Sediment Transport & Scour Analysis
BULLARD WASH OUTFALL CHANNEL IMPROVEMENTS
FCD #95-39

WOOD/PATEL

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1.0 INTRODUCTION

Sediment transport analyses examine the potential for sediment deposition impacts to the design water surface profile and potential undercutting of the natural bank or bank-lining by scour processes. The design of an erosion resistant bank protection system must consider the potential for scour of the channel bed, if the bed is to be left as natural earth. Failure to do so could lead to the toe of the bank protection material being undercut by scour processes that will be induced by flowing water. Should this situation occur, the bank lining material may collapse into the scour hole, thus exposing the bank to erosive velocities and possible lateral movement.

Vertical changes of the channel bed can occur in response to the following six processes:

1. <u>Long-Term Aggradation/Degradation</u>: Aggradation and degradation are defined as the vertical raising and lowering, respectively, of the channel bed over relatively long distances and time periods. Such changes, which are sometimes referred to as gradation changes, can be the result of both natural and man-induced changes in the watershed.

   Long-term gradation change occurs over a long period of time in response to an imbalance between the sediment transport capacity of the channel and the dominant sediment supply to the channel. When such imbalances occur, the channel will naturally adjust its slope to restore equilibrium between the transport capacity and incoming supply of sediment. The sediment continuity concept is the primary principle applied in both qualitative and quantitative analysis of gradation changes. If the transport capacity of the channel exceeds the sediment supply, the channel will flatten its slope (degrade). However, should the sediment supply exceed the transport capacity of the channel, the channel slope will increase (aggrade) in order to generate higher velocities that are capable of moving the sediment inflows.

2. <u>Local Scour:</u> Local scour will occur in response to objects being placed in the path of flowing water. The most common form of local scour is that occurring at bridge

piers and protruding bridge abutments or spur dikes. The procedures and methodology outlined in HEC-18 should be used for local scour analysis.

3. General Scour: General scour process occurs in response to changes in channel geometry from one reach of a channel to the next. As the channel cross-section contracts or expands, its flow velocity (and thus sediment transport capacity) will change. General scour, and/or sediment deposition, is usually quantified with a mobile-boundary sediment routing model such as HEC-6. Such models are capable of predicting scour and deposition patterns as a function of bed-material size, channel geometry, and changes in discharge that occur during passage of a specific flood hydrograph.

4. Bend Scour: The bends associated with meandering channels will induce transverse or "secondary" currents which will scour sediment from the outside of a bend and cause it to be deposited along the inside of the bend. The magnitude of bend scour can be estimated by Zeller's equation (1981), which is based on the assumption of constant stream power through the channel bend.

5. Low Flow Incisement: When large width-depth ratio exists in a channel, it is vulnerable to the formation of low-flow channels. For example, when trapezoidal channels, designed to carry large storm events such as the 100-year flood, are exposed to smaller, more frequent flows (2- to 5-year floods), the wide channel bottom widths may cause a shallow sheetflow condition. Rather than transporting these smaller flows in this manner, the channel will incise a low-flow channel that provides a more hydraulically efficient conveyance for these small discharges. There are no rigorous methodologies available for the prediction of low-flow channel incisement. A field inspection of the study area and engineering judgment are probably the best methods to determine the potential for low flow channel incisement.

6. Bed-Form Troughs: Sand and gravel-bed channels are prone to the development of transitory bedforms, such as dunes and antidunes. Such bedforms create troughs, or depressions, below the natural bed of the channel during a flow event. In order to account for the possibility of these troughs forming adjacent to the toe of the bank, it is prudent to include bedform troughs in the estimate of total scour.

2.0 PURPOSE OF STUDY

This study is a supplement to the Bullard Wash Outfall Channel Improvements, in which a revised channelization concept was agreed upon by Sverdrup, together with the Flood Control District, the City of Goodyear, and MCDOT. The concept addressed the City's requirements on the aesthetics, recreational, and equestrian needs, as well as maintenance issues. As a result, a workable channel cross-section, style of bank protection, and drop structure scheme have been mutually agreed upon for the channelization project.

The purpose of this study is limited to the estimation of the required toe down depths for the bank protection of the two channlized segments in the Bullard Wash. Specifically, the downstream reach is from the upstream face of the BID culvert to the downstream face of the MC85 Bridge (Sta. 29+00 to 73+00), and the middle reach is from Grade Break Top to the Bottom of Drop (Sta. 81+02 to 121+64).

Because the channel segments for the bridge, culverts, and transition areas will be protected using concrete lining, no bridge local scour estimation is necessary for this study. Also the two subject channel segments are quite uniform, so it is assumed that no general scour will occur. However, there is a significant bend near the downstream side of the Lower Buckeye Road.

Therefore, long-term aggradation/degradation, bend scour at the upstream of the middle reach, sill scour near the upstream area of each reach, bed-form troughs, and low flow incisement were analyzed in this study. The following sections present a technical discussion of the engineering assumptions and methodologies used for the estimations of the above mentioned scour components.

3.0 METHODOLOGIES

3.1 Hydrology

The recommended 100-year 24-hour peak flow for the Bullard Wash Outfall Channel Improvements is 3,200 cfs. The estimated 50-year, 25-year, and 10-year flows are 2,680 cfs, 2,020 cfs, and 1,370 cfs respectively. These flows were utilized for evaluating the scour potential in the channel.

3.2 Hydraulics

The hydraulics of the channel were modeled with the Army Corps of Engineers HEC-RAS Hydraulic Modeling Software. The profile summary tables for all return periods and the graphical profiles and cross sections for the 100-year flow are shown in Appendix B.

3.3 Soils

ATL, INC. investigated the soils in the wash in November of 1997. The soil in the upstream was classified as silty clay with sand, and in the downstream reach the soil was classified as a sandy-silty material. D_{16}, D_{50}, and D_{84} values were estimated from the soil sieve analysis curves provided for each of the channel reaches.

3.4 Sediment Transport Capacity Estimation

The Empirical Power Relationship (Zeller and Fullerton, 1983) was used to estimate to sediment transport capacity for each reach of the channel. The supporting calculations are included in Appendix A.

The representative cross sections chosen for the analysis are Sta. 131+20 for the upstream reach, Sta. 108+19 for the middle reach (Sta. 80+00 to 120+00), and Sta. 63+22 for the downstream reach (Sta. 30+00 to 80+00).

3.5 Watershed Load Estimation

In order to estimate the long-term aggradation/degradation trend of the channel, the watershed sediment load into the subject channel should be estimated first. The upstream reach consists of a small tailwater conveyance ditch representing the Bullard Wash thalweg. Based on the existing floodplain delineation, the floodplain will spread out over a broad area covered by agricultural fields. The velocities through this reach are very slow generally in a range of 1 to 4 fps. There is no physical evidence of any wash instability. For these reasons, it is assumed that the upstream natural wash is in equilibrium and the sediment transport capacity of the wash is equivalent to the watershed sediment supply. Cross section in at Sta. 131+20 represents the upstream natural wash conditions. As a part of the channelization design, a shallow concrete lined ditch is being incorporated into the middle reach channel bottom (Sta. 119+43 to Sta. 81+02). The purpose of the ditch is to convey irrigation tailwater flows (approximately 7 cfs) and its sediment load through this reach to an irrigation outlet structure located at the top of the Grade Break Drop. The ditch will keep tailwater flows to the east side of the channel so that the flows will not block maintenance access to the channel and to reduce contact with occasional recreational users of the channel.

Since the existing wash has a very limited drainage conveyance capacity, ponding occurs at the railroad and highway MC85 bridge structures. The limited conveyance including very poor outfall conditions at the existing bridge locations has resulted in localized sedimentation. With the proposed channel improvements, the drainage conveyance will be enhanced significantly and thereby eliminating the sedimentation concerns.

3.6 Long-Term Aggradation/Degradation - Equilibrium Slope Analysis

Equilibrium slope analysis was utilized to estimate the long-term gradation changes in the Bullard Wash channel. The equilibrium channel slope is defined as the slope at which the channel's sediment transporting capacity is equal to the incoming sediment supply. Under this condition, the channel neither aggrades nor degrades. When the present slope of the channel is greater than the equilibrium slope, the channel will degrade in order to reach its equilibrium slope.

The calculation of the equilibrium slope, which the channel will conform to, is accomplished by using the definition of a channel in equilibrium. That is, $Q_{s\ in} = Q_{s\ out}$, where $Q_{s\ in}$ represents the supply rate of sediment into the channel and $Q_{s\ out}$ represents the sediment transport rate out of the channel.

The procedure begins with a determination of the sediment transport rate into the channel. The upstream sediment supply was assumed to be the watershed sediment load and to be in equilibrium. The hydraulics of the current (designed) channel condition was modeled with the HEC-RAS program. Since a uniform flow condition was assumed to exist in each of the three channel reaches, Manning's equation was used (in an iterative process) to calculate the final equilibrium slope. The individual slopes of the study reaches were varied until the resulting sediment transport capacity equaled the incoming sediment supply for that reach. Once a slope was found at which the incoming sediment supply equaled the sediment load in the channel reach, this slope was assumed to be the equilibrium slope for that reach and the analysis of the next reach was initiated. This procedure was repeated until all reaches had been analyzed. A spreadsheet was developed to perform these calculations and the output is included in Appendix A. The 10-year flow was assumed to be the dominant flow condition.

3.7 Bend Scour Estimation

Zeller's equation (1981) was used to estimate the bend scour magnitude. The input data and calculations were shown in a spreadsheet output and included in Appendix A. The 100-year flow was used in the bend scour calculation. The bend scour was calculated for east bank from station 117+00 to 119+53.

3.8 Sill Scour Estimation

The equation developed by Veronese (1937) was used to estimate the sill scour depth in this study. The input data and calculations were given in a spreadsheet output and included in Appendix A. The 100-year flow was used in the sill scour computation.

3.9 Bed-Form Troughs Estimation

The relationship developed by Kennedy (1963) was used to estimate the depth of antidune troughs (below the existing channel bed) and the equation developed by Simons and Senturk (1977) was applied to compute the dune heights. Whichever is greater was used as the bed-form trough depth. The input data and calculation were shown in Appendix A - Bed-form trough estimation spreadsheet. The 100-year flow was used in the bed-form trough estimation.

4.0 RESULTS AND CONCLUSIONS

The equilibrium slope analysis results were shown in Table 1. For the middle reach of the channel, the equilibrium slope is 0.00091 ft/ft and the change from the present slope (0.001207 ft/ft) is 0.000297 ft/ft. For the downstream reach of the channel, the equilibrium slope is 0.00088 ft/ft and the change from the present slope (0.001365 ft/ft) is 0.000485 ft/ft.

The low flow incisement is assumed to be 15% of the 100-year flow depth which is about 1.0 ft for both middle and downstream reaches.

Based on the sediment transport and scour analysis the following conclusions are made:

4.1 Local Scour

Sill scour is anticipated at the downstream side of the lined grade control structures. This type of scour will be limited to a very localized area and can be significantly reduced or eliminated by providing a gabion mattress. Bend scour also occurs in a local area near the channel bend.

The total depth of local scour at the upper end of Middle Reach at Sta. 119+53 = 2.8 ft. (bend scour) +3.4 ft. (sill scour) = 6.2 ft;

The total depth of local scour at the upper end of Downstream Reach at Sta. 73+00 = 5.5 ft. (sill scour), bend scour not applicable at this location.

4.2 Toe Down Depths

Toe down depth = {long-term degradation + bedform troughs + low flow incisement + local scour (if applicable)} x safety factor

Middle Reach Corridor

Toe down depth = (1.21 + 0.38 + 1.0 + 0.0) x 1.3 = 3.4 ft.

Downstream Reach Corridor

Toe down depth = (2.12 + 0.54 + 1.0 + 0.0) x 1.3 = 4.8 ft.

Middle Reach at Sta. 119 + 53 (localized condition)

Toe down depth = (1.21 + 0.38 + 1.0 + 6.2) x 1.3 = 11.4 ft.

Downstream Reach at Sta. 73 + 00 (localized condition)

Toe down depth = (2.12 + 0.54 + 1.0 + 5.5) x 1.3 = 11.9 ft.

