TETRA TECH

MEMORANDUM

TNC – Fisher Slough Final Design and Permitting
Subject: Internal Memorandum for Levee Design – Groundwater Mounding

To: Internal Memo for Record

From: David Cline (Tetra Tech)

Date: Dec. 16, 2009

Introduction

During levee design seepage design review, concerns were brought forward by the DD3 and local landowners reviewing the project regarding possible groundwater mounding effects on adjacent farm properties that may occur from setting back the levees. Our understanding of the concerns is that high groundwater tables during late spring or early summer periods could effect plowing, planting and seed/root saturation and could cause crop damage. This memorandum is developed to address the potential effects from groundwater mounding conditions as a result of the Fisher Slough tidal marsh restoration levee setback.

Hydrologic Conditions

In order to assess the potential for groundwater mounding, the seasonal hydrologic conditions are defined in three periods of interest:

- Summer irrigation period (June 1 – Sept 30) – Floodgates fully open
- Fall/winter flood period (Oct. 1 – Feb. 28/29) – Floodgates operating at 7.5ft elevation
- Spring/early summer juvenile chinook migration period (Mar. 1 – May 31) – Floodgates operating at 9.5ft elevation

These periods correspond to specific operating periods for the Fisher Slough project and were defined at the outset of the project.

The farm crop drainage periods of interest are as follows:

- Spring planting period (Mar. 1 – May 31)
- Early summer growing period (June 1 – July 30)

For the fall/winter flood period, the gates will be set to operate at a setting of 7.5ft (NAVD88). This condition is somewhat similar to existing conditions. During this period, groundwater has been measured and observed at the surface of the ground during wet rainfall and flood periods. Agricultural operations do not typically occur during these periods, so the potential effects on agriculture are not evaluated.

For the spring/early summer juvenile chinook migration period, farm operations typically involve tilling and preparation of the soils in May, June and July. During the spring, the groundwater table varies in elevation and can high if precipitation and elevated Skagit River and tributary flows persist, or fairly low if dryer conditions exist.

During the summer irrigation period the floodgates are operated to remain fully open and allow frequent tidal inundation of the marsh. Inundation of the tidal marsh can be reasoned to benefit the local farms due to slight increases in the groundwater table, thereby improving growing conditions. Occasional summer rainfall events do occur, but the additional depth of storage in the marsh area is considered negligible.

During the recent meeting with local landowners and farmers, concern was expressed over the potential problems with wet and saturated fields during spring/early summer period. Specifically of interest are the conditions where late spring Skagit River flooding occurs (due to snowmelt runoff) and the tidal marsh is inundated for a long period of time. This case will be discussed and examined to demonstrate the potential groundwater mounding effects during these conditions.

To assess these farm crop drainage periods of interest the following cases were evaluated.

- Spring planting period (Mar. 1 – May 31) – Steady state seepage analysis of water surfaces at 9.5ft on the waterward side of the levee. This represents the conditions when the Skagit River is high for a period of time and the gates are shut at 9.5ft. This condition frequently occurs during the spring with the existing gates in that the Skagit is high, the gates are shut and Fisher Slough is also high behind the gates from local drainage.
- Early summer growing period (June 1 – July 30) – Unsteady state (transient) seepage analysis of early summer flood conditions that occur on the Skagit River as a result of late snowmelt runoff. Hydrologic conditions for the early summer growing period are described further in the following paragraphs.

The transient seepage analysis requires two hydrologic inputs including the inflow hydrograph for the late spring and early summer flood, as well as the underlying groundwater elevation for adjacent farm area and Slough.

Late Spring/Early Summer Hydrograph Inflow Conditions

Determining the inflow hydrograph involved looking a historical USGS and Fisher Slough gage data to study the number of occurrences and types of late spring and early summer flooding occur on the Skagit. Fortunately, during the summer of 2008, the Fisher Slough project collected surface water data that captured two late season high water events that are considered representative of the type of hydrologic conditions that are a concern for local farmers (**Figure X**). Two late season high water events were observed and compared with the Skagit River Mt. Vernon gage. The characteristics of the late season flood appear to be a 1 to 2 week long event. The rising limb of the hydrograph is approximately 2 to 4 days long, the peak varies in elevation over a 3 to 5 day period and the falling limb is 3 to 5 days long.

Also, the summer 2008 data collection period was compared to the USGS, Skagit River Mt. Vernon Gage No. 12200500. It is noted that the peaks between the Mount Vernon Gage (NGVD29

Datum) and the Fisher Slough Gage (NAVD88 Datum) have similar flooding characteristics and an average difference of 13.7ft. This is not the case for tidally influenced periods at Fisher Slough. These comparison data were used to evaluate the Skagit River USGS gage data for how often late spring flood stages occur. A stage at Mt. Vernon of 24.0ft (NGVD29) corresponding to a stage of 10.3ft (NAVD88) at Fisher slough was selected as the screening elevation that corresponds with the late spring high water conditions of concern for the project.

Using this relationship, the Mt. Vernon gage record from 1988 through 2009 was evaluated to determine the number of occurrences when the Skagit rises above a target elevation that would be considered problematic from a seepage perspective. The following four flow events were observed in the recent 25 year period:

- May 18-21, 2008
- June 30-July 4, 2008
- June 29, 2002
- June 1, 1997

This initial screening analysis would indicate that the late season peaks occur 1 in every 5 to 10 years.

The Mt. Vernon and the Fisher Slough gage data were analyzed in detail to develop a "representative" inflow hydrograph condition for the transient seepage analysis. This involved averaging the rising limb, peak, and falling limb durations, and estimating the average peak flow elevation. The following late season flow hydrograph was developed for the transient model input:

- Average rising limb duration – 3 days
- Average peak stage – 12.0ft (equivalent to the OHW)
- Average peak duration – 4 days
- Average falling limb duration – 4 days
- Total hydrograph duration – 11 days

Beginning and ending water surface elevations and groundwater conditions are discussed in the following section of the memorandum.

