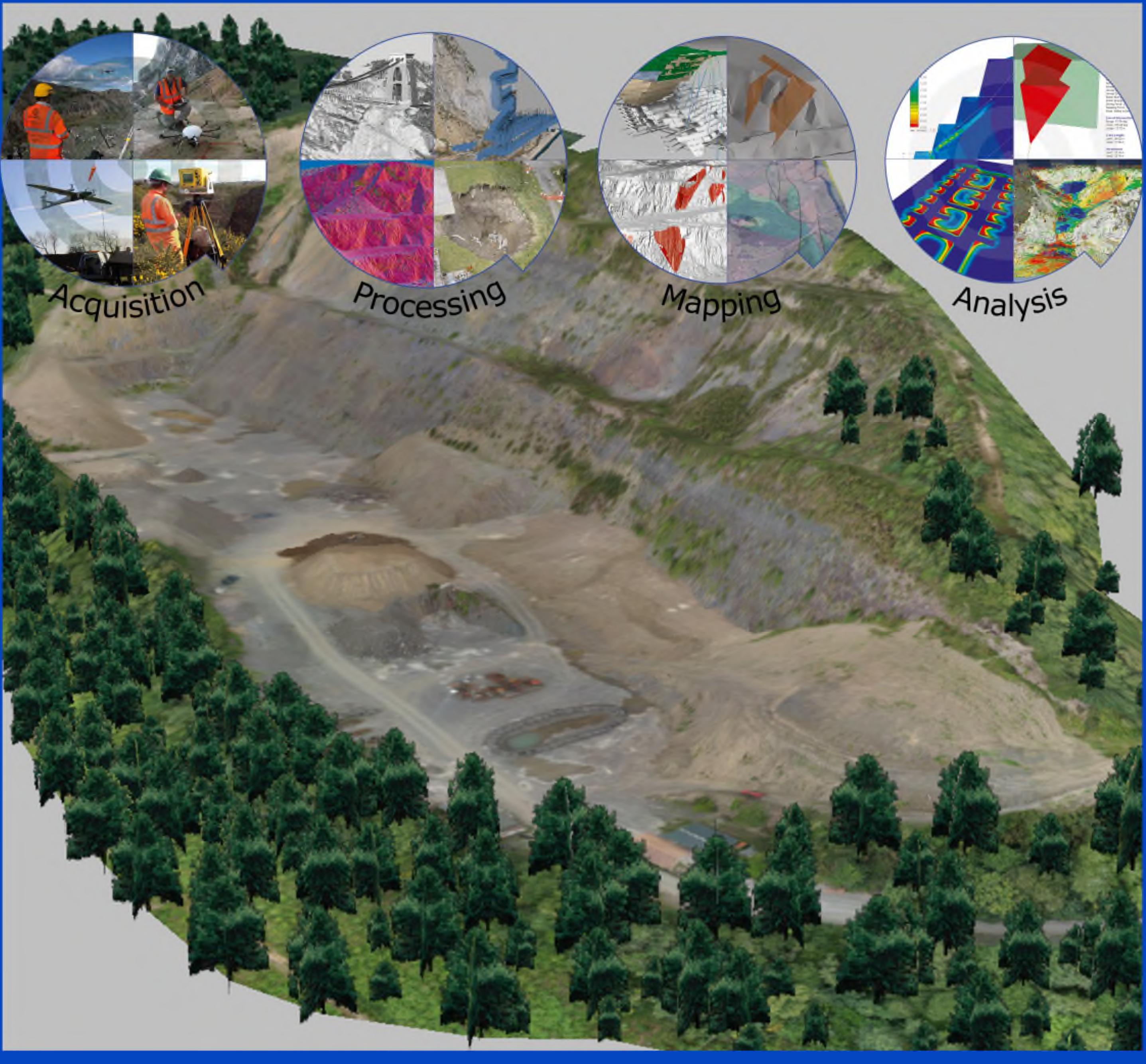
Beam Quarry

Recovery Permit

Stability Risk Assessment Report

December 2021



Land and Minerals Consulting Limited
Consulting Engineering Geologists and Surveyors

Beam Quarry

Recovery Permit Stability Risk Assessment Report

Site N° :	00464
Project N° :	200528/RSW - Revision 1
Report Date :	2nd December 2021

Prepared on behalf of Land and Minerals Consulting Limited by:

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Distribution List

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Author Profiles

Rupert Wilks *(Senior Engineer / UAS Pilot) has an honours degree in Environmental Science with Engineering Geology at the University of Lancaster in 1992. He is a Chartered Engineer and Chartered Environmentalist with the Institute of Materials, Minerals and Mining. He has previously been employed by AIG Consulting, Encia Consulting and Stratus Environmental where he has worked in the ground engineering, geotechnical, waste management and contaminated land sectors and was involved with the design and management of engineering projects in the waste management sector before joining LMCL in May 2016. Rupert served an 18 month secondment to Tarmac Northern as a Senior Development Geologist until March 2019. He also holds a Basic National UAS Certificate (BNUCs) to commercially fly Small Unmanned Aerial Systems.*

Land and Minerals Consulting Ltd (LMCL) *was formed in 2004 as a geological, geotechnical and surveying consultancy. The Company adopted the trading name* **QuarryDesign** *in 2006 to promote its links with the mineral planning consultancy QuarryPlan Ltd. LMCL specialise in the "remote" acquisition of survey, geological and geotechnical data using their various long-range high-accuracy LiDAR scanners and UAV mounted aerial systems. Since 2013, LMCL also trades under the name of* ***DroneSurv*** *(a name more suited to aerial work outside of the quarrying industry).*

LMCL not only has the expertise to acquire the data; but have the experience, software and hardware to process the data into formats required by a wide range of industry standard surveying, geological modelling, geotechnical analysis and numerical modelling software. With that software, they are able to undertake both the analysis and subsequent designs for excavations, tips and lagoons in both engineering soil materials and rock masses. They also provide Reserve and Resource Statements to The PERC Reporting Standard, Due Diligence for mineral acquisitions and act as Expert Witness.

LMCL have undertaken projects for a wide range of industries including surface and underground mining, surface mining and quarrying, mountain and desert cliff surveys, coastal erosion surveys, sink-hole and crown-hole surveys, rock-fall surveys, and slope monitoring surveys. They have worked extensively in the UK and also worked in Ireland, France, Norway, Spain, Portugal, Gibraltar, Bangladesh and Saudi Arabia.

Under the QuarryDesign trading name, the Company was awarded Joint Runner-up in the Engineering Initiatives category of the Mineral Planning Association's Health and Safety Awards 2013 for their use of Terrestrial LiDAR and UAV for remote Surveying and Geological / Geotechnical mapping (appended to the end of this document)

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TABLE OF CONTENTS

LIST OF APPENDICES

Appendix SRA1	SRA Drawings
Appendix SRA2	Phasing Drawings
Appendix SRA3	Model 1 Figures
Appendix SRA4	Model 2 Figures

1 INTRODUCTION

1.1 Report Context

Land and Minerals Consulting Limited (LMCL) were commissioned by **LJ Developments Limited** (TSL) to prepare a Stability Risk Assessment Report (SRAR) for the construction of a buttress against the north faces of the main quarry at Beam using imported inert recovery materials. This report forms part of the permit application for the environmental permit.

This SRAR has been prepared based on the Environment Agency (EA) SRAR template and guidance contained within the **Environment Agency R&D Technical Reports P1-385/TR1 and P1-385/TR2** (TR1 and TR2).

1.1.1 Outline of the Installation

Beam Quarry is located around 1km to the east of the village of Monkleigh in Devon and is accessed off the A386 road. The National Grid Reference for the site is 246999E, 120374N. The site is a sandstone quarry.

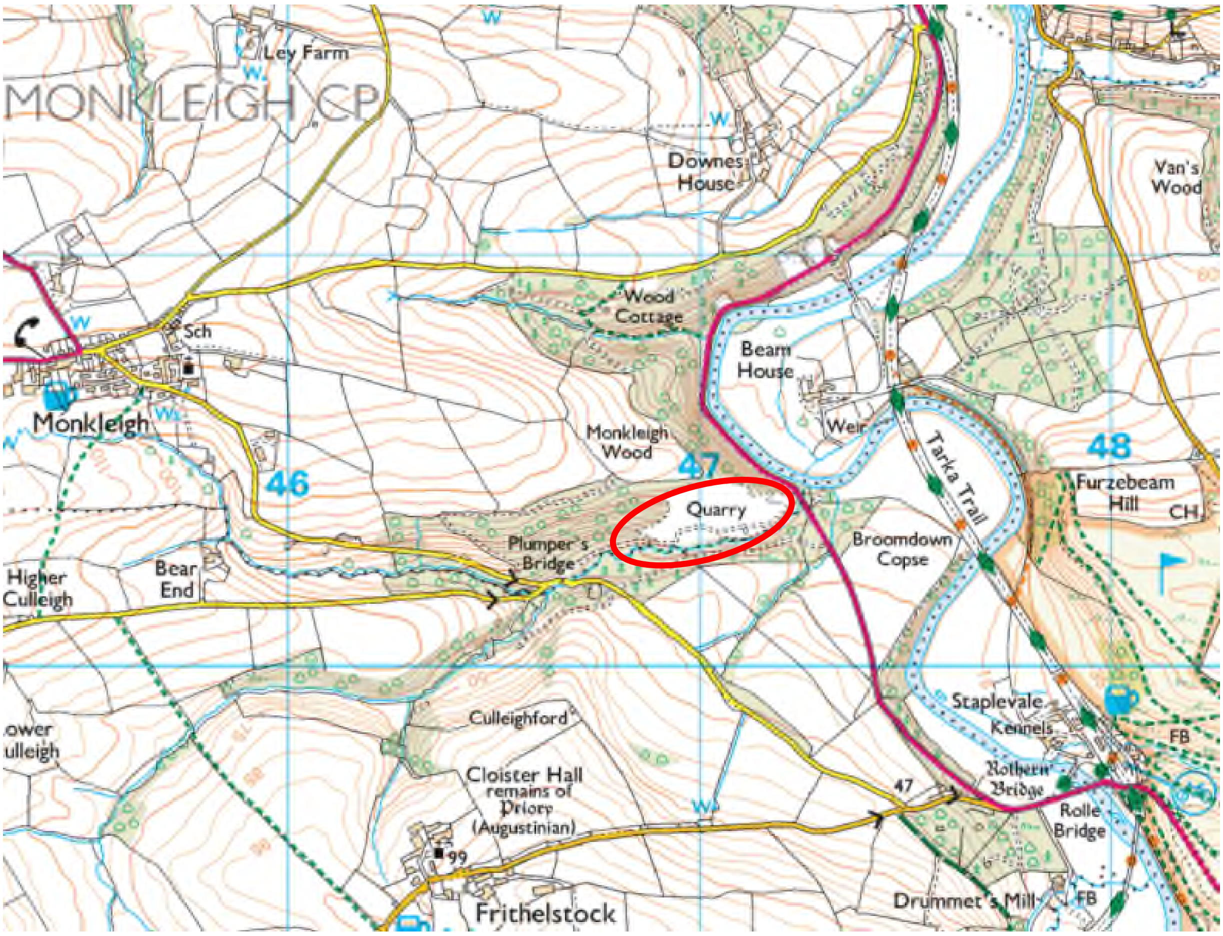


Figure SRA1: Site location Plan for Beam Quarry

1.1.2 Summary of Previous Work

As this is a proposed new recovery facility, no previous Stability Risk Assessment (SRA) has so far been undertaken for this site. However, several reports relating to the quarry have been examined. These reports are summarised in **Table SRA1**:

Table SRA1: Summary of Relevant Previous Reports

Ref No. *	Title (Ref No.)	Date	Author (Client)	Comments
1	Beam Quarry, Scheme for Surface Water Disposal	May 2001	Torrington Stone Limited	Provides a description of the surface and groundwater situation in the quarry at the time of reporting
2	A Geotechnical Assessment of the Stability of Excavated Slopes and Tips at Beam Quarry, Torrington (Report 188E)	July 2015	Fredrick Sherill Limited (on behalf of Torrington Stone Ltd)	The 2015 Geotechnical Assessment report for the site in accordance with the Quarries Regulations (1999). Assess the stability of excavations and the existing landfill tip and provides recommendations for future excavation and tip design.
3	Geodiversity Audit of active aggregate quarries – Quarries in Devon - Beam Quarry (2237/32 WS)	January 2004	David Roche GeoConsulting	Provides a description of the most important geological features on the site with respect to geodiversity
4	Monitoring Mining and Landfill Sites – Beam Quarry	20th May 2019	Devon County Council	Report of annual monitoring visit to the site by the Senior Planning Officer of the council. Passes comment on the application for future inert tipping at the site.

**Note The Report Ref No's will be referred to in the text of this report*

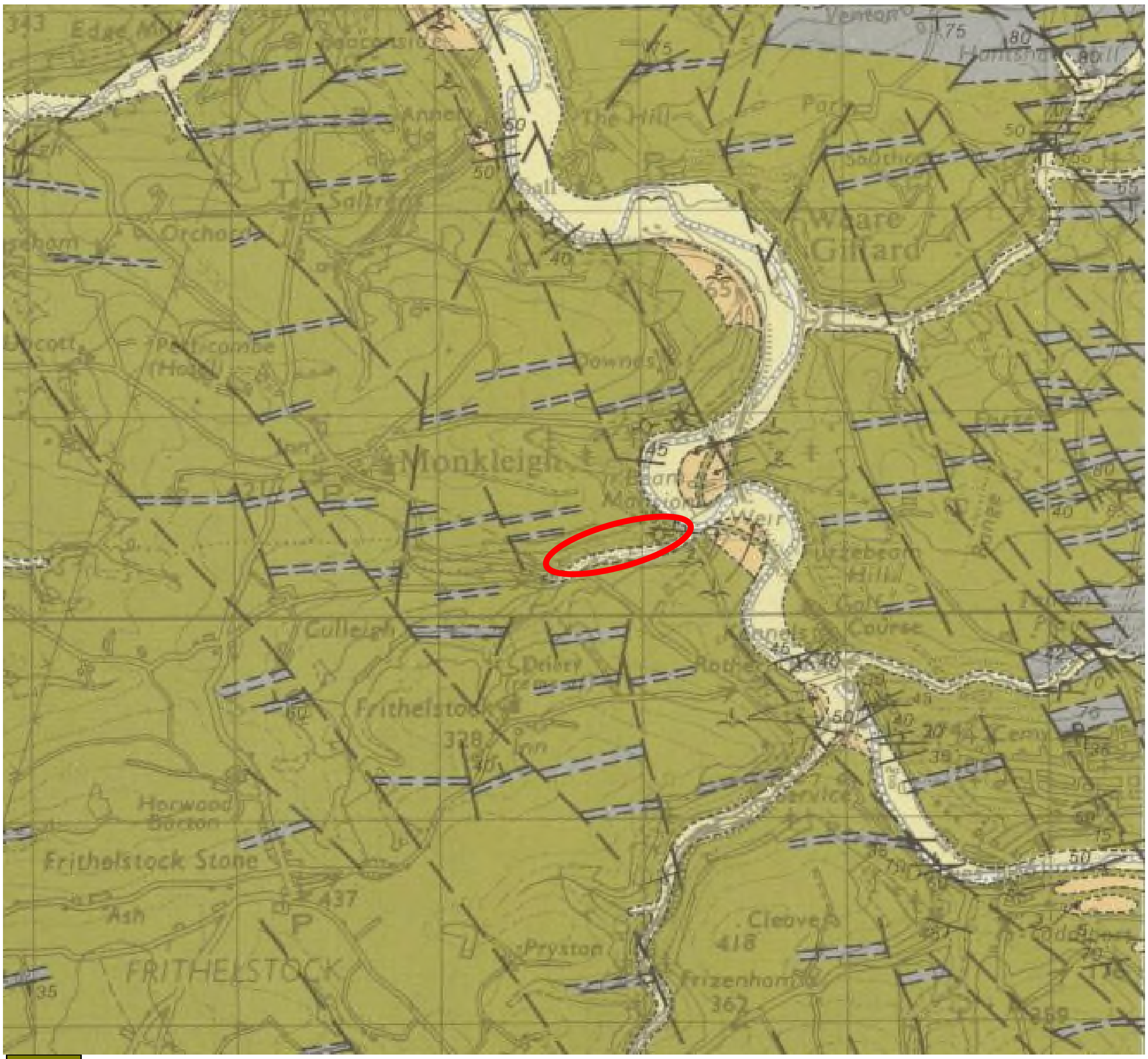
1.2 Conceptual Stability Site Model

The following sub-sections present a summary of the natural geological or fill materials (including engineered fill and un-engineered infill) used in the model.

