Appendix C. Settlement Memorandum

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Introduction

This memorandum summarizes the results of settlement analyses performed for the Mid-Barataria Sediment Diversion (MBSD) conveyance channel guide levees and interior stability berms as part of HDR Engineering, Inc. 30 percent design level studies. The purpose of these analyses is to characterize the settlement behavior of the site to assist the design team in assessing potential guide levee design alternatives and costing.

Settlement analysis were conducted using laboratory data obtained from current initial site characterization efforts as well as available data from past Untied States Corps of Engineers (USACE) geotechnical studies for the Non-Federal New Orleans to Venice project and the Myrtle Grove Sediment Diversion project. Additional geotechnical investigations and design are required and will be conducted during future phases of the MBSD project to refine these settlement analyses for the selected configuration.

Conveyance Channel Geometry

In September 2013 HDR Geotechnical Team prepared a channel configuration memorandum that included the results of excavated channel stability analyses that resulted in the following recommendations:

- The channel slope should be no steeper than 4.5:1 (horizontal to vertical) provided: 1) provided that the channel slopes are excavated in the wet; and 2) the foundation soils are first strengthened by placing soil surcharge for a minimum of one year to consolidate and strengthen the near surface foundation soils. The remaining soils surcharge will remain as the interior stability berm required to construct the earthen guide levees.
- The guide levees should set back a minimum of 80 feet from the excavated conveyance channel top of slope.

Based on the civil drawings dated February 2014, the following geometries were assumed for the settlement analyses:

- Top (daylight point) of excavated conveyance channel will be graded to Elevation +2 feet.
- Earthen Guide levees were modeled having 4.5:1 side slopes and 15-foot crown width.
- Long Term Guide Levee Design Crown Elevation +13 feet (Earthen levee)
- Earthen levees were setback 80 feet from the conveyance channel top of slope.

- Placement of surcharge materials for conveyance channel slope strengthening and fills associate with earthen embankments are separate operations (not combined as simultaneous loading conditions). The phasing of the project is currently unknown and will be more fully developed during the next phase of studies.

Settlement Analysis

Settlement analysis was conducted using the computer program Consol3 (Virginia Tech). The program calculates the change of stress due to irregular surcharge loads (such as an earthen embankment) and calculates settlement over time for a vertical soil column. The conveyance channel and guide levees are assumed to be linear features that are constructed on "virgin" ground and can be represented by a one dimensional model. This is judged to be appropriate for 30 percent design. More details two and three dimensional analyses will be required as more project details are developed and construction phasing is evaluated.

Five cross sections representing five reaches of the conveyance channel were developed to represent the variation of foundation conditions along the conveyance channel. Table 1 summarizes the five reaches of levee modeled with the associated foundation condition and dominant features. Settlement analyses were conducted as follows:

- Calculate total primary settlement for each model
- Evaluate the time rate of consolidation and the variation of time rate with depth
- Calculate effect of wick drains on the consolidation time rates within the foundation soils
- Where appropriate evaluate the effect of wick drain foundation treatment on guide levee settlement behavior, where appropriate
- Evaluate secondary compression effects
- Evaluate minimum height of surcharge for stability berm and excavation phasing
- Provide initial recommendations for project phasing and site preparation for wick drain installation.

Required Fill Height

Table 2 present the results of ultimate primary settlement analysis assuming no ground improvement and that the guide levee is placed "instantaneously" to calculate the total fill height (including overbuild) to attain a levee crown elevation of +13 feet. Existing site grades vary from approximately El. +3 feet on the east and El. -4 feet on the west, requiring total fill thickness of 10 to 21 feet to attain a crown elevation of +13 feet.

Time Rate of Settlement

To investigate the contribution of settlement within contributing substrata (assuming a vertical soil column), the percent of ultimate settlement that occurs between the depths of 0 to 30 feet, 30 to 60 feet and below 60 feet were calculated and summarizes in Table 2. Distribution of primary settlement values along the conveyance channel alignment are summarized in Table 3 and reported in units of feet. Plots used to develop Tables 2 and 3 of cumulative primary settlements versus depth are shown in Figures 1 through 6. Figures 1 and 2 include plots of cumulate settlement versus depth at 1-year, 2 years, 5 years, 10 years and 50 years intervals for Reach 1, Station 30+00. Figures 3 through 6 present's plots of

cumulative settlement versus depth at 1-year, 5, years, 10 years, 20 years, and 50 years time intervals for the remaining 4 reaches.

From this data the following can be concluded for areas outside of the point bar deposits:

- Approximately 50 percent of the settlement occurs in the upper 30 feet of the foundation soils and about 70 to 85 percent occurs in the upper 60 feet.
- Time rate of settlements analysis calculates the following percentage of ultimate primary settlement as occurring:
    - Year 5 - 45 to 55 percent
    - Year 10 - 60 to 70 percent
    - Year 20 – 80 to 94 percent
    - Year 50 – 80 to 94 percent

Within the point bar (station 30+00) 85 percent of the settlement occurs within the upper 30 feet of the foundation if groundwater levels are not lowered during construction. Figure 2 present settlement at Station 30+00 if groundwater levels are permanently lowered to elevation -60 feet (the bottom elevation of proposed conveyance entrance structure foundation). As can bee seen in the figure and in the settlement values presented in Table 2, the percent contribution distribution changes and total settlement increase with dewatering the site. Although permanent dewatering is not anticipated, temporary dewatering will be required during construction and will have an impact on the guide levee settlement behavior. For example, 0.5 feet of settlement is estimated if uniform dewatering is conducted for two years. The impacts of dewatering need to be considered in guide levee design but are beyond the scope of this memorandum since the construction sequence has not been defined. This will require a more detailed analysis during the next phase of design.

Phasing of Levee Construction – Reaches 1 through 4 Stations 29+00 to 92+00

Review of Table 3 shows that settlement for all the reaches except for Reach 5 range between 0.6 to 1.4 feet in 10 years and 1.3 feet to 1.7 feet in 20 years. In reaches 1 through 4 the analysis does not support installation of wick drains to accelerate settlements prior to operation of the diversion. Also, in lieu of constructing the levees to the full overbuilt height it may be prudent to overbuild the levees a nominal amount (1.0 to 1.25 feet) and observe the actual rate of crown settlement. Based upon this data a more accurate estimate of fill required to maintain the guide levee crown elevations. Or, as an alternative approach a short sheetpile flood wall could be installed along the levee crown to provide the required freeboard to reduce the volume of import fill. This option is discussed for Reach 5 below.

The levees should be constructed in phases and the pore pressure response in the foundation should be monitored to ensure the fill is stable. For initial planning purposes the compacted fill should be placed in 4 foot increments along the length of the levee. A settlement period of 6 to 8 weeks should be specified between fill phases to allow foundation pore pressure to dissipate to a pre-determined level (minimum 50 percent dissipation of the induced pore pressure increases) so that the next phase of fill placement will have adequate factors of safety for end of construction slope stability. The length of the settlement period can be reduced based upon the pore pressure monitoring results.

Reach 5 Station 92+00 to 140+00

As introduced above, settlement analysis results within Reach 5 indicate that consolidation rates would benefit from the installation of wick drains. Review of the data presented in Table 5 indicates that greater

settlement will occur in Reach 5 due to placement of new fill or other surcharge loads. Use of wick drain foundation treatment was evaluated to accelerate the rate of settlements and induce the settlements to occur before operation of the facility.