4.0 RESULTS AND CONCLUSIONS

The equilibrium slope analysis results were shown in Table 1. For the middle reach of the channel, the equilibrium slope is 0.00091 ft/ft and the change from the present slope (0.001207 ft/ft) is 0.000297 ft/ft. For the downstream reach of the channel, the equilibrium slope is 0.00088 ft/ft and the change from the present slope (0.001365 ft/ft) is 0.000485 ft/ft.

The low flow incisement is assumed to be 15% of the 100-year flow depth which is about 1.0 ft for both middle and downstream reaches.

Based on the sediment transport and scour analysis the following conclusions are made:

4.1 Toe Down Depths

Toe down depth = (long-term degradation + bedform troughs + low flow incisement) x safety factor

Middle Reach toe down depth = (1.21 + 0.38 + 1.0) x 1.5 = 4.0 ft

Downstream Reach toe down depth = (2.12 + 0.54 + 1.0) x 1.5 = 5.5 ft

4.2 Local Scour

Sill scour is anticipated at the downstream side of the lined grade control structures. This type of scour will be limited to a very localized area and can be significantly reduced or eliminated by providing a gabion mattress. Bend scour also occurs in a local area near the channel bend. Therefore, sill scour and bend scour were added to the toe down depth at following locations.

Local scour is calculated as a sill scour and the total local scour depth is obtained by adding the sill scour to the toe down depth:

Total depth of local scour at the upper end of Middle Reach at 119+53 = 3.4 (toe down depth) +28 (bend scour) +3.4 (sill scour) = 9.6 ft;

DROP @

Total depth of local scour at the upper end of Downstream Reach at Sta. 73+00 = 4.8 (toe down depth) + 5.5 (sill scour) =n 10.3 ft (Bend scour not applicable at this location).

Table 1

Equilibrium Slope Analysis Results

Return	Sediment Transport Capacity			Capcity Excess		Reach Length		Reach Slope		Equilibrium Slope		Slope Change		Long-Term Scour Depth	
Period (Year)	Upstream (cfs)	Middle (cfs)	Downstream (cfs)	Middle (cfs)	Downstream (cfs)	Middle (ft)	Downstream (ft)	Middle (ft/ft)	Downstream (ft/ft)	Middle (ft/ft)	Downstream (ft/ft)	Middle (ft/ft)	Downstream (ft/ft)	Middle (ft)	Downstream (ft)
10	2.56	3.83	5.20	1.27	1.37	4062	4380	0.001207	0.001365	0.00091	0.00088	0.000297	0.000485	1.21	2.12

APPENDIX A

Sediment Transport Capacity Estimation
and
Scour Estimation

Sediment Transport Capacity Computation Sheet for Upstream Reach (Sta. 131+20)

Sediment Transport Capacity Computation Sheet for Middle Reach (Sta. 108+19)

Sediment Transport Capacity Computation Sheet for Downstream Reach (Sta. 63+22)

Equilibrium Slope Computation Sheet for Upstream Reach (Sta. 131+20)

Equilibrium Slope Computation Sheet for Upstream Reach (Sta. 108+19)

Equilibrium Slope Computation Sheet for Upstream Reach (Sta. 63+22)

Bed-Form Trough Computation Sheet for Middle Reach (Sta. 108+19)

Bed-Form Trough Computation Sheet for Middle Reach (Sta. 108+19)

Bend Scour Computation Sheet for the Middle Reach

Sill Scour Computation Sheet for Both Middle and Downstream Reaches

Sediment Transport Computation Sheet

Reference: ADWR, Design Manual for Engineering Analysis of Fluvial Systems, 1985.

Calculation: Total Bed-Material Discharge. **Application:** Sand-Bed Channels.

Project Name: Bullard Wash **Section Name:** Sta 131+20

Sediment Transport Equation

Zeller and Fullerton (1983) developed the following equation based on the Empirical Power Relationship $qs = aY_h^b V^c$ by Simons, Li, and Fullerton (1981):

$$qs = \frac{0.0064\, n^{1.77} V^{4.32} G^{0.45}}{Y_h^{0.30} D_{50}^{0.61}}$$

Where:		Range:
	q_s = bed-material discharge in cfs per unit width;	
	n = Manning's roughness coefficient;	(0.018-0.035)
	V = mean velocity (ft/s);	(3 - 30)
	G = gradation coefficient = $0.5(D_{84}/D_{50}+D_{50}/D_{16})$;	(2 - 5)
	Y_h = hydraulic depth (ft);	(1 - 20)
	D_{50} = median diameter (mm).	

Input Data - 10-year Flow

Q =	1370	(cfs)	D_{50} =	0.03	(mm)
n =	0.03		D_{84} =	0.11	(mm)
Y_h =	1.04	(ft)	D_{16} =	0.01	(mm)
V =	2.03	(ft/s)	G =	3.33	
b =	646.36	(ft)	r_s =	165.4	(lb/ft^3)

Computed Sediment Discharge

q_s =	**0.00396**	**(cfs/ft)**
Q_s =	**2.56**	**(cfs)**
c =	**4934**	**(ppm by weight)**

Sediment Transport Computation Sheet

Reference: ADWR, Design Manual for Engineering Analysis of Fluvial Systems, 1985.

Calculation: Total Bed-Material Discharge. **Application:** Sand-Bed Channels.

Project Name: Bullard Wash **Section Name:** Sta 108+19

Sediment Transport Equation

Zeller and Fullerton (1983) developed the following equation based on the Empirical Power Relationship $qs = aY_h^b V^c$ by Simons, Li, and Fullerton (1981):

$$qs = \frac{0.0064\, n^{1.77} V^{4.32} G^{0.45}}{Y_h^{0.30} D_{50}^{0.61}}$$

		Range:
Where:	q_s = bed-material discharge in cfs per unit width;	
	n = Manning's roughness coefficient;	(0.018-0.035)
	V = mean velocity (ft/s);	(3 - 30)
	G = gradation coefficient = $0.5(D_{84}/D_{50}+D_{50}/D_{16})$;	(2 - 5)
	Y_h = hydraulic depth (ft);	(1 - 20)
	D_{50} = median diameter (mm).	

Input Data - 10-year Flow

Q =	1370	(cfs)	D_{50} =	0.06	(mm)
n =	0.0287		D_{84} =	0.31	(mm)
Y_h =	3.42	(ft)	D_{16} =	0.015	(mm)
V =	4.06	(ft/s)	G =	4.58	
b =	98.80	(ft)	r_s =	165.4	(lb/ft^3)

Computed Sediment Discharge

q_s =	**0.03874**	**(cfs/ft)**
Q_s =	**3.83**	**(cfs)**
c =	**7350**	**(ppm by weight)**

Sediment Transport Computation Sheet

Reference: ADWR, Design Manual for Engineering Analysis of Fluvial Systems, 1985.

Calculation: Total Bed-Material Discharge. **Application:** Sand-Bed Channels.

Project Name: Bullard Wash **Section Name:** Sta 63+22

Sediment Transport Equation

Zeller and Fullerton (1983) developed the following equation based on the Empirical Power Relationship $qs = aY_h^b V^c$ by Simons, Li, and Fullerton (1981):

$$qs = \frac{0.0064\, n^{1.77} V^{4.32} G^{0.45}}{Y_h^{0.30} D_{50}^{0.61}}$$

Where:		Range:
	q_s = bed-material discharge in cfs per unit width;	
	n = Manning's roughness coefficient;	(0.018-0.035)
	V = mean velocity (ft/s);	(3 - 30)
	G = gradation coefficient = $0.5(D_{84}/D_{50}+D_{50}/D_{16})$;	(2 - 5)
	Y_h = hydraulic depth (ft);	(1 - 20)
	D_{50} = median diameter (mm).	

Input Data - 10-year Flow

Q =	1370	(cfs)	D_{50} =	0.06	(mm)
n =	0.0276		D_{84} =	0.3	(mm)
Y_h =	3.44	(ft)	D_{16} =	0.015	(mm)
V =	4.57	(ft/s)	G =	4.50	
b =	87.17	(ft)	r_s =	165.4	(lb/ft^3)

Computed Sediment Discharge

q_s =	**0.05967**	**(cfs/ft)**
Q_s =	**5.20**	**(cfs)**
c =	**9963**	**(ppm by weight)**

Equilibrium Slope Computation Sheet

Reference: ADWR, Design Manual for Engineering Analysis of Fluvial Systems, 1985.

Calculation: Total Bed-Material Discharge. **Application:** Sand-Bed Channels.

Project Name: Bullard Wash **Section Name:** Sta 131+20

Sediment Transport Equation

Zeller and Fullerton (1983) developed the following equation based on the Empirical Power Relationship $qs = aY_h^b V^c$ by Simons, Li, and Fullerton (1981):

$$qs = \frac{0.0064\, n^{1.77} V^{4.32} G^{0.45}}{Y_h^{0.30} D_{50}^{0.61}}$$

		Range:
Where:	q_s = bed-material discharge in cfs per unit width;	
	n = Manning's roughness coefficient;	(0.018-0.035)
	V = mean velocity (ft/s);	(3 - 30)
	G = gradation coefficient = $0.5(D_{84}/D_{50}+D_{50}/D_{16})$;	(2 - 5)
	Y_h = hydraulic depth (ft);	(1 - 20)
	D_{50} = median diameter (mm).	

Input Data - 10-year Flow

Q =	1370	(cfs)	D_{50} =	0.03	(mm)
n =	0.03		D_{84} =	0.11	(mm)
Y_h =	1.04	(ft)	D_{16} =	0.01	(mm)
V =	2.03	(ft/s)	G =	3.33	
b =	646.36	(ft)	r_s =	165.4	(lb/ft^3)

Computed Sediment Discharge

q_s =	**0.00396**	**(cfs/ft)**
Q_s =	**2.56**	**(cfs)**
c =	**4934**	**(ppm by weight)**

Equilibrium Slope Computation Sheet

Reference: ADWR, Design Manual for Engineering Analysis of Fluvial Systems, 1985.

Calculation: Total Bed-Material Discharge.

Application: Sand-Bed Channels.

Project Name: Bullard Wash

Section Name: Sta 108+19

Sediment Transport Equation

Zeller and Fullerton (1983) developed the following equation based on the Empirical Power Relationship $qs = aY_h^b V^c$ by Simons, Li, and Fullerton (1981):

$$qs = \frac{0.0064\, n^{1.77} V^{4.32} G^{0.45}}{Y_h^{0.30} D_{50}^{0.61}}$$

Where:		Range:
	q_s = bed-material discharge in cfs per unit width;	
	n = Manning's roughness coefficient;	(0.018-0.035)
	V = mean velocity (ft/s);	(3 - 30)
	G = gradation coefficient = $0.5(D_{84}/D_{50}+D_{50}/D_{16})$;	(2 - 5)
	Y_h = hydraulic depth (ft);	(1 - 20)
	D_{50} = median diameter (mm).	

Input Data - 10-year Flow

Q =	1370	(cfs)	D_{50} =	0.06	(mm)
n =	0.0287		D_{84} =	0.31	(mm)
Y_h =	3.69	(ft)	D_{16} =	0.015	(mm)
V =	3.69	(ft/s)	G =	4.58	
b =	100.55	(ft)	r_s =	165.4	(lb/ft^3)

Computed Sediment Discharge

q_s =	**0.02510**	**(cfs/ft)**
Q_s =	**2.52**	**(cfs)**
c =	**4859**	**(ppm by weight)**

Equilibrium Slope Computation Sheet

Reference: ADWR, Design Manual for Engineering Analysis of Fluvial Systems, 1985.

Calculation: Total Bed-Material Discharge.

Application: Sand-Bed Channels.

Project Name: Bullard Wash

Section Name: Sta 63+22

Sediment Transport Equation

Zeller and Fullerton (1983) developed the following equation based on the Empirical Power Relationship $qs = aY_h^b V^c$ by Simons, Li, and Fullerton (1981):

$$qs = \frac{0.0064\, n^{1.77} V^{4.32} G^{0.45}}{Y_h^{0.30} D_{50}^{0.61}}$$

Where:		Range:
	q_s = bed-material discharge in cfs per unit width;	
	n = Manning's roughness coefficient;	(0.018-0.035)
	V = mean velocity (ft/s);	(3 - 30)
	G = gradation coefficient = $0.5(D_{84}/D_{50}+D_{50}/D_{16})$;	(2 - 5)
	Y_h = hydraulic depth (ft);	(1 - 20)
	D_{50} = median diameter (mm).	