The proposed inert recovery infill buttress has been designed without a formal basal or sidewall lining system. The landfill will be completed with inert soil materials following completion of the main inert material placement as part of the final restoration.

1.2.1 Geology and Ground Conditions

Detailed descriptions of the site geology are presented in **Reports 2 and 3** (**Table SRA1**). Based on the above information sources and BGS Map Sheet 308 (Bude), a summary of the geology and ground conditions is provided in **Table SRA2**. An extract from the 1 to 50,000 BGS sheet 308 is presented as **Figure SRA2**.



■ Bude Formation - Mainly Sandstone

▒ Bude Formation - Mainly Shale

□ Alluvium

Figure SRA2: Extract from BGS 1 to 50,000 map sheet 308 (Bude). Beam Quarry is circled in red

Table SRA2: Summary of Geological Succession

	Geological Unit	Description
Recent/ **Made Ground**	On site Tips	Quarry waste and imported inert waste above ground level in the east of the site and areas of old quarry waste in the south of the site.
Superficial Deposits	**Alluvium**	Clay, silt, sand or gravel shown in the south of the site in the vicinity of the river channel to the south.
Bedrock	**Bude Formation**	Sandstones, siltstones and shales of the Carboniferous sandstone series

Note: Words in bold indicate the terminology used to describe the ground types in the report text

The sandstones of the Bude formation are the main economic mineral of the quarry. The Bude Formation bedrock at the site is folded into a series of synclines and anticlines striking east-west. This creates a lower northern face with the bedding planes dipping north into the face with the face above comprising single bedding planes dipping to the south.

A north northwest to south southeast trending fault has been noted in the northwest of the site in **Report 2**. An extract from **Report 2**, which shows the location of the fault and other features of geotechnical interest is presented in **Appendix SRA 1**.

1.2.2 Mining Issues

The Coal Authority interactive mapping has been examined and LMCL have no additional information to suggest that the proposed inert recovery buttress area at Beam Quarry has been subject to any historic underground mining.

1.2.3 Hydrogeology and Groundwater

A hydrogeological assessment of the site by Hafren Water has not identified a continuous groundwater level between the site and surrounding ground and surface water observation locations.

However, **Report 1** notes that there are, or have been in the past, several seepages of groundwater evident around the quarry. The springs and seepages of most interest are the ones which have been noted within the proposed footprint of the tip, as follows:

1. **Reports 1 and 2** note a spring which appears periodically against the base of the northern wall of the quarry. This is situated in the lower eastern end of the quarry at around 20.5mAOD and has historically been channelled into the eastern surface water collection area. **Report 1** notes that the periodic spring location appears to move to the west as the last remaining bench has been progressed westwards.
2. **Report 1** notes occasional seepages from the lower western face of the quarry.

An extract from **Report 2**, which shows the location of these features is presented in **Appendix SRA1**. And the approximate location of the spring feature relative to the area infilling is shown on **Drawing 200528/17** in **Appendix SRA 1**.

Although no groundwater seepages or spring flows were noted in the recent Hafren water walkover of the site, the above information sources would suggest that occasional groundwater seepages should be anticipated from the lower face and quarry floor which the inert materials will be placed against.

In order to prevent saturation of the infill, which could lead to a reduction in strength of the infill material, a simple granular backwall drain is proposed which will provide a pathway for any seepages to drain outside the infill area. The two ends of the backwall drainage channel will remain open at all stages of infilling and at completion of infilling with any seepages being channelled to the settlement pond.

1.2.4 Basal Subgrade Model

The basal subgrade for the inert recovery material at the site will comprise in-situ Bude Formation bedrock. In **Table SRA2** this unit has been referred to as the '*Bude Formation'*

The basal sub-grade comprises materials which are considered to be relatively non-compressible.

The lowest current extent of mineral extraction ranges from ~20.5 mAOD in the east of the area rising to 23mAOD in the west of the site. However, the quarry floor is still to be extracted in the west which will lead to a floor level of approximately 20.5mAOD for the majority of the infilling area.

1.2.5 Side-Slope Subgrade Model

The subgrade for the side-slope of the inert at the site will comprise the Bude Formation bedrock. There will also be a back wall drain comprised of coarse granular drainage stone extending a minimum of 4m above the base of the quarry up the back wall of the inert recovery area.

The side slope sub-grade comprises materials which are considered to be relatively non-compressible.

The stability of the side-slope sub grades will be analysed in accordance with the details outlined above.

1.2.6 Basal Lining System Model

No basal lining system is proposed for the site. However, it is proposed that the lower 1,000mm of material placed should be cohesive (clayey) material.

1.2.7 Side-Slope Lining System Model

No side slope lining system is proposed for the site.

1.2.8 Waste Mass Model

The proposed inert recovery buttress final profile is presented on **Drawing 200528/17** (presented in **Appendix SRA 1** to this report) along with the location of the cross section used for the stability assessment models. This is considered to be the worst-case section of the proposed inert recovery buttress as the slope consists of a 17.5m high slope of 1v in 3.7h from 22.5mAOD to 40m AOD. There is also an additional depth of 2m of infilling below the toe of the slope to make the total proposed waste depth in this location 19.5m.

Cross sections further to the west have a shallower proposed slope angle of around 1v in 4h and cross sections further to the east have a lower waste depth.

The site will be permitted to accept inert waste materials. The maximum waste slope height proposed will be 17.5m.

As discussed in the hydrogeology section above, it is proposed to install backwall drainage of course granular drainage material along the base of all of the quarry faces which the inert material will lean against. This will mean drainage against the northern faces, the western faces and against the southern faces where the limited extraction of 2 to 3m of Bude Formation still needs to be undertaken.

The Drainage stone is proposed as at least 1,000mm in thickness from the quarry face and extending up to a height of 4m above the proposed final quarry floor level and this is what will be incorporated into the stability models.

Should groundwater seepages be identified in the quarry faces above this level, additional drains should connect the seepage location to the back wall toe drain.

1.2.9 Capping System Model

No engineered capping system will be required for the inert recovery buttress other than a soil cover. No further modelling will be required.

1.2.10 Model Sections Used

The proposed inert recovery buttress final profile is presented on **Drawing 200528/17** (presented in **Appendix SRA 1** to this report) along with the location of the cross section used for the stability assessment models. The model used in the assessments is presented in **Figure SRA3**. This shows the layout as described above in Sections 1.2.4 to 1.2.8.

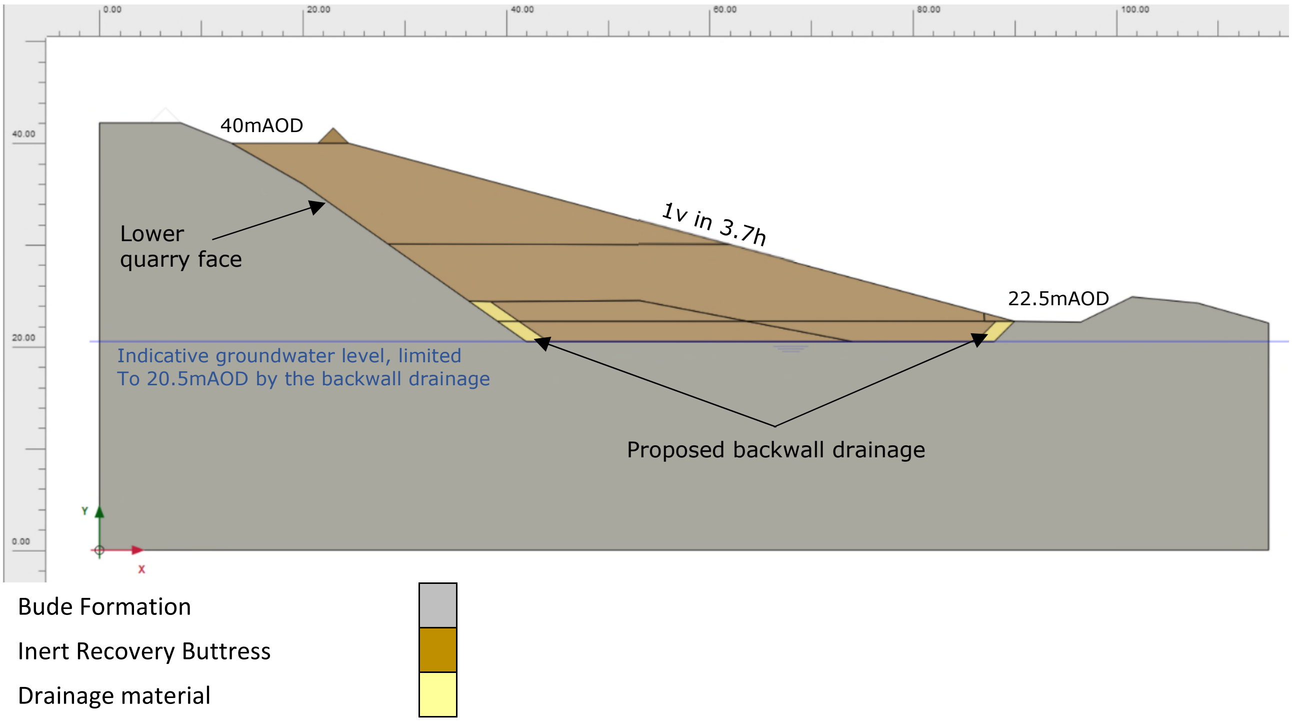


Figure SRA3 – Stability Model Cross Section of completed proposed inert recovery buttress slope – Stage 5 in Table SRA3.

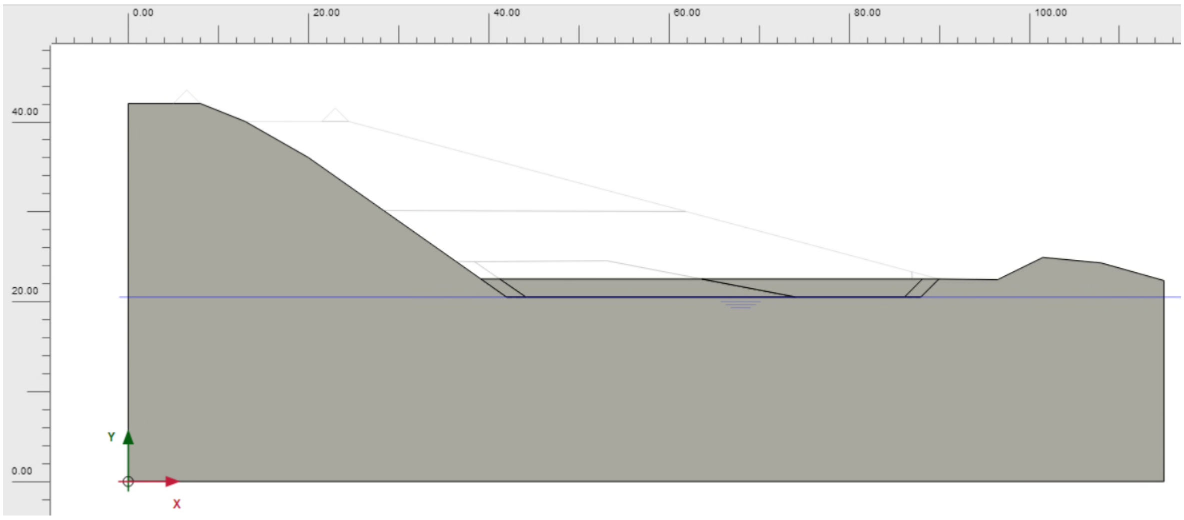
1.2.11 Model Timescales

The timescales of the proposed remaining mineral extraction and inert tipping have been considered in the modelling. The timescales for the various phases are shown on the phasing **Drawings 200528/01 to 201528/05**, presented in **Appendix SRA2**. The timescales and tipping phases relating specifically to the model cross section location are presented in Table SRA3.

Table SRA3 – Modelling Timescales

Modelling Stage		End of Modelling Stage
1	Initial Conditions	-
2	Remaining Mineral Extraction	Year 4
3	Filling to 24mAOD	Year 6
4	Infilling to 30mAOD	Year 8
5	Infilling Complete	Year 10

Diagrams of the first four modelling stages in **Table SRA3** are presented in **Figures SRA4 to SRA7** below with Stage 5 being represented in **Figure SRA3**.



Bude Formation ⬜
Inert Recovery Buttress 🟫
Drainage material 🟨

Figure SRA4 – Stage 1, Initial Conditions

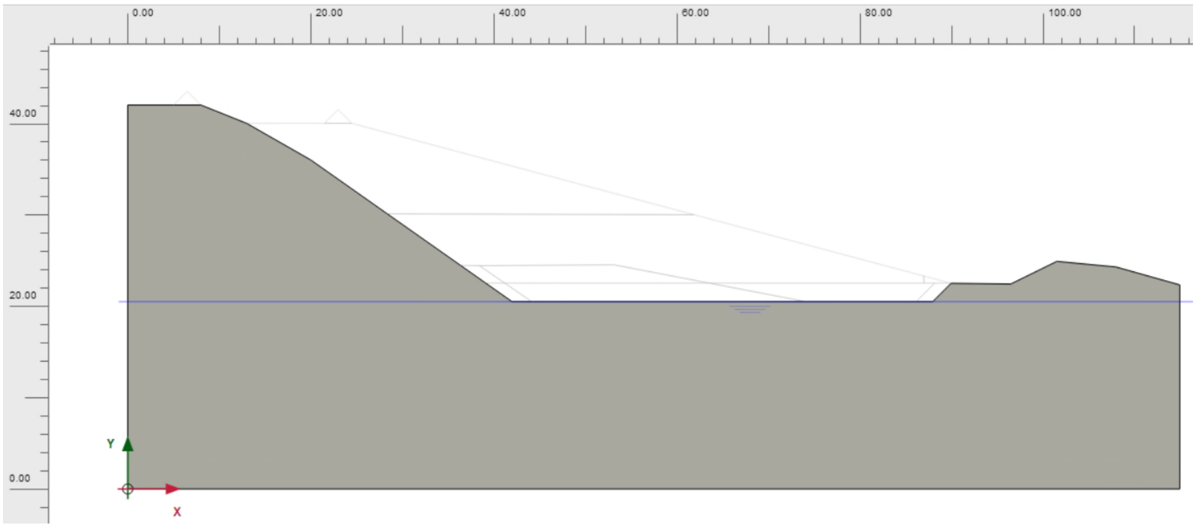


Figure SRA5 – Stage 2 Mineral Extraction

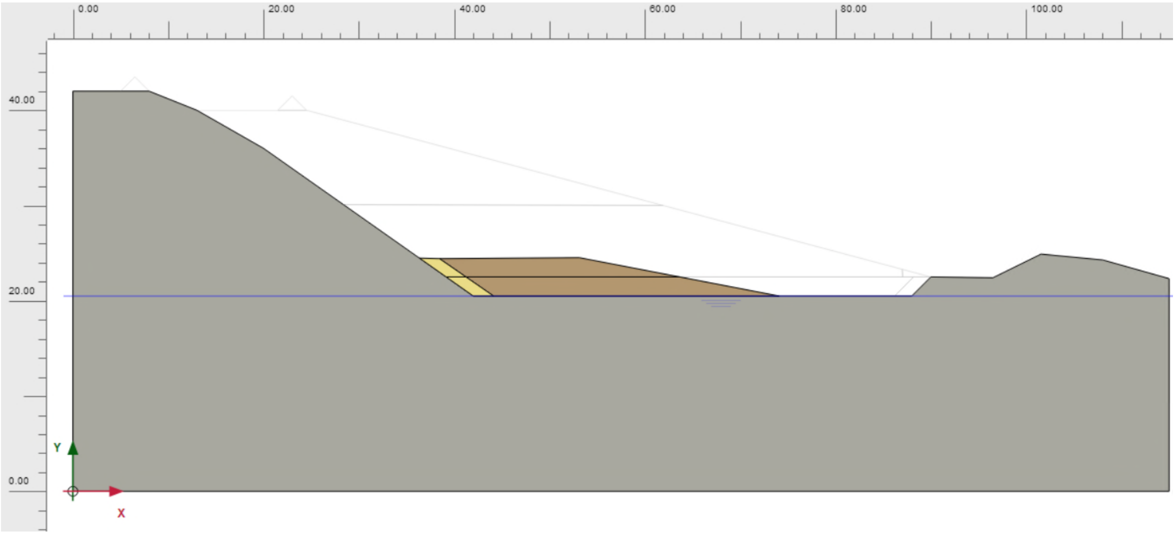


Figure SRA6 – Stage 3 Infill to 24mAOD

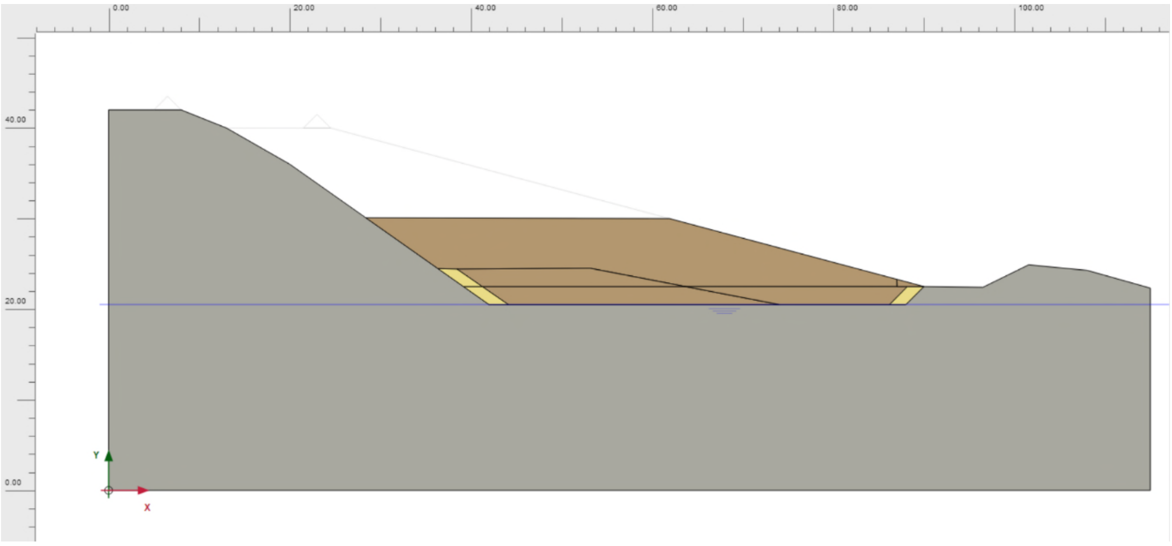


Figure SRA7 – Stage 4 Infill to 30mAOD

2 STABILITY RISK ASSESSMENT

The six principal components of the conceptual stability site model have been considered.

