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The uMkhomazi Water Project Phase 1: Module 1: Technical Feasibility Study: Raw Water

ENGINEERING FEASIBILITY DESIGN REPORT

SUPPORTING DOCUMENT 5: DAM TYPE SELECTION

FINAL

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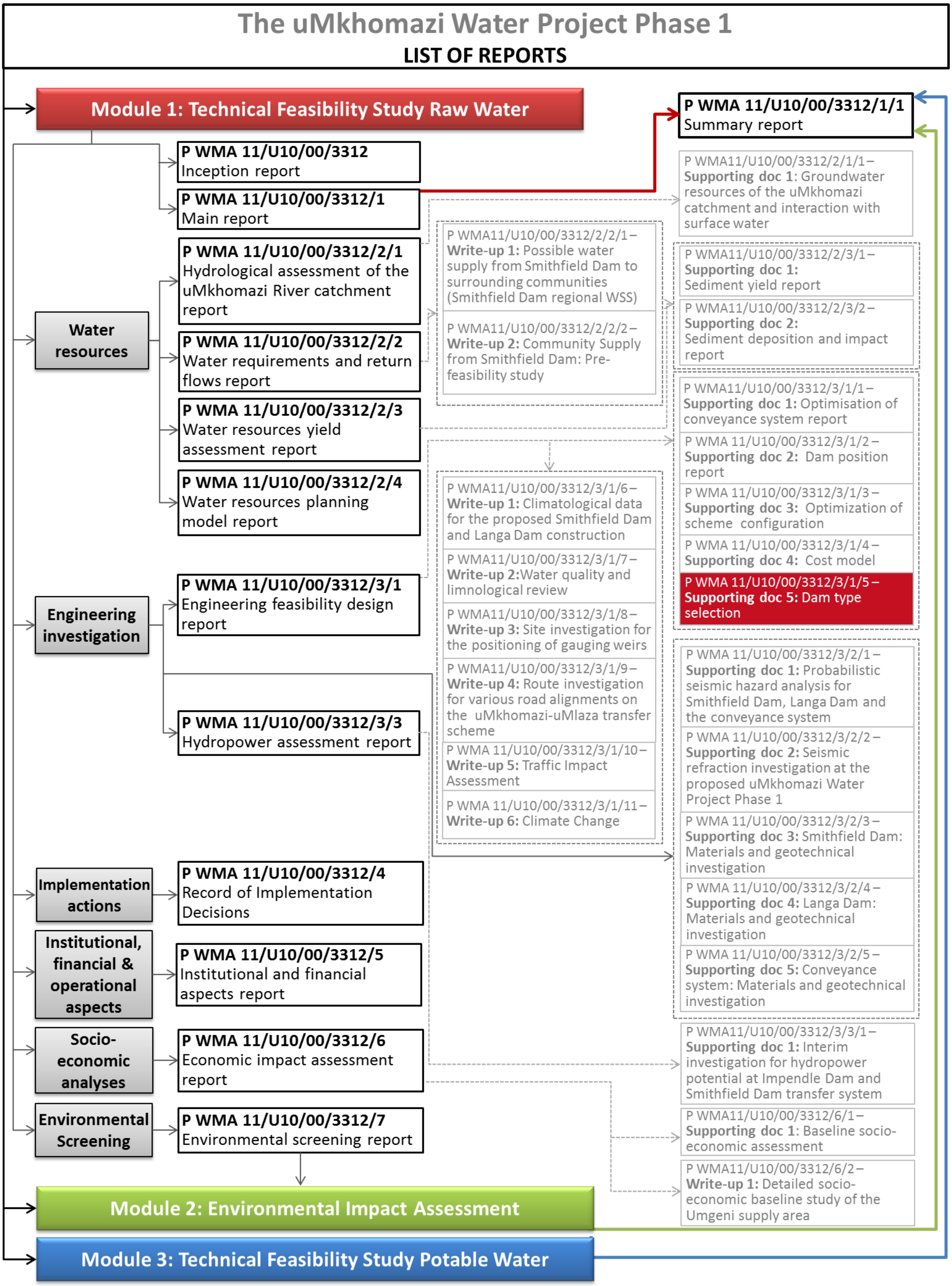
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LIST OF ABBREVIATIONS

ACRU	Agricultural catchments runoff units model
BoQ	Bill of Quantities
CFR	Concrete faced rockfill
CFRD	Concrete faced rockfill dam
CVC	Conventional vibrated concrete
DWA	Department of Water Affairs
ECR	Earth core rockfill
ECRD	Earth core rockfill dam
EIA	Environmental Impact Assessment
EWR	Ecological water requirement
FSL	Full supply level
HFY	Historic firm yield
ICOLD	International Commission on Large Dams
IVRCC	Immersion-vibrated roller compacted concrete
NGL	Natural ground level
NOCL	Non-overspill crest level
OCS	Off-channel storage
P&G	Preliminary & general
PSP	Professional Service Provider
RCC	Roller compacted concrete
RDF	Recommended design flood
SANCOLD	South African National Committee on Large Dams
MAR	Mean annual runoff
Masl	Metres above sea level
MOL	Minimum operating level
SEF	Safety evaluation flood
RCC	Roller compacted concrete
RCC	Roller compacted concrete dam
RID	Record of implementation decisions
RWSS	Regional Water Supply Scheme
TOR	Terms of Reference
URV	Unit reference value
USBR	United States Department of the Interior, Bureau of Reclamation
VAPS	Vaal Augmentation Planning Study
VAT	Value added tax (14%)
WRC	Water Research Commission
WRYM	Water Resources Yield Model
WRPM	Water Resources Planning Model

LIST OF UNITS

ha	hectare
km^2	square kilometre
m	metre
m^3	cubic metres
m^3/s	cubic metres per second
masl	metres above sea level
R	rand
$t/km^2.a$	tons per square kilometre per annum
t/a	tons per annum

1 INTRODUCTION

1.1 SCOPE OF THIS REPORT

The purpose of this report is to provide a description of the dam type selection study that was conducted as part of the *uMkhomazi Water Project Phase 1: Module 1: Technical Feasibility Study: Raw Water* to determine the best dam type for both ***Smithfield Dam*** and ***Langa Balancing Dam***.

For this purpose consideration was given to ***estimated construction costs*** as well as other factors such as the ***risk(s)*** and ***predicted construction periods/programmes*** associated with the different dam types.

Figure 1.1 provides a work flow diagram summarising the specific ***activities*** that were considered, the sequence of activities, as well as ***input*** that was required in the process of selecting the best dam type. From **Figure 1.1** it is clear that balancing studies of available materials on site with required materials in various zones of possible dams had to be considered.

1.2 LAYOUT OF THIS REPORT

This report has been structured as follows:

- Section 1: Introduction
- Section 2: Discussion on the ***required materials*** based on the dam type options considered for both Smithfield and Langa Balancing dams;
- Section 3: Discussion on the ***available materials*** based on the geotechnical (foundations) and materials investigations for both Smithfield and Langa Balancing dams;
- Section 4: Details of the ***cost model*** that was used in the selection of the best dam type;
- Section 5: Basic information for ***Smithfield Dam***;
- Section 6: Assessment of ***Smithfield Dam*** before the results from the geotechnical and material investigations became available;
- Section 7: Assessment of ***Smithfield Dam*** after the results from the geotechnical and material investigations became available;
- Section 8: Basic information for ***Langa Balancing Dam***;
- Section 9: Assessment of ***Langa Balancing Dam*** before the results from the geotechnical and material investigations became available;

- Section 10: Assessment of ***Langa Balancing Dam*** after the results from the geotechnical and material investigations became available.

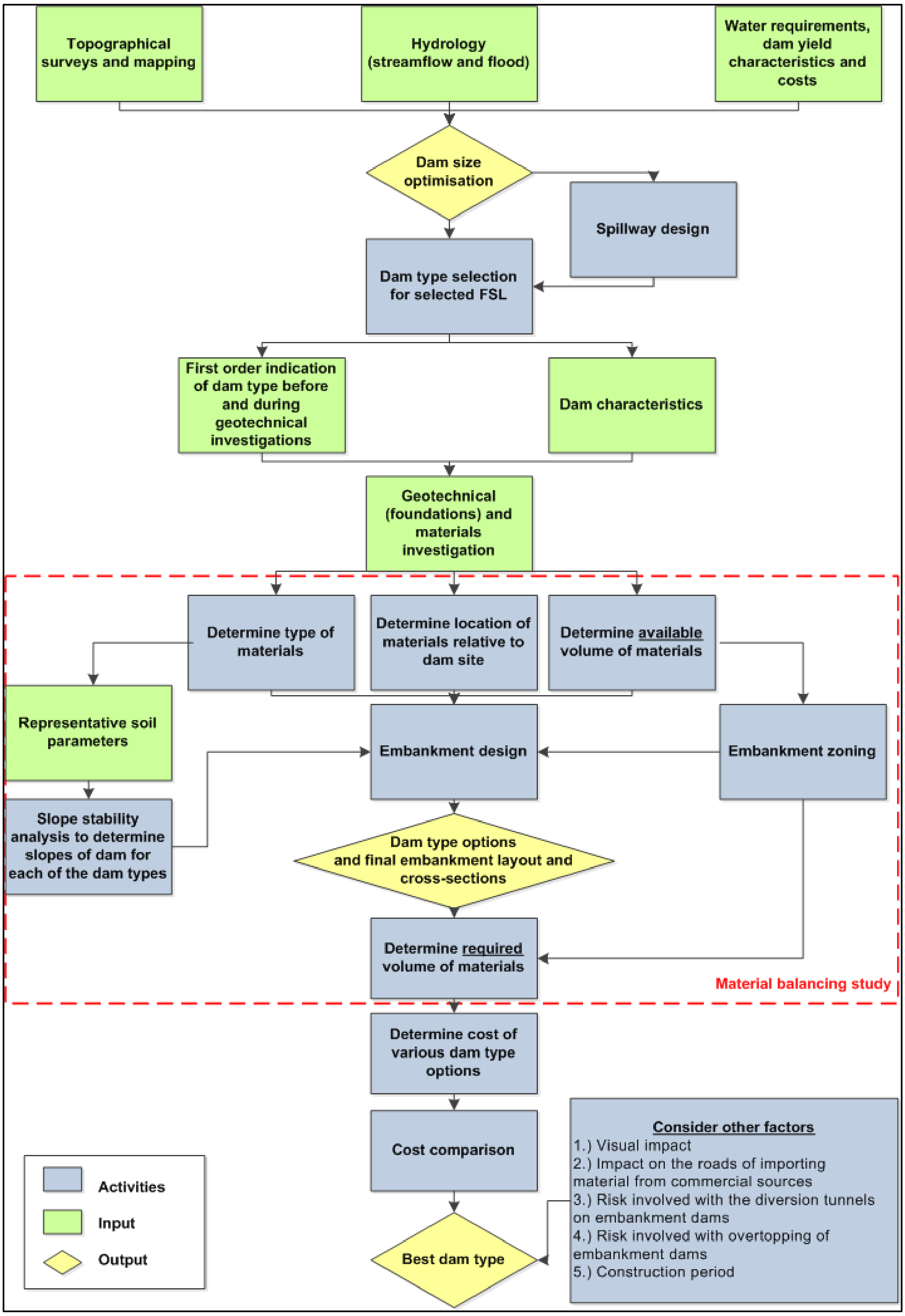


Figure 1.1: Work flow diagram adopted in the selection of the best dam type

2 DAM TYPE OPTIONS – REQUIRED MATERIALS

2.1 INTRODUCTION

For the purpose of selecting the best dam type for both Smithfield Dam and Langa Balancing Dam, many possible dam type options had to be considered. However, depending on the availability of materials on site, some of the dam type options had to be (1) eliminated, or (2) adjusted to include zones of alternative obtainable material.

2.2 DAM TYPE OPTIONS CONSIDERED

A summary of all possible dam type options is given in **Table 2.1**. As indicated in this table, six of the possible dam type options were eliminated from the start as it has traditionally proven to be extremely expensive and time-consuming or the topography at the chosen dam sites was not favourable for the specific option. Table provides the specifics with regard to the reasons for eliminating these options.

From the listed dam type options, and depending on the results from the geotechnical and materials investigations, various combinations or modifications of dam types were considered for Smithfield Dam and Langa Balancing Dam respectively. These are listed in **Table 7.1** (Smithfield Dam) and **Table 10.1** (Langa Balancing Dam) in the subsequent sections.

Table 2.1: Dam type options investigated for Smithfield Dam and Langa Balancing Dam

Dam type	Reason for not considering it in the dam type selection process of Smithfield Dam and Langa Balancing Dam
Roller compacted concrete (RCC) gravity dam	-
Zoned earthfill embankment dam	-
Earth core rockfill dam (including various options of zoning depending on availability of material)	-
Concrete faced rockfill dam (including various options of zoning depending on availability of material)	-
Composite dam (various options of concrete gravity dam with any of the above-mentioned embankment dams)	-
Conventional vibrated concrete (CVC) gravity dam	• *More expensive (with a higher cement content) and longer construction period than roller compacted concrete (RCC) gravity dam*
Conventional vibrated concrete (CVC) buttress dam	• *More expensive than both RCC and CVC gravity dams* • *Longer construction period*
Concrete arch dam	• *Valley shape not favourable* • *More expensive than both RCC and CVC gravity dams*
Hardfill concrete gravity dam	• *Would need a large quantity of aggregates that is not available on site* • *More expensive than both RCC and CVC gravity dams*
Asphalt concrete gravity dam	• *Too expensive* • *Earthfill materials for the core (more favourable than asphalt) are available on site*
Masonry/hand labour intensive methods	• *This dam type does not meet the time requirement*

3 GEOTECHNICAL (FOUNDATIONS) AND MATERIALS INVESTIGATION – AVAILABLE MATERIALS

3.1 INTRODUCTION

Geotechnical (foundations) and materials investigations were conducted as part of this study. This included the following:

- ***Seismic refraction surveys*** along and adjacent to the centre line of Smithfield Dam (including main and saddle dam walls), Langa Balancing Dam, the diversion tunnels and across the potential quarries, to guide the drilling investigation;
- ***Site specific probabilistic risk analysis*** for the Smithfield Dam as well as the Langa Balancing Dam areas;
- Additional ***geotechnical investigations for sources of dam construction materials*** by means of test pitting rotary core drilling and laboratory testing; and
- Additional ***geotechnical investigations for the foundations of Smithfield Dam (including main and saddle dam walls), Langa Balancing Dam as well as the spillway structures*** by means of rotary core drilling and Lugeon water pressure testing.

A description of the geotechnical (foundations) and materials investigations conducted can be found in the following reports (which are summarised in **Table 5.1**):

- *P WMA 11/U10/00/3312/3/2- Geotechnical report* (AECOM, AGES, MMA, & Urban-Econ, 2014)
- *P WMA 11/U10/00/3312/3/2/1 - Supporting document 1: Probabilistic seismic hazard analysis (Smithfield Dam)* (AECOM, AGES, MMA, & Urban-Econ, 2014)
- *P WMA 11/U10/00/3312/3/2/2 - Supporting document 2: Seismic refraction investigation at the proposed uMkhomazi Water Project Phase 1* (AECOM, AGES, MMA, & Urban-Econ, 2014)
- *P WMA 11/U10/00/3312/3/2/3 - Supporting document 3: Smithfield Dam: Materials and geotechnical investigation* (AECOM, AGES, MMA, & Urban-Econ, 2014)
- *P WMA 11/U10/00/3312/3/2/4 - Supporting document 4: Langa Balancing Dam: Materials and geotechnical investigation* (AECOM, AGES, MMA, & Urban-Econ, 2014)*;*

- *P WMA 11/U10/00/3312/3/2/5 - Supporting document 5: Conveyance system: Materials and geotechnical investigation* (AECOM, AGES, MMA, & Urban-Econ, 2014)

3.2 GEOTECHNICAL (FOUNDATIONS) INVESTIGATIONS

The geotechnical (foundations) investigations for Smithfield Dam are described in detail in **Section 5.6.2** of this report, and that for Langa Balancing Dam is described in **Section 8.6.2**.

3.3 MATERIALS INVESTIGATIONS

Based on information from the drilling, the various types of material available on the Smithfield and Langa Balancing Dam sites are described as follows:

- ***Overburden for soil: Organic topsoil*** (further referred to in this report as *Material Type A*);
- ***Clayey sand transported surface material*** (further referred to in this report as *Material Type B*) is suitable as impervious core material while the **sand, clay and boulders** might be considered as "dirty rockfill";
- ***Completely and highly weathered shale*** (further referred to in this report as *Material Type C*) can be considered for use as semi-pervious earthfill material or as transition material between a clay core and rockfill zones;
- ***Unweathered to moderately weathered shale*** (further referred to in this report as *Material Type D*) are generally medium strong to strong rocks in the in-situ location, but are prone to rapid slaking upon exposure to the atmosphere. With increased degree of induration, the potential for slaking decreases. This shale material, can be considered as rockfill, but when placed in an embankment must be covered by durable (dolerite) rock outer zones;
- ***Highly and moderately weathered dolerite*** (further referred to in this report as *Material Type E*) comprises strong boulders (corestones) in a matrix of clayey silt. This material can be considered for use as "dirty rockfill" or earthfill in certain zones of an embankment dam. Highly weathered dolerite at Smithfield Dam typically contains between 10% and 50% rock, while moderately weathered dolerite comprises of more than 50% corestones. These corestones can vary in size between 100 mm and 1 200 mm. Blasting is generally not very efficient and fragmentation is difficult to control. It might be necessary to remove the blocks that are too large for placing in a particular zone of the dam. These blocks might be suitable for use as rip-rap; and
- ***Slightly weathered and unweathered dolerite*** (further referred to in this report as *Material Type F*) is very sound, durable rock and is the only suitable source for concrete aggregate, rip-rap and filters.

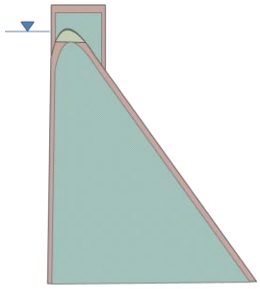
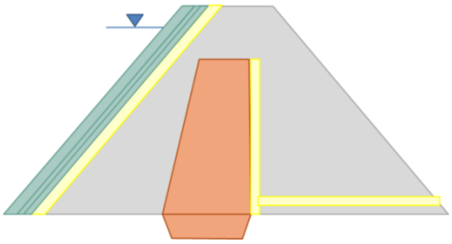
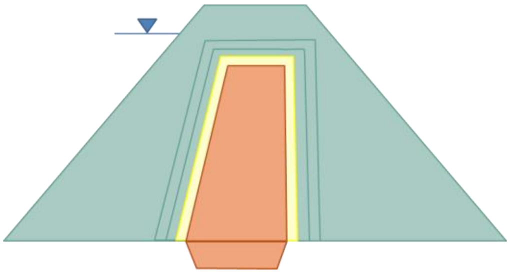
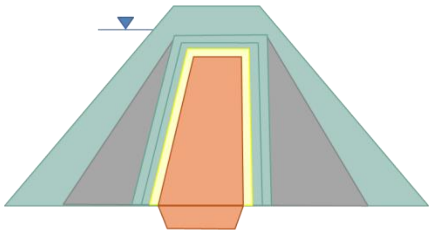
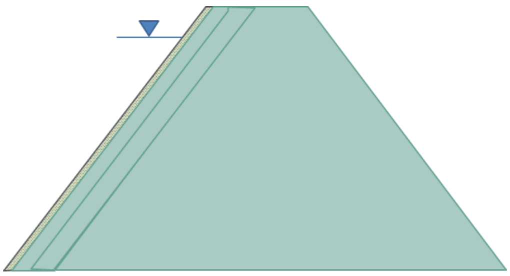
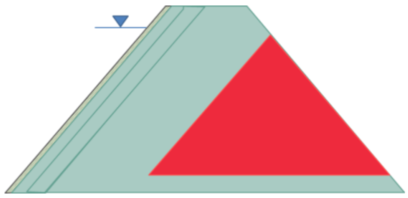
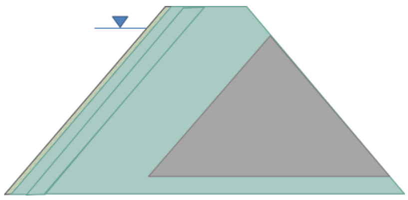
Based on the above, the uses for the various types of material are summarised in **Table 3.1** with a simplified graphical representations (refer to **Appendix D** for the detailed cross sections) for the different dam type options investigated in **Section 2** and given in **Table 3.2**. These cross-sections are simplified cross-sections and were used for identification purposes only.

Further details on the sources for the discussed material types for Smithfield Dam is given in **Section 5.6.1** of this report, whereas that for Langa Balancing Dam are described in **Section 8.6.1**.

Table 3.1: Legend and uses for the various types of material available on the Smithfield Dam site

No.	Colour	Material type	Use
A		Overburden for soil: Organic topsoil	*Landscaping* *Downstream protection of embankment dams*
B		Clayey sand, transported surface material	*Impervious core of embankment dams*
C		Completely and highly weathered shale	*Semi-pervious material of earthfill dams*
D		Unweathered to moderately weathered shale	*Rockfill (certain zones of a ECRD to be covered by slightly weathered / unweathered dolerite)* *Rockfill (certain zones of a CFRD on the downstream side)*
E		Highly and moderately weathered dolerite	*Rockfill (certain zones of a CFRD on the downstream side) – boulders to be removed*
F		Slightly weathered and unweathered dolerite	*Concrete aggregate and sand* *Rip rap* *Filters* *Rockfill* *Transition between sand layer(s) and rockfill zone(s) on an ECRD* *Transition between face slab and rockfill zone(s) on a CFRD*
G		Imported sand (from commercial source)	*Chimney and blanket drains for earthfill embankment dams* *Blanket drain* *Transition between gravel layer(s) and earthfill zone(s) for an earthfill dam* *Transition between gravel layer(s) and impervious core zone(s) on an ECRD*
-		Concrete	*See* **Table**
-		Conventional vibrated concrete (CVC)	*See* **Table**
-		Roller compacted concrete (RCC)	*See* **Table**
-		Immersion vibration roller compacted concrete (IVRCC)	*See* **Table**

Table 3.2: Simplified graphical presentation of required material for the four standard dam type options as well as zoning alternatives

Dam type	Standard zoning option		Alternative zoning option(s)	
Roller compacted concrete (RCC) gravity dam			None	
Zoned earthfill embankment dam			None	
Earth core rockfill dam	Zoning option 1		Zoning option 2	
Concrete faced rockfill dam	Zoning option 1		Zoning option 2	
			Zoning option 3	

4 COST MODEL

4.1 INTRODUCTION AND OBJECTIVE

A Microsoft Excel spreadsheet-based cost model was developed for the purpose of this study. The objective of the cost model was to develop an interactive, user friendly spreadsheet of cost estimates with interlinked facilities for each component of both the Smithfield Dam and Langa Balancing Dam to compare construction cost estimates for:

- Selection of the optimal dam size (i.e. FSL);
- Guidance of the geotechnical investigations;
- Selection of the optimal dam type; and ultimately;
- Selection of the best scheme.

The cost model made provision for various dam sizes in sufficiently small incremental steps within the envelope of required yields to allow for optimization of (1) the dam size (see report *P WMA 11/U10/00/3312/3/1/3: Optimization of scheme configuration* (AECOM, AGES, MMA, & Urban-Econ, 2014)), as well as, (2) the dam type (this report). As such provision was made for full supply levels up to 940 masl (Smithfield Dam) and 923 masl (Langa Balancing Dam) as well as the following dam types:

- Roller compacted concrete (RCC) gravity dam;
- Zoned earthfill embankment dam;
- Earth core rockfill dam (ECRD) *- including various options of zoning depending on availability of material*;
- Concrete faced rockfill dam (CFRD) *- including various options of zoning depending on availability of material*; and
- Composite dam *- various options*.

The cost model was developed early in the study and was updated as and when new information became available.

A comprehensive description of the cost model (as well as a user manual) is provided in *Report P WMA 11/U10/00/3312/2/3/1/4 - Supporting document 4: Cost model* (AECOM, AGES, MMA, & Urban-Econ, 2014).

4.2 BILL OF QUANTITIES AND RATES

The bill of quantities incorporated in the cost model for each of the different dam types was based on the *Vaal Augmentation Planning Study (VAPS)* (Consult 4, 1994) with a level of detail commensurate to a feasibility study.

The latest rates from tenders for the various dam components were obtained and incorporated into the cost model. Main Smithfield Dam components include the following:

- Main and saddle dam forming and excavation;
- Diversion works;
- Intake structure;
- Outlet works;
- Spillway, i.e. approach, chute and plunge pool;
- Measuring weirs;
- Landscaping;
- Planning design and supervision; and
- Others, i.e. miscellaneous, preliminary and general, and contingencies.

For dam type selection, costs for the following activities were excluded from the cost model: (1) road deviations, (2) housing and accommodation, (3) access road, (4) pipelines, (5) water to site, (6) electricity supply and deviation, (7) environmental, and (8) relocation, as these are common to all compared dam types. These costs will be taken into account in the feasibility design.

4.3 RATES FOR EMBANKMENT-FORMING MATERIALS

In accordance with the *South African Bureau of Standards' Standardized Specification for Civil Engineering Construction DE: Small Earth Dams* (South African Bureau of Standards, 1984) rates included in the cost model for all ***embankment forming-materials***, i.e. (1) impervious fill, (2) semi pervious fill, (3) rockfill, (4) rip-rap, (5) gravel and sand layer(s), (6) drains, (7) IVRCC, (8) RCC, and (9) CVC sand, consists of the following costs:

- Selecting and delivery of material excavated; or
- Excavating and selecting material from borrow pits in the designated borrow areas; as well as
- Haulage;
- Spreading;
- Addition of water or drying;

- Placing;
- Compacting;
- Grading in the relevant zones or sections of the embankment;
- Stockpiling or processing, or both, where necessary; and
- Final grading of borrow pits with in the dam basin.

Rates adopted for embankment forming-materials are summarised in **Table 4.1**.

Table 4.1: 2013 Rates adopted for embankment forming-materials

Item no	Item description		Rate (R/m³)
	Forming embankment		
8.3.5	a)	Core (impervious earthfill)	48.37
	b)	Upstream and downstream shells (semi pervious earthfill)	48.37
	c)	Rockfill (Impervious layer)	91.00
	d)	Rip-rap	438.52
	e)	Gravel layer	97.94
	f)	Sand layer transition zone	97.94
	g)	Blanket and chimney drains	789.45
	h)	IVRCC (1)	45.45
	i)	RCC concrete	1156.71
	j)	CVC concrete	1 981.85

(1) Explained in detail in Section 4.5 and is per square metre of dam surface area

4.4 RATES FOR EXCAVATION ACTIVITIES

In accordance with the *South African Bureau of Standards' Standardized Specification for Civil Engineering Construction DE: Small Earth Dams* (South African Bureau of Standards, 1984) rates included for all ***excavation activities*** distinguished between the following:

- Material from essential excavations, i.e. the embankment foundation excavations, that is excavated and ***unsuitable for use in the embankments***. These rates cover the cost of excavation in all materials, removal to the ***designated waste disposal site*** that was identified in the dam basin, spreading and trimming. The location of the waste disposal site is shown in **Figure A.5** in **Appendix A**.
- Material from essential excavations, i.e. the embankment foundation excavations, that is excavated and ***suitable for use in the embankments***. This rate covers the cost of excavation of the hole in all materials and trimming it ready for further construction activity. This material might need to be

stockpiled for later use in a ***designated stockpile area***. Provision is also made here for excavation in intermediate and hard rock material.

Rates adopted for excavation activities are summarised in **Table 4.2**.

Table 4.2: 2013 Rates adopted for excavation activities

Item no	Item description	Rate (R/m³)
	Excavation	
8.3.3	a) Material unsuitable for embankment (excavation, removal to designated waste disposal sites in the dam basin, spreading and trimming)	31.60
	b) Material suitable for embankment from essential excavations Stockpiled (excavation , possible removal to stockpile areas, and trimming it ready for further construction activity)	30.30
	c) Extra over items (b) for excavation in: 1) Intermediate material 2) Hard rock material	 Included in 8.3.3 (a) 36.50

4.5 RATES FOR CONCRETE

In accordance with the *South African Bureau of Standards' Standardized Specification for Civil Engineering Construction DE: Small Earth Dams* (South African Bureau of Standards, 1984) rates adopted for the ***different types of concrete*** used in the dam forming are summarised in **Table 4.3**.

Table 4.3: 2013 Rates adopted for different types of concrete used in the dam forming

Acronym	Item description	Definition	Component of dam	Rate (R/m3)
CVC	Conventional vibrated concrete	• A specific mix-design of concrete that produces a specific range of strengths and is delivered by dump trucks or conveyors, poured and compacted with concrete vibrators. • Two types of conventional vibrated concrete as follows were used: Mass concrete: • Concrete set without structural reinforcement. • Strength: 5 - 10 MPa Structural concrete: • A special type of concrete that is capable of carrying a structural load or forming an integral part of a structure. • Strength: 25 - 30 MPa	• Diversion works; • Intake structure; • Outlet works; • Spillway, i.e. approach, chute and plunge pool; • Measuring weirs.	1 981.85

Acronym	Item description	Definition	Component of dam	Rate (R/m3)
RCC	Roller compacted concrete	• A special blend of concrete that has essentially the same constituents as conventional concrete but in different ratios, and increasingly with partial substitution of fly ash for Portland cement. • A mix of cement/fly ash, water, sand, aggregate and common additives, but contains much less water. The produced mix is drier and essentially has no slump. • Placed in a manner similar to paving: the material is delivered by dump trucks or conveyors, spread by small bulldozers or specially modified asphalt pavers, and then compacted by vibratory rollers.	• Main dam and spillway forming on a concrete gravity dam	1 156.71
IVRCC	Immersion-vibrated roller compacted concrete	• A special blend of conventional roller compacted concrete that is used as interface concrete to achieve an excellent finish and prevents the ingress of water into the RCC, thus improving the durability of the RCC concrete.	• Facecrete layer on a concrete gravity dam	45.40 / m^2 of dam surface area

(1) All types sourced from local site processed dolerite materials.

The rate for ***roller compacted concrete (RCC)*** included in

Table **Table 4.3** covers the cost of (1) materials, (2) blasting and processing, (3) mixing, (4) transport, (5) spreading and (6) compacting, as well as (7) other costs i.e. curing, water pressure testing, etc.

The rate for ***conventional vibrated concrete (CVC)*** included in **Table 4.3** covers the cost of (1) materials, (2) blasting and processing, (3) mixing, (4) transport, (5) cooling and (6) vibration, as well as (7) other costs i.e. placing labour, placing plant and joints cleaning, etc.

Detailed cost breakdowns of RCC as well as CVC are included in **Appendix B**.

5 BASIC INFORMATION – SMITHFIELD DAM

5.1 INTRODUCTION AND OBJECTIVE

Basic information required for the ***Dam Type Selection task*** was sourced from existing reports as summarised in **Table 5.1**. For ease of reference, a summary of the obtained information is described in **Section 5.2** to **Section 5.3**.

Table 5.1: Summary of existing reports sourced for information on Smithfield Dam

Existing information	Report
Topographical surveys and mapping	Described in this report (**P WMA 11/U10/00/3312/3/1/5**)
Hydrology (streamflow)	P WMA 11/U10/00/3312/2/1 Hydrological assessment of the uMkhomazi River catchment report
Water requirements	P WMA 11/U10/00/3312/2/2 Water requirements and return flows report
Dam yield characteristics	P WMA 11/U10/00/3312/2/3 Water resources yield assessment report
Dam characteristics: (1) Dam position (2) Final layout	(1) P WMA 11/U10/00/3312/2/3/1/2 Supporting document 2: Dam position report (2) P WMA 11/U10/00/3312/2/3/1/3 Supporting document 3: Optimization of scheme configuration
Layout, costs and economics	(1) P WMA 11/U10/00/3312/2/3/1/3 Supporting document 3: Optimization of scheme configuration (2) P WMA 11/U10/00/3312/2/3/1/4 Supporting document 4: Cost model (3) P WMA 11/U10/00/3312/2/3/1/6 Supporting document 6: Economic comparison of the uMkhomazi-uMgeni transfer scheme with desalination and re-use option

Existing information	Report
Geotechnical and materials investigations	(1) P WMA 11/U10/00/3312/3/2 Geotechnical report (2) P WMA 11/U10/00/3312/3/2/1 Supporting document 1: Probabilistic seismic hazard analysis (Smithfield Dam) (3) P WMA 11/U10/00/3312/3/2/2 Supporting document 2: Seismic refraction investigation at the proposed uMkhomazi Water Project Phase 1 (4) P WMA 11/U10/00/3312/3/2/3 Supporting document 3: Smithfield Dam: Materials and geotechnical investigation (5) P WMA 11/U10/00/3312/3/2/4 Supporting document 4: Langa Balancing Dam: Materials and geotechnical investigation (6) P WMA 11/U10/00/3312/3/2/5 Supporting document 5: Conveyance system: Materials and geotechnical investigation

5.2 TOPOGRAPHICAL SURVEYS AND MAPPING

The DWA directorate ***Spatial and Land Information Management (SLIM)*** provided the study team with topographical survey data of the proposed dam basins of Smithfield, Impendle and Baynesfield dams (including the relevant river reaches of the uMkhomazi and uMlaza rivers), as well as the areas around the full extent of the conveyance tunnel and the water treatment works at Umlaas Road, conducted as part of the *Mkomazi/Mooi-Mgeni Transfer Scheme Pre-feasibility Study* (Ninham Shand, 1999).

5.3 WATER REQUIREMENTS, DAM YIELD CHARACTERISTICS AND COSTS

For a full description of the reasoning behind the selection of the final size for Smithfield Dam based on (1) water requirements, (2) yield calculations, and (3) costs i.e. URV calculations, the reader is referred to the following reports:

- *P WMA 11/U10/00/3312/2/2: Water requirements and return flows* (AECOM, AGES, MMA, & Urban-Econ, 2014)
- *P WMA 11/U10/00/3312/2/3: Water resources yield assessment report* (AECOM, AGES, MMA, & Urban-Econ, 2014)*; and*
- *P WMA 11/U10/00/3312/3/1/3: Optimization of scheme configuration* (AECOM, AGES, MMA, & Urban-Econ, 2014)

From report *P WMA 11/U10/00/3312/3/1/3: Optimization of scheme configuration* (AECOM, AGES, MMA, & Urban-Econ, 2014) it was concluded that the selected scheme will comprise of a ***Smithfield Dam at site B with a storage volume equal to 31% of the MAR with a resultant FSL of 930 masl*** (Final preferred layout included as **Figure A.4** in **Appendix A**). As such, the ***geotechnical investigations*** as well as the ***dam type selection*** was based on this dam size, position and layout.

5.4 Flood Hydrology

Flood absorption analyses were undertaken for the sizing of spillways and freeboard for the different dam types. The required freeboard above the full supply levels (FSL) of the various dam types was determined in accordance with the publication, *Interim Guidelines on Freeboard for Dams* (South African National Committee on Large Dams, 1990).

Flood frequency analyses were undertaken as part of the *uMkomazi/Mooi-Mgeni Transfer Scheme Pre-feasibility Study* (Ninham Shand, 1999) and were deemed adequate for undertaking flood absorption analyses for sizing the spillways and freeboard. The analysis results are summarised in **Table 5.2**.

Table 5.2: Flood peaks for the Smithfield Dam site (m^3/s)

Flood descriptions	Flood acronyms	Flood peaks (m^3/s)
100 year flood peak discharge	Q_{100}	1 812
200 year flood peak discharge	Q_{200}	2 540
Regional Maximum Flood	RMF	4 520
Recommended Design Flood	RDF	2 540
Safety Evaluation Flood	SEF	6 960

Spillway lengths were selected and the maximum water level in the dams for the safety evaluation flood (m^3/s) was obtained by routing various storm duration hydrographs through the reservoir. **Table 5.3** summarises the results for these analyses.

Table 5.3: Total required freeboard for different dam types - Smithfield Dam site

Dam Type	Spillway Type	C-Value	Spillway Length (m)	Total Required Freeboard (m)	Non-overspill Crest Level (masl)
RCC gravity dam	Ogee	2.18	300	5	935
Embankment dams (earthfill & rockfill)	Ogee	2.14	160	8	938

C relates to $Q = CLH^{3/2}$

Where:
Q = discharge
C = variable discharge coefficient
L = effective length of the crest
H = actual head being considered on the crest, including velocity of approach head

5.5 Dam Characteristics

Mutual parameters (dam characteristics) used for the cost comparison of various dam types for the selected Smithfield Dam (main dam wall as well as saddle dam wall) as discussed above, are indicated in **Table 5.4**.

Table 5.4: Dam characteristics for the selected Smithfield Dam

Parameter	Main dam	Saddle dam
Type of dam	Dependent on geotechnical investigations	
DWA classification	Category III	
Storage volume as a percentage of Mean Annual Runoff - MAR (%)	31	
Full supply level – FSL (masl)	930	
Minimum operating level – MOL (masl)	887.2	
Storage volume at FSL (million m^3)	251	
Surface area at FSL (km^2)	7.52	
Catchment area (km^2)	2 054	
Crest level (masl)	935 masl for gravity type dams 938 masl for embankment type dams	
Maximum wall height (m)	80.1 masl for gravity type dams 83.1 masl for embankment type dams	
Maximum water depth (m)	75.1 masl for gravity type dams 75.1 masl for embankment type dams	
Crest length of wall (m)	1224	1180
1:100 year yield (million m^3/a) (2012 in-catchment development levels)	241	
1:200 year yield (million m^3/a) (2050 in-catchment development levels)	219	

5.6 GEOTECHNICAL INVESTIGATIONS

5.6.1 Materials investigations

a) Sources for the various types of material

Required materials for Smithfield Dam can be sourced on site from (1) borrow area A, (2) borrow area B, (3) borrow area C, (4) quarry I (left flank), (5) quarry II (plunge pool), (6) quarry III (spillway approach), (7) quarry IV (tunnel inlet), (8) the main dam excavation, or (9) the saddle dam excavation. The location of these can be seen on **Figure A.6** in **Appendix A**.

Alternatively, if no sufficient material of a specific type is available on site, it can be (10) imported from nearby commercial sources. For this purpose, three commercial sources have been identified close to the Smithfield Dam site (see **Table 5.5**). In cases where sufficient materials are not available on site, transport costs to import the needed material from commercial sources are taken into account.

Table 5.5: Summary of commercial sources close to the Smithfield Dam site

Name	Material source	Distance from Smithfield Dam site (km)
Midmar Crushers	Aggregates	51.5
Natal Crushers	Aggregates	83.5
NPC	Natural sand	153

Table 5.6 and **Table 5.7** summarise the volumes of material available from the various sources (as defined and listed above) for an RCC and earthfill / rockfill dam respectively. Based on these a balancing exercise was conducted and construction costs estimated to determine the best dam type.

Table 5.6: Available material for Smithfield Dam – construction of an RCC dam

		Material (source)	A	B	C	D	E	F
			Overburden for soil: Organic topsoil	Clayey sand transported surface material	Completely and highly weathered shales	Unweathered to moderately weathered shales	Highly and moderately weathered dolerite	Slightly weathered and unweathered dolerite
			Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)
RCC dam	Available material	(1) **Borrow area A**	120 000	800 000	0	0	50 000	0
		(2) **Borrow area B**	100 000	850 000	0	0	100 000	0
		(3) **Borrow area C**	0 (2)	0	0	0	0	0
		(4) **Quarry I** (Left flank)	0 (2)	20 000	600 000	600 000	140 000	2 600 000
		(5) **Quarry II** (Plunge pool)	0 (2)	0	0	0	0	0
		(6) **Quarry III** (Spillway approach)	0 (2)	0	0	0	0	0
		(7) **Quarry IV** (Tunnel inlet)	0 (2)	7 000	110 000	13 500	0	0
		(8) **Excavation:** Main dam	0 (2)	120 000	210 000	0	62 000 (1)	0
		(9) **Excavation:** Saddle dam	0 (2)	0	11 000	0	0	0
		(10) **Other**	0 (2)	0	0	0	0	0
		TOTAL	220 000	1 829 455	987 796	613 500	368 768	2 600 000

(1) Alluvial borders in clayey matrix

(2) Not taken into account

Table 5.7: Available material for Smithfield Dam – construction of an embankment dam

		Material (source)	A	B	C	D	E	F
			Overburden for soil: Organic topsoil	Clayey sand transported surface material	Completely and highly weathered shales	Unweathered to moderately weathered shales	Highly and moderately weathered dolerite	Slightly weathered and unweathered dolerite
			Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)
Embankment dam	Available material	(1) **Borrow area A**	120 000	800 000	0	0	50 000	0
		(2) **Borrow area B**	100 000	850 000	0	0	100 000	0
		(3) **Borrow area C**	0 (2)	0	0	0	0	0
		(4) **Quarry I** (Left flank)	0 (2)	20 000	600 000	600 000	140 000	2 600 000
		(5) **Quarry II** (Plunge pool)	0 (2)	200 000	170 000	44 000	850 000	720 000
		(6) **Quarry III** (Spillway approach)	0 (2)	25 000	20 000	10 000	815 000	123 000
		(7) **Quarry IV** (Tunnel inlet)	0 (2)	7 000	110 000	13 500	0	0
		(8) **Excavation:** Main dam	0 (2)	380 000	0	0	200 000 (1)	0
		(9) **Excavation:** Saddle dam	0 (2)	0	11 000	0	0	0
		(10) **Other**	0 (2)	0	0	0	0	0
		TOTAL	220 000	3 488 319	967 796	667 500	2 789 592	3 443 000

(1) Alluvial borders in clayey matrix

(2) Not taken into account

b) Excavation volumes from Quarry I

The slightly weathered and unweathered dolerite within ***Quarry I*** are overlain by shale that needs to be removed and:

- ***Stockpiled*** for later use;
- Transported to the identified waste disposal site as ***spoil***; or
- Immediately ***used*** in either the embankments of the main or saddle dams.

As each of these options have a certain cost implication, this quarry was modelled in detail to determine the exact quantity of shale that would have to be removed for any given quantity of dolerite needed. Refer to **Appendix E** for the quarry cross sections.

The quarry was opened up on the north-western side (coordinates -91295.014, 3 295 451.995 (LO31)) as the more competent dolerite material is nearer to the surface at this point. As material is required, the quarry was expanded in a south easterly direction towards the saddle dam along section E-E, as shown in **Figure E.19** in **Appendix E**. **Figure 5.1** presents the excavation volumes for dolerite and shales respectively for every cubic metre of original ground level surface area quarried.

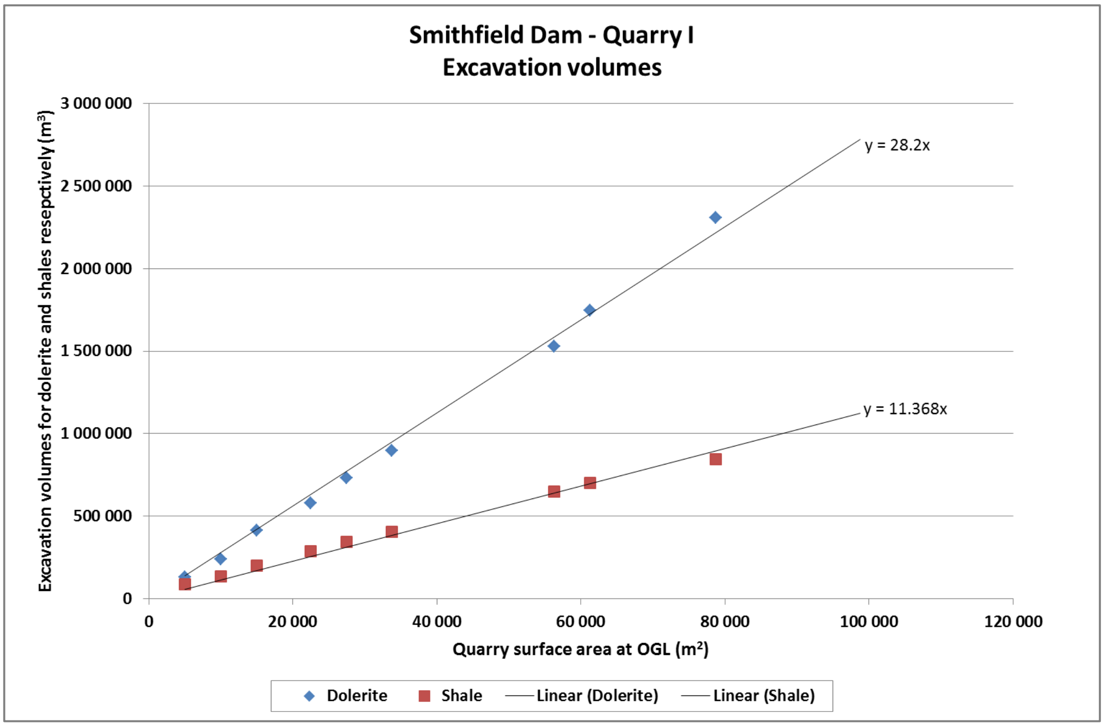


Figure 5.1: Quarry I – Excavation volumes

Slopes, as summarised in **Table 5.8**, were assumed for excavation in the different materials of the quarry.

Table 5.8: Slopes assumed for excavation in Quarry I

Material	Slope
Overburden for soil: Organic topsoil	1V:2H
Clayey sand transported surface material	1V:2H
Completely and highly weathered shales	1V:2H
Unweathered to moderately weathered shales	1V:2H
Highly and moderately weathered dolerite	1V:0.7H
Slightly weathered and unweathered dolerite	1V:0.7H

c) Main conclusions

The main conclusions of the ***materials investigations for sources of dam construction materials*** can be summarised as follows:

- Sufficient clay was identified for the core of either a zoned earthfill embankment dam or an earthcore rockfill dam;
- Limited semi-pervious material was identified for the outer zones of a zoned earthfill embankment dam;
- Both (1) carbon-rich baked and (2) no-carbon-rich baked shales have been identified which will be sufficient for any kind of rockfill dam;
- A volume of 2.6 million m^3 of good dolerite, i.e. ***slightly weathered and unweathered dolerite*** have been identified. However, this deposit is underlain by shale.

5.6.2 Geotechnical (foundation) investigations

a) Foundations of the dam and spillway structures

Excavation depths at borehole positions were recommended based on the results of the geotechnical investigation, i.e. seismic refraction surveys as well as rotary core drilling and Lugeon water pressure testing conducted along the centre line of Smithfield Dam (including main and saddle dam walls) and the spillway structure.

Table 5.9 to **Table 5.11** summarise the excavation depths for the various components of the different types of dams, as well as the spillway structure, based on the information as described above. Long-sections of these are provided in **Appendix E**, with the location of the various test pits and boreholes shown on **Figure A.7** and **Figure A.8** in **Appendix A**.

Table 5.9: Excavation depths (m) for Smithfield Dam (main dam wall) based on geotechnical investigations

Borehole No.	Elevation (masl)	RCC dam	Earthfill dam		ECR dam		CFR dam	
			Core	Shell	Core	Shell	Plinth	Shell
DLS 3	922.17	17.0	3.0	1.0	3.0	6.0	3.0	6.0
DL 1	916.23	23.0	10.6	0.5	10.6	10.3	10.6	10.3
DLS 2	914.34	30 +	8.4	0.7	8.4	8.4	8.4	8.4
DLS 1	904.25	14.0	4.0	0.3	4.0	3.0	4.0	3.0
DL 3	889.54	4.0	3.5	0.5	3.5	2.2	3.5	2.2
DL 4	879.25	2.0	2.0	0.5	2.0	1.5	2.0	1.5
DR 2	857.46	8.5	3.6	3.6	3.6	3.6	3.6	3.6
DR 1	857.32	10.0	10.0	2.5	10.0	5.0	10.0	5.0
DRS 1	884.58	11.0	1.5	1.1	1.5	4.5	1.5	4.5
DTS 1	888.42	8.0	3.0	0.6	3.0	5.2	3.0	5.2
DR 3	900.15	25.0	11.0	1.1	11.0	11.2	11.0	11.2
1004	901.20	13+	12.5	1.0	12.5	12.5	12.5	12.5
DRS 2	903.81	15.0	15.0	1.0	15.0	14.4	15.0	14.4
DR 4	909.44	25.0	7.5	0.5	7.5	7.5	7.5	7.5
DRS 3	925.13	18.0	3.5	0.9	3.5	3.2	3.5	3.2

Table 5.10: Excavation depths (m) for Smithfield Dam (saddle dam wall) based on geotechnical investigations

Borehole No.	Elevation (masl)	RCC dam	Earthfill dam		ECR dam		CFR dam	
			Core	Shell	Core	Shell	Plinth	Shell
SSS1	930.2	N/A	0.5	2	1.6	2	N/A	N/A
SES1	917.4	N/A	1.5	3.2	1.5	3.2	N/A	N/A
SES2	911.9	N/A	0.5	3	2	3	N/A	N/A
SES3	915.2	N/A	0.5	2.5	1.5	2.5	N/A	N/A

Table 5.11:Excavation depths (m) for Smithfield Dam's spillway structure (concrete chute) based on geotechnical investigations

Borehole No.	Elevation (masl)	Concrete chute
DLS 3	922.17	10.5
DL 1	916.23	11.0
DLS 2	914.34	8.5
DLS 1	904.25	6.0
DL 3	889.54	4.0
DL 4	879.25	2.0
DR 2	857.46	8.5
DR 1	857.32	10.0
DRS 1	884.58	11.0
DTS 1	888.42	8.0
DR 3	900.15	15.0
1004	901.20	13+
DRS 2	903.81	14.5
DR 4	909.44	8.0
DRS 3	925.13	6.0

b) Main conclusions

The main conclusions of the ***geotechnical investigations for the foundations of Smithfield Dam and the spillway structure*** can be summarised as follows:

- Foundation depths in the central part of the valley are shallower and favours a roller compacted concrete (RCC) gravity concrete or composite dam (RCC gravity and embankment dam combination). However, the outer parts include significantly deeper excavations. This does not favour concrete gravity type dams.

5.7 OTHER PARAMETERS

5.7.1 Filters and transition layers

The width of filters and transition layers that were considered in the assessments are listed in **Table 5.12**.

Table 5.12: NOC widths, curtain grout spacing and width of filters and transition layers for various dam types considered in cost comparison

Parameter		Roller compacted concrete gravity dam (RCC)	Zoned earthfill embankment dam	Earth core rockfill dam (ECRD)	Concrete faced rockfill dam (CFRD)
NOC crest width (m)		8	8	8	8
Curtain grouting spacing (m)		2	2	2	2
Filters and transition layers (Thicknesses) (m)	Rip rap	-	1	-	-
	Gravel protection / transition	-	2 * 0.4	2 * 1	2 * 2
	Sand filter	-	1	2	-
	Chimney drain	-	2	-	-
	Blanket drain	-	0.6	-	-

5.7.2 Slopes

Slope stability analyses were conducted with the tested parameters for the different soil types from the geotechnical investigations to determine the optimal slopes of each of the various dam types. Parameters used in this exercise are summarised in **Table 5.13**. The results from the soil stability analyses are included in **Appendix C**, with the resultant slopes for the various dam types summarised in **Table 5.14**.

All slope stability factors conform to minimum requirements except for embankments constructed with dolerite which show shallow slips with lower safety factors. These factors are acceptable.

In addition, the interaction of Quarry I with the saddle embankment in terms of slope stability was noted. The layout drawings show that the upstream toe of the saddle embankment was placed 70 m from the top of the quarry’s slope. It is proposed that slope protection on the quarry slope face nearest to the saddle embankment is used to accommodate this slope stability. This aspect must be refined in the detail design.

Table 5.13: Engineering properties for the various material types

Material No.	Material type	Phi – Φ (°)	Cohesion – C (kPa)	Density (kg/m^3)
A	Overburden for soil: Organic topsoil	26	23	1 300
B	Clayey sand transported surface material	26	23	1 730
C	Completely and highly weathered shales	35	0	2 049
D	Unweathered to moderately weathered shales	38	0	2 100
E	Highly and moderately weathered dolerite	36	0	2 100
F	Slightly weathered and unweathered dolerite	40	0	2 200
-	Undisturbed dolerite	40	100	2 720
-	Concrete	35	500	2 300

Table 5.14: Assumed slopes for various dam types considered in cost comparison

Dam type	Upstream slope	Downstream slope
Roller compacted concrete gravity dam (RCC)	1(V):0.1(H)	1(V):0.8(H)
Zoned earthfill embankment dam	1(V):3(H)	1(V):2.5(H)
Earth core rockfill dam (ECRD)	1(V):1.8(H)	Zoning option 1&2: 1(V):1.75(H)
Concrete faced rockfill dam (CFRD)	1(V):1.4(H)	• Zoning option 1: 1(V):1.4(H) • Zoning option 2: 1(V):2(H) • Zoning option 3: 1(V):1.8(H)

(1) Required to accommodate shear stability

6 SMITHFIELD DAM – ASSESSMENT BEFORE AND DURING GEOTECHNICAL INVESTIGATIONS

6.1 INTRODUCTION AND OBJECTIVE

The objective of this exercise was to consider various possible dam layouts and types for Smithfield Dam to guide the geotechnical investigations. The following aspects were considered:

- Construction costs of excavations;
- Layouts of spillways and chutes; and
- Social and environmental aspects.

6.2 DAM TYPES

Embankment and concrete gravity dam types were considered in this report. However, the concrete gravity and the embankment dams share the same centre lines, and therefore the scope for the geotechnical investigation would be the same for both, and so the differentiating factor for the embankment dam would be the spillway layout and position.

6.3 SPILLWAY LAYOUTS

Three spillway layout options were considered.

6.3.1 Option 1

The first option investigated had a side channel spillway discharging into a concrete lined chute, next to the main dam. The length of the chute was shortened by discharging the water into a small stream. The layout is shown in **Figure A.1** in **Appendix A**.

6.3.2 Option 2

The second option investigated had a side channel spillway and concrete chute next to the saddle wall and discharging with a ski jump into the uMkhomazi River from a high level. The layout of this option is shown in **Figure A.2** in **Appendix A**.

6.3.3 Option 3

The third option investigated was a side spillway at the escarpment with a long approach channel from the side of the saddle wall and a radially shaped ogee weir. This layout is shown in **Figure A.3**.

6.4 ASPECTS OF THE CONSTRUCTION COSTS

6.4.1 Costs for the excavation

Section 4.3 indicates all costs for forming the embankments. The excavation material for the spillway approach and chute was assumed to be used to form the embankments, and therefore no additional costs were allowed for other excavations in determining the cost of the spillways.

An important requirement from the geotechnical investigations was identified, namely to determine if the material in the spillway approach and chute will be acceptable in terms of quality and quantity for the forming of an embankment.

6.4.2 Costs for the spillway and chute

The spillway and chute costs for each option were determined for comparison purposes.

6.4.3 Costs for the embankment

All other costs excluding the spillway and excavation costs are common costs in this comparison.

6.5 SOCIAL AND ENVIRONMENTAL ASPECTS

The social and environmental aspects of the spillways were evaluated on the following main elements of (1) safety of people, (2) the visual impact on the environment and (3) the effective environmental footprint. A description of these elements follows:

6.5.1 Safety of people

A deep excavation for a spillway close to dwellings is much less favourable than a shallower excavation away from people. The size of the footprint of the excavation influences the ease of safeguarding the excavation.

6.5.2 Effective environmental footprint

The larger the footprint of the excavation the larger the effect will be on the physical environment. The footprint of the excavation should therefore be as small as possible.

6.6 COMPARISON OF OPTIONS

Aspects as discussed in the preceding section were evaluated by allocating a value of 1 to 10 for each. A score of 1 is the least favourable and, on the other hand, a score of 10 is the most favourable option. These are summarised in **Table 6.1**.

Table 6.1: Evaluation of different dam layouts for Smithfield Dam

Aspect		Score of options out of a possible 10		
		Option 1*	**Option 2***	**Option 3***
Cost				
Excavations	**Score**	**4**	**8**	**4**
	Comment	Medium quantity of material available for embankment forming.	Large quantity of material available for embankment forming. Long approach area.	Medium quantity of material available for embankment forming.
Chute	**Score**	**5**	**8**	**3**
	Comment	Medium length of chute.	Very short length of spillway and chute.	Longer length of chute than option 1 and will have topographical challenges.
Sub-Total		9	16	7
Social and environmental aspects				
Safety	**Score**	**8**	**2**	**5**
	Comment	Chute not near people.	Spillway has very deep excavations over a long length near people.	Chute has shorter distance than Option 1, but near people and also deep excavation.
Visual	**Score**	**7**	**2**	**5**
	Comment	Spillway smaller than option 2.	Spillway and excavations will scar the area.	Spillway not as large as Option 2.
Footprint	**Score**	**3**	**2**	**3**
	Comment	A large section of the hill will be demolished to create the approach.	Excavated footprint will be the largest of the options.	The approach will also have a deep excavation.
Sub-Total		18	6	13
TOTAL		**27**	**22**	**20**

**For definition of the options please refer to Section 6.3*

Based on the above comparisons the following were revealed:

- ***Option 2*** will have the lowest cost if the material discovered in this spillway area is of good embankment forming quality;
- ***Option 1*** could be the best safeguarded and provides the lowest safety risk;
- ***Option 1*** scores the best on cost and social and environmental aspects;
- ***Option 2*** scores the second best on cost and social and environmental aspects.

6.7 RECOMMENDATION

The following interim recommendations for design were thus made based on the assessment at this stage:

- The geotechnical investigations must determine the quality and quantity of material that could be obtained from excavations for the ***Option 1*** spillway layout;
- The erodibility of the stream for the discharge of the ***Option 1*** spillway layout must be determined during a site visit; and
- ***Option 1*** must be investigated for quality and quantity of material. The area downstream of the chute must also be investigated for a possible plunge pool. The stabilisation of the discharges from the spillway in the downstream area should be considered during the tender design of the spillway, to ensure that they do not erode the outlet works. In addition, hydraulic model studies should be undertaken during tender design.

6.8 DURING GEOTECHNICAL INVESTIGATIONS

6.8.1 Drilling programme

The above philosophy was used, but the initial drilling was done at Option 2 to determine the quantity and quality of material available in the approach channel. If the quality and the quantity of material were adequate, further investigations could be carried out at this option and the material could outweigh the negative impacts of this option. The drilling at Option 2 could also direct further investigations into Option 3 as the area is close to Option 2.

If the materials at Option 2 were not adequate Option 1 will then be investigated.

6.8.2 Findings during geotechnical investigations

The initial drilling showed that no dolerite existed in the approach channel of Option 2, but that dolerite was present at the chute and approach channel of Option 1. Option 3 is in close proximity of Option 2 and the same results were extrapolated for this option.

6.8.3 Results of interim geotechnical drilling investigation

The initial core drilling directed all further geotechnical investigations to Option 1.

7 SMITHFIELD DAM – ASSESSMENT AFTER GEOTECHNICAL INVESTIGATIONS

7.1 INTRODUCTION AND OBJECTIVE

With information available on the ***construction materials available on site*** as well as the ***foundation conditions along the centre line of Smithfield Dam*** (main dam wall as well as saddle dam wall) the objective of this exercise was to compare costs for various dam types to (1) select the optimal dam type, and ultimately to (2) select the best scheme. In order to do this a balancing exercise was conducted to ensure optimal use of available materials on site which also influenced the estimation of costs. This balancing exercise took into account the following:

- The total volume of material of each specific type ***required*** for the (1) main dam, (2) saddle dam, and all additional infrastructure including the (3) diversion works, (4) intake structure, (5) spillway i.e. approach, chute and plunge pool, and (6) outlet works;
- The total volume of material of each specific type ***available*** on site from (1) the main dam excavation, (2) the saddle dam excavation, (3) Quarry I (left flank), (4) Quarry II (plunge pool), (5) Quarry III (spillway approach), (6) Quarry IV (tunnel inlet), (7) Borrow area A, (8) Borrow Area B and (9) Borrow Area C;
- The total volume of material of each specific type that have to be ***imported from a commercial source***;
- The total volume of material of each specific type that need to be ***stockpiled*** for later use.
- The total volume of material of each specific type that need to be ***spoiled*** in the designated waste disposal site;
- The total volume of material of each specific type that need to be ***used in the forming of the specific dam type***;
- The total volume of material of each specific type that is kept ***undisturbed*** in the respective quarries or borrow areas.

During the construction materials investigation a "safety factor" is built in whereby twice the volume of material required for construction should be proved during the site investigation. However, a decision was made that, for the purpose of the balancing exercise, the ***required material*** was balanced against the ***available material*** on a one-to-one basis. **Table 7.2** to **Table 7.9** provide a summary of the material balance for each of the dam type options, which also give an indication of the volume of material of each specific type that remains within the respective quarries or borrow areas (i.e. that is kept undisturbed/untouched).

7.2 DAM TYPES

Based on the information received from the geotechnical and materials investigations, dam types that were considered for Smithfield Dam are summarised in **Table 7.1**. Typical cross-sections for each of the dam types listed are included in **Appendix D**.

Table 7.1: Dam type options investigated for Smithfield Dam

Option No.	Section	Dam type	
		Main Dam	Saddle Dam
1	7.5.1	Roller compacted concrete (RCC) gravity	Zoned earthfill embankment dam
2	7.5.2	Earth core rockfill dam *(zoning option 1)*	Zoned earthfill embankment dam
3	7.5.3	Concrete faced rockfill dam *(zoning option 1)*	Zoned earthfill embankment dam
4	7.5.4	Zoned earth core rockfill dam *(zoning option 2)*	Zoned earthfill embankment dam
5	7.5.5	Zoned earth core rockfill dam *(zoning option 2)*	Zoned earth core rockfill dam *(zoning option 2)*
6	7.5.6	Composite dam (RCC gravity and zoned ECRD *(zoning option 2)*)	Zoned earthfill embankment dam
7	7.5.7	Zoned concrete faced rockfill dam (option 1) *(zoning option 2)*	Zoned earthfill embankment dam
8	7.5.8	Zoned concrete faced rockfill dam (option 2) *(zoning option 3)*	Zoned earthfill embankment dam
9*	7.5.9	Zoned earthfill embankment dam	Zoned earthfill embankment dam
10*	7.5.9	Composite dam (RCC with zoned ECRD on the one flank and zoned earthfill embankment dam on the other)	Zoned earthfill embankment dam

These options were identified initially but not considered further, for reasons described in **Section 7.5.9.*

7.3 DAM SIZE AND LAYOUT

The dam size and layout were based on a ***Smithfield Dam at site B with a storage volume equal to 31% of the MAR with a resultant FSL of 930 masl*** as summarised in **Sections 5.2** and **5.4**. Further to this the ***Option 1*** spillway was selected as described in **Section 6**.

7.4 PRIORITY SEQUENCES

As mentioned in **Section 5.6.1** materials for the construction of Smithfield Dam can be sourced on site from (1) borrow area A, (2) borrow area B, (3) borrow area C, (4) quarry I (left flank), (5) quarry II (plunge pool), (6) quarry III (spillway approach), (7) quarry IV (tunnel inlet), (8) the main dam excavation, or (9) the saddle dam excavation. Alternatively, if sufficient material of a specific type is not available on site, it can be (10) imported from nearby sources.

For the purpose of selecting the optimal dam type, different priority sequences for the sourcing of materials were adopted for the various dam types. The combination of main dam and saddle dam were taken into account for this investigation, with various different combinations considered. These are discussed in **Section 7.4.1** to **7.4.4**.

7.4.1 Roller compacted concrete (RCC) gravity dam

For the ***roller compacted concrete (RCC) gravity dam*** material was sourced in the following priority sequence. If sufficient material of a specific type was not available on site, appropriate material was imported from nearby commercial sources as a last resource.

- Quarry IV (tunnel inlet);
- Main dam excavation;
- Saddle dam excavation;
- Quarry I (left flank); and
- Commercial source.

7.4.2 Zoned earthfill embankment dam

For the ***zoned earthfill embankment dam*** material was sourced in the following priority sequence. If sufficient material of a specific type was not available on site, appropriate material was imported from nearby commercial sources as a last resource.

- Quarry IV (tunnel inlet);
- Main dam excavation;
- Saddle dam excavation;
- Quarry II (plunge pool);
- Quarry III (spillway approach);
- Borrow area A;

- Borrow area B;
- Borrow area C; and
- Commercial source.

7.4.3 Earth core rockfill dam (ECRD)

For the ***earth core rockfill dam*** material was sourced in the following priority sequence. If sufficient material of a specific type was not available on site, appropriate material was imported from nearby commercial sources as a last resource.

- Quarry IV (tunnel inlet);
- Main dam excavation;
- Saddle dam excavation;
- Quarry II (plunge pool);
- Quarry III (spillway approach);
- Quarry I (left flank); and
- Commercial source.

7.4.4 Concrete faced rockfill dam (CFRD)

For the ***concrete faced rockfill dam*** material was sourced in the following priority sequence. If sufficient material of a specific type was not available on site, appropriate material was imported from nearby commercial sources as a last resource.

- Quarry IV (tunnel inlet);
- Main dam excavation;
- Saddle dam excavation;
- Quarry II (plunge pool);
- Quarry III (spillway approach);
- Quarry I (left flank); and
- Commercial source.

7.5 Comparison in terms of construction cost

Material quantities for all infrastructure components and for each dam option based on centre line natural ground levels (NGL) were calculated using the cost model described in **Section 2**. Following in **Sections 7.5.1** to **7.5.9** are a description of each of the dam types investigated, with a summary of the cost comparison included in **Section 7.5.10**. All options investigated are summarised in **Table 7.1** and the results of the balancing exercise are included in **Appendix F** and

Appendix G. This balancing exercise (and cost of the determined materials) considered the material required for the main dam and the saddle dam,

7.5.1 Option 1: Main dam - Roller compacted concrete (RCC) gravity; Saddle dam - Zoned earthfill embankment dam

a) Main dam

For this option, material utilised within the main dam will firstly be provided from ***Quarry IV***, after which the stockpiled material from the ***main dam and saddle dam excavations*** will be used prior to ***Quarry I*** being opened. As shown in **Table 7.2** approximately 1 123 593 m^3 of slightly weathered and unweathered dolerite material will be required as aggregate to construct the main dam, diversion works and intake and outlet works. Fortunately, the full volume of this material can be sourced from all the various on-site sources. Material quarried that is not needed in the forming of the main dam will either be taken to the identified waste disposal site or used within the saddle dam.

b) Saddle dam

For this option, sufficient impervious and pervious material will be obtained from the (1) the ***main dam excavation*** as well as (2) ***Quarry I*** where ***clayey sand transported surface material*** and ***completely and highly weathered shale*** will have to be removed and stockpiled to get to the underlying dolerites needed for the construction of the main dam. As such, there is no need to open up either borrow area A or B. Sand for the blanket and chimney drains will be sourced from ***NPC sand*** at the Umkomaas River mouth and transported 153 km to site.

c) General

Table 7.2 provides a summary of the balancing of materials for ***Option 1***.

As indicated in this table there are ***6% more*** of the clayey sand transported surface material, ***59% more*** of the completely and highly weathered shale, and ***131% more*** of the slightly weathered and unweathered dolerite, available from on-site sources (i.e. from the borrow areas, quarries and dam excavations) than what is ***required*** for this option.

Although not twice the volume of material required in the case of the ***clayey sand transported surface material*** and the ***completely and highly weathered shale***, it was deemed sufficient.

Table 7.2: Balancing of materials for Option 1

Material use		A	B	C	D	E	F	G
		Overburden for soil: Organic topsoil	Clayey sand transported surface material	Completely & highly weathered shales	Unweathered to moderately weathered shales	Highly & moderately weathered dolerite	Slightly weathered & unweathered dolerite	Sand
		Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)
Total required (1)		**0**	**336 835**	**861 785**	**0**	**0**	**1 123 593**	**86 544**
Available on site (2)		0	358 235	1 369 280	613 500	310 960	2 600 000	0
Imported (3)		0	0	0	0	0	0	86 544
Total available		**0**	**358 235**	**1 369 280**	**613 500**	**310 960**	**2 600 000**	**86 544**
Action	**Stockpiled (4)**	0	336 835	861 785	0	0	1 123 593	86 544
	Spoiled (5)	0	21 400	112 532	226 404	310 960	0	0
	Dam forming (6)	0	336 835	861 785	0	0	1 123 593	86 544
	Surplus (7)	0	0	394 963	387 096	0	1 476 407	0
	Percentage remaining (%)	*-*	*6*	*59*	*-*	*-*	*131*	*-*
	TOTAL	**0**	**358 235**	**1 369 280**	**613 500**	**310 960**	**2 600 000**	**86 544**

(1) *The total volume of material* ***required*** *for the (1) main dam, (2) saddle dam, and all additional infrastructure including the (3) diversion works, (4) intake structure, (5) spillway i.e. approach, chute and plunge pool, and (6) outlet works.*

(2) *The total volume of material* ***available on site*** *from (1) the main dam excavation, (2) the saddle dam excavation, (3) Quarry I (left flank), (4) Quarry II (plunge pool), (5) Quarry III (spillway approach), (6) Quarry IV (tunnel inlet), (7) Borrow area A, (8) Borrow Area B and (9) Borrow Area C.*

(3) *The total volume of material that have to be* ***imported from a commercial source****.*

(4) *The total volume of material that need to be* ***stockpiled*** *for later use.*

(5) *The total volume of material that need to be* ***spoiled*** *in the designated waste disposal site.*

(6) *The total volume of material that need to be* ***used in the forming of the specific dam type****.*

(7) *The total volume of surplus material that is kept* ***undisturbed*** *in the respective quarries or borrow areas.*

7.5.2 Option 2: Main dam - Earth core rockfill dam; Saddle dam - Zoned earthfill embankment dam

a) Main dam

For this option the material utilised within the main dam, i.e. primarily ***slightly weathered and unweathered dolerite*** as rockfill, will firstly be obtained (in this order) from ***Quarry IV***, the ***main dam excavation***, the ***saddle dam excavation***, ***Quarry II*** and ***Quarry III,*** prior to opening ***Quarry I***. Material quarried that is not needed in the forming of the main dam will either be taken to the identified waste disposal site or used in the saddle dam.

However, sufficient dolerite material cannot be obtained from the available on site sources to construct a complete outer shell with ***slightly weathered and unweathered dolerite material*** and therefore dolerite material will need to be imported from a commercial quarry. For this purpose 178 279 m^3 of this material will be sourced and transported from ***Midmar Crushers,*** which is 51.5 km from the Smithfield Dam site.

Similarly, with all on-site sources opened up as mentioned above there will also not be sufficient clay core material and therefore the deficient of clay material will be obtained from ***Borrow Area A***.

Sand for the transition zones will be obtained from ***NPC sand*** at the Umkomaas River mouth and transported 153 km to site.

b) Saddle dam

For this option sufficient impervious and pervious material will be opened up by the excavations needed for the main dam, i.e. ***Quarry IV***, the ***main dam excavation***, the ***saddle dam excavation***, ***Quarry II*** and ***Quarry III*** and ***Quarry I,*** to construct a zoned earthfill embankment dam. Sand for the blanket and chimney drains will be sourced from ***NPC sand*** and transported 153 km to site.

c) General

Table 7.3 provides a summary of the balancing of materials for ***Option 2***.

As indicated in this table there are ***50% more*** of the clayey sand transported surface material and ***15% more*** of the completely and highly weathered shales available from on-site sources (i.e. from the borrow areas, quarries and dam excavations) than what is ***required*** for this option. Although not twice the volume of material required, it was deemed sufficient.

However, as mentioned above there is not sufficient dolerite material to construct the complete outer shell with slightly weathered and unweathered dolerite material and therefore it is shown that ***0% more*** of this material is available from on-site sources than what is required, as a portion of this already needs to be imported from a commercial quarry.

In addition to this, should the estimated volume of this material of 3 912 823 m^3 not be found on site during construction, further material should be sourced and transported from ***Midmar Crushers*** which will significantly increase the construction cost of this option.

Table 7.3: Balancing of materials for option 2

Material use		A	B	C	D	E	F	G
		Overburden for soil: Organic topsoil	Clayey sand transported surface material	Completely & highly weathered shales	Unweathered to moderately weathered shales	Highly & moderately weathered dolerite	Slightly weathered & unweathered dolerite	Sand
		Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)
Total required (1)		**0**	**1 250 373**	**861 785**	**0**	**0**	**3 912 823**	**178 279**
Available on site (2)		120 000	1 872 852	992975	667500	2 259 300	3 443 000	0
Imported (3)		0	0	0	0	0	469 823	178 279
Total available		**120 000**	**1 872 852**	**992 975**	**667 500**	**2 259 300**	**3 912 823**	**178 279**
Action	**Stockpiled (4)**	0	1 250 373	861 785	0	0	3 912 823	178 279
	Spoiled (5)	25 806	0	131 190	667 500	2 209 300	0	0
	Dam forming (6)	0	1 250 373	861 785	0	0	3 912 823	178 279
	Surplus (7)	94 194	622 479	0	0	50 000	0	0
	Percentage remaining (%)	-	***50***	***15***	-	-	***0***	***0***
	TOTAL	**120 000**	**1 872 852**	**992 975**	**667 500**	**2 259 300**	**3 912 823**	**178 279**

(1) *The total volume of material **required** for the (1) main dam, (2) saddle dam, and all additional infrastructure including the (3) diversion works, (4) intake structure, (5) spillway i.e. approach, chute and plunge pool, and (6) outlet works.*

(2) *The total volume of material **available on site** from (1) the main dam excavation, (2) the saddle dam excavation, (3) Quarry I (left flank), (4) Quarry II (plunge pool), (5) Quarry III (spillway approach), (6) Quarry IV (tunnel inlet), (7) Borrow area A, (8) Borrow Area B and (9) Borrow Area C.*

(3) *The total volume of material that have to be **imported from a commercial source**.*

(4) *The total volume of material that need to be **stockpiled** for later use.*

(5) *The total volume of material that need to be **spoiled** in the designated waste disposal site.*

(6) *The total volume of material that need to be **used in the forming of the specific dam type**.*

(7) *The total volume of surplus material that is kept **undisturbed** in the respective quarries or borrow areas.*

7.5.3 Option 3: Main dam - Concrete faced rockfill dam; Saddle dam - Zoned earthfill embankment dam

a) Main dam

For this option the primary material utilised within the main dam is rockfill, i.e. ***primarily slightly weathered and unweathered dolerite***, will firstly be obtained (in this order) from ***Quarry IV***, the ***main dam excavation***, the ***saddle dam excavation***, ***Quarry II*** and ***Quarry III,*** prior to opening ***Quarry I***. Material quarried that is not needed in the forming of the main dam will either be taken to the identified waste disposal site or used in the saddle dam.

However, with all the on-site sources, there is still insufficient dolerite material to construct the complete main dam with ***slightly weathered and unweathered dolerite material*** and therefore dolerite material will need to be imported from a commercial quarry. For this purpose 584 180 m^3 of this material will be sourced and transported from ***Midmar Crushers,*** which is 51.5 km from the Smithfield Dam site. The aggregate for the concrete slab will be obtained from ***Quarry I***.

b) Saddle dam

For this option sufficient impervious and pervious material will be opened up by the excavations needed for the main dam, i.e. ***Quarry IV***, the ***main dam excavation***, the ***saddle dam excavation***, ***Quarry II*** and ***Quarry III*** and ***Quarry I,*** to construct a zoned earthfill embankment dam. As such, ***Borrow Area A*** will not have to be opened up in this case.

Sand for the blanket and chimney drains will be sourced from ***NPC sand*** and transported 153 km to site.

c) General

Table 7.4 provides a summary of the balancing of materials for ***option 3***.

As indicated in this table there are ***170% more*** of the clayey sand transported surface material and ***15% more*** of the completely and highly weathered shales available from on-site sources (i.e. from the borrow areas, quarries and dam excavations) than what is ***required*** for this option. Although not twice the volume of material required, it was deemed sufficient.

However, as mentioned above there is not sufficient dolerite material to construct the complete outer shell with slightly weathered and unweathered dolerite material and therefore it is shown that ***0% more*** of this material is available from on-site sources than what is required, as a portion of this already needs to be imported from a commercial quarry.

In addition to this, should the estimated volume of this material of 3 443 000 m^3 not be found on site during construction, further material should be sourced and transported from ***Midmar Crushers,*** which will significantly increase the construction cost of this option.

Table 7.4: Balancing of materials for option 3

Material use		A	B	C	D	E	F	G
		Overburden for soil: Organic topsoil	Clayey sand transported surface material	Completely & highly weathered shales	Unweathered to moderately weathered shales	Highly & moderately weathered dolerite	Slightly weathered & unweathered dolerite	Sand
		Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)
Total required (1)		**0**	**336 835**	**992 975**	**0**	**0**	**4 027 180**	**86 544**
Available on site (2)		0	908 551	992 975	667 500	2 128 376	3 443 000	0
Imported (3)		0	0	0	0	0	584 180	86 544
Total available		**0**	**908 551**	**992 975**	**667 500**	**2 168 376**	**4 027 180**	**86 544**
Action	**Stockpiled (4)**	0	336 835	861 785	0	0	4 027 180	86 544
	Spoiled (5)	0	571 716	131 190	667 500	2 128 376	0	0
	Dam forming (6)	0	336 835	861 785	0	0	4 027 180	86 544
	Surplus (7)	0	0	0	0	0	0	0
	Percentage remaining (%)	*-*	***170***	***15***	*-*	*-*	***0***	***0***
	TOTAL	**0**	**908 551**	**992 975**	**667 500**	**2 168 529**	**4 027 180**	**86 544**

(1) *The total volume of material **required** for the (1) main dam, (2) saddle dam, and all additional infrastructure including the (3) diversion works, (4) intake structure, (5) spillway i.e. approach, chute and plunge pool, and (6) outlet works.*

(2) *The total volume of material **available on site** from (1) the main dam excavation, (2) the saddle dam excavation, (3) Quarry I (left flank), (4) Quarry II (plunge pool), (5) Quarry III (spillway approach), (6) Quarry IV (tunnel inlet), (7) Borrow area A, (8) Borrow Area B and (9) Borrow Area C.*

(3) *The total volume of material that have to be **imported from a commercial source**.*

(4) *The total volume of material that need to be **stockpiled** for later use.*

(5) *The total volume of material that need to be **spoiled** in the designated waste disposal site.*

(6) *The total volume of material that need to be **used in the forming of the specific dam type**.*

(7) *The total volume of surplus material that is kept **undisturbed** in the respective quarries or borrow areas.*

7.5.4 Option 4: Main dam - Zoned earth core rockfill dam; Saddle dam - Zoned earthfill embankment dam

a) Main dam

In order to optimise the utilisation of materials available on site, an internal zone of ***unweathered to moderately weathered shales*** can be used overlain by a layer of ***slightly weathered and unweathered dolerite***. This will reduce the cost of having to import the shortfall of ***slightly weathered and unweathered dolerite*** but rather the ***unweathered to moderately weathered shales*** available on site can be used, which is in the order of 667 500 m^3 of material, before using the ***slightly weathered and unweathered dolerite.*** Therefore, no additional material will need to be imported from a commercial source.

Similar to Option 2 described above, the material utilised within the main dam will firstly be obtained (in this order) from ***Quarry IV***, the ***main dam excavation***, the ***saddle dam excavation***, ***Quarry II***, ***Quarry III,*** and lastly ***Quarry I***. Material quarried that is not needed in the forming of the main dam will either be taken to the identified waste disposal site or used in the saddle dam.

With all on-site sources opened up as mentioned above there will not be sufficient clay core material and therefore the deficient of clay material will be obtained from ***Borrow Area A***.

Sand for the transition zones will be obtained from ***NPC sand*** at the Umkomaas River mouth and transported 153 km to site.

b) Saddle dam

For this option sufficient impervious and pervious material will be opened up by the excavations need for the main dam, i.e. ***Quarry IV***, the ***main dam excavation***, the ***saddle dam excavation***, ***Quarry II*** and ***Quarry III*** and ***Quarry I,*** to construct a zoned earthfill embankment dam. Sand for the blanket and chimney drains will be sourced from ***NPC sand*** and transported 153 km to site.

c) General

Table 7.5 provides a summary of the balancing of materials for ***option 4***.

As indicated in this table there are ***50% more*** of the clayey sand transported surface material, ***15% more*** of the completely and highly weathered shales and ***15% more*** of the unweathered to moderately weathered shales available from on-site sources (i.e. from the borrow areas, quarries and dam excavations) than what is ***required*** for this option. Although not twice the volume of material required, it was deemed sufficient.

However, when it comes to the weathered and unweathered dolerite material there are only ***2% more*** of this material available from on-site sources than what is required. Therefore, should the estimated volume of 3 443 000 m^3 not be found on site during construction the additional material should be sourced and transported from ***Midmar Crushers*** (51.5 km from the Smithfield Dam site) which will significantly increase the construction cost of this option.

Table 7.5: Balancing of materials for option 4

Material use		A	B	C	D	E	F	G
		Overburden for soil: Organic topsoil	Clayey sand transported surface material	Completely & highly weathered shales	Unweathered to moderately weathered shales	Highly & moderately weathered dolerite	Slightly weathered & unweathered dolerite	Sand
		Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)
Total required (1)		**0**	**1 259 626**	**861 785**	**581 935**	**0**	**3 364 209**	**180 345**
Available on site (2)		120 000	1 891 924	992 975	667 500	2 268 694	3 443 000	0
Imported (3)		0	0	0	0	0	0	180 345
Total available		**120 000**	**1 891 924**	**992 975**	**667 500**	**2 268 694**	**3 443 000**	**180 345**
Action	**Stockpiled (4)**	0	1 259 626	861 785	581 935	0	3 364 209	180 345
	Spoiled (5)	120 000	0	0	85 565	2 268 694	0	0
	Dam forming (6)	0	1 259 626	861 785	581 935	0	3 364 209	180 345
	Surplus (7)	0	632 298	131 190	0	0	78 791	
	Percentage remaining (%)	*-*	***50***	***15***	***15***	*-*	***2***	*-*
	TOTAL	**120 000**	**1 891 924**	**992 975**	**667 500**	**2 268 694**	**3 443 000**	**180 345**

(1) *The total volume of material **required** for the (1) main dam, (2) saddle dam, and all additional infrastructure including the (3) diversion works, (4) intake structure, (5) spillway i.e. approach, chute and plunge pool, and (6) outlet works.*

(2) *The total volume of material **available on site** from (1) the main dam excavation, (2) the saddle dam excavation, (3) Quarry I (left flank), (4) Quarry II (plunge pool), (5) Quarry III (spillway approach), (6) Quarry IV (tunnel inlet), (7) Borrow area A, (8) Borrow Area B and (9) Borrow Area C.*

(3) *The total volume of material that have to be **imported from a commercial source**.*

(4) *The total volume of material that need to be **stockpiled** for later use.*

(5) *The total volume of material that need to be **spoiled** in the designated waste disposal site.*

(6) *The total volume of material that need to be **used in the forming of the specific dam type**.*

(7) *The total volume of surplus material that is kept **undisturbed** in the respective quarries or borrow areas.*

7.5.5 Option 5: Main dam - Zoned earth core rockfill dam; Saddle dam – Zoned earth core rockfill dam

a) Main dam

In order to optimise the utilisation of materials available on site, an internal zone of ***unweathered to moderately weathered shales*** can be used overlain by a layer of ***slightly weathered and unweathered dolerite***. This will reduce the cost of having to import the shortfall of ***slightly weathered and unweathered dolerite*** but rather use the total volume of ***unweathered to moderately weathered shales*** available on site. This comprises of 667 500 m^3 of material, before using the ***slightly weathered and unweathered dolerite.***

Similar to option 2 described above the material utilised within the main dam will firstly be obtained (in this order) from ***Quarry IV***, the ***main dam excavation***, the ***saddle dam excavation***, ***Quarry II***, ***Quarry III,*** and lastly ***Quarry I***. Material quarried that is not needed in the forming of the main dam will either be taken to the identified waste disposal site or used in the saddle dam.

However, with all the on-site sources, there will not be sufficient dolerite material to construct the portion of the main dam with ***slightly weathered and unweathered dolerite material*** and therefore dolerite material will still need to be imported from a commercial quarry.

With all on-site sources opened up as mentioned above there will also not be sufficient clay core material and therefore the deficient of clay material will be obtained from ***Borrow Area A***.

Sand for the transition zones will be obtained from ***NPC sand*** at the Umkomaas River mouth and transported 153 km to site.

b) Saddle dam

Similar for the main wall as described above the saddle wall will also comprise an internal zone of ***unweathered to moderately weathered shales*** overlain by a layer of ***slightly weathered and unweathered dolerite.*** In order to optimise the utilisation of materials available on site. This will reduce the cost of having to import the shortfall of ***slightly weathered and unweathered dolerite*** but rather use the total volume of ***unweathered to moderately***

weathered shales available on site. This comprises of 659 317 m^3 of material, before using the ***slightly weathered and unweathered dolerite.***

The material utilised within the saddle dam will firstly be obtained (in this order) from ***Quarry IV***, the ***main dam excavation***, the ***saddle dam excavation***, ***Quarry II***, ***Quarry III,*** and lastly ***Quarry I*** as this is opened up for the construction of the main wall. Material quarried that is not needed in the forming of the main dam will either be taken to the identified waste disposal site or used in the saddle dam.

However, with all this on-site sources there will not be sufficient dolerite material to construct the portion of the saddle dam with ***slightly weathered and unweathered dolerite material*** and therefore dolerite material will still need to be imported from a commercial quarry.

With all on-site sources opened up as mentioned above there will also not be sufficient clay core material and therefore the deficient of clay material will be obtained from ***Borrow Area A*** as this is opened up for the construction of the main wall.

Sand for the transition zones will be obtained from ***NPC sand*** at the Umkomaas umkomaas River mouth and transported 153 km to site.

c) General

Table 7.6 provides a summary of the balancing of materials for ***option 5***.

As indicated in this table there are ***68% more*** of the clayey sand transported surface material available from on-site sources (i.e. from the borrow areas, quarries and dam excavations) than what is ***required*** for this option. Although not twice the volume of material required, it was deemed sufficient.

However, when it comes to the ***unweathered to moderately weathered shales*** and ***slightly weathered and unweathered dolerite material,*** there are only ***1% and 0% more*** of this material respectively available from on-site sources than what is required (as a portion of this already needs to be imported from a commercial quarry). Therefore, should the estimated volumes not be found on site during construction, the additional material should be sourced and transported from commercial quarries which will significantly increase the construction cost of this option.

Table 7.6: Balancing of materials for option 5

Material use		A	B	C	D	E	F	G
		Overburden for soil: Organic topsoil	Clayey sand transported surface material	Completely & highly weathered shales	Unweathered to moderately weathered shales	Highly & moderately weathered dolerite	Slightly weathered & unweathered dolerite	Sand
		Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)
Total required (1)		**0**	**1 128 614**	**0**	**659 317**	**0**	**3 887 288**	**197 319**
Available on site (2)		120 000	1 891 924	1 048 650	667 500	2 268 694	3 443 000	0
Imported (3)		0	0	0	0	0	444 288	197 319
Total available		**120 000**	**1 891 924**	**1 048 650**	**667 500**	**2 268 694**	**3 887 288**	**197 319**
Action	**Stockpiled (4)**	0	1 128 614	0	659 317	0	3 887 288	197 319
	Spoiled (5)	14 500	0	952 074	8 183	2 268 694	0	0
	Dam forming (6)	0	1 128 614	0	659 317	0	3 887 288	197 319
	Surplus (7)	105 500	763 310	96 576	0	0	0	0
	Percentage remaining (%)	-	*68*	-	*1*	-	*0*	-
	TOTAL	**120 000**	**1 891 924**	**1 048 650**	**667 500**	**2 268 694**	**3 887 288**	**197 319**

(1) *The total volume of material* ***required*** *for the (1) main dam, (2) saddle dam, and all additional infrastructure including the (3) diversion works, (4) intake structure, (5) spillway i.e. approach, chute and plunge pool, and (6) outlet works.*

(2) *The total volume of material* ***available on site*** *from (1) the main dam excavation, (2) the saddle dam excavation, (3) Quarry I (left flank), (4) Quarry II (plunge pool), (5) Quarry III (spillway approach), (6) Quarry IV (tunnel inlet), (7) Borrow area A, (8) Borrow Area B and (9) Borrow Area C.*

(3) *The total volume of material that have to be* ***imported from a commercial source****.*

(4) *The total volume of material that need to be* ***stockpiled*** *for later use.*

(5) *The total volume of material that need to be* ***spoiled*** *in the designated waste disposal site.*

(6) *The total volume of material that need to be* ***used in the forming of the specific dam type****.*

(7) *The total volume of surplus material that is kept* ***undisturbed*** *in the respective quarries or borrow areas.*

7.5.6 Option 6: Main dam - Composite dam (RCC and zoned ECRD); Saddle dam - Zoned earthfill embankment dam

a) Main dam

Due to the poor foundation conditions on the left and right flanks a complete roller compacted concrete (RCC) gravity dam will require extremely deep excavations on the sides that would result in very high costs. Therefore, for this option, a composite dam comprising of a central spillway section of roller compacted concrete and an earthcore rockfill dam on both the left and right flanks will pose a much cheaper option. The length of the central spillway RCC section will comprise the length of the spillway section plus for each flank a concrete section comprising the height of the embankment multiplied by the respective embankment slope plus a fifty metre section that extends into the embankment.

For the material used within the central spillway section of the main dam will firstly be provided from ***Quarry IV***, where after the stockpiled material from the ***main dam and saddle dam excavations*** will be used before ***Quarry I*** is opened up. As shown in **Table 7.7** approximately 2 619 932 m^3 of ***slightly weathered and unweathered dolerite material*** will be required as aggregate to construct the main dam, diversion works and intake and outlet works. Fortunately, the full volume of this material can be sourced from all the various on-site sources. Material quarried that is not needed in the forming of the main dam will either be taken to the identified waste disposal site or used in the saddle dam.

On the other hand, material for the flanks, i.e. ***primarily slightly weathered and unweathered dolerite*** as rockfill, will firstly be obtained (in this order) from ***Quarry IV***, the ***main dam excavation***, the ***saddle dam excavation***, prior to opening ***Quarry I***. Material quarried that is not needed in the forming of the main dam will either be taken to the identified waste disposal site or used in the saddle dam.

In addition, the clay core material will be obtained from the ***main dam and saddle dam excavations*** and the deficient will be obtained from ***Borrow area A***. Sand for the transition zones will be obtained from ***NPC sand*** at the uMkhomazi River mouth and transported 153 km to site.

b) Saddle dam

For this option sufficient impervious and pervious material will be opened up by the excavations needed for the main dam, i.e. ***Quarry IV***, the ***main dam excavation***, the ***saddle dam excavation***, ***Quarry I,*** and ***Borrow Area A*** to construct a zoned earthfill embankment dam. Sand for the blanket and chimney drains will be sourced from ***NPC sand*** and transported 153 km to site. However, as most of the ***slightly weathered and unweathered dolerite*** material will be used in the main wall this material needed in the saddle wall for the rip-rap and gravel layer will need to be sourced and transported from ***Midmar Crushers*** which is 51.5 km from the Smithfield Dam site.

c) General

Table 7.7 provides a summary of the balancing of materials for ***option 6***.

As indicated in this table there are ***109% more*** of the clayey sand transported surface material, ***0.5% more*** of the completely and highly weathered shales, and ***47% more*** of the slightly weathered and unweathered dolerite, available from on-site sources (i.e. from the borrow areas, quarries and dam excavations) than what is ***required*** for this option.

Although not twice the volume of material required in the case of the ***completely and highly weathered shales*** and the ***unweathered to moderately weathered shales***, it was deemed sufficient.

However, as mentioned above there is not sufficient dolerite material to construct the complete main dam with slightly weathered and unweathered dolerite material and therefore it is shown that ***0% more*** of this material is available from on-site sources than what is required, as a portion of this already need to be imported from a commercial quarry.

In addition to this, should the estimated volume of this material of 2 600 000 m^3 not be found on site during construction, further material should be sourced and transported from ***Midmar Crushers*** which will significantly increase the construction cost of this option.

Table 7.7: Balancing of materials for option 6

Material use		A	B	C	D	E	F	G
		Overburden for soil: Organic topsoil	Clayey sand transported surface material	Completely & highly weathered shales	Unweathered to moderately weathered shales	Highly & moderately weathered dolerite	Slightly weathered & unweathered dolerite	Sand
		Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)
Total required (1)		**0**	**769 376**	**861 785**	**416 351**	**0**	**2 619 932**	**136 992**
Available on site (2)		120 000	1 607 065	865 883	613 500	542 287	2 600 000	0
Imported (3)		0	0	0	0	0	19 932	136 992
Total available		**120 000**	**1 607 065**	**865 883**	**613 500**	**542 287**	**2 619 932**	**136 992**
Action	**Stockpiled (4)**	**0**	**769 376**	**861 785**	**416 351**	**0**	**2 619 932**	**136 992**
	Spoiled (5)	20 400	0	0	197 149	491 772	0	0
	Dam forming (6)	**0**	**769 376**	**861 785**	**416 351**	**0**	**2 619 932**	**136 992**
	Surplus (7)	99 600	837 688	4 098	0	50 515	0	0
	Percentage remaining (%)	*-*	*109*	*0.5*	*47*	*-*	*0*	*-*
	TOTAL	**0**	**1 607 065**	**865 883**	**613 500**	**0**	**2 619 932**	**136 992**

(1) *The total volume of material **required** for the (1) main dam, (2) saddle dam, and all additional infrastructure including the (3) diversion works, (4) intake structure, (5) spillway i.e. approach, chute and plunge pool, and (6) outlet works.*

(2) *The total volume of material **available on site** from (1) the main dam excavation, (2) the saddle dam excavation, (3) Quarry I (left flank), (4) Quarry II (plunge pool), (5) Quarry III (spillway approach), (6) Quarry IV (tunnel inlet), (7) Borrow area A, (8) Borrow Area B and (9) Borrow Area C.*

(3) *The total volume of material that have to be **imported from a commercial source**.*

(4) *The total volume of material that need to be **stockpiled** for later use.*

(5) *The total volume of material that need to be **spoiled** in the designated waste disposal site.*

(6) *The total volume of material that need to be **used in the forming of the specific dam type**.*

(7) *The total volume of surplus material that is kept **undisturbed** in the respective quarries or borrow areas.*

7.5.7 Option 7: Main dam - Zoned concrete faced rockfill dam (option 1); Saddle dam - Zoned earthfill embankment dam

a) Main dam

In order to optimise the available material on site, a downstream toe consisting of ***highly and moderately weathered dolerite*** was used. As such approximately 1 488 042m^3 of the 2 196 533 m^3 of this material available on site can be used and therefore do not need to be spoiled. Also, this option has the additional advantage that extra ***slightly weathered and unweathered dolerite*** does not need to be imported. However, in order to use this material the downstream slope of the main dam had to be adjusted to 1:2 (V:H).

For this option the material utilised within the main dam as rockfill, i.e. primarily ***slightly weathered and unweathered dolerite*** and ***highly and moderately weathered dolerite***, will firstly be obtained (in this order) from ***Quarry IV***, the ***main dam excavation***, the ***saddle dam excavation***, ***Quarry II*** and ***Quarry III,*** prior to opening ***Quarry I***. Material quarried that is not needed in the forming of the main dam will either be taken to the identified waste disposal site or used in the saddle dam. The aggregate for the concrete slab will be obtained from ***Quarry I***.

b) Saddle dam

For this option sufficient impervious and pervious material will be available from the main dam excavations, i.e. ***Quarry IV***, the ***main dam excavation***, the ***saddle dam excavation***, ***Quarry II*** and ***Quarry III*** and ***Quarry I,*** to construct a zoned earthfill embankment dam. As such, ***Borrow Area A*** will not have to be opened up in this case.

Sand for the blanket and chimney drains will be sourced from ***NPC sand*** and transported 153 km to site.

c) General

Table 7.8 provides a summary of the balancing of materials for ***option 7***.

As indicated in this table there are ***211% more*** of the clayey sand transported surface material, ***15% more*** of the completely and highly weathered shales, and ***48% more*** of the highly and moderately weathered dolerite, available from on-site sources (i.e. from the borrow areas, quarries and dam excavations) than what is ***required*** for this option. Although not twice the volume of material required, it was deemed sufficient.

However, when it comes to the weathered and unweathered dolerite material there are only ***3% more*** of this material available from on-site sources than what is required. Therefore, should the estimated volume of 3 443 000 m^3 not be found on site during construction; additional material should be sourced and transported from ***Midmar Crushers*** (51.5 km from the Smithfield Dam site) which will significantly increase the construction cost of this option.