Input Data - 10-year Flow

Q =	1370	(cfs)	D_{50} =	0.06	(mm)
n =	0.0276		D_{84} =	0.3	(mm)
Y_h =	3.97	(ft)	D_{16} =	0.015	(mm)
V =	3.91	(ft/s)	G =	4.50	
b =	88.34	(ft)	r_s =	165.4	(lb/ft^3)

Computed Sediment Discharge

q_s =	**0.02904**	**(cfs/ft)**
Q_s =	**2.57**	**(cfs)**
c =	**4939**	**(ppm by weight)**

Bed-Form Trough Computation Sheet

Reference: ADWR, Design Manual for Engineering Analysis of Fluvial Systems, 1985.

Project Name: Bullard Wash **Section Name:** Sta 108+19

Depth of Antidune Troughs

Kennedy (1963) developed the following equation based on laboratory flume studies to estimate the maximum depth of antidune troughs (below the existing channel bed)

$$Da = 0.0135v^2$$

Where: Da = depth of antidune trough (ft);
v = mean velocity of the channel (ft/s).

Depth of Dune Height

Simons and Senturk (1977) developed the following relationship to estimate the depth of dune height.

$$\log(Yh) = 0.8271\log(Hd) + 0.8901$$

Where: Hd = depth of dune height (m);
Yh = hydraulic depth (m).

Input Data - 100-year Flow

Q =	3200	(cfs)	v =	5.29	(ft/s)
Yh =	5.42	(ft)			

Computed Depths

Da =	0.38	(ft)
Dd=0.5Hd =	0.25	(ft)

Recomended Value = 0.38 (ft) (greater of Da and Dd)

Bed-Form Trough Computation Sheet

Reference: ADWR, Design Manual for Engineering Analysis of Fluvial Systems, 1985.

Project Name: Bullard Wash **Section Name:** Sta 63+22

Depth of Antidune Troughs

Kennedy (1963) developed the following equation based on laboratory flume studies to estimate the maximum depth of antidune troughs (below the existing channel bed)

$$Da = 0.0135v^2$$

Where: Da = depth of antidune trough (ft);
v = mean velocity of the channel (ft/s).

Depth of Dune Height

Simons and Senturk (1977) developed the following relationship to estimate the depth of dune height.

$$\log(Yh) = 0.8271\log(Hd) + 0.8901$$

Where: Hd = depth of dune height (m);
Yh = hydraulic depth (m).

Input Data - 100-year Flow

Q =	3200	(cfs)	v =	6.33	(ft/s)
Yh =	5.51	(ft)			

Computed Depths

Da =	0.54	(ft)
Dd=0.5Hd =	0.26	(ft)

Recomended Value = 0.54 (ft) (greater of Da and Dd)

Bend Scour Calculation Sheet

Reference: ADWR, Design Manual for Engineering Analysis of Fluvial Systems, 1985. p5.105-5.110

Scour Depth Equation:

$$Z_{bs} = \frac{0.0685 Y V^{0.8}}{Y_h^{0.4} S_e^{0.3}} \left[2.1 \left(\frac{\sin^2(\alpha/2)}{\cos(\alpha)} \right)^{0.2} - 1 \right]$$

Where Z_{bs} = bend scour component of total scour depth (ft)
V = mean velocity of upstream flow (fps)
Y = maximum depth of upstream flow (ft)
Y_h = hydraulic depth of upstream flow (ft)
S_e = upstream energy slope (bed slope for uniform flow conditions, ft/ft)
a = angle formed by the projection of the channel centerline from the point of curvature to a point which meets a line tangent to the outer bank of the channel (degrees)

Scour Length Equation

$$X = 2.3 \left(\frac{C}{\sqrt{g}} \right) Y$$

Where X = distance from the end of channel curvature (point of tangency, P.T.) to the downstream point at which secondary currents have dissipated (ft)
C = Chezy coefficient = 1.486*R^(1/6)/n
g = gravitational acceleration (32.2 ft/s²)
Y = depth of flow (to be conservative, use maximum depth of flow, exclusive of scour, within the bend) (ft)

Input Data

V =	5.52	(ft/s)	n =	0.0287	
Y =	6.26	(ft)	A =	579.4	(ft²)
Y_h =	5.51	(ft)	P =	108	(ft)
S_e =	0.00121		R =	5.36	(ft)
a =	40	(degree)	C =	68.51	
		Stable bank side slope =		2.5	(H:V)

Computed Scour Values

Scour Depth:		Scour Length:		Scour Width:	
Z_{bs} =	2.82 (ft)	X =	174 (ft)	W =	7.0 (ft)

Sill Scour Computation Sheet

100-year Scour Estimate Downstream of a Sill Structure #1

Methodology from "Computing Degradation and Local Scour" by E. Pemberton and J. Lara, 1984, Technical Guideline for Bureau of Reclamation, pages 40-45, equation type "D"

100-year Discharge =	3,200	cfs				
Total Flow Area =	604.43	ft^2	1.5	ft Long-Term Degradation		
Total Top Width =	111.43	ft	0.0	ft Depth to Top of Soil-Cement		
Mean Flow Depth =	5.42	ft	Existing Bed Elevation		933.46	ft
Discharge per foot =	28.72	cfs/ft	Top of Sill Elevation		933.46	ft

Veronese (1937)

$$d_s = KH_T^{0.225} q^{0.54} - d_m$$

ds = 3.4 ft

d_s =		depth of scour (ft)
K =	1.32	1.32 inch-pound units
H_T =	1.50	head from U/S to D/S
q =	28.72	discharge per unit width (cfs per ft)
d_m =	5.42	D/S mean water depth

100-year Scour Estimate Downstream of a Sill Structure #2

Methodology from "Computing Degradation and Local Scour" by E. Pemberton and J. Lara, 1984, Technical Guideline for Bureau of Reclamation, pages 40-45, equation type "D"

100-yr Discharge =	3,200	cfs				
Total Flow Area =	505.91	ft^2	2.5	ft Long-Term Degradation		
Total Top Width =	91.78	ft	0	ft Depth to Top of Sill Structure		
Mean Flow Depth =	5.51	ft	Existing Bed Elevation		911.36	ft
Discharge per foot =	34.87	cfs/ft	Top of Floor Elevation		911.36	ft

Veronese (1937)

$$d_s = KH_T^{0.225} q^{0.54} - d_m$$

ds = 5.5 ft

d_s =		depth of scour (ft)
K =	1.32	1.32 inch-pound units
H_T =	2.5	head from U/S to D/S
q =	34.87	discharge per unit width (cfs per ft)
d_m =	5.51	D/S mean water depth

APPENDIX B

HEC-RAS Modeling Results

100-Year Flow Profile Table

50-Year Flow Profile Table

25-Year Flow Profile Table

10-Year Flow Profile Table

100-Year Flow Profile Plot

Cross Sections Plots

HEC-RAS Plan: 100-Year River: Bullard Wash Out Reach: Bullard Wash

Reach	River Sta	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
		(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Bullard Wash	13700	3200.00	948.50	951.63	951.31	951.96	0.009524	8.39	908.61	666.71	0.97
Bullard Wash	13120	3200.00	947.30	949.90	949.10	950.08	0.002052	3.96	1247.61	822.83	0.46
Bullard Wash	12640	3200.00	945.20	947.67	947.67	948.23	0.008973	7.55	863.65	818.39	0.93
Bullard Wash	12420	3200.00	943.40	947.04	945.85	947.16	0.001090	2.71	1179.13	550.44	0.33
Bullard Wash	12172.42	3200.00	943.10	945.89	945.89	946.49	0.010322	7.82	666.37	544.91	0.83
Bullard Wash	12164.42	3200.00	935.10	936.97	938.92	945.57	0.191243	23.53	136.00	83.08	3.24
Bullard Wash	11963	3200.00	934.86	941.04	938.68	941.65	0.002742	6.23	513.50	92.05	0.46
Bullard Wash	11943	3200.00	934.84	941.10	938.39	941.57	0.001209	5.52	579.40	105.15	0.41
Bullard Wash	11882.84	3200.00	934.76	941.03	938.32	941.50	0.001205	5.52	579.38	104.95	0.41
Bullard Wash	11735.25	3200.00	934.58	940.85	938.13	941.32	0.001204	5.52	579.77	105.01	0.41
Bullard Wash	11550	3200.00	934.36	940.65	937.89	941.09	0.001183	5.32	601.64	111.31	0.40
Bullard Wash	11300	3200.00	934.04	940.36	937.57	940.79	0.001164	5.28	605.93	111.74	0.40
Bullard Wash	11200	3200.00	933.92	940.20	937.48	940.67	0.001195	5.50	581.63	105.18	0.41
Bullard Wash	11100	3200.00	933.80	940.08	937.35	940.55	0.001195	5.50	581.47	105.13	0.41
Bullard Wash	11000	3200.00	933.68	939.99	937.21	940.42	0.001173	5.30	603.73	111.46	0.40
Bullard Wash	10819.37	3200.00	933.46	939.77	936.99	940.21	0.001168	5.29	604.43	111.43	0.40
Bullard Wash	10300	3200.00	932.84	939.18	936.37	939.61	0.001155	5.27	607.63	111.82	0.40
Bullard Wash	10200	3200.00	932.72	939.02	936.27	939.49	0.001185	5.49	583.38	105.25	0.41
Bullard Wash	10100	3200.00	932.60	938.90	936.15	939.37	0.001184	5.49	583.34	105.20	0.41
Bullard Wash	10000	3200.00	932.48	938.81	936.01	939.24	0.001161	5.28	605.84	111.56	0.40
Bullard Wash	9080	3200.00	931.37	937.76	934.90	938.19	0.001122	5.22	613.26	111.86	0.39
Bullard Wash	8102	3200.00	930.20	933.73	933.73	935.35	0.014693	10.21	313.30	97.64	1.00
Bullard Wash	8080	3200.00	929.25	932.25	932.86	934.82	0.027321	12.87	248.58	85.94	1.33
Bullard Wash	7700	3200.00	912.91	914.74	916.68	923.28	0.029552	23.46	136.41	83.12	3.23
Bullard Wash	7553	3200.00	912.74	919.00	916.46	919.57	0.000389	6.04	529.61	92.45	0.44
Bullard Wash	7543	Bridge									
Bullard Wash	7533	3200.00	912.73	918.96	916.46	919.53	0.000396	6.08	526.50	92.37	0.45
Bullard Wash	7500	3200.00	912.69	918.94	916.46	919.51	0.000400	6.10	524.78	92.43	0.45
Bullard Wash	7460	3200.00	912.64	918.93	916.41	919.50	0.000392	6.06	528.21	92.44	0.45
Bullard Wash	7430	3200.00	912.60	918.92	916.36	919.48	0.000385	6.03	531.05	92.45	0.44
Bullard Wash	7357	Bridge									
Bullard Wash	7300	3200.00	912.43	918.64	916.21	919.23	0.000408	6.14	521.50	92.28	0.45
Bullard Wash	7270	3200.00	912.40	918.63	916.01	919.18	0.001258	5.96	537.02	92.46	0.44
Bullard Wash	6322	3200.00	911.36	917.25	914.97	917.87	0.001503	6.33	505.91	91.78	0.47
Bullard Wash	3350	3200.00	907.03	913.42	910.64	913.95	0.001157	5.79	552.57	92.83	0.42
Bullard Wash	3330	3200.00	907.00	913.31	910.83	913.92	0.000415	6.26	510.82	88.00	0.46

HEC-RAS Plan: 100-Year River: Bullard Wash Out Reach: Bullard Wash (Continued)

