a potential sliding mass so as to produce a factor of safety of unity and thus cause it to experience permanent displacements.

For soils that do not develop large cyclic strains or pore pressures and maintain most of their original strength after earthquake shaking, the value of k_y can be calculated by stability analyses using limiting equilibrium methods. In conventional slope stability analyses the strength of the material is defined as either the maximum deviator stress in an undrained test, or the stress level that would cause a certain allowable axial strain, say 10%, in a test specimen. However, the behavior of the material under cyclic loading conditions is different than that under static conditions. Due to the transient nature of the earthquake loading, an embankment may be subjected to a number of stress pulses at levels equal to or higher than its static failure stress that simply produce some permanent deformation rather than complete failure. Thus the yield strength is defined, for the purpose of this analysis, as that maximum stress level below which the material exhibits a near elastic behavior (when subjected to cyclic stresses of numbers and frequencies similar to those induced by earthquake shaking) and above which the material exhibits permanent plastic deformation of magnitudes dependent on the number and frequency of the pulses applied. Fig. 1 shows the concept of cyclic yield strength. The material in this case has a cyclic yield strength equal to about 90% of its static undrained strength and as shown in Fig. 1(a) the application of 100 cycles of stress amounting to 80%

of the undrained strength resulted in essentially an elastic behavior with very little permanent deformation. On the other hand, the application of 10 cycles of stress level equal to 95% of the static undrained strength led to substantial permanent strain as shown in Fig. 1(*b*). On loading the material monotonically to failure after the series of cyclic stress applications, the material was found to retain the original undrained strength. This type of behavior is associated with various types of soils that exhibit small increases in pore pressure during cyclic loading. This would include clayey materials, dry or partially saturated cohesionless soils, or very dense saturated cohesionless materials that will not undergo significant deformations, even under cyclic loading conditions, unless the undrained static strength of the soil is exceeded.

Seed and Chan (20) conducted cyclic tests on samples of undisturbed and compacted silty clays and found that for conditions of no stress reversal and for different values of initial and cyclic stresses, the total stress required to produce large deformations in 10 cycles and 100 cycles ranged between 90%–110% of the undrained static strength.

Sangrey, et al. (15) investigated the effective stress response of clay under repeated loading. They tested undisturbed samples of clay (LL = 28, PI = 10) and found that the cyclic yield strength of this material was of the order of 60% of its static undrained strength.

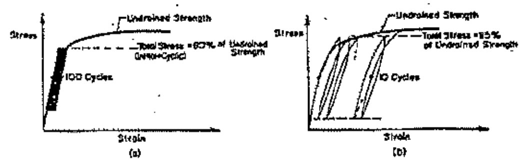


FIG. 1.—Determination of Dynamic Yield Strength

Rahman (14) performed similar tests on remolded samples of a brittle silty clay (LL = 91, PI = 49) and found that the cyclic yield strength was a function of the initial effective confining pressure. For practical ranges of effective confining pressures the cyclic yield strength for this material ranged between 80%–95% of its static undrained strength. At cyclic stress levels below the yield strength, in all cases, the material reached equilibrium and assumed an elastic behavior at strain levels less than 2% irrespective of the number of stress cycles applied.

Thiers and Seed (28) performed tests on undisturbed and remolded samples of different clayey materials to determine the reduction in static undrained strength due to cyclic loading. Their results are summarized in Fig. 2 which shows the reduction in undrained strength after cyclic loading as a function of the ratio of the "maximum cyclic strain" to the "static failure strain." These results were obtained from strain controlled cyclic tests; after the application of 200 cycles of a certain strain amplitude, the sample was loaded to failure monotonically at a strain rate of 3%/min. Thus from Fig. 2 it could be argued that if a clay is subjected to 200 cycles of strain with an amplitude less than half its static failure strain, the material may be expected to retain at least 90% of its original static undrained strength.

Andersen (2), on the basis of cyclic simple shear tests on samples of Drammen clay, determined that the reduction in undrained shear strength was found to be less than 25% as long as the cyclic shear strain was less than ±3% even after 1,000 cycles. Some North Sea clays, however, have shown a strength reduction of up to 40% for the same level of cyclic loading.

On the basis of the experimental data reported previously and for values

TABLE 1.—Maximum Cyclic Shear Strains Calculated from Dynamic Finite Element Response Analyses

Magnitude (1)	Embankment height, in feet (2)	Slope, $H:V$ (3)	Maximum base acceleration, g (4)	Maximum shear strain, as a percentage (5)
6-1/2 (Caltech record)	75	2:1	0.5	0.2–0.4
6-1/2 (Caltech record)	150	2:1	0.2	0.1–0.15
6-1/2 (Caltech record)	150	2:1	0.5	0.2–0.3
6-1/2 (Lake Hughes record)	150	2:1	0.2	0.1–0.15
6-1/2 (Caltech record)	150	2-1/2:1	0.5	0.2–0.3
7-1/2 (Taft record)	150	2:1	0.5	0.2–0.5
7-1/2 (Taft record)	150	2:1	0.2	0.1–0.2
8-1/4 (S-I record)	150	2:1	0.75	0.4–1.0
8-1/4 (S-I record)	135	—	0.4	0.2–0.5

Note: 1 ft = 0.305 m.

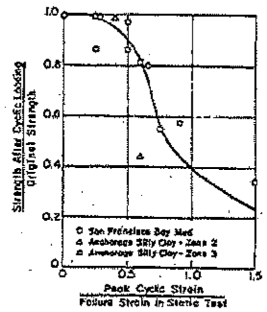


FIG. 2.—Reduction in Static Undrained Strength Due to Cyclic Loading (29)

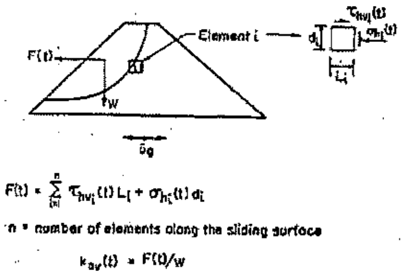


FIG. 3.—Calculation of Average Acceleration from Finite Element Response Analysis

of cyclic shear strains calculated from earthquake response analyses, the value of cyclic yield strength for a clayey material can be estimated. In most cases this value would appear to be 80% or more of the static undrained strength. This value in turn may be used in an appropriate method of stability analysis to calculate the corresponding yield acceleration.

Finite element response analyses (as will be described later) have been carried out to calculate time histories of crest acceleration and average acceleration for various potential sliding masses. The method of analysis employs the equivalent linear technique with strain-dependent modulus and damping. The ranges of calculated maximum shear strains, for different magnitude earthquakes and different embankment characteristics, are presented in Table 1. It can be seen from Table 1 that the maximum cyclic shear strain induced during the earthquakes ranged between 0.1% for a magnitude 6-1/2 earthquake with a base acceleration of 0.2 g and 1% for a magnitude 8-1/4 earthquake with a base acceleration of 0.75 g. For the compacted clayey material encountered in dam embankments "static failure strain" values usually range between 3%–10%, depending on whether the material was compacted on the dry or wet side of the optimum moisture content. Thus in both instances the ratio of the "cyclic strain" to "static failure strain" is less than 0.5.

It seems reasonable, therefore, to assume that for these compacted cohesive soils, very little reduction in strength may be expected as a result of strong earthquake loading of the magnitude described previously.

Once the cyclic yield strength is defined, the calculation of the yield acceleration can be achieved by using one of the available methods of stability analysis. In the present study the ordinary method of slices has been used to calculate the yield acceleration for circular slip surfaces using a pseudostatic analysis. As an alternative one of the writers (18) has suggested a method of combining both effective and total stress approaches, where the shear strength on the failure plane during the earthquake is considered to be a function of the initial effective normal stress on that same plane before the earthquake. This method is applicable to noncircular slip surfaces and the horizontal inertia force resulting in a factor of safety of unity can readily be calculated.

Having determined the yield acceleration for a certain location of the slip surface, the next step in the analysis is to determine the time history of earthquake-induced average accelerations for that particular sliding mass. This will be treated in the following section.

Determination of Earthquake Induced Acceleration

In order for the permanent deformations to be calculated for a particular slip surface, the time history of earthquake induced average accelerations must first be determined.

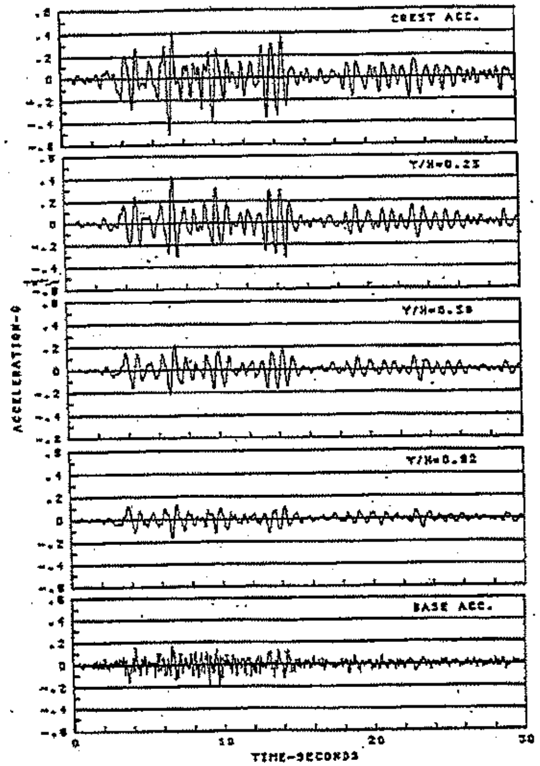
Two-dimensional finite element procedures using equivalent linear strain-dependent properties are available (6) and have been shown to provide response values in good agreement with measured values (8) and with closed-form one-dimensional wave propagation solutions (17).

For most of the case studies of embankments used in the present analysis, the response calculation was performed using the finite element computer program QUAD-4 (6) with strain-dependent modulus and damping. The program uses the Rayleigh damping approach and allows for variable damping to be used in different elements.

To calculate the time history of average acceleration for a specified sliding mass, the method described by Chopra (4) was adopted in the present study. The finite element calculation provides time histories of stresses for every element in the embankment. As shown in Fig. 3, at each time step the forces acting along the boundary of the sliding mass are calculated from the corresponding

ormal and shear stresses of the finite elements along that boundary. The resultant f these forces divided by the weight of the sliding mass would give the average cceleration, $k_{av}(t)$, acting on the sliding mass at that instant in time. The process repeated for every time step to calculate the entire time history of average cceleration.

For a 150-ft (46-m) high dam subjected to 30 sec of the Taft earthquake cord scaled to produce a maximum base acceleration of 0.2 g, the variation



IG. 4.—Time Histories of Average Acceleration for Various Depths of Potential Sliding ass

the time history of k_{av} with the depth of the sliding mass within the embankment, gether with the time history of crest accelerations, is shown in Fig. 4.

Comparing the time history of crest acceleration with that of the average celeration for different depths of the potential sliding mass, the similarity the frequency content is readily apparent (it generally reflects the first natural riod of the embankment), while the amplitudes are shown to decrease as e depth of the sliding mass increases towards the base of the embankment. e maximum crest acceleration is designated by $\ddot{u}_{max}$, and k_{max} is the maximum average acceleration for a potential sliding mass extending to a specified depth, y.

It would be desirable to establish a relationship showing the variation of the maximum acceleration ratio, $k_{max}/\ddot{u}_{max}$, with depth for a range of embankments and earthquake loading conditions. It would then be sufficient, for design purposes, to estimate the maximum crest acceleration in a given embankment due to a specified earthquake and use this relationship to determine the maximum average acceleration for any depth of the potential sliding mass. A simplified procedure to estimate the maximum crest acceleration and the natural period

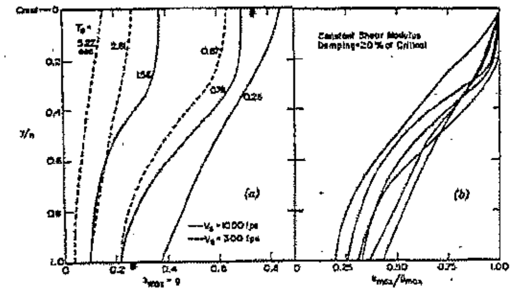


FIG. 5.—El Centro Record (12): (a) Variation of Maximum Average Acceleration with Depth of Sliding; (b) Variation of Ratio of Average Acceleration to Maximum Crest Acceleration with Depth of Sliding Surface

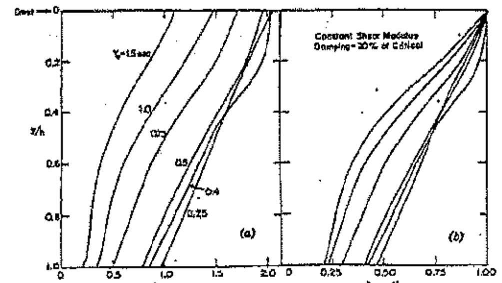


FIG. 6.—Average of Eight Strong Motion Records (1): (a) Variation of Maximum Average Acceleration with Depth of Sliding Mass; (b) Variation of Ratio of Maximum Average Acceleration to Maximum Crest Acceleration with Depth of Sliding Surface

of an embankment subjected to a given base motion is described in Appendix A of Ref. 11.

To determine the variation of maximum acceleration ratio with depth, use was made of published results of response computations using the one-dimensional shear slice method with visco-elastic material properties (1,26). Martin (12) calculated the response of embankments ranging in height between 100 ft–600 ft (30 m–180 m) and with shear wave velocities between 300 fps–1,000 fps (92 m/s–300 m/s). Using a constant shear modulus and a damping factor of 0.2,

the average acceleration histories for various levels were computed for embankments subjected to ground accelerations recorded in the El Centro earthquake of 1940. The variation of the maximum average acceleration, k_{max}, with depth for these embankments with natural periods ranging between 0.26 sec–5.22 sec is presented in Fig. 5(a). The maximum average acceleration in Fig. 5(a) is normalized with respect to the maximum crest acceleration and the ratio, $k_{max}/\ddot{u}_{max}$, plotted as a function of the depth of the sliding mass is presented in Fig. 5(b).

Ambraseys and Sarma (1) used essentially the same method reported by Seed and Martin (26) and calculated the response of embankments with natural periods ranging between 0.25 sec and 3.0 sec. They presented their results in terms of average response for eight strong motion records. The variation of maximum average acceleration with depth based on the results reported by Ambraseys and Sarma (1) is shown in Fig. 6(a) and that for the maximum acceleration ratio, $k_{max}/\ddot{u}_{max}$, is shown in Fig. 6(b). A summary of the results obtained

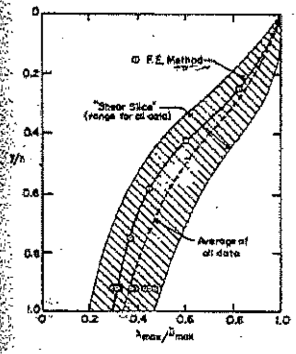


FIG. 7.—Variation of Maximum Acceleration Ratio with Depth of Sliding Mass

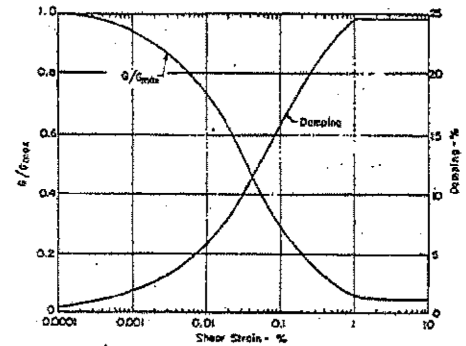


FIG. 8.—Shear Modulus and Damping Characteristics Used in Response Computations

from the different shear slice response calculations mentioned previously is presented in Fig. 7 together with results obtained from finite element calculations made in the present study. As can be seen from Fig. 7 the shape of the curves obtained using the shear slice method and the finite element method are very similar. The dashed curve in Fig. 7 is an average relationship of all data considered. The maximum difference between the envelope of all data and the average relationship ranges from ±10% to ±20% for the upper portion of the embankment and from ±20% to ±30% for the lower portion of the embankment.

Considering the approximate nature of the proposed method of analysis, the use of the average relationship shown in Fig. 7 for determining the maximum average acceleration for a potential sliding mass based on the maximum crest acceleration is considered accurate enough for practical purposes. For design computations where a conservative estimate of the accelerations is desired the upper bound curve shown in Fig. 7 may be used leading to values that are 10%–30% higher than those estimated using the average relationship.

Calculation of Permanent Deformations

Once the yield acceleration and the time history of average induced acceleration for a potential sliding mass have been determined, the permanent displacements can readily be calculated.

By assuming a direction of the sliding plane and writing the equation of motion for the sliding mass along such a plane, the displacements that would occur any time the induced acceleration exceeds the yield acceleration may be evaluated by simple numerical integration. For the purposes of the soil types considered in this study, the yield acceleration was assumed to be constant throughout the earthquake.

TABLE 2.—Embankment Characteristics for Magnitude 6-1/2 Earthquake

Case number (1)	Embankment description (2)	Height, in feet (3)	Base acceleration, g (4)	T_0, in seconds (5)[a]	k_{max}, g (6)[b]	Symbol[c] (7)
1	Example slope = 2:1 k_{2max} = 60	150	0.2 (Caltech record)	0.8	(1) 0.31 (2) 0.12	● ■
2	Example slope = 2:1 k_{2max} = 60	150	0.5 (Caltech record)	1.08	(1) 0.4 (2) 0.18	○ □
3	Example slope = 2:1 k_{2max} = 80	150	0.5 (Lake Hughes record)	0.84	(1) 0.33 (2) 0.16	⊙ △
4	Example slope = 2-1/2:1 k_{2max} = 80	150	0.5 (Caltech record)	0.95	(1) 0.49 (2) 0.22	◇ ▽
5	Example slope = 2:1 k_{2max} = 60	75	0.5 (Caltech record)	0.6	(1) 0.86 (2) 0.26	◑ ◪

[a] Calculated first natural period of the embankment.
[b] Maximum value of time history of: (1) Crest acceleration; and (2) average acceleration for sliding mass extending through full height of embankment.
[c] Legend used in Fig. 9(*a*).
Note: 1 ft = 0.305 m.

The direction of motion for a potential sliding mass once yielding occurs was assumed to be along a horizontal plane. This mode of deformation is not uncommon for embankments subjected to strong earthquake shaking, and is manifested in many cases in the field by the development of longitudinal cracks along the crest of the embankment. However studies made for other directions of the sliding surface showed that this factor had little effect on the computed displacements (11).

To calculate an order of magnitude of the deformations induced in embankments due to strong shaking a number of cases have been analyzed during the course of this study. The height of embankments considered ranged between 75 ft–150 ft (23 m–46 m) with varying slopes and material properties. The embankments were subjected to ground accelerations representing three different earthquake magnitudes: 6-1/2, 7-1/2, and 8-1/4.

