APPENDIX H

Technical Analysis

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APPENDIX H: TECHNICAL ANALYSIS

MEMORANDUM
Pickering And Ajax Dykes Environmental Assessment – Geotechnical Design Rationale

KGS GROUP

Memorandum

To:	Toronto and Region Conservation Authority ATTN: Melody Brown, P.Eng.	**Date:**	June 17, 2020
		Project No.:	19-2939-003
From:	Chris Robak, P.Eng., Rob Kenyon, Ph.D., P.Eng., FEIC	**Cc:**	Fuad Curi, M.Asc., P.Eng.
Re:	Pickering and Ajax Dykes Environmental Assessment – Geotechnical Design Rationale		

1.0 INTRODUCTION

Toronto and Region Conservation Authority (TRCA) is undertaking a Conservation Ontario Class Environmental Assessment for Remedial Flood and Erosion Control Projects (Conservation Ontario 2002, amended 2013) to rehabilitate the Pickering and Ajax Flood Control Dykes. The rehabilitation will ensure that the dykes meet current engineering standards and estimated factors of safety (FOS) while maintaining at minimum the level of flood protection associated with the existing dyke heights, to reduce the risk to public safety and loss of property.

This appendix supplements the Environmental Study Report (ESR) and includes the geotechnical rationale that were used to evaluate the stability conditions of the existing dykes and suitability of the preferred and alternative dyke remediation solutions. This memorandum should be used in conjunction with the geotechnical report, provided in Appendix B of the ESR.

2.0 ASSESSMENT CRITERIA

2.1 Guidelines and Standards

The applicable standards and guidelines that were required to be considered include:

- MNRF's Technical Bulletin for Geotechnical Design and Factors of Safety (2011), associated with the Lakes and Rivers Improvement Act (LRIA)
- Canadian Dam Association (CDA) guidelines and technical bulletins
- Ontario Dam Safety Act

2.1.1 SLOPE STABILITY DESIGN CRITERIA

Table 1 summarizes the slope stability factor of safety (FOS) criteria from the MNRF Technical Bulletin for Geotechnical Design and Factors of Safety (2011). These criteria are consistent with CDA guidelines. As noted on the table, we also considered the transient response for both the design flood loading and the rapid drawdown scenarios. Transient analysis models the actual response of the dyke to the design flood hydrograph.

TABLE 1 – 2: LOAD CASES ANALYZED

Loading Conditions	Minimum Factor of Safety (FS)	Slope[3]
1. Long-term (steady state seepage, normal river level)	1.5	Upstream and Downstream
2. IDF loading condition (Regional Flooding)	1.3	Downstream
2a. Modified IDF loading condition considering transient analysis	1.3[1]	Downstream
3. Rapid drawdown	1.2[2]	Upstream
3a. Modified Rapid drawdown considering transient analysis	1.2[1]	Upstream

Notes:

1. Note that the MNRF geotechnical design criteria require steady-state seepage analysis for the design flood, but for this concept stage KGS has also considered transient conditions.
2. FOS can vary from 1.2 to 1.3 based on the conditions based on MNRF criteria. Lower value selected due to infrequent drawdown conditions.
3. Upstream = Wet Side of Dyke, Downstream = Dry Side of Dyke

Load Case #1 – Long-term (Steady-state Seepage, Normal River Level)

This load case assumes that long-term steady-state seepage groundwater regime has been established within the dyke and foundation materials under normal operating conditions. Load Case 1, as defined by the MNRF Geotechnical Design and Factors of Safety, is most applicable to water retaining structures such as dams that see continuous impoundment at some normal maximum operating level for an extended period of years. The expectation is that steady-state conditions might eventually develop from the upstream side to the downstream side of the dyke. For the Ajax and Pickering Dykes, the river level for the normal condition is below the dry side toe elevation and therefore normal conditions are considered to be an analysis of dry dyke conditions. The assumed river level under the normal condition varies by location. The normal water level was assumed to vary from El. 78.9 m to 81 m at two representative sections of the Pickering Dyke. At the Ajax Dyke, this creek level was assumed to be El. 77.3 m at one representative section. The steady-state groundwater levels for this condition are assumed to be equal to the creek levels at the locations of the sections.

Load Case #2 – Modified Inflow Design Flood (IDF) or Design Condition

This load case assumes that long-term steady-state seepage groundwater regime has been established within the dyke and foundation materials under the design creek level (500-year event). Load Case 2, as defined by the MNRF Geotechnical Design and Factors of Safety, is applicable to any water retaining structure that may see temporary impoundment above the normal maximum operating level. Even though the increased level is temporary, the criteria stipulates that steady-state conditions for the design event should be assumed to eventually develop from the upstream side to the downstream side of the dyke. The 500-year water level was selected for this load case because the TRCA had indicated that it would be desirable to ensure that the dyke seepage control measures would be capable of sustaining this flood event even though the current and proposed crest levels are lower than the updated 500-year water surface profile. This is a proactive design requirement to allow for future raising of the dykes, if necessary. The creek level for this load case was assumed to vary from El. 82.6 m to 84.01 m at two representative sections of the Pickering Dyke. At the Ajax Dyke, this level was assumed to be El. 81.54 m at one representative section. Steady-state groundwater levels for this condition are defined based on a seepage analysis with the design water level set as a boundary condition on the upstream side of the model and a free draining boundary condition on the downstream side of the model.

This analysis case is most applicable to the dry side of the dyke as the wet side slope stability safety factor would be higher under this load condition than the safety factor determined for normal conditions (Load Case 1) due to the elevated river level acting on the wet side dyke slope. If the wet side slope satisfies the FOS for Load Case 1 it will also satisfy the required safety factor for Load Case 2.

Load Case #2a – Inflow Design Flood (IDF) Condition, Considering Transient Seepage Analysis

KGS Group has completed a modified form of analysis for Load Case 2 by considering time-dependent effects to examine how the existing dyke FOS values may compare to the steady-state analysis case. To examine this scenario, the 500-year flood hydrographs were used to develop additional inputs into transient seepage models. The quickest rate of staging and drawdown in the flood hydrographs was approximately 3 mm per minute and the longest flood peak duration was approximately 6 hours. In the transient models, KGS Group has assumed a doubled rate of flood staging (6 mm per minute) and a flood peak with a 24-hour duration. Note that MNRF design criteria require the assumption of steady-state seepage conditions. Now the model is run in the transient or time-step mode, allowing the pore pressures in the dyke to develop as a function of the flood hydrograph and duration as well as the actual permeability in the dyke and foundations. If a transient analysis is completed to optimize the final design of any dyke remediation measures, the desired duration for which the optimized design can be considered reliable should be determined in consultation with TRCA.

The minimum duration of reliability under flood conditions should not only consider the current 500-year flood hydrograph, but also an additional factor of safety to account for inherent variability in flood forecasting, as well as changes to the drainage basin over time, including changes from alterations to land use and development, the effects of climate change, and variations in soil permeability. If there is no tolerance for risk associated with design considering time-dependent effects, then detailed design should proceed according to the assumption of steady-state seepage conditions as required by MNRF geotechnical design and factors of safety (i.e. Load Case 2).

Load Case #3 – Rapid Drawdown

The stability of the dyke under rapid drawdown condition was evaluated by instantaneously lowering the river level from the design creek level (500-year storm) to the normal creek level. Similar to the previous analyses completed by Valdor, KGS Group utilized a single phreatic surface line to analyze this condition. The phreatic surface line corresponded to full saturation of the dyke fill material below the 500-year level with Duffins Creek at its normal water level.

Load Case #3a – Modified Rapid Drawdown Considering Transient Analysis

The stability of the dyke under rapid drawdown condition was also evaluated by examining slope stability conditions at discrete timesteps during the drawdown using the transient seepage models developed for analysis of Load Case #2a. Similar to Load Case #2a, this option is presented because there may be opportunities in detailed design to optimize solutions if a design considering time-dependent effects is permissible to TRCA. In addition to assuming a longer actual minimum flood peak duration prior to the drawdown, a quicker than actual anticipated rate of drawdown should also be considered The current preliminary analysis assumes twice the rate of drawdown versus the 500-year hydrograph. Final flood peak durations and drawdown rates should be developed during detailed design in conjunction with TRCA. If there is no tolerance for risk by considering time-dependent effects, detailed design should proceed according to the assumption of steady-state conditions being established in the dyke fill prior to drawdown and an instantaneous drawdown rate.

Seismic Pseudo-Static Analysis

The MNRF Technical Bulletin also requires a minimum stability factor of safety of 1.0 when evaluating a pseudo-static seismic load condition. The previous analyses by Valdor Engineering (2018) found that the existing dykes satisfied the minimum safety factor for this load case. The previous analysis considered that:

- The rehabilitated dykes would have better performance than the existing dykes.
- The earthquake conditions are not expected to govern the design of the dykes because they do not retain water permanently and are not expected to be holding back water during an earthquake.

Additional analysis of the pseudo-static load case was not considered necessary for this proof-of-concept level of design. However, the analysis of the pseudo-static load case, with a reasonable seismic load assumption, is recommended for the subsequent design phases, in which the concepts will be refined and detailed for construction. KGS Group considers soil liquefaction to be an unlikely mode of failure for the foundation conditions encountered during the site investigation and the material properties of the proposed dykes. This assumption should be corroborated in subsequent design stages.

2.1.2 SEEPAGE DESIGN CRITERIA

A key consideration for limiting potential damage from seepage is to limit the hydraulic exit gradient to minimize the potential for internal erosion and piping failure during a flood event,particularly with fine grained, cohesionless foundations that exhibit high permeability conditions.

When the hydraulic exit gradient within a soil approaches a critical level, the effective normal stress on any plane will converge toward zero; that is, gravitational forces on the soil particles having been negated by seepage forces. In the case of granular soils (cohesionless soil), the contact forces between the soil particles may become significantly reduced and the soil may lose its shear strength. The soil may behave as a fluid (i.e. exhibit “quick” condition), and result in “piping” or “boiling” as the particles are moved around with the upward flow of water, potentially leading to erosion of the foundation soils.

The critical gradient is defined by Terzaghi (1943) as:

$$i_{cr} = (\gamma' / \gamma_w)$$

Where:

- γ' - buoyant unit weight of soil
- γ_w - unit weight of water

The MNRF geotechnical design criteria requires hydraulic gradients to be below acceptable levels but there is no formal definition of acceptable levels in the MNRF criteria. Numerous technical journals document the exit gradients at which piping is possible and these exit gradients vary drastically based on soil type. Cohesionless, fine grained, poorly graded sands such as those encountered at this site are most susceptible to piping and under very low gradients. Lambe and Whitman (1979) suggests that a safety factor greater than 3 to 4 would be suitable considering that the consequences of piping or quick conditions at the toe of dyke are serious and that minor variations in soil conditions might cause relatively large errors in the computation for the exit gradient. Considering the variability in soil stratigraphy and the predominantly cohesionless foundation soils encountered at this site, KGS Group has selected a minimum estimated FOS of 5 as the minimum criteria for a suitable exit gradient. Using the recommended soil unit weight from the geotechnical investigation report (Appendix B), which is 19kN/m^3, this FOS corresponds to a recommended maximum soil exit gradient of 0.19.

3.0 STABILITY AND SEEPAGE ANALYSIS

KGS Group completed an independent seepage and slope stability analysis of the existing Ajax and Pickering Dykes using GeoStudio SLOPE/W and SEEP/W software. KGS Group obtained similar FOS values as those previously obtained by Valdor (2018). The analysis used the material parameters recommended in the geotechnical report included in Appendix B of the ESR. The station numbering describing the locations of the dyke sections below refer to the stations illustrated in Figures Y1 and Y2 for the Pickering and Ajax Dykes, respectively.

The slope stability was carried out using SLOPE/W software by Geo-Slope International Ltd. The Morgenstern-Price method of analysis was employed for the slope stability assessment using the limit equilibrium method. This method considers both shear and normal interslice forces, and it satisfies both moment and force equilibrium. A seepage model (SEEP/W) that incorporates the finite element method (FEM) was set-up as part of the stability analysis to establish both the long-term (steady-state) and short-term (transient) groundwater and porewater pressure response to the design flood event hydrograph.

3.1 Analysis of Existing Conditions

3.1.1 CROSS SECTIONS

Figures 1 and 2 illustrate the locations of the following three representative dyke sections that were analyzed as part of the slope stability assessment:

- Section 1 - Pickering Dyke Near West End at Sta. 0+870
- Section 2 - Pickering Dyke Near East End at Sta. 0+150
- Section 3 - Ajax Dyke Near Center of Dyke at Sta. 0+160

FIGURE 1 – CROSS SECTION LOCATIONS AT PICKERING DYKE

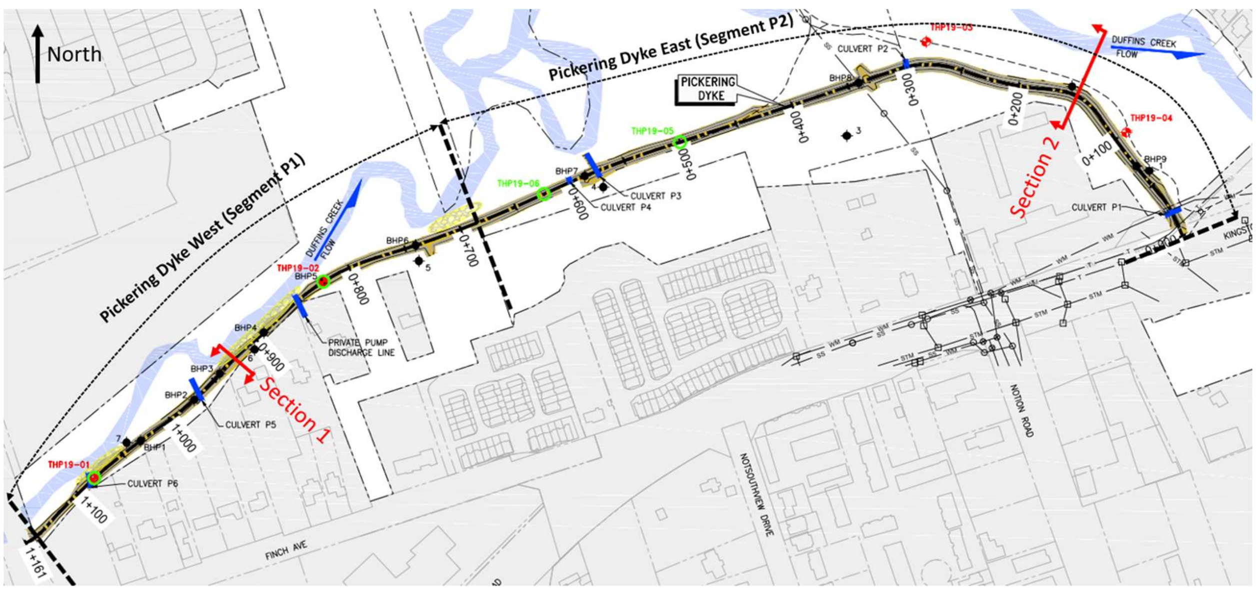
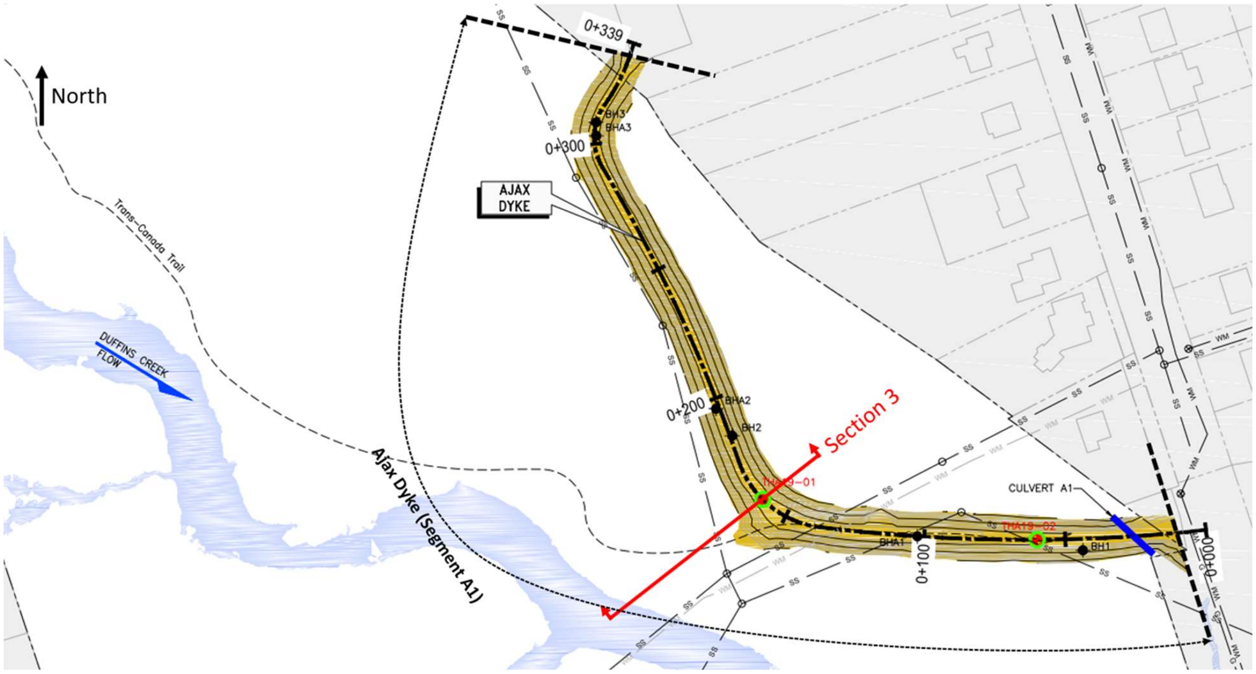


FIGURE 2 – CROSS SECTION LOCATIONS AT AJAX DYKE



Section 1 is located on the west end of the Pickering Dyke in an area where the dyke was constructed into the West Duffins Creek channel in the 1980's. The wet side slope is approximately 3.5 m high and as steep as 1.5H:1V. A riprap blanket is present along the lower half of the slope and trees and shrubs line the upper half. On the dry side, the slope is approximately 1 m high and slopes at 2H:1V. Private properties are located immediately behind the dry side of dyke. The existing crest of the dyke is 3 m wide, the crest is clear of vegetation and the crest is accessible. The stratigraphic conditions in the slope stability and seepage models for this section are taken from nearby Sta 0+925 where the geometry is similar to that at Sta 0+870 but where seepage conditions would be more critical owing to the presence of a confined sand and gravel layer approximately 2 m below the toe of dyke (See Appendix B Geotechnical Investigation Report stratigraphic profile). The water level for the 500-year event at this section is El. 84.01 m, or approximately 0.1 m higher than the dyke crest at this location (El. 83.9 m).