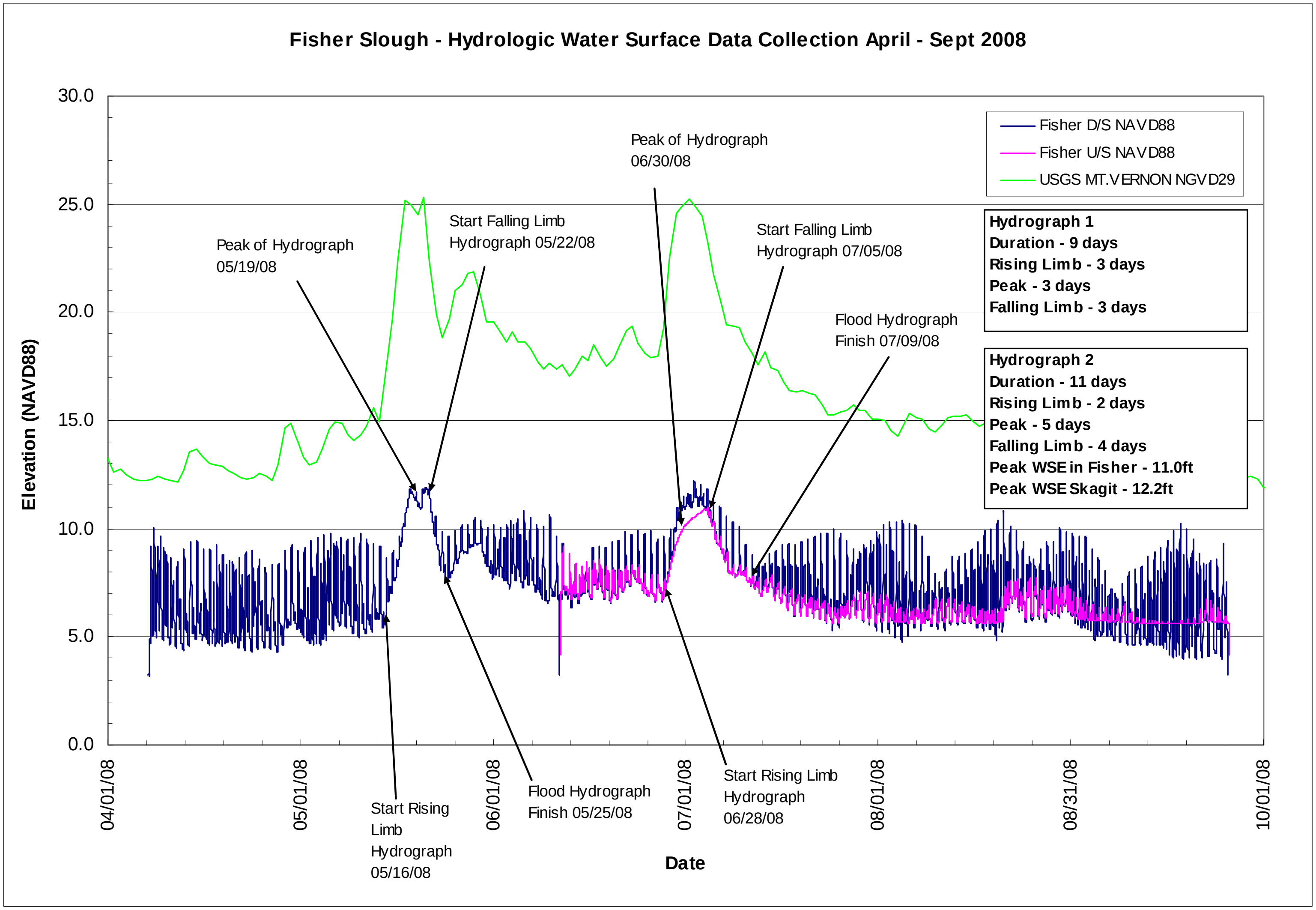


Figure 1. Surface Water Hydrology Measurements of Late Spring Flow Events at Fisher Slough

Groundwater and Surface Water Elevations in Late Spring/Early Summer Periods
There are several sets of groundwater data and studies available for the Fisher Slough restoration site. These include the following data sets and reports:

- Fisher Slough original groundwater measurements inside and outside the existing levee made during the summer of 2006.
- Fisher Slough recent groundwater monitoring measurements outside the levees made during 2009.
- Fisher Slough surface water measurements of Big Ditch which is a corollary to Skagit Delta groundwater elevations.
- USGS groundwater studies on the Skagit Delta having general information regarding seasonal groundwater stages on the central delta.

The original feasibility study on Fisher Slough evaluated the effects of daily tidal cycling inside and outside of the levee. A groundwater well was installed one each on the inside and outside of the levee (**Figure 2)**. The Orig-GW1 (inside Fisher Slough) and Orig-GW2 (located in Smith A) are approximately 300ft apart. It is observed that the groundwater surfaces in Smith A are associated with the underlying Skagit aquifer and only minimally influenced by the daily tidal fluctuations (**Figure 3**). This would indicate that the existing levee has soils within and underlying the levee prism that are have low permeability and do not readily transmit groundwater through and beneath the structure. This type of information was used to calibrate the transient seepage model, and to identify starting groundwater surface elevations for the model.

A note to the reader is that in late August 2006 the Orig-GW2 well went dry and the logger stopped reading water depths.

The next set of available data is the recent groundwater monitoring data at GW-1 located mid-way along the north-south levee section in Smith B (**Figure 4**). The groundwater data shows that for the single year of groundwater data collected, the groundwater is at an elevation between 2ft and 4ft (with adjacent ground elevations between 6ft and 7ft) in the late spring April to May period. The groundwater was observed as 2ft to 3ft below the ground surface. Then beginning in June the groundwater elevations dropped dramatically, nearly 12ft in a 3 month summer period. On average, the groundwater elevation of a -0.2ft (NAVD88) nearly 6 feet below the ground surface for the period of May through September, 2009.