The method used for calculating the response, as mentioned earlier, is a one-step finite element analysis using the equivalent linear method. The strain-dependent modulus and damping relations for the soils used in this study are

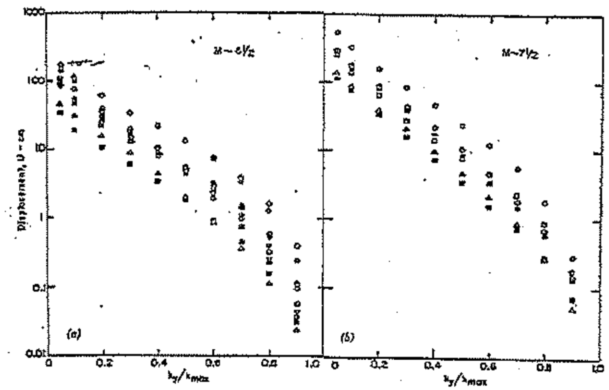


FIG. 9.—Variation of Permanent Displacement with Yield Acceleration: (*a*) Magnitude 6-1/2 Earthquake; (*b*) Magnitude 7-1/2 Earthquake

presented in Fig. 8. The response computation for each base motion was repeated for a number of iterations (mostly 3–4) until strain compatible material properties were obtained. In each case both time histories of crest acceleration and the average acceleration for a potential sliding mass extending through almost the full height of the embankment were calculated, together with the first natural period of the embankment. In one case however, time histories of average acceleration for sliding surfaces at five different levels in the embankment were obtained (see Fig. 4), and the corresponding permanent deformations for each time history were calculated for different values of yield acceleration. It was found that for the same ratio of yield acceleration to maximum average acceleration at each level, the computed deformations varied uniformly between a maximum value obtained using the crest acceleration time history to a minimum value obtained using the time history of average acceleration for a sliding mass extending through the full height of the embankment. Thus it was considered sufficient for the remaining cases to compute the deformations only for these two levels.

Table 2 shows details of the embankments analyzed using ground motions representative of a magnitude 6-1/2 earthquake. The two rock motions used were those recorded at the Cal Tech Seismographic Laboratory (S90W Component) and at Lake Hughes Station No. 12 (N12E) during the 1971 San Fernando earthquake, with maximum accelerations scaled to 0.2 g and 0.5 g. The computed natural periods and maximum values of the acceleration time histories are also presented in Table 2. The computed natural periods ranged between a value of 0.6 sec for the 75-ft (23-m) high embankment to a value of 1.08 sec for the 150-ft (46-m) high embankment. Because of the nonlinear strain-dependent behavior of the material, the response of the embankment is highly dependent on the amplitude of the base motion. This is clearly demonstrated in the first two cases in Table 2, where the same embankment was subjected to the same ground acceleration history but with different maximum accelerations for each case. In one instance, for a base acceleration of 0.2 g the calculated maximum crest accelerations was 0.3 g with a magnification of 1.5 and a computed natural period of the order of 0.8 sec. In the second case, for a base acceleration of 0.5 g the computed maximum crest acceleration was 0.4 g with an attenuation of 0.8 and a computed natural period of 1.1 sec.

TABLE 3.—Embankment Characteristics for Magnitude 7-1/2 Earthquake

Case number (1)	Embankment description (2)	Height, in feet (3)	Base acceleration, g (4)	T_0, in seconds (5)[a]	k_{max}, g (6)[b]	Symbol[c] (7)
1	Example slope = 2:1 k_{2max} = 60	150	0.2 (Taft record)	0.86	(1) 0.41 (2) 0.13	● ■
2	Example slope = 2:1 k_{2max} = 60	150	0.5 (Taft record)	1.18	(1) 0.54 (2) 0.21	○ □
3	Example slope = 2-1/2:1 k_{2max} = 80	150	0.2 (Taft record)	0.76	(1) 0.46 (2) 0.15	⊙ △

[a] Calculated first natural period of the embankment.
[b] Maximum value of time history of: (1) Crest acceleration; and (2) average acceleration for sliding mass extending through full height of embankment.
[c] Legend used in Fig. 9(b).
Note: 1 ft = 0.305 m.

From the time histories of induced acceleration calculated for all the cases

described in Table 2 and for various ratios of yield acceleration to maximum average acceleration, k_y/k_{max}, the permanent deformations were calculated by numerical double integration. The results are presented in Fig. 9(a) which shows that for relatively low values of yield acceleration, k_y/k_{max} of 0.2 for example, the range of computed permanent displacements was of the order of 10 cm–70 cm (4 in.–28 in.). However, for larger values of k_y/k_{max}, say 0.5 or more, the calculated displacements were less than 12 cm (4.8 in.). It should be emphasized that for very low values of yield accelerations (in this case $k_y/k_{max} \leq 0.1$) the basic assumptions used in calculating the response by the finite element method, i.e., the equivalent linear behavior and the small strain theory, become invalid. Consequently, the acceleration time histories calculated for such a case do not represent the real field behavior and the calculated displacements based on these time histories may not be realistic.

TABLE 4.—Embankment Characteristics of Magnitude 8-1/4 Earthquake

Case number (1)	Embankment description (2)	Height, in feet (3)	Base acceleration, g (4)	T_0, in seconds (5)[a]	k_{max}, g (6)[b]	Symbol[c] (7)
1	Chabot Dam (average properties)	135	0.4 (S-I Synth. record)	0.99	(1) 0.57	○
	Chabot Dam (Lower bound)	135	0.4 (S-I Synth. record)	1.07	(1) 0.53	△
	Chabot Dam (Upper bound)	135	0.4	0.83	(1) 0.68	□
2	Example slope = 2:1 k_{2max} = 60	150	0.75	1.49	(1) 0.74 (2) 0.34	● ■

[a] Calculated first natural period of the embankment.
[b] Maximum value of time history of: (1) Crest acceleration; and (2) average acceleration for sliding mass extending through full height of embankment.
[c] Legend used in Fig. 10(a).
Note: 1 ft = 0.305 m.

The procedure described previously was repeated for the case of a magnitude 7-1/2 earthquake. The base acceleration time history used for this analysis was that recorded at Taft during the 1952 Kern County earthquake and scaled to maximum accelerations of 0.2 g and 0.5 g. The details of the three cases analyzed are presented in Table 3 and the results of the computations of the permanent displacements are shown in Fig. 9(b). For a ratio of k_y/k_{max} of 0.2 the calculated displacements in this case ranged between 30 cm–200 cm (12 in.–80 in.), and for ratios greater than 0.5 the displacements were less than 25 cm (0.8 ft).

In the cases analyzed for the 8-1/4 magnitude earthquake, an artificial accelerogram proposed by Seed and Idriss (21) was used with maximum base accelerations of 0.4 g and 0.75 g. Two embankments were analyzed in this case and their calculated natural periods ranged between 0.8 sec and 1.5 sec. Table 4 shows the details of the calculations and in Fig. 10(a) the results of the permanent displacement computations are presented. As can be seen from Fig. 10(a) the permanent displacements computed for a ratio of k_y/k_{max} of 0.2 ranged between 200 cm–700 cm (80 in.–28 in.), and for ratios higher than 0.5 the values were less than 100 cm (40 in.). Note in this case that values of deformations calculated for a yield ratio less than 0.2 may not be realistic.

An envelope of the results obtained for each of the three earthquake loading

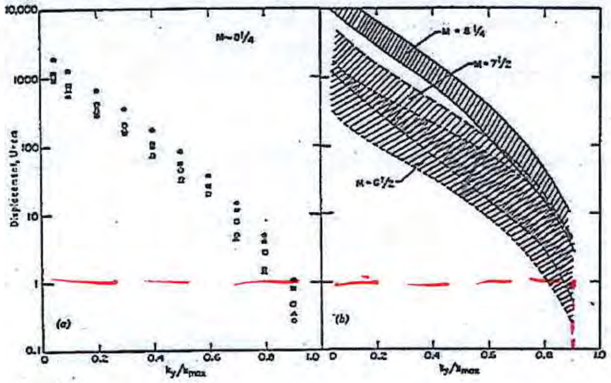


FIG. 10.—Variation of Permanent Displacement with Yield Acceleration: (a) Magnitude 8-1/4 Earthquake; (b) Summary of All Data

conditions is presented in Fig. 10(b) and reveals a large scatter in the computed results reaching, in the case of the magnitude 6-1/2 earthquake, about one order of magnitude.

It can reasonably be expected that for a potential sliding mass with a specified yield acceleration, the magnitude of the permanent deformation induced by a certain earthquake loading is controlled by the following factors: (1) The amplitude of induced average accelerations, which is a function of the base motion, the amplifying characteristics of the embankment, and the location of the sliding mass within the embankment; (2) the frequency content of the average acceleration time history, which is governed by the embankment height and stiffness characteristics, and is usually dominated by the first natural frequency of the embankment; and (3) the duration of significant shaking, which is a function of the magnitude of the specified earthquake.

Thus to reduce the large scatter exhibited in the data in Fig. 10(b), the permanent displacements for each embankment were normalized with respect to its calculated first natural period, T_0, and with respect to the maximum value, k_{max}, of the average acceleration time history used in the computation. The resulting normalized permanent displacements for the three different earthquakes are presented in Fig. 11(a). It may be seen that a substantial reduction in the scatter of the data is achieved by this normalization procedure as evidenced by comparing the results in Figs. 10(b) and 11(a). This shows that for the ranges of embankment heights considered in this study [75 ft–150 ft (50 m–65 m)] the first natural period of the embankment and the maximum value of acceleration time history may be considered as two of the parameters having a major influence on the calculated permanent displacements. Average curves for the normalized permanent displacements based on the results in Fig. 11(a) are presented in Fig. 11(b). Although some scatter still exists in the results as shown in Fig. 11(a), the average curves presented in Fig. 11(b) are considered adequate to provide an order of magnitude of the induced permanent displacements for different

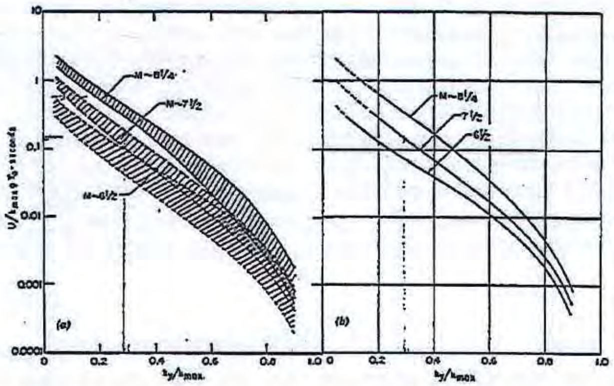


FIG. 11.—Variation of Yield Acceleration with: (a) Normalized Permanent Displacement—Summary of All Data; and (b) Average Normalized Displacement.

magnitude earthquakes. At yield acceleration ratios less than 0.2 the average curves are shown as dashed lines since, as mentioned earlier, the calculated displacements at these low ratios may be unrealistic.

Thus, to calculate the permanent deformation in an embankment constructed of a soil that does not change in strength significantly during an earthquake, it is sufficient to determine its maximum crest acceleration, $\ddot{u}_{max}$, and first natural period, T_0, due to a specified earthquake. Then by the use of the relationship presented in Fig. 7, the maximum value of average acceleration history, k_{max}, for any level of the specified sliding mass may be determined. Entering the curves in Fig. 11(b) with the appropriate values of k_{max} and T_0, the permanent displacements can be determined for any value of yield acceleration associated with that particular sliding surface.

It has been assumed earlier in this paper that in the majority of embankments, permanent deformations usually occur due to slip of a sliding mass on a horizontal failure plane. For those few instances where sliding might occur on an inclined failure plane it is of interest to determine the difference between the actual deformations and those calculated with the assumption of a horizontal failure plane having the same yield acceleration. A simple computation was made to investigate this condition using the analogy of a block on an inclined plane for a purely frictional material. It was found that for inclined failure planes with slope angles of 15° to the horizontal, the computed displacements were 10%–18% higher than those based on a horizontal plane assumption.

Application of Method to Embankment Subjected to 8-1/4 Magnitude Earthquake

To illustrate the use of the simplified procedure for evaluating earthquake-induced deformations, computations are presented herein for the 135-ft (41-m) high Chabot Dam, constructed of sandy clay and having the section shown in Fig. 12.

The shear wave velocity of the embankment was determined from a field investigation and the strain-dependent modulus and damping were determined from laboratory tests on undisturbed samples. The dam, located about 20 miles

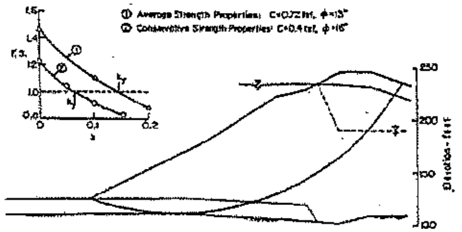


FIG. 12.—Yield Acceleration Values for Slide Mass Extending through Full Height of Embankment

(32 km) from the San Andreas fault, was shaken in 1906 by the magnitude 8-1/4 San Francisco earthquake with no significant deformations being noted; peak accelerations in the rock underlying the dam in this event are estimated to have been about 0.4 *g*. Accordingly the response of the embankment to ground accelerations representative of a magnitude 8-1/4 earthquake and having a maximum acceleration of 0.4 *g* was calculated by a finite element analysis. The maximum crest acceleration of the embankment, $\ddot{u}_{max}$, was calculated to be 0.57 *g* and the first natural period, T_o = 0.99 sec. The maximum values of the calculated shear strain were less than 0.5%. On the basis of static undrained tests on the embankment material, the static failure strains ranged between 3%–8%, so that for the purposes of this analysis the cyclic yield strength of this material can be considered equal to its static undrained strength. From consolidated undrained tests on representative samples of the embankment material two interpretations were made for the strength of the material: (1) Based on an average of all the samples tested resulting in a cohesion value, *c*, of 0.72 tsf (69 kN/m^2) and a friction angle, ϕ, of 13°; and (2) a conservative interpretation, based on the minimum strength values with a cohesion of 0.4 tsf (38 kN/m^2) and a friction angle of 16°. Using these strength estimates, values of yield accelerations were calculated for a sliding mass extending through the full height of the embankment as shown in Fig. 12.

Considering the average relationship of $k_{max}/\ddot{u}_{max}$ with depth shown in Fig. 7, the ratio for a sliding mass extending through the full height of the embankment ($y/h \simeq 0.95$) is 0.35, resulting in a maximum average acceleration, k_{max}, of $0.35 \times 0.57\ g = 0.2\ g$. From Fig. 12 the yield acceleration calculated for the average strength values is 0.14 *g*. Thus the parameters to be used in Fig. 11(*b*) to calculate the displacements for this particular sliding surface are as follows: magnitude = 8-1/4; T_o = 0.99 sec; k_{max} = 0.2; and k_y/k_{max} = 0.14/0.20 = 0.7. From Fig. 11(*b*): $U/k_{max} g\ T_o$ = 0.013 sec, therefore, the displacement $U = 0.013 \times 0.2 \times 32.2 \times 0.99 = 0.08$ ft (0.02 m).

Using the most conservative value of $k_{max}/\ddot{u}_{max}$ shown in Fig. 7 of 0.47, the computed displacement would have been 0.58 ft (0.18 m). Similarly using the conservative strength parameters for the soil (giving k_y = 0.07) and the average curve for $k_{max}/\ddot{u}_{max}$ shown in Fig. 7, the computed displacement would have been 1.5 ft (0.45 m). All of these values are in reasonable accord with the observed performance of the dam during the 1906 earthquake.

The calculation was repeated for a sliding mass extending through half the depth of the embankment. The computed permanent displacements ranged between 0.02 ft–1.08 ft (0.006 m–0.33 m) indicating that the critical potential sliding mass in this case was that extending through the full height of the embankment.

Conclusions

A simple yet rational approach to the design of small embankments under earthquake loading has been described herein. The method is based on the concept of permanent deformations as proposed by Newmark (13) but modified to allow for the dynamic response of the embankment as proposed by Seed and Martin (26) and restricted in application to compacted clayey embankments and dry or dense cohesionless soils that experience very little reduction in strength due to cyclic loading. The method is an approximate one and involves a number of simplifying assumptions that may lead to somewhat conservative results.

On the basis of response computations for embankments subjected to different ground motion records, a relationship for the variation of induced average acceleration with embankment depth has been established. Design curves to estimate the permanent deformations for embankments, in the height range of 100 ft–200 ft (30 m–60 m), have been established based on equivalent linear finite element dynamic analyses for different magnitude earthquakes. The use of these curves requires a knowledge of the maximum crest acceleration and the natural period of an embankment due to a specified ground motion.

It should be noted that the design curves presented are based on averages of a range of results that exhibit some degree of scatter, and are derived from a limited number of cases. These curves should be updated and refined as analytical results for more embankments are obtained.

Finally, the method has been applied to an actual embankment that was subjected to a magnitude 8-1/4 earthquake at an epicentral distance of some 20 miles. Depending on the degree of conservatism in estimating the undrained strength of the material and in estimat... the maximum accelerations in the embankment, the calculated deformations for this 135-ft (40-m) clayey embankment ranged between 0.1 ft–1.5 ft (0.3 m–0.46 m). These approximate displacement values are in good accord with the actual performance of the embankment during the earthquake.

Whereas the method described herein provides a rational approach to the design of embankments and offers a significant improvement over the conventional pseudostatic approach, the nature of the approximations involved requires that it be used with caution and good judgment especially in determining the soil characteristics of the embankment to which it may be applied.

For large embankments, for embankments where failure might result in a loss of life or major damage and property loss, or where soil conditions cannot be determined with a significant degree of accuracy to warrant the use of the method, the more rigorous dynamic method of analysis described earlier might well provide a more satisfactory alternative for design purposes.

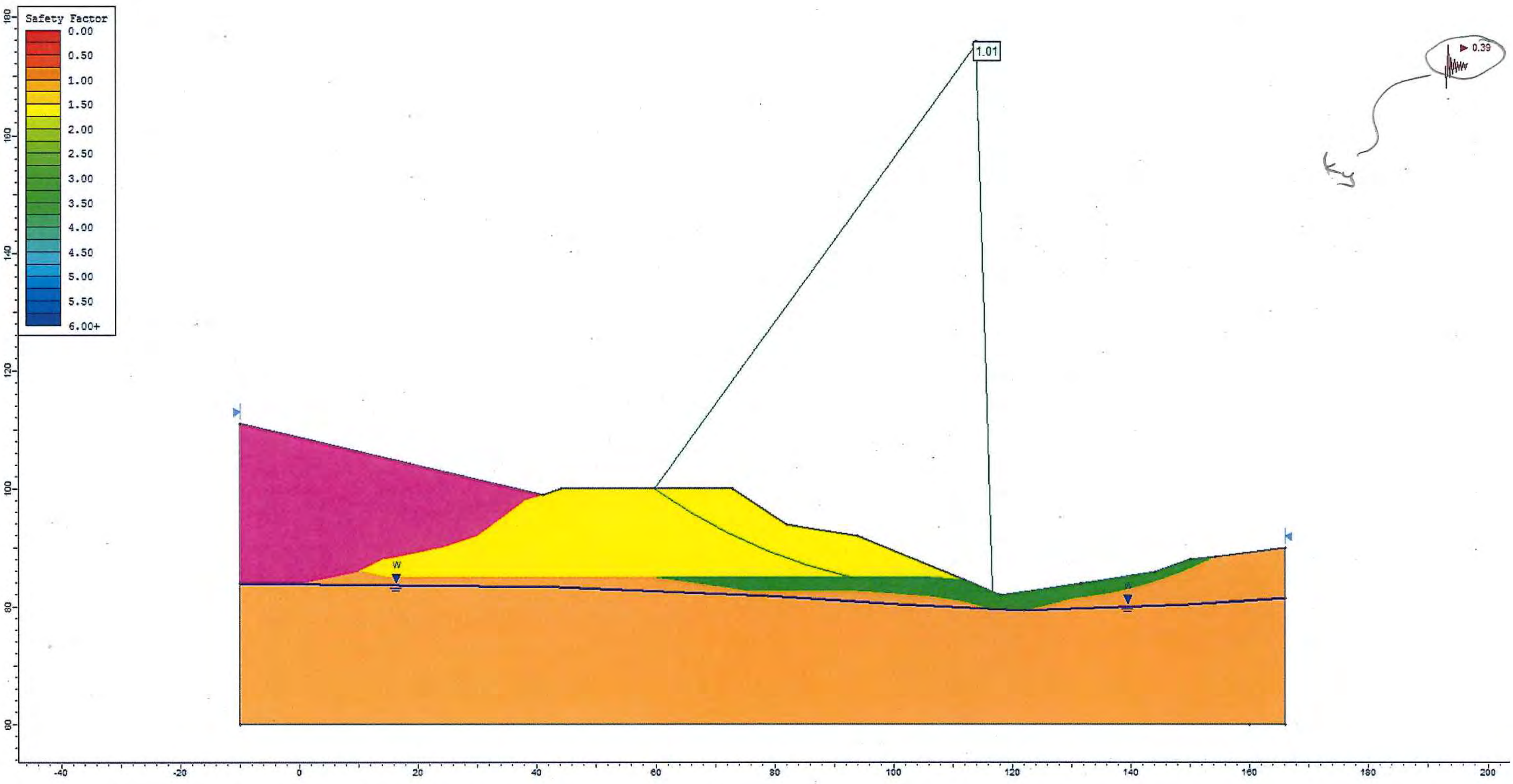
Acknowledgment

The study described in this paper was conducted under the sponsorship of the National Science Foundation (Grant ENV 75-21875). The support of the National Science Foundation is gratefully acknowledged.