Reach	River Sta	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
		(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Bullard Wash	3300	3200.00	906.88	913.19	910.91	913.90	0.000489	6.76	473.40	82.00	0.50
Bullard Wash	3130	3200.00	906.20	913.16	910.22	913.73	0.001209	6.07	527.58	82.00	0.42
Bullard Wash	3049	3200.00	905.87	910.90	910.90	913.41	0.002438	12.71	251.69	50.17	1.00
Bullard Wash	3003	3200.00	905.69	910.40	910.71	913.26	0.002990	13.58	235.72	50.15	1.10
Bullard Wash	2980	3200.00	904.65	908.04	909.50	912.89	0.039284	17.66	181.16	56.74	1.74
Bullard Wash	2920	3200.00	901.95	905.25	906.79	910.36	0.042995	18.15	176.31	56.91	1.82
Bullard Wash	2900.42	3200.00	900.25	908.04	905.19	909.04	0.000606	8.03	398.66	51.20	0.51
Bullard Wash	2890.42	Culvert									
Bullard Wash	2880.42	3200.00	900.16	906.04	905.10	907.79	0.001432	10.64	300.88	51.20	0.77
Bullard Wash	2840	3200.00	900.10	906.62	903.71	907.11	0.001084	5.64	567.14	94.00	0.40
Bullard Wash	2520	3200.00	899.44	906.34	903.04	906.78	0.000899	5.31	602.87	94.00	0.37
Bullard Wash	2499.74	3200.00	899.40	906.38	902.92	906.74	0.000582	5.00	748.36	135.07	0.33
Bullard Wash	2400	3200.00	899.20	906.40	902.69	906.66	0.000503	4.32	926.98	196.33	0.29
Bullard Wash	1860	3200.00	898.12	906.15	901.62	906.37	0.000509	3.82	881.08	167.60	0.25
Bullard Wash	1800	3200.00	898.00	906.30	901.56	906.30	0.000021	0.97	8189.77	2346.00	0.06

HEC-RAS Plan: 50-Year River: Bullard Wash Out Reach: Bullard Wash

Reach	River Sta	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
		(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Bullard Wash	13700	2680.00	948.50	951.43	951.16	951.76	0.009965	8.10	784.11	626.27	0.98
Bullard Wash	13120	2680.00	947.30	949.71	948.96	949.87	0.002004	3.70	1096.27	780.07	0.44
Bullard Wash	12640	2680.00	945.20	947.51	947.51	948.04	0.009151	7.21	734.57	767.53	0.93
Bullard Wash	12420	2680.00	943.40	946.84	945.70	946.94	0.001058	2.51	1068.06	548.41	0.32
Bullard Wash	12172.42	2680.00	943.10	945.70	945.70	946.29	0.010513	7.53	567.62	498.64	0.82
Bullard Wash	12164.42	2680.00	935.10	936.71	938.52	945.25	0.236651	23.45	114.29	82.53	3.51
Bullard Wash	11963	2680.00	934.86	940.42	938.28	940.95	0.002783	5.88	456.14	90.74	0.46
Bullard Wash	11943	2680.00	934.84	940.46	938.01	940.88	0.001205	5.22	512.96	102.58	0.41
Bullard Wash	11882.84	2680.00	934.76	940.39	937.93	940.81	0.001200	5.22	513.11	102.40	0.41
Bullard Wash	11735.25	2680.00	934.58	940.21	937.75	940.63	0.001198	5.22	513.55	102.47	0.41
Bullard Wash	11550	2680.00	934.36	940.01	937.51	940.40	0.001182	5.04	531.22	108.11	0.40
Bullard Wash	11300	2680.00	934.04	939.72	937.20	940.11	0.001160	5.01	535.32	108.52	0.40
Bullard Wash	11200	2680.00	933.92	939.57	937.09	939.99	0.001184	5.19	515.89	102.65	0.41
Bullard Wash	11100	2680.00	933.80	939.45	936.97	939.87	0.001183	5.19	515.89	102.60	0.41
Bullard Wash	11000	2680.00	933.68	939.35	936.83	939.74	0.001165	5.02	534.01	108.30	0.40
Bullard Wash	10819.37	2680.00	933.46	939.14	936.61	939.53	0.001158	5.01	534.97	108.29	0.40
Bullard Wash	10300	2680.00	932.84	938.55	936.00	938.93	0.001140	4.97	538.72	108.68	0.39
Bullard Wash	10200	2680.00	932.72	938.41	935.89	938.82	0.001160	5.16	519.59	102.79	0.40
Bullard Wash	10100	2680.00	932.60	938.29	935.77	938.70	0.001157	5.16	519.86	102.76	0.40
Bullard Wash	10000	2680.00	932.48	938.19	935.63	938.58	0.001138	4.98	538.50	108.50	0.39
Bullard Wash	9080	2680.00	931.37	937.19	934.52	937.56	0.001072	4.87	549.85	109.00	0.38
Bullard Wash	8102	2680.00	930.20	933.35	933.35	934.81	0.015197	9.69	276.51	95.73	1.01
Bullard Wash	8080	2680.00	929.25	931.87	932.46	934.25	0.029984	12.39	216.29	85.19	1.37
Bullard Wash	7700	2680.00	912.91	914.55	916.28	922.18	0.030732	22.17	120.90	82.74	3.23
Bullard Wash	7553	2680.00	912.74	918.36	916.06	918.87	0.000393	5.69	471.00	91.14	0.44
Bullard Wash	7543	Bridge									
Bullard Wash	7533	2680.00	912.73	918.32	916.06	918.83	0.000401	5.72	468.17	91.07	0.44
Bullard Wash	7500	2680.00	912.69	918.30	916.06	918.81	0.000405	5.75	466.40	91.10	0.45
Bullard Wash	7460	2680.00	912.64	918.29	916.01	918.80	0.000396	5.70	469.79	91.12	0.44
Bullard Wash	7430	2680.00	912.60	918.28	915.97	918.78	0.000389	5.67	472.62	91.14	0.44
Bullard Wash	7357	Bridge									
Bullard Wash	7300	2680.00	912.43	918.01	915.79	918.53	0.000413	5.78	463.47	90.97	0.45
Bullard Wash	7270	2680.00	912.40	917.99	915.61	918.48	0.001242	5.60	478.83	91.19	0.43
Bullard Wash	6322	2680.00	911.36	916.63	914.57	917.18	0.001505	5.97	449.19	90.54	0.47
Bullard Wash	3350	2680.00	907.03	912.62	910.24	913.11	0.001246	5.60	478.49	91.21	0.43
Bullard Wash	3330	2680.00	907.00	912.51	910.42	913.08	0.000464	6.09	440.11	86.98	0.48

HEC-RAS Plan: 50-Year River: Bullard Wash Out Reach: Bullard Wash (Continued)

Reach	River Sta	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
		(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Bullard Wash	3300	2680.00	906.88	912.39	910.48	913.06	0.000544	6.57	407.98	80.76	0.52
Bullard Wash	3130	2680.00	906.20	912.35	909.79	912.88	0.001276	5.81	461.29	82.00	0.43
Bullard Wash	3049	2680.00	905.87	910.32	910.32	912.57	0.002497	12.02	222.94	50.15	1.00
Bullard Wash	3003	2680.00	905.69	909.89	910.15	912.41	0.002998	12.74	210.31	50.14	1.10
Bullard Wash	2980	2680.00	904.65	907.66	908.98	912.05	0.041272	16.82	159.30	55.97	1.76
Bullard Wash	2920	2680.00	901.95	904.89	906.27	909.46	0.044139	17.16	156.17	56.16	1.81
Bullard Wash	2900.42	2680.00	900.25	907.35	904.64	908.19	0.000562	7.37	363.53	51.20	0.49
Bullard Wash	2890.42	Culvert									
Bullard Wash	2880.42	2680.00	900.16	906.14	904.55	907.33	0.000951	8.75	306.21	51.20	0.63
Bullard Wash	2840	2680.00	900.10	906.52	903.31	906.88	0.000798	4.80	558.04	93.83	0.35
Bullard Wash	2520	2680.00	899.44	906.33	902.65	906.64	0.000634	4.45	601.60	94.00	0.31
Bullard Wash	2499.74	2680.00	899.40	906.36	902.55	906.61	0.000414	4.20	744.80	134.85	0.28
Bullard Wash	2400	2680.00	899.20	906.37	902.34	906.55	0.000359	3.64	920.70	195.67	0.24
Bullard Wash	1860	2680.00	898.12	906.20	901.24	906.35	0.000349	3.18	888.89	168.71	0.21
Bullard Wash	1800	2680.00	898.00	906.30	901.32	906.30	0.000014	0.81	8189.77	2346.00	0.05

HEC-RAS Plan: 25-Year River: Bullard Wash Out Reach: Bullard Wash

Reach	River Sta	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
		(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Bullard Wash	13700	2020.00	948.50	951.15	950.94	951.46	0.010930	7.71	616.07	567.13	1.01
Bullard Wash	13120	2020.00	947.30	949.44	948.77	949.57	0.001919	3.32	894.94	719.25	0.43
Bullard Wash	12640	2020.00	945.20	947.25	947.25	947.76	0.009857	6.78	547.24	687.04	0.94
Bullard Wash	12420	2020.00	943.40	946.54	945.48	946.62	0.001042	2.24	903.23	545.40	0.31
Bullard Wash	12172.42	2020.00	943.10	945.44	945.44	945.98	0.010443	6.98	444.40	434.04	0.81
Bullard Wash	12164.42	2020.00	935.10	936.37	937.97	944.92	0.340595	23.47	86.06	81.81	4.03
Bullard Wash	11963	2020.00	934.86	939.54	937.73	939.98	0.002877	5.36	377.04	88.91	0.46
Bullard Wash	11943	2020.00	934.84	939.56	937.48	939.92	0.001203	4.78	422.68	98.98	0.41
Bullard Wash	11882.84	2020.00	934.76	939.49	937.40	939.84	0.001196	4.78	423.02	98.84	0.41
Bullard Wash	11735.25	2020.00	934.58	939.31	937.22	939.67	0.001194	4.77	423.47	98.90	0.41
Bullard Wash	11550	2020.00	934.36	939.11	936.98	939.44	0.001184	4.63	435.97	103.64	0.40
Bullard Wash	11300	2020.00	934.04	938.82	936.66	939.15	0.001159	4.59	439.69	104.00	0.39
Bullard Wash	11200	2020.00	933.92	938.68	936.56	939.03	0.001172	4.74	426.25	99.08	0.40
Bullard Wash	11100	2020.00	933.80	938.56	936.44	938.91	0.001170	4.74	426.42	99.05	0.40
Bullard Wash	11000	2020.00	933.68	938.46	936.30	938.79	0.001158	4.60	439.45	103.85	0.39
Bullard Wash	10819.37	2020.00	933.46	938.25	936.08	938.58	0.001148	4.58	440.60	103.86	0.39
Bullard Wash	10300	2020.00	932.84	937.67	935.46	937.99	0.001120	4.54	444.92	104.26	0.39
Bullard Wash	10200	2020.00	932.72	937.54	935.36	937.88	0.001129	4.68	431.75	99.31	0.40
Bullard Wash	10100	2020.00	932.60	937.42	935.24	937.76	0.001124	4.67	432.39	99.29	0.39
Bullard Wash	10000	2020.00	932.48	937.33	935.10	937.64	0.001108	4.53	446.22	104.17	0.39
Bullard Wash	9080	2020.00	931.37	936.38	933.99	936.67	0.000997	4.36	462.82	104.94	0.37
Bullard Wash	8102	2020.00	930.20	932.82	932.82	934.05	0.015974	8.89	227.21	93.12	1.00
Bullard Wash	8080	2020.00	929.25	931.37	931.92	933.46	0.034289	11.59	174.22	84.21	1.42
Bullard Wash	7700	2020.00	912.91	914.30	915.73	920.55	0.031719	20.05	100.74	82.24	3.19
Bullard Wash	7553	2020.00	912.74	917.49	915.52	917.90	0.000397	5.15	392.33	89.35	0.43
Bullard Wash	7543	Bridge									
Bullard Wash	7533	2020.00	912.73	917.45	915.51	917.87	0.000405	5.18	389.79	89.28	0.44
Bullard Wash	7500	2020.00	912.69	917.43	915.51	917.85	0.000410	5.21	387.99	89.29	0.44
Bullard Wash	7460	2020.00	912.64	917.42	915.46	917.83	0.000399	5.16	391.34	89.31	0.43
Bullard Wash	7430	2020.00	912.60	917.41	915.42	917.82	0.000390	5.13	394.12	89.34	0.43
Bullard Wash	7357	Bridge									
Bullard Wash	7300	2020.00	912.43	917.15	915.25	917.57	0.000419	5.24	385.52	89.17	0.44
Bullard Wash	7270	2020.00	912.40	917.13	915.07	917.52	0.001208	5.04	400.61	89.46	0.42
Bullard Wash	6322	2020.00	911.36	915.81	914.03	916.26	0.001468	5.38	375.75	88.90	0.46
Bullard Wash	3350	2020.00	907.03	911.52	909.70	911.96	0.001422	5.32	379.78	89.02	0.45
Bullard Wash	3330	2020.00	907.00	911.41	909.86	911.94	0.000563	5.84	345.62	84.70	0.51

