WASTE ROCK PILE SLOPE STABILITY ANALYSIS, SKYLINE MINE

Prepared for

CANYON FUEL COMPANY
Skyline Mine
Scofield, Utah

February 2007

Prepared by

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RICHARD B. WHITE
14 Feb 2007
STATE OF UTAH

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WASTE ROCK PILE SLOPE STABILITY ANALYSIS
SKYLINE MINE

CHAPTER 1

INTRODUCTION

The Canyon Fuels Skyline Mine Waste Rock Pile (WRP) is located at a former open pit mine approximately 0.5 miles east of the town of Scofield, Utah (see Figure 1, General Location Map). Waste rock has been stored inside the pit, as well as on its surrounding slopes. The former pit is almost completely filled, and plans exist for expanding the WRP above and/or to the west of the former pit. The construction and reclamation design of the expanded WRP will conform to the regulations detailed in Utah Administrative Code R645-301-500. This report presents slope stability analyses for the WRP in its current state as well as for its potential expansion.

CHAPTER 2

METHODS

2.1 BISHOP'S METHOD OF SLICES

Slope stability was evaluated using Bishop's Method of Slices. This method is a limit equilibrium analysis that calculates a factor of safety (FS) against rotational shear failure based on the ratio of forces that cause and resist failure. An FS of 1.0 would indicate that the driving and resisting forces are equal, and that failure, if it has not already occurred, is likely. A minimum FS of 1.5 is required for all waste rock pile slopes to meet the requirements of R645-301-500.

Bishop's Method of Slices tests various circular failure planes with radii that are centered at various distances above the slope. The FS is derived by calculating the moments of numerous vertical slices within the failing arc of soil about the center of the circular surface. The method applies strength (friction angle and cohesion) and density data for each soil type. The method also accounts for pore water pressures and the presence of a phreatic surface. Figure 2 shows a typical diagram of how Bishop's Method of Slices is applied. The computer program STABLE for Windows (M. Z. Associates, 2002) was used to perform the numerous calculations required to find the critical failure surfaces and their respective FS values.

The material properties characteristics and slope geometry incorporated into the slope stability model were based on the topography of the former pit, waste rock soil strength analyses, geophysical and soil survey interpretations, and engineering/geologic assumptions of the site. The data and assumptions used in the model are detailed below.

2.2 SLOPE FAILURE MECHANISM

The most likely scenario to cause slope failure at the waste rock pile was determined to be the presence of a perched groundwater table within the waste rock or based along the original ground surface. This is a common cause of slope failure in mine waste rock piles. A slope failure occurred at this waste rock pile in Spring 1997 in which a small seep was observed near the toe of the slope, while groundwater in a nearby well was recorded at nearly 100 feet below grade (Harding Lawson Associates, 1997). Thus the slope stability model used in this analysis incorporates a perched phreatic surface above the original ground surface to model the critical slope failure condition.

2.3 SLOPE GEOMETRY

Slope stability was modeled along four representative profiles of the existing and expanded WRP. The profiles consider the possibility that the WRP will be extended upwards from its current top elevation of approximately 8,050 feet to the current lease boundary at an elevation of approximately 8,150 feet. The profiles also consider the possibility that the WRP will be expanded outwards to the west so that the area of the existing sedimentation pond is filled so that it joins the existing WRP.

The geometry used in the slope stability model was derived from topographic survey data, geophysical data, soil test pit data, and site observations. The location of the former open pit mine was taken from a map of the pit that was drawn in 1982 (Coastal States Energy Company, 1982). The presence of this pit is also evident in the results from a seismic refraction survey performed at the site during fall 2006 (Clement Drilling and Geophysical, Inc., 2006a; see Appendix A). Except for the former pit, the depth to bedrock below the native soil (original) ground surface was assumed to range from 6 to 20 feet, and was based on the results of a soil survey performed at the site in December 2006 (Clement Drilling and Geophysical, 2006b).

Figures 3a and 3b shows the locations of each of the four profiles used to model the stability of the WRP. Figures 4-9 illustrate the geometries of each profile, which are briefly described below:

- **NE Profile**: The area represented by this profile will be used for waste rock storage only if the WRP is expanded to the lease boundary. The profile includes an access road at the bottom and a 2H:1V (26.6°) slope up to a gently sloping area at the top of the WRP. (See Figure 4)

- **NW Profile**: This profile represents the bulk of the existing WRP which has been placed inside the former open pit. The former pit measures between 25 and 75 feet deep and up to 65 feet wide. Waste rock has been piled from the drainage bottom to near the top of the former pit at a 2H:1V (26.6°) slope. If the WRP is expanded up to the lease boundary, it will be extended upwards for approximately 100 feet at the same slope, with a road cut at an elevation of approximately 8,060 feet. The underlying native soil surface above the former pit was taken to be 2.6H:1V (21.0°), based on the steepness of adjacent slopes. The top of the extended WRP will slope gradually to promote positive drainage. (See Figure 5)

- **W Profile – Expanded**: This profile had been modeled as two scenarios. The first scenario, which is depicted in Figure 6, represents the area on the western edge of the current WRP following expansion of the pile up to the elevation of the lease boundary (approximately 8,150 feet). This profile has been modeled for the pile to be angled at a slope of 2.2H:1V (24.4°). An access road cut has been placed at an elevation of 8,090 feet. The second scenario, which is depicted in Figure 7, represents the western slope following expansion of the pile into the existing sedimentation pond. The top of the pile for this profile is at the current elevation of the top of the pile (approximately 8,050 feet), and the slope angle is 2H:1V (25.6°). In both scenarios, at the bottom of the pile, the waste rock overlies a thin native soil surface (approximately 6.5 feet thick) that slopes at 2.1H:1V (25.4°). The top of the pile overlies the former pit.

- **W Profile – Current**: This profile represents the area on the western edge of the current WRP. The former open pit underlies the top portion of this profile. The bottom of the profile has been modeled as a veneer of waste rock placed at a slope of 2H:1V (26.6°) above a native soil surface that slopes at 2.1H:1V (25.4°). In 1997, a slope failure occurred near this slope profile, which at the time was sloped at 1.8H:1V (HLA, 1997). (See Figure 8)

- **Generic Road Cut Switchback Profile**: This profile represents an access road switchback on the WRP. The roads measure 15 feet wide and are sloped at 2.5H:1V (21.8°) between the two roads until they are separated by at least 10 vertical feet. The slopes below the lower road and above the upper road are inclined at 2H:1V (26.6°). The roads have been loaded on the road surface with a weight of 10 tons, which is assumed to be the maximum axle weight of a full haul truck. (See Figure 9)

2.4 MATERIALS PROPERTIES

Materials properties required for the slope stability model include the moist and saturated densities, the cohesion, and the friction angle of each rock/soil unit. The material properties of the waste rock were taken as the average results from three soil samples collected from the waste rock pile in 1997 (Harding Lawson Associates, 1997). Material properties for the native soil and the bedrock were conservatively assigned based on engineering judgment. The material properties used in the model are summarized below:

Material	Cohesion (psf)	Friction Angle (°)	Moist Unit Weight (pcf)	Saturated Unit Weight (pcf)
Bedrock	20,000	30.0	150	150
Native Soil	288	26.0	100	110
Waste Rock	0	40.0	64.5	84.2

2.5 GROUNDWATER

Slope stability analyses were performed on the waste rock pile for both the dry and saturated conditions. The location of the phreatic surface for the worst-case saturated condition was determined by simulating the 1997 slope failure on the west side of the pile. The groundwater surface was configured so that a critical failure surface with a FS of 1.0 was generated in the same location as the 1997 failure. The area of the phreatic surface under this profile was then used under the other profiles for the saturated condition.

CHAPTER 3
RESULTS

3.1 LOCATIONS OF PHREATIC SURFACES

The saturated condition phreatic surfaces for each of the stability analyses were estimated by recreating the conditions (FS=1.0) for the 1997 slope failure on the west side of the pile. For that analysis, the waste rock surface was modeled at 1.8H:1V, and the native soil surface was sloped at 2.1H:1V. When the phreatic surface was placed at 190 feet above the ground surface with an area of 810 ft^2, a slope failure at a similar location to the 1997 failure was predicted to have a FS of 1.011. The area under this phreatic surface was kept constant to model the saturated condition for the West and Northeast Profiles. The phreatic surface for the Northwest Profile was affected by the presence of the former pit, which keeps subsurface seepage from the top of the pile from reaching the toe of the slope. Figures 4-8 show the locations of the phreatic surfaces used in the slope stability analyses.

3.2 SLOPE STABILITY RESULTS

The following sections discuss the results of the slope stability analyses. Slope stability calculations are summarized in Table 1 and detailed in Appendix B. Because of the voluminous nature of the slope stability model output files, a single copy has been provided on CD (pdf format) for Canyon Fuels. Additional copies may be obtained on request from EarthFax Engineering, Inc.

3.2.1 Current Waste Rock Pile

According to the slope stability analyses, the current waste rock pile has a FS against rotational shear failure for the dry condition ranging from 1.63 for the West Profile to 1.72 for the Northwest Profile. For the design saturated condition for the current WRP, the FS ranges from 1.53 for the West Profile and 1.72 for the Northwest Profile.

3.2.2 Westward Expansion of the Waste Rock Pile to the Pond Area

The slope stability modeling results for the expansion of the WRP to cover the existing sedimentation pond are presented below. When the slope is constructed at an angle of 2H:1V (25.6°), the FS against rotational shear failure is 1.65 for the dry condition and 1.57 for the saturated condition.

3.2.3 Expansion of the Waste Rock Pile to the Lease Boundary

When the WRP is extended up to the lease boundary, the FS against rotational shear failure ranges from 1.63 (West Profile) to 1.69 (Northeast Profile) for the dry condition. The FS ranges from 1.52 (West Profile) to 1.61 (Northeast Profile) for the saturated condition. Note that this assumes that the west slope of the WRP is graded at 2.2H:1V. If the west side of the WRP is graded at 2H:1V, the FS is reduced to 1.51 for the dry condition and 1.44 for the saturated condition.

3.2.4 Roadcut Switchback Slopes

Results from stability analyses of roadcut switchbacks show that a FS against rotational shear failure of 1.69 can be achieved if the slopes are graded at 2.5H:1V in the hinge of the switchback until the roads are separated by 10 vertical feet. Since switchbacks will be located on the edge of the WRP, only the dry condition was evaluated.

3.3 DISCUSSION OF RESULTS

The stability analyses suggest that the WRP is stable in its current configuration, and that it may be expanded to cover the sedimentation pond and/or up to the lease boundary. If the WRP is expanded up to the lease boundary, it is recommended that the west side of the pile should be sloped at 2.2H:1V (22.4°) or less. If the WRP is expanded westward to cover the existing pond and constructed to the elevation of the current pile (approximately 8,050 feet) the western slopes may be graded at 2H:1V (25.6°). These recommendations will allow the WRP to satisfy the regulatory requirement of a FS of at least 1.5 for both the dry and design saturated conditions.

The Northeastern and Northwestern slopes of the WRP are recommended to be graded at 2H:1V.

Slopes between access road switchbacks should be sloped at 2.5H:1V until the roads are at least 10 vertical feet apart.

The overall stability of the WRP is dependent upon minimizing the saturation of the waste rock. The high porosity and lack of cohesion of the waste rock cause it to lose a great deal of strength when it becomes completely saturated. The steep outslopes and contemporaneously reclaimed/revegetated topsoil cover of the WRP minimizes infiltration. The top of the WRP should be sloped so that it promotes drainage away from the core of the pile, and especially away from its western slope. Similarly, drainage ditches along access roads on the WRP should be properly maintained. During operation, snow should be removed from the top of the pile, and placed along its northeast and northwest outslopes, or to the south of the WRP.

CHAPTER 4
REFERENCES

Clement Drilling and Geophysical, Inc., 2006a. *Seismic Refraction Survey Report*. Unpublished report.

Clement Drilling and Geophysical, Inc., 2006b. *Soil Survey, Waste Rock Site near Scofield, Utah*. Unpublished report.

Coastal States Energy Company, 1982. *Rock Disposal Site Drainage Diversion Channel and Access Fence Locations, Map 4.16.1-1B*. 1"=30'.

Harding Lawson Associates, 1997. *Slope Stability Analysis of Coal Refuse Pile Skyline Mine, Near the Community of Scofield, Utah*. Unpublished report.

M.Z. Associates, 2002. *Stable for Windows*. Slope Stability Modeling Software.