Appendix.—References

1. Ambraseys, N. N., and Sarma, S. K., "The Response of Earth Dams to Strong Earthquakes," *Geotechnique*, London, England, Vol. 17, Sept., 1967, pp. 181–213.
2. Andersen, K. H., "Behavior of Clay Subjected to Undrained Cyclic Loading," *Proceedings*, Conference on Behavior of Off-Shore Structures," Trondheim, Norway, Vol. 1, 1976, pp. 392–403.
3. "A Review of Earthquake Resistant Design of Dams," *Bulletin 27*, International Commission on Large Dams, Mar., 1975.
4. Chopra, A. K., "Earthquake Effects on Dams," thesis presented to the University of California, at Berkeley, Calif., in 1966, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.
5. Clough, R. W., and Chopra, A. K., "Earthquake Stress Analysis in Earth Dams," *Journal of the Engineering Mechanics Division*, ASCE, Vol. 92, No. EM2, Proc. Paper 4793, Apr., 1966, pp. 197–212.
6. Idriss, I. M., et al., "QUAD-4, A Computer Program for Evaluating the Seismic Response of Soil Structures by Variable Damping Finite Elements," *Report No. EERC 73 16*, Earthquake Engineering Research Center, University of California, Berkeley, Calif., June, 1973.
7. Idriss, I. M., and Seed, H. B., "Response of Earth Banks During Earthquakes," *Journal of the Soil Mechanics and Foundations Division*, ASCE, Vol. 93, No. SM3, Proc. Paper 5232, May, 1967, pp. 61–82.
8. Kovacs, W. D., Seed, H. B., and Idriss, I. M., "Studies of Seismic Response of Clay Banks," *Journal of the Soil Mechanics and Foundations Division*, ASCE, Vol. 97, No. SM2, Proc. Paper 7878, Feb., 1971, pp. 441–455.
9. Lee, K. L., "Seismic Permanent Deformations in Earth Dams," *Report No. UCLA-ENG-7497*, School of Engineering and Applied Science, University of California at Los Angeles, Los Angeles, Calif., Dec., 1974.
10. Lee, K. L., and Seed, H. B., "Dynamic Strength of Anisotropically Consolidated Sand," *Journal of the Soil Mechanics and Foundations Division*, ASCE, Vol. 93, No. SM5, Proc. Paper 5451, Sept., 1967, pp. 169–190.
11. Makdisi, F. I., and Seed, H. B., "A Simplified Procedure for Computing Maximum Crest Acceleration and Natural Period for Embankments," *Report No. UCB/EERC-77/19*, Earthquake Engineering Research Center, University of California, Berkeley, Calif., 1977.
12. Martin, G. R., "The Response of Earth Dams to Earthquakes," thesis presented to the University of California, at Berkeley, Calif., in 1965, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.
13. Newmark, N. M., "Effects of Earthquakes on Dams and Embankments," *Geotechnique*, London, England, Vol. 5, No. 2, June, 1965.
14. Rahman, M. S., "Undrained Behavior of Saturated Normally Consolidated Clay Under Repeated Loading," thesis presented to the Indian Institute of Technology, at Kharahpur, India, in July, 1972, in partial fulfillment of the requirements for the degree of Master of Science.
15. Sangrey, D., Henkel, D., and Esrig, M., "The Effective Stress Response of a Saturated Clay Soil to Repeated Loading," *Canadian Geotechnical Journal*, Vol. 6, No. 3, Aug., 1969, pp. 241–252.
16. Sarma, S. K., "Seismic Stability of Earth Dams and Embankments," *Geotechnique*, London, England, Vol. 25, No. 4, Dec., 1975, pp. 743–761.
17. Schnabel, P. B., and Seed, H. B., "Accelerations in Rock for Earthquakes in the Western United States," *Report No. EERC 72-2*, Earthquake Engineering Research Center, University of California, Berkeley, Calif., July, 1972.
18. Seed, H. B., "A Method for Earthquake-Resistant Design of Earth Dams," *Journal of the Soil Mechanics and Foundations Division*, ASCE, Vol. 92, No. SM1, Proc. Paper 4616, Jan., 1966, pp. 13–41.
19. Seed, H. B., "A Case Study of Seismic Instability and Terzaghi Foresight," Terzaghi Memorial Lecture Program, Bogazici University, Istanbul, Turkey, Aug. 14–16, 1973.
20. Seed, H. B., and Chan, C. K., "Clay Strength Under Earthquake Loading Conditions," *Journal of the Soil Mechanics and Foundations Division*, ASCE, Vol. 92, No. SM2, Proc. Paper 4723, Mar., 1966, pp. 53–78.
21. Seed, H. B., and Idriss, I. M., "Rock Motion Accelerograms for High Magnitude Earthquakes," *Report No. EERC 67-7*, Earthquake Engineering Research Center, University of California, Berkeley, Calif., Apr., 1969.
22. Seed, H. B., and Idriss, I. M., "Influence of Soil Conditions on Ground Motions During Earthquakes," *Journal of the Soil Mechanics and Foundations Division*, ASCE, Vol. 95, No. SM1, Proc. Paper 6347, Jan., 1969, pp. 99–137.
23. Seed, H. B., and Lee, K. L., "Liquefaction of Saturated Sands During Cyclic Loading," *Journal of the Soil Mechanics and Foundations Division*, ASCE, Vol. 92, No. SM6, Proc. Paper 4972, Nov., 1966, pp. 105–134.
24. Seed, H. B., Lee, K. L., and Idriss, I. M., "Analysis of the Sheffield Dam Failure," *Journal of the Soil Mechanics and Foundations Division*, ASCE, Vol. 95, No. SM6, Proc. Paper 6906, Nov., 1969, pp. 1453–1490.
25. Seed, H. B., et al., "Analysis of the Slides in the San Fernando Dams during the Earthquake of February 9, 1971," *Report No. EERC 73-2*, Earthquake Engineering Research Center, University of California, Berkeley, Calif., June, 1973.
26. Seed, H. B., and Martin, G. R., "The Seismic Coefficient in Earth Dam Design," *Journal of the Soil Mechanics and Foundations Division*, ASCE, Vol. 92, No. SM3, Proc. Paper 4824, May, 1966, pp. 25–58.
27. Serff, N., et al., "Earthquake Induced Deformations of Earth Dams," *Report No. EERC 76-4*, Earthquake Engineering Research Center, University of California, Berkeley, Calif., Sept., 1976.
28. Terzaghi, K., "Mechanisms of Landslides," The Geological Society of America, Engineering Geology (Berkey) Volume, Nov., 1950.
29. Thiers, G. R., and Seed, H. B., "Strength and Stress-Strain Characteristics of Clays Subjected to Seismic Loads," *ASTM STP 450*, Symposium on Vibration Effects of Earthquakes on Soils and Foundations, American Society for Testing and Materials, 1969, pp. 3–56.

Appendix C



Safety Factor
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
6.00+
1.01
0.39
Ky
W
180
160
140
120
100
80
60
-40
-20
0
20
40
60
80
100
120
140
160
180
200

Appendix G. Landfill Capping Concept Design Report

AB Lime Landfill

Landfill Capping Concept Design

IZ000400-0008-CG-MEM-0004 | 5

August 25, 2020

AB Lime Limited

AB Lime Landfill

Project No:	IZ000400
Document Title:	Landfill Capping Concept Design
Document No.:	IZ000400-0008-CG-MEM-0004
Revision:	5
Document Status:	
Date:	August 25, 2020
Client Name:	AB Lime Limited
Project Manager:	Katrina Wilkinson
Author:	
File Name:	Landfill Capping Concept Design - Rev 5.docx

Jacobs New Zealand Limited

Level 2, Wynn Williams Building
47 Hereford Street
Christchurch Central
PO Box 1147, Christchurch 8140
New Zealand
T +64 3 940 4900
F +64 3 940 4901
www.jacobs.com

Document history and status

Revision	Date	Description	Author	Checked	Reviewed	Approved
0	25/10/17	Memo for client review	RK	CW	CW	RG
1	15/11/17	Memo for peer review	RK	CW	CW	RG
2	10/04/18	Memo for peer review	RK	KT	CW	RG
3	23/04/18	Memo for peer review	RK	KT	CW	RG
4	25/07/18	Memo for peer review	RK	CW	CW	RG
5	25/08/20	For section 92 responses	DWH	CW	CW	VP

Contents

Important note about your report

The sole purpose of this report and the associated services performed by Jacobs New Zealand Limited (Jacobs) is to present the concept capping design in accordance with the scope of services set out in the contract between Jacobs and AB Lime Ltd. (Client). The scope of services was developed with the Client.

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by the Client. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our conclusions as expressed in this report may change.

Jacobs derived the data in this report from information sourced from the Client and/or available in the public domain at the time or times outlined in this report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report. Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to application, standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outline above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

This report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by Jacobs for use of any part of this report in any other context.

This report has been prepared on behalf of, and for the exclusive use of Jacobs Client, and is subject to, and issued in accordance with, the provision of the contract between Jacobs and the Client. Jacobs accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report by any third party.

1. Introduction

AB Lime no longer have a ready supply of suitable clay to continue using the current landfill capping arrangement. As a result, AB Lime have requested Jacobs to undertake an assessment of an alternative landfill capping option for the site. Following review of the Technical Guidelines for Disposal to Land, produced by the Waste Management Institute of New Zealand (August 2018) with respect to landfill capping, a landfill capping layer utilising a Geosynthetic Clay Liner (GCL) has been deemed the most appropriate replacement to the current design.

The benefits of using clay within the capping layer are that it is flexible, has a low permeability, it is resistant to puncture type damage, and it was previously easily accessed on site. However, the quality control and construction of the clay liner was a challenge in the Southland climate.

The proposed alternative GCL design is considered favourably, and is less permeable compared with the clay, is comparably flexible, is also resistant to puncture type damage with the swelling bentonite layer within the GCL. A GCL also forms part of the existing lining layer and therefore construction staff understand are familiar with the product and its construction.

This report provides a conceptual level design of the proposed alternative capping layer.

2. Current Capping Specification

The current capping design, as specified in Consent No 201346 – Discharge of Solid Waste and Leachate, is:

"Final cover and capping shall be constructed to the following minimum specification, from bottom to top, as each stage of the landfill is completed:

- *300 millimetres intermediate cover/regulating layer of compacted quarry overburden;*
- *600 millimetres of compacted clay, overburden or soil material, with a permeability coefficient (k) of not more than 1×10^{-7} metres per second; and*
- *150 millimetres of growing medium."*

AB Lime also added an additional 300 mm thick layer of knaprock between the clay layer and the growing medium. Figure 1 shows the current capping design as per the SKM design drawing: Landfill Cap, Area 1, Cap Cross Section Detail, dated 2 February 2009.

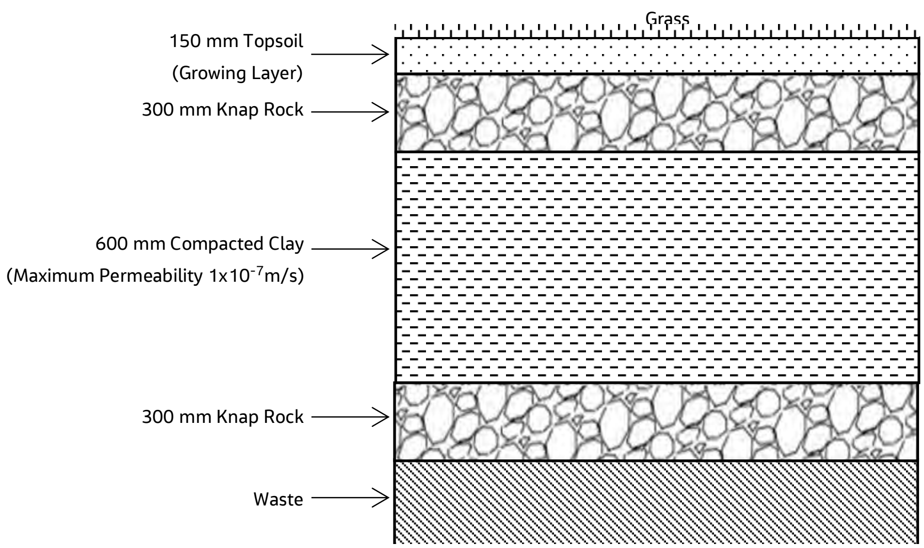


Figure 1: Current cap design.

3. Proposed Alternative Capping Option

The proposed alternative capping design, as shown in Figure 2, is a GCL and site sourced material solution.

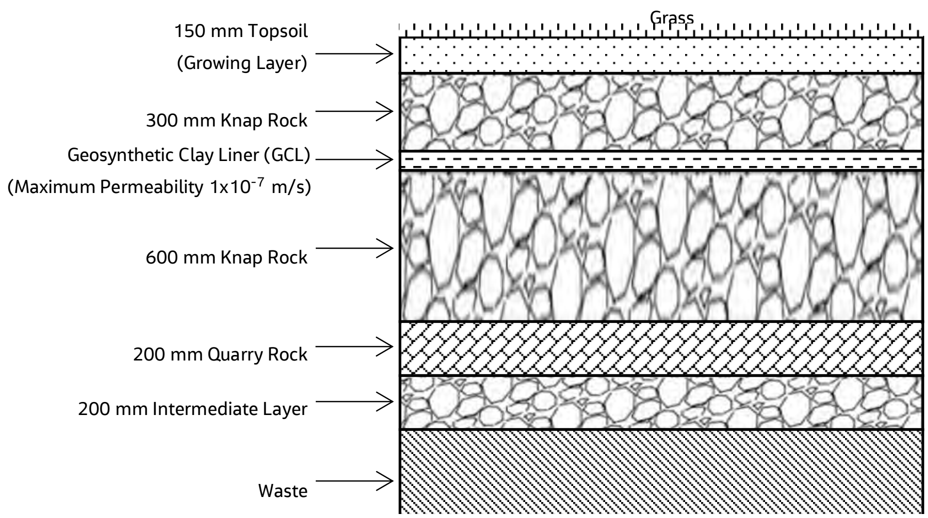


Figure 2: Conceptual GCL capping option.

The proposed design utilises various site sourced materials that are summarised below:

- Topsoil; the purpose of this layer is to provide a growing medium for vegetation to take growth on the landfill cap.
- Knaprock (top layer); the purpose of this layer is to provide a protective layer above the GCL.
- GCL layer with a maximum permeability of $1x10^{-7}$m/s.
- Knaprock (bottom layer); the purpose of this layer is to provide a smooth surface to place the GCL on top of, and to act as an additional contaminant barrier. This layer will need to be compacted to allow a smooth surface suitable for the GCL to be constructed on.
- Quarry Rock; the purpose of this layer is to provide a robust platform that will assist in the compaction of the above knaprock layer.
- Intermediate layer; this layer is also using a knaprock material, and its purpose is to provide a uniform platform of which the remaining layers of the capping design can be built upon.

The fundamental component of the design is the GCL layer; the proposed GCL will be from the EnviroFix X800-X2000 range, these of which have a permeability between 1.8 to $2.6x10^{-11}$m/s.

The principle advantage of using a GCL is that this will make the construction and quality assurance process of the capping construction significantly easier to undertake than previously required. This alternative capping arrangement will produce a superior landfill capping product due to the lower permeability of the GCL, as well as its ability to handle 15%-50% (product dependent) of elongation. Further information, design and construction requirements and installation guidance provided for the EnviroFix X800-X2000 range by the local supplier, AEL (Aspect Environmental Lining), are attached to this memorandum (Attachments 1-4).

4. Risk Assessment

4.1 Landfill Degradation and Gas Production

It is understood that the implementation of a GCL capping layer at the AB Lime landfill will not significantly change the rate of degradation within the landfill. However, owing to the lack of information around the current rates of degradation at AB Lime, it is recommended that the rate of waste degradation and associate settlement should be quantified going forward.

The GCL capping layer is regarded as being a very good gas boundary layer due to its low permeability (1.8 to 2.6×10^{-11}m/s), and given the current gas collection system, this should result in an increased volume of landfill gas being captured. However, we do understand that perforations through the landfill cap are areas where landfill gas is known to typically escape. Therefore, we recommend that the detailed design should address an appropriate cap perforation design. The design should specifically minimise the potential for landfill gas to escape around the perforations, and to minimise the potential for the bentonite within the GCL to come in contact with the knaprock.

4.2 Slope Stability

We understand that the EnviroFix range of products are approved for slopes up to 3.5H:1V with the addition of an appropriately designed anchor trench. The current landfill capping design does not exceed 3.5H:1V, and hence we do not foresee any major issues associated with the product itself. The stability of the slope and the requirements of the GCL and any associated anchor trenches will need to be evaluated at the detailed design stage. It is noted that if a steeper capping slope is required, or if issues arise during construction trial, then shearbox testing of the knaprock/GCL interface may be required.

It is important to note that when spreading the knaprock above the GCL, this will need to proceed in a bottom to top approach to eliminate the possibility having a perched mass of soil.

4.3 Total and Differential Settlement

Following discussions with the supplier (AEL), there is minimal concern around any detrimental effects on the GCL when subject to total settlements and it is believed that the performance of the GCL will be equivalent or in excess of an equivalent compacted clay layer design when subject to differential settlements. The X800/X1000 is product is noted to be able to elongate in excess of 15% prior to failure, and the X2000 is noted to be able to elongate in excess of 50% before failure.