HEC-RAS Plan: 25-Year River: Bullard Wash Out Reach: Bullard Wash (Continued)

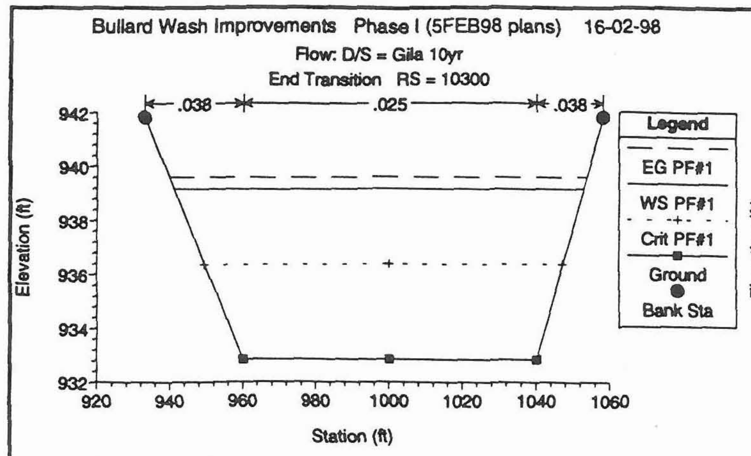
Reach	River Sta	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
		(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Bullard Wash	3300	2020.00	906.88	911.29	909.88	911.91	0.000657	6.30	320.68	78.55	0.55
Bullard Wash	3130	2020.00	906.20	911.24	909.20	911.70	0.001385	5.44	371.22	80.03	0.45
Bullard Wash	3049	2020.00	905.87	909.56	909.56	911.42	0.002565	10.94	184.70	50.12	1.00
Bullard Wash	3003	2020.00	905.69	909.14	909.38	911.26	0.003165	11.69	172.83	50.11	1.11
Bullard Wash	2980	2020.00	904.65	907.11	908.25	910.91	0.045547	15.64	129.15	54.89	1.80
Bullard Wash	2920	2020.00	901.95	904.41	905.55	908.19	0.045263	15.59	129.57	55.16	1.79
Bullard Wash	2900.42	2020.00	900.25	906.80	903.89	907.36	0.000409	6.02	335.27	51.20	0.41
Bullard Wash	2890.42	Culvert									
Bullard Wash	2880.42	2020.00	900.16	906.22	903.79	906.88	0.000519	6.51	310.28	51.20	0.47
Bullard Wash	2840	2020.00	900.10	906.42	902.76	906.63	0.000476	3.68	548.99	93.62	0.27
Bullard Wash	2520	2020.00	899.44	906.32	902.10	906.49	0.000363	3.36	600.40	94.00	0.23
Bullard Wash	2499.74	2020.00	899.40	906.33	902.02	906.48	0.000238	3.18	741.38	134.65	0.21
Bullard Wash	2400	2020.00	899.20	906.34	901.82	906.44	0.000207	2.75	914.71	195.04	0.18
Bullard Wash	1860	2020.00	898.12	906.24	900.72	906.33	0.000194	2.38	896.62	169.81	0.16
Bullard Wash	1800	2020.00	898.00	906.30	900.91	906.30	0.000008	0.61	8189.77	2346.00	0.04

HEC-RAS Plan: 10-Year River: Bullard Wash Out Reach: Bullard Wash

Reach	River Sta	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
		(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Bullard Wash	13700	1370.00	948.50	950.83	950.71	951.11	0.012291	7.19	445.00	499.79	1.03
Bullard Wash	13120	1370.00	947.30	949.12	948.54	949.22	0.001834	2.86	675.14	646.36	0.40
Bullard Wash	12640	1370.00	945.20	946.88	946.88	947.36	0.012162	6.43	356.84	412.55	1.00
Bullard Wash	12420	1370.00	943.40	946.18	945.21	946.24	0.001067	1.93	708.37	541.82	0.30
Bullard Wash	12172.42	1370.00	943.10	945.10	945.10	945.59	0.010513	6.31	312.15	351.73	0.79
Bullard Wash	12164.42	1370.00	935.10	936.03	937.37	944.55	0.559340	23.43	58.47	81.10	4.86
Bullard Wash	11963	1370.00	934.86	938.54	937.13	938.89	0.003060	4.73	289.51	86.83	0.46
Bullard Wash	11943	1370.00	934.84	938.55	936.89	938.83	0.001208	4.22	324.67	94.92	0.40
Bullard Wash	11882.84	1370.00	934.76	938.48	936.81	938.76	0.001200	4.21	325.15	94.81	0.40
Bullard Wash	11735.25	1370.00	934.58	938.30	936.63	938.58	0.001197	4.21	325.48	94.86	0.40
Bullard Wash	11550	1370.00	934.36	938.09	936.40	938.35	0.001195	4.11	333.04	98.57	0.39
Bullard Wash	11300	1370.00	934.04	937.80	936.08	938.06	0.001167	4.08	336.15	98.88	0.39
Bullard Wash	11200	1370.00	933.92	937.67	935.97	937.94	0.001171	4.18	328.04	95.03	0.40
Bullard Wash	11100	1370.00	933.80	937.55	935.85	937.82	0.001168	4.17	328.28	95.01	0.40
Bullard Wash	11000	1370.00	933.68	937.44	935.72	937.70	0.001161	4.07	336.46	98.78	0.39
Bullard Wash	10819.37	1370.00	933.46	937.24	935.50	937.49	0.001149	4.06	337.57	98.80	0.39
Bullard Wash	10300	1370.00	932.84	936.66	934.88	936.91	0.001111	4.01	341.80	99.16	0.38
Bullard Wash	10200	1370.00	932.72	936.53	934.77	936.79	0.001108	4.10	334.11	95.28	0.39
Bullard Wash	10100	1370.00	932.60	936.42	934.65	936.68	0.001099	4.09	334.99	95.29	0.38
Bullard Wash	10000	1370.00	932.48	936.32	934.52	936.57	0.001086	3.98	344.20	99.17	0.38
Bullard Wash	9080	1370.00	931.37	935.43	933.41	935.65	0.000906	3.74	365.98	100.24	0.35
Bullard Wash	8102	1370.00	930.20	932.24	932.24	933.21	0.017218	7.89	173.60	90.20	1.00
Bullard Wash	8080	1370.00	929.25	930.85	931.31	932.56	0.040620	10.52	130.26	83.17	1.48
Bullard Wash	7700	1370.00	912.91	914.05	915.13	918.63	0.031347	17.17	79.80	81.72	3.06
Bullard Wash	7553	1370.00	912.74	916.51	914.92	916.83	0.000400	4.48	306.13	87.35	0.42
Bullard Wash	7543	Bridge									
Bullard Wash	7533	1370.00	912.73	916.48	914.91	916.80	0.000409	4.50	304.15	87.29	0.43
Bullard Wash	7500	1370.00	912.69	916.46	914.91	916.78	0.000416	4.53	302.39	87.26	0.43
Bullard Wash	7460	1370.00	912.64	916.45	914.86	916.76	0.000402	4.48	305.67	87.30	0.42
Bullard Wash	7430	1370.00	912.60	916.44	914.82	916.75	0.000390	4.44	308.40	87.33	0.42
Bullard Wash	7357	Bridge									
Bullard Wash	7300	1370.00	912.43	916.18	914.65	916.50	0.000424	4.56	300.43	87.16	0.43
Bullard Wash	7270	1370.00	912.40	916.16	914.46	916.46	0.001157	4.35	315.15	87.52	0.40
Bullard Wash	6322	1370.00	911.36	914.94	913.42	915.27	0.001353	4.57	299.51	87.17	0.43
Bullard Wash	3350	1370.00	907.03	910.35	909.09	910.73	0.001726	4.95	276.92	86.67	0.49
Bullard Wash	3330	1370.00	907.00	910.22	909.23	910.70	0.000755	5.55	246.77	82.25	0.56

HEC-RAS Plan: 10-Year River: Bullard Wash Out Reach: Bullard Wash (Continued)

Reach	River Sta	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
		(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Bullard Wash	3300	1370.00	906.88	910.11	909.22	910.67	0.000873	5.97	229.36	76.17	0.61
Bullard Wash	3130	1370.00	906.20	910.04	908.54	910.42	0.001556	4.96	276.09	77.54	0.46
Bullard Wash	3049	1370.00	905.87	908.72	908.72	910.15	0.002687	9.61	142.58	50.09	1.00
Bullard Wash	3003	1370.00	905.69	908.32	908.54	910.00	0.003452	10.39	131.84	50.09	1.13
Bullard Wash	2980	1370.00	904.65	906.51	907.45	909.65	0.053530	14.23	96.29	53.69	1.87
Bullard Wash	2920	1370.00	901.95	906.40	904.74	906.89	0.002902	5.63	243.14	59.32	0.49
Bullard Wash	2900.42	1370.00	900.25	906.49	903.05	906.78	0.000218	4.29	319.56	51.20	0.30
Bullard Wash	2890.42	Culvert									
Bullard Wash	2880.42	1370.00	900.16	906.27	902.96	906.56	0.000233	4.38	312.64	51.20	0.31
Bullard Wash	2840	1370.00	900.10	906.36	902.16	906.46	0.000227	2.52	542.68	93.48	0.18
Bullard Wash	2520	1370.00	899.44	906.31	901.50	906.39	0.000167	2.28	599.58	94.00	0.16
Bullard Wash	2499.74	1370.00	899.40	906.31	901.43	906.38	0.000111	2.16	739.06	134.51	0.15
Bullard Wash	2400	1370.00	899.20	906.32	901.24	906.37	0.000096	1.88	910.68	194.62	0.13
Bullard Wash	1860	1370.00	898.12	906.27	900.15	906.31	0.000088	1.61	902.00	170.57	0.11
Bullard Wash	1800	1370.00	898.00	906.30	900.04	906.30	0.000004	0.41	8189.77	2346.00	0.03


Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
End Transition RS = 10300
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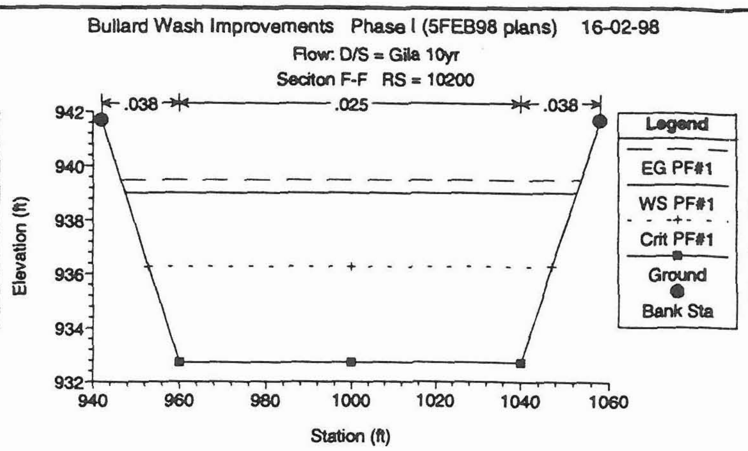
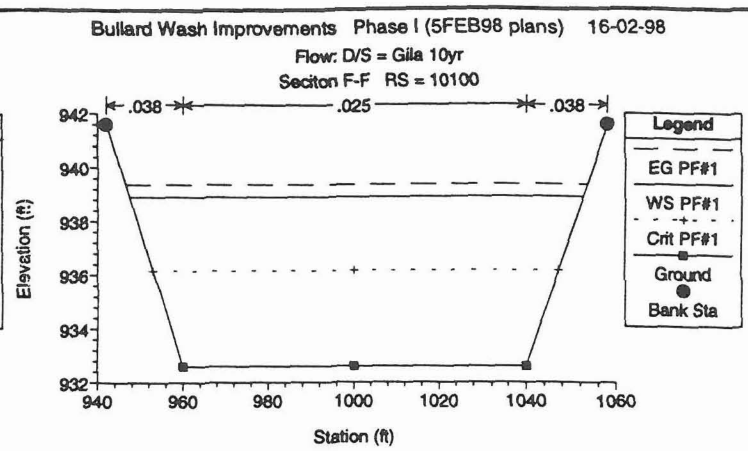
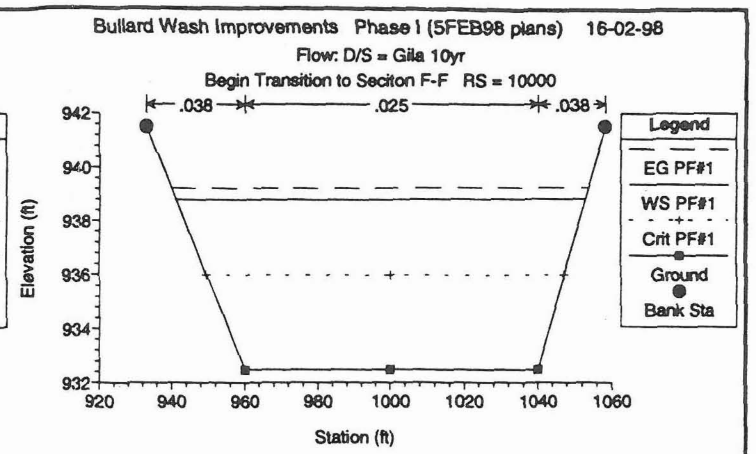
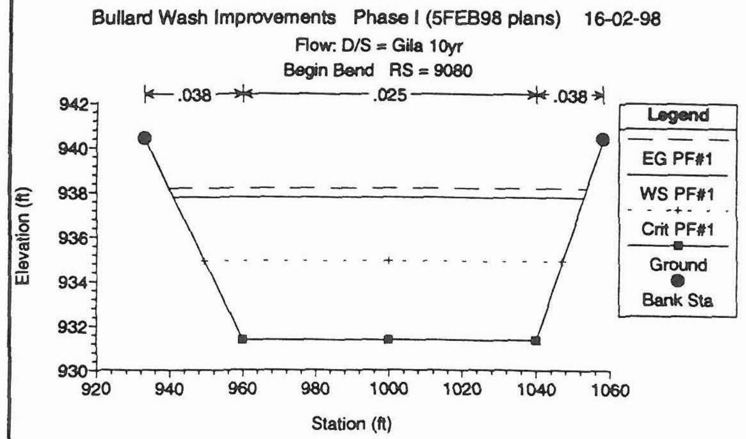
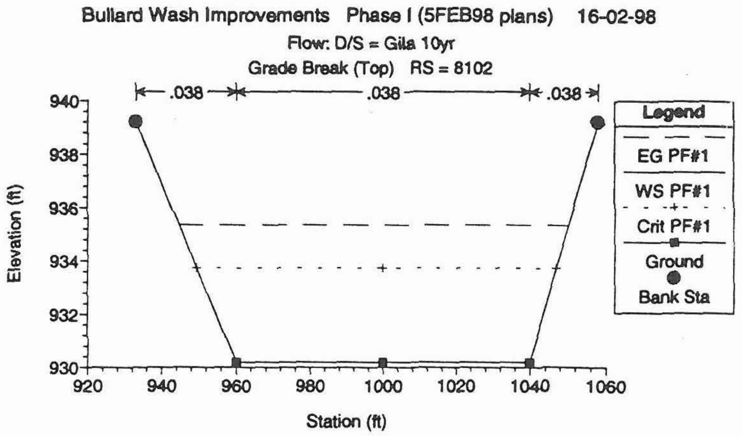
Elevation (ft)
Station (ft)
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Bank Sta

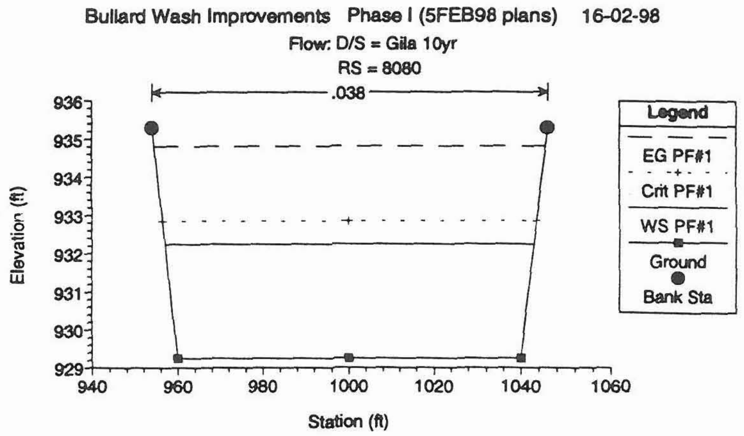

Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
Seciton F-F RS = 10200
.038 .025 .038
Elevation (ft)
Station (ft)
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Bank Sta

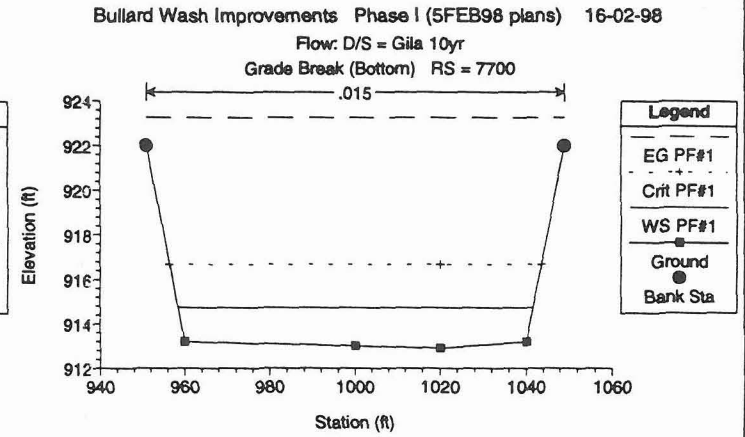

Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
Seciton F-F RS = 10100
.038 .025 .038
Elevation (ft)
Station (ft)
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Bank Sta

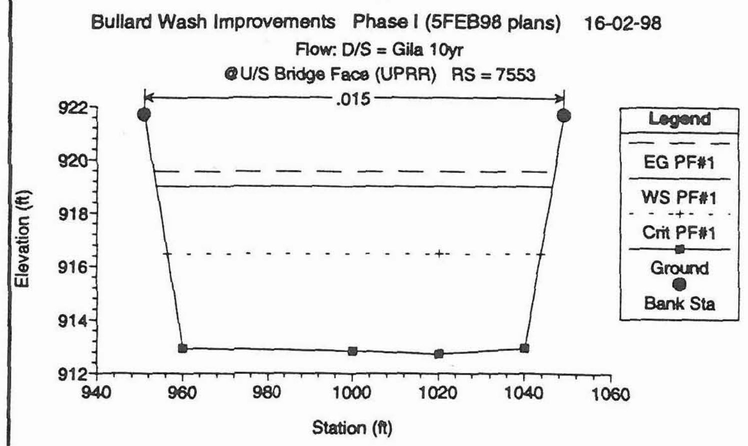

Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
Begin Transition to Seciton F-F RS = 10000
.038 .025 .038
Elevation (ft)
Station (ft)
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Bank Sta

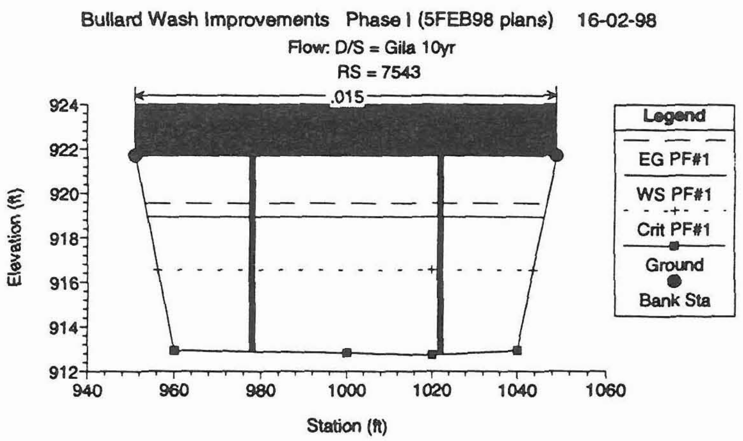

Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
Begin Bend RS = 9080
.038 .025 .038
Elevation (ft)
Station (ft)
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Bank Sta

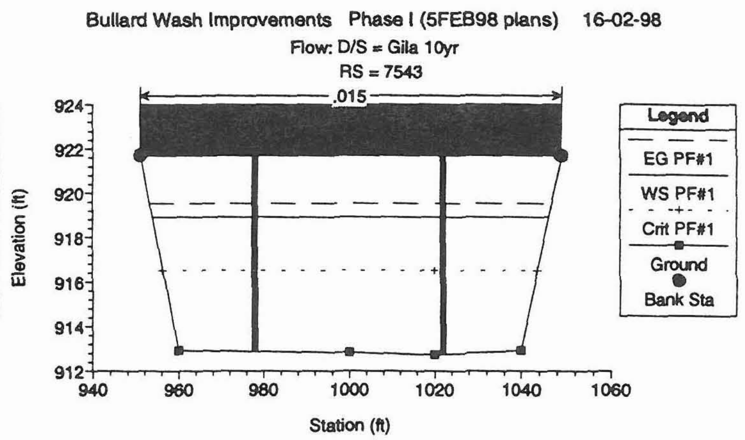

Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
Grade Break (Top) RS = 8102
.038 .038 .038
Elevation (ft)
Station (ft)
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Bank Sta

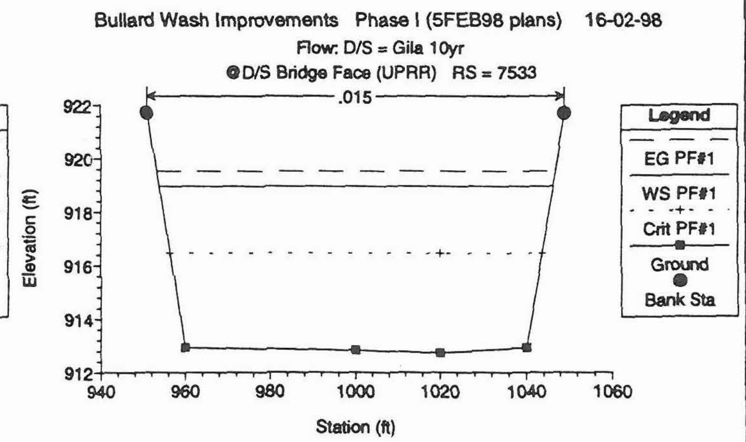

Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
RS = 8080
.038
Elevation (ft)
Station (ft)
Legend
EG PF#1
Crit PF#1
WS PF#1
Ground
Bank Sta

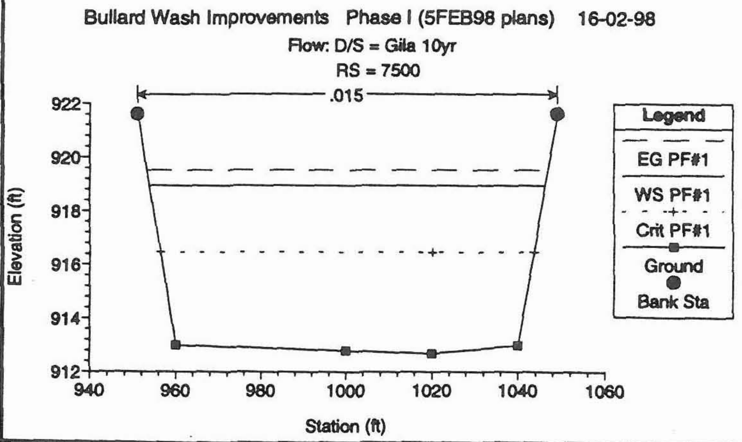

Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
Grade Break (Bottom) RS = 7700
.015
Elevation (ft)
Station (ft)
Legend
EG PF#1
Crit PF#1
WS PF#1
Ground
Bank Sta