Wick Drain Analysis

Idealized settlement of wick drain improved ground was calculated using methods develop by Hansbo that relates percent consolidation versus time. Key input parameters for the analysis include:

- wick drain spacing – (S)
- wick drain spacing factor (F_n)
- smear factor due to wick drain installation (F_s)
- wick drain drainage resistance factor (usually small) (F_r)
- relationship of horizontal and vertical coefficient of consolidation (C_h/C_v)
- relationship of horizontal and vertical hydraulic conductivity (K_h/K_v)

A 60-foot depth of improvement was assumed based upon the settlement results presented in Tables 2 and 3. Table 4 and Figure 7 present the percent consolidation versus time used in evaluating the effectiveness of wick drains for Reach 5. The following factors were using in the analysis:

- $C_v = 7.3\ ft^2/yr$
- $C_h/C_v = 1.4$
- $K_h/K_v = 3$
- $F_n = 2.49$ (square spacing), 2.57 (rectangular spacing)
- $F_s = 3.371$
- $F_r = 0.108$

Table 4 presents a tabular summary of percent consolidation at different time intervals for 4, 6 and 8-foot-on-center (OC) triangular array of wick drains. Figure 7 plots the results for both triangular and square arrays.

Table 5 and Figure 8 and 9 present the results of applying wick drain consolidation at an 8-foot OC triangular pattern to the upper 60 feet of the foundation while the material below 60 feet was assumed to consolidate at the rate of untreated soils. As can be seen on Figure 9 the levee can be constructed in phases with 21 feet of fill (Crown elevation +17 feet) and allowed to consolidate. Alternatively, to reduce the number of phases of fill placement the levee could be constructed with 17.5 feet of fill (Crown elevation +13.5 feet) and a 2.5-foot tall sheetpile floodwall be installed along the crown to maintain the design top of wall/levee elevation.

Wick Drain Construction

The site contains a number of drainage ditches and collection points which should be included as part of wick drain drainage blanket construction. For instance, drainage ditches slope towards the west and are spaced every 200 feet. The following sequence of construction is suggested for evaluation purposes.

1. Regrade the east-west drainage ditches to accommodate large diameter perforated drainage pipe (8 to 12 inch diameter to facilitate collection of water flowing from the wick drains. Install lateral

pipes every 100 feet to cross between the main collector pipes to maintain a maximum 200 foot drainage path.

2. Place 2 feet of sand fill over the area to be treated
3. Install wick drains at specified spacing and depth.
4. Install instrumentation (piezometers and settlement plates)
5. Install cutoff zone through the sand layer and into the foundation to restrict future lateral seepage beneath the levee. The cut off should extend 3 feet below sand layer
6. Place an additional 2 feet of sand over the entire treated area and allow to consolidate for 4 to 6 weeks or longer based upon pore pressure monitoring.
7. Begin sequence/phases of fill placement – 4-foot lifts followed by settlement periods (4 lifts).

Stability Berm Surcharge

As previously discussed the conveyance channel stability requires surcharging of a 200 foot wide area located between the guide levee and the toe of the conveyance channel. Figures 10 and 11 present the results of Bank analysis for Reaches 4 and 5. The figures present the calculated elevation of the ground surface over time at the top of channel. Wick drain improvement has not been reflected in either of these plots. In this analysis it was assumed that a 200 foot wide 8 foot tall surcharge was placed on the site and allowed to consolidate for 1.5 years and then the surcharge was removed to the proposed stability berm grade and the channel excavated to elevation -25 feet. Figure 10 indicates that for Reach 4 the combination of surcharging, surcharge removal and channel excavation result in limited future settlement of the top of stability berm. However Figure 11 indicates that for Reach 5 the stability berm will continue to settle after removal of the stability berm and channel excavation. The analyses indicate that the 8 foot surcharge is insufficient for Reach 5. Due to the magnitude of settlement wick drain are recommended for Reach 5 to accelerate settlements and ground strengthening. Also, wick drains are recommended within the limits of abandoned distributary channels to improve variable conditions encountered in the near surface foundation soils and provide more uniform long term performance.

Secondary Compression

Long term settlements in the upper 30 to 60 feet are anticipated upon the completion of the primary consolidation. As discussed above and presented in the subsequent tables, primary consolidation is anticipated to be completed within 20 of completion of fill placement. Settlements associated with secondary consolidation between 0.3 and 1.1 feet are anticipated. As is the case with primary consolidation, secondary consolidation magnitudes vary between reaches. Reaches 1 through 4 are anticipated to have settlements of approximately 0.3 to 0.45 feet. Reach 5 is anticipated to have settlements of approximately 0.7 to 1.1 feet associated with secondary consolidation.

Summary

This memorandum presents a summary of settlement analysis conducted for the 30 percent design of the MBSD project. Figure 12 presents a profile view of proposed fill heights and locations of wick drain improvement for consideration during 30 percent design.

For 30 percent design purposes it is recommended that the stability berm and channel slope surcharge be increased 4 feet to 12 feet thickness (top elevation +8 feet) to reduce future stability berm settlements. The originally proposed 8-foot high surcharge for the other reaches is judged to be valid for the other Reaches. Wick drains would be installed at 6-foot on center to accelerate settlements/ground

improvement to allow excavation of the channel. Wick drain improvements should also be installed within the limits fi the abandoned distributary channels. Wick drain installation is not recommended in other areas.

For the guide levees wick drain improvements are recommended for Reach 5 between station 92+00 and 140+00.

Replacing the upper portion of the earthen guide levees with sheetpile floodwalls appears reasonable from a settlement standpoint.

TABLES

Table 1: Settlement Model Summary

Model ID	Reach	Foundation Condition[1]	Dominant Foundation Feature	Comments
Station 30+00 Represents Station 29+00 to Station 45+00	1	Clay Blanket overlying point bar deposits	Compressible fine grained soils to a depth of 30 feet; interbedded medium dense/medium stiff and loose fine silts, silty sands and clays to a depth of 60 feet.	Boundary of Point Bar Assumed to be located at Station 45+00. To be confirmed during next phase of exploration. Representative from both the guide levees and the setback levees.
Station 55+00 Represents Station 45+00 to Station 60+00	2	Abandoned Distributary deposit	Interbedded compressible fine grain silts and clays and silty sand and sands to a depth of 55 to 60 feet underlain by thick sequence of clays	Eastern abandoned distributary deposit mapped by USACE as crossing the conveyance channel at station 52+00. Extended to Station 45+00 until the boundary can be determined during the next phase of investigations.
Station 67+00 Represents Station 60+00 to Station 77+00	3	Natural levee (clay) deposits	Uniform medium stiff clay soils to a depth of 38 feet underlain by thick sequence of clays	Highway crosses the conveyance channel between station 64+00 and 67+00
Station 82+00 Represents Station 77+00 to Station 92+00	4	Abandoned Distributary deposit	Interbedded compressible fine grain silts and clays and silty sand and sands to a depth of 45 to 50 feet underlain by thick sequence of clays	Extension of the Chenier Traverse Bayou channel crosses oblique to the conveyance channel alignment. Width to be confirmed during the next phase of investigation.
Station 110+00 Represents Station 92+00 to Station 140+00	5	Very soft interbedded silts and clays (Marsh Deposits)	Very soft, compressible interbedded silts and clays to a depth of 40 feet. Variable thickness permeable (sands and silty sand) layers encountered between Elevation -25 and - 30 feet underlain by thick sequence of clays explorations.	Review of explorations and aerial photographs indicate the former basin shoreline extended into the Polder to about stations between 90+00 and 95+00. Set boundary to Station 92+00.

1. All models extended to the stiff Pleistocene materials encountered at a depth of about El -120 feet. Pleistocene soils were generally overlain by three soils deposits. These deposits in order of occurrence are granular near shore deposits, overlain by prodelta clays that are overlain by interdistributary clays and the near surface foundations soils described above. The Point bar deposits extend to the Pleistocene soil contact.