Table 7.8: Balancing of materials for option 7

Material use		A	B	C	D	E	F	G
		Overburden for soil: Organic topsoil	Clayey sand transported surface material	Completely & highly weathered shales	Unweathered to moderately weathered shales	Highly & moderately weathered dolerite	Slightly weathered & unweathered dolerite	Sand
		Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)
Total required (1)		**0**	**336 835**	**861 785**	**0**	**1 488 042**	**3 351 600**	**86 544**
Available on site (2)		0	1 046 932	992 975	667 500	2 196 533	3 443 000	0
Imported (3)		0	0	0	0	0	0	86 544
Total available		**0**	**1 046 932**	**992 975**	**667 500**	**2 196 533**	**3 443 000**	86 544
Action	**Stockpiled (4)**	0	336 835	861 785	0	1 488 042	3 351 600	86 544
	Spoiled (5)	0	710 097	131 190	667 500	708 492	0	0
	Dam forming (6)	0	336 835	861 785	0	1 488 042	3 351 600	86 544
	Surplus (7)	0	0	0	0	0	91 400	
	Percentage remaining (%)	*-*	***211***	***15***	*-*	***48***	***3***	*-*
	TOTAL	**0**	**1 046 932**	**992 975**	**667 500**	**2 196 533**	**3 443 000**	86 544

(1) *The total volume of material **required** for the (1) main dam, (2) saddle dam, and all additional infrastructure including the (3) diversion works, (4) intake structure, (5) spillway i.e. approach, chute and plunge pool, and (6) outlet works.*

(2) *The total volume of material **available on site** from (1) the main dam excavation, (2) the saddle dam excavation, (3) Quarry I (left flank), (4) Quarry II (plunge pool), (5) Quarry III (spillway approach), (6) Quarry IV (tunnel inlet), (7) Borrow area A, (8) Borrow Area B and (9) Borrow Area C.*

(3) *The total volume of material that have to be **imported from a commercial source**.*

(4) *The total volume of material that need to be **stockpiled** for later use.*

(5) *The total volume of material that need to be **spoiled** in the designated waste disposal site.*

(6) *The total volume of material that need to be **used in the forming of the specific dam type**.*

(7) *The total volume of surplus material that is kept **undisturbed** in the respective quarries or borrow areas.*

7.5.8 Option 8: Main dam - Zoned concrete faced rockfill dam (option 2); Saddle dam - Zoned earthfill embankment dam

a) Main dam

In order to optimise the available material on site, a downstream toe consisting of ***unweathered to moderately weathered shales*** was used. As such approximately 598 366 m^3 of the 667 500 m^3 of this material available on site can be used. However, in order to optimise the downstream slope a portion of this material will still need to be spoiled. The downstream slope of the main dam was adjusted to 1:1.8 (V:H) for this purpose.

For this option the material utilised within the main dam as rockfill, i.e. primarily ***slightly weathered and unweathered dolerite*** and ***unweathered to moderately weathered shales***, will firstly be obtained (in this order) from ***Quarry IV***, the ***main dam excavation***, the ***saddle dam excavation***, ***Quarry II*** and ***Quarry III,*** prior to opening ***Quarry I***. Material quarried that is not needed in the forming of the main dam will either be taken to the identified waste disposal site or used in the saddle dam.

However, with all this on-site sources there will still not be sufficient dolerite material to construct the remaining portion of the main dam with ***slightly weathered and unweathered dolerite material*** and therefore dolerite material will need to be imported from a commercial quarry. For this purpose 550 439 m^3 of this material will be sourced and transported from ***Midmar Crushers*** which is 51.5 km from the Smithfield Dam site. The aggregate for the concrete slab will be obtained from ***Quarry I***.

b) Saddle dam

For this option sufficient impervious and pervious material will be opened up by the excavations needed for the main dam, i.e. ***Quarry IV***, the ***main dam excavation***, the ***saddle dam excavation***, ***Quarry II*** and ***Quarry III*** and ***Quarry I,*** to construct a zoned earthfill embankment dam. As such, ***Borrow Area A*** will not have to be opened up in this case.

Sand for the blanket and chimney drains will be sourced from ***NPC sand*** and transported 153 km to site.

c) *General*

Table 7.9 provides a summary of the balancing of materials for ***option 8***.

As indicated in this table there are ***198% more*** of the clayey sand transported surface material, ***15% more*** of the completely and highly weathered shale, and ***12% more*** of the highly and moderately weathered dolerite, available from on-site sources (i.e. from the borrow areas, quarries and dam excavations) than what is ***required*** for this option. Although not twice the volume of material required, it was deemed sufficient.

However, as mentioned above there is not sufficient dolerite material to construct a portion of the main dam with slightly weathered and unweathered dolerite material and therefore it is shown that ***0% more*** of this material is available from on-site sources than what is required, as a portion of this already need to be imported from a commercial quarry.

Should the estimated volume of this material of 3 443 000 m^3 not be found on site during construction, further material should be sourced and transported from ***Midmar Crushers*** which will significantly increase the construction cost of this option.

Table 7.9: Balancing of materials for option 8

Material use		A	B	C	D	E	F	G
		Overburden for soil: Organic topsoil	Clayey sand transported surface material	Completely & highly weathered shales	Unweathered to moderately weathered shales	Highly & moderately weathered dolerite	Slightly weathered & unweathered dolerite	Sand
		Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)
Total required (1)		**0**	**336 835**	**861 785**	**598 366**	**0**	**3 443 000**	**86 544**
Available on site (2)		0	1 005 252	992 975	667 500	2 187 247	3 443 000	0
Imported (3)		0	0	0	0	0	550 439	86 544
Total available		**0**	**1 005 252**	**992 975**	**667 500**	**2 187 247**	**3 993 439**	**86 544**
Action	**Stockpiled (4)**	0	336 835	861 785	598 366	0	3 993 439	86 544
	Spoiled (5)	0	668 417	131 190	69 134	2 187 247	0	0
	Dam forming (6)	0	336 835	861 785	598 366	0	3 993 439	86 544
	Surplus (7)	0	0	0	0	0	0	0
	Percentage remaining (%)	*-*	***198***	***15***	***12***	*-*	***0***	***0***
	TOTAL	**0**	**1 005 252**	**992 975**	**667 500**	**2 187 247**	**3 993 439**	**86 544**

(1) *The total volume of material **required** for the (1) main dam, (2) saddle dam, and all additional infrastructure including the (3) diversion works, (4) intake structure, (5) spillway i.e. approach, chute and plunge pool, and (6) outlet works.*
(2) *The total volume of material **available on site** from (1) the main dam excavation, (2) the saddle dam excavation, (3) Quarry I (left flank), (4) Quarry II (plunge pool), (5) Quarry III (spillway approach), (6) Quarry IV (tunnel inlet), (7) Borrow area A, (8) Borrow Area B and (9) Borrow Area C.*
(3) *The total volume of material that have to be **imported from a commercial source**.*
(4) *The total volume of material that need to be **stockpiled** for later use.*
(5) *The total volume of material that need to be **spoiled** in the designated waste disposal site.*
(6) *The total volume of material that need to be **used in the forming of the specific dam type**.*
(7) *The total volume of surplus materials that is kept undisturbed in the respective quarries or borrow areas.*

7.5.9 Other options

Further to the options described in **Sections 7.5.1** to **7.5.8** the following additional options were investigated:

- **Option 9:** Main dam - Zoned earthfill embankment dam; Saddle dam - Zoned earthfill embankment dam.

- **Option 10:** Main dam - Composite dam (RCC with zoned ECRD on the one flank and zoned earthfill embankment dam on the other); Saddle dam - Zoned earthfill embankment dam.

However, for both of the above options there is insufficient material found on site. They would require a large quantity of material to be imported from a commercial source, which would not be financially viable. Therefore, these options were eliminated from the final cost comparison.

7.5.10 Summary of cost comparison

The estimated dam costs (excl. VAT) for each dam type explained in the preceding sections are summarised in **Table 7.10**.

Based on the ***cost comparisons of different dam types*** for Smithfield Dam the following is revealed:

- Although ranging within R300 million from each other the following dam types have comparable construction costs (in increasing order):
  - **Option 4:** Main dam - Zoned earth core rockfill dam; Saddle dam - Zoned earthfill embankment dam;
  - **Option 5:** Main dam - Zoned earth core rockfill dam; Saddle dam - Zoned earth core rockfill dam;
  - **Option 7:** Main dam - Zoned concrete faced rockfill dam (option 1); Saddle dam - Zoned earthfill embankment dam;
  - **Option 2:** Main dam - Earth core rockfill dam; Saddle dam - Zoned earthfill embankment dam.
  - **Option 8:** Main dam - Zoned concrete faced rockfill dam (option 2); Saddle dam - Zoned earthfill embankment dam;
- The cost for the ***roller compacted concrete gravity dam*** is extremely high due to the required depths of excavation and the rate of RCC.
- The most suitable dam to construct in terms of cost is a ***zoned earth core rockfill dam*** for the main dam with a ***zoned earthfill embankment dam*** for the saddle dam (option 4).

Table 7.10: Cost estimates for various dam types for Smithfield Dam

Option No.	Dam type		Cost (R million excl. VAT)
	Main Dam	Saddle Dam	
1	Roller compacted concrete (RCC) gravity	Zoned earthfill embankment dam	R 4 382
2	Earth core rockfill dam *(zoning option 1)*	Zoned earthfill embankment dam	R 2 339
3	Concrete faced rockfill dam *(zoning option 1)*	Zoned earthfill embankment dam	R 2 695
4	Zoned earth core rockfill dam *(zoning option 2)*	Zoned earthfill embankment dam	R 2 029
5	Zoned earth core rockfill dam *(zoning option 2)*	Zoned earth core rockfill dam *(zoning option 2)*	R 2 227
6	Composite dam (RCC gravity and zoned ECRD *(zoning option 2)*)	Zoned earthfill embankment dam	R 2 941
7	Zoned concrete faced rockfill dam (option 1) *(zoning option 2)*	Zoned earthfill embankment dam	R 2 231
8	Zoned concrete faced rockfill dam (option 2) *(zoning option 3)*	Zoned earthfill embankment dam	R 2 412
9	Zoned earthfill embankment dam	Zoned earthfill embankment dam	-
10	Composite dam (RCC with zoned ECRD on the one flank and zoned earthfill embankment dam on the other)	Zoned earthfill embankment dam	-

These options were identified initially but not considered further, for reasons described in **Section 7.5.9.*

7.6 Comparison of Primary Main Dam Type Options (Options 1, 4, 6 and 7)

Based on previous experience with dam type selection where RCC dams had been favoured, a detailed comparison of the BoQs of the primary dam types was conducted to determine the optimal dam type. The primary dam types compared were RCC gravity (Option 1), ECRD (Option 4), composite (Option 6) and CFRD (Option 7). The comparison BoQ is shown in **Appendix H**. It shows all the dam construction activities, and includes the quantities for the main dam and saddle dam in combination.

The costs of the diversion works, spillway and chute, and intake and outlet works have been included as line items. The detailed cost estimates for these items are shown in **Appendix G** in **Table G.17**, **Table G.18** and **Table G.19**. It was assumed that for all embankment dam type options the spillway and chute are the same, and the diversion works costs are the same. Similarly, for RCC gravity and composite dams, these costs have been assumed to be the same. For all dam types, the intake and outlet works costs are equal.

This comparison, paralleling the cost of all activities individually, allows the major costs for each dam type to be noted and compared. It shows that for Options 1 and 6, the largest cost is for the RCC material, due to its relatively high rate and quantity. For the earthfill and rockfill dams, the primary cost is either the earthfill or rockfill material, as expected. This demonstrates that an RCC gravity dam or a composite dam are not favourable due to higher costs, and were therefore not selected.

7.7 COMPARISON IN TERMS OF AVAILABILITY OF MATERIAL AND MATERIAL HANDLING

a) On site

As the doleritic materials are in most cases overlain by shale within the various quarries and within excavations available on site, significant amounts of materials need to be moved and either (1) Spoiled or (2) Stockpiled depending on the need for it for the various dam type options.

As such the study team included various options in order to try and optimise the available material on site and minimise the (1) handling of material and (2) the volumes of material that will need to be spoiled.

b) From commercial sources

In addition, due to the significant impact that importation of material from commercial quarries has on the roads in the vicinity of the dam site, the study team also included various options in order to try and optimise the available material on site and minimise the need for sourcing and transporting (1) dolerites and (2) sand from commercial quarries.

c) General

The estimated volumes of material that (1) will need to be spoiled and (2) will need to be imported from commercial sources are summarised in **Table 7.11**. Based on this table the following is revealed:

- There is not enough material available to construct an earth core rockfill dam with a complete outer shell consisting of dolerite and therefore a ***zoned earth core rockfill dam*** is better suited.
- There is not enough material available to construct a concrete faced rockfill dam using only slightly weathered or unweathered dolerite and therefore the downstream toe of the dam will need to be constructed with either the ***highly and moderately weathered dolerite*** or ***unweathered and moderately weathered shale***.
- For all the various dam types ***quarry I*** will need to be opened to obtained the required volume of material.
- Although ranging within ± 2 million m^3 from each other the following dam type options have comparable volumes of material that need to be spoiled (in increasing order of volumes):
  - **Option 1:** Main dam - Roller compacted concrete (RCC) gravity; Saddle dam - Zoned earthfill embankment dam;
  - **Option 6**: Main dam - Composite dam (RCC and zoned ECRD); Saddle dam - Zoned earthfill embankment dam;
  - **Option 7**: Main dam - Zoned concrete faced rockfill dam (option 1); Saddle dam - Zoned earthfill embankment dam;
  - **Option 4**: Main dam - Zoned earth core rockfill dam; Saddle dam - Zoned earthfill embankment dam;
- Should the estimated volumes of dolerite material from on-site sources prove to be correct there will be no need for transporting this material from commercial sources for the following dam type option:
  - **Option 1:** Main dam - Roller compacted concrete (RCC) gravity; Saddle dam - Zoned earthfill embankment dam;
  - **Option 4:** Main dam - Zoned earth core rockfill dam; Saddle dam - Zoned earthfill embankment dam;
  - **Option 7:** Main dam - Zoned concrete faced rockfill dam (option 1); Saddle dam - Zoned earthfill embankment dam;
- The following dam type options will have the least amount of sand required:
  - **Option 1:** Main dam - Roller compacted concrete (RCC) gravity; Saddle dam - Zoned earthfill embankment dam;
  - **Option 3:** Main dam - Concrete faced rockfill dam; Saddle dam - Zoned earthfill embankment dam

- **Option 7:** Main dam - Zoned concrete faced rockfill dam (option 1); Saddle dam - Zoned earthfill embankment dam;
- **Option 8:** Main dam - Zoned concrete faced rockfill dam (option 2); Saddle dam - Zoned earthfill embankment dam;

♦ The most suitable dam to construct in terms of material handling (taking into consideration all aspects as mentioned above) is one of the following:

- A ***roller compacted concrete (RCC) gravity dam*** for the main dam with a ***zoned earthfill embankment dam*** for the saddle dam (option 1);
- A ***zoned earth core rockfill dam*** for the main dam with a ***zoned earthfill embankment dam*** for the saddle dam (option 4).
- A ***zoned concrete faced rockfill dam (option 1)*** for the main dam with a ***zoned earthfill embankment dam*** for the saddle dam (option 7).

Table 7.11: Material handling for various dam types for Smithfield Dam

Option No.	Dam type		Total volume of material to be Spoiled (m^3)	Total volume of material to be commercially sourced	
	Main Dam	Saddle Dam		Dolerite (m^3)	Sand (m^3)
1	Roller compacted concrete (RCC) gravity	Zoned earthfill embankment dam	671 296	0	86 544
2	Earth core rockfill dam *(zoning option 1)*	Zoned earthfill embankment dam	3 033 796	469 823	178 279
3	Concrete faced rockfill dam *(zoning option 1)*	Zoned earthfill embankment dam	3 498 782	584 180	86 544
4	Zoned earth core rockfill dam *(zoning option 2)*	Zoned earthfill embankment dam	2 474 259	0	180 345
5	Zoned earth core rockfill dam *(zoning option 2)*	Zoned earth core rockfill dam *(zoning option 2)*	3 243 450	444 288	197 319
6	Composite dam (RCC gravity and zoned ECRD *(zoning option 2)*)	Zoned earthfill embankment dam	709 321	19 932	136 992
7	Zoned concrete faced rockfill dam (option 1) *(zoning option 2)*	Zoned earthfill embankment dam	2 217 278	0	86 544
8	Zoned concrete faced rockfill dam (option 2) *(zoning option 3)*	Zoned earthfill embankment dam	2 961 477	550 439	86 544
9	Zoned earthfill embankment dam	Zoned earthfill embankment dam	-	-	-

Option No.	Dam type		Total volume of material to be Spoiled (m^3)	Total volume of material to be commercially sourced	
	Main Dam	Saddle Dam		Dolerite (m^3)	Sand (m^3)
10	Composite dam (RCC with zoned ECRD on the one flank and zoned earthfill embankment dam on the other)	Zoned earthfill embankment dam	-	-	-

*These options were identified initially but not considered further, for reasons described in **Section 7.5.9**.*

7.8 Comparison in terms of construction period

Different dam types can be constructed at different construction rates. As such, due to the current significant water requirement deficits experienced in the proposed supply area of the uMkhomazi Water Project the rate at which the uMkhomazi Water Project can be implemented plays a significant role in the final decision on the optimal dam type. Therefore, the study team had a look at the estimated construction times of a (1) roller compacted concrete (RCC) gravity dam, (2) earth core rockfill dam (ECRD), and (3) concrete faced rockfill dam (CFRD) respectively.

Production rates assumed for the main dam components are summarised in **Table 7.12** with a basic construction programme for each shown in **Figure 7.1**.

The following have been assumed for each:

Roller compacted concrete (RCC) gravity dam

- The diversion works of an RCC dam will comprise of two stages;
- The first stage will involve the construction of a cofferdam and culverts that will immediately be followed by the construction of the intake structure, outlet works and embankment on the right flank of the dam wall up to a certain level;
- After the river flow has been diverted through the culverts, stage two of the diversion works will involve the construction of a second cofferdam to continue construction of the embankment on the left flank of the dam wall up to a certain level, and ultimately plugging the culverts once water can start flowing through the intake structure and outlet works; and
- At this stage water will start accumulating behind the dam wall and construction of the embankment will continue up to the FSL.
- Earth core rockfill dam (ECRD)
- The diversion works of an ECRD will comprise of three stages:

- The first stage will involve the ***construction of the portals and diversion tunnels*** that will immediately be followed by the construction of the intake structure and outlet works on the right flank of the dam wall as well as construction of the embankment (both core and shell) up to a certain level on both flanks;
- After the river flow has been diverted through the diversion tunnels, stage two of the diversion works will involve the ***construction of an upstream and downstream cofferdam*** to continue construction of the embankment across the river section up to a certain level;
- Construction of the spillway on the left flank of the dam wall will commence immediately after the start of construction.; and
- Once construction has been completed up to the FSL ***the diversion tunnels will be plugged*** and water will start accumulating behind the dam wall.

Concrete faced rockfill dam (CFRD)

- The diversion works of a CFRD will comprise of three stages:
- The first stage will involve the construction of the portals and diversion tunnels that will immediately be followed by the construction of the intake structure and outlet works on the right flank of the dam wall as well as construction of the embankment up to a certain level on both flanks;
- After the river flow has been diverted through the diversion tunnels, stage two of the diversion works will involve the construction of an upstream and downstream cofferdam to continue construction of the embankment across the river section up to a certain level;
- Construction of the spillway on the left flank of the dam wall will commence immediately after the start of construction; and
- Once construction has been completed up to the FSL ***the diversion tunnels will be plugged*** and water will start accumulating behind the dam wall.

Should construction commence on the 1st of January 2019 which is deemed the earliest date for implementation of the uMWP, the earliest water delivery for the different dam types will be as follows:

- Roller compacted concrete (RCC) gravity dam: June 2023 (i.e. 56 months)
- Earth core rockfill dam (ECRD): August 2022 (i.e. 45 months)
- Concrete faced rockfill dam (CFRD): ***August 2022*** (i.e. 45 months)

Hence, the following can be concluded:

- The ***placement of the roller compacted concrete***, with an anticipated duration of ***49 months***, is on the critical path of the RCC dam. This was based on average rates of placement in the world (Shaw, 2013) and assumed an average rate of placement of 30 000 m3/month. It is doubtful whether a higher rate of placement can be achieved on the proposed Smithfield Dam;

- On the other hand, the intake structure, with an anticipated duration of 43 months is on the critical path of both the ECRD and CFRD. If this can be completed earlier, the construction period for these dams could be significantly decreased; and
- The ECRD and CFRD can be constructed at a faster pace than the RCC dam, hence, from a construction period point of view, the rockfill dams are favoured.

Table 7.12: Production rates for comparison of the construction programme of the three main dam types

No	Dam component	Unit	Production Rate			Time		
			Main dam volume	Rate/day	Rate/month (1)	Days	Months (1)	Years
2	**Diversion works**							
	Roller compacted concrete (RCC) gravity dam							
2.1	Stage 1: Cofferdam 1 and culverts	m^3	31 190.00	500.00 (5)	-	62.38	2.84	0.24
2.2	Stage 2: Cofferdam 2 and plug of culverts	m^3	31 190.00	500.00 (5)	-	62.38	2.84	0.24
	Earthcore rockfill dam (ECRD) and concrete faced rockfill dam (CFRD)							
2.1	Stage 1: Portals and diversion tunnels	m	250.00 (2)	-	125.00 (3)	44.00	2.00	0.17
2.2	Stage 2: Cofferdams 1 and 2 (u/s and d/s of embankment)	m^3	62 380.00	500.00 (5)	-	124.76	5.67	0.47
2.3	Stage 3: Medium pressure pipelines and plug of tunnel	-	-	-	-	-	1.00 (7)	-
3	**Main and saddle dam excavation**							
	Roller compacted concrete (RCC) gravity dam	m^3	1 068 500.00	5 000.00	-	213.70	9.71	0.81
	Earth core rockfill dam (ECRD)	m^3	1 197 848.00	5 000.00	-	239.57	10.89	0.91
	Concrete faced rockfill dam (CFRD)	m^3	1 158 049.00	5 000.00	-	231.61	10.53	0.88
4	**Intake structure**							
4.1	Excavation and foundation preparation	m^3	7 808.00	50.00	-	156.16	7.10	0.59
4.2	Reinforcement, formwork, concrete and unformed surfaces	m^3	12 883.00	15.00	-	858.87	39.04	3.25
5	**Outlet works**							
5.1	Excavation and foundation preparation	m^3		50.00	-	-	-	-
5.2	Reinforcement, formwork, concrete and unformed surfaces	m^3		15.00	-	-	-	-
6	**Main and saddle dam forming**							
	Roller compacted concrete (RCC) gravity dam							
	RCC concrete	m^3	1 498 979.00	-	30 000.00 (4)	1 099.25	49.97	4.16
	Earth core rockfill dam (ECRD)							
6.1	Core	m^3	922 791.00	2 100.00 (6)	-	439.42	19.97	1.66
6.2	Shell - Rockfill	m^3	3 810 316.00	10 000.00 (6)	-	381.03	17.32	1.44
	Concrete faced rockfill dam (CFRD)							
	Rockfill (Impervious layer)	m^3	4 078 337.00	10 000.00 (6)	-	407.83	18.54	1.54
7	**Spillway, i.e. approach, chute and plunge pool**							
7.1	Spillway excavation (trough, chute and flip bucket)	m^3	1 687 686.00	5 000.00	-	337.54	15.34	1.28
7.2	Formwork, reinforcing and structural concrete placement	m^3	37 254.00	150.00	-	248.36	11.29	0.94

(1) *Based on a 22 day working-month.*
(2) *Five diversion tunnels with a length of 250m each are proposed.*
(3) ***Source:** Vaal Augmentation Planning Study (Consult 4, 1994).*
(4) ***Source:** Roller Compacted Concrete Dams - The State of the Art 2013, Dr Quentin Shaw, ARQ (Pty) Ltd, Pretoria, South Africa (Shaw, 2013).*
(5) ***Source:** Ncwabeni Off-channel Storage Dam Feasibility Study: Module 1: Technical Study (BKS (Pty) Ltd, 2012).*
(6) ***Source:** Lesotho Highlands Water Project; Consulting Services for Mohale Dam; Stage 1 Services; Tender Design and Preparation of Tender Documents (Mohale Consultants Group, 1998).*
(7) *Assumed.*
(8) *Volumes captured in this table are for the **main dam only**, thus an assumption was made that the saddle dam of all options will be an earthfill dam.*

ID	Nur	Task Name	Duration	Start	Finish	Predecessors
1	0	**ROLLER COMPACTED CONCRETE (RCC) GRAVITY DAM**	55.55 mons	Tue 19/01/01	Mon 23/06/05	
2	1	Start of construction	0 mons	Tue 19/01/01	Tue 19/01/01	
3	2	Diversion works	5.68 mons	Mon 19/01/07	Thu 19/06/13	
4	2.1	Stage 1: Cofferdam 1 and culverts	2.84 mons	Mon 19/01/07	Tue 19/03/26	2
5	2.2	Stage 2: Cofferdam 2 and plug of culverts	2.84 mons	Tue 19/03/26	Thu 19/06/13	4
6	3	Main and saddle dam excavation	9.71 mons	Tue 19/02/12	Mon 19/11/11	4FS-1.5 mons
7	4	Intake structure	43.14 mons	Tue 19/02/12	Fri 22/07/29	
8	4.1	Excavation & foundation preparation	7.1 mons	Tue 19/02/12	Thu 19/08/29	4FS-1.5 mons
9	4.2	Reinforcement, formwork, concrete and unformed surfaces	39.04 mons	Thu 19/06/06	Fri 22/07/29	8FS-3 mons
10	5	Outlet works	43.14 mons	Tue 19/02/12	Fri 22/07/29	
11	5.1	Excavation & foundation preparation	7.1 mons	Tue 19/02/12	Thu 19/08/29	4FS-1.5 mons
12	5.2	Reinforcement, formwork, concrete and unformed surfaces	39.04 mons	Thu 19/06/06	Fri 22/07/29	11FS-3 mons
13	6	Main and saddle dam forming	49 mons	Tue 19/07/09	Mon 23/06/05	6FS-4.5 mons
14	7	Earliest water delivery	0 mons	Mon 23/06/05	Mon 23/06/05	13,12,9,5
15						
16						
17	0	**EARTH CORE ROCKFILL DAM (ECRD)**	45.14 mons	Tue 19/01/01	Wed 22/08/17	
18	1	Start of construction	0 mons	Tue 19/01/01	Tue 19/01/01	
19	2	Diversion works	23.86 mons	Mon 19/01/07	Wed 20/11/25	
20	2.1	Stage 1: Portals and diversion tunnels	2 mons	Mon 19/01/07	Fri 19/03/01	18
21	2.2	Stage 2: Cofferdams 1 and 2 (u/s and d/s of embankment	5.67 mons	Mon 19/03/04	Thu 19/08/08	20
22	2.3	Stage 3: Medium pressure pipelines and plug of tunnel	1 mon	Wed 20/10/28	Wed 20/11/25	31,32
23	3	Main and saddle dam excavation	10.89 mons	Mon 19/01/07	Wed 19/11/06	18
24	4	Intake structure	43.14 mons	Mon 19/03/04	Wed 22/08/17	
25	4.1	Excavation & foundation preparation	7.1 mons	Mon 19/03/04	Tue 19/09/17	20
26	4.2	Reinforcement, formwork, concrete and unformed surfa	39.04 mons	Wed 19/06/26	Wed 22/08/17	25FS-3 mons
27	5	Outlet works	43.14 mons	Mon 19/03/04	Wed 22/08/17	
28	5.1	Excavation & foundation preparation	7.1 mons	Mon 19/03/04	Tue 19/09/17	20
29	5.2	Reinforcement, formwork, concrete and unformed surfa	39.04 mons	Wed 19/06/26	Wed 22/08/17	28FS-3 mons
30	6	Main and saddle dam forming	19.97 mons	Wed 19/03/27	Wed 20/10/28	
31	6.1	Core	19.97 mons	Wed 19/03/27	Wed 20/10/28	23FS-8 mons,21F
32	6.2	Shell - Rockfill	17.32 mons	Wed 19/03/27	Fri 20/08/14	23FS-8 mons,21F
33	7	Spillway i.e. approach, chute and plunge pool	19.13 mons	Mon 19/01/07	Wed 20/07/15	
34	7.1	Spillway excavation	15.34 mons	Mon 19/01/07	Tue 20/03/31	18
35	7.2	Formwork, reinforcing and structural concrete placement	11.29 mons	Tue 19/08/13	Wed 20/07/15	34FS-7.5 mons
36	8	Earliest water delivery	0 mons	Wed 22/08/17	Wed 22/08/17	22,35,29,31,26,3
37						
38						
39	0	**CONCRETE FACED ROCKFILL DAM (CFRD)**	45.14 mons	Tue 19/01/01	Wed 22/08/17	
40	1	Start of construction	0 mons	Tue 19/01/01	Tue 19/01/01	
41	2	Diversion works	25.07 mons	Mon 19/01/07	Fri 21/01/15	
42	2.1	Stage 1: Portals and diversion tunnels	2 mons	Mon 19/01/07	Fri 19/03/01	40
43	2.2	Stage 2: Cofferdams 1 and 2 (u/s and d/s of embankme	5.67 mons	Mon 19/03/04	Thu 19/08/08	42
44	2.3	Stage 3: Medium pressure pipelines and plug of tunnel	1 mon	Tue 20/12/01	Fri 21/01/15	52
45	3	Main and saddle dam excavation	10.53 mons	Mon 19/01/07	Mon 19/10/28	40
46	4	Intake structure	43.14 mons	Mon 19/03/04	Wed 22/08/17	
47	4.1	Excavation & foundation preparation	7.1 mons	Mon 19/03/04	Tue 19/09/17	42
48	4.2	Reinforcement, formwork, concrete and unformed sur	39.04 mons	Wed 19/06/26	Wed 22/08/17	47FS-3 mons
49	5	Outlet works	43.14 mons	Mon 19/03/04	Wed 22/08/17	
50	5.1	Excavation & foundation preparation	7.1 mons	Mon 19/03/04	Tue 19/09/17	42
51	5.2	Reinforcement, formwork, concrete and unformed sur	39.04 mons	Wed 19/06/26	Wed 22/08/17	50FS-3 mons
52	6	Main and saddle dam forming	18.54 mons	Mon 19/06/10	Tue 20/12/01	42,45FS-5 mons,4
53	7	Spillway i.e. approach, chute and plunge pool	19.13 mons	Mon 19/01/07	Wed 20/07/15	
54	7.1	Spillway excavation	15.34 mons	Mon 19/01/07	Tue 20/03/31	40
55	7.2	Formwork, reinforcing and structural concrete placem	11.29 mons	Tue 19/08/13	Wed 20/07/15	54FS-7.5 mons
56	8	Earliest water delivery	0 mons	Wed 22/08/17	Wed 22/08/17	48,51,55,44

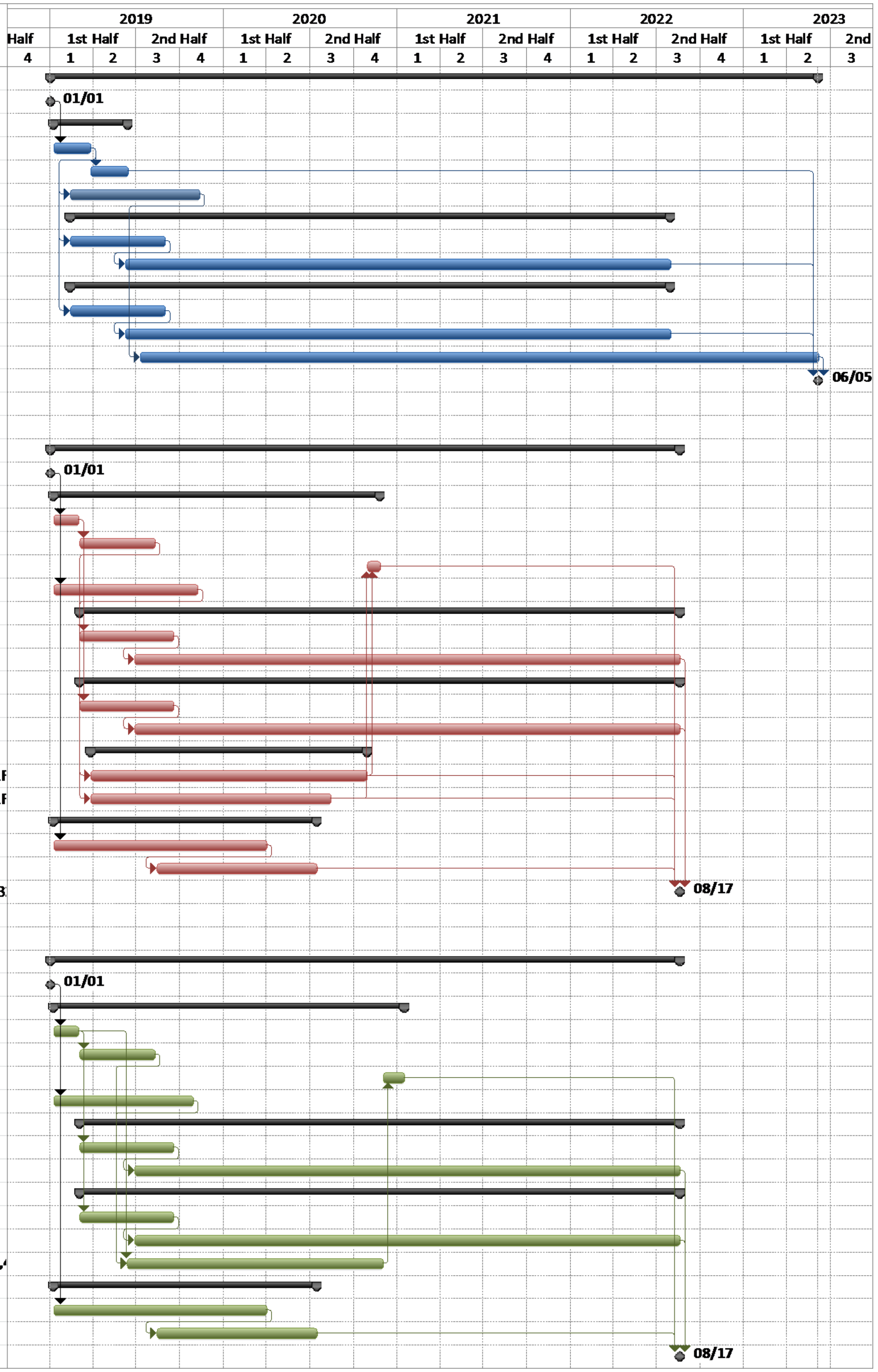


Figure 7.1: Construction programmes for different dam types

7.9 OTHER FACTORS INFLUENCING THE DAM TYPE DECISION

Further to the comparison of the ***(1) cost*** as well as ***(2) availability of material and material handling,*** and ***(3) construction period*** comparisons of different dam types for Smithfield Dam as discussed in the preceding sections of this report, a number of ***other factors*** have also been considered in the selection of the best dam type. These include the following (also summarised in **Table 7.13**):

7.9.1 Visual impact

The ***approach*** to the side channel spillway for both the earthfill and rockfill embankment dams comprise the excavation of the top of the hill on the left flank of the Main Dam. The spillway is located from this approach towards an approximately 30m deep quarry for construction material on the downstream side of the Main Dam. The quarry will be used as a ***stilling basin*** / plunge pool arrangement.

The visual impact of the removed top of the hill as well as the quarry/plunge pool was considered.

It was concluded that the change in the top of the hill will not impact seriously on the surroundings. In fact, if worked off with pleasing lines the spillway approach/ ogee weir/ spillway chute arrangement will suit the environment and the removed top of the hill with the spillway arrangement will have a positive appearance.

It is also planned to excavate the plunge pool in a pleasing benched shape as being done for many high dams. This plunge pool is hidden away and is also not in the public eye.

In comparison with a concrete dam which will have a solid grey structure inserted into the visual environment an embankment dam will have a light blue rip-rap appearance on a sloped fill. No preference regarding the one to the other is mentioned regarding visual appearance.

7.9.2 Risk involved with the diversion on embankment dams

The risk associated with failure of the embankment coffer dams, due to overtopping, is normally taken at the 1:20 year return period level. For concrete gravity dams the risk of delays and damages to shuttering due to overtopping events is significantly lower. For Smithfield Dam; six (6) large tunnels have to be provided on the right bank in-situ rock of the river and an upstream cofferdam for river diversion purposes.

In order to assess the two options on the same level regarding risk it has been decided for the embankment option to provide a low concrete gravity wall (as part of the embankment) supporting rockfill at the upstream toe of the proposed embankment to serve as a cofferwall. Only two tunnels or conduit outlets have to be considered for this option. During the first summer of construction the dam can be overtopped without any damages or delays. During winter the portion of the embankment downstream of the cofferdam can be constructed. During winter the dam will not be overtopped. By this way the two types of dams can have the same risk. This option will be considered in detail during the feasibility design phase.

The conclusion regarding dam type selections is that both options can be engineered to the same level of risk. Theses aspects do not provide a reason for the selection of the one option as a preferred option.

7.10 Comparison and Conclusion

The above-mentioned activities are summarised in **Table 7.13** for the first six lowest cost options.

Table 7.13: Summary of the lowest cost dam type options

Reference section in this report	Aspect	Order of option preference					
		1	2	3	4	5	6
7.5	Lowest construction cost (R Million excluding VAT)	**Option 4** (2.029)	**Option 5** (2.227)	**Option 7** (2.230)	**Option 2** (2.339)	**Option 8** (2.412)	**Option 3** (2.695)
7.7	Shortest construction period	All Options*					
7.6	Aggregates to be imported from Midmar & Pietermaritzburg (Less EMP & public roads related problems)	**Options 4 & 7** (0m^3)	**Option 6** (20 000m^3)	**Option 5** (444 000 m^3)	**Option 2** (470 000 m^3)	**Option 8** (550 439 m^3)	**Option 3** (584 180m^3)
7.6	Sand to be imported from Umkomaas (Less EMP & public roads related problems)	**Options 3, 7 & 8** (87 000m^3)	**Option 6** (137 000m^3)	**Options 2 & 4** (180 000 m^3)	**Option 5** (200 000 m^3)	-	-
7.6	Less volume of material to be spoiled	**Option 6** (710 000 m^3)	**Option 4** (2.5 million m^3)	**Options 2 & 8** (3.06million m^3)	**Option 5** (3.25million m^3)	**Option 3** (3.5million m^3)	-
7.8.1	Visual impact	All equal					
7.8.2	Delay/damages risk involved with river diversion	All equal					

(1) Option 1 construction period is longer than all presented in this table.

From Table 7.13 the following is clear:

- ***Option 1***, the RCC gravity dam is too expensive, it was not included in the preference order of options;
- Many embankment dam options are cheaper than ***Option 1***. The composite RCC gravity/embankment dam is R840 million more expensive than the lowest cost embankment type dam. This represents about 40% of the cost of the lowest cost embankment dam type;
- The embankment types of dams vary in cost within 13% from the lowest cost option. Any of these types can therefore be considered. However, ***Option 4, 7 and 8*** are within the same margin below 10%;
- Rockfill of embankment types can be constructed quicker than the RCC of gravity types. This may have an influence on the completion date. However, it is foreseen that the composite RCC gravity/ECRD type can be constructed in the same time as the embankment type dams; and
- ***Option 4***, the lowest cost option is the best option selected with only a small negative aspect in the amount of sand to be imported from Umkomaas. There may be an impact for the import of materials from Umkomaas. More materials will be spoiled, but this can be a positive factor as these materials may be used for other purposes e.g. rehabilitation of borrow and camp areas, or to be used for gravelling roads.

7.11 Recommendation

It is recommended that the best dam type to be considered for Smithfield Dam's feasibility design is ***Option 4*** which is

- A ***zoned earth core rockfill dam*** for the main dam and
- A ***zoned earthfill embankment dam*** for the saddle dam.

8 BASIC INFORMATION – LANGA BALANCING DAM

8.1 INTRODUCTION

Basic information required for the ***Dam Type Selection-task*** was sourced from existing reports as summarised in **Table 8.1**. For ease of reference a summary of the acquired information is described in **Sections 8.2** to **8.5**.

Table 8.1: Summary of existing reports sourced for information on Langa Balancing Dam

Required information	Report
Topographical surveys and mapping	Described in this report
Hydrology (streamflow)	P WMA 11/U10/00/3312/2/1 Hydrological assessment of the uMkhomazi River catchment report
Water requirements	P WMA 11/U10/00/3312/2/2 Water requirements and return flows report
Dam yield characteristics	P WMA 11/U10/00/3312/2/3 Water resources yield assessment report
Dam characteristics: (1) Dam position (2) Final layout	(1) & (2) P WMA 11/U10/00/3312/2/3/1/3 Supporting document 3: Optimization of scheme configuration
Layout, costs and economics	(1) P WMA 11/U10/00/3312/2/3/1/3 Supporting document 3: Optimization of scheme configuration (2) P WMA 11/U10/00/3312/2/3/1/4 Supporting document 4: Cost model
Geotechnical and materials investigations	(1) P WMA 11/U10/00/3312/3/2 Geotechnical report (2) P WMA 11/U10/00/3312/3/2/1 Supporting document 1: Probabilistic seismic hazard analysis (Smithfield Dam) (3) P WMA 11/U10/00/3312/3/2/2 Supporting document 2: Seismic refraction investigation at the proposed uMkhomazi Water Project Phase 1 (4) P WMA 11/U10/00/3312/3/2/4 Supporting document 4: Langa Balancing Dam: Materials and geotechnical investigation (5) P WMA 11/U10/00/3312/3/2/5 Supporting document 5: Conveyance system: Materials and geotechnical investigation

8.2 Topographical Surveys and Mapping

Aerial topographical surveys were conducted as part of this study and used for the proposed dam and reservoir of the Langa Balancing Dam.

8.3 Water Requirements, Dam Yield Characteristics and Costs

For a full description of the reasoning behind the selection of the final size for Langa Balancing Dam based on (1) water requirements, (2) yield calculations, and (3) costs i.e. URV calculations, see the following reports:

- *P WMA 11/U10/00/3312/2/2: Water requirements and return flows* (AECOM, AGES, MMA, & Urban-Econ, 2014)
- *P WMA 11/U10/00/3312/2/3: Water resources yield assessment report* (AECOM, AGES, MMA, & Urban-Econ, 2014)*; and*
- *P WMA 11/U10/00/3312/3/1/3: Optimization of scheme configuration* (AECOM, AGES, MMA, & Urban-Econ, 2014)

From report *P WMA 11/U10/00/3312/3/1/3: Optimization of scheme configuration* (AECOM, AGES, MMA, & Urban-Econ, 2014) it was concluded that the selected scheme will comprise of a ***Langa Balancing Dam with a storage volume of 12.5 million m^3 with a resultant FSL of 919 masl*** (final preferred layout included as **Figure A.9** in **Appendix A**). As such, the ***geotechnical investigations*** as well as the ***dam type selection*** was based on this dam position, size and layout. However, the feasibility design report describes the selected dam as having a live storage volume of 14.82×10^6 m^3 with a resultant FSL of 923 masl, which correlates with a 24-day supply at 7.10 m^3/s.

8.4 Flood Hydrology

Flood absorption analyses were undertaken for the sizing of spillways and freeboard for the different dam types. The required freeboard above the full supply levels (FSL) of the various dam types was determined in accordance with the publication, *Interim Guidelines on Freeboard for Dams* (South African National Committee on Large Dams, 1990).

Flood frequency analyses were carried out for the Langa Balancing Dam site as part of this study. These analyses are summarised in **Table 8.2**.

Table 8.2: Flood peaks for the Langa Balancing Dam site

Flood descriptions	Flood acronyms	Flood peaks (m^3/s)
100 year flood peak discharge	Q_{100}	145
200 year flood peak discharge	Q_{200}	167
Regional Maximum Flood	RMF	252
Recommended Design Flood	RDF	167
Safety Evaluation Flood	SEF	285

Spillway lengths were selected and the maximum water level in the dams for the safety evaluation flood (m^3/s) was obtained by routing various storm duration hydrographs through the reservoir. **Table 8.3** summarises the results for these analyses.

Table 8.3: Total required freeboard for different dam types – Langa Balancing Dam site

Dam Type	Spillway Type	C-Value	Spillway Length (m)	Total Required Freeboard (m)	Non-overspill Crest Level (masl)
RCC gravity dam	Ogee	2.14	20	3.6	926.6
Embankment dams (earthfill & rockfill)	Ogee	2.14	20	3.6	926.6

C relates to $Q = CLH^{3/2}$
Where:
Q = discharge (m^3/s)
C = variable discharge coefficient
L = effective length of the crest (m)
H = actual head being considered on the crest, including velocity of approach head (m)

8.5 DAM CHARACTERISTICS

Mutual parameters (dam characteristics) used for the cost comparison of various dam types for the selected Langa Balancing Dam as discussed above, are indicated in **Table 8.4**.

Table 8.4: Dam characteristics for the selected Langa Balancing Dam

Type of dam	Dependent on geotechnical investigations
DWA classification	Category III
Full supply level – FSL (masl)	919
Minimum operating level – MOL (masl)	890
Storage volume at FSL (million m³)	12.5
Surface area at FSL (km²)	0.95
Catchment area (km²)	5.4
Crest level (masl)	923 masl for gravity type dams 923 masl for embankment type dams
Maximum wall height (m)	46 masl for gravity type dams 46 masl for embankment type dams
Maximum water depth (m)	46 masl for gravity type dams 46 masl for embankment type dams
Crest length of wall (m)	970
1:100 year yield (million m³/a) (2012 in-catchment development levels)	N/A (Provide 8.65 m³/s for 21 days)
1:200 year yield (million m³/a) (2050 in-catchment development levels)	N/A (Provide 8.65 m³/s for 21 days)

8.6 GEOTECHNICAL INVESTIGATIONS

8.6.1 Materials investigations

a) *Sources for the various types of material*

Required materials for Langa Balancing Dam can be sourced on site from the following sources:

- Spoil from the conveyance tunnel excavation;
- Excavated material from the tunnel outlet portal;
- Excavated material from the spillway approach area on the upper left flank;
- Material from a borrow area/quarry located below FSL in the dam basin.

The location of these can be seen on **Figure A.6** in **Appendix A**.

Alternatively, if no sufficient material of a specific type is available on site, it can be imported from nearby commercial sources. For this purpose three commercial sources have been identified close to the Langa Balancing Dam site (see **Table 8.5**). In cases where no sufficient material existed on site, transport costs to import the needed material from commercial sources were taken into account.

Table 8.5: Commercial sources close to the Langa Balancing Dam site

Name	Material source	Distance from Langa Balancing Dam site (km)
Midmar Crushers	Aggregates	66.8
Natal Crushers	Aggregates	44.2
NPC	Natural sand	87.2

Table 8.6 and **Table 8.7** summarises the volumes of material available from the various sources (as defined and listed above) for an RCC and earthfill / rockfill respectively. Based on these a balancing exercise was conducted and construction costs estimated to determine the optimal dam type.

Table 8.6: Available material for Langa Balancing Dam – construction of an RCC dam

		Material (source)	A	B	C	D	E	F
			Overburden for soil: Organic topsoil	Clayey sand transported surface material	Completely and highly weathered shales	Unweathered to moderately weathered shales	Highly and moderately weathered dolerite	Slightly weathered and unweathered dolerite
			Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)
Roller Compacted Dam	Available material	(1) Tunnel excavation	0	0	0	0	0	250 000
		(2) Tunnel outlet portal	8 000	0	230 000	70 000	50 000	40 000
		(3) Spillway approach	15 000	0	35 000	280 000	20 000	0
		(4) Dam excavation[(1)]	71 200	0	0	150 200	150 200	175 300
		(5) Quarry/ Borrow area	20 000	0	120 000	180 000	350 000	1 200 000
		(6) Other	0	0	0	0	0	0
		TOTAL	114 200	0	385 000	680 200	570 200	1665 300

(1) *Dam excavation volumes obtained from the cost model calculations*

Table 8.7: Available material for Langa Balancing Dam – construction of a CFRD

		Material (source)	A	B	C	D	E	F
			Overburden for soil: Organic topsoil	Clayey sand transported surface material	Completely and highly weathered shales	Unweathered to moderately weathered shales	Highly and moderately weathered dolerite	Slightly weathered and unweathered dolerite
			Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)
Concrete faced rockfill dam	Available material	(1) Tunnel excavation	0	0	0	0	0	250 000
		(2) Tunnel outlet portal	8 000	0	230 000	70 000	50 000	40 000
		(3) Spillway approach	15 000	0	35 000	280 000	20 000	0
		(4) Dam excavation(1)	138 300	0	0	182 500	182 500	213 000
		(5) Quarry/ Borrow area	20 000	0	120 000	180 000	350 000	1 200 000
		(6) Other	0	0	0	0	0	0
		TOTAL	181 300	0	385 000	712 500	602 500	1 703 000

(1) *Dam excavation volumes obtained from the cost model calculations*

b) *Excavation volumes from Quarry/Borrow area*

A large volume of soft rockfill (weathered shale) will have to be removed from the quarry in order to reach the hard shale and dolerite rockfill, however, the soft material can be used in certain zones of any of the alternative embankment dam types. The quarry will provide sufficient hard rockfill for the construction of a CFR or ECR Dam.

The quarry contains approximately 1 200 000 m^3 of hard rockfill (unweathered shale and dolerite) and 350 000 m^3 of soft rockfill (moderately weathered shale), which is sufficient for a concrete faced rockfill dam.

c) *Main conclusions*

The main conclusions of the ***materials investigations for sources of dam construction materials*** can be summarised as follows:

- No impervious earthfill materials were identified therefore an earthfill dam or earthcore rockfill dam are not suitable;
- No unweathered dolerite was identified;

- Shales of various weathered nature have been identified; and
- Hard rockfill (unweathered shale and dolerite) found in the quarry is sufficient for a concrete faced rockfill dam or for the aggregate of a RCC dam.

8.6.2 Geotechnical (foundation) investigations

a) Foundations of the dam and spillway structures

Excavation depths at borehole positions were recommended based on the results of the geotechnical investigation, i.e. seismic refraction surveys as well as rotary core drilling and Lugeon water pressure testing conducted along the centre line of Langa Balancing Dam and the spillway structure.

Table 8.8 and **Table 8.9** summarise the excavation depths for the various components of the different types of dams, as well as the spillway structure, based on the information as described above. Long-sections of these are provided in **Appendix K**, with the location of the various boreholes shown in **Appendix A**.

Table 8.8: Excavation depths (m) for Langa Balancing Dam based on geotechnical investigations

Borehole No.	Elevation (masl)	RCC dam	Earthfill dam		ECR dam		CFR dam	
			Core	Shell	Core	Shell	Plinth	Shell
NM9	916.31	10.0	3.1	2.3	3.1	2.3	5.0	2.3
NM1	894.68	12.0	5.0	1.6	5.0	1.6	5.0	1.6
NM2	888.36	8.5	3.5	3.5	3.5	3.5	6.2	3.5
NM3	882.03	6.0	5.5	3.0	5.5	3.0	5.0	3.0
NM4	886.90	5.0	2.6	2.6	2.6	2.6	3.0	2.6
NM5	891.31	11.0	5.3	5.3	5.3	5.3	6.0	5.3
NM6	908.24	20.0	5.0	17.3	5.0	17.3	17.5	17.3
NM7	912.61	23.0	6.0	3.0	6.0	3.0	8.0	3.0
NM8	919.00	N/A	5.0	7.6	5.0	7.6	7.6	7.6
NM10	N/A	7.0	5.5	2.0	5.5	2.0	5.5	2.0

Table 8.9: Excavation depths (m) for Langa Balancing Dam's spillway structure (concrete chute) based on geotechnical investigations

Borehole No.	Elevation (masl)	Concrete chute
NM9	916.31	5.0
NM1	894.68	5.0
NM2	888.36	6.2
NM3	882.03	5.0
NM4	886.90	3.0
NM5	891.31	6.0
NM6	908.24	17.5
NM7	912.61	8.0
NM8	919.00	7.6
NM10	N/A	5.5

b) Main conclusions

The main conclusions of the ***geotechnical investigations for the foundations of Langa Balancing Dam and the spillway structure*** can be summarised as follows:

- Foundation conditions on the left side of the river is better than on the right side;
- The spillway is to be located on the left side;
- The foundation conditions in the central river section is good for a roller compacted concrete (RCC) gravity dam.

8.7 OTHER PARAMETERS

8.7.1 Filters and transition layers

The width of filters and transition layers that were considered in the assessments are listed in **Table 8.10**.

Table 8.10: NOC widths, curtain grout spacing and width of filters and transition layers for various dam types considered in cost comparison

Parameter		Roller compacted concrete gravity dam (RCC)	Concrete faced rockfill dam (CFRD)	Composite Dam CFRD + RCC spillway section
NOC crest width (m)		8	8	8
Curtain grouting spacing (m)		2	2	2
Filters and transition layers (Thicknesses) (m)	Rip rap	-	-	-
	Gravel protection / transition	-	2 x 2	2 x 2
	Sand filter	-	-	-
	Chimney drain	-	-	-
	Blanket drain	-	-	-

8.7.2 Slopes

Slope stability analyses were conducted with the tested parameters for the different soil types from the geotechnical investigations to determine the optimal slopes of each of the various dam types. Parameters used in this exercise are summarised in **Table 8.11**. The results from the soil stability analyses are included in **Appendix I**, with the resultant slopes for the various dam types summarised in **Table 8.12**.

Table 8.11: Parameters for the various soil types

No.	Material type	Phi – Φ (°)	Cohesion – C (kPa)	Density (kg/m^3)
F	Hard rockfill: Unweathered shale and dolerite	35	0	2100
-	Undisturbed dolerite	40	100	2 720
-	Concrete	35	500	2 300

Table 8.12: Resultant slopes for various dam types considered in cost comparison

Dam type	Upstream slope	Downstream slope
Roller compacted concrete gravity dam (RCC)	1 (V): 0.1 (H)	1 (V): 0.8 (H)
Concrete faced rockfill dam (CFRD)	1 (V): 2 (H)	1 (V): 2.2 (H)

9 LANGA BALANCING DAM – ASSESSMENT BEFORE AND DURING GEOTECHNICAL INVESTIGATIONS

9.1 INTRODUCTION AND OBJECTIVE

The objective of this exercise was to consider various possible dam layouts and types for Langa Balancing Dam to guide the geotechnical investigations. The following aspects were considered:

- Layouts of the dam, approach and chutes; and
- Construction costs of excavations.

9.2 DAM TYPES

Embankment and concrete gravity dam types were considered with the same position of the centre lines.

9.3 DAM LAYOUTS

Initial site investigation indicated that a spillway on the right flank will not be feasible due to possible deep foundation weathering. A spillway on the left flank was proposed.

The position of the centre of the dam wall was important as a marshy area exists in the stream. The marshy area increased the cost for the construction of the dam wall, as the excavation in this area would be deep and expensive.

These aspects dictated that only one position for the dam wall and the spillway was identified for the geotechnical investigation. This position and layout is shown in **Figure A.3** in **Appendix A**.

9.4 ASPECTS OF THE CONSTRUCTION COSTS

9.4.1 Costs for the excavation

Section 4.3 indicates all costs for forming the embankments. The excavation material from the spillway approach and chute was assumed to be used to form the embankments.

However, the following requirements for the geotechnical investigation were identified:

- To determine if the material in the spillway approach and chute will be acceptable in terms of quality and quantity and
- To determine the availability of suitable (quality and quantity) material inside the dam basin area for the forming of an embankment.

9.5 RECOMMENDATION

The following recommendations were thus made:

- The geotechnical investigation must determine the depth of founding material for the embankment;
- The geotechnical investigations must determine the quality and quantity of material at the position of the approach channel and chute.
- The geotechnical investigation must identify material suitable for the construction of the dam wall inside the dam basin.

9.6 DURING GEOTECHNICAL INVESTIGATIONS

9.6.1 Drilling programme

The programme provided for investigations on the centre line, on the left flank and inside the basin at possible identified borrow/quarry areas. If the materials at Option 2 were not adequate Option 1 will then be investigated.

10 LANGA BALANCING DAM – ASSESSMENT AFTER GEOTECHNICAL INVESTIGATIONS

10.1 INTRODUCTION AND OBJECTIVE

With information available on the ***construction materials available on site*** as well as the ***foundation conditions along the centre line of Langa Balancing Dam,*** the objective of this exercise was to compare costs for various dam types to (1) select the optimal dam type, and ultimately to (2) select the best scheme. In order to do this a balancing exercise was conducted to ensure optimal use of available materials on site that will also influence the cost estimate. This balancing exercise took into account the following:

- The total volume of material of each specific type ***required*** for the (1) dam, and all additional infrastructure including the (2) diversion works, (3) intake structure, (4) spillway i.e. approach, chute and plunge pool, and (5) outlet works;
- The total volume of material of each specific type ***available*** on site from (1) the tunnel excavation, (2) the tunnel outlet portal, (3) the spillway approach, (4) the dam excavation, and (5) the quarry/borrow area;
- The total volume of material of each specific type that have to be ***imported from a commercial source***;
- The total volume of material of each specific type that need to be ***stockpiled*** for later use;
- The total volume of material of each specific type that need to be ***spoiled*** in the designated waste disposal site;
- The total volume of material of each specific type that need to be ***used in the forming of the specific dam type***; and
- The total volume of material of each specific type that is kept ***undisturbed*** in the respective quarries or borrow areas.

During the construction materials investigation a ‘’safety factor’’ is built in whereby twice the volume of material required for construction should be proved during the site investigation. However, a decision was made that, for the purpose of the balancing exercise, the ***required material*** was balanced against the ***available material*** on a one-to-one basis. An indication of the volume of material of each specific type that remains within the respective quarries or borrow areas (i.e. that is kept is kept undisturbed/untouched) is given in **Table 10.2** to **Table 10.4**.

10.2 Dam Types

Based on the information received from the geotechnical and materials investigations, dam types that were considered for Langa Balancing Dam are summarised in **Table 10.1**. Typical cross-sections for each of the dam types listed above are included in **Appendix J**.

Table 10.1: Dam type options investigated for Langa Balancing Dam

Option No.	Section	Dam type
1	10.5.1	Concrete faced rockfill dam (CFRD)
2	10.5.2	Roller compacted concrete (RCC) gravity dam
3	10.5.3	Composite dam (Central RCC section with CFRD left and right flank)

10.3 Dam Size and Layout

The dam size and layout was based on a ***Langa Balancing Dam with a storage volume of 12.5 million m^3 with a resultant FSL of 919 masl*** as summarised in **Section 8**.

10.4 Priority Sequences

As mentioned in **Section 8** materials for the construction of Langa Balancing Dam can be sourced on site from (1) the tunnel excavation, (2) the tunnel outlet portal, (3) the spillway approach, (4) the dam excavation, and (5) the quarry/borrow area. Alternatively, if sufficient material of a specific type is not available on site, it can be (6) imported from nearby sources.

For the purpose of selecting the optimal dam type, different priority sequences for the sourcing of materials were adopted for the various dam types. These are discussed in **Section 10.4.1** to **10.4.2**.

10.4.1 Concrete faced rockfill dam (CFRD)

For the ***concrete faced rockfill dam*** material was sourced in the following priority sequence:

(1) The identified quarry;

(2) Material excavated for the dam foundation; and

(3) Material obtained from the tunnel and portal excavation.

If sufficient material of a specific type was not available on site, appropriate material was imported from nearby commercial sources as a last resource.

10.4.2 Roller compacted concrete (RCC) gravity dam

For the ***roller compacted concrete (RCC) gravity dam*** material was sourced in the following priority sequence:

(1) The identified quarry;

(2) Material excavated for the dam foundation; and

(3) Material obtained from the tunnel and portal excavation.

If sufficient material of a specific type was not available on site, appropriate material was imported from nearby commercial sources as a last resource.

10.5 COMPARISON IN TERMS OF CONSTRUCTION COST

Material quantities for all infrastructure components and for each dam option based on centre line natural ground levels (NGL) were calculated using the cost model described in **Section 4**. Following in **Sections 10.5.1** to **10.5.3** are a description of each of the dam types investigated, with a summary of the cost comparison included in **Section 10.5.4**. All options investigated are summarised in **Table 10.1** and the results of the balancing exercise are included in **Appendix L** and **Appendix M**.

10.5.1 Option 1: Concrete Faced Rockfill Dam (CFRD)

The concrete faced rockfill dam will consist of material obtained from the quarry situated within the dam basin. A gravel protection layer is placed on the downstream slope in order to provide a durable protective layer above the shale and dolerite shale mixture.

Table 10.2 provides a summary of the balancing exercise for ***Option 1***.

Table 10.2: Balancing of materials for Option 1

Material use		A	B	C	D	E	F	G
		Overburden for soil: Organic topsoil	Impervious core	Semi-pervious fill: Residual silty clayey sand and sandy silty clay	Semi pervious fill: Highly weathered shale	Soft rockfill: Moderately weathered shale	Hard rockfill: Unweathered shale and dolerite	Imported dolerite
		Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)
Total required (1)		**0**	**0**	**0**	**0**	**350 000**	**785 046**	**0**
Available on site (2)		181 261	0	385 000	712 516	602 516	1 702 936	0
Imported (3)		0	0	0	0	0	0	186 010
Total available		181 261	0	385 000	712 516	602 516	1 702 936	186 010
Action	**Stockpiled** (4)	0	0	0	0	0	0	0
	Spoiled (5)	165 963	0	293 211	574 833	252 516	0	0
	Dam forming (6)	0	0	0	0	350 000	785 046	186 010
	Surplus (7)	15 302	0	91 811	137 717	0	917 890	0
	Percentage remaining (%)	***8***	***0***	***24***	***19***	***0***	***54***	***0***
	TOTAL	**181 261**	**0**	**385 000**	**712 516**	**602 516**	**1 702 936**	**186 10**

(1) *The total volume of material of each specific type* ***required*** *for the (1) dam, and all additional infrastructure including the (2) diversion works, (3) intake structure, (4) spillway i.e. approach, chute and plunge pool, and (5) outlet works;*

(2) *The total volume of material of each specific type* ***available*** *on site from (1) the tunnel excavation, (2) the tunnel outlet portal, (3) the spillway approach, (4) the dam excavation, and (5) the quarry/borrow area;*

(3) *The total volume of material that have to be* ***imported from a commercial source****.*

(4) *The total volume of material that need to be* ***stockpiled*** *for later use.*

(5) *The total volume of material that need to be* ***spoiled*** *in the designated waste disposal site.*

(6) *The total volume of material that need to be* ***used in the forming of the specific dam type****.*

(7) *The total volume of surplus materials that is kept undisturbed in the respective quarries or borrow areas.*

10.5.2 Option 2: Roller Compacted Concrete Dam (RCC)

The entire dam will be constructed with roller compacted concrete with a central spillway section. The aggregates to be used within the concrete will be obtained from the quarry identified in the dam basin.

Table 10.3 provides a summary of the balancing exercise for ***option 2***.

Table 10.3: Balancing of materials for option 2

Material use		A	B	C	D	E	F	G
		Overburden for soil: Organic topsoil	Impervious core	Semi-pervious fill: Residual silty clayey sand and sandy silty clay	Semi pervious fill: Highly weathered shale	Soft rockfill: Moderately weathered shale	Hard rockfill: Unweathered shale and dolerite	Imported dolerite
		Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)
Total required (1)		**0**	**0**	**0**	**0**	**0**	**621 764**	**0**
Available on site (2)		114 155	0	385 000	680 203	570 203	1 665 236	0
Imported (3)		0	0	0	0	0	0	0
Total available		114 155	0	385 000	680 203	570 203	1 665 236	0
Action	**Stockpiled (4)**	0	0	0	0	0	0	0
	Spoiled (5)	96 764	0	280 653	523 682	265 857	465 236	0
	Dam forming (6)	0	0	0	0	0	621 764	0
	Surplus (7)	17 391	0	104 347	156 521	304 346	578 236	0
	Percentage remaining (%)	***15***	***0***	***27***	***23***	***53***	***35***	***0***
	TOTAL	**114 155**	**0**	**385 000**	**680 203**	**570 203**	**1 665 236**	**0**

(1) *The total volume of material of each specific type **required** for the (1) dam, and all additional infrastructure including the (2) diversion works, (3) intake structure, (4) spillway i.e. approach, chute and plunge pool, and (5) outlet works;*
(2) *The total volume of material of each specific type **available** on site from (1) the tunnel excavation, (2) the tunnel outlet portal, (3) the spillway approach, (4) the dam excavation, and (5) the quarry/borrow area;*
(3) *The total volume of material that have to be **imported from a commercial source**.*
(4) *The total volume of material that need to be **stockpiled** for later use.*
(5) *The total volume of material that need to be **spoiled** in the designated waste disposal site.*
(6) *The total volume of material that need to be **used in the forming of the specific dam type**.*
(7) *The total volume of surplus materials that is kept undisturbed in the respective quarries or borrow areas.*

10.5.3 Option 3: Composite Dam – Central RCC section with CFRD left and right flank

A composite dam comprising of a central spillway section constructed from roller compacted concrete with concrete faced rockfill left and right flank. The materials obtained from the quarry will be used for aggregates for the RCC and fill material for the shell of the concrete faced rockfill sections of the dam. The shell of the dam will be comprised of unweathered shale and dolerite with a durable protective layer on the downstream slope of the concrete faced rockfill sections of the dam.

Table 10.4 provides a summary of the balancing exercise for ***option 3***.

Table 10.4: Balancing of materials for option 3

Material use		A	B	C	D	E	F	G
		Overburden for soil: Organic topsoil	Impervious core	Semi-pervious fill: Residual silty clayey sand and sandy silty clay	Semi pervious fill: Highly weathered shale	Soft rockfill: Moderately weathered shale	Hard rockfill: Unweathered shale and dolerite	Imported dolerite
		Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)
Total required (1)		**0**	**0**	**0**	**0**	**350 000**	**688 021**	**0**
Available on site (2)		141 315	0	385 000	675 455	565 455	1 659 698	0
Imported (3)		0	0	0	0	0	0	0
Total available		141 315	0	385 000	675 455	565 455	1 659 698	0
Action	Stockpiled (4)	0	0	0	0	0	0	0
	Spoiled (5)	125 121	0	287 832	529 704	215 455	459 698	0
	Dam forming (6)	0	0	0	0	350 000	688 021	0
	Surplus (7)	16 195	0	97 168	145 752	0	511 979	0
	Percentage remaining (%)	***11***	***0***	***25***	***22***	***0***	***31***	***0***
	TOTAL	141 315	0	385 000	675 455	565 455	1 659 698	0

(1) *The total volume of material of each specific type **required** for the (1) dam, and all additional infrastructure including the (2) diversion works, (3) intake structure, (4) spillway i.e. approach, chute and plunge pool, and (5) outlet works;*

(2) *The total volume of material of each specific type **available** on site from (1) the tunnel excavation, (2) the tunnel outlet portal, (3) the spillway approach, (4) the dam excavation, and (5) the quarry/borrow area;*

(3) *The total volume of material that have to be **imported from a commercial source**.*

(4) *The total volume of material that need to be **stockpiled** for later use.*

(5) *The total volume of material that need to be **spoiled** in the designated waste disposal site.*

(6) *The total volume of material that need to be **used in the forming of the specific dam type**.*

(7) *The total volume of surplus materials that is kept undisturbed in the respective quarries or borrow areas.*

10.5.4 Summary of cost comparison

The estimated dam costs (excl. VAT) for each dam type explained in the preceding sections are summarised in Table 10.5.

Table 10.5: Cost estimates for various dam types for the Langa Balancing Dam

Option No.	Dam type	Cost (excl. VAT)
1	Concrete faced rockfill dam (CFRD)	R 549 087 699
2	Roller compacted concrete dam (RCC)	R 1 591 187 651
3	Composite comprising of a RCC central spillway section and CFRD left and right flank	R 1 125 550 530

Based on the ***cost comparisons of different dam types*** for Langa Balancing Dam the following is revealed:

- A concrete faced rockfill dam (Option 1) provides the lowest cost and maximises the use of the available materials on site;
- A roller compacted concrete dam is considerably more expensive in comparison to the other dam options;

10.6 Comparison in terms of availability of material and material handling

10.6.1 On site

As the doleritic material are in most cases overlain by shales within the various quarries and excavations available on site, significant amounts of materials need to be moved and either (1) spoiled or (2) stockpiled depending on the need for it for the various dam type options.

As such the study team included various options in order to try and optimise the available material on site and minimise the (1) handling of material and (2) the volumes of material that will need to be spoiled.

10.6.2 From commercial sources

In addition, due to the significant impact that importation of material from commercial quarries have on the roads and residents within the vicinity of the dam site, the study team also included various options in order to try and optimise the available material on site and minimise the need for sourcing and transporting (1) dolerites and (2) sand from commercial quarries. The use of a concrete faced rockfill dam will render the need for importing material unnecessary as there is sufficient material available on site within the quarry located within the dam basin.

10.6.3 General

The estimated volumes of material that (1) will need to be spoiled and (2) will need to be imported from commercial sources are summarised in **Table 10.6**. Based on this table the following is revealed:

Table 10.6: Material handling for various dam types for the Langa Balancing Dam

Option No.	Dam type	Total volume of material to be spoiled (m^3)	Total volume of material to be commercially sourced	
			Dolerite (m^3)	Sand (m^3)
1	Concrete faced rockfill dam (CFRD)	1 286 523	0	0
2	Roller compacted concrete dam (RCC)	1 632 192	0	0
3	Composite comprising of a RCC central spillway section and CFRD left and right flank	1 617 810	0	0

10.7 OTHER FACTORS INFLUENCING THE DAM TYPE SELECTION

Further to the comparison of the ***(1) cost*** as well as ***(2) availability of material and material handling*** comparisons of different dam types for Langa Balancing Dam as discussed in the preceding sections of this report, a number of ***other factors*** should also be considered in the selection of the optimal dam type. This includes the following:

10.7.1 Construction period

As described in this report, different dam types can be constructed at different construction rates. As such, due to the current significant water requirement deficits experienced in the proposed supply area of the uMkhomazi Water Project the rate at which the uMkhomazi Water Project can be implemented plays a significant role in the final decision on the optimal dam type.

Therefore, the study team had a look at the estimated construction times of a (1) roller compacted concrete (RCC) gravity dam, (2) earth core rockfill dam (ECRD), and (3) concrete faced rockfill dam (CFR dam) respectively.

According to this assessment the CFR dam can be constructed at a faster pace than the RCC dam, hence, from a construction period point of view, the CFR dam are favoured.

10.8 COMPARISON AND CONCLUSION

The above-mentioned activities are summarised in **Table 10.7** for the three cost options.

Table 10.7: Summary of the three five preferred dam type options (with regard to various aspects for Langa Balancing Dam)

Reference section in this report	Aspect	Order of option preference		
		1	2	3
10.5.4	Lowest construction cost (R Million excluding VAT)	Option 1	Option 3	Option 2
10.7.1	Shortest construction period	Option 1	Option 3	Option 2
10.6	Less volume of material to be spoiled	Option 1 (1 287)	Option 3 (1 618)	Option 2 (1 632)
10.7.2	Visual impact	All equal		
10.7.3	Delay/damages risk involved with river diversion	All equal		

From **Table 10.7** the following is clear:

- Option 1, the concrete faced rockfill dam, is the best suited for the Langa Balancing Dam site position as it provides the lowest cost of the investigated options and the least amount of material that will need to be spoiled; and
- A roller compacted concrete dam is significantly more expensive in comparison to other dam options.

10.9 RECOMMENDATION

It is recommended that the best dam type to be considered for Langa Balancing Dam's feasibility design is a ***Concrete Faced Rockfill Dam (CFRD)***.

11 SENSITIVITY ANALYSIS

11.1 INTRODUCTION

Following a meeting with DWA: Infrastructure Development on 29 May 2014, a request was made that the Study Team should undertake a sensitivity analysis to finalise the dam type selection for the proposed Smithfield and Langa dams and assess the risk on a few critical parameters. Subsequent to this request, a Variation Order on the original uMkhomazi Water Project was granted to undertake this task, amongst others.

The critical parameters that were addressed as part of this sensitivity analysis are as follows:

- Deeper foundation depth and increase in volumes of excavation;
- Haulage distance if quarry site does not deliver adequate construction materials; and
- Possible impacts of climate change on the magnitude of the floods.

This section describes the assumptions and calculations for assessing the sensitivity of each parameter described above and the results obtained from each assessment, as well as the overall recommendation from the sensitivity analysis.

11.2 BASE OPTIONS CONSIDERED

The four primary main dam type options were considered in this analysis, namely RCC gravity dam, zoned ECRD, composite dam (RCC gravity and zoned ECRD) and zoned CFRD. The options with the lowest cost identified previously in this report for each of the above dam types were used in this analysis, namely option 1, 4, 6 and 7.

11.3 SENSITIVITY RESULTS

11.3.1 Increased foundation depth and excavations

a) Smithfield Dam

This item dealt with the potential for variation in the depth of the foundations from what was assumed. This would necessitate increased excavations below concrete structures, and for the cores of embankment dams to be founded on lower levels. For the purpose of this sensitivity analysis, the effect of having the founding level 2 m lower than originally assumed was investigated.

The effect of the increased foundation depths on the saddle dam was not taken into account in this analysis, because the saddle dam was common to all main dam types under investigation.

The cost model was used to estimate the influence that a lower foundation depth would have on the four dam types. This was done by increasing the "depth to founding level" (RCC) or the "depth to trench founding level" (ECRD and CFRD) in the main dam long section input table. The increase in excavation volume and volume of materials required for dam forming were then assessed, and percentage-based increases were noted. These are summarised in **Table 11.1**.

Table 11.1: Effect of increased foundation depth on cost of dam type options, per item (Smithfield Dam)

Main dam type	Increase in costs (%)				
	Excavation	Dam forming materials			
		Concrete	Clay core	Transition	Rockfill
RCC gravity	19%	7%	-	-	-
Zoned ECRD	2%	-	3%	-	-
Zoned CFRD	9%	4%	-	5%	1%
Composite (RCC + ECRD)	7%	6%	2%	-	0%

As can be seen, increased foundation depths have the biggest impact on the RCC gravity dam type. These percentage increases were applied to the costs originally determined in this dam type selection process (**Appendix G**). **Table 11.2** shows the actual cost increases incurred for each of the dam type options.

Table 11.2: Effect of increased foundation depth on cost of dam type options, in total (Smithfield Dam) (R, excl. VAT)

Dam type option	Main dam type	Original cost	Increase in costs			Revised cost
		Total	Excavation	Dam forming materials	Total	Total
1	RCC gravity	2 248 298 426	15 549 198	123 558 704	139 107 902	2 387 406 327
4	Zoned ECRD	1 073 000 404	4 019 604	1 827 843	5 847 447	1 078 847 851
6	Composite (RCC + ECRD)	1 433 356 494	8 262 943	43 959 035	52 221 978	1 485 578 473
7	Zoned CFRD	1 179 663 693	22 204 161	9 199 108	31 403 270	1 211 066 963

This table shows that the order of preference of the dam types does not change with the revised costs for increased foundation depth. This is valid for deeper foundation levels below the outer sides of the embankment dams. Therefore, it can be concluded that the risk of a variation in dam type based on this parameter is negligible for Smithfield Dam.

b) Langa Dam

The same assessment was undertaken on the dam type selection for Langa Dam, in the same fashion as described for Smithfield Dam.

The percentage-based increase in excavation volume and volume of materials required for dam forming are summarised in **Table 11.3**.

Table 11.3: Effect of increased foundation depth on cost of dam type options, per item (Langa Dam)

Main dam type	Increase in costs (%)				
	Excavation	Dam forming materials			
		Concrete	Clay core	Transition	Rockfill
Zoned CFRD	19%	8%	-	9%	4%
RCC gravity	24%	11%	-	-	-
Composite (RCC + CFRD)	25%	9%	-	14%	8%

Increased foundation depths have a similar impact on all of the dam types investigated for Langa Dam, but with the biggest impact on the RCC gravity dam and composite dam types. These percentage increases were applied to the costs originally determined in this dam type selection process (**Appendix M**). **Table 11.4** shows the actual cost increases incurred for each of the dam type options.

Table 11.4: Effect of increased foundation depth on cost of dam type options, in total (Langa Dam) (R, excl. VAT)

Dam type option	Main dam type	Original cost	Increase in costs			Revised cost
		Total	Excavation	Dam forming materials	Total	Total
1	Zoned CFRD	199 688 230	19 703 037	5 400 522	25 103 559	224 791 789
2	RCC gravity	742 473 438	22 346 668	71 429 855	93 776 523	836 249 962
3	Composite (RCC + CFRD)	510 705 559	26 921 899	36 118 055	63 039 954	573 745 512

This table shows that, as found with the investigation into Smithfield Dam, the order of preference of the dam types does not change with the revised costs for increased foundation depth. Therefore, it can be concluded that the risk of a variation in dam type based on this parameter is negligible for Langa Dam as well.

11.3.2 Haulage distance, relating to material availability

This item related to the possibility that the quarries and borrow areas identified to supply the rockfill and earthfill material would not be adequate for forming the embankments and for use as concrete aggregate, and therefore excess haulage and cost for acquiring materials may be experienced to source other materials.

a) Smithfield Dam

Several zoning options were identified for the different embankment dam types during the dam type selection process for Smithfield Dam.

- For the ECRD, the rockfill shell for the primary zoning option comprises dolerite (slightly weathered and unweathered) only. The alternative ECRD zoning option comprises dolerite (as above) and shale (unweathered to moderately weathered).
- For the CFRD, the rockfill for the primary zoning option comprises dolerite (slightly weathered and unweathered). The first alternative zoning option comprises dolerite (as above) and shales (unweathered to moderately weathered). The second alternative zoning option comprises two types of dolerite, namely slightly weathered and unweathered.

Section 7.5 of this report compares the construction cost of all of the investigated dam types, and shows that the ECRD options are most and second most preferable of the options, with a CFRD option being third most preferable. In addition, all of the rockfill main dam types and zoning options are preferable to the composite and RCC gravity dam types. **Table 11.5** summarises the estimated dam costs (excl. VAT) for each dam type explained in **Section 7.5**.

Table 11.5: Cost estimates for various dam types for Smithfield Dam

Option No.	Dam type		Cost (R million excl. VAT)
	Main Dam	Saddle Dam	
1	Roller compacted concrete (RCC) gravity	Zoned earthfill embankment dam	R 4 382
2	Earth core rockfill dam *(zoning option 1)*	Zoned earthfill embankment dam	R 2 339
3	Concrete faced rockfill dam *(zoning option 1)*	Zoned earthfill embankment dam	R 2 695
4	Zoned earth core rockfill dam *(zoning option 2)*	Zoned earthfill embankment dam	R 2 029
5	Zoned earth core rockfill dam *(zoning option 2)*	Zoned earth core rockfill dam *(zoning option 2)*	R 2 227
6	Composite dam (RCC gravity and zoned ECRD *(zoning option 2)*)	Zoned earthfill embankment dam	R 2 941
7	Zoned concrete faced rockfill dam (option 1) *(zoning option 2)*	Zoned earthfill embankment dam	R 2 231
8	Zoned concrete faced rockfill dam (option 2) *(zoning option 3)*	Zoned earthfill embankment dam	R 2 412
9	Zoned earthfill embankment dam	Zoned earthfill embankment dam	-
10	Composite dam (RCC with zoned ECRD on the one flank and zoned earthfill embankment dam on the other)	Zoned earthfill embankment dam	-

This shows that, should the situation arise where the intended material is not available for Option 4 (ECRD zoning option 2), the dam type for Smithfield Dam would most likely not change due to an alternative zoning option still being preferable to other dam type options.

In addition to this high-level assessment, an assessment was undertaken to estimate what cost impact there would be to import materials where availability from quarries and borrow areas is limited. It was assumed that 50% of the required rockfill, impermeable core, earthfill and concrete aggregate materials would need to be imported. The impact on the ranking of the dam type options is shown in **Table 11.6**.

Table 11.6: Impact of importing material on the ranking of dam type options for Smithfield Dam

Rank	Dam type option	
	Original	Revised
1	Option 4 (Zoned ECRD)	Option 4 (Zoned ECRD)
2	Option 5 (Zoned ECRD)	Option 5 (Zoned ECRD)
3	Option 7 (Zoned CFRD)	Option 3 (CFRD)
4	Option 2 (ECRD)	Option 7 (Zoned CFRD)
5	Option 3 (CFRD)	Option 2 (ECRD)
6	Option 8 (Zoned CFRD)	Option 8 (Zoned CFRD)
7	Option 6 Composite (RCC + ECRD)	Option 6 Composite (RCC + ECRD)
8	Option 1 (RCC)	Option 1 (RCC)

The results in the above table indicate a variation in preference of dam type only in the mid-range, with the most preferable and least preferable dam type options remaining the same. This further corroborates the finding that inadequate rockfill and earthfill material will most likely not have an impact on the selection of a dam type for Smithfield Dam.

b) Langa Dam

Different zoning options for the embankment dam type (CFRD) were not identified for Langa Dam. However, the principle described above for Smithfield Dam would apply. It was assumed that 50% of the required rockfill and concrete aggregate materials would need to be imported from the identified commercial sources.

The same assessment of the effect of importing material described for Smithfield Dam was carried out for Langa Dam. **Table 11.7** summarises the results.

Table 11.7: Impact of importing material on the ranking of dam type options for Langa Dam

Rank	Dam type option	
	Original	Revised
1	Option 1 (CRFD)	Option 1 (CRFD)
2	Option 3 Composite (RCC + CFRD)	Option 3 Composite (RCC + CFRD)
3	Option 2 (RCC)	Option 2 (RCC)

The results in the above table indicate no variation in preference of dam types. This further corroborates the finding that inadequate rockfill and earthfill material will most likely not have an impact on the selection of a dam type for Langa Dam.

11.3.3 Impact of climate change on Smithfield Dam

A detailed climate change impact assessment was undertaken on Smithfield Dam as part of the Variation Order mentioned in **Section 11.1**. Its purpose was to assess the impact on the flood design capacity and the dam's ability to accommodate future flood peaks, and the impact on the yield of the dam. This assessment is documented in detail in the report titled *Climate Change Impact Assessment (Engineering Feasibility Design Report: Write-up 6 (P WMA 11/U10/00/3312/3/1/11))*.

According to the above-mentioned report, a range of flood hydrographs with various peaks were routed through the spillway arrangement for Smithfield Dam for the purpose of testing the flood design capacity of Smithfield Dam to accommodate future climatic conditions. These flood peaks ranged from the historically-based SEF in increasing 5% increments up to a maximum flood of the SEF plus 30%.

This routing analysis showed that a 30% higher flood can be safely passed through the spillway without overtopping the embankment.

The proposed NOC level of 936 masl, including a parapet wall, will accommodate the settlement of the wall, the Probable Maximum Flood and the effect of climate change up to a 30% flood increase. Therefore, it was concluded that the impact of climate change on Smithfield Dam would not change the preference of the dam type selected.

11.4 CONCLUSIONS AND RECOMMENDATIONS

The purpose of this sensitivity analysis was to assess the impact of certain critical parameters on the dam type selection of Smithfield and Langa Dams. These critical parameters were foundation depth, increase in volumes of excavation, haulage distance and possible impacts of climate change.

The findings for each parameter were as follows:

- **Foundation depth and increase in volumes of excavation:** The cost impact of increasing the dam foundation depths is most significant for dam types that were identified as the least preferable, namely RCC gravity for Smithfield Dam and RCC gravity and composite (RCC & CFRD) for Langa Dam. This therefore means that the selected dam types only become more preferable by changing this parameter.

- **Haulage distance, relating to material availability:** A limit in the availability of material from quarries and borrow areas will most likely not affect the preference of dam type for Smithfield Dam or Langa Dam. This is because several zoning options have been identified, so a shortage in one type of rockfill material will be able to be supplemented by another type. In addition, importing part of the material requirement will most likely not affect the dam type preferences.
- **Possible impacts of climate change:** Climate change will not impact the dam type preference for Smithfield Dam, as estimated provisions that were originally made in terms of the non-overspill crest remain sufficient.

Based on these findings, it is recommended that the dam types that were concluded as preferable in the preceding portion of this report remain as the selected dam types. This is summarised in **Section 12**.

12 CONCLUSIONS AND RECOMMENDATIONS

12.1 SMITHFIELD DAM

The best dam type to be considered for Smithfield Dam's feasibility design is ***Option 4*** which is (1) a ***zoned earthcore rockfill dam*** for the main dam and (2) a ***zoned earthfill embankment dam*** for the saddle dam.

12.2 LANGA BALANCING DAM

The best dam type to be considered for Langa Balancing Dam's feasibility design ***Option 1*** which is a ***Concrete Faced Rockfill Dam (CFRD)***.

