SUB-ATTACHMENT E

SEEPAGE ANALYSIS

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SEEPAGE ANALYSIS

1. General: The embankment was evaluated for seepage through and beneath the embankment. Since the duration of a flood event at or above the design water surface is very brief, it is unlikely that a condition of full saturation of the embankment will occur. However, the seepage analysis did assume a full steady state condition, causing saturation of the levee embankment. Any seepage through the embankment will be collected by the sand blanket drain and discharged at the toe of the levee, which will prevent saturation of the landside portion of the levee embankment. However, because of the pervious aquifer and varying thickness of blanket, analysis of underseepage was performed.

2. Embankment and Foundation Conditions:

a. In general, the proposed levee embankment will have a 10-foot wide crest and 1 vertical on 2.5 horizontal (1.0V:2.5H) side slopes. A 6-foot deep trapezoidal inspection trench will be located beneath the levee centerline. The embankment will be constructed primarily using select earth material from a borrow source obtained by the contractor. In addition, a combination sand blanket and gravel toe drain will be placed along the landside levee toe.

b. Foundation Conditions beneath Levee Centerline. Subsurface exploration indicates the existence of three general foundation overburden zones within the top 60 feet along the centerline of the levee embankment alignment. The top stratum consists of an upper blanket zone of silt, clay and silty or clayey sand. This blanket material varies in thickness from 5 to 16 feet, with an average thickness of 8 feet. Beneath this blanket stratum is a pervious stratum of silty sand and gravel varying from 2 to 13 feet thick: however, at drill holes DH-1 and 4, the poorly graded sand and gravel stratum was not encountered and only a 2-foot thick zone of silty gravel was encountered in DH-2. Mechanical sieve analysis performed on the foundation sand and gravel samples showed that the material contained 3 to 12 percent fines (material passing the 200 sieve). Beneath the top two strata is a thick deposit of very hard clay, with varying amounts of sand and gravel. In some borings, seams of clayey, silty sand were encountered within the clay deposit. A summary of gradation curves for each of the different foundation strata are provided on the following pages.

Based on visual classification and mechanical sieve analyses of selective soil samples, a range of hydraulic conductivity values were selected for the various foundation strata or deposits encountered. The table below shows the typical ranges of values used in the analyses for foundation and embankment materials:

Zone/Stratum	Hydraulic conductivity, k
Upper Blanket of Clay, Silt, & Clayey Sand	1×10^{-4} to 1×10^{-6} cm/sec
Sand & Gravel Aquifer Layer	1×10^{-3} to 2×10^{-2} cm/sec
Lower Clay Stratum	1×10^{-6} to 1×10^{-8} cm/sec
Sand Blanket Drain	1×10^{-2} to 1×10^{-3} cm/sec
Gravel Toe Drain	1×10^{-1} cm/sec
Impervious Levee Fill	1×10^{-5} to1×10^{-6} cm/sec

3. Underseepage Analysis:

a. Since the foundation condition consist of semi-impervious blanket overlying an aquifer, significant hydrostatic pressures within the aquifer and beneath the foundation blanket could develop during high river stages. These potentially high pressures should be considered when analyzing foundation conditions at the toe of the levee embankment. Preliminary seepage analysis was performed using techniques presented in EM 1110-2-1913, Design and Construction of Levees (30 April 2000), Appendix B, "Mathematical Analysis of Underseepage and Substratum Pressures." Calculations for this analysis are presented on the following pages. The results indicated that the uplift pressures and exit gradients at the landside toe of the levee are generally within acceptable ranges, with certain exceptions. The analysis did show that landward of the levee in the vicinity of the proposed ponding area, the exit gradient is slightly above the recommended minimum. Therefore, it is recommended that a toe drain be included with the sand blanket drain to collect and control seepage.

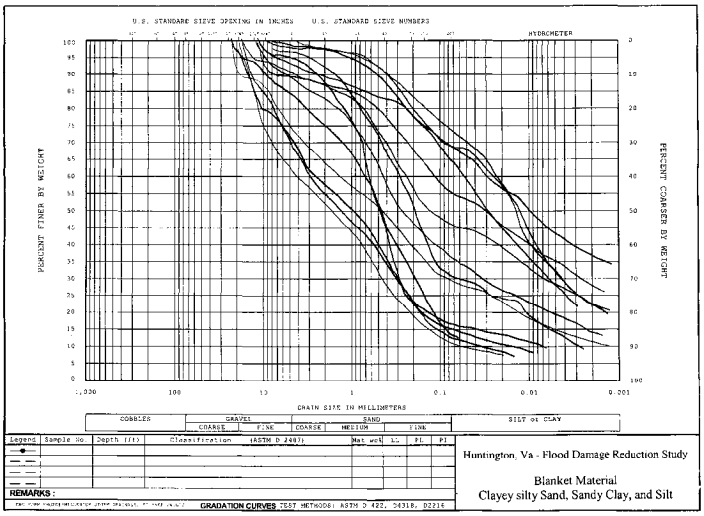
b. Additional underseepage analysis was performed to evaluate the toe drain and its impact on reducing seepage pressures at the levee toe and landward of the toe. The analysis provided data on flow rates, exit gradients, and pressures heads within the levee embankment and foundation. The finite element seepage program, SEEP/W 2007, developed by GEO-Slope International was used to analyze seepage conditions. To perform the seepage analysis, a typical levee section and foundation profile was developed to provide a conservative model for the conditions of the site. The foundation was divided into 3 zones. The foundation semi-impervious top blanket was modeled being 6 feet thick, the sand and gravel aquifer being 10 feet thick, and the clay deposit being 30 feet thick. The section included the sand blanket and gravel toe drains located beneath the levee embankment and toe to control and collect seepage. Certain critical parameters were varied in the model to determine their influence and impacts, which are listed below:

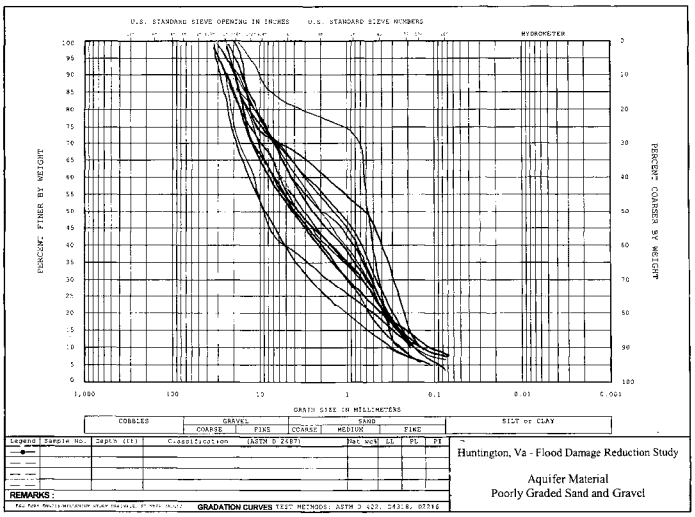
- Water levels at both the top of protection and design water surface were assumed it the analysis, which created a maximum differential head of approximately 13 and 10 feet, respectively.
- Tailwater levels used in the analysis were at the ground surface and ponding level, elevation 6.0 and 9.0, respectively.
- The hydraulic conductivity values for the foundation materials were varied.
- The toe drain was modeled for 2 conditions. The first condition assumed that the toe drain only partially penetrates through the semi-impervious blanket and does not make contact with the underlying sand and gravel aquifer stratum. The other condition assumed that the bottom of toe drain does fully penetrate the upper blanket and makes fully contact with the aquifer.

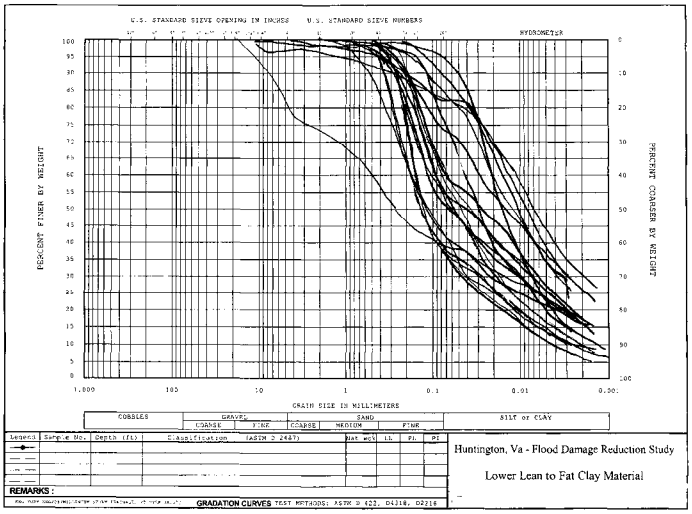
Several output plots (flow net figures) are provided at the end of this section, which show the various conditions that were modeled. The data presented on the figures show potential head contours, flow quantities, and seepage gradients at the toe and farther landward of the levee embankment. For the river at the design water surface level, the analysis showed the exit gradients and hydrostatic heads to be within acceptable ranges. For condition with the river at top of protection, the analysis showed the exit gradients and hydrostatic heads to be higher; however, these values are considered to be within acceptable ranges based on the extreme event. In general, the analysis showed that the excess hydrostatic pressures would dissipate through the blanket layer and be controlled by the drains.

c. As stated above, during the design it was determined that additional area is required for ponding interior drainage run-off. In order to provide space for ponding, the area landward of the levee toe will be excavated to elevation 6.0. The depth for the excavation would vary from 0 to 3 feet. The excavation would begin 50 feet from the levee toe and would extend out to about 250 feet from the levee toe. The toe drain would help to relieve excess hydrostatic pressures that could develop farther landward in the vicinity of the ponding area.

Typical Gradation Curves for Embankment and Foundation Materials







Mathematical Analysis of Underseepage and Substratum Pressures.

