TETRA TECH

MEMORANDUM

TNC – Fisher Slough Final Design and Permitting
Subject: DRAFT Technical Memorandum:
Levee Emergency Spillway Design

To: Internal Memorandum For Record
Yen Hsu Chen (Tetra Tech)

From: David Cline (Tetra Tech)
Jon Olmsted (Tetra Tech)

Date: Nov. 9, 2009

Introduction

This hydraulic design technical memorandum is the engineering analyses performed for the emergency spillway on the South Levee Setback structure for the Fisher Slough Project. The design analysis includes the following elements:

- Evaluation of existing spillway capacity
- Sizing and evaluation of the S. Levee Setback spillway capacity
- Design of protective riprap for spillway elements and material specifications
- Design of filter fabric installation
- Grading design of spillway structure

Evaluation of the existing spillway capacity

The existing emergency spillway for the South Levee is located at the current Big Ditch culvert crossing **Figure 1**. When Fisher Slough reaches flood stage (at approximately an elevation of 14.0ft) the overflow spillway is engaged and spills from Fisher Slough, and plunges onto the downstream concrete apron of the Big Ditch sag-culvert crossing. The spillway was originally designed to have 12"x12" weir boards placed in stop-log slots at the top of the structure. The boards were removed (taken) from the project site, and have not been used in the last 15-20 years. The current spillway is allowed to overflow at an elevation of 14.0ft.

The dimensions of the spillway include a 34ft wide section, as shown on the 1935 as-builts (Skagit County, 2009), with (2) 2ft wide concrete stoplog walls. The effective width of the existing overflow spillway is 30ft wide. It is noted in **Figure 1** that the crest of the spillway is overgrown with thick grass and weeds, and limits the flow across the spillway. The estimate provided herein is likely generous to the actual amount of flow across the spillway.

Figure 1. Fisher Slough Existing Emergency Spillway and Existing Big Ditch Culvert Crossing

The spillway discharge capacity was determined using a broad-crested spillway equation with the following parameters (**Equation 1,** Roberson, 1995).

Eqn. 1 $$Q = (0.385)CL\sqrt{2g}H^{3/2}$$

Q = Weir discharge (cfs) = 400cfs
C = Weir coefficient adjusted for broad-crested weir = 0.86
L = Weir length (ft) = 34ft
g = Gravitational acceleration (ft^2/s) = 32.2 ft^2/s
H = Head above the weir = (Skagit/Fisher Q100 WSE – Weir Crest Elevation)
= 16.7ft–14.0ft = 2.7ft

Sizing of the S. Levee Setback spillway capacity
An emergency overflow spillway is being designed for the Fisher Slough South Levee Setback structure. This structure is being designed to exceed the existing spillway capacity. A number of methods were proposed by the Diking and Drainage District on the configuration of the spillway, including long, depressed levee sections with sheet flow on the backside of the structure.

Due to site and grading constraints, a shorter rock spillway section is proposed by the design engineers. A main spillway length of 110ft was selected, which is nearly three times of the existing spillway.

Q_{main} = Weir discharge (cfs) = 1,414cfs
C = Weir coefficient adjusted for broad-crested weir = 0.86
L = Weir length (ft) = 120ft
g = Gravitational acceleration (ft^2/s) = 32.2 ft^2/s
H = Head above the weir = (Skagit/Fisher Q100 WSE – Weir Crest Elevation)
= 16.7ft–14.0ft = 2.7ft

Also, the spillway is designed as a dip crossing and the structure has 10H:1V sideslopes on the levee profile for vehicle access. A triangle weir equation was used to estimate flow over the sideslope areas (**Equation 2, Roberson 2005**).

Eqn. 2 $$Q = \frac{8}{15} K \sqrt{2g} \tan\left(\frac{\theta}{2}\right) H^{5/2}$$

Q_{sides} = Weir discharge (cfs) = 308cfs
K = Triangle weir coefficient = 0.6
θ = 168.6°
g = Gravitational acceleration (ft^2/s) = 32.2 ft^2/s
H = Head above the weir = (Skagit/Fisher Q100 WSE – Weir Crest Elevation)
= 16.7ft–14.0ft = 2.7ft

$Q_{total} = Q_{main} + Q_{sides}$ = 1,414cfs + 308cfs = 1,722cfs

The estimated total discharge of 1,722cfs for the proposed spillway is 4.0 times the estimated discharge of the existing spillway of 400cfs. The spillway design capacity is slightly greater than estimated 24hr, 100year, routed flood peak estimate for Hill Ditch, Big Fisher and Little Fisher Creeks combined which is 1,680cfs for the future build out conditions in the watershed.

Design of protective riprap for spillway embankment
The spillway design includes placement and protection of rock in three key areas:

- Spillway crest/dip crossing
- Spillway slope embankment
- Spillway toe rock scour depth

For each of these areas, the following design criteria were evaluated:

- Protective rock size
- Filter size and ratios
- Layer thickness

Rock Sizing Method Comparisons
A number of methods are available for sizing rock on steep slopes, embankments or spillways. A variety of methods were evaluated to determine the appropriate riprap protective cover.

Frizell and Ruff, 1998
Figure 2 is the a set of design guidelines curves used to determine the size of rock on a steep spillway embankment (CSU, 1998). The first step in estimating the riprap size on the embankment is to determine the unit discharge. The primary flow is along crest of the spillway at an estimated flow rate of 1,296cfs. This discharge is increased by 25% to account for flow constriction for a spillway discharge of 1,620cfs (conservative as it is higher than the total estimated weir capacity). The unit discharge along the primary portion of the spillway using a spillway length of 110ft is 14.7sf/s. Converting to metric units provides a unit discharge of 1.36m^3/s/m. A slope line of 0.333ft/ft (m/m) was extrapolated from the curves in Figure 2 for a D50, Cu empirical value of 0.7. This value does not have a factor of safety. The Cu (coefficient of uniformity) for the analysis ranges from 1.5 to 2.1. Using the range of Cu gives D_{50} riprap size estimates from 1.9ft to 2.1ft. Applying a factor of safety of 1.5 gives a D_{50} of 2.9ft to 3.2ft. A D_{50} of 3.0ft was selected.