FIGURES

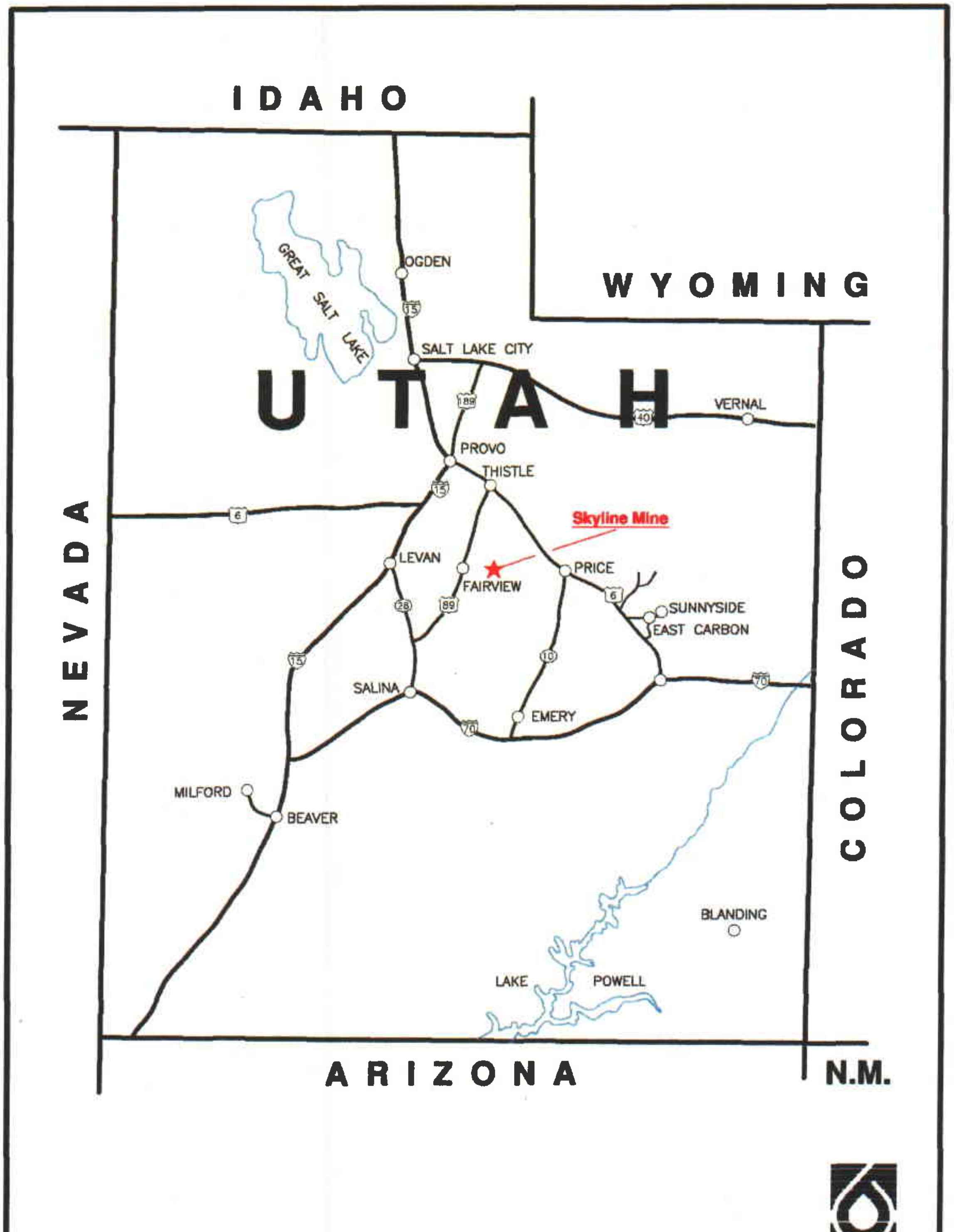
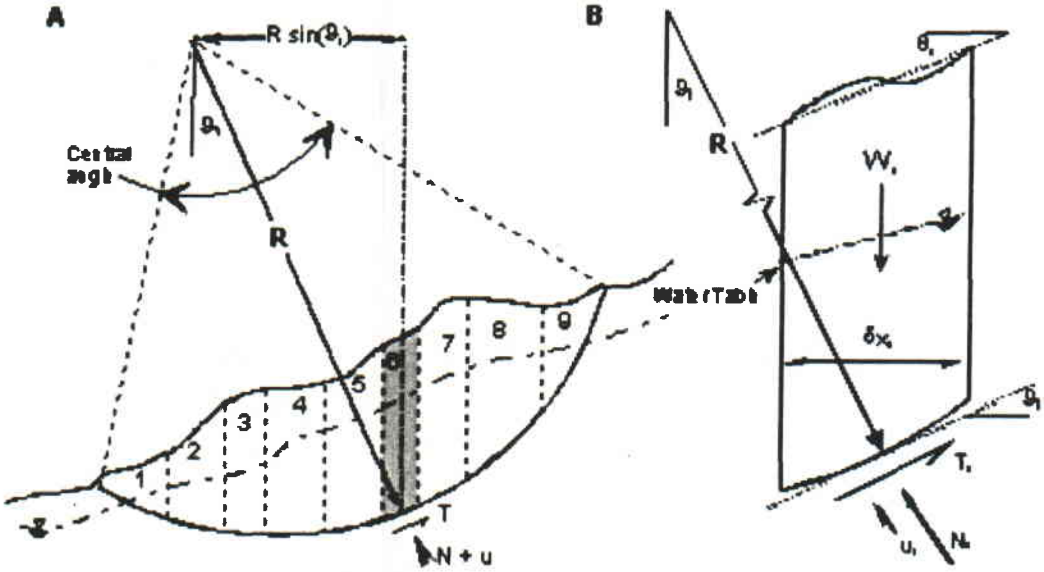


FIGURE 1. GENERAL LOCATION MAP

G:\UC784\13 - Waste rock expansion\FIG-1GENLOC-sky.dwg, Layout5-Layout1, 1/23/2007 3:29:19 PM



$$F_s = \frac{RT_i}{R\Sigma W_i \sin(\vartheta_i)} = \frac{\Sigma\left[\frac{b\ \delta x_i}{\cos(\vartheta_i)}(c - u_i \tan(\phi)) + N_i \tan(\phi)\right]}{\Sigma W_i \sin(\vartheta_i)}$$

Where:

R = radius of circle
T = shear force
W = sum of the unit weights
c = cohesion
ϕ = angle of internal friction
u = pore water pressure
δx = width of the slice
b = width (in and out of paper)
ϑ = slope angle (θ)
N=normal force

FIGURE 2. ILLUSTRATION OF BISHOP'S METHOD OF SLICES TO DETERMINE THE FACTOR OF SAFETY (FS) AGAINST ROTATIONAL SHEAR FAILURE

Source: http://nwdata.geol.pdx.edu/Thesis/FullText/1999/BurnsW/Figures/image042.gif

EarthFax

FIGURE 3A. MAP OF WASTE ROCK PILE, CURRENT CONFIGURATION

G:\UC794\13 - Waste rock expansion\WRP Slope Stability\ABI-SLOPE STAB FIG 3CURRENT.dwg Layout5-Layout1 2/13/2007 5:40:44 PM

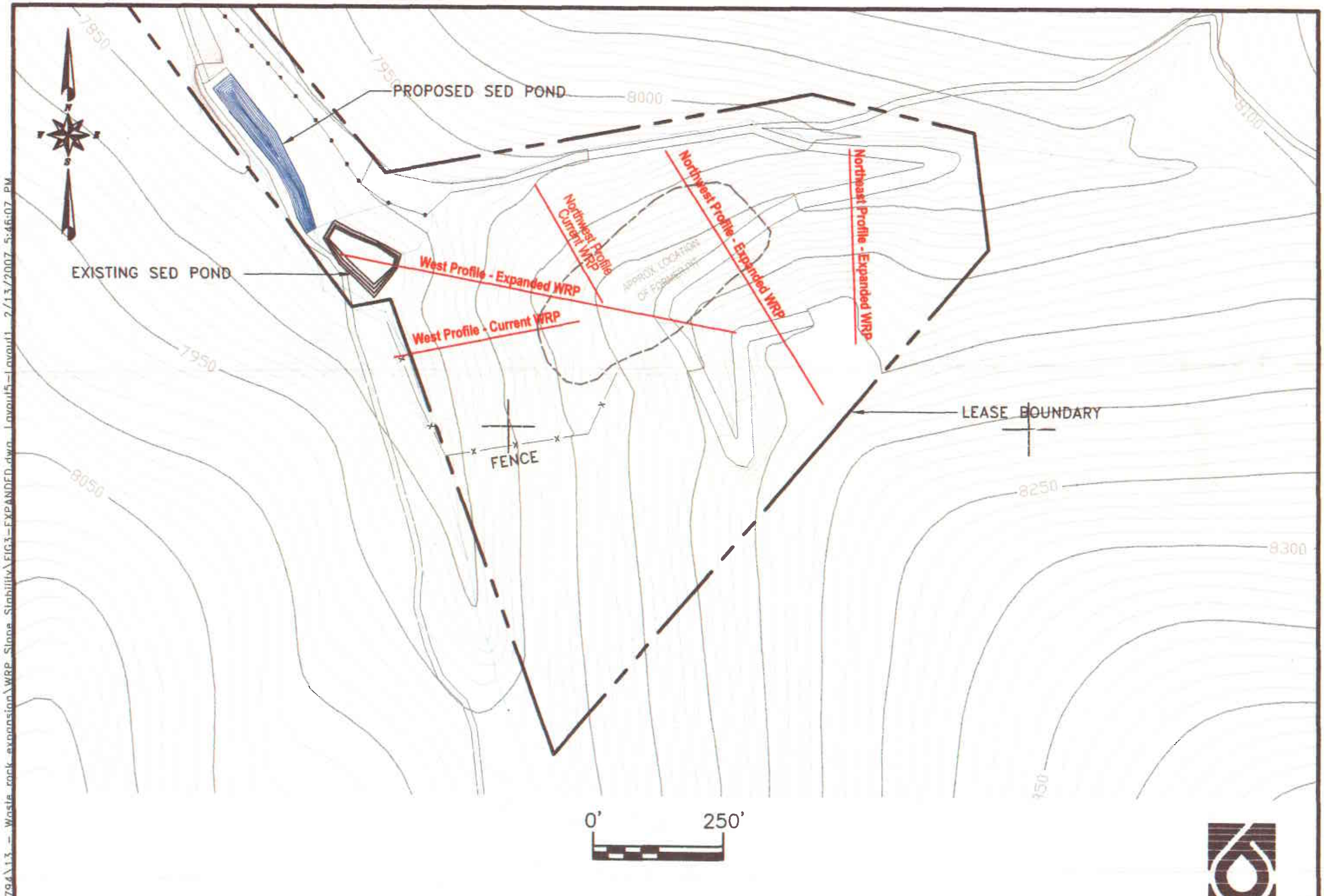


FIGURE 3B. MAP OF WASTE ROCK PILE, EXPANDED CONFIGURATION

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G:\UC794\13 - Waste rock expansion\WRP Slope Stability\FIG3-EXPANDED.dwg Layout5-Layout1 2/13/2007 5:46:07 PM