Table 2: Summary of Calculated Primary Settlement by Model Location

Modeled Location		Ground Surface Elev-ation (feet)	Required Levee Over Build to Obtain Elev. +13 feet	Required Levee Total Fill Thickness (feet)	Ultimate Primary Settlement (feet) [2]	Percent Contribution by Depth Range		
Reach	Station					0 to 30 feet	30 to 60 feet	60+ feet
1	30+00	+3.0	Build to +13 feet	10	1.40 (3.0)[1]	85 (63)	14 (16)	1 (20)
2	55+00	+2.0	2	13	1.6	50	34	16
3	67+00	+0.0	2	15	1.8	60	10	28
4	82+00	+0.0	3.5	16.5	2	50	32	18
5	110+00	-4.0	7	21	7	53	26	21

1. (value) - Settlement with groundwater drawn down to El -50 feet.
2. Guide Levee fill modeled with 4.5:1 slopes and a 15 foot wide crown width

Table 3: Summary of the Distribution of Primary Settlements over 50 years – No Ground Improvement or Dewatering

Modeled Location (station)	Depth Range of Settlement	Amount of Primary Settlement at time T years, feet [1,2] (percent of total settlement)			
		5 years	10 years	20 years	50 years
30+00[3]	Full Depth	**0.4 (29%)**	**0.6 (42%)**	**--**	**1.3 (93%)**
	0 to 30 feet	0.35	0.5	--	1.1
	30 to 60 feet	0.04	0.1	--	0.2
	60+ feet	--	--	--	--
55+00	**Full Depth**	**0.8 (50%)**	**1.0 (63%)**	**1.3 (81%)**	**1.5 (94%)**
	0 to 30 feet	0.6	0.7	0.8	0.8
	30 to 60 feet	<0.5	<0.5	0.50	0.6
	60+ feet	<0.1	<0.1	<0.1	0.2
67+00	**Full Depth**	**1.0 (56%)**	**1.3 (72%)**	**1.5 (83%)**	**1.6 (89%)**
	0 to 30 feet	0.75	1.0	1.1	1.1
	30 to 60 feet	<0.5	<0.5	<0.5	<0.5
	60+ feet	<0.1	<0.1	<0.1	0.1
82+00	**Full Depth**	**1.1 (50%)**	**1.4 (64%)**	**1.7 (77%)**	**1.8 (82%)**
	0 to 30 feet	0.8	0.9	1.1	1.2
	30 to 60 feet	<0.5	<0.5	<0.5	0.6
	60+ feet	<0.1	<0.1	<0.1	0.1
110+00[4]	**Full Depth**	**3.2 (46%)**	**4.2 (60%)**	**4.9 (70%)**	**5.6 (80%)**
	0 to 30 feet	2.5	3.2	3.6	3.7
	30 to 60 feet	0.6	0.8	1.0	1.3
	60+ feet	0.1	0.2	0.3	0.6

1. Guide Levee modeled as having 4.5:1 side slopes and a 15-foot wide crown width.
2. Model assumes Guide levee fill was placed at one time. Phased fill placement will be required and will likely increase the time to attain the levels of consolidation listed above.
3. Assumes no effects from site dewatering. Uniformly dewatering the site to Elev. -50 feet increases settlements a 2 years and 5 years to 0.45 feet and 0.9 feet of settlement, respectively. The dewatering induced settlements could effectively remove long term settlement when groundwater levels are allowed to equilibrate to pre-construction levels.
4. Assumes a permeable layer is present at Elev. -25 to-30 feet. If permeable layer is not present settlements are calculated to be 40% of the values listed.

Table 4: Percent Consolidation versus Time - Wick Drain Ground Improvement

Wick Drain Triangular Spacing	Percent Consolidation			
	2 years	5 years	10 years	15 years
4-foot OC	68%	99%	100%	100%
6-foot OC	48%	84%	98%	99%
8-foot OC	36%	68%	88%	94%

Table 5: Guide Levee Primary Settlement with 60-feet of Wick Drain Treated Foundation Soils - Station 110+00 (Station 92+00 to 130+00)

Wick Drain Triangular Spacing	Depth Range of Settlement	Amount of Primary Settlement at time T years (feet)			
		2 years	5 years	10 years	15 years
4-foot OC	**Full Depth**	**1.6**	**2.5**	**2.7**	**2.7**
	0 to 60 feet	1.6	2.4	2.5	2.5
	60+ feet	<0.1	0.1	0.2	0.2
6-foot OC	**Full Depth**	**1.2**	**2.1**	**2.6**	**2.7**
	0 to 60 feet	1.2	2.0	2.4	2.5
	60+ feet	<0.1	0.1	0.2	0.2
8-foot OC	**Full Depth**	**0.9**	**1.8**	**2.4**	**2.6**
	0 to 60 feet	0.9	1.7	2.2	2.4
	60+ feet	<0.1	0.1	0.2	0.2