The GW-1 data from June 1, 2009 was used for a starting downstream groundwater elevation of 2.1ft at a distance of 300ft outside the levee (similar to observations of interior and exterior levee groundwater elevations and tidal influences as observed with the Orig-GW1 and Orig-GW2 data). The modeling starting conditions are discussed further in following sections of the memorandum.

Big Ditch groundwater data were collected during the mid-late summer period of June through Sept. 2008 (**Figure 5**). Big Ditch surface water elevations fluctuate due to tidal and diurnal evapotranspiration and irrigation pumping activities. The daily fluctuations are above and below the adjacent groundwater table, but the average water surface elevations are somewhat indicative of the underlying groundwater table. The average water surface elevation in the ditch for July and August 2008 was 1.9ft.

Finally, the USGS Skagit Groundwater Monitoring Report for the North Fork Skagit (USGS, 2009) was reviewed to see if general trends along the North Fork were similar to the observations made in the S. Fork. Overall, the seasonal Fisher Slough data and USGS report data and maps correlate well and show similar groundwater elevations for similar delta ground surface elevations (6.0ft to 7.0ft in land surface elevations).

Overall, the following boundary conditions were established for the both the steady state and unsteady flow models:

- Furthest downstream water surface elevation in Big Ditch = 2.1ft (GW-1 observed June 1, 2009 stage)
- 300ft downstream water surface starting elevation in Smith Farm area = 2.1ft (GW-1 observed June 1, 2009 using assumption from tidal groundwater relationship inside/outside levees Orig-GW1 and Orig-GW2)
- Starting groundwater elevation inside the slough on the upstream side of the levee = 7.0ft (equal to the ground surface elevation in the slough)

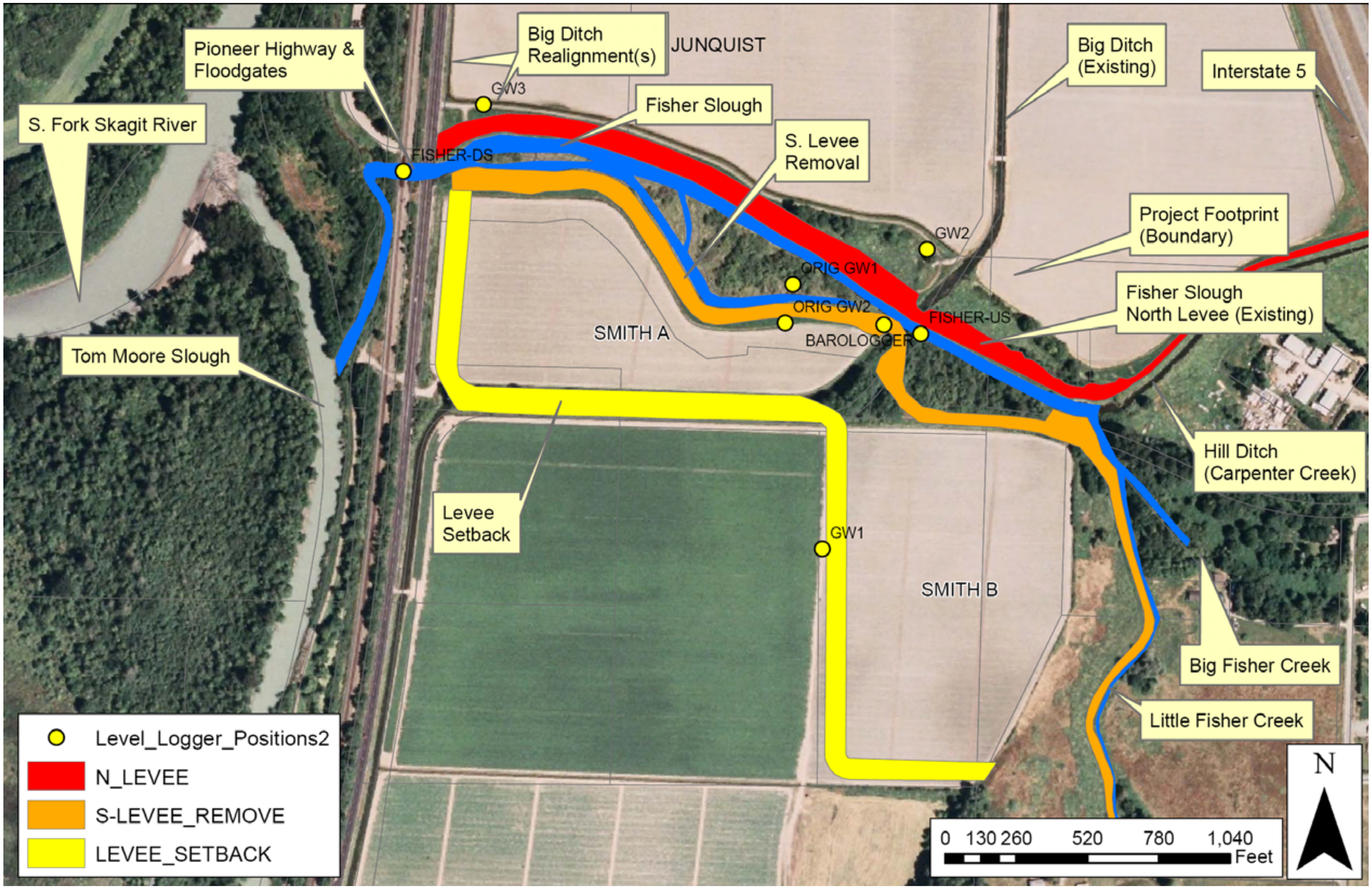


Figure 2. Surface Water Hydrology Measurements of Late Spring Flow Events at Fisher Slough