Section 2 is located on the east end of the Pickering Dyke where the dyke was constructed at least 30 m away from Duffins Creek. The wet slope is approximately 2.2 m high and has an average slope of 2.6H:1V. The dry slope is approximately 2.4 m high and slopes at 2.5H:1V. The crest of the dyke is currently inaccessible due to overgrown vegetation and it has a narrow crest width of approximately 2 m. Private properties are located within 6 m of the dry side toe of dyke and the TransCanada Trail follows the wet side toe of dyke. The water level for the 500 year event at this section is El. 82.6 m, or approximately 0.6 m lower than the dyke crest (El. 83.21 m).

Section 3 is located at the center of the Ajax Dyke where the dyke was constructed at least 50 m away from Duffins Creek. The wet slope at this section is approximately 2.3 m high and the average slope is 2.8H:1V. The dry slope is approximately 2.8 m high and slopes at 2.8H:1V. The dyke crest is approximately 5 m wide.

Both slopes are overgrown with vegetation along the downstream length of the dyke where the dyke crest also functions as the TransCanada Trail. On the upstream length of the dyke, both the dyke crest and slopes are overgrown with vegetation and access along the crest is limited to foot traffic. Private properties are located as far as 70 m away from the toe of dyke at the apex of the bend in the dyke where Section 3 was taken. The water level for the 500 year event at this section is El. 81.54 m, or approximately 0.23 m higher than the dyke crest (El. 81.3 m).

3.1.2 MATERIAL PARAMETERS

The key engineering parameters assigned to the various materials for the seepage and slope stability analyses were consistent with those summarized in the Appendix B geotechnical report. See Table 2.

For the transient analyses, the materials in Table 2 require the definition of volumetric water content and hydraulic conductivity functions. At this concept stage, the preliminary transient analysis assumed volumetric water content and saturated hydraulic conductivity functions that were estimated from typical functions that are built-in to SEEP/W for similar material types to those listed in Table 2. The coefficient of volume compressibility for all material types was assumed to be 6.7 x 10^{-5} 1/kPa. If a transient analysis is selected to optimize the proposed dyke rehabilitation at subsequent stages of design, a sensitivity analysis of the transient analysis input parameters should be completed to ensure a robust design.

TABLE 2 – SOIL MATERIAL PARAMETERS

MATERIAL (USCS SOIL TYPES)	SATURATED HYDRAULIC CONDUCTIVITY, K_{SAT} (cm/s)	UNIT WEIGHT, γ (kN/m^3)	EFFECTIVE FRICTION ANGLE Φ'	COHESION, C' (kPa)
Dyke Fill (Clayey Silt Till Fill)	1 x 10^{-5}	19.5	30°	0
Clayey Silt /Silty Sand	1 x 10^{-3} - Pickering 1 x10^{-5} - Ajax	18	30°	0
Sand with Gravel	1 x 10^{-1} - Pickering 1 x10^{-3} - Ajax	21	34°	0
Clayey Silt Till	1 x 10^{-5}	21.5	35°	0

3.1.3 GROUNDWATER CONDITIONS

The groundwater conditions in the slope stability and seepage models are consistent with the levels presented in the criteria definition section of this memorandum (Section 2.1.1). Where groundwater levels are not stated in Section 2.1.1, they are calculated using the SEEP/W program with boundary conditions consistent with flooding on the wet side of the dyke and a free draining face on the dry side of the dyke and assuming the hydraulic conductivity input parameters listed above.

In the transient models, KGS Group has assumed a hydrograph function for the upstream boundary condition with a doubled rate of flood staging (6 mm per minute) relative to the actual flood hydrograph and a flood peak with a 24-hour duration. Timesteps were examined in 2-hour intervals. If a transient analysis is selected to optimize the proposed dyke rehabilitation at subsequent stages of design, a sensitivity analysis of the transient analysis input parameters should be completed to ensure a robust design. Timesteps in the transient models should also be appropriately adjusted if a sensitivity analysis is completed to examine the effects of varied rates of flood staging and flood durations.

3.1.4 STABILITY ANALYSIS RESULTS

The calculated FOS values for the three cross sections are summarized in Table 3 for comparison to MNRF criteria. Figures 3 to 14 illustrate the slope stability analyses results. Note that all reference figures are oriented such that the view is facing upstream. The dry side of the dyke is therefore on the left side of the figures for the Pickering Dyke at Section 1 and 2, and on the right side of the figures for the Ajax Dyke.

The results illustrate that the dykes typically satisfy MNRF criteria under normal conditions but they do not achieve the necessary FOS on the dry side of the dyke under the design flood conditions. Additionally, the dykes do not achieve the necessary FOS on the wet side of the dyke under an instantaneous drawdown event. Section 1 is unique in that it does not meet the required FOS on the wet side of the dyke even under normal conditions. The comparatively low FOS at Section 1 on the wet side occurs because this section is located where the Pickering Dyke was built into West Duffins Creek and the overall dyke slope on the wet side is highest and steepest.

TABLE 3 – STABILITY ANALYSIS RESULTS FOR EXISTING CONDITIONS COMPARED TO MNRF CRITERIA

Load Case Description	Design Criteria (FOS)	Section	Slope	FOS	Reference Figure
1. Long-term (steady state seepage, normal river level)	1.5	Section 1	Dry Side	2.07	3
			Wet Side	**1.11**	4
		Section 2	Dry Side	1.70	5
			Wet Side	1.75	6
		Section 3	Dry Side	1.81	7
			Wet Side	1.77	8
2. IDF loading condition (Regional Flooding)	1.3	Section 1	Dry Side	**0.71**	9
		Section 2	Dry Side	**1.05**	10
		Section 3	Dry Side	**1.03**	11
3. Rapid drawdown	1.2	Section 1	Wet Side	**0.83**	12
		Section 2	Wet Side	**0.85**	13
		Section 3	Wet Side	**0.91**	14

KGS Group's calculated FOS values are generally higher than those calculated in the 2018 Valdor report for sections that were analyzed at similar locations. The difference in results could be because we have utilized actual TRCA topographic survey data while the Valdor Study analyzed simplified cross-sections with 2H:1V slopes, a 3 m dyke crest, and the same slope height on both the wet and dry sides. The surveyed dyke slopes show that the wet side slope is steeper than 2H:1V at Section 1, and both the wet and dry side slopes in Sections 2 and 3 are flatter than 2H:1V. Nevertheless, the overall conclusion remains the same that the dykes do not achieve the required FOS under steady-state flood conditions or under instantaneous drawdown.

KGS Group also examined the transient response of groundwater conditions to the design flood hydrograph. The results of those models are summarized in Table 4 and illustrated in Figures 15 to 20.

TABLE 4 - STABILITY ANALYSIS RESULTS FOR EXISTING CONDITIONS CONSIDERING TIME DEPENDENT EFFECTS

Load Case Description	Design Criteria (FS)	Section	Slope	FoS	Reference Figure
2a. Modified IDF loading condition considering transient analysis	1.3[1]	Section 1	Dry Side	**1.03**	15
		Section 2	Dry Side	**1.13**	16
		Section 3	Dry Side	1.66	17
3a. Modified Rapid drawdown considering transient analysis	1.2[1]	Section 1	Wet Side	**1.02**	18
		Section 2	Wet Side	1.48	19
		Section 3	Wet Side	**1.10**	20

1. Note that the MNRF geotechnical design criteria require steady-state seepage analysis at IDF; but for this concept stage of design it is also used for transient conditions.

The transient modelling results illustrate that Section 1 does not satisfy the minimum recommended FOS on either side of the dyke. For Section 2, the calculated FOS on the dry side of the dyke is below the recommended criteria even considering the more representative transient model conditions. The FOS on the wet side of the same section would be improved compared to the steady-state model and would meet the recommended FOS for drawdown. For Section 3, the calculated FOS on the dry side of the dyke, assuming transient conditions, would be high enough to satisfy the recommended criteria but the wet side of dyke would not have an adequate FoS under the rapid drawdown analysis, even considering transient seepage effects.