Computation for Undersepage Pressures Beneath Semi-Impervious Blanket

Because of the foundation conditions beneath the proposed levee, significant hydrostatic pressures within the aquifer and beneath the foundation blanket could develop during high river stages. These potential high pressures should be considered when analyzing foundation conditions at the toe of the levee embankment. Preliminary seepage analysis was performed using techniques presented in EM 1110-2-1913, Design and Construction of Levees (30 April 2000), Appendix B, “Mathematical Analysis of Underseepage and Substratum Pressures.” On the following pages are computations for determining underseepage flows and pressures beneath the landside semi-impervious blanket for the Huntington levee. This analysis indicated that the uplift pressures and exit gradients at the landside toe of the levee are generally within acceptable ranges, with certain exceptions.

At the toe of the levee, it is generally desirable to have exit gradients less than 0.6 and factors-of-safety against uplift greater than 1.7 for a river stage at the design water surface (DWS) elevation and a blanket unit weight greater than 120pcf. For the river at top of protection, it is considered reasonable to allow higher gradients at the levee toe but not greater than about 0.8, which yields a FS against uplift of 1.25. Also, additional evaluation of the areas landward of the levee toe that would be excavated for the creation of the ponding areas were analyzed to ensure that the exit gradients and uplift were acceptable. For a significant reach of the levee, addition fill will be placed along the toe for the access ramp and to cover the culverts for the pump station. This additional fill will assist in providing resistance to uplift, and therefore, significantly increases the factor-of-safety against uplift at the levee toe.

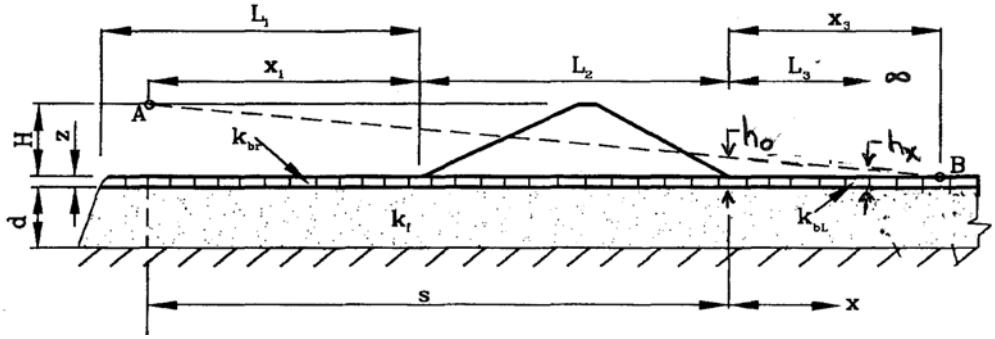
The following summary tables provide data on the calculated exit gradients and uplift factors of safety at the levee toe and at some distance landward of the toe. In general, all the exit gradients and uplift FS are adequate with certain exceptions. It is recommended that a toe drain be included with the sand blanket drain to control seepage. A finite element seepage analysis was performed to evaluate the toe drain and its impact on reducing seepage pressures at the levee toe and landward. Results and output plots are provided in the next section.

Reach	Tailwater	Head at Levee Toe, h_0		Exit Gradient at Levee Toe, i_o		Factor of Safety at Levee Toe		Factor of Safety at Toe with Addition fill	
	EL.	DWS	TP	DWS	TP	DWS	TP	DWS	TP
0+00 to 5+00	6	4.75	6.77	0.59	0.85	1.69	1.19	2.70	1.91
0+00 to 5+00	9	3.23	5.25	0.40	0.66	2.48	1.53	3.73	2.29
5+00 to 10+00	6	4.83	6.82	0.80	1.14	1.25	0.88	2.70	1.91
5+00 to 10+00	9	3.25	5.25	0.54	0.87	1.85	1.15	4.00	2.48
10+00 to 17+00	8	3.41	5.16	0.43	0.64	2.36	1.56		
10+00 to 17+00	9	2.9	4.66	0.36	0.58	2.76	1.72		
17+00 to 24+00	8	3.22	4.84	0.36	0.54	2.8	1.87		
17+00 to 24+00	9	2.72	4.33	0.30	0.48	3.32	2.08		
24+00 to 29+00	6	3.99	5.44	0.36	0.49	2.76	2.03		
24+00 to 29+00	9	2.55	3.99	0.23	0.36	4.33	2.76		

Reach	Tailwater	Head at Levee Toe, h_x		Exit Gradient at Levee Toe, i_x		Factor of Safety at Levee Toe		"X" distance from toe
	EL.	DWS	TP	DWS	TP	DWS	TP	
0+00 to 5+00	6	3.41	4.86	0.43	0.61	2.35	1.65	60
0+00 to 5+00	9	2.32	3.77	0.29	0.47	3.46	2.13	60
5+00 to 10+00	6	3.69	5.21	0.61	0.87	1.63	1.16	60
5+00 to 10+00	9	2.49	4.01	0.41	0.67	2.42	1.50	60
10+00 to 17+00	8	3.01	4.56	0.50	0.76	2.00	1.32	30
10+00 to 17+00	9	2.57	4.12	0.43	0.69	2.34	1.46	30
17+00 to 24+00	8	2.71	4.06	0.30	0.45	3.34	2.22	50
17+00 to 24+00	9	2.28	3.64	0.25	0.40	3.95	2.48	50
24+00 to 29+00	6	3.35	4.56	0.30	0.41	3.29	2.42	50
24+00 to 29+00	9	2.14	3.35	0.19	0.30	5.16	3.29	50

Undersepage Pressures Beneath Semi-Impervious Blanket

Below are computations for determining underseepage flows and pressures beneath the landside semi-impervious blanket. Analysis was performed using equations and techniques presented in EM 1110-2-1913, Design and Construction of Levees (30 April 2000), Appendix B, "Mathematical Analysis of Underseepage and Substratum Pressures."



Project: Huntington, VA - FDR Study ***Reach: Station 0+00 to 5+00***
Date: Oct-08

Top of Protection (TP) El. =	19.4	Head (TP -TW) H_{TP} =	13.4	L_1 =	75
Design Water Surface (DWS) El. =	15.4	Head (DWS -TW) H_{DWS} =	9.4	L_2 =	70
Top of Ground (TG) EL. =	6.0			L_3 =	0
Tailwater (TW) El.=	**6.0**			distance landward from levee toe, x =	60
				Blanket Thinkness at x distance (z_x)=	8
Blanket Thinkness (z_{bl})=	8	Blanket k_{bl} cm/s =	1.00E-05		
Aquifer Thickness (d)=	5	Aquifer k_f cm/s =	5.00E-03		
Blanket Unit Wt. (pcf) =	125				

EQUATIONS

For $L_3 = \infty$ where $c = \sqrt{\dfrac{k_{bl}}{k_f z_{bl} d}}$ $\quad x_3 = \dfrac{1}{c} = \sqrt{\dfrac{k_f z_{bl} d}{k_{bl}}}$ $\quad x_1 = \dfrac{\tanh cL_1}{c}$

HEAD BENEATH TOP STRATUM AT LANDSIDE LEVEE TOE..... $h_o = \dfrac{Hx_3}{x_1 + L_2 + x_3}$

HEAD LANDWARD OF THE LEVEE TOE: $h_x = h_o e^{-cx}$, e= 2.718

SEEPAGE PER UNIT LENGTH OF LEVEE..... $Q_s = S k_f H = \dfrac{d k_f H}{x_1 + L_2 + x_3}$

Computations: ***Assumes No Toe Drain or additional fills for ramp, etc at levee toe***

c =	0.00707107	
Dist to eff seepage entrance X_1 =	69	Seepage/ lf of levee - Q (gpm/lf) = 0.02
Dist to effective seepage exit X_3 =	141	
S = (X_1+L_2) =	139	

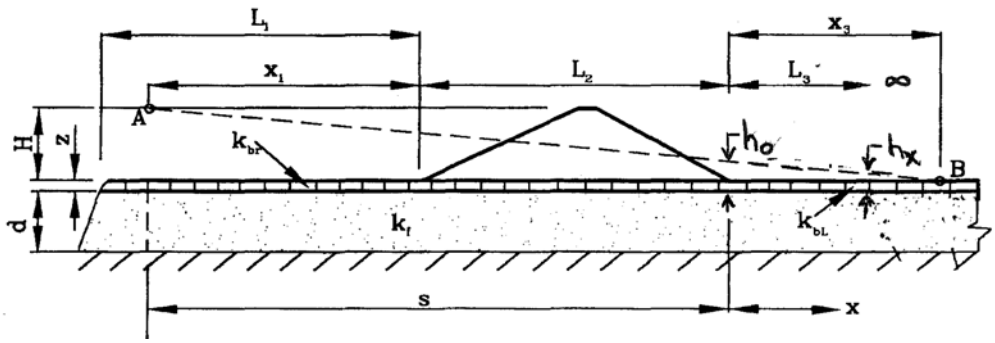
River Level at	Head at Levee Toe, h_0	Exit Gradient at toe, $i_o = h_o/z_{bl}$	Factor of Safety at Toe FS= z_{bl} (125-62.4)/h_o(62.4)
Design Water Surface	4.75	0.59	1.69
Top of Protection	6.77	0.85	1.19

River Level at	"x" distance from toe Head, h_x	Gradient, i_x
Design Water Surface	3.41	0.43
Top of Protection	4.86	0.61

Note: There is about 3.5 ft of additional fill along the levee toe for the ramp and to cover the pump sta conduit. This will provide additional resistance at the toe against uplift- for river at DWS & TP- FS =2.70 & 1.91, respectively

Undersepage Pressures Beneath Semi-Impervious Blanket

Below are computations for determining underseepage flows and pressures beneath the landside semi-impervious blanket. Analysis was performed using equations and techniques presented in EM 1110-2-1913, Design and Construction of Levees (30 April 2000), Appendix B, "Mathematical Analysis of Underseepage and Substratum Pressures."



