PRESENTATION ON PEER REVIEW, SUPPLEMENTAL INVESTIGATION AND SEEPAGE ANALYSIS FOR KINGSTON FOSSIL PLANT, DREDGE CELL KINGSTON, TENNESSEE

Prepared for
Tennessee Valley Authority

Prepared by
GeoSyntec Consultants

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GEOSYNTEC CONSULTANTS

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INTRODUCTION

- Plans are presently under development to construct a lateral and vertical expansion over the existing dredge cells of the Kingston Fossil Plant.
- Prior to implementation of the planned expansion, excessive seepage (blow-out) occurred near the base of Dredge Cell III perimeter dike adjacent to Swan Pond Road.
- Fly-ash was reported to "flow" along the perimeter ditch and across Swan Pond Road.
- Due to the importance of this project, Tennessee Valley Authority (TVA) requested GeoSyntec Consultants (GeoSyntec) perform a peer review of the proposed expansion and an independent analysis of the seepage-related issues.
- This presentation presents the findings and recommendations relative to seepage conditions near the base of Dredge Cell III perimeter dike.

Site Reconnaissance

- GeoSyntec conducted a one-day site reconnaissance to observe and evaluate the cause of failure.

- Based on the site reconnaissance, piping and excessive seepage was hypothesized to be the triggering mechanisms for the "blow-out".

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Overview of the Approach

- The Project Team (TVA, Parsons and GeoSyntec) reviewed the findings of previous site investigation conducted at the site, in particular, for the dredge cell area to define cause of blow-out.

- Based on this review, the Project Team decided that additional investigations would be beneficial.

- A supplemental site investigation was performed to complement existing data and fill data gaps regarding the hydrogeology and stratigraphy within the dredge cell.

- Seepage analysis was used as a tool to: (i) evaluate the cause of blow-out; and (ii) develop potential remedies for both existing and future conditions for the dredge cells. (note: Project Team developed and agreed upon the model geometry and material properties; Parsons and GeoSyntec then performed independent seppage analyses.)

Review of Previous Site Investigation

Performed by MACTEC Engineering and Consulting, Inc.

Report Date: May 2004

Purpose:

- Evaluate subsurface stratigraphy within the footprint of existing dredge cells and proposed lateral expansion area.

Field activities performed within the Dredge cells consisted of:

- Drilling Six (6) boreholes for the characterization of subsurface stratigraphy
- Installing Three (3) piezometers within the vicinity of the failure cross section.
- Conducting six (6) Cone Penetration Test with pressure dissipation tests at selected locations within the dredge cells.
- Performing two (2) in-situ hydraulic conductivity tests.

Laboratory tests preformed on disturbed and undisturbed samples involved grain size analysis, specific gravity, Atterberg limits, permeability tests, consolidation tests, and triaxial tests.

Data Gaps Identified from Review of Site Investigation

- Review of previous site investigation indicated that:
  - Stratigraphy within the dredge cells is not well defined.
  - Water levels under existing conditions needed to be established.
  - In-situ hydraulic conductivity of construction materials and fly ash needed to be evaluated.
- Available information was not sufficient to identify the cause of blow-out and additional information was needed to perform seepage analysis with meaningful data.
- GeoSyntec recommended supplemental site investigation to be conducted within the Dredge Cells.
- The Project Team developed and agreed upon the scope of the supplemental site investigation.

Supplemental Site Investigation

Performed by MACTEC Engineering and Consulting, Inc.

Date: January 2005

Purpose:

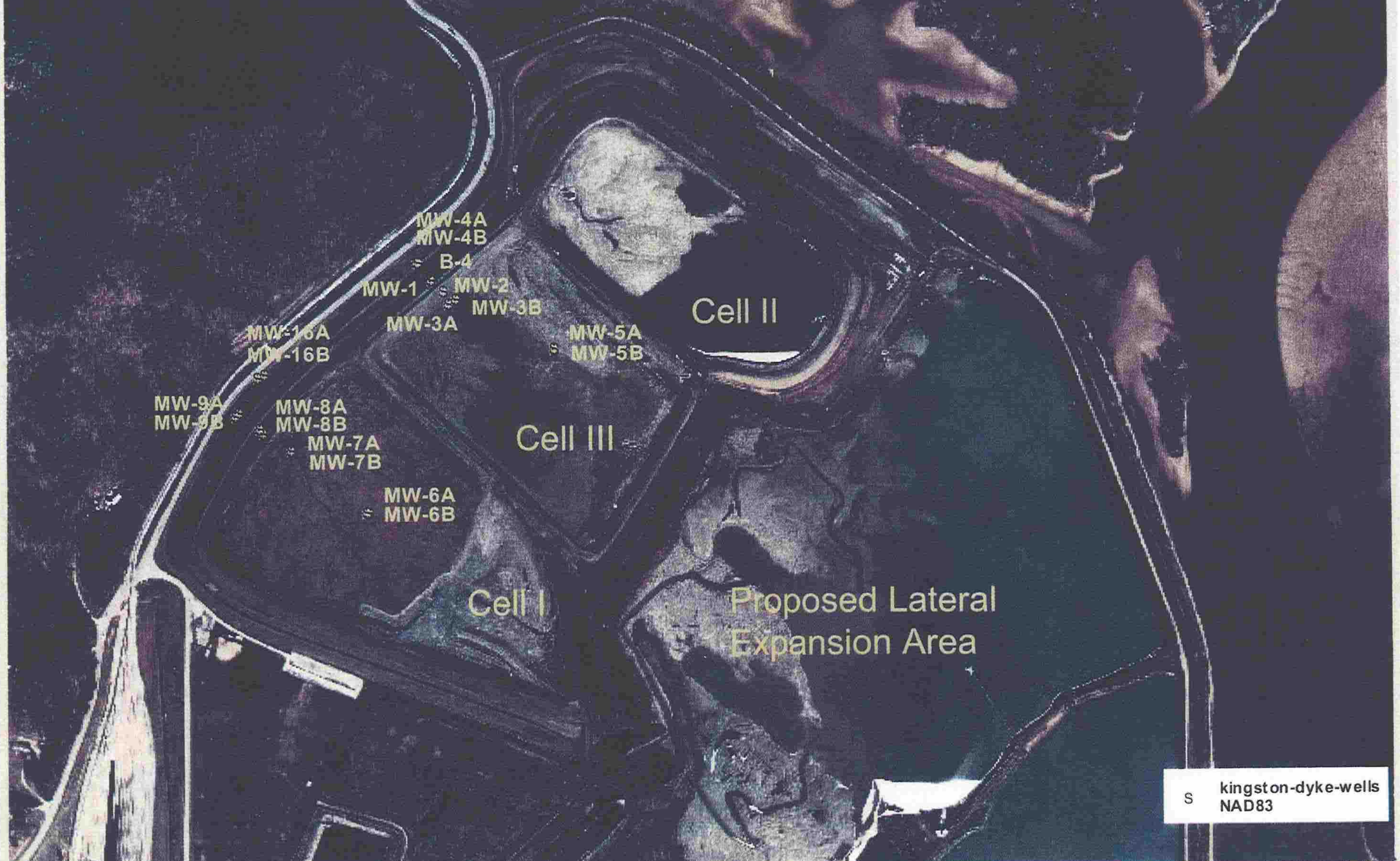
- Characterize subsurface stratigraphy within the dredge cells, in the vicinity of the blow-out area (Dredge Cell III) and in adjoining Dredge Cell I.
- Establish current groundwater elevations within the dredge cells.
- Estimate the in-situ hydraulic conductivity of subsurface materials encountered within the dredge cells

Field activities performed as part of this investigation consisted of:

- Drilling of seven (7) boreholes
- Installation of additional 13 piezometers within the dredge cells
- Performing in-situ hydraulic conductivity tests (13 slug tests, and 3 constant rate pumping test).