Figures

Figure 1 – Cumulative Settlement Versus Depth Station 30+00 no Dewatering

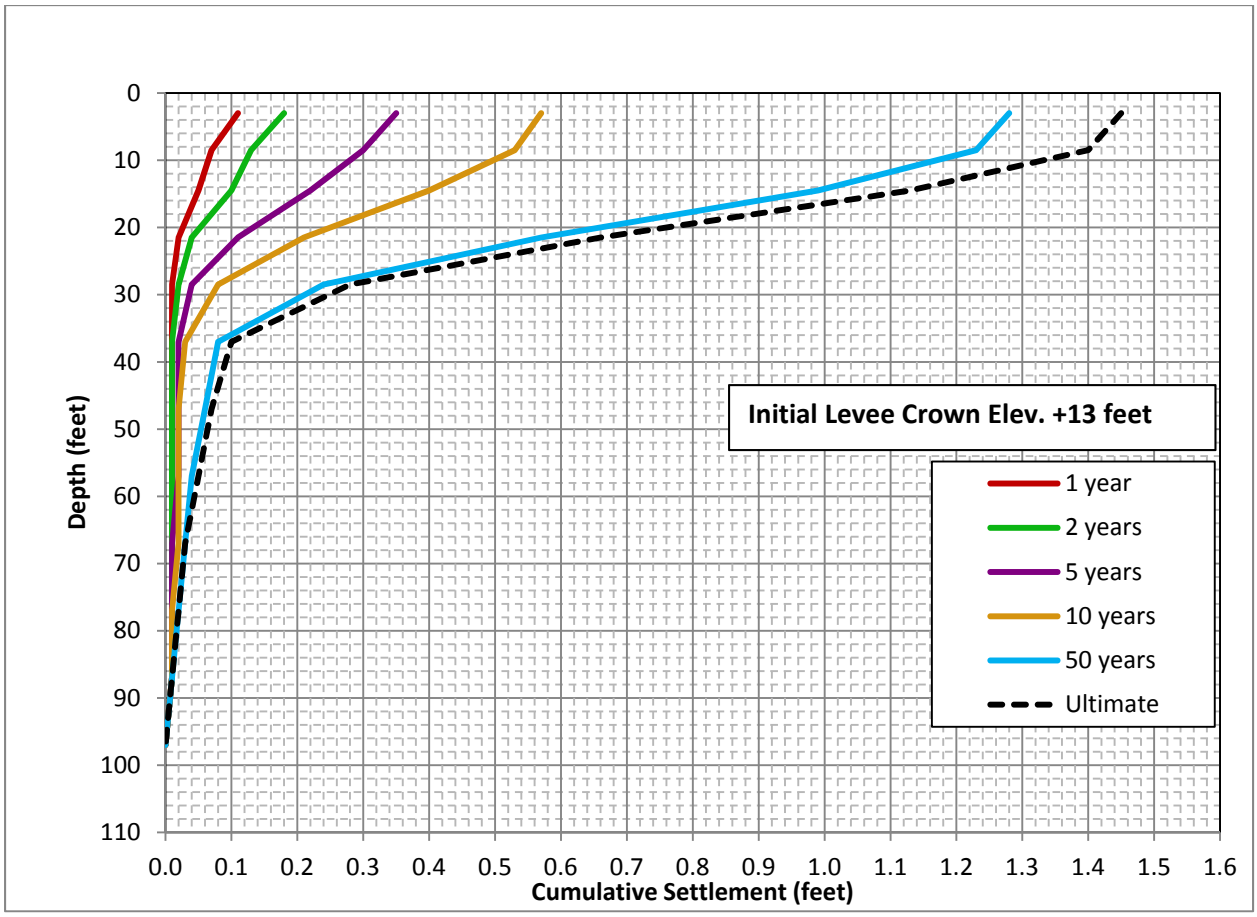

Figure 2 – Cumulative Settlement Versus Depth Station 30+00 with Dewatering to Elev. -50 feet