FIGURE 3 – SECTION 1 ANALYSIS RESULT FOR LOAD CASE 1 ON DRY SIDE OF DYKE

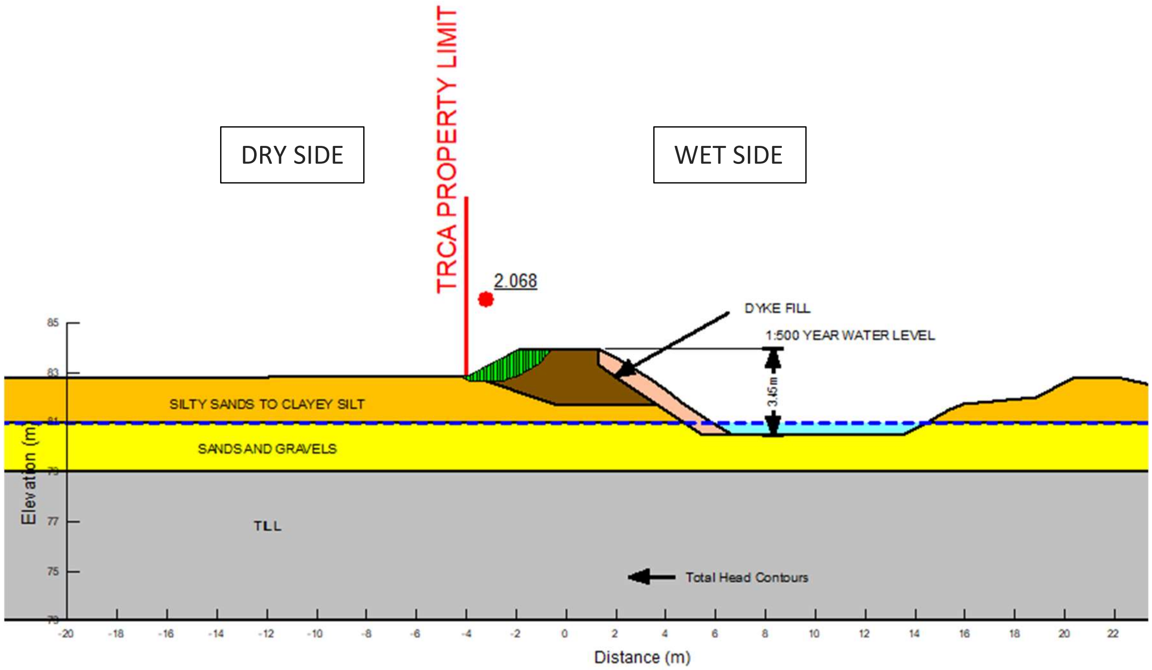


FIGURE 4 – SECTION 1 ANALYSIS RESULT FOR LOAD CASE 1 ON WET SIDE OF DYKE

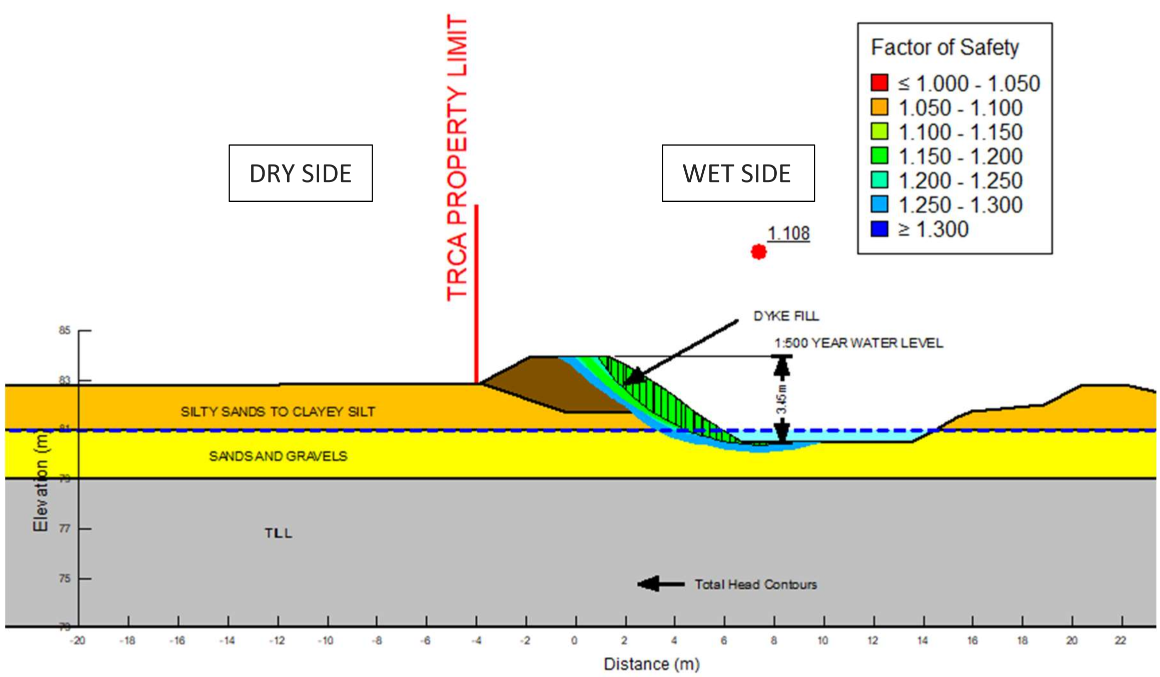


FIGURE 5 – SECTION 2 ANALYSIS RESULT FOR LOAD CASE 1 ON DRY SIDE OF DYKE

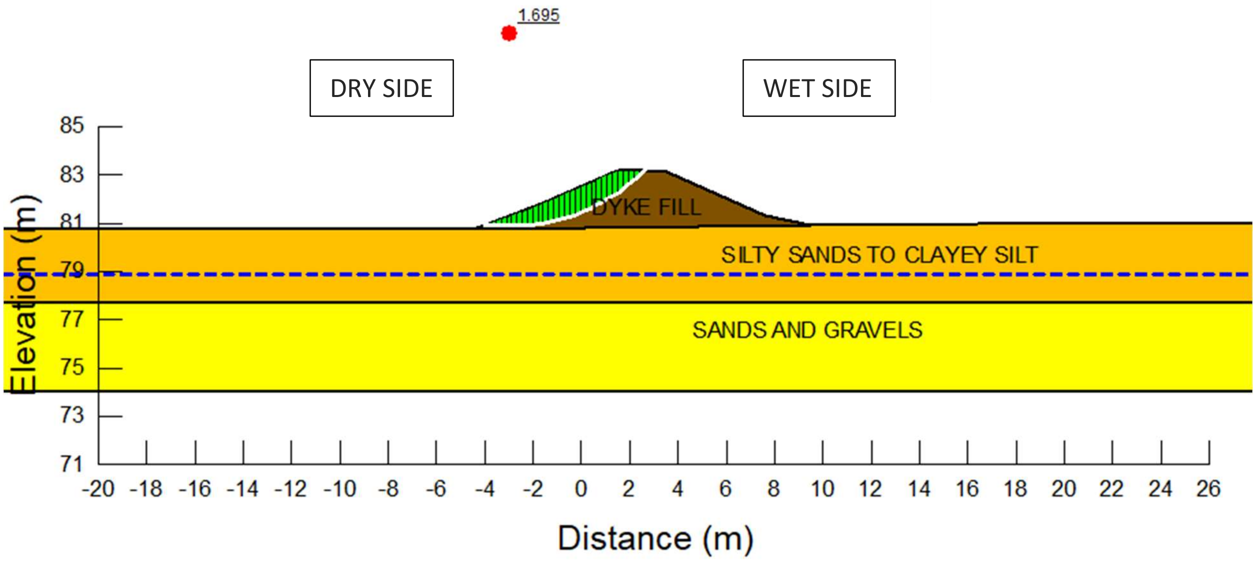


FIGURE 6 – SECTION 2 ANALYSIS RESULT FOR LOAD CASE 1 ON WET SIDE OF DYKE

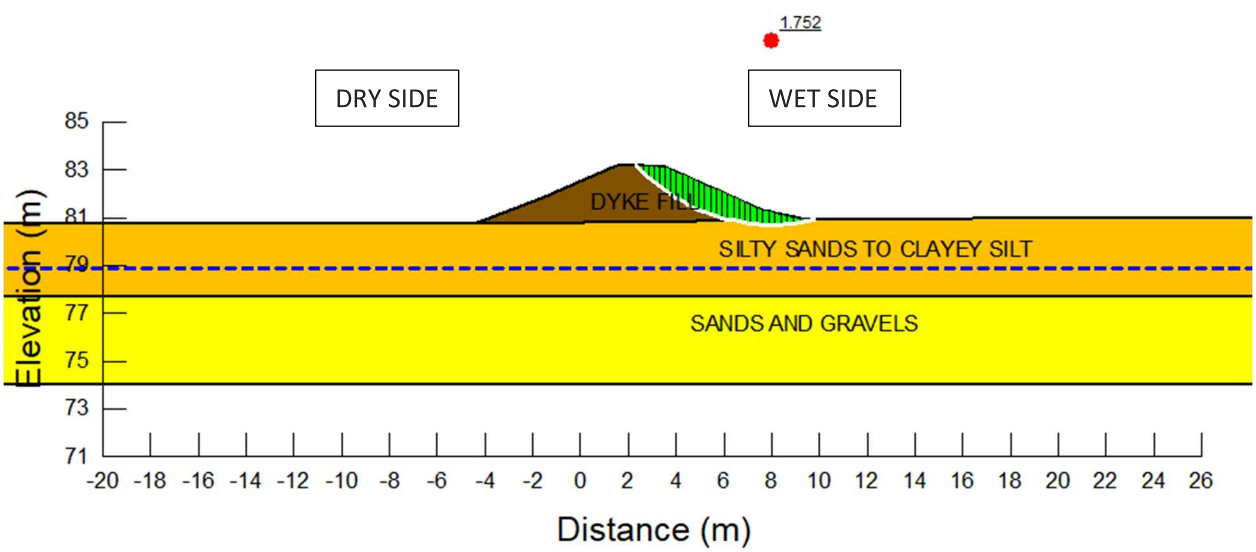


FIGURE 7 – SECTION 3 ANALYSIS RESULT FOR LOAD CASE 1 ON DRY SIDE OF DYKE

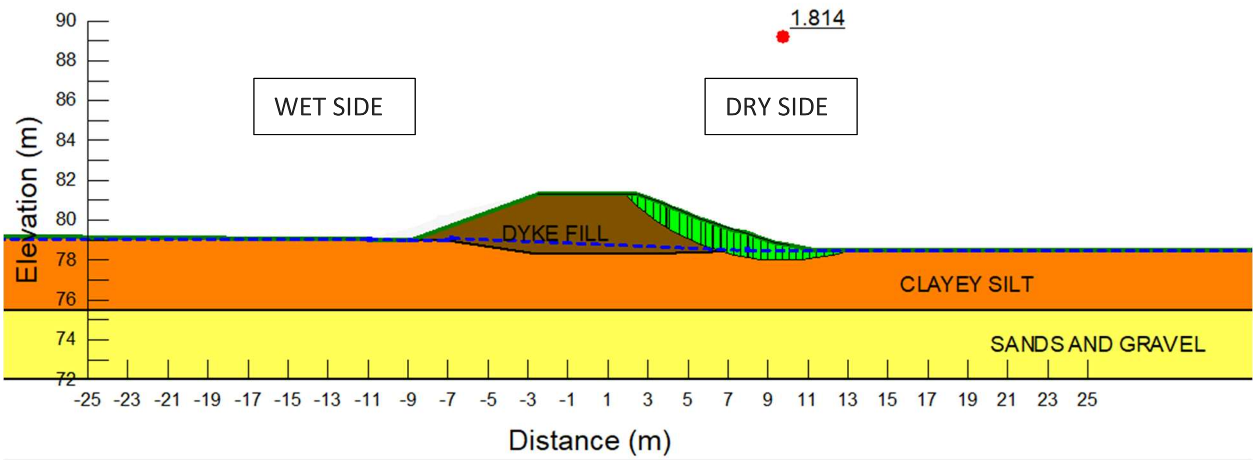


FIGURE 8 – SECTION 3 ANALYSIS RESULT FOR LOAD CASE 1 ON DRY SIDE OF DYKE

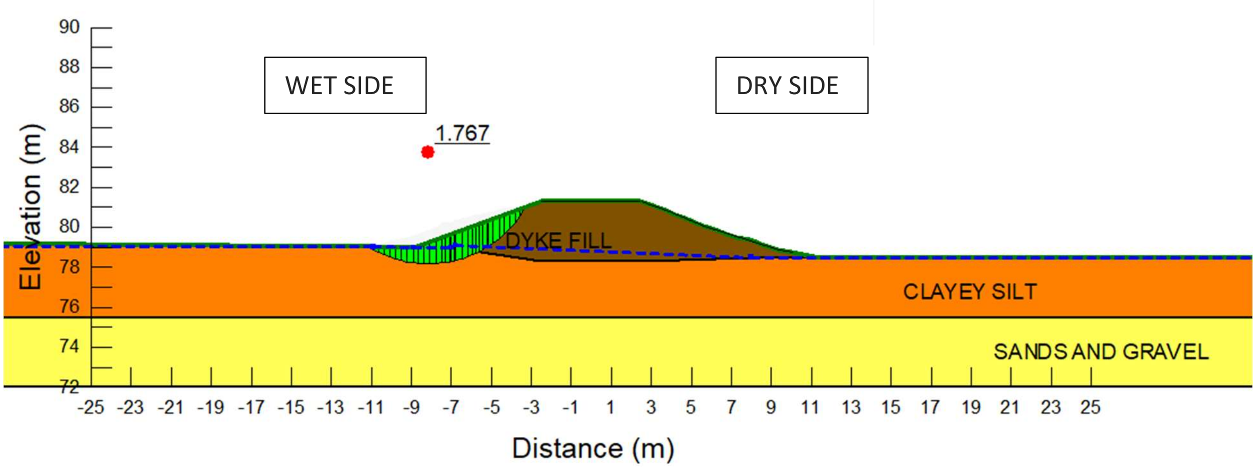


FIGURE 9 – SECTION 1 ANALYSIS RESULT FOR LOAD CASE 2 ON DRY SIDE OF DYKE

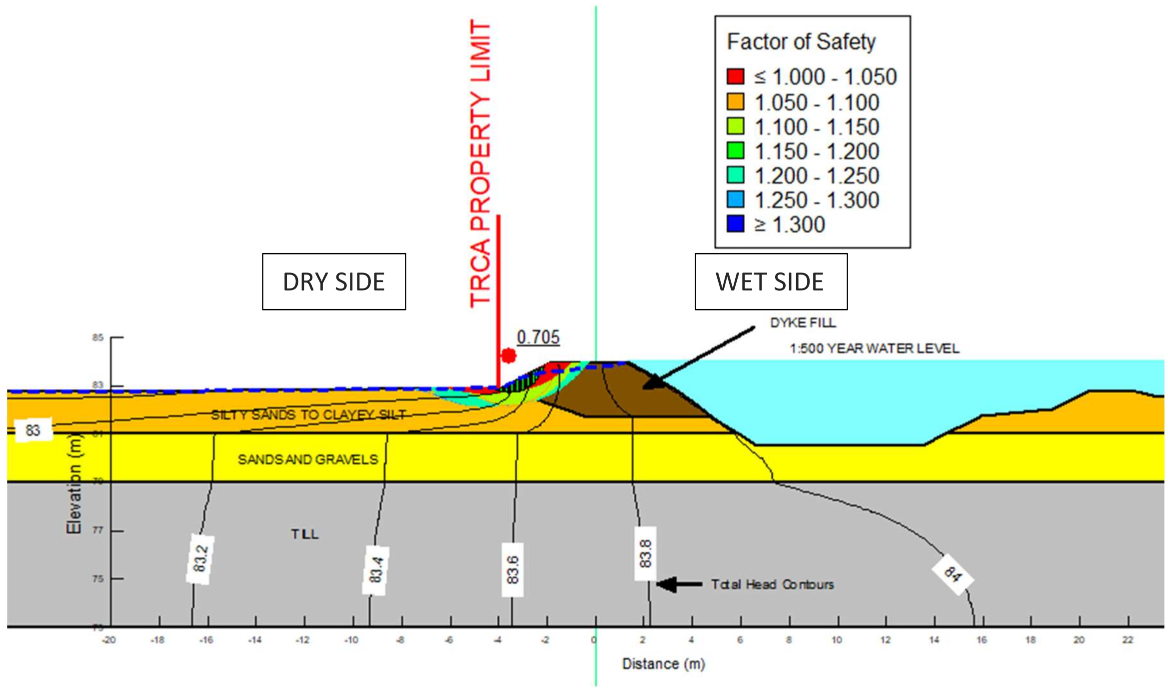


FIGURE 10 – SECTION 2 ANALYSIS RESULT FOR LOAD CASE 2 ON DRY SIDE OF DYKE

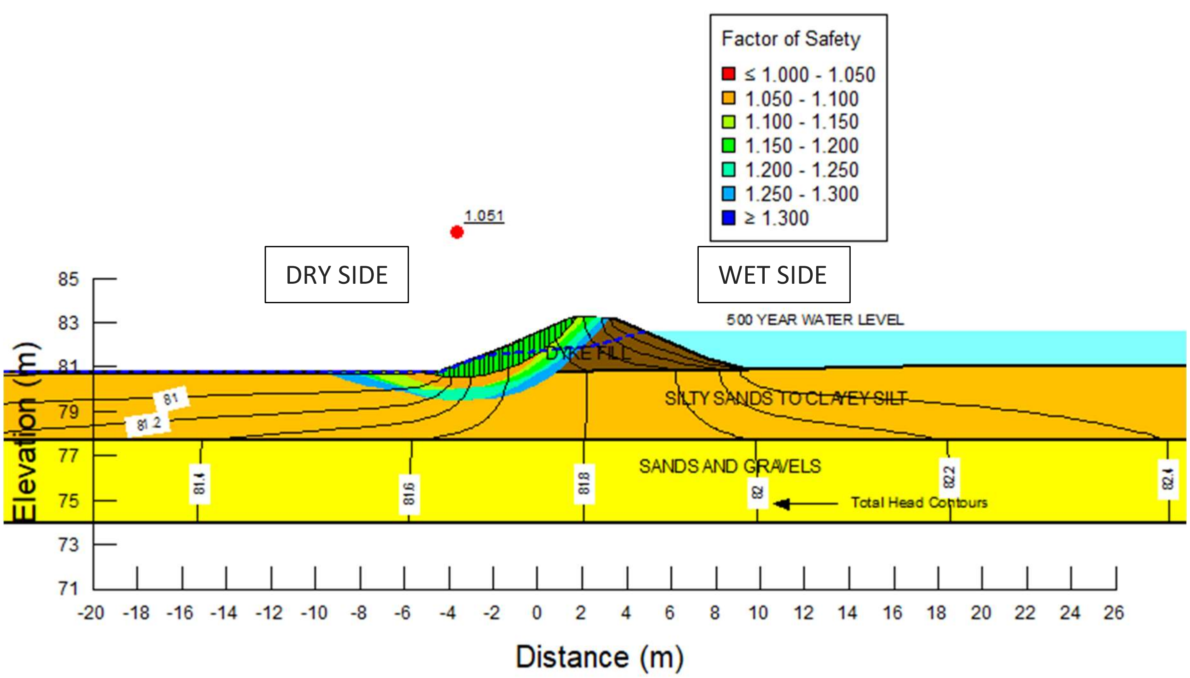


FIGURE 11 – SECTION 3 ANALYSIS RESULT FOR LOAD CASE 2 ON DRY SIDE OF DYKE

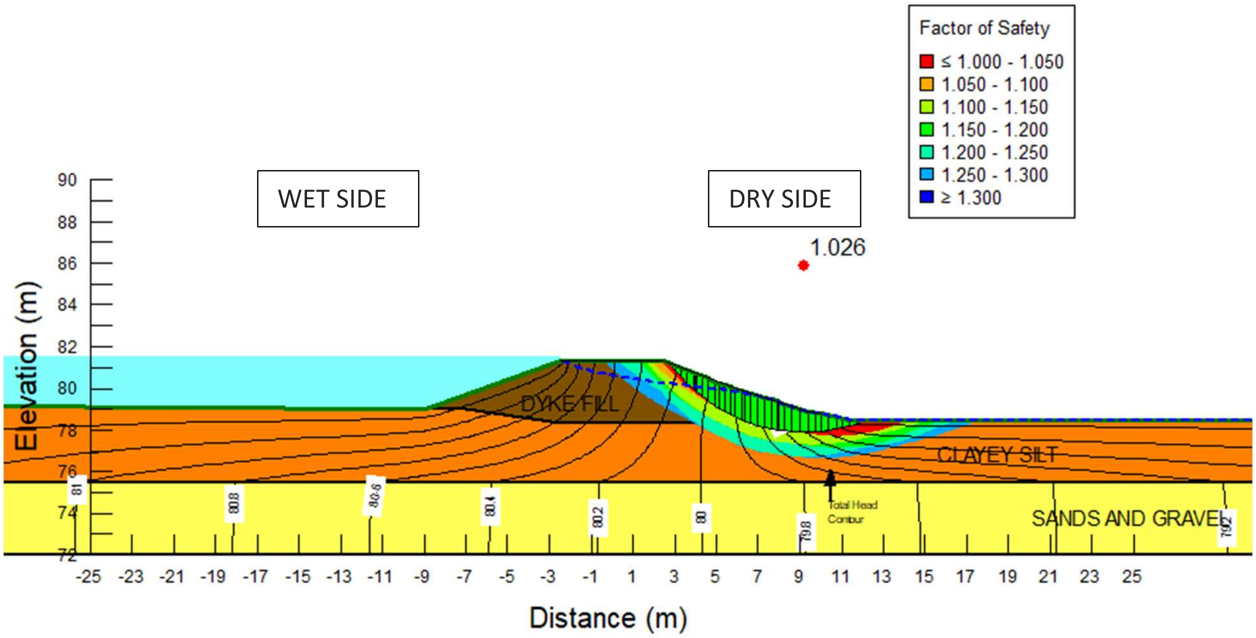


FIGURE 12 – SECTION 1 ANALYSIS RESULT FOR LOAD CASE 3 ON WET SIDE OF DYKE

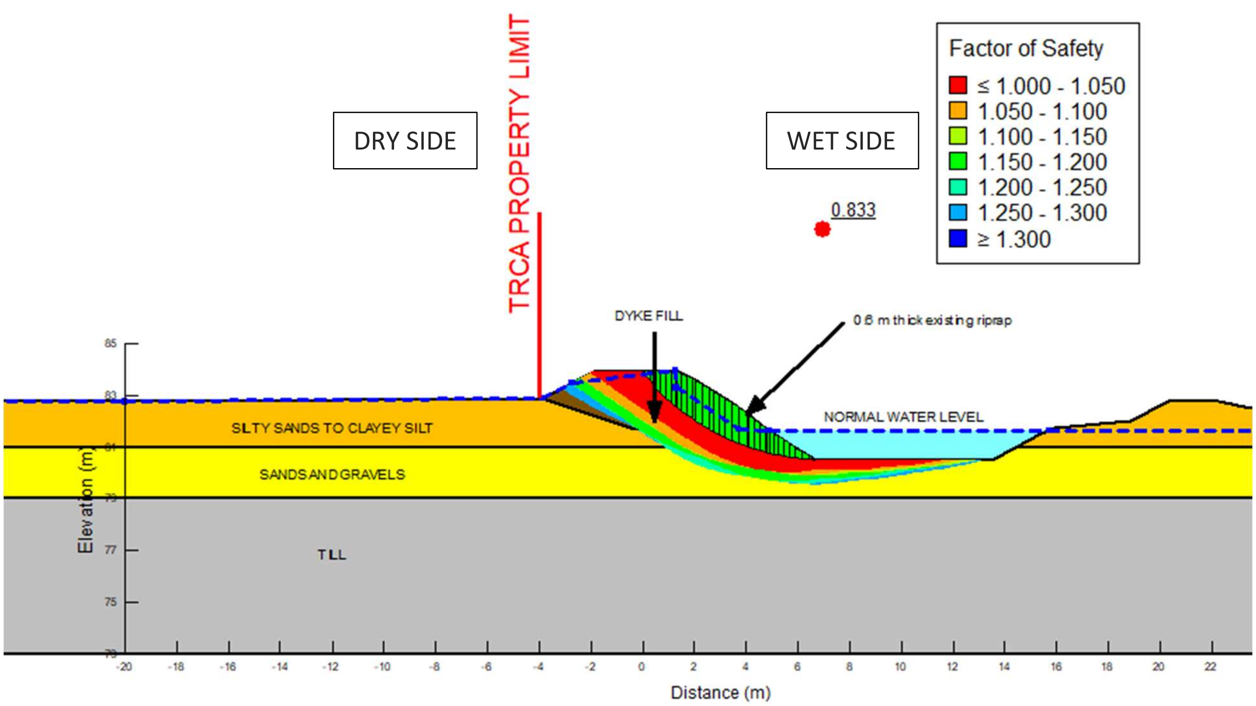


FIGURE 13 – SECTION 2 ANALYSIS RESULT FOR LOAD CASE 3 ON WET SIDE OF DYKE

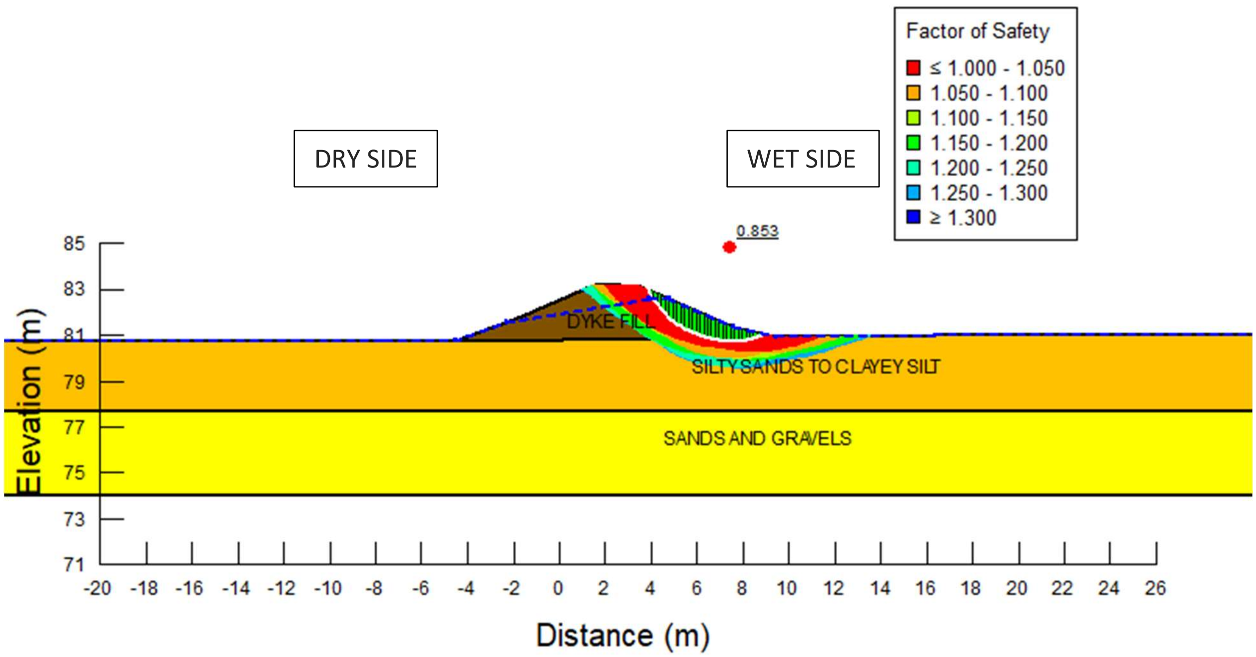


FIGURE 14 – SECTION 3 ANALYSIS RESULT FOR LOAD CASE 3 ON WET SIDE OF DYKE

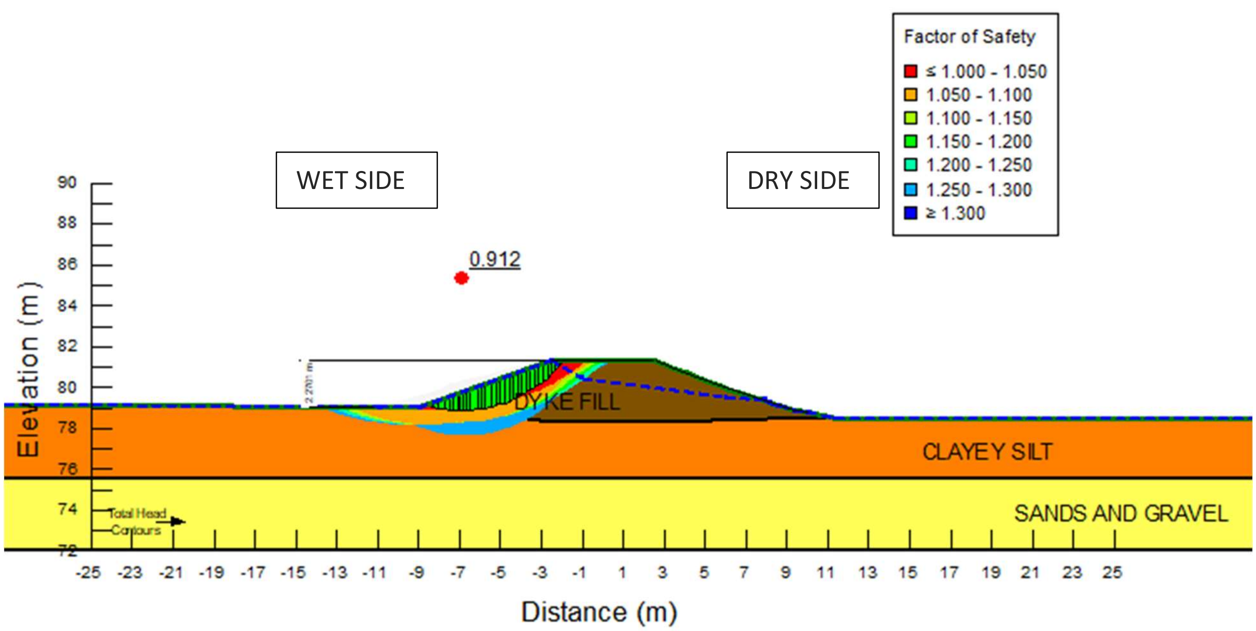


FIGURE 15 – SECTION 1 ANALYSIS RESULT FOR LOAD CASE 2A ON DRY SIDE OF DYKE (TRANSIENT MODEL)