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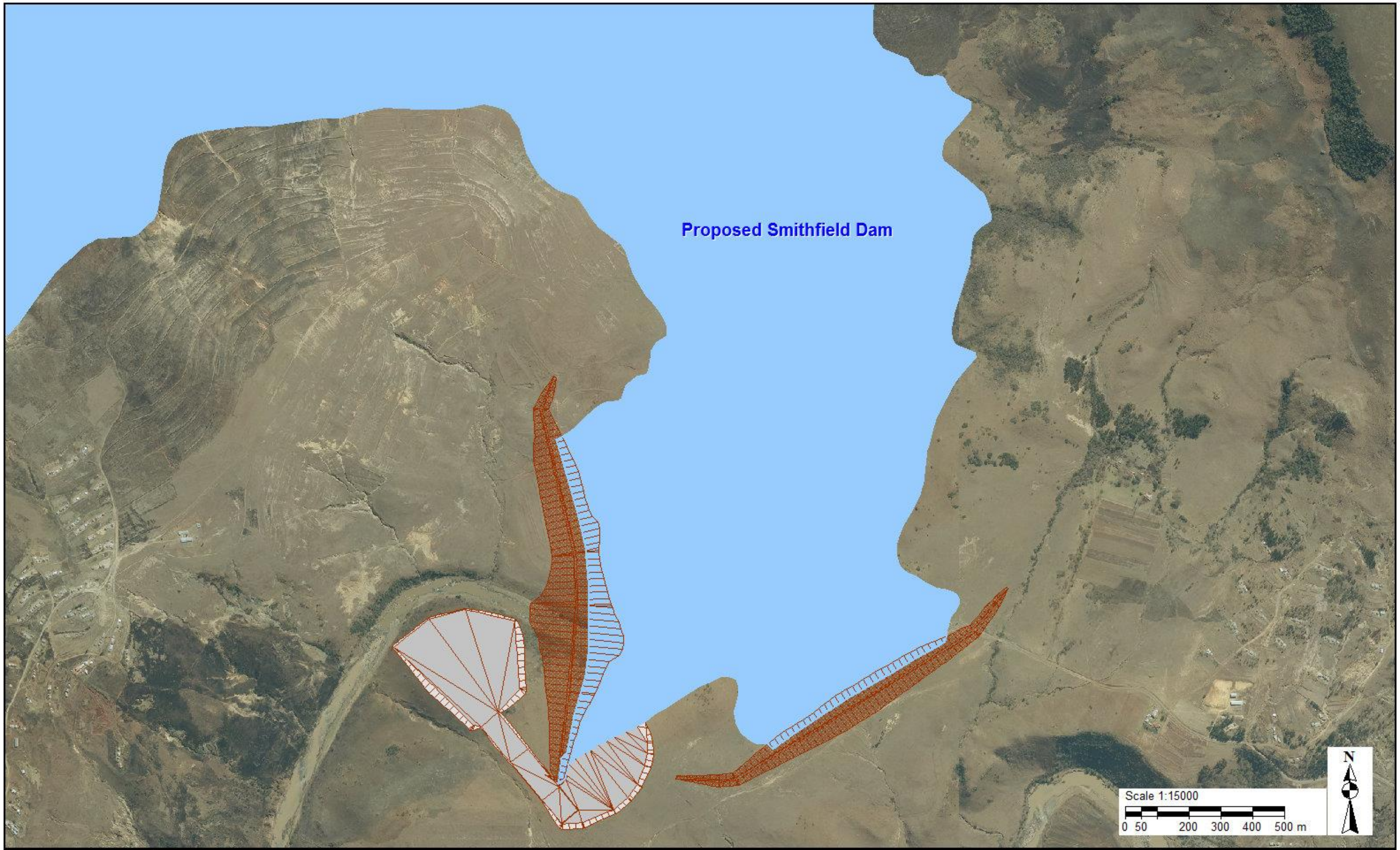
Appendix A

Figures



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uMkhomazi Water Project Phase 1: Module 1:
Technical Feasibility Study: Raw Water (uMWP1-1/RW)
Smithfield Dam - Layout Option 1

FIGURE A.1

Drawn:	LC Gallagher
Checked:	D vd Merwe
Date:	2014-05-08
Map Ref:	uMkhomazi_Environ.map
View Ref:	Option 4
Project No:	J01763

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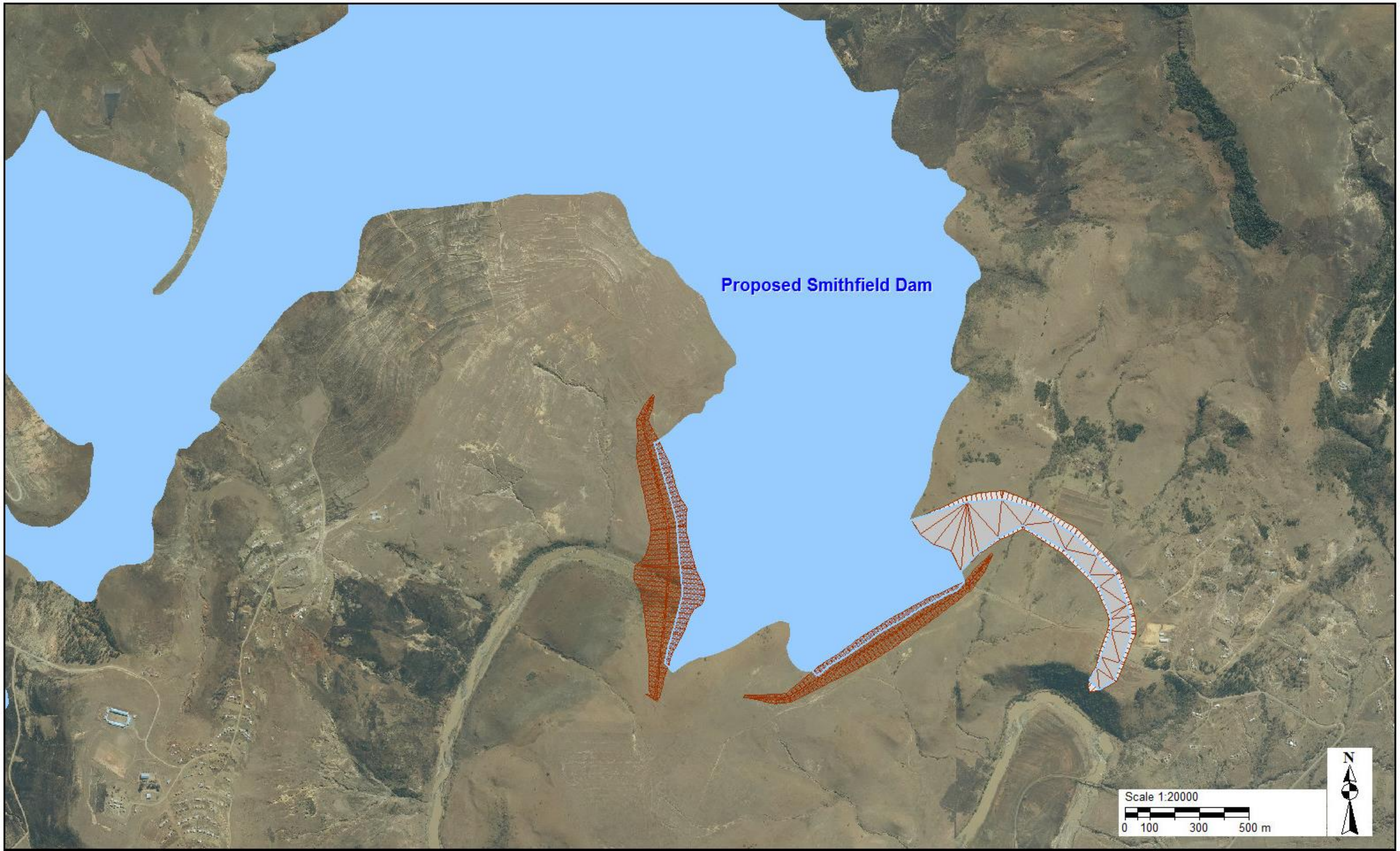
uMkhomazi Water Project Phase 1: Module 1:
Technical Feasibility Study: Raw Water (uMWP1-1/RW)
Smithfield Dam - Layout Option 2

FIGURE A.2

Drawn:	LC Gallagher
Checked:	D vd Merwe
Date:	2014-05-08
Map Ref:	uMkhomazi.Environ.map
View Ref:	Option 2
Project No:	J01763



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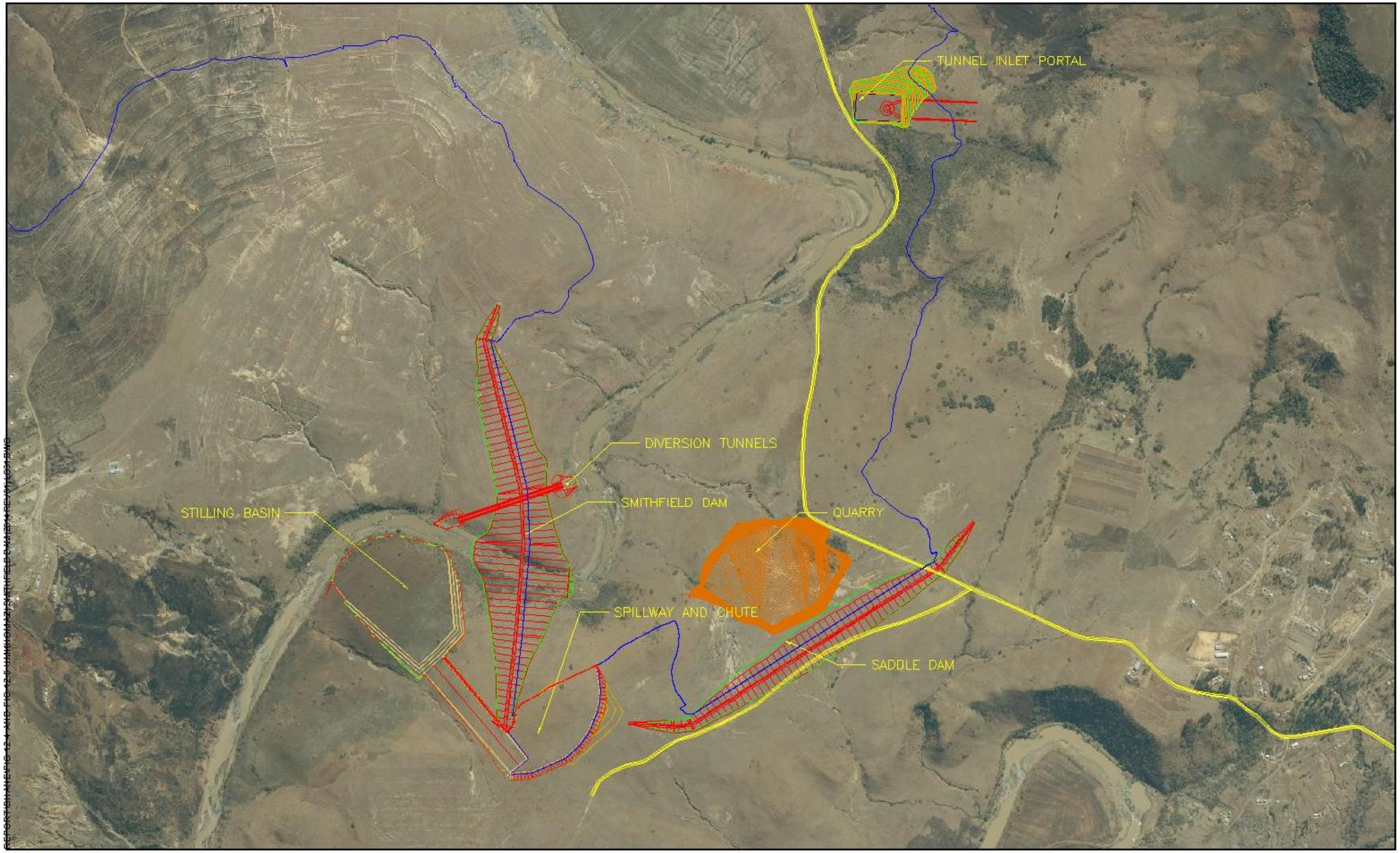
uMkhomazi Water Project Phase 1: Module 1:
Technical Feasibility Study: Raw Water (uMWP1-1/RW)
Smithfield Dam - Layout Option 3

FIGURE A.3

Drawn:	LC Gallagher
Checked:	D vd Merwe
Date:	2014-05-08
Map Ref:	uMkhomazi_Environ.map
View Ref:	Option 3
Project No:	J01763



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uMkhomazi Water Project Phase 1 : Module 1
Technical Feasibility Study : Raw Water (uMWP1-1/RW)

SMITHFIELD DAM
FINAL PREFERRED LAYOUT

FIGURE A.4

SCALE: 1:10000
DATE: 2013 12 02

water affairs Department: Water Affairs REPUBLIC OF SOUTH AFRICA AECOM	Project Name : **uMkhomazi Water Project Phase 1: Module 1: Technical Feasibility Study: Raw Water (uMWP1-1/RW) Inlet portal (upstream): Waste disposal sites - Alternatives**	**Legend** 3. Presssure tunnels to Langa BD area (option C) Alternatives Option 1	**FIGURE A.5** Drawn: LC Gallagher Checked: A Combrinck Date: 2013-10-17 Map Ref: uMkomzi.map View Ref: Outlet portal Project No: J01763

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Department:
Water Affairs
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Project Name :

uMkhomazi Water Project Phase 1: Module 1:
Technical Feasibility Study: Raw Water (uMWP1-1/RW)
Smithfield Dam: Quarries & borrow areas - Alternatives

Legend

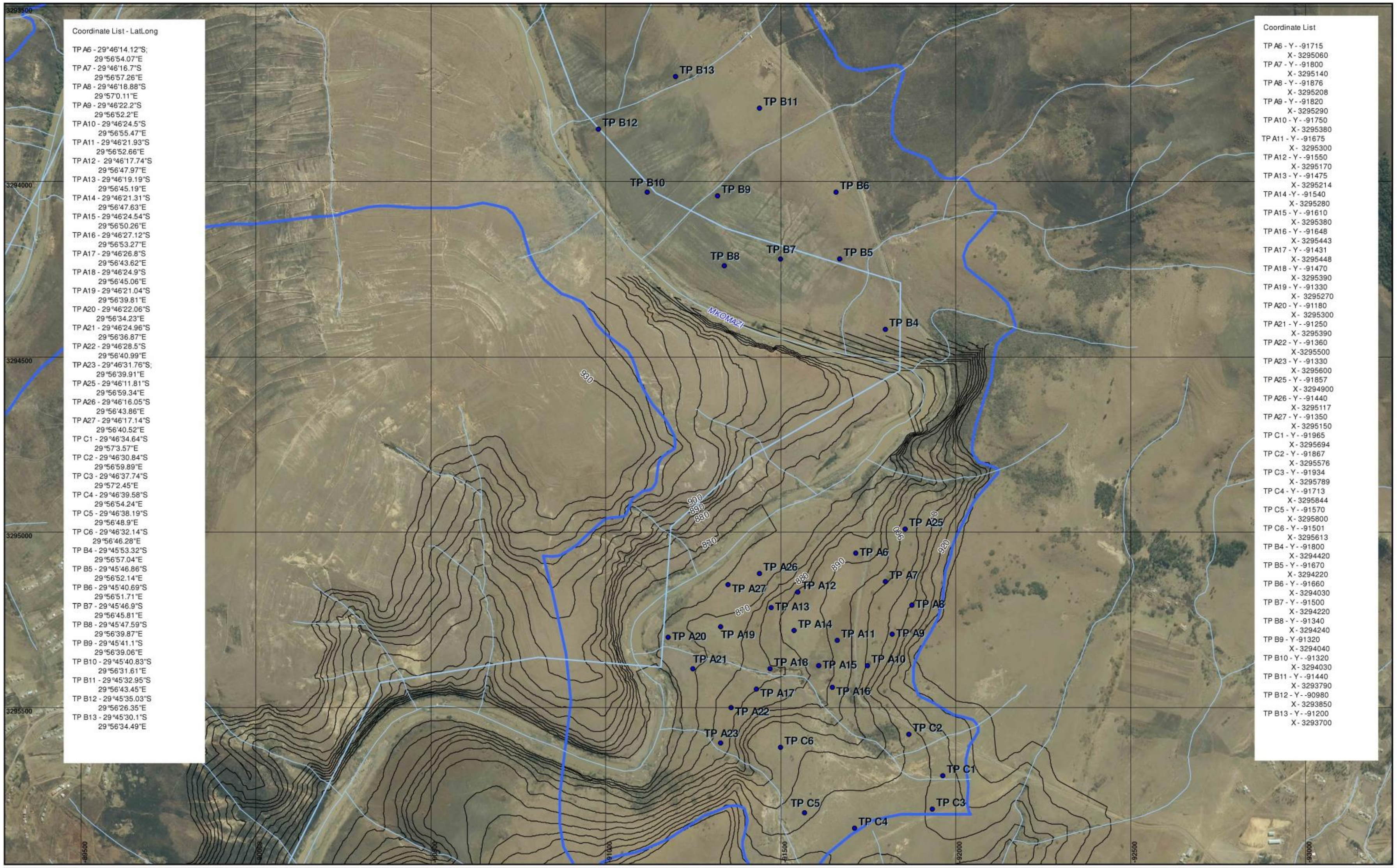
Main Rivers

Alternatives - Quarries
- Quarry I
- Quarry II
- Quarry III
- Quarry IV

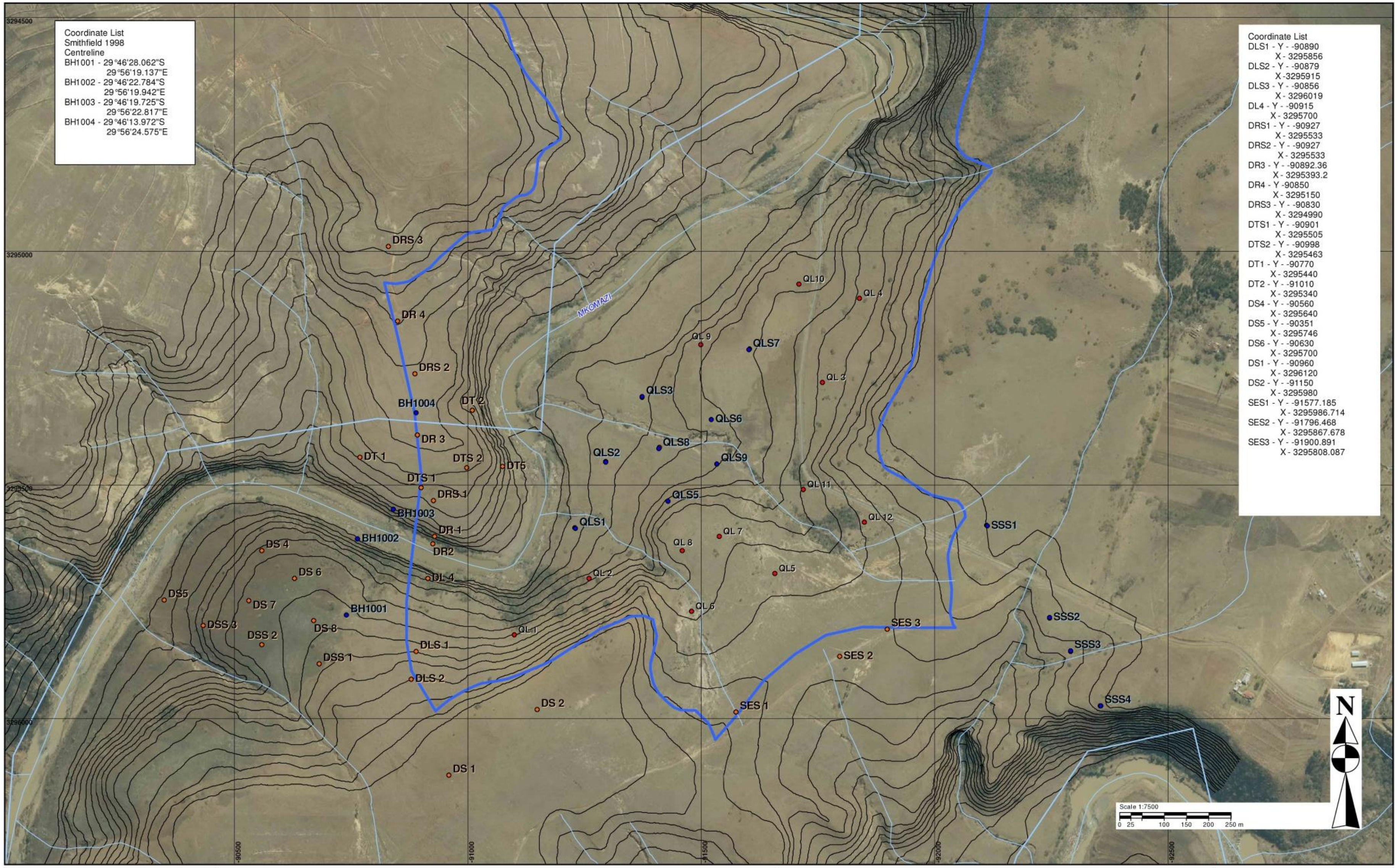
Alternatives - Borrow areas
- Borrow Area A
- Borrow Area B

FIGURE A.6

Drawn: LC Gallagher
Checked: A Combrinck
Date: 2013-11-17
Map Ref: uMkomzi.map
View Ref: Quarries - Smithfield Dam
Project No: J01763



water affairs Department: Water Affairs REPUBLIC OF SOUTH AFRICA AECOM	Project Name : **uMkhomazi Water Project Phase 1: Module 1: Technical Feasibility Study: Raw Water (uMWP1-1/RW) Smithfield Dam - Test pit positions**	**Legend** Contours Proposed Dams Main Rivers Test Pit Positions	**FIGURE A.7** Drawn: LC Gallagher Checked: D vd Merwe Date: 2013-04-07 Map Ref: P\GIS\Water\uMkhomazi_WG29.map View Ref: Smithfiled - Test pit positons Project No: J01763



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Project Name :

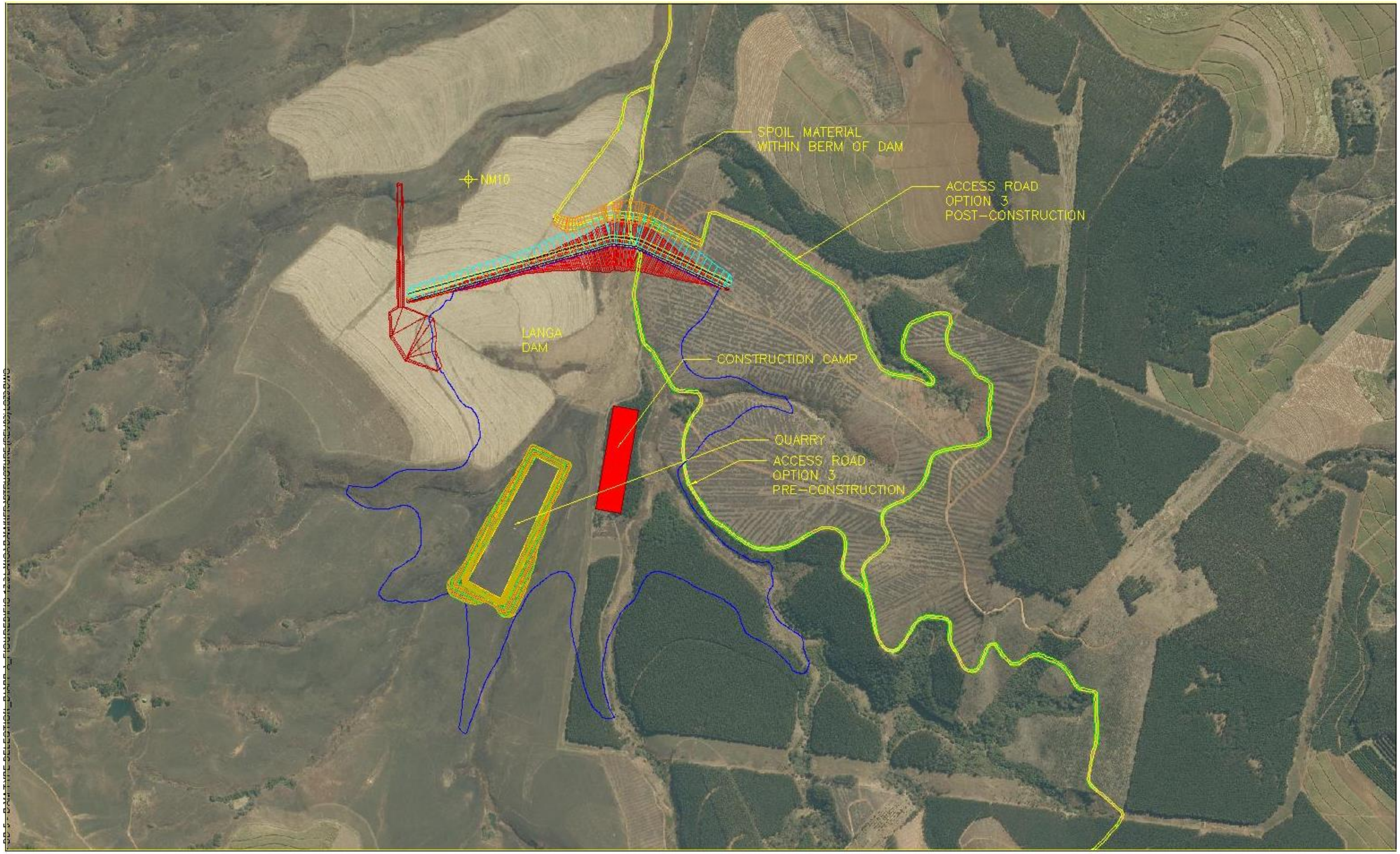
uMkhomazi Water Project Phase 1: Module 1:
Technical Feasibility Study: Raw Water (uMWP1-1/RW)
Smithfield Dam - Borehole Positions

Legend

- Contours
- Proposed Dams
- Main Rivers
- Geotechnical and Materials Boreholes

FIGURE A.8

Drawn:	LC Gallagher
Checked:	D vd Merwe
Date:	2013-04-14
Map Ref:	P:\GIS\Water\uMkhomazi_WG29.map
View Ref:	Smithfiled - Borehole Positions
Project No:	J01763



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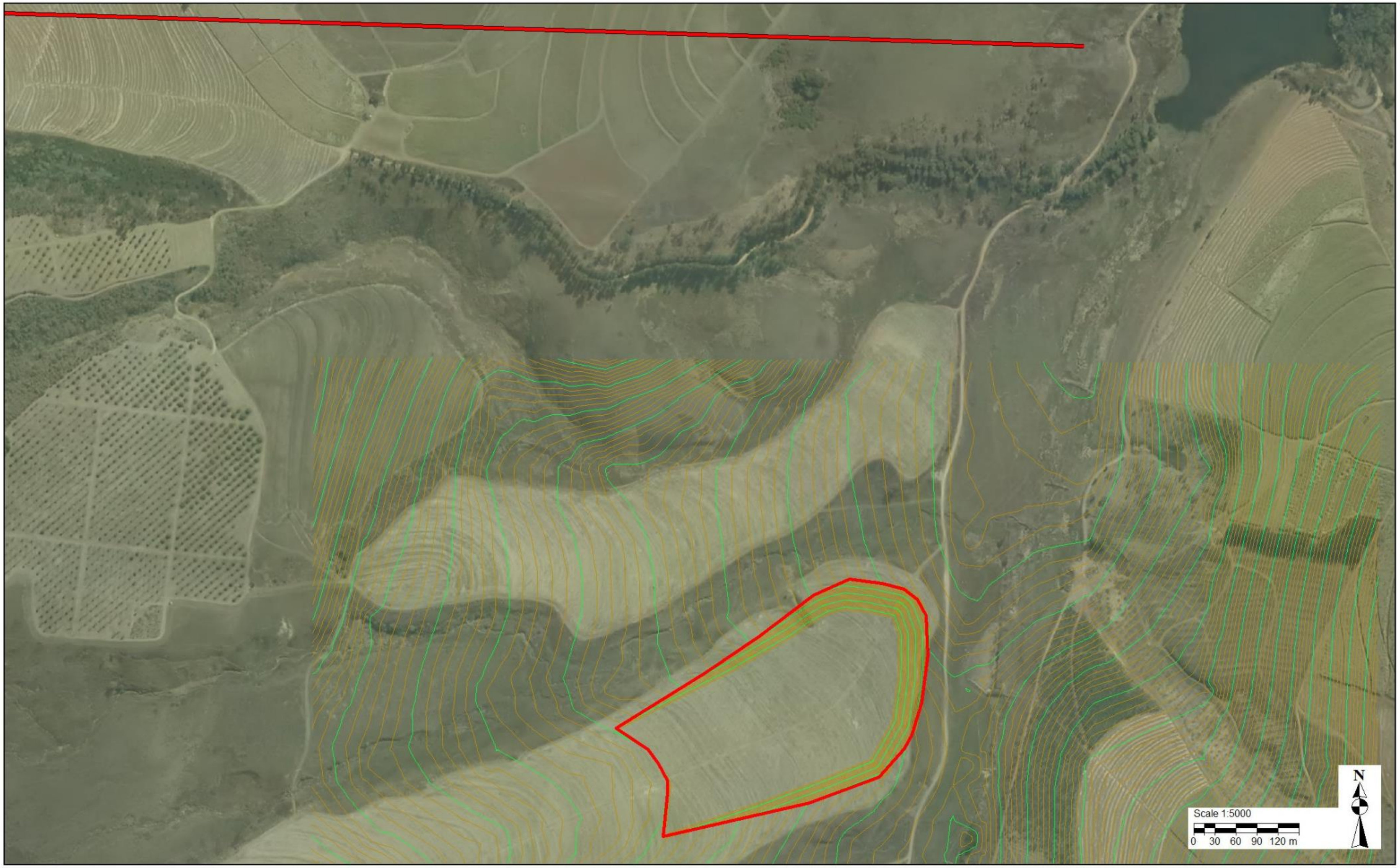
uMkhomazi Water Project Phase 1 : Module 1
Technical Feasibility Study : Raw Water (uMWP1-1/RW)

LANGA BALANCING DAM
FINAL PREFERRED LAYOUT

FIGURE A.9

SCALE: 1:10000
DATE: 2013 12 02



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AECOM

Project Name :

uMkhomazi Water Project Phase 1: Module 1: Technical Feasibility Study: Raw Water (uMWP1-1/RW) Outlet portal (downstream): Waste disposal sites - Alternatives

Legend

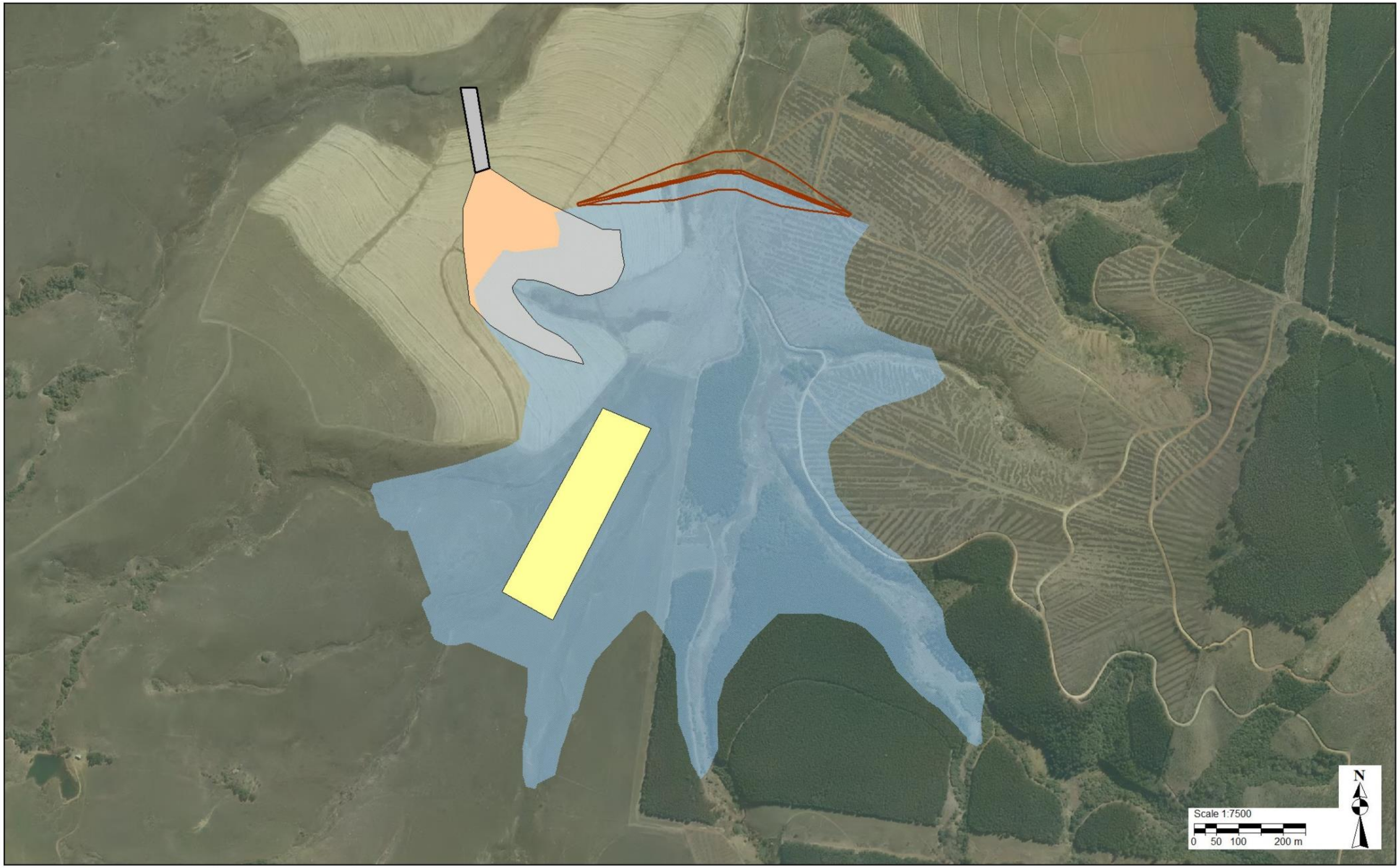
3. Presssure tunnels to Langa BD area (option C)

Alternatives

Option 1

FIGURE A.10

Drawn: LC Gallagher
Checked: A Combrinck
Date: 2013-10-17
Map Ref: uMkomzi.map
View Ref: Outlet portal
Project No: J01763



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AECOM

Project Name :

uMkhomazi Water Project Phase 1: Module 1: Technical Feasibility Study: Raw Water (uMWP1-1/RW)
Langa Balancing Dam: Quarries & borrow areas - Alternatives

Legend

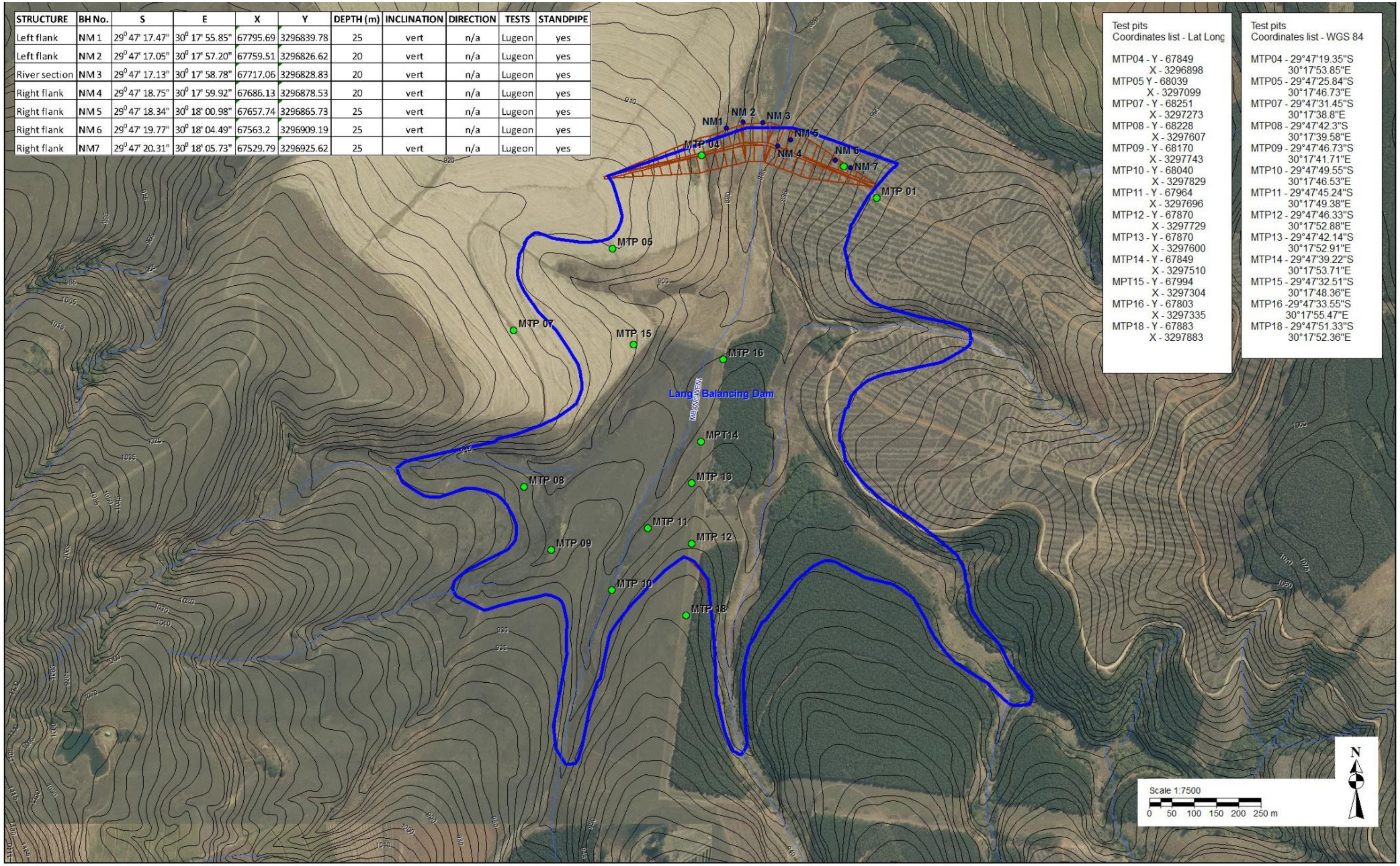
- Spillway chute
- Approach Area

Alternatives Quarries and Borrow Areas

- Quarry & Borrow Area I

FIGURE A.11

Drawn: LC Gallagher
Checked: A Combrinck
Date: 2013-10-17
Map Ref: uMkomzi.map
View Ref: Langa Dam - Quarries
Project No: J01763



STRUCTURE	BH No.	S	E	X	Y	DEPTH (m)	INCLINATION	DIRECTION	TESTS	STANDPIPE
Left flank	NM 1	29° 47' 17.47"	30° 17' 55.85"	67795.69	3296839.78	25	vert	n/a	Lugeon	yes
Left flank	NM 2	29° 47' 17.05"	30° 17' 57.20"	67759.51	3296826.62	20	vert	n/a	Lugeon	yes
River section	NM 3	29° 47' 17.13"	30° 17' 58.78"	67717.06	3296828.83	20	vert	n/a	Lugeon	yes
Right flank	NM 4	29° 47' 18.75"	30° 17' 59.92"	67686.13	3296878.53	20	vert	n/a	Lugeon	yes
Right flank	NM 5	29° 47' 18.34"	30° 18' 00.98"	67657.74	3296865.73	25	vert	n/a	Lugeon	yes
Right flank	NM 6	29° 47' 19.77"	30° 18' 04.49"	67563.2	3296909.19	25	vert	n/a	Lugeon	yes
Right flank	NM7	29° 47' 20.31"	30° 18' 05.73"	67529.79	3296925.62	25	vert	n/a	Lugeon	yes

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Project Name :

uMkhomazi Water Project Phase 1: Module 1: Technical Feasibility Study: Raw Water (uMWP1-1/RW)
Langa Balancing Dam - Borehole & Test pit positions

Legend

- 5 m Contours
- Langd Dam Layout and FSL
- Langa Dam Test Pits Positions
- NM Boreholes
- Main Rivers

FIGURE A.12

Drawn: LC Gallagher
Checked: H Pieterse
Date: 2014-07-16
Map Ref: P\GISProjects/Water\uMkhomazi_WG31.m
View Ref: Smithfiled - Borholes&Test pits
Project No: J01763

Appendix B

Breakdown of RCC and CVC rates

Rate breakdown for CVC

1 – CVC placing		
Materials	m^3	R 1136.42
Mixing	m^3	R 171.98
Transport	m^3	R 135.26
Cooling	m^3	R 218.11
Vibration	m^3	R 28.74
Subtotal		R 1690.52
2 - Other costs		
Placing labour	m^3	R 171.95
Placing plant	m^3	R 56.30
Joints cleaning	m^3	R 63.09
Subtotal		R 291.33
Total		R 1981.85

Rate breakdown for RCC

1 – RCC Placing		
Materials	m^3	R 740.25
Mixing	m^3	R 119.15
Transport	m^3	R 40.00
Spread and compact	m^3	R 116.90
Subtotal		R 1016.30
2 - Other costs		
Greencut joints	m^3	R 16.88
Curing	m^3	R 16.45
RCC bedding mortar	m^2	R 61.42
RCC bedding concrete	m^2	R 0.42
Treatment of cold RCC layer	m^2	R 1.95
Filler and levelling concrete	m^3	R 1.73
Preparation of receiving surface	m^3	R 1.48
Test section	m^3	R 26.24
Crack inducers in upstream face	m	R 0.21
Crack inducers in downstream face	m	R 0.35
Crack inducers (Groutable)	m	R 1.23
Set ups for 150mm core drilling in RCC	No	R 0.44
Standby for 150 mm or core drilling rig	Hrs	R 0.21
Drilling and recovery of 150 mm core in RCC	m	R 9.64
Water pressure testing in 150 mm core holes in RCC	No	R 0.22
Grouting of core holes	t	R 1.54
Sub total		R 140.41
Total		R 1156.71

Appendix C

Smithfield Dam: Results from slope stability analysis

Table C.1: Soil parameters

Material	Description	Unit weight (kN/m^3)	Cohesion (kPa)	Angle of internal friction (Ø) (Degrees)
A	Organic topsoil	13	23	26
B	Clayey sand	17	23	26
C	Completely and highly weathered shale	20.1	0	35
D	Unweathered to moderately weathered shale	20.6	0	38
E	Highly and moderately weathered dolerite	20.6	0	36
F	Slightly weathered and unweathered dolerite	21.6	0	40
G	CVC concrete	23	500	35

Table C.2: Slope stability analysis results

Embankment Type	Analysis	Outer Shell	Inner Shell	Core	Transition Zone	Slopes		Upstream slope				Downstream Slope			
								Steady State (1)		Seismic (2)		Steady State (1)		Seismic (2)	
						US	DS	FOS(3)	Req (4)	FOS(3)	Req (4)	FOS(3)	Req (4)	FOS(3)	Req (4)
Earthfill embankment	1	C	-	B	C	2.5	2	1.81 (ok)	> 1.5	1.22 (ok)	> 1	1.44 (Not ok)	> 1.5	1.17 (ok)	> 1
	2	C	-	B	C	3	2.5	2.13 (ok)	> 1.5	1.38 (ok)	> 1	1.79 (ok)	> 1.5	1.41 (ok)	> 1
Earthcore rockfill dam	1	F	-	B	C	1.75	1.7	1.5 (ok)	> 1.5	1.09 (ok)	> 1	1.54 (ok)	> 1.5	1.26 (ok)	> 1
	2	F	-	B	C	1.8	1.75	1.54 (ok)	> 1.5	1.12 (ok)	> 1	1.56 (ok)	> 1.5	1.27 (ok)	> 1
Concrete faced rockfill dam	1	F	-	-	-	1.4	1.4	1.62 (ok)	> 1.5	1.20 (ok)	> 1	1.21 (not ok)	> 1.5	1.01 (ok)	> 1
	2	F	-	-	-	1.4	1.5					1.46 (not ok)	> 1.5	1.20 (ok)	> 1
	3	F	-	-	-	1.4	1.7					1.51 (ok)	> 1.5	1.24 (ok)	> 1
	4	F	-	-	-	1.4	1.75					1.54 (ok)	> 1.5	1.26 (ok)	> 1

Table C.3: Slope stability analysis results

Embankment Type	Analysis	Outer Shell	Toe section	Core	Transition Zone	Slopes		Upstream slope				Downstream Slope			
								Steady State (1)		Seismic (2)		Steady State (1)		Seismic (2)	
						US	DS	FOS(3)	Req (4)	FOS(3)	Req (4)	FOS(3)	Req (4)	FOS(3)	Req (4)
Option 1 Zoned Concrete faced rock fill dam	1	F	E	-	-	1.4	1.4					1.09 (Not ok)	> 1.5	0.89 (Not ok)	> 1
	2	F	E	-	-	1.4	1.5					1.13 (Not ok)	> 1.5	0.94 (Not ok)	> 1
	3	F	E	-	-	1.4	1.75					1.30 (Not ok)	> 1.5	1.06 (ok)	> 1
	4	F	E	-	-	1.4	1.8					1.35 (Not ok)	> 1.5	1.10 (ok)	> 1
	5	F	E	-	-	1.4	2					1.50 (ok)	> 1.5	1.20 (ok)	> 1
Option 2 Zoned Concrete faced rock fill dam	1	F	D	-	-	1.4	1.4					1.13 (Not ok)	> 1.5	0.89 (Not ok)	> 1
	2	F	D	-	-	1.4	1.5					1.21 (Not ok)	> 1.5	1.01 (ok)	> 1
	3	F	D	-	-	1.4	1.75					1.40 (ok)	> 1.5	1.19 (ok)	> 1
	4	F	D	-	-	1.4	1.8					1.55 (ok)	> 1.5	1.27 (ok)	> 1
	5	F	D	-	-	1.4	2					1.60 (ok)	> 1.5	1.29 (ok)	> 1

Table C.4: Slope stability analysis results

Embankment Type	Analysis	Outer Shell	Toe section	Core	Transition Zone	Slopes		Upstream slope				Downstream Slope			
								Steady State [1]		Seismic [2]		Steady State [1]		Seismic [2]	
						US	DS	FOS[3]	Req [4]	FOS[3]	Req [4]	FOS[3]	Req [4]	FOS[3]	Req [4]
Option 2 Zoned rockfill fill dam	1	F	D	B	C	1.4	1.4	1.20 (Not ok)	> 1.5	0.89 (Not ok)	> 1	1.20 (Not ok)	> 1.5	1.00 (ok)	> 1
	2	F	D	B	C	1.5	1.5	1.28 (Not ok)	> 1.5	0.94 (Not ok)	> 1	1.28 (Not ok)	> 1.5	1.06 (ok)	> 1
	3	F	D	B	C	1.7	1.7	1.44 (Not ok)	> 1.5	1.05 (ok)	> 1	1.48 (Not ok)	> 1.5	1.21 (ok)	> 1
	4	F	D	B	C	1.75	1.75	1.47 (Not ok)	> 1.5	1.07 (ok)	> 1	1.50 (ok)	> 1.5	1.09 (ok)	> 1
	5	F	D	B	C	1.8	1.8	1.52 (ok)	> 1.5	1.10 (ok)	> 1	1.56 (ok)	> 1.5	1.27 (ok)	> 1
	6	F	D	B	C	2	2	1.68 (ok)	> 1.5	1.20 (ok)	> 1	1.71 (ok)	> 1.5	1.38 (ok)	> 1

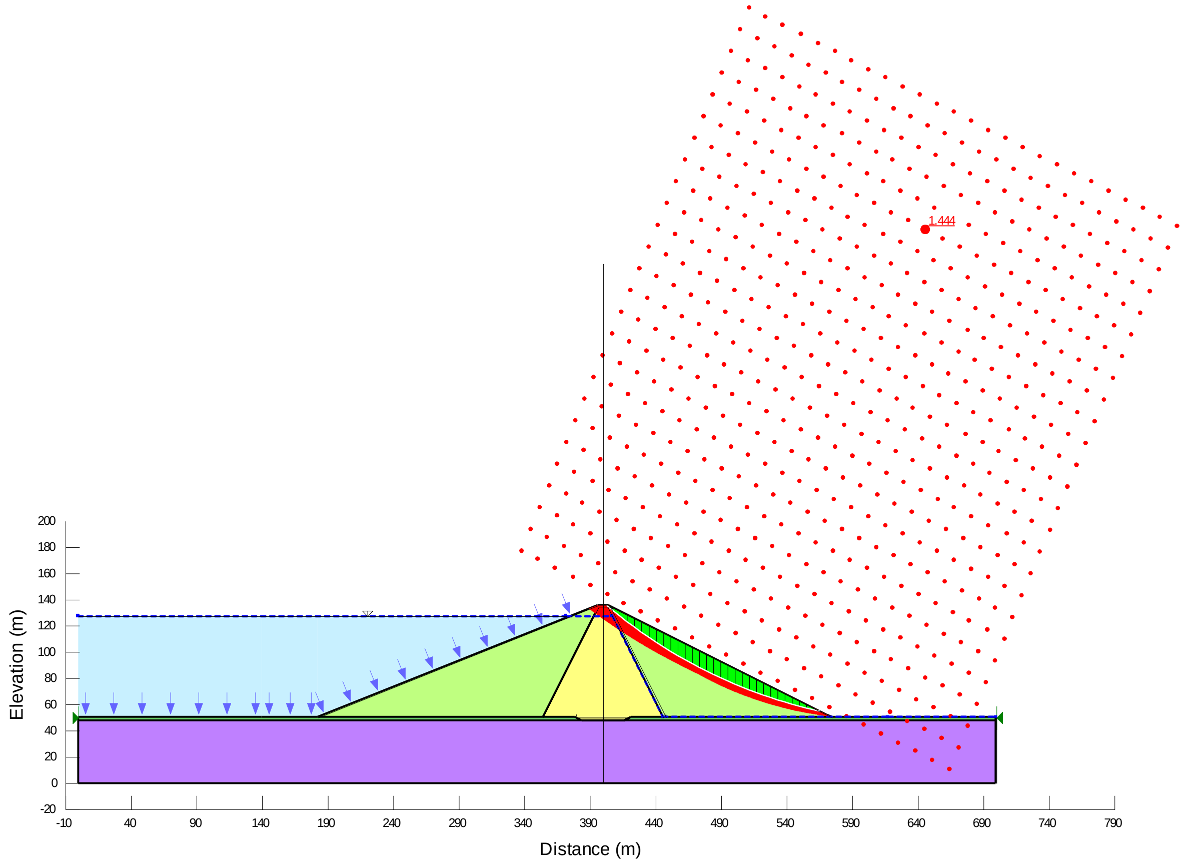


Figure C.1: Earthfill dam: Upstream slope 1:2.5 (V:H), Downstream slope 1:2 (V:H), Analysis 1.1, Downstream, dam full with steady state flow

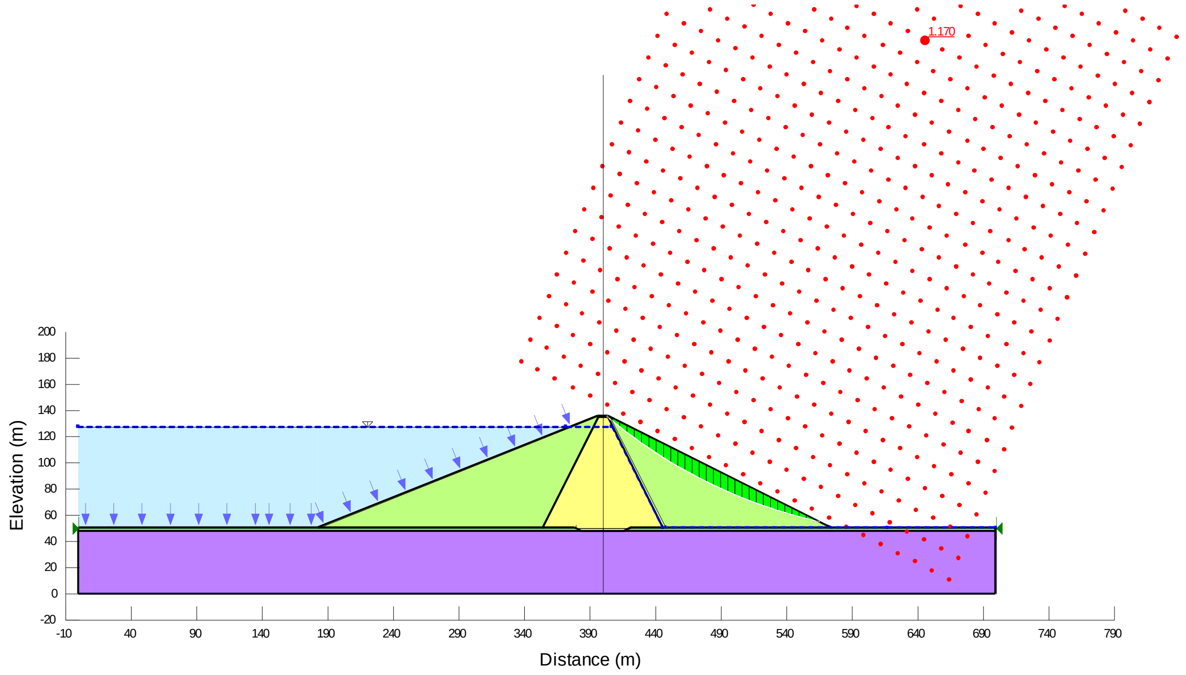


Figure C.2: Earthfill dam: Upstream slope 1:2.5 (V:H), Downstream slope 1:2 (V:H), Analysis 1.2, Downstream, dam full with seismic action

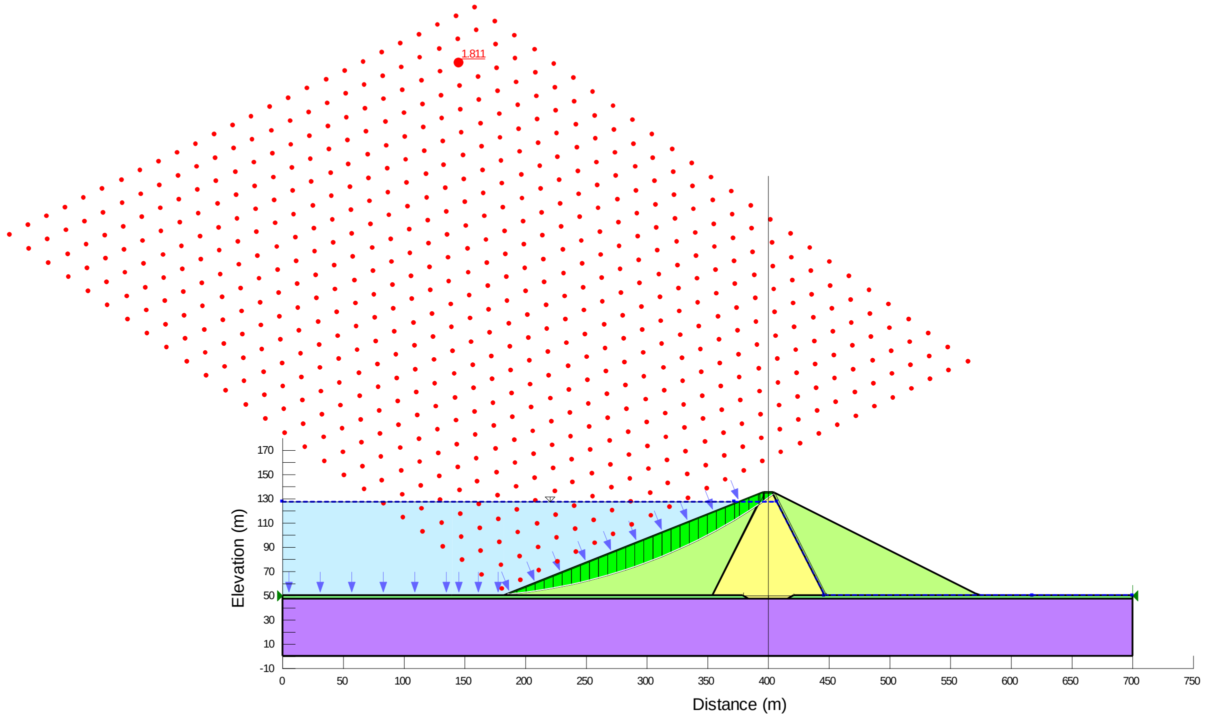


Figure C.3: Rockfill dam: Upstream slope 1:2.5 (V:H), Downstream slope 1:2 (V:H), Analysis 1.3, Upstream, dam full with seismic action

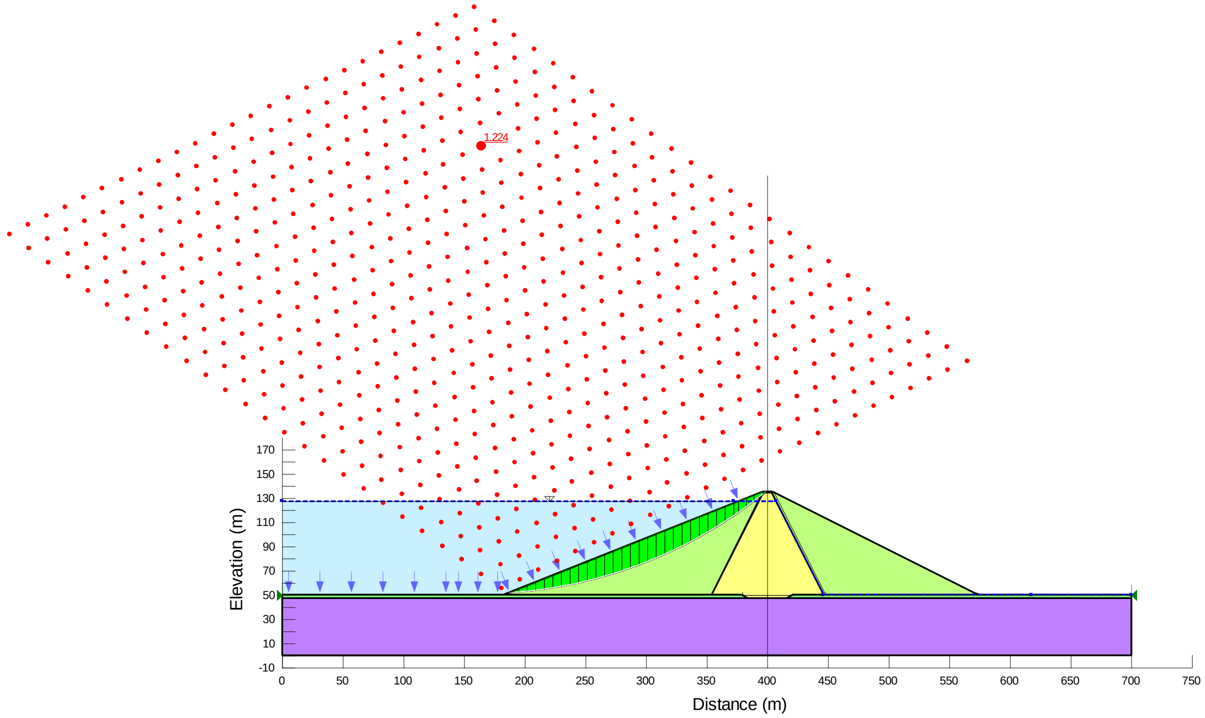


Figure C.4: Rockfill dam: Upstream slope 1:2.5 (V:H), Downstream slope 1:2 (V:H), Analysis 1.4, Upstream, dam full with seismic action

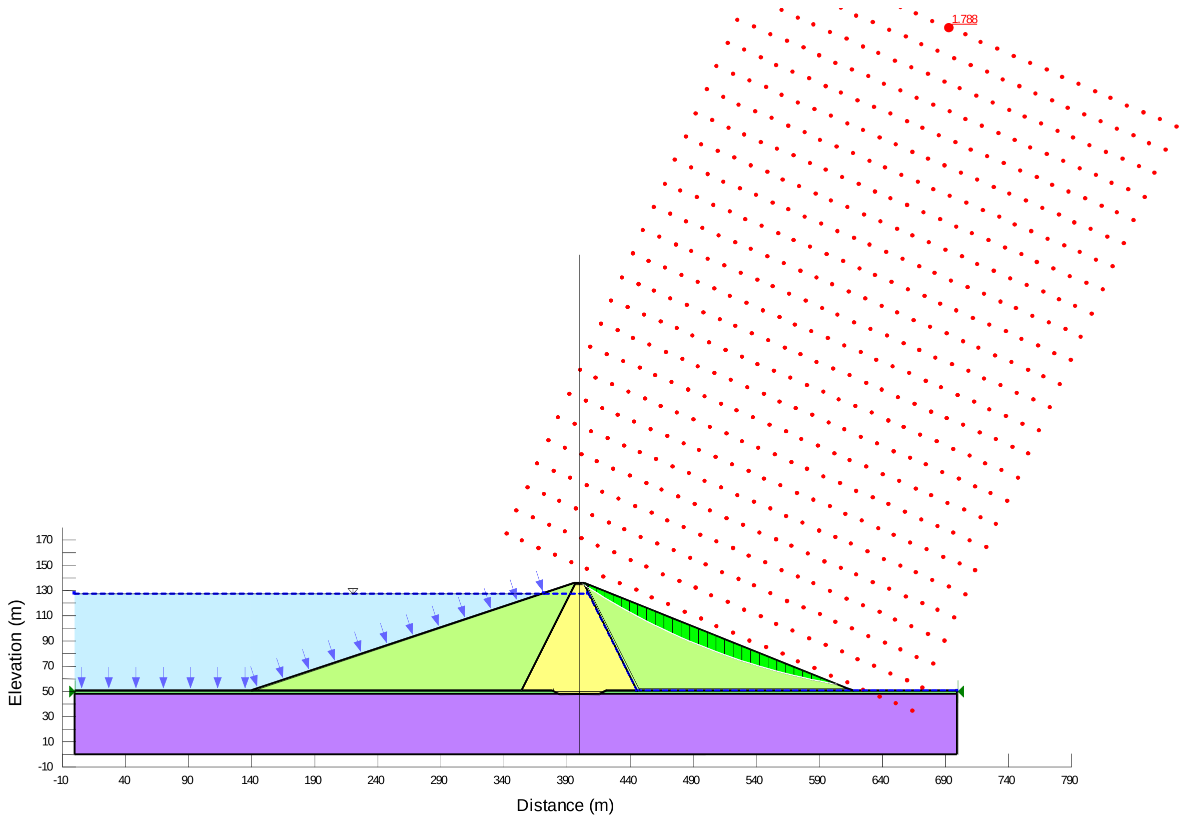


Figure C.5: Earthfill dam: Upstream slope 1:3 (V:H), Downstream slope 1:2.5 (V:H), Analysis 2.1, Downstream, dam full with steady state flow

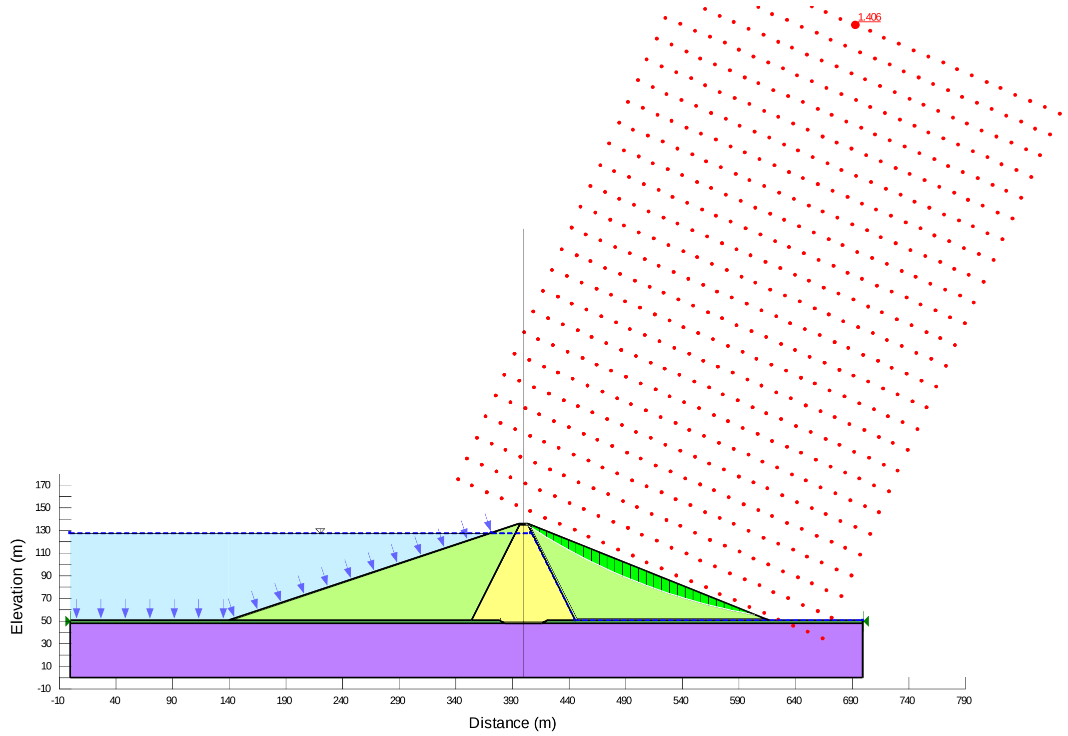


Figure C.6: Earthfill dam: Upstream slope 1:3 (V:H), Downstream slope 1:25 (V:H), Analysis 2.2, Downstream, dam full with seismic action

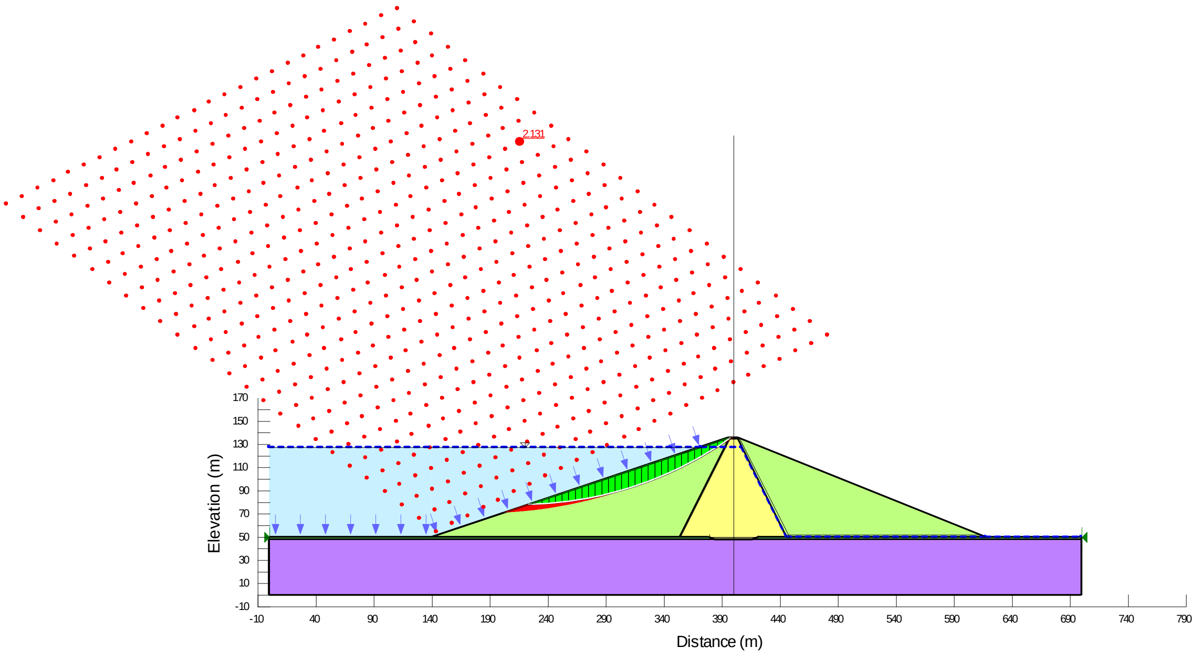


Figure C.7: Rockfill dam: Upstream slope 1:3 (V:H), Downstream slope 1:2.5 (V:H), Analysis 2.3, Upstream, dam full with steady state

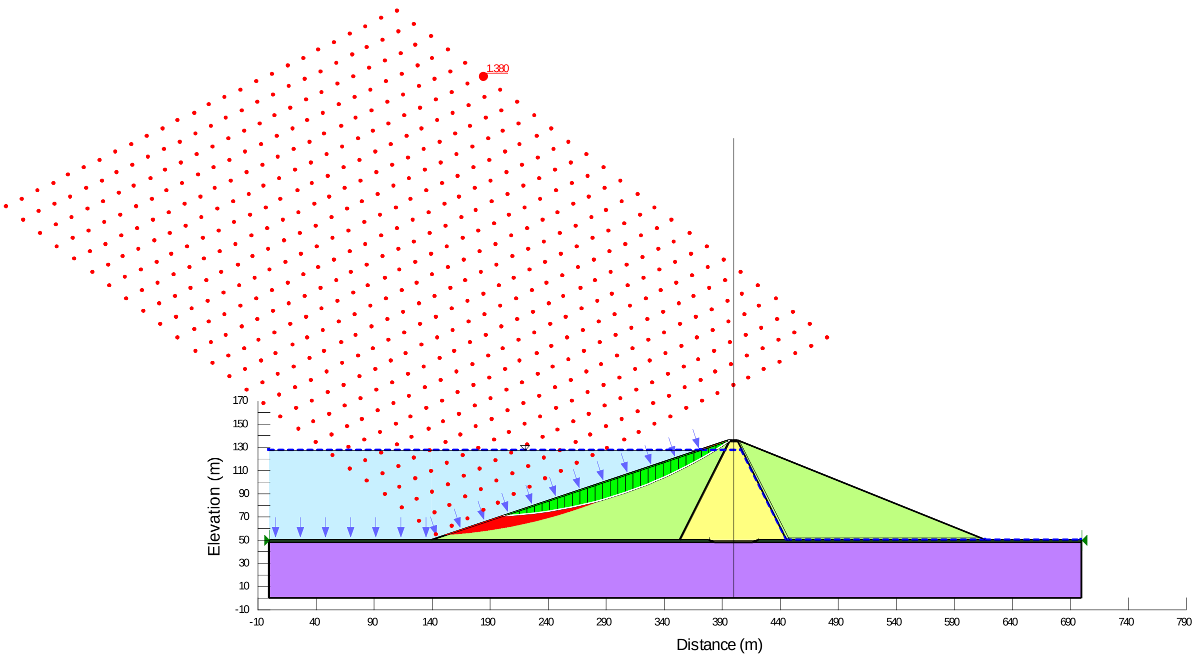


Figure C.8: Rockfill dam: Upstream slope 1:3 (V:H), Downstream slope 1:2.5 (V:H), Analysis 2.4, Upstream, dam full with seismic action

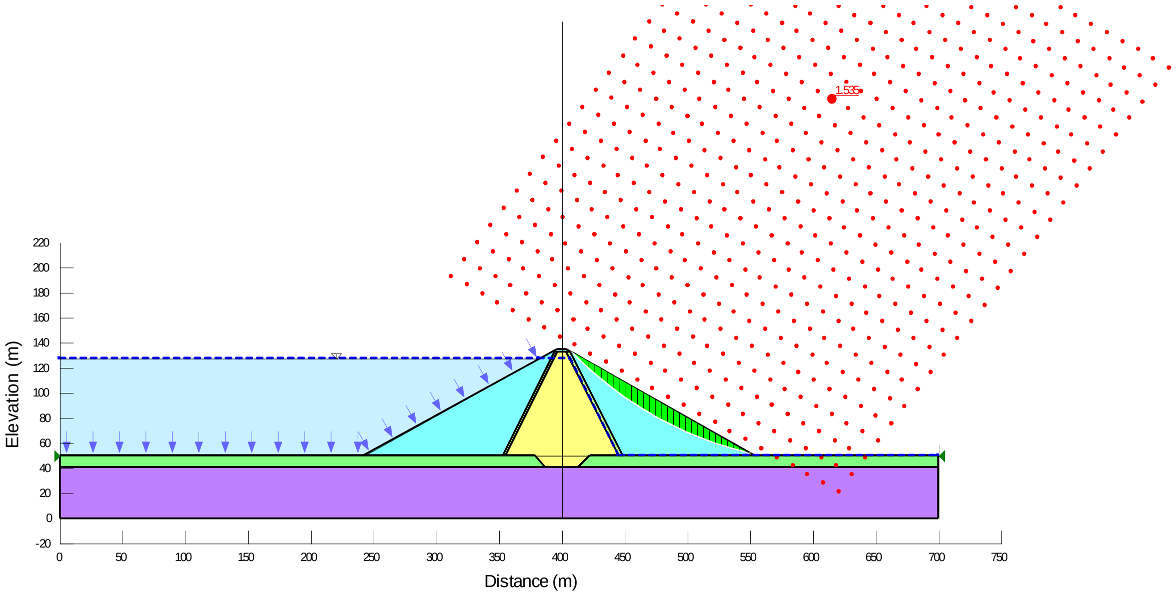


Figure C.9: Earthcore rockfill dam: Upstream slope 1.75 (V:H), Downstream slope 1:1.7 (V:H), Analysis 1.1, Downstream, dam full with steady state flow

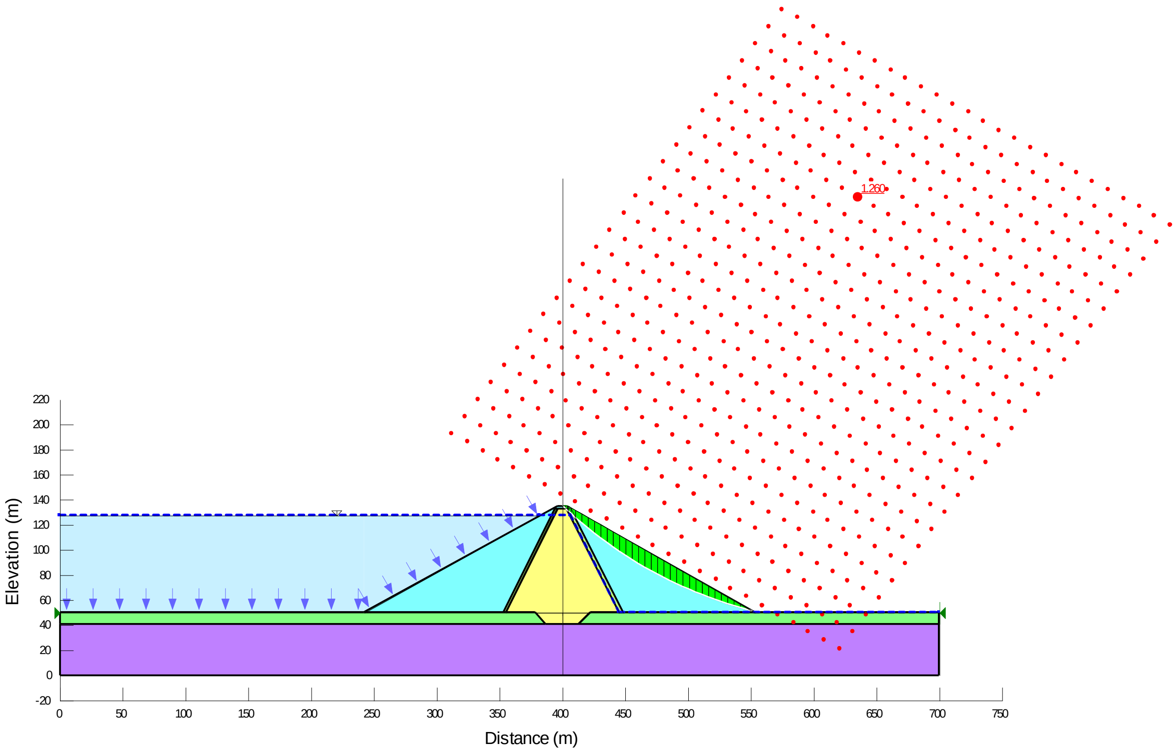


Figure C.10: Earthcore rockfill dam: Upstream slope 1.75 (V:H), Downstream slope 1:1.7 (V:H), Analysis 1.2, Downstream, dam full with seismic action

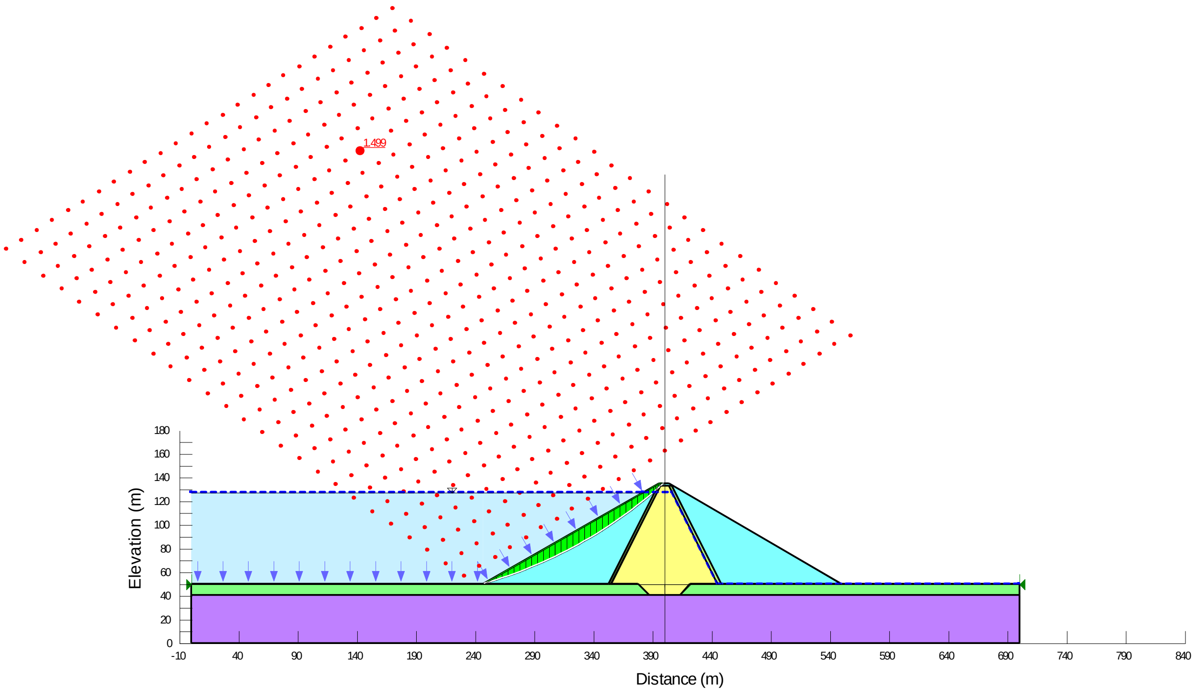


Figure C.11: Earthcore rockfill dam: Upstream slope 1.75 (V:H), Downstream slope 1:1.7 (V:H), Analysis 1.3, Upstream, dam full with steady state flow

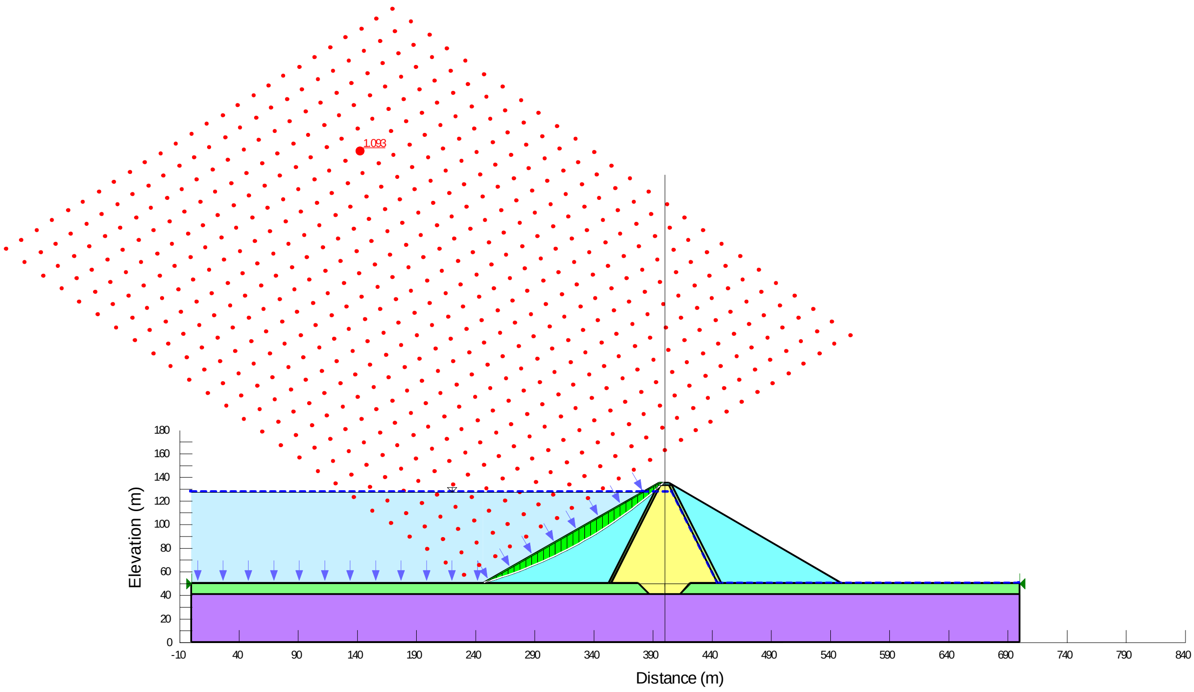


Figure C.12: Earthcore rockfill dam: Upstream slope 1.75 (V:H), Downstream slope 1:1.7 (V:H), Analysis 1.4, Downstream, dam full with seismic action

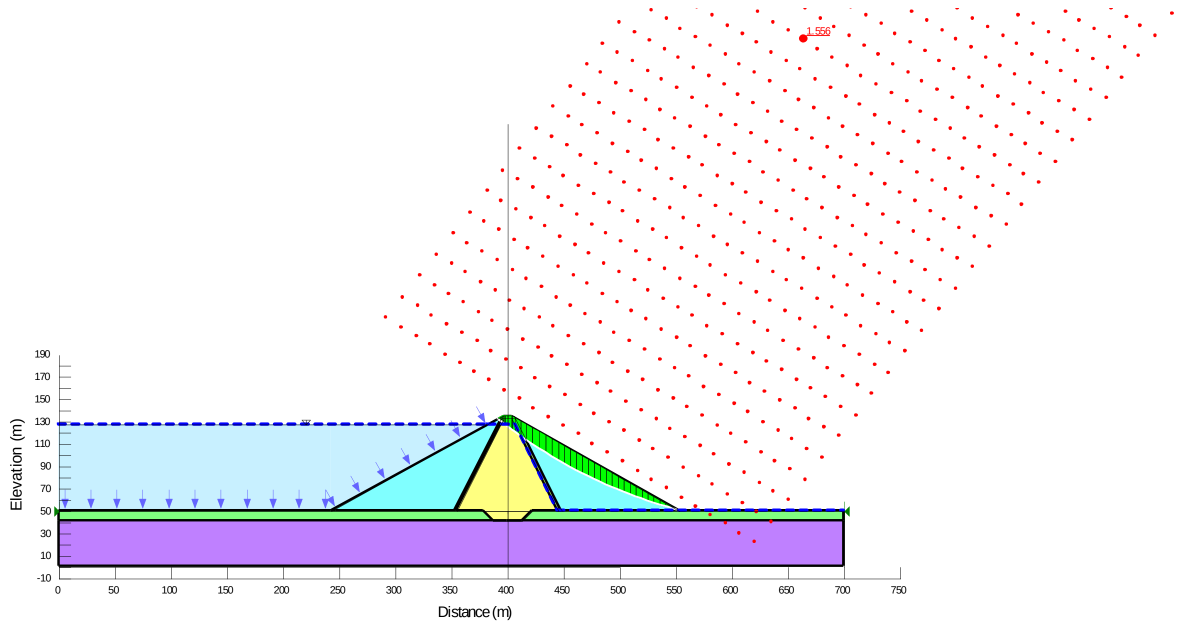


Figure C.13: Earthcore rockfill dam: Upstream slope 1.8 (V:H), Downstream slope 1:1.75 (V:H), Analysis 2.1, Downstream, dam full with steady state flow

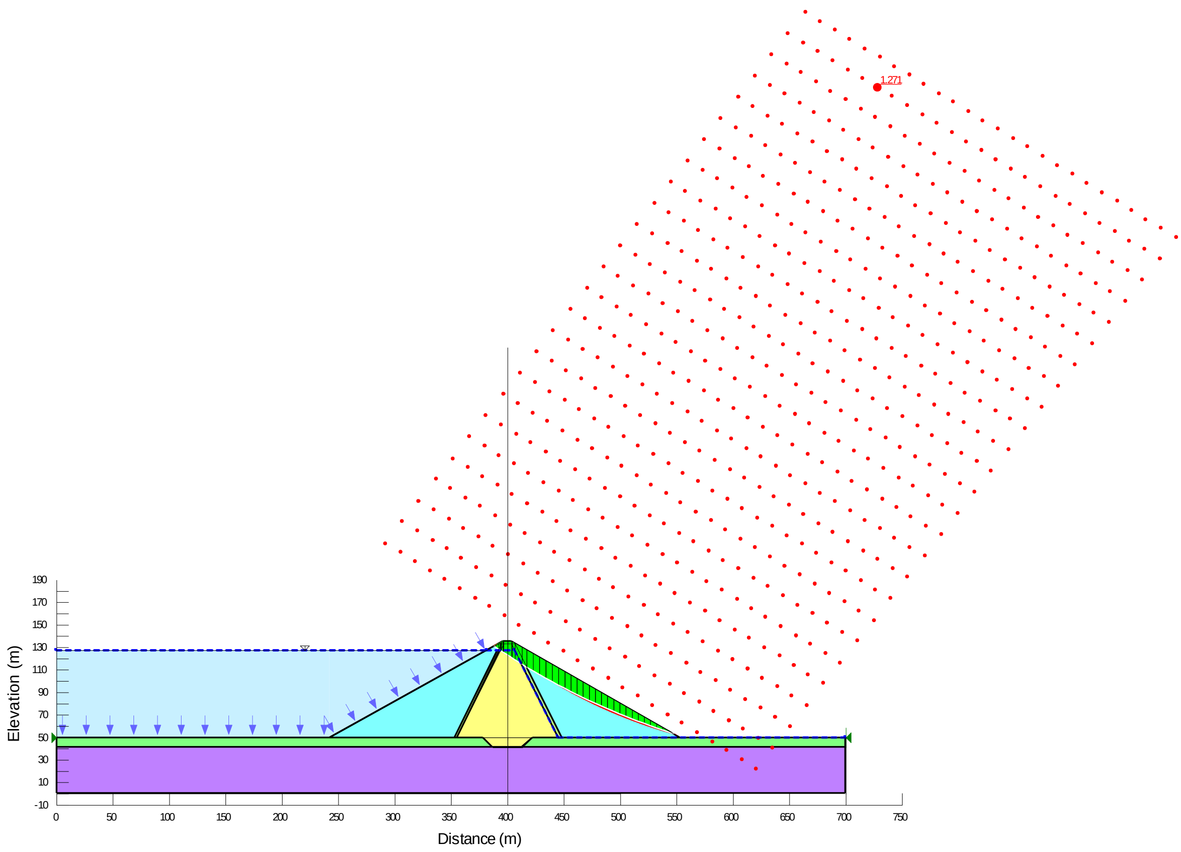


Figure C.14: Earthcore rockfill dam: Upstream slope 1.8 (V:H), Downstream slope 1:1.75 (V:H), Analysis 2.2, Downstream, dam full with seismic action

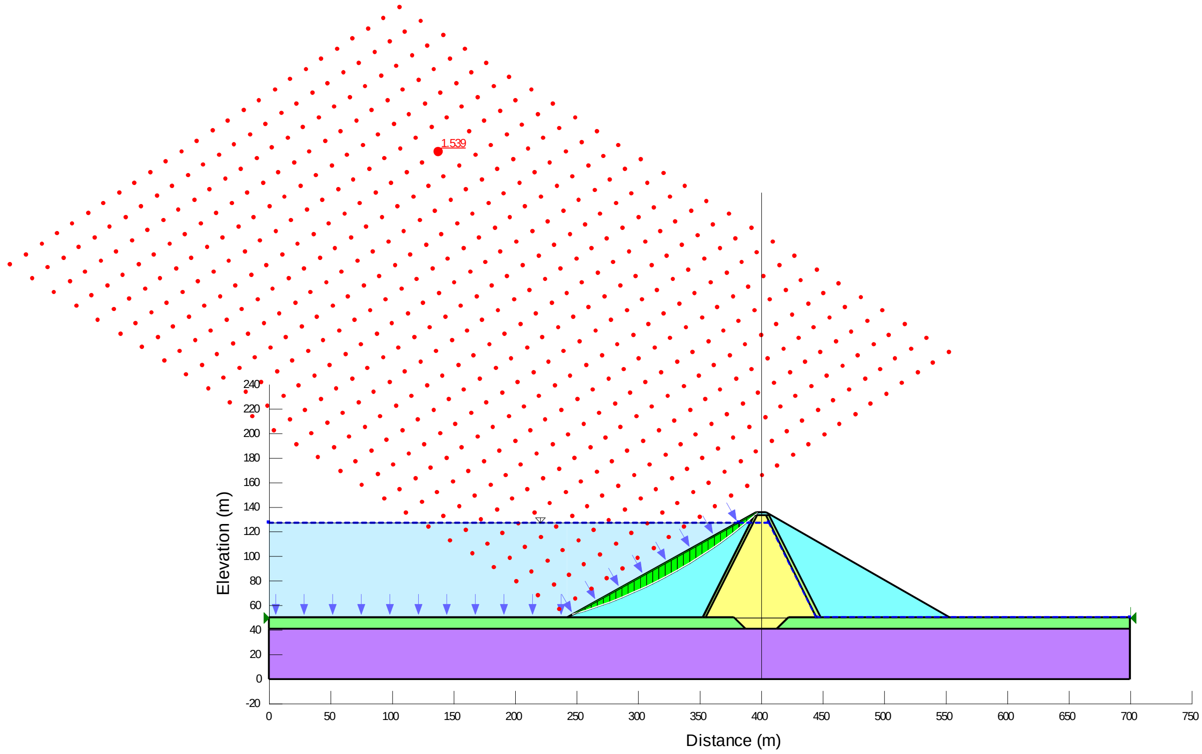


Figure C.15: Earthcore rockfill dam: Upstream slope 1.8 (V:H), Downstream slope 1:1.75 (V:H), Analysis 2.3, Upstream, dam full with steady state flow

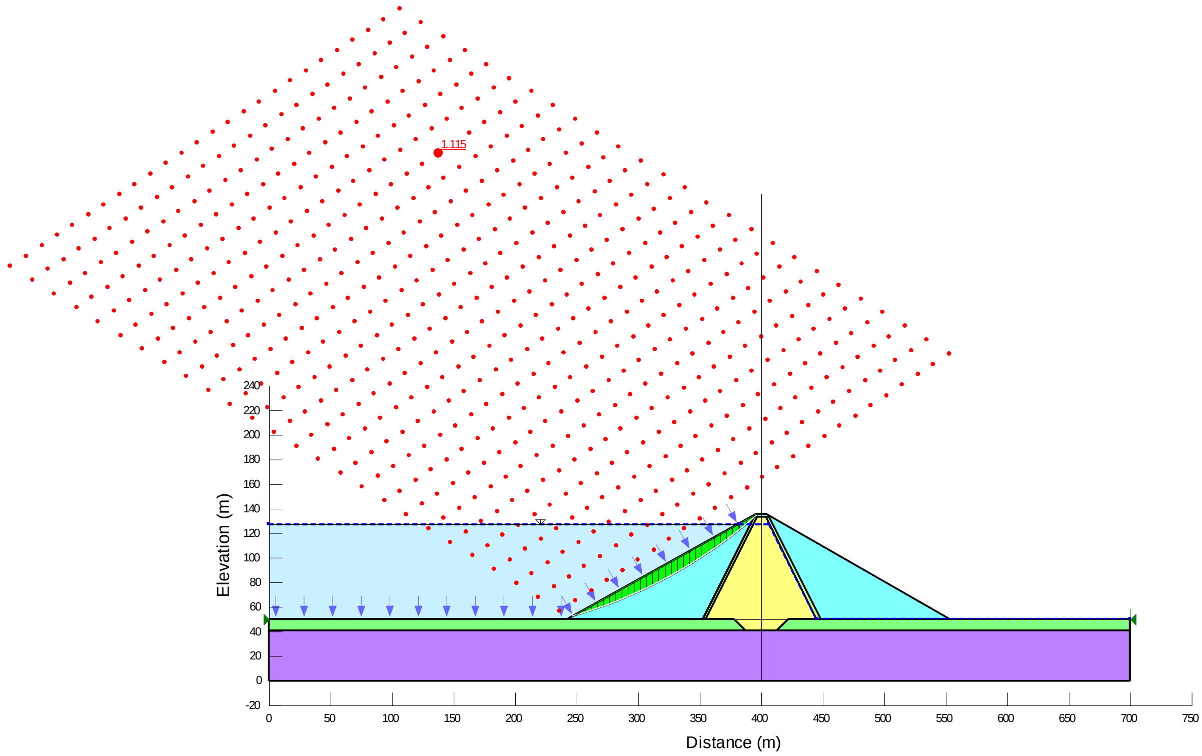


Figure C.16: Earthcore rockfill dam: Upstream slope 1.8 (V:H), Downstream slope 1:1.75 (V:H), Analysis 2.2, Upstream, dam full with seismic action

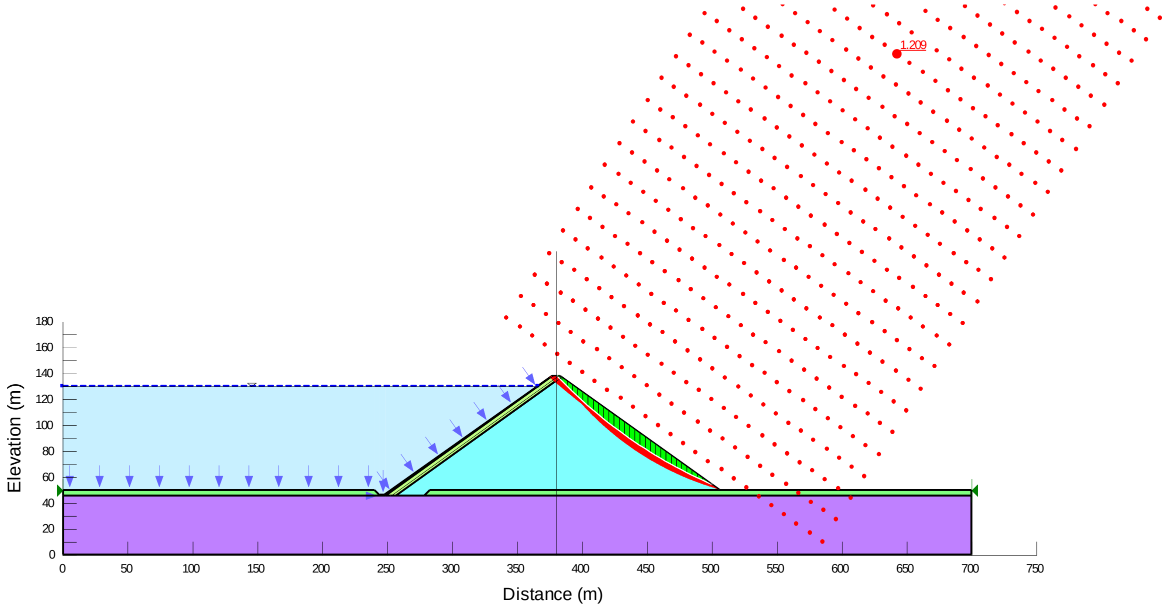


Figure C.17: Concrete faced rockfill dam: Upstream slope 1:1.4 (V:H), Downstream slope 1:1.4 (V:H), Analysis 1.1, Downstream, dam full with steady state flow

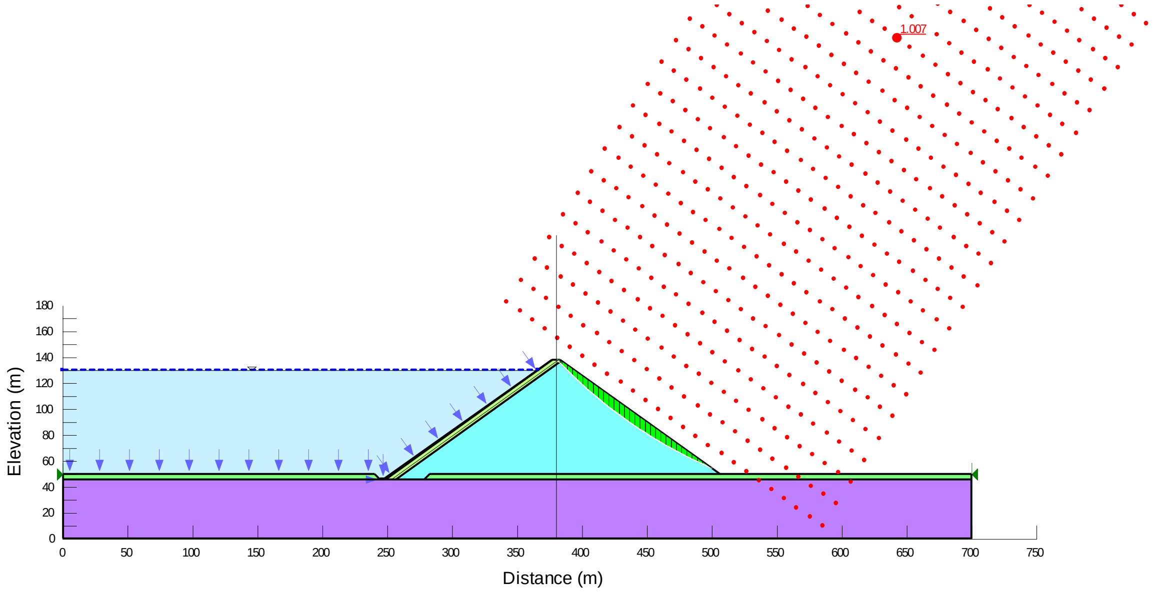


Figure C.18: Concrete faced rockfill dam: Upstream slope 1:1.4 (V:H), Downstream slope 1:1.4 (V:H), Analysis 1.2, Downstream, dam full with seismic load

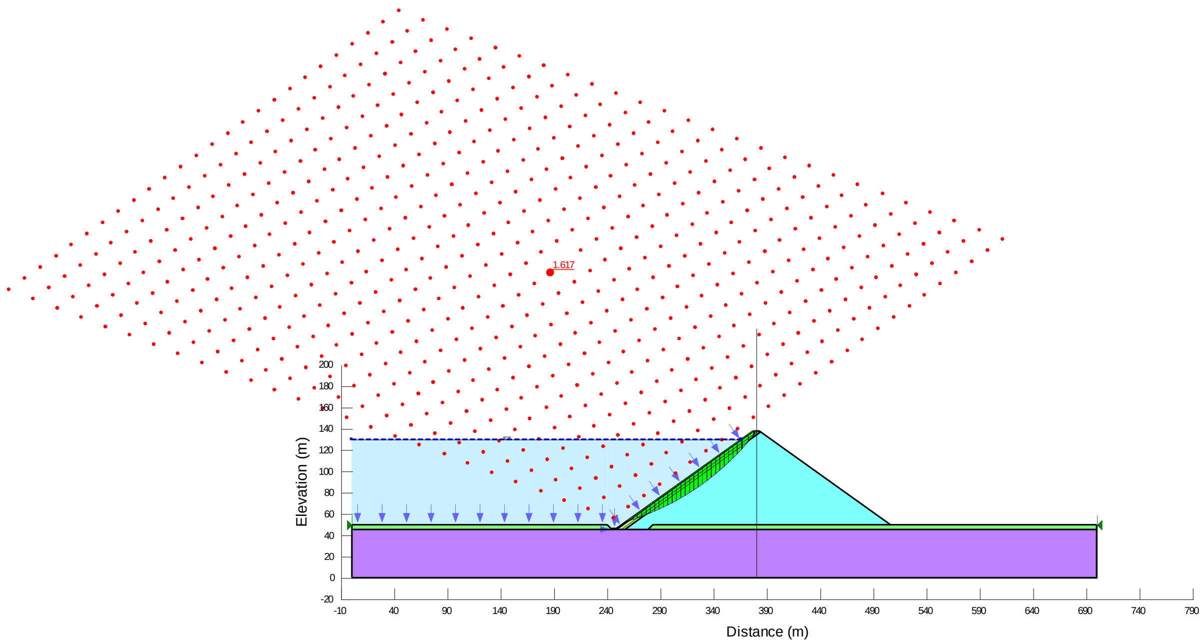


Figure C.19: Concrete faced rockfill dam: Upstream slope 1:1.4 (V:H), Downstream slope 1:1.4 (V:H), Analysis 1.3, upstream, dam full with steady state flow

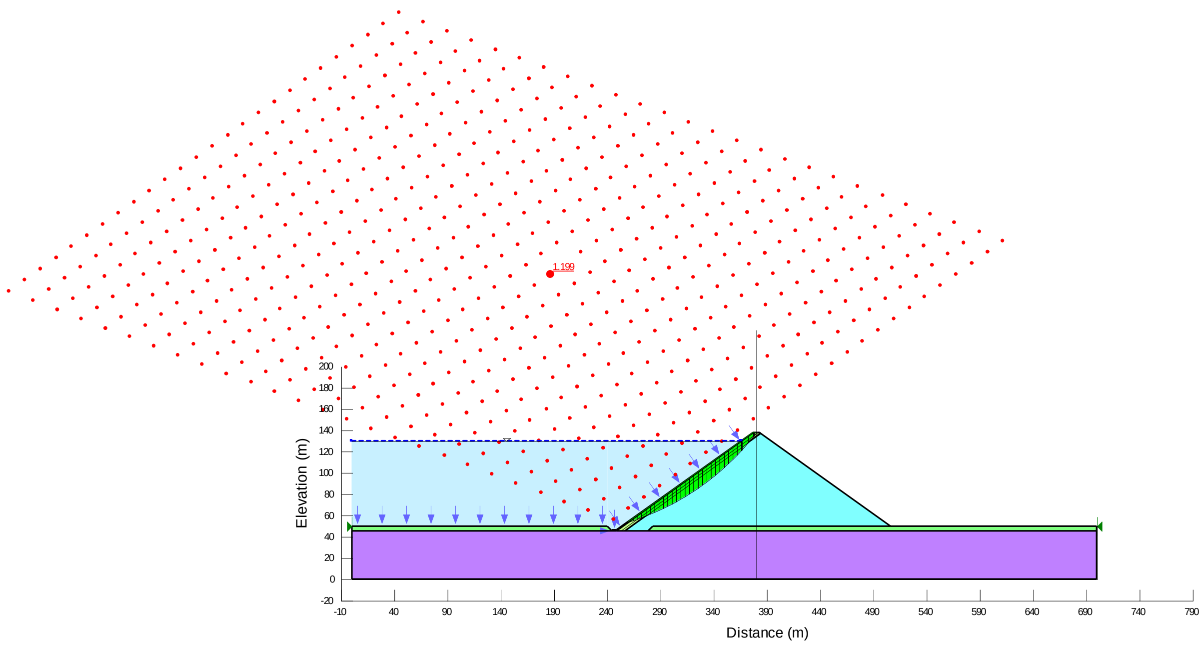


Figure C.20: Concrete faced rockfill dam: Upstream slope 1:1.4 (V:H), Downstream slope 1:1.4 (V:H), Analysis 1.4, Upstream, dam full with seismic load

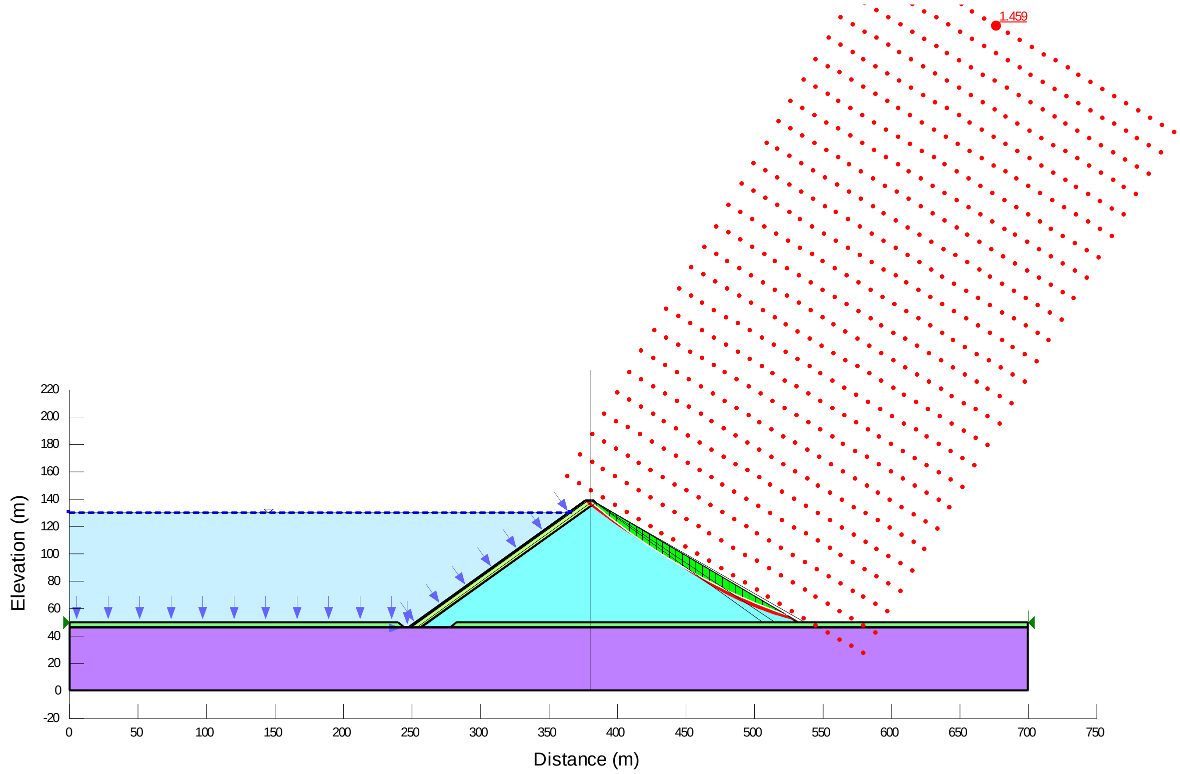


Figure C.21: Concrete faced rockfill dam: Upstream slope 1:1.4 (V:H), Downstream slope 1:1.5 (V:H), Analysis 2.1, Downstream, dam full with steady state flow

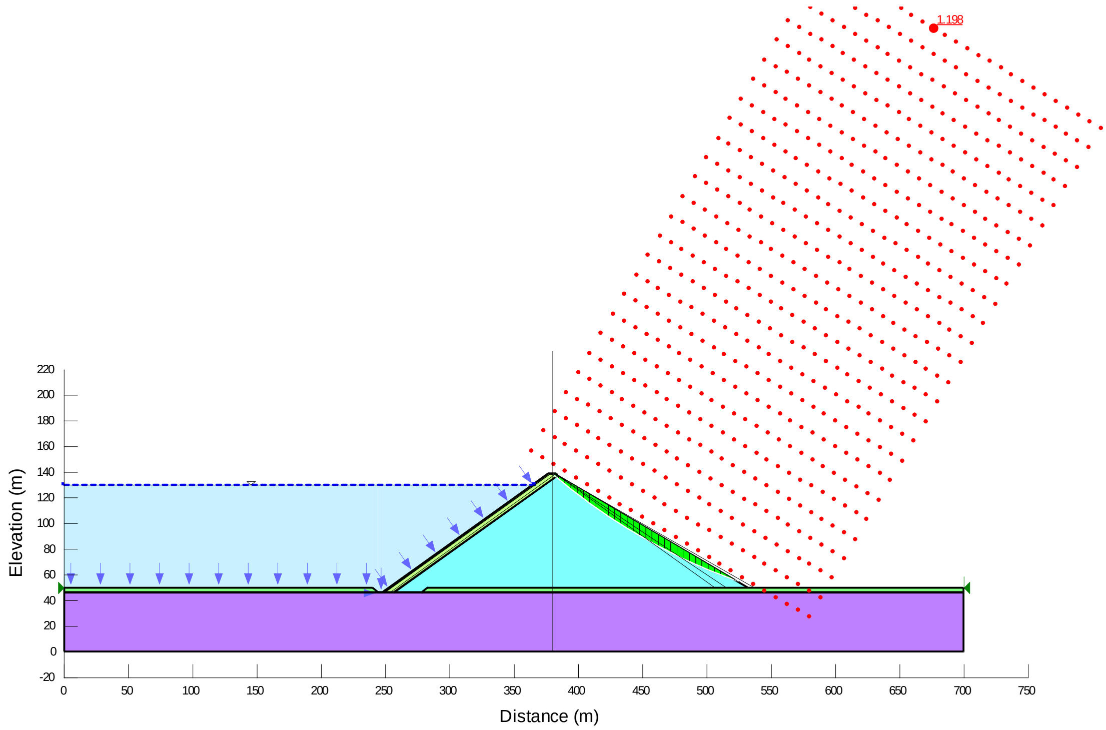


Figure C.22: Concrete faced rockfill dam: Upstream slope 1:1.4 (V:H), Downstream slope 1:1.5 (V:H), Analysis 2.2, Downstream, dam full with seismic load