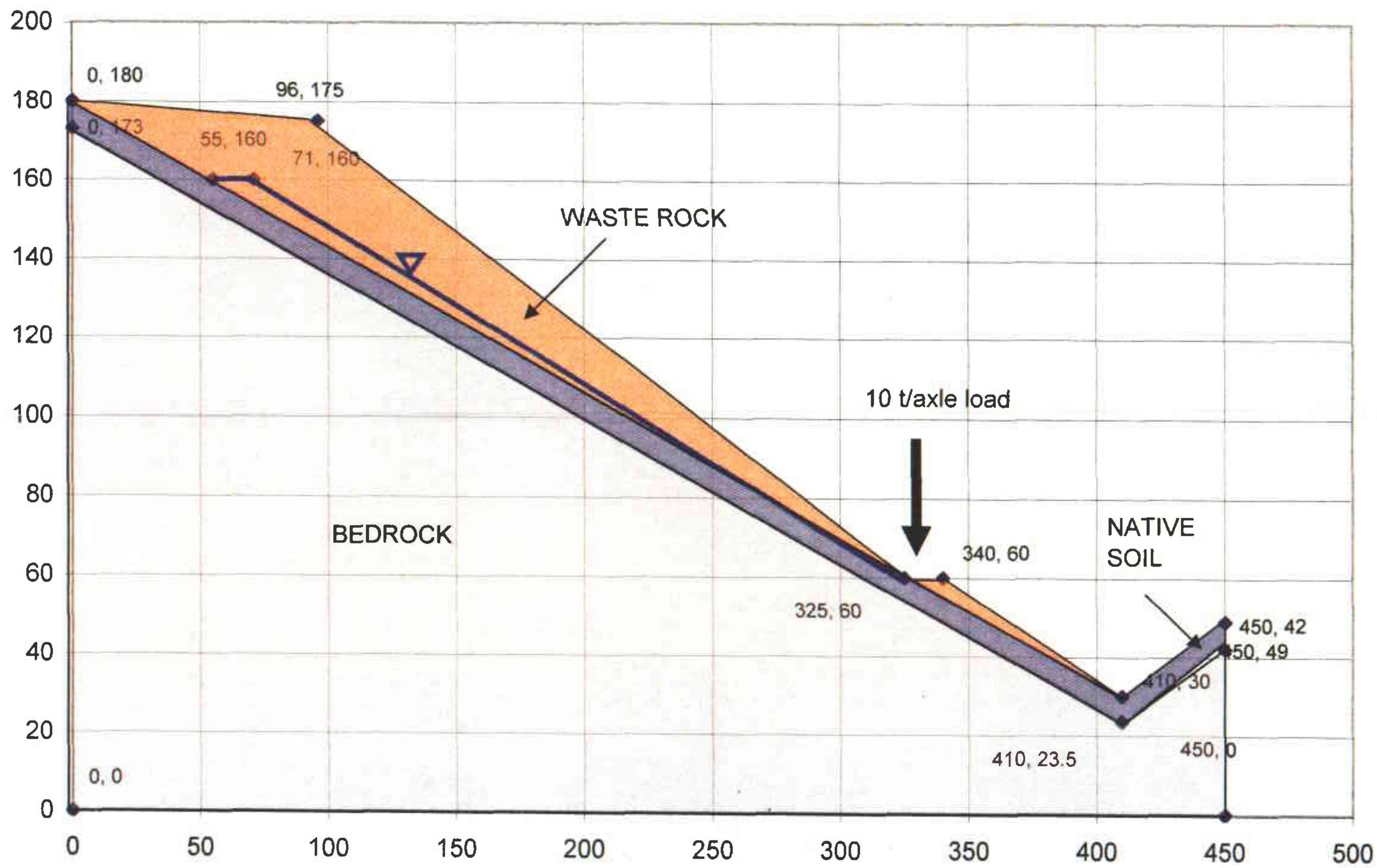

FIGURE 4. NORTHEAST PROFILE

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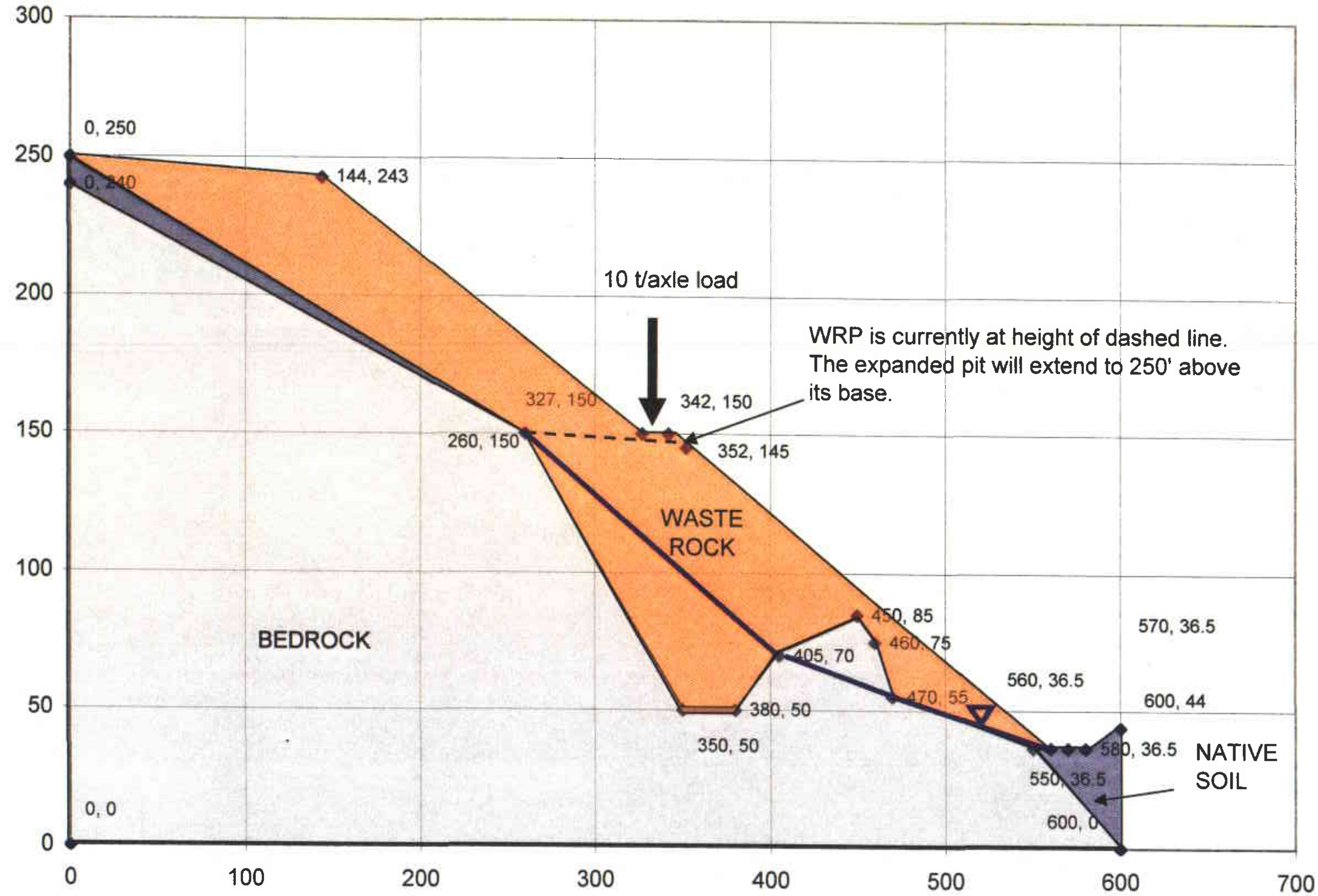

FIGURE 5. NORTHWEST PROFILE

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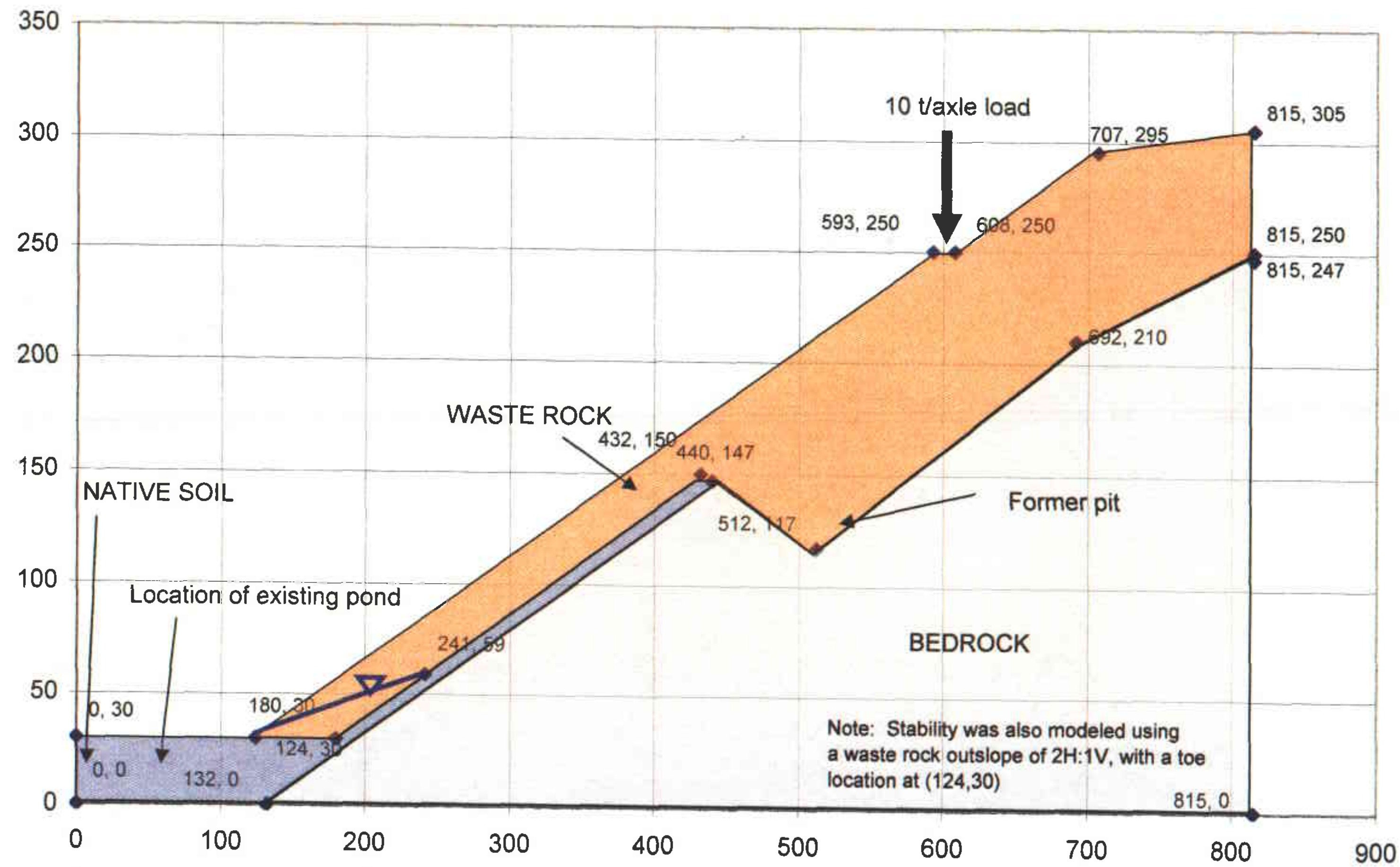

FIGURE 6. EXPANDED WEST PROFILE, 2.2H:1V OUTSLOPE

EarthFax

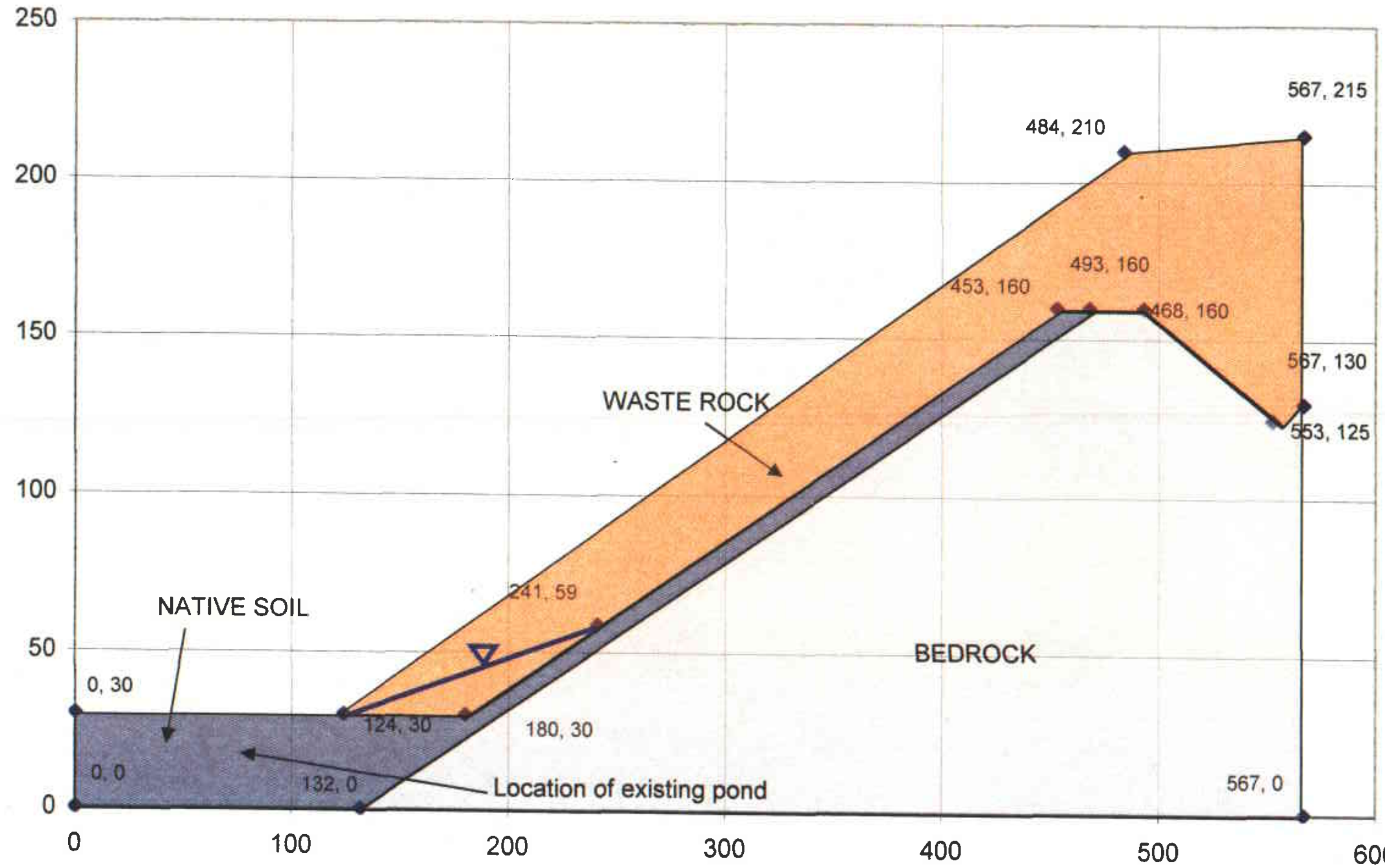

FIGURE 7. CURRENT WEST PROFILE, 2H:1V OUTSLOPE

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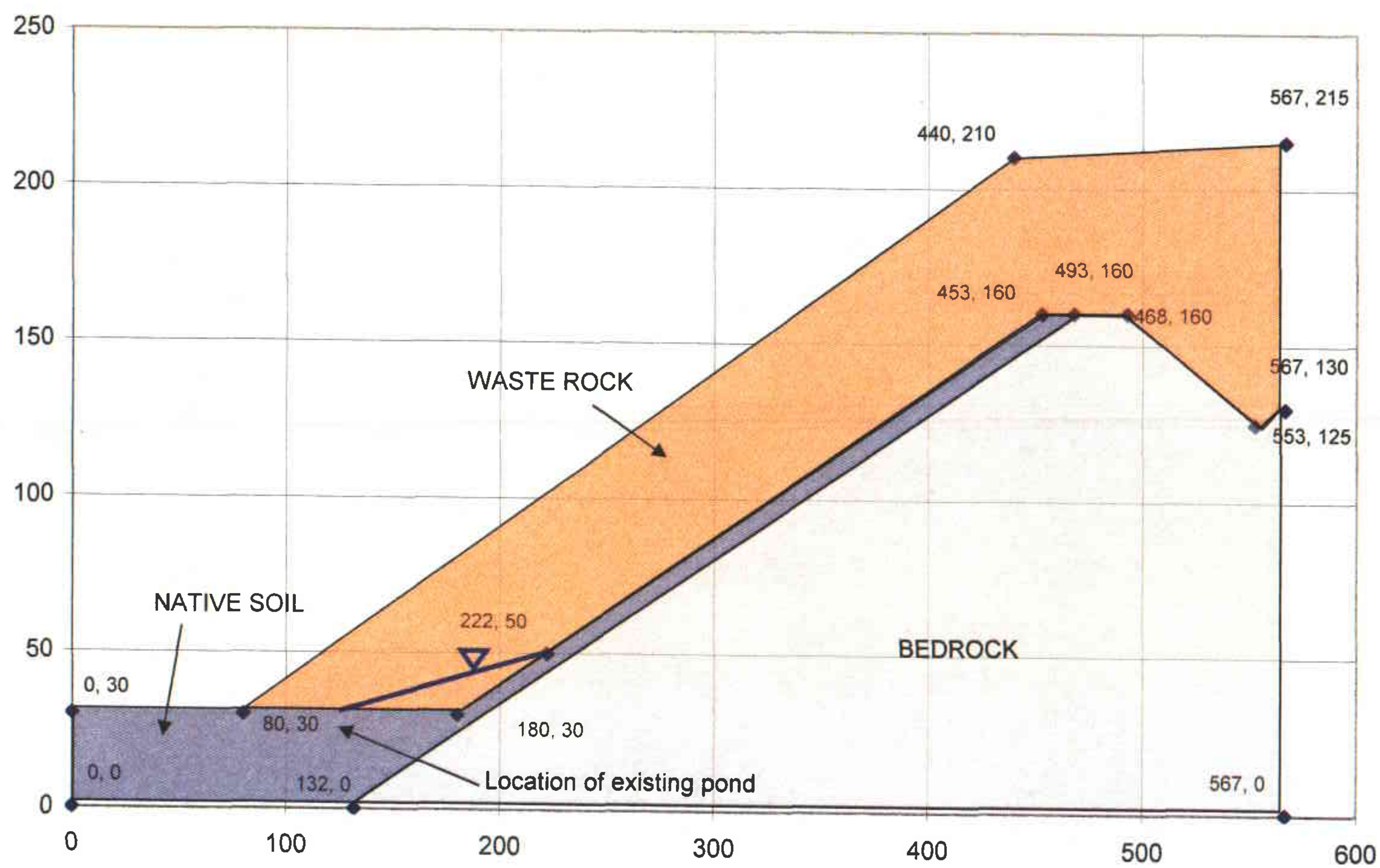