Riprap layer thickness is typically identified as 1.5 D_{50} to 2.0 D_{50}, and at least 1 D_{100}. For the purposes of this design, a 1.5 D_{50} was selected (4.5ft).

In addition to the spillway embankment, the spillway crest rock size and toe rock are of concern.

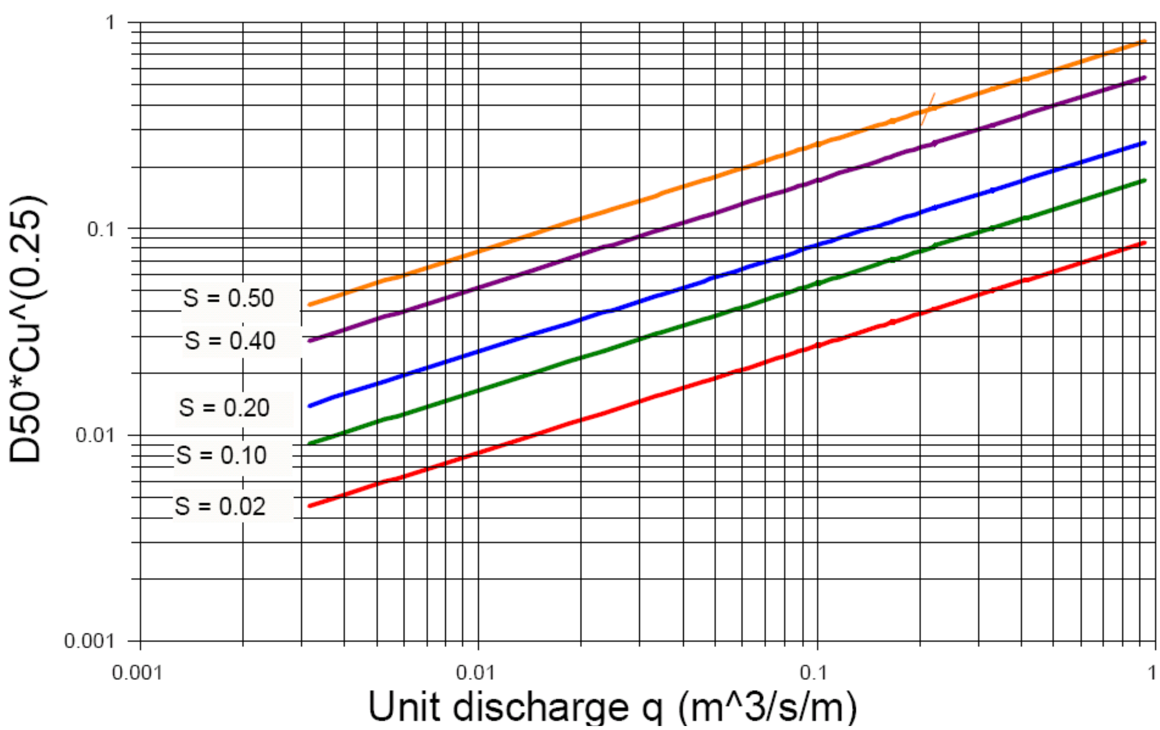


Figure 2. CSU Riprap Design Curves

Corps, 1994
The Corps design method for rock on steep embankments is described in **Equation 3.** This equation was used to determine the size of rock on a steep spillway embankment (Corps, 1994). The limitations of this equation were that the

Eqn. 3 $$D_{30} = \frac{1.95 S^{0.555} q^{2/3}}{g^{1/3}} \quad \text{For } 1\% < S < 20\%$$

Where,

D_{30} = 30% passing diameter (ft) = 2.1ft
S = Slope of the spillway = 0.333
q = Unit discharge assumed Qtotal/100ft = 15.9ft^2/s
g = Gravitational acceleration (ft^2/s) = 32.2 ft^2/s

Equation 4 was used to translate the riprap size estimate to D_{50}. The gradation ratio of D_{85}/D_{15} was assumed 2.0. A D_{50} = 2.65ft.

Eqn. 4 $$D_{50} = D_{30} \frac{D_{85}}{D_{15}}^{1/3}$$

Where,
D_{30} = 30% passing diameter (ft) = 2.1ft
D_{85}/D_{15} = 2.0 (selected)
D_{50} = 50% passing diameter (ft) = 2.65ft

Ferro, 1999
A second equation developed by Ferro was evaluated to determine the D_{50} of the spillway embankment design **Equation 5**.

$$D_{50} = B\phi_e \left(\frac{0.95}{\left(D_{84}/D_{16} \right)^{0.562}} \right) \bullet \left(\frac{QS_o}{B^{5/2} g^{1/2}} \bullet \frac{\gamma_s - \gamma}{\gamma} \right)^{1/2}$$

D_{50} = 3.5ft
B = Channel width (ft) = 110ft
Φ_e = Coefficient = 1.4
Q' = Flow Rate = 1,604cfs
S_o = Slope of ramp = 0.33ft/ft
g = Gravitational acceleration = 32.2 ft^2/s
D_{84}/D_{16} = 2.0 (selected)
γ_s = Unit weight of soil = 165pcf
γ = Unit weight of water = 62.4pcf

Robinson, 1998
Robinson evaluated a rock sizing **Equation 6.**

$$D_{50} = \left(\frac{q}{(8.07e10^{-6})(S_o^{-0.58})} \right)^{0.529}$$

For $0.10 < S_o < 0.40$ and diameters ranging from 15mm to 297mm

Where,

D_{50} = 415mm (1.36ft)
q = Unit discharge in (1.36 $m^3/s/m$)
S_o = Slope of ramp = 0.33ft/ft

No one particular rock sizing equation is fully represented by the site specific conditions at Fisher Slough, and each method has their limitations for application. In order to accommodate for these variances, average values were determined using by compiling all of the above rock size estimates. Average rock sizes were determine for both FS = 1.0 and FS = 1.5. The results were as follows:

Avg. D_{50} (FS1.0) = 2.4ft
Avg. D_{50} (FS1.5) = 3.6ft

Considering some inherent factors of safety in certain equations, a stone size of D_{50} was selected for the design. A rock size, weight relationship was evaluated to identify a size specification by weight using the following equations:

$$D_{50} = \left(\frac{6W_{50}}{\pi \gamma_s} \right)^{1/3}$$

Rearranged the equation becomes:

$$W_{50} = \frac{\pi \gamma_s D_{50}^{\ 3}}{6}$$

The D50 weight using this method is 2,332 lbs (1.16tons). The WSDOT specifications were reviewed to determine if a standard specification would be appropriate for use at the embankment. The heavy loose riprap specified in WSDOT Standard Specifications Section 9-13.1(1) was examined for use at the site. Unfortunately, the heavy loose riprap has no maximum material sizes, which can lead to having extremely large material being placed on site. A spillway embankment specification was therefore developed for this project. The specification has broad gradation coefficients (Gc) and coefficient of uniformity (Cu) to assist with filter design requirements. At a minimum, these shall not fall below a value of 2.