Project: Huntington, VA - FDR Study ***Reach: Station 0+00 to 5+00***
Date: Oct-08

Top of Protection (TP) El. =	19.4	Head (TP -TW) H_{TP} =	10.4	L_1 =	75
Design Water Surface (DWS) El. =	15.4	Head (DWS -TW) H_{DWS} =	6.4	L_2 =	70
Top of Ground (TG) EL. =	6.0			L_3 =	0
Tailwater (TW) El.=	**9.0**			distance landward from levee toe, x =	60
				Blanket Thinkness at x distance (z_x)=	8
Blanket Thinkness (z_{bl})=	8	Blanket k_{bl} cm/s =	1.00E-05		
Aquifer Thickness (d)=	5	Aquifer k_f cm/s =	5.00E-03		
Blanket Unit Wt. (pcf) =	125				

EQUATIONS

For $L_3 = \infty$ where $c = \sqrt{\dfrac{k_{bl}}{k_f z_{bl} d}}$ $\quad x_3 = \dfrac{1}{c} = \sqrt{\dfrac{k_f z_{bl} d}{k_{bl}}}$ $\quad x_1 = \dfrac{\tanh cL_1}{c}$

HEAD BENEATH TOP STRATUM AT LANDSIDE LEVEE TOE..... $h_o = \dfrac{Hx_3}{x_1 + L_2 + x_3}$

HEAD LANDWARD OF THE LEVEE TOE: $h_x = h_o e^{-cx}$, e= 2.718

SEEPAGE PER UNIT LENGTH OF LEVEE..... $Q_s = S k_f H = \dfrac{d k_f H}{x_1 + L_2 + x_3}$

Computations: ***Assumes No Toe Drain or additional fills for ramp, etc at levee toe***

c =	0.00707107	
Dist to eff seepage entrance X_1 =	69	Seepage/ lf of levee - Q (gpm/lf) = 0.01
Dist to effective seepage exit X_3 =	141	
S = (X_1+L_2) =	139	

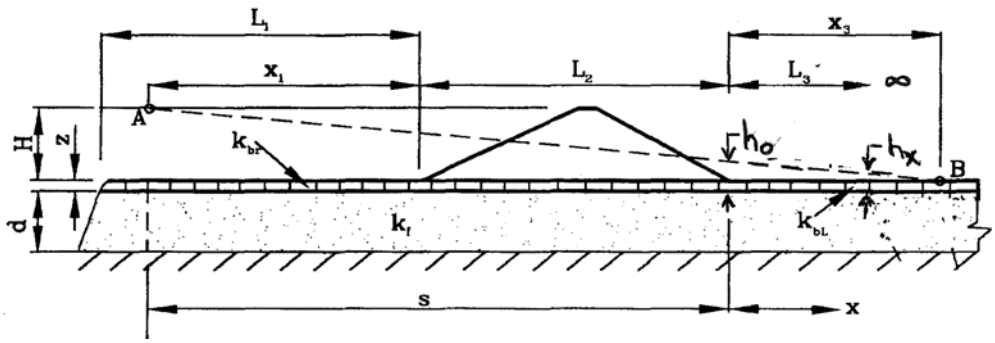
River Level at	Head at Levee Toe, h_0	Exit Gradient at toe, $i_o = h_o/z_{bl}$	Factor of Safety at Toe FS= z_{bl} (125-62.4)/h_o(62.4)
Design Water Surface	3.23	0.40	2.48
Top of Protection	5.25	0.66	1.53

River Level at	"x" distance from toe Head, h_x	Gradient, i_x
Design Water Surface	2.32	0.29
Top of Protection	3.77	0.47

Note: There is about 3.5 ft of additional fill along the levee toe for the ramp and to cover the pump sta conduit. This will provide additional resistance at the toe against uplift- for river at DWS & TP- FS =3.73 & 2.29, respectively

Undersepage Pressures Beneath Semi-Impervious Blanket

Below are computations for determining underseepage flows and pressures beneath the landside semi-impervious blanket. Analysis was performed using equations and techniques presented in EM 1110-2-1913, Design and Construction of Levees (30 April 2000), Appendix B, "Mathematical Analysis of Underseepage and Substratum Pressures."



Project: Huntington, VA - FDR Study ***Reach: Station 5+00 to 10+00***
Date: Oct-08

Top of Protection (TP) El. =	19.0	Head (TP -TW) H_{TP} =	13.0	L_1 =	80
Design Water Surface (DWS) El. =	15.2	Head (DWS -TW) H_{DWS} =	9.2	L_2 =	82
Top of Ground (TG) EL. =	6.0			L_3 =	0
Tailwater (TW) El.=	**6.0**			distance landward from levee toe, x =	60
				Blanket Thinkness at x distance (z_x)=	6
Blanket Thinkness (z_{bl})=	6	Blanket k_{bl} cm/s =	1.00E-05		
Aquifer Thickness (d)=	10	Aquifer k_f cm/s =	5.00E-03		
Blanket Unit Wt. (pcf) =	125				

EQUATIONS

For $L_3 = \infty$ where $c = \sqrt{\dfrac{k_{bl}}{k_f z_{bl} d}}$ $x_3 = \dfrac{1}{c} = \sqrt{\dfrac{k_f z_{bl} d}{k_{bl}}}$ $x_1 = \dfrac{\tanh cL_1}{c}$

HEAD BENEATH TOP STRATUM AT LANDSIDE LEVEE TOE..... $h_o = \dfrac{Hx_3}{x_1 + L_2 + x_3}$

HEAD LANDWARD OF THE LEVEE TOE: $h_x = h_o e^{-cx}$, e= 2.718

SEEPAGE PER UNIT LENGTH OF LEVEE..... $Q_s = S k_f H = \dfrac{d k_f H}{x_1 + L_2 + x_3}$

Computations: ***Assumes No Toe Drain or additional fills for ramp, etc at levee toe***

c =	0.0057735	
Dist to eff seepage entrance X_1 =	75	Seepage/ lf of levee - Q (gpm/lf) = 0.03
Dist to effective seepage exit X_3 =	173	
S = (X_1+L_2) =	157	

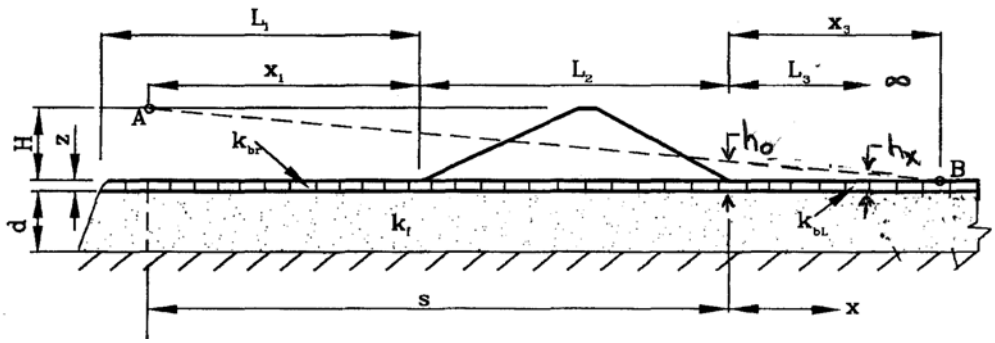
River Level at	Head at Levee Toe, h_0	Exit Gradient at toe, $i_o = h_o/z_{bl}$	Factor of Safety at Toe FS= z_{bl} (125-62.4)/h_o(62.4)
Design Water Surface	4.83	0.80	1.25
Top of Protection	6.82	1.14	0.88

River Level at	"x" distance from toe Head, h_x	Gradient, i_x
Design Water Surface	3.69	0.61
Top of Protection	5.21	0.87

Note: There is about 3.5 ft of additional fill along the levee toe for the ramp and to cover the pump sta conduit. This will provide additional resistance at the toe against uplift- for river at DWS & TP- FS =2.70 & 1.91, respectively

Undersepage Pressures Beneath Semi-Impervious Blanket

Below are computations for determining underseepage flows and pressures beneath the landside semi-impervious blanket. Analysis was performed using equations and techniques presented in EM 1110-2-1913, Design and Construction of Levees (30 April 2000), Appendix B, "Mathematical Analysis of Underseepage and Substratum Pressures."



Project: Huntington, VA - FDR Study ***Reach: Station 5+00 to 10+00***
Date: Oct-08

Top of Protection (TP) El. =	19.0	Head (TP -TW) H_{TP} =	10.0	L_1 =	80
Design Water Surface (DWS) El. =	15.2	Head (DWS -TW) H_{DWS} =	6.2	L_2 =	82
Top of Ground (TG) EL. =	6.0			L_3 =	0
Tailwater (TW) El.=	**9.0**			distance landward from levee toe, x =	60
				Blanket Thinkness at x distance (z_x)=	6
Blanket Thinkness (z_{bl})=	6	Blanket k_{bl} cm/s =	1.00E-05		
Aquifer Thickness (d)=	10	Aquifer k_f cm/s =	5.00E-03		
Blanket Unit Wt. (pcf) =	125				

EQUATIONS

For $L_3 = \infty$ where $c = \sqrt{\dfrac{k_{bl}}{k_f z_{bl} d}}$ $x_3 = \dfrac{1}{c} = \sqrt{\dfrac{k_f z_{bl} d}{k_{bl}}}$ $x_1 = \dfrac{\tanh cL_1}{c}$

HEAD BENEATH TOP STRATUM AT LANDSIDE LEVEE TOE..... $h_o = \dfrac{Hx_3}{x_1 + L_2 + x_3}$

HEAD LANDWARD OF THE LEVEE TOE: $h_x = h_o e^{-cx}$, e= 2.718

SEEPAGE PER UNIT LENGTH OF LEVEE..... $Q_s = S k_f H = \dfrac{d k_f H}{x_1 + L_2 + x_3}$