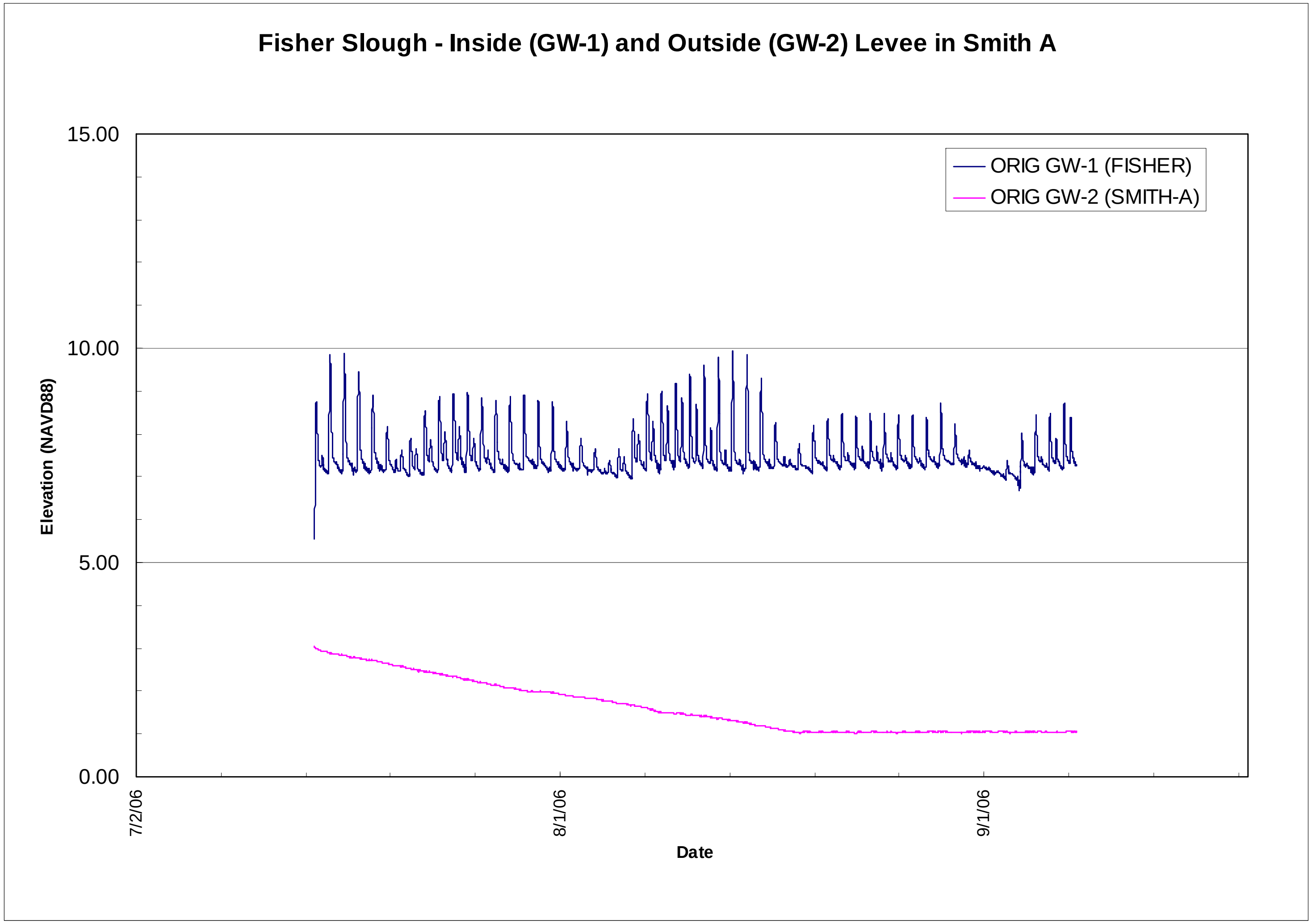


Figure 3. Groundwater measurements inside and outside the existing Fisher Slough levee