2.1 Risk Screening

Issues relating to stability and integrity for each principal component have been subject to a preliminary review to determine the need to undertake further detailed geotechnical analyses. The following sections present the results of this screening exercise

2.1.1 Basal Subgrade Screening

The key considerations for the basal subgrade and the implications for stability and integrity are as follows:

- **Compressible subgrade:** The basal subgrade comprises natural in situ bedrock of the Bude Formation. Values used for the basal sub-grade material have been taken from a BRE technical data sheet for Torrington Sandstone from Beam Quarry. Where engineering values are not available, conservative values will be used.
- **Basal Heave, Groundwater**: There is not considered to be a continuous groundwater level across the Bude formation, in addition, bedrock is fissured and is considered unlikely to be affected by heave. Therefore, heave via this mechanism will not be considered further.
- **Basal Heave, Excess Pore Pressures**: Not considered further due to the fissured nature of the strata, allowing seepages to occur where necessary
- **Cavities in the Subgrade:** None anticipated
- **Filling on Waste:** Not applicable

2.1.2 Side-Slope Subgrade Screening

The key considerations for the side slope subgrade and the implications for stability and integrity are considered to be as follows:

- **Compressible subgrade:** The side slope subgrade comprises natural in situ bedrock of the Bude Formation. The values used for the basal sub-grade material have been taken from a BRE technical data sheet for Torrington Sandstone from Beam Quarry. Where engineering values are not available, conservative values will be used.
- **Heave, Groundwater**: There is not considered to be a continuous groundwater level across the Bude formation, in addition, bedrock is fissured and is considered unlikely to be affected by heave. Therefore, heave via this mechanism will not be considered further.
- **Heave, Excess Pore Pressures**: Not considered further for the natural sandstone strata due to the fissured nature of the strata.
- **Cavities in the Subgrade:** None anticipated
- **Filling on Waste:** Not applicable

2.1.3 Basal Lining System Screening – AEGB

No basal lining system is proposed for this site.

2.1.4 Side-Slope Lining System Screening - AEGB

No side-slope lining system is proposed for this site.

2.1.5 Waste Mass Screening

The most critical situation will be when the waste is deposited to full height, and this is the situation that will be analysed in more detail.

The controlling factors that influence the stability of the waste mass are presented below:

- **Stability of Waste Mass**: The maximum waste slope height possible at the site will be 17.5m with a waste depth of 19.5m. It is proposed to analyse this slope at a gradient of 1 in 3.7.
- **Stability of Waste and AEGB Lining System**: Not applicable – no lining system proposed.
- **Integrity of Lining System with Waste**: Not applicable – no lining system proposed.

2.1.6 Capping System Screening

No formal capping system, other than a final soil cover, is required for this site. Therefore, no assessment for a capping system will be undertaken as part of this assessment.

2.2 Selection of Appropriate Factors of Safety

The factor of safety is the numerical expression of the degree of confidence that exists for a given set of conditions, against a particular failure mechanism occurring. It is commonly expressed as the ratio of the load or action that would cause failure against the actual load or actions likely to be applied during service. This is readily determined for some types of analysis, for example limit equilibrium slope stability analyses. However, greater consideration must be given to analyses that do not report factors of safety directly. For example, a finite difference analysis of strains within a lining system would not usually indicate overall failure of the model even though the strains could be high enough to indicate a failure of the integrity of the system. In such cases, it is necessary to define an upper limit for shear strains and to express the factor of safety as the ratio of allowable strain to actual strain.

The factor of safety adopted for each component of the model would be related to the consequences of a failure.

BS6031 - Code of Practice for Earthworks (Clause 6.5.1.2 Safety Factors) states that suitable safety factors in a particular case can only be arrived at after careful consideration of all the relevant factors, and the exercise of sound engineering judgement. The factors to be considered include:

- The complexity of the soil conditions;
- The adequacy of the site investigation;
- The certainty with which the design parameters represent the actual in-situ conditions;
- The length of time over which the stability has to be assured;
- The likelihood of unfavourable changes in groundwater regime in the future;
- The likelihood of unfavourable changes in the surface profile in the future;
- The speed of any movement which might take place; and,
- The consequences of any failure.

2.2.1 Factor of Safety for the Basal Subgrade

The stability of the Bude formation quarry floor is not required to be assessed.

2.2.2 Factor of Safety for the Side-Slope Subgrade

As the side slope sub-grade is the existing quarry face, the stability of this feature will not be assessed. The quarry faces have been designed in accordance with Report 2 and previous geotechnical assessments for the quarry and, in accordance with Report 2 are considered to be stable. Addition of the inert Recovery buttress will improve the stability of the lower quarry face long term,

2.2.3 Factor of Safety for the Basal Lining System

No basal lining system is proposed.

2.2.4 Factor of Safety for the Side-Slope Lining System (Confined & unconfined)

No side slope lining system is proposed.

2.2.5 Factor of Safety for Waste Mass

A minimum factor of safety of 1.3 is considered acceptable for stability, assuming that reasonably conservative values are used.

2.2.6 Factor of Safety for Capping System

Not required.

2.3 Justification for Modelling Approach and Software

In order to perform a comprehensive stability risk assessment (SRA), the components of the landfill containment systems have to be considered not only individually, but also in conjunction with one another, where relevant. Any analytical techniques adopted for such an assessment should adequately represent all of the considered scenarios for both the unconfined and confined conditions (where appropriate). The methodology and the software should also achieve the desired output parameters for the assessment. This equates to the determination of factors of safety for stability assessments, or the calculation of strains within liner components, for integrity assessments.

The analytical methods used in this stability risk assessment review include:

- **Finite element analyses** for the calculation of factors of safety for the stability of the waste mass.

2.3.1 Finite Element Analyses

The proprietary software **PLAXIS** (Version 2D 2019) has been used for the stability assessment Models 1 and 2. Plaxis is a two-dimensional finite element programme intended for the analysis of deformation and stability in geotechnical engineering. It is equipped for the simulation of non-linear, time dependent and anisotropic behaviour of soils and rock. In addition, since soil is multi-phase material, special procedures are required to deal with hydrostatic and non-hydrostatic pore pressures in the soil.

A safety analysis in PLAXIS is undertaken by reducing the strength parameters of the soils. This process is termed '**Phi-C reduction**', and is carried out as a separate calculation mode. Phi-C reduction is used when it is required to calculate a factor of safety, for the situation under consideration.

In the Phi-C reduction approach, the strength parameters φ and c of the soils (and interface shear strengths) are incrementally reduced until failure of the system occurs. For slopes, the Phi-C reduction approach resembles the method of calculating safety factors as conventionally adopted in traditional slip-circle analyses.

The model used within PLAXIS for these assessments is the Mohr-Coulomb model which considers both the elastic and plastic properties of the soils. The mesh used for all models comprises 15-Node triangles which provide 4th order interpolation. The Plaxis finite element mesh used in the model section is illustrated in **Figure SRA8**.

To summarise, assessments have been carried out to assess the future development of this inert recovery buttress for the following design scenarios:

- Assessment of the stability of the worst-case inert recovery buttress slope through the modelling timescales proposed using both total and effective stress analysis.

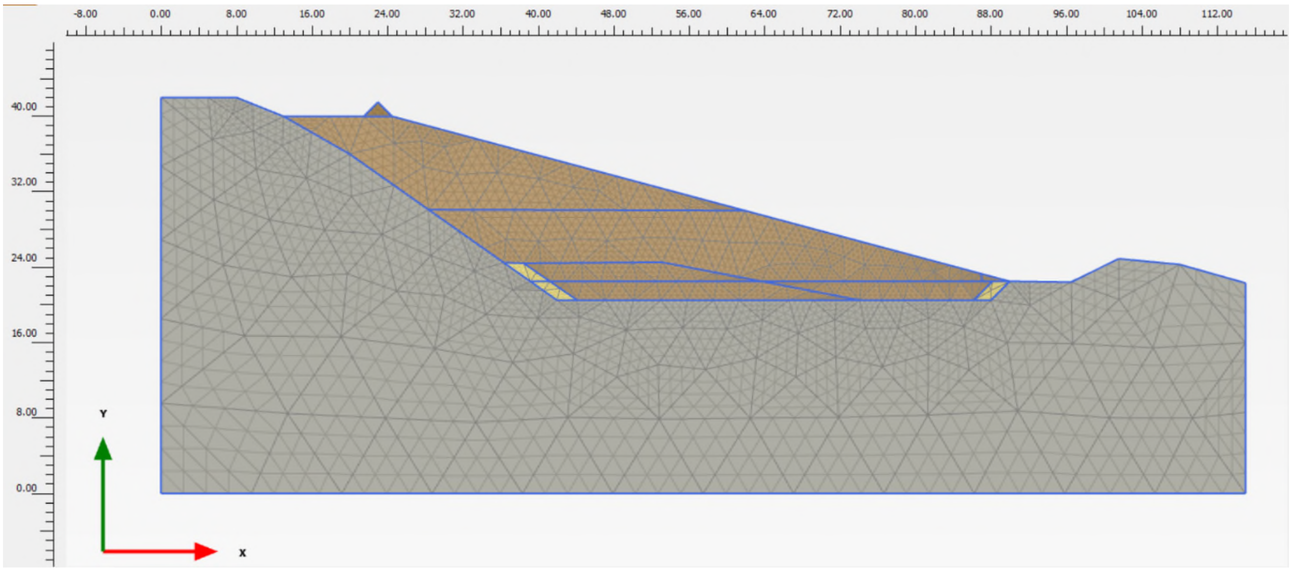


Figure SRA8 – Plaxis Finite Element Mesh used in the modelling.

2.4 Justification for Geotechnical Parameters Selected for Analysis

The parameters selected for material properties consider the analyses undertaken, and where there was uncertainty, a sensitivity analysis was used to assess the potential for instability.

In terms of inert recovery material parameters, the values for c' and ø' adopted throughout the modelling were 1 kPa and 21 degrees, respectively. These are considered to be very conservative for an inert recovery material compared with parameters generally used for non-hazardous waste of 5 kPa and 25 degrees from Jones, D.R.V. and Dixon, N. 2003 (full reference in Section 6). For the total stress analysis, a similarly conservative value of 40kPa has been selected for the undrained shear strength of the inert recovery material.

Two values for the unit weight of the inert recovery material have been modelled: 15kN/m^3 and 18kN/m^3 based on engineering judgement of the likely main constituents of the recovery material being soils and sub-soils.

Further justification and explanation of the chosen parameters is provided in Tables SRA4a and SRA 5a.

2.5 Summary of Material Parameters for Finite Element Analyses

Tables SRA4 and SRA5 below summarise effective stress and total stress parameters utilised in the analyses. Cut slopes in cohesive soils are kept stable by pore water suctions and, as these suctions dissipate, stability decreases. Therefore, consideration has been given to both the **long-term – effective stress** (drained) and **short-term – total stress** (un-drained) states for each scenario. In long-term analyses (drained conditions) the materials are reliant on their frictional properties (i.e. ϕ’) for shear strength, and little from their apparent cohesion (c’).

The parameters used in the analyses have been obtained from a combination of published literature and site-specific laboratory testing. Engineering properties for the waste mass were obtained using guidance from **Environment Agency R&D Technical Reports TR1 and TR2** (full references in Section 6). Notes on the derivation of the parameters used are presented in **Tables SRA4a and SRA5a**.

Table SRA4: Summary of Effective Stress Material Parameters for Finite Element Analysis

Material	Unit Weight	Cohesion with respect to effective stress	Angle of friction with respect to effective stress	Water Permeability (K)	Poisson's Ratio	Young's Modulus
	kN/m^3	kN/m^2	°	m/s	-	MN/m^2
Granular Drainage Material	17 to 19	0	30	1x10^{-3}	0.33	10.0
Inert Recovery Material	15 to 18	1	21	1x10^{-6} to 1x10^{-7}	0.35	1.0

Table SRA4a: Derivation and Suitability of Parameters in Table SRA4

(References noted are provided in full in Section 6)

Material	Unit Weight	Cohesion	Angle of friction	Permeability (K)	Poisson's Ratio	Young's Modulus
	kN/m^3	kN/m^2	°	m/s	-	MN/m^2
Granular Drainage Material	Strength values are based on engineering judgement and experience using general guidance from **Bolton M.D. (1986)** and other sources.				The value of Poisons Ratio for this material has been derived from engineering judgement and experience. Based on values from **Essien, U.E. et al (2014) and Bowles, J. E. (1996).** These values are considered to be realistic values.	Based on the lower end value for loose granular material from **Bowles, J. E. (1996).**
Inert Recovery Material	The inert waste mass will be made up of a variety of materials from a wide range of sources not yet known. Therefore, these parameters cannot be measured at present. The report **TR1: Jones, D.R.V. and Dixon, N. (2003)** provides general guidance on waste parameters and the parameters for the future inert waste mass have been selected as more conservative than those for typical non-hazardous waste from TR1.					

Table SRA5: Summary of Total Stress Material Parameters for Finite Element Analyses (No Excess Pore Water Pressures)

Material	**Unit Weight**	**Cohesion (un-drained shear strength S_u)**	**Angle of friction**	**Water Permeability (No excess pore water pressures)**	**Poisson's Ratio**	**Young's Modulus**
	kN/m^3	**kN/m^2**	**°**	**m/s**	**-**	**MN/m^2**
Inert Recovery Material	15 to 18	40	0	Not applicable to a total stress analysis	0.495	1.0

Table SRA5a: Derivation and suitability of Parameters in Table SRA5

(References noted are provided in full in Section 6)

Material	**Unit Weight**	**Cohesion (un-drained shear strength S_u)**	**Angle of friction**	**Water Permeability**	**Poisson's Ratio**	**Young's Modulus**
	kN/m^3	**kN/m^2**	**°**	**m/s**	**-**	**MN/m^2**
Inert Recovery Material	Value of 40kPa selected as worst case, conservative value based on engineering judgement and experience of similar cohesive inert materials			Not applicable	(See Note 1)	**Duncan J.M. & Buchignani A. I. (1976)**

Notes:

1. Generally, Poisson's ratio is taken as 0.5 for a Total Stress (undrained) assessment. However, the Plaxis model for undrained assessment requires the adoption of a slightly lower value of 0.495.

3 ANALYSIS

3.1 Introduction

The key areas of the future proposed inert recovery buttress which require analysis have been assessed in the models listed below:

- ***Model 1***: The **stability** of the inert recovery material constructing the buttress over a time period of 10 years against the existing quarry face. Modelled using **Effective Stress** parameters; and,
- ***Model 2***: The **stability** of the inert recovery material constructing the buttress over a time period of 10 years against the existing quarry face. Modelled using **Total Stress** parameters.

Note that the magnitude of the displacements reported by the Plaxis program on the Phi-c reduction analysis printouts do not relate to any 'real world' values as the model has been taken past its point of failure and these displacements should be ignored.