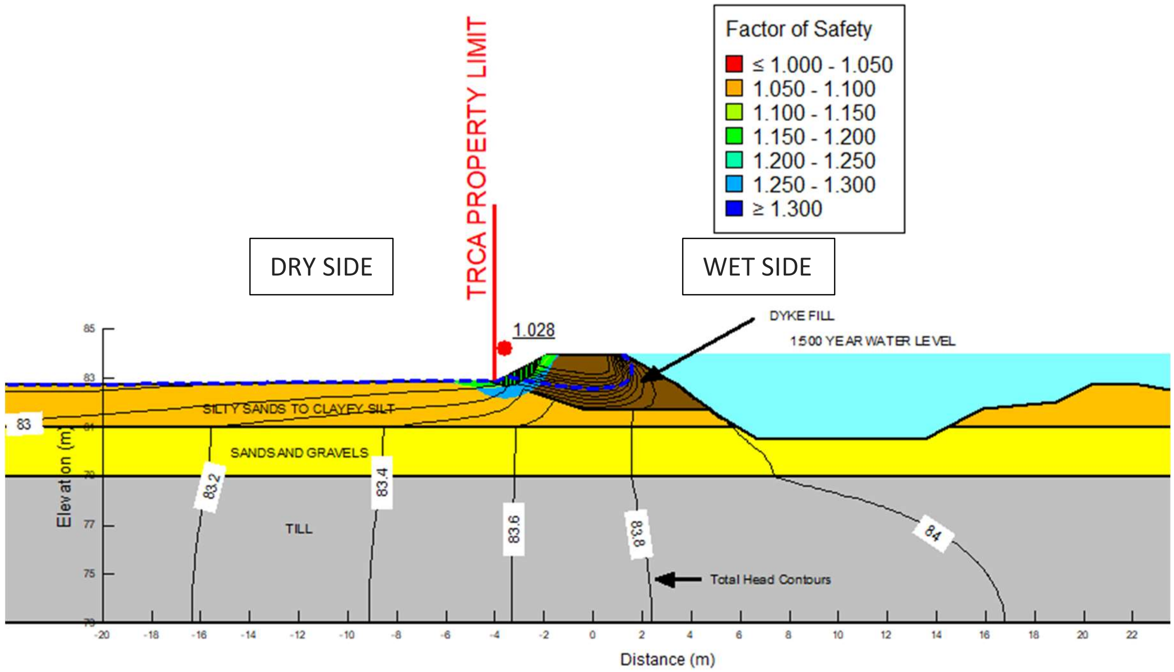


FIGURE 16 – SECTION 2 ANALYSIS RESULT FOR LOAD CASE 2A ON DRY SIDE OF DYKE (TRANSIENT MODEL)

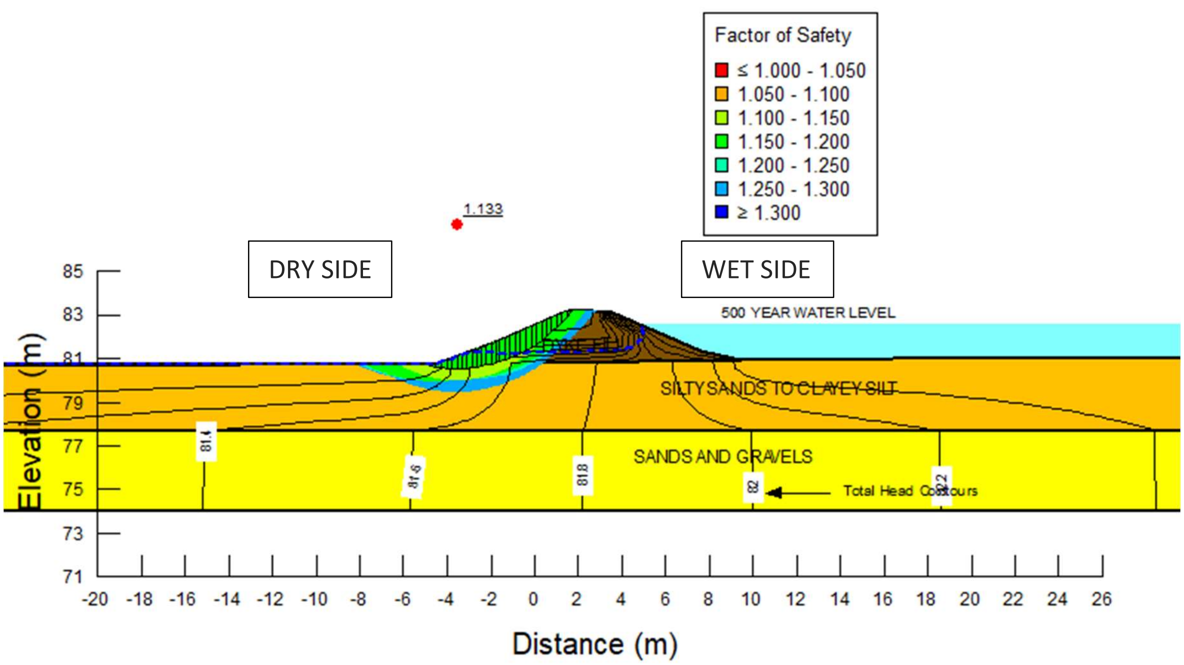


FIGURE 17 – SECTION 3 ANALYSIS RESULT FOR LOAD CASE 2A ON DRY SIDE OF DYKE (TRANSIENT MODEL)

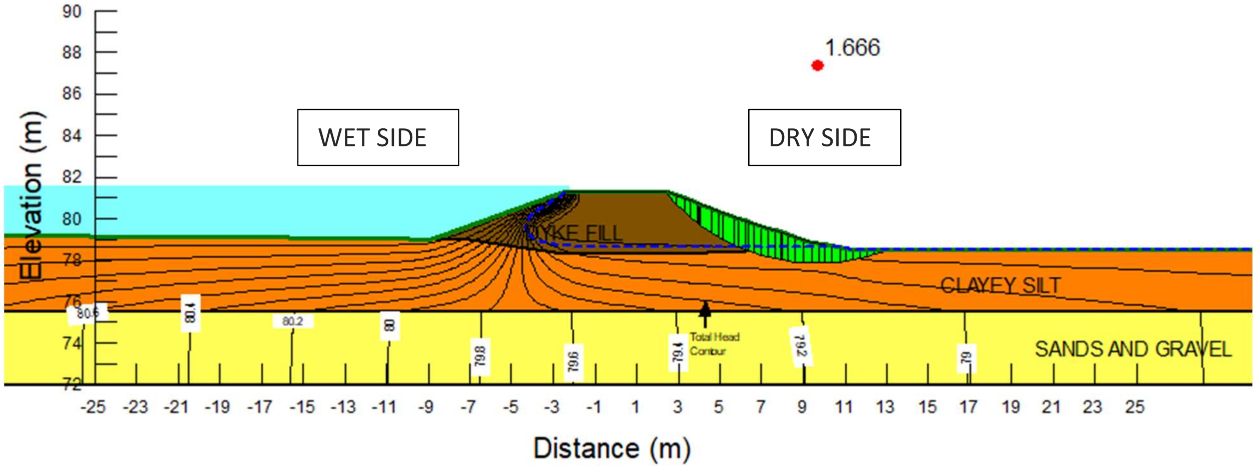


FIGURE 18 – SECTION 1 ANALYSIS RESULT FOR LOAD CASE 3A ON WET SIDE OF DYKE (TRANSIENT MODEL)

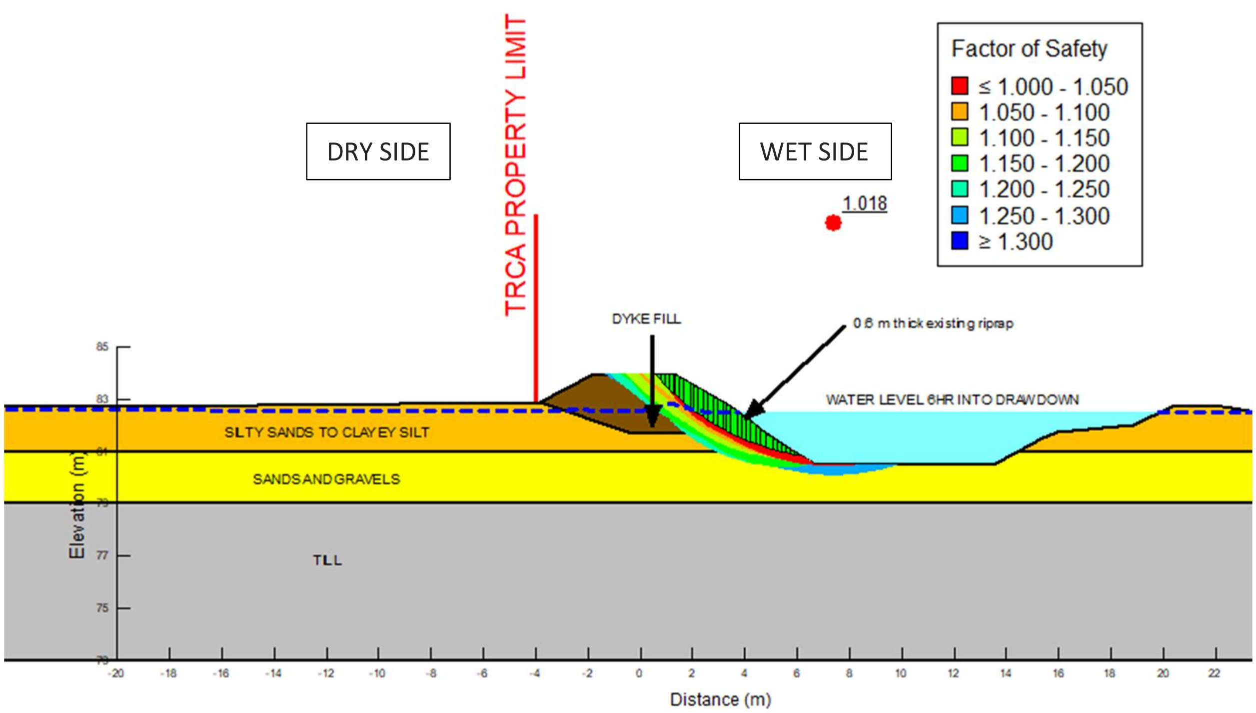


FIGURE 19 – SECTION 2 ANALYSIS RESULT FOR LOAD CASE 3A ON WET SIDE OF DYKE (TRANSIENT MODEL)

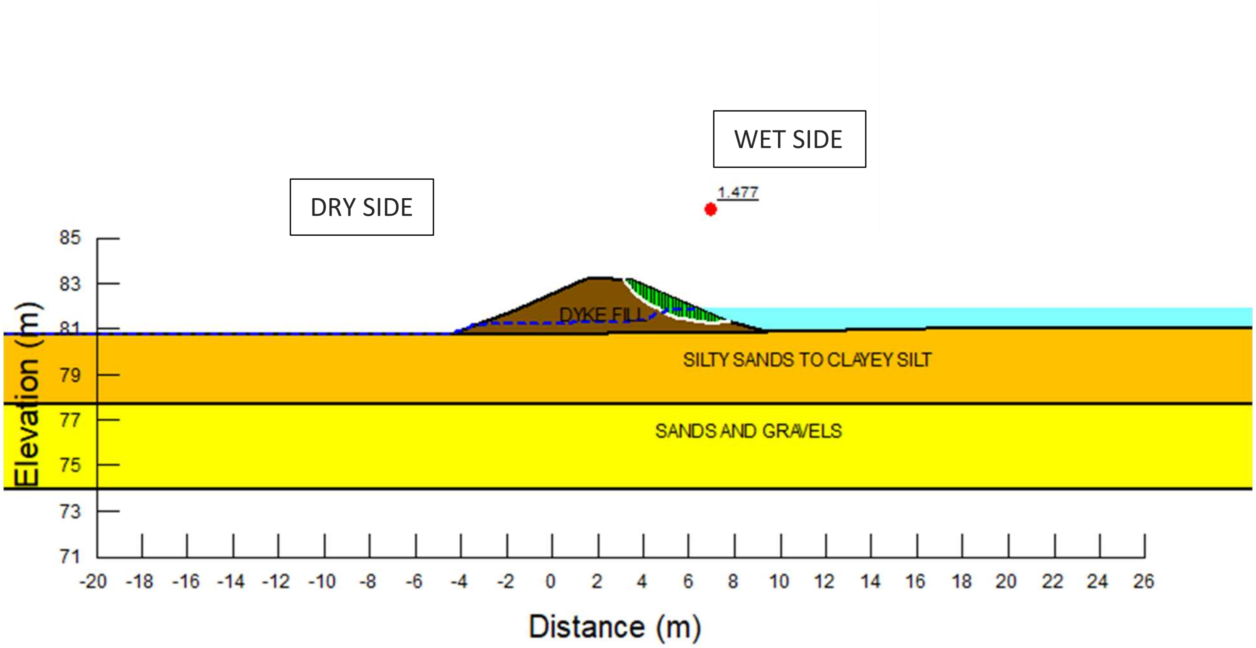
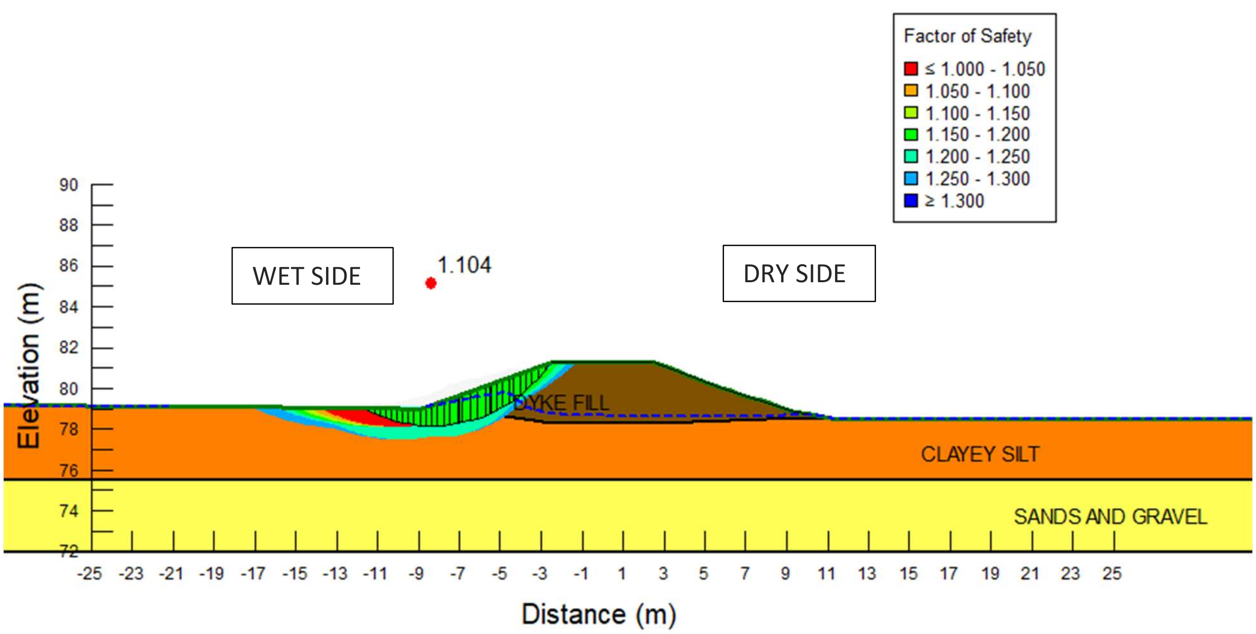


FIGURE 20 – SECTION 3 ANALYSIS RESULT FOR LOAD CASE 3A ON WET SIDE OF DYKE (TRANSIENT MODEL)



3.1.5 SEEPAGE ANALYSIS RESULTS

A 2D seepage model was developed to evaluate both the steady-state and transient groundwater and porewater pressure response of the dyke and foundation soils under flood events. Seepage modeling was completed for two reasons:

a.) to estimate time required to achieve a steady-state condition within the dyke during flood events; and
b.) to determine stability implications on the dry side of the dyke with respect to exit gradient and potential for blow-out/particle migration.

The results of both steady-state and transient seepage models were also imported directly into the slope stability analysis of Load Cases 2, 3, 2a, and 3a, discussed in Section 3.2.4.

The hydraulic conductivity parameters assigned to the various geological layers were consistent with those recommended in the Appendix B of the Geotechnical Investigation Report. The geometry, and stratigraphy used for the analyses is consistent with those described in Sections 3.1.1, 3.1.2, and 3.1.3 of this memorandum.

Exit Gradients

The exit gradient at the downstream toe of the dyke relates to the vulnerability of the dyke to piping. Section 2.1.2 of this memorandum explains the rationale for selecting the limiting exit gradient for the Ajax and Pickering Dykes. Table 5 summarizes: the calculated exit gradient under steady-state seepage conditions, the calculated exit gradient at the end of a 24-hour flood peak in the transient seepage models, and the estimated time from the start of the flood peak to when the calculated exit gradients may begin to exceed the recommended limiting exit gradient.

TABLE 5: ESTIMATED EXIT GRADIENT (DRY SIDE) DURING FLOOD EVENTS

Model	Limiting Gradient Criteria (i_{cr})	Calculated Exit Gradient (i_e)		Time for Gradient to Exceed Criteria
		Steady-State Analysis	Transient Analysis at 24 hours	
Section 1 – Pickering Dyke (West Side)	0.19	**0.39**	**0.39**	< 1 hr
Section 2 – Pickering Dyke (East Side)		**0.32**	**0.32**	< 1 hr
Section 3 – Ajax Dyke (Representative)		**0.42**	**0.20**	22 hr

Table 4 indicates that the dykes do not achieve the recommended seepage exit gradient criteria under steady-state seepage conditions. Additionally, it shows that the estimated steady-state seepage conditions could be achieved in the foundation soils beneath the Pickering Dyke in less than an hour. At the Ajax Dyke, steady-state seepage conditions are not expected to fully develop in the foundation soils within the duration of a 24 hour flood peak, but the model shows that the exit gradient limit would be exceeded after 22 hours.

Figures 9 and 15 illustrate a comparison of the seepage model results under steady-state conditions and transient seepage conditions at Section 1. Figures 10 and 16 illustrate that comparison at Section 2 and Figures 11 and 17 illustrate that comparison at Section 3. These figures show that the critical exit gradient occurs just beyond the toe of the existing dykes and that seepage control measures are required to contend with unfavourable conditions in the dyke foundations.