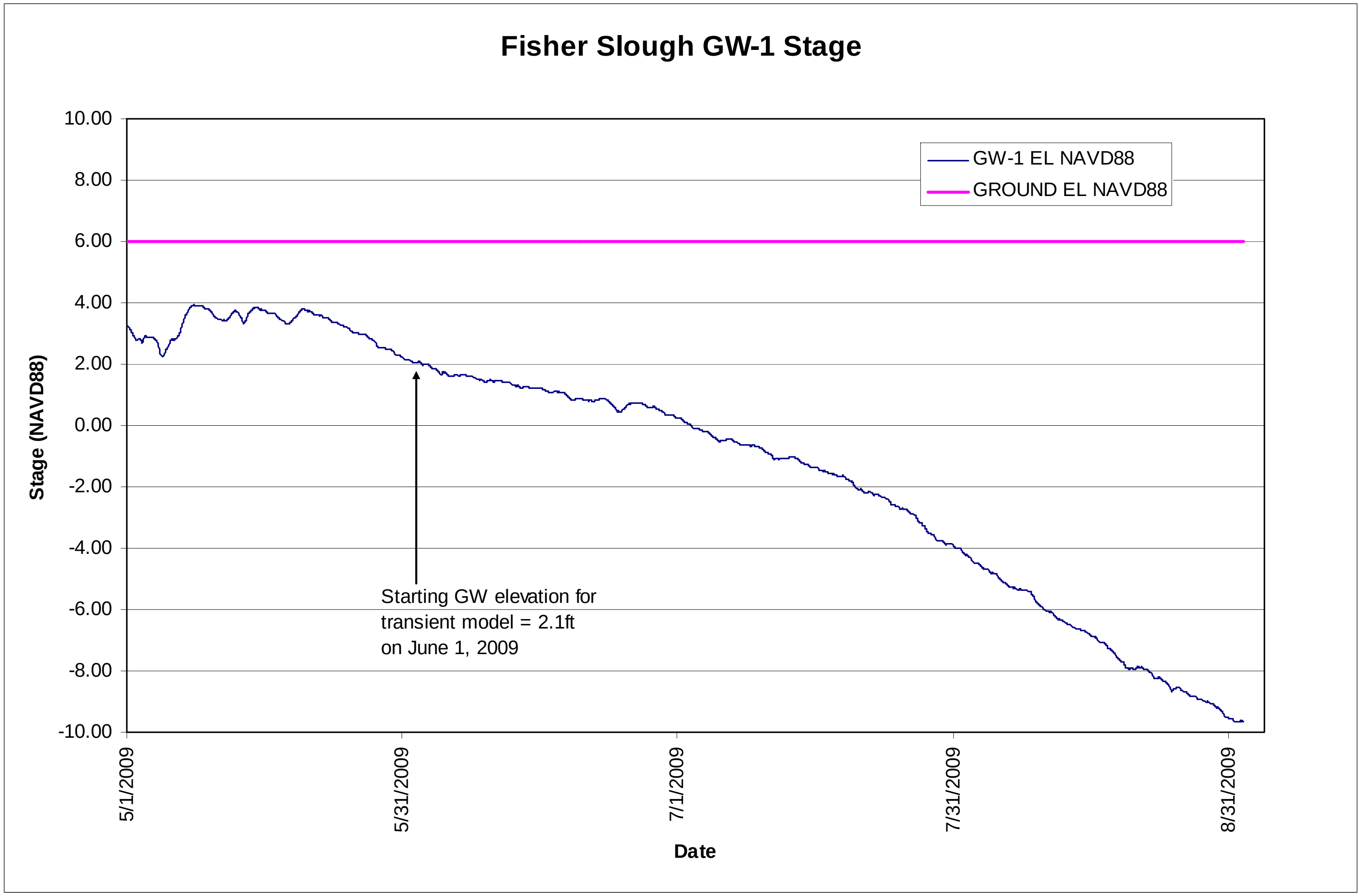


Figure 4. Groundwater measurements for existing conditions mid-way along Smith B, north-south levee section

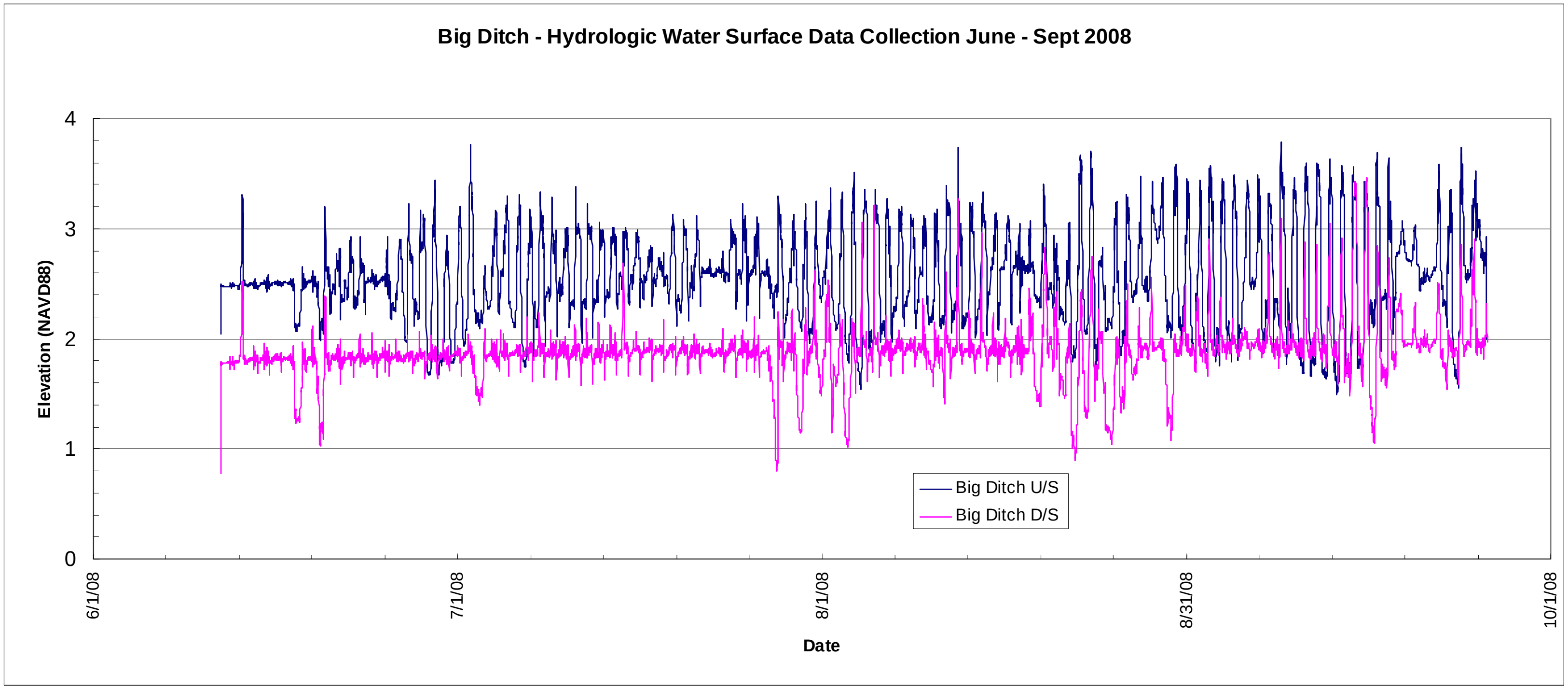


Figure 6. Big Ditch Water Surface Elevations Summer 2008

Empirical Groundwater Mounding Analysis
In order to assess the potential effects of late spring extended runoff and summer time tidal marsh inundation, a groundwater mounding analysis. A number of methods are available for evaluating groundwater mounding beneath ponds, reservoirs and stormwater infiltration facilities.