There has been no settlement monitoring carried out to date, however, initial expectations suggest that the X800 – X2000 range will provide sufficient capacity to allow for the likely settlements. However, this should be confirmed at the detailed design stage as further assessment needs to be undertaken to quantify the likely total and differential settlements. It is also expected that the landfill will experience a significant amount of settlement prior to the installation of the capping layer. AEL suggest that the X2000 should be used if there is any doubt or if a higher factor of safety is required.

4.4 Cation Exchange Potential

The permeability coefficient of the proposed GCL is in excess of the consent requirements, however there is a potential for the calcium cations from the knaprock to exchange with the sodium cations of the sodium bentonite within the GCL, and resultantly increase the permeability of the GCL layer. The SmecTech site specific analysis, (appended to the Jacobs 2014 report) suggests that the increase in GCL permeability with 1 m of overburden material, and with a groundwater ionic strength of 1000mM, was calculated to increase to 1.3×10^{-10}m/s. As a result, the GCL permeability is still orders of magnitude lower than the consent requirement (1×10^{-7}m/s).

SmecTech suggests using the X1000 or equivalent GCL due to its bentonite mass of ≥4kg/m^2.

4.5 Installation

As per the current AB Lime basal liner design, the use of a GCL is not new onsite and hence AB Lime is familiar with working with such a product. This reduces the risk of handling errors, and damage to the GCL during transportation and installation. The quality assurance and quality control associated with the GCL is believed to be simpler than that required for the compacted clay. This should result in a higher confidence of the final product.

Low ground pressure equipment should be used to spread the upper knaprock and topsoil layers, and if any temporary roads or semi-regular traffic loadings are expected then this will need to be allowed for in the design.

5. Discussions and Recommendations

The permeability of the GCL is well below the maximum permeability that has been approved within the consent, and thus the proposed new design can be considered equivalent and likely in excess of the current consented design in terms of the cap permeability. When differential and total settlements are considered it is believed that the performance of the GCL will be equivalent or in excess of the current compacted clay design. Given the recommendations from SmecTech and the unknown settlements the GCL needs to be able to withstand at this preliminary stage, we recommend that the X2000 GCL is used within the capping design to provide a sufficiently robust capping design.

We recommend a construction trial of the proposed new liner on the landfill to ensure its constructability. Then when this construction trial is complete the capping design should be progressed to the detailed design phase.

Attachment 1 – Envirofix Data Sheets

Johannesburg +27 (0)11 922 3300
Pinetown +27 (0)31 717 2300
Cape Town +27 (0)21 531 8110
East London +27 (0)43 727 1055
www.kaytech.co.za

TECHNICAL DATA SHEET

Product Name enviroFIX X 800

Reference No: DS WAST 0498-08/2013 Rev 1

Date of Issue 06 November 2015

Description Envirofix is a geosynthetic clay liner

1213-CP

(European Conformity)

			MARV (min average roll value)	Factory QC Test Frequency (m^2)	
Geotextile Cover Layer	PP nonwoven, white	g/m^2	200	4 000	ASTM D5261
Geotextile Carrier Layer	PP slit film, woven	g/m^2	110	4 000	ASTM D5261
	PP nonwoven, white	g/m^2	N/A		
	Composite	g/m^2	N/A		
Bentonite Layer (bentonite mass at 0% moisture content)	Quality	Montmorillonite content > 75 %, Sodium Cation Na^+ > 60 %			
	Sodium Bentonite Powder	g/m^2	3 700	4 000	ASTM D5993
	Swell Index (minimum)	mℓ/2 g	≥ 24	35 tonnes	ASTM D5890
GCL Mass per Unit Area		g/m^2	4 010	4 000	ASTM D5993
Bonding Process		Needlepunched and Thermal Lock™			
Grab Strength	MD	N	600	4 000	ASTM D4632
	XD	N	600		
CBR Burst	Strength	N	1 400	20 000	ISO 12236
	Elongation	%	≥ 15		
Hydraulic Conductivity (maximum)		m/s	$\leq 2.56 \times 10^{-11}$	25 000	ASTM D5887
Index Flux (pre-hydration thickness 4.5 mm)		$m^3/m^2/s$	6.0×10^{-9}	25 000	ASTM D5887
Peel Strength (excl Edge Treatment)		N/m	> 360	4 000	ASTM D6496
Edge Treatment		800 g/m^2 x 300 mm self-sealing bentonite edge enhancement			
Roll Size (standard)	width x length	m	5.35 x 40	1 % tolerance on width and length	
	diameter	cm	58	Nominal	
	Average roll mass	kg	1 040	Typical	

Manufactured by Kaytech to the ISO 9001:2000 Quality Management System Standard

PP = Polypropylene MD = Machine Direction XD = Cross Direction

KAYTECH
ENGINEERED FABRICS

Johannesburg +2711 922 3300
Pinetown +2731 717 2300
Cape Town +2721 531 8110
East London +2743 727 1055
Port Elizabeth +2741 453 0755
www.kaytech.co.za

TECHNICAL DATA SHEET

Product Name: envirOFIX X 1000

Reference No: DS WAST 0497-08/2013 Rev 1

Date of Issue: 18 July 2014

Description: Envirofix is a geosynthetic clay liner

1213-CP

(European Conformity)

			M A R V (min average roll value)	Factory QC Test Frequency (m^2)	
Geotextile Cover Layer	PP nonwoven, white	g/m^2	200	4 000	ASTM D5261
Geotextile Carrier Layer	PP slit film, woven	g/m^2	110	4 000	ASTM D5261
	PP nonwoven, white	g/m^2	N/A		
	Composite	g/m^2	N/A		
Bentonite Layer (bentonite mass at 0% moisture content)	Quality	Montmorillonite content > 75 %, Sodium Cation Na^+ > 60 %			
	Sodium Bentonite Powder	g/m^2	4 000	4 000	ASTM D5993
	Swell Index (minimum)	mℓ/2 g	≥ 24	35 tonnes	ASTM D5890
GCL Mass per Unit Area		g/m^2	4 310	4 000	ASTM D5993
Bonding Process		Needlepunched and Thermal Lock™			
Grab Strength	MD	N	600	4 000	ASTM D4632
	XD	N	600		
CBR Burst	Strength	N	1 600	20 000	ISO 12236
	Elongation	%	≥ 15		
Hydraulic Conductivity (maximum)		m/s	$\leq 1.85 \times 10^{-11}$	25 000	ASTM D5887
Index Flux (pre-hydration thickness 4.5 mm)		$m^3/m^2/s$	4.0×10^{-9}	25 000	ASTM D5887
Peel Strength (excl Edge Treatment)		N/m	> 360	4 000	ASTM D6496
Edge Treatment		800 g/m^2 x 300 mm self-sealing bentonite edge enhancement			
Roll Size (standard)	width x length	m	5.35 x 35	1 % tolerance on width and length	
	diameter	cm	60	Nominal	
	Average roll mass	kg	970	Typical	

Manufactured by Kaytech to the ISO 9001:2000 Quality Management System Standard

PP = Polypropylene MD = Machine Direction XD = Cross Direction

KAYTECH
ENGINEERED FABRICS

Johannesburg +27 (0)11 922 3300
Pinetown +27 (0)31 717 2300
Cape Town +27 (0)21 531 8110
East London +27 (0)43 727 1055
www.kaytech.co.za

TECHNICAL DATA SHEET

Product Name	enviroFIX X 2000
Reference No:	DS WAST 0496-08/2013 Rev1
Date of Issue	06 November 2015
Description	Envirofix is a geosynthetic clay liner

CE 1213-CP

(European Conformity)

			M A R V (min average roll value)	Factory QC Test Frequency (m^2)	
Geotextile Cover Layer	PP nonwoven, white	g/m^2	200	4 000	ASTM D5261
Geotextile Carrier Layer	PP slit film, woven	g/m^2	110	4 000	ASTM D5261
	PP nonwoven, white	g/m^2	200		
	Composite	g/m^2	310		
Bentonite Layer (bentonite mass at 0% moisture content)	Quality	Montmorillonite content > 75 %, Sodium Cation Na^+ > 60 %			
	Sodium Bentonite Powder	g/m^2	3 700	4 000	ASTM D5993
	Swell Index (minimum)	mℓ/2 g	≥ 24	35 tonnes	ASTM D5890
GCL Mass per Unit Area		g/m^2	4 210	4 000	ASTM D5993
Bonding Process		Needlepunched and Thermal Lock™			
Grab Strength	MD	N	1 500	4 000	ASTM D4632
	XD	N	1 500		
CBR Burst	Strength	N	2 500	20 000	ISO 12236
	Elongation	%	≥ 50		
Hydraulic Conductivity (maximum)		m/s	≤ 1.92 x 10^{-11}	25 000	ASTM D5887
Index Flux (pre-hydration thickness 4.5 mm)		$m^3/m^2/s$	4.5 x 10^{-9}	25 000	ASTM D5887
Peel Strength (excl Edge Treatment)		N/m	> 600	4 000	ASTM D6496
Edge Treatment		800 g/m^2 x 300 mm self-sealing bentonite edge enhancement			
Roll Size (standard)	width x length	m	5.35 x 35	1 % tolerance on width and length	
	diameter	cm	60	Nominal	
	Average roll mass	kg	950	Typical	

Manufactured by Kaytech to the ISO 9001:2000 Quality Management System Standard

PP = Polypropylene   MD = Machine Direction   XD = Cross Direction

Attachment 2 – ELCOSEAL General Information

lining systems

ELCOSEAL®

General Information

The Next Generation,
Australian Made Geosynthetic Clay Liner
Engineered For Performance

NCS INTERNATIONAL
CERTIFIED QUALITY MANAGEMENT SYSTEM
ISO 9001
Accreditation number: S1220792AS
ELCO Solutions Pty Ltd
Certification Number: 8264

ELCO SOLUTIONS PTY LTD
Australian manufacturers of a diverse range of specialist geosynthetics

ELCOSEAL® Geosynthetic Clay Liners

ELCOSEAL® Geosynthetic Clay Liners (GCLs) are needle-punched reinforced composites which combine two durable geotextile outer layers with a uniform core of premium quality sodium bentonite clay to form a hydraulic barrier.

The sodium bentonite clay utilised in ELCOSEAL® GCL's is a high grade clay mineral that swells as water enters between its clay platelets. When hydrated under confinement, the bentonite swells to form a low permeability clay layer with the equivalent hydraulic protection of approximately 1 metre of compacted clay.

ELCOSEAL® GCL's are produced by distributing a uniform layer of the sodium bentonite between two geotextiles. High-tenacity fibres from the upper non-woven geotextile are then needle-punched through the layer of bentonite and incorporated into the lower geotextile (either a woven or a non-woven/woven composite) to provide consistant reinforcement and transfer of shear stresses to the geotextiles.

This process results in a strong mechanical bond between the geotextiles. A proprietary heat treating process — the 'Thermal Lock' process — is used to lock the needle-punched fibres into place. Unique properties, including increased internal shear resistance and long term creep resistance, result from this process.

Typical Applications

LANDFILLS

- Final cover systems
- Base liner systems (single and composite)

ELCOSEAL® can completely or partially replace thick, multi-lift compacted clay layers in composite landfill liners and caps due to the efficiency of the high swelling sodium bentonite clay.

LIQUID CONTAINMENT

- Effluent ponds
- Landscaped ponds and wetlands
- Canal lining

ELCOSEAL® provides exceptional liquid containment - in reservoirs and irrigation canals, as well as industrial ponds and lagoons, due to its low permeability and high internal shear strength.

SECONDARY CONTAINMENT

- Tank farms
- Cut-off trenches

ELCOSEAL® GCL's can also be used as a secondary containment barrier in above ground tank impoundments, due to the ease of installation and reliable pipe penetration construction.

MINING

- Tailing ponds
- Mine closures

ELCOSEAL® GCL's can reduce contaminant transport and help achieve environmental compliance in mining applications such as tailing ponds and mine closures/ rehabilitation.

Properties of Bentonite

The unique swelling properties and low permeability performance of ELCOSEAL®s sodium bentonite can be attributed to the following parameters, to name a few:

- Layer charge distribution & cation exchange capacity;
- Bentonite fluid loss;
- Bentonite swelling pressure;
- Bentonite particle size & pore size distribution;
- Clay fabric.

Refer to the ELCOSEAL® Bentonite Technical Notes for further information.

Uniform Bentonite Content

The uniform confinement provided by the fibres from the needle-punching process resist lateral migration of the bentonite clay within ELCOSEAL® in either the dry or hydrated state. As a result, a consistent bentonite content is preserved throughout the composite, in turn resulting in a consistently low permeability.

High Shear Resistance

Needle-punching reinforces the otherwise weak layer of sodium bentonite clay, producing a uniform, reinforced GCL. Unreinforced bentonite is susceptible to shear failure, even on gentle slopes.

The ELCOSEAL® needle-punching process reinforces the bentonite layer with thousands of high tenacity fibres. These fibres resist and transfer the shearing stresses into the encapsulating geotextiles to provide shear strength and stability advantages important to any application.

Edge Sealing

The edges of ELCOSEAL® GCL are overlocked to prevent loss of bentonite along the edges of the roll. This is achieved by extending the woven carrier geotextile around the edge of the GCL. This technique provides a sealed GCL edge that prevents bentonite loss along the edges which can reduce the sealing performance of the system.

Permeability Performance

When specifying GCL's, particularly in landfill applications, a historical data set that consistently exceeds specification values provides peace of mind for consulting engineers and specifiers. ELCOSEAL® GCL's demonstrate a measured permeability performance that has been reliably better than the specification value over a considerable period of time. Refer to the graph of ELCOSEAL® X1000 measured permeabilities from 2002 to 2006 compared to the X1000 specified permeability

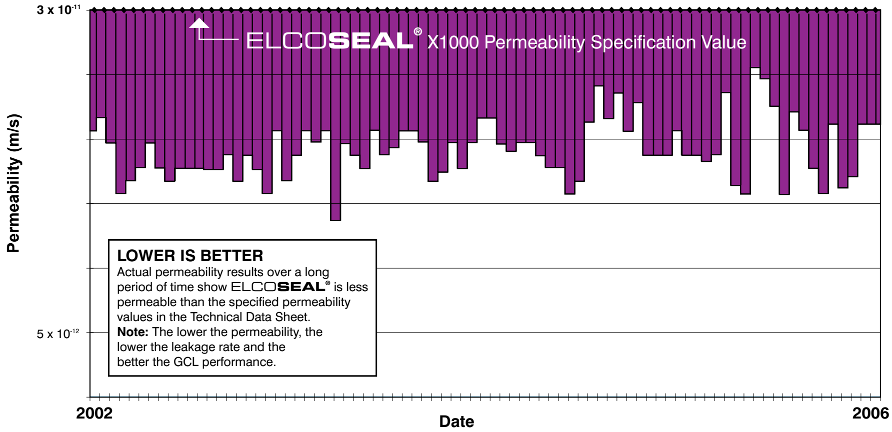
Assured Quality Control

ELCOSEAL® is a factory manufactured liner product, therefore, the controlled environment of the production facility allows for greater control over critical performance characteristics. The intensive ELCOSEAL® quality control program ensures consistent hydraulic and physical properties through the latest AS and ASTM procedures. Additionally, the published specification values for each ELCOSEAL® GCL grade are independently verified by a 3rd party accredited GAI-LAP laboratory on an annual basis. Refer to the Manufacturers QA & QC for ELCOSEAL® GCL's document for further information. The thorough manufacturing quality control minimises the expensive and time consuming on-site quality assurance testing, which is required for other lining systems.

Installation Quality Control

Due to the simplicity of ELCOSEAL® GCL deployment, specialist labour and equipment is not required for installation. Therefore, GCL installation quality control is generaly less complicated than other types of lining systems. **Geofabrics Australasia** is able to provide on-site assistance, in accordance with the ELCOSEAL® Installation Guidelines, to personnel unfamiliar with the installation of ELCOSEAL® GCL's.

ELCOSEAL® X1000 Permeability Results - 2002 to 2006

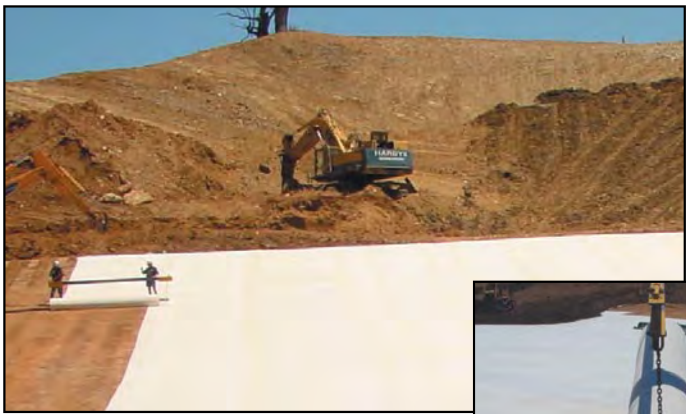


Installation

ELCOSEAL® GCL is an exceptionally easy to use hydraulic barrier. During installation, the needle-punched fibres hold the bentonite in place and prevent the GCL from separating. ELCOSEAL® is more durable over a wider range of installation conditions, and because it is needle-punched, it can greatly reduce the adverse effects of premature hydration during installation.

Edge Impregnation

ELCOSEAL® has bentonite impregnated longitudinal overlaps which allow simple on-site joining. This, combined with overlap witness markings 300mm from each edge of the roll, enable fast, easy deployment of GCL.



Manufacturing Flexibility

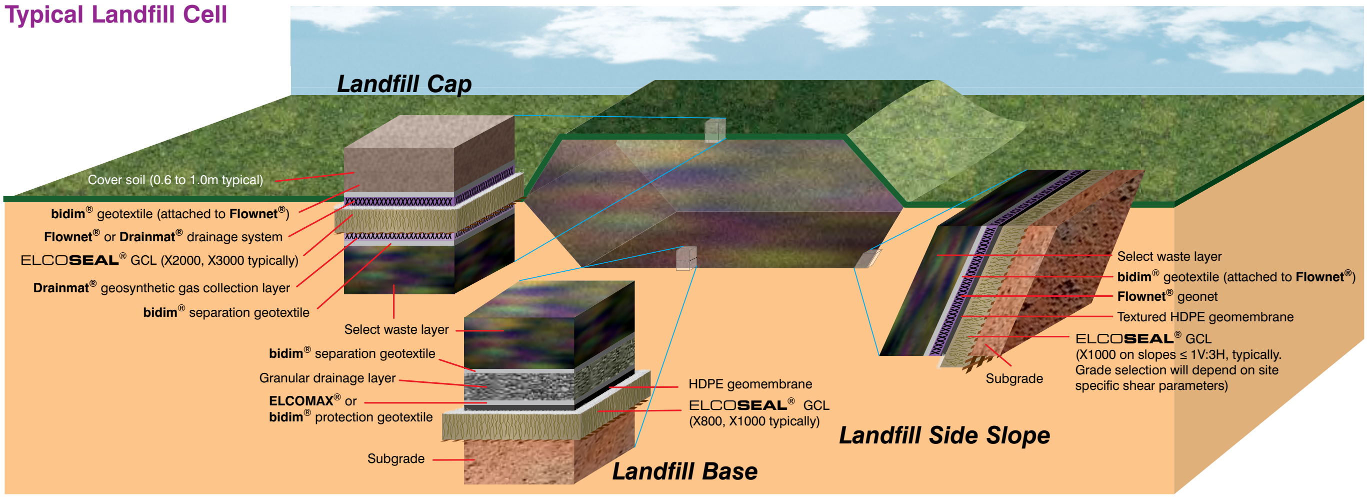
ELCO Solutions have manufactured geosynthetics since 1978 and GCL's since 1995 at their plant in Southport, Qld. This extensive experience enables flexibility in the manufacture of ELCOSEAL® GCL's. The ELCOSEAL® manufacturing plant has the ability to produce both custom grades and non-standard roll lengths, within reasonably short lead times. The plant has the flexibility to manufacture a GCL to suit virtually any specification. ELCOSEAL® GCL's can also be supplied in custom roll lengths to suit project specific requirements, such as long slope lengths.