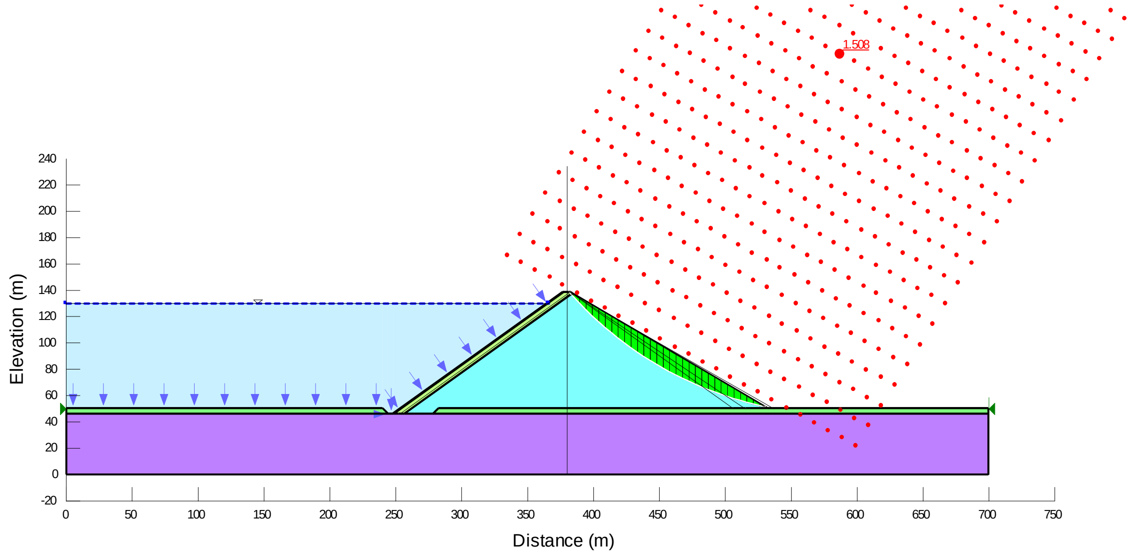


Figure C.23: Concrete faced rockfill dam: Upstream slope 1:1.4 (V:H), Downstream slope 1:1.7 (V:H), Analysis 3.1, Downstream, dam full with steady state flow

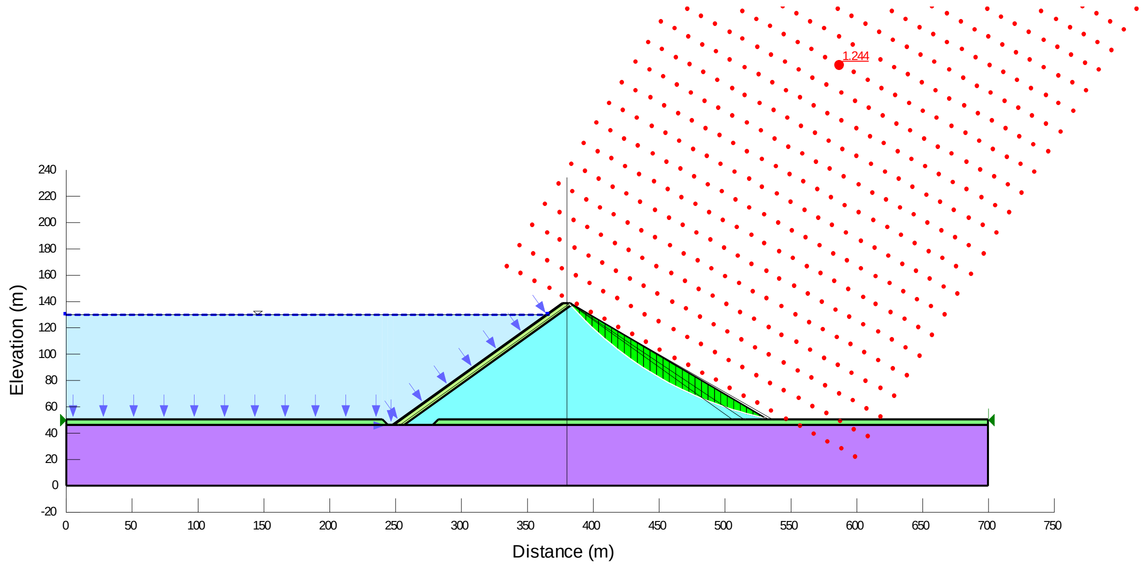


Figure C.24: Concrete faced rockfill dam: Upstream slope 1:1.4 (V:H), Downstream slope 1:1.7 (V:H), Analysis 3.2, Downstream, dam full with seismic action

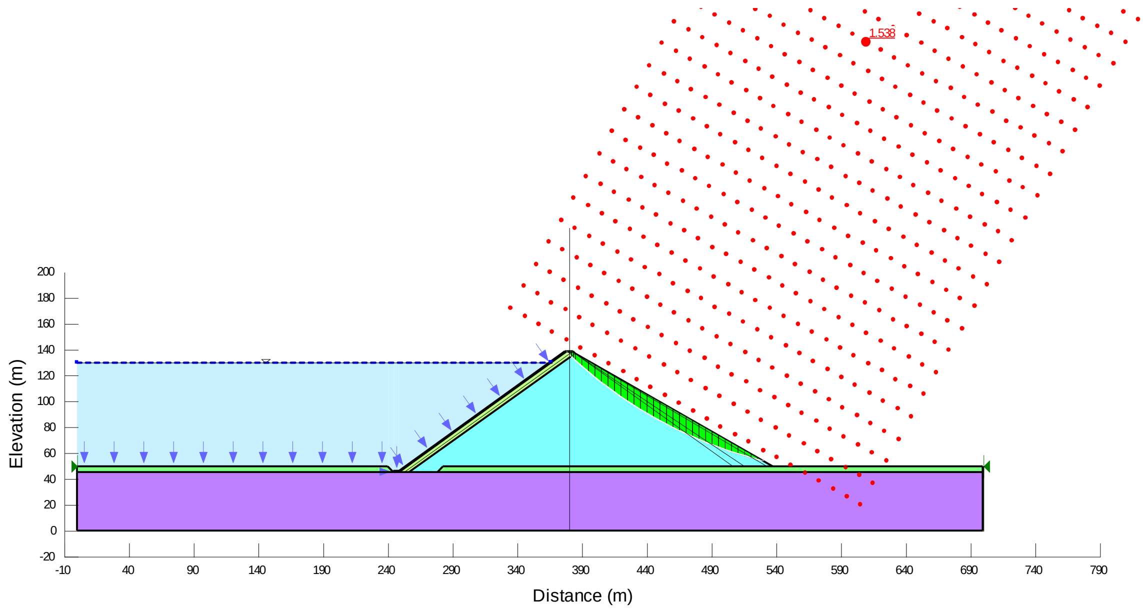


Figure C.25: Concrete faced rockfill dam: Upstream slope 1:1.4 (V:H), Downstream slope 1:1.75 (V:H), Analysis 4.1, Downstream, dam full with steady state flow

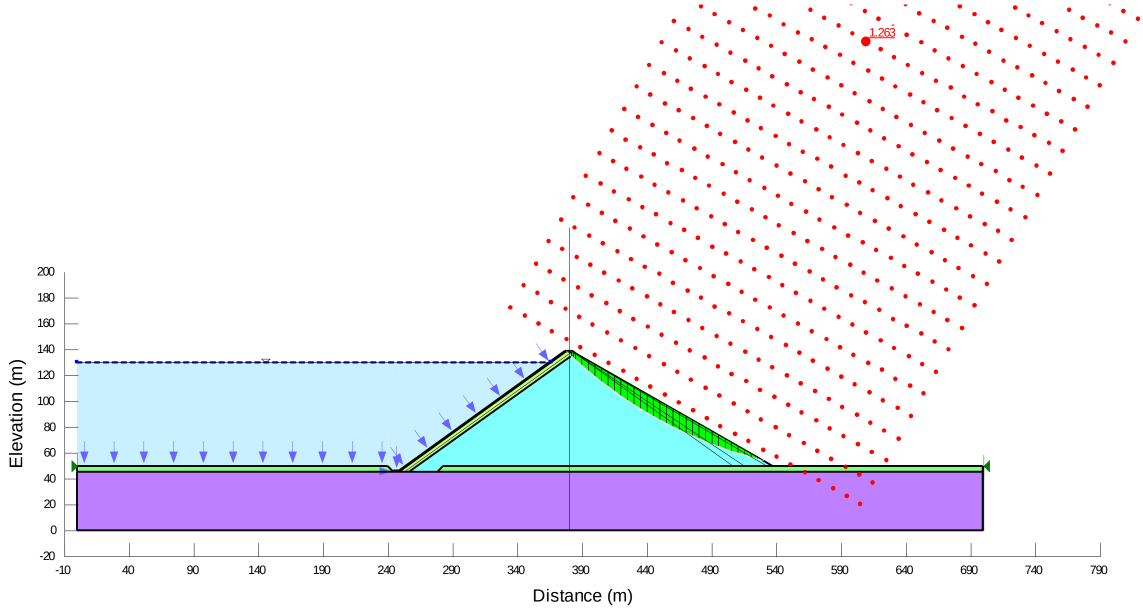


Figure C.26: Concrete faced rockfill dam: Upstream slope 1:1.4 (V:H), Downstream slope 1:1.75 (V:H), Analysis 4.2, Downstream, dam full with seismic action

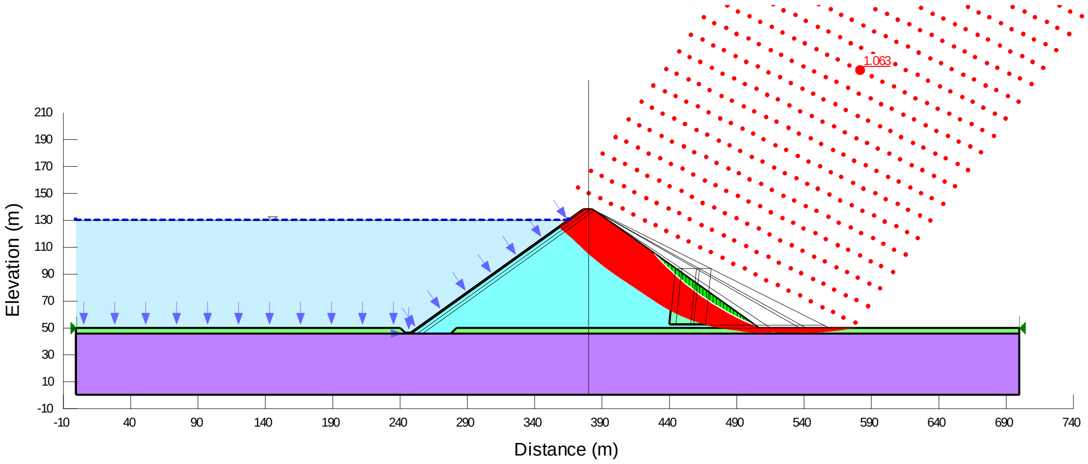


Figure C.27: Zoned CFRD Option 1: Upstream slopes 1:1.4 (V:H), downstream slope 1:1.4 (V:H), Analysis 1.1 Dam full and steady state flow

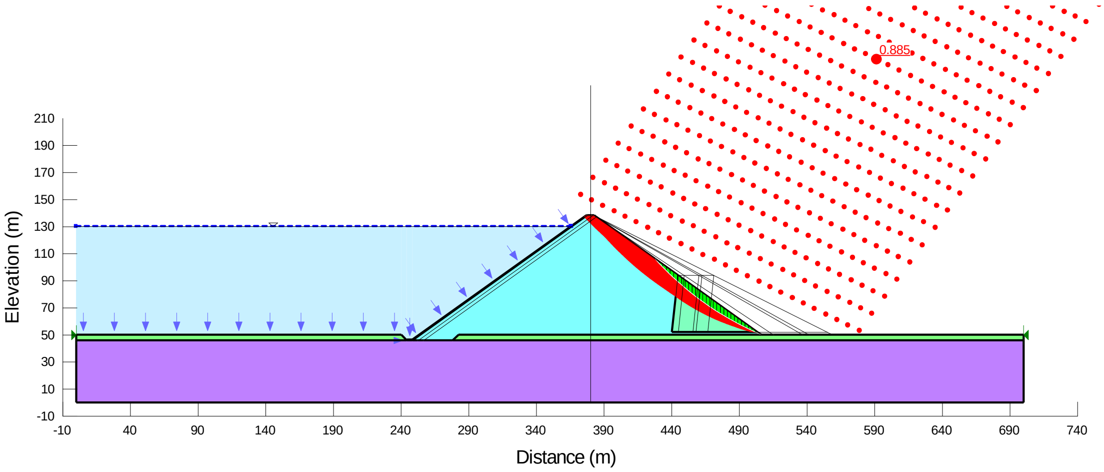


Figure C.28: Zoned CFRD Option 1: Upstream slopes 1:1.4 (V:H), downstream slope 1:1.4 (V:H), Analysis 1.2 Seismic load

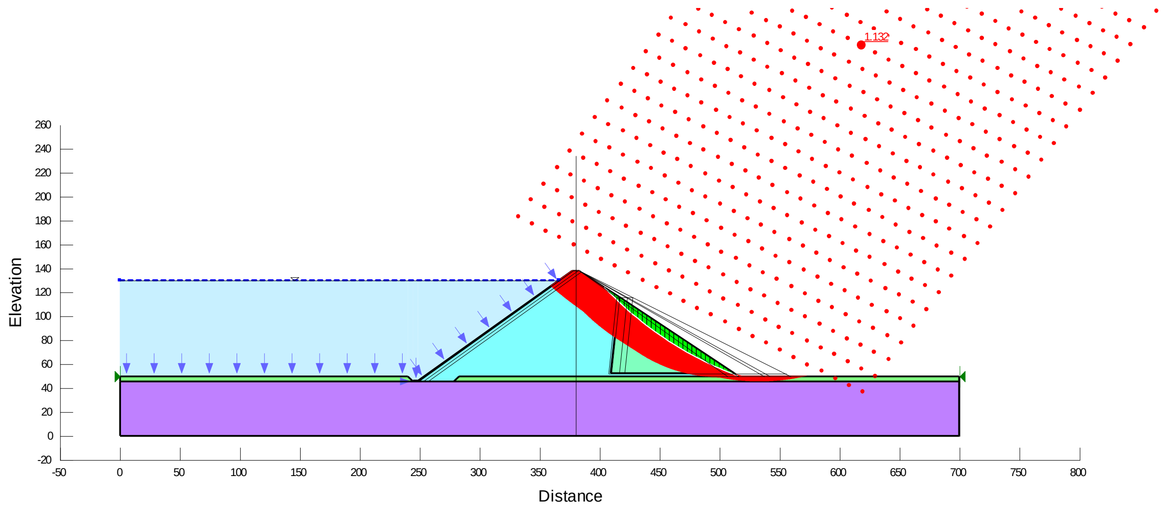


Figure C.29: Zoned CFRD Option 1: Upstream slopes 1:1.4 (V:H), downstream slope 1:1.5 (V:H), Analysis 2.1 Dam full and steady state flow

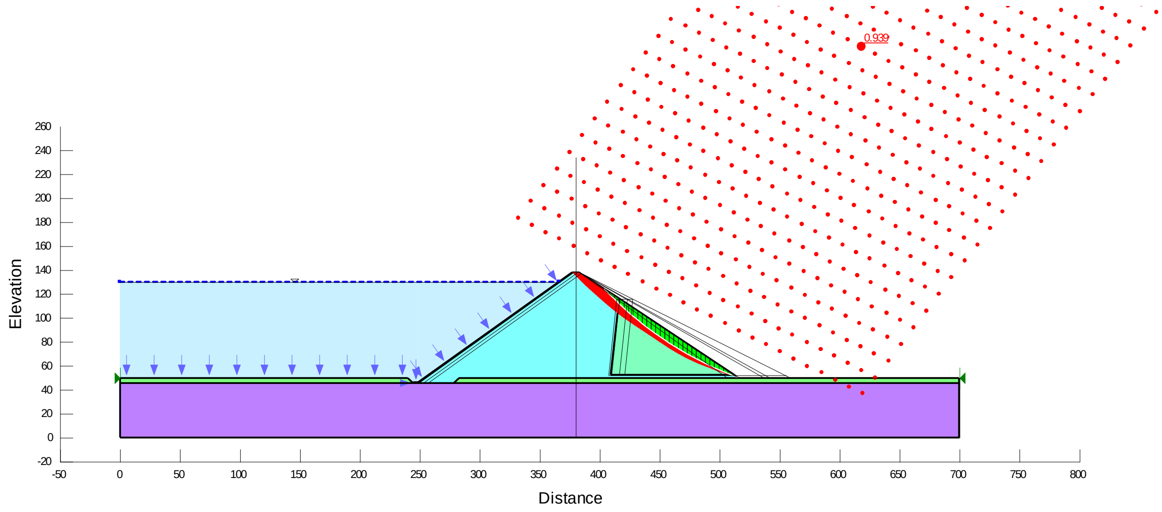


Figure C.30: Zoned CFRD Option 1: Upstream slopes 1:1.4 (V:H), downstream slope 1:1.5 (V:H), Analysis 2.2 Seismic load

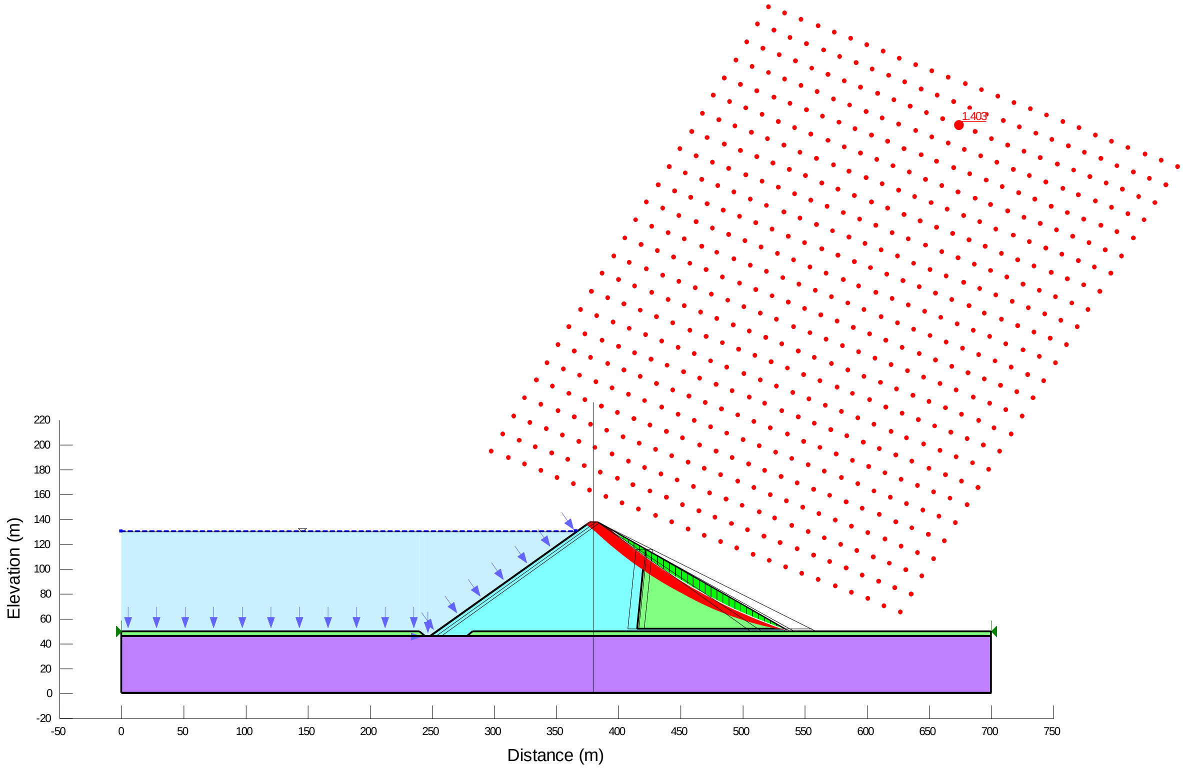


Figure C.31: Zoned CFRD Option 1: Upstream slopes 1:1.4 (V:H), downstream slope 1:1.75 (V:H), Analysis 3.1 Dam full and steady state flow

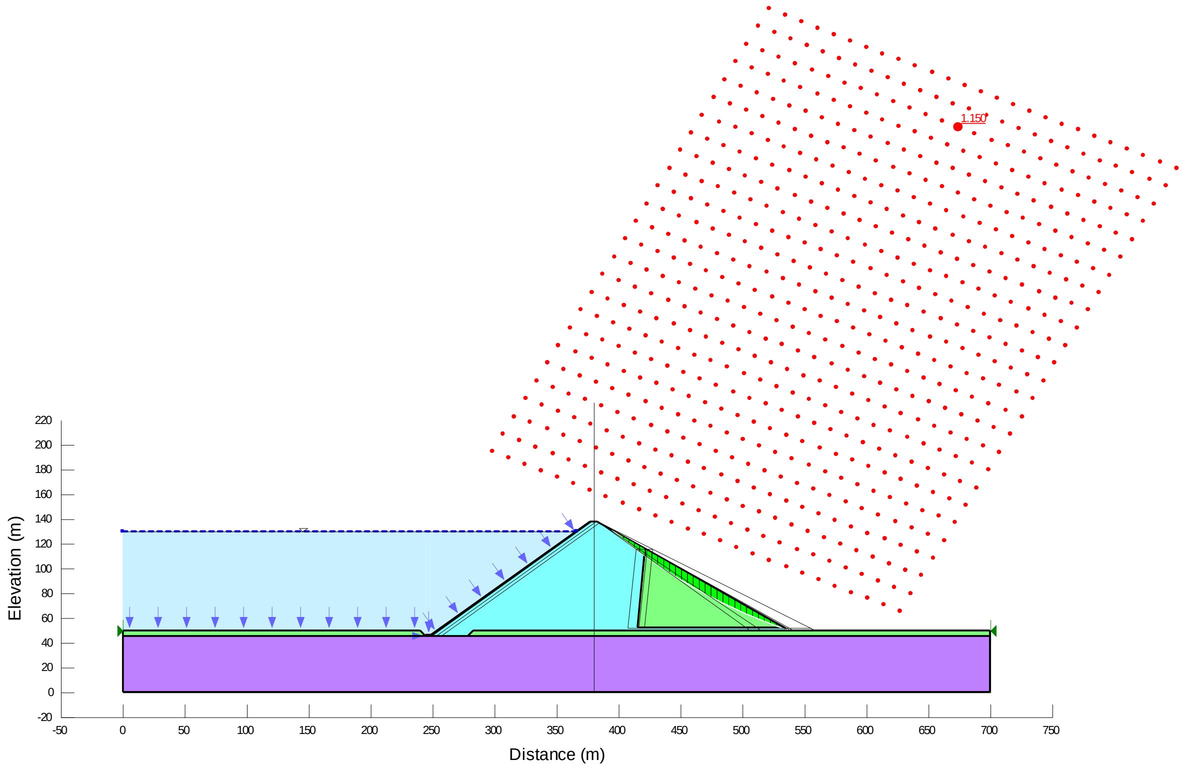


Figure C.32: Zoned CFRD Option 1: Upstream slopes 1:1.4 (V:H), downstream slope 1:1.4 (V:H), Analysis 3.2 Seismic load

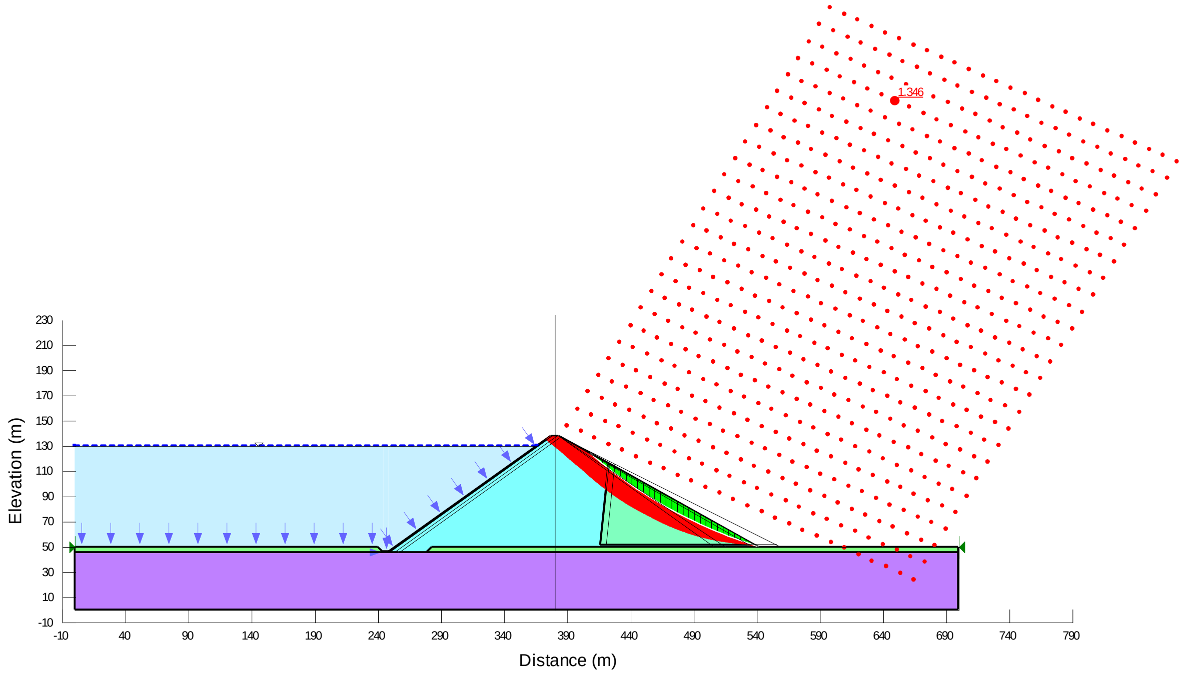


Figure C.33: Zoned CFRD Option 1: Upstream slopes 1:1.4 (V:H), downstream slope 1:1.8 (V:H), Analysis 4.1 Dam full and steady state flow

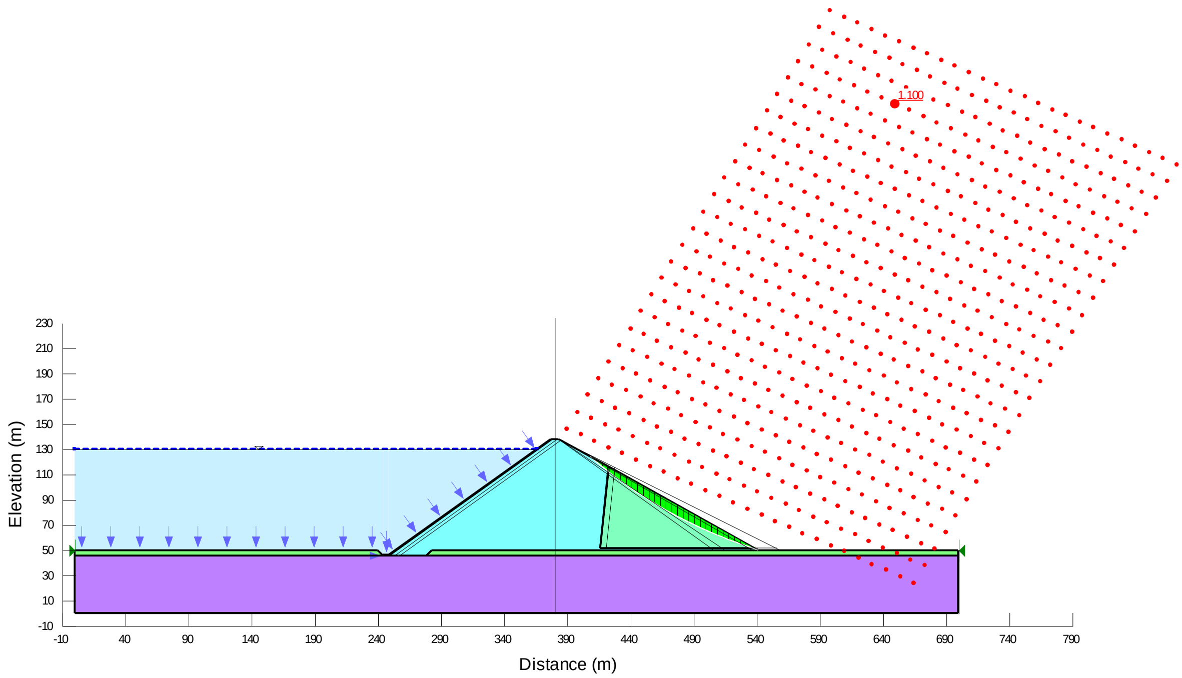


Figure C.34: Zoned CFRD Option 1: Upstream slopes 1:1.4 (V:H), downstream slope 1:1.8 (V:H), Analysis 4.2 Seismic load

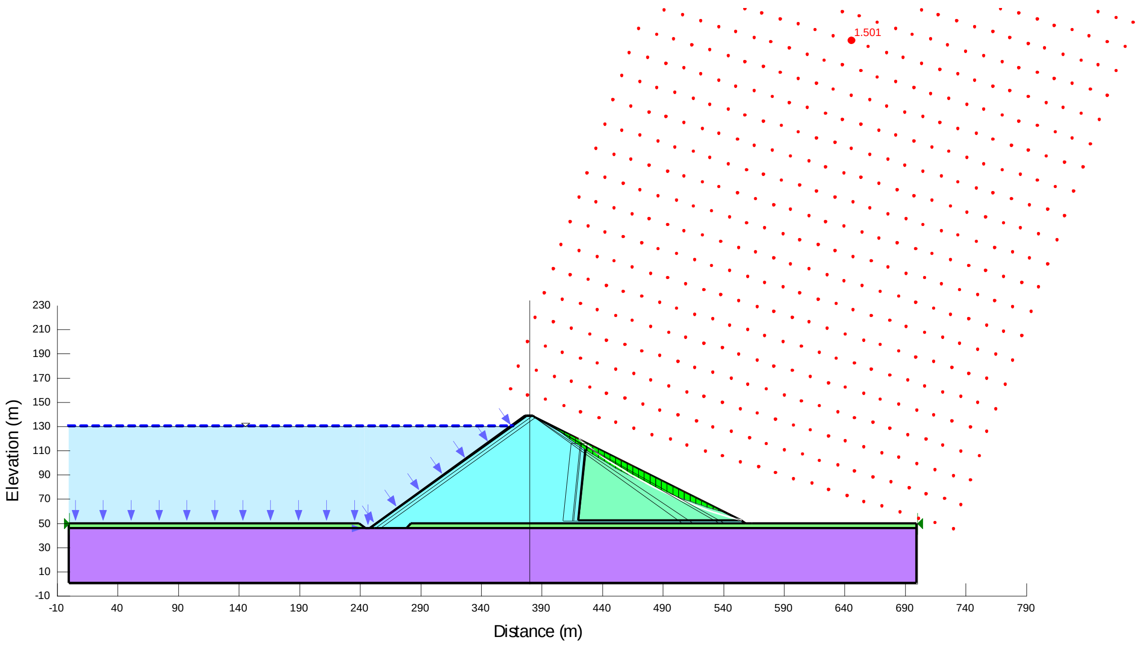


Figure C.35: Zoned CFRD Option 1: Upstream slopes 1:1.4 (V:H), Downstream slope 1:2 (V:H), Analysis 5.1 Dam full and steady state flow

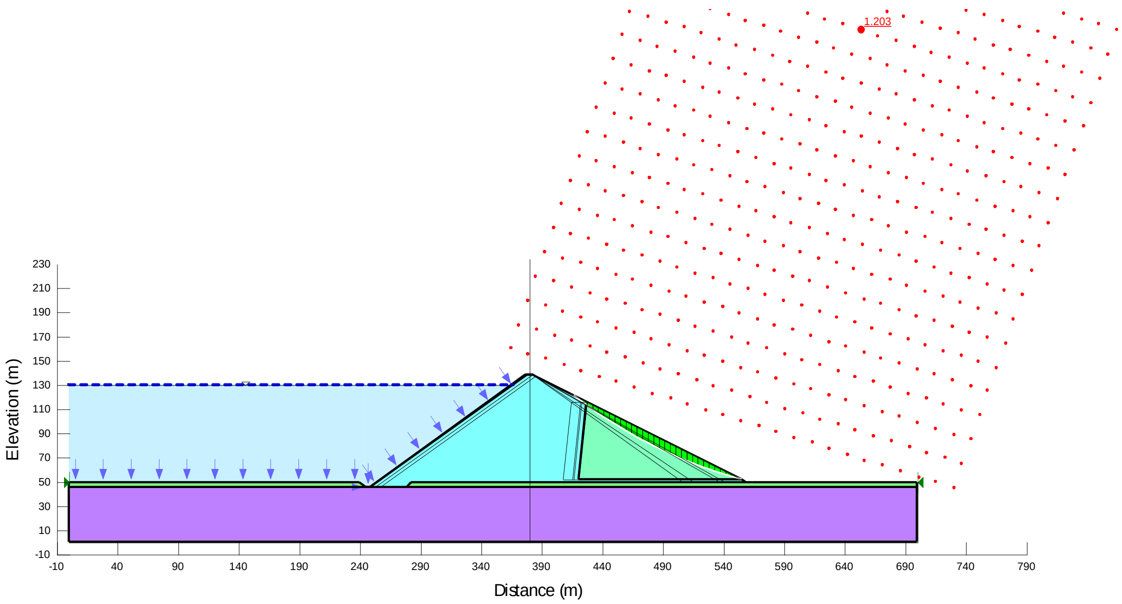


Figure C.36: Zoned CFRD Option 1: Upstream slopes 1:1.4 (V:H), downstream slope 1:2 (V:H), Analysis 5.2 Seismic load

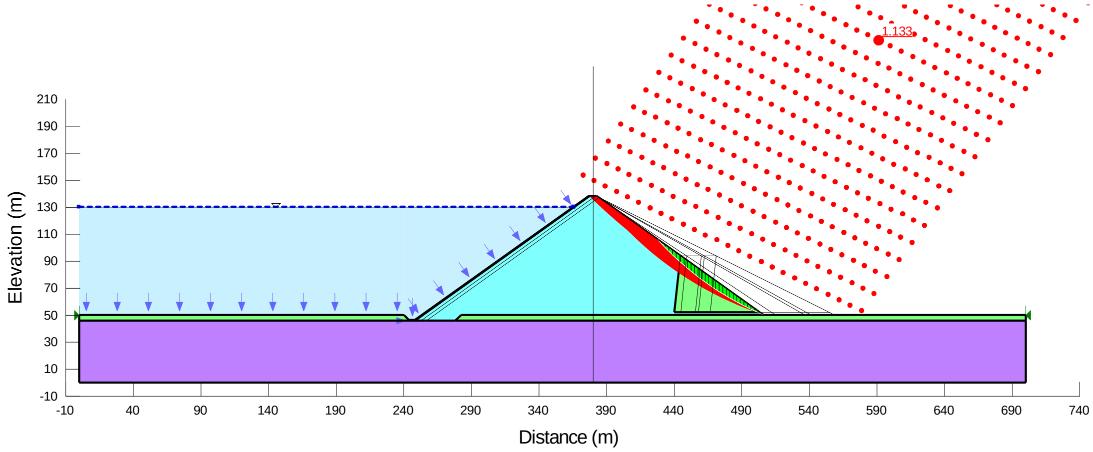


Figure C.37: Zoned CFRD Option 2: Upstream slopes 1:1.4 (V:H), downstream slope 1:1.4 (V:H), Analysis 1.1 Dam full and steady state flow

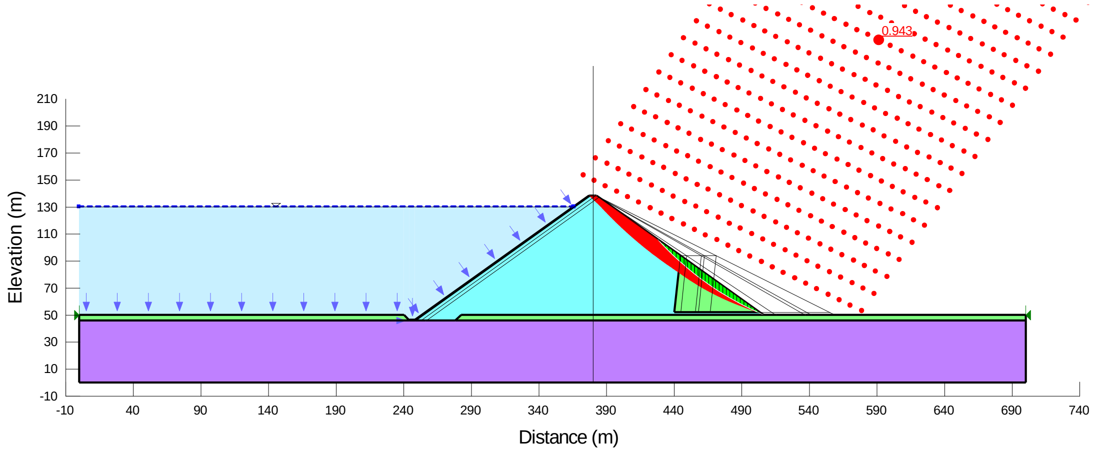


Figure C.38: Zoned CFRD Option 2: Upstream slopes 1:1.4 (V:H), downstream slope 1:1.4 (V:H), Analysis 1.2 Seismic load

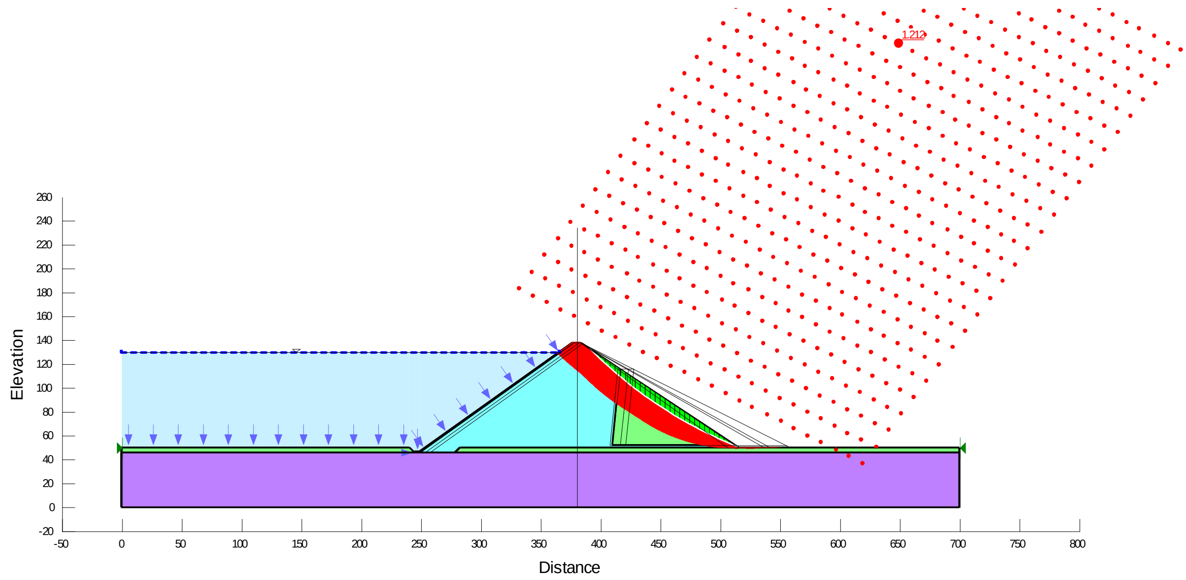


Figure C.39: Zoned CFRD Option 2: Upstream slopes 1:1.4 (V:H), downstream slope 1:1.4 (V:H), Analysis 2.1 Dam full and steady state flow

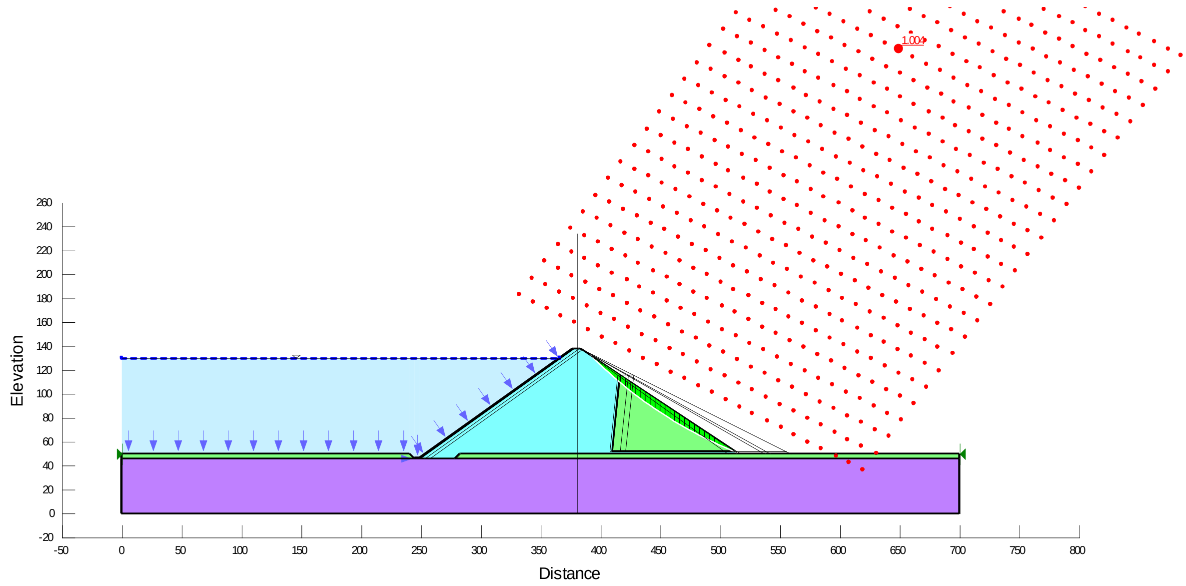


Figure C.40: Zoned CFRD Option 2: Upstream slopes 1:1.4 (V:H), downstream slope 1:1.5 (V:H), Analysis 2.2 Seismic load

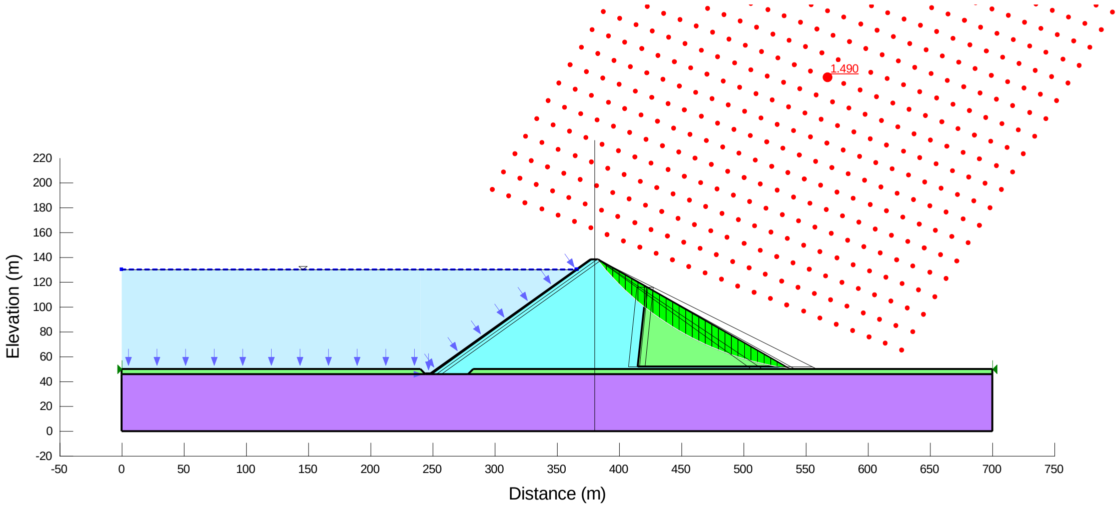


Figure C.41: Zoned CFRD Option 2: Upstream slopes 1:1.4 (V:H), downstream slope 1:1.75 (V:H), Analysis 3.1 Dam full and steady state flow

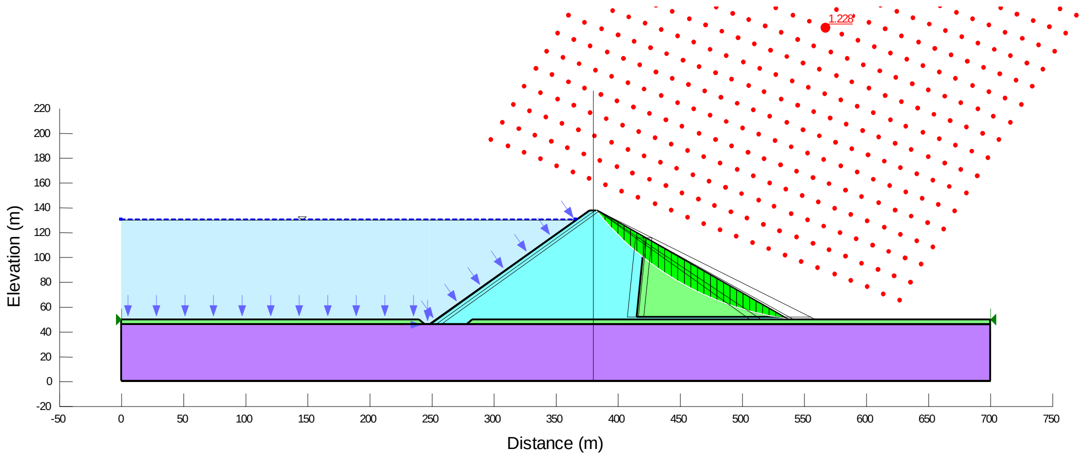


Figure C.42: Zoned CFRD Option 2: Upstream slopes 1:1.4 (V:H), downstream slope 1:1.75 (V:H), Analysis 3.2 Seismic load

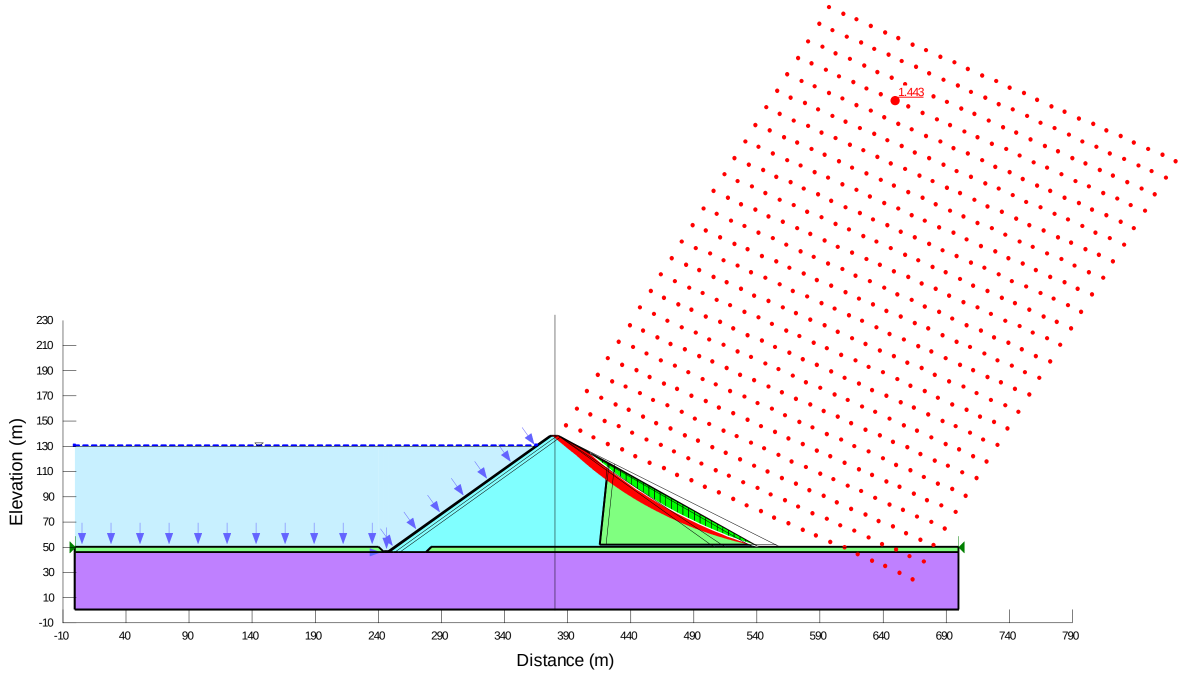


Figure C.43: Zoned CFRD Option 2: Upstream slopes 1:1.4 (V:H), downstream slope 1:1.8 (V:H), Analysis 4.1 Dam full and steady state flow

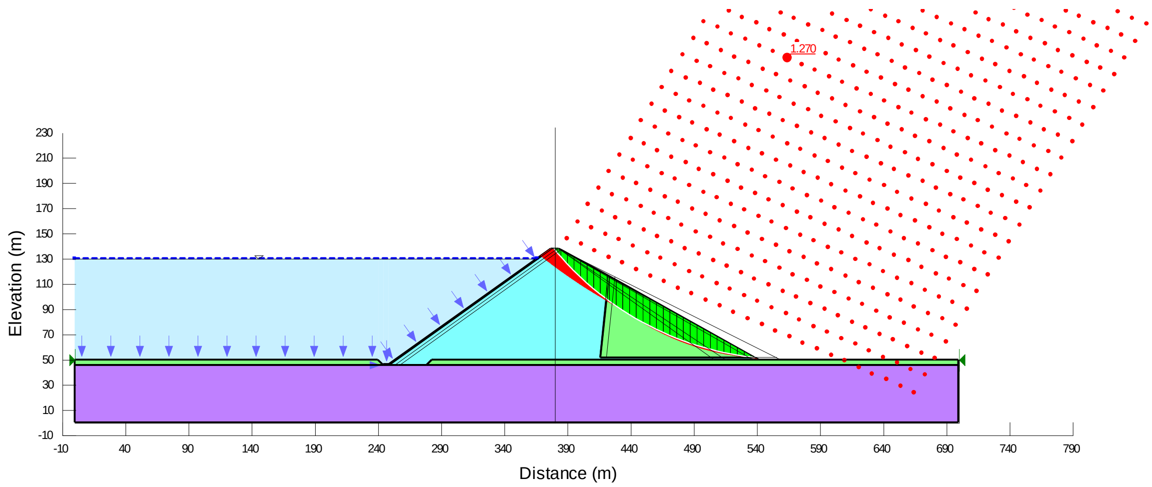


Figure C.44: Zoned CFRD Option 2: Upstream slopes 1:1.4 (V:H), downstream slope 1:1.8 (V:H), Analysis 4.2 Seismic load

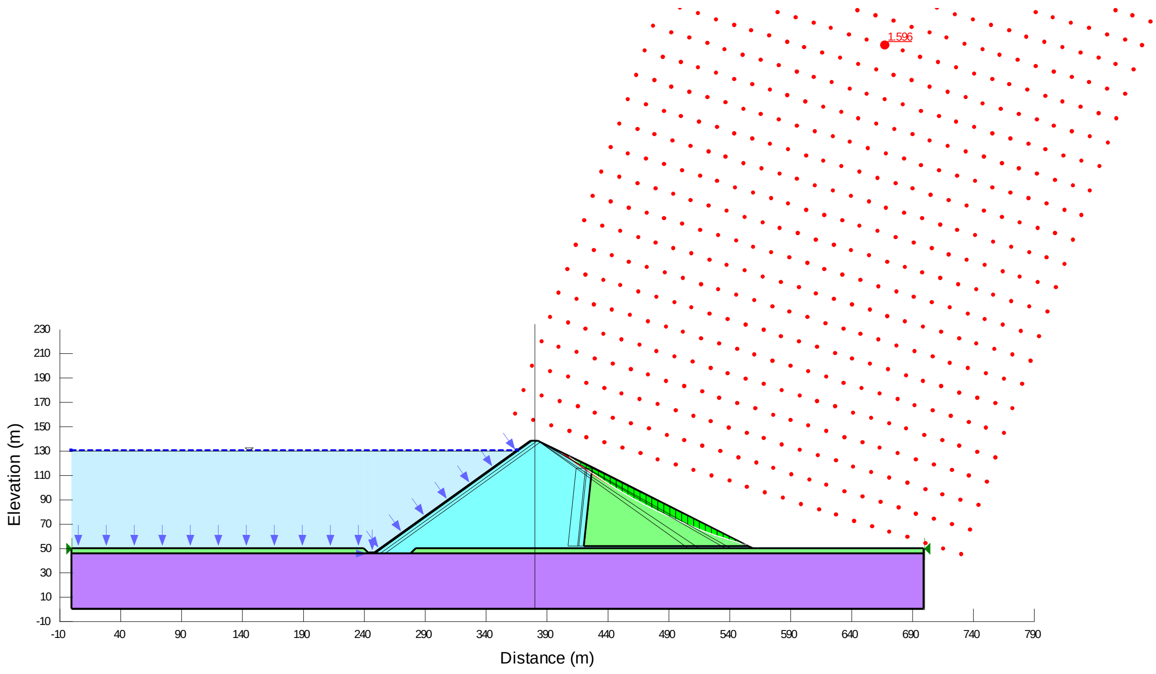


Figure C.45: Zoned CFRD Option 2: Upstream slopes 1:1.4 (V:H), downstream slope 1:2 (V:H), Analysis 5.1 Dam full and steady state flow

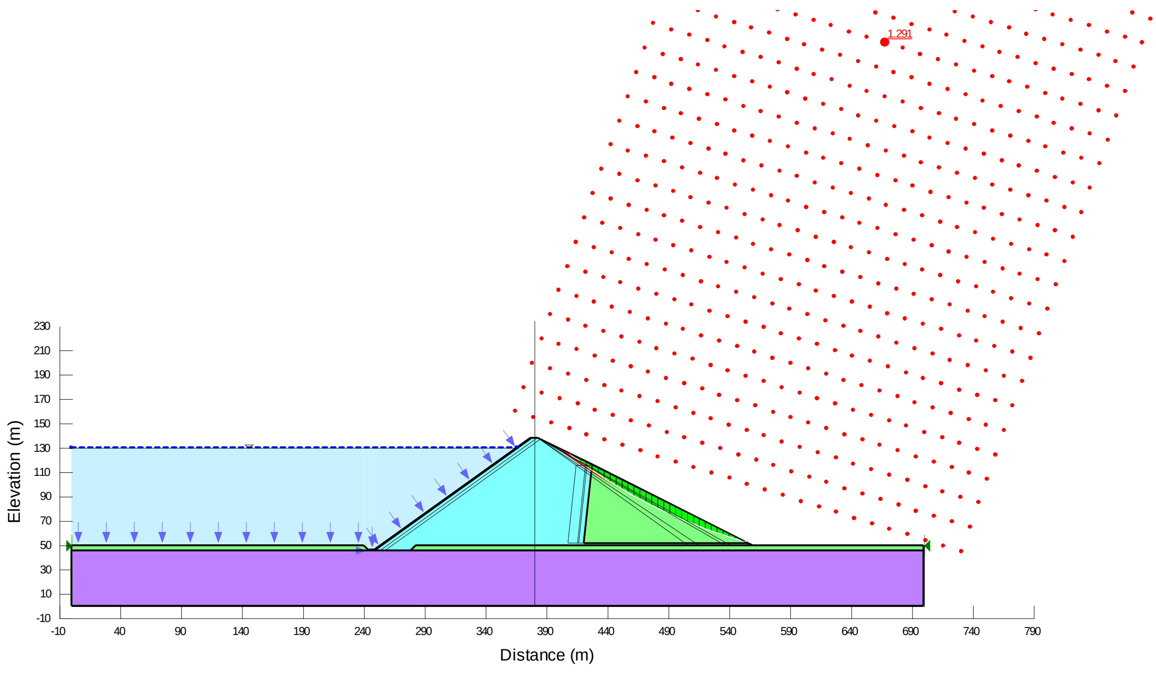


Figure C.46: Zoned CFRD Option 2: Upstream slopes 1:1.4 (V:H), downstream slope 1:2 (V:H), Analysis 5.2 Seismic load

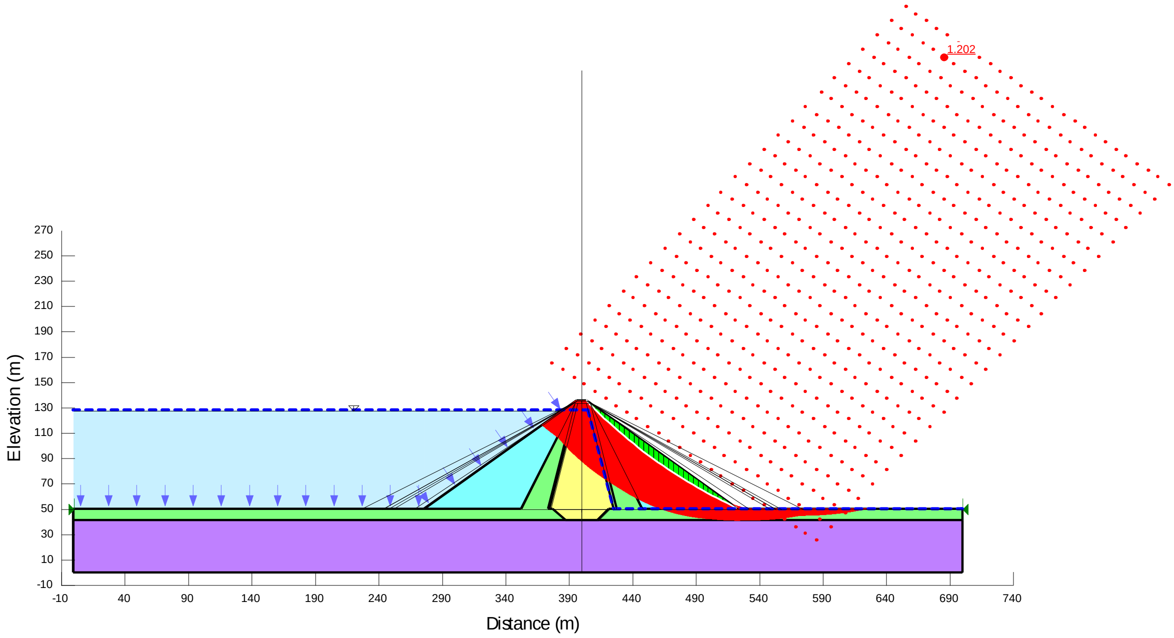


Figure C.47: Zoned earth core rock fill dam: Upstream slopes 1:1.4 (V:H), downstream slope 1:1.4 (V:H), Analysis 1.1 Dam full and steady state flow

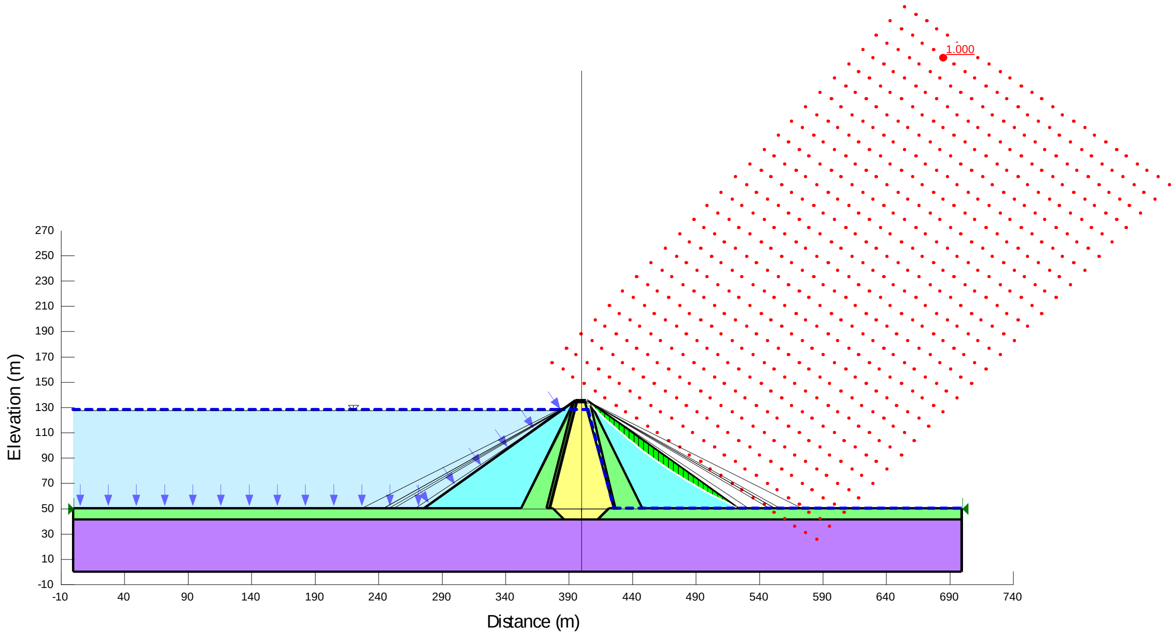


Figure C.48: Zoned earth core rock fill dam: Upstream slopes 1:1.4 (V:H), downstream slope 1:1.4 (V:H), Analysis 1.2 Seismic load

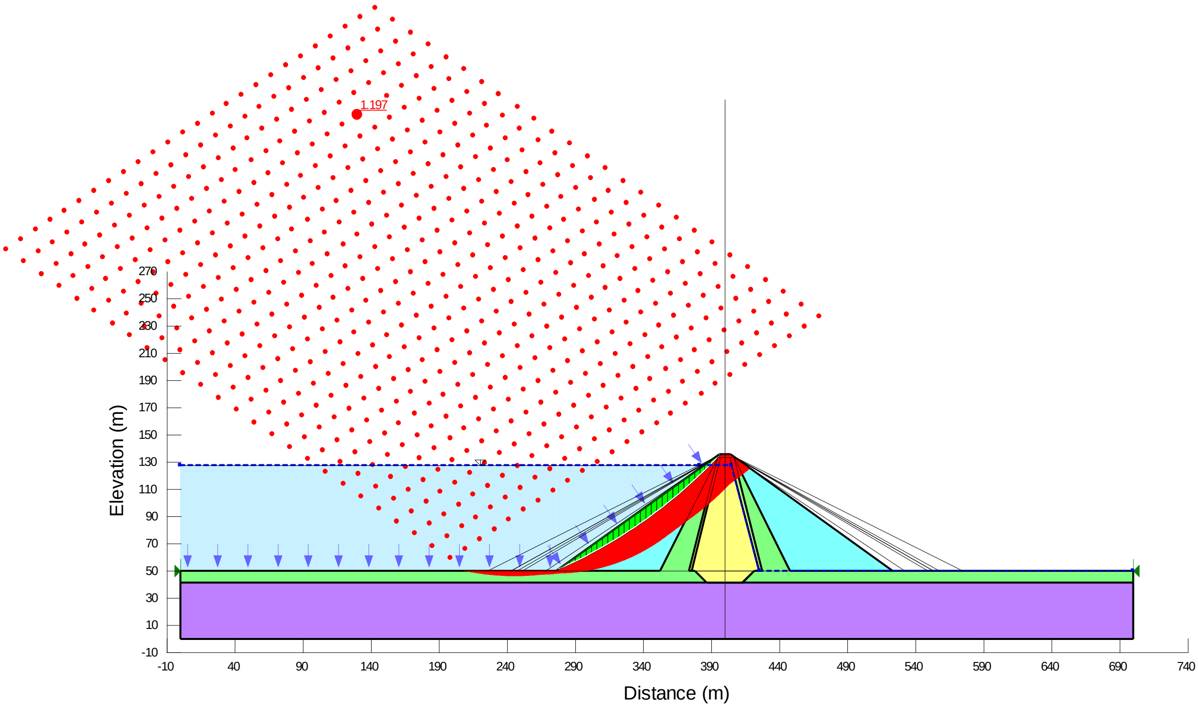


Figure C.49: Zoned earth core rock fill dam: Upstream slopes 1:1.4 (V:H), downstream slope 1:1.4 (V:H), Analysis 1.3 Dam full and steady state flow

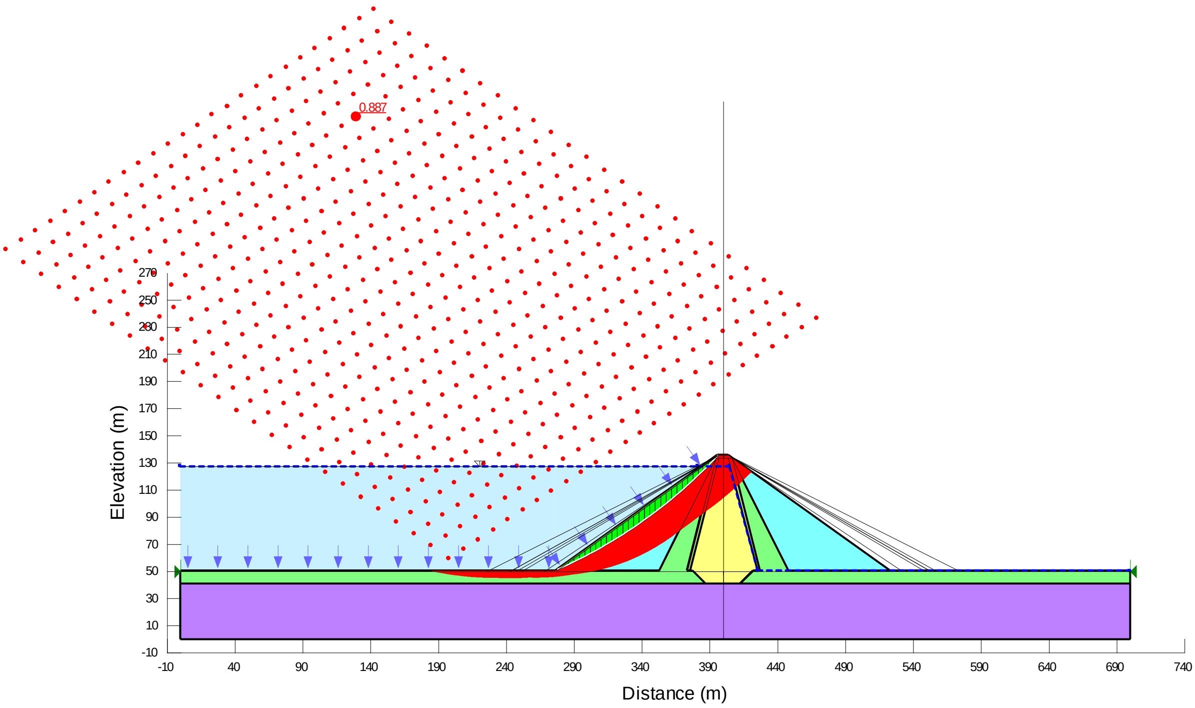


Figure C.50: Zoned earth core rock fill dam: Upstream slopes 1:1.4 (V:H), downstream slope 1:1.4 (V:H), Analysis 1.4 Seismic load

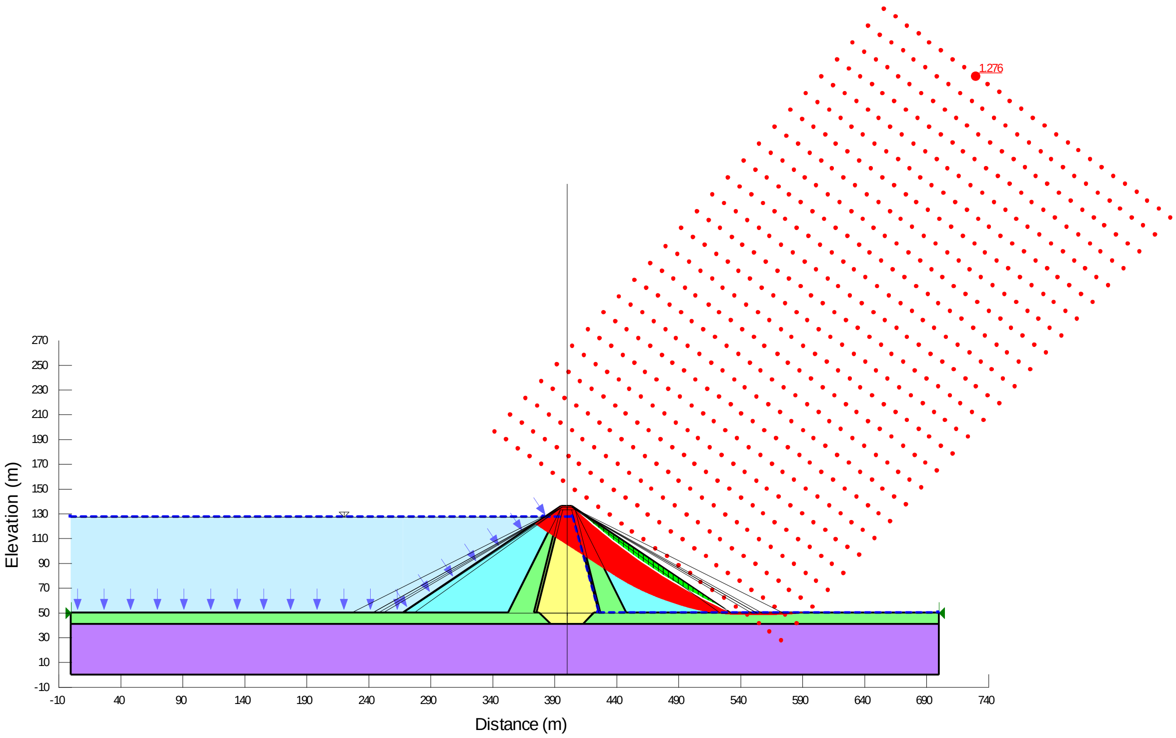


Figure C.51: Zoned earth core rock fill dam: Upstream slopes 1:1.5 (V:H), downstream slope 1:1.5 (V:H), Analysis 2.1 Dam full and steady state flow

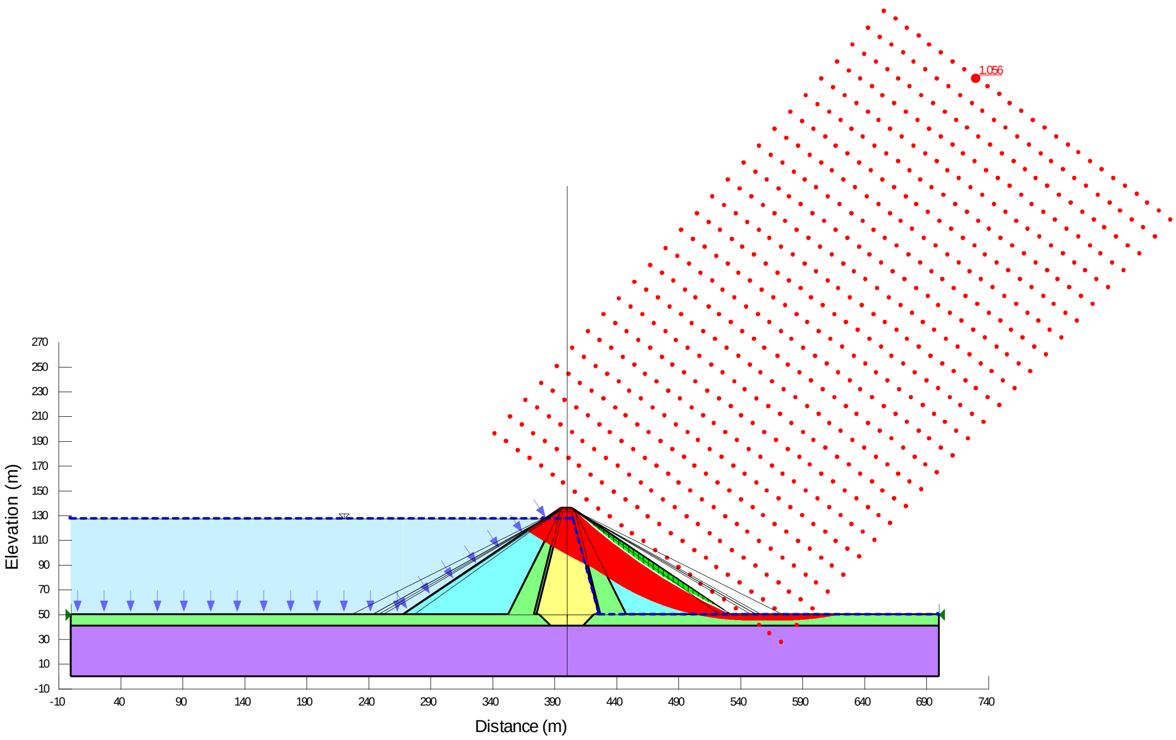


Figure C.52: Zoned earth core rock fill dam: Upstream slopes 1:1.5 (V:H), downstream slope 1:1.5 (V:H), Analysis 2.2 Seismic load

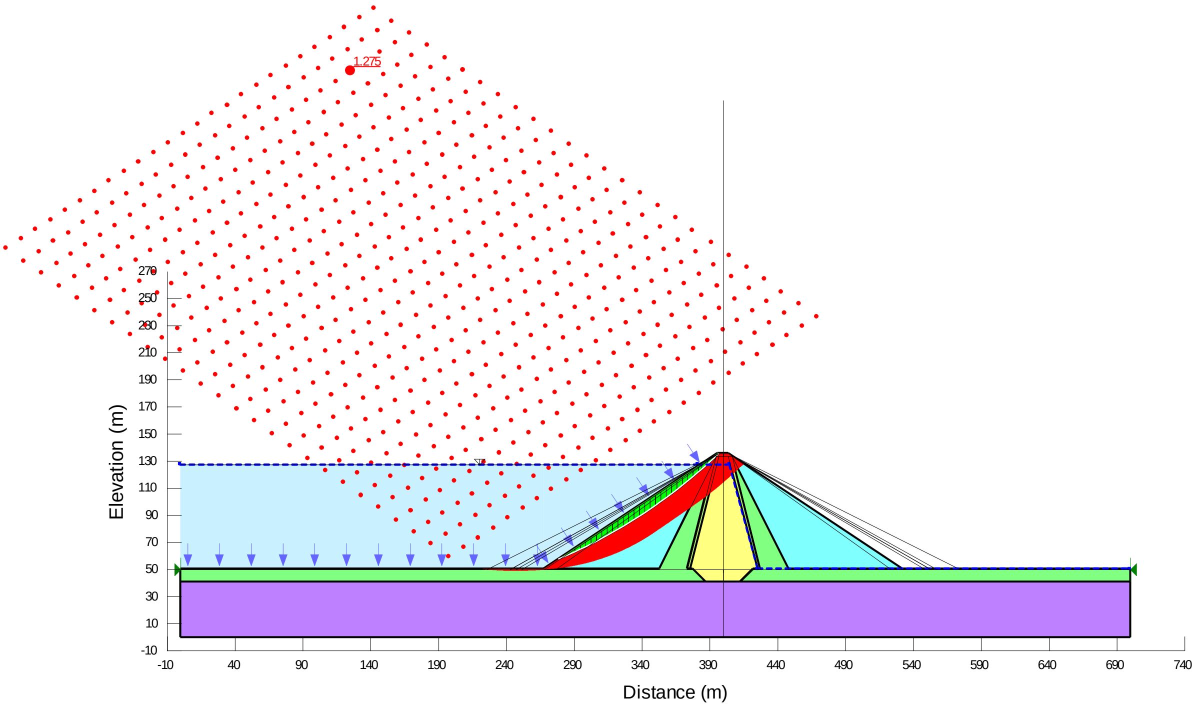


Figure C.53: Zoned earth core rock fill dam: Upstream slopes 1:1.5 (V:H), downstream slope 1:1.5 (V:H), Analysis 2.3 Dam full and steady state flow

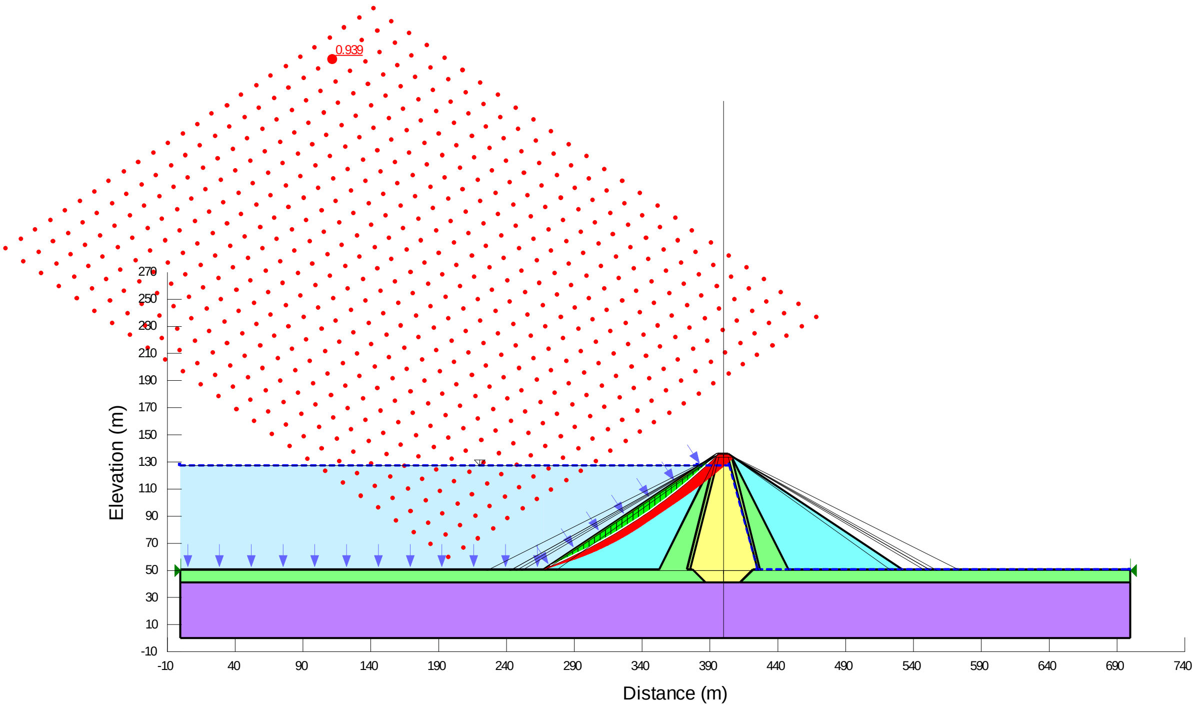


Figure C.54: Zoned earth core rock fill dam: Upstream slopes 1:1.5 (V:H), downstream slope 1:1.5 (V:H), Analysis 2.4 Seismic load

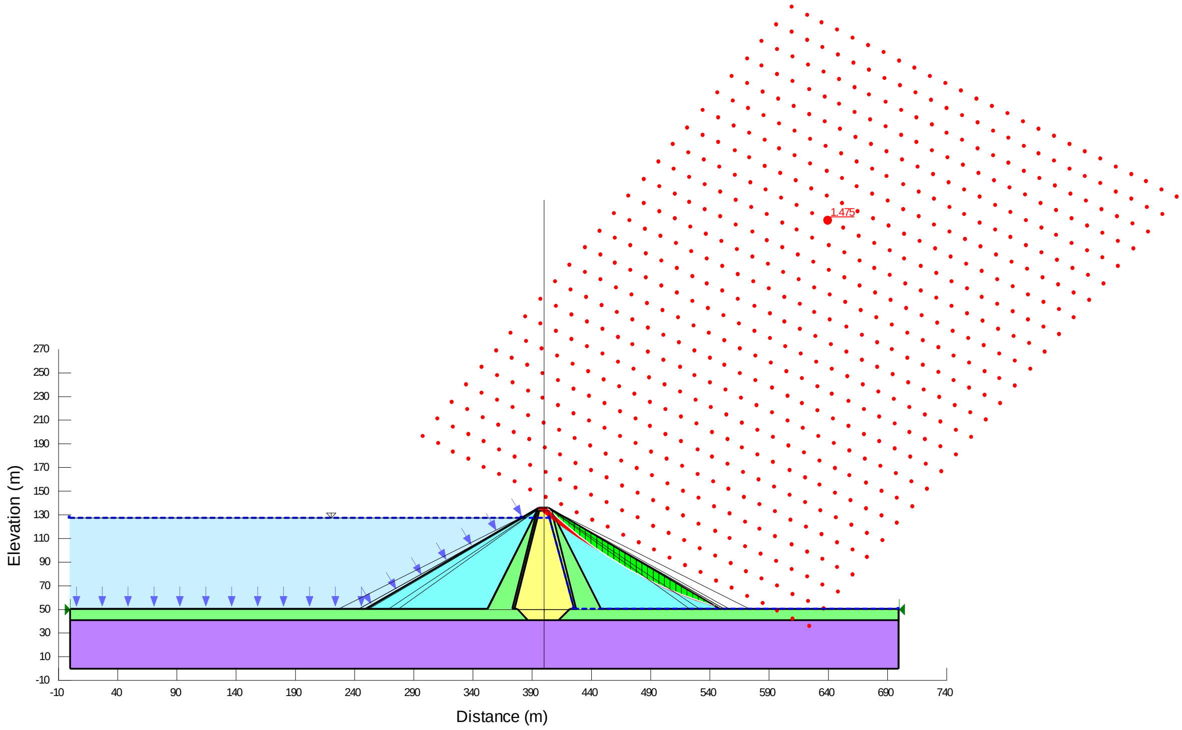


Figure C.55: Zoned earth core rock fill dam: Upstream slopes 1:1.7 (V:H), downstream slope 1:1.7 (V:H), Analysis 3.1 Dam full and steady state flow

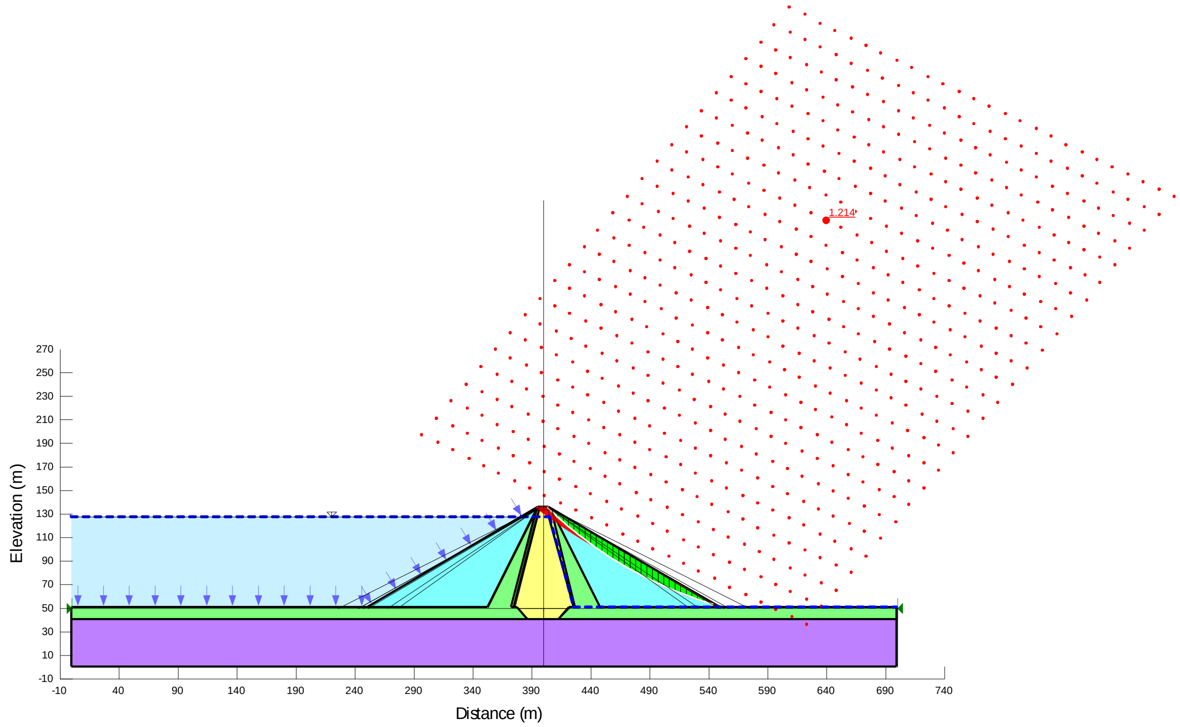


Figure C.56: Zoned earth core rock fill dam: Upstream slopes 1:1.7 (V:H), downstream slope 1:1.7 (V:H), Analysis 3.2 Seismic load

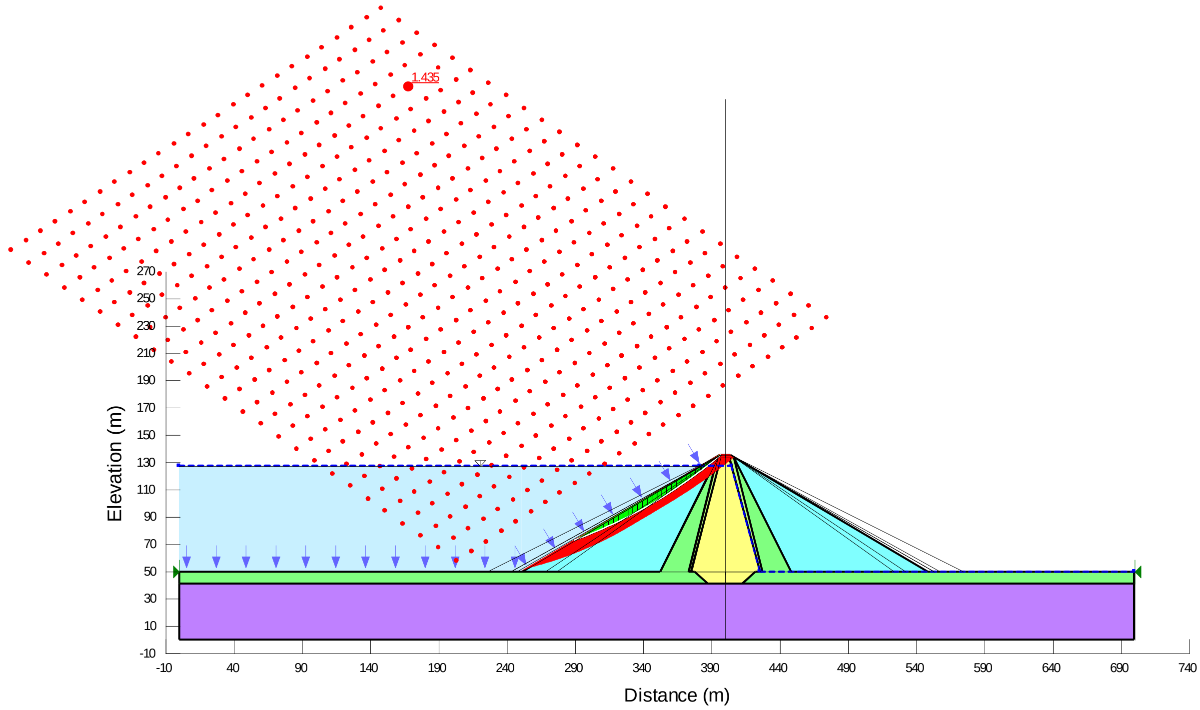


Figure C.57: Zoned earth core rock fill dam: Upstream slopes 1:1.7 (V:H), downstream slope 1:1.7 (V:H), Analysis 3.3 Dam full and steady state flow

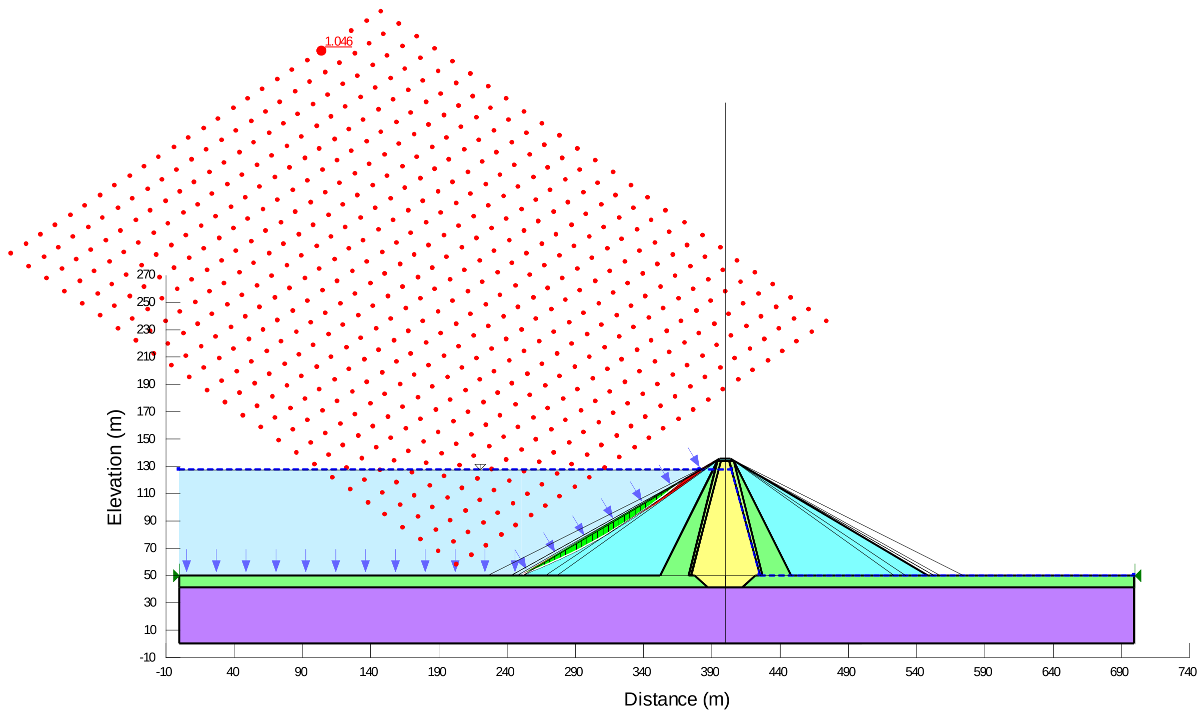


Figure C.58: Zoned earth core rock fill dam: Upstream slopes 1:1.7 (V:H), downstream slope 1:1.7 (V:H), Analysis 3.4 Seismic load

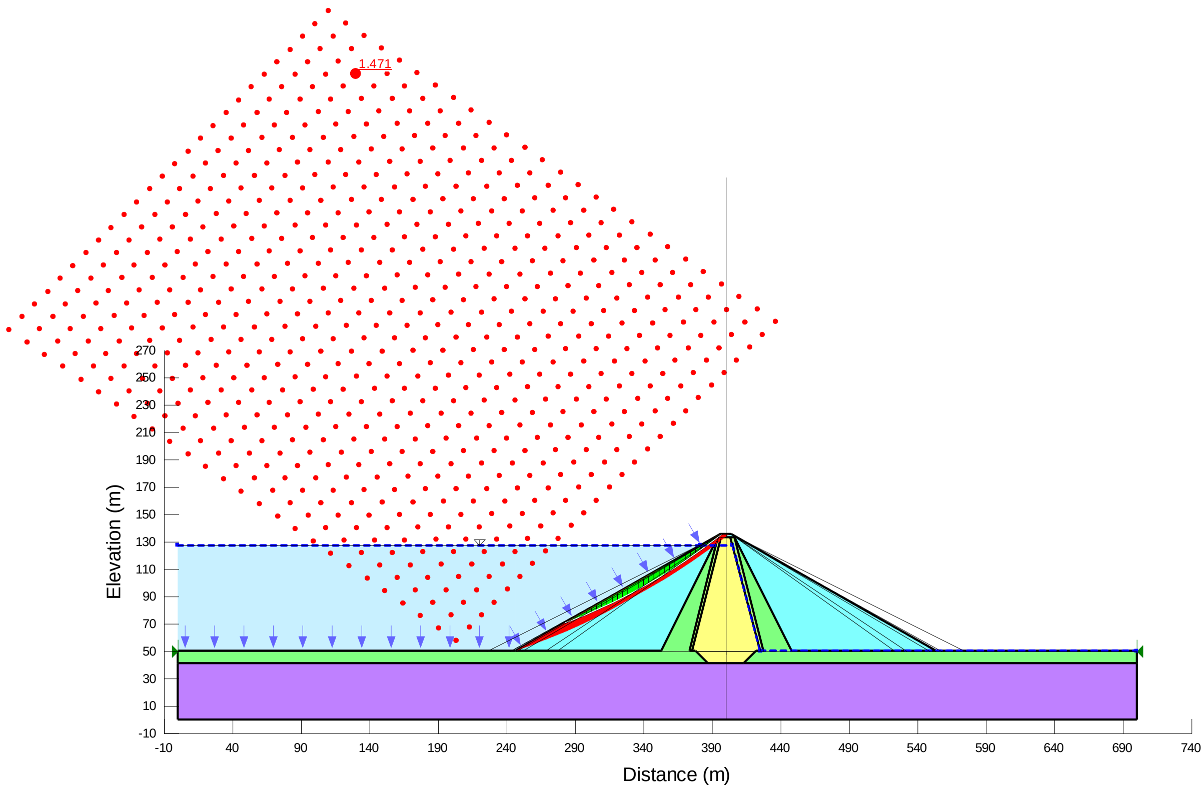


Figure C.59: Zoned earth core rock fill dam: Upstream slopes 1:1.75 (V:H), downstream slope 1:1.75 (V:H), Analysis 4.3 Dam full and steady state flow

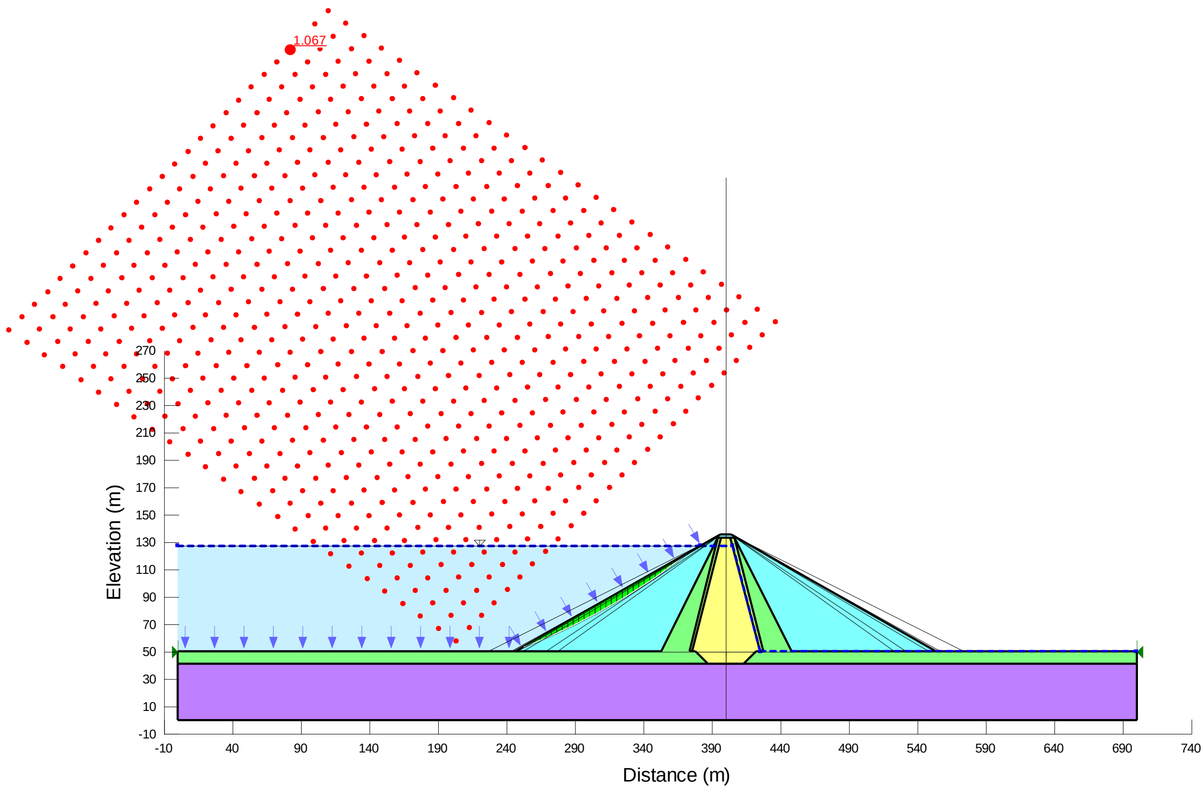


Figure C.60: Zoned earth core rock fill dam: Upstream slopes 1:1.75 (V:H), downstream slope 1:1.75 (V:H), Analysis 4.4 Seismic load