3.2 Model 1: Stability Analyses

A summary of the results from the phi-c reduction runs for the various stages of the construction of the lining system are presented in **Table SRA6**:

Table SRA6: Summary of Model 1: Stability Analysis (Phi-C reduction)
Effective Stress Parameters

Parameters modelled	Stage of the construction process	Critical slope identified during analysis	Lowest Factor of Safety	Figure in Appendix SRA3
Unit weight **15kN/m^3**, Permeability of inert material **1x10^{-6}**	Stage 4 – Inert material to 30mAOD, to Year 8.	Inert Recovery Material slope	1.45	9
	Stage 5 – Inert material complete, to Year 10.	Inert Recovery Material slope	1.33	10
Unit weight **18kN/m^3**, Permeability of inert material **1x10^{-6}**	Stage 4 – Inert material to 30mAOD, to Year 8.	Inert Recovery Material slope	1.42	-
	Stage 5 – Inert material complete, to Year 10.	Inert Recovery Material slope	1.32	11
Unit weight **15kN/m^3**, Permeability of inert material **1x10^{-7}**	Stage 4 – Inert material to 30mAOD, to Year 8.	Inert Recovery Material slope	1.45	-
	Stage 5 – Inert material complete, to Year 10.	Inert Recovery Material slope	1.32	12
Unit weight **18kN/m^3**, Permeability of inert material **1x10^{-7}**	Stage 4 – Inert material to 30mAOD, to Year 8.	Inert Recovery Material slope	1.42	-
	Stage 5 – Inert material complete, to Year 10.	Inert Recovery Material slope	1.31	13

Graphical representations of selected analyses (including failure modes) are shown in **Appendix SRA3**.

3.3 Model 2: Stability Analyses

A summary of the results from the phi-c reduction runs for the various stages of the construction are presented in **Table SRA7** below. For these models, total stress parameters have been adopted for the inert recovery material. Model 2 uses an undrained shear strength value of 40kPa for the inert recovery material.

Table SRA7: Summary of Model 2a: Stability Analysis (Phi-C reduction)

Inert Recovery Material Shear Strength @ 40kPa

Parameters modelled	Stage of the construction process	Critical slope identified during analysis	Lowest Factor of Safety	Figure in Appendix SRA4
Unit weight **15kN/m³**	Stage 4 – Inert material to 30mAOD, to Year 8.	Inert Recovery Material slope	3.02	-
	Stage 5 – Inert material complete, to Year 10.	Inert Recovery Material slope	1.58	14
Unit weight **18kN/m³**,	Stage 4 – Inert material to 30mAOD, to Year 8.	Inert Recovery Material slope	2.52	15
	Stage 5 – Inert material complete, to Year 10.	Inert Recovery Material slope	1.32	16

Graphical representations of selected analyses (including failure modes) are shown in **Appendix SRA4**.

4 ASSESSMENT

The assessments outlined above are presented in the order described.

4.1 Model 1: Stability Assessment

Model 1 examined the stability of the inert recovery buttress against the existing configuration of the lower quarry face using **effective stress** parameters and realistic timescales. The face angle of the inert recovery buttress was set to 1 in 3.7. Conservative infill strength parameters of c=1 and phi=21 were adopted.

Unit weights of 15kN/m^3 and 18kN/m^3 were examined as well as permeabilities of 1x10^{-6}m/s and 1x10^{-7}m/s. The predicted failure areas lie within the inert recovery material slope for all models examined.

From **Table SRA7**, factors of safety for the situation at Year 8 (with the inert material at 30mAOD) were found to be between 1.42 and 1.45. As anticipated, factors of safety for the highest slope, at the completion of infilling were lower, between 1.31 and 1.33.

The factors of safety for the final proposed infilled slope are considered acceptable.

4.2 Models 2: Stability Assessment

Model 1 looked at the stability of the inert recovery buttress against the existing configuration of the lower quarry face using **total stress** parameters for the inert recovery material. The face angle of the inert recovery buttress was set to 1 in 3.7. A conservative infill strength parameter of 40kN/m2 was adopted for the inert recovery material.

Unit weights of 15kN/m^3 and 18kN/m^3 were examined. The predicted failure areas lie within the inert recovery material slope for all models examined.

From **Table SRA8**, factors of safety for the situation at Year 8 (with the inert material at 30mAOD) were found to be between 2.5 and 3.0. As anticipated, factors of safety for the highest slope, at the completion of infilling were lower, between 1.32 and 1.58.

Using total stress parameters, the factors of safety for the final proposed buttress are considered acceptable.

5 CONCLUSIONS, RECOMMENDATIONS AND MONITORING

5.1 General

This stability risk assessment (SRA) has addressed the stability of the worst-case slope of the proposed design for an inert recovery buttress to be constructed against the northern face of Beam Quarry.

Analyses have been based on the available site investigation information, conservative materials parameters, and a worst-case interpretation.

Recommendations for construction and monitoring are listed in the following sections.

5.2 Construction of the Backwall Drainage

In order to prevent saturation of the infill material from occasional groundwater seepages, a simple granular backwall drain is proposed which will provide a pathway for any seepages to drain outside the infill area.

The backwall drainage material must comprise a course, free draining granular material of predominantly gravel and cobble sized particles with a limited fines content.

The backwall drainage must be placed along the base of all of the quarry faces which the inert recovery material will lean against. This will mean drainage against the base of the northern faces, the western faces, and the southern faces.

The Drainage stone shall be placed at least 1,000mm in thickness (measured perpendicular the quarry face) and extend up to a minimum height of 4m above the final quarry floor level (or the top of the infill material, where lower, such as at the ends of the infill buttress).

Should groundwater seepages be identified in the quarry faces above the proposed level of the top of the drain, additional drainage material should be placed to connect the observed seepage location into the back wall toe drain.

It should be ensured that the two open ends of the backwall drainage remain open after completion and restoration of the infill buttress and that any seepages can drain freely away form the buttress to the proposed eastern restoration pond.

5.3 Inert recovery buttress Construction

The worst case (highest / steepest) inert recovery buttress slope geometry was examined for both total and effective stress conditions using conservative parameters. The factors of safety returned by the Plaxis models are acceptable and it is considered that the inert recovery material buttress should be stable if constructed in the proposed design configuration.

The inert recovery buttress should be constructed in general accordance with the phased drawings presented in Appendix SRA2. The infill material should be placed in maximum 1,000mm layers with compaction of each layer by the dozer or excavator being undertaken prior to placing the subsequent layer to ensure that no voids are present. It is recommended that the initial 1000mm layer at the base of the buttress comprise cohesive (clayey) material.

Unsuitable material such as soft, wet, or organic (peat) materials should be excluded from the infill buttress

In wet weather, where the surface of the placed layers of infill become saturated, no further layers of infill should be placed until either the previous saturated layer has dried out or been removed or mixed with drier material.

Inert recovery material which has become saturated and then has had to be removed can be replaced once it has dried out enough to be placed in a firm (not soft) state.

Adequate drainage should be provided through the tip construction, so that standing water does not form at the crest or the toe of inert recovery material faces.

NOTE: The shorter the time period over which a slope or embankment comprising cohesive materials is constructed the greater the build-up of pore water pressures within the material which can lead to a reduction in the factor of safety for the system. **The factors of safety for the heights and gradients of the waste slopes are based on the timescales proposed for the site. Should actual or anticipated tipping rates on site exceed this, then a re-assessment of the waste slope stability is recommended.**

5.4 Monitoring

The following monitoring is proposed throughout the phased construction of the inert recovery buttress.

The quarry faces which the inert material will be buttressed against should be monitored on an ongoing basis for any groundwater seepages and these locations noted so that additional drainage can be installed if required.

Temporary infill slopes and tip haul roads should be monitored daily before each shift for any signs of instability (slumping, tension cracks, seepages etc.) whilst the tip is active.

Areas of the infill buttress which have reached their completed levels should be monitored periodically for signs of instability – this should continue through the restoration and aftercare period.

5.5 Rockfall Safety

The quarry faces have been designed in accordance with the previous Geotechnical Assessments for the site. It is anticipated that quarrying will re-start at Beam, in accordance with the proposed phasing plans, and a new Geotechnical Assessment will be required for the site in accordance with the Quarries Regulations (1999) prior to the re-start of quarrying.

The Geotechnical Assessment for the site will provide recommendations for the safe operation of the faces and tips at the site. The proposed inert recovery buttress will be classified as a solid tip under the Quarries Regulations whilst the site is an active quarry.

As the tip is being constructed against exiting quarry faces, protection of plant and personnel from rockfall will have to be considered. Guidance for safe stand-offs, and rock trap dimensions provided in the site Geotechnical Assessment should be followed during tip construction.

Falling Object Protection Systems (FOPS) should be installed on any items of plant used for the inert recovery buttress construction.

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Appendices

Appendix SRA1 – SRA Drawings

Appendix SRA2 – Phasing Drawings

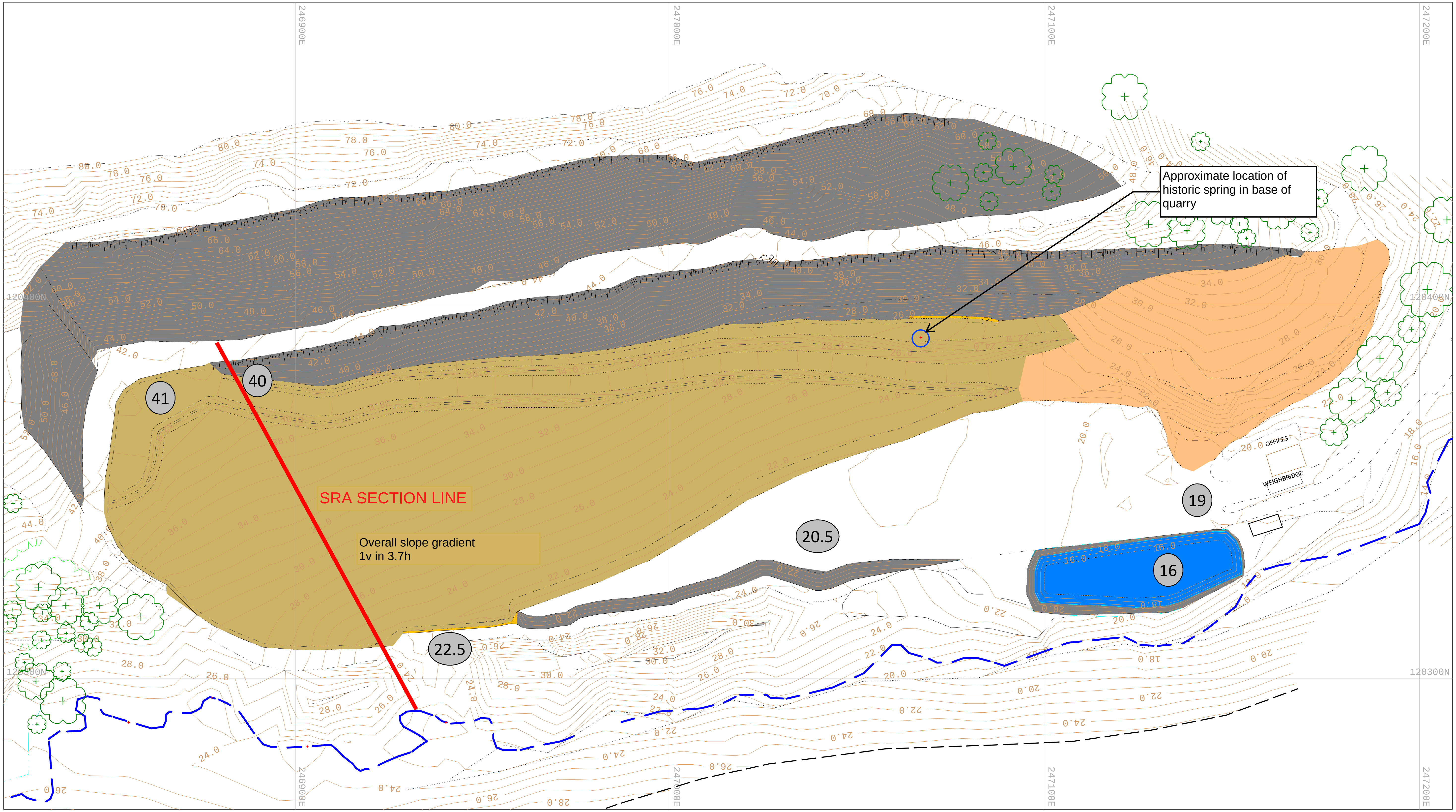
Appendix SRA3 – Model 2 Figures

Appendix SRA4 – Model 3 Figures

Appendix SRA1

Drawings

200528/17	SRA Drawing
1884E	2015 Geotechnical Assessment: Figure 2



Legend

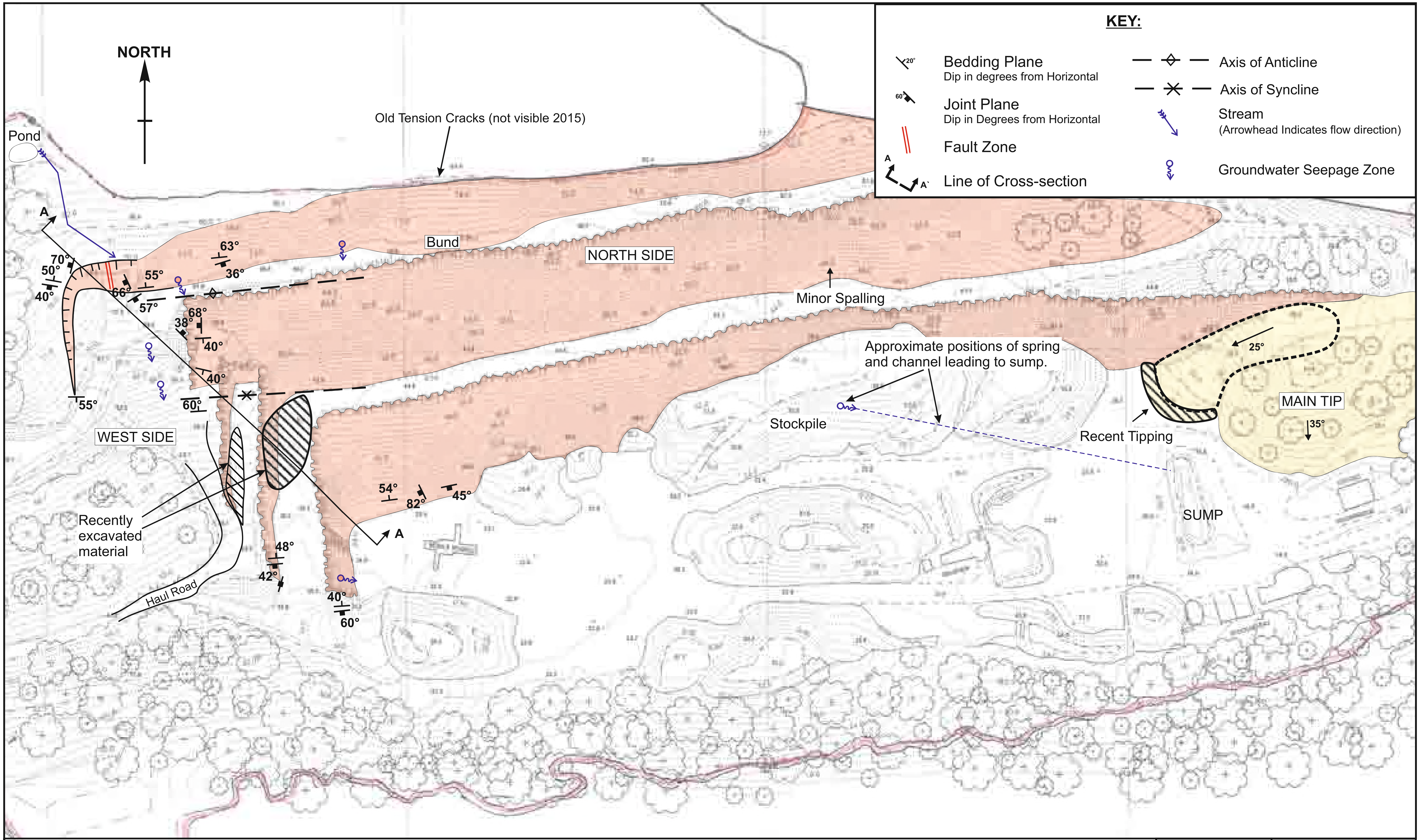
⬛	Existing quarry face	🟦	Surface water body
🟩	New quarry faces at end of Phase	╱	Line of Surface Watercourse
🟧	Existing inert landfill waste	⇢	Direction of surface water flow
🟨	Granular backwall drainage	╱	Line of Groundwater Seepage Flow
🟫	Newly placed inert landfill waste	⇠	Direction of Groundwater Seepage Flow