Laboratory tests preformed on samples included grain size analysis, Atterberg limits, natural moisture content, specific gravity.

Supplemental Site Investigation (cont.) Piezometer Locations



Supplemental Site Investigation (cont.)
Summary of Results

- Findings of the supplemental site investigation revealed that subsurface stratigraphy within dredge cells is a complex layered system with subtle but important hydraulic conductivity differences. The stratigraphy consists of mainly (from top to bottom) fly ash, alluvium, and bedrock. Other subsurface layers encountered within the dredge cells include clay, shale and fly ash/bottom ash mixture (outer dike material).

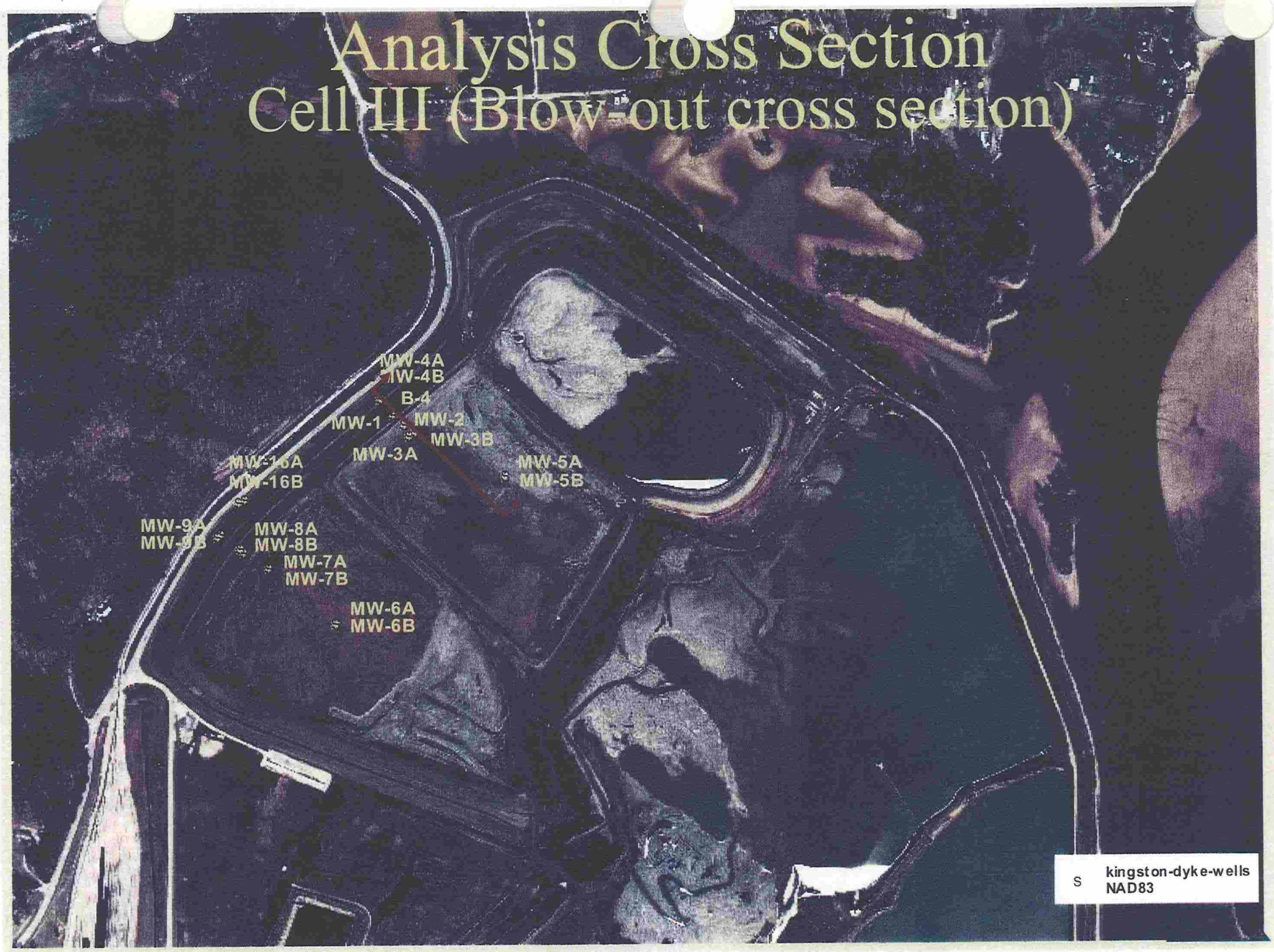
- Groundwater measurements were used to estimate the phreatic surface and pore water pressures at key points along the section used for analysis.

- In-situ hydraulic conductivities for subsurface materials were estimated to be:

Fly ash	From 1.14×10^{-6} to 5.96×10^{-5}
Fly ash/Bottom ash	From 1.29×10^{-4} to 1.56×10^{-4}
Bottom ash	From 1.21×10^{-5} to 1.32×10^{-3}
Alluvium	From 1.29×10^{-4}

Seepage Analysis

- Parsons performed seepage analysis using TIMES Software.
- To validate the TIMES analytical results, GeoSyntec performed independent seepage analysis using SEEP/W® software.
- SEEP/W® is a finite element program that can be used to model flow of water in saturated and unsaturated zones under steady and unsteady state conditions.
- The remaining slides provide information on analysis cross section, analyses cases, input parameters, and sample output of SEEP/W results.
- For the sake of comparison, excerpts of TIMES graphical output, provided by Parsons, are also presented.