3.1.6 SUMMARY

The following conclusions are made regarding the condition of the existing Ajax and Pickering Dykes:

1.) Under normal (non-flood) conditions, the dykes generally have an adequate FOS with the exception of those areas of the Pickering Dyke where the existing dyke was built into West Duffins Creek.
2.) Under the design flood condition (500 year flood), the dykes do not have an adequate FOS on the dry side.
3.) Under a rapid drawdown condition from the 500 year flood, the dykes do not have an adequate FOS on the wet side.
4.) Considering the anticipated soil foundation permeability, the calculated exit gradients immediately beyond the toe of the existing dykes exceed the recommended limiting criterion. A conservative criterion (FOS against piping of 5) is recommended considering the susceptibility of fine-grained, poorly graded, cohesionless foundation soils to piping effects and the significant variability in stratigraphic conditions beneath the dykes.
5.) Although the transient analysis shows more favourable results than the steady-state analysis, the calculated FOS values near the west end of the Pickering Dyke remain quasi-stable. Other areas that would be analytically stable for flood events up to 24-hours, still require seepage control measures because steady-state seepage conditions, that are conducive to piping, can occur within 22 hours of a flood peak.
6.) The analyses confirm the need to rehabilitate the existing dykes to achieve the design criteria (i.e. MNRF geotechnical design and factors of safety).
7.) Optimization of the design and the adopted criteria can be considered during detailed design of any dyke rehabilitation solution. In that case, the duration of the flood event must be stated as a limitation of the design, and should be determined conservatively, considering potential changes in the watershed and the channel morphology that can occur with time.

3.2 Analysis of Options for Dyke Rehabilitation

As part of the Class Environmental Assessment, several dyke rehabilitation Design Concepts were developed. The technical rationale for those Design Concepts is described below. Detailed evaluation (at concept level) are provided for the preferred Design Concept, in Section 3.3.

3.2.1 PICKERING DYKE (WEST) DESIGN CONCEPTS

The following design concepts were assessed in terms of their capability of improving the existing dykes to the degree necessary to satisfy the minimum design criteria for the west end of the Pickering Dyke (Dyke Segment P1):

Design Concept H1: A 7.5 m (25 ft) long sheetpile with vegetated rock buttress on the wet side of the dyke and a mechanically stabilized earth (MSE) retaining wall on the dry side of the dyke.

Design Concept H2: A 7.5 m (25 ft) long sheetpile with vegetated rock buttress on the wet side of the dyke and a dry side slope modified to include a granular reverse filter trench.

Design Concept H3: A deep cantilever sheetpile installed along the wet side crest of the dyke and the same dry side slope as the existing conditions.

Design Concept H4: A concrete wall and dry side slope modified to include a granular filter trench.

Design Concept H2 was assessed to be the most favourable in the Class EA considering a number of criteria which included effects to natural environment, effects to cultural/social environment, technical aspects, and cost.

Functionality of Wet Side Dyke Rehabilitation Components

The 7.5 m deep sheet pile for design concepts H1 and H2 functions by sealing off a high permeability sand and gravel layer observed in the foundation soils wherever there is a dense lower permeability of till at depth for the bottom of the sheet pile to tie-in to. A complete seal of the sand and gravel layer would reduce the phreatic surface on the dry side of the dyke under flood conditions to a degree that would achieve the necessary FOS. The sheet pile would also improve the stability on the wet side of the dyke above the required FOS by forcing potential slope movements under the tip of the sheet pile. A vegetated rock buttress would be required against the sheet pile on the wet side to ensure that the soil support on the wet side of the sheet pile does not erode with time. The supporting weight on the wet side of the sheet pile for design concepts H1 and H2 is required because the embedment depth of the sheet pile below the bottom of the creek bed would be insufficient for the sheet pile to adequately function as a cantilever.

The deep cantilever sheet pile for design concept H3 functions in a similar manner to the shorter sheet pile of design concepts H1 and H2; however, the H3 sheet pile would be embedded deep enough to function as a cantilever without the need for a vegetated rock buttress. This would be accomplished by embedding the sheet pile approximately two times the retained soil height above the bottom of the creek bed. A sheet pile of this depth would change the critical mode of failure on the wet side of the dyke from a potential slope failure to a potential overturning rotational failure and, considering previous experience, an embedment depth that is twice the retained soil height would typically be required to achieve a minimum FOS of 1.5 against a potential overturning wall failure. The overall length of sheet pile would therefore need to be 10 m to 12 m long if it were to function without anchor support.

The concrete retaining wall for design concept H4 would be installed with the base at the approximate creek bed and would satisfy MNRF stability FOS by driving potential slope movements under the concrete wall. The critical slope stability slip surfaces of the existing dyke are relatively shallow movements and forcing them deeper would increase their FOS. If this solution had been elected to advance to detailed design, it would also need to be designed to achieve the minimum FOS to resist overturning and sliding. Based on previous experience, such a reinforced concrete floodwall would need to be at least 4 m wide at the base and at least 0.4 m thick. The wall footing should also be provided with erosion protection to prevent undercutting with time.

Functionality of Dry Side Dyke Rehabilitation Components

Near the far west end of the Pickering Dyke (approximately Sta. 1+075 to 1+160 of the Pickering Dyke profile), dense till can be deeper than the required sheet pile length of 7.5 m from the top of dyke assumed for design concepts H1 and H2. The results is that seepage could still flow preferentially beneath the sheetpile cut-off in the underlying sand and gravel and continue to induce high exit gradients beyond the downstream toe of dyke. The concrete floodwall of design concept H4 would similarly be unable to adequately provide complete seepage control for areas where the underlying till is deep. For that reason, concepts H1, H2 and H4 should also be augmented with a granular filter on the dry side of the dyke to intercept potential bypass seepage beneath the upstream flood control measures. The granular filter could be installed as either a trench as per Design Concept H2 and H4, or it could be integrated into the granular backing and foundation of the MSE wall as per Design Concept H1. The filter would function to drawdown the phreatic surface on the dry side of the dyke and reduce exit gradients beyond the downstream toe. The depth of the granular filter is expected to vary from 0.5 m to 2m depending on the thickness of the confining silty sand to clayey silt layer. On average, the granular filter depth is assumed to be 1 m. The width of the granular filter should be at least 1.2 m to accommodate compaction equipment. The granular filter would need to be zoned appropriately in detailed design to filter both the confining silty sand to clayey silt layer as well as the underlying sand and gravel layer.

The MSE wall component of design concept H1 would also need to be designed to resist overturning, sliding, bearing capacity, and reinforcement pull-out failures in addition to providing the requisite slope stability FOS. Based on previous experience, and considering the required wall heights and soil conditions, it is anticipated that the granular backing and block face of the MSE wall would need to be 2.5 m wide on a preliminary basis to resist all potential modes of failure.

No modifications are included to the dry side slope for Design Concept H3 because a sheet pile driven to refusal in dense till is expected to completely seal permeable sand and gravel layers. With a complete upstream cut-off, the phreatic surface in the dyke under flood conditions would be reduced near the dry side toe of dyke to the degree necessary to achieve the minimum FOS criteria. It was also accepted as a characteristic of Design Concept H3, that if there was a failure on either slope, the cantilever sheet pile would still stand, providing flood protection.

3.2.2 PICKERING DYKE (EAST) AND AJAX DYKE DESIGN CONCEPTS

The following design concepts were assessed to be capable of rehabilitating the existing dykes to the degree necessary to satisfy the minimum design criteria for the east side of the Pickering Dyke and the entire Ajax Dyke:

Design Concept S1: A 4H:1V slope on the wet side of the dyke and a 3H:1V slope coupled with full height granular filter on the dry side of the dyke.

Design Concept S2: A 4H:1V slope on the wet side of the dyke with a cut-off (sheet pile, slurry wall, or other) potential seepage through the dyke fill and shallow foundation soils. The dry side slope would be 3H:1V and covered with a smaller filter blanket on the dry side of the dyke.

Design Concept S1 was assessed to be the most favourable in the Class EA considering several criteria which included effects to natural environment, effects to cultural/social environment, technical aspects, and cost.

Functionality of Wet Side Dyke Rehabilitation Components

For both Design Concepts S1 and S2, a flatter 4H:1V side slope on the wet side would satisfy the minimum slope stability FOS requirements for the rapid drawdown analysis. Additionally, a shallower slope of 3H:1V may be able to satisfy rapid drawdown design criteria if transient seepage effects can be considered to optimize the proposed design; however, this will depend on the desired design flood duration over which time the optimized solution can be considered reliable. The proposed 4H:1V slope will satisfy MNRF criteria and it can be optimized during detailed design.

The Design Concept S2 cut-off ensures that there are no preferable seepage paths through the dyke and shallow foundation soils. A complete deep cut-off solution without filter was determined not to be feasible because a low permeability layer below the underlying sand and gravel was not encountered in several boreholes within the depth of exploration. Such a layer would be necessary to ensure the functionality of a cut-off solution without filter.

Functionality of Dry Side Dyke Rehabilitation Components

For both Design Concepts S1 and S2, a flatter 3H:1V side slope on the dry side coupled with a filter would satisfy the minimum slope stability FOS requirements under the design flood event. For Design Concept S1, and also for S2, when a complete cut-off is not feasible or practical, this slope is coupled with a filter. A larger filter is necessary for Design Concept S1 to adequately filter the entire mass of the dyke fill as well as the near surface foundation soils. A smaller filter will suffice for Design Concept S2 because seepage would be forced by the cut-off down below the dyke fill which would negate the need to filter the entire dyke slope. This smaller filter is required for Design Concept S2 because higher exit gradients could still be present immediately beyond the toe of the dyke due to a deeper sand and gravel layer that would not be adequately intersected by the proposed upstream cut-off. Depending on site conditions, it could be preferable to include this filter, rather than to increase the length of the cut-off to provide a complete seal. This would need to be refined in detailed design, should this Design Concept be selected.

3.3 Supporting Analysis Results for Preferred Design Solutions

In the Class Environmental Assessment, Design Concept H2 was deemed to be preferred on the west side of the Pickering Dyke (Dyke Segment P1) and Design Concept S1 was deemed to be preferred on the east side of the Pickering Dyke (Dyke Segment P2) and also for the Ajax Dyke (Dyke Segment A1). Table 6 summarizes the seepage exit gradients under steady-state conditions at the exit point of the proposed filters. Table 7 summarizes the slope stability FOS at each of the three representative slope stability sections used in this memorandum with the preferred design solutions superimposed. Figures Y21 to Y33 illustrate the slope stability analysis results.

Tables 6 and 7 indicate that the proposed Concept Designs satisfy the recommended MNRF design criteria. Note that Figures 27 and 28 illustrate the range of seepage behaviour anticipated for the Design Concept H2 solution. Figure 27 would be representative where the cut-off completely penetrates a deeper layer of till and Figure 28 would be representative where the cut-off does not completely penetrate a deeper layer of till and the filter must function for seepage control. In both cases the necessary design criteria are satisfied.

TABLE 6 – ESTIMATED EXIT GRADIENT (DRY SIDE) DURING FLOOD EVENTS FOR PREFERRED SOLUTION

Model	**Limiting Gradient Criteria (i_{cr})**	**Calculated Exit Gradient (i_e)** Steady-State Analysis
Section 1 – Pickering Dyke (West Side) With Design Concept H2 CASE 1 – Dense Till Present at Depth	0.19	0.00
Section 1 – Pickering Dyke (West Side) With Design Concept H2 CASE 2 – No Dense Till at Depth		0.13
Section 2 – Pickering Dyke (East Side) With Design Concept S1		0.11
Section 3 – Ajax Dyke (Representative) With Design Concept S1		0.13

TABLE 7 – STABILITY ANALYSIS RESULTS FOR PREFERRED SOLUTION COMPARED TO MNRF CRITERIA

Load Case Description	Design Criteria (FOS)	Section	Slope	FOS	Reference Figure
1. Long-term (steady state seepage, normal river level)	1.5	Section 1 (H2)	Dry Side	2.16	21
			Wet Side	1.5	22
		Section 2 (S1)	Dry Side	2.32	23
			Wet Side	3.02	24
		Section 3 (S1)	Dry Side	2.04	25
			Wet Side	2.37	26
2. IDF loading condition (Regional Flooding)	1.3	Section 1 (H2) *deep till	Dry Side	1.71	27
		Section 1 (H2) *no deep till	Dry Side	1.46	28
		Section 2 (S1)	Dry Side	1.87	29
		Section 3 (S1)	Dry Side	1.83	30
3. Rapid drawdown	1.2	Section 1 (H2)	Wet Side	1.47	31
		Section 2 (S1)	Wet Side	1.46	32
		Section 3 (S1)	Wet Side	1.21	33