Computations: ***Assumes No Toe Drain or additional fills for ramp, etc at levee toe***

c =	0.0057735	
Dist to eff seepage entrance X_1 =	75	Seepage/ lf of levee - Q (gpm/lf) = 0.02
Dist to effective seepage exit X_3 =	173	
S = (X_1+L_2) =	157	

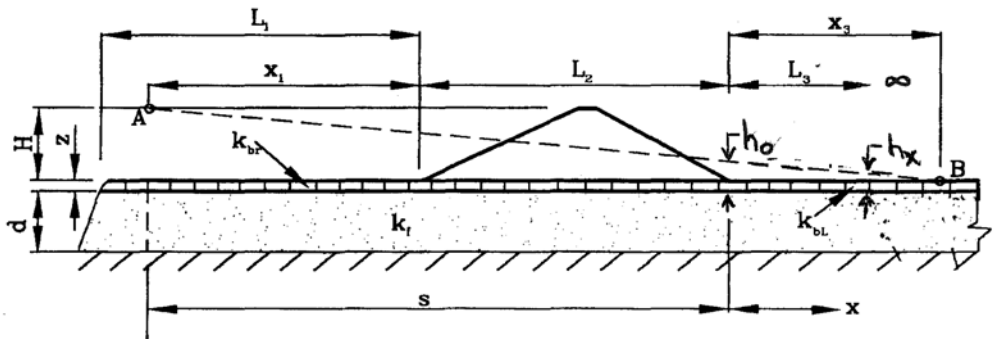
River Level at	Head at Levee Toe, h_0	Exit Gradient at toe, $i_o = h_o/z_{bl}$	Factor of Safety at Toe FS= z_{bl} (125-62.4)/h_o(62.4)
Design Water Surface	3.25	0.54	1.85
Top of Protection	5.25	0.87	1.15

River Level at	"x" distance from toe Head, h_x	Gradient, i_x
Design Water Surface	2.49	0.41
Top of Protection	4.01	0.67

Note: There is about 3.5 ft of additional fill along the levee toe for the ramp and to cover the pump sta conduit. This will provide additional resistance at the toe against uplift- for river at DWS & TP- FS =4.0 & 2.48, respectively

Undersepage Pressures Beneath Semi-Impervious Blanket

Below are computations for determining underseepage flows and pressures beneath the landside semi-impervious blanket. Analysis was performed using equations and techniques presented in EM 1110-2-1913, Design and Construction of Levees (30 April 2000), Appendix B, "Mathematical Analysis of Underseepage and Substratum Pressures."



Project: Huntington, VA - FDR Study ***Reach: Station 10+00 to 17+00***
Date: Oct-08

Top of Protection (TP) El. =	18.3	Head (TP -TW) H_{TP} =	10.3	L_1 =	140
Design Water Surface (DWS) El. =	14.8	Head (DWS -TW) H_{DWS} =	6.8	L_2 =	70
Top of Ground (TG) EL. =	8.0			L_3 =	0
Tailwater (TW) El.=	**8.0**			distance landward from levee toe, x =	30
				Blanket Thinkness at x distance (z_x)=	6
Blanket Thinkness (z_{bl})=	8	Blanket k_{bl} cm/s =	1.00E-05		
Aquifer Thickness (d)=	9	Aquifer k_f cm/s =	5.00E-03		
Blanket Unit Wt. (pcf) =	125				

EQUATIONS

For $L_3 = \infty$ where $c = \sqrt{\dfrac{k_{bl}}{k_f z_{bl} d}}$ $x_3 = \dfrac{1}{c} = \sqrt{\dfrac{k_f z_{bl} d}{k_{bl}}}$ $x_1 = \dfrac{\tanh cL_1}{c}$

HEAD BENEATH TOP STRATUM AT LANDSIDE LEVEE TOE..... $h_o = \dfrac{Hx_3}{x_1 + L_2 + x_3}$

HEAD LANDWARD OF THE LEVEE TOE: $h_x = h_o e^{-cx}$, e= 2.718

SEEPAGE PER UNIT LENGTH OF LEVEE..... $Q_s = S k_f H = \dfrac{d k_f H}{x_1 + L_2 + x_3}$

Computations: ***Assumes No Toe Drain or additional fills for ramp, etc at levee toe***

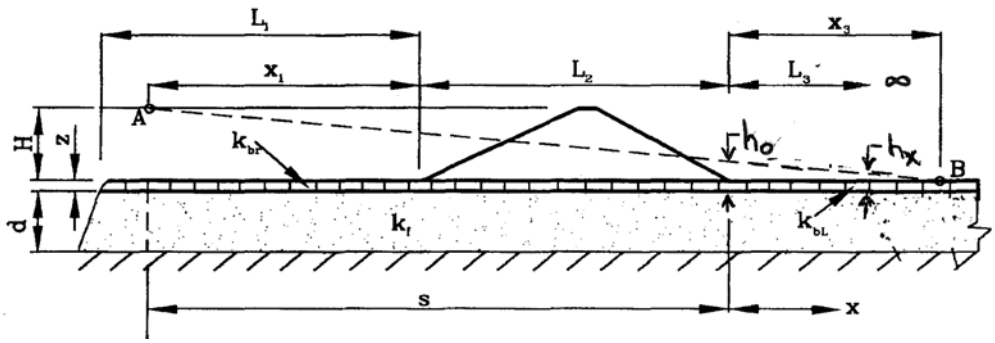
c =	0.00527046		
Dist to eff seepage entrance X_1 =	119	Seepage/ lf of levee - Q (gpm/lf) =	0.02
Dist to effective seepage exit X_3 =	190		
S = (X_1+L_2) =	189		

River Level at	Head at Levee Toe, h_0	Exit Gradient at toe, $i_o = h_o/z_{bl}$	Factor of Safety at Toe FS= z_{bl} (125-62.4)/h_o(62.4)
Design Water Surface	3.41	0.43	2.36
Top of Protection	5.16	0.64	1.56

River Level at	"x" distance from toe Head, h_x	Gradient, i_x
Design Water Surface	3.01	0.50
Top of Protection	4.56	0.76

Undersepage Pressures Beneath Semi-Impervious Blanket

Below are computations for determining underseepage flows and pressures beneath the landside semi-impervious blanket. Analysis was performed using equations and techniques presented in EM 1110-2-1913, Design and Construction of Levees (30 April 2000), Appendix B, "Mathematical Analysis of Underseepage and Substratum Pressures."



Project: Huntington, VA - FDR Study ***Reach: Station 10+00 to 17+00***
Date: Oct-08

Top of Protection (TP) El. =	18.3	Head (TP -TW) H_{TP} =	9.3	L_1 =	140
Design Water Surface (DWS) El. =	14.8	Head (DWS -TW) H_{DWS} =	5.8	L_2 =	70
Top of Ground (TG) EL. =	8.0			L_3 =	0
Tailwater (TW) El.=	**9.0**			distance landward from levee toe, x =	30
				Blanket Thinkness at x distance (z_x)=	6
Blanket Thinkness (z_{bl})=	8	Blanket k_{bl} cm/s =	1.00E-05		
Aquifer Thickness (d)=	9	Aquifer k_f cm/s =	5.00E-03		
Blanket Unit Wt. (pcf) =	125				

EQUATIONS

For $L_3 = \infty$ where $c = \sqrt{\dfrac{k_{bl}}{k_f z_{bl} d}}$ $\quad x_3 = \dfrac{1}{c} = \sqrt{\dfrac{k_f z_{bl} d}{k_{bl}}}$ $\quad x_1 = \dfrac{\tanh cL_1}{c}$

HEAD BENEATH TOP STRATUM AT LANDSIDE LEVEE TOE..... $h_o = \dfrac{Hx_3}{x_1 + L_2 + x_3}$

HEAD LANDWARD OF THE LEVEE TOE: $h_x = h_o e^{-cx}$, e= 2.718

SEEPAGE PER UNIT LENGTH OF LEVEE..... $Q_s = S k_f H = \dfrac{d k_f H}{x_1 + L_2 + x_3}$

Computations: ***Assumes No Toe Drain or additional fills for ramp, etc at levee toe***

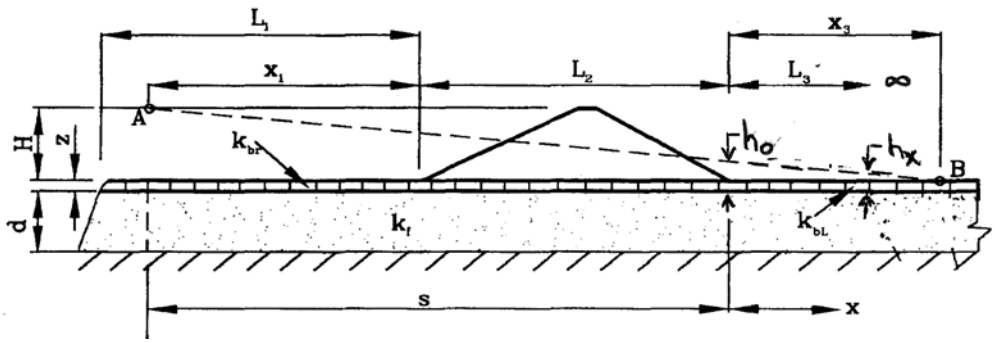
c =	0.00527046	
Dist to eff seepage entrance X_1 =	119	Seepage/ lf of levee - Q (gpm/lf) = 0.02
Dist to effective seepage exit X_3 =	190	
S = (X_1+L_2) =	189	

River Level at	Head at Levee Toe, h_0	Exit Gradient at toe, $i_o = h_o/z_{bl}$	Factor of Safety at Toe FS= z_{bl} (125-62.4)/h_o(62.4)
Design Water Surface	2.90	0.36	2.76
Top of Protection	4.66	0.58	1.72

River Level at	"x" distance from toe Head, h_x	Gradient, i_x
Design Water Surface	2.57	0.43
Top of Protection	4.12	0.69

Undersepage Pressures Beneath Semi-Impervious Blanket

Below are computations for determining underseepage flows and pressures beneath the landside semi-impervious blanket. Analysis was performed using equations and techniques presented in EM 1110-2-1913, Design and Construction of Levees (30 April 2000), Appendix B, "Mathematical Analysis of Underseepage and Substratum Pressures."