ELCOSEAL® Geosynthetic Clay Liners

ELCOSEAL® GCL's are More Versatile Than Compacted Clay

ELCOSEAL® GCL's are part of an important trend toward the combined use of geosynthetics and clay materials in containment applications. In a typical composite liner system, GCL's work synergistically with polyethylene and other geomembrane materials to maximise liner system efficiency.

Typical Landfill Cell



Increased Airspace and Liner Efficiency

In a composite landfill liner system, ELCOSEAL® can in many cases completely replace, or significantly reduce, the required thickness of the compacted clay layer. This results in less excavation and recompaction, as well as increased containment volume. In a landfill, increased airspace means increased revenues. With ELCOSEAL® GCL's, the clay component is no longer the limiting factor on side slopes. You can use ELCOSEAL® to replace compacted clay layers on steep side slopes and be assured of low permeability without sacrificing slope stability. The inherent confining stress from the needle-punching also improves the hydraulic properties of ELCOSEAL® under low confining stress applications.

Contact your nearest ELCO Solutions office for any further information on:

- ELCOSEAL® Installation Guidelines
- Technical Data Sheet
- GCL Technical Notes
- Bentonite Technical Notes
- Manufacturers Quality Assurance & Control for ELCOSEAL® Geosynthetic Clay Liners
- GCL Model Specification

Manufactured by ELCO **Solutions Pty Ltd** to the ISO 9001:2000 Quality Management System Standard
ELCOSEAL® is a registered trademark of ELCO SOLUTIONS PTY LTD

www.elcos.com

PO Box 727 Southport Queensland 4215, Australia
Telephone: + 61 7 5500 1400 - Fax: + 61 7 5539 4027
Email: sales@elcos.com.au

Attachment 3 – ELCOSEAL Installation Guidelines

lining systems

ELCOSEAL®

Installation Guidelines

**The Next Generation,
Australian Made Geosynthetic Clay Liner
Engineered For Performance**

NCS INTERNATIONAL
CERTIFIED QUALITY MANAGEMENT SYSTEM
ISO 9001
Accreditation number: S1220792AS
ELCO Solutions Pty Ltd
Certification Number: 8264

ELCO
SOLUTIONS PTY LTD
Australian manufacturers of a diverse range of specialist geosynthetics

Index

1. INTRODUCTION

ELCOSEAL®[1] is a needle-punched Geosynthetic Clay Liner (or GCL) produced in Australia in accordance with the ISO 9001:2000 Quality Management System.

ELCOSEAL® consists of premium grade sodium bentonite powder, which acts as the swelling and sealing component, embedded and sandwiched between two or more geotextiles. The composite is then needle-punched through all layers and thermally-locked developing high connection strength. Thus, ELCOSEAL® is a shear strength transmitting GCL.

ELCOSEAL® is generally fast and easy to install, however the performance of the GCL is dependent on the quality of its installation. It is the installer's responsibility to follow these guidelines and the project specifications and drawings whenever possible. It is the engineer's and owner's responsibility to provide construction quality assurance (CQA) for the installation to ensure that the installation has been executed properly. Variance from this guideline is at the engineer's discretion.

Recommended further reading:-

1. ASTM D5888 - "Standard Guide for Storage and Handling of GCL's"
2. ASTM D6102 - "Standard Guide for Installation of GCL's"
3. ASTM D5889 - "Standard Practice for Quality Control of GCL's"
4. ASTM D6072 - "Standard Guide for Obtaining Samples of GCL's"

2. PACKAGING, TRANSPORTATION & UNLOADING ON SITE

ELCOSEAL® rolls are packed in moisture tight plastic wrapping. The standard roll dimensions and weights are listed in Table 1. Every ELCOSEAL® roll has a unique roll number on the wrapping label and on the panel itself.

Table 1 - ELCOSEAL® standard grade roll dimensions and weight.

Grade	Width (m)	Length (m)	Diameter (m)	Mass (kg)
X800	4.7	35 or 45	~0.55	~800 or ~975
X1000	4.7	35	~0.52	~875
X2000	4.7	30	~0.52	~730
X3000	4.7	30	~0.55	~825

Note: Up to 15% of rolls may contain a join over the length. These rolls are marked on the outside of the wrapping with a green circular sticker indicating a join and the individual panel lengths.

ELCOSEAL® rolls are usually delivered to site in closed containers or covered trailers on flatbed trucks. At the point of unloading the rolls need to be accessible either from the top of the trailer or the container opening.

Should any damage to rolls occur in transit it must be immediately brought to the attention of the Supplier, who will advise on the required course of action.

A flat, hard, dry and free draining surface must be provided for unloading and storage. Rolls may be off-loaded using:-

- **a Spreader Bar with steel tube insert through the core of the rolls. Refer to Section 8 and the "ELCOSEAL® Spreader Bar Safe Usage Guideline" in the ELCOSEAL® Product folder for detailed information.**
- or ELCOSEAL® may be unloaded and handled using a 'carpet prong' protruding from the front end of a forklift (>3.5 tonne) or other equipment. The prong should be at least 3/4 the length of the core and also must be capable of supporting the full weight of ELCOSEAL® without significant bending.
- the two slings provided by the manufacturer (upon request) wrapped around the ELCOSEAL® roll at third (1/3) points, fixed to an excavator bucket or a front-end loader. Slings should not be used for general lifting and transportation around the site. If excessive deformation or bending of the roll occurs the integrity of the composite may be affected. A steel tube or similar reinforcement can be inserted into the core of the roll to prevent excessive deformation across the roll during off-loading.

Under no circumstances should ELCOSEAL® rolls be dragged, lifted by one end only, pushed to the ground from the delivery vehicle, or otherwise unloaded in a fashion which could damage the roll.

After transportation and unloading the plastic wrapping should be checked. Minor damage should be repaired with weather-resistant adhesive tape. Wrapping should only be removed immediately before use. The maximum storage height is four rolls.

1. ELCOSEAL® is a trademark of ELCO SOLUTIONS PTY LTD

3. STORAGE

ELCOSEAL® rolls should be stored in their original, unopened packaging in a location away from construction traffic but sufficiently close to the active work area to minimise handling.

The designated storage area should be level, dry, well-drained, stable, and should protect the product from:-

- precipitation
- chemicals
- standing water
- excessive heat
- ultraviolet radiation
- vandalism and animals

ELCOSEAL® rolls should always be stored lying flat, continuously supported, and should never be stored standing on one end. Enclosed indoor storage such as shipping containers or a warehouse environment is preferred if ELCOSEAL® is to be stored for long periods.

4. INSTALLATION REQUIREMENTS

- Excavator (tracked or wheeled) or front-end loader
- Spreader Bar/Loading Frame
- Bentonite Paste, available in 2 options:-
  Option A - Premixed from the supplier in 20 litre buckets (Undercoat and Topcoat).
  Option B - 25 kg bag of TruGel® powder to be mixed on site.
  - Water (water container)
  - Heavy duty drill with industrial whisk (high shear force required)
  - Mixing containers
- Trowel
- Carpet knife or knife with covered blade (for safety)
- Felt pens or chalk
- Measuring tape
- Broom
- Dusk Masks & Goggles (optional) - refer to ELCOSEAL® MSDS for recommended Dust Mask.

5. INSTALLATION TEAM

Before installing ELCOSEAL® this guideline should be read thoroughly by the installation personnel. The installation team should be aware of their individual roles in ensuring a quality installation. Any questions raised by the installation team that cannot be answered by this document should be referred immediately to the Supplier.

6. SUBGRADE PREPARATION

The preparation of the subgrade before placement of any lining material is critical to the system's performance. The surface(s) upon which ELCOSEAL® is to be laid should be suitable for the intended application and function.

ELCOSEAL® will generally be placed on either an earthen (eg. compacted clay) or geosynthetic (eg. geotextile or geocomposite) subgrade.

6.1 Earthen Subgrades

The surface upon which ELCOSEAL® will be deployed should conform to the following:-

- The subgrade should be firm and unyielding (typically compacted to >90% density), without abrupt elevation changes, and be proof rolled with a smooth drum roller immediately prior to deployment of the panels. The subgrade should not be disturbed or rutted by the equipment deploying the rolls or other traffic. No foreign matter or stones loose on the surface or penetrating out of the subgrade >10mm should be allowed. The engineers approval of the sugbrade needs to be obtained immediately prior to roll deployment.

- In applications where ELCOSEAL® is the sole or primary barrier, and will be subjected to constant or long-term hydraulic heads exceeding 300mm (1 foot), subgrade surfaces consisting of gravel or granular soils may not be appropriate due to their large void contents and puncture potential. In these applications, the top 150mm of the subgrade should possess a particle size distribution where at least 80% of the soil is finer than 0.25mm (or #60 sieve) - unless the ELCOSEAL® grades X2000 or X3000 are being used, (see below).

  For X2000 and X3000 grades (with a composite woven/nonwoven carrier geotextile) in high hydraulic head applications:-

  Subgrade materials **recommended** without further investigation are:-

  - Clays or clay-based mixes
  - Sandy Clays (with > 20 % fines)
  - Silty or Loamy Clays (with > 20% fines)
    [fine grained soils should be placed at suitable moisture contents for construction operations and roll deployment - that provide adequate bearing capacity to deploy the rolls without disturbance of the subgrade - ie no rutting or large deflections]
  - Well graded sands and gravels (d_{max} < 32 mm, d_{60} < 5mm, d_{20} < 0.15mm)
    [these materials should bind and have good bearing capacity when compacted/rolled.]

  Subgrade materials **not recommended** without further investigation:-

  - Single-sized and gap-graded sands and gravels of any size or description.
  - Sands or soils that have low bearing capacity at the moisture contents during the construction/ deployment operations (ie materials that do not bind when rolled, or will heave or shove under equipment or foot traffic during or after deployment).
  - Subgrades that have a bony or porous appearance after compaction and rolling.

6.2 Geosynthetic Subgrades

When deploying ELCOSEAL® over a geosynthetic material such as a geomembrane or geotextile, the surface should be firm and unyielding as per the requirements for Earthen Subgrades. The equipment used to deploy ELCOSEAL® should be approved for use by the Design Engineer and/or the Supplier of the underlying geosynthetic material. Generally, the underlying geosynthetic and ELCOSEAL® rolls will be deployed consecutively such that each layer is side-cast from equipment tracking over the earthen subgrade - unless specialised light rubber tyred dispensers are available and approved by the Design Engineer that allow direct trafficking over the geosynthetics.

6.3 Anchor Trenches

Anchor trench and slope stability considerations should be assessed by the Design Engineer.

As a general guide: -

- An anchor trench should be used at the top of slopes steeper than 7H: 1V. (see Figure 15 for a typical anchor trench detail).
- The anchor trench should be constructed free of sharp edges or corners and maintained in a dry condition. The ELCOSEAL® panels should be placed down the front face and along the base of the anchor trench. The base of the anchor trench should not contain large gravel or loose material and the trench backfill material should be compacted.

7. WEATHER CONDITIONS FOR INSTALLATION

Light rainfall[1] should not affect the installation of ELCOSEAL® provided deployed panels are covered and confined by 300mm of cover soil (or equivalent) within 2 hours of first exposure to the light rain. Heavy direct raindrop impact should be avoided. The ELCOSEAL® panels can be covered during heavy rainfall events with a tarpaulin or plastic sheet if there is not enough time to complete soil cover placement.

Avoid placing ELCOSEAL® in areas where water is ponding unless panels can be confined immediately (with 300 mm cover soil or equivalent).

1. Light rainfall is defined as < 5mm / hr intensity

8. ELCOSEAL® GCL PLACEMENT

The ELCOSEAL® roll wrapping should only be removed immediately prior to installation. On site, ELCOSEAL® is unrolled along the prepared subgrade using the Spreader Bar assembly as shown in Figures 1 and 2.

ELCOSEAL® should only be trafficked by light, low tyre pressure vehicles (no tracked vehicles).

Rolls must be laid without folds on the subgrade with a standard overlap of 300 mm in both the longitudinal and transverse direction. For longitudinal or edge overlaps, the blue coloured line on the underside of the panels can be used to ensure the correct overlap width. The edge of deployed or previously placed panels needs to coincide or match with the visible blue line on the roll being deployed.

The transverse or end overlaps need to be sealed using bentonite paste that is applied in 2 layers with different consistencies. The treatment of end (transverse) overlaps is detailed in Section 10.

Rolls can be cut to length with a carpet/stanley knife. When overlapping cut panels bentonite paste will need to be applied as per the requirements for end (transverse) overlaps in Table 2 of Section 9.

No trafficking or walking should occur over the overlap region. The overlap must also be free from folds and foreign matter (eg. soil). Any soil particles on the laps must be swept away carefully.

Overlaps should occur in the direction of ground slope in a similar manner to roof tiles.

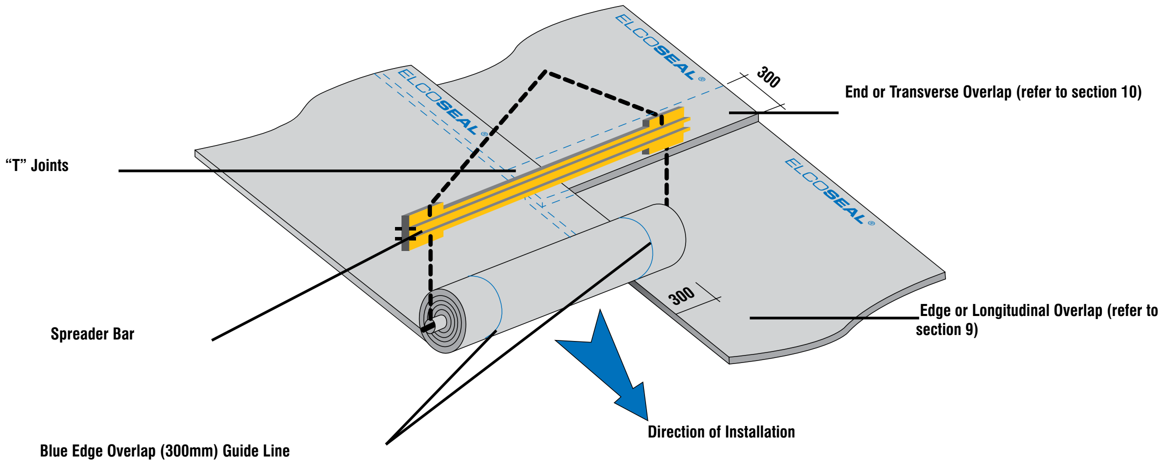


Figure 1. ELCOSEAL® deployment using the standard ELCOSEAL® Spreader Bar
[Important: Refer to the "ELCOSEAL® Spreader Bar Safe Usage Guideline" prior to using the lifting equipment and ensure Occupational Health and Safety requirements have been met and potential hazards are eliminated]

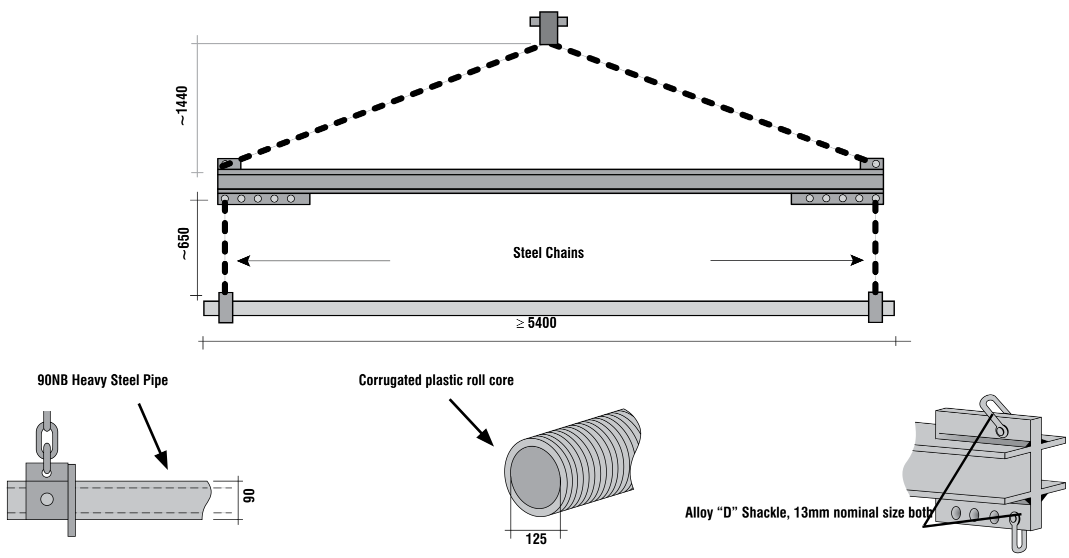


Figure 2. Spreader Bar Assembly - 1000 kg safe working load (Structural Engineer shop drawings provided upon request)

9. TREATMENT OF ELCOSEAL® PANEL OVERLAPS

The composition of the various ELCOSEAL® grades are not identical, and as a result the treatment of the panel overlaps differ slightly. Figures 3, 4, and 5 show the grades in cross-section and highlight how the panel edges in the roll (or longitudinal) direction differ. The treatment of the overlaps for each grade has been summarised in Table 2. **Selection of the appropiate ELCOSEAL® grade should be discussed prior to installation with the Supplier.**

Table 2 - Summary of ELCOSEAL® panel overlap treatment to be performed on site.

ELCOSEAL® Grade	Minimum Overlap Length (mm)	Edge (or longitudinal) Overlaps	End (or transverse) Overlaps			
		Are edges self sealing?	Undercoat	Topcoat	Fillet of Bentonite	XRoll
X800 (Figure 3)	300	✓ 1	✓ 2	✓ 2	✗	✗
X1000 (Figure 3)	300	✓ 1	✓ 2	✓ 2	✗	✗
X2000 & X3000 (Figure 4)	300	✓ 1	✓ 3	✓ 3	✓ 3	✓ 3

Notes:

1. During the ELCOSEAL® manufacturing process, bentonite powder is encapsulated into the upper nonwoven geotextiles along the edges of each roll. Subsequently, the Edge (or longitudinal) overlaps do not require any additional treatment. See Figure 5.
2. See Figure 10 for a cross section of treated End (or transverse) overlaps.
3. See Figure 13 for a cross section of treated End (or transverse) overlaps.