Table 1. Spillway Embankment Riprap Rock Specification

Rock Dia. (in)	**Rock Dia. (ft)**	**Rock Weight (lbs) (γ=165pcf)**	**Percent Passing**	
			Max	**Min**
48	4.0	5,529	100%	100%
36	3.0	2,333	90%	40%
24	2.0	691	60%	20%
3	0.3	1	10%	0%

Gc = 6.7
Cu = 8.0

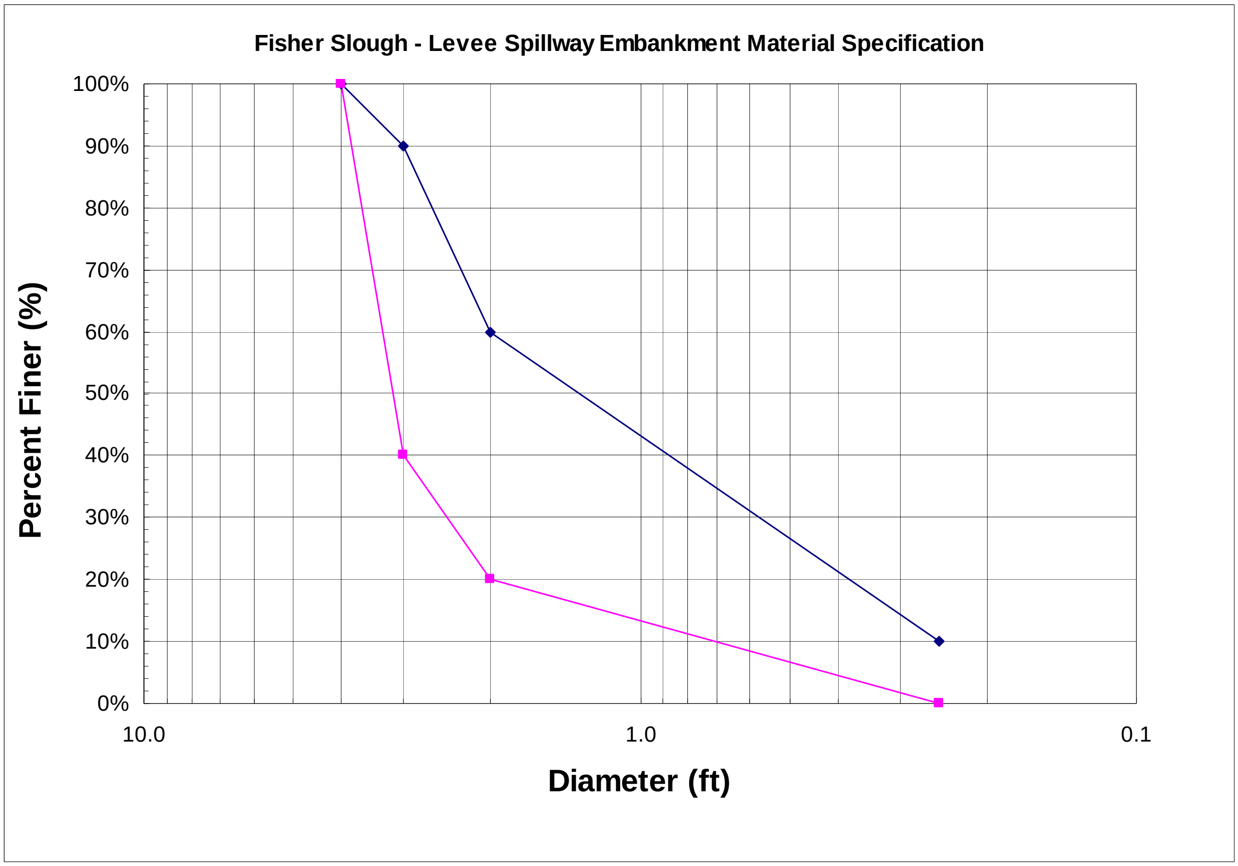


Figure 3. Fisher Slough Spillway Embankment Riprap Material Specification

Embankment Rock Layer Thickness

Rock placement layer thickness is typically evaluated using 1.5 D_{50} to 2.0 D_{50} with a minimum thickness of 1.0D_{100} (Corps 1994, USBR 2007). Again, the D_{50} has been selected as 3.0ft. A thickness factor of 1.5 D_{50} of 4.5ft is considered adequate for the design.

Table 2. Rock Layer Thickness Evaluation

Thickness Factor	Layer Thickness (ft)
1.5 D_{50}	4.5
2.0 D_{50}	6.0
1.0D_{100}	4.0

Filter and bedding material design for riprap

The placement of riprap will need bedding and filter materials to prevent soil erosion and piping from beneath the riprap placement. A filter fabric layer will be placed on the levee embankment soils to allow for both filtering of soil materials, as well as maximizing drainage of the embankment. A Mirafi 180N geotextile material has been specified to be placed between the embankment soils and the rock bedding material.