The first method evaluated used the methods developed by Hantush 1967. An online calculator is available through Hydrosolve to evaluate the groundwater mounding (Hydrosolve, 2009). The following parameters were used in the evaluation based on the existing soil conditions and expected hydraulic loading (Maidenment, 1993).

The groundwater mounding analysis indicates that daily tidal inundations would mound the underlying aquifer up to 0.3ft above the Skagit baseline aquifer elevations. With a starting groundwater surface elevation of 2.1ft, and an additional 0.3ft of mounding the predicted groundwater mounding elevation is 2.4ft, which is 4ft to 5ft below the ground surface and considered acceptable.

In addition to tidal inundation, an initial groundwater mounding analysis was performed to evaluate the late spring flood condition. It indicated that a 5-day flood event would raise the local groundwater between 1.4ft and 2.8ft and would extend 300ft beyond the levee. This indicates that the groundwater surface elevations would be between 1ft and 2ft below the ground surface for the shortened flood condition. During this empirical analysis, it was observed that the selections of parameters were sensitive and affected the outcome. A recommendation was made to perform more rigorous, site specific transient seepage analysis to predict the expected seepage conditions along Smith B during late spring floods.

Transient Seepage Analysis
The transient seepage analysis was performed using SEEP/W (SEEP/W 2007) a finite element numerical model used for evaluating seepage conditions through embankments, levees and dam structures. The steps involved in the transient seepage analysis included the following:

- Identification of embankment geometry, underlying soil stratigraphy, groundwater and hydrologic inflow conditions as model inputs.
- Calibrate the model to match observed seepage rates through the existing levee based on Orig-GW1 and Orig-GW2 tidal inundation and groundwater characteristics
- Run an 11-day unsteady state model for the following alternatives at Smith B
  - Smith B without clay blanket/cutoff trench and without toe drain
  - Smith B with clay blanket/cutoff trench and without toe drain
  - Smith B without clay blanket/cutoff trench and with toe drain
  - Smith B with clay blanket/cutoff trench and with toe drain

The associated geotechnical appendix and report addenda dated Dec. 15, 2009 go into lengthy detail regarding the setup and configuration of the SEEP/W model. This memorandum briefly summarizes the results of four modeling alternatives. **Figure 7** and **Table 1** contain the results of the transient groundwater mounding analysis. The results are described herein.

Smith B (without clay blanket/cutoff and without toe drain)

The levee only alternative does show that groundwater mounding occurs and the groundwater gradient exceeds the ground surface, indicating that full saturation and ponding would occur on the farm side of the levee. The model predicts more than 6in of ponding would occur. The distance from the toe of the levee where the groundwater mound is more than 1ft below the ground surface is on the order of 77ft.

Smith B with clay blanket/cutoff and (without toe drain)

The levee with clay blanket and cutoff (without a toe drain) alternative also shows that groundwater mounding occurs and the groundwater gradient exceeds the ground surface, indicating that full saturation and ponding would occur on the farm side of the levee. The model predicts 1in of ponding would occur. The distance from the toe of the levee where the groundwater mound is more than 1ft below the ground surface is on the order of 61ft.

Smith B (without clay blanket/cutoff) and with toe drain

The levee (without clay blanket and cutoff) and with a toe drain alternative shows that groundwater mounding occurs, but the groundwater gradient remains below the ground surface. This indicates that the soils are nearly fully saturated, with the groundwater table less than 1in from the ground surface. The distance from the toe of the levee where the groundwater mound is more than 1ft below the ground surface is on the order of 62ft.

Smith B with clay blanket/cutoff and with toe drain

The levee with clay blanket and cutoff and with a toe drain alternative shows that groundwater mounding occurs, but the groundwater gradient remains the lowest below the ground surface. This indicates that the soils are partially saturated, with the groundwater table less than 5in from the ground surface. The distance from the toe of the levee where the groundwater mound is more than 1ft below the ground surface is on the order of 45ft.

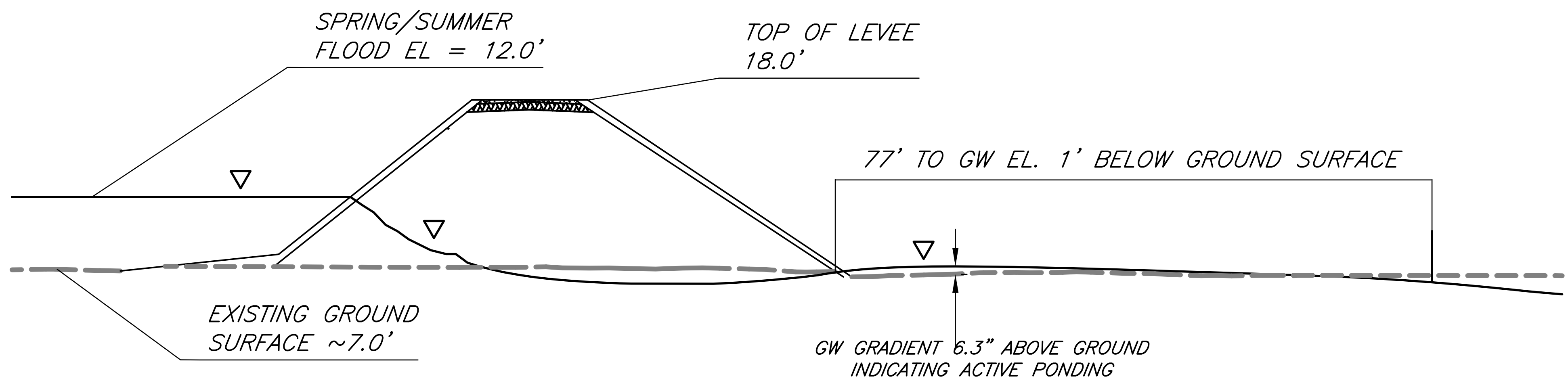
In addition to the transient analysis, the original seepage exit gradient and embankment stability analysis were updated to reflect the changes in the levee configuration. This information combined with cost information has also been included in the **Table 1** seepage design summary table.