9.1 Cross sections of the different ELCOSEAL® grades

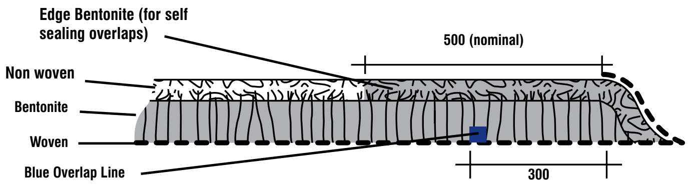


Figure 3. ELCOSEAL® X800 & X1000 roll Edge

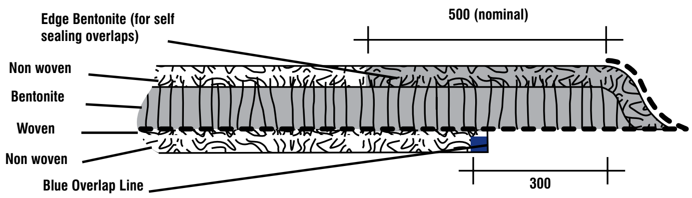


Figure 4. ELCOSEAL® X2000 & X3000 roll Edges (note: X3000 is approximately 10% thicker than X2000)

9.2 Treatment of Edge (or longitudinal) overlaps (refer to note 1 above)

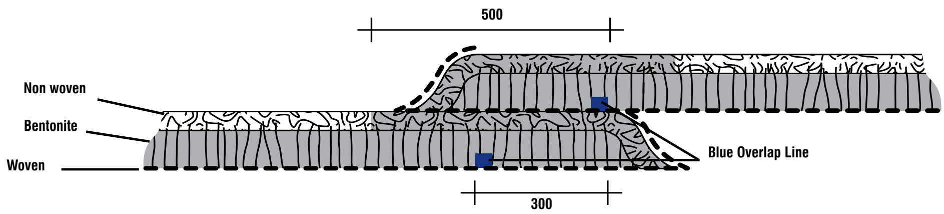


Figure 5. Edge (or longitudinal) overlaps, with self-sealing edges - X800, X1000, X2000, X3000 (X1000 Shown)

10. TREATMENT OF END OVERLAPS (TRANSVERSE DIRECTION)

To ensure the integrity of the ELCOSEAL® lining system it is essential that the treatment of end overlaps be carefully supervised. End overlaps in sumps or inverts are to be avoided.

All End overlaps must be sealed with bentonite paste.

10.1 Preparation of End overlap area

It is recommended that the topside of the underlying ELCOSEAL® panel be marked (as per Figure 6) as a reference point for paste placement. The top ELCOSEAL® panel is then pulled back after marking.

10.2 Undercoat application

A thin-fluid paste is applied as an undercoat in the overlap area. The aim is to fill the pores in the top nonwoven geotextile of the underlying ELCOSEAL® panel.

The Undercoat is prepared as follows:-

- A sufficiently big mortar tub or bucket is filled with water and bentonite powder is added incrementally through a sieve whilst mixing: 9 parts water to 1 part bentonite (for the recommended TruGel® bentonite available from the Supplier – other bentonites will swell differently and may not be of the same quality). An electric drill with an industrial whisk is required to ensure a smooth paste is acheived.
- The paste is spread with a trowel or broom into the overlap area as shown in Figure 7. The paste is applied into the cover nonwoven of the bottom ELCOSEAL® sheet to a width of 200 mm, 150 mm behind the recommended marking and 50 mm in front of the marking.

10.3 Topcoat application

A thick bentonite paste is required for the Topcoat in the overlap area and is prepared as previously indicated: using a mix of 6 parts water to 1 part bentonite (for the recommended TruGel® bentonite). The aim is to fill the free pore space of the overlap area.

This paste is evenly spread using a trowel applied over the Undercoat to a thickness of approximately 10 mm. The Topcoat is also spread to a width of 200 mm, 150 mm in the overlap and 50 mm in front of the overlap area (Figure 8).

Both the Undercoat and Topcoat can be purchased pre-mixed in 20 litre containers from the Supplier.

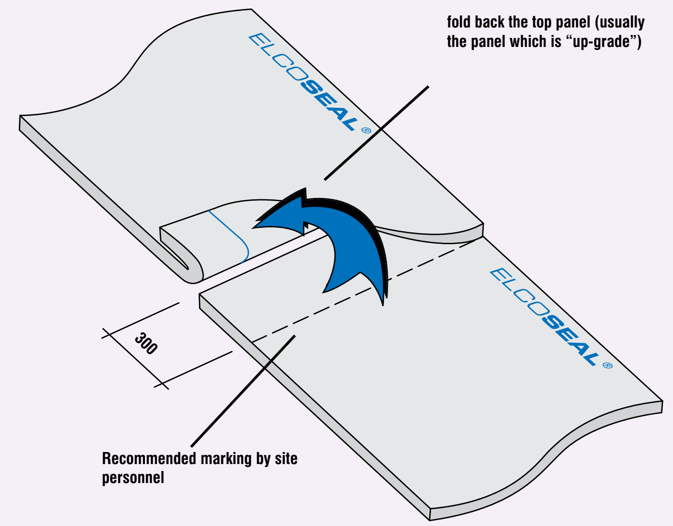


Figure 6. End overlap preparation

Undercoat

Topcoat

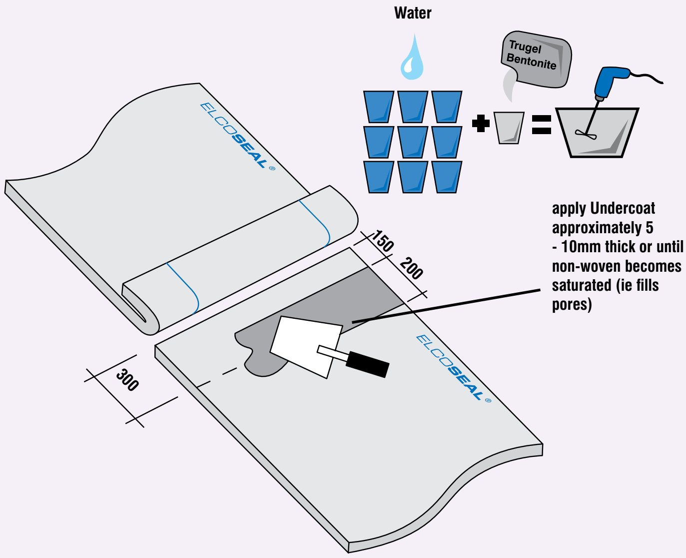


Figure 7. Applying the Undercoat

10.4 Closing the Overlap

The top panel is then rolled back into place and pressed down (Figure 9). Care should be taken to prevent folds or creases. The completed End (or transverse) overlap is shown in Figure 10.

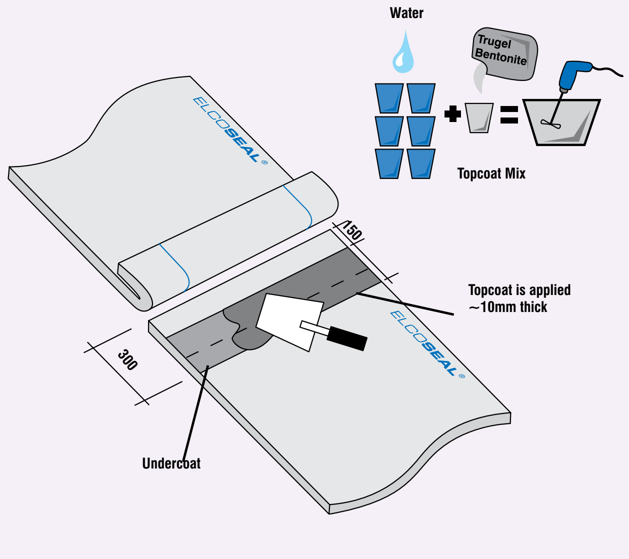


Figure 8. Applying the Topcoat

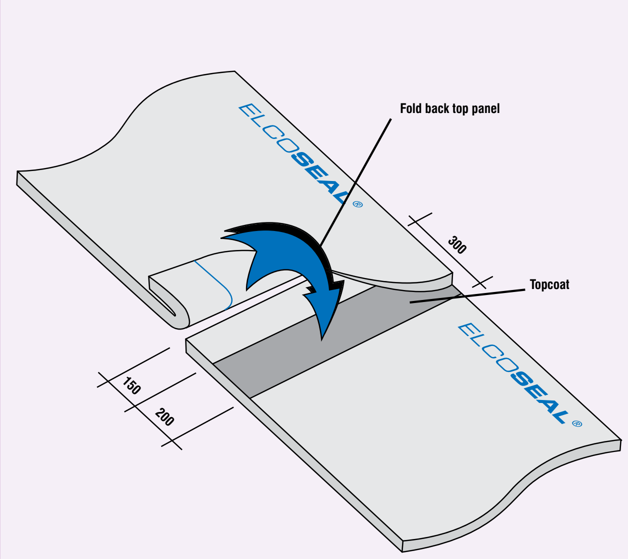


Figure 9. Closing the treated overlap (required all grades)

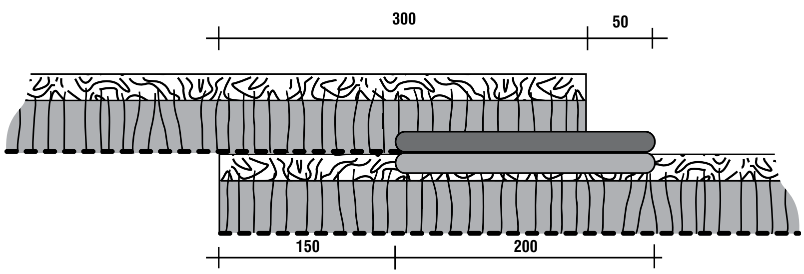


Figure 10. End (or Transverse) overlap treatment for X800 & X1000

10.5 Additional requirements for ELCOSEAL® X2000 and X3000

ELCOSEAL® X2000 and X3000 requires an additional fillet of bentonite paste over the end (transverse) seam area. After rolling back the upper ELCOSEAL® panel, the overlap edge is covered with thick bentonite paste to a thickness of approximately 10 - 20 mm and to a width of 100 mm either side of the overlap (Figure 11). A nonwoven fabric strip (XRoll – available from the Supplier) is then placed over the bentonite fillet to prevent cover soil ingress (Figure 12).

Applying the bentonite Fillet

This step is not required with ELCOSEAL® X800 or ELCOSEAL® X1000.

The completed end (transverse) overlap for X2000 and X3000 is shown in Figure 13.

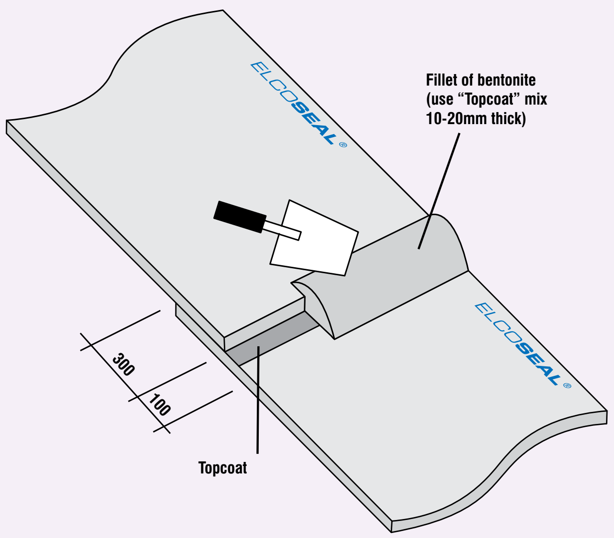


Figure 11. Addtional bentonite Fillet application (required for X2000 and X3000 only)

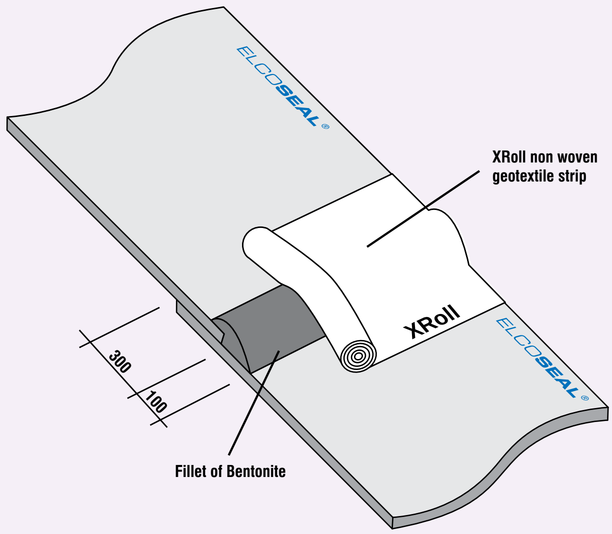


Figure 12. Cover the overlap zone with XRoll and geotextile strip (required for X2000 and X3000 only)

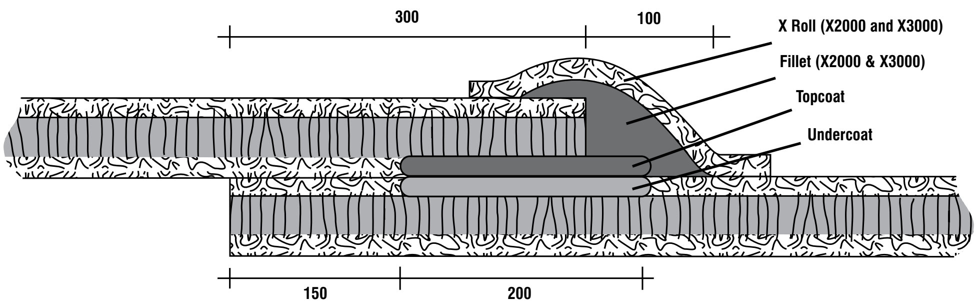


Figure 13 - End (or Transverse) overlap treatment for X2000 and X3000

11. INSTALLATION ON SLOPES

The stability of lining system components on slopes should be assessed on a case-by-case basis. The Supplier can assist in this respect upon request.

ELCOSEAL® panels should be deployed in the direction of the slope as per Figure 14 and anchored at the crest of the slope (Figure 15). End (or transverse) overlaps on steep slopes should be avoided. If they are unavoidable, the panels should be placed according to the roof tile principle and intermediate anchorage on the slope may be required.

Cover soil should be placed up the slope (starting at the toe). It must not be installed down the slope unless stability for this approach has been carefully investigated.

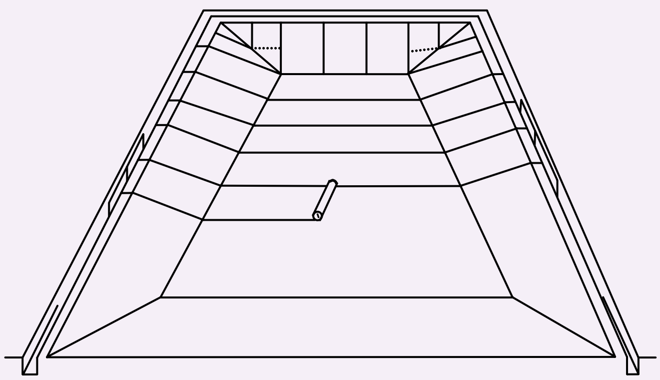


Figure 14. Recommended panel layout for sloping sites

12. CONNECTIONS & PENETRATIONS

Overlaps around connections, penetrations, and where panels have been cut should be carried out according to the principles outlined in Section 10. Most situations require site specific design input, however some commonly used details are shown below:-

- Integration with thick compacted clay liners is shown in Figure 16.
- Cut- off trenches using ELCOSEAL® GCL in cohesive soil are typically constructed as shown in Figure 17.
- Attachment and sealing against concrete structures, can be achieved according to Figure 18. This typical connection is appropriate where the structure needs to be waterproofed to a height above the maximum containment level. Temporary fixing of the vertical ELCOSEAL® panel to the structure (as shown) may be required to allow the backfill placement.
- Penetrations such as pipe ducts are typically carried out according to Figure 19.
- Further connection methods and penetrations details can be discussed with the Supplier.

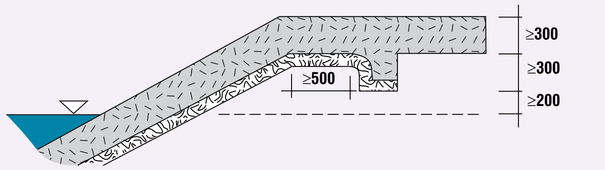


Figure 15. Typical anchor trench (all dimensions shown are typical values only)

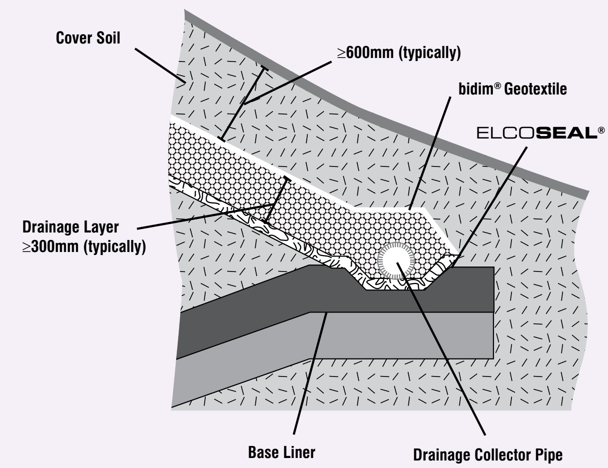


Figure 16. ELCOSEAL® cap connection with base liner

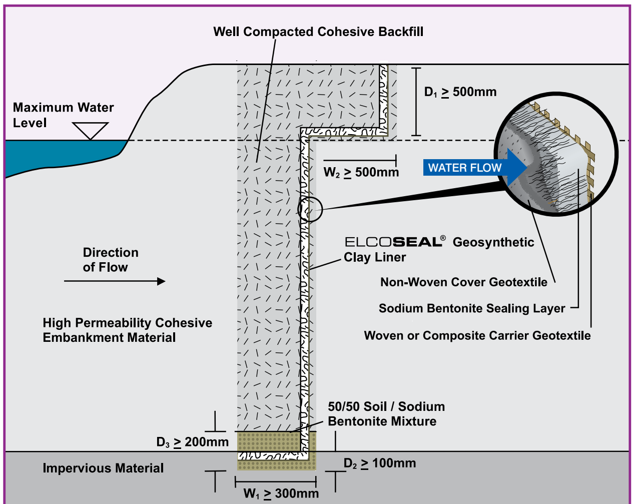


Figure 17. Typical ELCOSEAL® cut off trench detail for cohesive soils

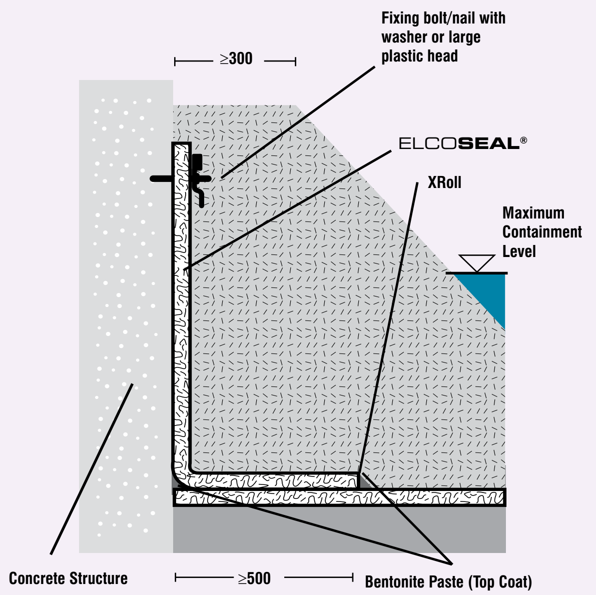


Figure 18. Typical connection to a concrete structure where the ELCOSEAL® panel is required to extend above the maximum containment level

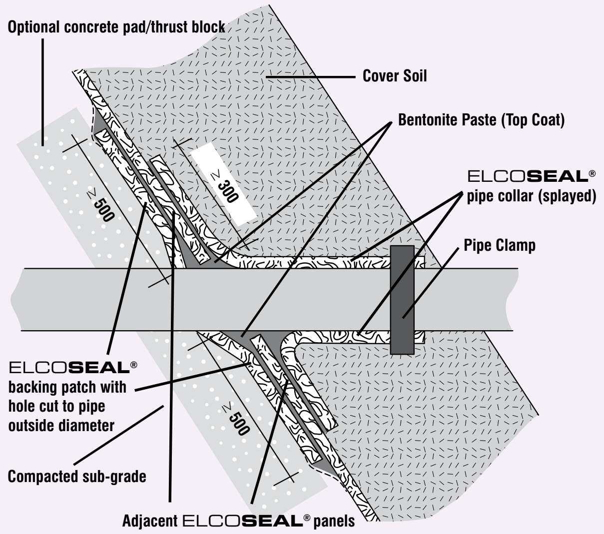


Figure 19. Typical pipe penetration detail

13. PREPARATION FOR PLACING SOIL COVER

Where the ELCOSEAL® is not confined by the cover soil the same working day as deployment, a temporary layer of plastic should be laid to protect ELCOSEAL® from prematurely hydrating (Figure 20).