Project: Huntington, VA - FDR Study ***Reach: Station 17+00 to 24+00***
Date: Oct-08

Top of Protection (TP) El. =	17.6	Head (TP -TW) H_{TP} =	9.6	L_1 =	200
Design Water Surface (DWS) El. =	14.4	Head (DWS -TW) H_{DWS} =	6.4	L_2 =	60
Top of Ground (TG) EL. =	8.0			L_3 =	0
Tailwater (TW) El.=	**8.0**			distance landward from levee toe, x =	50
				Blanket Thinkness at x distance (z_x)=	9
Blanket Thinkness (z_{bl})=	9	Blanket k_{bl} cm/s =	1.00E-05		
Aquifer Thickness (d)=	11	Aquifer k_f cm/s =	5.00E-03		
Blanket Unit Wt. (pcf) =	125				

EQUATIONS

For $L_3 = \infty$ where $c = \sqrt{\dfrac{k_{bl}}{k_f z_{bl} d}}$ $\quad x_3 = \dfrac{1}{c} = \sqrt{\dfrac{k_f z_{bl} d}{k_{bl}}}$ $\quad x_1 = \dfrac{\tanh cL_1}{c}$

HEAD BENEATH TOP STRATUM AT LANDSIDE LEVEE TOE..... $h_o = \dfrac{Hx_3}{x_1 + L_2 + x_3}$

HEAD LANDWARD OF THE LEVEE TOE: $h_x = h_o e^{-cx}$, e= 2.718

SEEPAGE PER UNIT LENGTH OF LEVEE..... $Q_s = S k_f H = \dfrac{d k_f H}{x_1 + L_2 + x_3}$

Computations: ***Assumes No Toe Drain or additional fills for ramp, etc at levee toe***

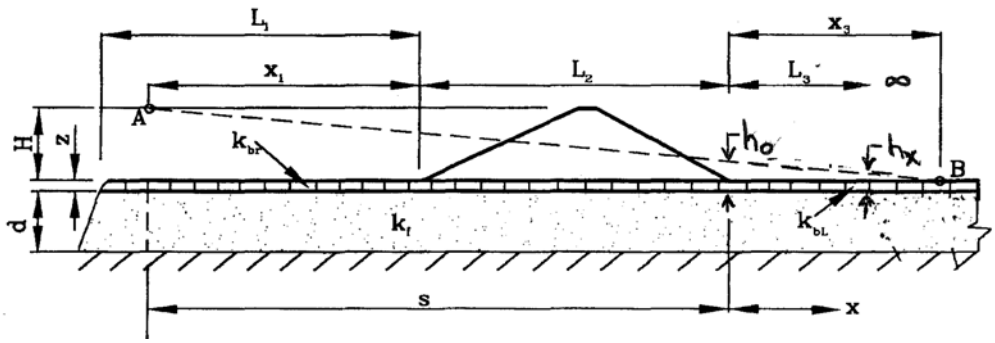
c =	0.00449467		
Dist to eff seepage entrance X_1 =	159	Seepage/ lf of levee - Q (gpm/lf) =	0.02
Dist to effective seepage exit X_3 =	222		
S = (X_1+L_2) =	219		

River Level at	Head at Levee Toe, h_0	Exit Gradient at toe, $i_o = h_o/z_{bl}$	Factor of Safety at Toe FS= z_{bl} (125-62.4)/h_o(62.4)
Design Water Surface	3.22	0.36	2.80
Top of Protection	4.84	0.54	1.87

River Level at	"x" distance from toe Head, h_x	Gradient, i_x
Design Water Surface	2.71	0.30
Top of Protection	4.06	0.45

Undersepage Pressures Beneath Semi-Impervious Blanket

Below are computations for determining underseepage flows and pressures beneath the landside semi-impervious blanket. Analysis was performed using equations and techniques presented in EM 1110-2-1913, Design and Construction of Levees (30 April 2000), Appendix B, "Mathematical Analysis of Underseepage and Substratum Pressures."



Project: Huntington, VA - FDR Study ***Reach: Station 17+00 to 24+00***
Date: Oct-08

Top of Protection (TP) El. =	17.6	Head (TP -TW) H_{TP} =	8.6	L_1 =	200
Design Water Surface (DWS) El. =	14.4	Head (DWS -TW) H_{DWS} =	5.4	L_2 =	60
Top of Ground (TG) EL. =	8.0			L_3 =	0
Tailwater (TW) El.=	**9.0**			distance landward from levee toe, x =	50
				Blanket Thinkness at x distance (z_x)=	9
Blanket Thinkness (z_{bl})=	9	Blanket k_{bl} cm/s =	1.00E-05		
Aquifer Thickness (d)=	11	Aquifer k_f cm/s =	5.00E-03		
Blanket Unit Wt. (pcf) =	125				

EQUATIONS

For $L_3 = \infty$ where $c = \sqrt{\dfrac{k_{bl}}{k_f z_{bl} d}}$ $\quad x_3 = \dfrac{1}{c} = \sqrt{\dfrac{k_f z_{bl} d}{k_{bl}}}$ $\quad x_1 = \dfrac{\tanh cL_1}{c}$

HEAD BENEATH TOP STRATUM AT LANDSIDE LEVEE TOE..... $h_o = \dfrac{Hx_3}{x_1 + L_2 + x_3}$

HEAD LANDWARD OF THE LEVEE TOE: $h_x = h_o e^{-cx}$, e= 2.718

SEEPAGE PER UNIT LENGTH OF LEVEE..... $Q_s = S k_f H = \dfrac{d k_f H}{x_1 + L_2 + x_3}$

Computations: ***Assumes No Toe Drain or additional fills for ramp, etc at levee toe***

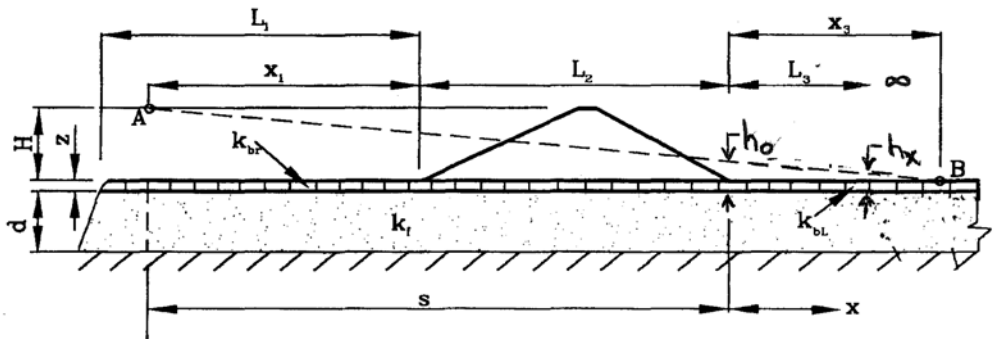
c =	0.00449467	
Dist to eff seepage entrance X_1 =	159	Seepage/ lf of levee - Q (gpm/lf) = 0.02
Dist to effective seepage exit X_3 =	222	
S = (X_1+L_2) =	219	

River Level at	Head at Levee Toe, h_0	Exit Gradient at toe, $i_o = h_o/z_{bl}$	Factor of Safety at Toe FS= z_{bl} (125-62.4)/h_o(62.4)
Design Water Surface	2.72	0.30	3.32
Top of Protection	4.33	0.48	2.08

River Level at	"x" distance from toe Head, h_x	Gradient, i_x
Design Water Surface	2.28	0.25
Top of Protection	3.64	0.40

Undersepage Pressures Beneath Semi-Impervious Blanket

Below are computations for determining underseepage flows and pressures beneath the landside semi-impervious blanket. Analysis was performed using equations and techniques presented in EM 1110-2-1913, Design and Construction of Levees (30 April 2000), Appendix B, "Mathematical Analysis of Underseepage and Substratum Pressures."



Project: Huntington, VA - FDR Study ***Reach: Station 24+00 to 29+00***
Date: Oct-08

Top of Protection (TP) El. =	17.3	Head (TP -TW) H_{TP} =	11.3	L_1 =	250
Design Water Surface (DWS) El. =	14.3	Head (DWS -TW) H_{DWS} =	8.3	L_2 =	60
Top of Ground (TG) EL. =	8.0			L_3 =	0
Tailwater (TW) El.=	**6.0**			distance landward from levee toe, x =	50
				Blanket Thinkness at x distance (z_x)=	11
Blanket Thinkness (z_{bl})=	11	Blanket k_{bl} cm/s =	1.00E-05		
Aquifer Thickness (d)=	9	Aquifer k_f cm/s =	5.00E-03		
Blanket Unit Wt. (pcf) =	125				

EQUATIONS

For $L_3 = \infty$ where $c = \sqrt{\dfrac{k_{bl}}{k_f z_{bl} d}}$ $\quad x_3 = \dfrac{1}{c} = \sqrt{\dfrac{k_f z_{bl} d}{k_{bl}}}$ $\quad x_1 = \dfrac{\tanh cL_1}{c}$

HEAD BENEATH TOP STRATUM AT LANDSIDE LEVEE TOE..... $h_o = \dfrac{Hx_3}{x_1 + L_2 + x_3}$

HEAD LANDWARD OF THE LEVEE TOE: $h_x = h_o e^{-cx}$, e= 2.718

SEEPAGE PER UNIT LENGTH OF LEVEE..... $Q_s = S k_f H = \dfrac{d k_f H}{x_1 + L_2 + x_3}$

Computations: ***Assumes No Toe Drain or additional fills for ramp, etc at levee toe***