Bedding materials lying between the geotextiles and the riprap spillway embankment materials must provide a foundation for which to place and seat the riprap, while providing some level of filtering so that the bedding materials are not lost through piping through the riprap. The following set of equations were utilized to asses the filter criteria for the embankment, bedding and riprap layers (FHWA, 1995b).

$$\frac{D_{15-Riprap}}{D_{85-Bedding}} < 5 < \frac{D_{15-Riprap}}{D_{15-Bedding}} < 40$$

The WSDOT Gravel Borrow material specification 9-03.14(1) was identified as a likely candidate for good riprap bedding material and possible filter layer. However, due to the size of the riprap material, a slightly more coarse material was needed for the smaller size fractions. The following table summarizes the specified riprap bedding/filter material for the embankment. This material will be laid a minimum thickness of 6" deep (more than D_{100} or $2D_{50}$). The filter criteria are 3.0 and 12.6 respectively for the above equation.

Table 3. 4" Minus, Quarry Spall Riprap Bedding/Filter Material Specification

Rock Dia. (in)	Rock Dia. (ft)	Rock Weight (lbs) (γ=165pcf)	Percent Passing	
			Max	Min
4	0.33	3.1998	100%	100%
2	0.16	0.4000	100%	50%
0.5	0.04	0.0000	20%	0%

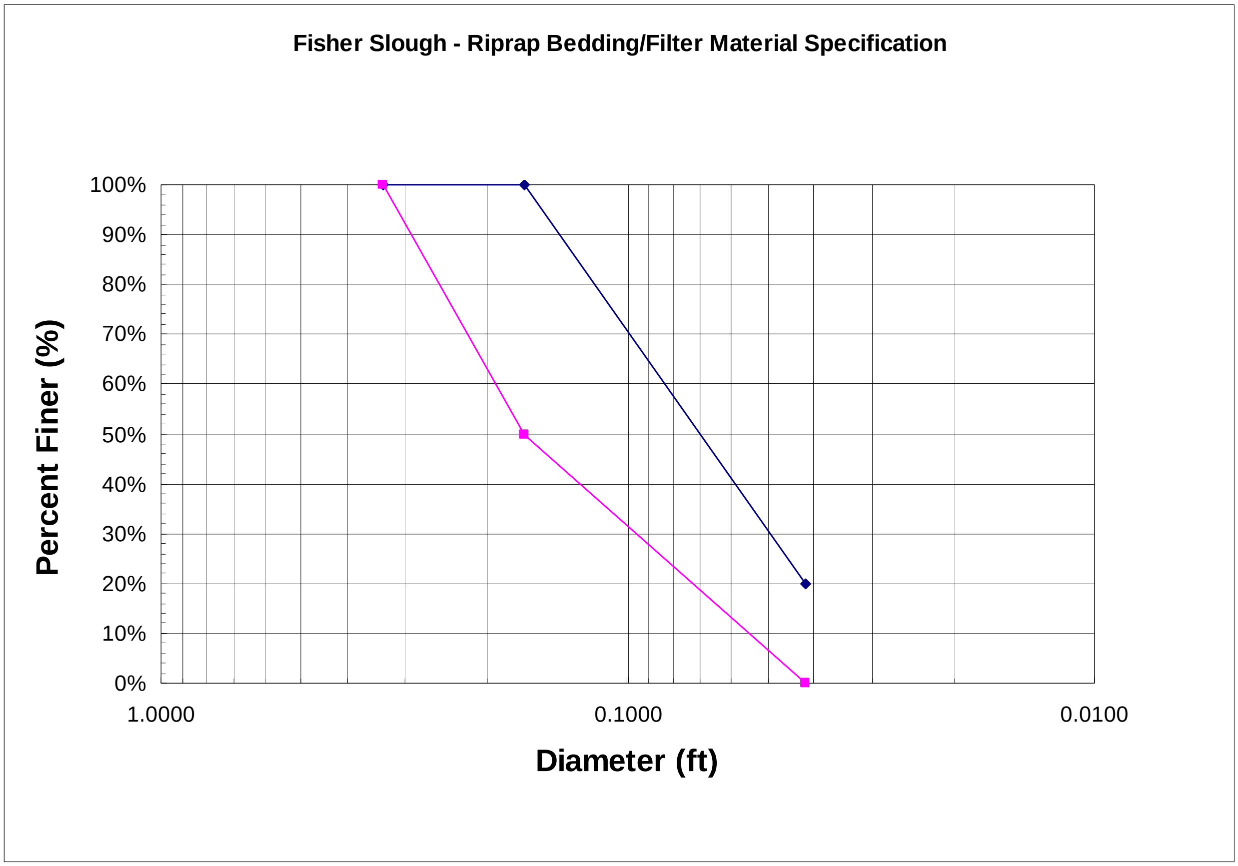


Figure 3. Fisher Slough Riprap Bedding/Filter Material Specification

Spillway Crest Rock Sizing Check

Rock along the spillway crest will need to be installed in such a manner that vehicles can travel across the spillway during dry periods. A separate design analysis was performed to check the use of quarry spall, 4" minus riprap bedding/filter material. A Shield's incipient motion analysis was performed to size the critical diameter of rock during the estimated 100-year flood event. **Equation 5** was used to solve for the critical rock diameter, which is the maximum particle size in motion for the given event. Shear stresses were determined by evaluating the water surface slope across the spillway using the upstream 16.7ft water surface elevation and the assumed downstream critical water surface elevation. Using this analysis, a Dc of 2.2ft is needed along the spillway crest which is assumed equivalent to the D_{100}. For specification purposes, this will be assumed to be 2.5ft rock. The D_{50} will be selected as 2.0ft diameter rock. This rock specificaiton is too large to drive across. Instead, the approach will be to sweep and compact the riprap bedding/filter material into the spillway rock. These rocks will need to be periodically replaced after spill events occur.

Eqn. 5 $$D_c = FS \frac{\tau}{\gamma_s' S^*}$$

Eqn. 5 $\tau = \gamma_w RS$

Dc = 2.2ft
τ = Bed shear along spillway crest = 9.0psf
γ_w = Unit weight of water = 62.4pcf
R = Hydraulic Radius = 6.9ft
S = Water Suface Slope Across Weir = 0.33(2.7ft)/(14ft) = 0.064ft/ft

FS = Factor of safety = 1.5
γ_s' = Buoyant unit weight of sediment = 102.6pcf
S^* = Shield parameter for large rock = 0.06

In addition to placement of this riprap bedding/filter material beneath the riprap, this same material will be used and placed, graded and compacted onto the surface of the riprap embankment material along the spillway crest. This will allow for vehicle access across the spillway. This material will likely be mobilized when the spillway has flow events. The Diking District will need to perform maintenance of the spillway and spread/compact the 4” minus material back onto the spillway driving surface.