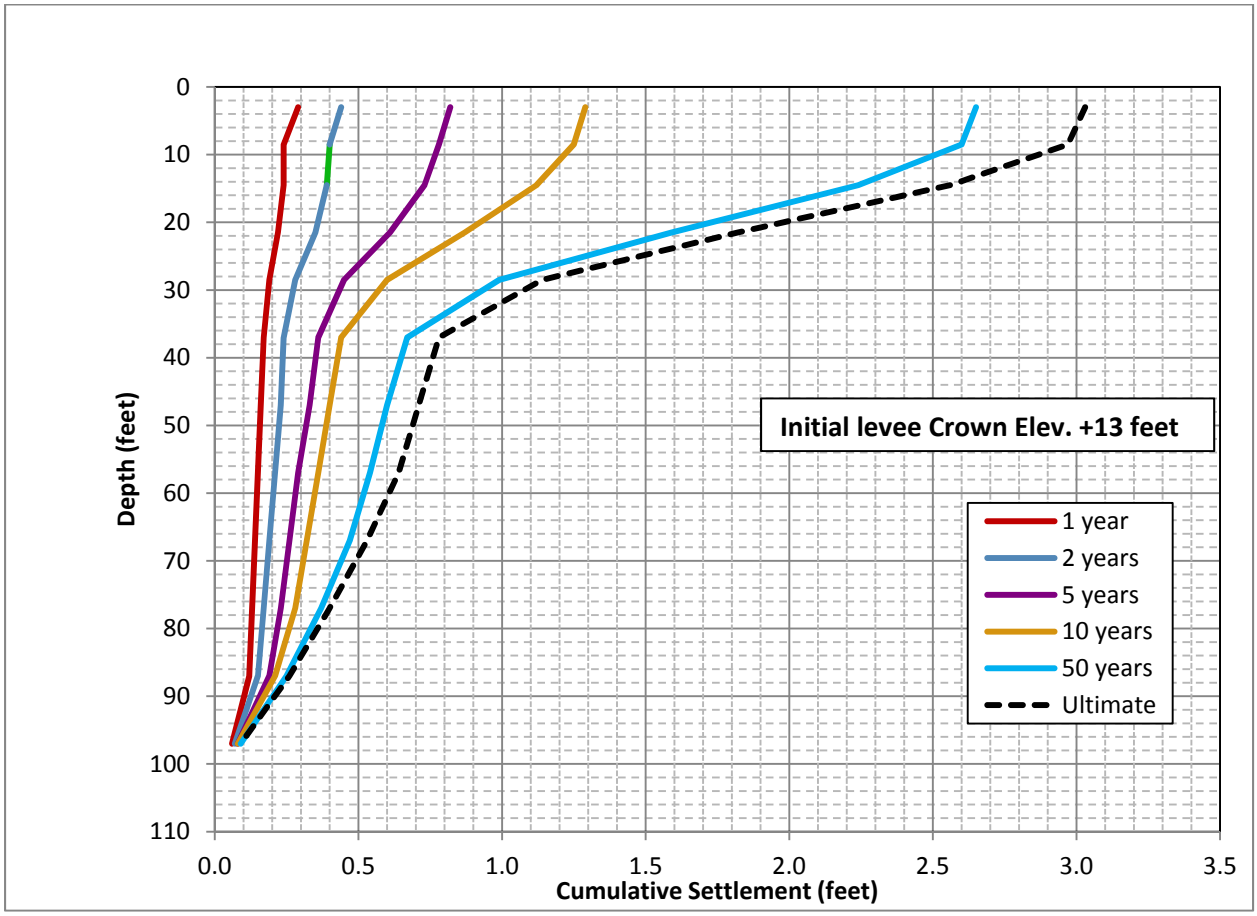

Figure 3: Cumulative Settlement Versus Depth Station 55+00

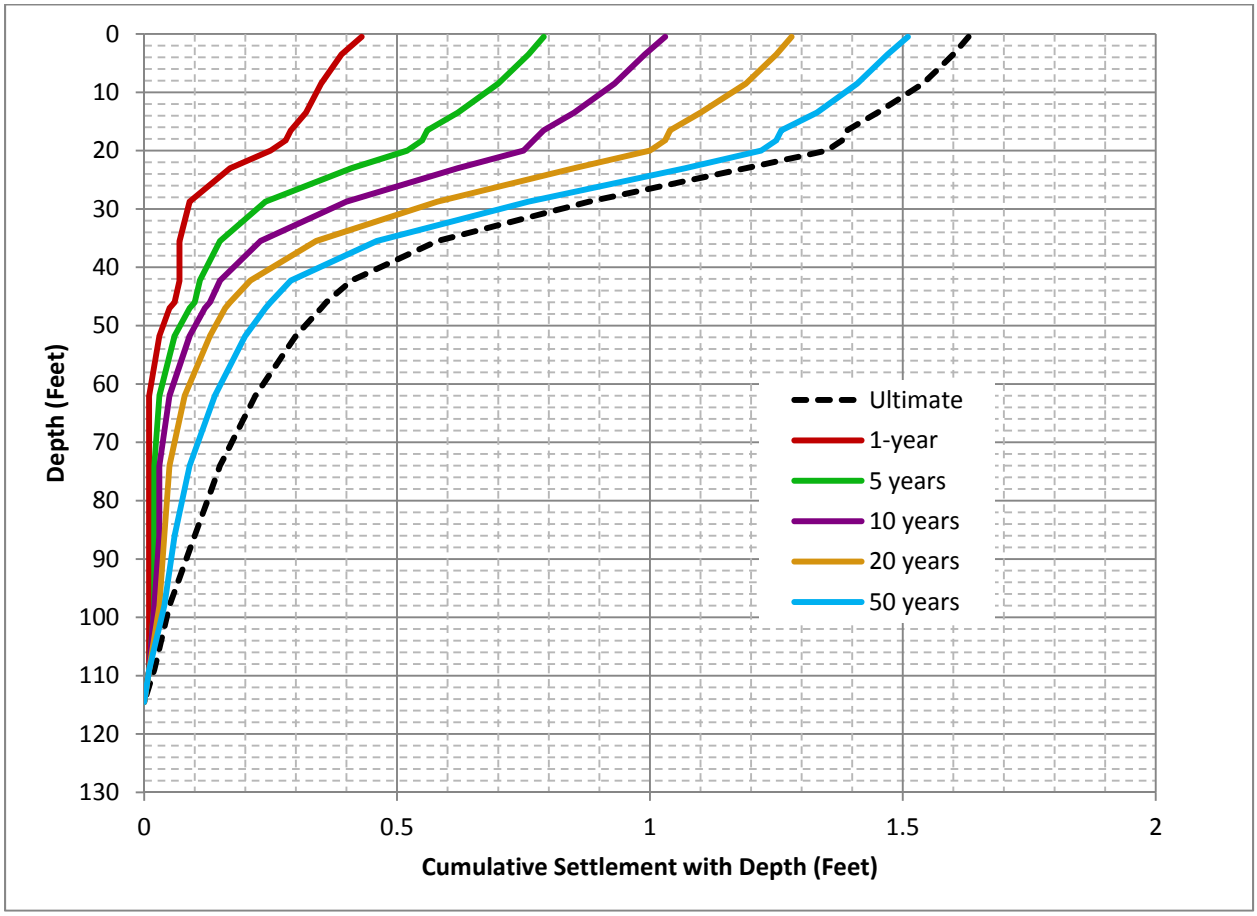

Figure 4: Cumulative Settlement Versus Depth Station 67+00

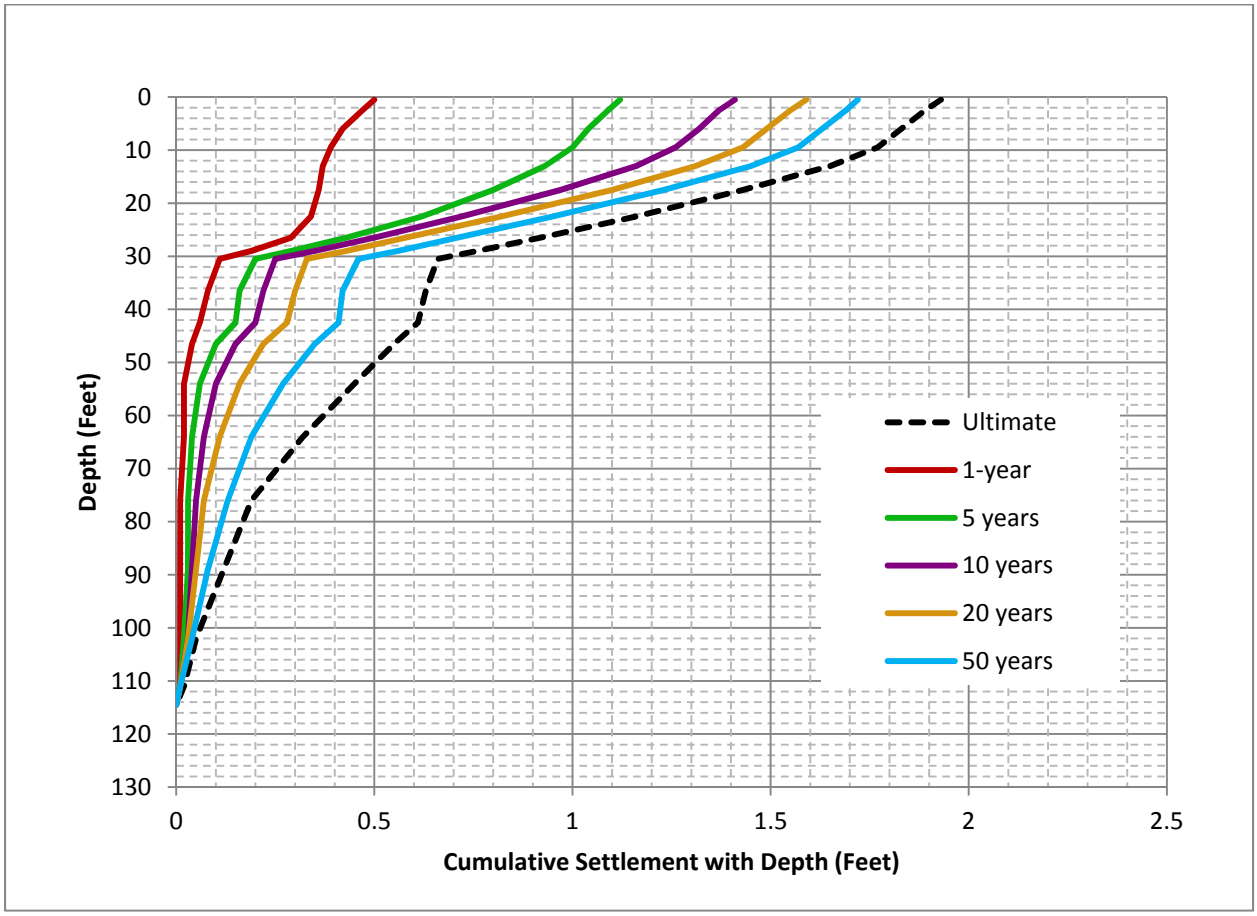

Figure 5: Cumulative Settlement Versus Depth Station 82+00

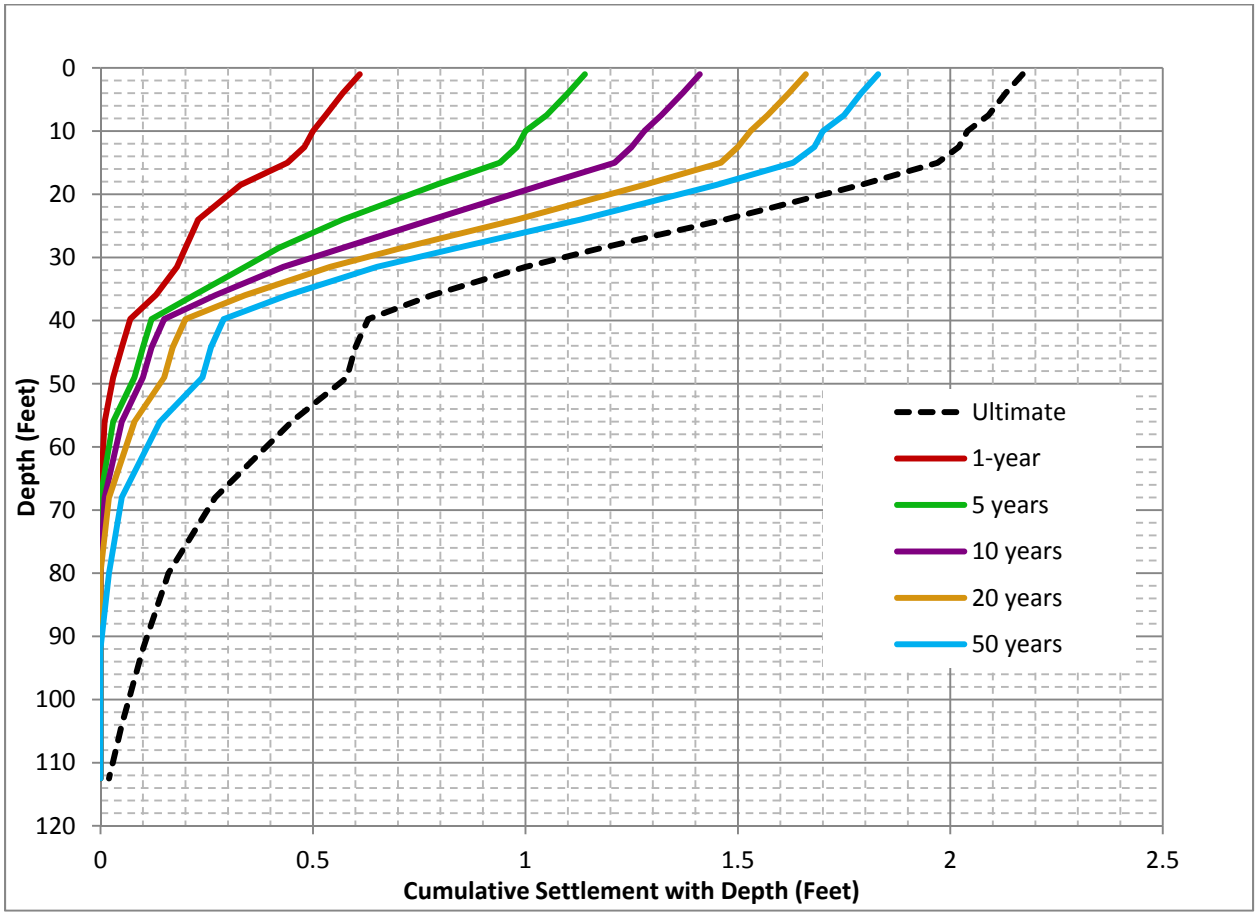