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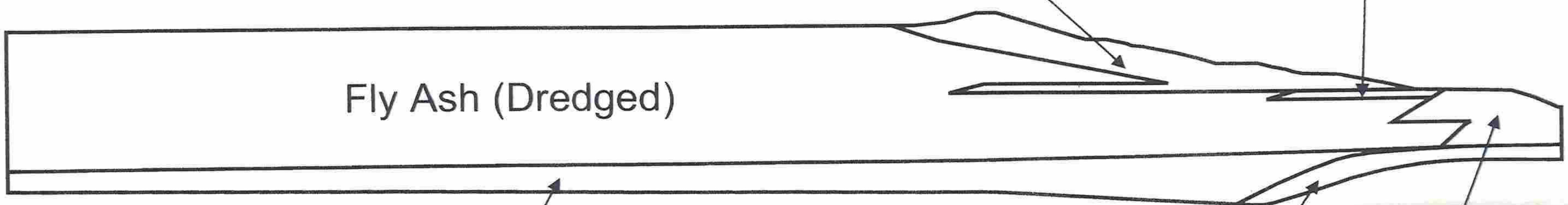
Model Stratigraphy and Existing Geometry



- Vertical and horizontal extent of subsurface stratigraphy were estimated based on visual field identification, SPT data, knowledge of the likely construction sequence, and in-situ hydraulic conductivity obtained during the January 2005 site investigation.
- Model geometry and subsurface stratigraphy were agreed on by the Project Team during the meeting that took place on 31st January 2005.

Model Input Parameters

1. Saturated hydraulic conductivities

Material	Horizontal hydraulic conductivity (K_h)		K_h/K_v
	cm/sec	ft/sec	
Fly Ash (1)	3.74×10^{-5}	1.24×10^{-6}	2
Outer Dike (1)	1.00×10^{-4}	3.28×10^{-6}	2
Clay at the toe (2)	5.00×10^{-6}	1.64×10^{-7}	1
Shale (2)	1.00×10^{-6}	3.28×10^{-8}	1
Base material (1)	1.70×10^{-5}	5.58×10^{-7}	2
Alluvium (1)	1.29×10^{-4}	4.23×10^{-6}	2

(1) Saturated hydraulic conductivity data presented in the above table was estimated from in-situ hydraulic conductivity test performed during the January 2005 site investigation.
(2) Saturated hydraulic conductivity were estimated based on typical values available in the literature.

Model Input Parameters (cont.)

2. Soil water characteristic curves

- Flow in unsaturated zone requires information on soil water characteristic curves for the unsaturated zone materials, specifically, fly ash and outer dike material.

- The soil water characteristic curve for Kingston fly ash and outer dike material was obtained from the February 1993 report titled "*Physical and Hydraulic Properties of Fly ash and Other By-products from Coal Combustion*" prepared by TVA.

Analyses Cases

***Case 1* - Existing Condition**

- Analysis was performed for existing condition to ensure that the seepage model could represent groundwater elevations recorded in the field. This case was used as a means of calibrating the model. A calibrated model is needed to provide an acceptable level of confidence to proceed with the analysis of future conditions.

***Case 2* - Conditions at the time of Blow out ("Blow-out" Condition)**

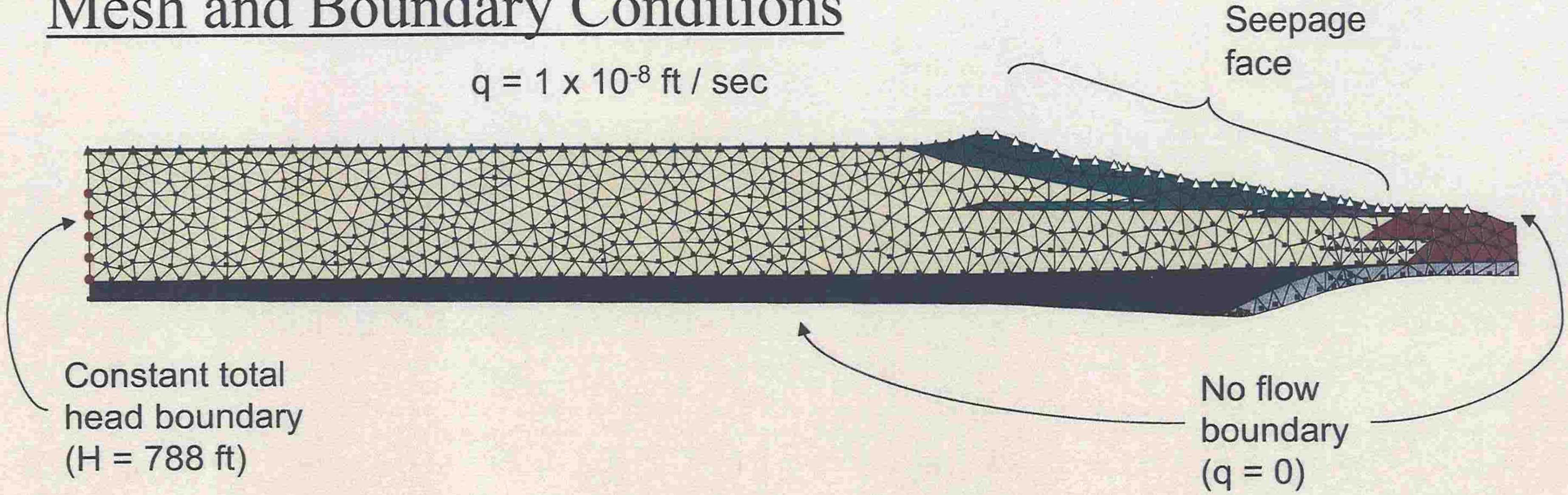
- Analysis was performed for the conditions that were observed at the time of blow-out to identify/confirm blow-out triggering mechansim(s).

***Case 3* - Future condition and proposed improvement features**

- This case was analyzed to: (i) evaluate seepage conditions in the the dredge cells under future conditions (i.e., vertical expansion) and (ii) evaluate the effectiveness of proposed improvements in terms of providing an adequate factor of safety against seepage failure under future conditions.

Case 1 (Existing Condition)

Mesh and Boundary Conditions



- The total head value assigned along the constant head boundary (left-hand side boundary) is the average total head recorded in piezometer MW-5A and MW-5B.
- The bottom boundary of the model was considered the top of the competent and impervious bedrock; therefore, no flow was assumed along this boundary.
- A no flow boundary was assumed along the model's right-hand side boundary.
- Infiltration, q, on the top and sideslope of the dredge cell represent the portion of rainfall that is anticipated to infiltrate into the cell. This portion is mainly rainfall minus runoff, evaporation and evapotranspiration. HELP model performed indicated that this portion is approximately 7 percent of total rainfall.