FIGURE 8. WEST PROFILE FILLING EXISTING POND, 2H:1V OUTSLOPE

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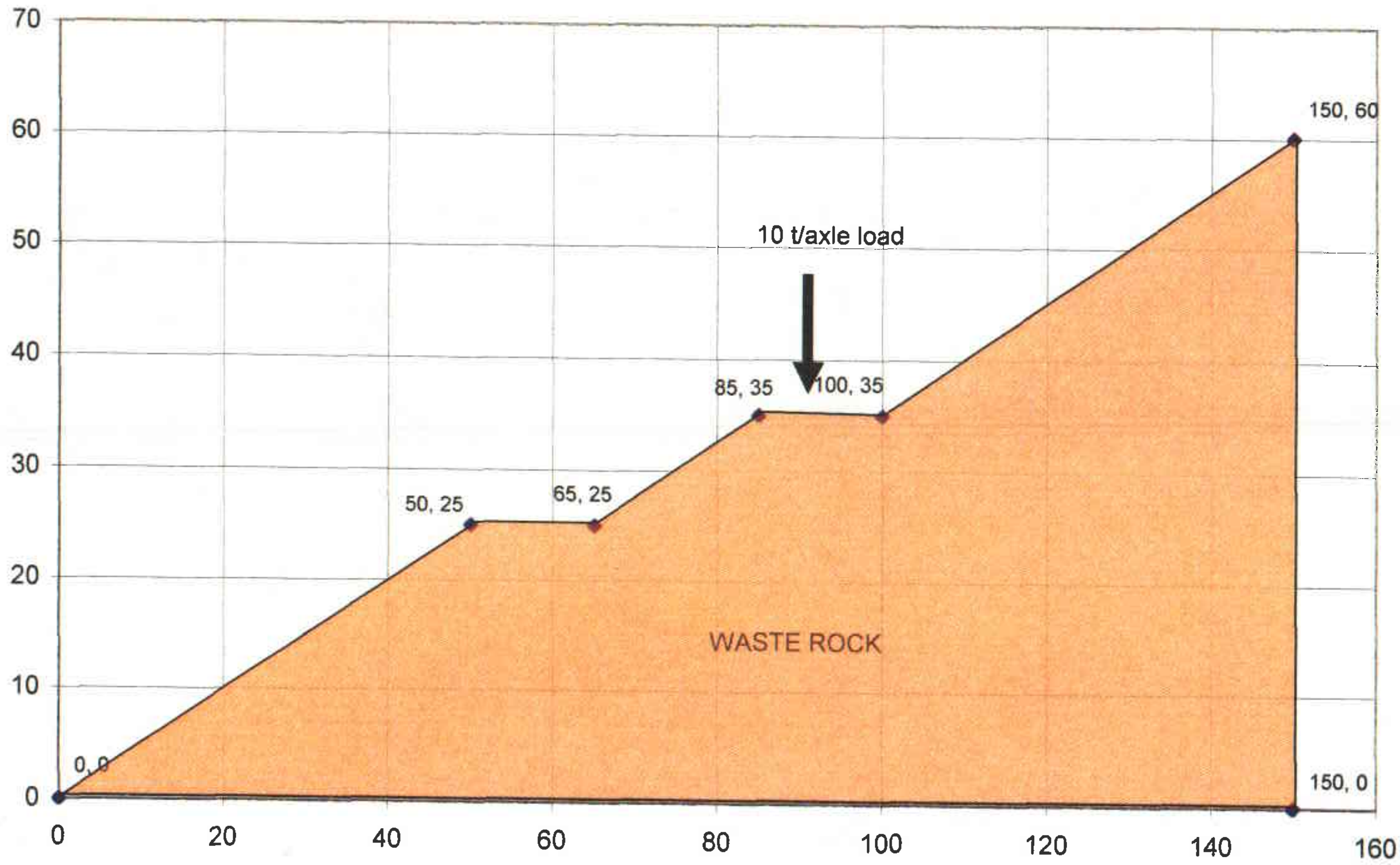

FIGURE 9. ROADCUT SWITCHBACK PROFILE

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TABLES

TABLE 1
Summary of Slope Stability Analysis Results
Waste Rock Pile
Canyon Fuels Skyline Mine
Scofield, Utah

Profile	FS (Dry)	FS (Saturated)
Northeast		
Expanded WRP	1.69	1.61
Northwest		
Current	1.72	1.72
Expanded	1.63	1.58
West		
Current (2:1)	1.63	1.53
Expanded to Lease Boundary (2:1)	1.51	1.44
Expanded to Lease Boundary (2.2:1)	1.61	1.52
Expanded Over Sed Pond (2:1)	1.65	1.57

APPENDIX A

Geophysical Report

CLEMENT DRILLING
& GEOPHYSICAL, INC.

4114 West 9950 North
Cedar Hills, Utah 84062
Phone 801-372-3685
Fax 801-785-5748

December 27, 2006

Mr. Rich White,
Earthfax Engineering
7324 South Union Park Ave.
Midvale, UT 84047

Dear Mr. White,

This letter report summarizes the methodology and results of the seismic refraction testing conducted by Clement Drilling & Geophysical, Inc. at the Skyline Mine Waste Rock site, near Scofield, Utah.

Seismic Refraction Testing

Five refraction surveys were conducted at the project site in order to determine the compression wave (P-wave) velocities of the shallow subsurface material. The locations of the refraction surveys are shown on Figure 1. The data were collected utilizing a Geometrics SmartSeis S12 seismograph, 8 Hz geophones and 12-pound hammer source. Each spread was approximately 220 feet long with 12 geophones placed at 20-foot intervals. Data collection consisted of center shot and two off end shots at each end of the seismic spreads. The auto-stacking feature of the seismograph was used to stack multiple shots at each location in order to reduce the signal to noise ratio of the data. Data from the test was recorded by and stored in the seismograph.

The data were processed using Rimrock Geophysics SIP software to pick the first arrivals at each geophone location and create an ASCII input file. The five seismic lines were combined into three profiles for input into the processing software. The three input files were processed using Optim's SeisOpt Pro modeling software. The refraction profiles show the calculated P-wave velocities for the subsurface materials and are presented on Figures 2, 3 and 4.

Seismic Refraction Results

Line 1 includes refraction surveys 1 and 2. Line 2 includes refraction survey 3. Line 3 includes refraction surveys 4 and 5.

Profiles of the results of the seismic modeling for Lines 1, 2 and 3 are presented in Figures 2,3 and 4. The profiles for Lines 1 and 3 generally indicate increasing velocity with depth. Line 3 does have low velocity material extending deeper at approximately 400 feet. The profile for Line 2 indicates a very low velocity zone at the northern end of the profile the line drops off the northern edge of the waste rock pile

Please feel free to contact me if you have any questions regarding the results of the geophysical testing. I appreciate the opportunity to work with you on this project.

Sincerely,
Clement Drilling & Geophysical, Inc.

Craig M. Clement

Craig M. Clement, P.G.

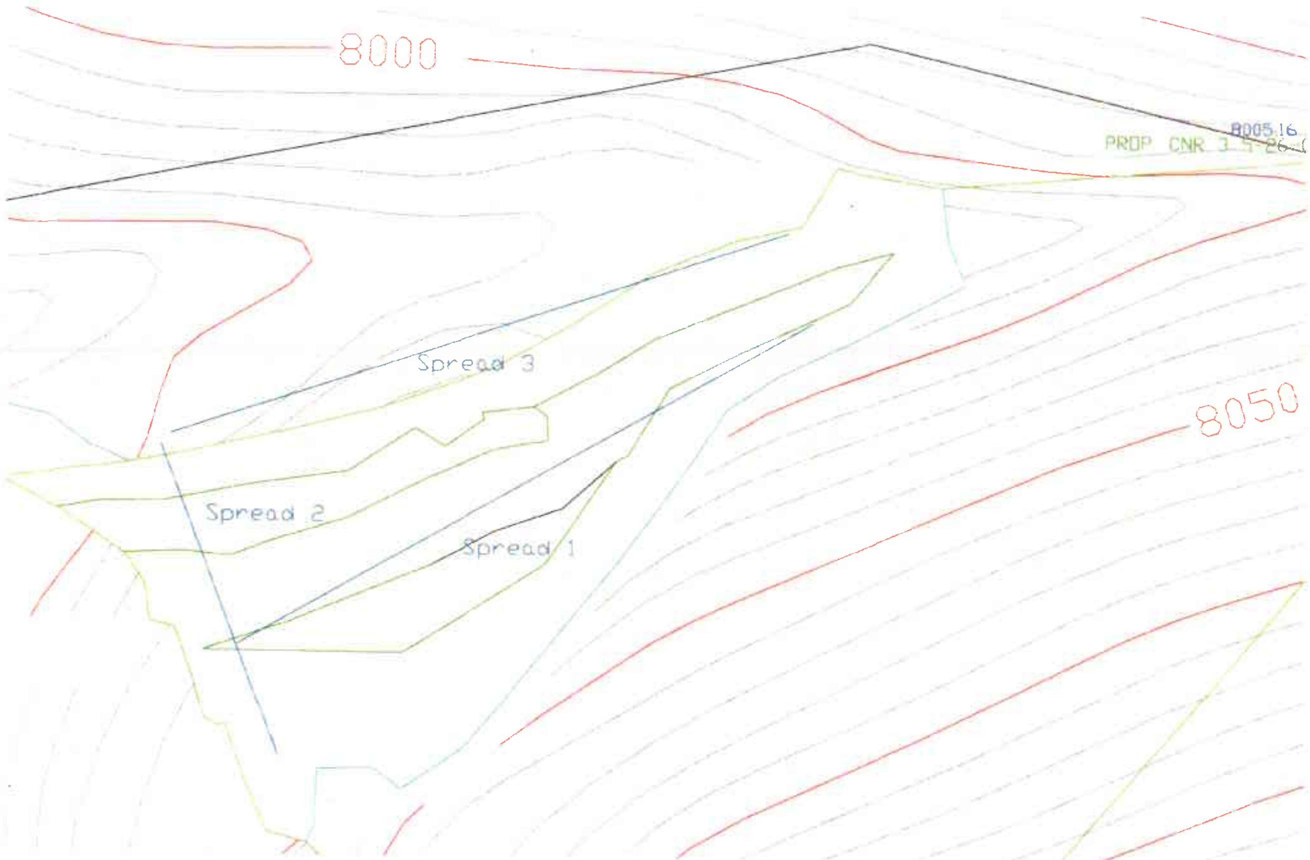

Figure 1

Sk

Locations of Seismic Refraction Lines

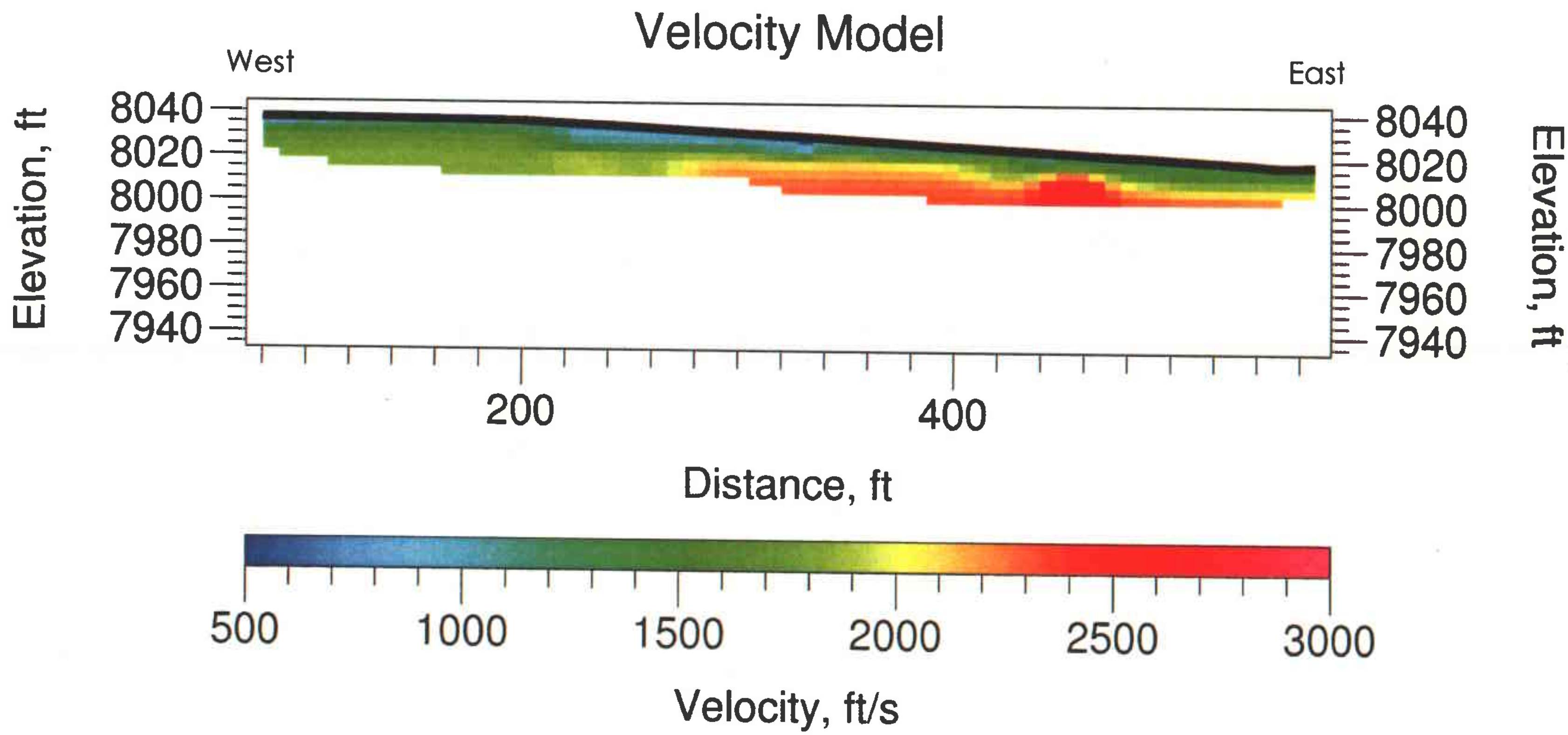
Velocity Model
West
East
8040
8020
8000
7980
7960
7940
Elevation, ft
200
400
Distance, ft
500
1000
1500
2000
2500
3000
Velocity, ft/s