Table 4. Spillway Crest Rock Material Specification

Rock Dia. (in)	Rock Dia. (ft)	Rock Weight (lbs) (γ=165pcf)	Percent Passing	
			Max	Min
30	2.50	0.0000	100%	100%
24	2.00	0.0000	100%	50%
12	1.00	0.0000	20%	0%

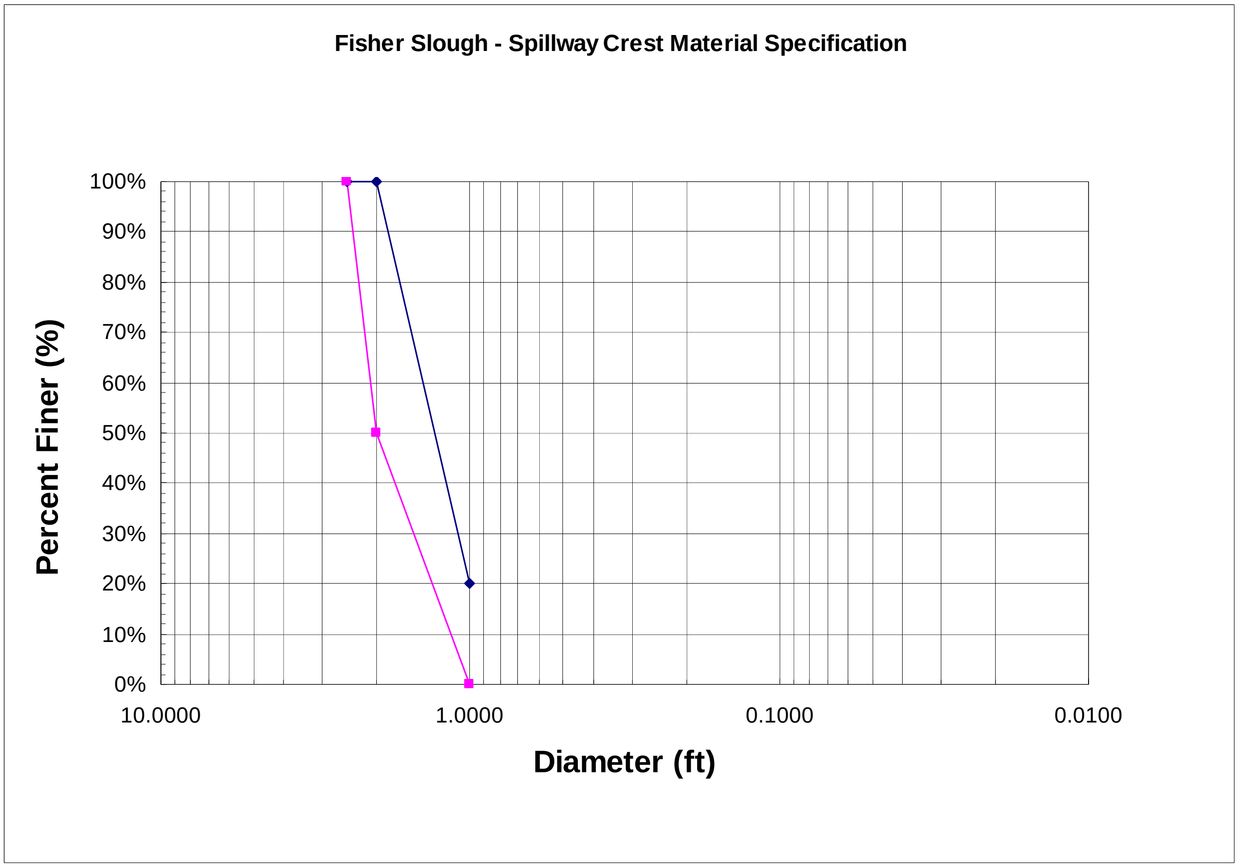


Figure 4. Fisher Slough Riprap Bedding/Filter Material Specification

Spillway Crest Rock Layer Thickness
Rock placement layer thickness is typically evaluated using 1.5 D_{50} to 2.0 D_{50} with a minimum thickness of 1.0D_{100} (Corps 1994, USBR 2007). Again, the D_{50} has been selected as 2.0ft. A thickness factor of 1.5 D_{50} of 2.3ft is considered adequate for the design.

Table 5. Spillway Crest Rock Layer Thickness Evaluation

Thickness Factor	Layer Thickness (ft)
1.5 D_{50}	2.3
2.0 D_{50}	3.0
1.0D_{100}	4.0

Toe down design of protective riprap for spillway
The CSU study specifically evaluated toe rock performance in relation to the embankment and spillway rock size. The study consistently found that the rock placed on the steep embankment was much less stable than toe rock of similar size. The design guidelines therefore specify that the toe

rock be similarly size to the embankment spillway rock. For this study, toe rock will be sized to a D_{50} of 3.0ft, similar to the spillway rock.

For the S. Levee Setback, the depth of scour was estimated at the bottom of the spillway, which is essentially an energy dissipater using the following Equation 6 (which is a metric equation). The equation is a metric equation, which was converted for a total estimated scour depth of 3.2ft. A factor of safety was applied of 2.0 for a toe down depth 6.4ft. Scour depth is measured from the water surface (El. 6.0ft) downward to a depth of -0.4ft. The estimated scour depth is only 0.5ft below the existing bed. For design purposes, rock will be placed $1D_{50}$ (3.0ft) below the scour depth as a conservative measure. The invert of the Big Ditch channel is at 0.0ft, predicted scour depth of -0.5ft, and the toe down depth is therefore $1D_{50}$ (3.0ft) below the scour depth at -3.5ft.