Figure 6: Cumulative Settlement Versus Depth Station 110+00

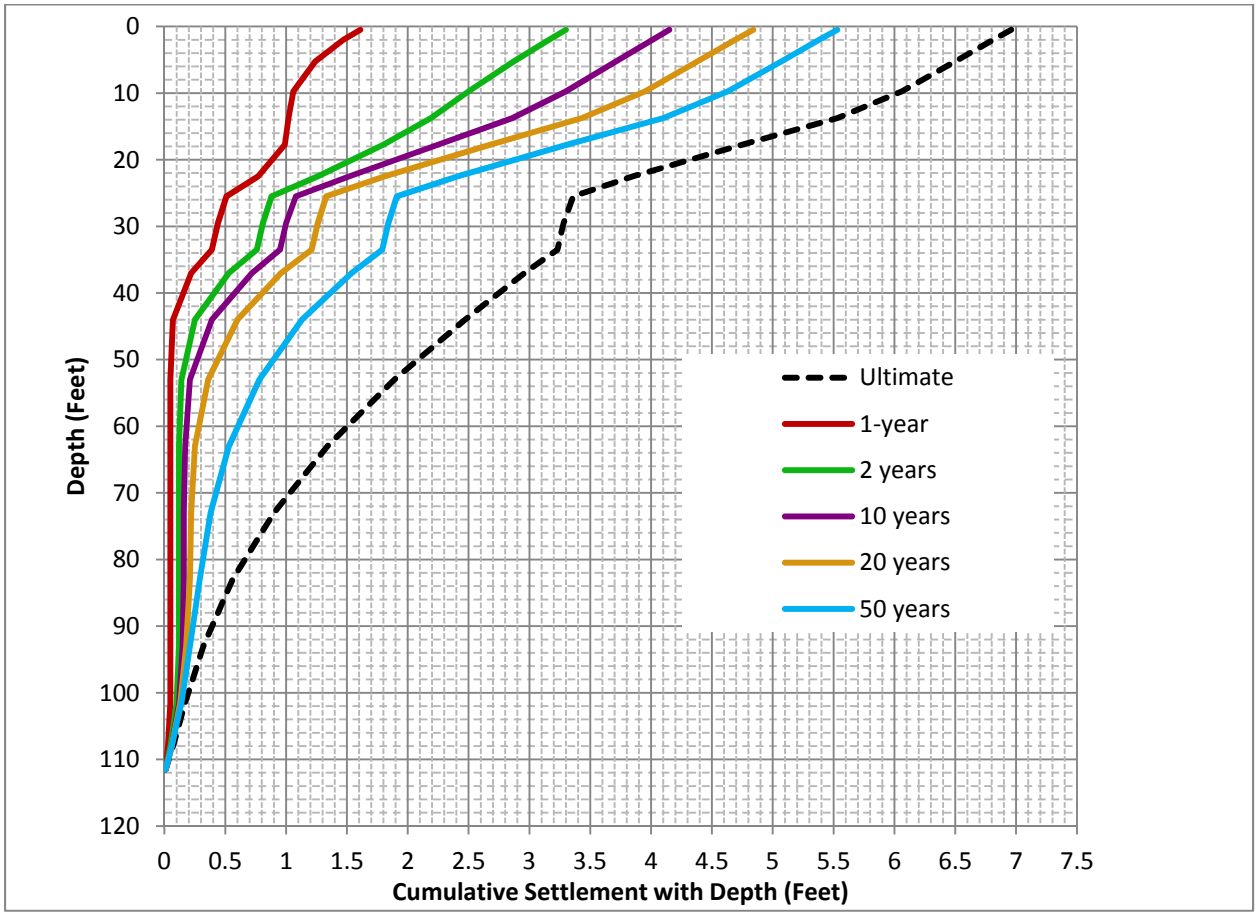

Figure 7: Idealized Percent Consolidation versus Time for Wick Drain Treated Soils

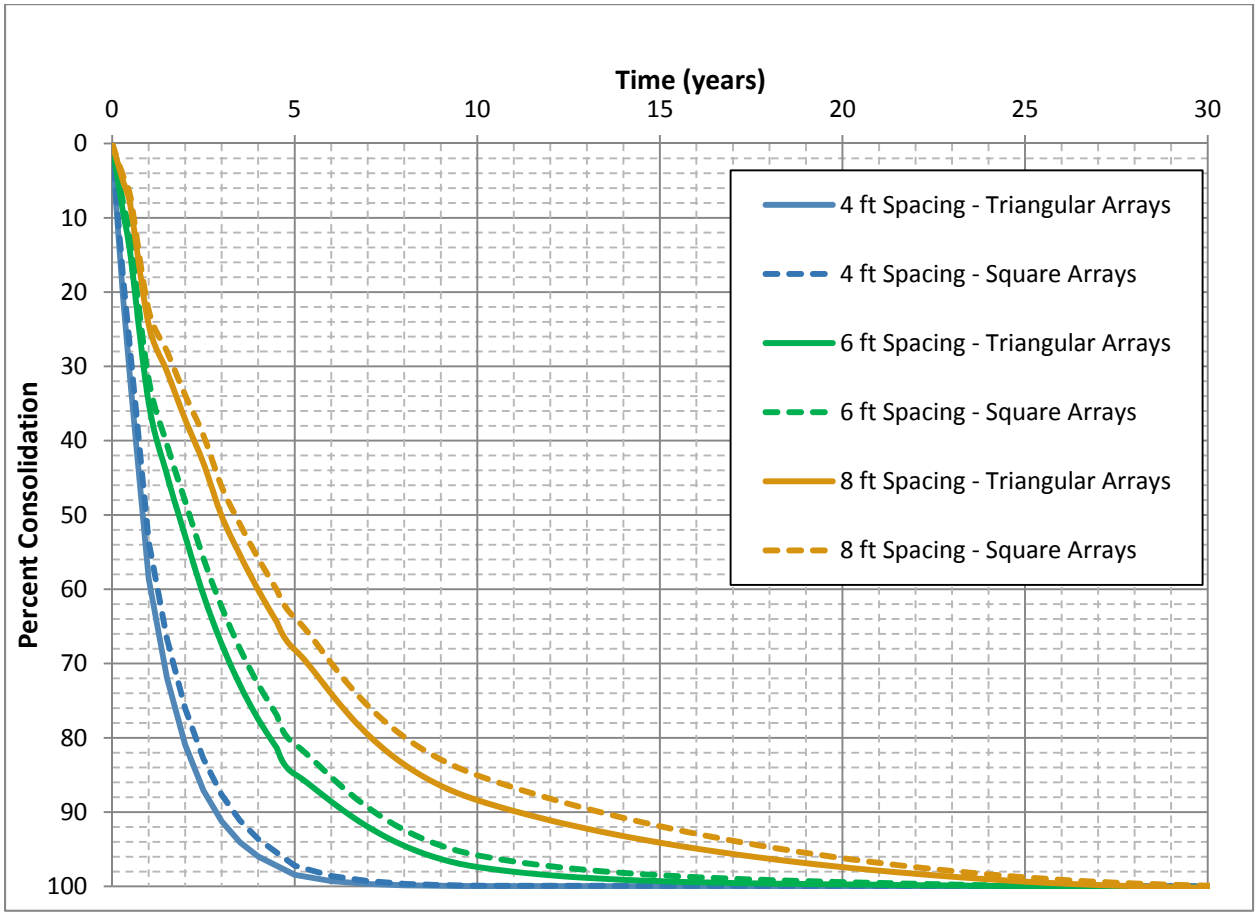

Figure 8: Idealized Guide Levee Settlement with Wick Drain Treated Foundation Soils Station 110+00