Figure 2

Seismic Refraction Profile
Line 1

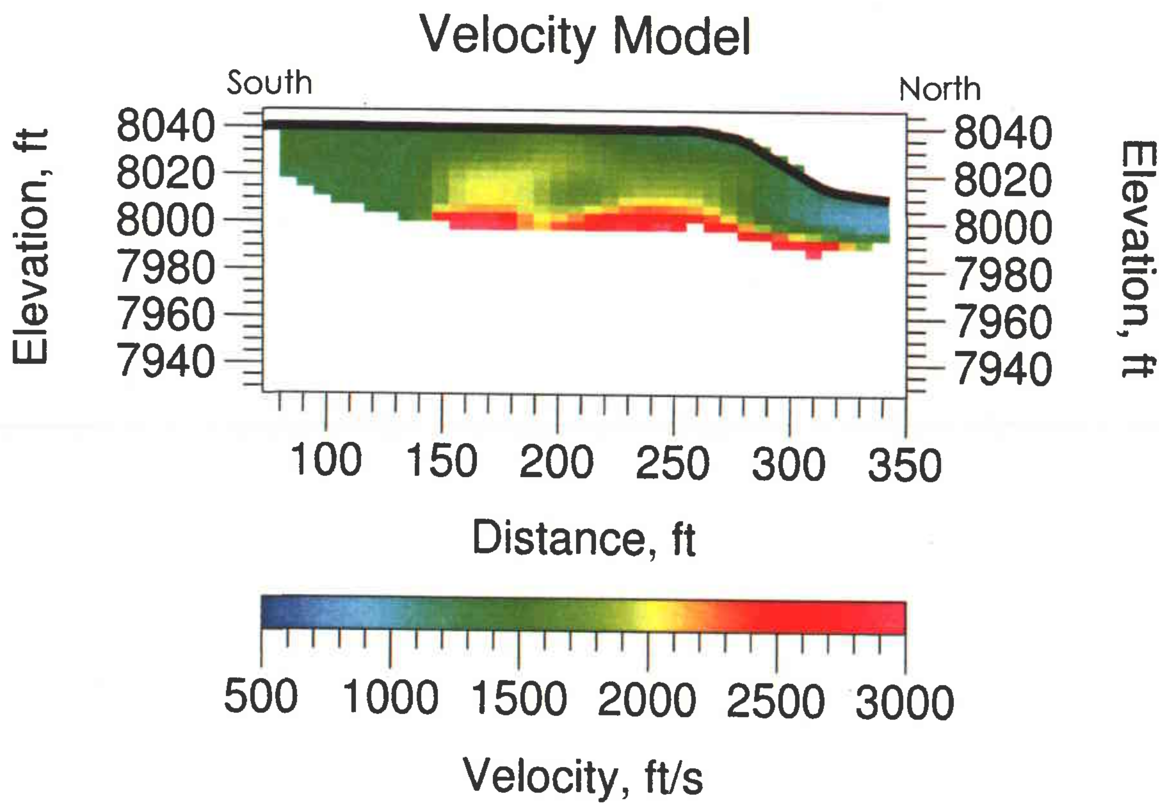

Figure 3
Seismic Refraction Profile
Line 2

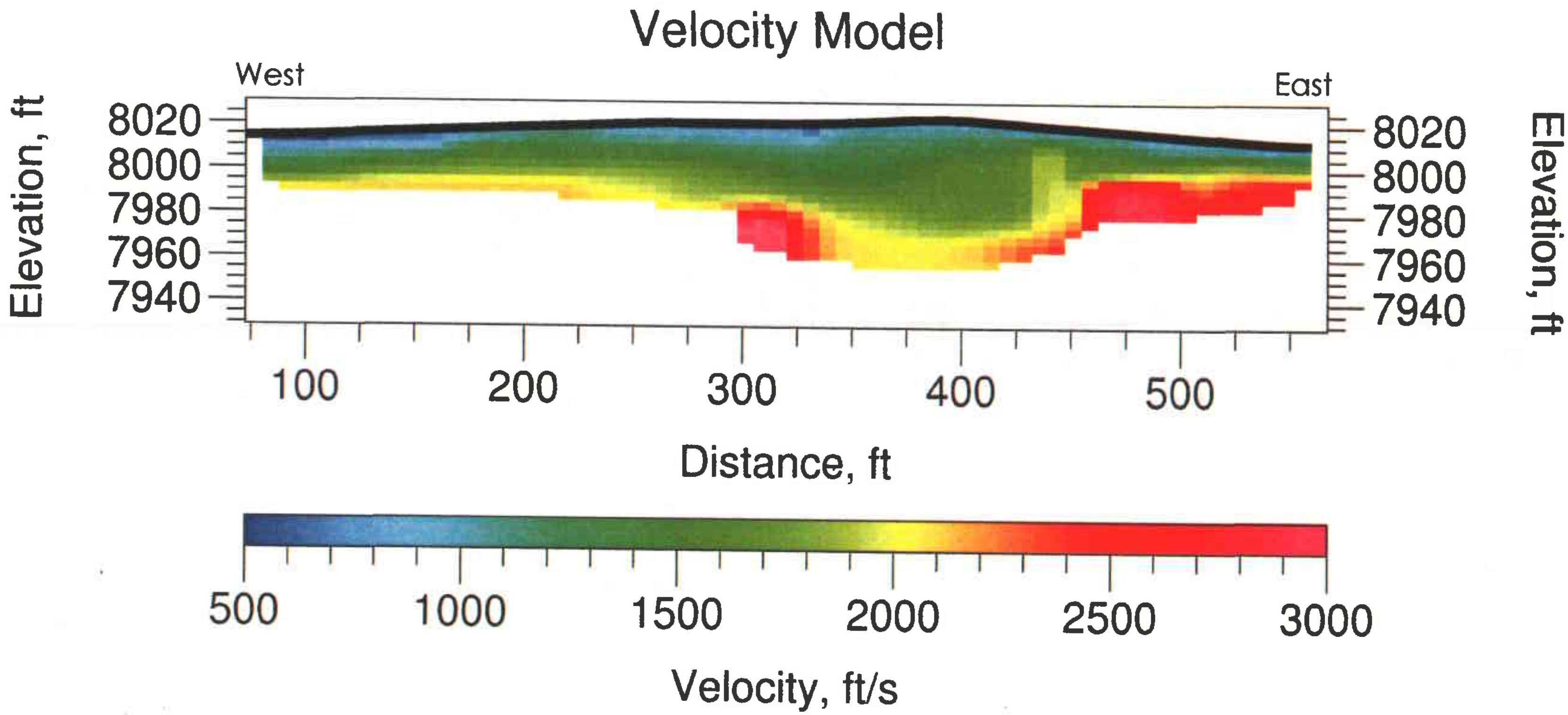

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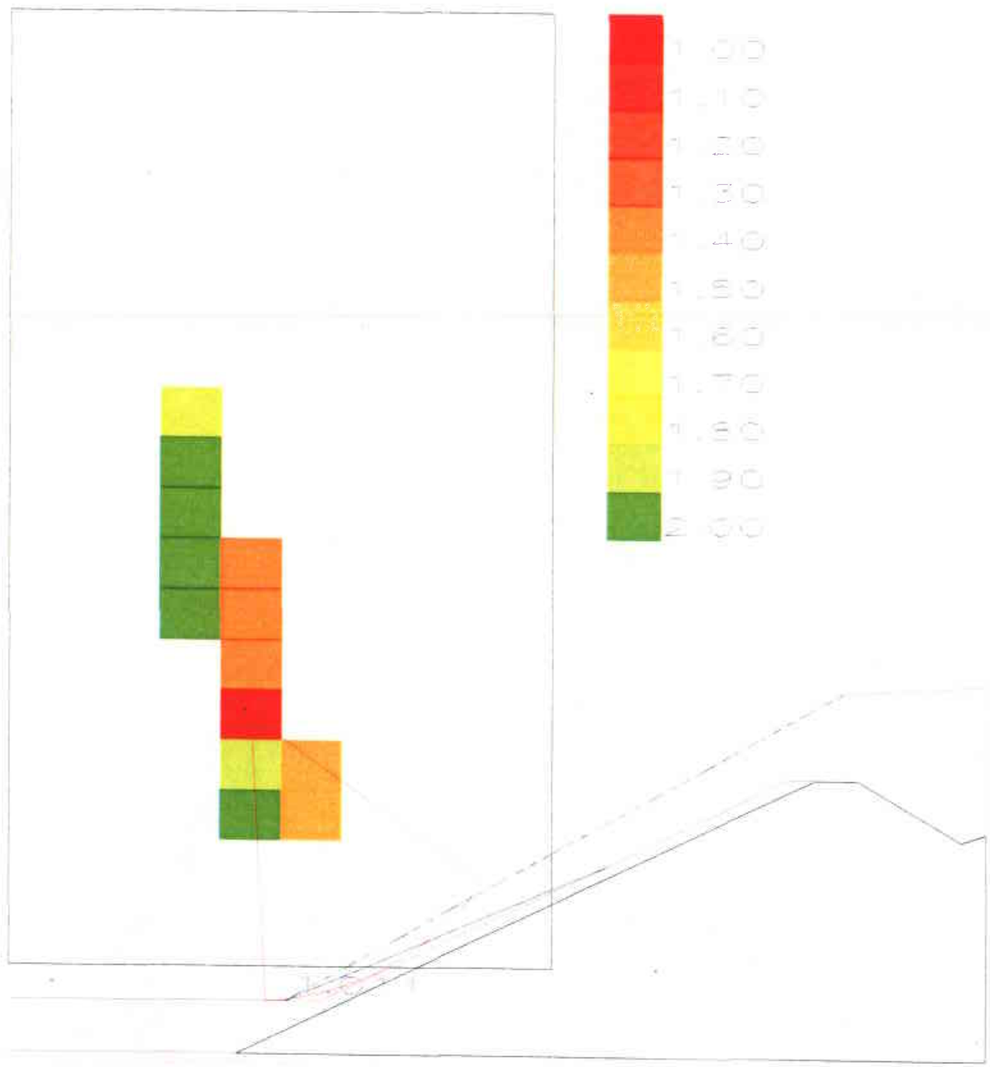
Figure 4
Seismic Refraction Profile
Line 3