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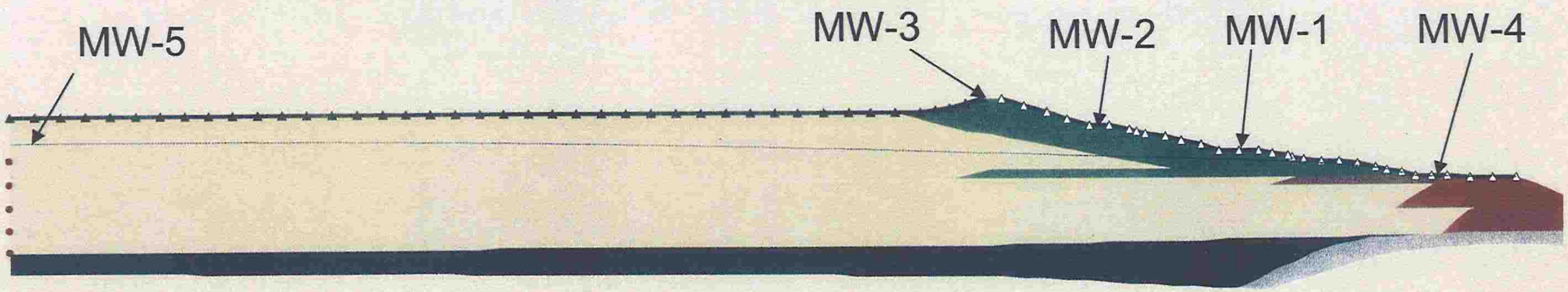
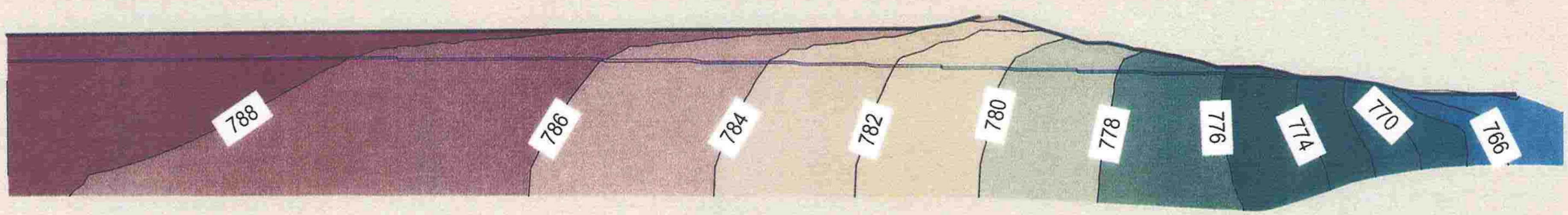
Case 1 (Existing condition)
SEEP/W Output Summary

Model-predicted Phreatic Surface



Model-predicted Total Head Distribution (equipotential lines)



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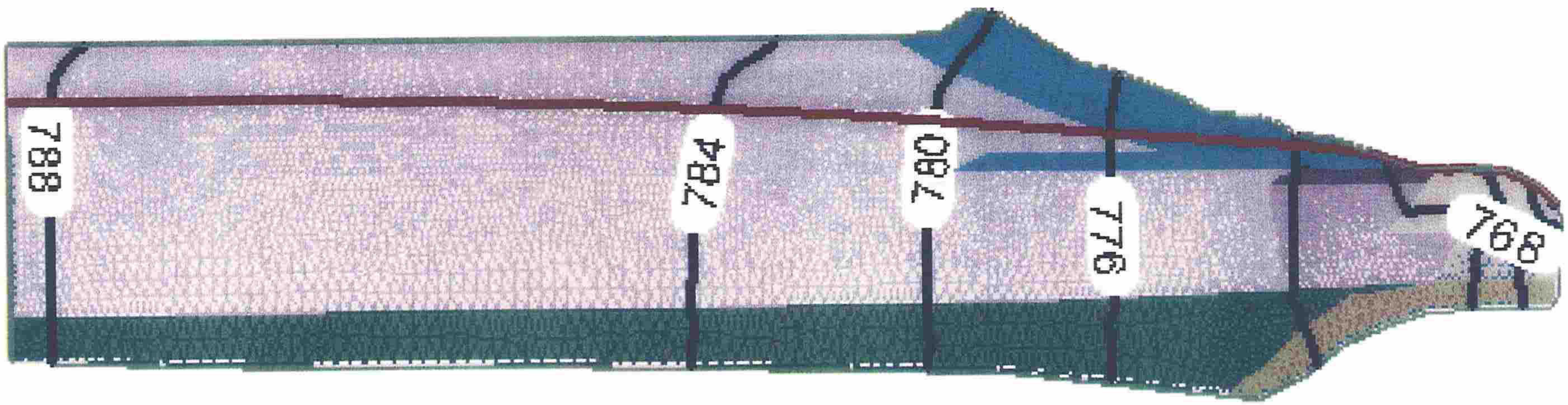
Case 1 (Existing condition)

TIMES Output



Note: Please note that the above figure has Vertical exaggeration

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Case 1 (Existing condition)
SEEP/W Output Summary (Cont.)
Comparison Table of Total Heads

Well ID	Field-measured Total Head[1] at screen interval A [2] (ft, MSL)	Model-predicted Total Head[1] at screen interval A [2] (ft, MSL)	Field-measured Total Head[1] at screen interval B [2] (ft, MSL)	Model-predicted Total Head[1] at screen interval B [2] (ft, MSL)
MW-1	774.1	775.42	N/A	N/A
MW-2	777.1	778.24	N/A	N/A
MW-3	780.6	780.32	772.9	779.84
MW-4	765.6	766.16	761.8	768.94
MW-5	786.5	788.06	789.70	788.02

Notes:

(1) Field–measured total head correspond to water levels elevations recorded on 21 January 2005.

(2) For piezometer locations with two screen intervals, 'A' represent screen interval at a shallow depth and 'B' represent screen interval at a deep depth.

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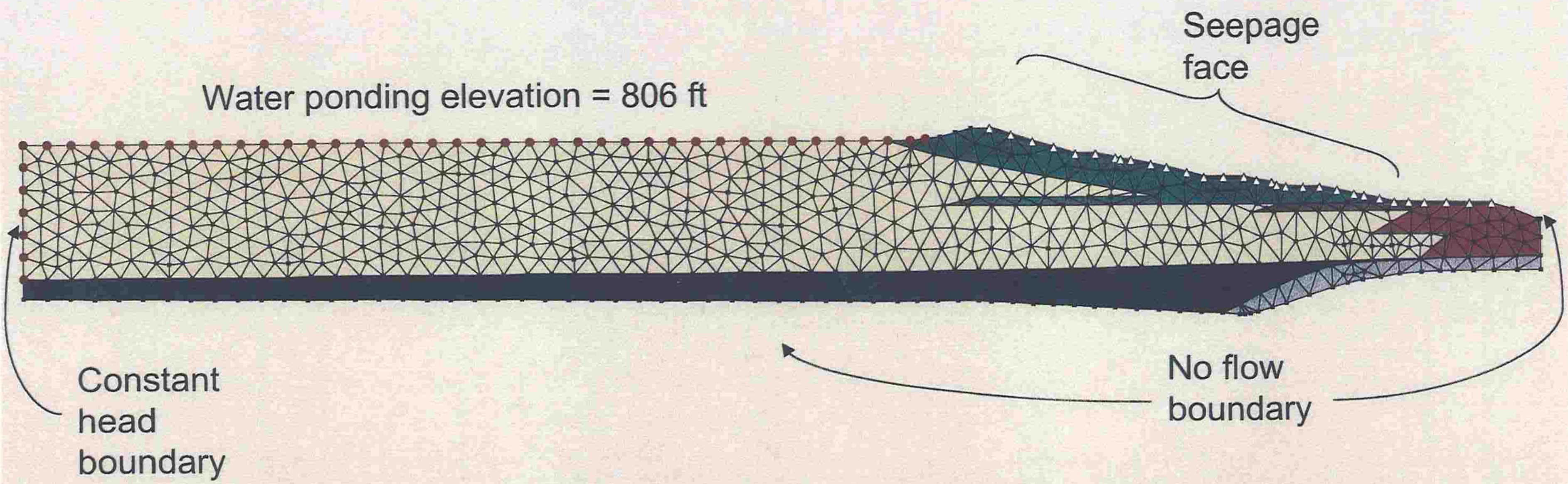
Observations and Conclusions

- Analytical results of Case 1 are in close agreement with total head measurements recorded in the field during the January 2005 site investigation.
- This analysis provides a good calibration for model input parameters (e.g., hydraulic conductivity). Close agreement between model-predicted and field observations provides an appropriate level of confidence in input parameters used.
- Input parameters specified in this analysis (i.e., material properties) were therefore used in subsequent analyses cases.