(56) Ground Level (mAOD)

(00464) Beam Quarry

SRA Drawing

Drawn By **RSW**	Scale **1 : 1000**
Dwg Nº **200528/17**	Paper Size **A3**



Title			
BEAM QUARRY, TORRINGTON **PLAN OF QUARRY SHOWING GEOLOGICAL STRUCTURE**	Approximate Scale 1:1000@A3	Drawing No. **FIGURE 2**	
	Drawn JR	Checked RG	Date Jun. 2015
			Job Ref. 1884E

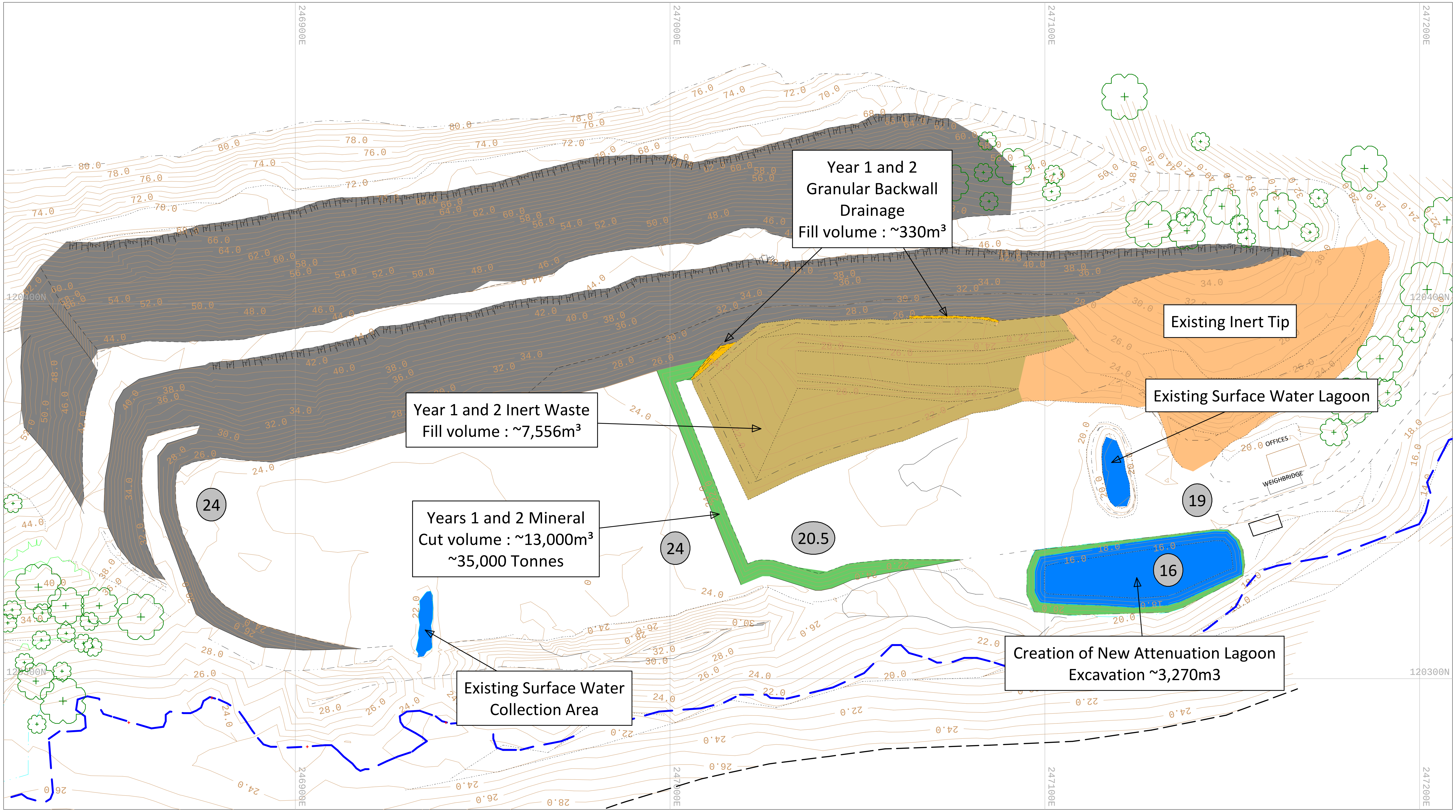
Client
TORRINGTON STONE LIMITED

FREDERICK SHERRELL LTD
CONSULTING ENGINEERING GEOLOGISTS AND GEOTECHNICAL ENGINEERS

Appendix SRA2

Phasing Drawings

200528/01	Years 1 and 2
200528/02	Years 3 and 4
200528/03	Years 5 and 6
200528/04	Years 7 and 8
200528/05	Years 9 and 10



Year 1 and 2
Granular Backwall
Drainage
Fill volume : ~330m³

Existing Inert Tip

Existing Surface Water Lagoon

Year 1 and 2 Inert Waste
Fill volume : ~7,556m³

Years 1 and 2 Mineral
Cut volume : ~13,000m³
~35,000 Tonnes

Existing Surface Water
Collection Area

Creation of New Attenuation Lagoon
Excavation ~3,270m3

Legend

■	Existing quarry face
🟩	New quarry faces at end of Phase
🟧	Existing inert landfill waste
🟨	Granular backwall drainage
▨	Newly placed inert landfill waste
🟦	Surface water body
⁄	Line of Surface Watercourse
→	Direction of surface water flow
⁄	Line of Groundwater Seepage Flow
←	Direction of Groundwater Seepage Flow
(56)	Ground Level (mAOD)

N

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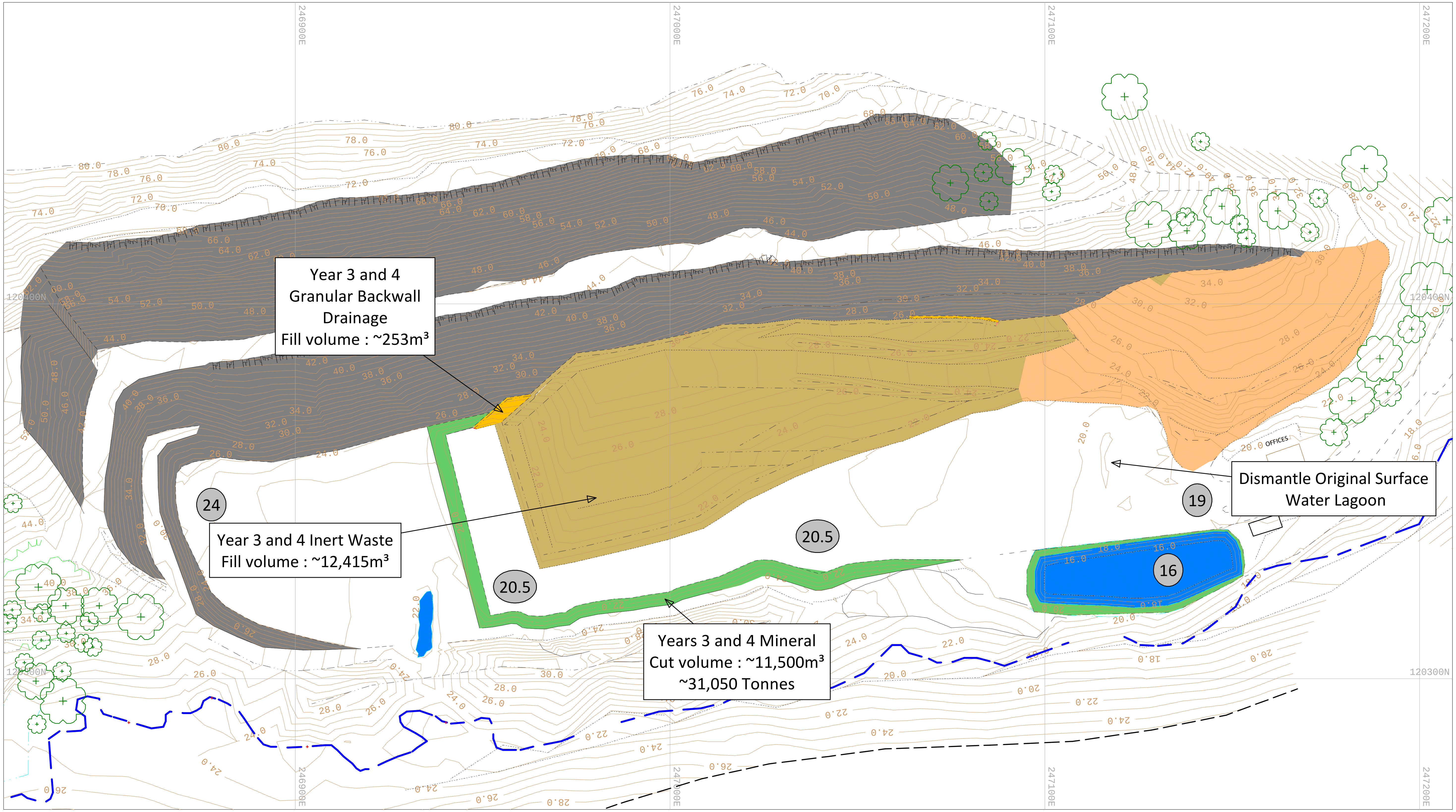
(00464) Beam Quarry

Phasing Plan
Years 1 and 2

Drawn By **RSW**	Scale **1 : 1000**
Dwg Nº **200528/01rev3**	Paper Size **A3**



Year 3 and 4
Granular Backwall
Drainage
Fill volume : ~253m³

Year 3 and 4 Inert Waste
Fill volume : ~12,415m³

Years 3 and 4 Mineral
Cut volume : ~11,500m³
~31,050 Tonnes

Dismantle Original Surface
Water Lagoon

Legend

⬛	Existing quarry face	🟦	Surface water body	(56)	Ground Level (mAOD)
🟩	New quarry faces at end of Phase	╱	Line of Surface Watercourse		
🟧	Existing inert landfill waste	⇢	Direction of surface water flow		
🟨	Granular backwall drainage	╱	Line of Groundwater Seepage Flow		
▨	Newly placed inert landfill waste	⇠	Direction of Groundwater Seepage Flow		

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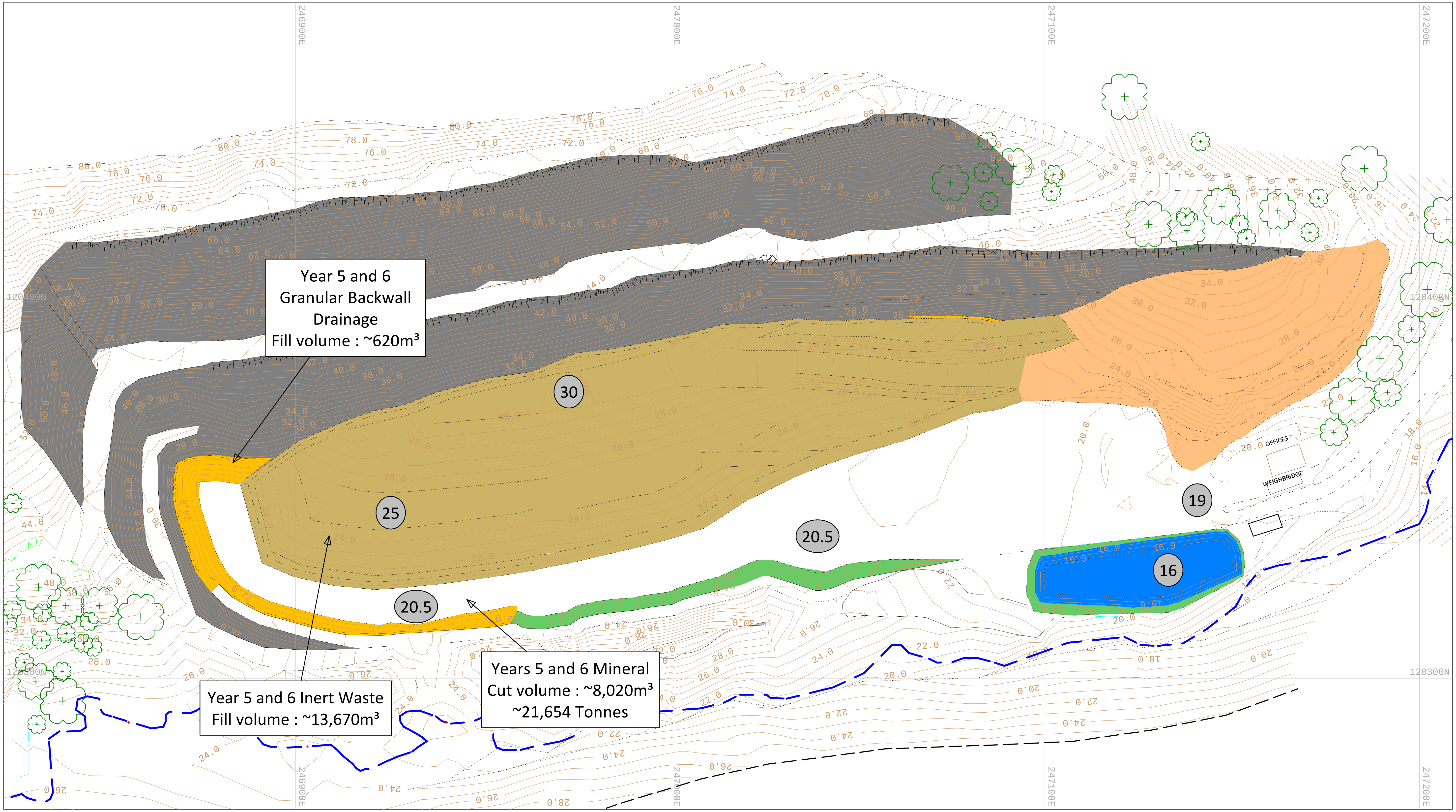
(00464) Beam Quarry

Phasing Plan
Years 3 and 4

Drawn By **RSW**	Scale **1 : 1000**
Dwg Nº **200528/02rev3**	Paper Size **A3**



Year 5 and 6
Granular Backwall
Drainage
Fill volume : ~620m³

Years 5 and 6 Mineral
Cut volume : ~8,020m³
~21,654 Tonnes

Year 5 and 6 Inert Waste
Fill volume : ~13,670m³

Legend

⬛	Existing quarry face
🟩	New quarry faces at end of Phase
🟧	Existing inert landfill waste
🟨	Granular backwall drainage
🟫	Newly placed inert landfill waste
🟦	Surface water body
/	Line of Surface Watercourse
- - ->	Direction of surface water flow
/	Line of Groundwater Seepage Flow
<- - -	Direction of Groundwater Seepage Flow
⑸⑹ 56	Ground Level (mAOD)

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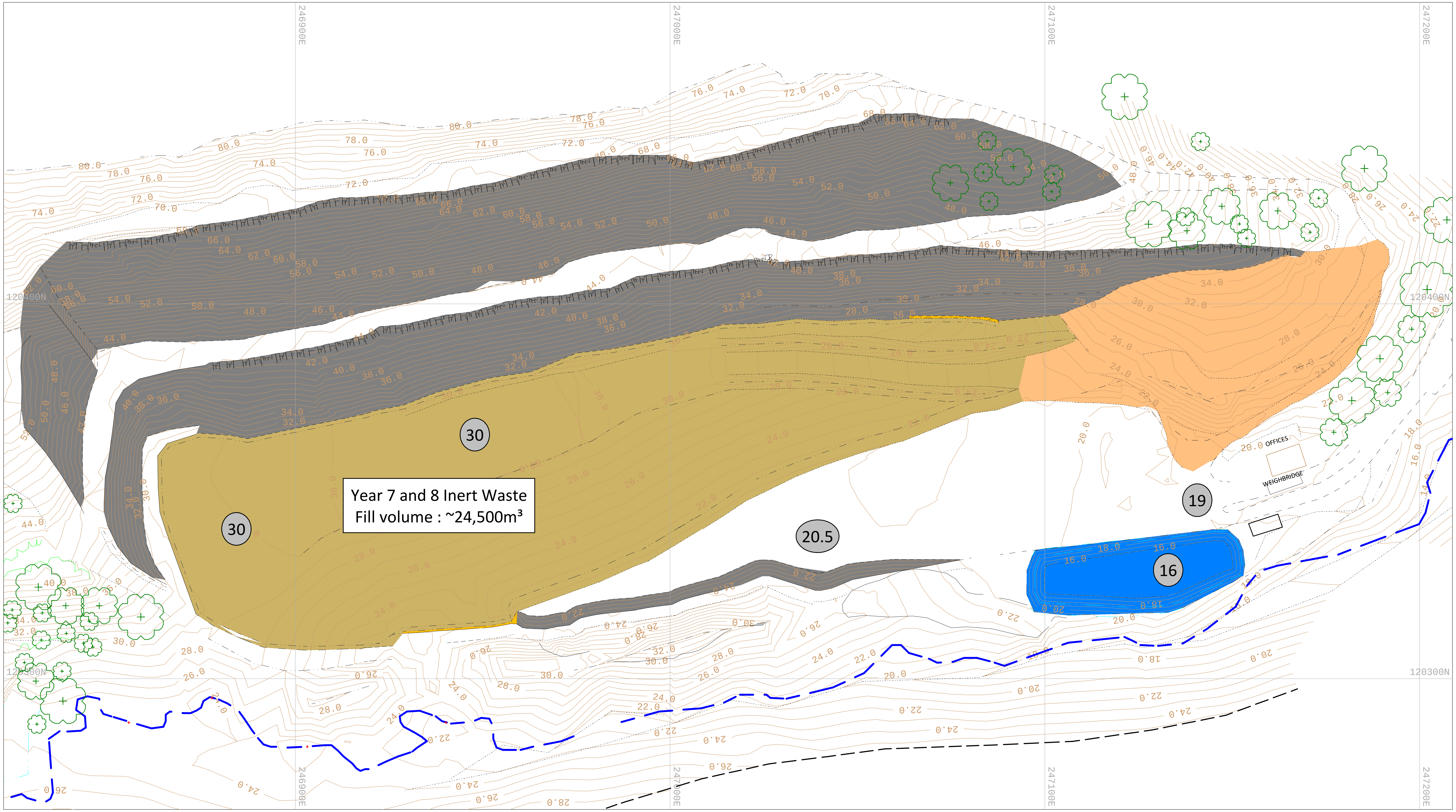
(00464) Beam Quarry