APPENDIX B

Slope Stability Calculations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1.20
1.30
1.40
1.50
1.60
1.70
1.80
1.90
2.00
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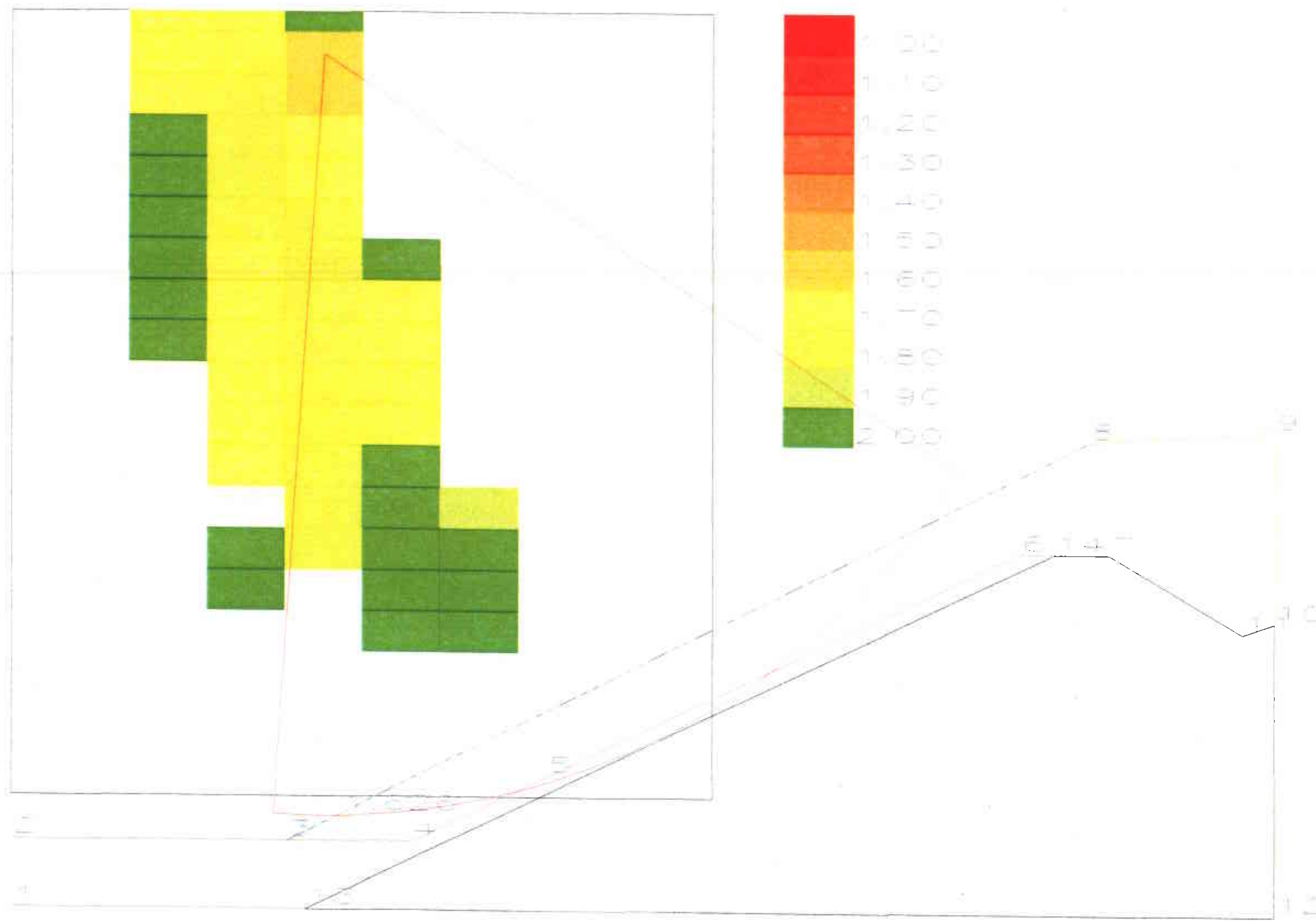
Analysis : Bishop
STABLE2002 MZ Associates Ltd



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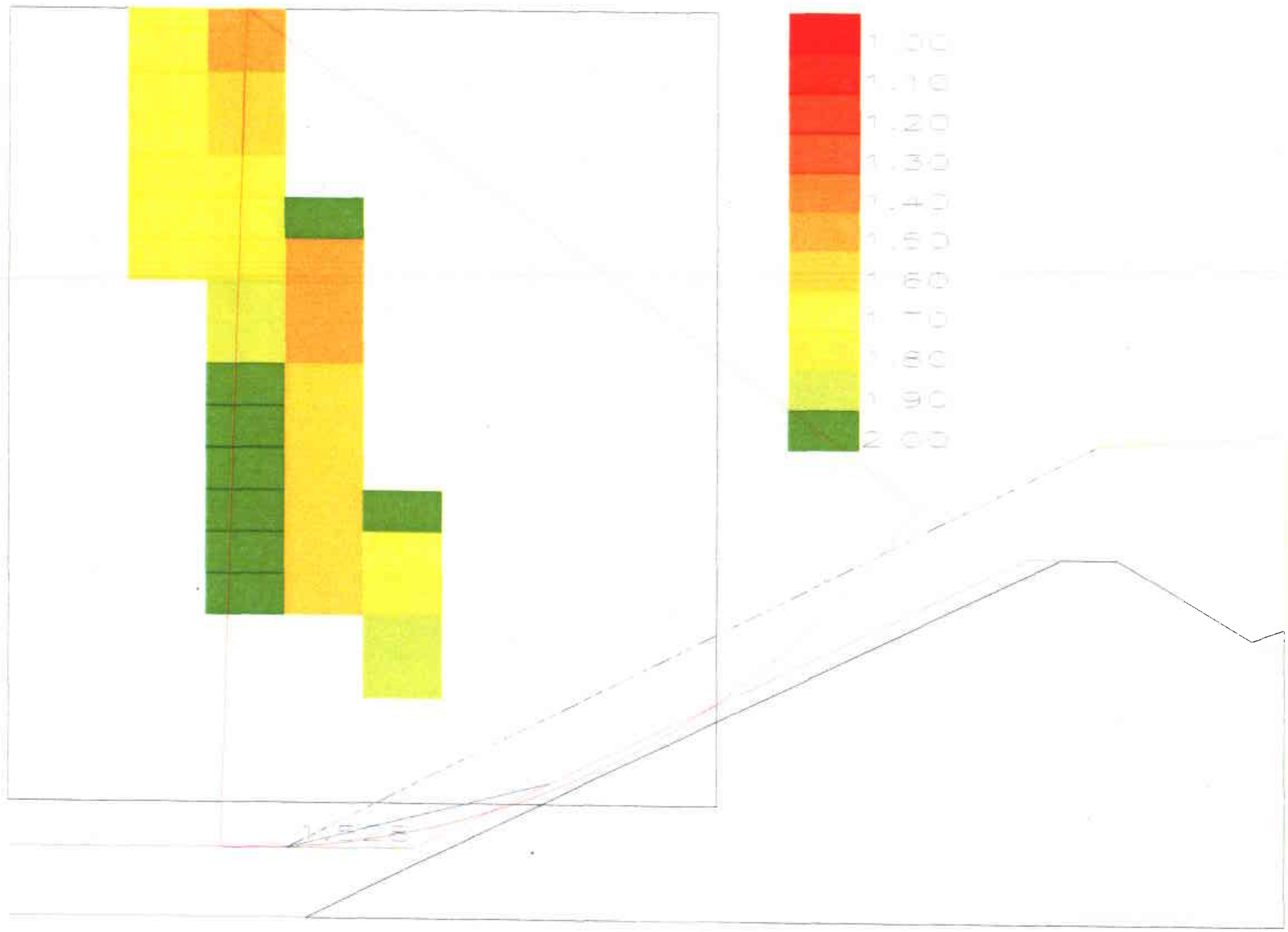
STABLE 2002 MZ Associates Ltd



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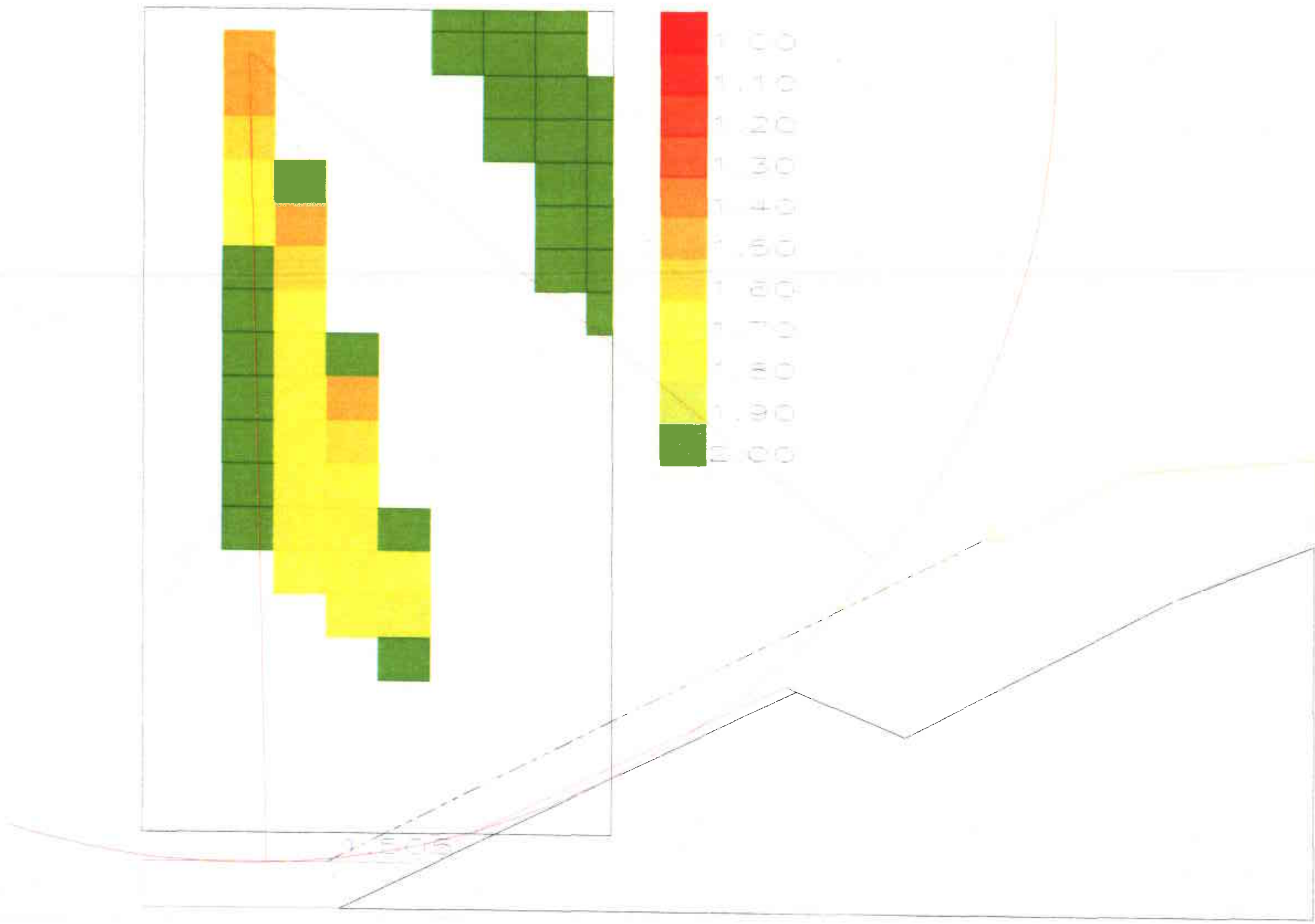
Datafile : 200cm US W CURRENT WET
Analysis : Bishop
STABLE 2002 MZ Associates Ltd



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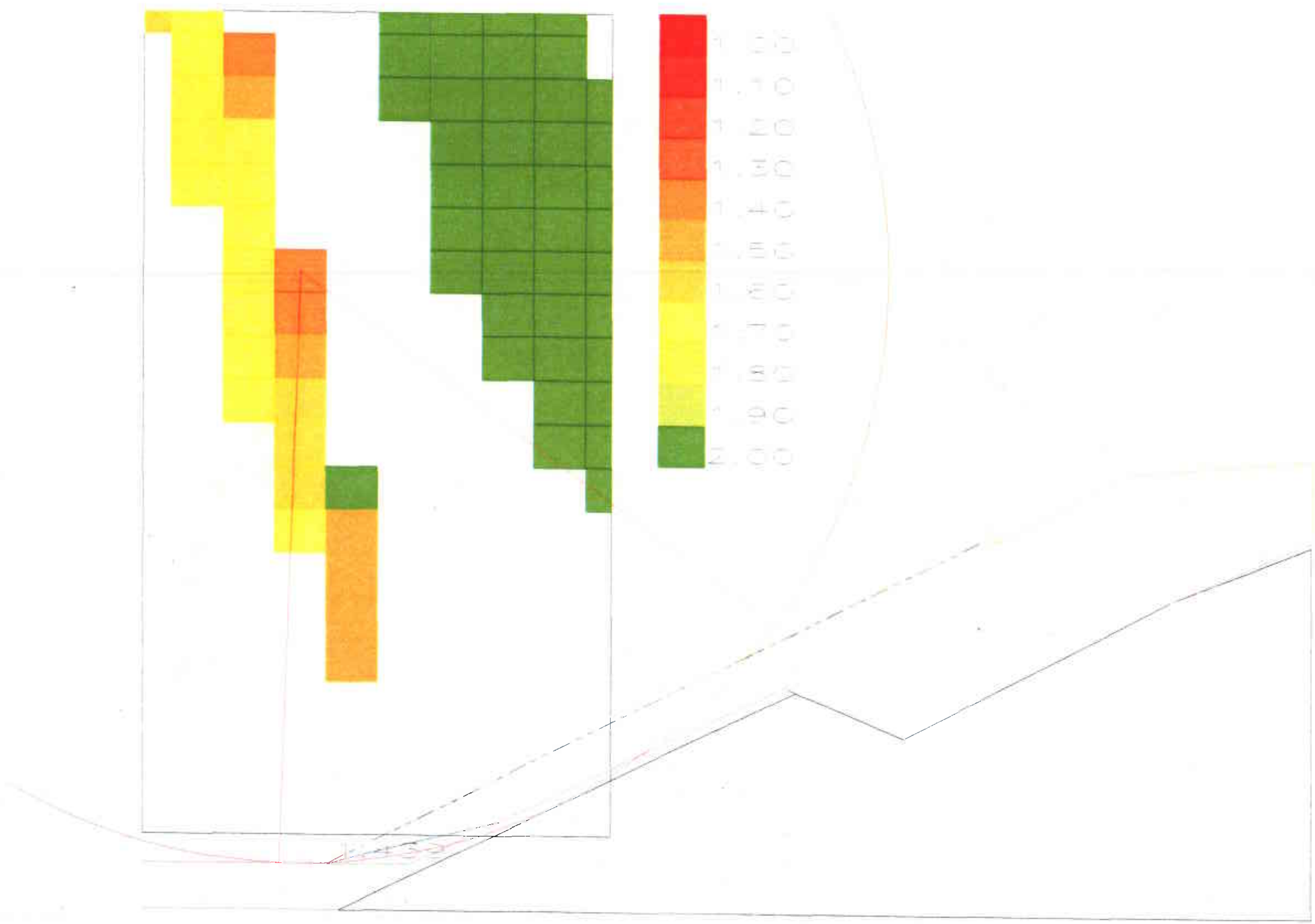
Analysis : Bishop
STABLE 2002 MZ Associates Ltd