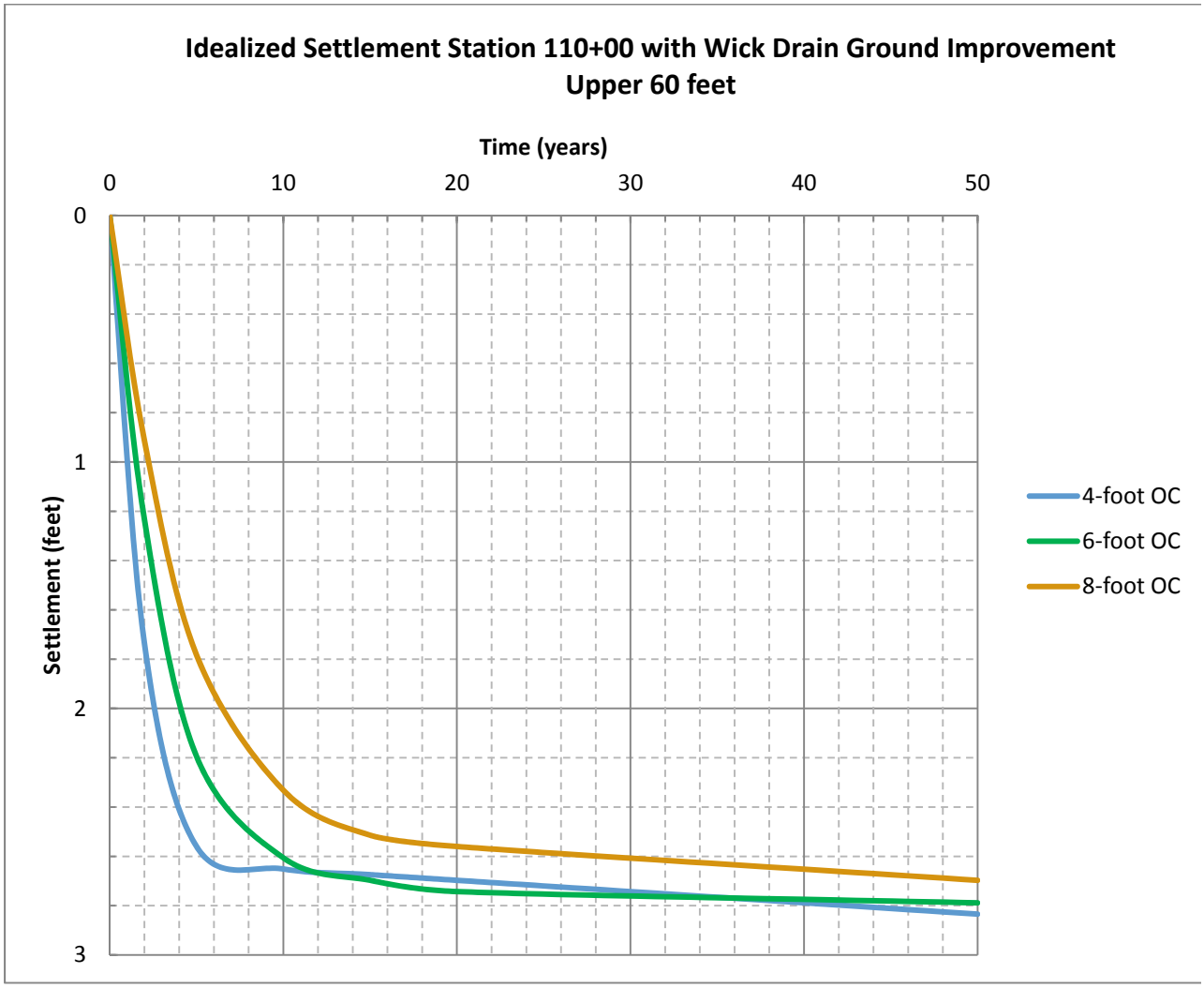

Figure 9: Guide Levee Crown Elevation Over Time – Station 110+00 with 8-foot OC Wick Drain Foundation Treatment in upper 60 feet.