Eqn. 6

$$Y_s = 6h^{0.25}q^{0.5}\left(\frac{y_d}{d_{90}}\right)^{\frac{1}{3}}$$

Ys = Scour depth = 6.4ft (as measured from the water surface downward)
h = Head difference across drop = 0.33ft/ft (used 0.33ft)
q = Unit discharge = 14.7ft^2/s
Yd = Depth of flow downstream = 6ft
D90 = 90% finer sediment = sand = 0.004ft

Emergency Spillway Rock Design Elevation Targets
The final step in design of the emergency spillway is establishment of the target elevations of the spillway rock. The intent is for the spillway rock to begin spilling at an elevation of 14.0ft. The top of the spillway will be constructed slightly higher, but will still discharge at an elevation of 14.0ft. The discharge elevation will be controlled by the underlying seepage clay blanket, built up to an elevation of 14.0ft along the spillway crest. In order to meet thickness requirements of the spillway rock, mixed and compacted with quarry spalls, it will be placed up to an elevation of 14.7ft. These materials will effectively "leak" due to their porous nature at elevation 14.0ft, but surface flows will begin at 14.7ft. An 8.0inch layer of 4" minus bedding materials will be spread and compacted into the spillway crest to form a driving surface across the spillway. These materials will need to be periodically replaced after spill events.

Emergency Spillway Quantities
Spillway Embankment Rock (D50 ~ 3ft)
Length = 170ft
Width = 48ft
Depth = 4.5ft
Total = 1,360CY

Spillway Crest Rock (D50 ~ 2ft)
Length = 170ft

Width = 15ft
Depth = 4.ft
Total = 331CY

Levee Embankment Bedding Materials (4” minus)
Length = 170ft
Width = 97ft
Depth = 9in
Total = 386CY

Geotextile Fabric – Mirafi 180N equivalent or better
Length = 170ft
Width = 92ft
Total = 1,738SY

Emergency Spillway Design Plans
Pertinent design plans and details containing the emergency spillway structure are located in Attachment B.

References

Federal Highways Administration (FHWA, 1995). HEC-15 Design of Roadside Channels with Flexible Linings

Federal Highways Administration (FHWA, 1995b). HEC-11 Riprap Design

Frizell, K.H. (CSU, 1998). Simplified Design Guidelines for Riprap Subjected to Overtopping Flow.

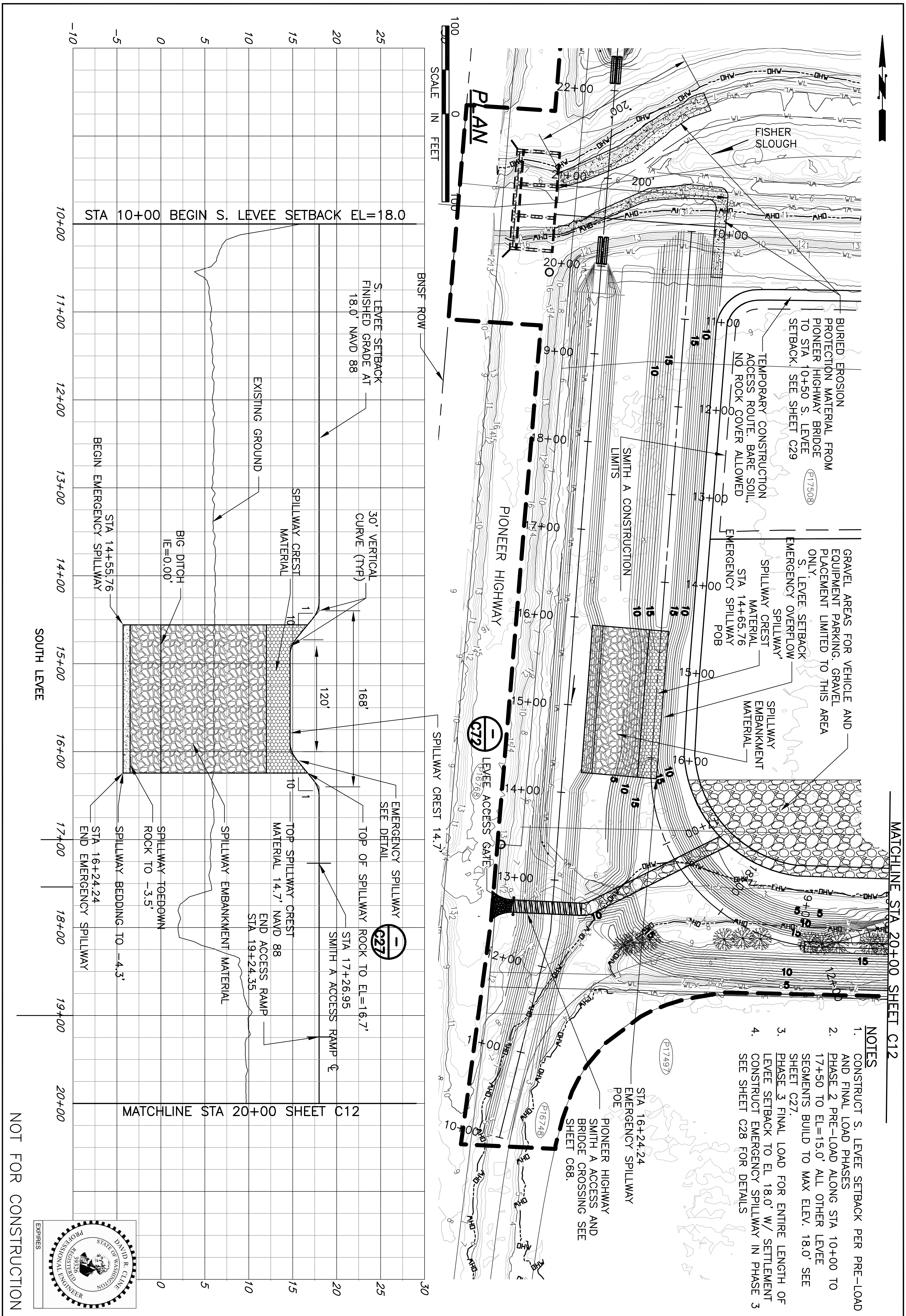
Ferro, V. (Ferro, 1999). Design Relationships for Rock Chute Channels. Transactions of the ASAE. 43(3) pp. 585-590. Nov

Roberson, J.A., et al. 1995. Hydraulic Engineering.