Phasing Plan
Years 5 and 6

Drawn By **RSW**	Scale **1 : 1000**
Dwg Nº **200528/03rev3**	Paper Size **A3**



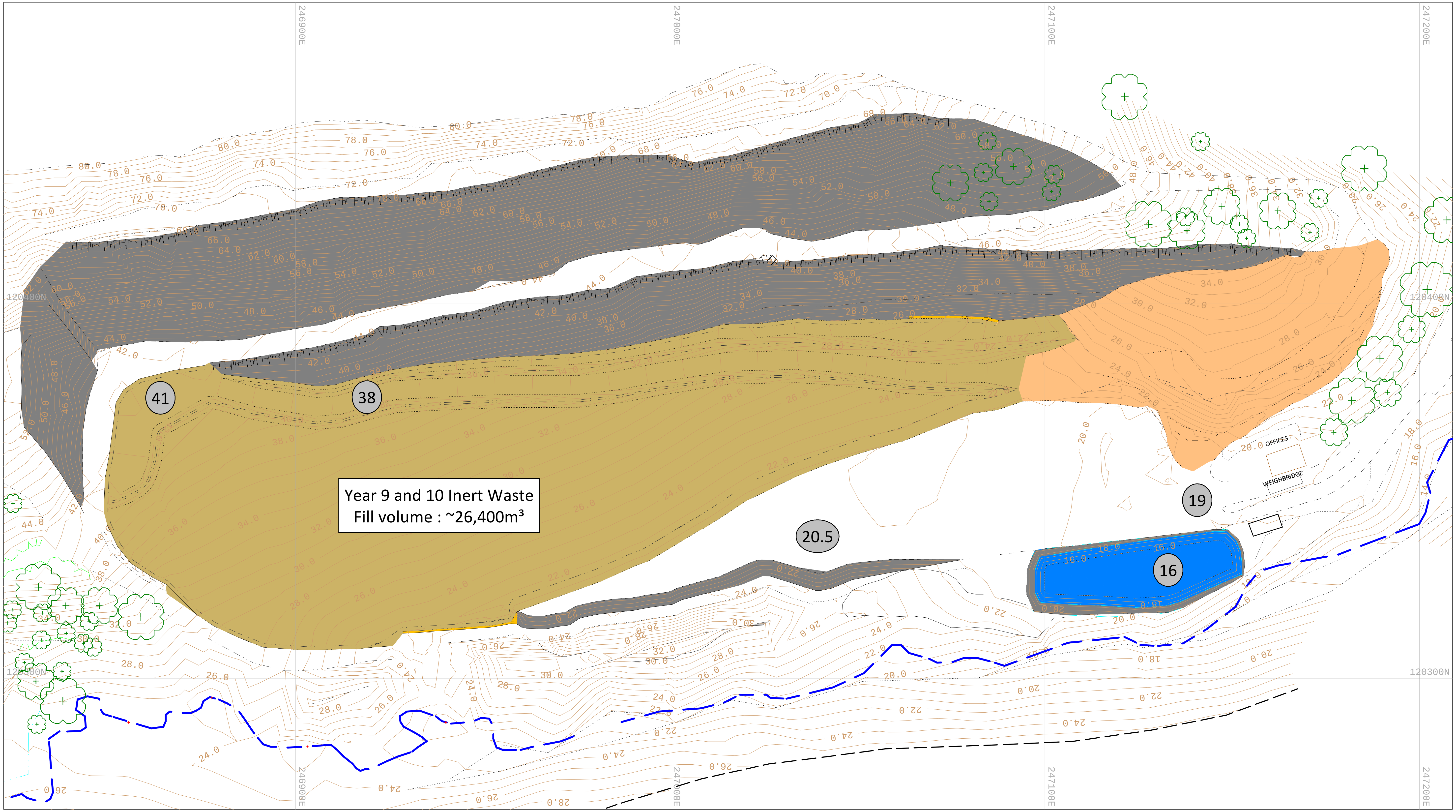
Legend

- ⬛ Existing quarry face
- 🟩 New quarry faces at end of Phase
- 🟧 Existing inert landfill waste
- 🟨 Granular backwall drainage
- 🟫 Newly placed inert landfill waste
- 🟦 Surface water body
- ╱ Line of Surface Watercourse
- ⇢ Direction of surface water flow
- ╱ Line of Groundwater Seepage Flow
- ⇠ Direction of Groundwater Seepage Flow
- 56 Ground Level (mAOD)

(00464) Beam Quarry

Phasing Plan
Years 7 and 8

Drawn By	Scale
RSW	1 : 1000
Dwg Nº	Paper Size
200528/04 rev3	A3



Legend

- ■ Existing quarry face
- 🟩 New quarry faces at end of Phase
- 🟧 Existing inert landfill waste
- 🟨 Granular backwall drainage
- 🟫 Newly placed inert landfill waste
- 🟦 Surface water body
- ╱ Line of Surface Watercourse
- → Direction of surface water flow
- ╱ Line of Groundwater Seepage Flow
- ← Direction of Groundwater Seepage Flow
- 56 Ground Level (mAOD)

Quarry Design ®

(00464) Beam Quarry

Phasing Plan
Years 9 and 10

Drawn By	Scale
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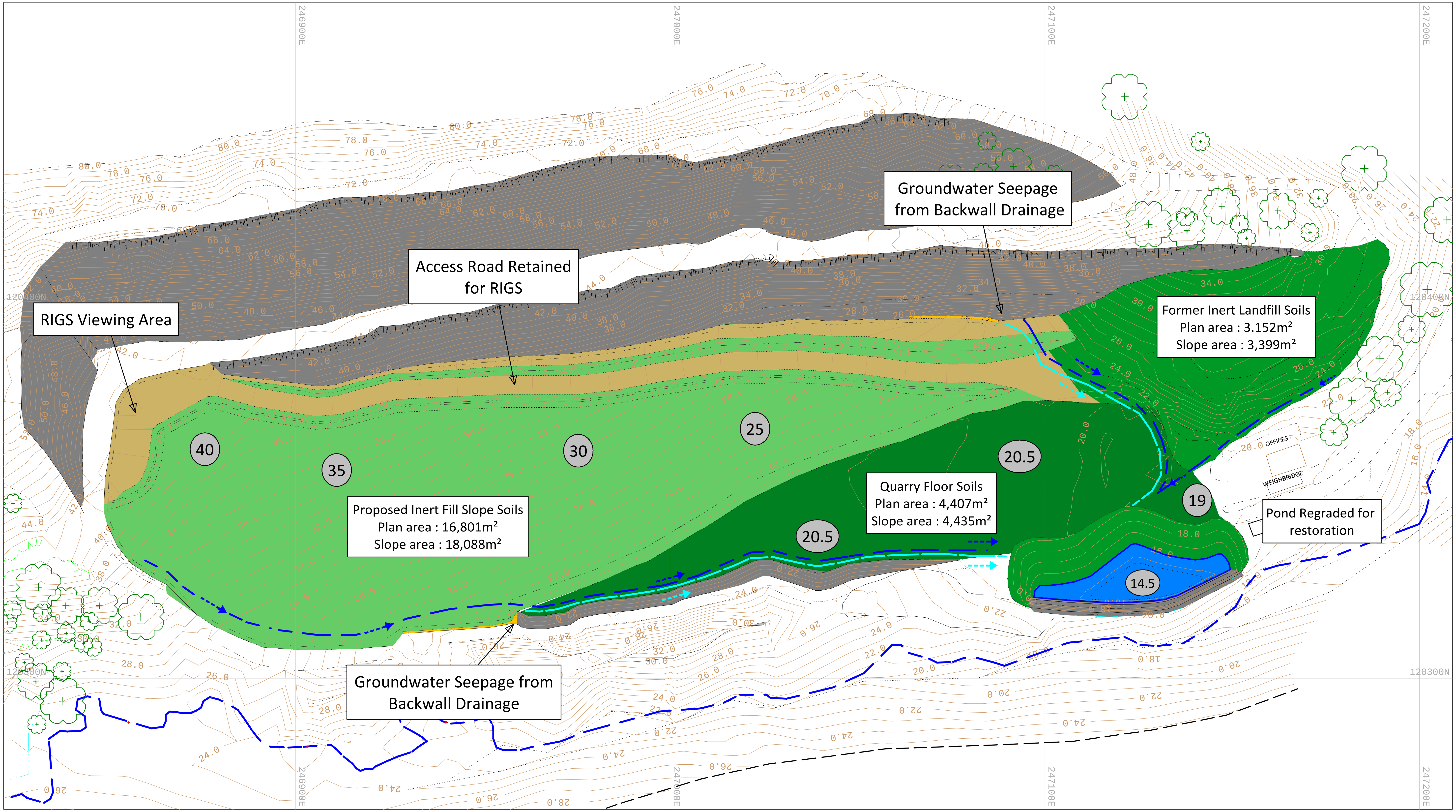
Dwg Nº	Paper Size
200528/05rev3	**A3**



Groundwater Seepage from Backwall Drainage

Access Road Retained for RIGS

RIGS Viewing Area

Former Inert Landfill Soils
Plan area : 3.152m^2
Slope area : 3,399m^2

Proposed Inert Fill Slope Soils
Plan area : 16,801m^2
Slope area : 18,088m^2

Quarry Floor Soils
Plan area : 4,407m^2
Slope area : 4,435m^2

Pond Regraded for restoration

Groundwater Seepage from Backwall Drainage

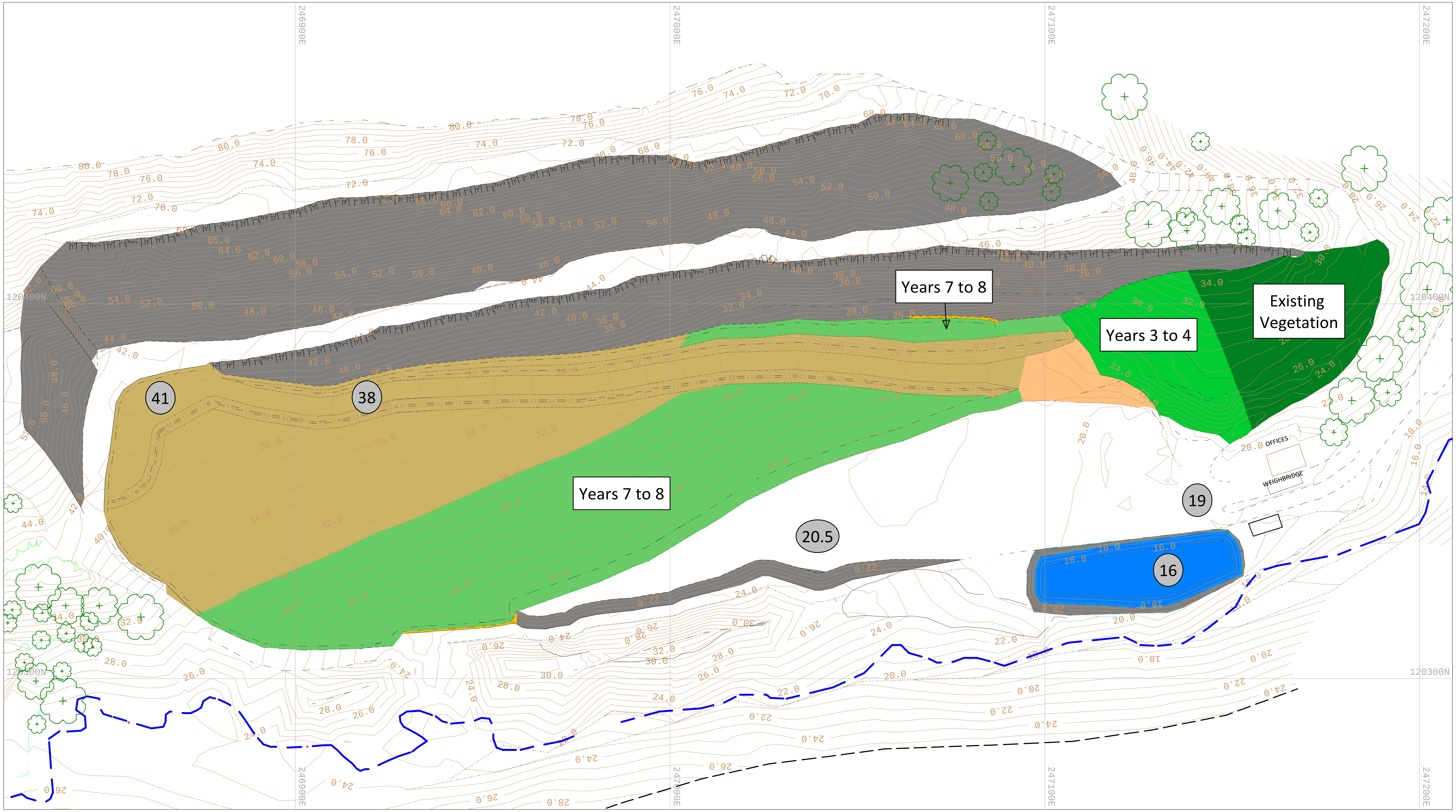
Legend

■	Existing quarry face	■	Surface water body	⇠	Direction of Groundwater Seepage Flow
🟩	Restoration of landfill slope	🟧	Granular backwall drainage	╱	Line of Groundwater Seepage Flow
🟩	Restoration of quarry floor	⇢	Direction of surface water flow		
🟩	Restoration of former landfill area	╱	Line of Surface Watercourse		
■	Access track	(56)	Level (mAOD)		

(00464) Beam Quarry

Phasing Plan
Restoration

Drawn By **RSW**	Scale **1 : 1000**
Dwg Nº **200528/06rev4**	Paper Size **A3**



Legend

■ Existing quarry face

🟩 Existing Vegetation

🟩 Restoration Years 3 to 4

🟩 Restoration Years 7 to 8

🟫 Inert Waste

🟦 Surface water body

🟧 Granular backwall drainage

---> Direction of surface water flow

/ Line of Surface Watercourse

(56) Level (mAOD)