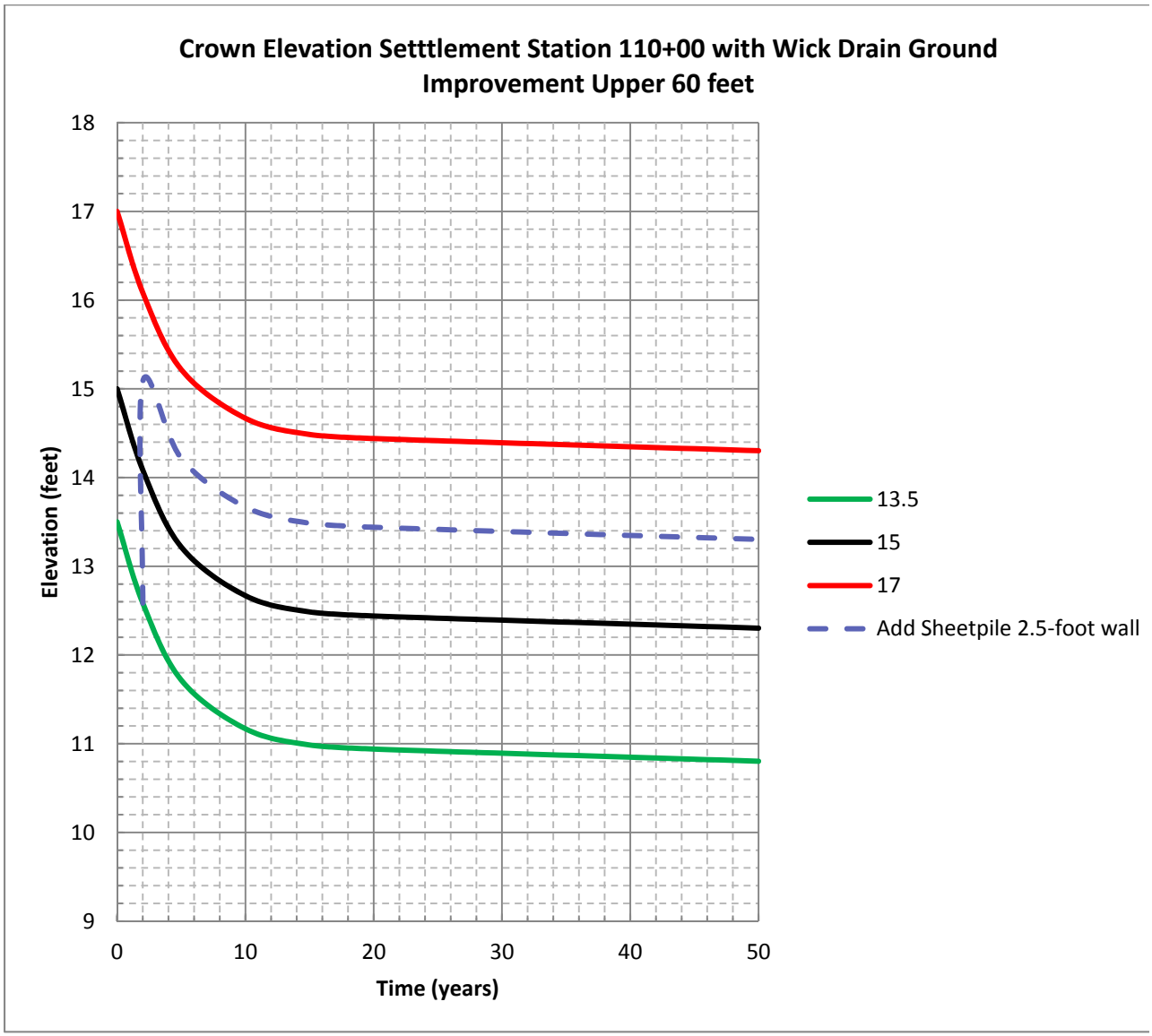

Figure 10: Bank Settlement at Top of Conveyance Channel No Wick Drains – Station 82+00

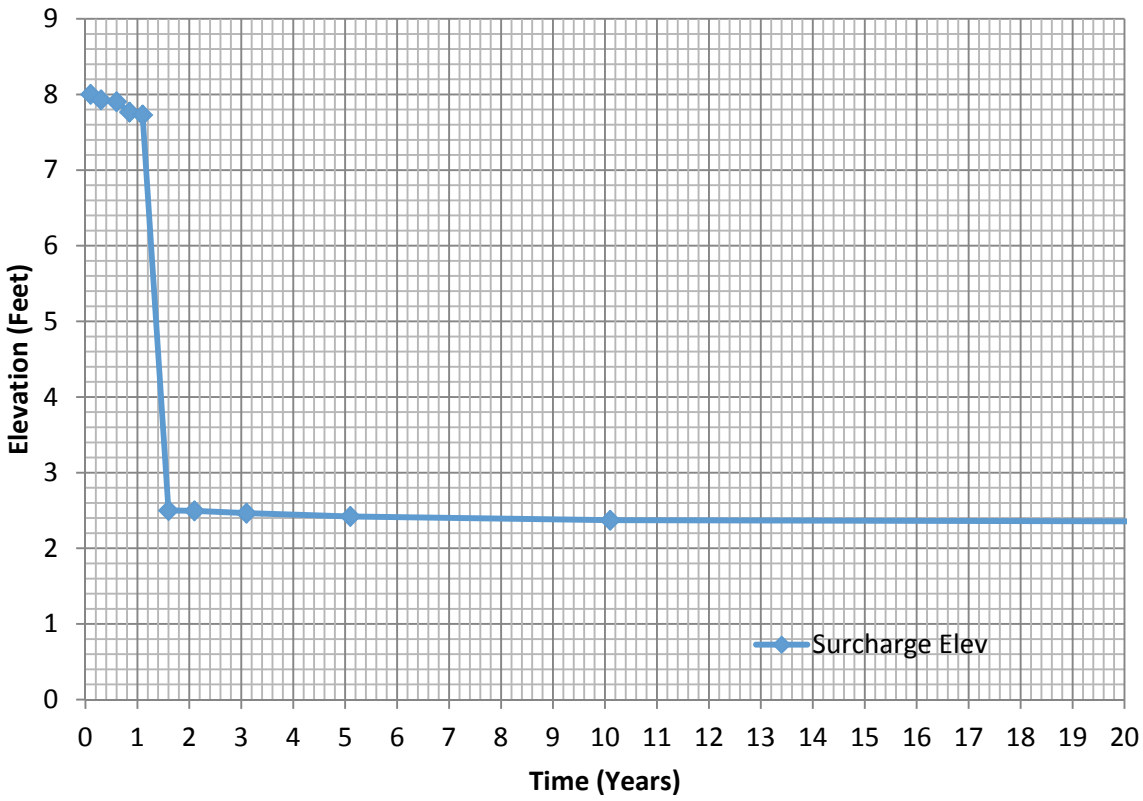

Figure 11: Bank Settlement at Top of Conveyance Channel No Wick Drains – Station 110+00

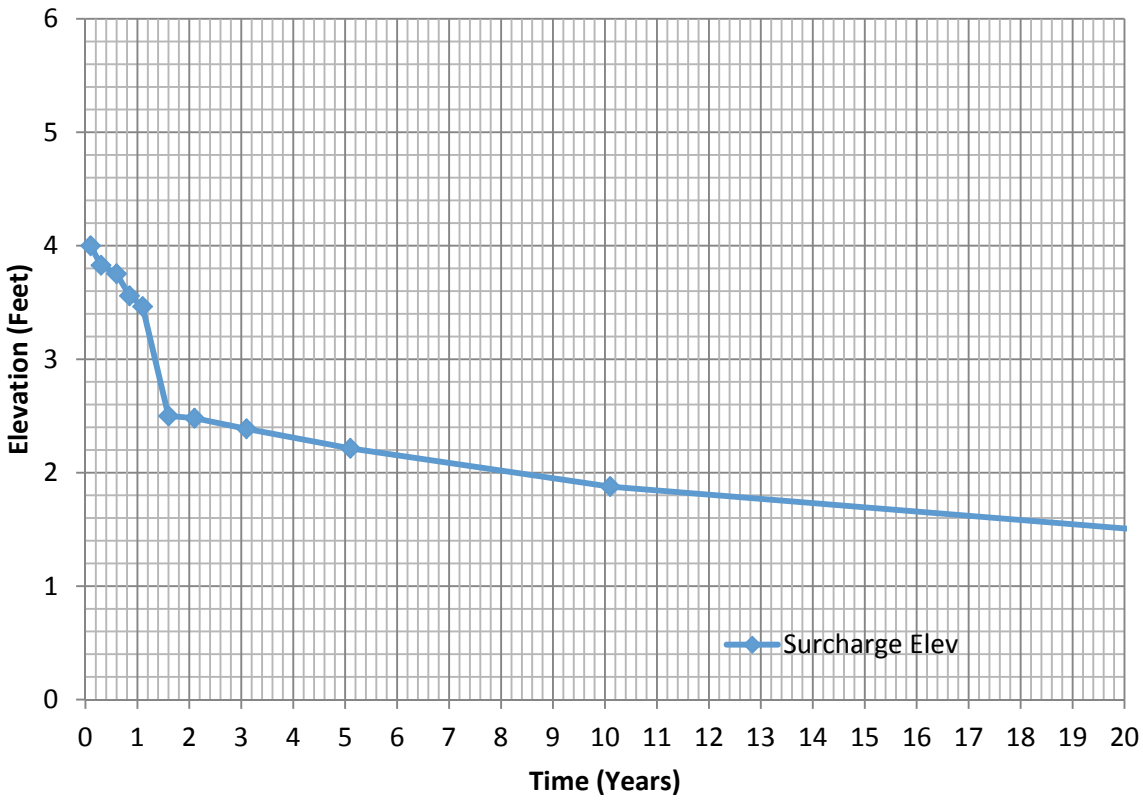

Figure 12: Summary of fill height with recommended overbuild and foundation treatment