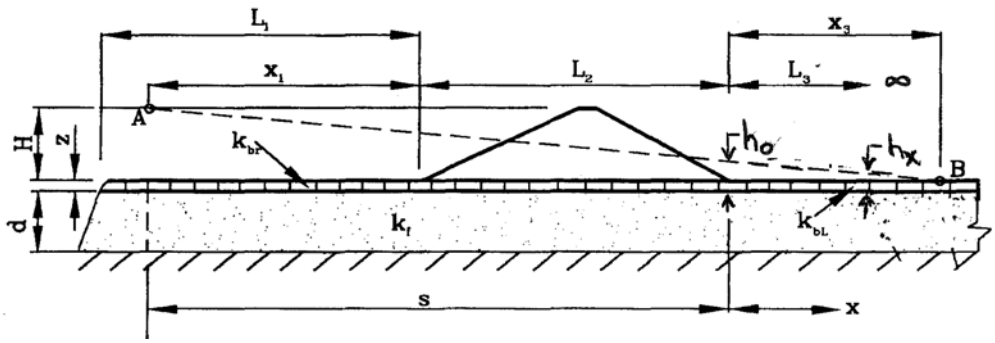
c =	0.00449467	
Dist to eff seepage entrance X_1 =	180	Seepage/ lf of levee - Q (gpm/lf) = 0.02
Dist to effective seepage exit X_3 =	222	
S = (X_1+L_2) =	240	

River Level at	Head at Levee Toe, h_0	Exit Gradient at toe, $i_o = h_o/z_{bl}$	Factor of Safety at Toe FS= z_{bl} (125-62.4)/h_o(62.4)
Design Water Surface	3.99	0.36	2.76
Top of Protection	5.44	0.49	2.03

River Level at	"x" distance from toe Head, h_x	Gradient, i_x
Design Water Surface	3.35	0.30
Top of Protection	4.56	0.41

Undersepage Pressures Beneath Semi-Impervious Blanket

Below are computations for determining underseepage flows and pressures beneath the landside semi-impervious blanket. Analysis was performed using equations and techniques presented in EM 1110-2-1913, Design and Construction of Levees (30 April 2000), Appendix B, "Mathematical Analysis of Underseepage and Substratum Pressures."



Project: Huntington, VA - FDR Study ***Reach: Station 24+00 to 29+00***
Date: Oct-08

Top of Protection (TP) El. =	17.3	Head (TP -TW) H_{TP} =	8.3	L_1 =	250
Design Water Surface (DWS) El. =	14.3	Head (DWS -TW) H_{DWS} =	5.3	L_2 =	60
Top of Ground (TG) EL. =	8.0			L_3 =	0
Tailwater (TW) El.=	**9.0**			distance landward from levee toe, x =	50
				Blanket Thinkness at x distance (z_x)=	11
Blanket Thinkness (z_{bl})=	11	Blanket k_{bl} cm/s =	1.00E-05		
Aquifer Thickness (d)=	9	Aquifer k_f cm/s =	5.00E-03		
Blanket Unit Wt. (pcf) =	125				

EQUATIONS

For $L_3 = \infty$ where $c = \sqrt{\dfrac{k_{bl}}{k_f z_{bl} d}}$ $\quad x_3 = \dfrac{1}{c} = \sqrt{\dfrac{k_f z_{bl} d}{k_{bl}}}$ $\quad x_1 = \dfrac{\tanh cL_1}{c}$

HEAD BENEATH TOP STRATUM AT LANDSIDE LEVEE TOE..... $h_o = \dfrac{Hx_3}{x_1 + L_2 + x_3}$

HEAD LANDWARD OF THE LEVEE TOE: $h_x = h_o e^{-cx}$, e= 2.718

SEEPAGE PER UNIT LENGTH OF LEVEE..... $Q_s = S k_f H = \dfrac{d k_f H}{x_1 + L_2 + x_3}$

Computations: ***Assumes No Toe Drain or additional fills for ramp, etc at levee toe***

c =	0.00449467	
Dist to eff seepage entrance X_1 =	180	Seepage/ lf of levee - Q (gpm/lf) = 0.01
Dist to effective seepage exit X_3 =	222	
S = (X_1+L_2) =	240	

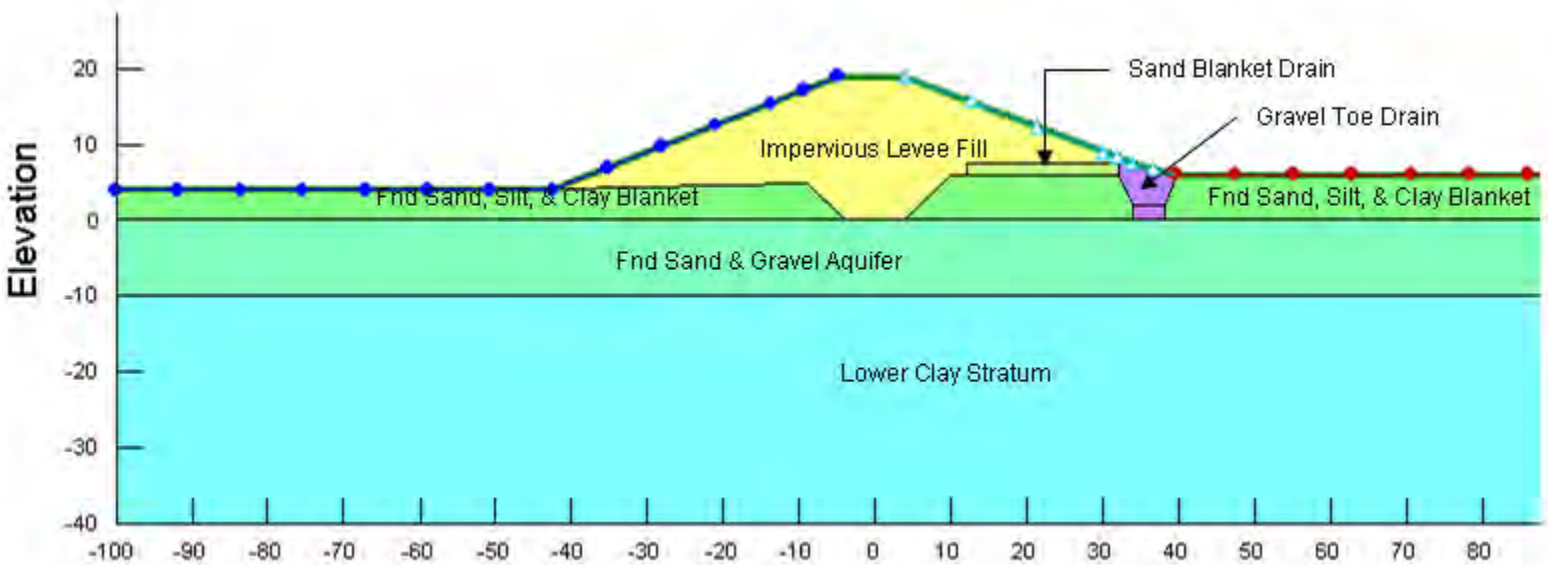
River Level at	Head at Levee Toe, h_0	Exit Gradient at toe, $i_o = h_o/z_{bl}$	Factor of Safety at Toe FS= z_{bl} (125-62.4)/h_o(62.4)
Design Water Surface	2.55	0.23	4.33
Top of Protection	3.99	0.36	2.76

River Level at	"x" distance from toe Head, h_x	Gradient, i_x
Design Water Surface	2.14	0.19
Top of Protection	3.35	0.30