<--- Direction of Groundwater Seepage Flow

/ Line of Groundwater Seepage Flow

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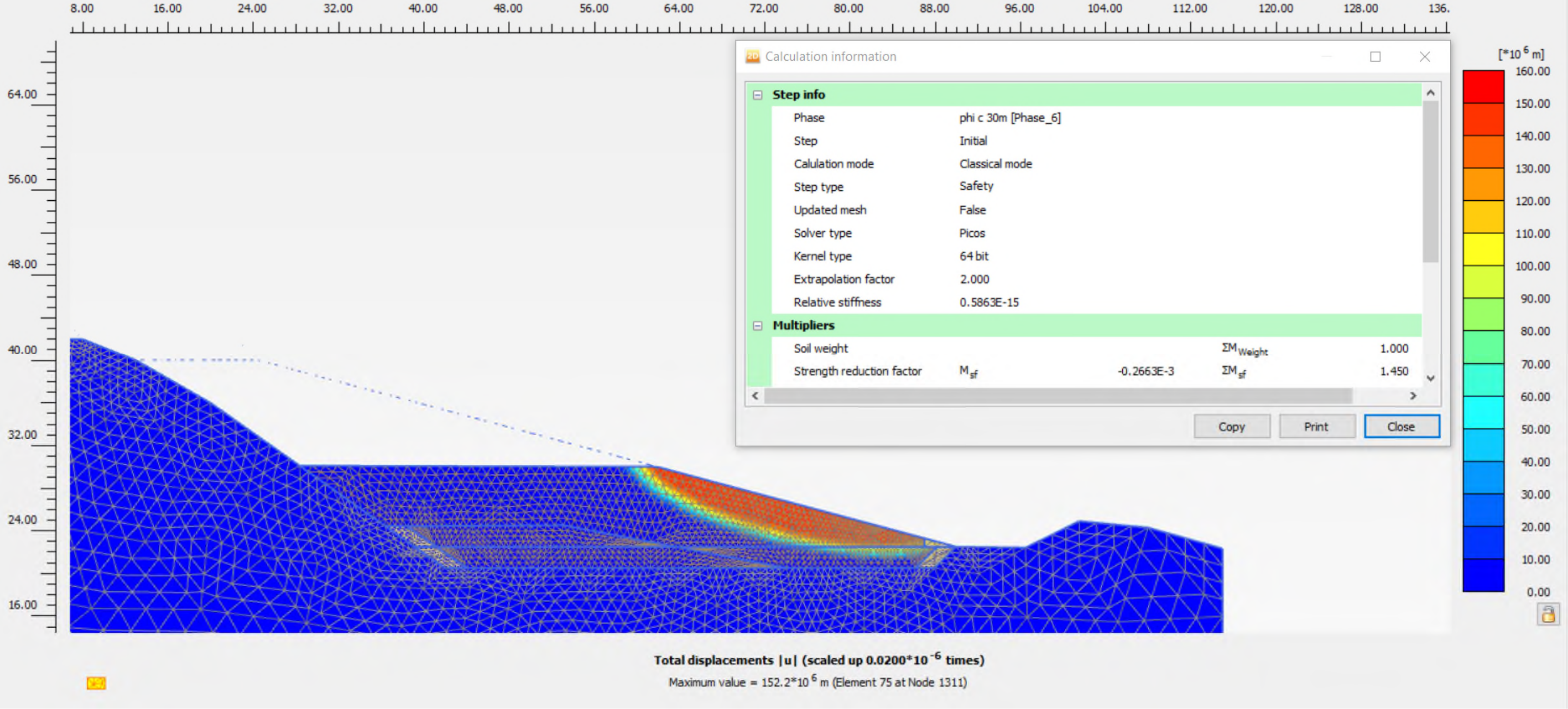
(00464) Beam Quarry

Phasing Plan
Restoration Phasing

Drawn By **RSW**	Scale **1 : 1000**
Dwg Nº **200528/06a r3**	Paper Size **A3**

Appendix SRA3

Model 1 Figures



⊟ **Step info**

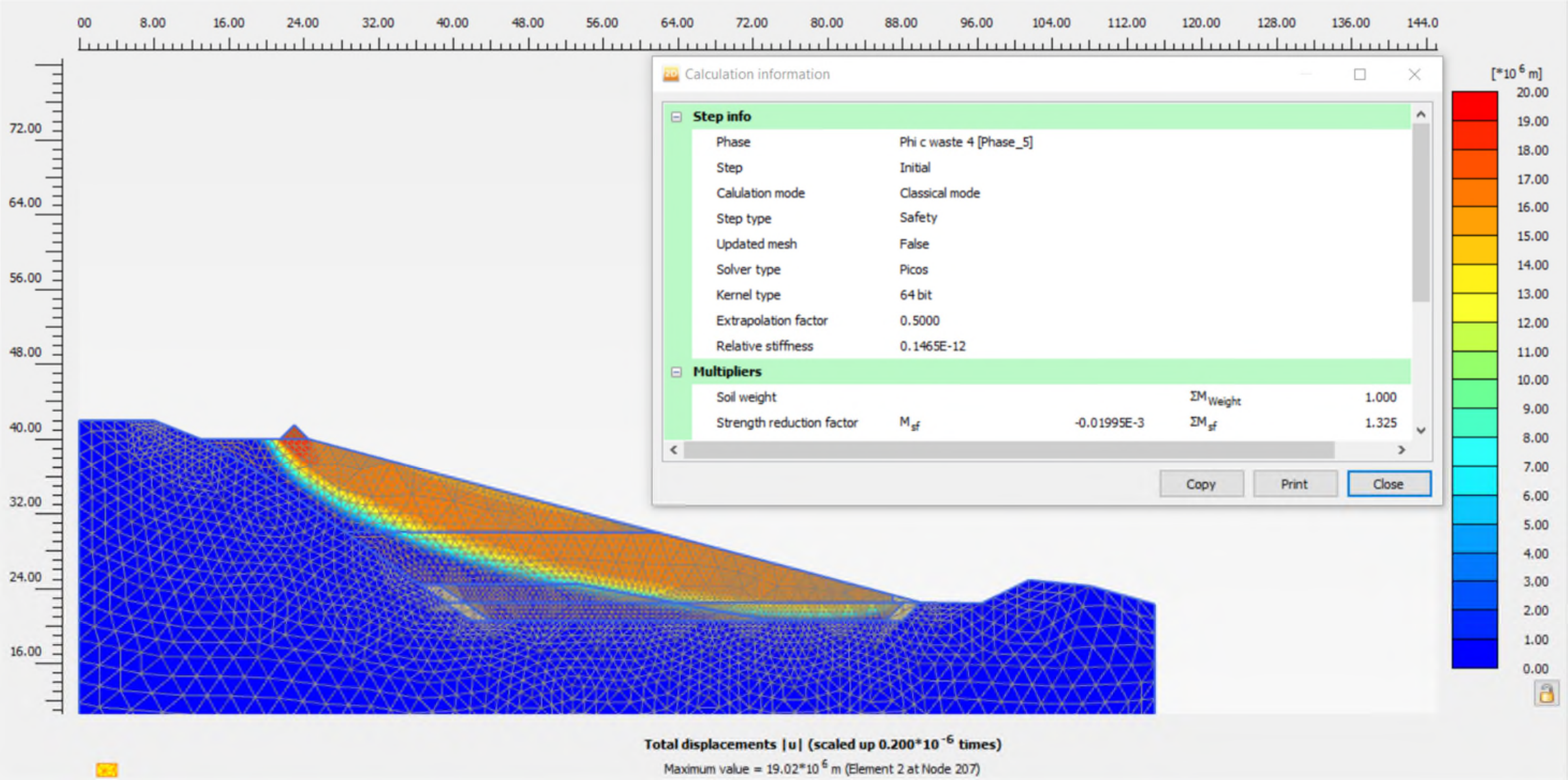
Phase	phi c 30m [Phase_6]
Step	Initial
Calulation mode	Classical mode
Step type	Safety
Updated mesh	False
Solver type	Picos
Kernel type	64 bit
Extrapolation factor	2.000
Relative stiffness	0.5863E-15

⊟ **Multipliers**

Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	-0.2663E-3	ΣM_{sf}	1.450

Total displacements |u| (scaled up 0.0200*10^{-6} times)
Maximum value = 152.2*10^{6} m (Element 75 at Node 1311)

Figure 9: Model 1 – Effective Stress Analysis – Phi C Reduction - Predicted Failure Mode – Stage 4, Waste to 30mAOD
Unit Weight **15kN/m^3,** Permeability **1x10^{-6}**



Step info

Phase	Phi c waste 4 [Phase_5]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	0.5000			
Relative stiffness	0.1465E-12			

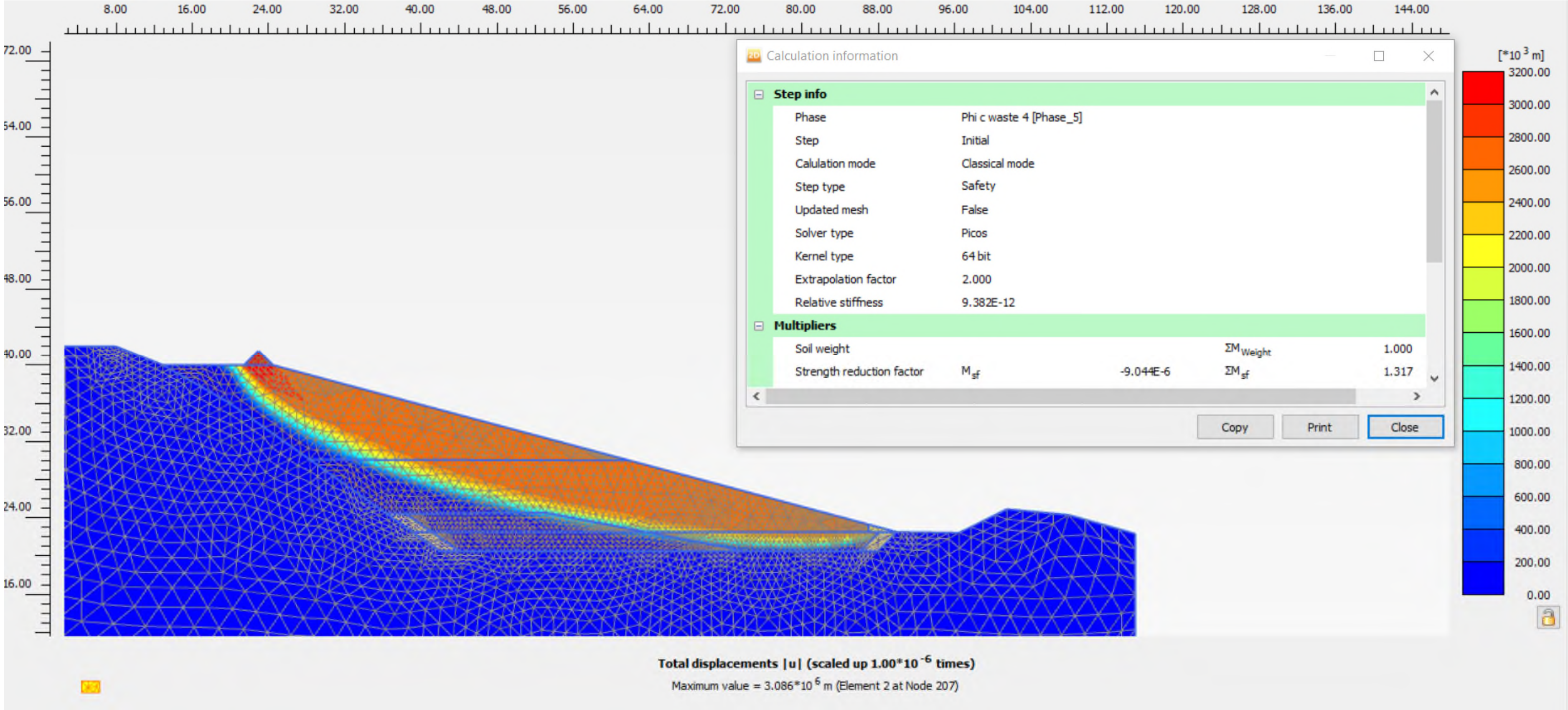
Multipliers

Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	-0.01995E-3	ΣM_{sf}	1.325

Total displacements |u| (scaled up 0.200*10^{-6} times)

Maximum value = 19.02*10^{-6} m (Element 2 at Node 207)

Figure 10: Model 1 – Effective Stress Analysis – Phi C Reduction - Predicted Failure Mode – Final Profile
Unit Weight **15kN/m^3,** Permeability **1x10^{-6}**



Calculation information

Step info

Phase	Phi c waste 4 [Phase_5]
Step	Initial
Calulation mode	Classical mode
Step type	Safety
Updated mesh	False
Solver type	Picos
Kernel type	64 bit
Extrapolation factor	2.000
Relative stiffness	9.382E-12

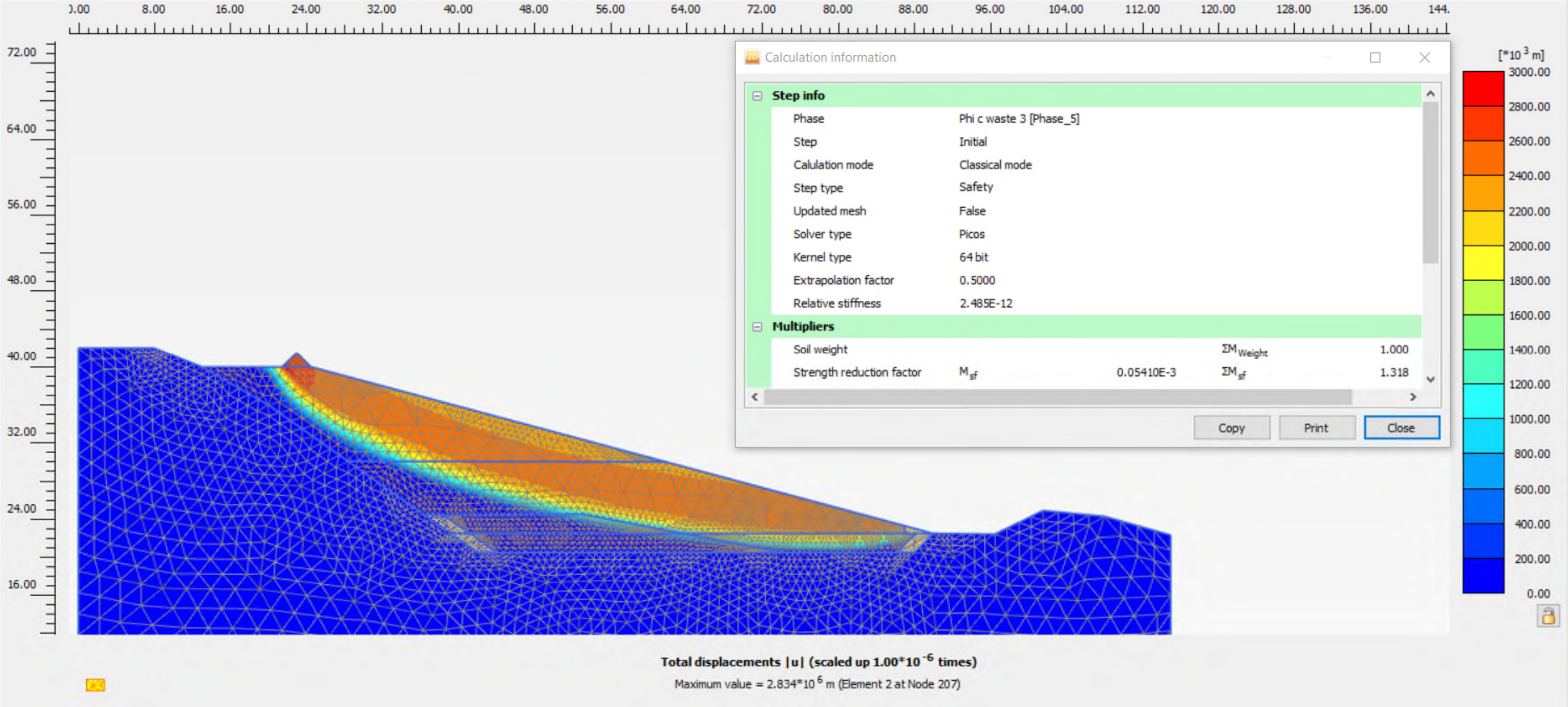
Multipliers

Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	-9.044E-6	ΣM_{sf}	1.317

Total displacements |u| (scaled up $1.00*10^{-6}$ times)

Maximum value = $3.086*10^{6}$ m (Element 2 at Node 207)

Figure 11: Model 1 – Effective Stress Analysis – Phi C Reduction - Predicted Failure Mode – Final Profile
Unit Weight **18kN/m^3,** Permeability **1x10^{-6}**



Calculation information

Step info

Phase	Phi c waste 3 [Phase_5]
Step	Initial
Calulation mode	Classical mode
Step type	Safety
Updated mesh	False
Solver type	Picos
Kernel type	64 bit
Extrapolation factor	0.5000
Relative stiffness	2.485E-12