If the deployed ELCOSEAL® panels have hydrated (for example during a rainfall event) without confinement, special operating conditions may need to be imposed during cover soil placement.

ie	If ELCOSEAL® **m.c.**[1] < 50%	>	no special considerations
	If ELCOSEAL® 50% < **m.c.** < 100%	>	avoid direct traffic (including foot traffic) on the panels.
	If ELCOSEAL® **m.c.** > 100%	>	contact the Supplier for further advice.

14. SOIL COVER PLACEMENT

A cover soil layer at least 300 mm thick (approx. 6 kN/m² confining stress) should be placed and compacted over ELCOSEAL® each working day immediately after the deployed panels have been inspected. In general, fine-grained cohesive material is recommended, although stones up to 32 mm are acceptable if the material is well graded (C_u > 5) or stones up to 16 mm if single sized. Silty soils or organic material are not recommended without further stability analysis. Calcareous or limestone - based cover soils are unsuitable for use, without pre- treatment.

Disturbance of the overlap area during placement (by means of vehicles spreading cover soil) must be avoided. It may be necessary to place the cover soil in this area manually or carefully using vertical placement by an excavator. The cover should not be pushed or graded in a direction that may cause the overlap to move (Figure 21).

ELCOSEAL® may not be trafficked directly. The cover material should be pushed in front of the construction equipment thus creating a safe working platform. Overlaps should not be moved or squeezed during this process. In the case of an expected repeated dynamic load on ELCOSEAL®, a sand layer of at least 300 mm should be laid first on the ELCOSEAL®.

Generally, temporary access roads should not go over deployed panels. These areas should be sealed last to minimise traffic volume over deployed material. Where site traffic cannot be avoided (eg. the delivery of cover material by lorries) additional protection measures will be required. For temporary roads, a minimum roadbase thickness over ELCOSEAL® of 600 mm is acceptable without any further analysis. Shallower coverage or alternative cover materials may be allowed after further analysis or field trials to assess the damage potential.

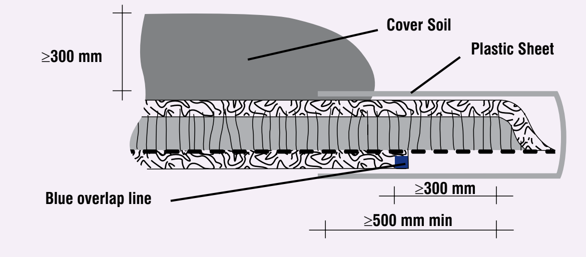


Figure 20. Covering ELCOSEAL® with plastic sheet overnight or during wet weather

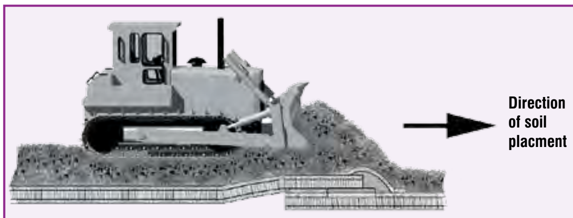


Figure 21. Cover soil replacement

15. REPAIRS

Where ELCOSEAL® has been damaged during installation, covering with an overlapping piece of ELCOSEAL® can repair such areas. The overlap should be at least 500 mm and should be completed in accordance with Section 10.

Manufactured by **ELCO Solutions Pty Ltd** to the ISO 9001:2000 Quality Management System Standard
ELCOSEAL® is a registered trademark of ELCO SOLUTIONS PTY LTD

www.elcos.com

PO Box 727 Southport Queensland 4215, Australia
Telephone: + 61 7 5500 1400 - Fax: + 61 7 5539 4027
Email: sales@elcos.com.au

1. "m.c" - moisture content of the bentonite, % by weight

Attachment 4 – Model GCL Specification

MODEL GCL SPECIFICATION

Scope - This specification details the technical requirements for the supply and installation of a needle-punched Geosynthetic Clay Liner (GCL). The material(s) furnished and installation performed shall be in strict accordance with these requirements and the contract drawings.

The following specification guideline reflects industry accepted installation procedures and current quality control test protocol. It is to be used as the general format, not as a direct substitute for a project specific Geosynthetic Clay Liner (GCL) specification.

DEFINITION OF TERMS

For the purposes of this specification the following definitions shall apply:

CBR - California Bearing Ratio – 50mm Plunger

CQA – Construction Quality Assurance – A planned system of activities that provide assurance that the facility was constructed as specified in the design

C_u – Coefficient of Uniformity of a soil particle grading – D_{60} / D_{10}

Geosynthetic Clay Liner (GCL) - A factory manufactured hydraulic barrier consisting of powdered Sodium Bentonite clay, sandwiched between, supported and encapsulated by two geotextiles, held together by needle-punching

Geotextile - Woven or nonwoven fabrics used to contain the bentonite in a GCL

Index Test - This is a product acceptance test used for quality control and classification of various grades of GCL

MARV – Minimum Average Roll Value – A statistical value which represents the mean less 2 standard deviations, effectively providing a 97.5% confidence limit. This value is based on either project testing or historical data of a particular property

MaxARV – Maximum Average Roll Value – A statistical value which represents the mean plus 2 standard deviations, effectively providing a 97.5% confidence limit. This value is based on either project testing or historical data of a particular property

MQA – Manufacturing Quality Assurance – A planned system of activities that provides assurance that the materials were constructed as specified in the certification documents and contract specifications

Needle-punching - A GCL manufacturing process whereby boards of barbed needles incorporate the staple fibres from a nonwoven geotextile, through a Sodium Bentonite clay layer, into the matrix of a second or more geotextile layers

Performance Test - A test on a particular product or process typically used to simulate actual field conditions

PP - Polypropylene polymer

Thermal Locking - A needle-punching enhancement process utilising heat to bind the needle-punched fibres between the upper and lower geotextile layers to increase the internal shear strength characteristics of GCL's

Typical (or Mean) – A typical value is the arithmetic mean of a set of results. This implies that 50% of the tested specimens will typically exceed this value and 50% will typically not meet this value

1.0 GENERAL

The GCL product supplied to the project shall be in full accordance with the requirements of this specification.

1.1. The GCL shall be manufactured by mechanically bonding the cover and carrier geotextiles using a needle-punching process to enhance frictional and internal shear strength characteristics.

1.2. In order to maintain these characteristics, no glues, adhesives or other non-mechanical bonding processes shall be used instead of the needle-punching process.

1.3. The GCL shall contain a woven scrim component for dimensional stability.

1.4. The needle-punched GCL shall be thermally locked. The thermal lock process must heat set the nonwoven fibres where they protrude from the carrier geotextile (woven or nonwoven depending upon product) to more permanently secure the reinforcement in place.

1.5. No other manufacturing techniques shall be approved unless it can be suitably demonstrated that the GCL exhibits uniform shear strength characteristics across the entire width of the panel. Isolated sewn, stitched or stapled rows do not constitute uniform reinforcement for the purposes of this specification

1.6. To ensure correct joining between adjacent GCL panels, the GCL shall be factory bentonite powder impregnated along both top long edges to enable self-sealing along these edges. This impregnation is to extend inward a minimum of 300mm from the edges of the roll, in the long direction.

1.7. A minimum overlap guideline shall be imprinted with non-toxic ink on both long edges of the GCL roll to ensure the accuracy of overlap seams. These lines shall be used during CQA to ensure the minimum overlap is achieved. The minimum overlap guideline shall indicate where the edge of the panel must be placed in order to achieve a full 300 mm of Bentonite overlap for each panel.

1.8. The minimum acceptable dimensions for the GCL panels shall be 4.5 metres wide and 30 metres long. Short rolls (rolls less than 30 metres long) may be supplied, but at a rate not to exceed 7% of the total product area produced for this project. Two short rolls may be joined to form a full roll. Short rolls shall not be less than 5 metres. An additional 1.0 metre of GCL shall be supplied to accommodate the longitudinal overlap. Any joined rolls shall be clearly identified.

1.9. To demonstrate the uniformity of the manufacturing process, no de-lamination of the geotextile components from the Bentonite core shall occur when the GCL is immersed in tap water at ambient temperature for one hour.

1.10. The bentonite component should be inspected visually for lack of homogeneity. The bentonite must have a consistent particle size, colour and appearance, and can be rejected on this basis.

2.0 BENTONITE SPECIFICATION

PROPERTY	TEST METHOD	UNITS	VALUE
Bentonite Particle Size	Dry Screen	% passing 75µm	80
	Wet Screen	% retained 75µm	2
	AS 1289-3.6.2[1]	% ≤0.5µm	≥ 55
Swell Index	ASTM D-5890[2]	mL/2g	≥ 24
Fluid Loss	ASTM D-5891[3]	mL	≤ 15
Montmorillonite Content	XRD Quantitative Mineralogy Analysis[4]	% of Bulk Sample	≥ 70
	ASTM C-837 – Methylene Blue Index[4]	% of Bulk Sample	≥ 70
Montmorillonite Content of Bentonite Particles ≤0.5µm	XRD Quantitative Mineralogy Analysis[4]	% ≤0.5µm	≥ 95
Calcium Carbonate Content ($CaCO_3$)	XRD Quantitative Mineralogy Analysis[5]	% of Bulk Sample	< 1
Layer Charge and Layer Charge Distribution	Chemical analysis and structural formula calculation[6]	e- per unit cell ($O_{20}(OH)_4$)	0.80 to 0.85
		% in tetrahedral sheet	<35
Cation Exchange Capacity (CEC)	NH_4 displacement[7]	cmol/kg of Bulk Sample	75 – 85
	Barium Saturation Method - (e.g., Battaglia et al., 2006)[7]	cmol/kg (≤0.5µm Particles)	95 - 100

2.0.1 EXPLANATION OF TEST METHODS

1. **BENTONITE PARTICLE SIZE - AS 1289-3.6.2 – 'Methods of testing soils for engineering purposes - Soil classification tests - Determination of the particle size distribution of a soil - Analysis by sieving in combination with hydrometer analysis (subsidiary method)'** – *Particle size provides an indication of the reactive surfaces. Smaller particle sizes generally react more efficiently and effectively with water to result in better swelling, lower fluid loss, higher swelling pressure, greater gel strength and lower permeability.*

2. **SWELL INDEX - ASTM D5890 – 'Standard Test Method for Swell Index of Clay Mineral Component of Geosynthetic Clay Liners'** – *This is an index test that evaluates the swelling potential of the bentonite component of a GCL. The index relates to bulk swelling under minimal confinement. The swell index is generally inversely related to GCL permeability, ie. the higher the swell index, the lower the GCL permeability.*

3. **FLUID LOSS - ASTM D5891 – 'Standard Test Method for Fluid Loss of Clay Component of Geosynthetic Clay Liners'** – *This is an index test that evaluates the fluid loss properties of the bentonite component of a GCL, under 100psi (690 MPa) pressure, over a specified period of time. A low Fluid Loss value is indicative of the ability of the bentonite to restrict movement of liquid under load. Fluid Loss is directly related to GCL permeability, ie. the lower the fluid loss, the lower the GCL permeability.*

4. **MONTMORILLONITE CONTENT –**
   XRD Quantitative Mineralogy Analysis – *The method enables quantification of the mineralogy of a bentonite by powder X-ray diffraction and Reitveldt refinement. The XRD method can be performed on bulk bentonite, showing montmorillonite content as a % of bulk; or on size-fractionated materials, showing montmorillonite content as a % of size fraction (ie. ≤0.5µm).*
   <u>REFERENCE</u>
   Taylor, J.C., Hinczak, (2004). Reitveldt Made Easy. *Sietronics, Pty Ltd, Belconnen Australia, 201p*.
   or ASTM C837 'Methylene Blue Index' – *This traditional method is based on the assumption that the smectite clay has a CEC of 100 cmol/Kg and was originally used to differentiate different smectite species.*
   The XRD Quantitative Mineralogy Analysis is the preferred method.

5. **CALCIUM CARBONATE CONTENT – 'XRD Quantitative Mineralogy Analysis' –** *As for Montmorillonite content, quantitative mineralogy analysis enables quantification of carbonate minerals present in bentonite.*

6. **LAYER CHARGE AND LAYER CHARGE DISTRIBUTION – 'Chemical analysis and structural formula calculation'** – *This method enables calculation, from chemical analysis, of layer charge characteristics of the smectite clay component of a GCL. Chemical analysis is quantified by XRF on* ***calcium*** *saturated purified smectite samples. Smectite layer charge is responsible for the cation exchange capacity of bentonite, but also influences swelling, sealing and gel formation. Layer charge values <0.85e⁻ per unit cell in combination with a tetrahedral layer charge <30%, indicates a good swelling bentonite.*

REFERENCES

1. Norrish, K., Hutton,J.T. (1969). "An accurate X-ray spectroscopic method for the analysis of a wide range of geologic samples", *Geochemical Cosmochimical Acta*, 33, 431-453.
2. Bodine, M.W.Jr. (1987). "CLAYFORM: A FORTRAN 77 computer program apportioning the constituents in the chemical analysis of a clay or other silicate mineral in a structural formula", *Computers and Geosciences*, 13:77-88.

7. **CATION EXCHANGE CAPACITY – 'NH_4 Displacement Method'** – *'This method has traditionally been used to determine CEC in SOILS. The NH_4 displacement method can be modified to enable direct determination of the cation exchange capacity of the smectite clay component of a GCL. The amount of NH_4 retained by the clay is quantified by X-ray Fluorescence (XRF). This method can be performed on the bulk bentonite, in which case "Bentonite CEC" is recorded. or on the monomineralic smectite isolated from the bentonite, in which case the "Smectite CEC" is recorded. The ranges in CEC values specified provide the best combination of good swelling and cation retention capabilities – see Note 6* ***- LAYER CHARGE AND LAYER CHARGE DISTRIBUTION****.*

or 'Barium Saturation Method' – *'The barium (Ba) displacement method enables direct determination of the cation exchange capacity of the smectite clay component of a GCL. The amount of Ba retained by the clay is quantified by X-ray Fluorescence (XRF). This method can be performed on the bulk bentonite, in which case "Bentonite CEC" is recorded. or on the monomineralic smectite isolated from the bentonite, in which case the "Smectite CEC" is recorded. The ranges in CEC values specified provide the best combination of good swelling and cation retention capabilities – see Note 6* ***- LAYER CHARGE AND LAYER CHARGE DISTRIBUTION****.*

REFERENCE

Battaglia, S.; Leoni, L.; Sartori, F. (2006). "A method for determining the CEC and chemical composition of clays via XRF", *Clay Minerals*, 41:717-725.

2.1 GCL MATERIAL SPECIFICATION – MARV VALUES (Unless stated otherwise)

Grade 1: Base Liner (firm unyielding subgrades)
Grade 2: Caps and Steep Slopes (> 3.5H: 1V)
Grade 3: Caps (High Differential Settlement)

GCL SPECIFICATION		UNIT	GRADE 1 Medium Internal Shear (MS)	GRADE 2 High Internal Shear (HS)	GRADE 3 (+High Bentonite Mass (HM, HS)	TEST METHOD
GEOTEXTILE PROTECTION LAYER	PP nonwoven white	g/m^2	270	270	300	AS 3706.1 [1]
GEOTEXTILE CARRIER LAYER	PP slit film woven	g/m^2	110	110	110	
	PP nonwoven white	g/m^2	none	270	270	
BENTONITE LAYER	Sodium Bentonite Sealing Layer (@ 0% m.c.)	g/m^2	4000	3700	4250	ASTM D5993 [2]
	Moisture Content (maximum from factory)	%	15	15	15	
	Sodium Bentonite Side Overlap Area (@ 0% m.c.) – Typical Values	g/m^2	800	800	800	Strew Test [3]
WIDE WIDTH TENSILE STRENGTH	Machine Direction	kN/m	8	10	12	ASTM D4595 [4]
	Cross-Machine Direction	kN/m	8	25	30	
WIDE WIDTH TENSILE ELONGATION	Machine Direction	%	11	100	100	ASTM D4595 [4]
	Cross-Machine Direction	%	11	70	70	
CBR BURST	Strength	N	≥ 1600	≥ 2500	≥ 3000	AS 3706.4 [5]
	Elongation	%	≥ 20	≥ 50	≥ 50	
HYDRATED PEAK INTERNAL SHEAR STRENGTH – TYPICAL VALUES	@ 10kPa Normal Stress [a]	kPa	30	35	40	ASTM D6243 [6]
	@ 30kPa Normal Stress [a]	kPa	50	60	70	
PERMEABILITY [b]	k-VALUE (t_{GCL}=10mm) [c]	m/s	$\leq 3 \times 10^{-11}$	$\leq 3 \times 10^{-11}$	$\leq 2 \times 10^{-11}$	ASTM D5887 [7]

Notes:

a. **Peak value reported at 10kPa and 30kPa normal stress. [The reported values are not intended to replace site specific internal shear or interface friction testing required for design]**
b. **Permeability ‘k’ values are Maximum Average Roll Values (MaxARV)**
c. **t_{GCL} = thickness of GCL for calculation of permeability (10mm provides conservative values)**

2.1.1 EXPLANATION OF TEST METHODS

1. **AS 3706.1 – 'Geotextiles - Methods of test - General requirements, sampling, conditioning, basic physical properties and statistical analysis'** – *Determination of mass of geotextile. The woven geotextile is required for dimensional stability of the GCL. A higher mass of the geotextile component of the GCL will improve GCL performance by increasing damage resistance and reducing potential for bentonite erosion.*

2. **ASTM D5993 – 'Standard Test Method for Measuring Mass Per Unit of Geosynthetic Clay Liners'** – *The dry mass (0% moisture content) of the clay within a GCL is calculated. The moisture content of the GCL can also be estimated using this method.*

3. **Strew Test** – *A MQC Production Test – Refer to the GCL Manufacturer's Quality Assurance and Control documentation for further information.*

4. **ASTM D4595 – 'Standard Test Method for Tensile Properties of Geotextiles by the Wide-Width Strip Method'** – *The tensile strength vs elongation of a GCL is required to assess necking/shrinkage potential under a sustained load. GCL's with low strengths at elongations less than 20% have a propensity to creep/neck.*

5. **AS 3706.4 – 'Geotextiles - Methods of test - Determination of burst strength - California bearing ratio (CBR) - Plunger method' -** *This test applies a load normal to the plane of the GCL to simulate aggregate pushing through an unsupported GCL under vertical load. The elongation at the ultimate load is reported. This test represents the failure mechanism if a void forms beneath a GCL subjected to a vertical load.*

6. **ASTM D6243 – 'Standard Test Method for Determining the Internal and Interface Shear Resistance of Geosynthetic Clay Liner by the Direct Shear Method'** – *This method outlines a procedure for determining the internal shear resistance of a hydrated GCL under a constant rate of displacement or constant stress. This test can be classified as a performance test. Normal stresses should be selected to represent actual site conditions.*

7. **ASTM D5887-Appendix X2 – 'Standard Test Method for Measurement of Index Flux Through Saturated Geosynthetic Clay Liner Specimens Using a Flexible Wall Permeameter – Calculation of Hydraulic Conductivity Using Index Flux Test Data'** – *This is an index test that outlines the laboratory measurement of flux through saturated GCL specimens using a flexible wall permeameter, with 550kPa confining pressure and 15kPa (1.5m) head differential. The permeability must be calculated from an assumed GCL thickness of 10mm. This thickness of GCL is typically conservative. Permeability for on-site conditions depends on a number of factors such as confining pressure, type of hydration fluid, degree of hydration, degree of saturation, type of permeating fluid and hydraulic gradient.*

3.0 PRODUCT ACCEPTANCE

Acceptable GCL's for this project include any needle-punched GCL's that meet all the requirements of this specification.