FIGURE 21 – SECTION 1 ANALYSIS RESULT FOR LOAD CASE 1 ON DRY SIDE OF DYKE WITH DESIGN CONCEPT H2

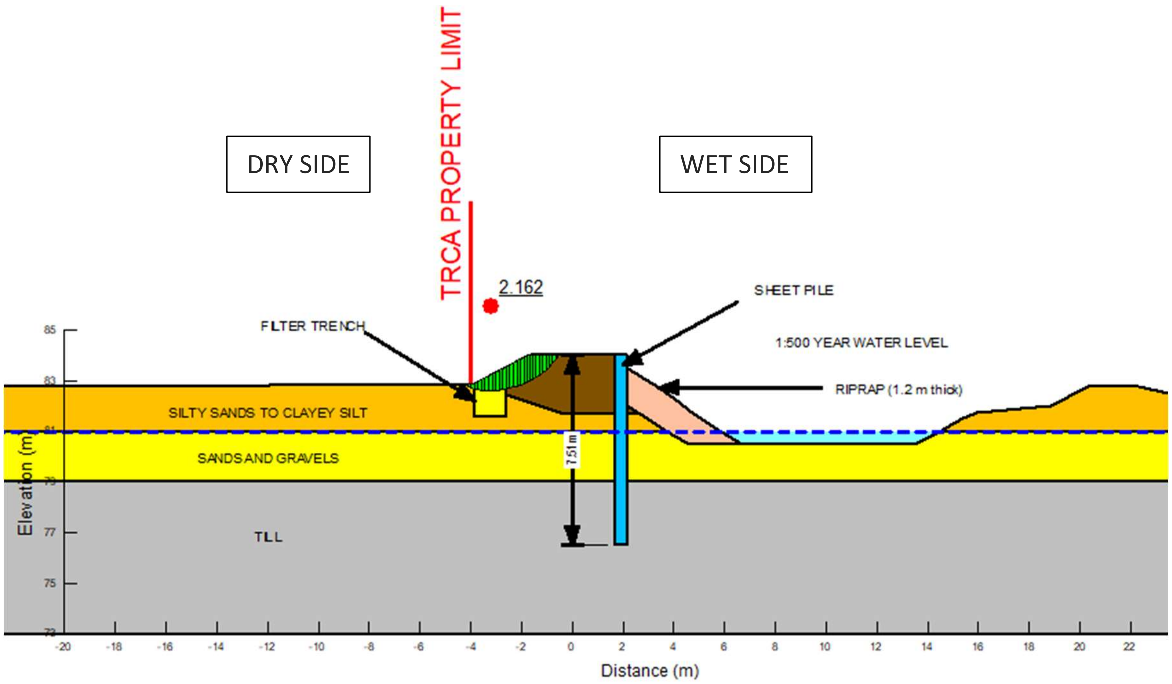


FIGURE 22 – SECTION 1 ANALYSIS RESULT FOR LOAD CASE 1 ON WET SIDE OF DYKE WITH DESIGN CONCEPT H2

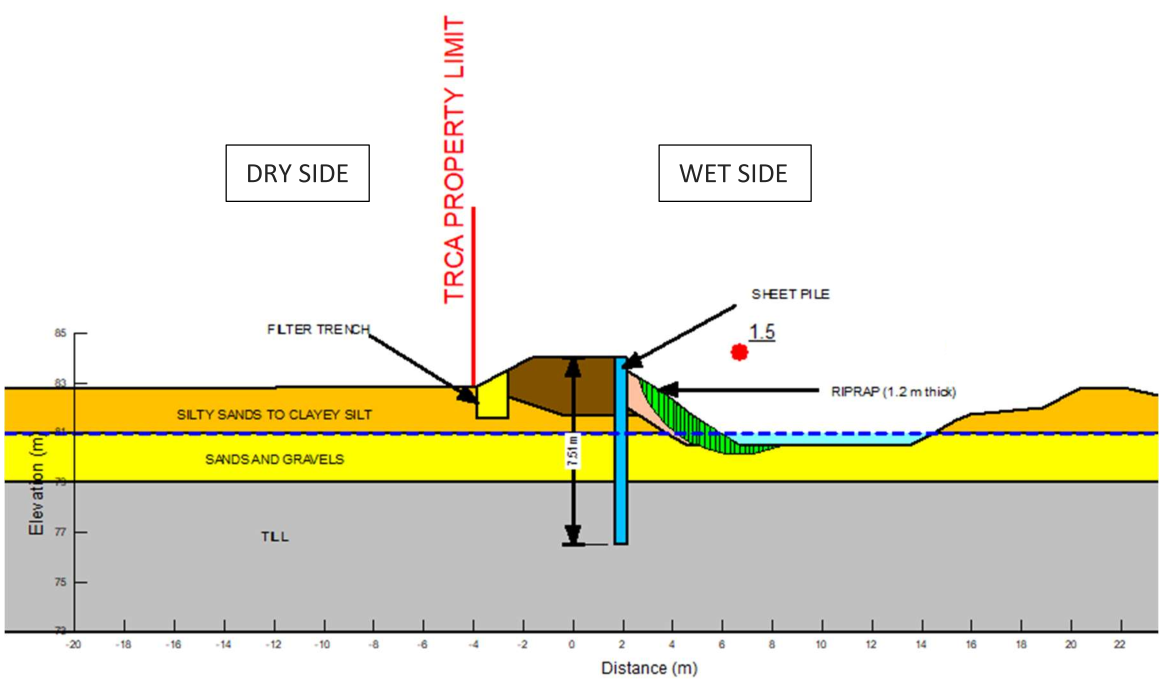


FIGURE 23 – SECTION 2 ANALYSIS RESULT FOR LOAD CASE 1 ON DRY SIDE OF DYKE WITH DESIGN CONCEPT S1

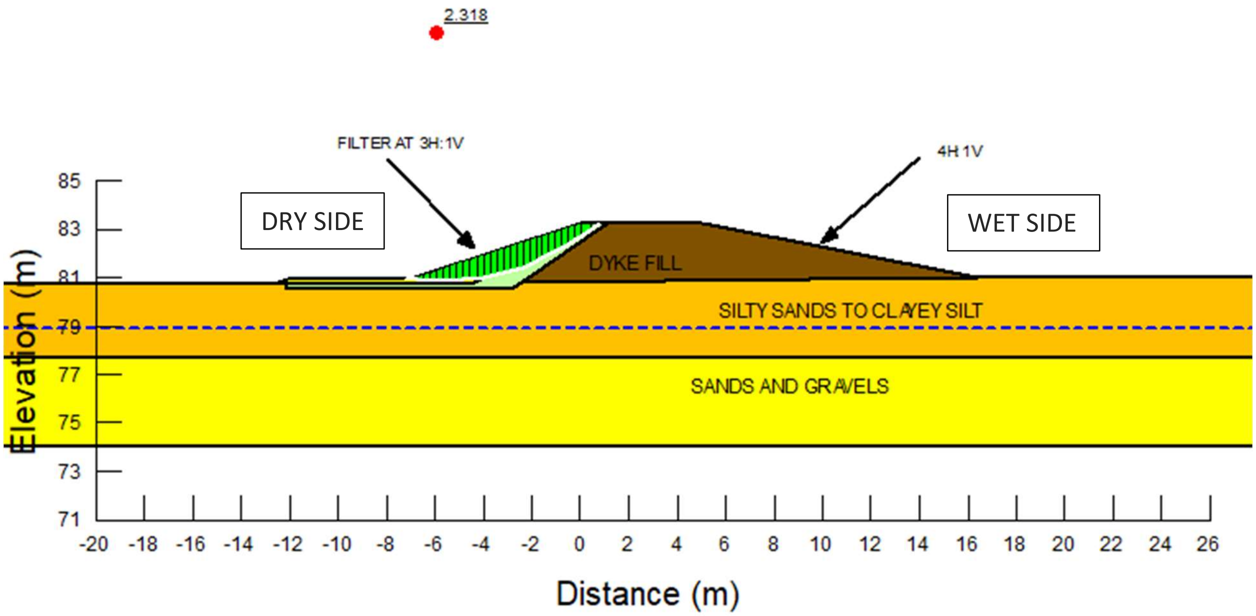


FIGURE 24 – SECTION 2 ANALYSIS RESULT FOR LOAD CASE 1 ON WET SIDE OF DYKE WITH DESIGN CONCEPT S1

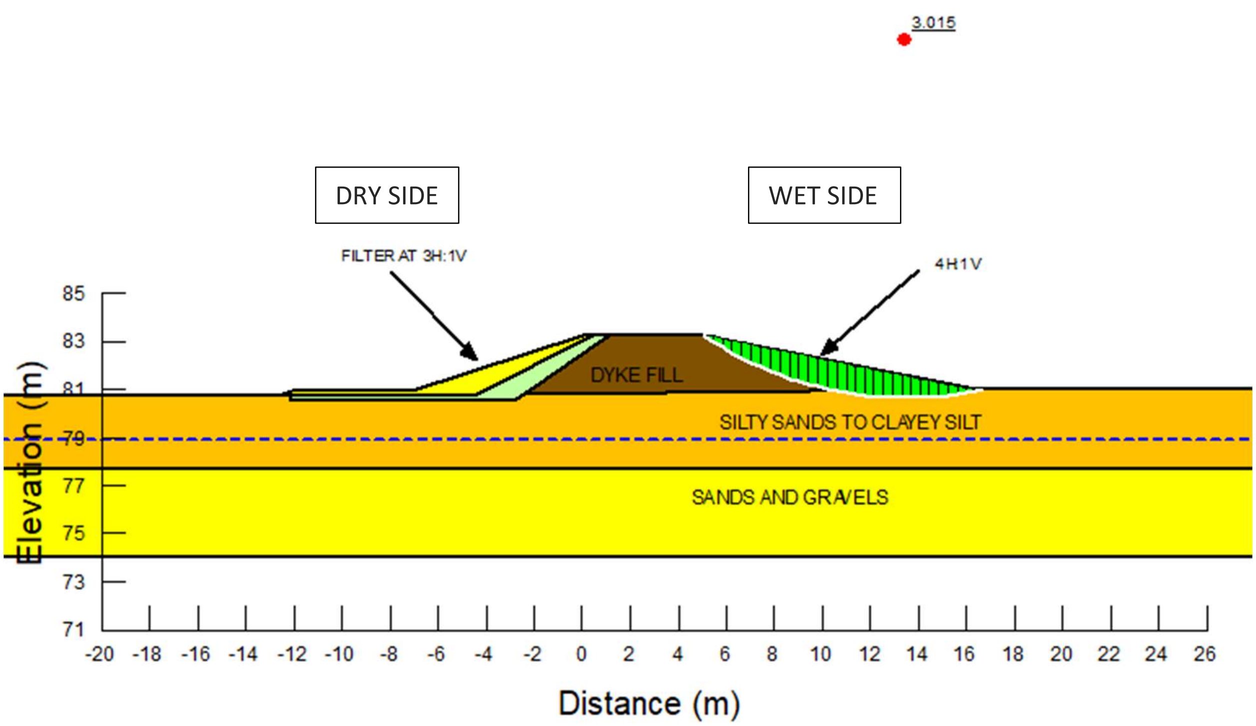


FIGURE 25 – SECTION 3 ANALYSIS RESULT FOR LOAD CASE 1 ON DRY SIDE OF DYKE WITH DESIGN CONCEPT S1

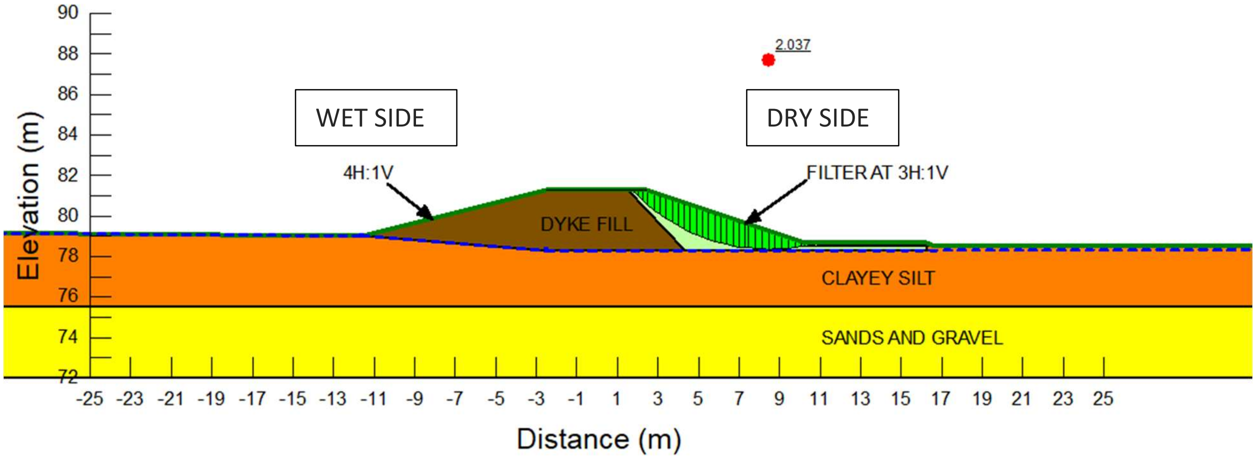


FIGURE 26 – SECTION 3 ANALYSIS RESULT FOR LOAD CASE 1 ON DRY SIDE OF DYKE WITH DESIGN CONCEPT S1

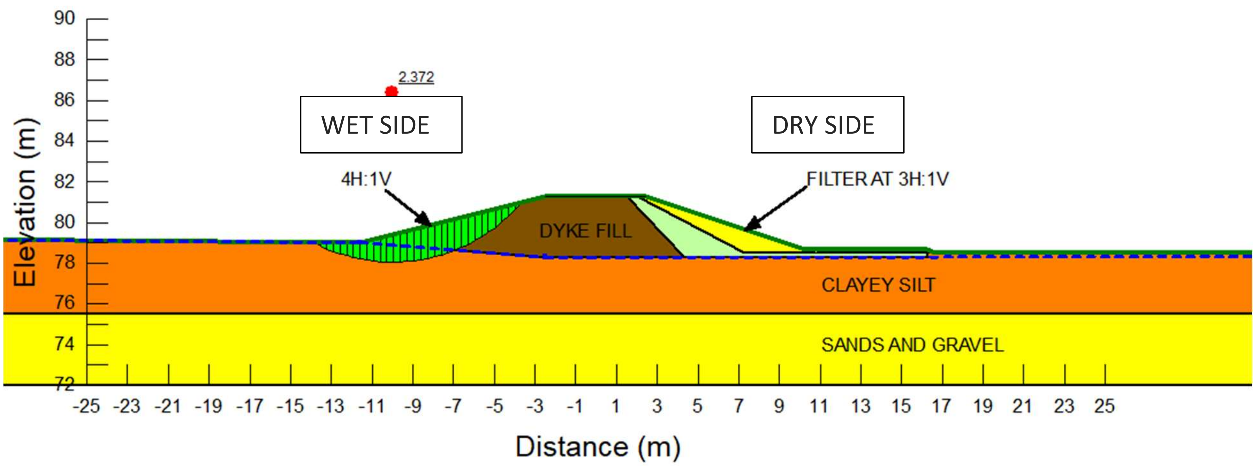


FIGURE 27 – SECTION 1 ANALYSIS RESULT FOR LOAD CASE 2 ON DRY SIDE OF DYKE WITH DESIGN CONCEPT H2 (CASE 1 – DEEP TILL)

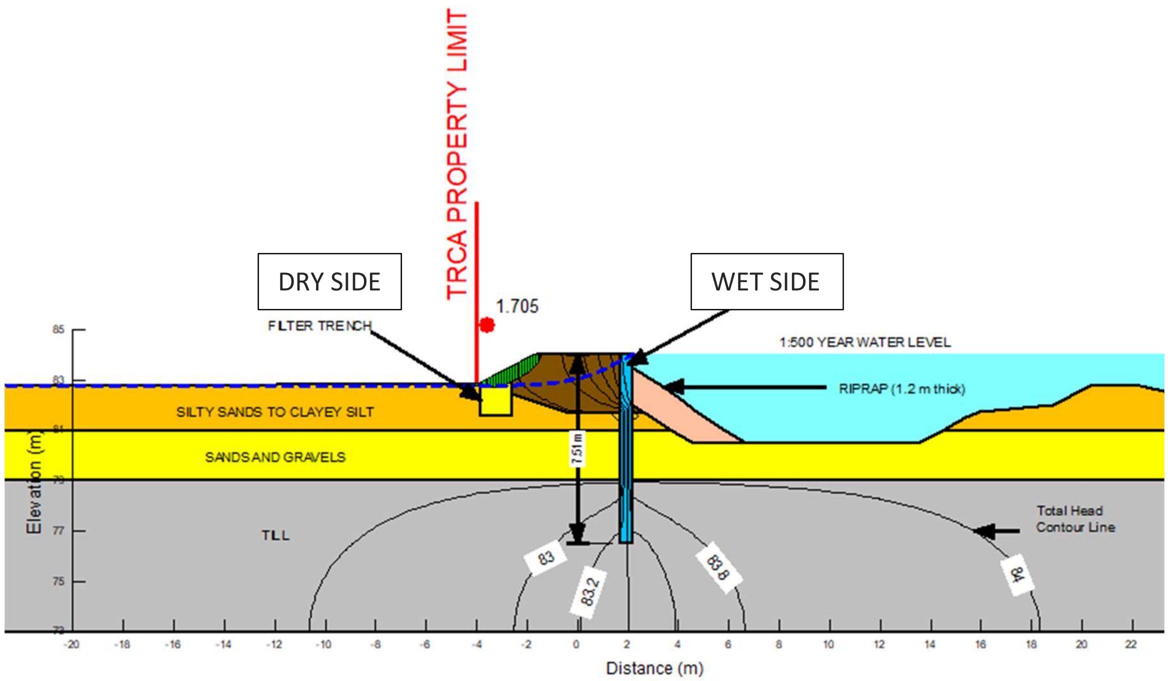


FIGURE 28 – SECTION 1 ANALYSIS RESULT FOR LOAD CASE 2 ON DRY SIDE OF DYKE WITH DESIGN CONCEPT H2 (CASE 2 – NO TILL)