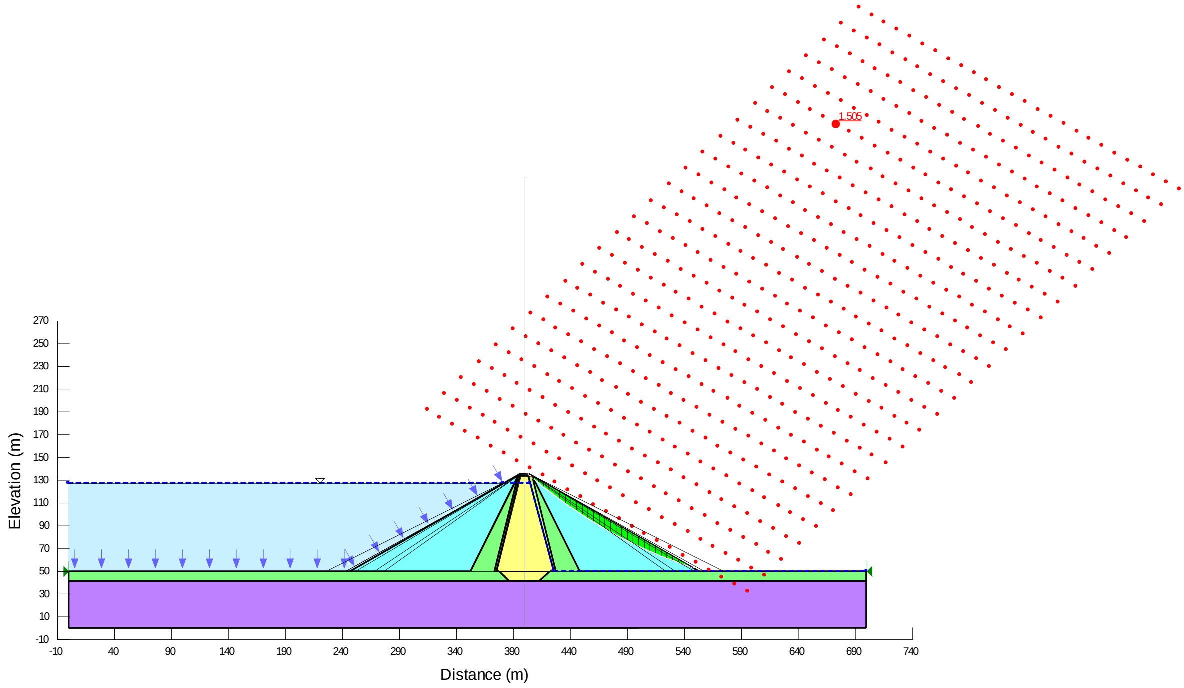


Figure C.61: Zoned earth core rock fill dam: Upstream slopes 1:1.75 (V:H), downstream slope 1:1.75 (V:H), Analysis 5.1 Dam full and steady state flow

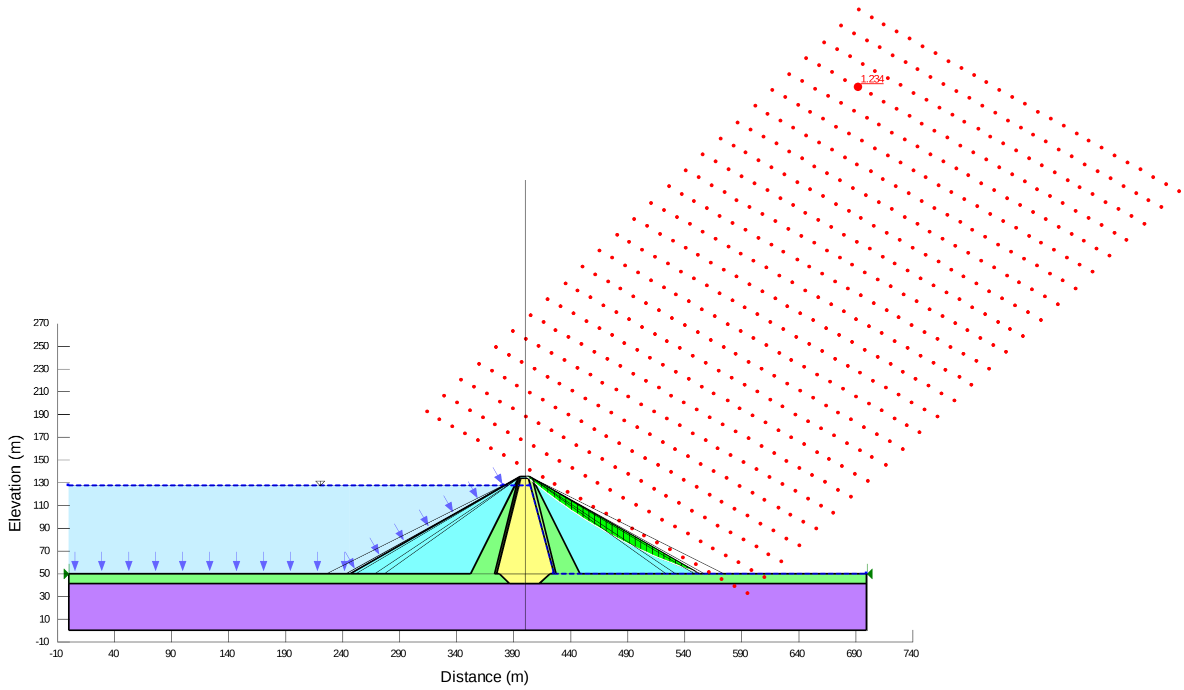


Figure C.62: Zoned earth core rock fill dam: Upstream slopes 1:1.8 (V:H), downstream slope 1:1.8 (V:H), Analysis 5.2 Seismic load

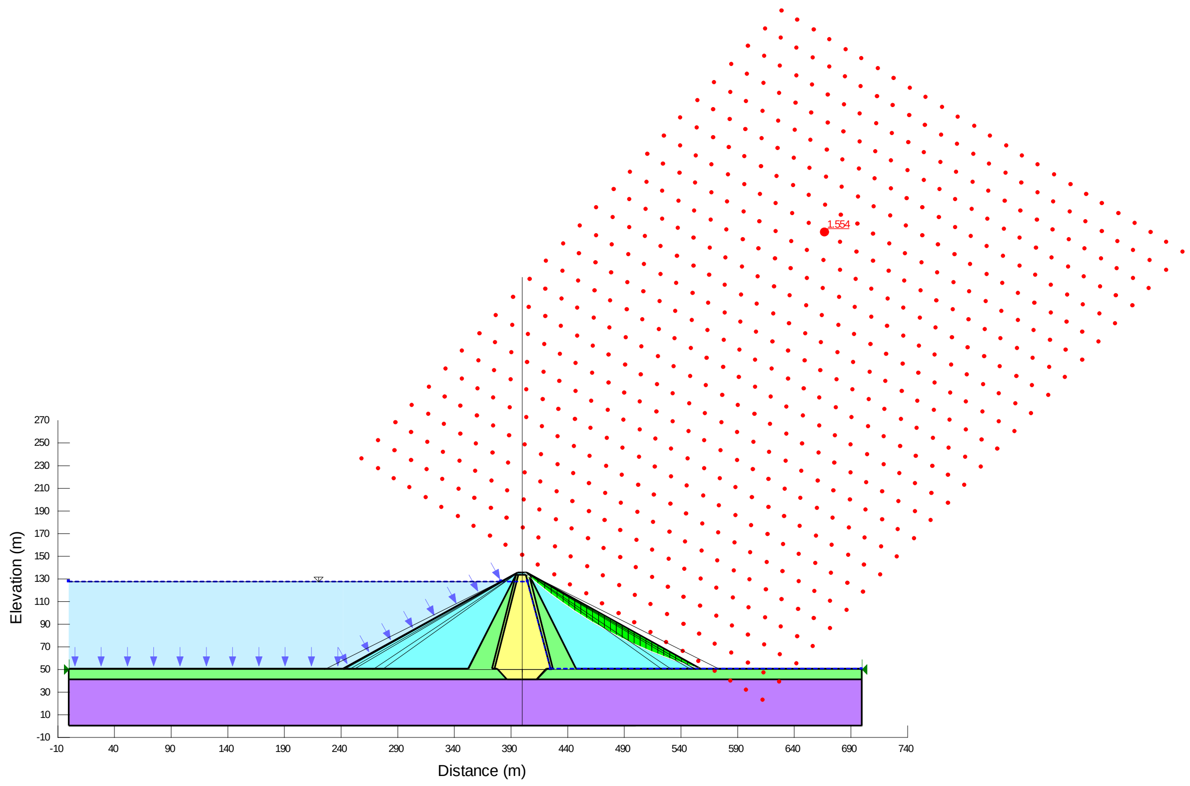


Figure C.63: Zoned earth core rock fill dam: Upstream slopes 1:1.8 (V:H), downstream slope 1:1.8 (V:H), Analysis 5.1 Dam full and steady state flow

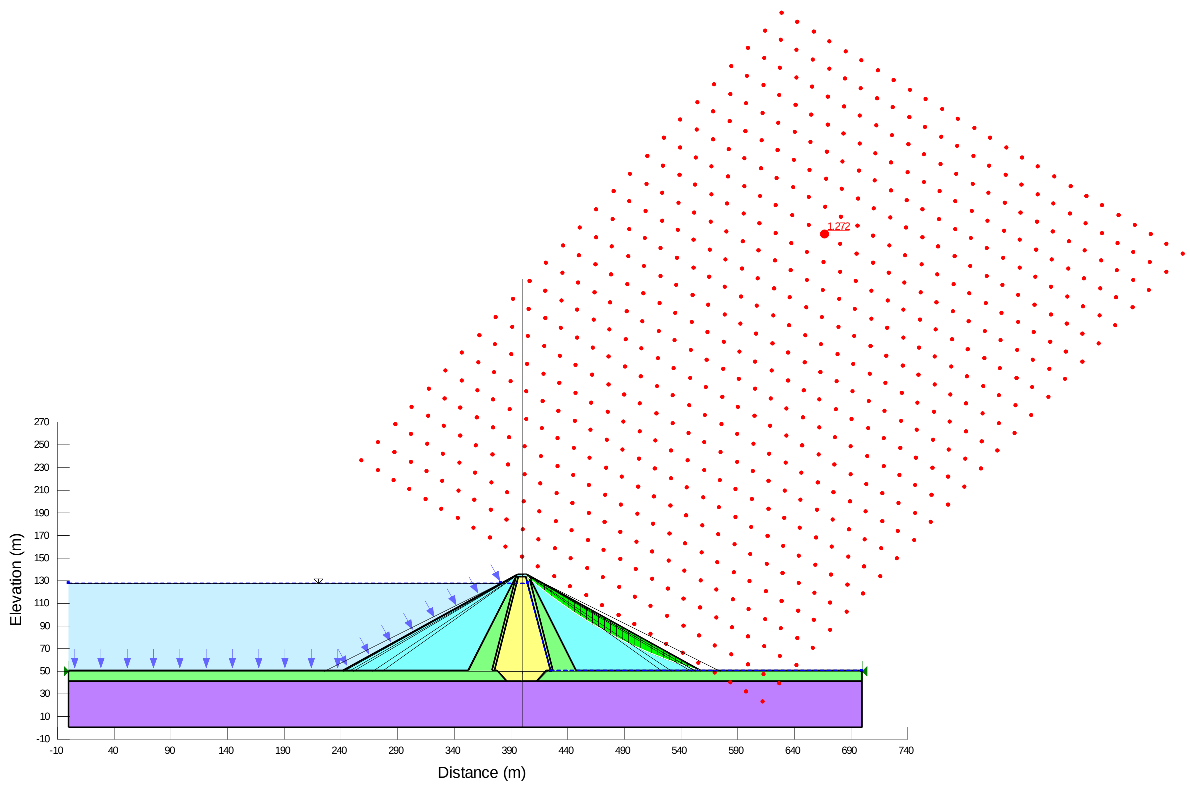


Figure C.64: Zoned earth core rock fill dam: Upstream slopes 1:1.8 (V:H), downstream slope 1:1.8 (V:H), Analysis 5.4 Seismic load

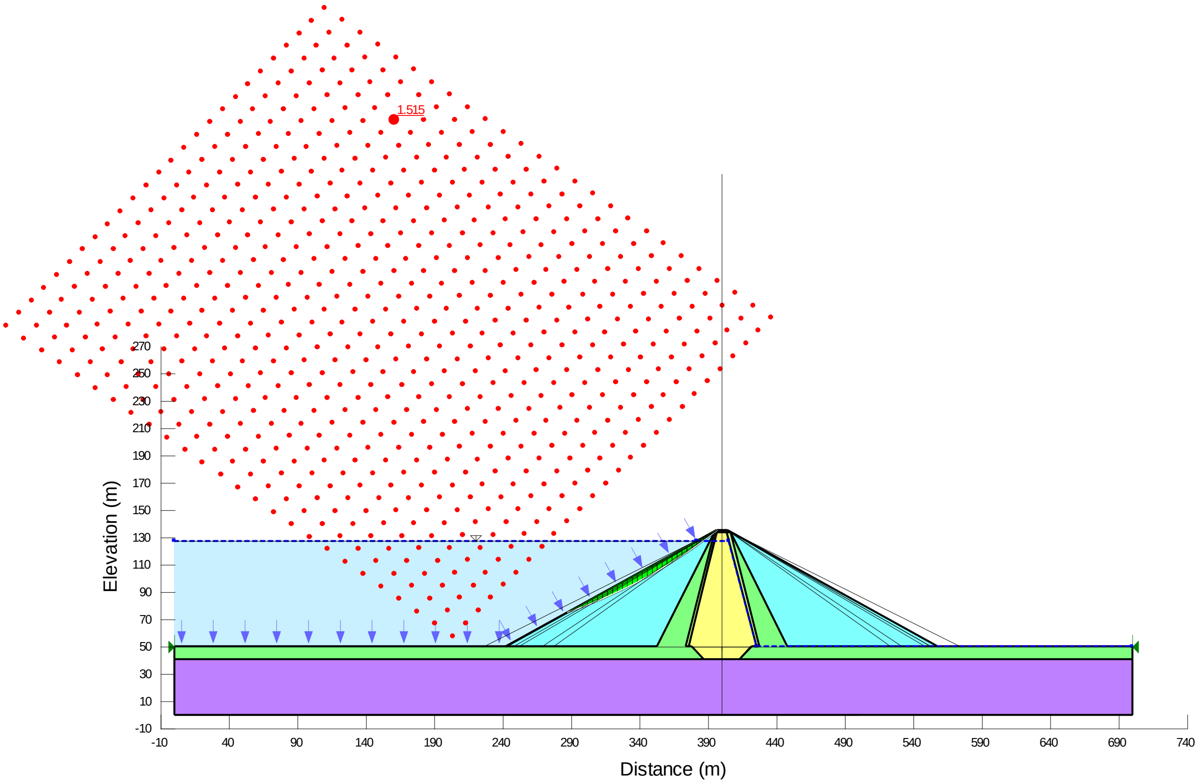


Figure C.65: Zoned earth core rock fill dam: Upstream slopes 1:1.8 (V:H), downstream slope 1:1.8 (V:H), Analysis 5.3 Dam full and steady state flow

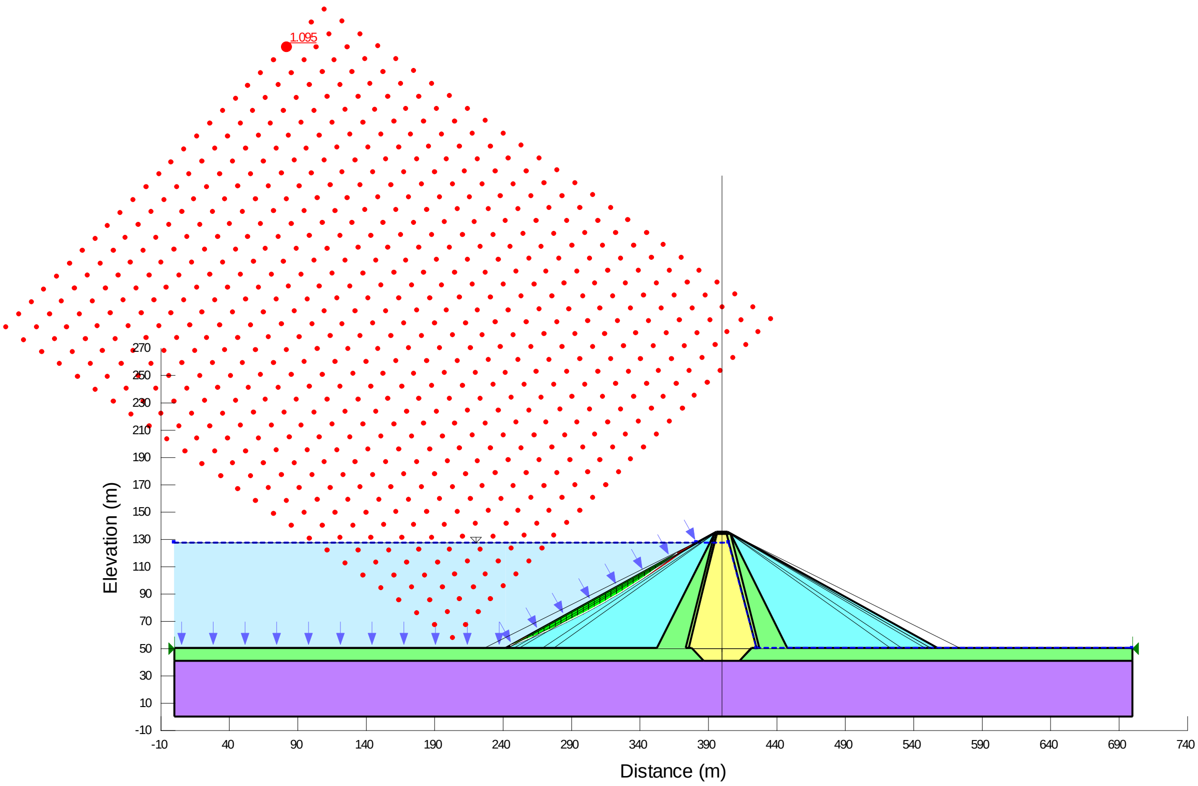


Figure C.66: Zoned earth core rock fill dam: Upstream slopes 1:1.8 (V:H), downstream slope 1:1.8 (V:H), Analysis 5.4 Seismic load

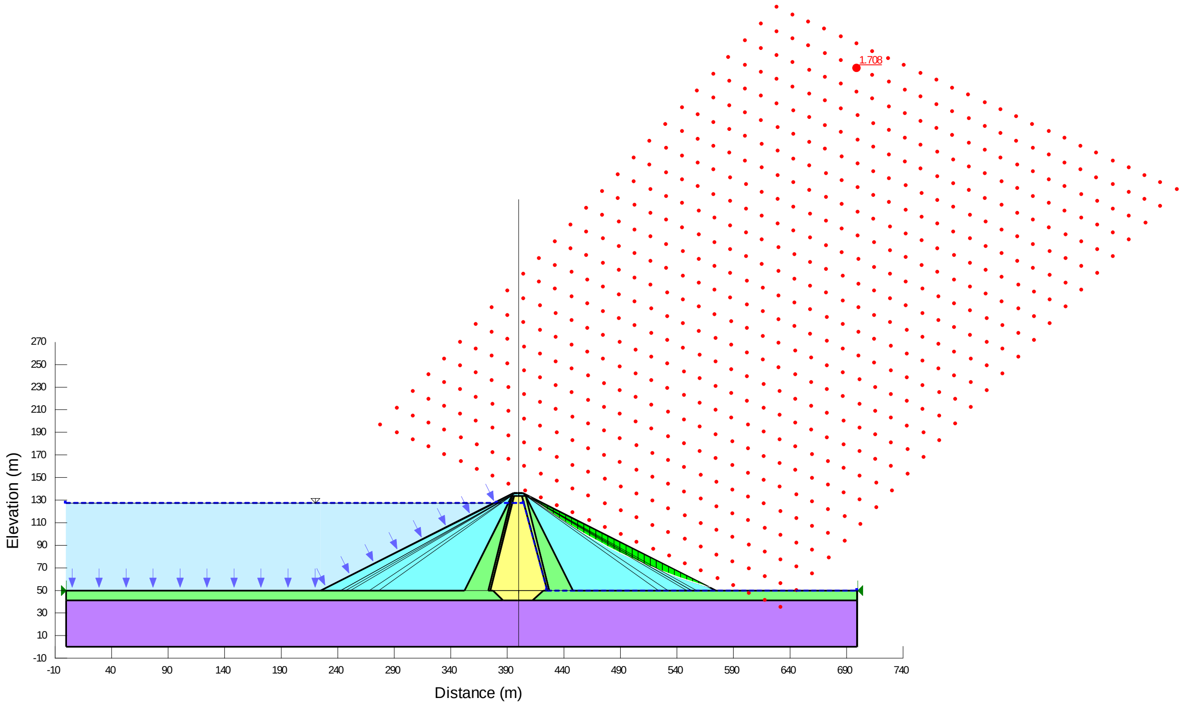


Figure C.67: Zoned earth core rock fill dam: Upstream slopes 1:2 (V:H), downstream slope 1:2 (V:H), Analysis 6.1 Dam full and steady state flow

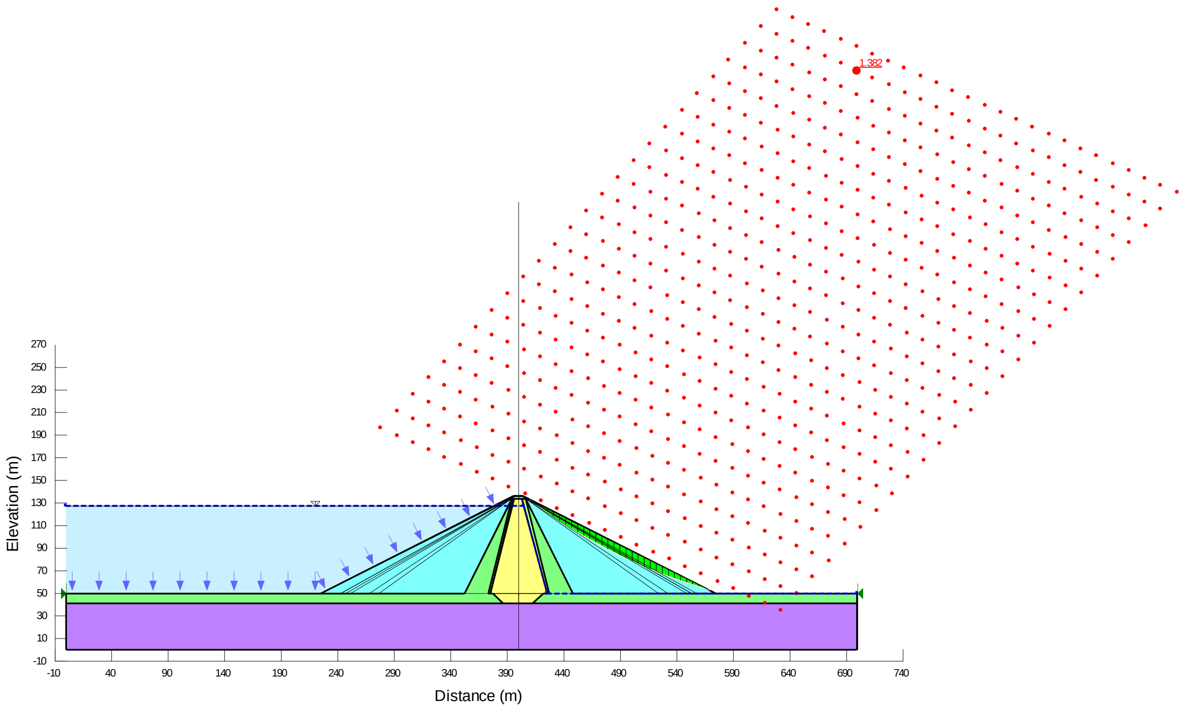


Figure C.68: Zoned earth core rock fill dam: Upstream slopes 1:2 (V:H), downstream slope 1:2 (V:H), Analysis 6.4 Seismic load

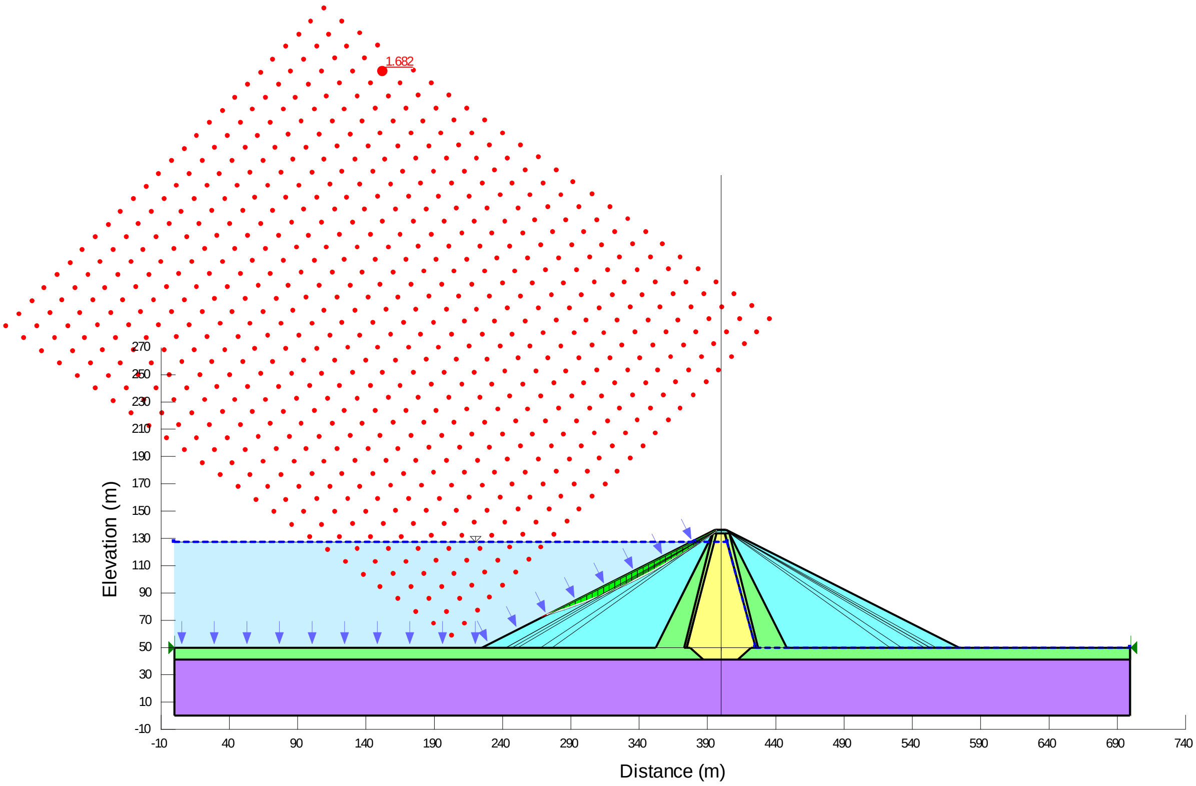


Figure C.69: Zoned earth core rock fill dam: Upstream slopes 1:2 (V:H), downstream slope 1:2 (V:H), Analysis 6.3 Dam full and steady state flow

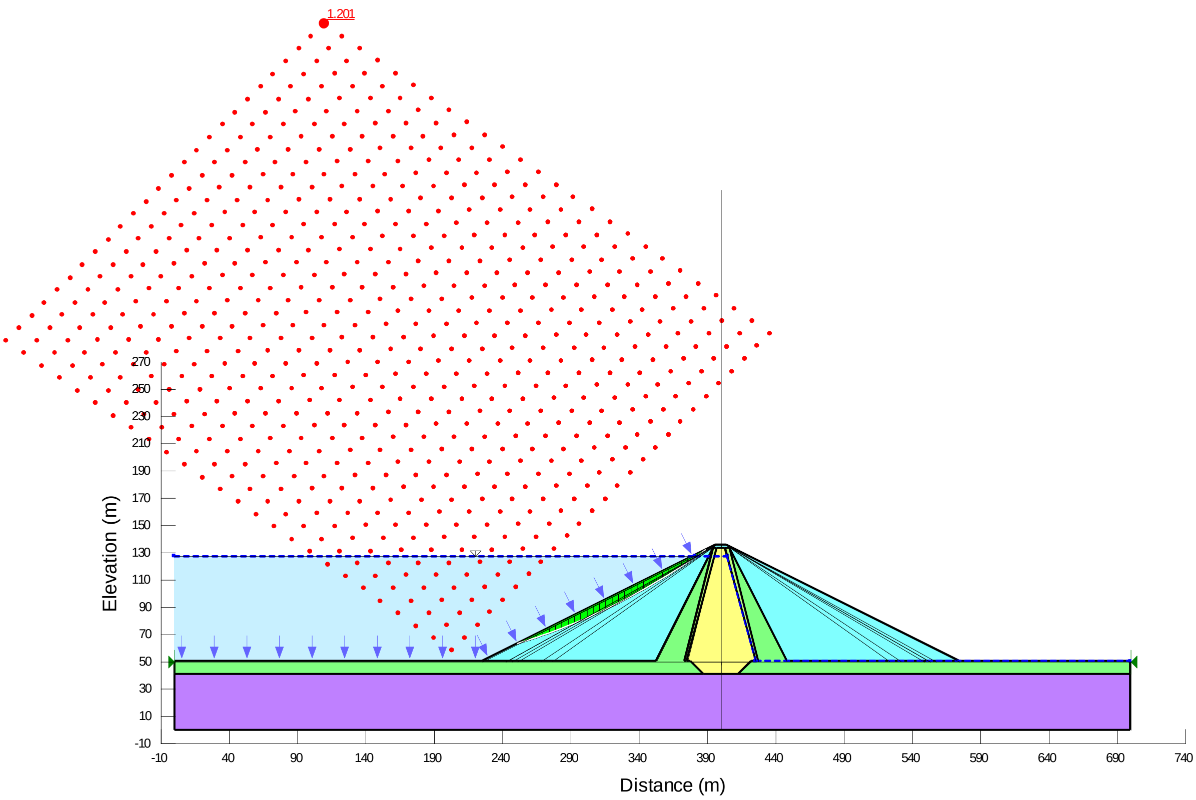
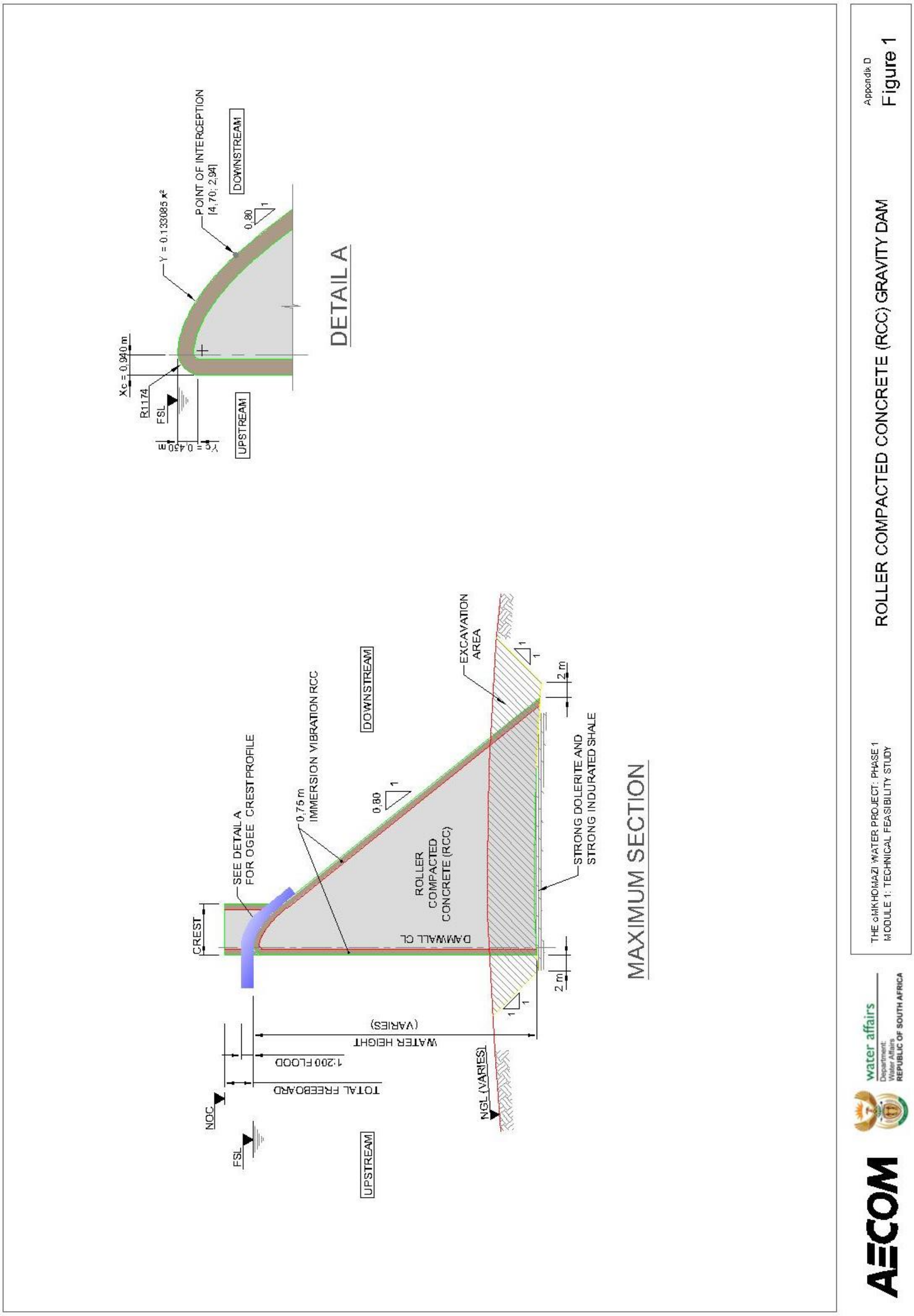
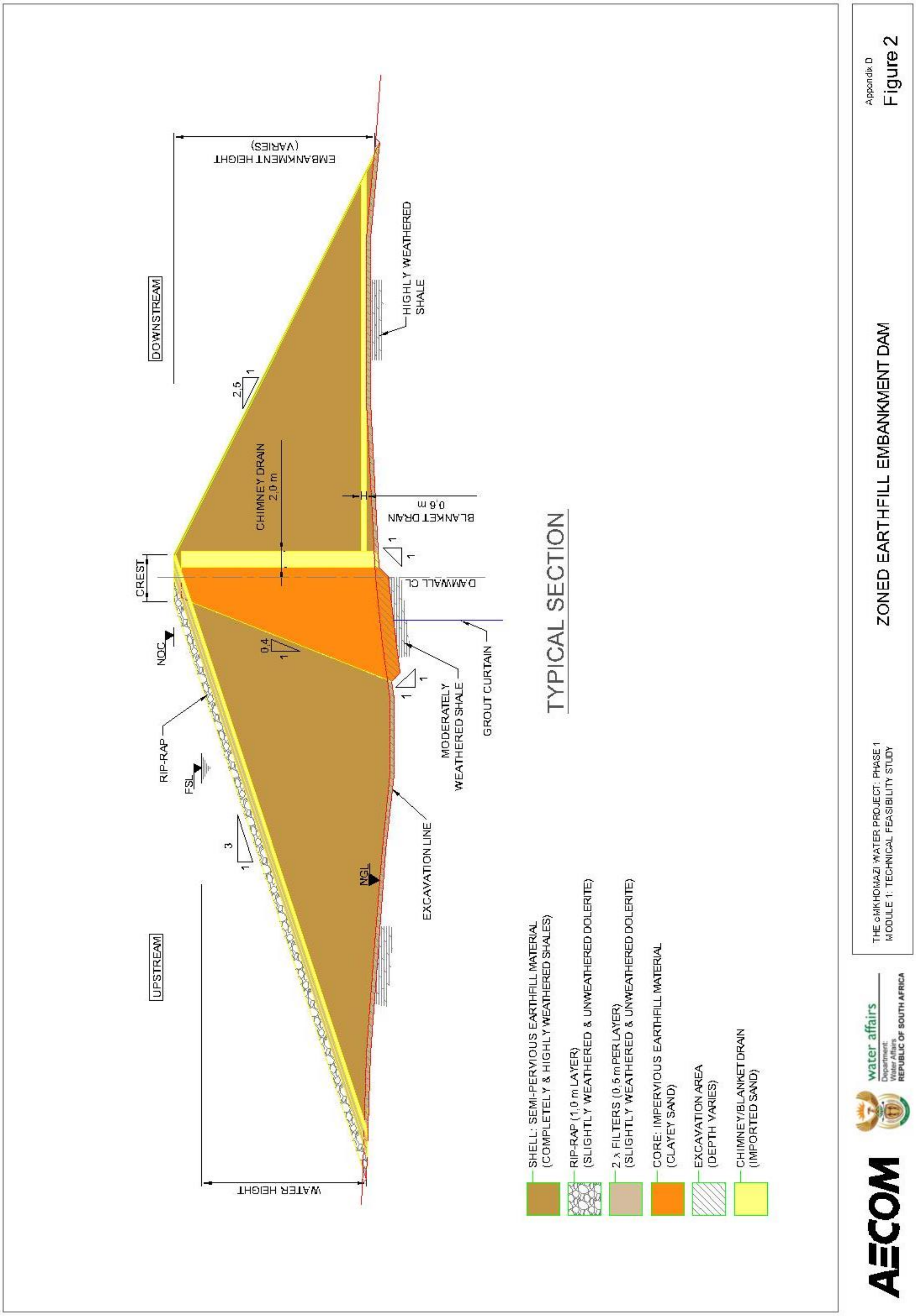


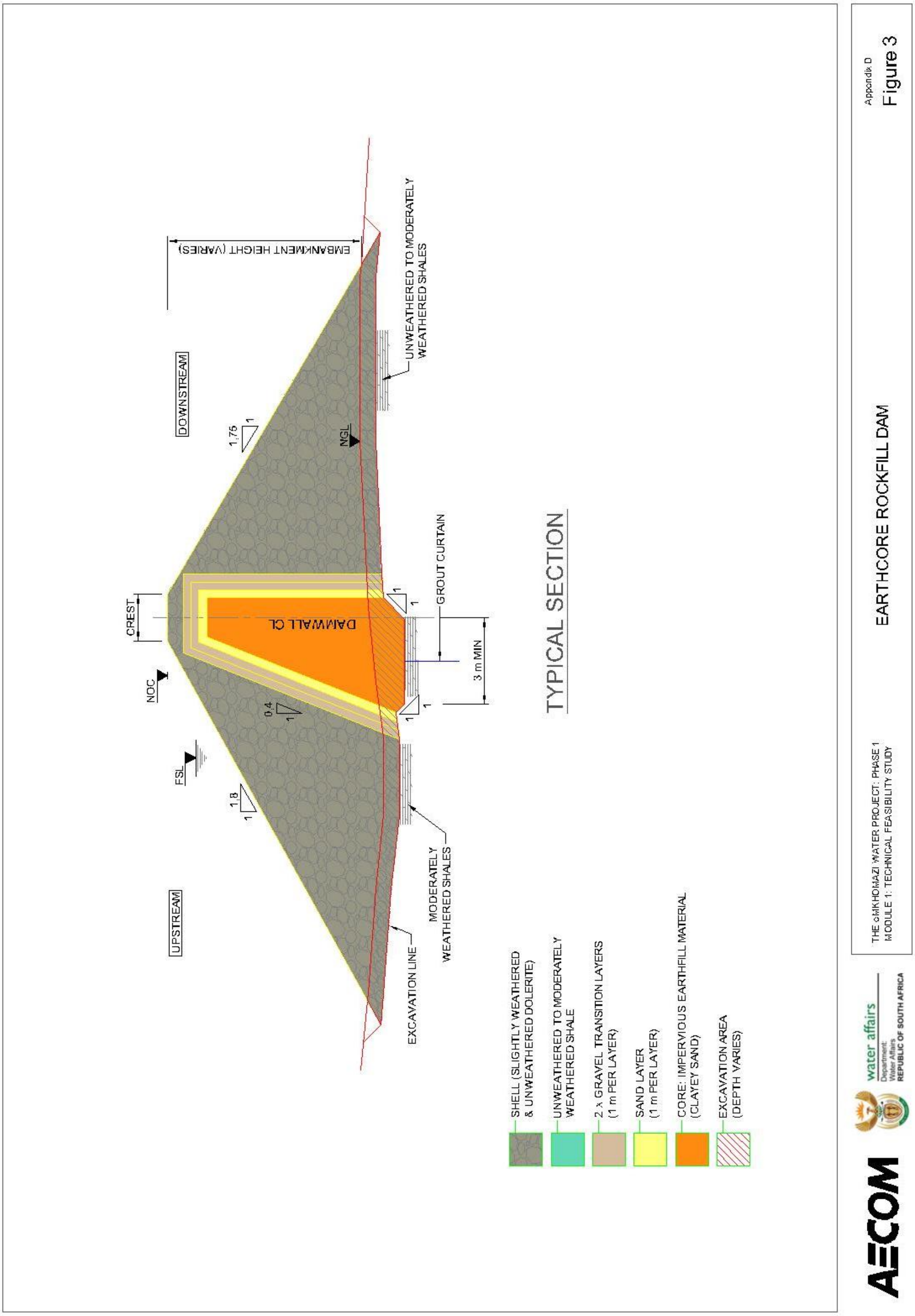
Figure C.70: Zoned earth core rock fill dam: Upstream slopes 1:2 (V:H), downstream slope 1:2 (V:H), Analysis 6.4 Seismic load

Appendix D

Smithfield Dam: Typical cross-sections for each of the chosen dam types


DETAIL A
UPSTREAM
DOWNSTREAM
FSL
R1174
Xc = 0.940 m
Yc = 0.450 m
Y = 0.133085 x²
POINT OF INTERCEPTION [4,70; 2,94]
0,80
1
MAXIMUM SECTION
UPSTREAM
DOWNSTREAM
FSL
NOC
TOTAL FREEBOARD
1:200 FLOOD
WATER HEIGHT (VARIES)
NGL (VARIES)
CREST
SEE DETAIL A FOR OGEE CREST PROFILE
0,75 m IMMERSION VIBRATION RCC
ROLLER COMPACTED CONCRETE (RCC)
DAMWALL CL
EXCAVATION AREA
STRONG DOLERITE AND STRONG INDURATED SHALE
2 m
THE uMKHOMAZI WATER PROJECT: PHASE 1
MODULE 1: TECHNICAL FEASIBILITY STUDY
ROLLER COMPACTED CONCRETE (RCC) GRAVITY DAM
Appendix D
Figure 1
AECOM
water affairs
Department: Water Affairs REPUBLIC OF SOUTH AFRICA


TYPICAL SECTION
UPSTREAM
DOWNSTREAM
WATER HEIGHT
EMBANKMENT HEIGHT (VARIES)
CREST
NOC
FSL
NGL
RIP-RAP
CHIMNEY DRAIN 2,0 m
BLANKET DRAIN 0,6 m
DAMWALL CL
GROUT CURTAIN
MODERATELY WEATHERED SHALE
HIGHLY WEATHERED SHALE
EXCAVATION LINE
SHELL: SEMI-PERVIOUS EARTHFILL MATERIAL (COMPLETELY & HIGHLY WEATHERED SHALES)
RIP-RAP (1,0 m LAYER) (SLIGHTLY WEATHERED & UNWEATHERED DOLERITE)
2 x FILTERS (0,5 m PER LAYER) (SLIGHTLY WEATHERED & UNWEATHERED DOLERITE)
CORE: IMPERVIOUS EARTHFILL MATERIAL (CLAYEY SAND)
EXCAVATION AREA (DEPTH VARIES)
CHIMNEY/BLANKET DRAIN (IMPORTED SAND)
AECOM
water affairs
Department: Water Affairs REPUBLIC OF SOUTH AFRICA
THE uMKHOMAZI WATER PROJECT: PHASE 1 MODULE 1: TECHNICAL FEASIBILITY STUDY
ZONED EARTHFILL EMBANKMENT DAM
Appendix D
Figure 2


TYPICAL SECTION
UPSTREAM
DOWNSTREAM
CREST
NOC
FSL
NGL
DAMWALL CL
1,8
1
1,75
1
0,4
1
3 m MIN
GROUT CURTAIN
EMBANKMENT HEIGHT (VARIES)
UNWEATHERED TO MODERATELY WEATHERED SHALES
MODERATELY WEATHERED SHALES
EXCAVATION LINE
SHELL (SLIGHTLY WEATHERED & UNWEATHERED DOLERITE)
UNWEATHERED TO MODERATELY WEATHERED SHALE
2 x GRAVEL TRANSITION LAYERS (1 m PER LAYER)
SAND LAYER (1 m PER LAYER)
CORE: IMPERVIOUS EARTHFILL MATERIAL (CLAYEY SAND)
EXCAVATION AREA (DEPTH VARIES)
AECOM
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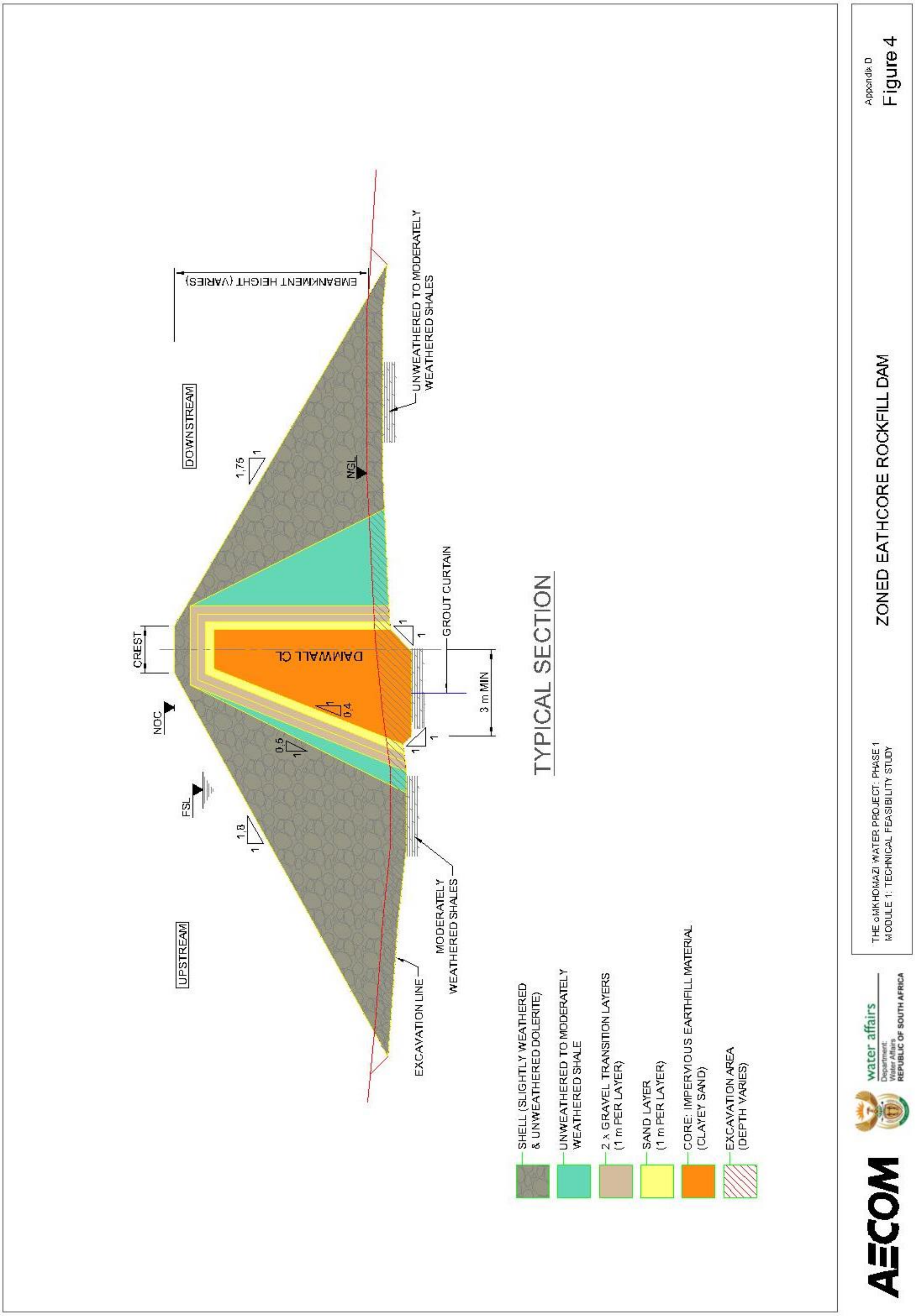
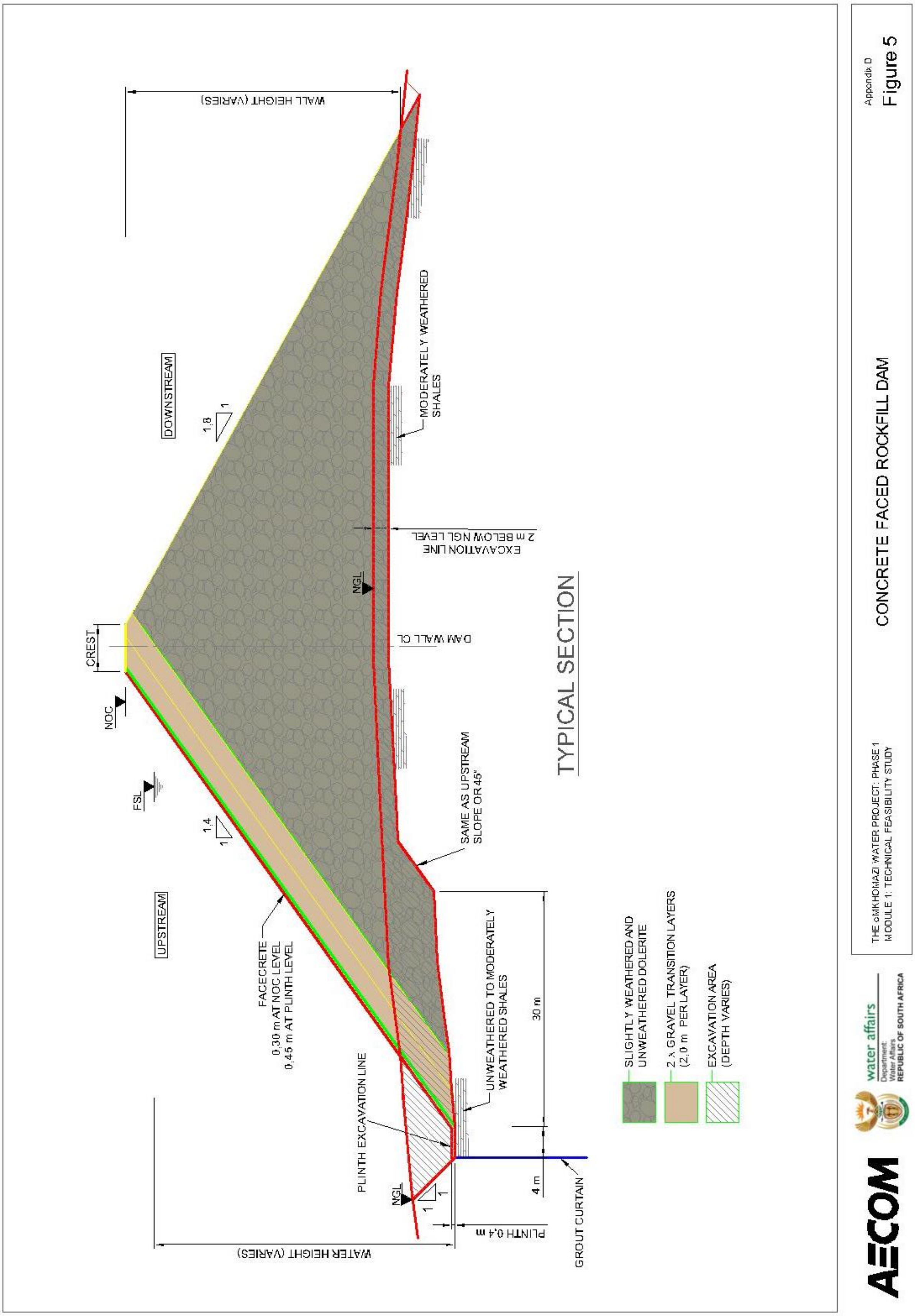
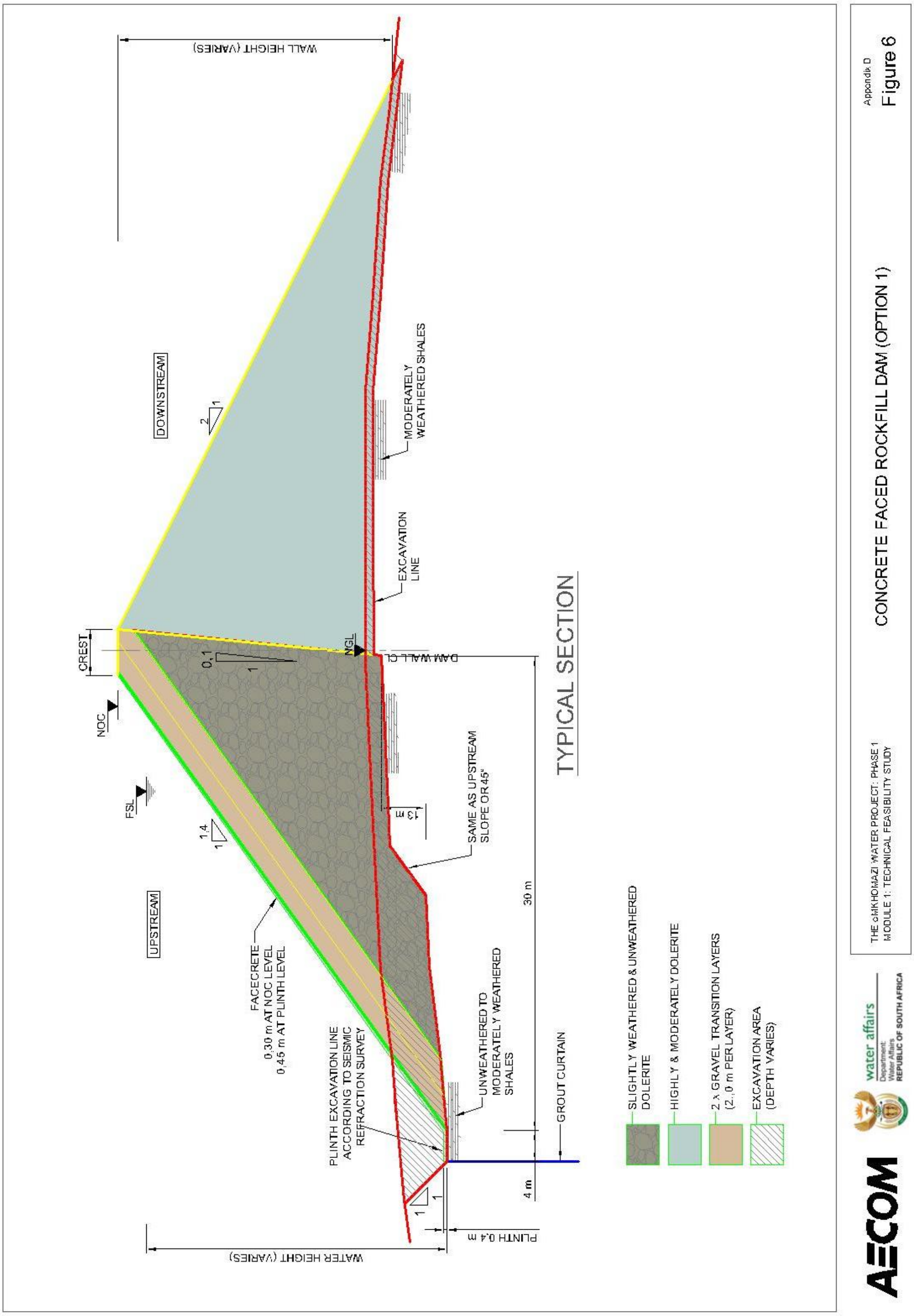
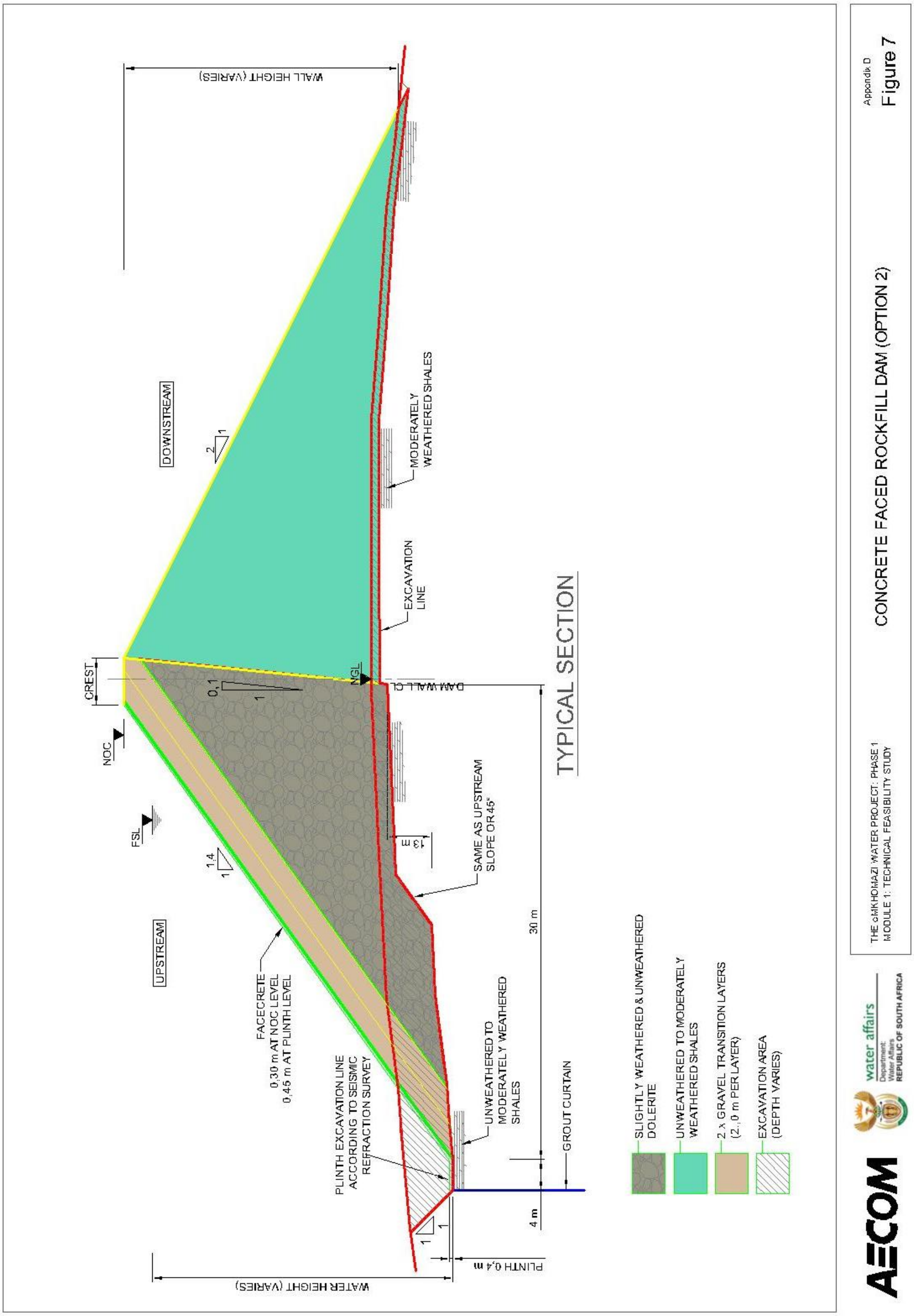
Department: Water Affairs REPUBLIC OF SOUTH AFRICA
THE uMKHOMAZI WATER PROJECT: PHASE 1
MODULE 1: TECHNICAL FEASIBILITY STUDY
EARTHCORE ROCKFILL DAM
Appendix D
Figure 3


EMBANKMENT HEIGHT (VARIES)
DOWNSTREAM
UPSTREAM
CREST
NOC
FSL
NGL
DAMWALL CL
1,8
1
1,75
1
0,5
1
1
0,4
1
1
1
1
3 m MIN
GROUT CURTAIN
UNWEATHERED TO MODERATELY WEATHERED SHALES
MODERATELY WEATHERED SHALES
EXCAVATION LINE
TYPICAL SECTION
SHELL (SLIGHTLY WEATHERED & UNWEATHERED DOLERITE)
UNWEATHERED TO MODERATELY WEATHERED SHALE
2 x GRAVEL TRANSITION LAYERS (1 m PER LAYER)
SAND LAYER (1 m PER LAYER)
CORE: IMPERVIOUS EARTHFILL MATERIAL (CLAYEY SAND)
EXCAVATION AREA (DEPTH VARIES)
AECOM
water affairs
Department: Water Affairs REPUBLIC OF SOUTH AFRICA
THE uMKHOMAZI WATER PROJECT: PHASE 1
MODULE 1: TECHNICAL FEASIBILITY STUDY
ZONED EATHCORE ROCKFILL DAM
Appendix D
Figure 4



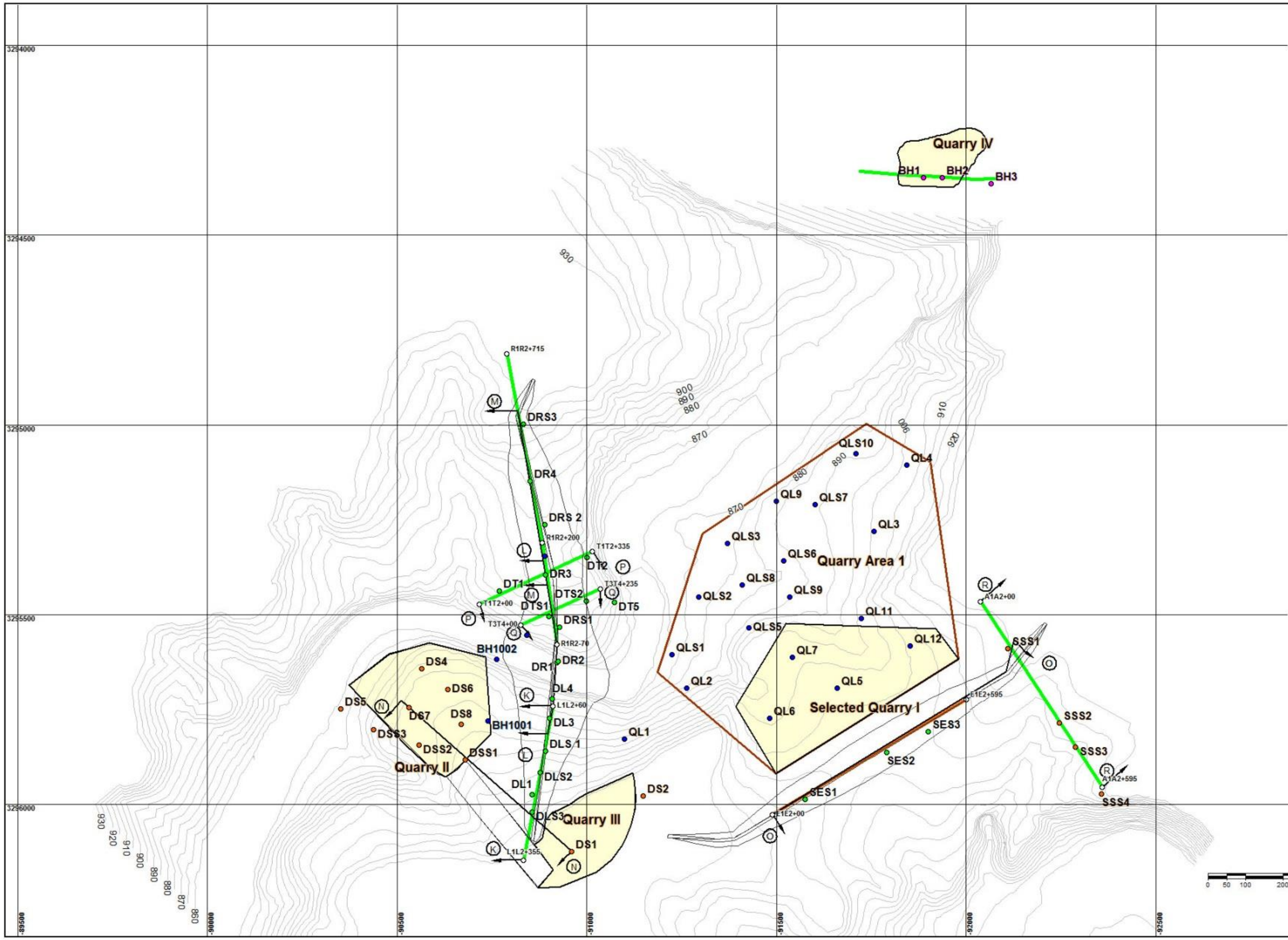
TYPICAL SECTION
UPSTREAM
DOWNSTREAM
WALL HEIGHT (VARIES)
WATER HEIGHT (VARIES)
CREST
NOC
FSL
NGL
DAM WALL CL
1,4
1
1,8
1
FACECRETE
0,30 m AT NOC LEVEL
0,45 m AT PLINTH LEVEL
PLINTH EXCAVATION LINE
PLINTH 0,4 m
GROUT CURTAIN
4 m
30 m
UNWEATHERED TO MODERATELY WEATHERED SHALES
SAME AS UPSTREAM SLOPE OR 45°
EXCAVATION LINE
2 m BELOW NGL LEVEL
MODERATELY WEATHERED SHALES
SLIGHTLY WEATHERED AND UNWEATHERED DOLERITE
2 x GRAVEL TRANSITION LAYERS (2,0 m PER LAYER)
EXCAVATION AREA (DEPTH VARIES)
AECOM
water affairs
Department: Water Affairs REPUBLIC OF SOUTH AFRICA
THE uMKHOMAZI WATER PROJECT: PHASE 1
MODULE 1: TECHNICAL FEASIBILITY STUDY
CONCRETE FACED ROCKFILL DAM
Appendix D
Figure 5


WALL HEIGHT (VARIES)
DOWNSTREAM
2
1
MODERATELY WEATHERED SHALES
EXCAVATION LINE
CREST
NOC
FSL
0,1
1
NGL
DAM WALL CL
TYPICAL SECTION
1,4
1
13 m
SAME AS UPSTREAM SLOPE OR 45°
UPSTREAM
30 m
FACECRETE
0,30 m AT NOC LEVEL
0,45 m AT PLINTH LEVEL
PLINTH EXCAVATION LINE ACCORDING TO SEISMIC REFRACTION SURVEY
UNWEATHERED TO MODERATELY WEATHERED SHALES
GROUT CURTAIN
4 m
1
1
PLINTH 0,4 m
WATER HEIGHT (VARIES)
SLIGHTLY WEATHERED & UNWEATHERED DOLERITE
HIGHLY & MODERATELY DOLERITE
2 x GRAVEL TRANSITION LAYERS (2,0 m PER LAYER)
EXCAVATION AREA (DEPTH VARIES)
AECOM
water affairs
Department: Water Affairs
REPUBLIC OF SOUTH AFRICA
THE uMKHOMAZI WATER PROJECT: PHASE 1
MODULE 1: TECHNICAL FEASIBILITY STUDY
CONCRETE FACED ROCKFILL DAM (OPTION 1)
Appendix D
Figure 6


WALL HEIGHT (VARIES)
DOWNSTREAM
UPSTREAM
CREST
NOC
FSL
NGL
DAM WALL CL
1,4
1
2
1
0,1
1
MODERATELY WEATHERED SHALES
EXCAVATION LINE
TYPICAL SECTION
SAME AS UPSTREAM SLOPE OR 45°
13 m
30 m
4 m
FACECRETE
0,30 m AT NOC LEVEL
0,45 m AT PLINTH LEVEL
PLINTH EXCAVATION LINE ACCORDING TO SEISMIC REFRACTION SURVEY
UNWEATHERED TO MODERATELY WEATHERED SHALES
GROUT CURTAIN
PLINTH 0,4 m
WATER HEIGHT (VARIES)
SLIGHTLY WEATHERED & UNWEATHERED DOLERITE
UNWEATHERED TO MODERATELY WEATHERED SHALES
2 x GRAVEL TRANSITION LAYERS (2,0 m PER LAYER)
EXCAVATION AREA (DEPTH VARIES)
AECOM
water affairs
Department: Water Affairs REPUBLIC OF SOUTH AFRICA
THE uMKHOMAZI WATER PROJECT: PHASE 1
MODULE 1: TECHNICAL FEASIBILITY STUDY
CONCRETE FACED ROCKFILL DAM (OPTION 2)
Appendix D
Figure 7

Appendix E

Smithfield Dam: Long-sections of geotechnical (foundation and quarry) investigations



Point	Y	X	Z
BH1	-91888.355	3294347.533	881.966
BH2	-91937.428	3294347.833	885.139
BH3	-92066.817	3294363.901	910.253
QL1	-91099.827	3295825.444	895.411
QL2	-91263.687	3295691.777	881.326
QL3	-91758.576	3295279.262	900.388
QL4	-91844.101	3295105.650	901.319
QL5	-91661.178	3295691.723	907.771
QL6	-91483.182	3295771.205	902.074
QL7	-91542.458	3295610.738	903.461
QL8	-91601.947	3295209.271	889.586
QL9	-91499.977	3295200.977	882.237
QLS10	-91711.102	3295074.322	889.193
QL11	-91724.268	3295508.458	900.476
QL12	-91852.742	3295581.043	911.372
QLS1	-91226.124	3295604.683	867.260
QLS2	-91295.014	3295451.995	872.104
QLS3	-91372.327	3295311.548	873.236
QLS5	-91428.899	3295534.165	890.913
QLS6	-91520.385	3295357.505	883.058
QLS7	-91602.0492	3295209.278	889.5401
QLS8	-91409.753	3295419.777	876.725
QLS9	-91535.349	3295452.327	884.643
SSS1	-92111.273	3295588.927	930.234
SSS2	-92246.256	3295784.210	924.020
SSS3	-92287.984	3295848.209	916.651
SSS4	-92357.274	3295971.685	927.833
DS1	-90960.829	3296122.133	946.059
DS2	-91149.035	3295976.834	948.922
DS4	-90565.218	3295640.409	885.590
DS5	-90352.867	3295746.777	861.131
DS6	-90634.031	3295696.377	892.922
DS7	-90531.845	3295743.707	890.629
DS8	-90670.255	3295787.966	897.886
DSS1	-90679.711	3295881.130	902.871
DSS2	-90559.278	3295842.043	891.703
DSS3	-90437.763	3295801.279	881.383
DL1	-90856.356	3295972.609	918.233
DL3	-90903.282	3295772.393	889.542
DL4	-90909.125	3295720.899	879.250
DLS 1	-90891.1126	3295857.475	904.2547
DLS2	-90877.696	3295914.206	914.337
DLS3	-90856.370	3296018.539	922.166
DRS1	-90928.946	3295532.490	885.581
DRS 2	-90889.5524	3295262.083	903.8107
DRS3	-90834.530	3294997.543	925.129
DR1	-90922.673	3295625.887	857.321
DR2	-90924.617	3295620.853	857.457
DR3	-90892.368	3295394.651	900.153
DR4	-90850.828	3295148.029	909.438
DTS1	-90901.271	3295503.859	888.424
DTS2	-90999.857	3295462.988	895.4449
DT5	-91073.4962	3295467.275	876.6828
DT1	-90770.295	3295436.268	891.303
DT2	-91001.072	3295349.155	891.317
SES1	-91575.607	3295984.511	917.386
SES2	-91791.017	3295861.429	911.962
SES3	-91900.250	3295807.054	915.178

water affairs
Department: Water Affairs
REPUBLIC OF SOUTH AFRICA

AECOM

Project Name :

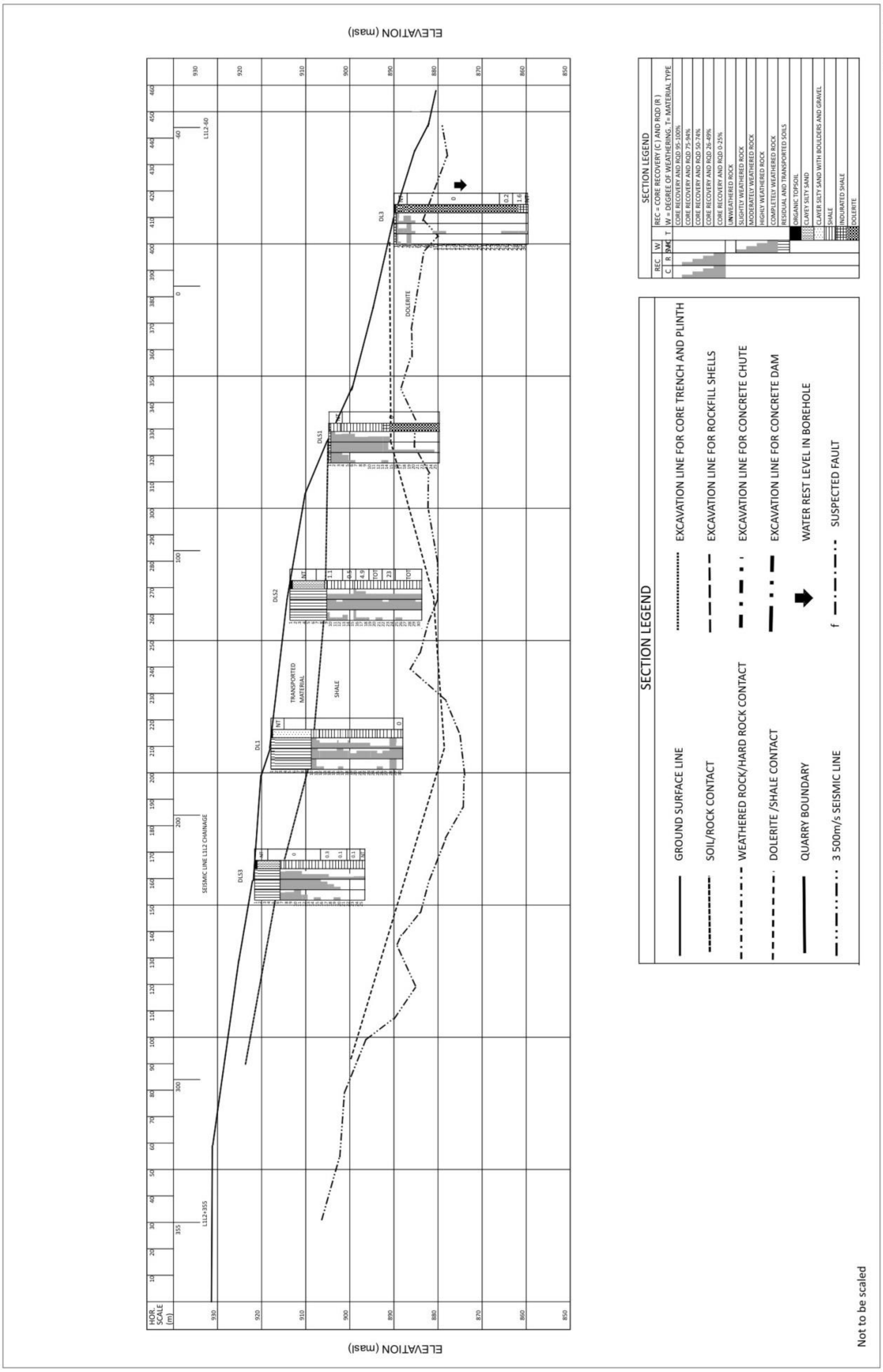
uMkhomazi Water Project Phase 1: Module 1: Technical Feasibility Study: Raw Water (uMWP1-1/RW) Plan showing Dam Centre Line, Spillway Chute, Diversion Tunnels and Saddle Dam

Legend

Contours
Seismic Refraction Traverses
Borehole Positions
Quarry
Proposed Quarries

FIGURE E.1

Drawn: LC Gallagher
Checked: D vd Merwe
Date: 2013-07-29
Map Ref: uMkhomazi.map
View Ref: Centre Line
Project No: J01763

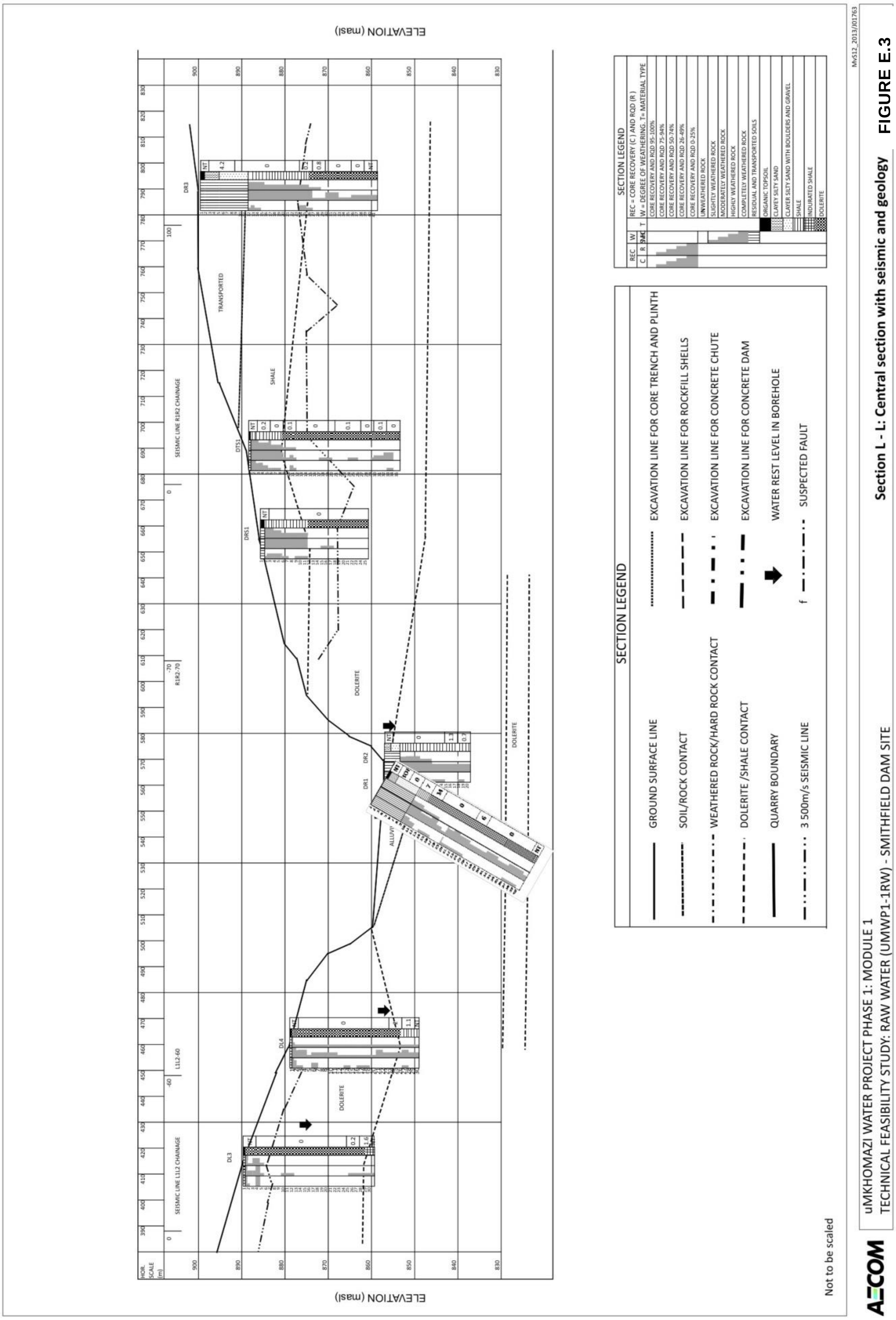


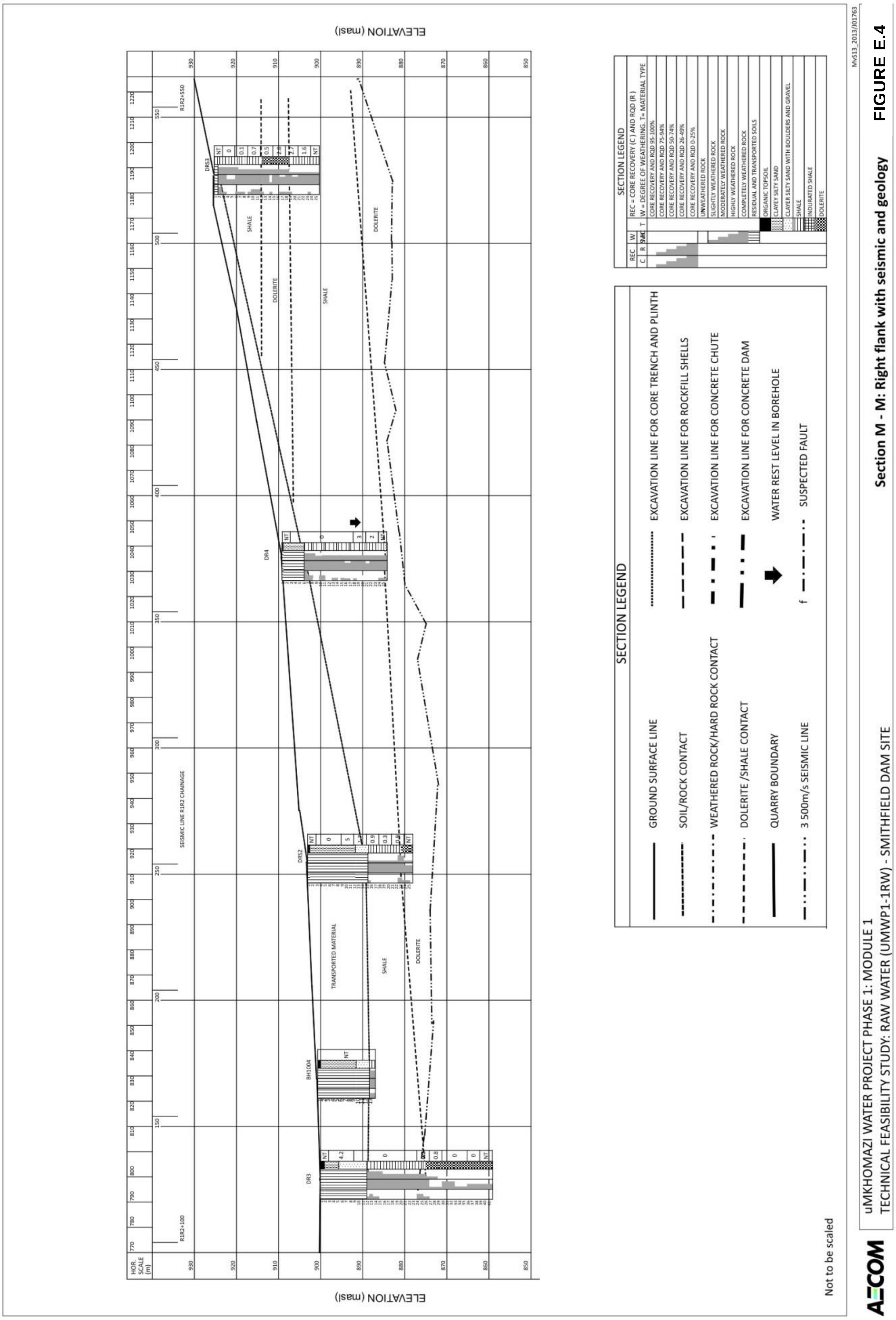
MvS11_2013/J01763

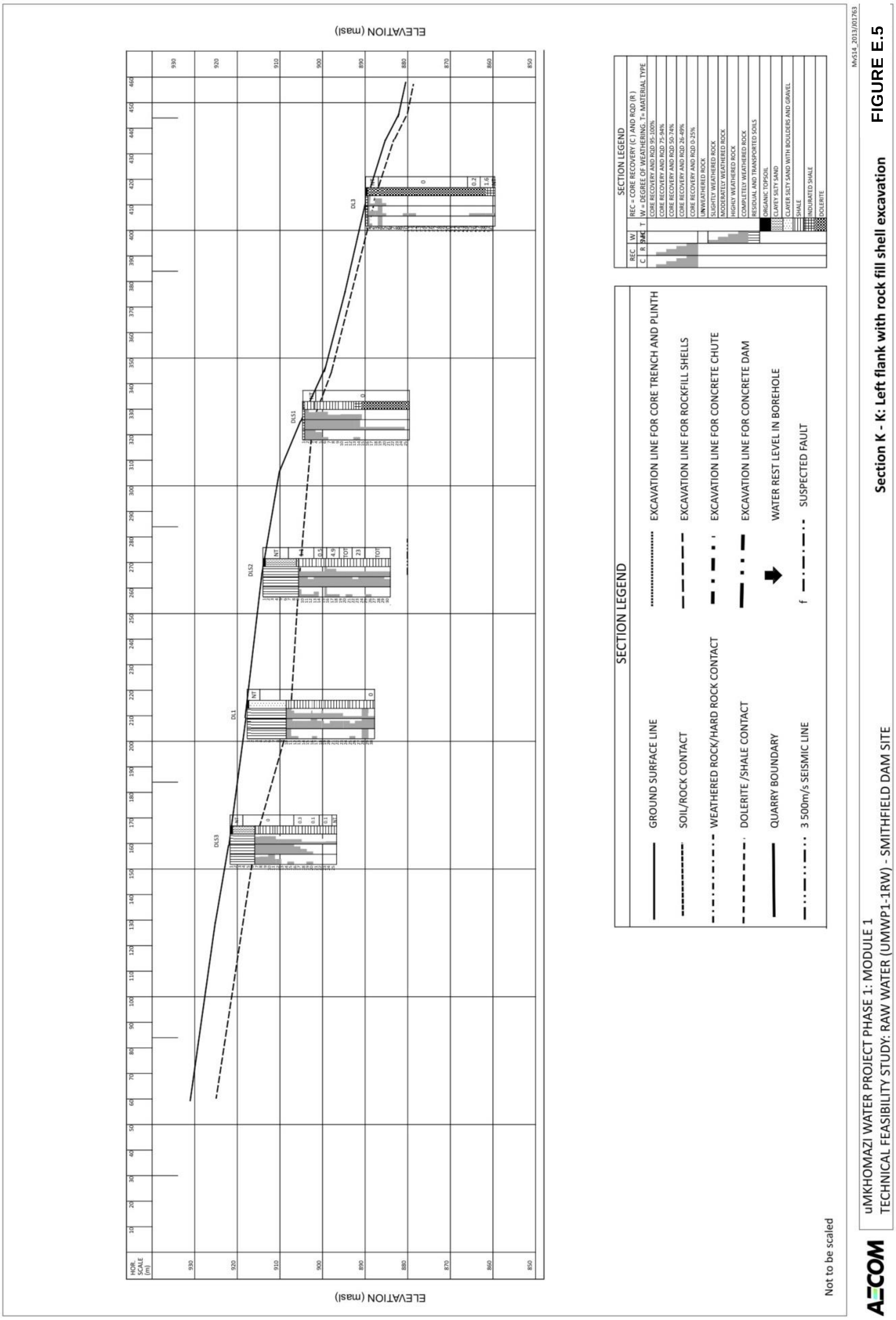
uMKHOMAZI WATER PROJECT PHASE 1: MODULE 1
TECHNICAL FEASIBILITY STUDY: RAW WATER (UMWP1-1RW) - SMITHFIELD DAM SITE

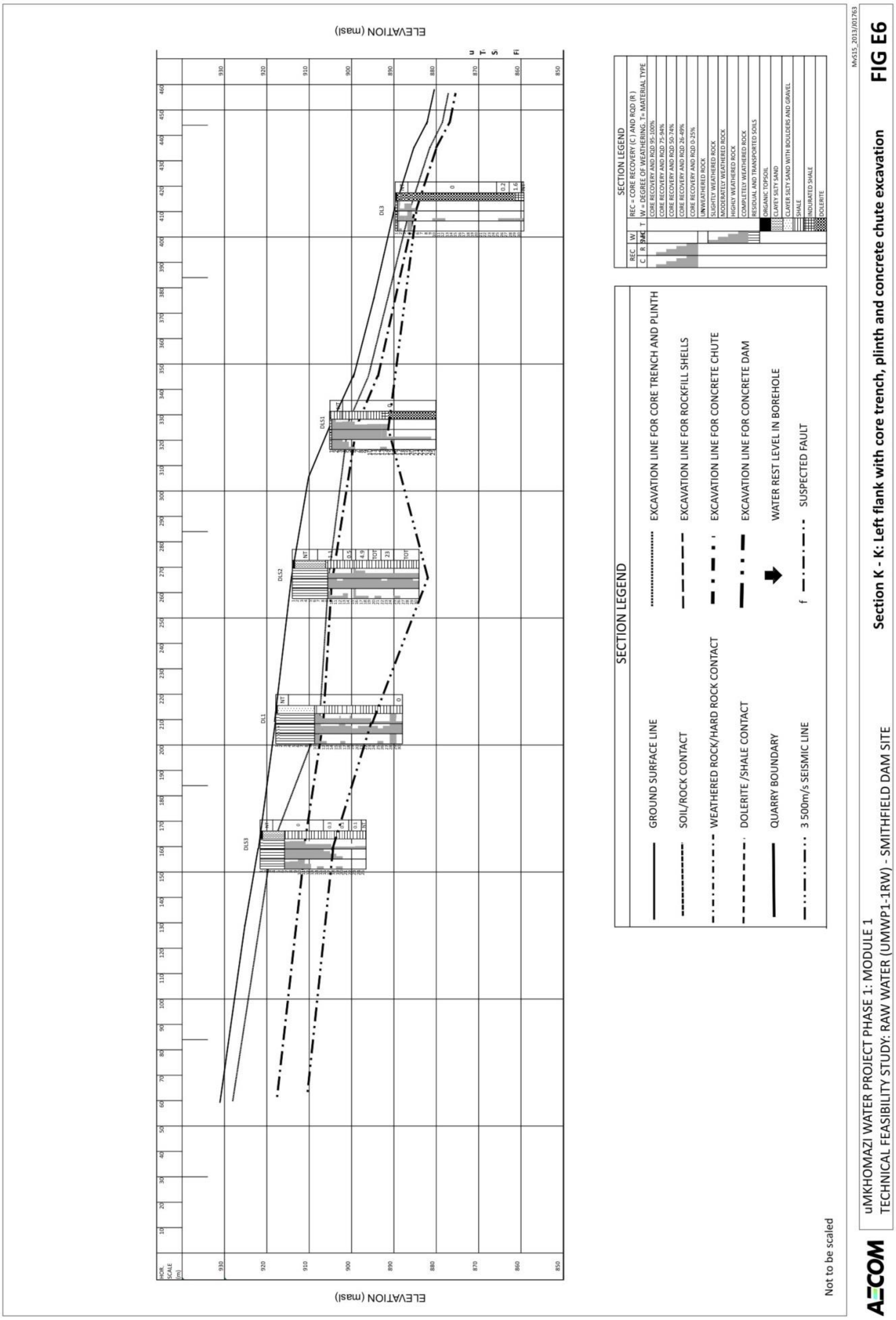
Section L - L: Left flank with seismic and geology

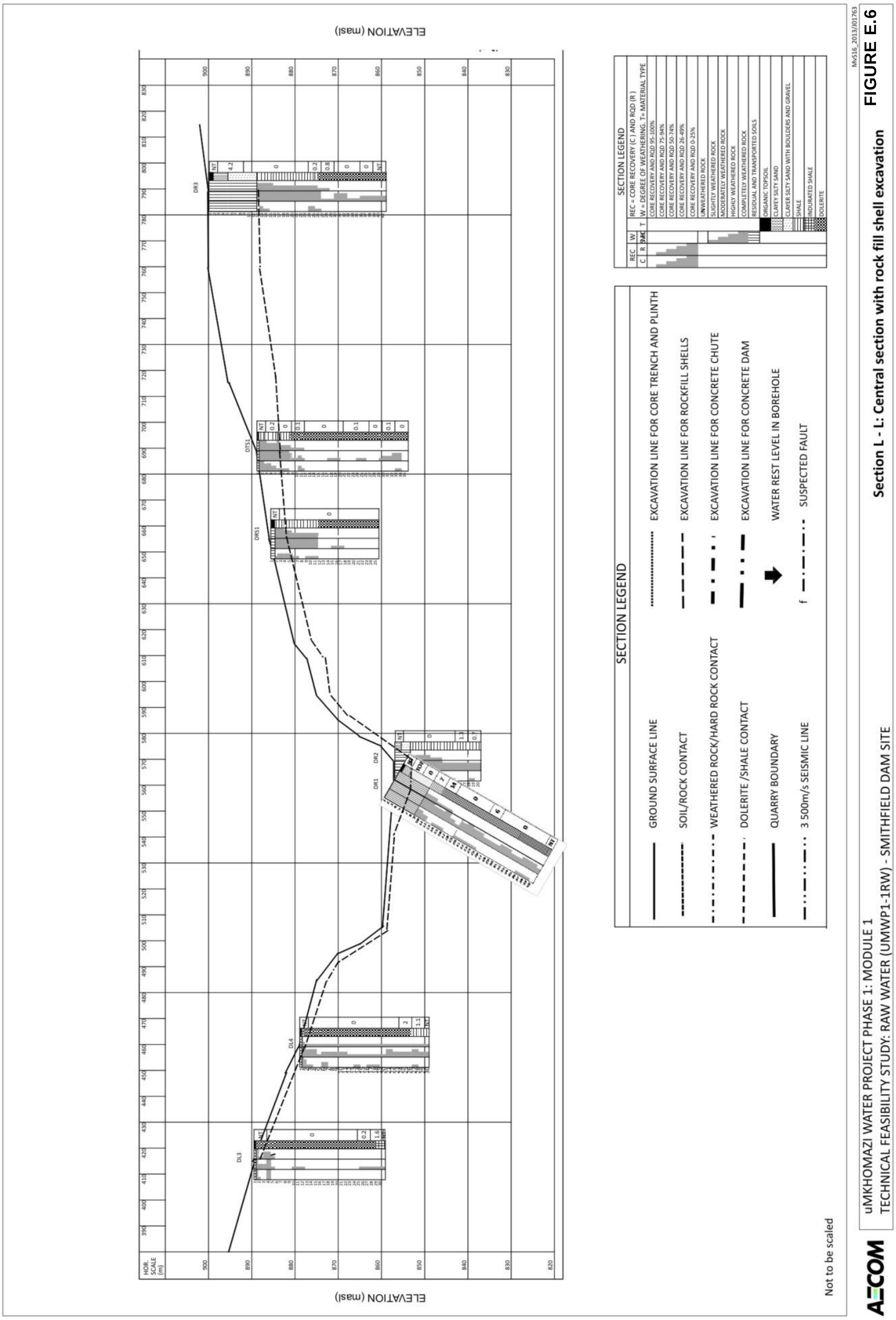
FIGURE E.2

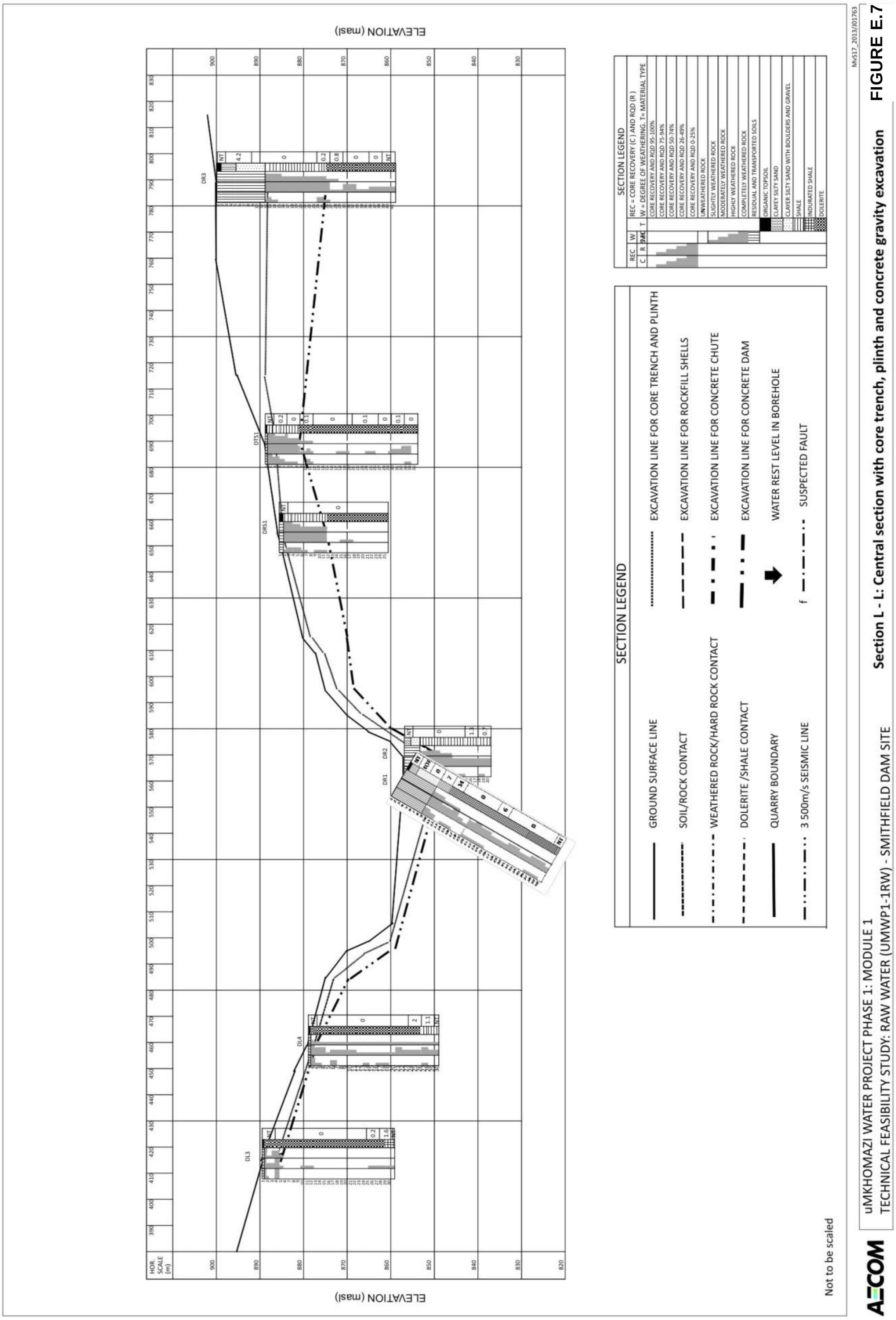

ELEVATION (masl)
SEISMIC LINE L1L2 CHAINAGE
SEISMIC LINE R1R2 CHAINAGE
DOLERITE
SHALE
TRANSPORTED
ALLUVIUM
SECTION LEGEND
GROUND SURFACE LINE
SOIL/ROCK CONTACT
WEATHERED ROCK/HARD ROCK CONTACT
DOLERITE /SHALE CONTACT
QUARRY BOUNDARY
3 500m/s SEISMIC LINE
EXCAVATION LINE FOR CORE TRENCH AND PLINTH
EXCAVATION LINE FOR ROCKFILL SHELLS
EXCAVATION LINE FOR CONCRETE CHUTE
EXCAVATION LINE FOR CONCRETE DAM
WATER REST LEVEL IN BOREHOLE
SUSPECTED FAULT
REC = CORE RECOVERY (C) AND RQD (R)
W = DEGREE OF WEATHERING, T= MATERIAL TYPE
Not to be scaled
MvS12_2013/01763
uMKHOMAZI WATER PROJECT PHASE 1: MODULE 1
TECHNICAL FEASIBILITY STUDY: RAW WATER (UMWP1-1RW) - SMITHFIELD DAM SITE
Section L - L: Central section with seismic and geology
FIGURE E.3
AECOM