Table 1. Summary results of seepage, embankment stability, transient seepage and cutoff design costs by levee section

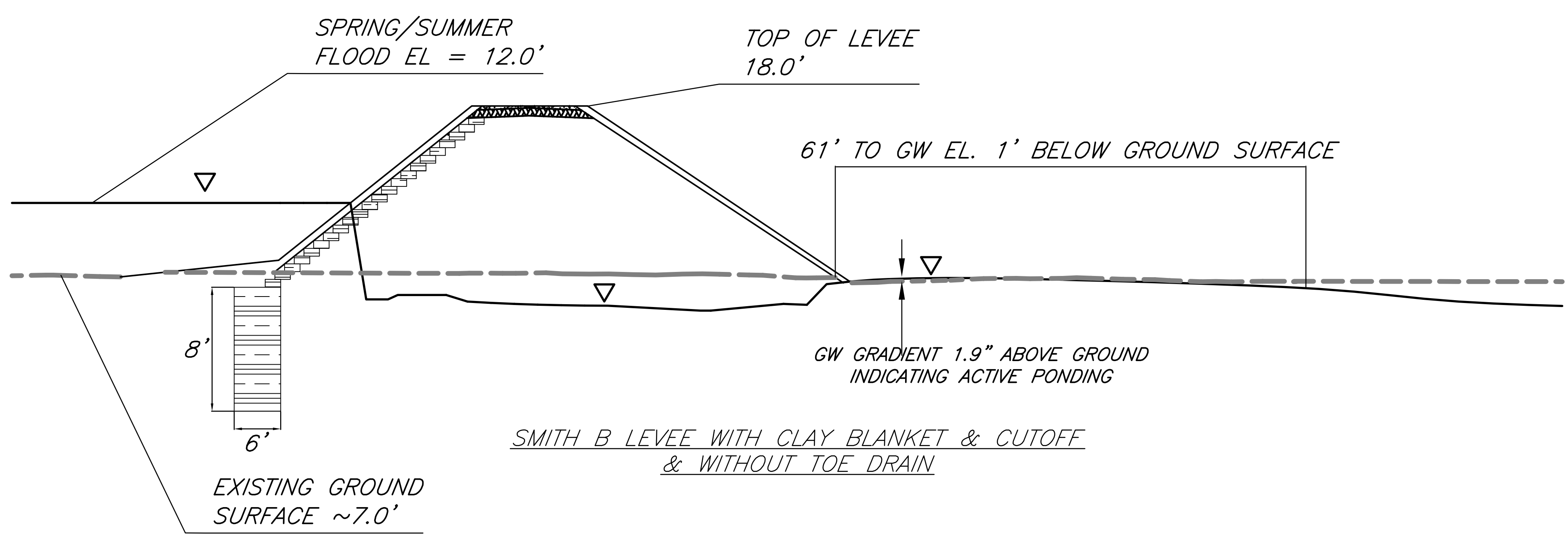
Location	Seepage Design Alt.	Avg. Exit Gradient[1]	Meets Corps Criteria	Long Term Embankment Stability FS	Transient Farm Drainage Conditions			Additional Cost[2]
					Depth to Groundwater (in)	GW Table Above/Below Ground Surface	Distance From Levee Toe to GW Depth @ 1ft	
Smith A	W/O Seepage Protection	0.54	No	-	-		-	-
	Impermeable Berm/Blanket	0.36	Yes	1.45	-		-	[redacted]
	Sheet Pile Cutoff	0.43	Yes	-	-		-	[redacted]
	Clay Blanket & Cutoff Trench	0.50	Yes - Marginal	1.72	-		-	[redacted]
Abandoned RR	W/O Seepage Protection	0.21	Yes	1.52	-		-	-
	Clay Blanket & Cutoff Trench	0.25	Yes	1.58	-		-	[redacted]
Smith B	W/O Seepage Protection	0.38	Yes	1.57	-6	Above	77	-
	Clay Blanket & Cutoff Trench	0.36	Yes	1.61	-1	Above	61	[redacted]
	Toe Drain	-	-	-	1	Below	62	[redacted]
	Clay Blanket & Cutoff Trench & Toe Drain	-	-	-	5	Below	45	[redacted]

1 Corps criteria for low risk for vertical exit gradients is 0.5ft/ft

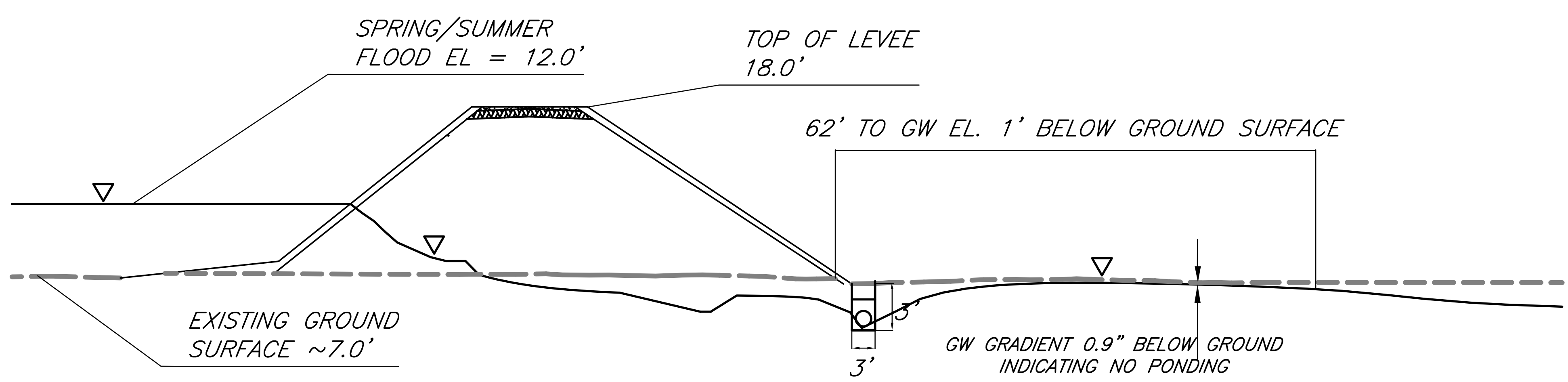
2 Additional costs beyond base include 7.8% tax and 10% contingency, except Smith A cutoff includes 20% contingency for unstable soils and high groundwater seepage conditions.