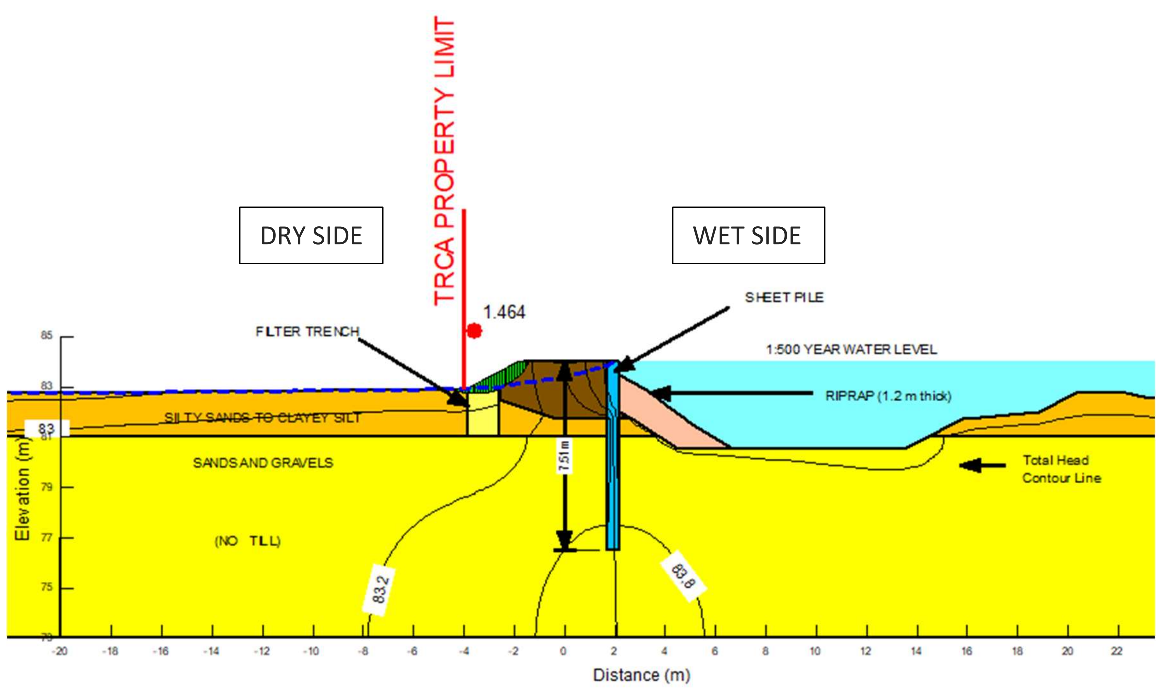


FIGURE 29 – SECTION 2 ANALYSIS RESULT FOR LOAD CASE 2 ON DRY SIDE OF DYKE WITH DESIGN CONCEPT S1

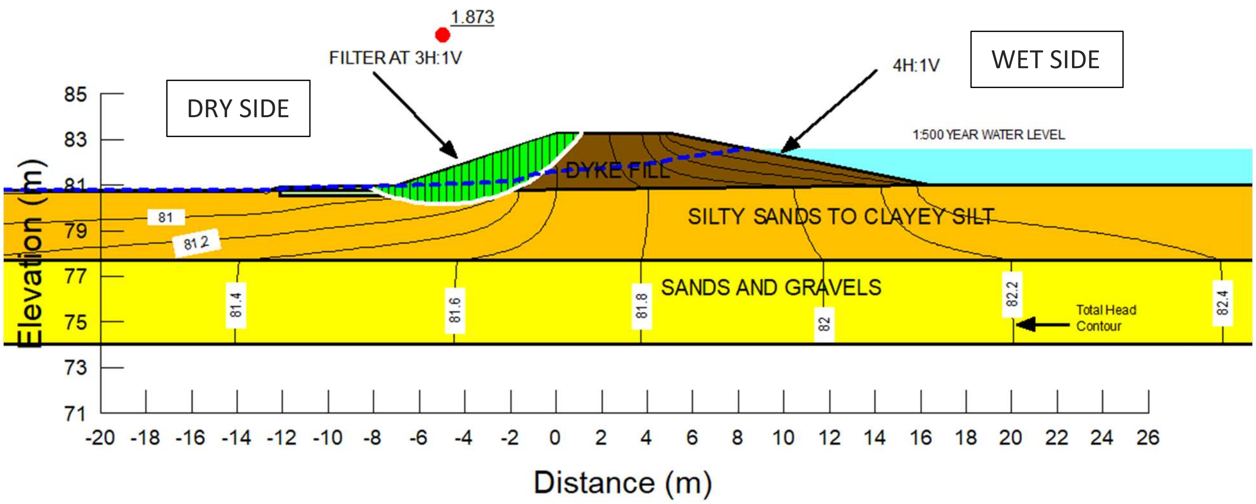


FIGURE 30 – SECTION 3 ANALYSIS RESULT FOR LOAD CASE 2 ON DRY SIDE OF DYKE WITH DESIGN CONCEPT S1

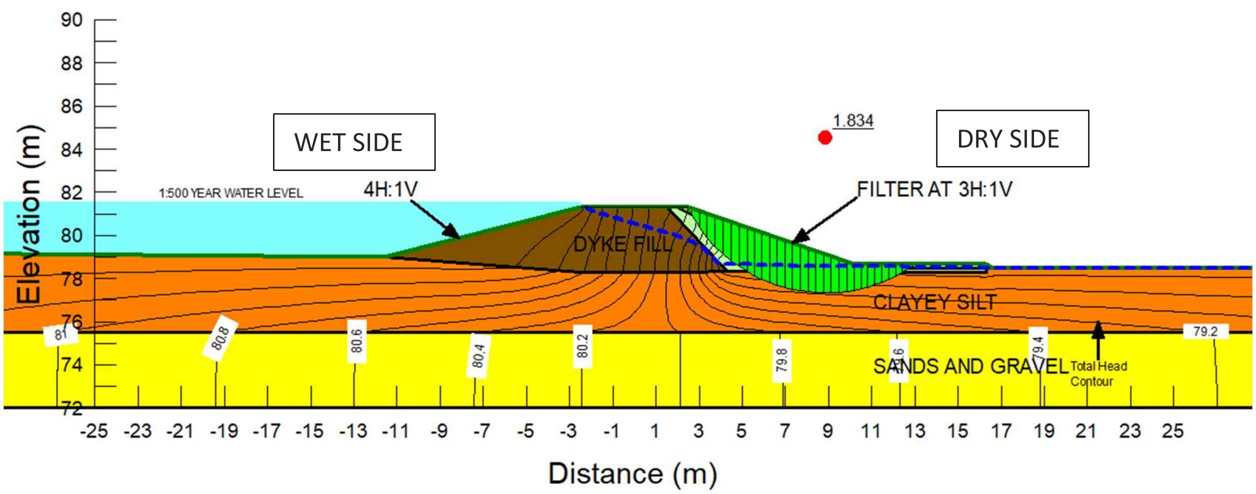


FIGURE 31 – SECTION 1 ANALYSIS RESULT FOR LOAD CASE 3 ON WET SIDE OF DYKE WITH DESIGN CONCEPT H2

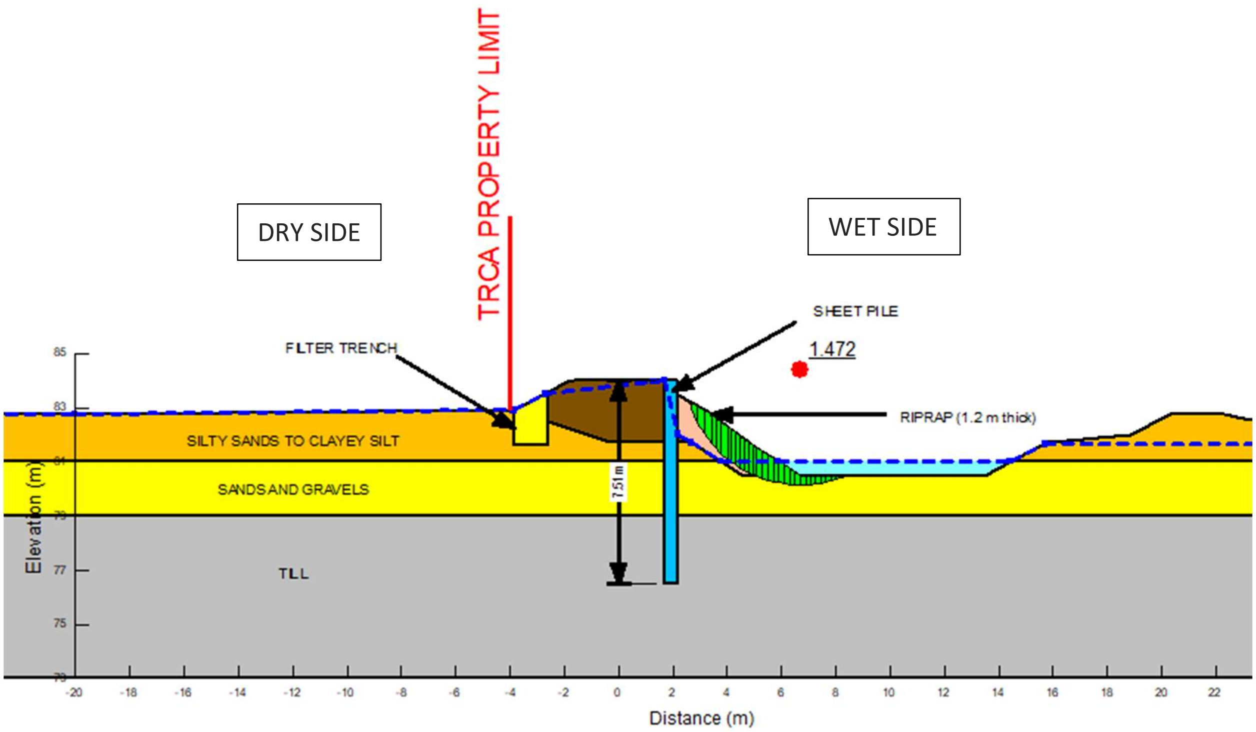


FIGURE 32 – SECTION 2 ANALYSIS RESULT FOR LOAD CASE 3 ON WET SIDE OF DYKE WITH DESIGN CONCEPT S1

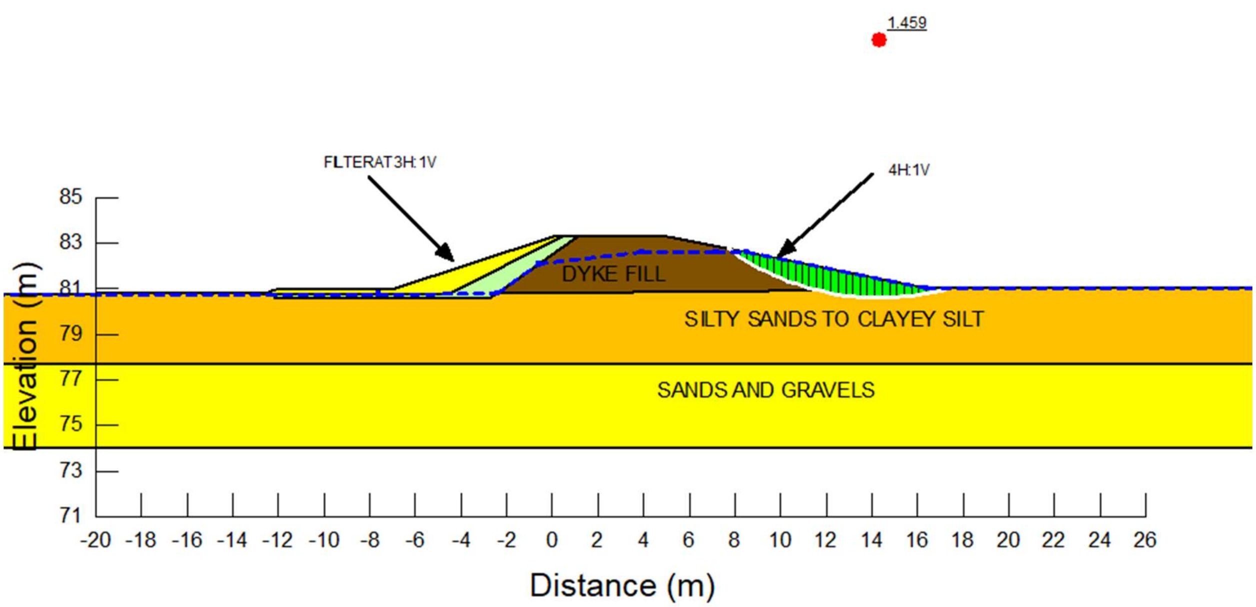
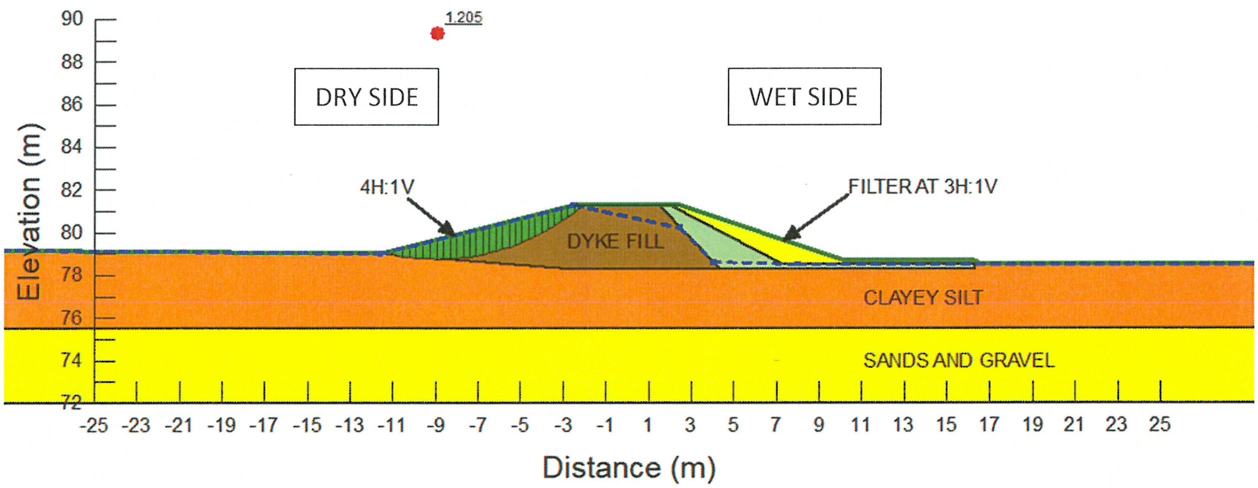


FIGURE 33 – SECTION 3 ANALYSIS RESULT FOR LOAD CASE 3 ON WET SIDE OF DYKE



3.4 Closure

The existing Pickering and Ajax Dykes do not satisfy the minimum criteria for MNRF geotechnical design and factors of safety as supported by the above analyses. Implementing the preferred Design Concepts derived from the Class Environmental Assessment would rehabilitate the dykes to achieve the MNRF criteria. There are opportunities to optimize the final design that should be explored during that design stage. One such opportunity could be by considering transient seepage effects; however, the minimum flood duration over which the proposed solutions should be considered reliable would need to be established in consultation with TRCA. The duration of reliability of any optimized solution that does not consider steady-state seepage conditions should be stated as a limitation of any design optimization.

Prepared By:

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Specialist Advisor – Geotechnical Engineering

REFERENCES

KGS Group, *Geotechnical Investigation in Support of Conservation Ontario Class Environmental Assessment for the Rehabilitation of the Pickering and Ajax Flood Control Dyke 2019 Geotechnical Investigation Report*, May 2020.

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STATEMENT OF LIMITATIONS AND CONDITIONS

Limitations

This report has been prepared for the Toronto & Region Conservation Authority (TRCA) in accordance with the agreement between KGS Group and the TRCA (the "Agreement"). This report represents KGS Group's professional judgment and exercising due care consistent with the preparation of similar reports. The information, data, recommendations and conclusions in this report are subject to the constraints and limitations in the Agreement and the qualifications in this report. This report must be read as a whole and sections or parts should not be read out of context.

This report is based on information made available to KGS Group by the TRCA and unless stated otherwise, KGS Group has not verified the accuracy, completeness or validity of such information, makes no representation regarding its accuracy and hereby disclaims any liability in connection therewith. KGS Group shall not be responsible for conditions/issues it was not authorized or able to investigate or which were beyond the scope of its work. The information and conclusions provided in this report apply only as they existed at the time of KGS Group's work.

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Any use a third party makes of this report or any reliance on or decisions made based on it, are the responsibility of such third parties. KGS Group accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions undertaken based on this report.

Geo-Environmental Statement of Limitations

KGS Group prepared the geo-environmental conclusions and recommendations for this report in a professional manner using the degree of skill and care exercised for similar projects under similar conditions by reputable and competent environmental consultants. The information contained in this report is based on the information that was made available to KGS Group during the investigation and upon the services described, which were performed within the time and budgetary requirements of the TRCA. As this report is based on the available information, some of its conclusions could be different if the information upon which it is based is determined to be false, inaccurate or contradicted by additional information. KGS Group makes no representation concerning the legal significance of its findings or the value of the property investigated.

Geotechnical Investigation Statement of Limitations

The geotechnical investigation findings and recommendations of this report were prepared in accordance with generally accepted professional engineering principles and practice. The findings and recommendations are based on the results of field and laboratory investigations, combined with an interpolation of soil and groundwater conditions found at and within the depth of the test holes drilled by KGS Group at the site at the time of drilling. If conditions encountered during construction appear to be different from those shown by the test holes drilled by KGS Group or if the assumptions stated herein are not in keeping with the design, KGS Group should be notified in order that the recommendations can be reviewed and modified if necessary.

TECHNICAL MEMO:
Pickering And Ajax Dykes Rehabilitation Class EA – Hydraulic Modelling

Technical Memo

To: Fuad Curi, M.ASC., P.Eng, KGS Group
From: Melody Brown, P.Eng., TRCA
Cc: Nick Lorrain, TRCA
Date: 05/13/2020
Re: Pickering and Ajax Dykes Rehabilitation Class EA – Hydraulic Modelling

TRCA completed all hydraulic modelling required for the Pickering and Ajax Dykes Rehabilitation Class Environmental Assessment (EA) project. Model results of water surface elevation, water velocity and water depth were provided to KGS Group for interpretation and analysis. This memo provides documentation of the hydraulic modelling completed for the project.

In 2018 the regulatory floodplain mapping for the Village East Special Policy Area (SPA) and Notion Road/Pickering Village SPA, in Pickering and Ajax respectively, was updated. The mapping update was completed by Valdor Engineering Inc. using a new 1D-2D coupled hydraulic model (the model) for the area produced with MIKE Flood software. This MIKE Flood model was utilized for existing conditions simulations for the Pickering and Ajax Dykes Rehabilitation Class EA project.

Hydraulic Modelling of Proposed Dyke Rehabilitation

Valdor's MIKE Flood model was modified as needed to simulate flood changes due to the proposed dyke rehabilitation works. KGS Group provided TRCA with a digital terrain model (DEM) of the proposed dyke surface as well as a description of the dyke surface treatment. TRCA used this information to update the MIKE Flood model to reflect proposed conditions.

It should be noted that the dyke rehabilitation design completed by KGS Group was completed to a 30% level of design detail and therefore the hydraulic model of the proposed conditions also represents a 30% level of detail. All proposed conditions simulations must be verified at an appropriate higher level of detail in later design phases prior to permitting and implementation.

Details of the model are documented in the report *MIKE Flood 1D-2D Model Development and Regulatory Floodplain Mapping, Valdor 2018* and will not be repeated herein. Changes made to the model to simulate the proposed rehabilitated dykes will be described generally in this memo for documentation purposes.

The model includes multiple files or layers that define different attributes including the ground topography and surface roughness.

The layer that defines the ground topography was updated to reflect the new dyke geometry. The height, footprint and shape of the dyke was updated. The topography of the surrounding lands was not changed and remained as under existing condition. KGS Group provided TRCA with a DEM file (*.asc* format) of the proposed dyke topography. This was used to update the model. Although the preferred solution for the Pickering Dyke is concept design H2 for Segment P1 and design S1 for Segment P2, the modelled dyke gemotery reflects the H2 design at P1 and the S2 design at P2. Similarily the S2 design was modelled for the Ajax dyke, although the S1 design is the preferred solution. This was done for conservatism, to test the worst case scenrio, as the S2 design has a marginally larger footprint than the S1 design.

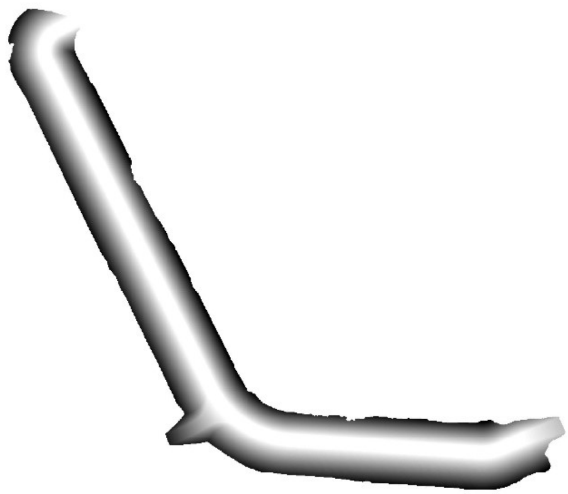

Figure 1 - Screen capture of DEM from KGS Group of Proposed Ajax Dyke Rehabilitation Solution S2 for Segment A1.

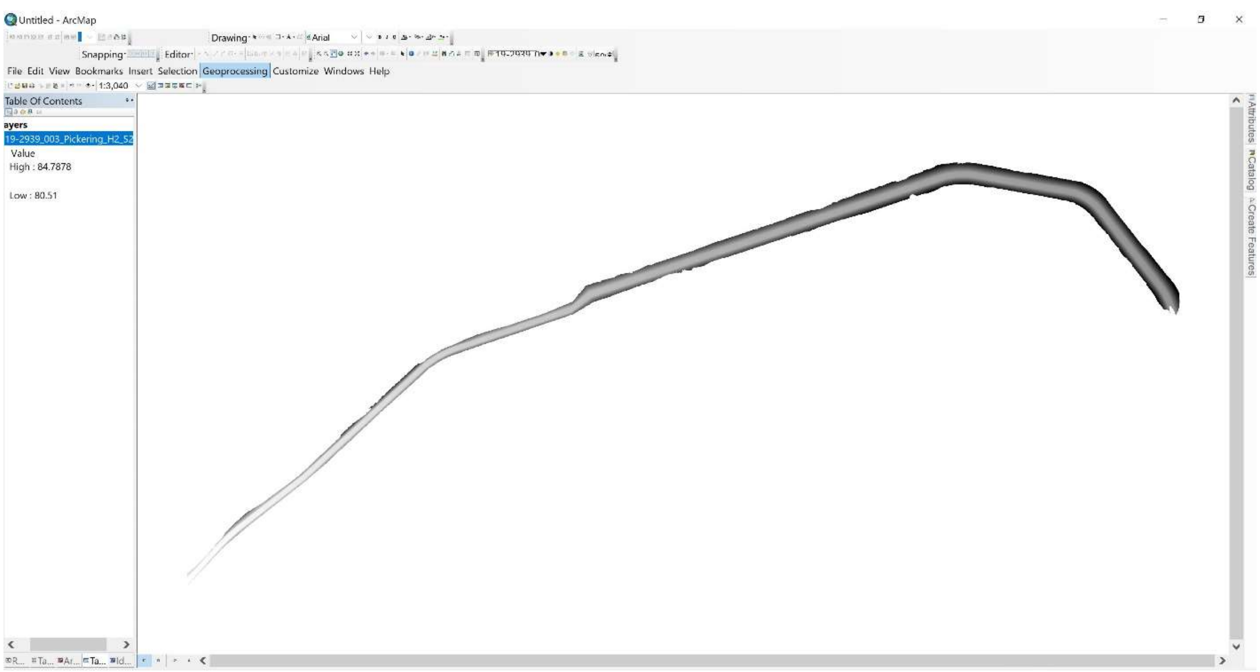

Figure 2 – Screen capture of DEM from KGS Group of Proposed Pickering Dyke Rehabilitation Solutions H2 for Segment P1 and S2 for Segment P2.

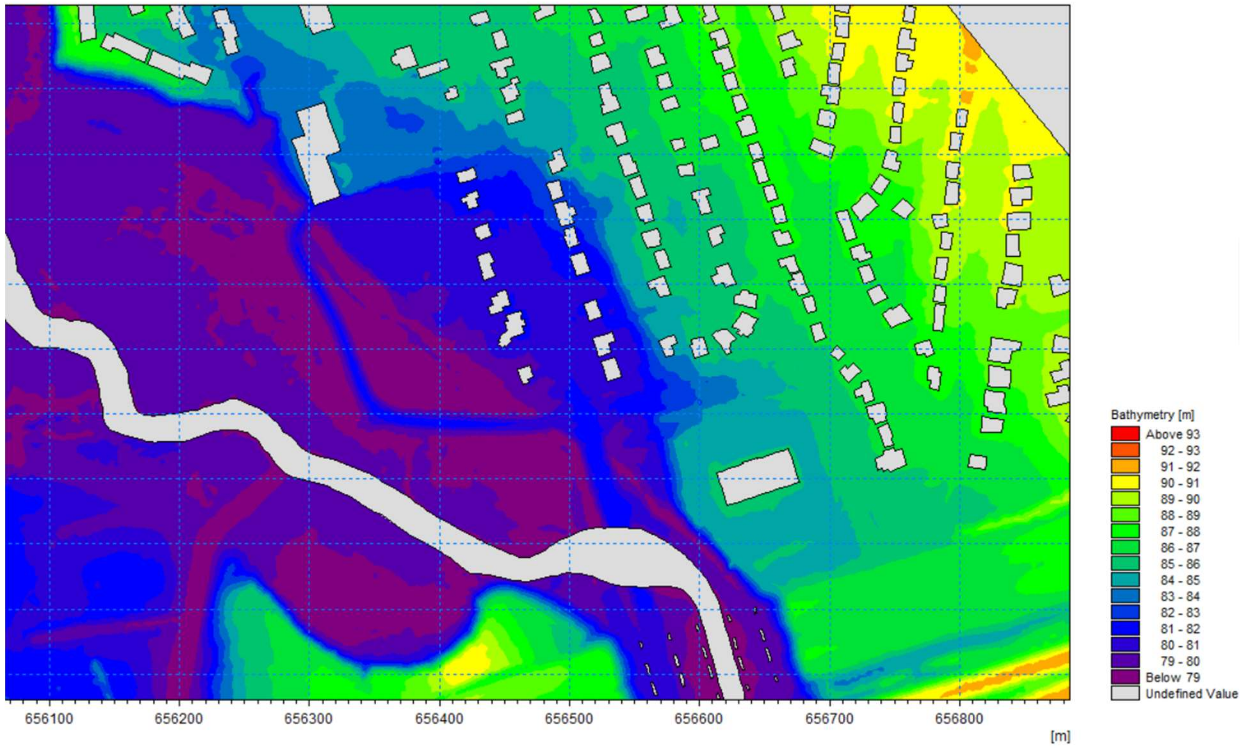

Figure 3 - Screen capture of the ground topography model layer at the Ajax Dyke from the existing condition hydraulic model.