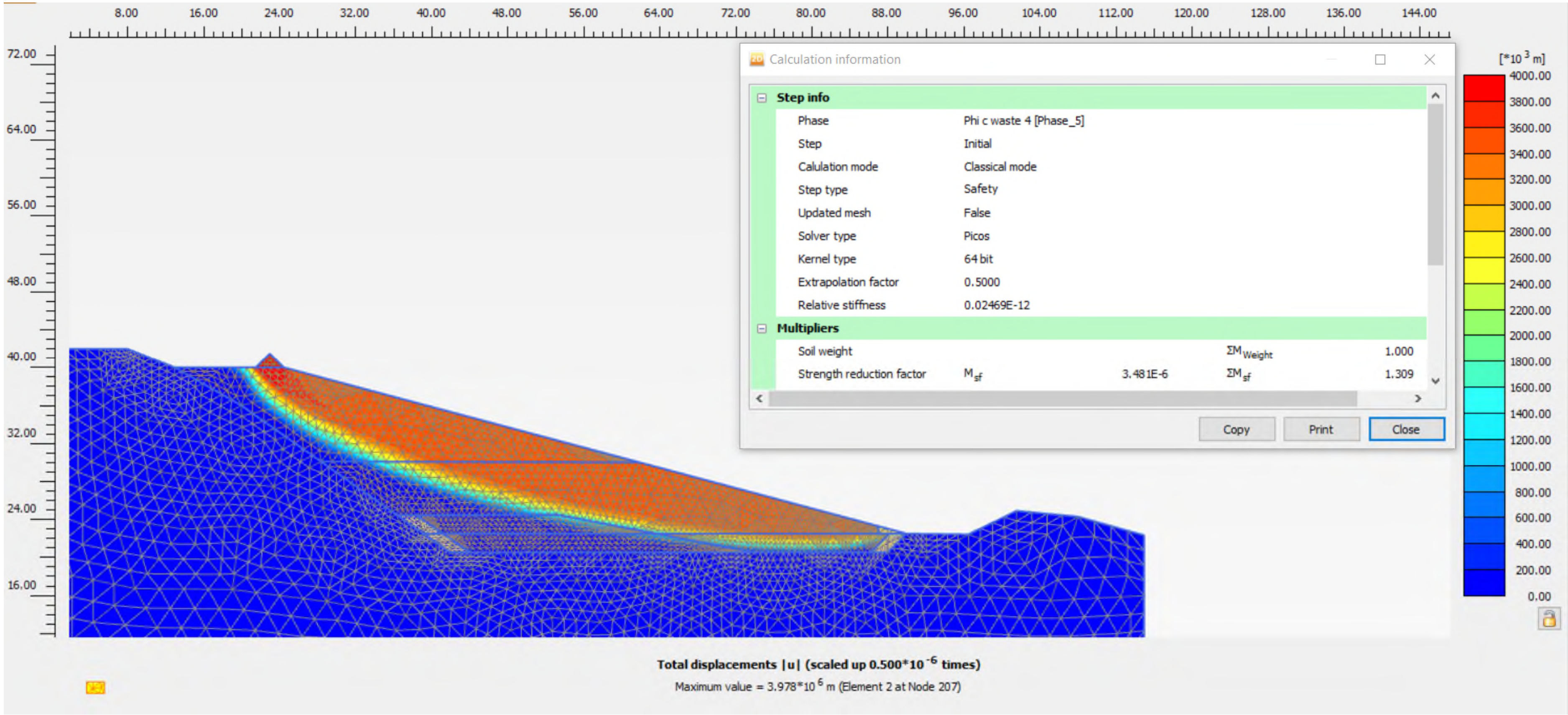
Multipliers

Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	0.05410E-3	ΣM_{sf}	1.318

Total displacements |u| (scaled up $1.00*10^{-6}$ times)

Maximum value = $2.834*10^{6}$ m (Element 2 at Node 207)

Figure 12: Model 1 – Effective Stress Analysis – Phi C Reduction - Predicted Failure Mode – Final Profile
Unit Weight **15kN/m^3,** Permeability **1x10^{-7}**



Step info

Phase	Phi c waste 4 [Phase_5]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	0.5000			
Relative stiffness	0.02469E-12			

Multipliers

Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	3.481E-6	ΣM_{sf}	1.309

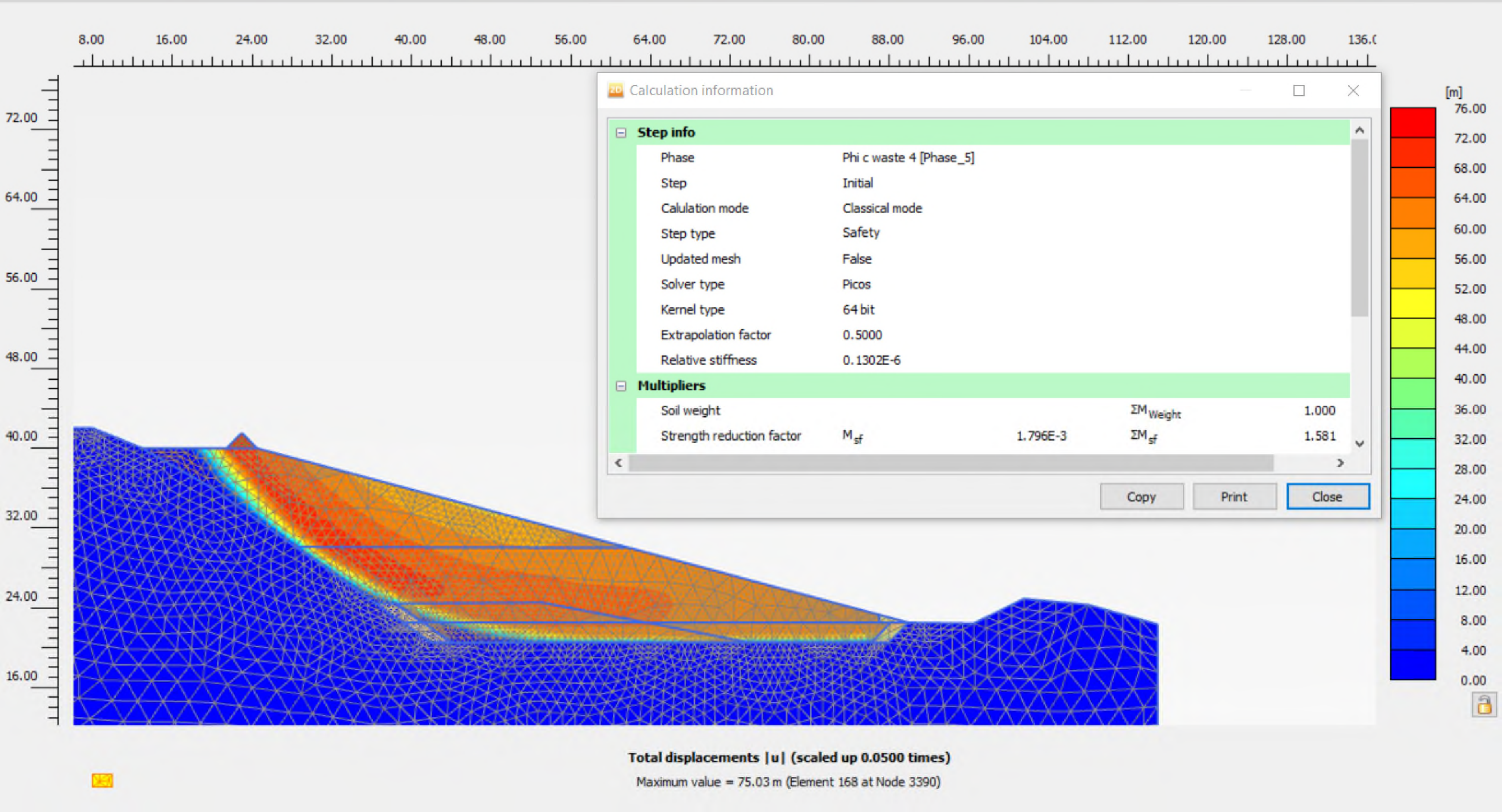
Total displacements |u| (scaled up 0.500*10 $^{-6}$ times)

Maximum value = 3.978*10 ^{6} m (Element 2 at Node 207)

Figure 13: Model 1 – Effective Stress Analysis – Phi C Reduction - Predicted Failure Mode – Final Profile
Unit Weight **18kN/m^3,** Permeability **1x10^{-7}**

Appendix SRA4

Model 2 Figures



Step info

Phase	Phi c waste 4 [Phase_5]
Step	Initial
Calulation mode	Classical mode
Step type	Safety
Updated mesh	False
Solver type	Picos
Kernel type	64 bit
Extrapolation factor	0.5000
Relative stiffness	0.1302E-6

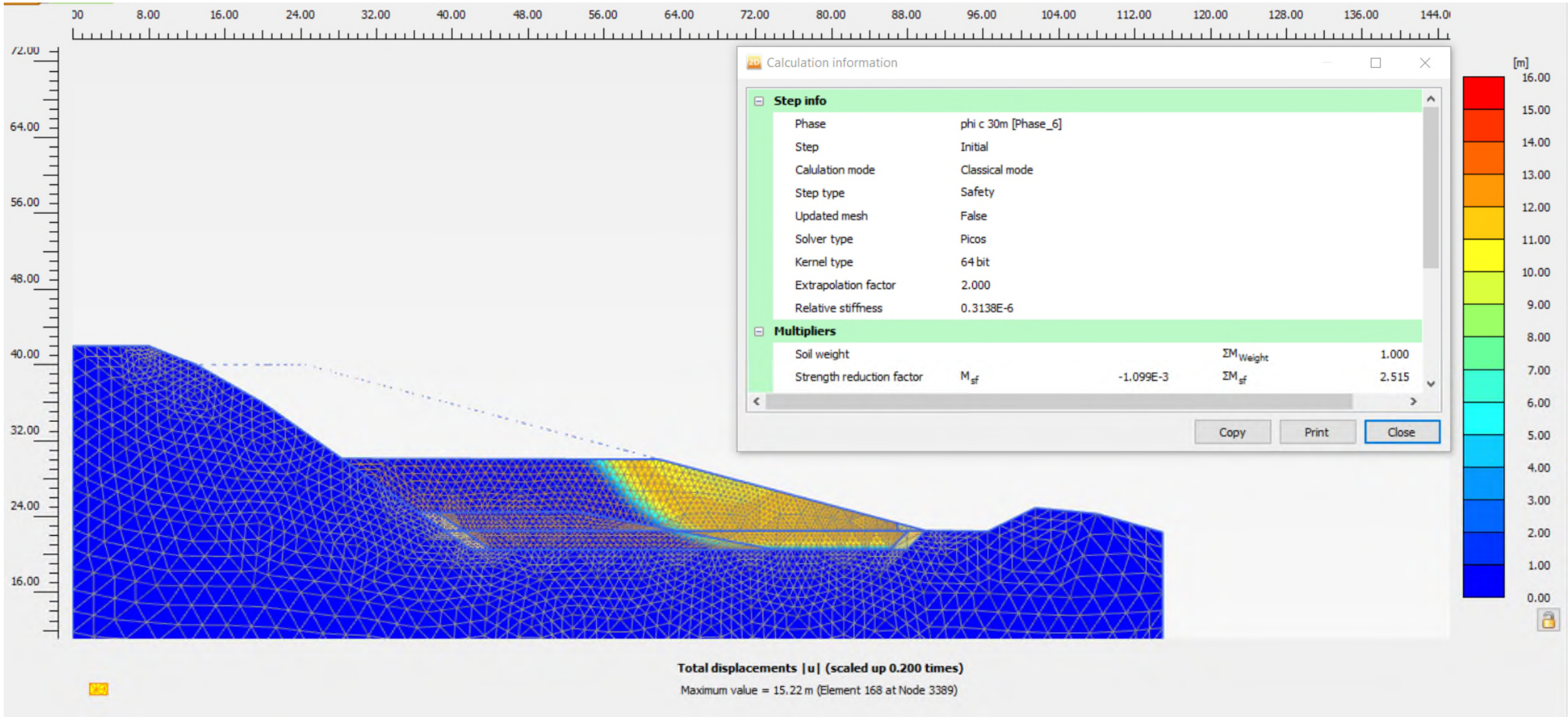
Multipliers

Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	1.796E-3	ΣM_{sf}	1.581

Total displacements |u| (scaled up 0.0500 times)

Maximum value = 75.03 m (Element 168 at Node 3390)

Figure 14: Model 2 – Total Stress Analysis – Phi C Reduction - Predicted Failure Mode – Final Profile
Unit Weight **15kN/m**



Calculation information

Step info

Phase	phi c 30m [Phase_6]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	2.000			
Relative stiffness	0.3138E-6			

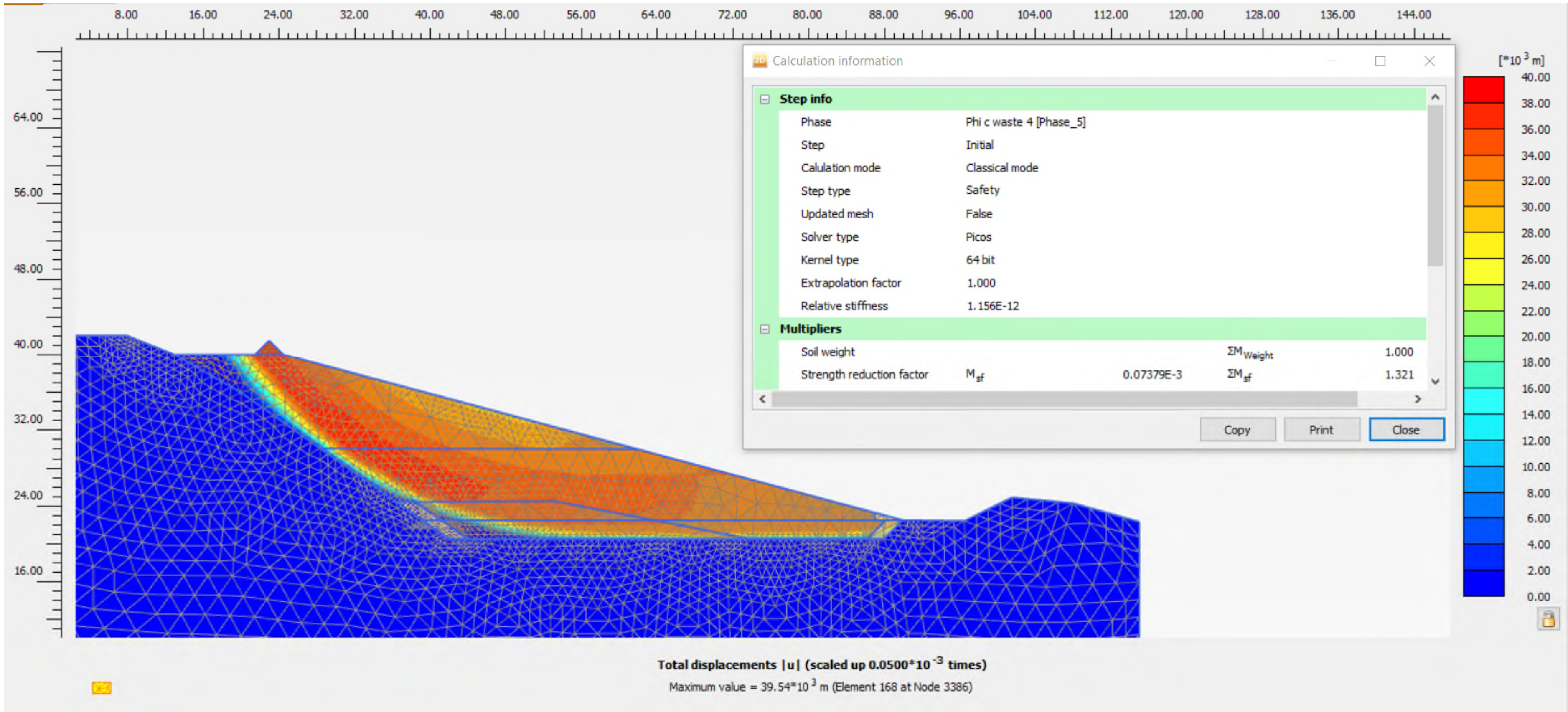
Multipliers

Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	-1.099E-3	ΣM_{sf}	2.515

Total displacements |u| (scaled up 0.200 times)

Maximum value = 15.22 m (Element 168 at Node 3389)

Figure 15: Model 2 – Total Stress Analysis – Phi C Reduction - Predicted Failure Mode – Stage 4 inert material to 30mAOD Unit Weight **18kN/m^3**



Step info

Phase	Phi c waste 4 [Phase_5]
Step	Initial
Calulation mode	Classical mode
Step type	Safety
Updated mesh	False
Solver type	Picos
Kernel type	64 bit
Extrapolation factor	1.000
Relative stiffness	1.156E-12

Multipliers

Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	0.07379E-3	ΣM_{sf}	1.321

Total displacements |u| (scaled up 0.0500*10 $^{-3}$ times)

Maximum value = 39.54*10 ^{3} m (Element 168 at Node 3386)

Figure 16: Model 2 – Total Stress Analysis – Phi C Reduction - Predicted Failure Mode – Final Profile