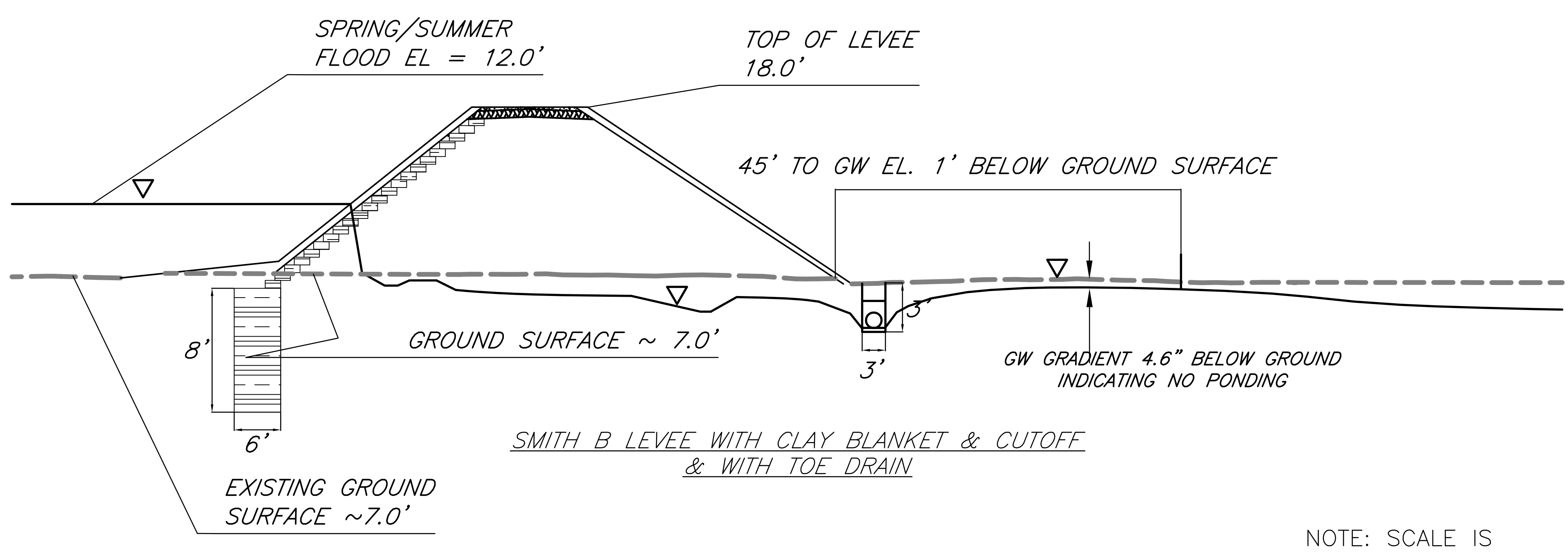
SMITH B LEVEE WITHOUT CLAY BLANKET & CUTOFF
& WITHOUT TOE DRAIN



SMITH B LEVEE WITH CLAY BLANKET & CUTOFF
& WITHOUT TOE DRAIN



SMITH B LEVEE WITHOUT CLAY BLANKET & CUTOFF
& WITH TOE DRAIN



SMITH B LEVEE WITH CLAY BLANKET & CUTOFF
& WITH TOE DRAIN

NOTE: SCALE IS
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Sheet of	Drawing No.	File Name	TETRA TECH 1420 Fifth Avenue, Suite 550 Seattle, Washington 98101 206-728-9655 Fax: 206-728-9670	THE NATURE CONSERVANCY FIG 7. SMITH B LEVEE TRANSIENT SEEPAGE ANALYSIS	Designed Drawn Checked Approved Title	Date

Seepage Analysis Recommendations

In review of the findings, our recommendations for the project design are as follows:

- Install a clay slope blanket and 6ft x 8ft cutoff trench with low permeable clay material along the entire length of the levee.
- Install a 3ft wide by 4ft deep, gravel toe drain with a 5ft offset from the levee toe. This structure does not need topsoil cover as it is within the 15ft offset to The Nature Conservancy property line.
- If the cost of the bids comes in too high, or if The Nature Conservancy wishes to negotiate on certain design items the following seepage measures could be eliminated to reduce cost, while maintaining adequate levee seepage exit gradient criteria, embankment stability and meet farm drainage needs.
    - The clay cutoff along Smith B could be thinner and shallower to reduce materials and installation costs.
    - Consider multiple drain tiles along Smith B instead of a clay blanket and cutoff. They may be more effective at managing shallow groundwater behind the levee than the installation of the cutoff. The cost of 6 full drain tiles is approximately equal to the cost of a single clay blanket and cutoff trench. Additional tiles out in the Smith B farm area will require 2ft of topsoil over the drain to allow for normal farm activities.
    - Reduce or eliminate the cutoff along the railroad embankment as it has a large drainage channel running along the farm side of the structure which acts as a toe drain.

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