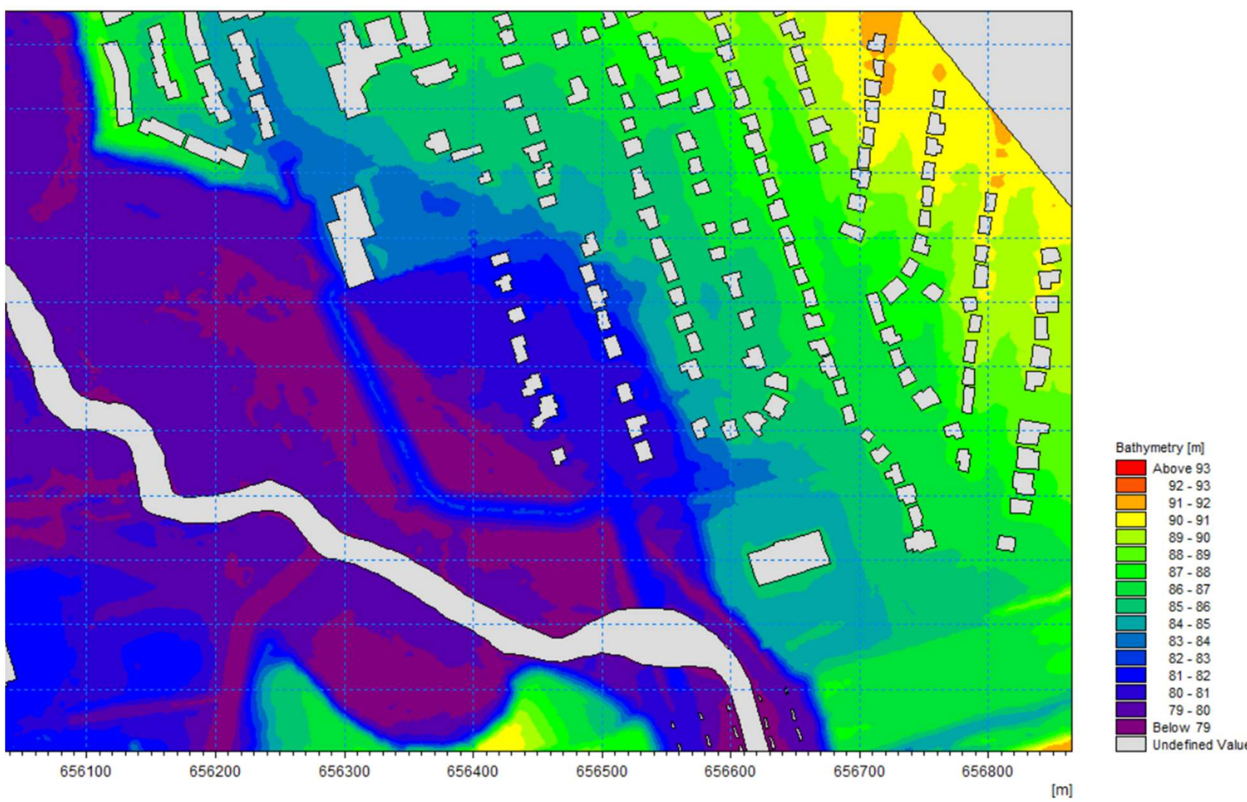

Figure 4 - Screen capture of the ground topography model layer at the Ajax Dyke from the proposed dyke rehabilitation hydraulic model.

The layer that defines surface roughness was updated to reflect mowed grass along the entirely of the dykes and a mowed grass buffer on either side of the dyke. A mowed buffer around the dyke is recommended for maintenance access and to keep the granular drainage filter 'tail' (which extends from the dry side of the soft solutions) clear of woody vegetation. At the time of the modelling exercise, it was unknown exactly how large of a mowed buffer would be recommended for maintenance but early discussions had suggested 3m. As such, a 3m buffer of mowed grass (lower roughness than the surrounding valley lands) was applied to each of the dykes, extending from both the wet and dry toes. The buffer was reduced to less than 3m in areas where the 3m extended into private property, the watercourse, roads or buildings.

The changes in Manning's n from existing to proposed conditions are listed in the table below and are illustrated in **Figures 5 - 8**.

Table 1 - Manning's Roughness Coefficients Used in Hydraulic Models

Land Use	**Existing Conditions Model**	**Proposed Conditions Model (Dyke Rehabilitation)**
Dyke + 3m buffer around Dyke	0.08	0.05
Valley Lands	0.08	0.08
Roads and Buildings	0.025	0.025

The computational grid spacing was the same in the proposed dyke rehabilitation model as was used in Valdor's existing condition model. Simulations of the 100-year return period storm event and the regional storm event were run using the same simulation run settings as in the existing condition model. The resultant water surface, water velocity and water depth data were converted into *.asc* files and provided to KGS for analysis.

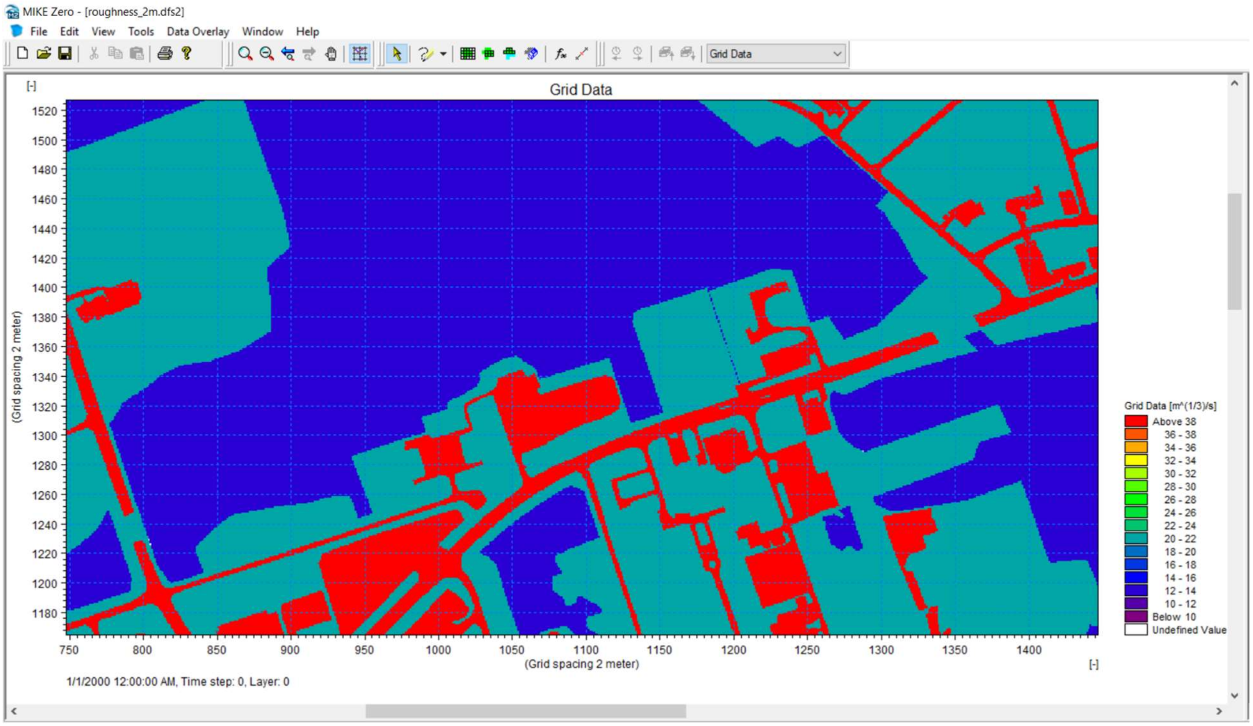

Figure 5 - Screen capture of the Manning's n model layer at the Pickering Dyke from the existing condition hydraulic model.

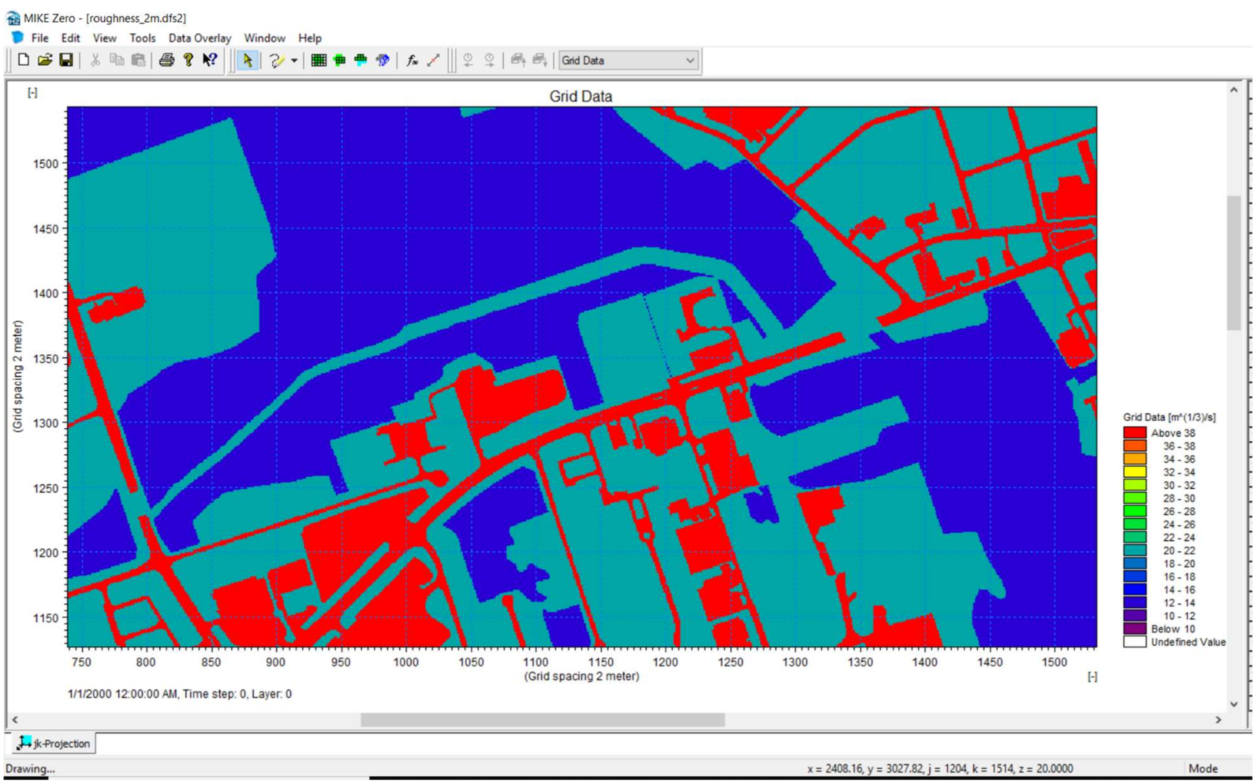

Figure 6 - Screen capture of the Manning's n model layer at the Pickering Dyke from the proposed dyke rehabilitation hydraulic model.

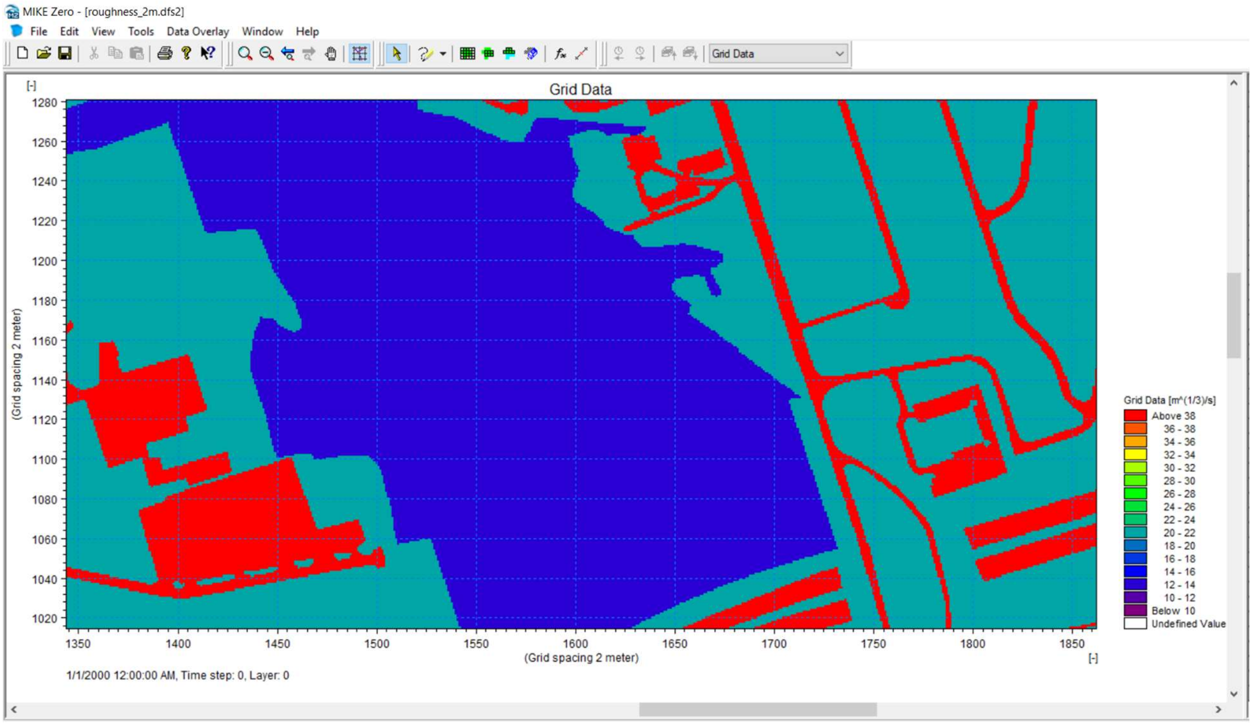

Figure 7 - Screen capture of the Manning's n model layer at the Ajax Dyke from the existing hydraulic model.

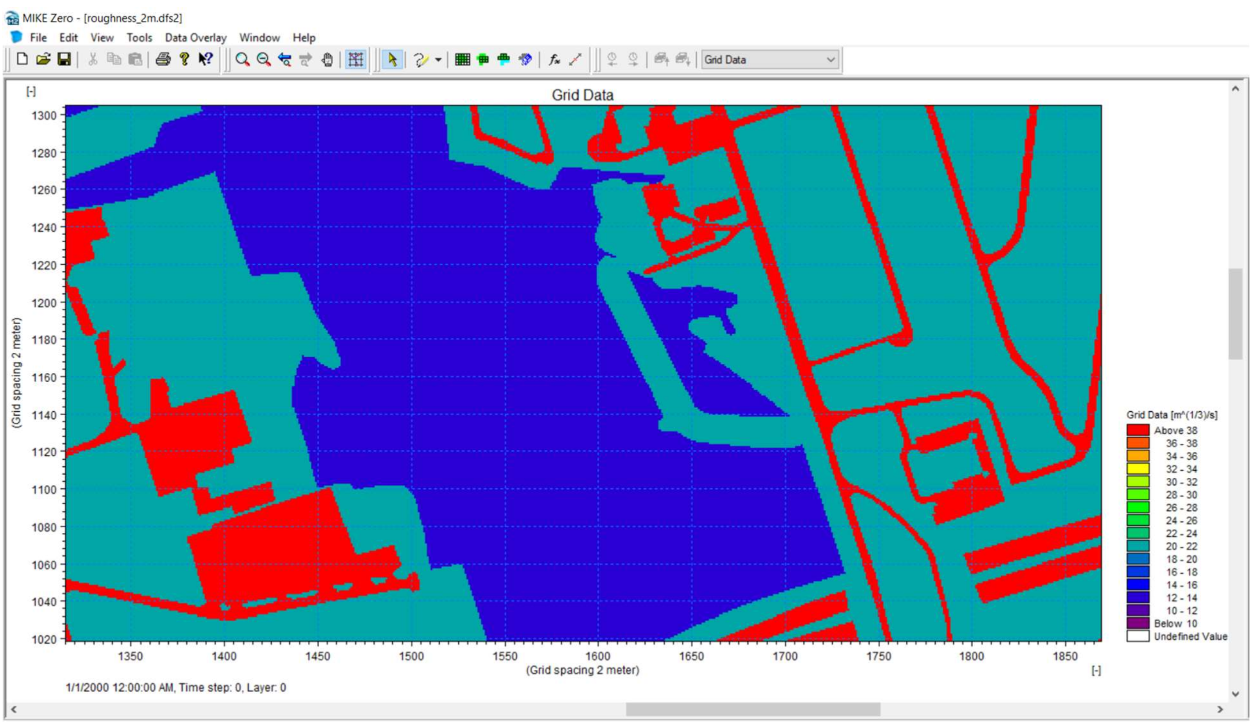

Figure 8 - Screen capture of the Manning's n model layer at the Ajax Dyke from the proposed dyke rehabilitation hydraulic model.

Hydraulic Modelling of Dyke Failure Flood Extents

Valdor's MIKE Flood model was modified as needed to simulate the flood extents if the dykes were to fail. This was modelled by modifying the ground topography layer to 'remove' the dykes – the ground within the dyke footprints was changed to be a similar elevation to the ground adjacent to the dykes. Recognizing that the flood extents during a dyke failure would differ from these results, as a flood wave would occur during failure which can spread differently, it was felt to be sufficient for the impact analysis/comparison needed under the Class EA project, which included designs to only a 30% level of detail. No other changes were made to existing condition model under the dyke failure scenario. Simulations of the 50-year and 100-year return period storm events were run using the same simulation run settings as in the existing condition model.