Case 2 (Blow-out condition)

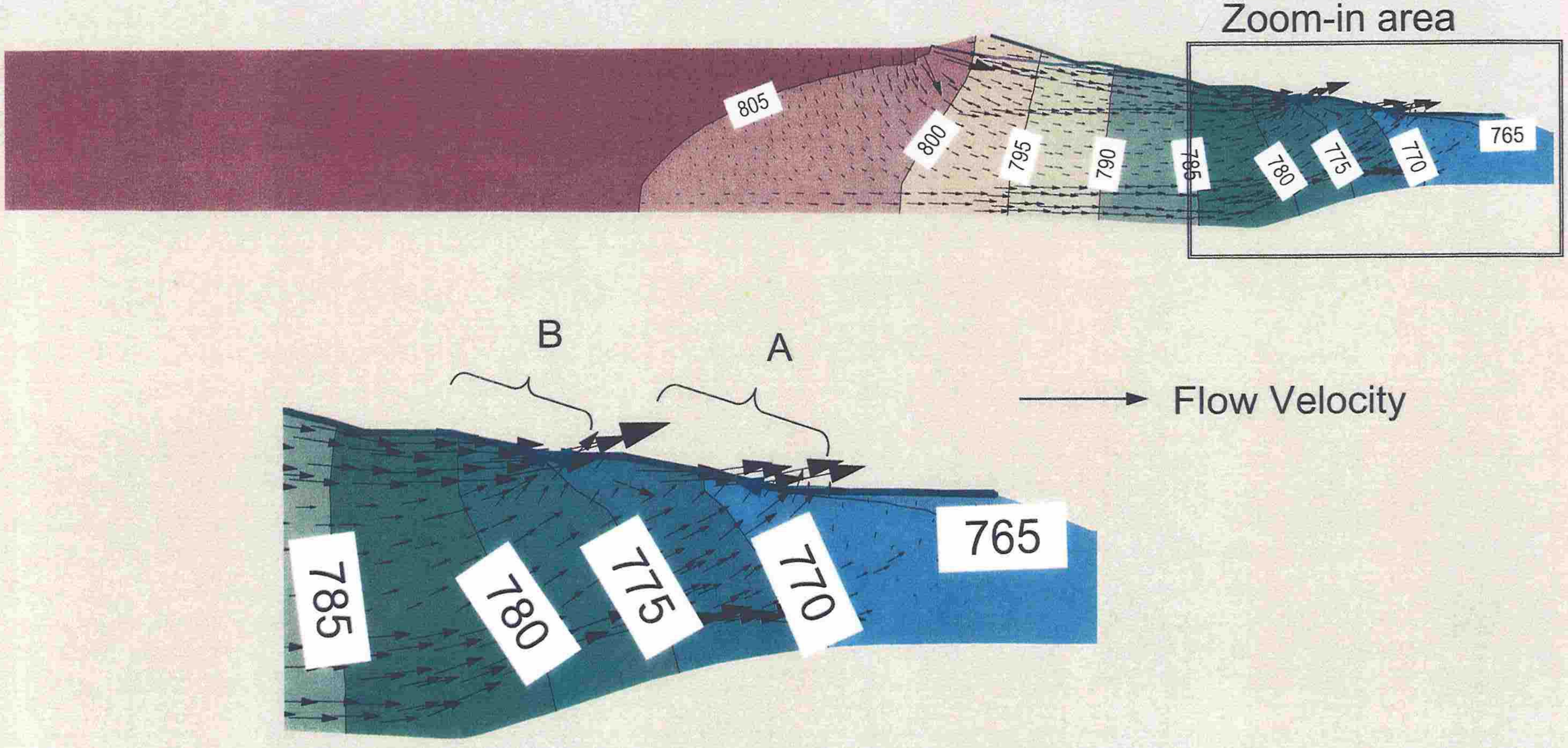
Mesh and Boundary Conditions



Information regarding the depth of water in the dredge cells at the time of blow-out was estimated based on field observations and was provided by TVA personnel during the January 2005 meeting. Water depth in the dredge cell was observed to be 4 feet below the elevation of the top dike (i.e., elevation 810 ft MSL).

Case 2 (Blow-out condition)
SEEP/W Output Summary

Model-predicted Total Head Distribution (equipotential lines)



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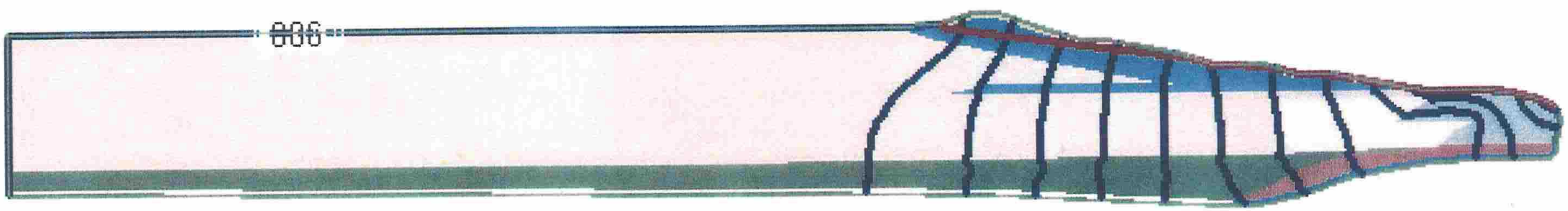
Case 2 (Blow-out condition)

TIMES Output



Case 2 (Blow-out condition)
SEEP/W Output Summary (cont.)

Model-predicted Exit Hydraulic Gradients

	Model-predicted Hydraulic Gradient, i	**Critical Hydraulic Gradient, i_c**	**Piping will occur? (Y/N)**	**Factor of safety against piping F.S. = i_c / i**
Slope face A	**0.25 – 0.31**	**0.28**	**Y**	**0.90 – 1.12**
Slope face B	**0.14 - 0.25**	**0.28**	**N**	**1.12 – 2.00**
Base of slope	**0.21-0.24**	**0.28**	**N**	**1.17 -- 1.33**

Critical hydraulic gradient = $i_c = \gamma_{sub} / \gamma_w$

Where: γ_{sub}= submerged unit weight of fly ash; and γ_w = unit weight of water

Considering the unit weight of fly ash to be 80 pcf, the critical hydraulic gradient = (80-62.4)/62.4 = 0.28.