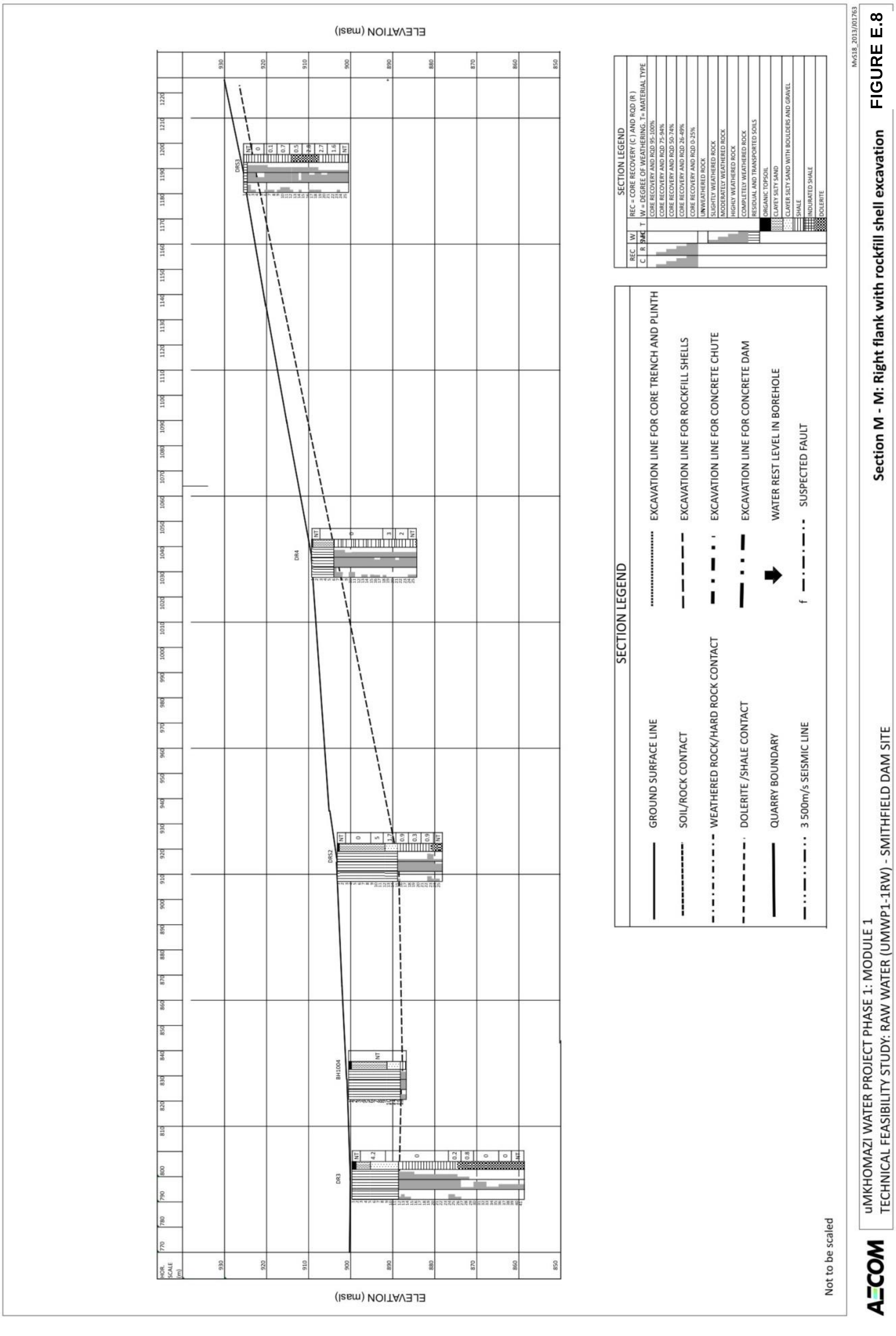

ELEVATION (masl)
SEISMIC LINE R1R2 CHAINAGE
DR3
BH1004
DR52
DR4
DR53
TRANSPORTED MATERIAL
SHALE
DOLERITE
SECTION LEGEND
GROUND SURFACE LINE
SOIL/ROCK CONTACT
WEATHERED ROCK/HARD ROCK CONTACT
DOLERITE /SHALE CONTACT
QUARRY BOUNDARY
3 500m/s SEISMIC LINE
EXCAVATION LINE FOR CORE TRENCH AND PLINTH
EXCAVATION LINE FOR ROCKFILL SHELLS
EXCAVATION LINE FOR CONCRETE CHUTE
EXCAVATION LINE FOR CONCRETE DAM
WATER REST LEVEL IN BOREHOLE
SUSPECTED FAULT
Not to be scaled
uMKHOMAZI WATER PROJECT PHASE 1: MODULE 1
TECHNICAL FEASIBILITY STUDY: RAW WATER (UMWP1-1RW) - SMITHFIELD DAM SITE
Section M - M: Right flank with seismic and geology
FIGURE E.4

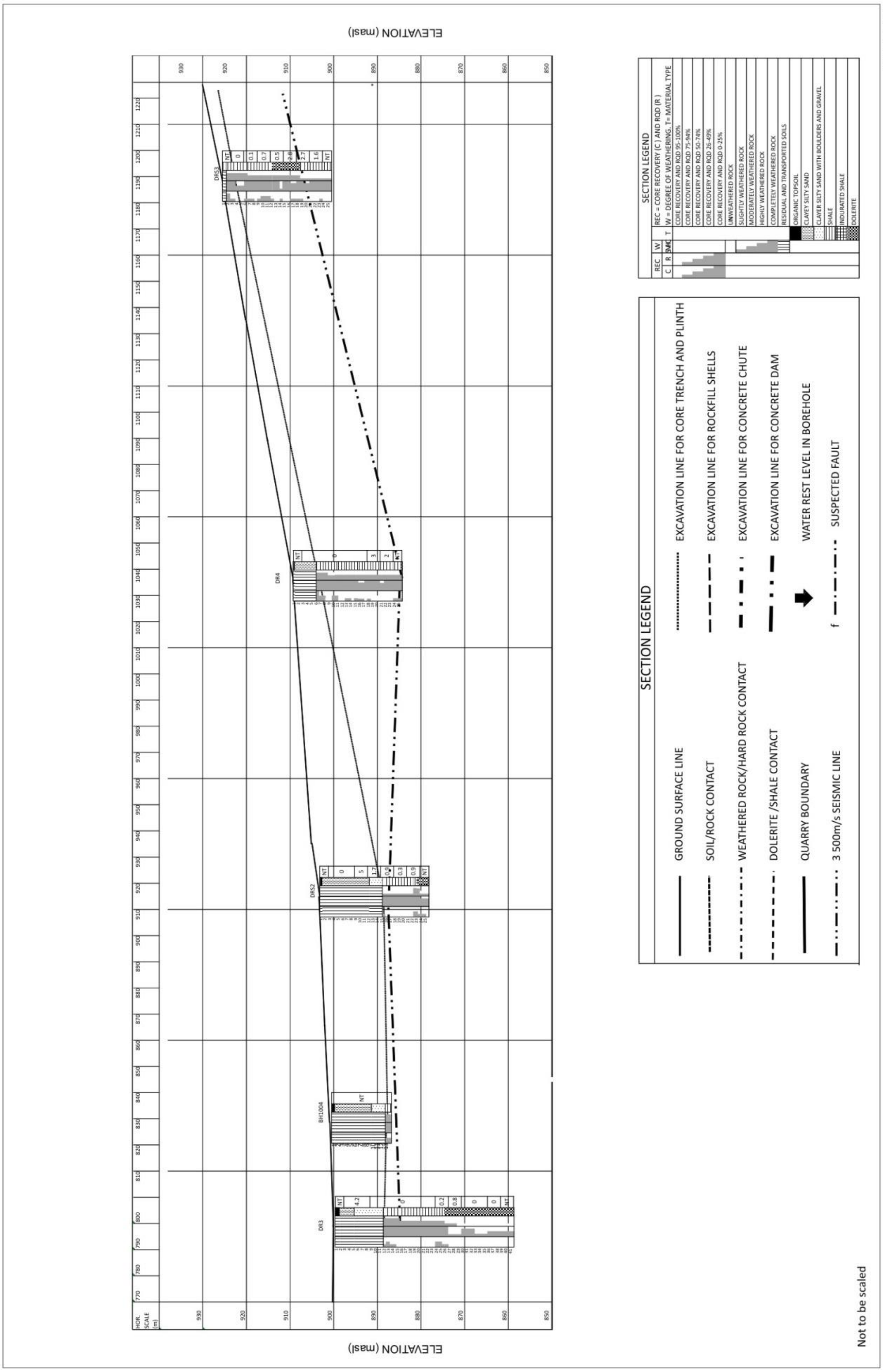

ELEVATION (masl)
HOR. SCALE (m)
DLS3
DL1
DLS2
DLS1
DL3
SECTION LEGEND
GROUND SURFACE LINE
SOIL/ROCK CONTACT
WEATHERED ROCK/HARD ROCK CONTACT
DOLERITE /SHALE CONTACT
QUARRY BOUNDARY
3 500m/s SEISMIC LINE
EXCAVATION LINE FOR CORE TRENCH AND PLINTH
EXCAVATION LINE FOR ROCKFILL SHELLS
EXCAVATION LINE FOR CONCRETE CHUTE
EXCAVATION LINE FOR CONCRETE DAM
WATER REST LEVEL IN BOREHOLE
SUSPECTED FAULT
Not to be scaled
AECOM
uMKHOMAZI WATER PROJECT PHASE 1: MODULE 1
TECHNICAL FEASIBILITY STUDY: RAW WATER (UMWP1-1RW) - SMITHFIELD DAM SITE
Section K - K: Left flank with rock fill shell excavation
FIGURE E.5
MvS14_2013/01763


ELEVATION (masl)
HOR. SCALE (m)
DLS3
DL1
DLS2
DLS1
DL3
SECTION LEGEND
GROUND SURFACE LINE
SOIL/ROCK CONTACT
WEATHERED ROCK/HARD ROCK CONTACT
DOLERITE /SHALE CONTACT
QUARRY BOUNDARY
3 500m/s SEISMIC LINE
EXCAVATION LINE FOR CORE TRENCH AND PLINTH
EXCAVATION LINE FOR ROCKFILL SHELLS
EXCAVATION LINE FOR CONCRETE CHUTE
EXCAVATION LINE FOR CONCRETE DAM
WATER REST LEVEL IN BOREHOLE
SUSPECTED FAULT
SECTION LEGEND
REC = CORE RECOVERY (C) AND RQD (R)
W = DEGREE OF WEATHERING, T= MATERIAL TYPE
Not to be scaled
AECOM
uMKHOMAZI WATER PROJECT PHASE 1: MODULE 1
TECHNICAL FEASIBILITY STUDY: RAW WATER (UMWP1-1RW) - SMITHFIELD DAM SITE
Section K - K: Left flank with core trench, plinth and concrete chute excavation
FIG E6
MvS15_2013/J01763


ELEVATION (masl)
HOR. SCALE (m)
DL3
DL4
DR1
DR2
DRS1
DTS1
DR3
SECTION LEGEND
GROUND SURFACE LINE
SOIL/ROCK CONTACT
WEATHERED ROCK/HARD ROCK CONTACT
DOLERITE /SHALE CONTACT
QUARRY BOUNDARY
3 500m/s SEISMIC LINE
EXCAVATION LINE FOR CORE TRENCH AND PLINTH
EXCAVATION LINE FOR ROCKFILL SHELLS
EXCAVATION LINE FOR CONCRETE CHUTE
EXCAVATION LINE FOR CONCRETE DAM
WATER REST LEVEL IN BOREHOLE
SUSPECTED FAULT
Not to be scaled
AECOM
uMKHOMAZI WATER PROJECT PHASE 1: MODULE 1
TECHNICAL FEASIBILITY STUDY: RAW WATER (UMWP1-1RW) - SMITHFIELD DAM SITE
Section L - L: Central section with rock fill shell excavation
FIGURE E.6
MvS16_2013/01763


ELEVATION (masl)
SECTION LEGEND
GROUND SURFACE LINE
SOIL/ROCK CONTACT
WEATHERED ROCK/HARD ROCK CONTACT
DOLERITE /SHALE CONTACT
QUARRY BOUNDARY
3 500m/s SEISMIC LINE
EXCAVATION LINE FOR CORE TRENCH AND PLINTH
EXCAVATION LINE FOR ROCKFILL SHELLS
EXCAVATION LINE FOR CONCRETE CHUTE
EXCAVATION LINE FOR CONCRETE DAM
WATER REST LEVEL IN BOREHOLE
SUSPECTED FAULT
Not to be scaled
AECOM
uMKHOMAZI WATER PROJECT PHASE 1: MODULE 1
TECHNICAL FEASIBILITY STUDY: RAW WATER (UMWP1-1RW) - SMITHFIELD DAM SITE
Section L - L: Central section with core trench, plinth and concrete gravity excavation
FIGURE E.7
MvS17_2013/J01763

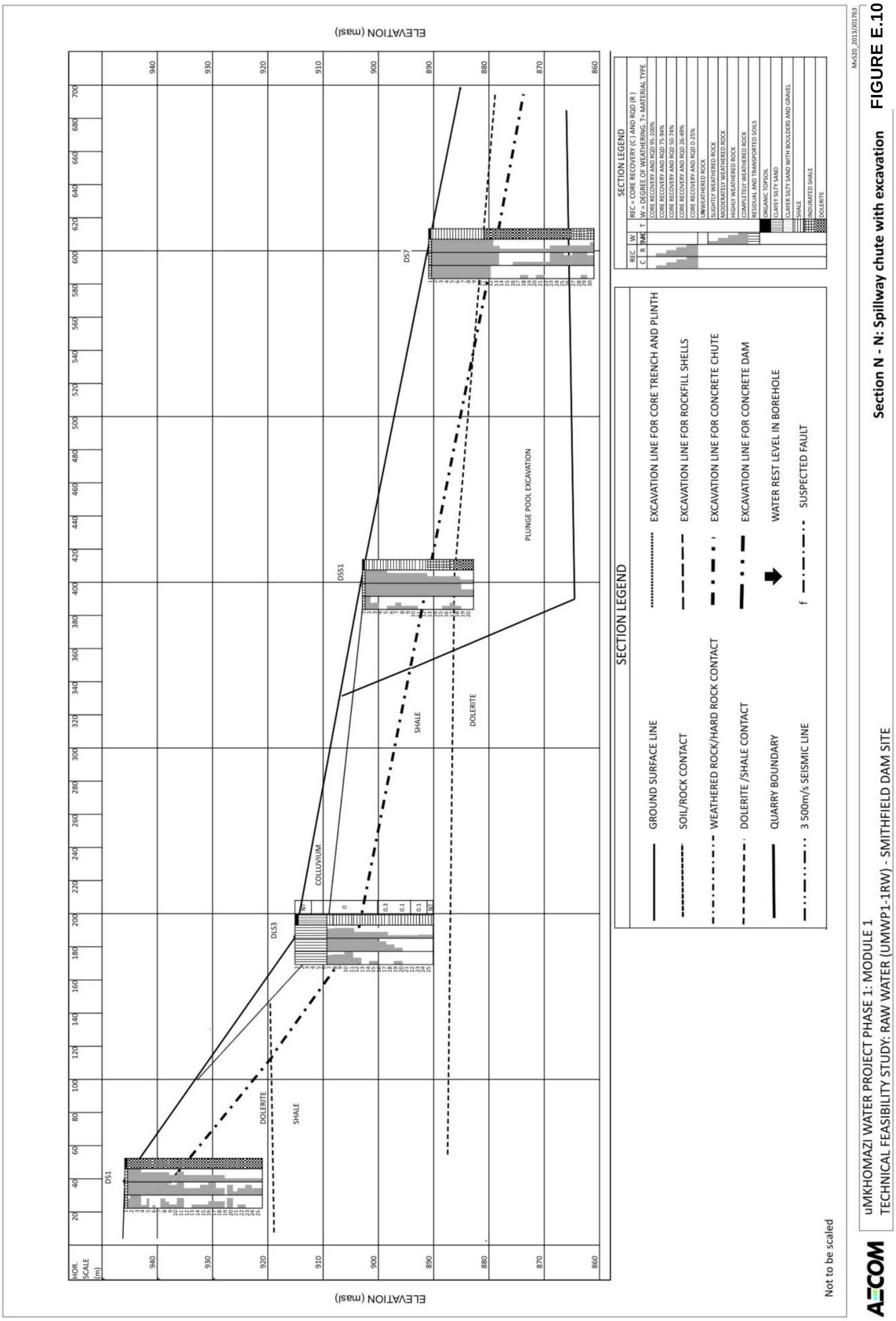

ELEVATION (masl)
HOR. SCALE (m)
DR3
BH1004
DRS2
DR4
DRS3
SECTION LEGEND
GROUND SURFACE LINE
SOIL/ROCK CONTACT
WEATHERED ROCK/HARD ROCK CONTACT
DOLERITE /SHALE CONTACT
QUARRY BOUNDARY
3 500m/s SEISMIC LINE
EXCAVATION LINE FOR CORE TRENCH AND PLINTH
EXCAVATION LINE FOR ROCKFILL SHELLS
EXCAVATION LINE FOR CONCRETE CHUTE
EXCAVATION LINE FOR CONCRETE DAM
WATER REST LEVEL IN BOREHOLE
SUSPECTED FAULT
REC = CORE RECOVERY (C) AND RQD (R)
W = DEGREE OF WEATHERING, T= MATERIAL TYPE
Not to be scaled
AECOM
uMKHOMAZI WATER PROJECT PHASE 1: MODULE 1
TECHNICAL FEASIBILITY STUDY: RAW WATER (UMWP1-1RW) - SMITHFIELD DAM SITE
Section M - M: Right flank with rockfill shell excavation
FIGURE E.8
MvS18_2013/J01763

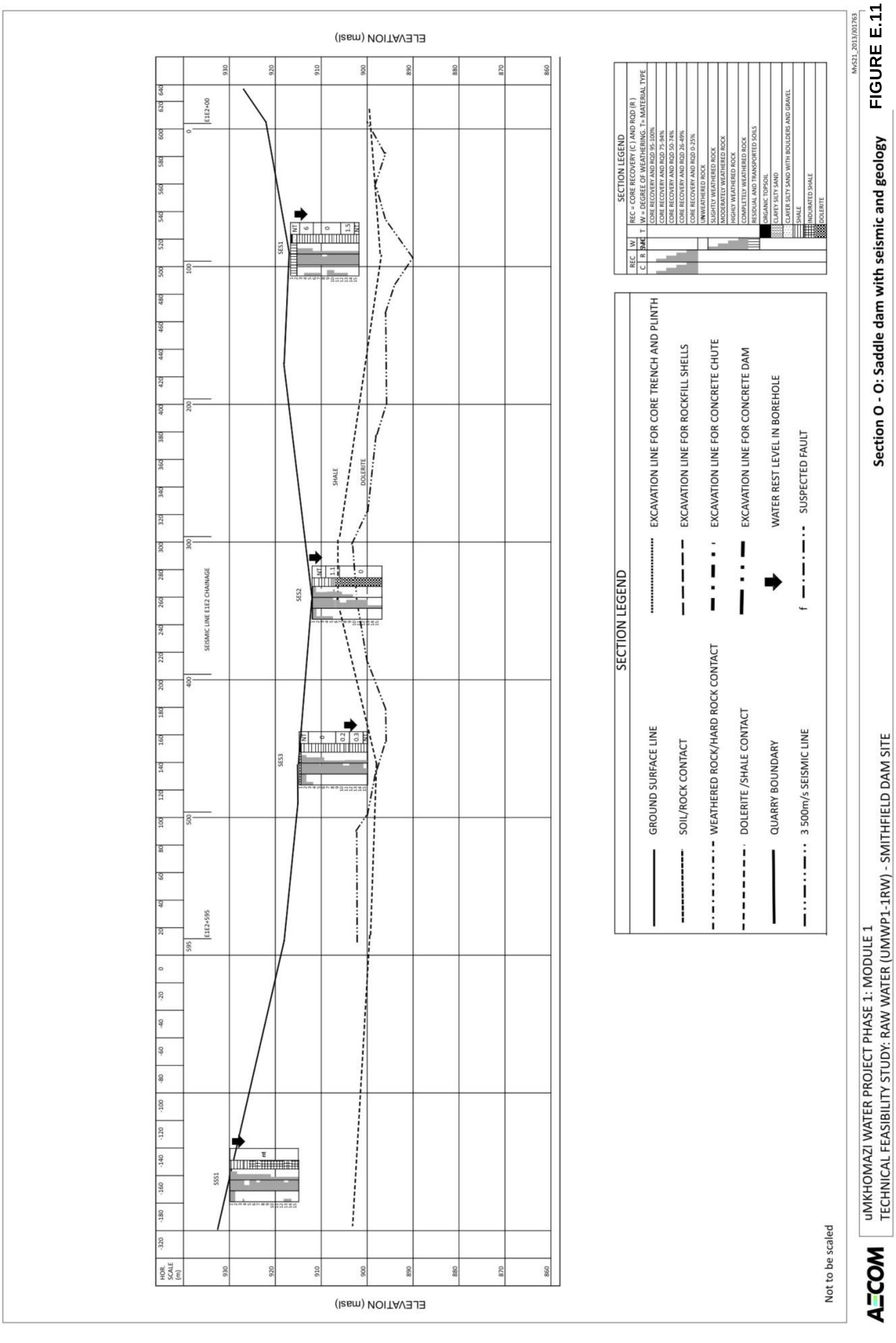


AECOM

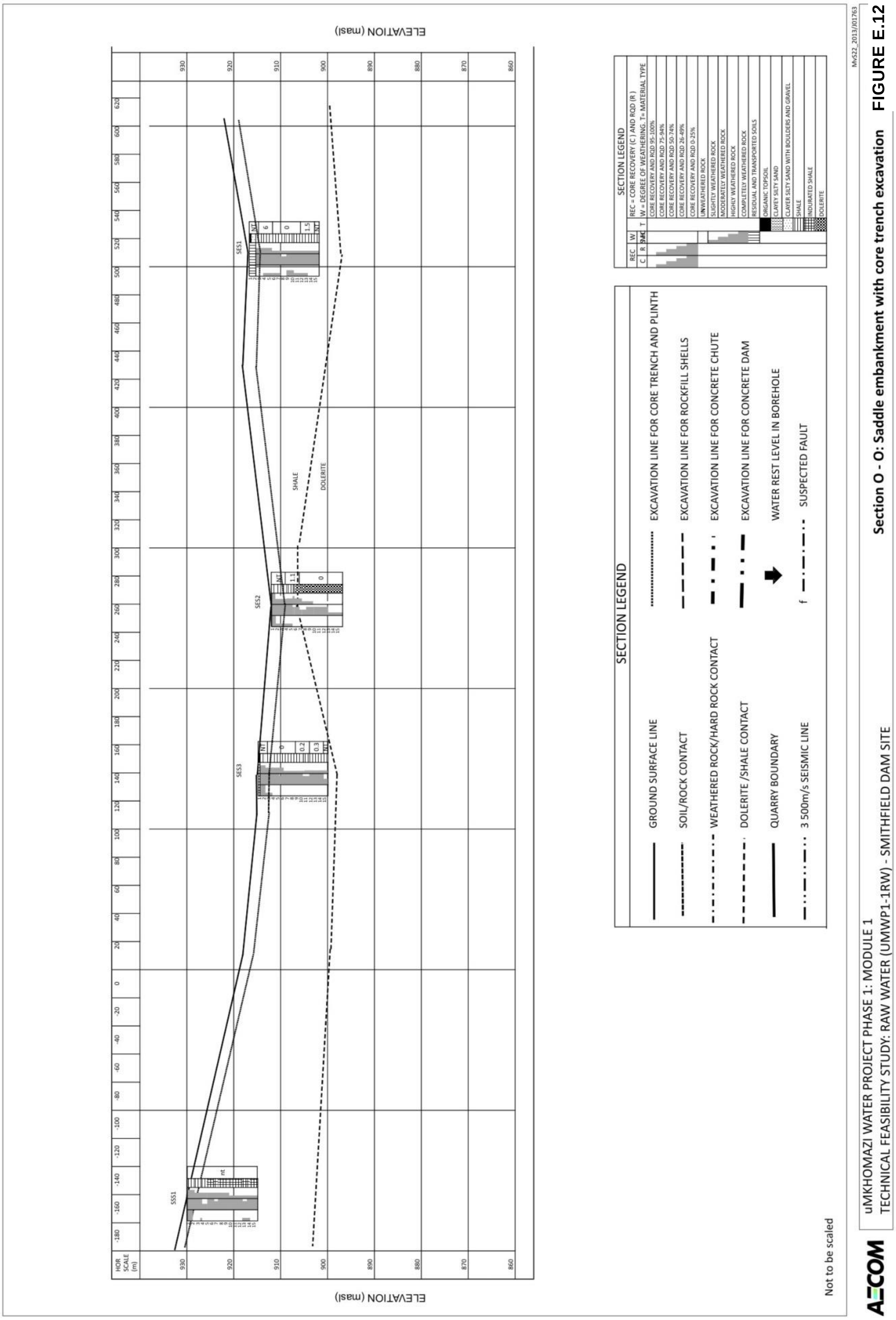
uMKHOMAZI WATER PROJECT PHASE 1: MODULE 1
TECHNICAL FEASIBILITY STUDY: RAW WATER (UMWP1-1RW) - SMITHFIELD DAM SITE

FIGURE E.9 Section M - M: Right flank with core trench, plinth and concrete gravity excavation


ELEVATION (masl)
HOR. SCALE (m)
DS1
DLS3
DSS1
DS7
DOLERITE
SHALE
COLLUVIUM
PLUNGE POOL EXCAVATION
SECTION LEGEND
GROUND SURFACE LINE
SOIL/ROCK CONTACT
WEATHERED ROCK/HARD ROCK CONTACT
DOLERITE /SHALE CONTACT
QUARRY BOUNDARY
3 500m/s SEISMIC LINE
EXCAVATION LINE FOR CORE TRENCH AND PLINTH
EXCAVATION LINE FOR ROCKFILL SHELLS
EXCAVATION LINE FOR CONCRETE CHUTE
EXCAVATION LINE FOR CONCRETE DAM
WATER REST LEVEL IN BOREHOLE
SUSPECTED FAULT
REC = CORE RECOVERY (C) AND RQD (R)
W = DEGREE OF WEATHERING, T= MATERIAL TYPE
Not to be scaled
uMKHOMAZI WATER PROJECT PHASE 1: MODULE 1
TECHNICAL FEASIBILITY STUDY: RAW WATER (UMWP1-1RW) - SMITHFIELD DAM SITE
Section N - N: Spillway chute with excavation
FIGURE E.10
AECOM



ELEVATION (masl)
HOR. SCALE (m)
SEISMIC LINE E1E2 CHAINAGE
SS51
SES1
SES2
SES3
SHALE
DOLERITE
SECTION LEGEND
GROUND SURFACE LINE
SOIL/ROCK CONTACT
WEATHERED ROCK/HARD ROCK CONTACT
DOLERITE /SHALE CONTACT
QUARRY BOUNDARY
3 500m/s SEISMIC LINE
EXCAVATION LINE FOR CORE TRENCH AND PLINTH
EXCAVATION LINE FOR ROCKFILL SHELLS
EXCAVATION LINE FOR CONCRETE CHUTE
EXCAVATION LINE FOR CONCRETE DAM
WATER REST LEVEL IN BOREHOLE
SUSPECTED FAULT
Not to be scaled
AECOM
uMKHOMAZI WATER PROJECT PHASE 1: MODULE 1
TECHNICAL FEASIBILITY STUDY: RAW WATER (UMWP1-1RW) - SMITHFIELD DAM SITE
Section O - O: Saddle dam with seismic and geology
FIGURE E.11


ELEVATION (masl)
HOR SCALE (m)
SSS1
SES1
SES2
SES3
SHALE
DOLERITE
SECTION LEGEND
GROUND SURFACE LINE
SOIL/ROCK CONTACT
WEATHERED ROCK/HARD ROCK CONTACT
DOLERITE /SHALE CONTACT
QUARRY BOUNDARY
3 500m/s SEISMIC LINE
EXCAVATION LINE FOR CORE TRENCH AND PLINTH
EXCAVATION LINE FOR ROCKFILL SHELLS
EXCAVATION LINE FOR CONCRETE CHUTE
EXCAVATION LINE FOR CONCRETE DAM
WATER REST LEVEL IN BOREHOLE
SUSPECTED FAULT
REC = CORE RECOVERY (C) AND RQD (R)
W = DEGREE OF WEATHERING, T= MATERIAL TYPE
Not to be scaled
AECOM
uMKHOMAZI WATER PROJECT PHASE 1: MODULE 1
TECHNICAL FEASIBILITY STUDY: RAW WATER (UMWP1-1RW) - SMITHFIELD DAM SITE
Section O - O: Saddle embankment with core trench excavation
FIGURE E.12

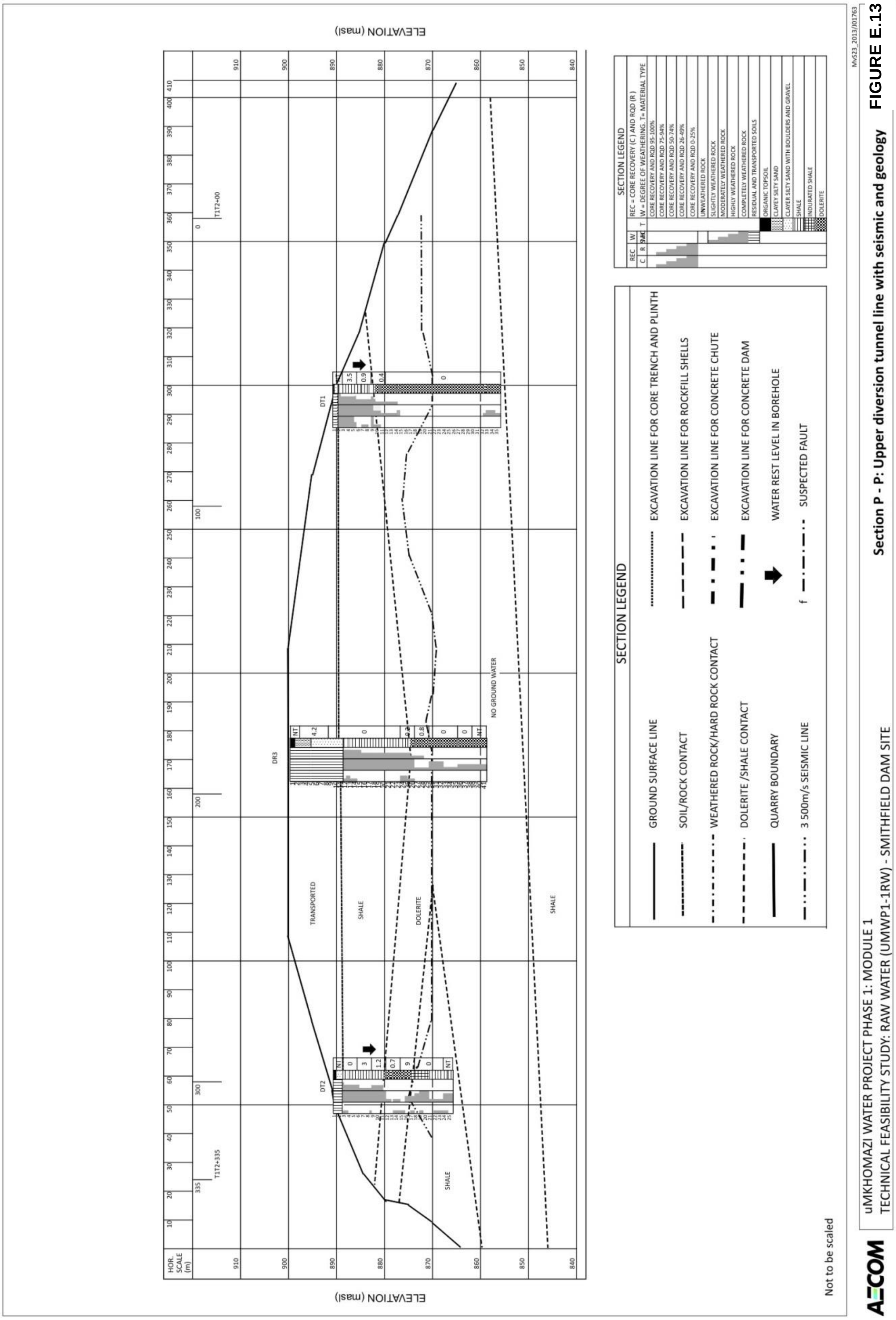
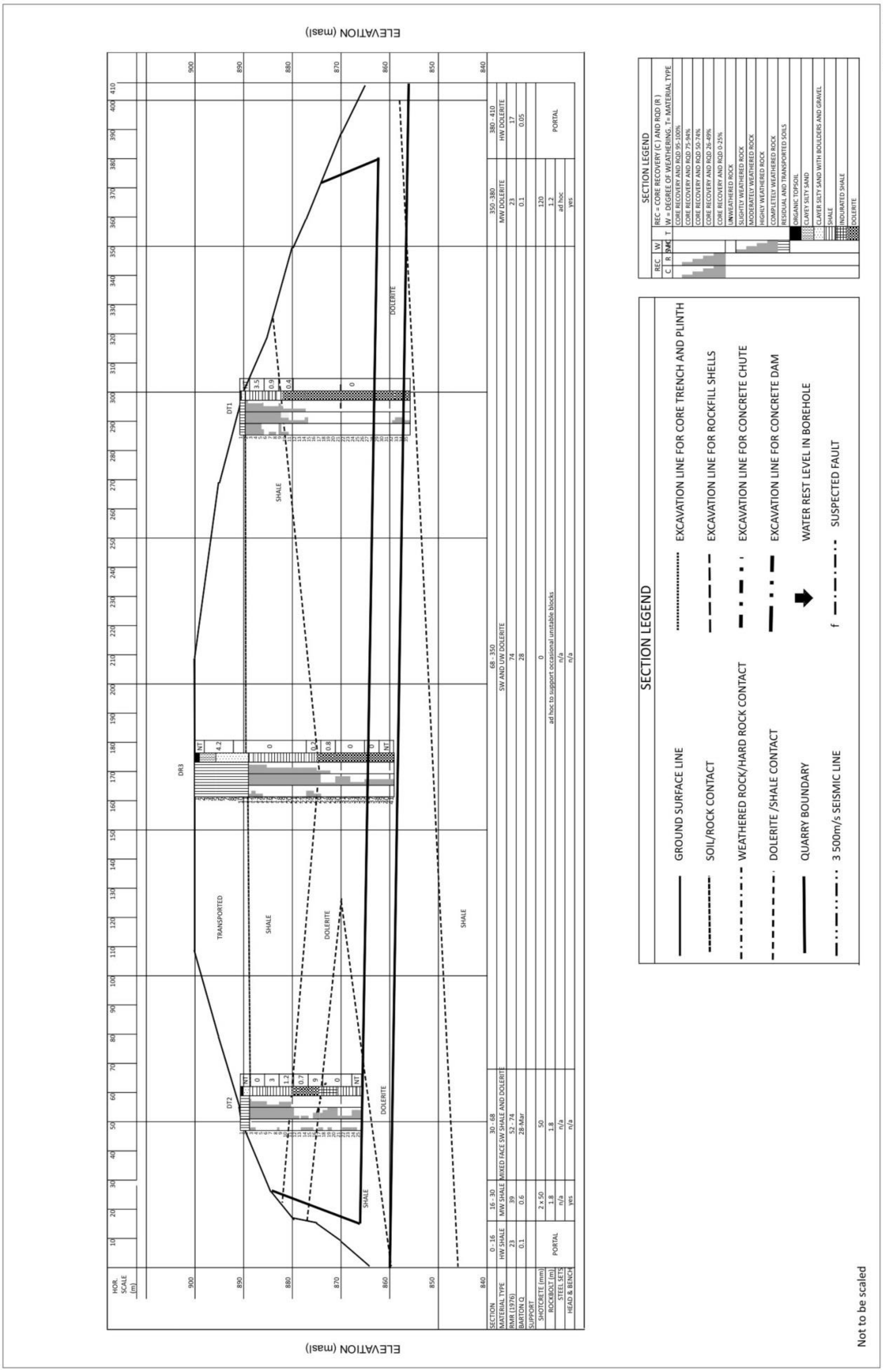


FIGURE E.13 Section P - P: Upper diversion tunnel line with seismic and geology

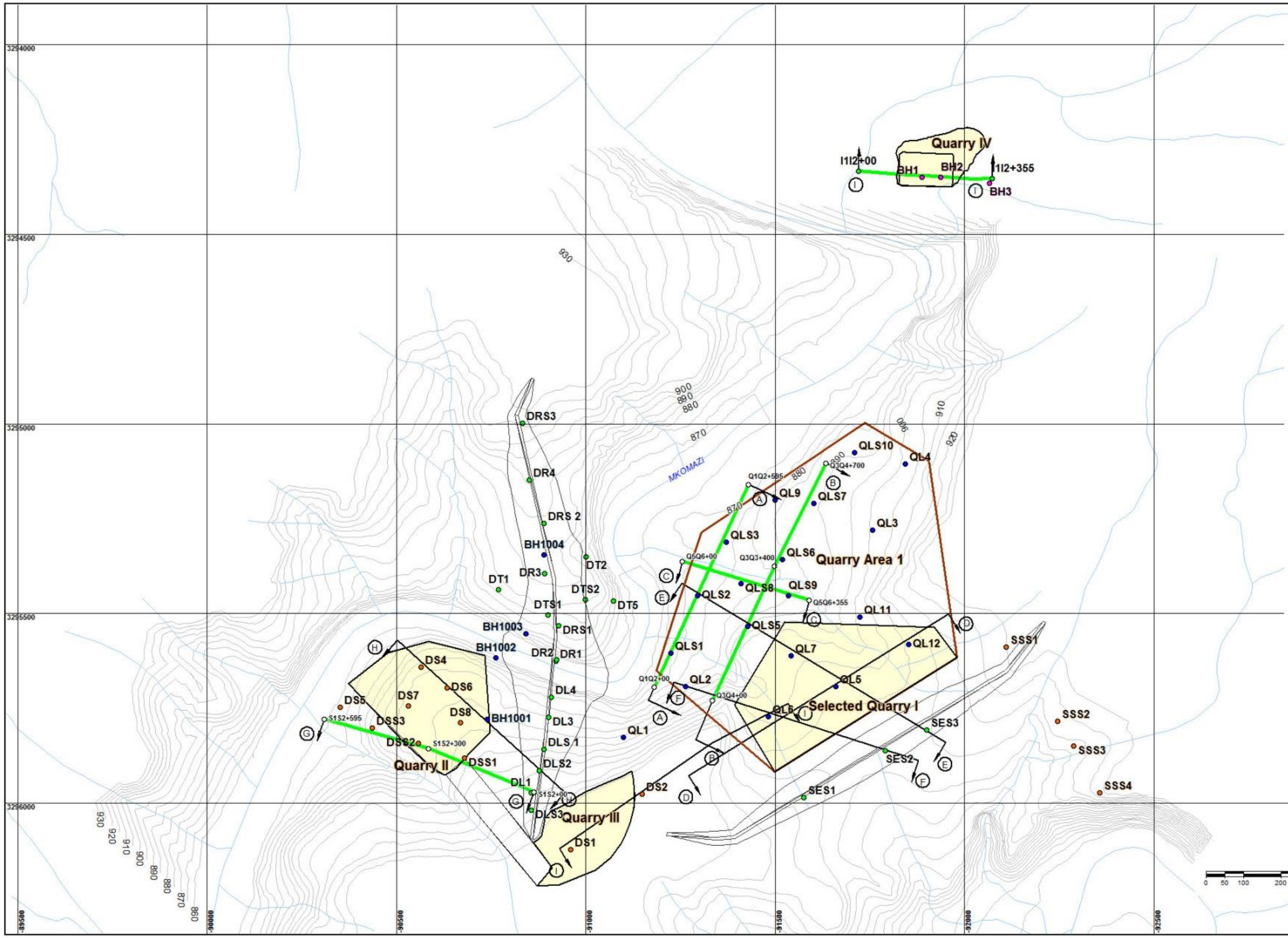


Not to be scaled

uMKHOMAZI WATER PROJECT PHASE 1: MODULE 1
TECHNICAL FEASIBILITY STUDY: RAW WATER (UMWP1-1RW) - SMITHFIELD DAM SITE

Section P - P: Upper diversion tunnel line with rock mass classification and support

FIGURE E.14



Point	Y	X	Z
BH1	-91888.355	3294347.533	881.966
BH2	-91937.428	3294347.833	885.139
BH3	-92066.817	3294363.901	910.253
QL1	-91099.827	3295825.444	895.411
QL2	-91263.687	3295691.777	881.326
QL3	-91758.576	3295279.262	900.388
QL4	-91844.101	3295105.650	901.319
QL5	-91661.178	3295691.723	907.771
QL6	-91483.182	3295771.205	902.074
QL7	-91542.458	3295610.738	903.461
QL8	-91601.947	3295209.271	889.586
QL9	-91499.977	3295200.977	882.237
QLS10	-91711.102	3295074.322	889.193
QL11	-91724.268	3295508.458	900.476
QL12	-91852.742	3295581.043	911.372
QLS1	-91226.124	3295604.683	867.260
QLS2	-91295.014	3295451.995	872.104
QLS3	-91372.327	3295311.548	873.236
QLS5	-91428.899	3295534.165	890.913
QLS6	-91520.385	3295357.505	883.058
QLS7	-91602.0492	3295209.278	889.5401
QLS8	-91409.753	3295419.777	876.725
QLS9	-91535.349	3295452.327	884.643
SSS1	-92111.273	3295588.927	930.234
SSS2	-92246.256	3295784.210	924.020
SSS3	-92287.984	3295848.209	916.651
SSS4	-92357.274	3295971.685	927.833
DS1	-90960.829	3296122.133	946.059
DS2	-91149.035	3295976.834	948.922
DS4	-90565.218	3295640.409	885.590
DS5	-90352.867	3295746.777	861.131
DS6	-90634.031	3295696.377	892.922
DS7	-90531.845	3295743.707	890.629
DS8	-90670.255	3295787.966	897.886
DSS1	-90679.711	3295881.130	902.871
DSS2	-90559.278	3295842.043	891.703
DSS3	-90437.763	3295801.279	881.383
DL1	-90856.356	3295972.609	918.233
DL3	-90903.282	3295772.393	889.542
DL4	-90909.125	3295720.899	879.250
DLS 1	-90891.1126	3295857.475	904.2547
DLS2	-90877.696	3295914.206	914.337
DLS3	-90856.370	3296018.539	922.166
DRS1	-90928.946	3295532.490	885.581
DRS 2	-90889.5524	3295262.083	903.8107
DRS3	-90834.530	3294997.543	925.129
DR1	-90922.673	3295625.887	857.321
DR2	-90924.617	3295620.853	857.457
DR3	-90892.368	3295394.651	900.153
DR4	-90850.828	3295148.029	909.438
DTS1	-90901.271	3295503.859	888.424
DTS2	-90999.857	3295462.988	895.4449
DT5	-91073.4962	3295467.275	876.6828
DT1	-90770.295	3295436.268	891.303
DT2	-91001.072	3295349.155	891.317
SES1	-91575.607	3295984.511	917.386
SES2	-91791.017	3295861.429	911.962
SES3	-91900.250	3295807.054	915.178

water affairs
Department: Water Affairs
REPUBLIC OF SOUTH AFRICA

AECOM

Project Name:

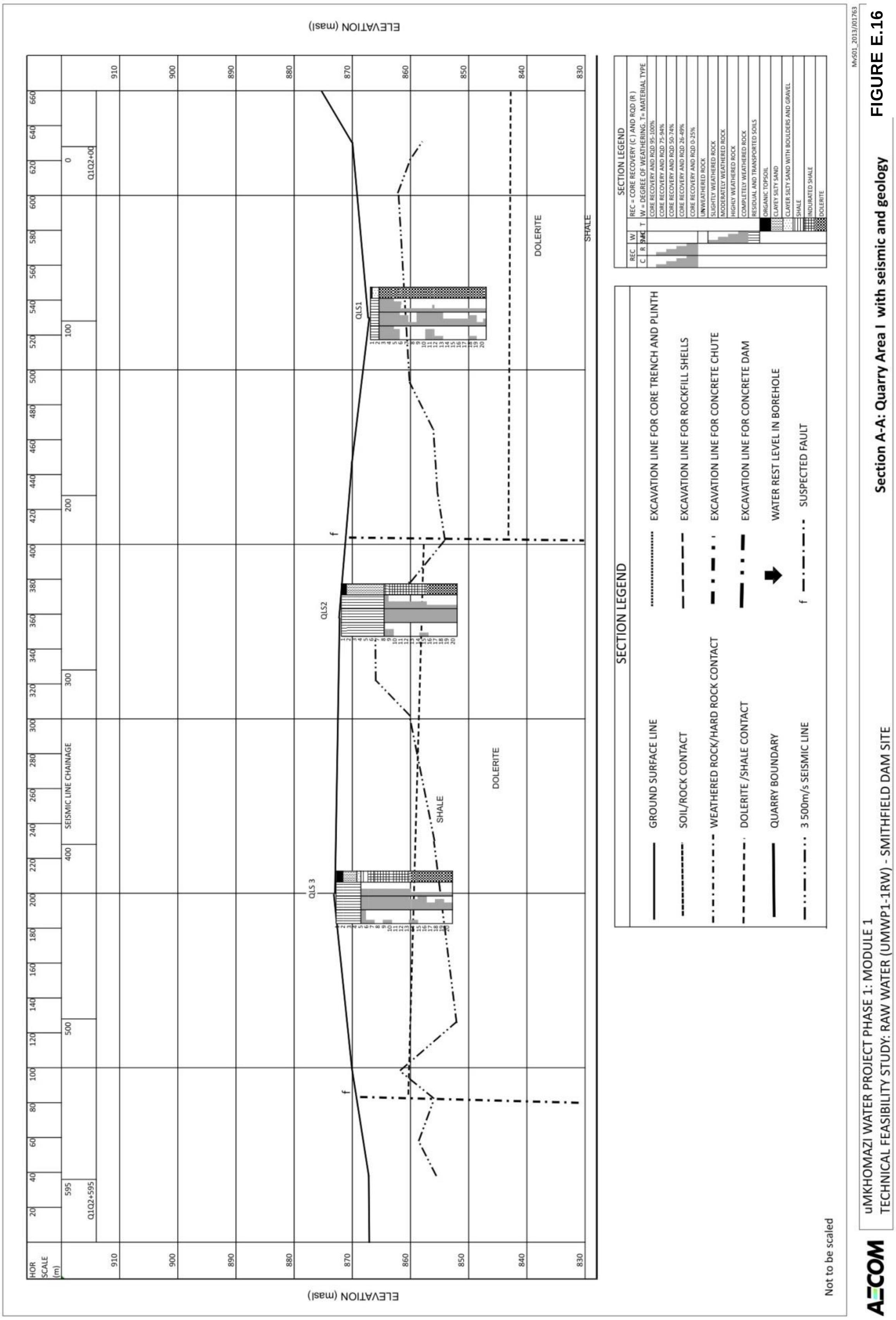
uMkhomazi Water Project Phase 1: Module 1:
Technical Feasibility Study: Raw Water (uMWP1-1/RW)
Plan showing Quarry Areas,
Smithfield Dam: Seismic Lines, Boreholes and Sections

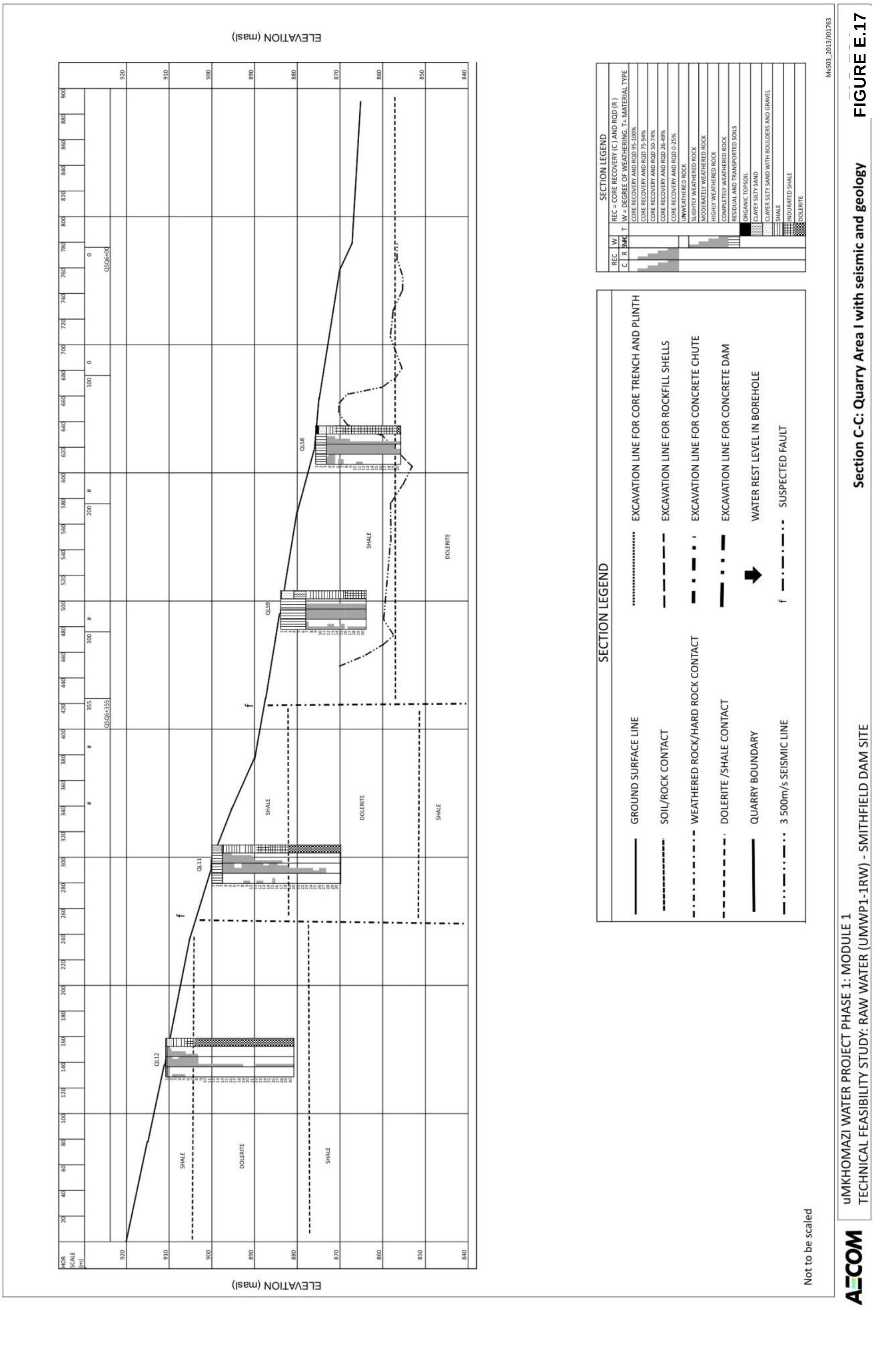
Legend

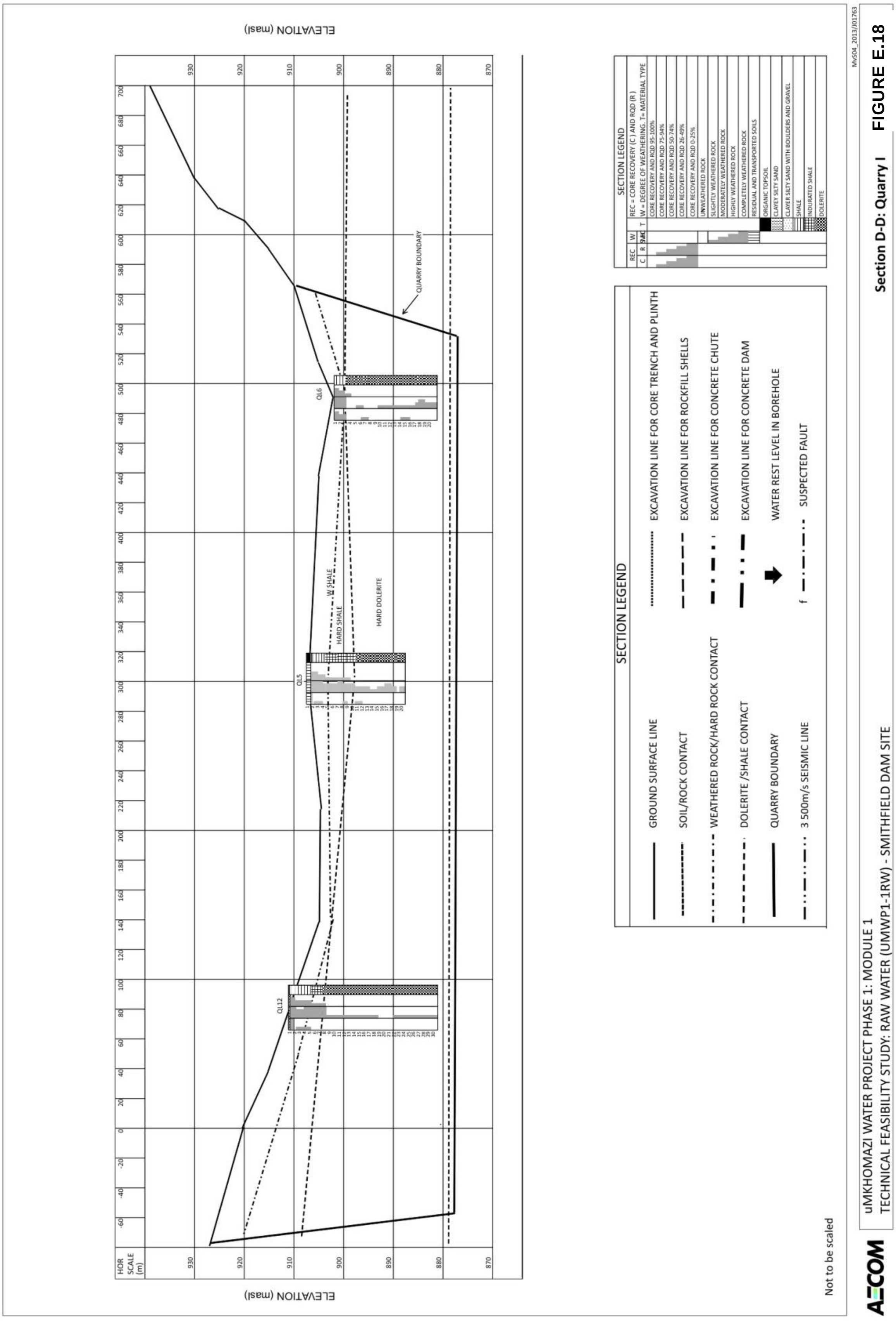
- Contours
- Seismic Refraction Traverses
- Borehole Positions
- Proposed Quarries

FIGURE E.15

Drawn:	LC Gallagher
Checked:	D vd Merwe
Date:	2013-07-29
Map Ref:	uMkhomazi.map
View Ref:	Quarry Areas, Seismic Lines
Project No:	J01763


ELEVATION (masl)
HOR SCALE (m)
SEISMIC LINE CHAINAGE
QLS 3
QLS2
QLS1
DOLERITE
SHALE
SECTION LEGEND
GROUND SURFACE LINE
SOIL/ROCK CONTACT
WEATHERED ROCK/HARD ROCK CONTACT
DOLERITE /SHALE CONTACT
QUARRY BOUNDARY
3 500m/s SEISMIC LINE
EXCAVATION LINE FOR CORE TRENCH AND PLINTH
EXCAVATION LINE FOR ROCKFILL SHELLS
EXCAVATION LINE FOR CONCRETE CHUTE
EXCAVATION LINE FOR CONCRETE DAM
WATER REST LEVEL IN BOREHOLE
SUSPECTED FAULT
Not to be scaled
AECOM
uMKHOMAZI WATER PROJECT PHASE 1: MODULE 1
TECHNICAL FEASIBILITY STUDY: RAW WATER (UMWP1-1RW) - SMITHFIELD DAM SITE
Section A-A: Quarry Area I with seismic and geology
FIGURE E.16


ELEVATION (masl)
HOR SCALE (m)
SHALE
DOLERITE
QL12
QL11
QL59
QL58
SECTION LEGEND
GROUND SURFACE LINE
SOIL/ROCK CONTACT
WEATHERED ROCK/HARD ROCK CONTACT
DOLERITE /SHALE CONTACT
QUARRY BOUNDARY
3 500m/s SEISMIC LINE
EXCAVATION LINE FOR CORE TRENCH AND PLINTH
EXCAVATION LINE FOR ROCKFILL SHELLS
EXCAVATION LINE FOR CONCRETE CHUTE
EXCAVATION LINE FOR CONCRETE DAM
WATER REST LEVEL IN BOREHOLE
SUSPECTED FAULT
Not to be scaled
uMKHOMAZI WATER PROJECT PHASE 1: MODULE 1
TECHNICAL FEASIBILITY STUDY: RAW WATER (UMWP1-1RW) - SMITHFIELD DAM SITE
Section C-C: Quarry Area I with seismic and geology
FIGURE E.17
AECOM


ELEVATION (masl)
HOR SCALE (m)
QL12
QL5
QL6
HARD SHALE
W SHALE
HARD DOLERITE
QUARRY BOUNDARY
SECTION LEGEND
GROUND SURFACE LINE
SOIL/ROCK CONTACT
WEATHERED ROCK/HARD ROCK CONTACT
DOLERITE /SHALE CONTACT
QUARRY BOUNDARY
3 500m/s SEISMIC LINE
EXCAVATION LINE FOR CORE TRENCH AND PLINTH
EXCAVATION LINE FOR ROCKFILL SHELLS
EXCAVATION LINE FOR CONCRETE CHUTE
EXCAVATION LINE FOR CONCRETE DAM
WATER REST LEVEL IN BOREHOLE
SUSPECTED FAULT
SECTION LEGEND
REC = CORE RECOVERY (C) AND RQD (R)
W = DEGREE OF WEATHERING, T= MATERIAL TYPE
CORE RECOVERY AND RQD 95-100%
CORE RECOVERY AND RQD 75-94%
CORE RECOVERY AND RQD 50-74%
CORE RECOVERY AND RQD 26-49%
CORE RECOVERY AND RQD 0-25%
UNWEATHERED ROCK
SLIGHTLY WEATHERED ROCK
MODERATELY WEATHERED ROCK
HIGHLY WEATHERED ROCK
COMPLETELY WEATHERED ROCK
RESIDUAL AND TRANSPORTED SOILS
ORGANIC TOPSOIL
CLAYEY SILTY SAND
CLAYEY SILTY SAND WITH BOULDERS AND GRAVEL
SHALE
INDURATED SHALE
DOLERITE
Not to be scaled
AECOM
uMKHOMAZI WATER PROJECT PHASE 1: MODULE 1
TECHNICAL FEASIBILITY STUDY: RAW WATER (UMWP1-1RW) - SMITHFIELD DAM SITE
Section D-D: Quarry I
FIGURE E.18
MvS04_2013/01763

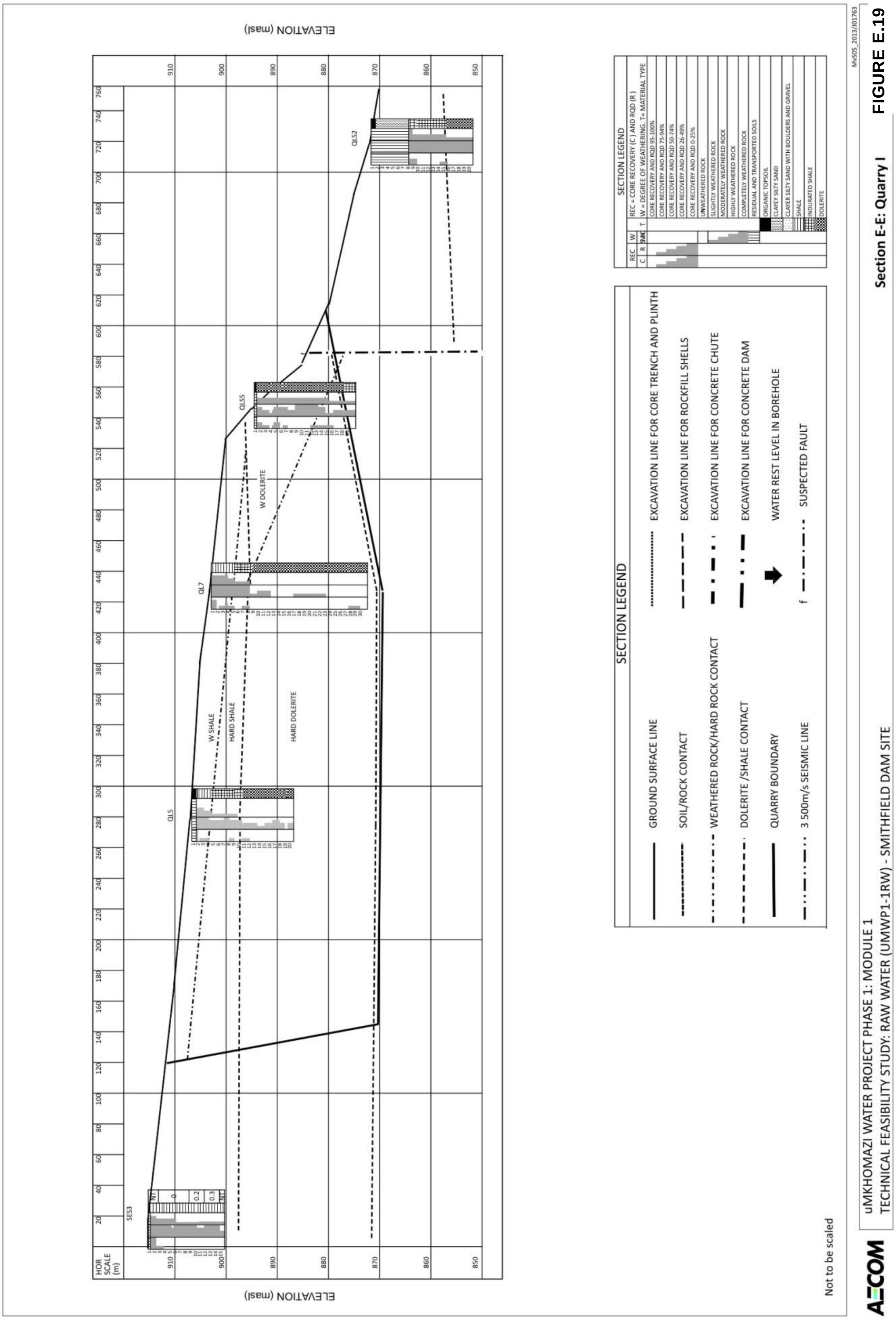
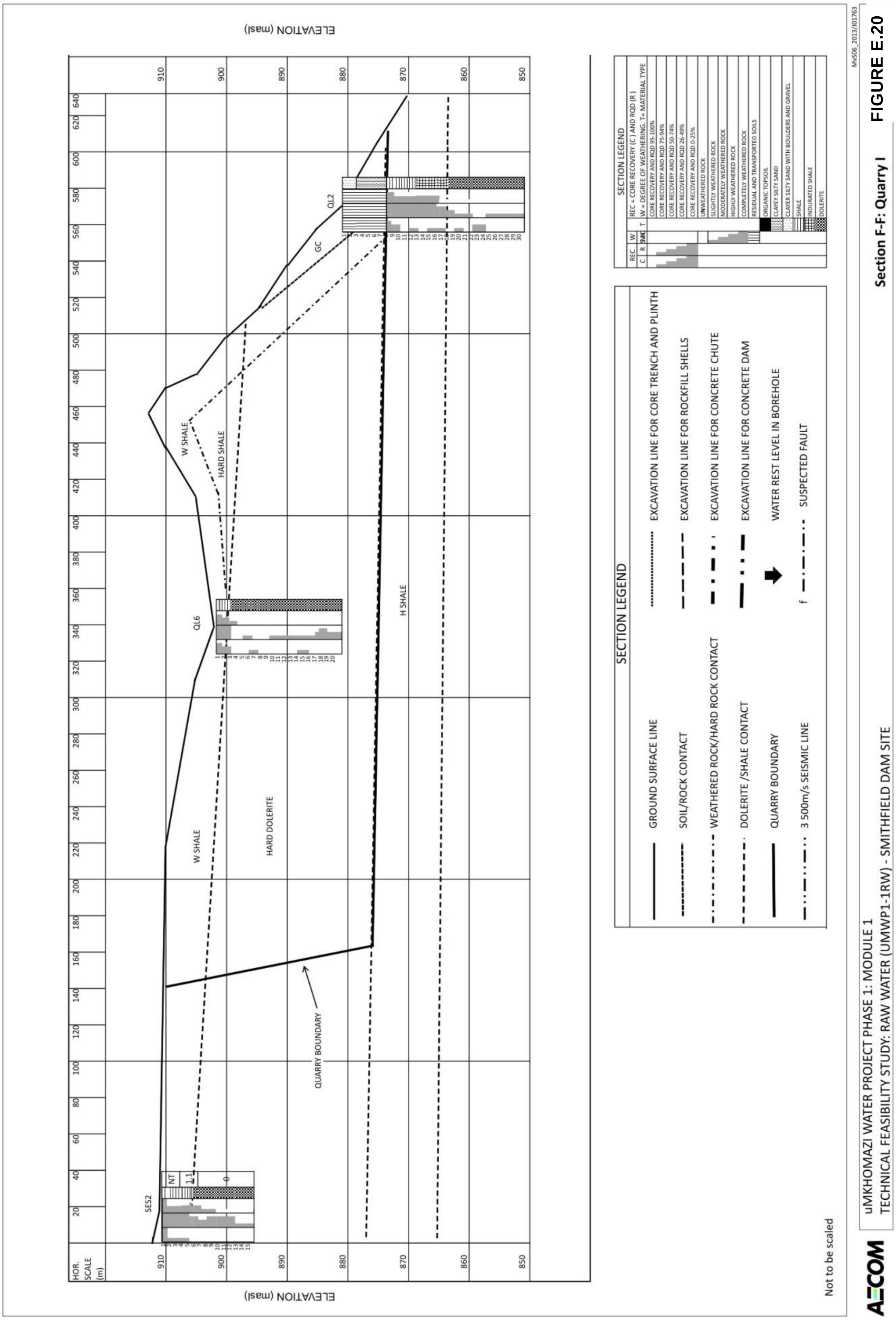


FIGURE E.19
Section E-E: Quarry I
uMKHOMAZI WATER PROJECT PHASE 1: MODULE 1
TECHNICAL FEASIBILITY STUDY: RAW WATER (UMWP1-1RW) - SMITHFIELD DAM SITE
Not to be scaled
AECOM
ELEVATION (masl)
HOR SCALE (m)
SECTION LEGEND
GROUND SURFACE LINE
SOIL/ROCK CONTACT
WEATHERED ROCK/HARD ROCK CONTACT
DOLERITE /SHALE CONTACT
QUARRY BOUNDARY
3 500m/s SEISMIC LINE
EXCAVATION LINE FOR CORE TRENCH AND PLINTH
EXCAVATION LINE FOR ROCKFILL SHELLS
EXCAVATION LINE FOR CONCRETE CHUTE
EXCAVATION LINE FOR CONCRETE DAM
WATER REST LEVEL IN BOREHOLE
SUSPECTED FAULT
W SHALE
HARD SHALE
HARD DOLERITE
W DOLERITE
SES3
QL5
QL7
QLS5
QLS2


ELEVATION (masl)
HOR. SCALE (m)
SES2
QL6
QL2
GC
W SHALE
HARD SHALE
HARD DOLERITE
H SHALE
QUARRY BOUNDARY
SECTION LEGEND
GROUND SURFACE LINE
SOIL/ROCK CONTACT
WEATHERED ROCK/HARD ROCK CONTACT
DOLERITE /SHALE CONTACT
QUARRY BOUNDARY
3 500m/s SEISMIC LINE
EXCAVATION LINE FOR CORE TRENCH AND PLINTH
EXCAVATION LINE FOR ROCKFILL SHELLS
EXCAVATION LINE FOR CONCRETE CHUTE
EXCAVATION LINE FOR CONCRETE DAM
WATER REST LEVEL IN BOREHOLE
SUSPECTED FAULT
REC = CORE RECOVERY (C) AND RQD (R)
W = DEGREE OF WEATHERING, T= MATERIAL TYPE
Not to be scaled
AECOM
uMKHOMAZI WATER PROJECT PHASE 1: MODULE 1
TECHNICAL FEASIBILITY STUDY: RAW WATER (UMWP1-1RW) - SMITHFIELD DAM SITE
Section F-F: Quarry I
FIGURE E.20

Appendix F

Smithfield Dam: Results from balancing exercise - Balancing spreadsheets

Table F.1: Option 1: Main dam - Roller compacted concrete (RCC) gravity; Saddle dam -zoned earthfill embankment dam balancing spreadsheet

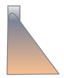
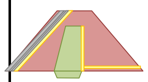
No.	Dam type	Configuration	Material (source)	A	B	C	D	E	F	G		Total cost (ZAR)
				MAIN & SADDLE DAM WALLS + DIVERSION TUNNELS								
				Overburden for soil: Organic topsoil	Clayey sand transported surface material	Completely and highly weathered shales	Unweathered to moderately weathered shales	Highly and moderately weathered dolerite	Slightly weathered and unweathered dolerite	Imported sand	SUM	
				Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	
1	(1) RCC dam & (2) Zoned embankment (earthfill) dam		(1) Required material - Main wall									4 382 157 854
			(a) Core (impervious earthfill)								0	
			(b) Upstream and downstream shells (semi pervious earthfill)								0	
			(c) Rockfill (Impervious layer)								0	
			(d) Rip-rap								0	
			(e) Gravel layer								0	
			(f) Sand layer transition zone								0	
			(g) Blanket and chimney drains								0	
			(h) Concrete						1 050 965		1 050 965	
			(2) Required material - Saddle wall									
			(a) Core (impervious earthfill)		336 835						336 835	
			(b) Upstream and downstream shells (semi pervious earthfill)			861 785					861 785	
			(c) Rockfill (Impervious layer)								0	
			(d) Rip-rap						19 876		19 876	
			(e) Gravel layer						39 752		39 752	
			(f) Sand layer transition zone							19 876	19 876	
			(g) Blanket and chimney drains							66 669	66 669	
			(h) Concrete aggregate								0	
			(3) Required material - Infrastructure									
			(a) Diversion works concrete aggregate						2 000		2 000	
			(b) Intake structure concrete aggregate						6 000		6 000	
			(c) Spillway and chute concrete aggregate								0	
			(d) Outlet works concrete aggregate						1 300		1 300	
			(e) Apron slab						3 700		3 700	
			TOTAL REQUIRED	0	336 835	861 785	0	0	1 123 593	86 544		
			Available material: (1) Borrow area A									
			(2) Borrow area B									
			(3) Borrow area C									
			(4) Quarry I (Left flank)	0	20 000	600 000	600 000	140 000	2 600 000			
			(5) Quarry II (Plunge pool)									
			(6) Quarry III (Spillway approach)									
			(7) Quarry IV (Tunnel inlet)	0	7 000	110 000	13 500	0	0			
			(8) Excavation: Main wall	0	331 235	566 305	0	170 960	0			
			(9) Excavation: Saddle wall	0	0	92 975	0	0	0			
			(10) Other							86 544		
			TOTAL AVAILABLE	0	358 235	1 369 280	613 500	310 960	2 600 000	86 544		
			Material needed	*0*	*21 400*	*507 495*	*613 500*	*310 960*	*1 476 407*			
			To be stockpiled for later use									
			To be dumped	*0*	*21 400*	*112 532*	*226 404*	*310 960*				
			Dam forming	*0*	*336 835*	*861 785*	*0*		*1 123 593*	*86 544*		
			Untouched	*0*		*394 963*	*387 096*	*0*	*1 476 407*			
			Percentage remaining (%)		*6%*	*59%*	*Not used*	*Not used*	*131%*	*0%*		

Table F.2: Option 2: Main dam - Earth core rockfill dam; Saddle dam - Zoned earthfill embankment dam balancing spreadsheet

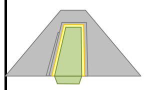
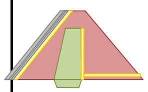
No.	Dam type	Configuration	Material (source)	A: Overburden for soil: Organic topsoil Volume (m^3)	B: Clayey sand transported surface material Volume (m^3)	C: Completely and highly weathered shales Volume (m^3)	D: Unweathered to moderately weathered shales Volume (m^3)	E: Highly and moderately weathered dolerite Volume (m^3)	F: Slightly weathered and unweathered dolerite Volume (m^3)	G: Imported sand Volume (m^3)	SUM Volume (m^3)	Total cost (ZAR)
			MAIN & SADDLE DAM WALLS + DIVERSION TUNNELS									
2	(1) Earth core rockfill dam & (2) Zoned embankment dam (earthfill)		(1) Required material - Main wall									2 339 438 013
			(a) Core (impervious earthfill)		913 538						913 538	
			(b) Upstream and downstream shells (semi pervious earthfill)								0	
			(c) Rockfill (Impervious layer)						3 732 161		3 732 161	
			(d) Rip-rap								0	
			(e) Gravel layer						91 735		91 735	
			(f) Sand layer transition zone							91 735	91 735	
			(g) Blanket and chimney drains								0	
			(h) Concrete								0	
			(2) Required material - Saddle wall									
			(a) Core (impervious earthfill)		336 835						336 835	
			(b) Upstream and downstream shells (semi pervious earthfill)			861 785					861 785	
			(c) Rockfill (Impervious layer)								0	
			(d) Rip-rap						19 876		19 876	
			(e) Gravel layer						39 752		39 752	
			(f) Sand layer transition zone							19 876	19 876	
			(g) Blanket and chimney drains							66 669	66 669	
			(h) Concrete aggregate								0	
			(3) Required material - Diversion tunnels									
			(a) Diversion works concrete aggregate						2 000		2 000	
			(b) Intake structure concrete aggregate						6 000		6 000	
			(c) Spillway and chute concrete aggregate						20 000		20 000	
			(d) Outlet works concrete aggrgate						1 300		1 300	
			(e) Apron slab								0	
			TOTAL REQUIRED	0	1 250 373	861 785	0	0	3 912 823	178 279		
			Available material: (1) Borrow area A	120 000	800 000	0	0	50 000	0			
			(2) Borrow area B									
			(3) Borrow area C									
			(4) Quarry I (Left flank)	0	20 000	600 000	600 000	140 000	2 600 000			
			(5) Quarry II (Plunge pool)	0	200 000	170 000	44 000	850 000	720 000			
			(6) Quarry III (Spillway approach)	0	25 000	20 000	10 000	815 000	123 000			
			(7) Quarry IV (Tunnel inlet)	0	7 000	110 000	13 500	0	0			
			(8) Excavation: Main wall	0	820 852	0	0	404 300	0		1 225 153	
			(9) Excavation: Saddle wall	0	0	92 975	0	0	0			
			(10) Other (Imported)						469 823	178 279		
			TOTAL AVAILABLE	120 000	1 872 852	992 975	667 500	2 259 300	3 912 823	178 279		
			Material needed	*120 000*	*622 479*	*131 190*	*667 500*	*2 259 300*	*0*			
			To be stockpiled for later use									
			To be dumped	*25 806*		*131 190*	*667 500*	*2 209 300*				
			Dam forming		*1 250 373*	*861 785*		*0*	*3 912 823*	*178 279*		
			Untouched	*94 194*	*622 479*			*50 000*				
			Percentage remaining (%)	*Not used*	*50%*	*15%*	*Not used*	*Not used*	*0%*	*0%*		

Table F.3: Option 3: Main dam - Concrete faced rockfill dam; Saddle dam - Zoned earthfill embankment dam balancing spreadsheet

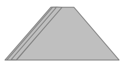
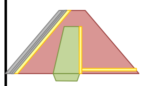
No.	Dam type	Configuration	Material (source)	A: Overburden for soil: Organic topsoil	B: Clayey sand transported surface material	C: Completely and highly weathered shales	D: Unweathered to moderately weathered shales	E: Highly and moderately weathered dolerite	F: Slightly weathered and unweathered dolerite	G: Imported sand	SUM	Total cost (ZAR)
			MAIN & SADDLE DAM WALLS + DIVERSION TUNNELS									
				Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	
			(1) Required material - Main wall									
			(a) Core (impervious earthfill)								0	
			(b) Upstream and downstream shells (semi pervious earthfill)								0	
			(c) Rockfill (Impervious layer)						3 586 837		3 586 837	
			(d) Rip-rap								0	
			(e) Gravel layer						328 738		328 738	
			(f) Sand layer transition zone								0	
			(g) Blanket and chimney drains								0	
			(h) Concrete						22 676		22 676	
			(2) Required material - Saddle wall									
			(a) Core (impervious earthfill)		336 835						336 835	
			(b) Upstream and downstream shells (semi pervious earthfill)			861 785					861 785	
			(c) Rockfill (Impervious layer)								0	
			(d) Rip-rap						19 876		19 876	
			(e) Gravel layer						39 752		39 752	
			(f) Sand layer transition zone							19 876	19 876	
			(g) Blanket and chimney drains							66 669	66 669	
			(h) Concrete aggregate								0	
			(3) Required material - Diversion tunnels									
			(a) Diversion works concrete aggregate						2 000		2 000	
			(b) Intake structure concrete aggregate						6 000		6 000	
3	(1) Concrete faced rockfill dam & (2) Zoned embankment dam (earthfill)		(c) Spillway and chute concrete aggregate						20 000		20 000	2 694 842 852
			(d) Outlet works concrete aggragate						1 300		1 300	
			(e) Apron slab								0	
			TOTAL REQUIRED	0	336 835	861 785	0	0	4 027 180	86 544		
			Available material: (1) Borrow area A									
			(2) Borrow area B									
			(3) Borrow area C									
			(4) Quarry I (Left flank)	0	20 000	600 000	600 000	140 000	2 600 000			
			(5) Quarry II (Plunge pool)	0	200 000	170 000	44 000	850 000	720 000			
			(6) Quarry III (Spillway approach)	0	25 000	20 000	10 000	815 000	123 000			
			(7) Quarry IV (Tunnel inlet)	0	7 000	110 000	13 500	0	0			
			(8) Excavation: Main wall	0	656 551	0	0	323 376	0		979 927	
			(9) Excavation: Saddle wall	0	0	92 975	0	0	0			
			(10) Other (Imported material)						584 180	86 544		
			TOTAL AVAILABLE	0	908 551	992 975	667 500	2 128 376	4 027 180	86 544		
			Material needed	*0*	*571 716*	*131 190*	*667 500*	*2 128 376*	*0*			
			To be stockpiled for later use									
			To be dumped		*571 716*	*131 190*	*667 500*	*2 128 376*				
			Dam forming		*336 835*	*861 785*			*4 027 180*	*86 544*		
			Untouched									
				0	*0*	*0*	*0*	*0*	*0*			
			Percentage remaining (%)		*170%*	*15%*	*Not used*	*Not used*	*0%*	*0%*		

Table F.4: Option 4: Main dam - Zoned earth core rockfill dam; Saddle dam - Zoned earthfill embankment dam balancing spreadsheet

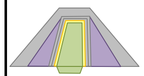
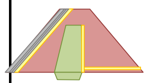
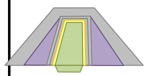
No.	Dam type	Configuration	Material (source)	MAIN & SADDLE DAM WALLS + DIVERSION TUNNELS								Total cost (ZAR)
				A	B	C	D	E	F	G		
				Overburden for soil: Organic topsoil	Clayey sand transported surface material	Completely and highly weathered shales	Unweathered to moderately weathered shales	Highly and moderately weathered dolerite	Slightly weathered and unweathered dolerite	Imported sand	SUM	
				Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	
4	(1) Zoned earth core rockfill dam & (2) Zoned embankment dam (earthfill)	 	(1) Required material - Main wall									2 029 231 539
			(a) Core (impervious earthfill)		922 791						922 791	
			(b) Upstream and downstream shells (semi pervious earthfill)								0	
			(c) Rockfill (Impervious layer)				581 935		3 228 381		3 810 316	
			(d) Rip-rap								0	
			(e) Gravel layer						46 900		46 900	
			(f) Sand layer transition zone								0	
			(g) Blanket and chimney drains							93 801	93 801	
			(h) Concrete								0	
			(2) Required material - Saddle wall									
			(a) Core (impervious earthfill)		336 835						336 835	
			(b) Upstream and downstream shells (semi pervious earthfill)			861 785					861 785	
			(c) Rockfill (Impervious layer)								0	
			(d) Rip-rap						19 876		19 876	
			(e) Gravel layer						39 752		39 752	
			(f) Sand layer transition zone							19 876	19 876	
			(g) Blanket and chimney drains							66 669	66 669	
			(h) Concrete aggregate								0	
			(3) Required material - Diversion tunnels									
			(a) Diversion works concrete aggregate						2 000		2 000	
			(b) Intake structure concrete aggregate						6 000		6 000	
			(c) Spillway and chute concrete aggregate						20 000		20 000	
			(d) Outlet works concrete aggregate						1 300		1 300	
			(e) Apron slab								0	
			TOTAL REQUIRED	0	1 259 626	861 785	581 935	0	3 364 209	180 345		
			Available material: (1) Borrow area A	120 000	800 000	0	0	50 000	0			
			(2) Borrow area B									
			(3) Borrow area C									
			(4) Quarry I (Left flank)	0	20 000	600 000	600 000	140 000	2 600 000			
			(5) Quarry II (Plunge pool)	0	200 000	170 000	44 000	850 000	720 000			
			(6) Quarry III (Spillway approach)	0	25 000	20 000	10 000	815 000	123 000			
			(7) Quarry IV (Tunnel inlet)	0	7 000	110 000	13 500	0	0			
			(8) Excavation: Main wall	0	839 924	0	0	413 694	0			
			(9) Excavation: Saddle wall	0	0	92 975	0	0	0			
			(10) Other							180 345		
			TOTAL AVAILABLE	120 000	1 891 924	992 975	667 500	2 268 694	3 443 000	180 345		
			Material needed	*120 000*	*632 298*	*131 190*	*85 565*	*2 268 694*	*78 791*	*0*		
			To be stockpiled for later use									
			To be dumped	*120 000*			*85 565*	*2 268 694*				
			Dam forming	*0*	*1 259 626*	*861 785*	*581 935*	*0*	*3 364 209*	*180 345*		
			Untouched		*632 298*	*131 190*			*78 791*			
			Percentage remaining (%)	*Not used*	*50%*	*15%*	*15%*	*Not used*	*2%*	*0%*		

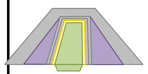
Table F.5: Option 5: Main dam - Zoned earth core rockfill dam; Saddle dam - Earth core rockfill dam balancing spreadsheet

No.: 5

Dam type: (1) Zoned earth core rockfill dam for both the main and saddle walls

Configuration:





Total cost (ZAR): 2 227 052 432

MAIN & SADDLE DAM WALLS + DIVERSION TUNNELS

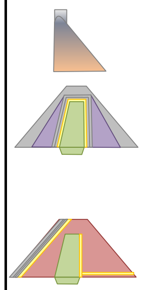
Material (source)	A: Overburden for soil: Organic topsoil Volume (m^3)	B: Clayey sand transported surface material Volume (m^3)	C: Completely and highly weathered shales Volume (m^3)	D: Unweathered to moderately weathered shales Volume (m^3)	E: Highly and moderately weathered dolerite Volume (m^3)	F: Slightly weathered and unweathered dolerite Volume (m^3)	G: Imported sand Volume (m^3)	SUM Volume (m^3)
(1) Required material - Main wall								
(a) Core (impervious earthfill)		922 791						922 791
(b) Upstream and downstream shells (semi pervious earthfill)								0
(c) Rockfill (Impervious layer)				581 935		3 228 381		3 810 316
(d) Rip-rap								0
(e) Gravel layer								0
(f) Sand layer transition zone							140 701	140 701
(g) Blanket and chimney drains								0
(h) Concrete								0
(2) Required material - Saddle wall								
(a) Core (impervious earthfill)		205 823						205 823
(b) Upstream and downstream shells (semi pervious earthfill)								0
(c) Rockfill (Impervious layer)				77 382		629 608		706 990
(d) Rip-rap								0
(e) Gravel layer								0
(f) Sand layer transition zone							56 618	56 618
(g) Blanket and chimney drains								0
(h) Concrete aggregate								0
(3) Required material - Diversion tunnels								
(a) Diversion works concrete aggregate						2 000		2 000
(b) Intake structure concrete aggregate						6 000		6 000
(c) Spillway and chute concrete aggregate						20 000		20 000
(d) Outlet works concrete aggragate						1 300		1 300
(e) Apron slab								0
TOTAL REQUIRED	0	1 128 614	0	659 317	0	3 887 288	197 319	
Available material: (1) Borrow area A	120 000	800 000	0	0	50 000	0		
Available material: (2) Borrow area B								
Available material: (3) Borrow area C								
Available material: (4) Quarry I (Left flank)	0	20 000	600 000	600 000	140 000	2 600 000		
Available material: (5) Quarry II (Plunge pool)	0	200 000	170 000	44 000	850 000	720 000		
Available material: (6) Quarry III (Spillway approach)	0	25 000	20 000	10 000	815 000	123 000		
Available material: (7) Quarry IV (Tunnel inlet)	0	7 000	110 000	13 500	0	0		
Available material: (8) Excavation: Main wall	0	839 924	0	0	413 694	0		
Available material: (9) Excavation: Saddle wall	0	0	148 650	0	0	0		
Available material: (10) Other (Imported)						444 288	197 319	
TOTAL AVAILABLE	120 000	1 891 924	1 048 650	667 500	2 268 694	3 887 288	197 319	
Material needed	*120 000*	*763 310*	*1 048 650*	*8 183*	*2 268 694*	*0*		
To be stockpiled for later use								
To be dumped	*14 500*		*952 074*	*8 183*	*2 268 694*			
Dam forming	*0*	*1 128 614*	*0*	*659 317*	*0*	*3 887 288*	*197 319*	
Untouched	*105 500*	*763 310*	*96 576*			*0*		
Percentage remaining (%)	*Not used*	*68%*	*Not used*	*1%*	*Not used*	*0%*	*0%*	

Table F.6: Option 6: Main dam - Composite dam (RCC and zoned ECRD); Saddle dam - Zoned earthfill embankment dam balancing spreadsheet

No.: 6

Dam type: (1) Composite Dam (RCC & zoned ECRD) + (2) Zoned embankment dam (earthfill)

Configuration:



Total cost (ZAR): 2 941 290 919

MAIN & SADDLE DAM WALLS + DIVERSION TUNNELS

Material (source)	A: Overburden for soil: Organic topsoil Volume (m^3)	B: Clayey sand transported surface material Volume (m^3)	C: Completely and highly weathered shales Volume (m^3)	D: Unweathered to moderately weathered shales Volume (m^3)	E: Highly and moderately weathered dolerite Volume (m^3)	F: Slightly weathered and unweathered dolerite Volume (m^3)	G: Imported sand Volume (m^3)	SUM Volume (m^3)
(1) Required material - Main wall								
(a) Core (impervious earthfill)		432 541						432 541
(b) Upstream and downstream shells (semi pervious earthfill)								0
(c) Rockfill (Impervious layer)				416 351		1 923 797		2 340 148
(d) Rip-rap								0
(e) Gravel layer						25 224		25 224
(f) Sand layer transition zone								0
(g) Blanket and chimney drains							50 447	50 447
(h) Concrete						598 283		598 283
(2) Required material - Saddle wall								
(a) Core (impervious earthfill)		336 835						336 835
(b) Upstream and downstream shells (semi pervious earthfill)			861 785					861 785
(c) Rockfill (Impervious layer)								0
(d) Rip-rap						19 876		19 876
(e) Gravel layer						39 752		39 752
(f) Sand layer transition zone							19 876	19 876
(g) Blanket and chimney drains							66 669	66 669
(h) Concrete aggregate								0
(3) Required material - Diversion tunnels								
(a) Diversion works concrete aggregate						2 000		2 000
(b) Intake structure concrete aggregate						6 000		6 000
(c) Spillway and chute concrete aggregate								0
(d) Outlet works concrete aggregate						1 300		1 300
(e) Apron slab						3 700		3 700
TOTAL REQUIRED	0	769 376	861 785	416 351	0	2 619 932	136 992	
Available material: (1) Borrow area A	120 000	800 000	0	0	50 000	0		
(2) Borrow area B								
(3) Borrow area C								
(4) Quarry I (Left flank)	0	20 000	600 000	600 000	140 000	2 600 000		
(5) Quarry II (Plunge pool)								
(6) Quarry III (Spillway approach)								
(7) Quarry IV (Tunnel inlet)	0	7 000	110 000	13 500	0	0		
(8) Excavation: Main wall	0	780 065	62 908	0	352 287	0		
(9) Excavation: Saddle wall	0	0	92 975	0	0	0		
(10) Other						19 932	136 992	
TOTAL AVAILABLE	120 000	1 607 065	865 883	613 500	542 287	2 619 932	136 992	
Material needed	*120 000*	*837 688*	*4 098*	*197 149*	*542 287*	*0*		
To be stockpiled for later use								
To be dumped	*20 400*			*197 149*	*491 772*			
Dam forming	*0*	*769 376*	*861 785*	*416 351*	*0*	*2 619 932*	*136 992*	
Untouched	*99 600*	*837 688*	*4 098*		*50 515*	*0*		
Percentage remaining (%)	*Not used*	*109%*	*0%*	*47%*	*Not used*	*0%*	*0%*	

Table F.7: Option 7: Main dam - Zoned concrete faced rockfill dam (option 1); Saddle dam - Zoned earthfill embankment dam balancing spreadsheet

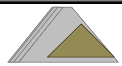
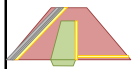
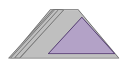
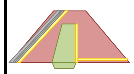
No.	Dam type	Configuration	Material (source)	A: Overburden for soil: Organic topsoil – Volume (m³)	B: Clayey sand transported surface material – Volume (m³)	C: Completely and highly weathered shales – Volume (m³)	D: Unweathered to moderately weathered shales – Volume (m³)	E: Highly and moderately weathered dolerite – Volume (m³)	F: Slightly weathered and unweathered dolerite – Volume (m³)	G: Imported sand – Volume (m³)	SUM – Volume (m³)	Total cost (ZAR)
			MAIN & SADDLE DAM WALLS + DIVERSION TUNNELS									
7	(1) Zoned concrete faced rockfill dam - Option 1 + (2) Zoned embankment dam (earthfill)		(1) Required material - Main wall									2 230 950 484
			(a) Core (impervious earthfill)								0	
			(b) Upstream and downstream shells (semi pervious earthfill)								0	
			(c) Rockfill (Impervious layer)					1 488 042	2 848 134		4 336 176	
			(d) Rip-rap								0	
			(e) Gravel layer						391 199		391 199	
			(f) Sand layer transition zone								0	
			(g) Blanket and chimney drains								0	
			(h) Concrete						23 339		23 339	
			(2) Required material - Saddle wall									
			(a) Core (impervious earthfill)		336 835						336 835	
			(b) Upstream and downstream shells (semi pervious earthfill)			861 785					861 785	
			(c) Rockfill (Impervious layer)								0	
			(d) Rip-rap						19 876		19 876	
			(e) Gravel layer						39 752		39 752	
			(f) Sand layer transition zone							19 876	19 876	
			(g) Blanket and chimney drains							66 669	66 669	
			(h) Concrete aggregate								0	
			(3) Required material - Diversion tunnels									
			(a) Diversion works concrete aggregate						2 000		2 000	
			(b) Intake structure concrete aggregate						6 000		6 000	
			(c) Spillway and chute concrete aggregate						20 000		20 000	
			(d) Outlet works concrete aggregate						1 300		1 300	
			(e) Apron slab								0	
			TOTAL REQUIRED	0	336 835	861 785	0	1 488 042	3 351 600	86 544		
			Available material: (1) Borrow area A									
			(2) Borrow area B									
			(3) Borrow area C									
			(4) Quarry I (Left flank)	0	20 000	600 000	600 000	140 000	2 600 000			
			(5) Quarry II (Plunge pool)	0	200 000	170 000	44 000	850 000	720 000			
			(6) Quarry III (Spillway approach)	0	25 000	20 000	10 000	815 000	123 000			
			(7) Quarry IV (Tunnel inlet)	0	7 000	110 000	13 500	0	0			
			(8) Excavation: Main wall	0	794 932	0	0	391 533	0			
			(9) Excavation: Saddle wall	0	0	92 975	0	0	0			
			(10) Other							86 544		
			TOTAL AVAILABLE	0	1 046 932	992 975	667 500	2 196 533	3 443 000	86 544		
			Material needed ('+' = Surplus; '-' = Deficit)	*0*	*710 097*	*131 190*	*667 500*	*708 492*	*91 400*			
			To be stockpiled for later use									
			To be dumped	*0*	*710 097*	*131 190*	*667 500*	*708 492*				
			Dam forming	*0*	*336 835*	*861 785*	*0*	*1 488 042*	*3 351 600*	*86 544*		
			Untouched	*0*					*91 400*			
			Percentage remaining (%)		*211%*	*15%*	*Not used*	*48%*	*3%*	*0%*		

Table F.8: Option 8: Main dam - Zoned concrete faced rockfill dam (option 2); Saddle dam - Zoned earthfill embankment dam balancing spreadsheet

No.	Dam type	Configuration	Material (source)		A	B	C	D	E	F	G		Total cost (ZAR)
					MAIN & SADDLE DAM WALLS + DIVERSION TUNNELS								
					Overburden for soil: Organic topsoil	Clayey sand transported surface material	Completely and highly weathered shales	Unweathered to moderately weathered shales	Highly and moderately weathered dolerite	Slightly weathered and unweathered dolerite	Imported sand	SUM	
					Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	
8	(1) Zoned concrete faced rockfill dam - option 2 + (2) Zoned embankment dam (earthfill)		(1) Required material - Main wall										2 412 068 788
				(a) Core (impervious earthfill)								0	
				(b) Upstream and downstream shells (semi pervious earthfill)				598 366		3 479 971		4 078 337	
				(c) Rockfill (Impervious layer)								0	
				(d) Rip-rap								0	
				(e) Gravel layer						391 199		391 199	
				(f) Sand layer transition zone								0	
				(g) Blanket and chimney drains								0	
				(h) Concrete						33 341		33 341	
			(2) Required material - Saddle wall										
				(a) Core (impervious earthfill)		336 835						336 835	
				(b) Upstream and downstream shells (semi pervious earthfill)			861 785					861 785	
				(c) Rockfill (Impervious layer)								0	
				(d) Rip-rap						19 876		19 876	
				(e) Gravel layer						39 752		39 752	
				(f) Sand layer transition zone							19 876	19 876	
				(g) Blanket and chimney drains							66 669	66 669	
				(h) Concrete aggregate								0	
			(3) Required material - Diversion tunnels										
				(a) Diversion works concrete aggregate						2 000		2 000	
				(b) Intake structure concrete aggregate						6 000		6 000	
				(c) Spillway and chute concrete aggregate						20 000		20 000	
				(d) Outlet works concrete aggregate						1 300		1 300	
				(e) Apron slab								0	
			Available material	**TOTAL REQUIRED**	0	336 835	861 785	598 366	0	3 993 439	86 544		
				(1) Borrow area A									
				(2) Borrow area B									
				(3) Borrow area C									
				(4) Quarry I (Left flank)	0	20 000	600 000	600 000	140 000	2 600 000			
				(5) Quarry II (Plunge pool)	0	200 000	170 000	44 000	850 000	720 000			
				(6) Quarry III (Spillway approach)	0	25 000	20 000	10 000	815 000	123 000			
				(7) Quarry IV (Tunnel inlet)	0	7 000	110 000	13 500	0	0			
				(8) Excavation: Main wall	0	753 252	0	0	382 247	0			
				(9) Excavation: Saddle wall	0	0	92 975	0	0	0			
				(10) Other						550 439	86 544		
				TOTAL AVAILABLE	**0**	**1 005 252**	**992 975**	**667 500**	**2 187 247**	**3 993 439**	**86 544**		
				Material needed	*0*	*668 417*	*131 190*	*69 134*	*2 187 247*	*0*			
				To be stockpiled for later use									
				To be dumped		*668 417*	*131 190*	*69 134*	*2 187 247*				
				Dam forming	*0*	*336 835*	*861 785*	*598 366*	*0*	*3 993 439*	*86 544*		
				Untouched									
				Percentage remaining (%)		*198%*	*15%*	*12%*	*Not used*	*0%*	*0%*		