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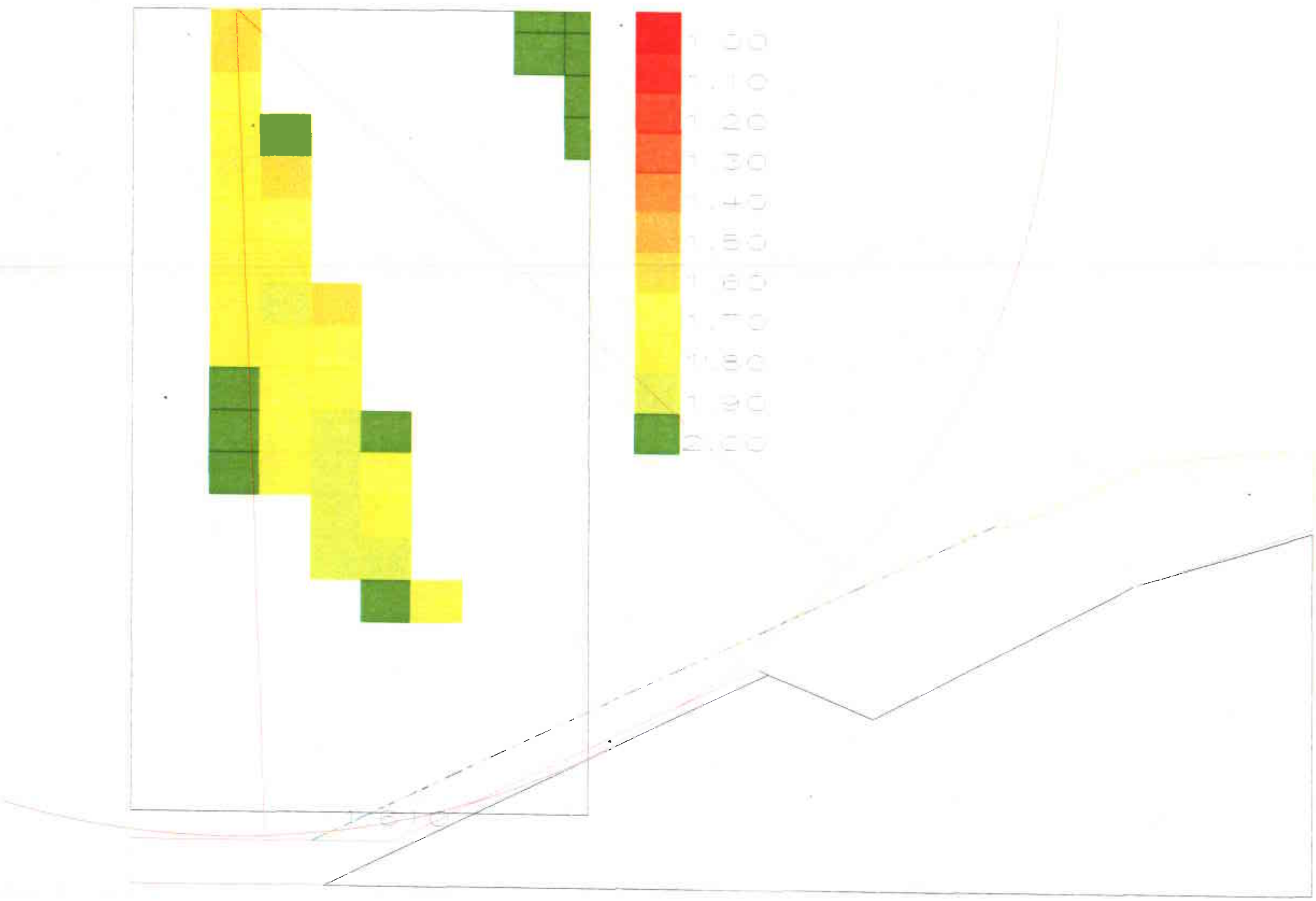

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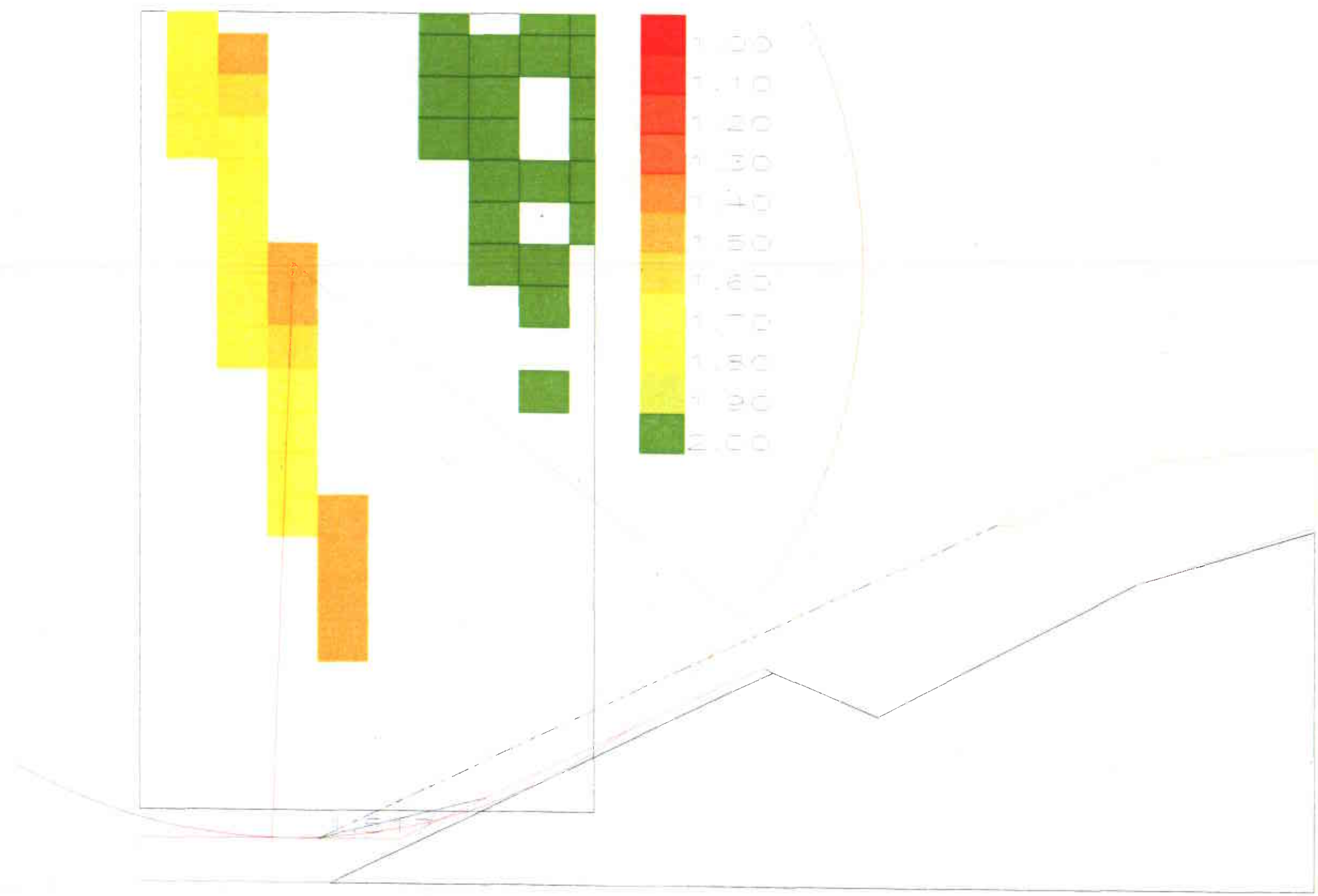

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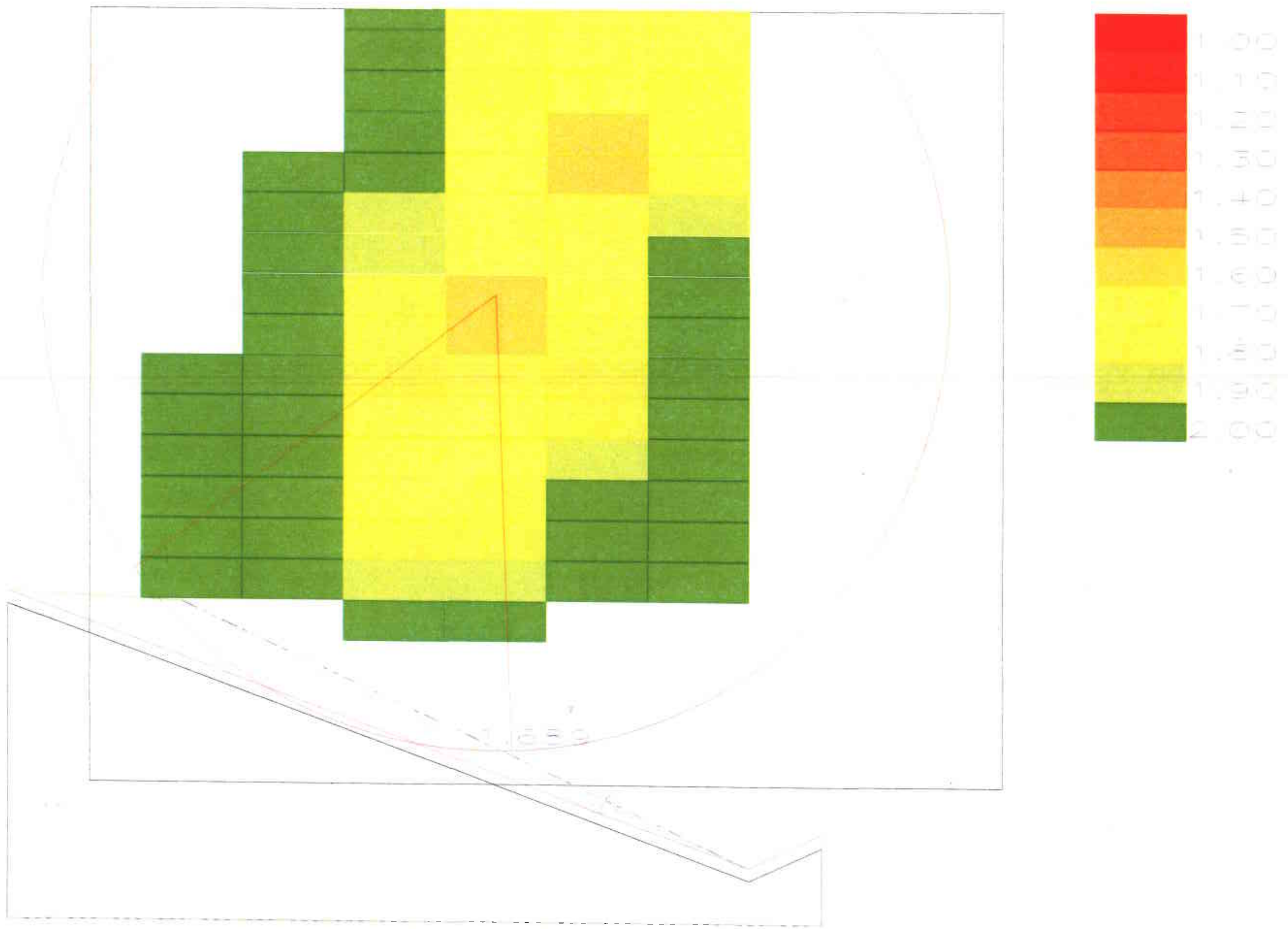
STABLE 2002 MZ Associates Ltd