Acceptable factor of safety against piping is 1.50.

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Case 2 (Blow-out condition)

SEEP/W Output Summary (cont.)

Model-predicted Flow Rates

	Flow rate	
	(ft^3/day/ft)	gpd/ft
Slope face A	**0.85**	**6.36**
Slope face B	**0.57**	**3.63**

Observations

- The computed hydraulic gradient at the lower portions along exit face 'A' is greater than the critical hydraulic gradient, confirming the likelihood that piping and blow-out will occur consistent with that observed in field.

- Model-predicted location of blow-out (i.e., exit face 'A') coincides with blow-out location observed in the field (i.e., at elevation 766 ft MSL).

- Qualitative assessment of analysis results performed for blow-out condition (Case 2) are consistent with visual observations reported in the field (e.g. wet spots on slope, vegetation on downstream slope and estimated quantity of seepage through the blow-out area).

Case 3 (Future conditions)

- As indicated from the analytical results of Case 2 (blow-out condition), blow-out resulted from the development of internal pore water pressure on the face of the slope that caused piping to occur that led eventually to excessive seepage.

- To prevent further piping action and to maintain the stability of the outer slopes, several improvement features need to be incorporated in the future design.

- The design of the proposed vertical and lateral expansion prepared by Parsons will incorporate a series of underdrains located at successive elevations within the outer dike. Notwithstanding these measures, additional measures are needed to assure long-term stability of the lower portion of the side slopes.

- The Project Team have considered several improvement options. These options were evaluated on the basis of: (i) effectiveness to reduce pore pressure at the downstream slope; and (ii) ability to reliably construct/implement.

Case 3 (Future conditions)

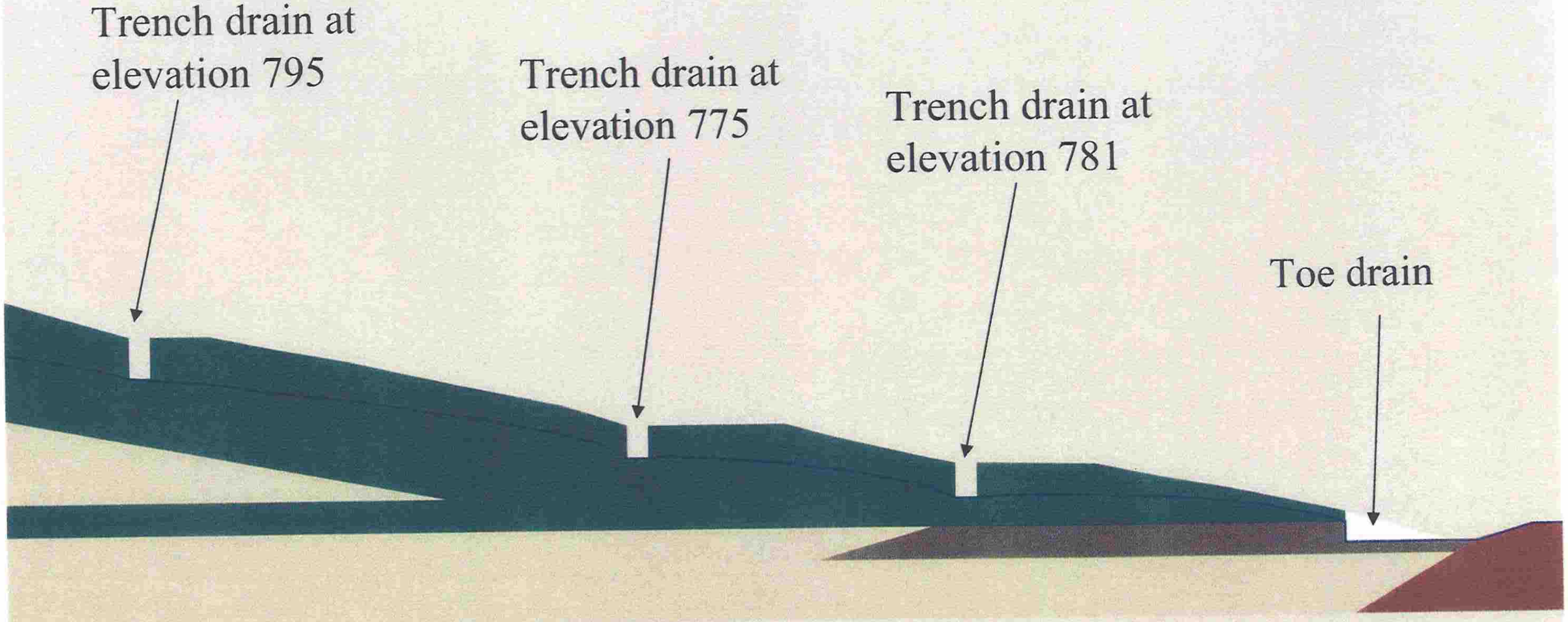
Proposed Improvement

The proposed improvements for the lower portion of the dredge cell side slope consists of the following major items:

- A trench drain constructed to a minimum depth of 6 feet deep from the existing bench at EL 795 feet
- A trench drain constructed to a minimum depth of 5 feet deep from the existing bench at EL 781 feet
- A trench drain constructed to a minimum depth of 5 feet deep from the existing bench at EL 775 feet
- A buttress type toe drain pipe with minimum rip rap lining to the existing drainage channel adjacent to Swan Pond Road.

All trench drains have an assumed width of 3.0 feet.