3.1. The supplier shall provide current 3rd party certified test results showing that the product meets the specification.

3.2. The supplier shall provide a detailed project list of the proposed material to be supplied, in the following format;

- 3.2.1. Project Name
- 3.2.2. Date of Installation
- 3.2.3. Product
- 3.2.4. Quantity
- 3.2.5. Contact Details

3.3. The supplier shall provide the standard MQA procedures set in place during normal manufacturing processes.

4.0 MANUFACTURING QUALITY ASSURANCE (MQA)

The GCL shall be tested for compliance with this specification by the test methods indicated on the material specification. During production, needle punched GCL's shall be continuously inspected for broken needles using an in-line metal detector and broken needles shall be removed. Candidate GCL materials may be tested and pre-approved at the manufacturing location.

The level of MQA documentation is dependant on the risks associated with the project. Based on the level of risk, the following certification shall be provided;

Level 1 Certification – Low Risk Project – General Conformance Certificate;
Level 2 Certification – Medium to High Risk Project – Mean QC results of supplied GCL;
Level 3 Certification – Extremely High Risk Project – Highly detailed, roll specific data and 3rd party testing.

4.1 Manufacturer Quality Control - Quality Control submittals shall be issued by the GCL manufacturer to the project engineer, CQA inspector or other designated party for each lot of material, if necessary. The submittals shall include the following information:

4.1.1 Bentonite Manufacturer Certification - Bentonite manufacturer quality documentation for the particular lot of clay used in the production of the rolls delivered.

4.1.2 Manufacturing Quality Control Data - The manufacturing quality control test data indicating the actual test frequencies as per requirements in table 1 below.

TABLE 1 – MQA Testing Frequency

Property	**Frequency (Minimum)**
Cover Geotextile Mass	4 000m^2
Carrier Geotextile Mass	4 000m^2
Swell Index	40 tonnes of raw material
Fluid Loss	40 tonnes of raw material
Bentonite Mass	2 500m^2
Grab Strength	4 000m^2
CBR Strength	20 000m^2
Peel Strength	2 500m^2
Hydraulic Conductivity	20 000m^2
Wide Width Tensile Strength	20 000m^2

4.2 Packaging - All GCL rolls shall be packaged in opaque moisture resistant plastic sleeves. The roll cores shall be sufficiently strong to resist collapse during transit and handling.

4.3 Roll Identification and Labelling - Before shipment, the manufacturer shall label each roll, both on the GCL roll and on the surface of the plastic protective sleeve. Labels shall be resistant to fading and moisture degradation to ensure legibility at the time of the installation. At a minimum, the roll shall identify the following:

Country of Manufacture
Product Name
Product Grade
Length and width of roll
Individual roll number
Length and position of join

4.4 Any accessory Bentonite used for sealing seams, penetrations, or repairs, shall be from the same supplier / source as used in the GCL manufacture.

5.0 SHIPPING & HANDLING

The following operational procedures are as specific as possible while recognising that the specific requirements of the project may necessitate minor modifications. Significant deviations from these procedures shall be pre-approved by the project engineer or other designated party, in writing prior to implementation of deviations.

5.1 Shipping and Handling Equipment - The party responsible for unloading the GCL shall contact the supplier before shipment to determine the correct unloading methods and equipment if different from the pre-approved and specified methods.

5.2 GCL's must be supported during handling to ensure worker safety and prevent damage to the product. Under no circumstances should the rolls be dragged, lifted from one end, lifted with only the forks of a lift truck or dropped on to the ground from the delivery vehicle.

5.3 The CQA inspector shall verify that proper handling equipment, which does not pose any danger to installation personnel or risk of damage or deformation to the liner material itself, is available and ready for use at relevant locations. Suitable handling equipment is described below:

5.3.1. Lifting Slings – Lifting slings shall be certified to the appropriate Australian Standard and shall be used as per GCL manufacturer's recommendations.

5.3.2. Spreader Bar Assembly – The spreader bar assembly shall be certified for the rated load and shall be used as per GCL manufacturer's recommendations. The spreader bar assembly shall include both a core pipe or bar and a spreader bar beam. The core pipe shall be used to uniformly support the roll when inserted through the GCL core while the spreader bar beam will prevent chains or straps from chafing the roll edges.

5.3.3. Carpet Spike - A carpet spike is a rigid pipe or rod with one end directly connected to a forklift or other handling equipment and the other end rounded to allow easy insertion into roll material cores. If a carpet spike is used, it should be at least 3.0 metres long and inserted to its full length into the roll core to prevent excessive bending of the roll when lifted.

5.4 GCL Inspection Upon Delivery - Each roll shall be visually inspected when unloaded to determine if any packaging or material has been damaged during transit. Repairs to damaged GCL shall be performed in accordance with **Section 7** of this specification.

5.4.1. Rolls exhibiting damage shall be marked and set aside for closer examination prior to and during deployment.
5.4.2. Minor rips or tears in the plastic packaging shall be repaired with moisture resistant tape before being placed in storage to prevent moisture damage.
5.4.3. The presence of free-flowing water within any roll packaging shall require that roll to be set aside for further examination to ascertain the extent of any damage.
5.4.4. GCL rolls delivered to the project site shall be only those indicated on GCL manufacturing quality control certificates.

6.0 STORAGE & STOCKPILING

Storage / Stockpiling and Staging of the GCL rolls shall be the responsibility of the installer or other designated party.

6.1 GCL rolls shall be stockpiled and maintained dry in a well-drained flat location area away from high-traffic areas but sufficiently close to the active work area to minimise handling.

6.2 Rolls shall not be stacked on uneven or discontinuous surfaces. Such stacking might cause bending, deformation, and damage to the GCL or cause difficulty inserting the carpet spike or core pipe, and such adversely affected rolls might be subject to rejection.

6.3 GCL's should be stored no higher than four rolls high, or limited to the height at which installation personnel may safely manoeuvre the handling apparatus. Stacks or tiers of rolls should be supported in a manner that prevents sliding or rolling by chocking the bottom layer of the rolls.

6.4 An additional tarpaulin or plastic sheet shall be used over the stacked rolls to provide extra protection for GCL material stored outdoors.

6.5 Bagged Bentonite material shall be stored under cover. Bags shall be stored on pallets or other suitably dry surfaces that will prevent prehydration and prevent contact of the bags with the ground or other potentially wet surface.

7.0 SITE PREPARATION

The surfaces upon which the GCL is to be laid shall be suitable for the placement of GCL material.

7.1 Earthen Subgrades
The surface upon which the GCL material will be installed shall be inspected by the CQA inspector and certified by the earthwork contractor to be in accordance with the requirements of this specification.

7.1.1 The subgrade shall be firm and unyielding (typically compacted to >90% Standard Proctor density), without abrupt elevation changes.
7.1.2 The subgrade should not be disturbed or rutted by the equipment deploying the rolls or other traffic.
7.1.3 In applications where the GCL is the sole barrier and will be subjected to a hydraulic head that exceeds the confining stress, subgrade surfaces consisting of gravel or granular soils may not be appropriate due to their large void content. For these applications, the top 150 mm of the subgrade soil should possess a particle size distribution where at least 80 percent of the soil is finer than 0.2 mm (#60 sieve).
7.1.4 The surfaces to be lined shall be smooth and free of any debris, vegetation, roots, sticks, sharp rocks, or other deleterious materials larger than 10 mm in any dimension, as well as free of any voids, large cracks or standing water.
7.1.5 Directly before deployment of the GCL, the subgrade shall be final-graded to fill remaining voids or desiccation cracks and proof-rolled. The surfaces to be lined shall be maintained in this smooth condition.
7.1.6 The engineer's approval must be obtained immediately prior to roll deployment.

7.2 Geosynthetic Subgrade
Prior to GCL deployment, the geosynthetic surface, as well as other underlying geosynthetics upon which the GCL material will be installed, shall be inspected and approved by the third party CQA inspector in accordance with the requirements of the project specification documents.

7.3 Anchor Trench - An anchor trench shall be excavated by the earthwork contractor or liner installer to the lines and grades shown on the project drawings at the top of slopes steeper than 7h: 1v.

7.3.1 The anchor trench shall be constructed free of sharp edges or corners and maintained in a dry condition. No loose soil shall be permitted beneath the GCL within the trench.
7.3.2 The anchor trench shall be inspected as well as approved by the CQA inspector before GCL placement, back filling and compaction of the anchor key material.
7.3.3 Standard Anchor - The GCL shall be placed into and across the base of the excavated trench, stopping at the back wall of the excavation.
7.3.4 "Run-Out" Anchor - On gentle slopes or locations where it is difficult to create an anchor trench, the GCL may alternatively be anchored by a material run-out past the crest of the slope. The length of the run-out shall be pre-approved by the project engineer before the use of this method.

7.4 Subsequent to the CQA inspector's approval, it shall be the installer's responsibility to indicate to the Engineer any change in the subgrade condition that could cause it to be out of compliance with any of the requirements of this section or the project specification.

8.0 CONSTRUCTION QUALITY ASSURANCE (CQA)

Before Installation the following information shall be supplied to the project engineer for review within 10 business days of the Contract Award to ensure that the materials and parties selected for use on the project meet the requirements of this specification:

8.1 Samples of the proposed GCL shall be taken from undamaged rolls prior to deployment.
8.2 Reference list supplied by GCL Manufacturer indicating the appropriate experience level significant to the project.
8.3 Reference list supplied by the GCL Installer indicating the appropriate experience level significant to the project.

The GCL properties indicated in Section 2.0 are required to satisfy the requirements of the GCL to be deployed in the construction of the liner. As such, the Construction Quality Assurance Inspector shall sample the GCL delivered to site at the frequency set out in table 2 below for testing at an independent 3rd party certified laboratory.

TABLE 2 – CQA Testing Frequency

Property	Frequency
Cover Geotextile Mass	7 500m^2 or part thereof
Carrier Geotextile Mass	7 500m^2 or part thereof
Swell Index	7 500m^2 or part thereof
Fluid Loss	7 500m^2 or part thereof
Bentonite Mass	7 500m^2 or part thereof
Grab Strength	7 500m^2 or part thereof
CBR Strength	7 500m^2 or part thereof
Peel Strength	7 500m^2 or part thereof
Hydraulic Conductivity	7 500m^2 or part thereof
Wide Width Tensile Strength	7 500m^2 or part thereof

The third party project inspector shall be designated a minimum of 15 business days prior to construction in order to facilitate the possibility of in plant material pre-qualification.

8.4 The specific CQA inspector designated by the CQA contractor shall be responsible for all aspects of the QA program, including the documentation and monitoring of the manufacturing and installation processes.
8.5 The CQA inspector shall be an independent, third party consultant with a minimum of 100 000 square metres of GCL inspection experience, on a minimum of 5 projects.
8.6 Reference list supplied by the proposed CQA Inspector indicating the appropriate experience level significant to the project.

9.0 INSTALLATION

GCL Material shall be placed in accordance with GCL manufacturer's installation guidelines, or approved modifications to account for site-specific conditions. Additional guidelines are given below.

9.1 GCL shall not be installed during precipitation events or in the presence of standing water on subgrade.

9.2 GCL Orientation - In the absence of specific guidelines, GCL panels should be placed with the woven (thermal locked) side down on slopes to maximise the shear strength characteristics.

9.3 GCL Panel Position - Where possible, all slope panels should be installed running down the slope with the overlaps shingled to suit the drainage contours.

9.4 Deployment should proceed from the highest elevation to the lowest to facilitate drainage in case of precipitation.

9.5 The GCL may be deployed on slopes by pulling the material slowly from a suspended roll, or securing a roll end into an anchor trench and unrolling each panel as the handling equipment slowly moves backwards. The roll must not be allowed to roll down the slope freely without any form of restraint.

9.6 A slip-sheet may be used to facilitate positioning of the liner while ensuring the GCL is not damaged from underlying sources.

9.7 Overlaps shall be a minimum of 300 mm on panel edges and ends, and be free of wrinkles, folds or "fish-mouths". If folds are unavoidable, they shall be treated using the procedure described in **Section 10.0** DAMAGE REPAIR, for the appropriate grade of GCL.

9.8 Bentonite paste manufactured in accordance with the GCL supplier's specification shall be placed between panels on end overlaps, cut pieces or patches.

9.9 The contractor shall only install as much GCL as can be covered at the end of a working day. Only those GCL panels, which can be anchored and covered in the same day, shall be unpacked and installed. If exposed GCL cannot be permanently covered before the end of a working day, it shall be temporarily covered with plastic or other waterproof material to prevent hydration. No GCL shall be left exposed overnight. Exposed edges of the GCL shall be covered by temporary water-resistant sheeting until work commences again.

9.10 In the event of strong winds on site, the GCL shall be weighted along the overlaps using sandbags or similar means.

9.11 Detailing - Detail work, defined as the sealing of the liner to pipe penetrations, foundation walls, drainage structures, spillways, and other appurtenances, shall be performed as recommended by the GCL Manufacturer.

10.0 DAMAGE REPAIR

Before cover material placement, damage to the GCL shall be identified and repaired by the installer. Damage is defined as any rips or tears in the geotextiles, delamination of geotextiles or a displaced panel.

10.1 Rip and Tear Repair (Flat Surfaces) - Rips or tears may be repaired by completely exposing the affected area, removing all foreign objects or soil, and by then placing a patch cut from unused GCL over the damage (damaged material may be left in place), with a minimum overlap of 500 mm on all edges.

10.2 Accessory Bentonite paste shall be placed between the patch edges and the repaired material as per the manufacturer's recommendations.

10.3 Rip and Tear Repair (Slopes) - Damaged GCL material on slopes shall be repaired by the same procedures above; however, the edges of the patch should also be adhered to the repaired liner with an adhesive to keep the patch in position during backfill or cover operations.

10.4 Displaced Panels - Displaced panels shall be adjusted to the correct position and orientation. The adjusted panel shall then be inspected for any geotextile damage or bentonite loss. Damage shall be repaired by the above procedure.

10.5 Premature Hydration. If the GCL is prematurely hydrated, the installer shall notify the QA/QC technician and project engineer for a site-specific determination as to whether the material is acceptable or if alternative measures must be taken to ensure the quality of the design, <u>dependent upon the degree of damage</u>.

11.0 COVER MATERIAL

The cover materials shall be compatible as well as suitable for use over the GCL, and placed in a manner appropriate to the particular subgrade. Regardless of the cover material, the uncovered edge of GCL panels shall be protected at the end of the working day with a waterproof sheet adequately secured with ballast.

11.1 Earthen Cover Soil - If the cover material is soil or gravel, a nominal thickness of 300 mm shall be placed and compacted over the GCL, to provide a minimum pressure of $6kN/m^2$. The soil cover shall be free of sharp-edged stones greater than 32 mm in size. Laboratory analysis of especially calcareous or limestone-based cover material shall be required to ensure compatibility with the GCL.

11.1.1. Type of Cover Soil – Fine grained non-erodible cohesive material is recommended, although stones of up to 32mm are acceptable if the material is well graded (C_u>5). For base liners in deep landfills, the maximum stone size may need to be reduced. The Contractor shall obtain written approval from the Engineer for use of proposed cover materials.

11.1.2. Equipment - Soil cover shall be placed with low ground pressure equipment. Care should be taken to avoid damaging the GCL by making sharp turns or pivots with equipment as well as sudden starts or stops.

11.1.3. Placement - Soils may be placed on the GCL by pushing with a track dozer or by carefully placing it with a loader or a backhoe. The use of construction machinery directly over the GCL is strictly prohibited.

11.1.4. Thickness - A minimum thickness of 300 mm of cover shall be kept between heavy equipment and the GCL at all times. No vehicles should be driven directly over the GCL until the proper thickness of cover has been placed.

11.1.5. Haul or Access Roads – generally temporary road access shall not be constructed over GCL panels. However, where traffic cannot be avoided, additional protection measures will be required. For temporary or haul roads, a minimum layer thickness of 600mm over the GCL is recommended, without further analysis.

11.1.6. Compaction - To prevent damage to the GCL, the initial lift(s) of soil cover shall be lightly compacted or otherwise treated, as specified by the engineer.

11.1.7. Slope Placement - When covering GCL on sloped areas steeper than 4h: 1v, cover should be pushed up-slope to minimise tension on the GCL.

11.2 Geosynthetic Cover - Precautions shall be taken to prevent damage to the GCL by restricting the use of heavy equipment over the liner system.

11.2.1. Equipment - Installation of the overlying geosynthetic component can be accomplished using *lightweight*, rubber-tired equipment such as a 4-wheel all-terrain vehicle (ATV). This vehicle can be driven directly on the GCL, provided the ATV makes no sudden stops, starts, or turns. ATV's shall only be operated directly on the GCL by operators with appropriate experience and authority to do so.

11.2.2. Placement - Smooth HDPE may be dragged across the GCL surface with equipment or by hand labour during positioning. Similarly, the HDPE may be unrolled with the use of low ground pressure equipment.

11.3 Textured Liners **-** If a textured geomembrane is placed over the GCL, a slip sheet (such as 0.5 mm smooth plastic) shall first be placed over the GCL in order to allow the geomembrane to slide into its proper position. Once the overlying geomembrane is properly positioned, the slip-sheet shall be carefully removed paying close attention to avoiding any movement to the geomembrane or the GCL.

End