Appendix G

Smithfield Dam: Results from balancing exercise – Bill of quantities

Table G.1: Option 1: Main dam - Roller compacted concrete (RCC) gravity; Saddle dam - zoned earthfill embankment dam – Bill of quantities

No	PAY REF	DESCRIPTION	UNIT	RATE	QUANTITY	AMOUNT Total Rand
		SABS 1200 DE-1984 DE: Small earth dams				
		Embankment excavation and formation				
8.3.1	8.3.1	Site clearance				
	8.3.1.1	Clear and strip site	ha	23 250.00	19.9	R 462 277.19
	8.3.1.2	Clear and grub large trees				
		a) over 1m and up to and including 2 m	No			R 0.00
		b) over 2 m and up to and including 3 m	No			R 0.00
		c) over 3 m, in increments of 1 m	No			R 0.00
	8.3.1.6	Clearing of basin	ha			R 0.00
8.3.2	8.3.2	Remove topsoil to nominal depth 150 mm (or other stated depth), stockpile and maintain	m^3	20.00	198 829	R 3 976 577.97
8.3.3	8.3.3	Excavation				
		a) Material unsuitable for embankment				
		(i) Removal to designated spoil dumps in the dam basin, spreading and trimming	m^3	31.60	671 296	R 21 212 954.54
		b) Material suitable for embankment from essential excavations for (Stockpiled):	m^3	30.30	2 322 213	R 70 363 049.94
		c) Extra over items (b) (1) - (4) for excavation in:				
		1) Intermediate material	m^3	INCL		
		2) Hard rock material	m^3	36.50	1 660 957	R 60 624 928.28
		Importing material				
		a) Dolerite	m^3	300.00		R 0.00
		b) River Sand	m^3	290.00	86 544	R 25 097 760.00
8.3.2	8.3.5	Forming embankment from stockpiled material 8.33b				
		(a) Core (impervious earthfill)	m^3	48.37	336 835	R 16 292 715.54
		(b) Upstream and downstream shells (semi pervious earthfill)	m^3	48.37	861 785	R 41 684 531.92
		(c) Rockfill (Impervious layer)	m^3	65.00	0	R 0.00
		(d) Rip-rap	m^3	438.52	19 876	R 8 716 008.48
		(e) Gravel layer	m^3	97.94	39 752	R 3 893 304.16
		(f) Sand layer transition zone	m^3	97.94	19 876	R 1 946 652.08
		(g) Blanket and chimney drains	m^3	789.45	66 669	R 52 631 460.52
		(h) IVRCC	m^3	45.40	120 634	R 5 476 766.85
		(h) RCC concrete	m^3	1 156.71	1 498 979	R 1 733 883 523.84
		(i) CVC concrete	m^3	1 981.85	13 000	R 25 764 050.00
8.3.3		**Formwork**				
		(a) Gang formed	m^2	475.00	120 634	R 57 300 974.78
		(b) Intricate	m^2			
		SABS 1200 D-1988 D: Earthworks				
		Quarry excavation to stockpile or dispose				
8.3.4	8.3.2	Bulk excavation				
		a) Excavate in all materials and backfill or dispose, as ordered	m^3			R 0.00
		b) Extra over for:				
		1) Intermediate excavation	m^3			R 0.00
		2) Hard rock excavation	m^3			R 0.00
		3) Boulder excavation, Class A	m^3			R 0.00
		4) Boulder excavation, Class B	m^3			R 0.00
		SUB-TOTAL				R 2 129 327 536

Table G.2: Option 1: Main dam - Roller compacted concrete (RCC) gravity; Saddle dam - zoned earthfill embankment dam – Cost breakdown

Item		Unit	Rate	Cost
DIRECT COSTS				
Dam forming and excavation		Sum		2 129 327 536.08
Diversion works		Sum		83 635 941.00
Intake and outlet works		Sum		104 197 998.73
Spillway and chute		Sum		
Measurng weirs		Sum		
SUB TOTAL (ACTIVITIES)				R 2 317 161 475.81
Landscaping		% Direct Costs	5	R 115 858 073.79
Miscellaneous		% Direct Costs	10	R 231 716 147.58
SUB TOTAL A				R 2 664 735 697.18
Preliminery and General		% of Sub total A	30	R 799 420 709.15
Infrastructure				
Road deviations		R/km		R 0.00
Housing and accomodation		Lump sum		0
Access roads		R/km		R 0.00
Pipeline		R/km		0
Water to site- Construction		Lump sum		0
Electricty Supply and deviation		Lump sum		0
Social (Relocation)		Lump sum		0
Environmental		Lump sum		0
SUB TOTAL B				R 3 464 156 406.33
Contingencies		% of sub total B	10	R 346 415 640.63
SUB TOTAL C				R 3 810 572 046.96
Planning design and supervision		% of sub total C	15	R 571 585 807.04
SUB TOTAL D				R 4 382 157 854.01
VAT		% of sub total D	0	R 0.00
NETT PROJECT COST				R 4 382 157 854
Social (Relocation)				0
Environmental				0
Total Project Cost				R 4 382 157 854

Table G.3: Option 2: Main dam - Earth core rockfill dam; Saddle dam – Zoned earthfill embankment dam – Bill of quantities

No	PAY REF	DESCRIPTION	UNIT	RATE	QUANTITY	AMOUNT Total Rand
		SABS 1200 DE-1984 DE: Small earth dams				
		Embankment excavation and formation				
8.3.1	8.3.1	Site clearance				
	8.3.1.1	Clear and strip site	ha	23 250.00	29.0	R 673 361.66
	8.3.1.2	Clear and grub large trees				
		a) over 1m and up to and including 2 m	No			R 0.00
		b) over 2 m and up to and including 3 m	No			R 0.00
		c) over 3 m, in increments of 1 m	No			R 0.00
	8.3.1.6	Clearing of basin	ha			R 0.00
8.3.2	8.3.2	Remove topsoil to nominal depth 150 mm (or other stated depth), stockpile and maintain	m^3	20.00	289 618	R 5 792 358.36
8.3.3	8.3.3	Excavation				
		a) Material unsuitable for embankment				
		(i) Removal to designated spoil dumps in the dam basin, spreading and trimming	m^3	31.60	3 033 796	R 95 867 968.48
		b) Material suitable for embankment from essential excavations for (Stockpiled):	m^3	30.30	6 024 982	
		c) Extra over items (b) (1) - (4) for excavation in:				
		1) Intermediate material	m^3	INCL		
		2) Hard rock material	m^3	36.50	3 912 823	R 142 818 052.02
		Importing material				
		a) Dolerite	m^3	300.00	469 823	R 140 946 900.00
		b) River Sand	m^3	290.00	178 279	R 51 700 910.00
8.3.2	8.3.5	Forming embankment				
		(a) Core (impervious earthfill)	m^3	48.37	1 250 373	R 60 480 558.47
		(b) Upstream and downstream shells (semi pervious earthfill)	m^3	48.37	861 785	R 41 684 531.92
		(c) Rockfill (Impervious layer)	m^3	65.00	3 732 161	R 242 590 448.37
		(d) Rip-rap	m^3	438.52	19 876	R 8 716 008.48
		(e) Gravel layer	m^3	97.94	131 487	R 12 877 800.84
		(f) Sand layer transition zone	m^3	97.94	111 611	R 10 931 148.76
		(g) Blanket and chimney drains	m^3	789.45	66 668.5	R 52 631 460.52
		(h) RCC	m^3	1 156.71	0	R 0.00
		(i) IVRCC	m^3	45.40		R 0.00
		(j) Structural	m^3	1 981.85	29 300	R 58 068 205.00
		SABS 1200 D-1988 D: Earthworks				
		Quarry excavation to stockpile or dispose				
8.3.2	8.3.2	Bulk excavation				
		a) Excavate in all materials and backfill or dispose, as ordered	m^3	31.60		R 0.00
		b) Extra over for:				
		1) Intermediate excavation	m^3	5.40		R 0.00
		2) Hard rock excavation	m^3	36.50		R 0.00
		3) Boulder excavation, Class A	m^3			R 0.00
		4) Boulder excavation, Class B	m^3			R 0.00
		SUB-TOTAL				R 925 779 713

Table G.4: Option 2: Main dam - Earth core rockfill dam; Saddle dam - Zoned earthfill embankment dam – Cost breakdown

Item		Unit	Rate	Cost
DIRECT COSTS				
Dam forming and excavation		Sum		925 779 712.88
Diversion works		Sum		83 635 941.00
Intake and outlet works		Sum		105 697 998.73
Spillway and chute		Sum		121 915 185.33
Measurng weirs		Sum		
SUB TOTAL (ACTIVITIES)				R 1 237 028 837.94
Landscaping		% Direct Costs	5	R 61 851 441.90
Miscellaneous		% Direct Costs	10	R 123 702 883.79
SUB TOTAL A				R 1 422 583 163.63
Preliminery and General		% of Sub total A	30	R 426 774 949.09
Infrastructure				
Road deviations		R/km		R 0.00
Housing and accomodation		Lump sum		0
Access roads		R/km		R 0.00
Pipeline		R/km		0
Water to site- Construction		Lump sum		0
Electricty Supply and deviation		Lump sum		0
Social (Relocation)		Lump sum		0
Environmental		Lump sum		0
SUB TOTAL B				R 1 849 358 112.72
Contingencies		% of sub total B	10	R 184 935 811.27
SUB TOTAL C				R 2 034 293 923.99
Planning design and supervision		% of sub total C	15	R 305 144 088.60
SUB TOTAL D				R 2 339 438 012.59
VAT		% of sub total D	0	R 0.00
NETT PROJECT COST				R 2 339 438 013
Social (Relocation)				0
Environmental				0
Total Project Cost				R 2 339 438 013

Table G.5: Option 3: Main dam - Concrete faced rockfill dam; Saddle dam - Zoned earthfill embankment dam – Bill of quantities

No	PAY REF	DESCRIPTION	UNIT	RATE	QUANTITY	AMOUNT Total Rand
		SABS 1200 DE-1984 DE: Small earth dams				
		Embankment excavation and formation				
8.3.1	8.3.1	Site clearance				
	8.3.1.1	Clear and strip site	ha	23 250.00	27.2	R 631 978.83
	8.3.1.2	Clear and grub large trees				
		a) over 1m and up to and including 2 m	No			R 0.00
		b) over 2 m and up to and including 3 m	No			R 0.00
		c) over 3 m, in increments of 1 m	No			R 0.00
	8.3.1.6	Clearing of basin	ha			
8.3.2	8.3.2	Remove topsoil to nominal depth 150 mm (or other stated depth), stockpile and maintain	m^3	20.00	271 819	R 5 436 377.03
8.3.3	8.3.3	Excavation				
		a) Material unsuitable for embankment (i) Removal to designated spoil dumps in the dam basin, spreading and trimming	m^3	31.60	3 033 796	R 95 867 968.48
		b) Material suitable for embankment from essential excavations for (Stockpiled):	m^3	30.30	6 024 982	R 182 556 939.66
		c) Extra over items (b) (1) - (4) for excavation in:				
		1) Intermediate material	m^3	INCL		
		2) Hard rock material	m^3	36.50	3 912 823	R 142 818 052.02
		Importing material				
		a) Dolerite	m^3	300.00	584 180	R 175 254 000.00
		b) River Sand	m^3	290.00	86 544	R 25 097 760.00
8.3.2	8.3.5	Forming embankment				
		(a) Core (impervious earthfill)	m^3	48.37	336 835	R 16 292 715.54
		(b) Upstream and downstream shells (semi pervious earthfill)	m^3	48.37	861 785	R 41 684 531.92
		(c) Rockfill (Impervious layer)	m^3	65.00	3 586 837	R 233 144 434.20
		(d) Rip-rap	m^3	438.52	19 876	R 8 716 008.48
		(e) Gravel layer	m^3	97.94	368 490	R 36 089 951.10
		(f) Sand layer transition zone	m^3	97.94	19 876	R 1 946 652.08
		(g) Blanket and chimney drains	m^3	789.45	66 669	R 52 631 460.52
		(h) RCC	m^3	1 156.71	32 394	R 37 470 732.91
		(i) IVRCC	m^3	45.40		R 0.00
		(j) Structural	m^3	1 981.85	29 300	R 58 068 205.00
		SABS 1200 D-1988 D: Earthworks				
		Quarry excavation to stockpile or dispose				
8.3.2	8.3.2	Bulk excavation				
		a) Excavate in all materials and backfill or dispose, as ordered	m^3	31.60		R 0.00
		b) Extra over for:				
		1) Intermediate excavation	m^3	5.40		R 0.00
		2) Hard rock excavation	m^3	36.50		R 0.00
		3) Boulder excavation, Class A	m^3			R 0.00
		4) Boulder excavation, Class B	m^3			R 0.00
		SUB-TOTAL				R 1 113 707 768

Table G.6: Option 3: Main dam - Concrete faced rockfill dam; Saddle dam - Zoned earthfill embankment dam – Cost breakdown

Item		Unit	Rate	Cost
DIRECT COSTS				
Dam forming and excavation		Sum		1 113 707 767.77
Diversion works		Sum		83 635 941.00
Intake and outlet works		Sum		105 697 998.73
Spillway and chute		Sum		121 915 185.33
Measurng weirs		Sum		
SUB TOTAL (ACTIVITIES)				R 1 424 956 892.83
Landscaping		% Direct Costs	5	R 71 247 844.64
Miscellaneous		% Direct Costs	10	R 142 495 689.28
SUB TOTAL A				R 1 638 700 426.75
Preliminery and General		% of Sub total A	30	R 491 610 128.03
Infrastructure				
Road deviations		R/km		R 0.00
Housing and accomodation		Lump sum		0
Access roads		R/km		R 0.00
Pipeline		R/km		0
Water to site- Construction		Lump sum		0
Electricty Supply and deviation		Lump sum		0
Social (Relocation)		Lump sum		0
Environmental		Lump sum		0
SUB TOTAL B				R 2 130 310 554.78
Contingencies		% of sub total B	10	R 213 031 055.48
SUB TOTAL C				R 2 343 341 610.25
Planning design and supervision		% of sub total C	15	R 351 501 241.54
SUB TOTAL D				R 2 694 842 851.79
VAT		% of sub total D	0	R 0.00
NETT PROJECT COST				R 2 694 842 852
Social (Relocation)				0
Environmental				0
Total Project Cost				R 2 694 842 852

Table G.7: Option 4: Main dam - Zoned earth core rockfill dam; Saddle dam - Zoned earthfill embankment dam – Bill of quantities

No	PAY REF	DESCRIPTION	UNIT	RATE	QUANTITY	AMOUNT Total Rand
		SABS 1200 DE-1984 DE: Small earth dams				
		Embankment excavation and formation				
8.3.1	8.3.1	Site clearance				
	8.3.1.1	Clear and strip site	ha	23 250.00	29.5	R 686 067.60
	8.3.1.2	Clear and grub large trees				
		a) over 1m and up to and including 2 m	No			R 0.00
		b) over 2 m and up to and including 3 m	No			R 0.00
		c) over 3 m, in increments of 1 m	No			R 0.00
	8.3.1.6	Clearing of basin	ha			R 0.00
8.3.2	8.3.2	Remove topsoil to nominal depth 150 mm (or other stated depth), stockpile and maintain	m^3	20.00	295 083	R 5 901 656.76
8.3.3	8.3.3	Excavation				
		a) Material unsuitable for embankment				
		(i) Removal to designated spoil dumps in the dam basin, spreading and trimming	m^3	31.60	2 474 259	R 78 186 584.43
		b) Material suitable for embankment from essential excavations for (Stockpiled):	m^3	30.30	6 067 555	
		c) Extra over items (b) (1) - (4) for excavation in:				
		1) Intermediate material	m^3	INCL		
		2) Hard rock material	m^3	36.50	3 364 209	R 122 793 630.59
		Importing material				
		a) Dolerite	m^3	300.00		
		b) River Sand	m^3	290.00		
8.3.2	8.3.5	Forming embankment				
		(a) Core (impervious earthfill)	m^3	48.37	1 259 626	R 60 928 103.67
		(b) Upstream and downstream shells (semi pervious earthfill)	m^3	48.37	861 785	R 41 684 531.92
		(c) Rockfill (Impervious layer)	m^3	65.00	3 810 316	R 247 670 521.87
		(d) Rip-rap	m^3	438.52	19 876	R 8 716 008.48
		(e) Gravel layer	m^3	97.94	86 652	R 8 486 734.32
		(f) Sand layer transition zone	m^3	97.94	19 876	R 1 946 652.08
		(g) Blanket and chimney drains	m^3	789.45	160 469	R 126 682 582.32
		(h) RCC	m^3	1 156.71	0	R 0.00
		(i) IVRCC	m^2	45.40		R 0.00
		(j) Structural concrete	m^3	1 981.85	29 300	R 58 068 205.00
		SABS 1200 D-1988 D: Earthworks				
		Quarry excavation to stockpile or dispose				
8.3.2	8.3.2	Bulk excavation				
		a) Excavate in all materials and backfill or dispose, as ordered	m^3	31.60		R 0.00
		b) Extra over for:				
		1) Intermediate excavation	m^3	5.40		R 0.00
		2) Hard rock excavation	m^3	36.50		R 0.00
		3) Boulder excavation, Class A	m^3			R 0.00
		4) Boulder excavation, Class B	m^3			R 0.00
		SUB-TOTAL				R 761 751 279

Table G.8: Option 4: Main dam - Zoned earth core rockfill dam; Saddle dam - Zoned earthfill embankment dam – Cost breakdown

Item		Unit	Rate	Cost
DIRECT COSTS				
Dam forming and excavation		Sum		761 751 279.03
Diversion works		Sum		83 635 941.00
Intake and outlet works		Sum		105 697 998.73
Spillway and chute		Sum		121 915 185.33
Measurng weirs		Sum		
SUB TOTAL (ACTIVITIES)				R 1 073 000 404.08
Landscaping		% Direct Costs	5	R 53 650 020.20
Miscellaneous		% Direct Costs	10	R 107 300 040.41
SUB TOTAL A				R 1 233 950 464.70
Preliminery and General		% of Sub total A	30	R 370 185 139.41
Infrastructure				
Road deviations		R/km		R 0.00
Housing and accomodation		Lump sum		0
Access roads		R/km		R 0.00
Pipeline		R/km		0
Water to site- Construction		Lump sum		0
Electricty Supply and deviation		Lump sum		0
Social (Relocation)		Lump sum		0
Environmental		Lump sum		0
SUB TOTAL B				R 1 604 135 604.11
Contingencies		% of sub total B	10	R 160 413 560.41
SUB TOTAL C				R 1 764 549 164.52
Planning design and supervision		% of sub total C	15	R 264 682 374.68
SUB TOTAL D				R 2 029 231 539.19
VAT		% of sub total D	0	R 0.00
NETT PROJECT COST				R 2 029 231 539
Social (Relocation)				0
Environmental				0
Total Project Cost				R 2 029 231 539

Table G.9: Option 5: Main dam - Zoned earth core rockfill dam; Saddle dam - Earth core rockfill dam – Bill of quantities

No	PAY REF	DESCRIPTION	UNIT	RATE	QUANTITY	AMOUNT Total Rand
		SABS 1200 DE-1984 DE: Small earth dams				
		Embankment excavation and formation				
8.3.1	8.3.1	Site clearance				
	8.3.1.1	Clear and strip site	ha	23 250.00	26.2	R 609 845.38
	8.3.1.2	Clear and grub large trees				
		a) over 1m and up to and including 2 m	No			R 0.00
		b) over 2 m and up to and including 3 m	No			R 0.00
		c) over 3 m, in increments of 1 m	No			R 0.00
	8.3.1.6	Clearing of basin	ha			R 0.00
8.3.2	8.3.2	Remove topsoil to nominal depth 150 mm (or other stated depth), stockpile and maintain	m^3	20.00	262 299	R 5 245 981.78
8.3.3	8.3.3	Excavation				
		a) Material unsuitable for embankment (i) Removal to designated spoil dumps in the dam basin, spreading and trimming	m^3	31.60	3 243 450	R 102 493 030.74
		b) Material suitable for embankment from essential excavations for (Stockpiled):	m^3	30.30	5 675 219	
		c) Extra over items (b) (1) - (4) for excavation in:				
		1) Intermediate material	m^3	Incl		
		2) Hard rock material	m^3	36.50	3 887 288	R 141 886 021.13
		Importing material				
		a) Dolerite	m^3	300.00	444 288	R 133 286 400.00
		b) River Sand	m^3	290.00	197 319	R 57 222 550.81
8.3.2	8.3.5	Forming embankment				
		(a) Core (impervious earthfill)	m^3	48.37	1 128 614	R 54 591 052.19
		(b) Upstream and downstream shells (semi pervious earthfill)	m^3	48.37	0	R 0.00
		(c) Rockfill (Impervious layer)	m^3	65.00	4 517 306	R 293 624 864.15
		(d) Rip-rap	m^3	438.52	0	R 0.00
		(e) Gravel layer	m^3	97.94	0	R 0.00
		(f) Sand layer transition zone	m^3	97.94	197 319	R 19 325 436.64
		(g) Blanket and chimney drains	m^3	789.45	0	R 0.00
		(h) RCC	m^3	1 156.71	0	R 0.00
		(i) IVRCC	m^2	45.40		R 0.00
		(j) Structural concrete	m^3	1 981.85	29 300	R 58 068 205.00
		SABS 1200 D-1988 D: Earthworks				
		Quarry excavation to stockpile or dispose				
8.3.2	8.3.2	Bulk excavation				
		a) Excavate in all materials and backfill or dispose, as ordered	m^3	31.60		R 0.00
		b) Extra over for:				
		1) Intermediate excavation	m^3	5.40		R 0.00
		2) Hard rock excavation	m^3	36.50		R 0.00
		3) Boulder excavation, Class A	m^3			R 0.00
		4) Boulder excavation, Class B	m^3			R 0.00
		SUB-TOTAL				R 866 353 388

Table G.10: Option 5: Main dam - Zoned earth core rockfill dam; Saddle dam - Earth core rockfill dam – Cost breakdown

Item		Unit	Rate	Cost
DIRECT COSTS				
Dam forming and excavation		Sum		866 353 387.81
Diversion works		Sum		83 635 941.00
Intake and outlet works		Sum		105 697 998.73
Spillway and chute		Sum		121 915 185.33
Measurng weirs		Sum		
SUB TOTAL (ACTIVITIES)				R 1 177 602 512.87
Landscaping		% Direct Costs	5	R 58 880 125.64
Miscellaneous		% Direct Costs	10	R 117 760 251.29
SUB TOTAL A				R 1 354 242 889.80
Preliminery and General		% of Sub total A	30	R 406 272 866.94
Infrastructure				
Road deviations		R/km		R 0.00
Housing and accomodation		Lump sum		0
Access roads		R/km		R 0.00
Pipeline		R/km		0
Water to site- Construction		Lump sum		0
Electricty Supply and deviation		Lump sum		0
Social (Relocation)		Lump sum		0
Environmental		Lump sum		0
SUB TOTAL B				R 1 760 515 756.74
Contingencies		% of sub total B	10	R 176 051 575.67
SUB TOTAL C				R 1 936 567 332.41
Planning design and supervision		% of sub total C	15	R 290 485 099.86
SUB TOTAL D				R 2 227 052 432.27
VAT		% of sub total D	0	R 0.00
NETT PROJECT COST				R 2 227 052 432
Social (Relocation)				0
Environmental				0
Total Project Cost				R 2 227 052 432

Table G.11: Option 6: Main dam - Composite dam (RCC and zoned ECRD); Saddle dam - Zoned earthfill embankment dam – Bill of quantities

No	PAY REF	DESCRIPTION	UNIT	RATE	QUANTITY	AMOUNT Total Rand
		SABS 1200 DE-1984 DE: Small earth dams				
		Embankment excavation and formation				
8.3.1	8.3.1	Site clearance				
	8.3.1.1	Clear and strip site	ha	23 250.00		R 0.00
	8.3.1.2	Clear and grub large trees				
		a) over 1m and up to and including 2 m	No			R 0.00
		b) over 2 m and up to and including 3 m	No			R 0.00
		c) over 3 m, in increments of 1 m	No			R 0.00
	8.3.1.6	Clearing of basin	ha			R 0.00
8.3.2	8.3.2	Remove topsoil to nominal depth 150 mm (or other stated depth), stockpile and maintain	m^3	20.00		R 0.00
8.3.3	8.3.3	Excavation				
		a) Material unsuitable for embankment				
		(i) Removal to designated spoil dumps in the dam basin, spreading and trimming	m^3	31.60	709 321	R 22 414 543.60
		b) Material suitable for embankment from essential excavations for (Stockpiled):	m^3	30.30	4 667 444	
		c) Extra over items (b) (1) - (4) for excavation in:				
		1) Intermediate material	m^3	Incl		
		2) Hard rock material	m^3	36.50	2 619 932	R 95 627 503.49
		Importing material				
		a) Dolerite	m^3	300.00		R 0.00
		b) River Sand	m^3	290.00	136 992	R 39 727 546.01
8.3.4	8.3.5	Forming embankment				
		(a) Core (impervious earthfill)	m^3	48.37	769 376	R 37 214 728.35
		(b) Upstream and downstream shells (semi pervious earthfill)	m^3	48.37	861 785	R 41 684 531.92
		(c) Rockfill (Impervious layer)	m^3	65.00	2 340 148	R 152 109 610.94
		(d) Rip-rap	m^3	438.52	19 876	R 8 716 008.48
		(e) Gravel layer	m^3	97.94	64 975	R 6 363 696.47
		(f) Sand layer transition zone	m^3	97.94	19 876	R 1 946 652.08
		(g) Blanket and chimney drains	m^3	789.45	117 116	R 92 456 888.52
		(h) RCC	m^3	1 156.71	598 283	R 692 040 224.32
		(i) IVRCC	m^2	45.45	53 716	R 2 441 399.03
		(j) Structural/ CVC	m^3	1 981.85	13 000	R 25 764 050.00
8.3.5		**Formwork**				
		(a) Gang formed	m^2	475.00	53 716	R 25 515 171.35
		(b) Intricate	m^2			
		SABS 1200 D-1988 D: Earthworks				
		Quarry excavation to stockpile or dispose				
8.3.2	8.3.2	Bulk excavation				
		a) Excavate in all materials and backfill or dispose, as ordered	m^3	31.60		R 0.00
		b) Extra over for:				
		1) Intermediate excavation	m^3	5.40		R 0.00
		2) Hard rock excavation	m^3	36.50		R 0.00
		3) Boulder excavation, Class A	m^3			R 0.00
		4) Boulder excavation, Class B	m^3			R 0.00
		SUB-TOTAL				R 1 244 022 555

Table G.12: Option 6: Main dam - Composite dam (RCC and zoned ECRD); Saddle dam - Zoned earthfill embankment dam – Cost breakdown

Item		Unit	Rate	Cost
DIRECT COSTS				
Dam forming and excavation		Sum		1 244 022 554.55
Diversion works		Sum		83 635 941.00
Intake and outlet works		Sum		105 697 998.73
Spillway and chute		Sum		121 915 185.33
Measurng weirs		Sum		
SUB TOTAL (ACTIVITIES)				R 1 555 271 679.61
Landscaping		% Direct Costs	5	R 77 763 583.98
Miscellaneous		% Direct Costs	10	R 155 527 167.96
SUB TOTAL A				R 1 788 562 431.55
Preliminery and General		% of Sub total A	30	R 536 568 729.47
Infrastructure				
Road deviations		R/km		R 0.00
Housing and accomodation		Lump sum		0
Access roads		R/km		R 0.00
Pipeline		R/km		0
Water to site- Construction		Lump sum		0
Electricty Supply and deviation		Lump sum		0
Social (Relocation)		Lump sum		0
Environmental		Lump sum		0
SUB TOTAL B				R 2 325 131 161.02
Contingencies		% of sub total B	10	R 232 513 116.10
SUB TOTAL C				R 2 557 644 277.12
Planning design and supervision		% of sub total C	15	R 383 646 641.57
SUB TOTAL D				R 2 941 290 918.69
VAT		% of sub total D	0	R 0.00
NETT PROJECT COST				R 2 941 290 919
Social (Relocation)				0
Environmental				0
Total Project Cost				R 2 941 290 919

Table G.13: Option 7: Main dam - Zoned concrete faced rockfill dam (option 1); Saddle dam - Zoned earthfill embankment dam – Bill of quantities

No	PAY REF	DESCRIPTION	UNIT	RATE	QUANTITY	AMOUNT Total Rand
		SABS 1200 DE-1984 DE: Small earth dams				
		Embankment excavation and formation				
8.3.1	8.3.1	Site clearance				
	8.3.1.1	Clear and strip site	ha	23 250.00	30.7	R 713 068.99
	8.3.1.2	Clear and grub large trees				
		a) over 1m and up to and including 2 m	No			R 0.00
		b) over 2 m and up to and including 3 m	No			R 0.00
		c) over 3 m, in increments of 1 m	No			R 0.00
	8.3.1.6	Clearing of basin	ha			R 0.00
8.3.2	8.3.2	Remove topsoil to nominal depth 150 mm (or other stated depth), stockpile and maintain	m^3	20.00	306 696	R 6 133 926.84
8.3.3	8.3.3	Excavation				
		a) Material unsuitable for embankment				
		(i) Removal to designated spoil dumps in the dam basin, spreading and trimming	m^3	31.60	2 217 278	R 70 065 991.21
		b) Material suitable for embankment from essential excavations for (Stockpiled):	m^3	30.30	6 038 261	
		c) Extra over items (b) (1) - (4) for excavation in:				
		1) Intermediate material	m^3	Incl		
		2) Hard rock material	m^3	36.50	4 839 641	R 176 646 912.41
		Importing material				
		a) Dolerite	m^3	300.00		R 0.00
		b) River Sand	m^3	290.00	86 544	R 25 097 899.90
8.3.4	8.3.5	Forming embankment				
		(a) Core (impervious earthfill)	m^3	48.37	336 835	R 16 292 715.54
		(b) Upstream and downstream shells (semi pervious earthfill)	m^3	48.37	861 785	R 41 684 531.92
		(c) Rockfill (Impervious layer)	m^3	65.00	4 336 176	R 281 851 430.68
		(d) Rip-rap	m^3	438.52	19 876	R 8 716 008.48
		(e) Gravel layer	m^3	97.94	430 951	R 42 207 313.21
		(f) Sand layer transition zone	m^3	97.94	19 876	R 1 946 652.08
		(g) Blanket and chimney drains	m^3	789.45	66 669	R 52 631 460.52
		(h) Structural	m^3	1 981.85	52 639	R 104 322 397.63
8.3.5		**Formwork**				
		(a) Gang formed	m^2	475.00	84 430	R 40 104 258.27
		(b) Intricate	m^2			
		SABS 1200 D-1988 D: Earthworks				
		Quarry excavation to stockpile or dispose				
8.3.2	8.3.2	Bulk excavation				
		a) Excavate in all materials and backfill or dispose, as ordered	m^3	31.60		R 0.00
		b) Extra over for:				
		1) Intermediate excavation	m^3	5.40		R 0.00
		2) Hard rock excavation	m^3	36.50		R 0.00
		3) Boulder excavation, Class A	m^3			R 0.00
		4) Boulder excavation, Class B	m^3			R 0.00
		SUB-TOTAL				R 868 414 568

Table G.14: Option 7: Main dam - Zoned concrete faced rockfill dam (option 1); Saddle dam - Zoned earthfill embankment dam – Cost breakdown

Item		Unit	Rate	Cost
DIRECT COSTS				
Dam forming and excavation		Sum		868 414 567.69
Diversion works		Sum		83 635 941.00
Intake and outlet works		Sum		105 697 998.73
Spillway and chute		Sum		121 915 185.33
Measurng weirs		Sum		
SUB TOTAL (ACTIVITIES)				R 1 179 663 692.74
Landscaping		% Direct Costs	5	R 58 983 184.64
Miscellaneous		% Direct Costs	10	R 117 966 369.27
SUB TOTAL A				R 1 356 613 246.65
Preliminery and General		% of Sub total A	30	R 406 983 974.00
Infrastructure				
Road deviations		R/km		R 0.00
Housing and accomodation		Lump sum		0
Access roads		R/km		R 0.00
Pipeline		R/km		0
Water to site- Construction		Lump sum		0
Electricty Supply and deviation		Lump sum		0
Social (Relocation)		Lump sum		0
Environmental		Lump sum		0
SUB TOTAL B				R 1 763 597 220.65
Contingencies		% of sub total B	10	R 176 359 722.07
SUB TOTAL C				R 1 939 956 942.72
Planning design and supervision		% of sub total C	15	R 290 993 541.41
SUB TOTAL D				R 2 230 950 484.12
VAT		% of sub total D	0	R 0.00
NETT PROJECT COST				R 2 230 950 484
Social (Relocation)				0
Environmental				0
Total Project Cost				R 2 230 950 484

Table G.15: Option 8: Main dam - Zoned concrete faced rockfill dam (option 2); Saddle dam - Zoned earthfill embankment dam – Bill of quantities

No	PAY REF	DESCRIPTION	UNIT	RATE	QUANTITY	AMOUNT Total Rand
		SABS 1200 DE-1984 DE: Small earth dams				
		Embankment excavation and formation				
8.3.1	8.3.1	Site clearance				
	8.3.1.1	Clear and strip site	ha	23 250.00	29.7	R 690 249.61
	8.3.1.2	Clear and grub large trees				
		a) over 1m and up to and including 2 m	No			R 0.00
		b) over 2 m and up to and including 3 m	No			R 0.00
		c) over 3 m, in increments of 1 m	No			R 0.00
	8.3.1.6	Clearing of basin	ha			R 0.00
8.3.2	8.3.2	Remove topsoil to nominal depth 150 mm (or other stated depth), stockpile and maintain	m^3	20.00	296 882	R 5 937 631.03
8.3.3	8.3.3	Excavation				
		a) Material unsuitable for embankment (i) Removal to designated spoil dumps in the dam basin, spreading and trimming	m^3	31.60	3 055 988	R 96 569 207.53
		b) Material suitable for embankment from essential excavations for (Stockpiled):	m^3	30.30	5 790 425	
		c) Extra over items (b) (1) - (4) for excavation in:				
		1) Intermediate material	m^3	Incl		
		2) Hard rock material	m^3	36.50	3 993 439	R 145 760 532.42
		Importing material				
		a) Dolerite	m^3	300.00	550 439	R 165 131 700.00
		b) River Sand	m^3	290.00	86 544	R 25 097 760.00
8.3.4	8.3.5	Forming embankment				
		(a) Core (impervious earthfill)	m^3	48.37	336 835	R 16 292 715.54
		(b) Upstream and downstream shells (semi pervious earthfill)	m^3	48.37	4 940 122	R 238 953 706.88
		(c) Rockfill (Impervious layer)	m^3	65.00	0	R 0.00
		(d) Rip-rap	m^3	438.52	19 876	R 8 716 008.48
		(e) Gravel layer	m^3	97.94	430 951	R 42 207 313.21
		(f) Sand layer transition zone	m^3	97.94	19 876	R 1 946 652.08
		(g) Blanket and chimney drains	m^3	789.45	66 669	R 52 631 460.52
		(h) Structural	m^3	1 981.85	62 641	R 124 145 623.04
8.3.5		**Formwork**				
		(a) Gang formed	m^2	475.00	84 430	R 40 104 258.27
		(b) Intricate	m^2			
		SABS 1200 D-1988 D: Earthworks				
		Quarry excavation to stockpile or dispose				
8.3.2	8.3.2	Bulk excavation				
		a) Excavate in all materials and backfill or dispose, as ordered	m^3	31.60		R 0.00
		b) Extra over for:				
		1) Intermediate excavation	m^3	5.40		R 0.00
		2) Hard rock excavation	m^3	36.50		R 0.00
		3) Boulder excavation, Class A	m^3			R 0.00
		4) Boulder excavation, Class B	m^3			R 0.00
		SUB-TOTAL				R 964 184 819

Table G.16: Option 8: Main dam - Zoned concrete faced rockfill dam (option 2); Saddle dam - Zoned earthfill embankment dam – Cost breakdown

Item		Unit	Rate	Cost
DIRECT COSTS				
Dam forming and excavation		Sum		964 184 818.61
Diversion works		Sum		83 635 941.00
Intake and outlet works		Sum		105 697 998.73
Spillway and chute		Sum		121 915 185.33
Measurng weirs		Sum		
SUB TOTAL (ACTIVITIES)				R 1 275 433 943.66
Landscaping		% Direct Costs	5	R 63 771 697.18
Miscellaneous		% Direct Costs	10	R 127 543 394.37
SUB TOTAL A				R 1 466 749 035.21
Preliminery and General		% of Sub total A	30	R 440 024 710.56
Infrastructure				
Road deviations		R/km		R 0.00
Housing and accomodation		Lump sum		0
Access roads		R/km		R 0.00
Pipeline		R/km		0
Water to site- Construction		Lump sum		0
Electricty Supply and deviation		Lump sum		0
Social (Relocation)		Lump sum		0
Environmental		Lump sum		0
SUB TOTAL B				R 1 906 773 745.77
Contingencies		% of sub total B	10	R 190 677 374.58
SUB TOTAL C				R 2 097 451 120.35
Planning design and supervision		% of sub total C	15	R 314 617 668.05
SUB TOTAL D				R 2 412 068 788.40
VAT		% of sub total D	0	R 0.00
NETT PROJECT COST				R 2 412 068 788
Social (Relocation)				0
Environmental				0
Total Project Cost				R 2 412 068 788

Table G.17: Diversion works – Bill of quantities

DIVERSION WORKS BOQ						
ITEM NO	**PAY-MENT**	**DESCRIPTION**	**UNIT**	**RATE (R)**	**QTY**	**AMOUNT (R)**
		STAGE 1: PORTALS AND TUNNELS				
1	**1.0**	**SITE CLEARANCE**				
	1.1	**Clear and grub**				
		(a) Portal footprints	ha	16 946.00	0.85	R 14 319.37
	1.2	**Remove and grub large trees and tree stumps of girth**				
		(a) Over 1 m and up to and including 2m	No			R 0.00
	1.3	**Remove topsoil to nominal depth of 150 mm and stockpile**	m³	30.86	1268	R 39 115.05
2	**2.0**	**EXCAVATION AND BACKFILL FOR DAMS AND WATERWAYS**				
		Bulk Excavation				
	2.1	**Inlet portal**				
		(a) Excavate in all materials				
		(i) Excavation (stockpile)	m³	30.33	29 250	R 887 152.50
		(b) Extra over for:				
		(i) Intermediate	m³	0.00	2 925	R 0.00
		(ii) Hard Rock	m³	42.60	2 925	R 124 605.00
		(iii) Boulder, Class A	m³	163.76	1 463	R 239 499.00
		(iv) Boulder, Class B	m³	42.58	1 463	R 62 273.25
	2.2	**Outlet Portal**				
		(a) Excavate in all materials				
		(i) Excavation (stockpile)	m³	30.33	46 800	R 1 419 444.00
		(b) Extra over for:				
		(i) Intermediate	m³	0.00	11 700	R 0.00
		(ii) Hard Rock	m³	42.60	11 700	R 498 420.00
		(iii) Boulder, Class A	m³	163.76	7 020	R 1 149 595.20
		(iv) Boulder, Class B	m³	42.58	2 340	R 99 637.20
	2.3	**Dewatering**	Sum	100 000.00	1	R 100 000.00
		SUB TOTAL: STAGE 1				R 4 634 060.57
		STAGE 2 Cofferdam				
3		**SITE CLEARANCE**				
	3.1	**Clear and grub**				
		(a) Embankment footprint	ha	16 946.00	0.56	R 9 548
	3.2	Remove and grub large trees and tree stumps of girth				
		(a) over 1 m and up to and including 2 m	No		0	R 0
	3.3	Remove topsoil to nominal depth of 150 mm and stockpile	m³	30.86	846	R 26 108
4	**4.1**	**EXCAVATIONS AND BACKFILL FOR DAMS AND WATERWAYS**				
		(a) Excavate all materials				
		(i) Topsoil at Upstream & Downstream cofferdam	m³	30.33	5 634	R 170 885
5	**5.1**	**EMBANKMENT CONSTRUCTION**				
		Earthfill Upstream & Downstream Cofferdam Construction.				
		(a) Forming Embankment				
		Using material from designated borrow areas or commercial sources				
		(i) Soil cement at 3% cement	m³	257.08	5130	R 1 318 836
		(ii) Rockfill	m³	113.12	31190	R 3 528 105
		SUB TOTAL: COFFERDAM				R 5 053 481
6		**TUNNEL CONSTRUCTION**				
	6.1	TUNNEL EXCAVATION				
		(a) Tunnel	m³	1 542.50	37 181	R 57 351 245
	6.2	ROCK SUPPORT				
		(a) Rockbolts	m	257.08	15 780	R 4 056 771
		(b) Shotcrete	m³	5 398.74	413	R 2 230 326
		(c) Reinforcing mesh	m²	77.12	74 361	R 5 735 125
	6.3	DEWATERING	Sum	550 000.00	1	R 550 000
		SUB TOTAL: TUNNEL				R 69 923 466

		SUB TOTAL: STAGE 1 + STAGE 2				R 79 611 008
		STAGE 3				
7		**MEDIUM PRESSURE PIPELINES**				
		Supply, lay, and bed pipes complete with couplings				
		(a) 500 mm diameter concrete pipe (class 75D) in concrete	m	138.82	263	R 36 511
		(b) Water control in tunnel	Prov Sum	500 000.00	1	R 500 000
8		**PLUG OF TUNNEL**				
	8.1	Scheduled Formwork items- Class 1				
		(a) Vertical formwork	m²	636.60	310	R 197 346
	8.2	Scheduled Concrete items				
		Strength and Mass concrete				
		(a) Sealing of bulkheads shaft with mass concrete 25 Mpa/19 mm	m³	1 658.00	1 050	R 1 740 900
		(b) Plug 25 MPa/19 mm	m³	1 658.00	708	R 1 173 035
	8.3	Joints				
		(a) Swellable water stops	m	231.37	30	R 6 941
	8.4	Miscellaneous and Sundry items				
		(a) Bulkheads incl reinforcement at 120 kg/m³	No	1 542.50	240	R 370 200
		Sub total: STAGE 3				R 4 024 933
		Nett cost				**R 83 635 941**

Table G.18: Spillway and chute – Bill of quantities

SPILLWAY AND CHUTE						
ITEM NO	PAYMEN	DESCRIPTION	UNIT	RATE (R) #REF!	QTY	AMOUNT (R)
		SABS 1200 - GA				
8		**CONVENTIONAL CONCRETE FOR DAMS**				
	8.1.1	Scheduled Formwork items				
	8.1.1.1	Class F4				
		(a) Verical				
		(i) Chute	m²	637	20 000	R 12 732 000
		(b) Sloped				
		(i) Ogee of spillway	m²	822	2 390	R 1 964 371
		(ii) Round	m²	822	0	R 0
		(c) Sloping				
		(i) Stilling basin blocks	m²	822	33	R 27 126
		(ii) Horizontal	m²	822	0	R 0
	8.1.2	Scheduled Reinforcement items	t	9 720	3 149	R 30 603 732
	8.1.2.1	Anchors				
		(a) Anchor bars (Y32 @ 2.5 m x 2 m)	t	12 854	199	R 2 562 987
	8.1.3	Scheduled Concrete items				
	8.1.3.1	Strength & Mass Concrete				
		(a) Grade 25 MPa/19 mm				
		(i) Spillway, bridges and retaining wall	m³	1 542	43 904	R 67 722 424
	8.1.3.2	Secondary Concrete				
		(a) Grade 25 MPa/19 mm	m³	1 542	439	R 677 224
	8.1.3.3	Keyways on contraction joints				
		(a) Bridges dimensions to be given in detail design	m	100	20	R 2 000
	8.1.3.4	Unformed Surface Finishes				
		Class U2 (Wood-floated) finish				
		(a) Chute and Stilling basin floor	m²	16	53 909	R 835 590
		(b) Top of bridges	m²	16		R 0
TOTAL CARRIED FORWARD						**R 117 127 454**

TOTAL BROUGHT FORWARD						**R 117 127 454**
16		**WATERSTOPS, JOINTING AND BEARINGS**				R 0
						R 0
	16.1	Scheduled items				R 0
						R 0
		Waterstops				R 0
						R 0
		(a) 250 mm Centre bulb PVC waterstop	m	685	264	R 180 956
						R 0
	16.2	Joint sealants				R 0
		(a) Chute wall - 12mm expanding cork	m	10	264	R 2 641
		(b) Chute wall - 12m Impregnated Bitumen Fibre board	m	10	264	R 2 641
		(c) Chute wall - 12 x 12 mm Polysulphide sealant	m	10	264	R 2 641
						R 0
17		**SUB-SOIL DRAINAGE**				R 0
	17.1	Scheduled items				R 0
		Excavating soft material situated within the following depth ranges below the surface level:				R 0
		(a) 0 m to 1,5 m	m³	21	213	R 4 477
		(b) Extra over sub-item (a), irrespective of depth, for:				R 0
		(i) Excavation in hard material	m³	4	107	R 426
						R 0
	17.2	Natural permeable material in sub-soil drainage systems				R 0
		(a) Sand as specified on detail drawings	m³	550	6 077	R 3 342 291
						R 0
	17.3	Pipes in sub-soil drainage system				R 0
		(a) 110 NB, Class 6, HDPE pressure pipe, non perforated, complying with SANS 533, Part II	m	400	564	R 225 600
		(b) 75 NB, flexible slotted drainage pipes with smooth bore, "Drainex" or equivalent by Kaytech	m	330	2 538	R 837 540
						R 0
	17.4	Caps to higher ends of sub-surface drain pipes				R 0
		(a) High end of pipes of Drainex pipes	No	50	28	R 1 410
						R 0
	17.5	Concrete outlet structures for sub-soil drainage systems complete as per drawings				R 0
		(a) Concrete 1500 mm dia	No	600	8	R 4 800
						R 0
	17.6	Overhaul for material hauled in excess of 1.0 km freehaul				R 0
		(a) Sand for filter material (10 km)	m³.km	3	60 769	R 182 307
						R 0
TOTAL CARRIED FORWARD TO SUMMARY						**R 121 915 185**

Table G.19: Intake and outlet works – Bill of quantities

Intake and outlet works						
ITEM NO	PAYMENT		UNIT	RATE #REF! (R)	QTY	AMOUNT (R)
1	1.1	Earthworks				
		(a) Clearing and grubbing	ha	20 567	0.23	R 4 739
		(b) Excavation - soft	m^3	180	3 904	R 702 557
		(c) Excavation - rock	m^3	298	3 904	R 1 164 237
		(d) Rockfill to abutments	m^3	50		R 0
2	2.1	Rock Support				
		(a) Rockbolts - 3m long	no	437		R 0
		(b) Rock anchors - 20m long	no	2 982		R 0
		(c) Rock anchors - 2m long, 25mm	no	219		R 0
		(d) Shotcrete and mesh - 75 mm long	m^2	300		R 0
3		ACCESS BRIDGE				
	3.1	Formwork				
		(a) Smooth vertical	m^2	488	1 373	R 670 513
		(b) Smooth horizontal	m^2	488	294	R 143 607
		(c) Smooth balustrade	m^2	730		R 0
	3.2	Unformed surface finish	m^2	14		R 0
	3.3	Reinforcing				R 0
		(a) Mild steel	t	14 140		R 0
		(b) High yield steel	t	9 720	51	R 491 849
		(c) Mesh	t	59		R 0
	3.4	Concrete				
		(a) Mass	m^3	1 157		R 0
		(b) Structural	m^3	1 414	506	R 715 487
	3.5	Miscellaneous				
		(a) Bridge bearings	No	16 196		R 0
		(b) Joints	m	171		R 0
		(c) Other e.g.. Rainwater goods, ducting, etc	Sum	102 833		R 0
4		INTAKE TOWER AND OUTLET WORKS				
	4.1	Drilling and grouting				
		(a) Consolidation grouting	m drill	0		R 0
	4.2	Formwork				
		(a) Smooth vertical - curved and plain	m^2	540	1 576	R 851 199
		(b) Smooth horizontal	m^2	850	162	R 137 660
		(c) Intricate	m^2	685		R 0
		(d) Form openings	m^2			R 0
	4.3	Uniform surface finish	m^2	16	451	R 6 991
	4.4	Reinforcing				
		(a) Mild steel	t	14 140		R 0
		(b) High yield steel	t	9 720	1 662	R 16 150 213
		(c) Mesh	t	77		R 0
		(d) Mechanical rebar couples	No			R 0
	4.5	Concrete				
		(a) Mass	m^3	1 474		R 0
		(b) Structural	m^3	1 591	20 086	R 31 957 534
TOTAL CARRIED FORWARD						**R 52 996 584**

TOTAL BROUGHT FORWARD						**R 52 996 584**
	4.6	Structural Steelwork				
		(a) Steel sections	t	35 992		R 0
		(b) Sheeting	m^2	411		R 0
	4.7	Miscellaneous				
		(a) Waterstops	m	685		R 0
		(b) Other e.g.. Conduits, outlets, water proofing, etc.	Sum	154 250		R 0
		SUB TOTAL A				R 52 996 584
5	5.1	Site works				
		(a) Site access roads	km	1 500 000	1	R 1 500 000
		(b) Site services	Sum	0		R 0
6	6.1	Contractors accommodation				R 0
		CIVIL CONSTRUCTION WORK				R 54 496 584
7	7.1	Mechanical Items				
		(a) Gates and screens	Sum	17 918 494	1	R 17 918 494
		(b) Lifting equipment	Sum	8 339 060	1	R 8 339 060
		(c) Pipework and valves	Sum	22 132 348	1	R 22 132 348
8	8.1	Electrical Installation	Sum	2 811 513	1	R 2 811 513
		MECHANICAL TOTAL				R 51 201 415
TOTAL CARRIED FORWARD TO SUMMARY						**R 105 697 999**

Appendix H

Smithfield Dam: Comparison of BoQs for Primary Main Dam Type Options

Table H.1: Comparison of BoQs for Primary Main Dam Type Options

				Option 1			Option 4			Option 6			Option 7		
		Main dam type:		RCC			Zoned ECRD			Composite (RCC + ECRD)			Zoned CFRD		
		Saddle dam type:		Earthfill			Earthfill			Earthfill			Earthfill		
ITEM NO.	PAY ITEM	DESCRIPTION	UNIT	RATE	QUANTITY	AMOUNT	RATE	QUANTITY	AMOUNT	RATE	QUANTITY	AMOUNT	RATE	QUANTITY	AMOUNT
		SABS 1200 DE-1984 DE: Small earth dams													
		Embankment excavation and formation													
8.3.1	8.3.1	Site clearance													
	8.3.1.1	Clear and strip site	ha	23 250.00	19.9	R 462 277.19	23 250.00	29.5	R 686 067.60	23 250.00		R 0.00	23 250.00	30.7	R 713 068.99
	8.3.1.2	Clear and grub large trees													
		a) over 1m and up to and including 2 m	No			R 0.00			R 0.00			R 0.00			R 0.00
		b) over 2 m and up to and including 3 m	No			R 0.00			R 0.00			R 0.00			R 0.00
		c) over 3 m, in increments of 1 m	No			R 0.00			R 0.00			R 0.00			R 0.00
	8.3.1.6	Clearing of basin	ha			R 0.00			R 0.00			R 0.00			R 0.00
8.3.2	8.3.2	Remove topsoil to nominal depth 150 mm (or other stated depth), stockpile and maintain	m^3	20.00	198 829	R 3 976 577.97	20.00	295 082.8	R 5 901 656.76	20.00		R 0.00	20.00	306 696.3	R 6 133 926.84
8.3.3	8.3.3	Excavation													
		a) Material unsuitable for embankment													
		(i) Removal to designated spoil dumps in the dam basin, spreading and trimming	m^3	31.60	671 296	R 21 212 954.54	31.60	2 474 259.0	R 78 186 584.43	31.60	709 321.0	R 22 414 543.60	31.60	2 217 278.2	R 70 065 991.21
		b) Material suitable for embankment from essential excavations for (Stockpiled):	m^3	30.30	2 322 213		30.30	6 067 554.8		30.30	4 667 443.6		30.30	6 038 261.4	
		c) Extra over items (b) (1) - (4) for excavation in:													
		1) Intermediate material	m^3	INCL			INCL			Incl			Incl		
		2) Hard rock material	m^3	36.50	1 660 957	R 60 624 928.28	36.50	3 364 209.1	R 122 793 630.59	36.50	2 619 931.6	R 95 627 503.49	36.50	4 839 641.4	R 176 646 912.41
		Importing material													
		a) Dolerite	m^3	300.00		R 0.00	300.00			300.00		R 0.00	300.00		R 0.00
		b) River Sand	m^3	290.00	86 544	R 25 097 760.00	290.00			290.00	136 991.5	R 39 727 546.01	290.00	86 544.5	R 25 097 899.90
8.3.2	8.3.5	Forming embankment from stockpiled material 8.33b													
		(a) Core (impervious earthfill)	m^3	48.37	336 835	R 16 292 715.54	48.37	1 259 625.9	R 60 928 103.67	48.37	769 376.2	R 37 214 728.35	48.37	336 835.1	R 16 292 715.54
		(b) Upstream and downstream shells (semi pervious earthfill)	m^3	48.37	861 785	R 41 684 531.92	48.37	861 784.8	R 41 684 531.92	48.37	861 784.8	R 41 684 531.92	48.37	861 784.8	R 41 684 531.92
		(c) Rockfill (Impervious layer)	m^3	65.00	0	R 0.00	65.00	3 810 315.7	R 247 670 521.87	65.00	2 340 147.9	R 152 109 610.94	65.00	4 336 175.9	R 281 851 430.68
		(d) Rip-rap	m^3	438.52	19 876	R 8 716 008.48	438.52	19 876.0	R 8 716 008.48	438.52	19 876.0	R 8 716 008.48	438.52	19 876.0	R 8 716 008.48
		(e) Gravel layer	m^3	97.94	39 752	R 3 893 304.16	97.94	86 652.4	R 8 486 734.32	97.94	64 975.5	R 6 363 696.47	97.94	430 950.7	R 42 207 313.21
		(f) Sand layer transition zone	m^3	97.94	19 876	R 1 946 652.08	97.94	19 876.0	R 1 946 652.08	97.94	19 876.0	R 1 946 652.08	97.94	19 876.0	R 1 946 652.08
		(g) Blanket and chimney drains	m^3	789.45	66 669	R 52 631 460.52	789.45	160 469.4	R 126 682 582.32	789.45	117 115.6	R 92 456 888.52	789.45	66 668.5	R 52 631 460.52
		(h) RCC concrete	m^3	1 156.71	1 498 979	R 1 733 883 523.84	1 156.71	0.0	R 0.00	1 156.71	598 283.3	R 692 040 224.32			
		(i) IVRCC concrete	m^3	45.40	120 634	R 5 476 766.85	45.40		R 0.00	45.45	53 716.2	R 2 441 399.03			
		(j) Structural/CVC concrete	m^3	1 981.85	13 000	R 25 764 050.00	1 981.85	29 300.0	R 58 068 205.00	1 981.85	13 000.0	R 25 764 050.00	1 981.85	52 638.9	R 104 322 397.63
8.3.3		**Formwork**													
		(a) Gang formed	m^2	475.00	120 634	R 57 300 974.78				475.00	53 716.2	R 25 515 171.35	475.00	84 430.0	R 40 104 258.27
		(b) Intricate	m^2												
		SABS 1200 D-1988 D: Earthworks													
		Quarry excavation to stockpile or dispose													
8.3.4	8.3.2	Bulk excavation													
		a) Excavate in all materials and backfill or dispose, as ordered	m^3			R 0.00	31.60		R 0.00	31.60		R 0.00	31.60		R 0.00
		b) Extra over for:													
		1) Intermediate excavation	m^3			R 0.00	5.40		R 0.00	5.40		R 0.00	5.40		R 0.00
		2) Hard rock excavation	m^3			R 0.00	36.50		R 0.00	36.50		R 0.00	36.50		R 0.00
		3) Boulder excavation, Class A	m^3			R 0.00			R 0.00			R 0.00			R 0.00
		4) Boulder excavation, Class B	m^3			R 0.00			R 0.00			R 0.00			R 0.00
		SUB-TOTAL: DAM FORMING AND EXCAVATION				**R 2 058 964 486.14**			**R 761 751 279.03**			**R 1 244 022 554.55**			**R 868 414 567.69**
		SUB-TOTAL: DIVERSION WORKS				**R 83 635 941.00**			**R 83 635 941.00**			**R 83 635 941.00**			**R 83 635 941.00**
		SUB-TOTAL: INTAKE AND OUTLET WORKS				**R 105 697 998.73**			**R 105 697 998.73**			**R 105 697 998.73**			**R 105 697 998.73**
		SUB-TOTAL: SPILLWAY AND CHUTE							**R 121 915 185.33**						**R 121 915 185.33**
		TOTAL				**R 2 248 298 425.87**			**R 1 073 000 404.08**			**R 1 433 356 494.28**			**R 1 179 663 692.74**

Appendix I

Langa Balancing Dam: Results from slope stability analysis

Table I.1: Langa soil parameters

Material	Description	Unit weight (kN/m^3)	Cohesion (kPa)	Angle of internal friction (Ø) (Degrees)
A	Hard rockfill: Unweathered shale and dolerite	35	0	20.6
B	Concrete	35	250	23
C	Undisturbed earth dolerite foundation	40	0	21.58

Table I.2: Slope stability analysis results

Embankment Type	Analysis	Shell	Transition Zone	Slopes		Upstream slope				Downstream Slope			
						Steady State (1)		Seismic (2)		Steady State (1)		Seismic (2)	
				US	DS	FOS(3)	Req (4)	FOS(3)	Req (4)	FOS(3)	Req (4)	FOS(3)	Req (4)
Concrete faced rockfill dam	1	C	C	1.4	1.4	1.213 (Not ok)	> 1.5	1.125 (Not ok)	> 1	1.028 (Not ok)	> 1.5	0.986 (Not ok)	< 1
	2	C	C	1.6	1.6	1.335 (Not ok)	> 1.5	1.233 (Not ok)	> 1	1.163 (Not ok)	> 1.5	1.112 (ok)	> 1
	1	C	C	1.7	1.7	1.397 (Not ok)	> 1.5	1.287 (Not ok)	> 1	1.230 (Not ok)	> 1.5	1.175 (ok)	> 1
	1	C	C	1.8	1.8	1.457 (Not ok)	> 1.5	1.339 (Not ok)	> 1	1.303 (Not ok)	> 1.5	1.243 (ok)	> 1
	1	C	C	2	2	1.502 (ok)	> 1.5	1.456 (ok)	> 1	1.462 (Not ok)	> 1.5	1.391 (ok)	> 1
	1	C	C		2.2					1.577 (ok)	> 1.5	1.495 (ok)	> 1

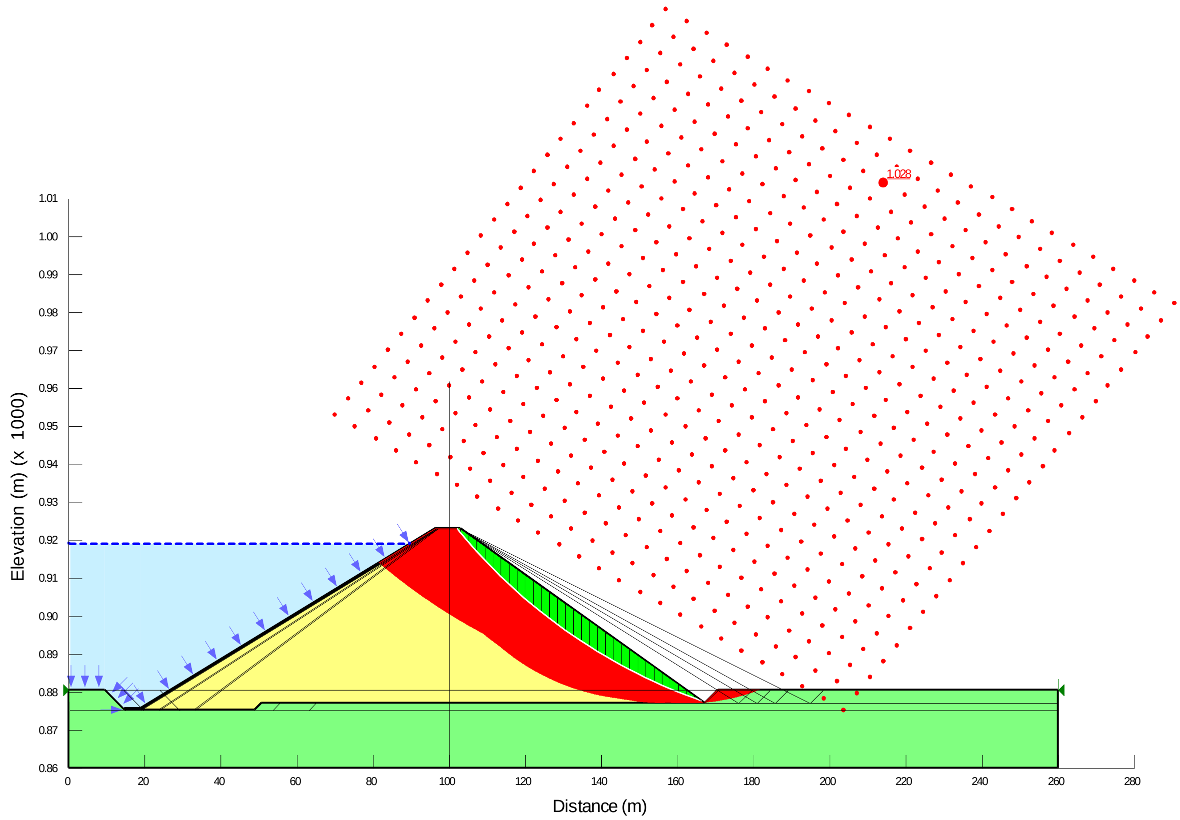


Figure I.1: CFRD Downstream slope analysis, 1 (V):1.4 (H), steady state flow analysis

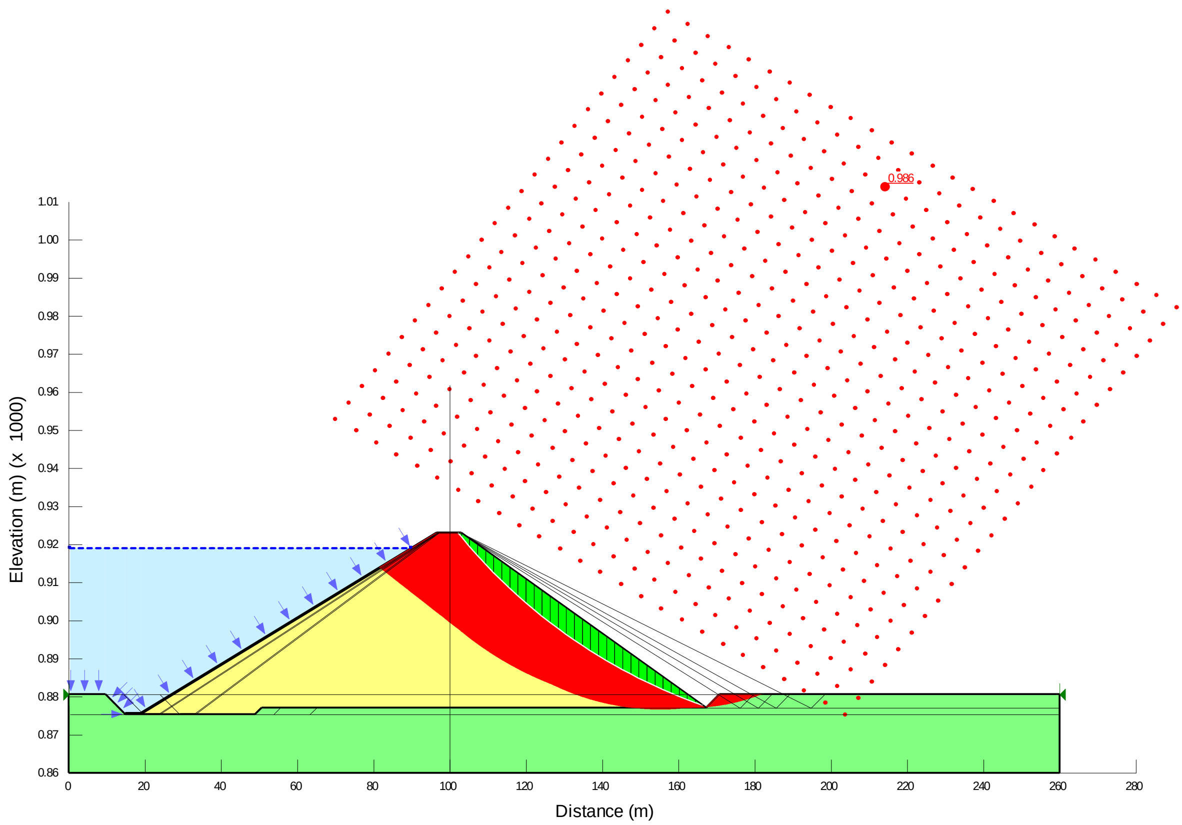


Figure I.2: CFRD Downstream slope analysis, 1 (V):1.4 (H), seismic analysis

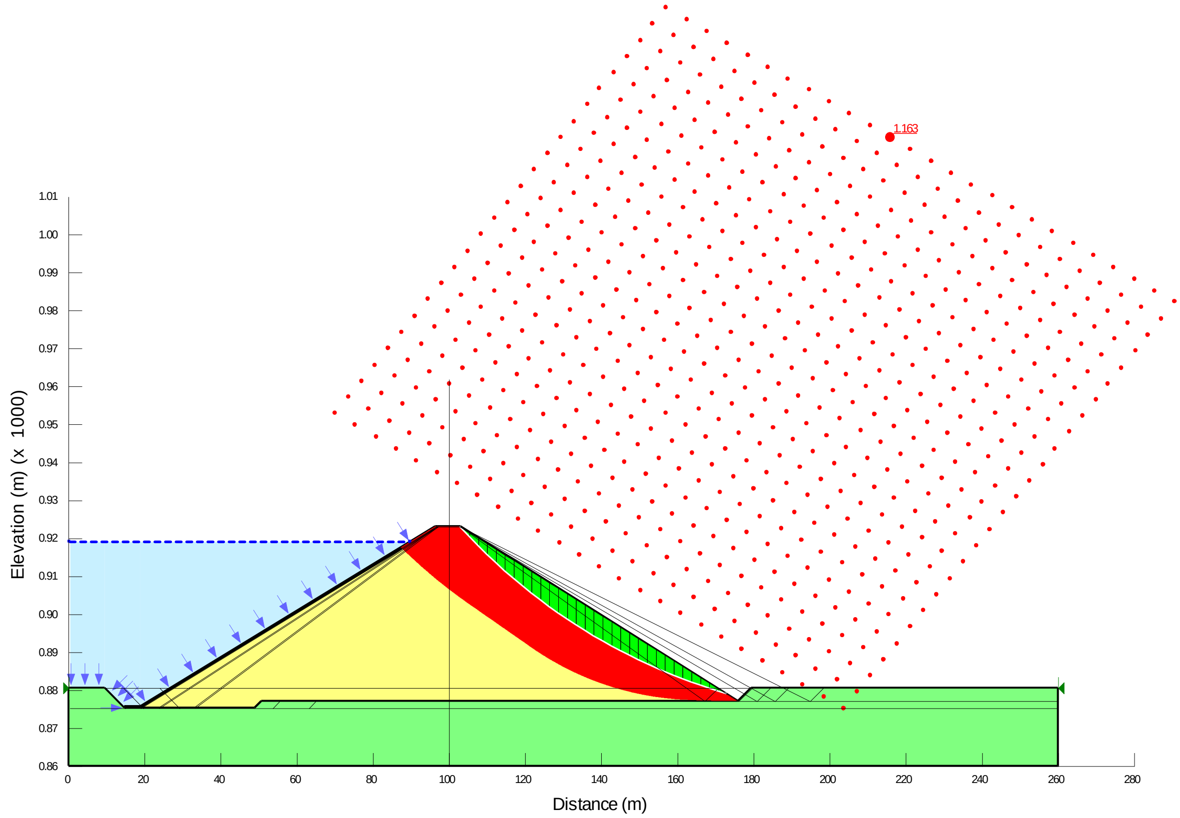


Figure I.3: CFRD Downstream slope analysis, 1 (V):1.6 (H), steady state flow analysis

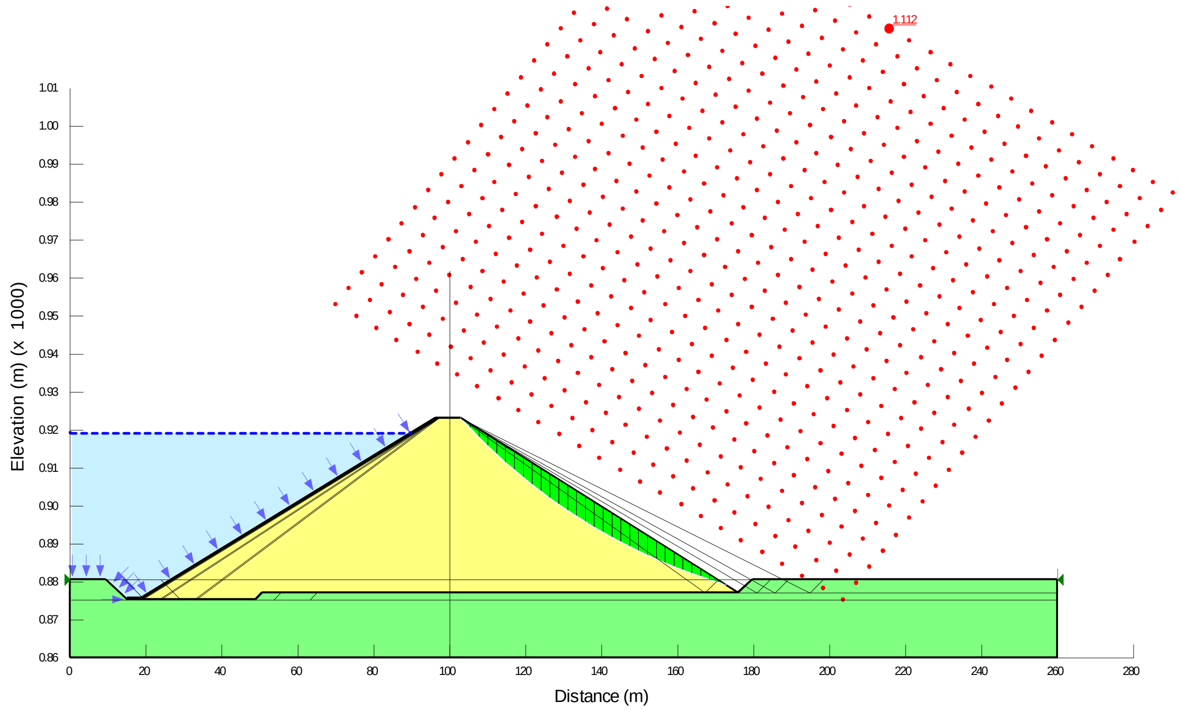


Figure I.4: CFRD Downstream slope analysis, 1 (V):1.6 (H), seismic analysis

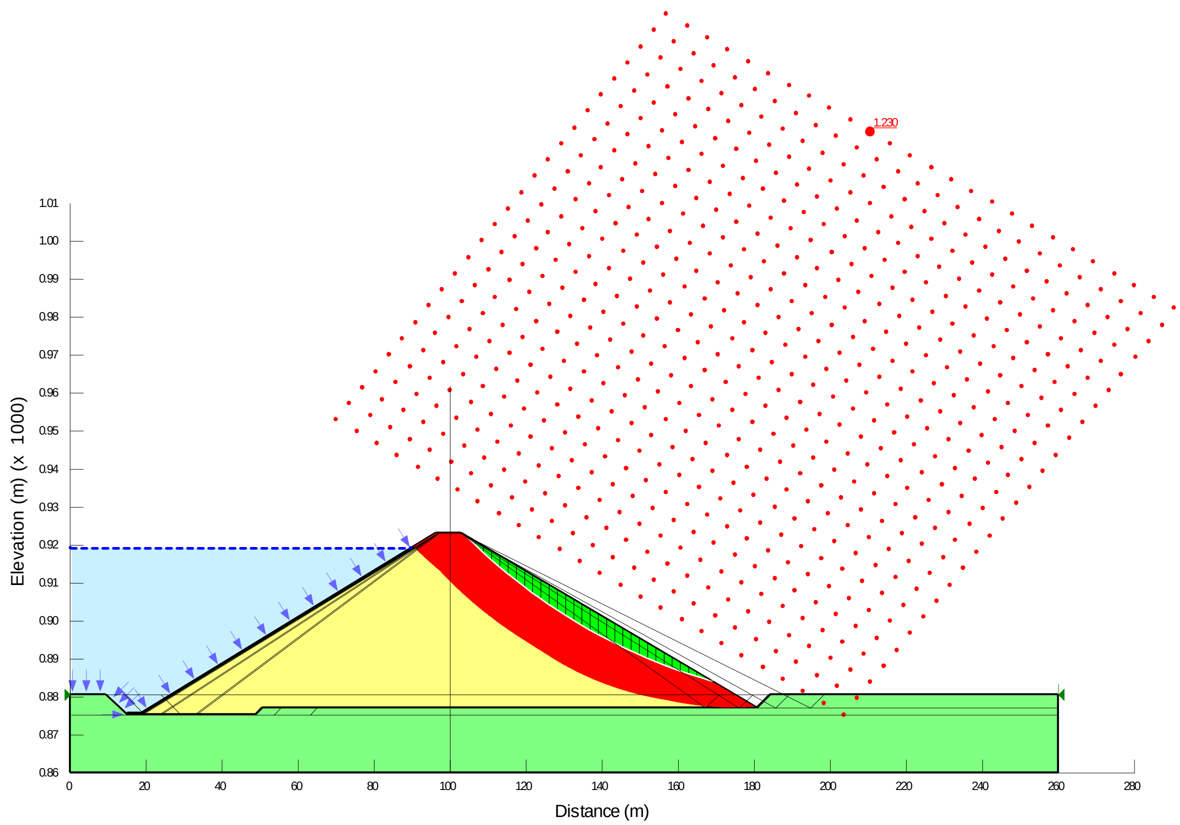


Figure I.5: CFRD Downstream slope analysis, 1 (V):1.7 (H), steady state flow analysis

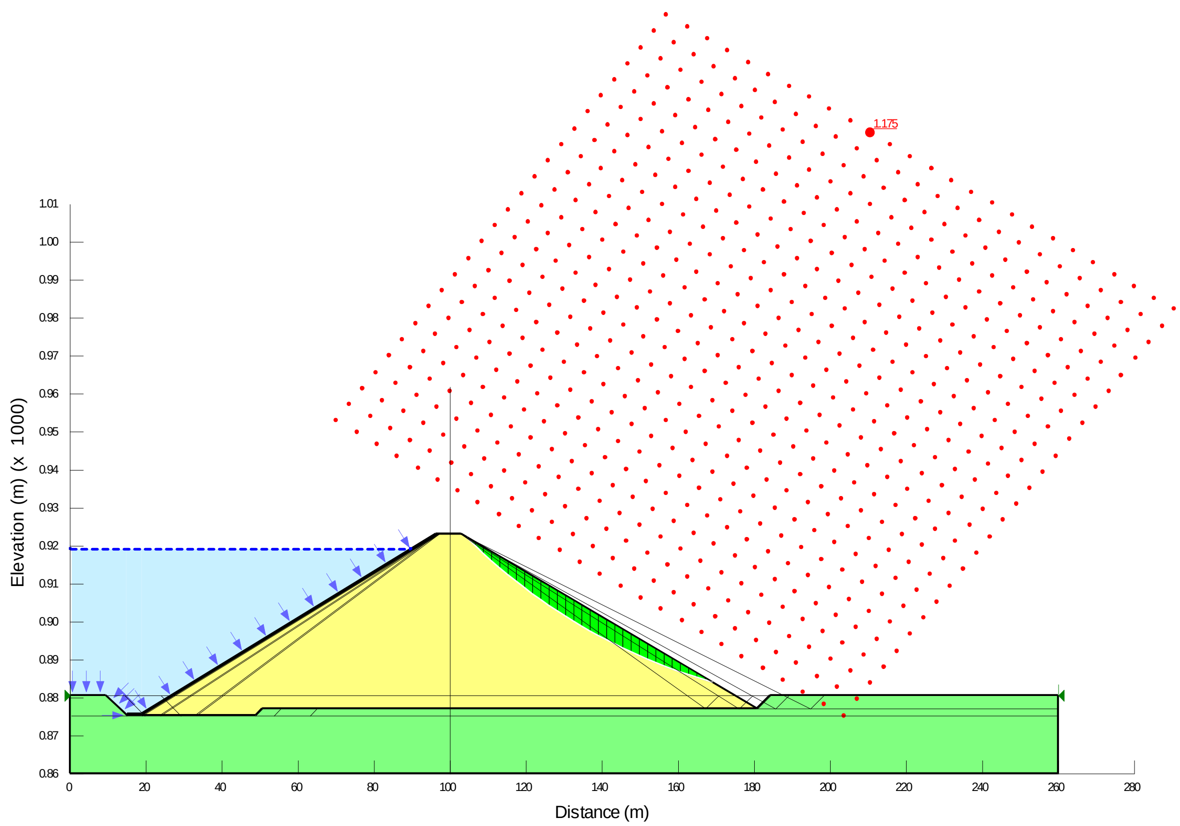


Figure I.6: CFRD Downstream slope analysis, 1 (V):1.7 (H), seismic analysis

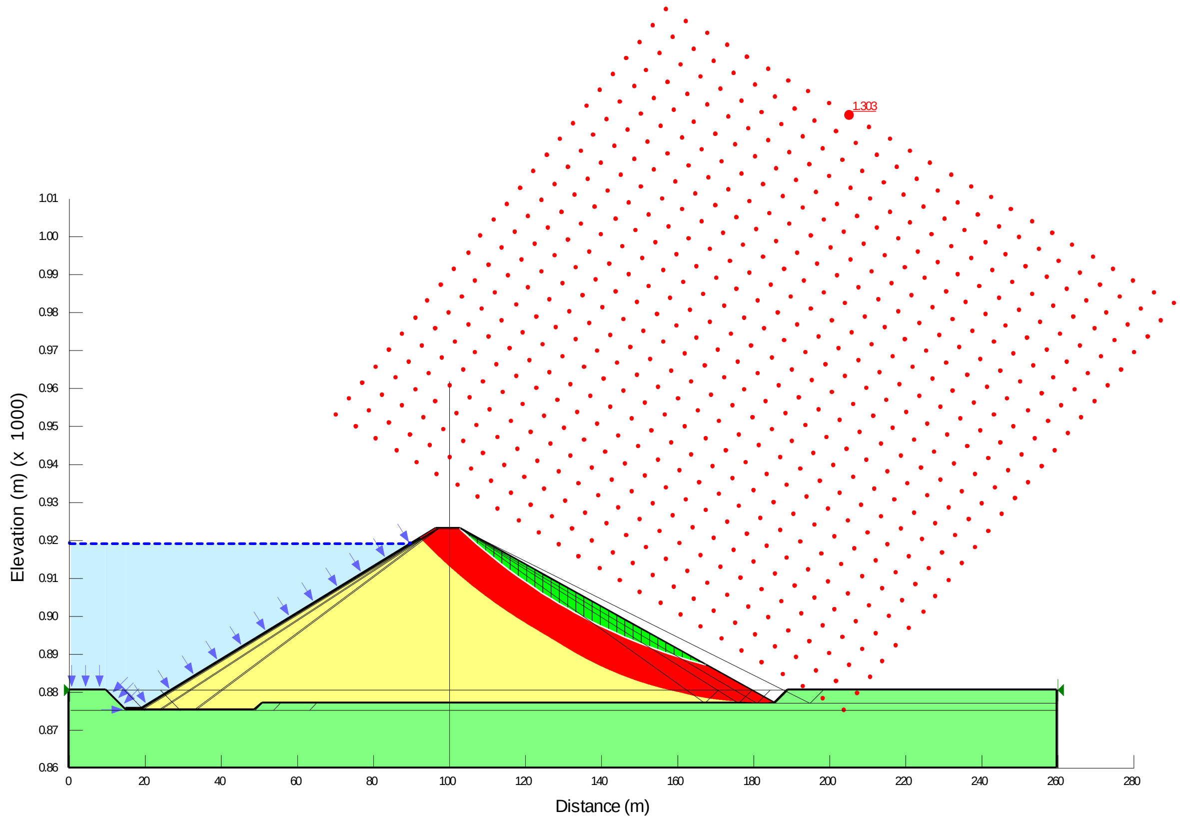


Figure I.7: CFRD Downstream slope analysis, 1 (V):1.8 (H), steady state flow analysis

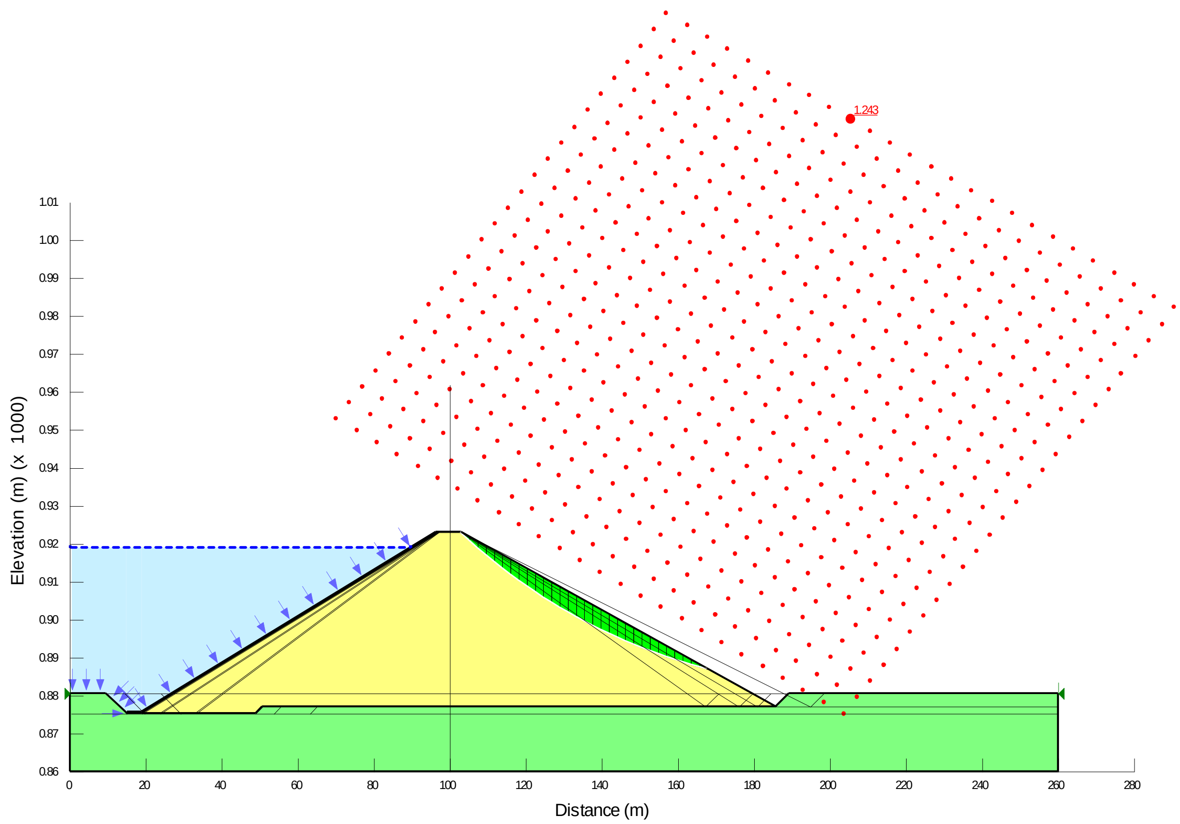


Figure I.8: CFRD Downstream slope analysis, 1 (V):1.8 (H), seismic analysis

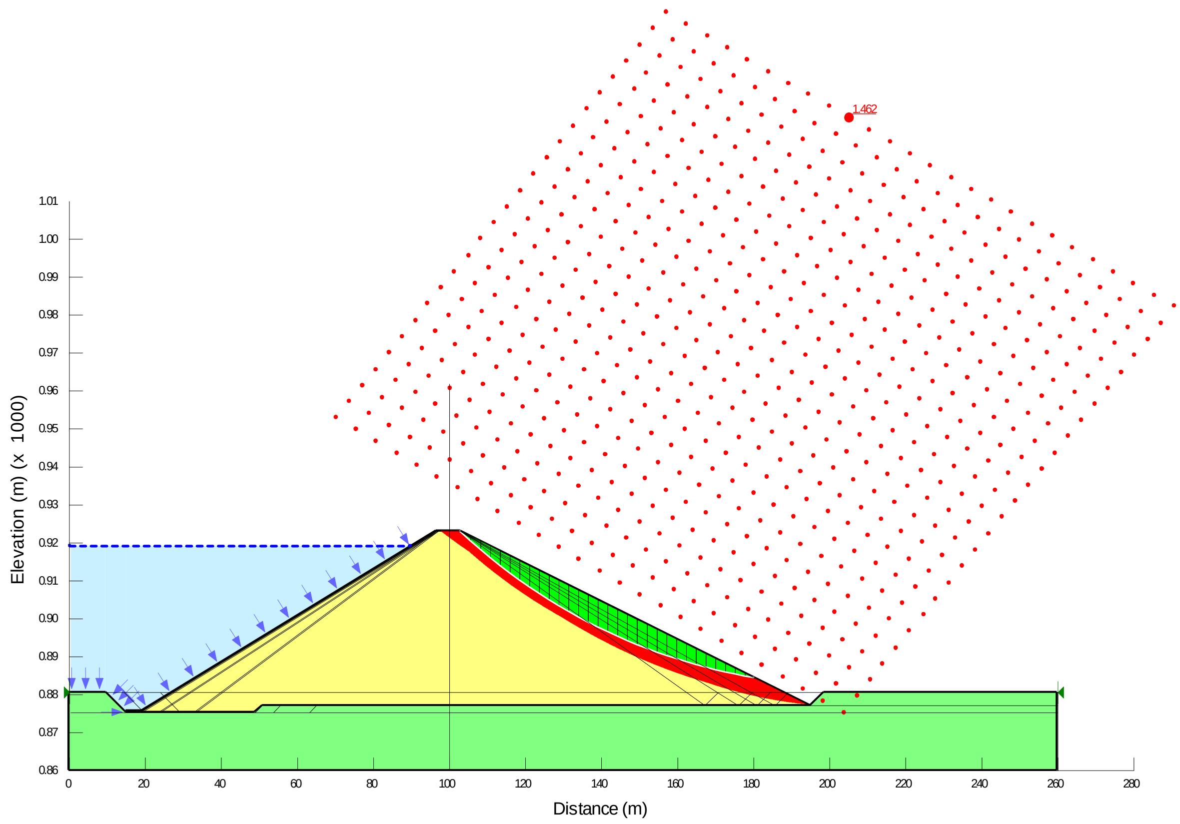


Figure I.9: CFRD Downstream slope analysis, 1 (V):2 (H), steady state flow analysis

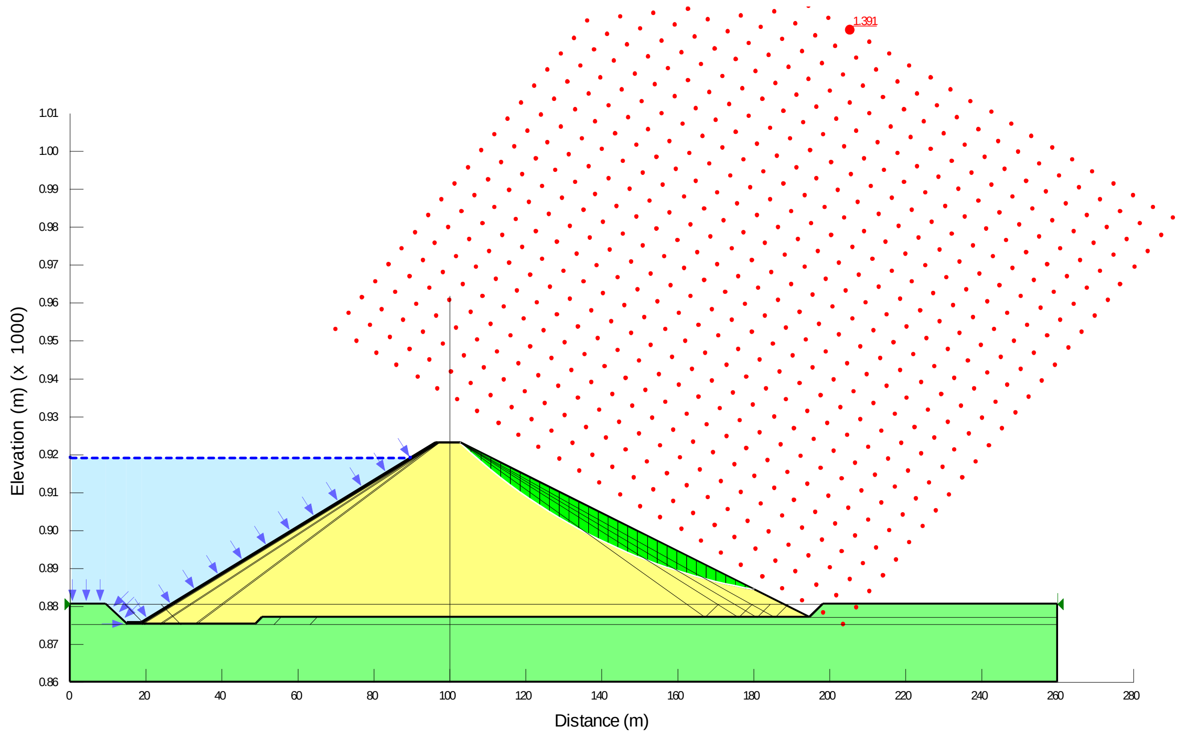


Figure I.10: CFRD Downstream slope analysis, 1 (V):2 (H), seismic analysis

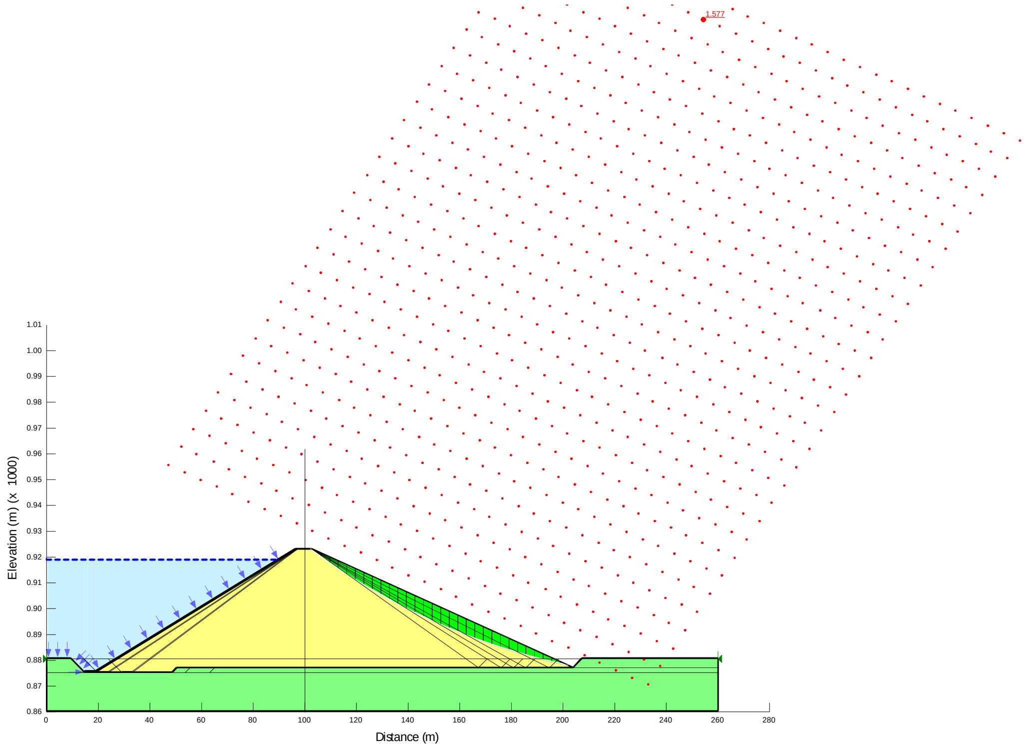


Figure I.11: CFRD Downstream slope analysis, 1 (V): 2.2 (H), steady state flow analysis

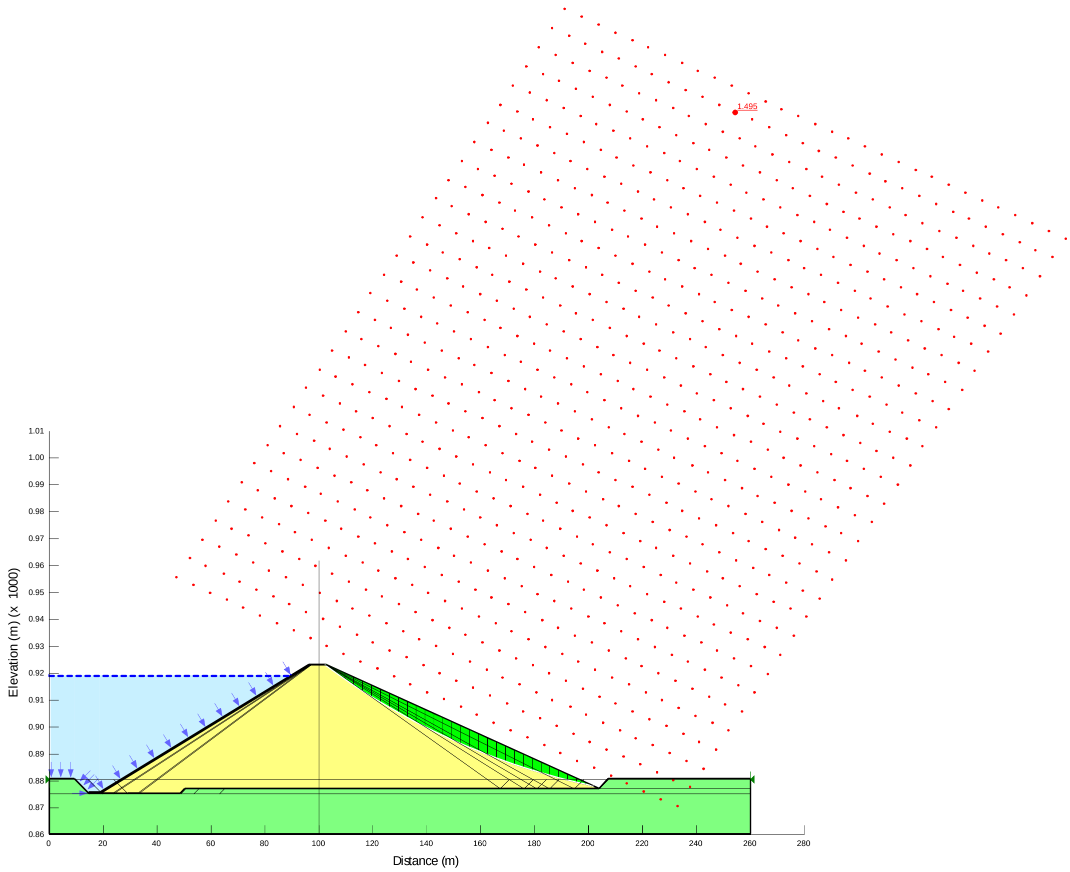


Figure I.12: CFRD Downstream slope analysis, 1 (V):2.2 (H), seismic analysis

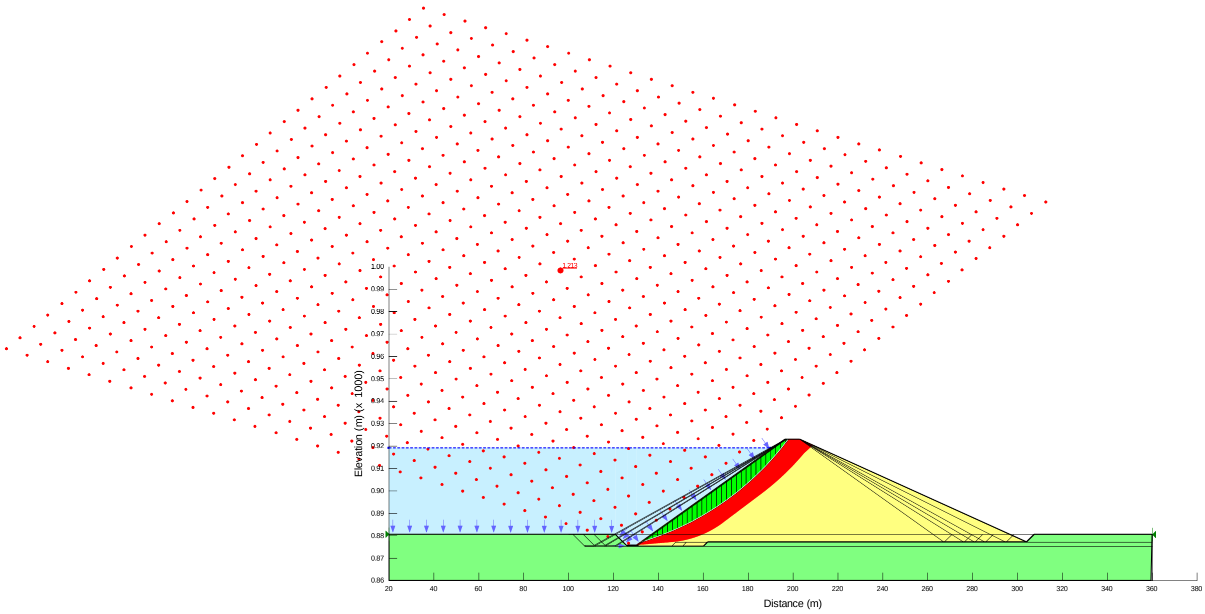


Figure I.13: CFRD Upstream slope analysis, 1 (V):1.4 (H), steady state flow analysis