Proposed Improvement



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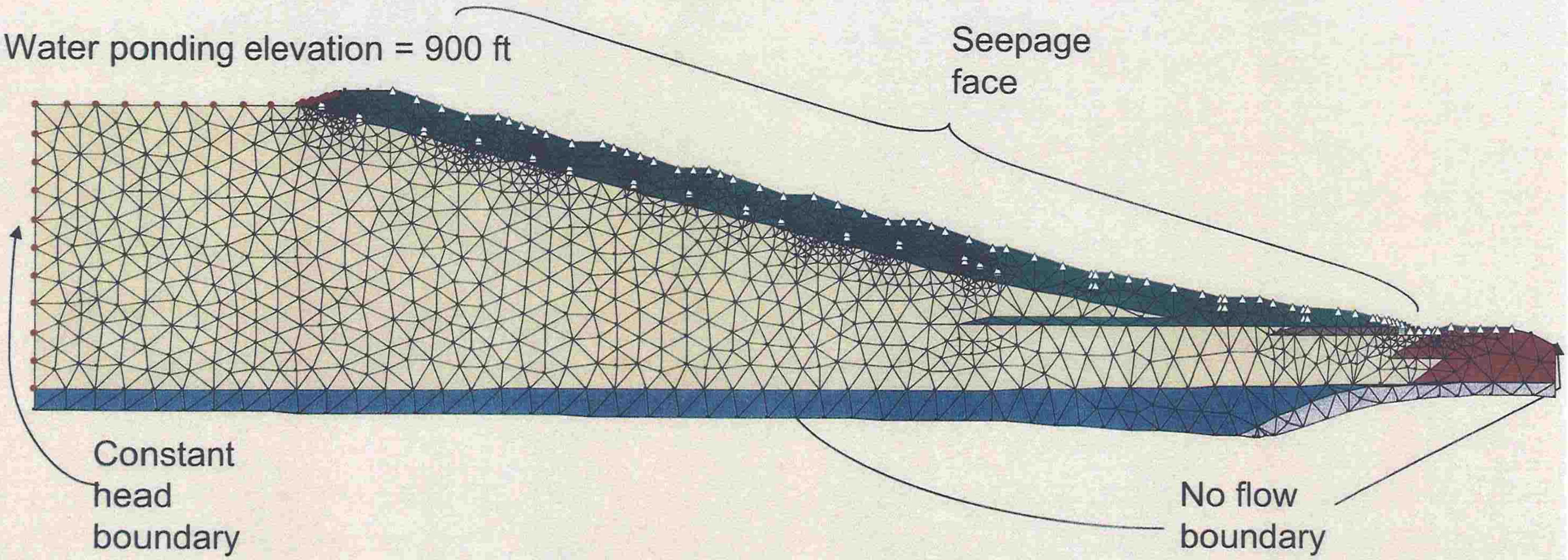
Case 3 (Future condition)

Mesh and Boundary Conditions



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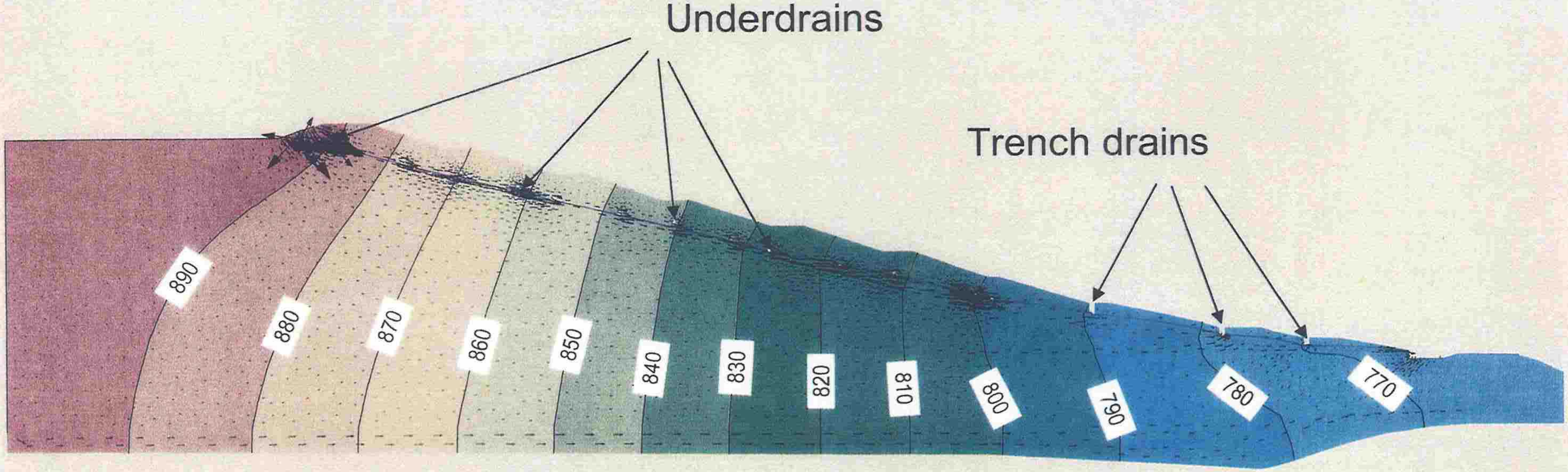
Case 3 (Future condition)

Mesh and Boundary Conditions (cont.)

- Dredge cell configuration under future condition (i.e., Case 3) represents the point in time after which operations in the cell will switch from wet disposal to dry disposal of fly ash.
- Change in disposal operations will take place when the dredge cell disposal area becomes considerably small resulting in a short disposal life.
- Future dredge cell configuration and underdrain locations presented in the previous slide are considered approximate. Configuration for Case 3 based on design drawings shall be considered in the final seepage analysis.
- Water depth in the dredge cell was assumed to be 2.0 feet below the elevation of the top dike (i.e., elevation 902 ft MSL).

Case 3 (Future condition)
SEEP/W Output Summary

Model-predicted Total Head Distribution (equipotential lines)



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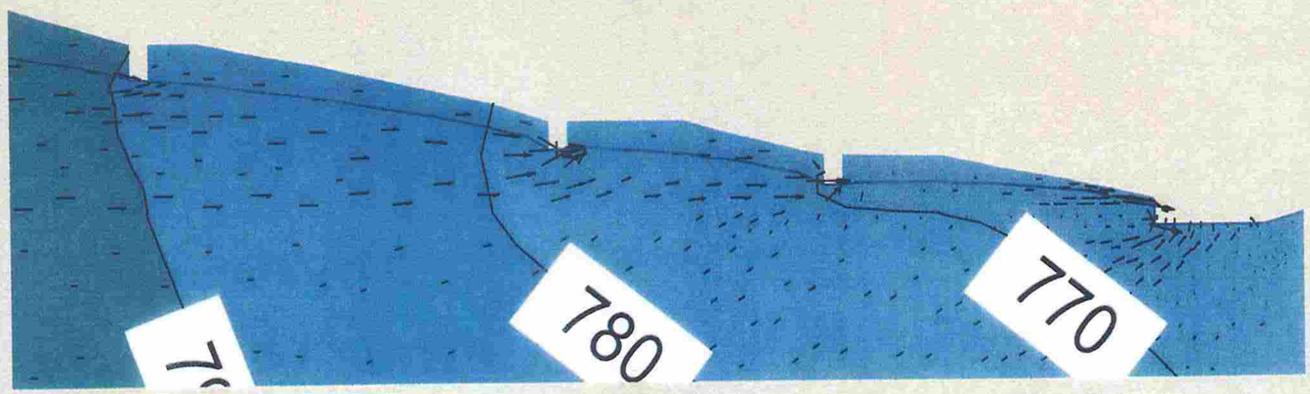
Case 3 (Future Condition)
SEEP/W Output Summary (cont.)

Model-predicted Flow rates

	Elevation	Flow rate into drains	
		ft^3/day/ft	gpd/ft
Trench drain	795	0.33	2.43
Trench drain	781	0.98	7.33
Trench drain	775	0.90	6.74
Toe Drain		0.68	5.08

Flow rates estimated from the analytical model are used for trench drain design and perimeter ditch cross section design.