U.S. Bureau of Reclamation (USBR, 2007). Rock Ramp Design Guidelines.

U.S. Army Corps of Engineers (Corps, 1994). EM-1110-2-1601 Hydraulic Design of Flood Control Channels.

Attachment A – Emergency Spillway Design Plans



THE NATURE CONSERVANCY

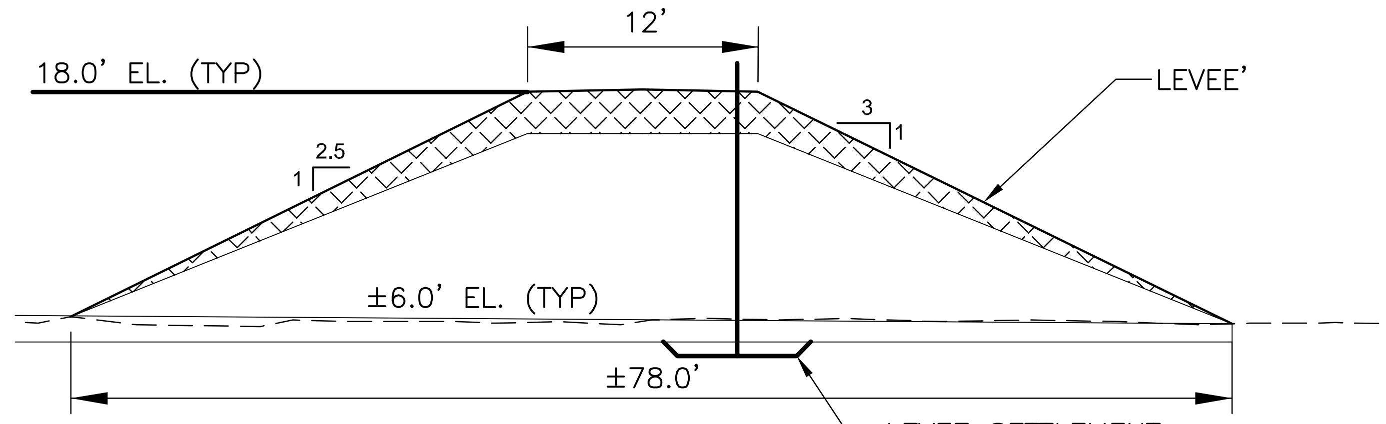
FISHER SLOUGH RESTORATION PROJECT

LEVEE SETBACK PLAN & PROFILE
SKAGIT COUNTY, WASHINGTON

TETRA TECH
1420 Fifth Avenue, Suite 550
Seattle, Washington 98101
206-728-9655 Fax: 206-728-9670

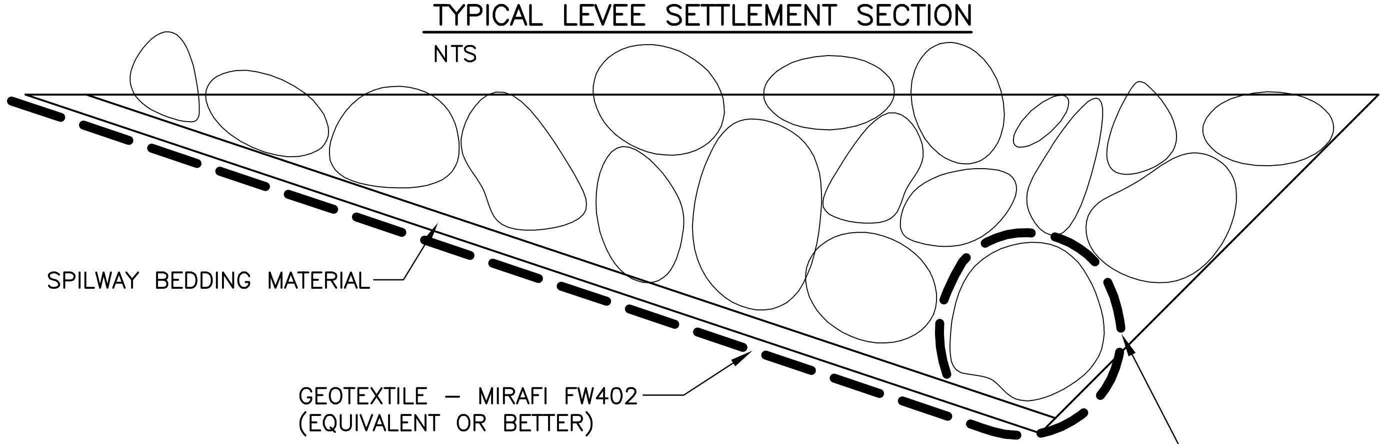
		Date
Designed	D CLINE	DEC 18 2009
Drawn	J OLMSTED	DEC 18 2009
Checked	Y CHEN	DEC 18 2009
Approved		
Title		

File Name
Drawing No. C11



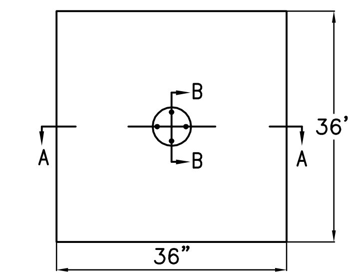
TYPICAL LEVEE SETTLEMENT SECTION

NTS



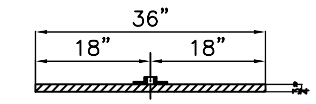
SPILLWAY TOE PROTECTION ROCK KEY–IN DETAIL