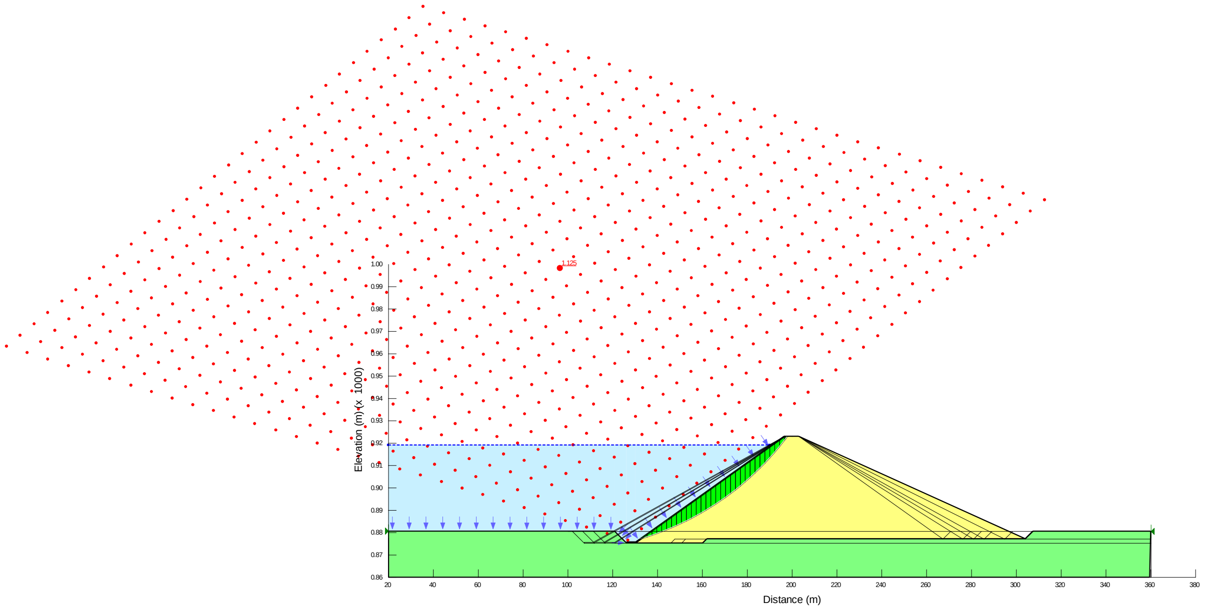


Figure I.14: CFRD Upstream slope analysis, 1 (V):1.4 (H), seismic analysis

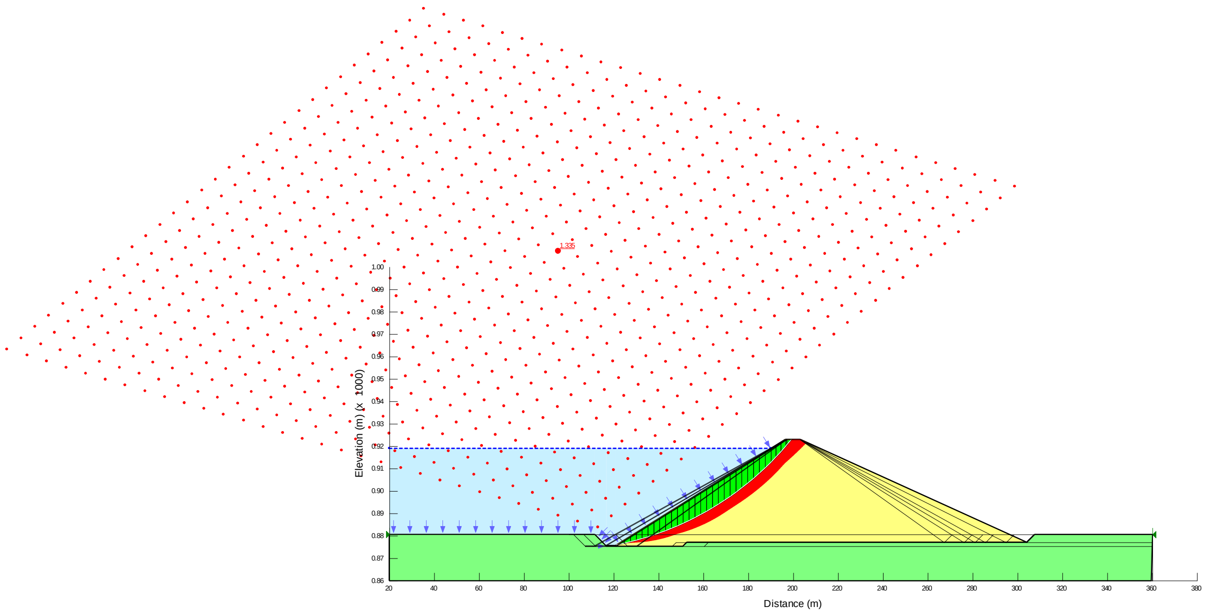


Figure I.15: CFRD Upstream slope analysis, 1 (V):1.6 (H), steady state flow analysis

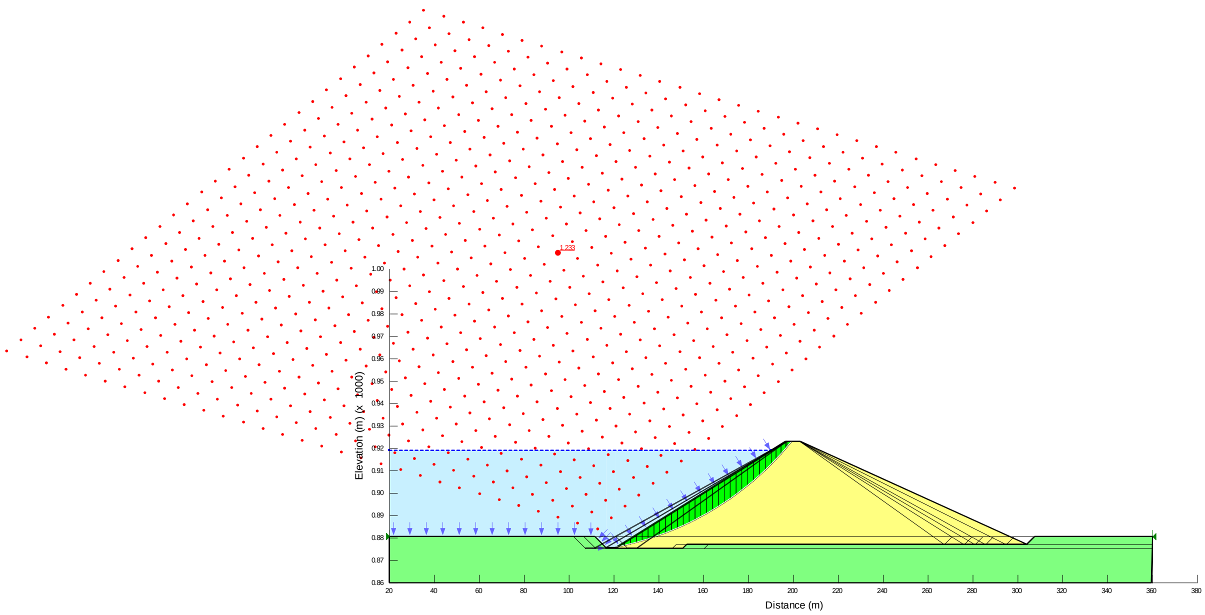


Figure I.16: CFRD Upstream slope analysis, 1 (V):1.6 (H), seismic analysis

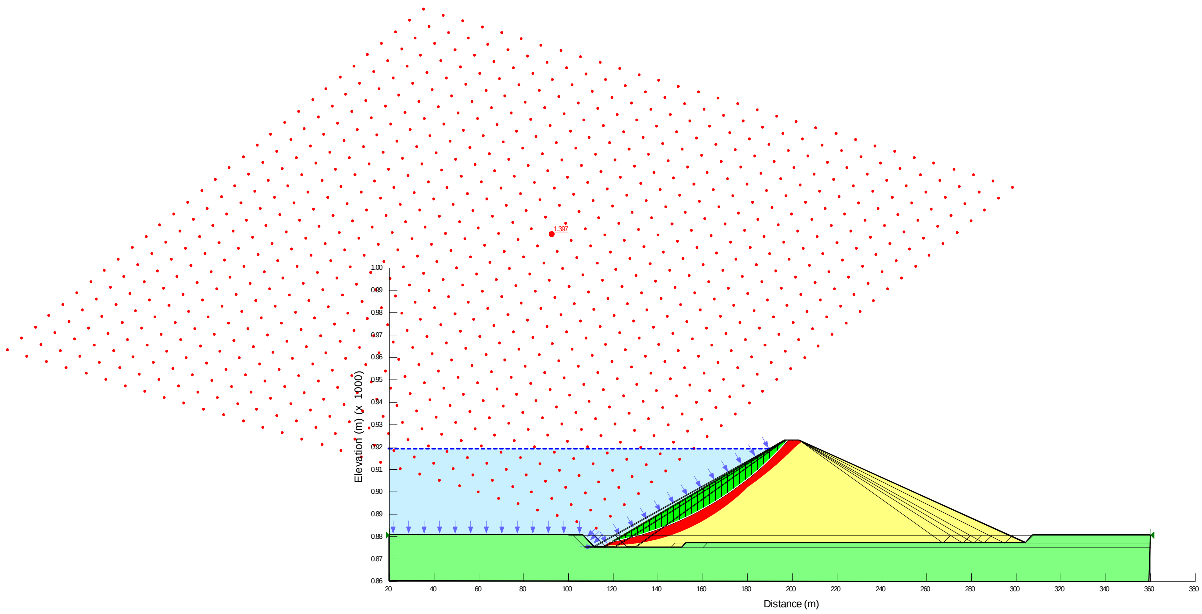


Figure I.17: CFRD Upstream slope analysis, 1 (V):1.7 (H), steady state flow analysis

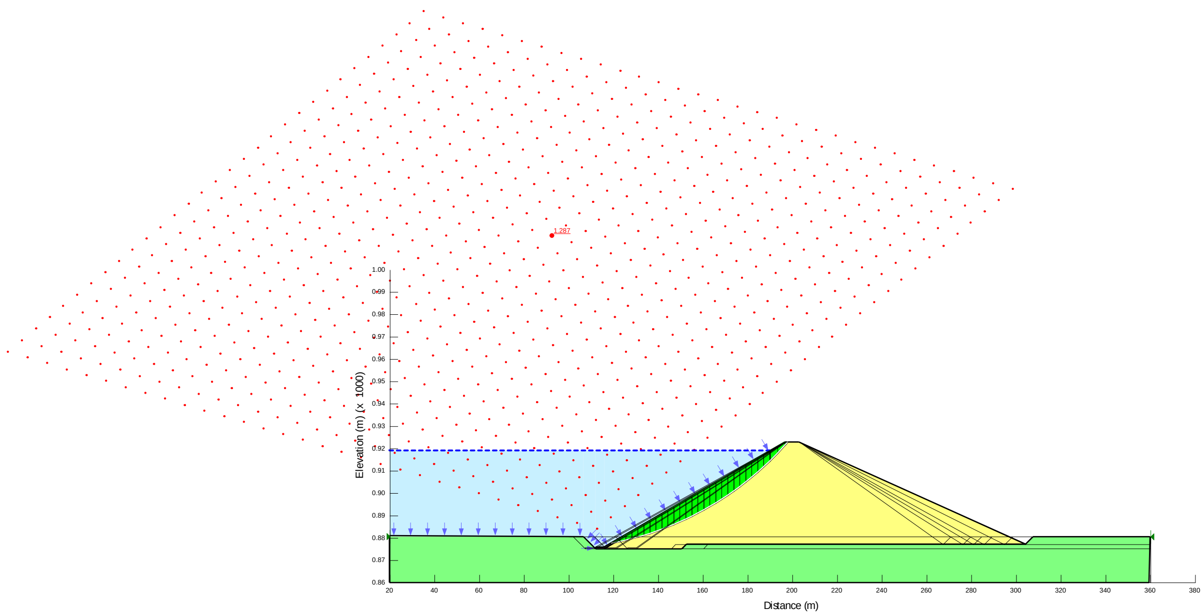


Figure I.18: CFRD Upstream slope analysis, 1 (V):1.7 (H), seismic analysis

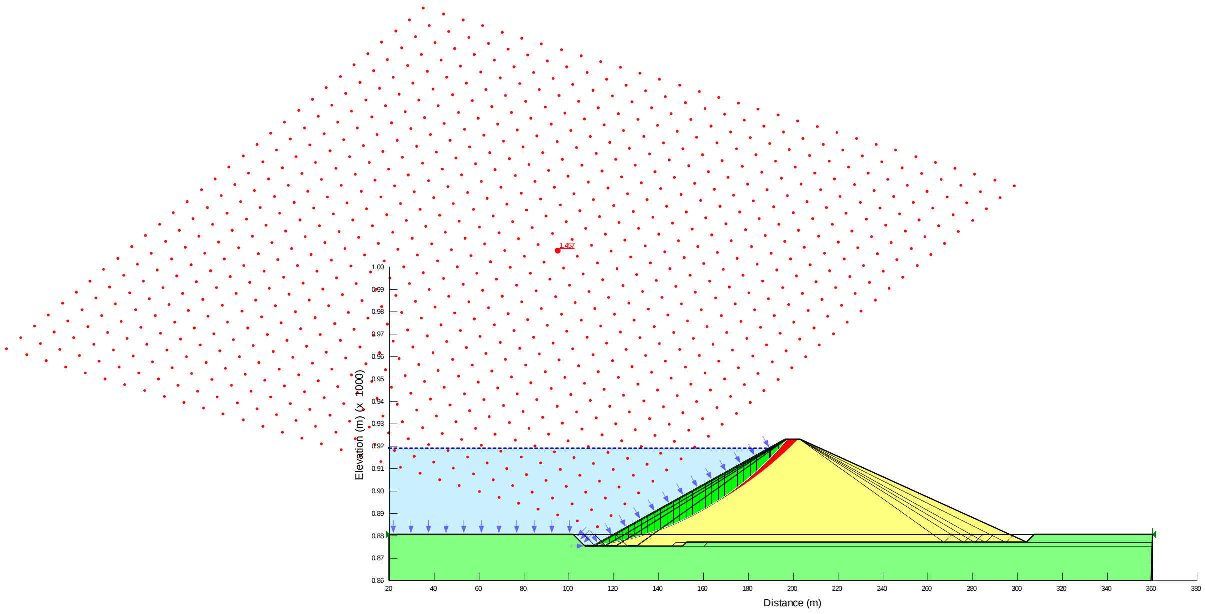


Figure I.19: CFRD Upstream slope analysis, 1 (V):1.8 (H), steady state flow analysis

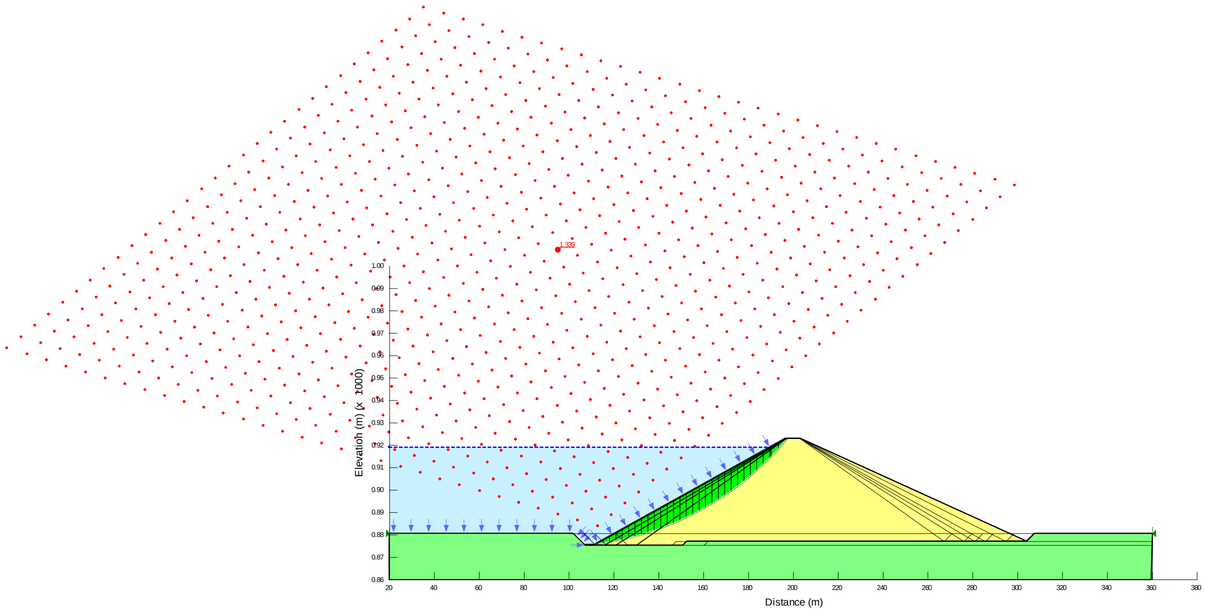


Figure I.20: CFRD Upstream slope analysis, 1 (V):1.8 (H), seismic analysis

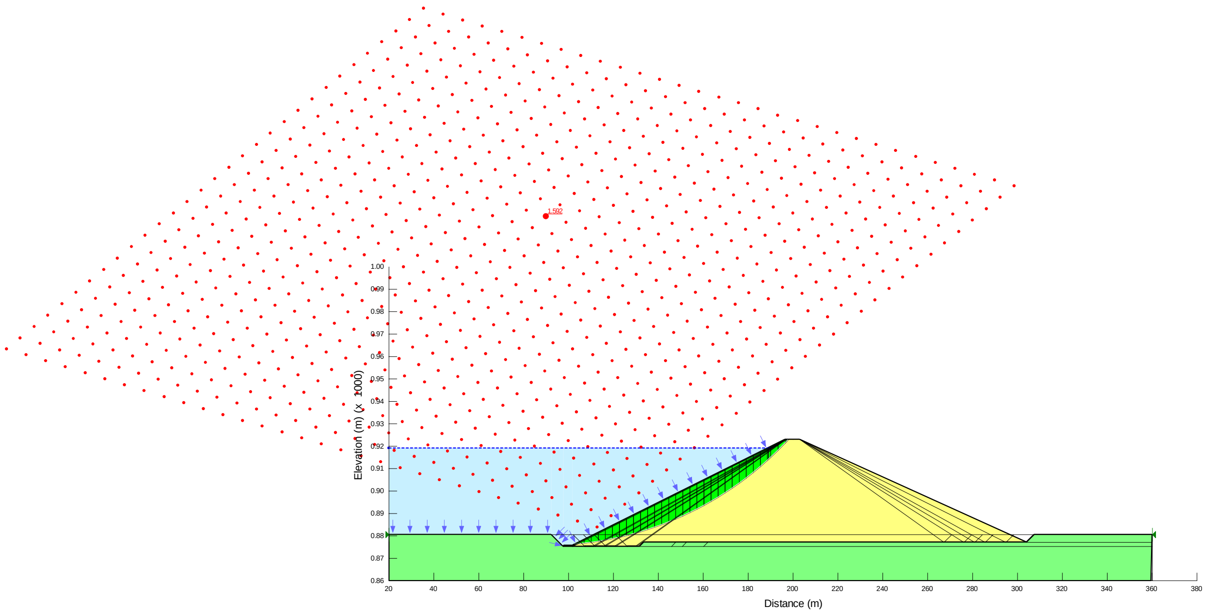


Figure I.21: CFRD Upstream slope analysis, 1 (V): 2 (H), steady state flow analysis

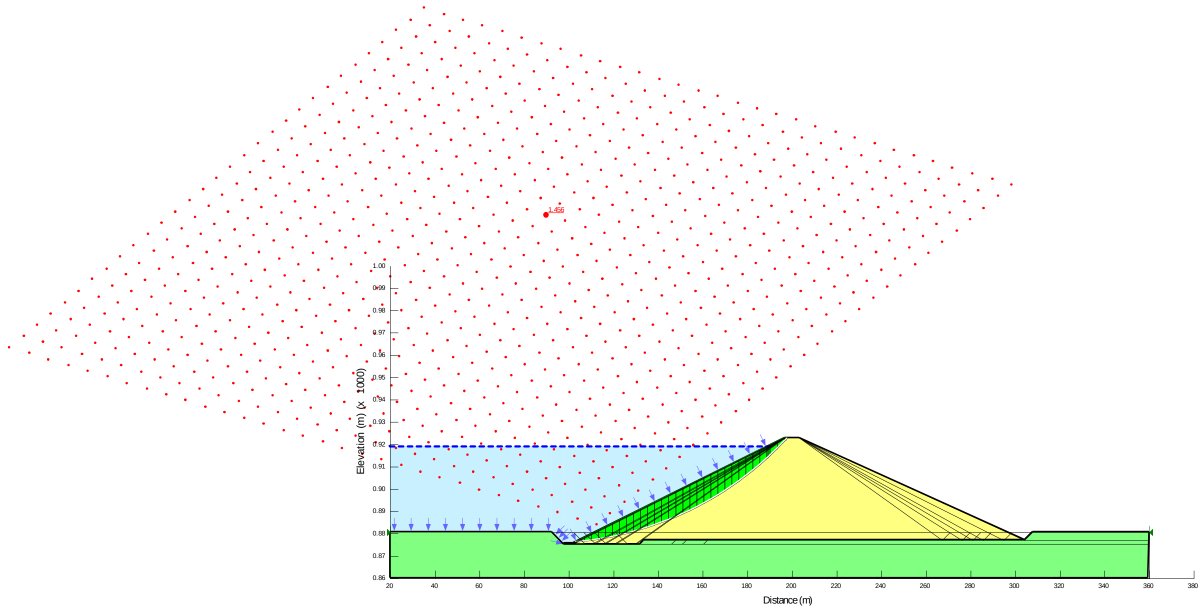
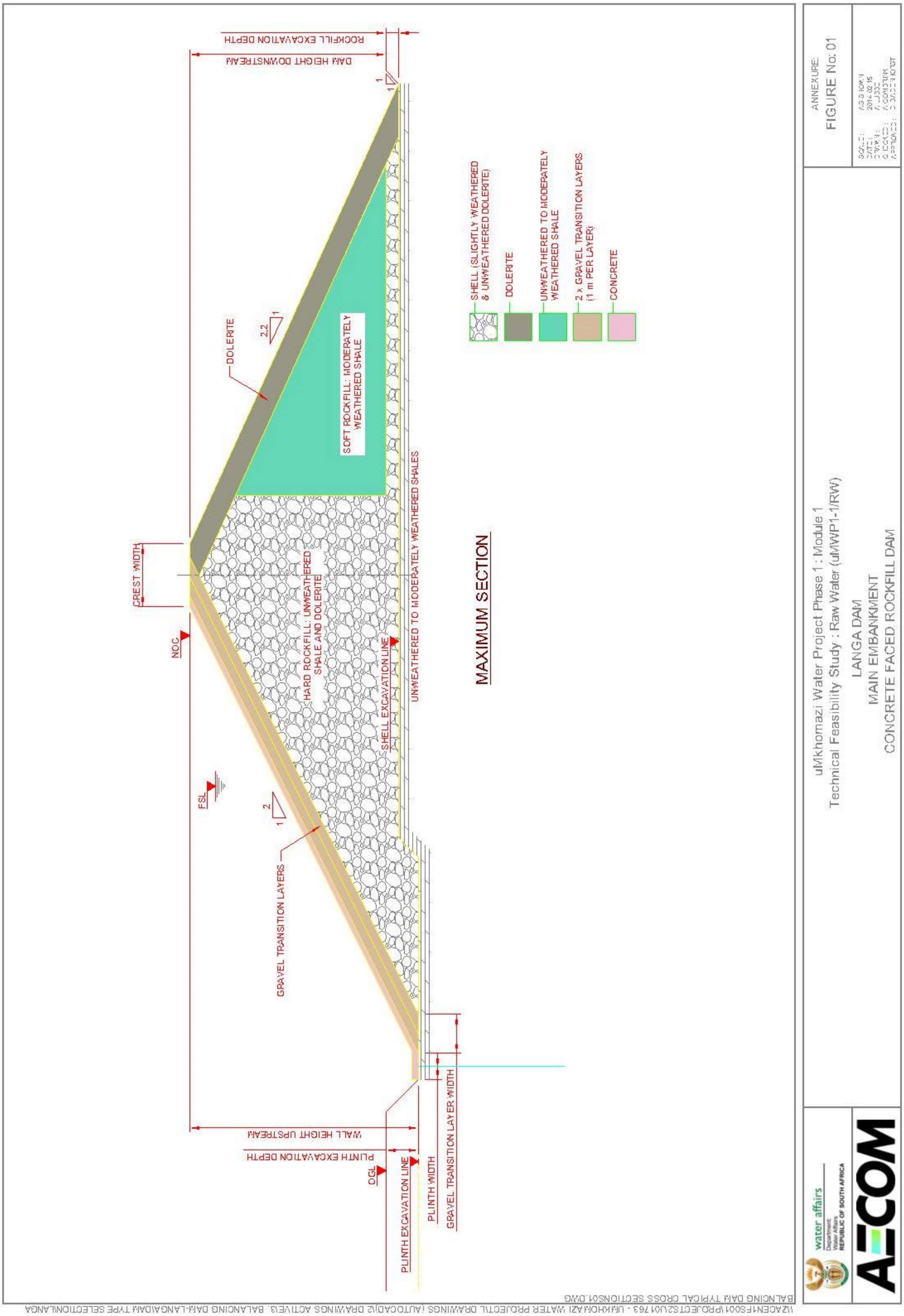
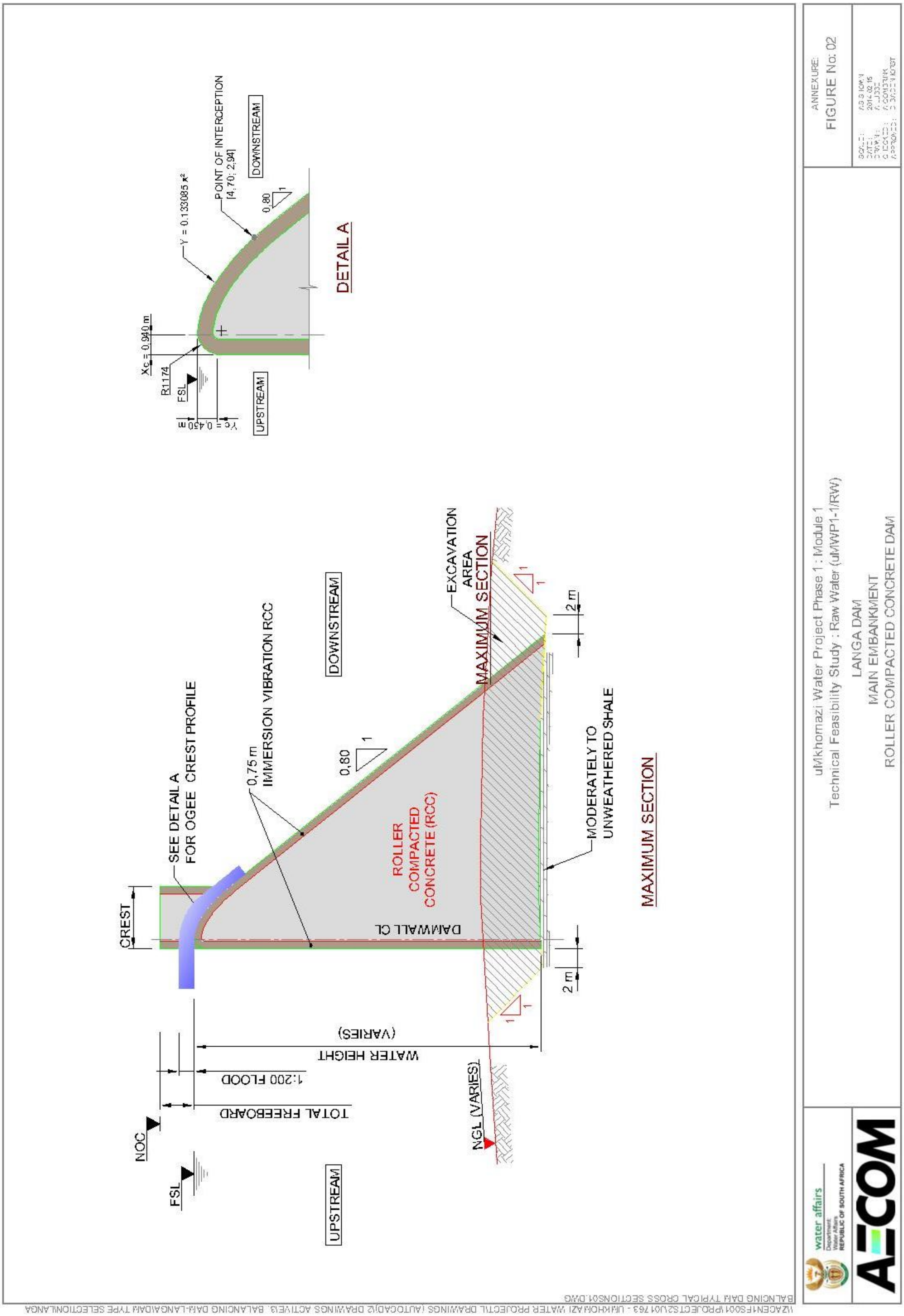


Figure I.22: CFRD Upstream slope analysis, 1 (V):2 (H), seismic analysis

Appendix J

Langa Balancing Dam: Typical cross-sections for each of the chosen dam types

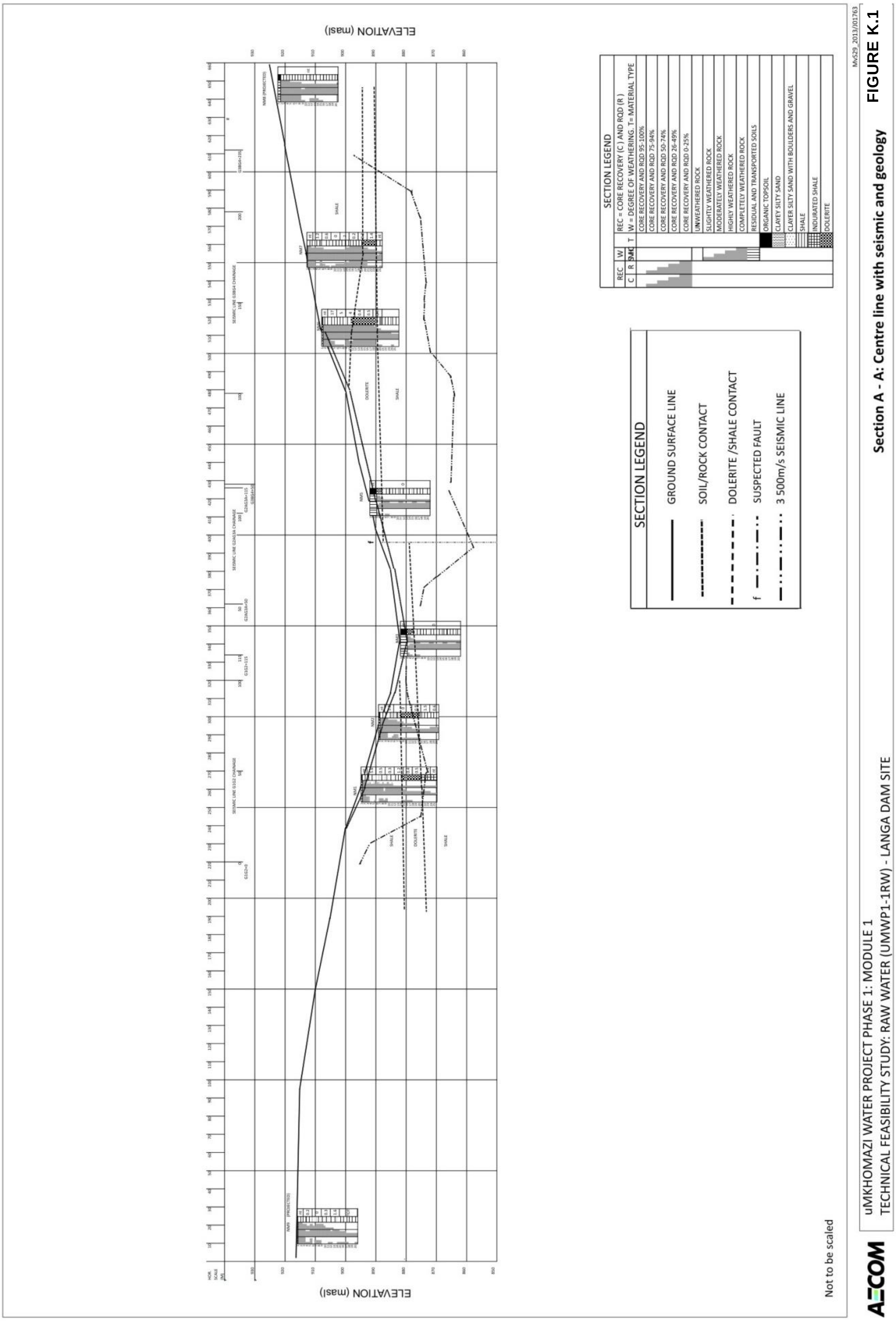

ROCKFILL EXCAVATION DEPTH
DAM HEIGHT DOWNSTREAM
CREST WIDTH
NOC
FSL
DOLERITE
2.2
1
2
1
SOFT ROCKFILL: MODERATELY WEATHERED SHALE
HARD ROCKFILL: UNWEATHERED SHALE AND DOLERITE
SHELL EXCAVATION LINE
UNWEATHERED TO MODERATELY WEATHERED SHALES
GRAVEL TRANSITION LAYERS
MAXIMUM SECTION
SHELL (SLIGHTLY WEATHERED & UNWEATHERED DOLERITE)
DOLERITE
UNWEATHERED TO MODERATELY WEATHERED SHALE
2 x GRAVEL TRANSITION LAYERS (1 m PER LAYER)
CONCRETE
WALL HEIGHT UPSTREAM
PLINTH EXCAVATION DEPTH
OGL
PLINTH EXCAVATION LINE
PLINTH WIDTH
GRAVEL TRANSITION LAYER WIDTH
ANNEXURE:
FIGURE No: 01
uMkhomazi Water Project Phase 1 : Module 1
Technical Feasibility Study : Raw Water (uMWP1-1/RW)
LANGA DAM
MAIN EMBANKMENT
CONCRETE FACED ROCKFILL DAM
water affairs
AECOM

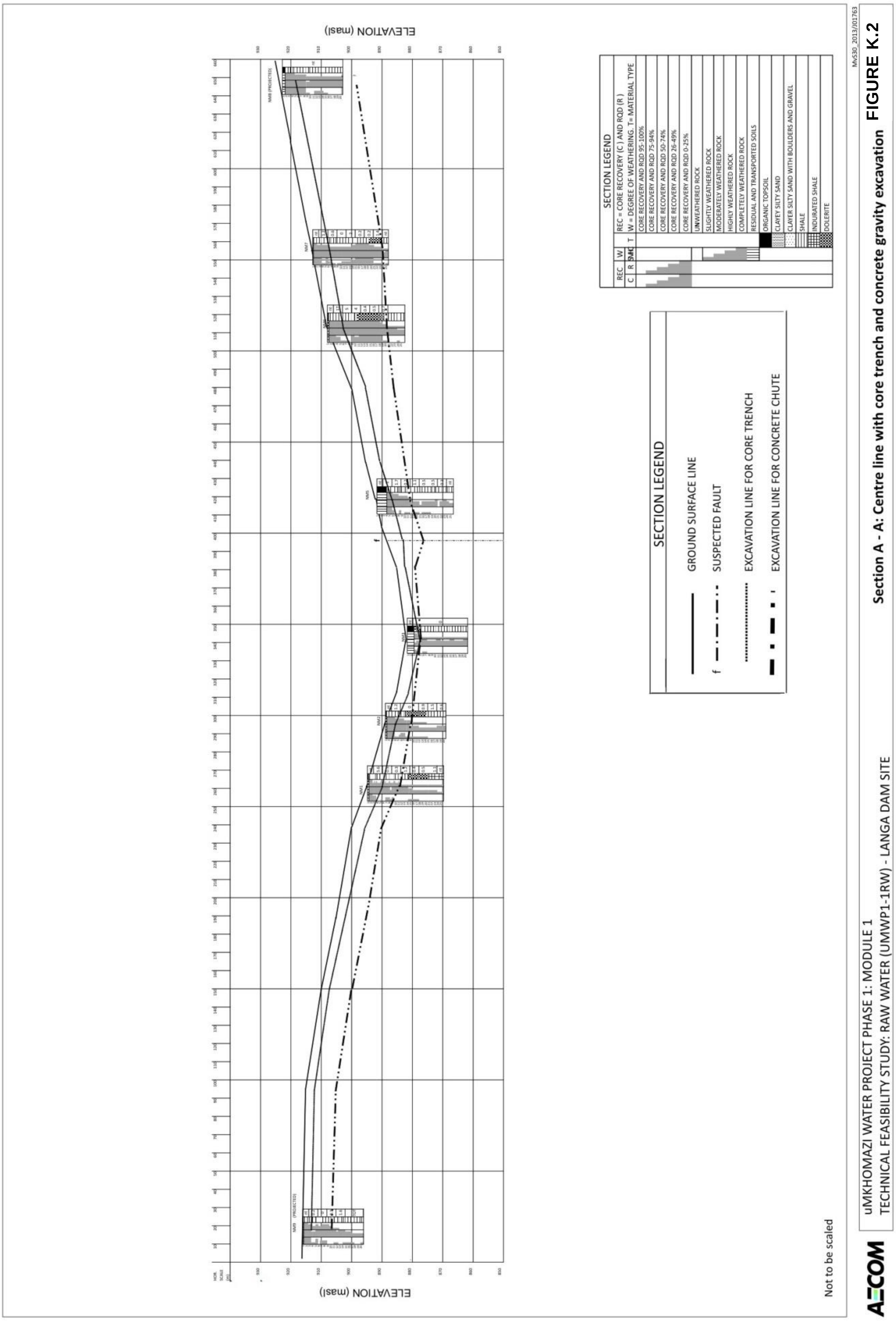


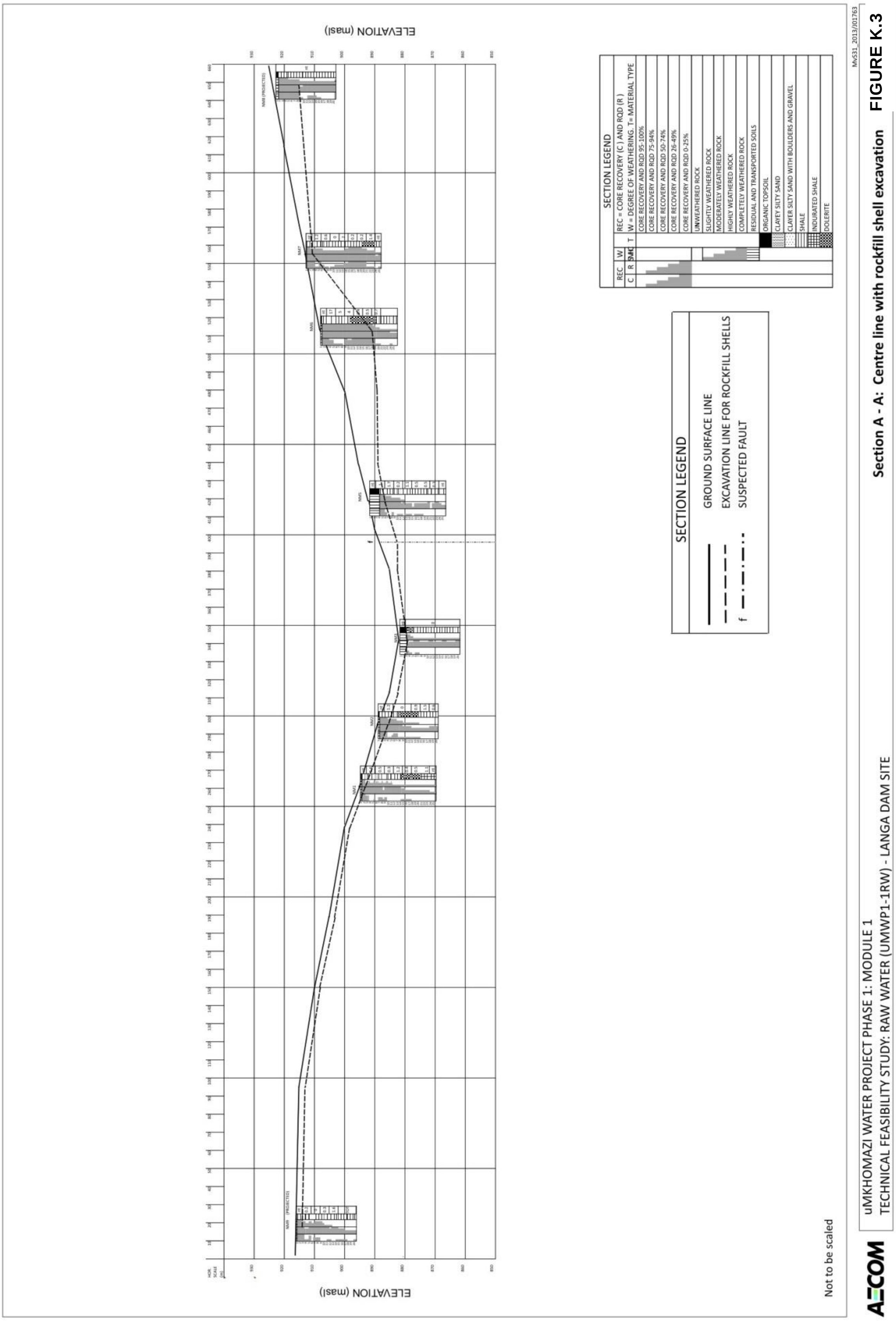
DETAIL A
UPSTREAM
DOWNSTREAM
POINT OF INTERCEPTION [4,70; 2,94]
Y = 0.133085 x²
Xc = 0,940 m
Yc = 0,450 m
R1174
FSL
NOC
TOTAL FREEBOARD
1:200 FLOOD
WATER HEIGHT
(VARIES)
CREST
SEE DETAIL A FOR OGEE CREST PROFILE
0,75 m IMMERSION VIBRATION RCC
0,80
1
ROLLER COMPACTED CONCRETE (RCC)
DAMWALL CL
EXCAVATION AREA
MAXIMUM SECTION
MODERATELY TO UNWEATHERED SHALE
NGL (VARIES)
2 m
MAXIMUM SECTION
ANNEXURE:
FIGURE No: 02
uMkhomazi Water Project Phase 1 : Module 1
Technical Feasibility Study : Raw Water (uMWP1-1/RW)
LANGA DAM
MAIN EMBANKMENT
ROLLER COMPACTED CONCRETE DAM
water affairs
AECOM
BALANCING DAM TYPICAL CROSS SECTIONS01.DWG

Appendix K

Langa Balancing Dam: Long-sections of geotechnical (foundation) investigations

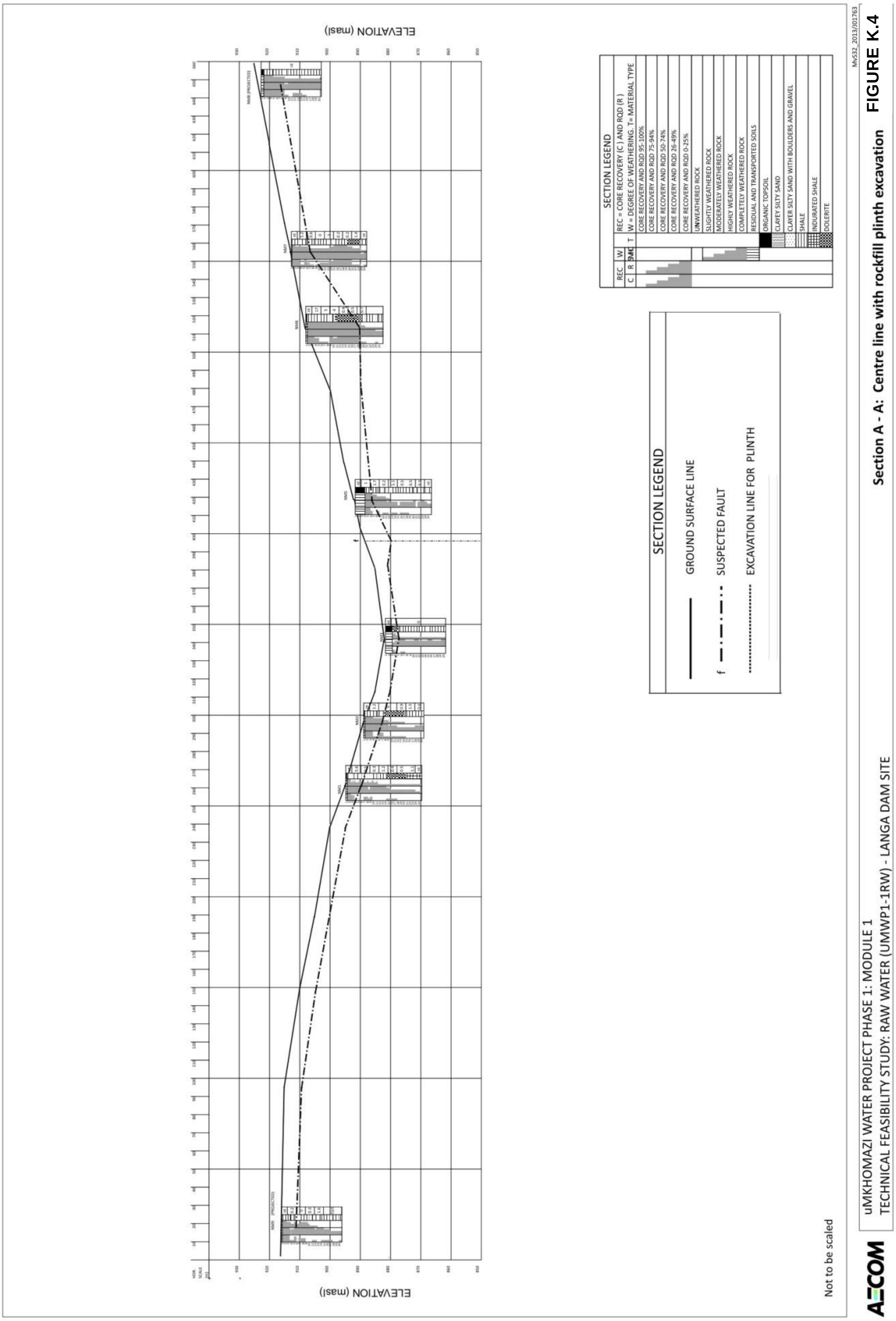

ELEVATION (masl)
SECTION LEGEND
GROUND SURFACE LINE
SOIL/ROCK CONTACT
DOLERITE /SHALE CONTACT
f SUSPECTED FAULT
3 500m/s SEISMIC LINE
SECTION LEGEND
REC = CORE RECOVERY (C) AND RQD (R)
W = DEGREE OF WEATHERING T= MATERIAL TYPE
CORE RECOVERY AND RQD 95-100%
CORE RECOVERY AND RQD 75-94%
CORE RECOVERY AND RQD 50-74%
CORE RECOVERY AND RQD 26-49%
CORE RECOVERY AND RQD 0-25%
UNWEATHERED ROCK
SLIGHTLY WEATHERED ROCK
MODERATELY WEATHERED ROCK
HIGHLY WEATHERED ROCK
COMPLETELY WEATHERED ROCK
RESIDUAL AND TRANSPORTED SOILS
ORGANIC TOPSOIL
CLAYEY SILTY SAND
CLAYEY SILTY SAND WITH BOULDERS AND GRAVEL
SHALE
INDURATED SHALE
DOLERITE
SHALE
DOLERITE
Not to be scaled
AECOM
uMKHOMAZI WATER PROJECT PHASE 1: MODULE 1
TECHNICAL FEASIBILITY STUDY: RAW WATER (UMWP1-1RW) - LANGA DAM SITE
Section A - A: Centre line with seismic and geology
FIGURE K.1
MvS29_2013/01763

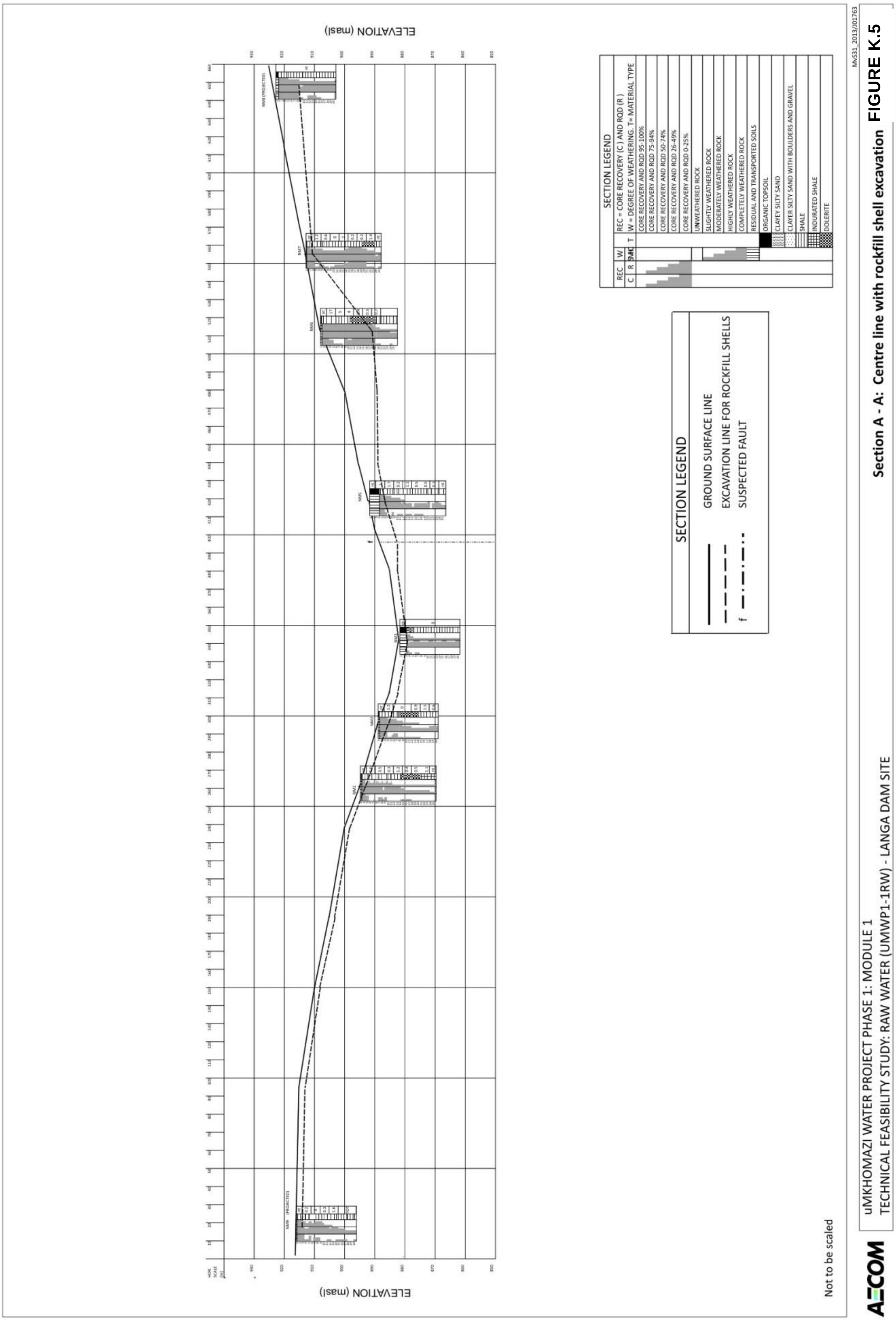

ELEVATION (masl)
SECTION LEGEND
REC = CORE RECOVERY (C) AND RQD (R)
W = DEGREE OF WEATHERING. T= MATERIAL TYPE
CORE RECOVERY AND RQD 95-100%
CORE RECOVERY AND RQD 75-94%
CORE RECOVERY AND RQD 50-74%
CORE RECOVERY AND RQD 26-49%
CORE RECOVERY AND RQD 0-25%
UNWEATHERED ROCK
SLIGHTLY WEATHERED ROCK
MODERATELY WEATHERED ROCK
HIGHLY WEATHERED ROCK
COMPLETELY WEATHERED ROCK
RESIDUAL AND TRANSPORTED SOILS
ORGANIC TOPSOIL
CLAYEY SILTY SAND
CLAYEY SILTY SAND WITH BOULDERS AND GRAVEL
SHALE
INDURATED SHALE
DOLERITE
SECTION LEGEND
GROUND SURFACE LINE
SUSPECTED FAULT
EXCAVATION LINE FOR CORE TRENCH
EXCAVATION LINE FOR CONCRETE CHUTE
Not to be scaled
uMKHOMAZI WATER PROJECT PHASE 1: MODULE 1
TECHNICAL FEASIBILITY STUDY: RAW WATER (UMWP1-1RW) - LANGA DAM SITE
Section A - A: Centre line with core trench and concrete gravity excavation
FIGURE K.2

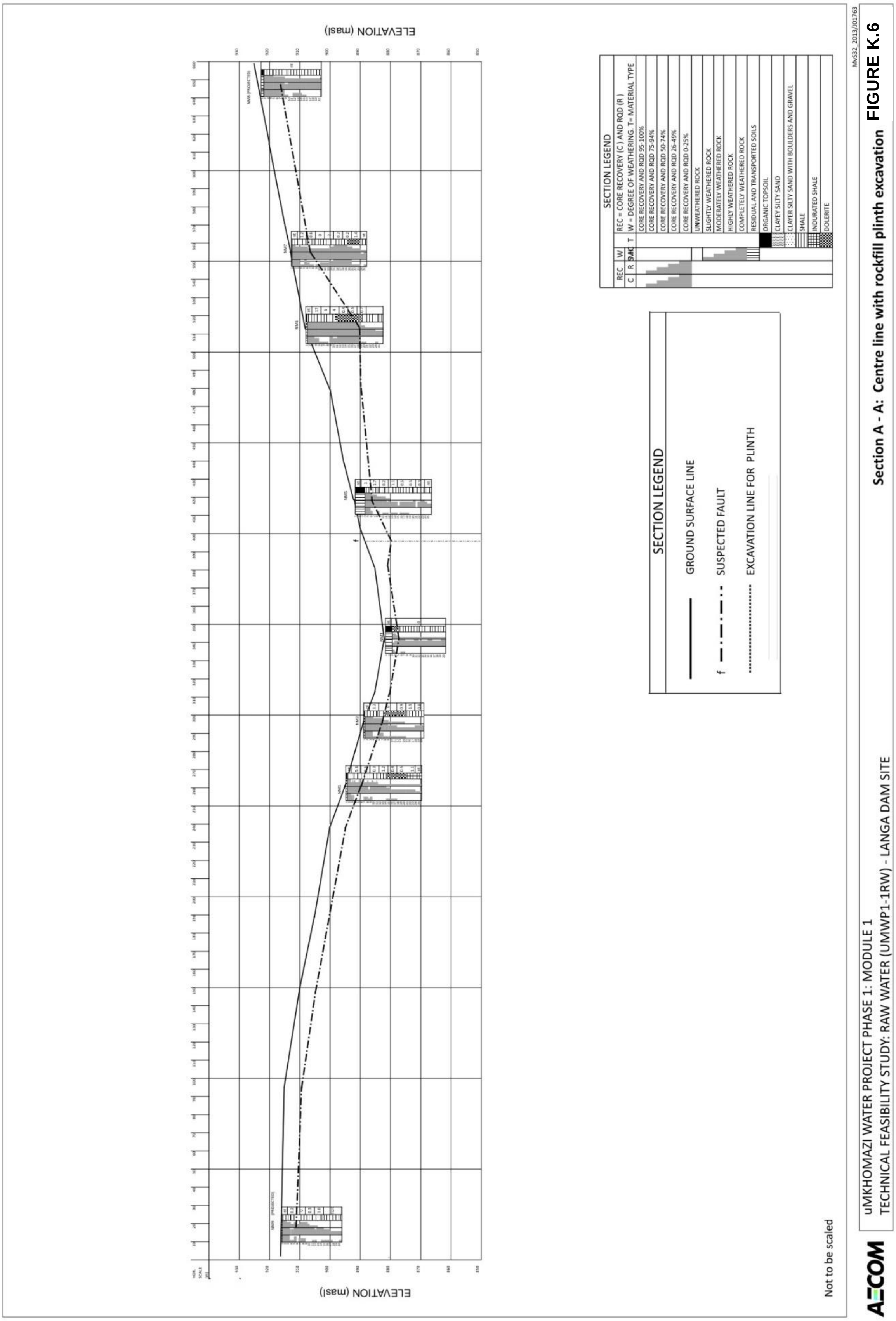


Section A - A: Centre line with rockfill shell excavation

FIGURE K.3


ELEVATION (masl)
NM9 (PROJECTED)
NM1
NM2
NM3
NM5
NM6
NM7
NM8 (PROJECTED)
SECTION LEGEND
GROUND SURFACE LINE
SUSPECTED FAULT
EXCAVATION LINE FOR PLINTH
SECTION LEGEND
REC = CORE RECOVERY (C) AND RQD (R)
W = DEGREE OF WEATHERING. T= MATERIAL TYPE
CORE RECOVERY AND RQD 95-100%
CORE RECOVERY AND RQD 75-94%
CORE RECOVERY AND RQD 50-74%
CORE RECOVERY AND RQD 26-49%
CORE RECOVERY AND RQD 0-25%
UNWEATHERED ROCK
SLIGHTLY WEATHERED ROCK
MODERATELY WEATHERED ROCK
HIGHLY WEATHERED ROCK
COMPLETELY WEATHERED ROCK
RESIDUAL AND TRANSPORTED SOILS
ORGANIC TOPSOIL
CLAYEY SILTY SAND
CLAYEY SILTY SAND WITH BOULDERS AND GRAVEL
SHALE
INDURATED SHALE
DOLERITE
Not to be scaled
AECOM
uMKHOMAZI WATER PROJECT PHASE 1: MODULE 1
TECHNICAL FEASIBILITY STUDY: RAW WATER (UMWP1-1RW) - LANGA DAM SITE
Section A - A: Centre line with rockfill plinth excavation
FIGURE K.4
Mv532_2013/J01763


ELEVATION (masl)
SECTION LEGEND
REC = CORE RECOVERY (C) AND RQD (R)
W = DEGREE OF WEATHERING. T= MATERIAL TYPE
CORE RECOVERY AND RQD 95-100%
CORE RECOVERY AND RQD 75-94%
CORE RECOVERY AND RQD 50-74%
CORE RECOVERY AND RQD 26-49%
CORE RECOVERY AND RQD 0-25%
UNWEATHERED ROCK
SLIGHTLY WEATHERED ROCK
MODERATELY WEATHERED ROCK
HIGHLY WEATHERED ROCK
COMPLETELY WEATHERED ROCK
RESIDUAL AND TRANSPORTED SOILS
ORGANIC TOPSOIL
CLAYEY SILTY SAND
CLAYEY SILTY SAND WITH BOULDERS AND GRAVEL
SHALE
INDURATED SHALE
DOLERITE
SECTION LEGEND
GROUND SURFACE LINE
EXCAVATION LINE FOR ROCKFILL SHELLS
SUSPECTED FAULT
Not to be scaled
AECOM
uMKHOMAZI WATER PROJECT PHASE 1: MODULE 1
TECHNICAL FEASIBILITY STUDY: RAW WATER (UMWP1-1RW) - LANGA DAM SITE
Section A - A: Centre line with rockfill shell excavation
FIGURE K.5
MvS31_2013/01763


ELEVATION (masl)
SECTION LEGEND
GROUND SURFACE LINE
SUSPECTED FAULT
EXCAVATION LINE FOR PLINTH
SECTION LEGEND
REC = CORE RECOVERY (C) AND RQD (R)
W = DEGREE OF WEATHERING, T= MATERIAL TYPE
CORE RECOVERY AND RQD 95-100%
CORE RECOVERY AND RQD 75-94%
CORE RECOVERY AND RQD 50-74%
CORE RECOVERY AND RQD 26-49%
CORE RECOVERY AND RQD 0-25%
UNWEATHERED ROCK
SLIGHTLY WEATHERED ROCK
MODERATELY WEATHERED ROCK
HIGHLY WEATHERED ROCK
COMPLETELY WEATHERED ROCK
RESIDUAL AND TRANSPORTED SOILS
ORGANIC TOPSOIL
CLAYEY SILTY SAND
CLAYEY SILTY SAND WITH BOULDERS AND GRAVEL
SHALE
INDURATED SHALE
DOLERITE
Not to be scaled
AECOM
uMKHOMAZI WATER PROJECT PHASE 1: MODULE 1
TECHNICAL FEASIBILITY STUDY: RAW WATER (UMWP1-1RW) - LANGA DAM SITE
Section A - A: Centre line with rockfill plinth excavation
FIGURE K.6
MvS32_2013/01763

Appendix L

Langa Balancing Dam: Results from balancing exercise – Balancing spreadsheets

Table L.1: Option 1 - Concrete faced rockfill dam balancing spreadsheet

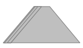
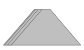
No.	Dam type	Configuration	Material (source)	MAIN & SADDLE DAM WALLS + DIVERSION TUNNELS								Total cost (ZAR)
				A	B	C	D	E	F	G		
				Overburden for spoil: Organic topsoil	Impervious core	Semi-pervious fill: Residual silty clayey sand and sandy silty clay	Semi pervious fill: Highly weathered shale	Soft rockfill: Moderately weathered shale	Hard rockfill: Unweathered shale and dolerite	Imported dolerite	SUM	
				Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)		
1	(1) Concrete faced rockfill dam		**(1) Required material - Main wall**									R 549 087 699
			(a) Core (impervious earthfill)								0	
			(b) Upstream and downstream shells (semi pervious earthfill)								0	
			(c) Rockfill (Impervious layer)					350 000	591 713		941 713	
			(d) Rip-rap								0	
			(e) Gravel layer						173 507		173 507	
			(f) Sand layer transition zone								0	
			(g) Blanket and chimney drains								0	
			(h) Concrete						8 973		8 973	
			(i) Downstream protection layer							0	0	
			(3) Required material - Infrastructure									
			(a) Diversion works concrete aggregate								0	
			(b) Intake structure concrete aggregate						4 748		4 748	
			(c) Spillway and chute concrete aggregate						6 105		6 105	
			(d) Outlet works concrete aggregate								0	
			(e) Apron slab								0	
			TOTAL REQUIRED	0	0	0	0	350 000	785 046	0		
			Available material: (1) **Quarry I**	20 000	0	120 000	180 000	350 000	1 200 000			
			Available material: (2) Portal excavation	8 000	0	230 000	70 000	50 000	40 000			
			Available material: (3) Tunnel spoil	0	0	0	0	0	250 000			
			Available material: (4) Spillway approach	15 000	0	35 000	280 000	20 000	0			
			Available material: (5) Dam Excavation	138 261	0	0	182 516	182 516	212 936			
			Available material: (6) **Other**	0	0	0	0	0	0			
			TOTAL AVAILABLE	181 261	0	385 000	712 516	602 516	1 702 936	0		
			Material needed ('+' = Surplus; '-' = Deficit)	*181 261*	*0*	*385 000*	*712 516*	*252 516*	*917 890*	*0*		
			To be stockpiled for later use									
			To be dumped	*165 963*	*0*	*293 211*	*574 833*	*252 516*			*1 286 523*	
			Dam forming	*0*	*0*	*0*	*0*	*350 000*	*785 046*	*0*		
			Untouched	*15 302*		*91 811*	*137 717*		*917 890*			
			Percentage remaining (%)	*8*		*24*	*19*	*0*	*54*			

Table L.2: Option 2 - Roller compacted concrete dam balancing spreadsheet

No.	Dam type	Configuration	Material (source)	MAIN & SADDLE DAM WALLS + DIVERSION TUNNELS								Total cost (ZAR)
				A	B	C	D	E	F	G		
				Overburden for spoil: Organic topsoil	Impervious core	Semi-pervious fill: Residual silty clayey sand and sandy silty clay	Semi pervious fill: Highly weathered shale	Soft rockfill: Moderately weathered shale	Hard rockfill: Unweathered shale and dolerite	Imported sand	SUM	
				Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)		
2	(2) Roller compacted concrete dam (RCC)		(1) Required material - Main wall									R 1 591 187 651
			(a) Core (impervious earthfill)								0	
			(b) Upstream and downstream shells (semi pervious earthfill)								0	
			(c) Rockfill (Impervious layer)								0	
			(d) Rip-rap								0	
			(e) Gravel layer								0	
			(f) Sand layer transition zone								0	
			(g) Blanket and chimney drains								0	
			(h) Concrete						617 016		617 016	
			(i) Downstream protection layer							0	0	
			(3) Required material - Infrastructure									
			(a) Diversion works concrete aggregate								0	
			(b) Intake structure concrete aggregate						4 748		4 748	
			(c) Spillway and chute concrete aggregate								0	
			(d) Outlet works concrete aggregate								0	
			(e) Apron slab								0	
			TOTAL REQUIRED	0	0	0	0	0	621 764	0		
			Available material: (1) **Quarry I**	20 000	0	120 000	180 000	350 000	1 200 000			
			Available material: (2) Portal excavation	8 000	0	230 000	70 000	50 000	40 000			
			Available material: (3) Tunnel spoil	0	0	0	0	0	250 000			
			Available material: (4) Spillway approach	15 000	0	35 000	280 000	20 000	0			
			Available material: (5) Dam Excavation	71 155	0	0	150 203	150 203	175 236			
			Available material: (6) **Other**	0	0	0	0	0	0			
			TOTAL AVAILABLE	114 155	0	385 000	680 203	570 203	1 665 236	0		
			Material needed ('+' = Surplus; '-' = Deficit)	*114 155*	*0*	*385 000*	*680 203*	*570 203*	*1 043 472*	*0*		
			To be stockpiled for later use									
			To be dumped	*96 764*	*0*	*280 653*	*523 682*	*265 857*	*465 236*		*1 632 192*	
			Dam forming	*0*	*0*	*0*	*0*	*0*	*621 764*	*0*		
			Untouched	*17 391*		*104 347*	*156 521*	*304 346*	*578 236*			
			Percentage remaining (%)	*15*		*27*	*23*	*53*	*35*			

Table L.3: Option 3 - Composite dam balancing spreadsheet

No.	Dam type	Configuration	Material (source)	MAIN & SADDLE DAM WALLS + DIVERSION TUNNELS								Total cost (ZAR)
				A	B	C	D	E	F	G		
				Overburden for spoil: Organic topsoil	Impervious core	Semi-pervious fill: Residual silty clayey sand and sandy silty clay	Semi pervious fill: Highly weathered shale	Soft rockfill: Moderately weathered shale	Hard rockfill: Unweathered shale and dolerite	Imported sand	SUM	
				Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)	Volume (m^3)		
3	(3) Composite dam: RCC spillway section and CFRD left and right flank	 	(1) Required material - Main wall									R 1 125 550 530
			(a) Core (impervious earthfill)								0	
			(b) Upstream and downstream shells (semi pervious earthfill)								0	
			(c) Rockfill (Impervious layer)					350 000	285 657		635 657	
			(d) Rip-rap								0	
			(e) Gravel layer						86 764		86 764	
			(f) Sand layer transition zone								0	
			(g) Blanket and chimney drains								0	
			(h) Concrete						310 852		310 852	
			(i) Downstream protection layer								0	
			(3) Required material - Infrastructure									
			(a) Diversion works concrete aggregate								0	
			(b) Intake structure concrete aggregate						4 748		4 748	
			(c) Spillway and chute concrete aggregate								0	
			(d) Outlet works concrete aggregate								0	
			(e) Apron slab								0	
			TOTAL REQUIRED	0	0	0	0	350 000	688 021	0		
			Available material: (1) **Quarry I**	20 000	0	120 000	180 000	350 000	1 200 000			
			Available material: (2) Portal excavation	8 000	0	230 000	70 000	50 000	40 000			
			Available material: (3) Tunnel spoil	0	0	0	0	0	250 000			
			Available material: (4) Spillway approach	15 000	0	35 000	280 000	20 000	0			
			Available material: (5) Dam Excavation	98 315	0	0	145 455	145 455	169 698			
			Available material: (6) **Other**	0	0	0	0	0	0			
			TOTAL AVAILABLE	141 315	0	385 000	675 455	565 455	1 659 698	0		
			Material needed ('+' = Surplus; '-' = Deficit)	*141 315*	*0*	*385 000*	*675 455*	*215 455*	*971 677*	*0*		
			To be stockpiled for later use									
			To be dumped	*125 121*	*0*	*287 832*	*529 704*	*215 455*	*459 698*		*1 617 810*	
			Dam forming	*0*	*0*	*0*	*0*	*350 000*	*688 021*	*0*		
			Untouched	*16 195*		*97 168*	*145 752*		*511 979*			
				0	*0*	*0*	*0*	*0*	*0*			
			Percentage remaining (%)	*11*		*25*	*22*	*0*	*31*			

Appendix M

Langa Balancing Dam: Results from balancing exercise – Bill of quantities

Table M.1: Langa Dam: Option 1: Concrete faced rockfill dam (CFRD) – Bill of quantities

AECOM — Option 1: Concrete faced rockfill dam

No	PAY	DESCRIPTION	UNIT	RATE (Rand)	QUANTITY	Total Amount (Rand)
		SABS 1200 DE-1984 DE: Small earth dams				
		Embankment excavation and formation				
8.3.1	8.3.1	Site clearance				
	8.3.1.1	Clear and strip site	ha	23 250.00	10.8	R 250 732.10
	8.3.1.2	Clear and grub large trees				
		a) over 1m and up to and including 2 m	No			R 0.00
		b) over 2 m and up to and including 3 m	No			R 0.00
		c) over 3 m, in increments of 1 m	No			R 0.00
	8.3.1.6	Clearing of basin	ha			R 0.00
8.3.2	8.3.2	Remove topsoil to nominal depth 150 mm (or other stated depth), stockpile and maintain	m^3	20.00	107 842	R 2 156 835.30
8.3.3	8.3.3	Excavation				
		a) Material unsuitable for embankment				
		(i) Removal to designated spoil dumps in the dam basin, spreading and trimming	m^3	31.60	1 286 523	R 40 654 129.40
		b) Material suitable for embankment from essential excavations for (Stockpiled):	m^3	30.30	1 135 046	R 34 391 890.15
		c) Extra over items (b) (1) - (4) for excavation in:				
		1) Intermediate material	m^3	INCL		
		2) Hard rock material	m^3	36.50	785 046	R 28 654 174.60
		Importing material				
		a) Dolerite	m^3	300.00	0	R 0.00
		b) River Sand	m^3	290.00		R 0.00
8.3.2	8.3.5	Forming embankment from stockpiled material 8.33b				
		(a) Core (impervious earthfill)	m^3	48.37	0	R 0.00
		(b) Upstream and downstream shells (semi pervious earthfill)	m^3	48.37	0	R 0.00
		(c) Rockfill (Impervious layer)	m^3	65.00	941 713	R 61 211 341.37
		(d) Rip-rap	m^3	438.52	0	R 0.00
		(e) Gravel layer	m^3	97.94	173 507	R 16 993 275.88
		(f) Sand layer transition zone	m^3	97.94	0	R 0.00
		(g) Blanket and chimney drains	m^3	789.45	0	R 0.00
		(h) IVRCC	m^3	45.40		R 0.00
		(h) RCC concrete	m^3	1 156.71		R 0.00
		(i) CVC concrete	m^3	1 981.85	8 973	R 17 783 419.03
8.3.3		**Formwork**				
		(a) Gang formed	m^2	475.00	0	R 0.00
		(b) Intricate	m^2			
		SABS 1200 D-1988 D: Earthworks				
		Quarry excavation to stockpile or dispose				
8.3.4	8.3.2	Bulk excavation				
		a) Excavate in all materials and backfill or dispose, as ordered	m^3			R 0.00
		b) Extra over for:				
		1) Intermediate excavation	m^3			R 0.00
		2) Hard rock excavation	m^3			R 0.00
		3) Boulder excavation, Class A	m^3			R 0.00
		4) Boulder excavation, Class B	m^3			R 0.00
		SUB-TOTAL				R 202 095 798

Table M.2: Langa Dam: Option 1: Concrete faced rockfill dam (CFRD) – Total cost summary

AECOM Option 1: Summary

Item		Unit	Rate	Cost
DIRECT COSTS				
Dam forming and excavation		Sum		202 095 797.82
Diversion works		Sum		4 587 520.00
Intake and outlet works		Sum		65 675 453.50
Spillway and chute		Sum		17 983 317.11
Measurng weirs		Sum		
SUB TOTAL (ACTIVITIES)				R 290 342 088.44
Landscaping		% Direct Costs	5	R 14 517 104.42
Miscellaneous		% Direct Costs	10	R 29 034 208.84
SUB TOTAL A				R 333 893 401.71
Preliminery and General		% of Sub total A	30	R 100 168 020.51
Infrastructure				
Road deviations		R/km		R 0.00
Housing and accomodation		Lump sum		0
Access roads		R/km		R 0.00
Pipeline		R/km		0
Water to site- Construction		Lump sum		0
Electricty Supply and deviation		Lump sum		0
Social (Relocation)		Lump sum		0
Environmental		Lump sum		0
SUB TOTAL B				R 434 061 422.22
Contingencies		% of sub total B	10	R 43 406 142.22
SUB TOTAL C				R 477 467 564.44
Planning design and supervision		% of sub total C	15	R 71 620 134.67
SUB TOTAL D				R 549 087 699.11
VAT		% of sub total D	0	R 0.00
NETT PROJECT COST				R 549 087 699
Social (Relocation)				0
Environmental				0
Total Project Cost				R 549 087 699

Table M.3: Langa Dam: Option 2: Roller compacted concrete (RCC) dam – Bill of quantities

AECOM Option 2: Roller compacted concrete dam

No	PAY	DESCRIPTION	UNIT	RATE (Rand)	QUANTITY	Total Amount (Rand)
		SABS 1200 DE-1984 DE: Small earth dams				
		Embankment excavation and formation				
8.3.1	8.3.1	Site clearance				
	8.3.1.1	Clear and strip site	ha	23 250.00	4.6	R 107 232.42
	8.3.1.2	Clear and grub large trees				
		a) over 1m and up to and including 2 m	No			R 0.00
		b) over 2 m and up to and including 3 m	No			R 0.00
		c) over 3 m, in increments of 1 m	No			R 0.00
	8.3.1.6	Clearing of basin	ha			R 0.00
8.3.2	8.3.2	Remove topsoil to nominal depth 150 mm (or other stated depth), stockpile and maintain	m^3	20.00	46 121	R 922 429.44
8.3.3	8.3.3	Excavation				
		a) Material unsuitable for embankment				
		(i) Removal to designated spoil dumps in the dam basin, spreading and trimming	m^3	31.60	1 632 192	R 51 577 259.13
		b) Material suitable for embankment from essential excavations for (Stockpiled):	m^3	30.30	621 764	R 18 839 459.64
		c) Extra over items (b) (1) - (4) for excavation in:				
		1) Intermediate material	m^3	INCL		
		2) Hard rock material	m^3	36.50	621 764	R 22 694 398.57
		Importing material				
		a) Dolerite	m^3	300.00	0	R 0.00
		b) River Sand	m^3	290.00		R 0.00
8.3.2	8.3.5	Forming embankment from stockpiled material 8.33b				
		(a) Core (impervious earthfill)	m^3	48.37	0	R 0.00
		(b) Upstream and downstream shells (semi pervious earthfill)	m^3	48.37	0	R 0.00
		(c) Rockfill (Impervious layer)	m^3	65.00	0	R 0.00
		(d) Rip-rap	m^3	438.52	0	R 0.00
		(e) Gravel layer	m^3	97.94	0	R 0.00
		(f) Sand layer transition zone	m^3	97.94	0	R 0.00
		(g) Blanket and chimney drains	m^3	789.45	0	R 0.00
		(h) IVRCC	m^2	45.40	58 124	R 2 638 846.53
		(h) RCC concrete	m^3	1 156.71	558 592	R 646 128 919.40
		(i) CVC concrete	m^3	1 981.85	300	R 594 555.00
8.3.3		**Formwork**				
		(a) Gang formed	m^2	475.00	58 124	R 27 609 077.14
		(b) Intricate	m^2			
		SABS 1200 D-1988 D: Earthworks				
		Quarry excavation to stockpile or dispose				
8.3.4	8.3.2	Bulk excavation				
		a) Excavate in all materials and backfill or dispose, as ordered	m^3			R 0.00
		b) Extra over for:				
		1) Intermediate excavation	m^3			R 0.00
		2) Hard rock excavation	m^3			R 0.00
		3) Boulder excavation, Class A	m^3			R 0.00
		4) Boulder excavation, Class B	m^3			R 0.00
		SUB-TOTAL				R 771 112 177

Table M.4: Langa Dam: Option 2: Roller compacted concrete (RCC) dam – Total cost summary

AECOM Option 2: Summary

Item		Unit	Rate	Cost
DIRECT COSTS				
Dam forming and excavation		Sum		771 112 177.28
Diversion works		Sum		4 587 520.00
Intake and outlet works		Sum		65 675 453.50
Spillway and chute		Sum		
Measurng weirs		Sum		
SUB TOTAL (ACTIVITIES)				R 841 375 150.78
Landscaping		% Direct Costs	5	R 42 068 757.54
Miscellaneous		% Direct Costs	10	R 84 137 515.08
SUB TOTAL A				R 967 581 423.40
Preliminery and General		% of Sub total A	30	R 290 274 427.02
Infrastructure				
Road deviations		R/km		R 0.00
Housing and accomodation		Lump sum		0
Access roads		R/km		R 0.00
Pipeline		R/km		0
Water to site- Construction		Lump sum		0
Electricty Supply and deviation		Lump sum		0
Social (Relocation)		Lump sum		0
Environmental		Lump sum		0
SUB TOTAL B				R 1 257 855 850.42
Contingencies		% of sub total B	10	R 125 785 585.04
SUB TOTAL C				R 1 383 641 435.46
Planning design and supervision		% of sub total C	15	R 207 546 215.32
SUB TOTAL D				R 1 591 187 650.78
VAT		% of sub total D	0	R 0.00
NETT PROJECT COST				R 1 591 187 651
Social (Relocation)				0
Environmental				0
Total Project Cost				R 1 591 187 651

Table M.5: Langa Dam: Option 2: Composite dam – Bill of quantities

Option 3: Composite dam

No	PAY	DESCRIPTION	UNIT	RATE (Rand)	QUANTITY	Total Amount (Rand)
		SABS 1200 DE-1984 DE: Small earth dams				
		Embankment excavation and formation				
8.3.1	8.3.1	Site clearance				
	8.3.1.1	Clear and strip site	ha	23 250.00	7.4	R 172 218.88
	8.3.1.2	Clear and grub large trees				
		a) over 1m and up to and including 2 m	No			R 0.00
		b) over 2 m and up to and including 3 m	No			R 0.00
		c) over 3 m, in increments of 1 m	No			R 0.00
	8.3.1.6	Clearing of basin	ha			R 0.00
8.3.2	8.3.2	Remove topsoil to nominal depth 150 mm (or other stated depth), stockpile and maintain	m^3	20.00	74 073	R 1 481 452.77
8.3.3	8.3.3	Excavation				
		a) Material unsuitable for embankment				
		(i) Removal to designated spoil dumps in the dam basin, spreading and trimming	m^3	31.60	1 617 810	R 51 122 790.64
		b) Material suitable for embankment from essential excavations for (Stockpiled):	m^3	30.30	1 038 021	R 31 452 037.07
		c) Extra over items (b) (1) - (4) for excavation in:				
		1) Intermediate material	m^3	INCL		
		2) Hard rock material	m^3	36.50	688 021	R 25 112 767.42
		Importing material				
		a) Dolerite	m^3	300.00	0	R 0.00
		b) River Sand	m^3	290.00		R 0.00
8.3.2	8.3.5	Forming embankment from stockpiled material 8.33b				
		(a) Core (impervious earthfill)	m^3	48.37	0	R 0.00
		(b) Upstream and downstream shells (semi pervious earthfill)	m^3	48.37	0	R 0.00
		(c) Rockfill (Impervious layer)	m^3	91.00	635 657	R 57 844 770.75
		(d) Rip-rap	m^3	438.52	0	R 0.00
		(e) Gravel layer	m^3	97.94	86 764	R 8 497 714.48
		(f) Sand layer transition zone	m^3	97.94	0	R 0.00
		(g) Blanket and chimney drains	m^3	789.45	0	R 0.00
		(h) IVRCC	m^2	45.40	26 394	R 1 198 289.61
		(h) RCC concrete	m^3	1 156.71	276 650	R 320 004 180.68
		(i) CVC concrete	m^3	1 981.85	7 807	R 15 473 007.89
8.3.3		**Formwork**				
		(a) Gang formed	m^2	475.00	26 394	R 12 537 170.99
		(b) Intricate	m^2			
		SABS 1200 D-1988 D: Earthworks				
		Quarry excavation to stockpile or dispose				
8.3.4	8.3.2	Bulk excavation				
		a) Excavate in all materials and backfill or dispose, as ordered	m^3			R 0.00
		b) Extra over for:				
		1) Intermediate excavation	m^3			R 0.00
		2) Hard rock excavation	m^3			R 0.00
		3) Boulder excavation, Class A	m^3			R 0.00
		4) Boulder excavation, Class B	m^3			R 0.00
		SUB-TOTAL				R 524 896 401

Table M.6: Langa Dam: Option 2: Composite dam – Total cost summary

AECOM

Option 3: Summary

Item		Unit	Rate	Cost
DIRECT COSTS				
Dam forming and excavation		Sum		524 896 401.20
Diversion works		Sum		4 587 520.00
Intake and outlet works		Sum		65 675 453.50
Spillway and chute		Sum		
Measurng weirs		Sum		
SUB TOTAL (ACTIVITIES)				R 595 159 374.70
Landscaping		% Direct Costs	5	R 29 757 968.74
Miscellaneous		% Direct Costs	10	R 59 515 937.47
SUB TOTAL A				R 684 433 280.91
Preliminery and General		% of Sub total A	30	R 205 329 984.27
Infrastructure				
Road deviations		R/km		R 0.00
Housing and accomodation		Lump sum		0
Access roads		R/km		R 0.00
Pipeline		R/km		0
Water to site- Construction		Lump sum		0
Electricty Supply and deviation		Lump sum		0
Social (Relocation)		Lump sum		0
Environmental		Lump sum		0
SUB TOTAL B				R 889 763 265.18
Contingencies		% of sub total B	10	R 88 976 326.52
SUB TOTAL C				R 978 739 591.70
Planning design and supervision		% of sub total C	15	R 146 810 938.75
SUB TOTAL D				R 1 125 550 530.45
VAT		% of sub total D	0	R 0.00
NETT PROJECT COST				R 1 125 550 530
Social (Relocation)				0
Environmental				0
Total Project Cost				R 1 125 550 530

Table M.7: Langa Dam: Bill of quantities for costs common to all options – Diversion works

AECOM		Diversion works				
ITEM NO	PAY-MENT	DESCRIPTION	UNIT	RATE (R)	QTY	AMOUNT (R)
		STAGE 1: PORTALS AND TUNNELS				
1	**1.0**	**SITE CLEARANCE**				
	1.1	**Clear and grub**				
		(a) Portal footprints	ha	16 946.00		R 0.00
	1.2	**Remove and grub large trees and tree stumps of girth**				
		(a) Over 1 m and up to and including 2m	No			R 0.00
	1.3	**Remove topsoil to nominal depth of 150 mm and stockpile**	m³	30.86		R 0.00
2	**2.0**	**EXCAVATION AND BACKFILL FOR DAMS AND WATERWAYS**				
		Bulk Excavation				
	2.1	**Inlet portal**				
		(a) Excavate in all materials				
		(i) Excavation (stockpile)	m³	30.33		R 0.00
		(b) Extra over for:				
		(i) Intermediate	m³	0.00		R 0.00
		(ii) Hard Rock	m³	42.60		R 0.00
		(iii) Boulder, Class A	m³	163.76		R 0.00
		(iv) Boulder, Class B	m³	42.58		R 0.00
	2.2	**Outlet Portal**				
		(a) Excavate in all materials				
		(i) Excavation (stockpile)	m³	30.33		R 0.00
		(b) Extra over for:				
		(i) Intermediate	m³	0.00		R 0.00
		(ii) Hard Rock	m³	42.60		R 0.00
		(iii) Boulder, Class A	m³	163.76		R 0.00
		(iv) Boulder, Class B	m³	42.58		R 0.00
	2.3	**Dewatering**	Sum	100 000.00		R 0.00
		SUB TOTAL: STAGE 1				R 0.00
		STAGE 2 Culvert				
3	3.1	Excavation for culvert	m³	85.00	960	R 81 600
	3.2	Construction of 25MPa/19mm Reinforced Concrete Base for culvert	m³	1 320.00		R 0
	3.3	75mm minimum thickness Grade 15MPa/19mm concrete blinding layer underneath base	m^2	127.00	960	R 121 920
	3.4	Supply and install 2x3m*3m Box culvert, with pre-fabricated slab	m	13 700.00	320.00	R 4 384 000
	3.5	Backfill around culverts	m³	56.50		R 0
		SUB TOTAL: COFFERDAM				R 4 587 520
6		**TUNNEL CONSTRUCTION**				
	6.1	TUNNEL EXCAVATION				
		(a) Tunnel	m³	1 542.50		R 0
	6.2	ROCK SUPPORT				
		(a) Rockbolts	m	257.08		R 0
		(b) Shotcrete	m³	5 398.74		R 0
		(c) Reinforcing mesh	m²	77.12		R 0
	6.3	DEWATERING	Sum	550 000.00		R 0
		SUB TOTAL: TUNNEL				R 0
		SUB TOTAL: STAGE 1 + STAGE 2				R 4 587 520
		STAGE 3				
7		**MEDIUM PRESSURE PIPELINES**				
		Supply, lay, and bed pipes complete with couplings				
		(a) 500 mm diameter concrete pipe (class 75D) in concrete	m	138.82		R 0
		(b) Water control in tunnel	Prov Sum	500 000.00		R 0
8		**PLUG OF TUNNEL**				
	8.1	Scheduled Formwork items- Class 1				
		(a) Vertical formwork	m²	636.60		R 0
	8.2	Scheduled Concrete items				
		Strength and Mass concrete				
		(a) Sealing of bulkheads shaft with mass concrete 25 Mpa/19 mm	m³	1 658.00		R 0
		(b) Plug 25 MPa/19 mm	m³	1 658.00		R 0
	8.3	Joints				
		(a) Swellable water stops	m	231.37		R 0
	8.4	Miscellaneous and Sundry items				
		(a) Bulkheads incl reinforcement at 120 kg/m³	No	1 542.50		R 0
		Sub total: STAGE 3				R 0
		Nett cost				**R 4 587 520**

Table M.8: Langa Dam: Bill of quantities for costs common to all options – Spillway and chute

AECOM — Spillway and chute

ITEM NO	PAYMENT	DESCRIPTION	UNIT	Quantity	Rate	AMOUNT (R)
		SABS 1200 DE				
	8.3.3	Excavation				
		a) Material unsuitable for embankment	m3	51 038	51	R 2 624 181
		b) Material suitable for embankment from essential excavations for:				
		2) Spillway	m3	0	0	R 0
		3) Pipe trenches	m3	0	0	R 0
		4) Outlet works	m3	0	0	R 0
		SABS 1200 - GA				
		CONVENTIONAL CONCRETE FOR DAMS				
8	8.1.1	Scheduled Formwork items				
	8.1.1.1	Class F4				
		(a) Verical				
		(i) Chute	m²	14 619	334	R 4 885 823
		(b) Sloped				
		(i) Ogee of spillway	m²	308	411	R 126 754
		(ii) Round	m²	0	411	R 0
		(c) Sloping				
		(i) Stilling basin blocks	m²	0	0	R 0
		(ii) Horizontal	m²	0	0	R 0
	8.1.2	Scheduled Reinforcement items	t	112	12 854	R 1 438 584
	8.1.2.1	Anchors				
		(a) Anchor bars	m	62	0	R 0
	8.1.3	Scheduled Concrete items				
	8.1.3.1	Strength & Mass Concrete				
		(a) Grade 25 MPa/19 mm	m³	6 105	1 414	R 8 631 912
		(i) Spillway, bridges and retaining wall	m³	0	1 414	R 0
	8.1.3.2	Secondary Concrete				
		(a) Grade 25 MPa/19 mm	m³	0	1 414	R 0
	8.1.3.3	Keyways on contraction joints				
		(a) Bridges dimensions to be given in detail design	m		0	R 0
	8.1.3.4	Unformed Surface Finishes				
		Class U2 (Wood-floated) finish				
		(a) Chute and Stilling basin floor	m2	8 314	14	R 117 558
		(b) Top of bridges	m2	0	14	R 0
16		**WATERSTOPS, JOINTING AND BEARINGS**				
	16.1	Scheduled items				
		Waterstops				R 0
		(a) 250 mm Centre bulb PVC waterstop	m	231	685	R 158 505
	16.2	Joint sealants				
		(a) Chute wall - 12mm expanding cork	m	0	0	R 0
		(b) Chute wall - 12m Impregnated Bitumen Fibre board	m	0	0	R 0
		(c) Chute wall - 12 x 12 mm Polysulphide sealant	m	0	0	R 0
17		**SUB-SOIL DRAINAGE**				
	17.1	Scheduled items				
		Excavating soft material situated within the following depth ranges below the surface level:				
		(a) 0 m to 1,5 m	m³	108	0	R 0
		(b) Extra over sub-item (a), irrespective of depth, for:				
		(i) Excavation in hard material	m³	0	0	R 0
	17.2	Natural permeable material in sub-soil drainage systems				
		(a) Sand as specified on detail drawings	m³	102	0	R 0
	17.3	Pipes in sub-soil drainage system				
		(a) 110 NB, Class 6, HDPE pressure pipe, non perforated, complying with SANS 533, Part II	m	0	0	R 0
		(b) 75 NB, flexible slotted drainage pipes with smooth bore, "Drainex" or equivalent by Kaytech	m	299	0	R 0
	17.4	Caps to higher ends of sub-surface drain pipes				
		(a) High end of pipes of Drainex pipes	No	0	0	R 0
	17.5	Concrete outlet structures for sub-soil drainage systems complete as per drawings				
		(a) Concrete 1500 mm dia	No	0	0	R 0
	17.6	Overhaul for material hauled in excess of 1.0 km freehaul				
		(a) Sand for filter material (10 km)	m³.km	0	0	R 0
						R 0
TOTAL CARRIED FORWARD TO SUMMARY						**R 17 983 317**

Table M.9: Langa Dam: Bill of quantities for costs common to all options – Intake and outlet works

AECOM — Intake and outlet works

ITEM NO	PAYMENT		UNIT	Quantity	Rate (R)	AMOUNT (R)
1	1.1	Earthworks				
		(a) Clearing and grubbing	ha	0.08	23 250.00	R 1 907
		(b) Excavation - soft	m^3	1 070.00	180.00	R 192 600
		(c) Excavation - rock	m^3	1 070.00	300.00	R 321 000
		(d) Rockfill to abutments	m^3	0.00	50.39	R 0
2	2.1	Rock supports				
		(a) Rockbolts - 3m long	no	0.00	437.04	R 0
		(c) Rock anchors - 20m long, 25mm	no	0.00	218.52	R 0
		(d) Shotcrete and mesh - 75 mm long	m^2	0.00	299.50	R 0
					0.00	
3		ACCESS BRIDGE				
	3.1	Formwork				
		(a) Smooth vertical	m^2	512.00	488.46	R 250 090
		(b) Smooth horizontal	m^2	336.00	488.46	R 164 122
		(c) Smooth balustrade	m^2	0.00	730.12	R 0
	3.2	Unformed surface finish	m^2	336.00	14.14	R 4 751
	3.3	Reinforcing				R 0
		(a) Mild steel	t	0.00	12 854.15	R 0
		(b) High yield steel	t	46.60	13 419.74	R 625 360
		(c) Mesh	t	0.00	59.13	R 0
	3.4	Concrete				
		(a) Mass	m^3	0.00	1 156.87	R 0
		(b) Structural	m^3	460.00	1 413.96	R 650 420
	3.5	Miscellaneous				
		(a) Bridge bearings	No	4.00	16 196.23	R 64 785
		(b) Joints	m	4.00	170.96	R 684
		(c) Other e.g.. Rainwater goods, ducting, etc	Sum	0.00	102 833.23	R 0
4		INTAKE TOWER AND OUTLET WORKS				
	4.1	Drilling and grouting				
		(a) Consolidation grouting	m drill	0.00	287.93	R 0
	4.2	Formwork				
		(a) Smooth vertical - curved and plain	m^2	5 668.00	591.29	R 3 351 438
		(b) Smooth horizontal	m^2	442.00	591.29	R 261 351
		(c) Intricate	m^2	0.00	1 619.62	R 0
		(d) Form openings	m^2	0.00	796.96	R 0
	4.3	Uniform surface finish	m^2	592.00	14.65	R 8 675
	4.4	Reinforcing				
		(a) Mild steel	t	0.00	14 139.57	R 0
		(b) High yield steel	t	409.00	13 419.74	R 5 488 672
		(c) Mesh	t	0.00	64.27	R 0
		(d) Mechanical rebar couples	No	0.00	442.18	R 0
	4.5	Concrete				
		(a) Mass	m^3	0.00	1 156.87	R 0
		(b) Structural	m^3	4 288.00	1 700.00	R 7 289 600
	4.6	Structural Steelwork				
		(a) Steel sections	Sum	1.00	2 000 000.00	R 2 000 000
		(b) Sheeting	m^2	0.00	0.00	R 0
					0.00	
	4.7	Miscellaneous			0.00	
		(a) Waterstops	m	0.00	951.32	R 0
		(b) Other e.g.. Conduits, outlets, water proofing, etc.	Sum	0.00	0.00	R 0
5	5.1	Site works				
		(a) Site access roads	km	1.00	0.00	R 0
		(b) Site services	Sum	0.00	0.00	R 0
6	6.1	Contractors accommodation				R 0
7	7.1	Mechanical Items				
		(a) Gates and screens	Sum	1.00	20 000 000.00	R 20 000 000
		(b) Lifting equipment	Sum	1.00	10 000 000.00	R 10 000 000
		(c) Pipework and valves	Sum	1.00	15 000 000.00	R 15 000 000
8	8.1	Electrical Installation	Sum	0.00	0.00	R 0
TOTAL CARRIED FORWARD TO SUMMARY						R 65 675 454