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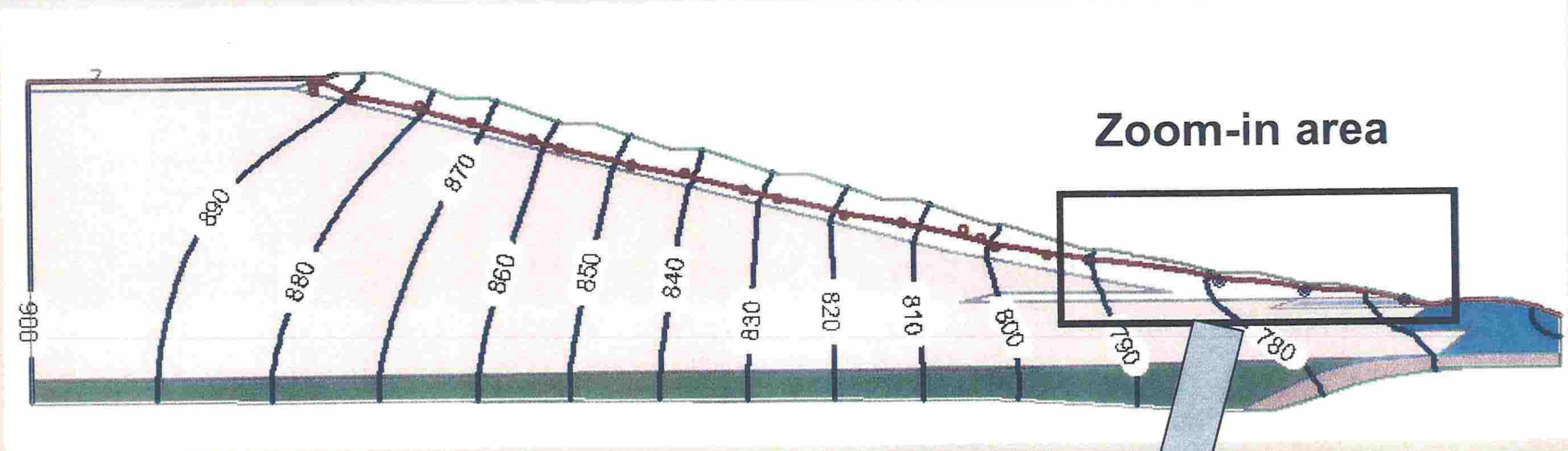
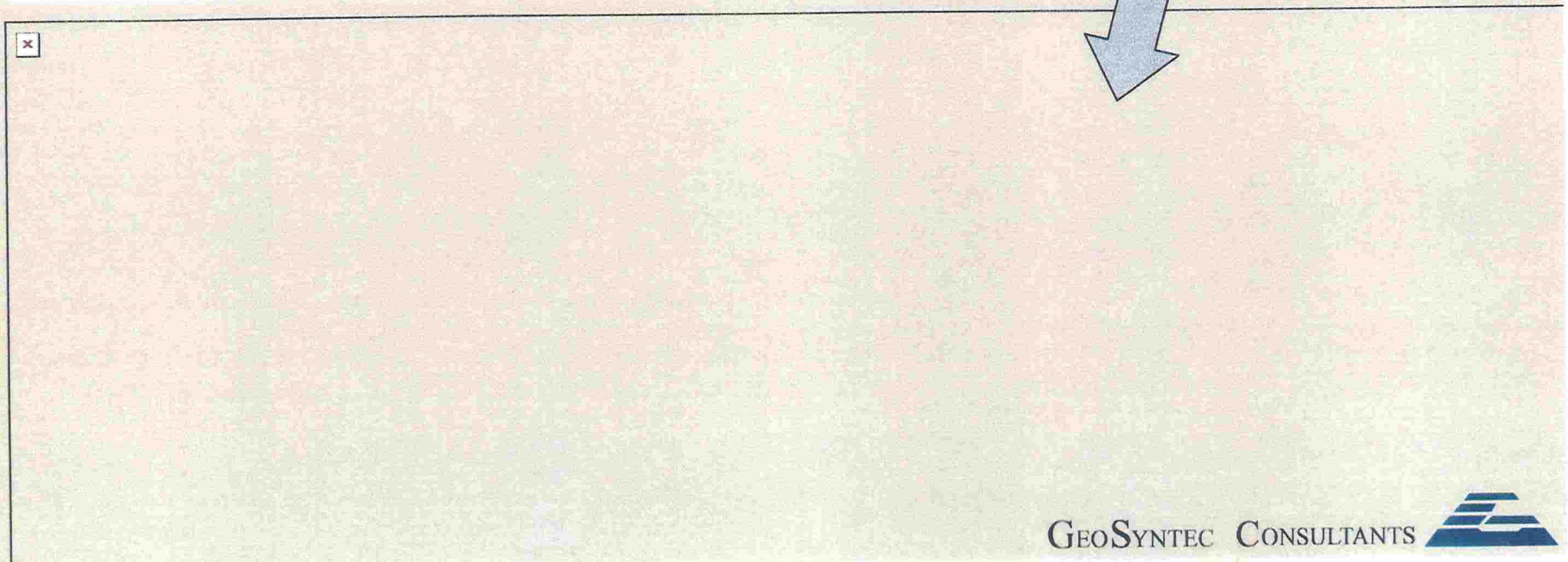
Case 3 (Future condition)
TIMES Output





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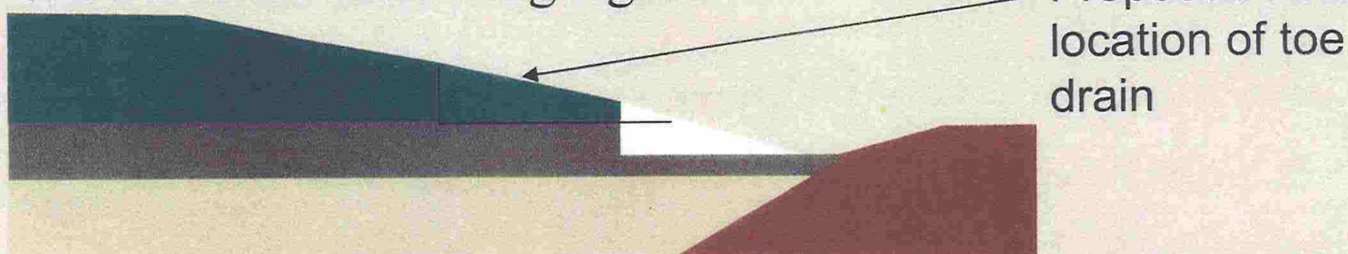
Conclusions and Final Recommendations

- Based on analytical results for Case 3, the proposed improvements are expected to lower the phreatic surface away from the face of the lower portion of the side slope significantly reducing the future potential for piping and providing an acceptable factor of safety.

- An alternative to the proposed improvement include relocating the toe drain is shown in the following figure



- In addition to the seepage analyses presented herein, GeoSyntec recommends that Parsons review/re-evaluate the slope stability analysis to assess the factor of safety against global stability under future conditions.

- The independent seepage analyses prepared by GeoSyntec are in general agreement with the analyses prepared by Parsons.