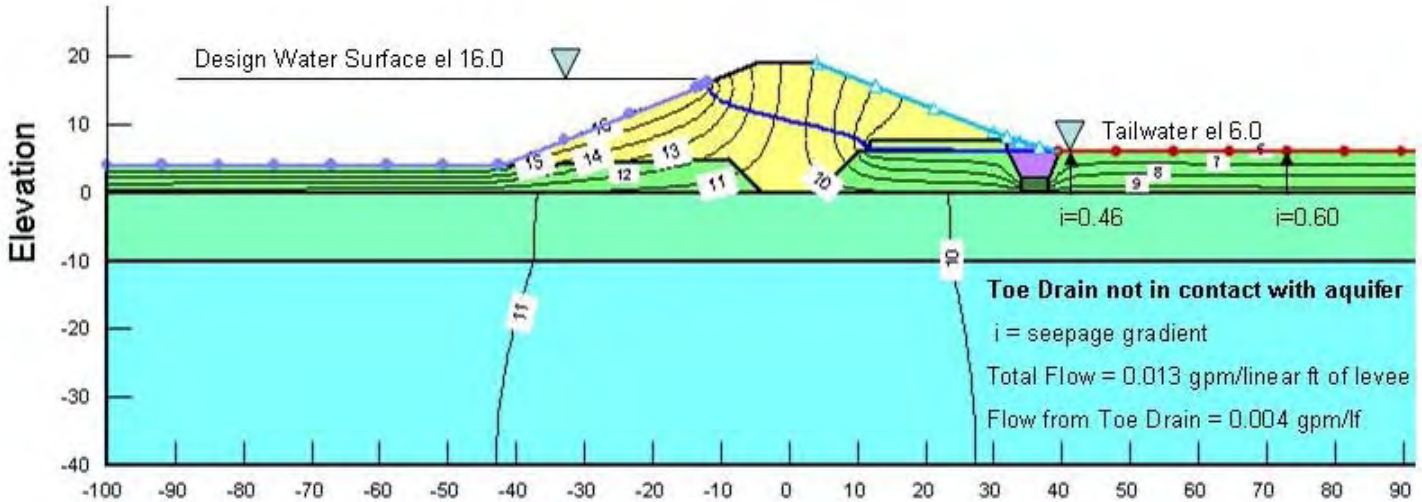
SEEPW Finite Element – Flow Net

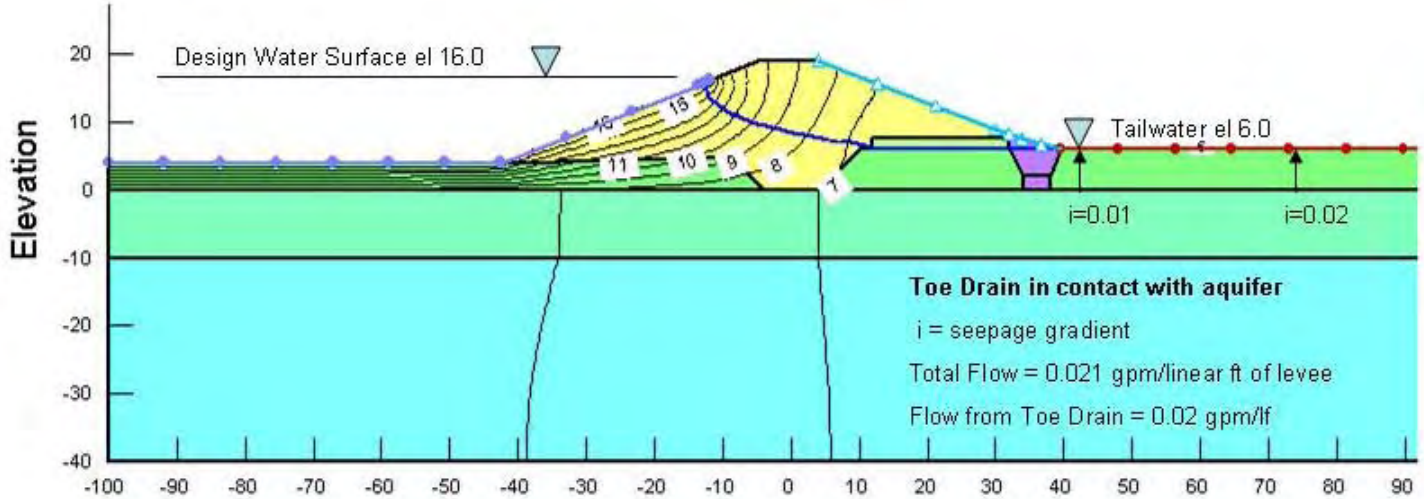
Hydraulic Conductivity Properties of Embankment Foundation Materials

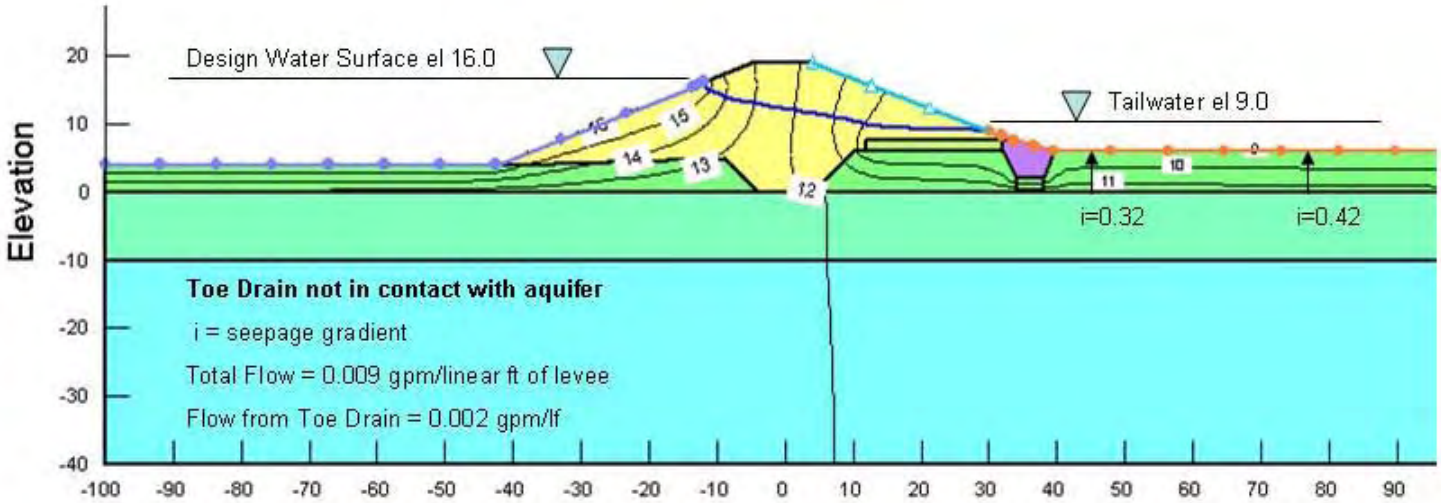
Material	Range of Hydraulic Conductivity (k)	K assumed in analysis
Upper Fnd Blanket of Clay, Silt, & Clayey Sand	1×10^{-4} to 1×10^{-6} cm/sec	1×10^{-5} cm/sec
Fnd Sand & Gravel Aquifer Layer	1×10^{-3} to 2×10^{-2} cm/sec	5×10^{-3} cm/sec
Lower Clay Stratum	1×10^{-6} to 1×10^{-8} cm/sec	1×10^{-7} cm/sec
Sand Blanket Drain	1×10^{-2} to 1×10^{-3} cm/sec	5×10^{-3} cm/sec
Gravel Toe Drain	1×10^{-1} cm/sec	1×10^{-1} cm/sec
Impervious Levee Fill	1×10^{-5} to1×10^{-6} cm/sec	1×10^{-5} cm/sec