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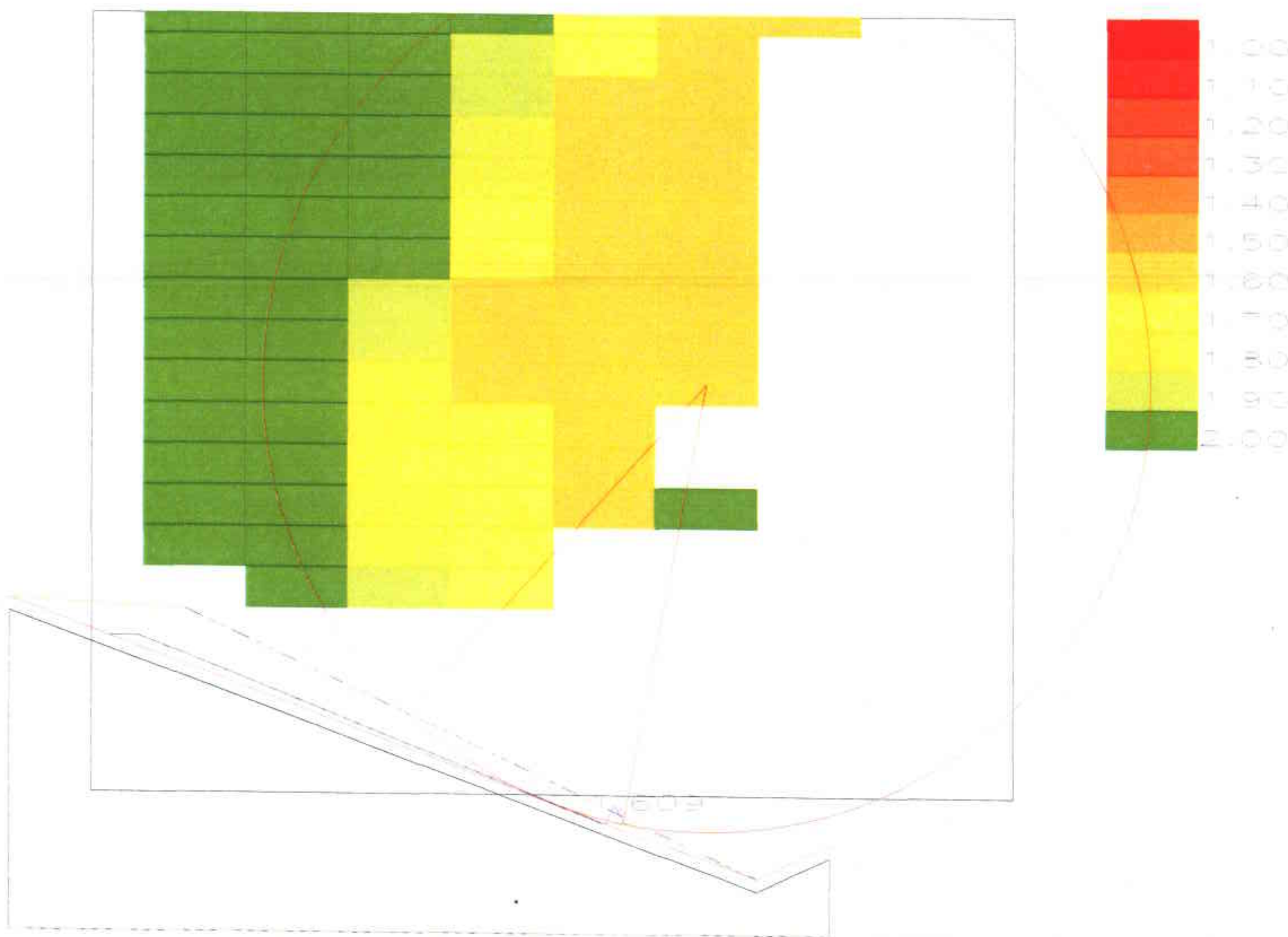
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1.20
1.30
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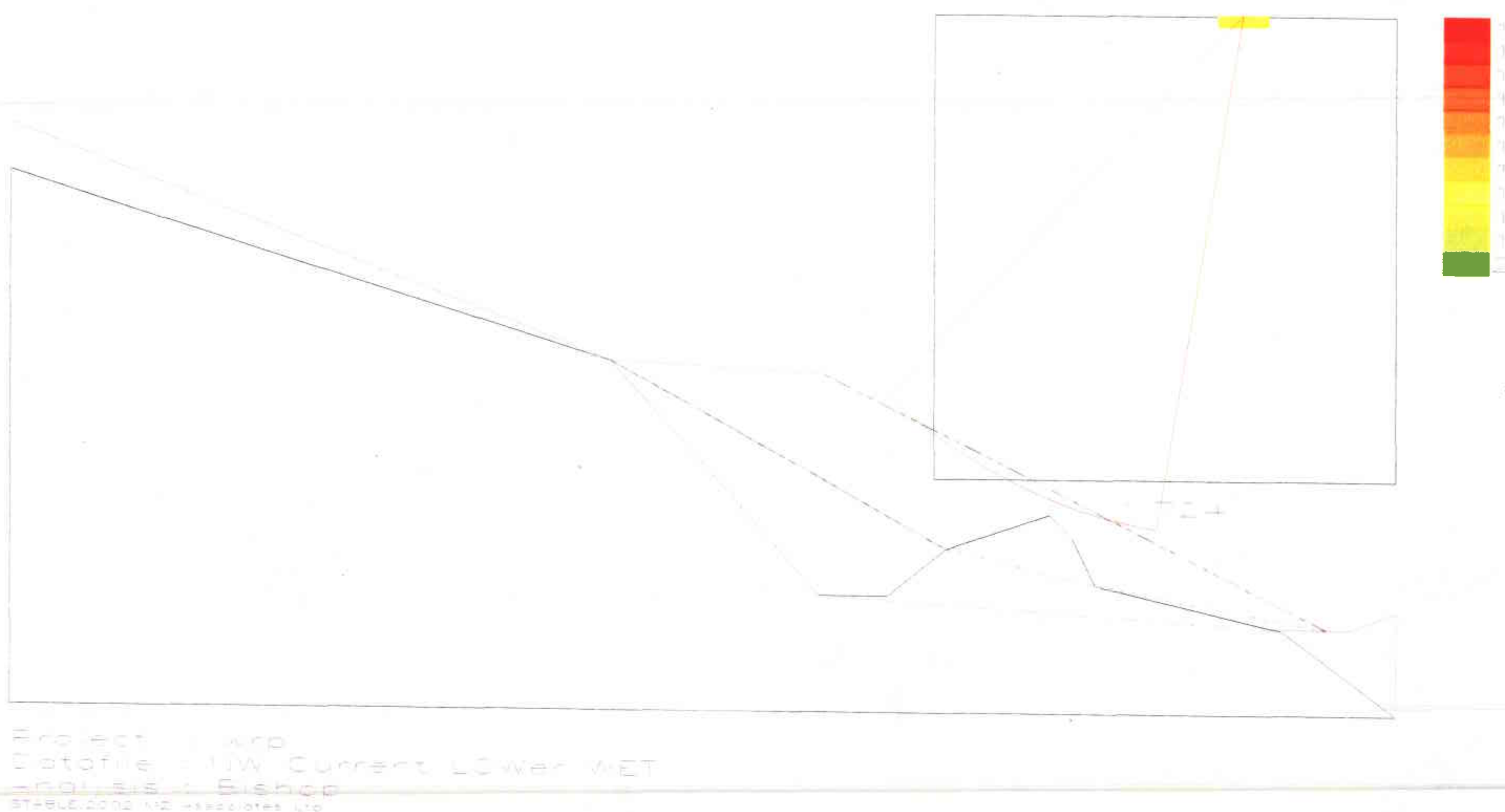
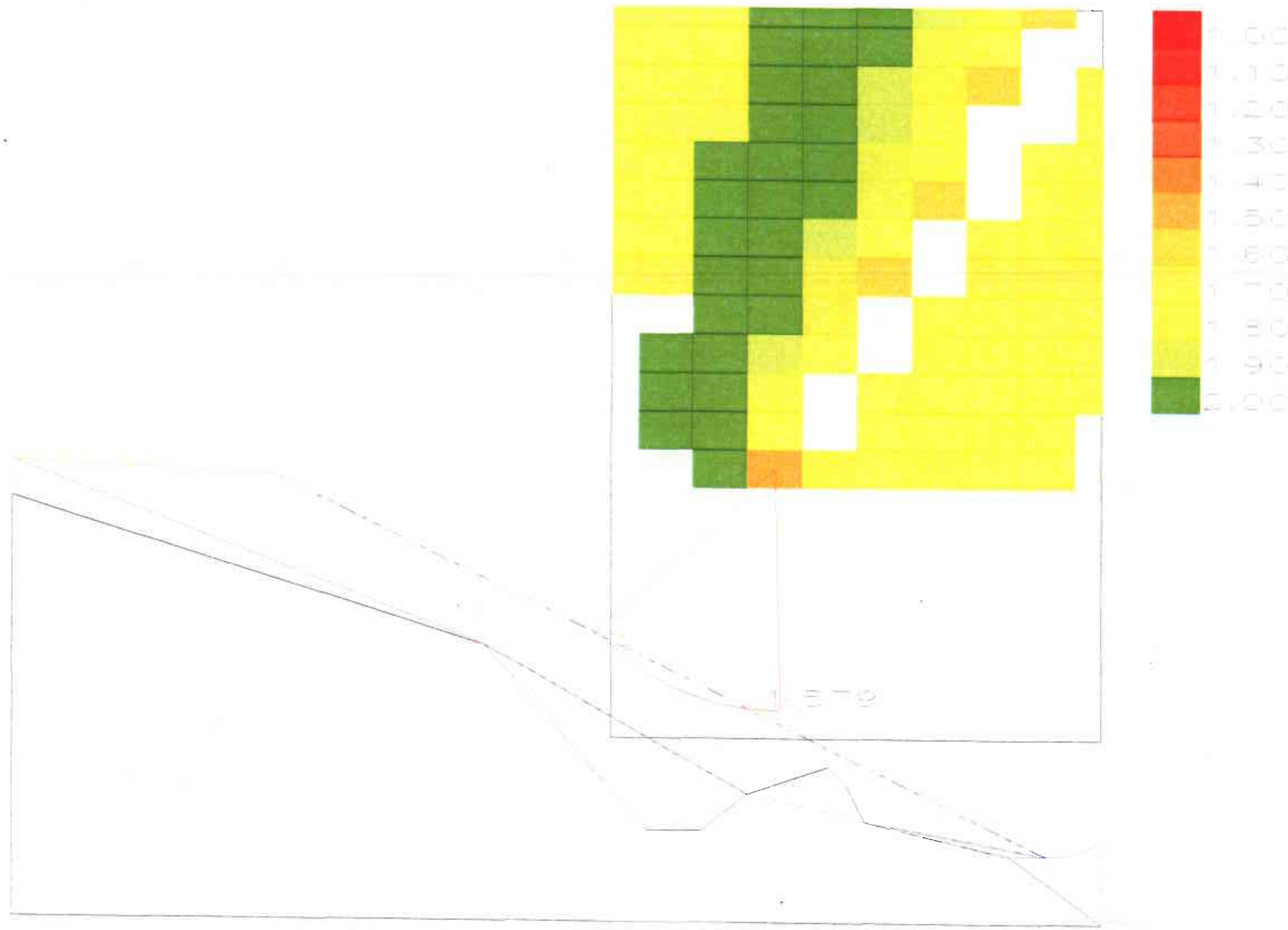
1.50
1.60
1.70
1.80
1.90
2.00
1.609
Project : WPP 02080
Datafile : CFS NE E-P WET
Analysis : Bishop
STABLE2002 MZ Associates Ltd


Project : wrc
Datafile : HW Current DF
Analysis : Bishop
STABLE2002 [illegible] Associates Ltd

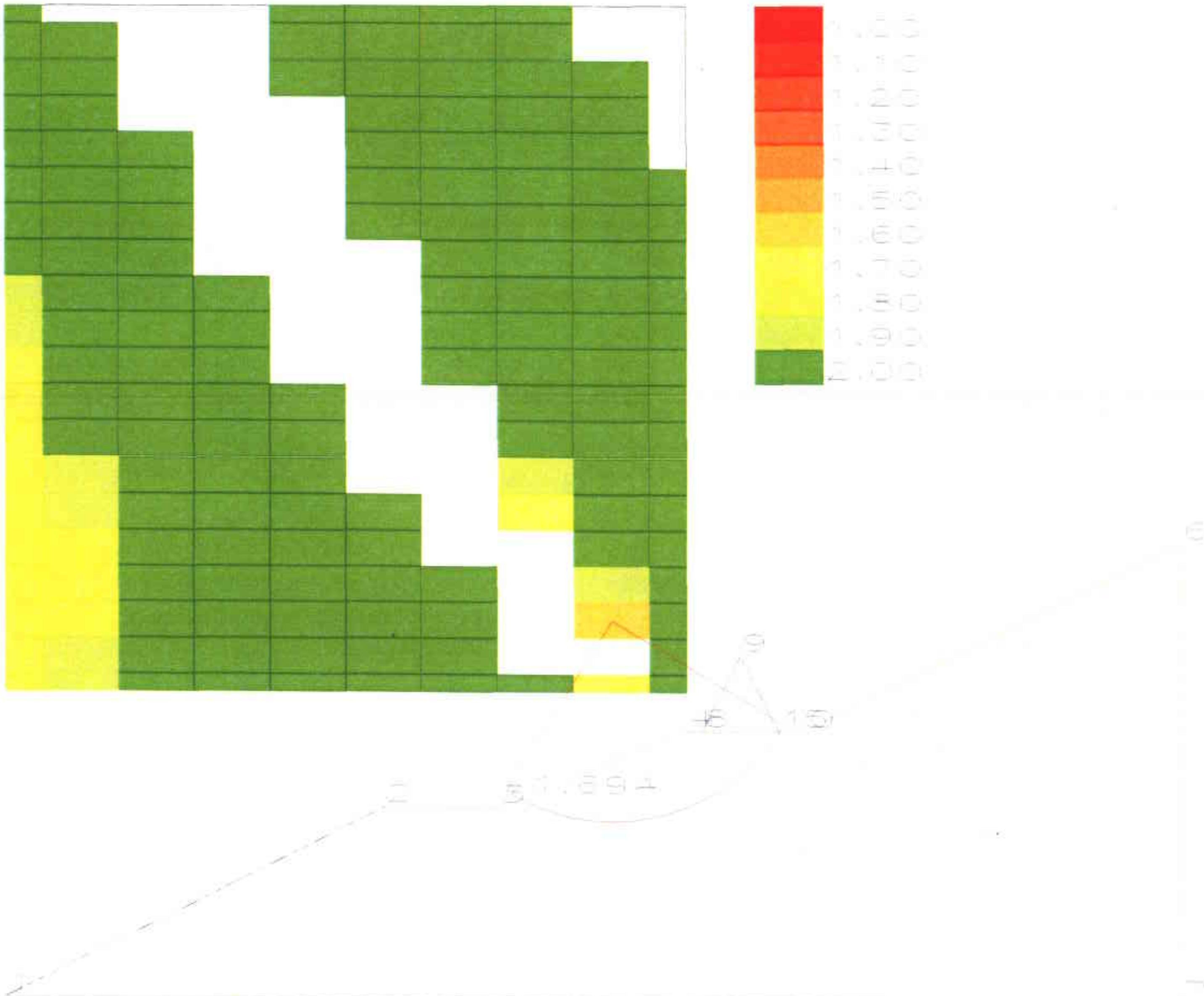


Project
Datafile
Current Lower WET
Bishop

Project
Datafile
Analysis : Bishop
STABLE 2012 MZ associates Ltd


1.00
1.10
1.20
1.30
1.40
1.50
1.60
1.70
1.80
1.90
2.00
1.578
Datafile : DPS NW UPPER E&B WET
Analysis : Bishop
STABLE2002

Project : wrd
Datafile : CPS NW TOE EXP WET
analysis : Bishop
STABLE 2002 MZ Associates Ltd



Project
Datafile : Road Cuts 2.5:1 FS= 1.694
Analysis : Bishop