NTS



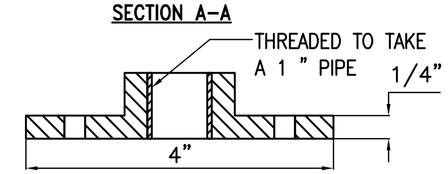
SETTLEMENT PLATE

PLAN VIEW

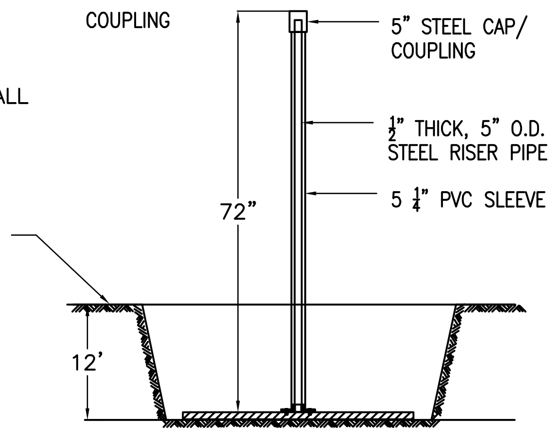


FLOOR FLANGE SHALL BE BOLTED TO THE PLATE WITH A MINIMUM OF FOUR

SECTION A–A

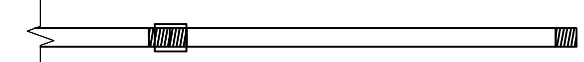


SECTION B–B



SETTLEMENT PLATE INSTALLATION

RISER PIPE & COUPLING

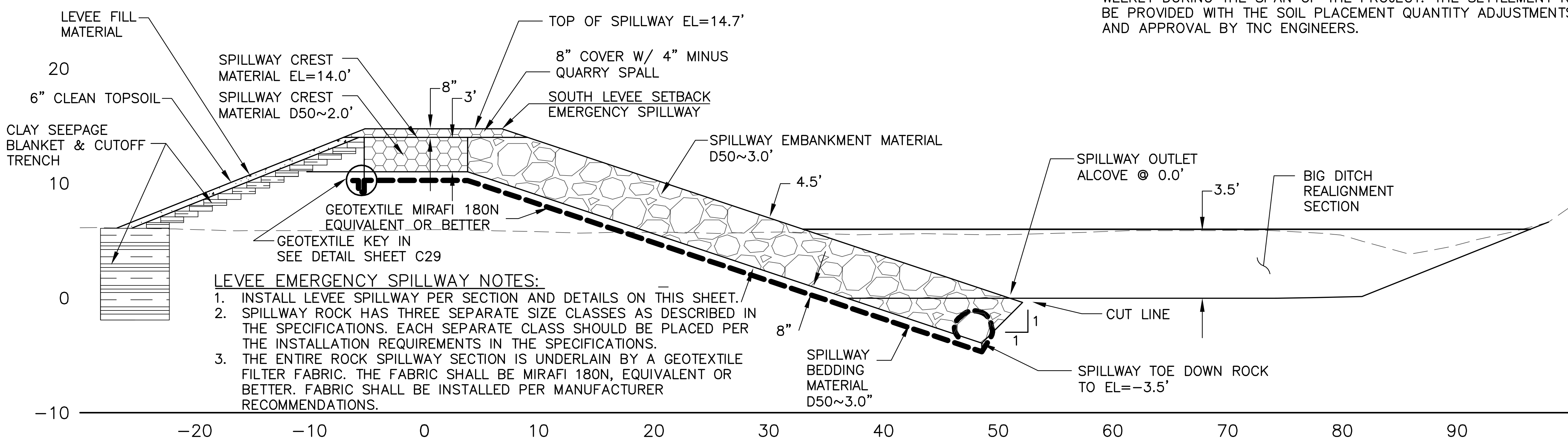


IN SEATING THE PLATE, THE 12" TRENCH SHALL BE BACKFILLED WITH GRANULAR BORROW AND COMPACTED WITH ORDINARY COMPACTION

(OPTION OF SUPPLIER)
WEIGHT BLACK STEEL PIPE (ASTM A120)
RISER PIPE SHALL BE A 1" STANDARD

LEVEE SETTLEMENT NOTES:

1. LEVEE SETTLEMENT PLATES SHOULD BE INSTALLED (1) EVERY 1,000FT OF LEVEE TOTAL LENGTH. THE SETTLEMENT PLATES WILL BE USED TO MEASURE AND ESTIMATE SETTLEMENT AND MODIFIED QUANTITIES OF PLACED AND COMPACTED SOILS DURING CONSTRUCTION. SETTLEMENT PLATE INSTALLATION, RATE ESTIMATES AND QUANTITIES ADJUSTMENTS WILL BE PER THE SPECIFICATIONS. SETTLEMENT PIPE ELEVATIONS WILL BE MEASURED ONCE, WEEKLY DURING THE SPAN OF THE PROJECT. THE SETTLEMENT REPORTS WILL BE PROVIDED WITH THE SOIL PLACEMENT QUANTITY ADJUSTMENTS FOR REVIEW AND APPROVAL BY TNC ENGINEERS.



LEVEE EMERGENCY SPILLWAY NOTES:

1. INSTALL LEVEE SPILLWAY PER SECTION AND DETAILS ON THIS SHEET.
2. SPILLWAY ROCK HAS THREE SEPARATE SIZE CLASSES AS DESCRIBED IN THE SPECIFICATIONS. EACH SEPARATE CLASS SHOULD BE PLACED PER THE INSTALLATION REQUIREMENTS IN THE SPECIFICATIONS.
3. THE ENTIRE ROCK SPILLWAY SECTION IS UNDERLAIN BY A GEOTEXTILE FILTER FABRIC. THE FABRIC SHALL BE MIRAFI 180N, EQUIVALENT OR BETTER. FABRIC SHALL BE INSTALLED PER MANUFACTURER RECOMMENDATIONS.

SPILLWAY SECTION

NTS

DAVID R. CLINE STATE OF WASHINGTON 39326 REGISTERED PROFESSIONAL ENGINEER

EXPIRES

NOT FOR CONSTRUCTION

Designed D CLINE	DEC 18 2009
Drawn J OLMSTED	DEC 18 2009
Checked Y CHEN	DEC 18 2009
Approved	
Title	

THE NATURE CONSERVANCY

FISHER SLOUGH RESTORATION PROJECT

SPILLWAY AND SETTLEMENT SECTIONS
SKAGIT COUNTY, WASHINGTON

TETRA TECH
1420 Fifth Avenue, Suite 550
Seattle, Washington 98101
206-728-9655 Fax: 206-728-9670

File Name

Drawing No. C28