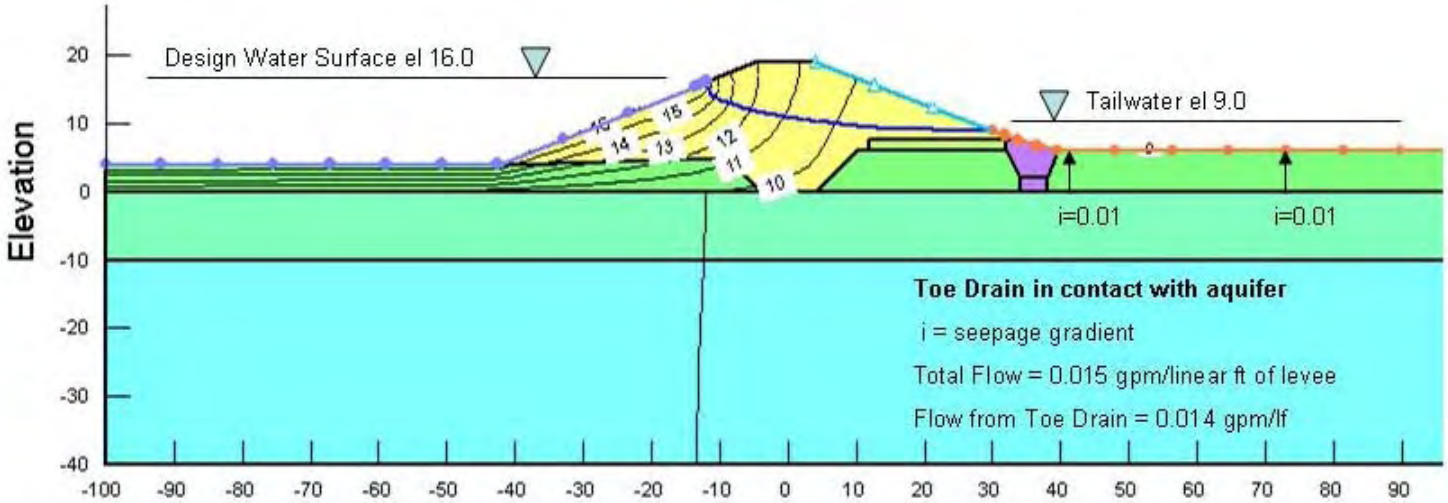


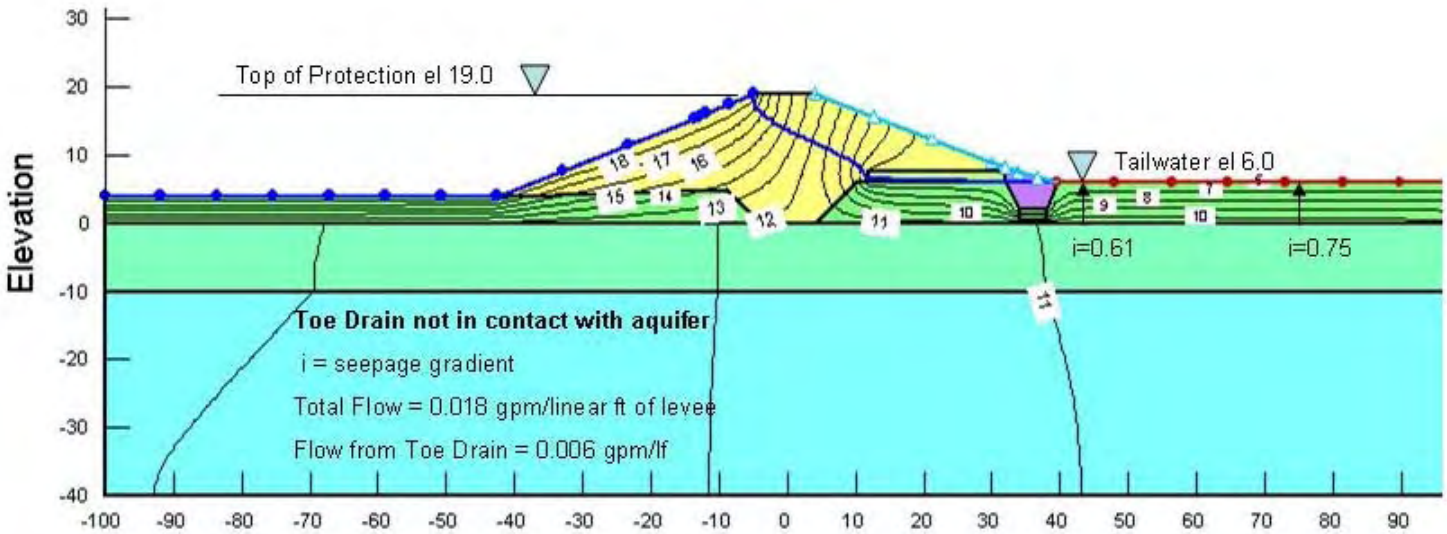
Typical Section

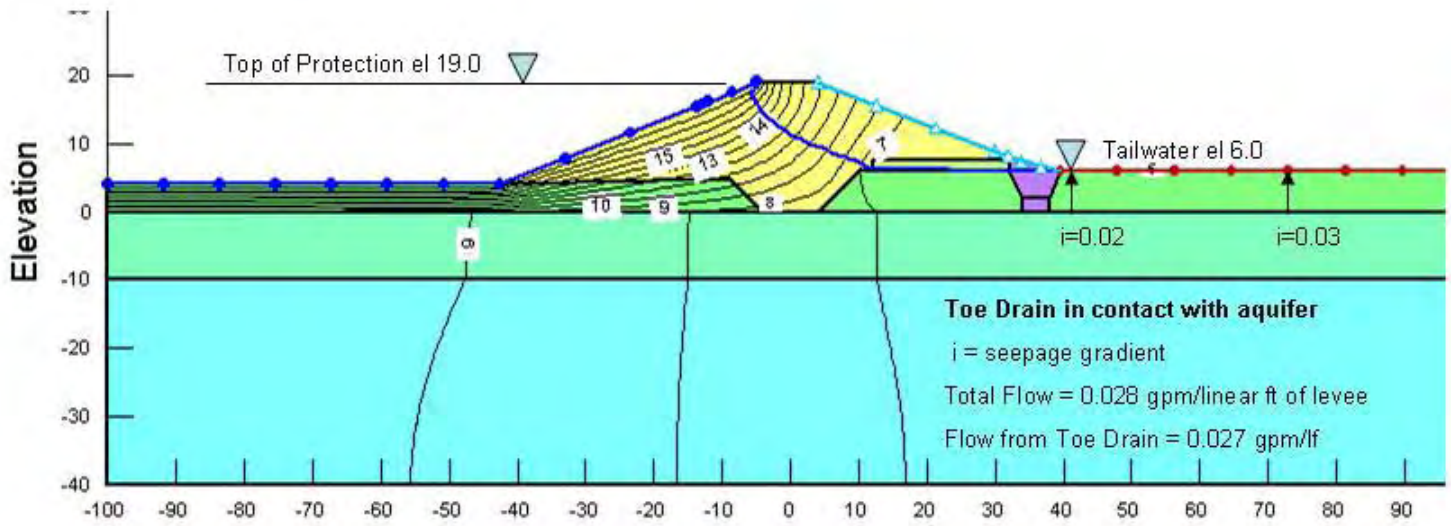

Design Water Surface el 16.0
Tailwater el 6.0
Elevation
i=0.46
i=0.60
Toe Drain not in contact with aquifer
i = seepage gradient
Total Flow = 0.013 gpm/linear ft of levee
Flow from Toe Drain = 0.004 gpm/lf

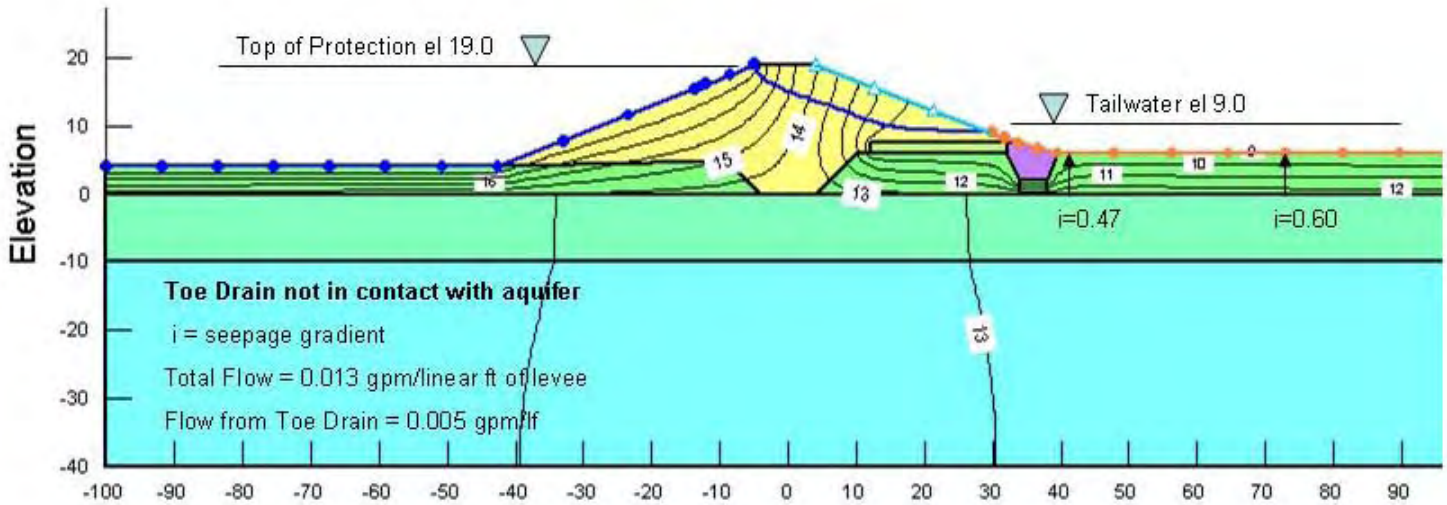

Design Water Surface el 16.0
Tailwater el 6.0
Elevation
i=0.01
i=0.02
Toe Drain in contact with aquifer
i = seepage gradient
Total Flow = 0.021 gpm/linear ft of levee
Flow from Toe Drain = 0.02 gpm/lf

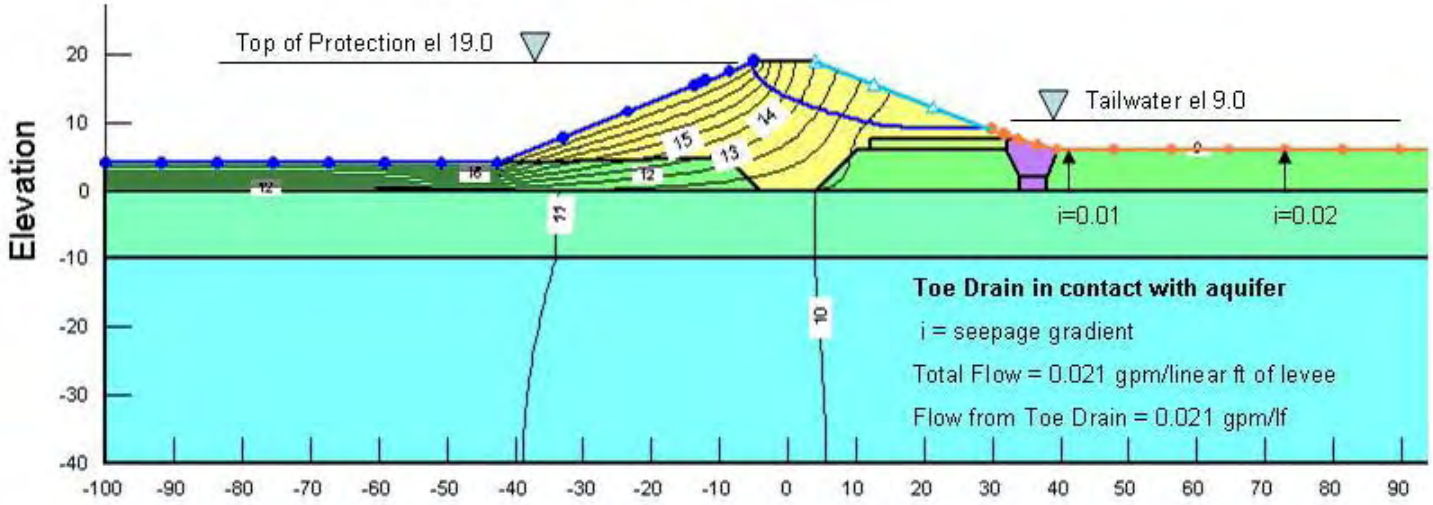

Design Water Surface el 16.0
Tailwater el 9.0
Elevation
i=0.32
i=0.42
Toe Drain not in contact with aquifer
i = seepage gradient
Total Flow = 0.009 gpm/linear ft of levee
Flow from Toe Drain = 0.002 gpm/lf


Design Water Surface el 16.0
Tailwater el 9.0
Elevation
i=0.01
i=0.01
Toe Drain in contact with aquifer
i = seepage gradient
Total Flow = 0.015 gpm/linear ft of levee
Flow from Toe Drain = 0.014 gpm/lf


Top of Protection el 19.0
Tailwater el 6.0
Elevation
i=0.61
i=0.75
Toe Drain not in contact with aquifer
i = seepage gradient
Total Flow = 0.018 gpm/linear ft of levee
Flow from Toe Drain = 0.006 gpm/lf


Top of Protection el 19.0
Tailwater el 6.0
Elevation
i=0.02
i=0.03
Toe Drain in contact with aquifer
i = seepage gradient
Total Flow = 0.028 gpm/linear ft of levee
Flow from Toe Drain = 0.027 gpm/lf


Top of Protection el 19.0
Tailwater el 9.0
Elevation
i=0.47
i=0.60
Toe Drain not in contact with aquifer
i = seepage gradient
Total Flow = 0.013 gpm/linear ft of levee
Flow from Toe Drain = 0.005 gpm/lf


Top of Protection el 19.0
Tailwater el 9.0
Elevation
i=0.01
i=0.02
Toe Drain in contact with aquifer
i = seepage gradient
Total Flow = 0.021 gpm/linear ft of levee
Flow from Toe Drain = 0.021 gpm/lf