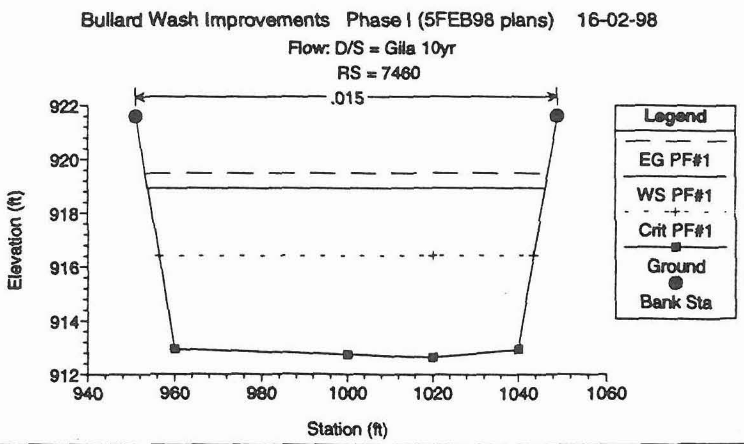

Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
@U/S Bridge Face (UPRR) RS = 7553
.015
Elevation (ft)
Station (ft)
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Bank Sta

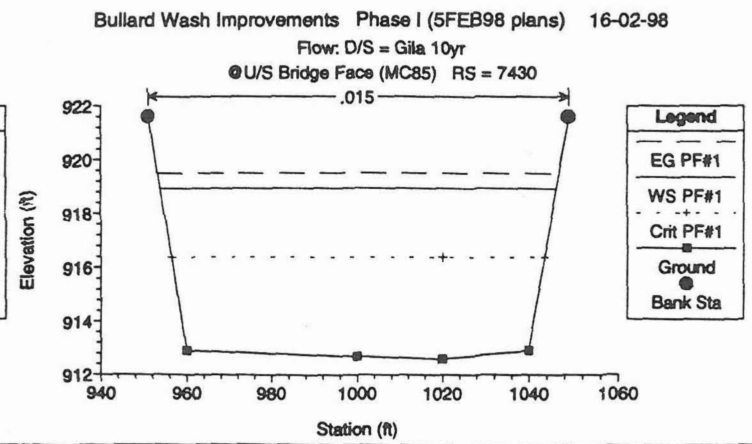

Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
RS = 7543
.015
Elevation (ft)
Station (ft)
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Bank Sta

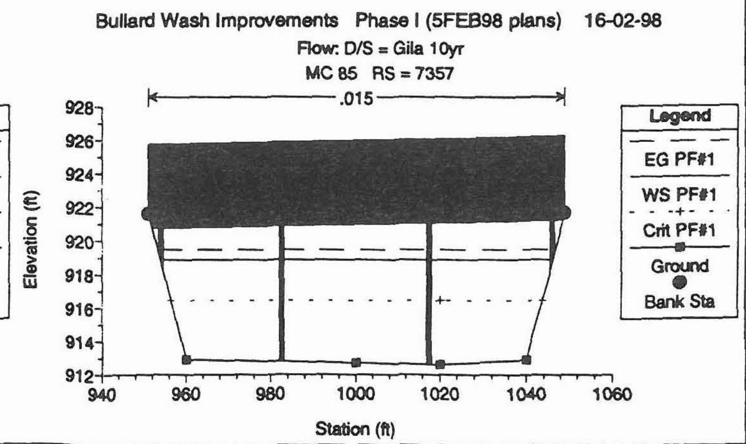

Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
RS = 7543
.015
Elevation (ft)
Station (ft)
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Bank Sta

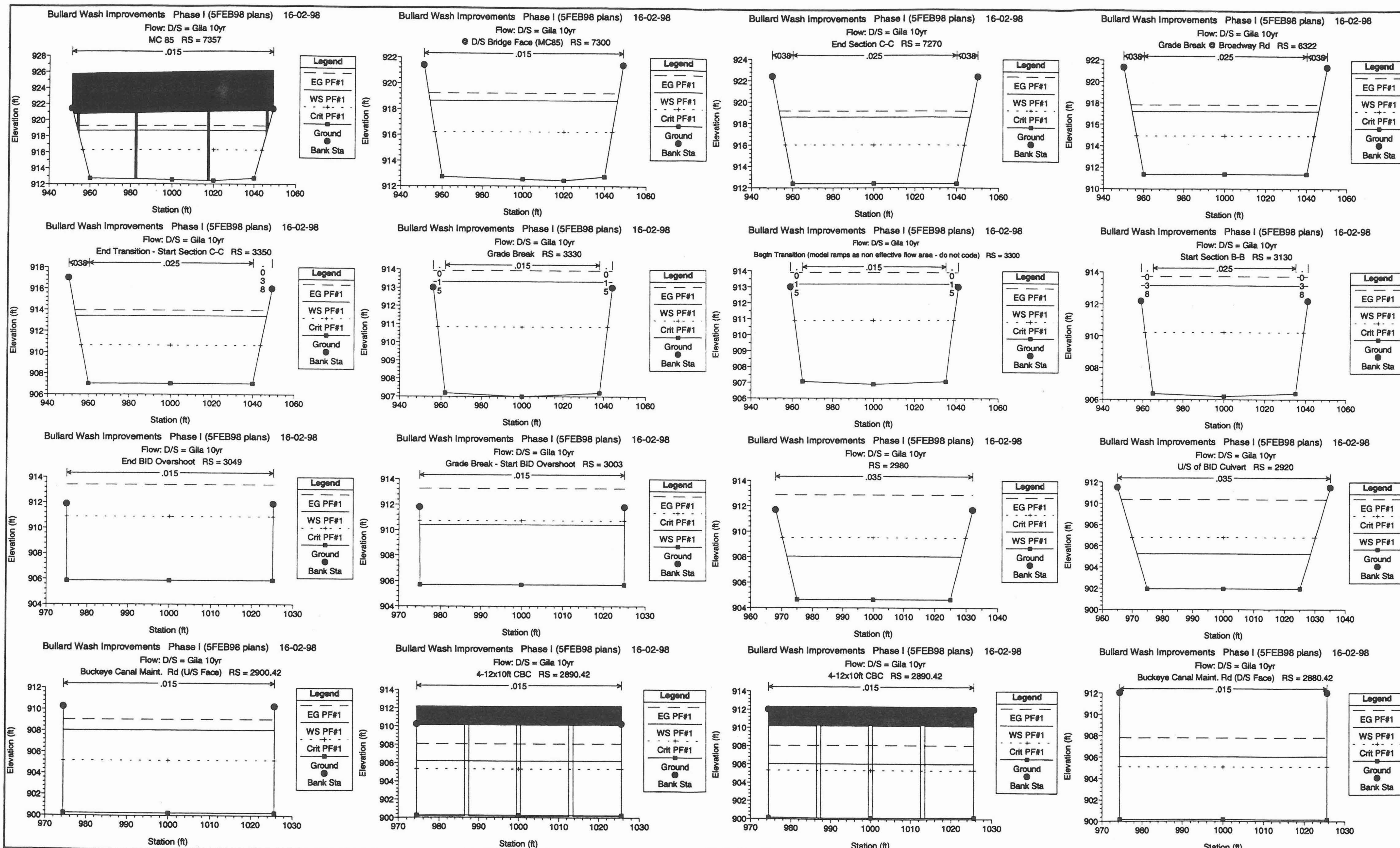

Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
@D/S Bridge Face (UPRR) RS = 7533
.015
Elevation (ft)
Station (ft)
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Bank Sta


Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
RS = 7500
.015
Elevation (ft)
Station (ft)
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Bank Sta

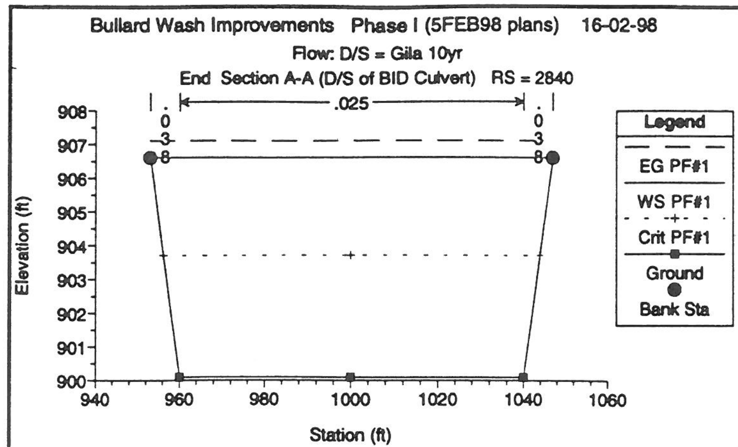

Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
RS = 7460
.015
Elevation (ft)
Station (ft)
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Bank Sta


Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
@U/S Bridge Face (MC85) RS = 7430
.015
Elevation (ft)
Station (ft)
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Bank Sta


Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
MC 85 RS = 7357
.015
Elevation (ft)
Station (ft)
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Bank Sta



Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
MC 85 RS = 7357
Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
@ D/S Bridge Face (MC85) RS = 7300
Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
End Section C-C RS = 7270
Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
Grade Break @ Broadway Rd RS = 6322
Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
End Transition - Start Section C-C RS = 3350
Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
Grade Break RS = 3330
Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
Begin Transition (model ramps as non effective flow area - do not code) RS = 3300
Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
Start Section B-B RS = 3130
Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
End BID Overshoot RS = 3049
Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
Grade Break - Start BID Overshoot RS = 3003
Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
RS = 2980
Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
U/S of BID Culvert RS = 2920
Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
Buckeye Canal Maint. Rd (U/S Face) RS = 2900.42
Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
4-12x10ft CBC RS = 2890.42
Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
4-12x10ft CBC RS = 2890.42
Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
Buckeye Canal Maint. Rd (D/S Face) RS = 2880.42
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Bank Sta
Elevation (ft)
Station (ft)
.015
.025
.035
.038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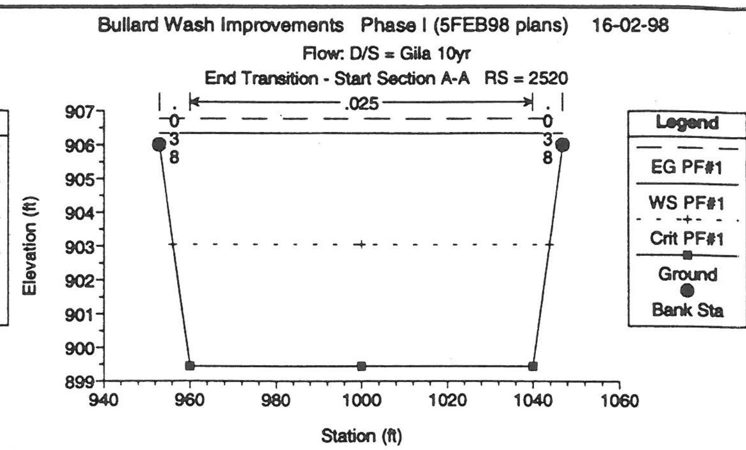
Flow: D/S = Gila 10yr
End Section A-A (D/S of BID Culvert) RS = 2840
.025
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Bank Sta
Elevation (ft)
Station (ft)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Flow: D/S = Gila 10yr
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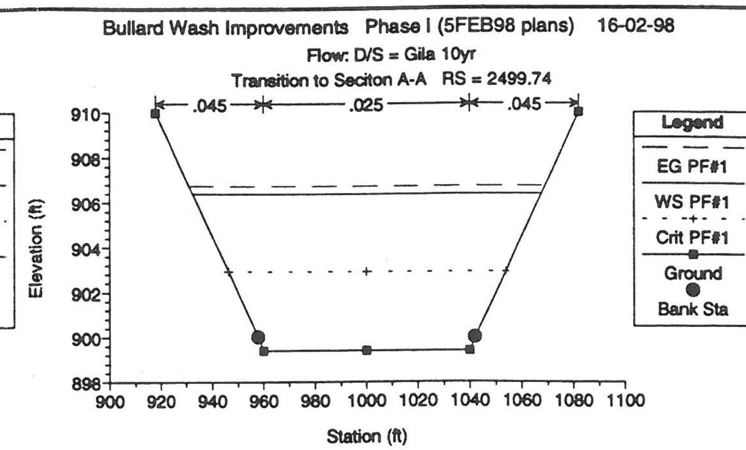
WS PF#1
Crit PF#1
Ground
Bank Sta
Elevation (ft)
Station (ft)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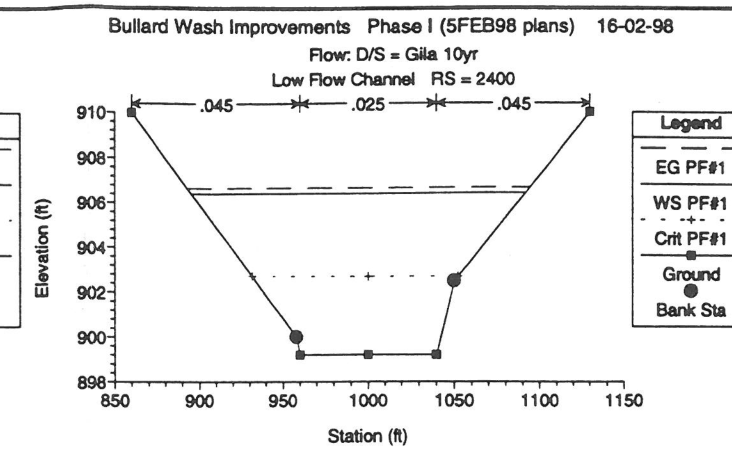
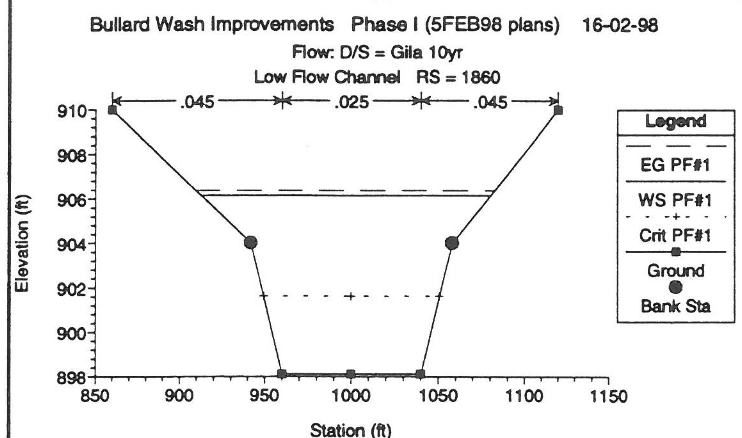
Flow: D/S = Gila 10yr
Transition to Seciton A-A RS = 2499.74
.045
.025
.045
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Bank Sta
Elevation (ft)
Station (ft)


Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
Low Flow Channel RS = 2400
.045
.025
.045
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Bank Sta
Elevation (ft)
Station (ft)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Flow: D/S = Gila 10yr
Low Flow Channel RS = 1860
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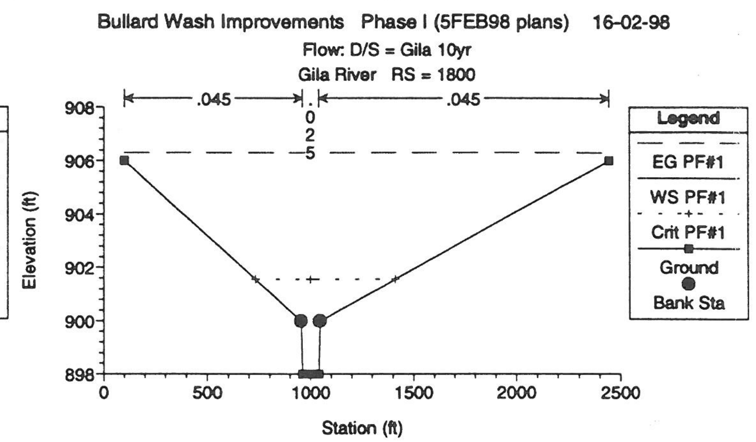
.025
.045
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Bank Sta
Elevation (ft)
Station (ft)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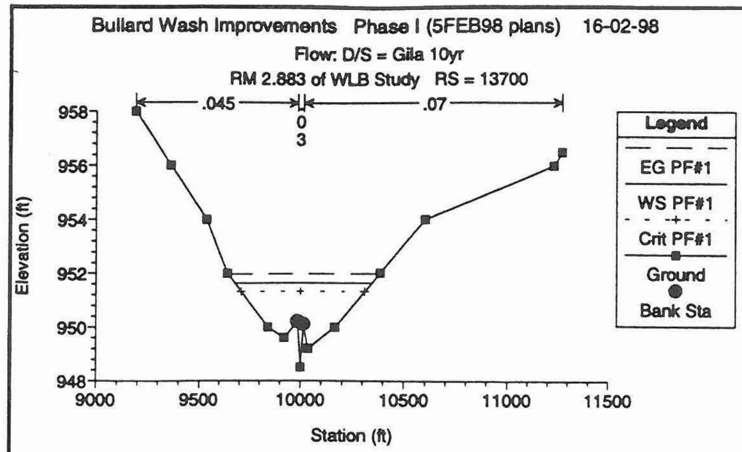
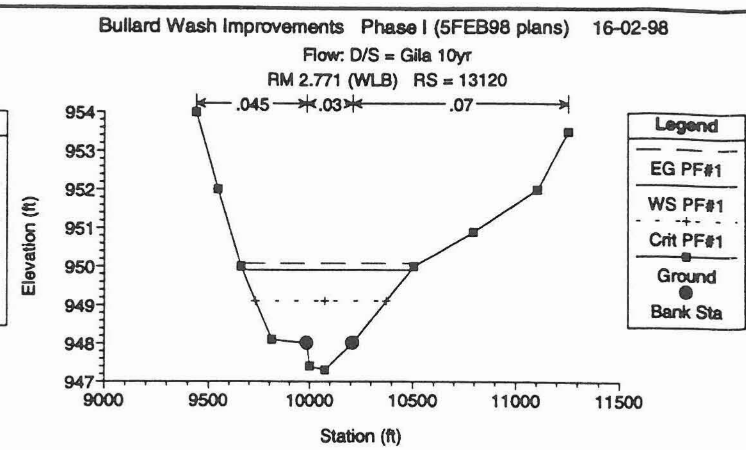
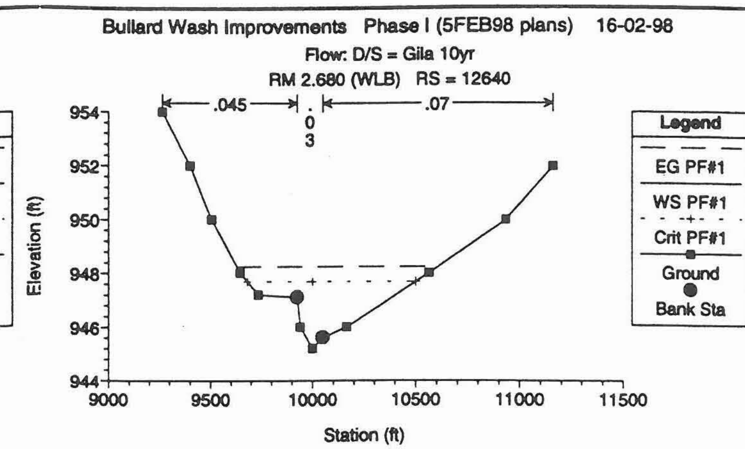
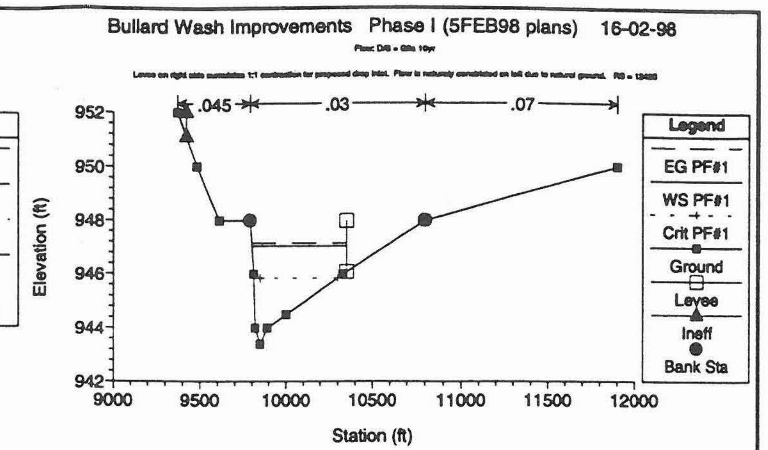
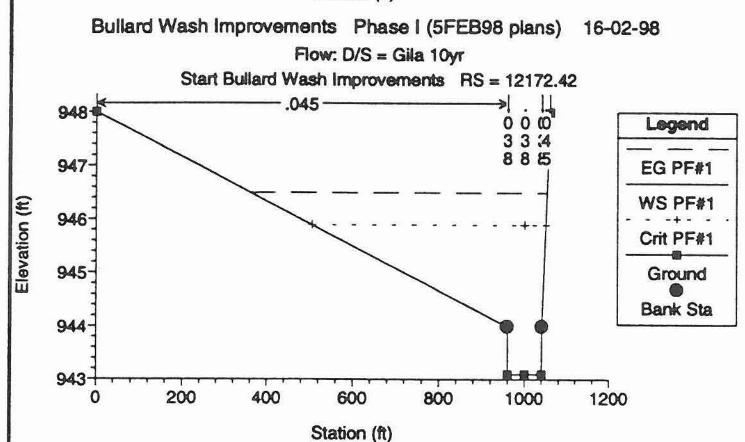
Flow: D/S = Gila 10yr
Gila River RS = 1800
.045
.045
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Bank Sta
Elevation (ft)
Station (ft)

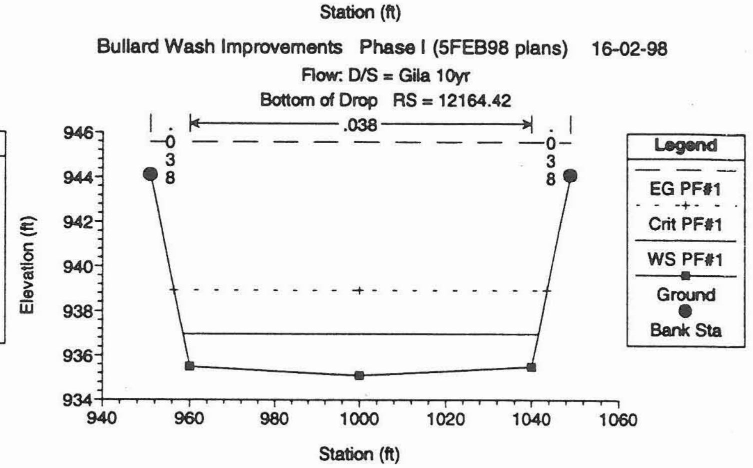

Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
RM 2.883 of WLB Study RS = 13700
.045
.07
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Bank Sta
Elevation (ft)
Station (ft)

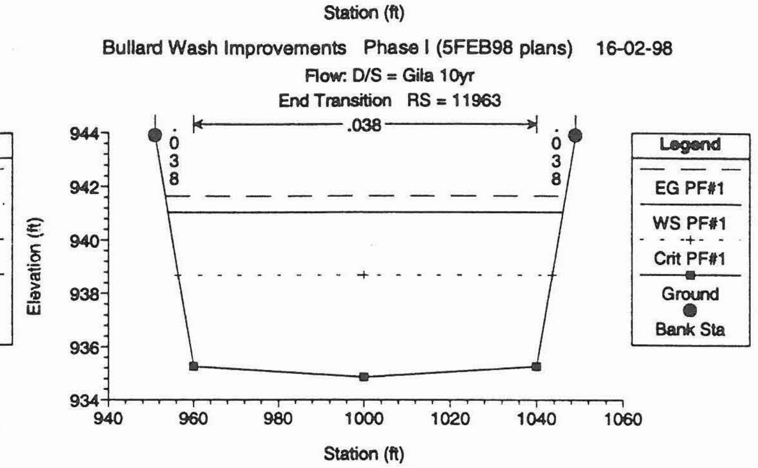

Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
RM 2.771 (WLB) RS = 13120
.045
.03
.07
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Bank Sta
Elevation (ft)
Station (ft)


Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
RM 2.680 (WLB) RS = 12640
.045
.07
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Bank Sta
Elevation (ft)
Station (ft)


Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
.045
.03
.07
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Levee
Ineff
Bank Sta
Elevation (ft)
Station (ft)


Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
Start Bullard Wash Improvements RS = 12172.42
.045
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Bank Sta
Elevation (ft)
Station (ft)


Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
Bottom of Drop RS = 12164.42
.038
Legend
EG PF#1
Crit PF#1
WS PF#1
Ground
Bank Sta
Elevation (ft)
Station (ft)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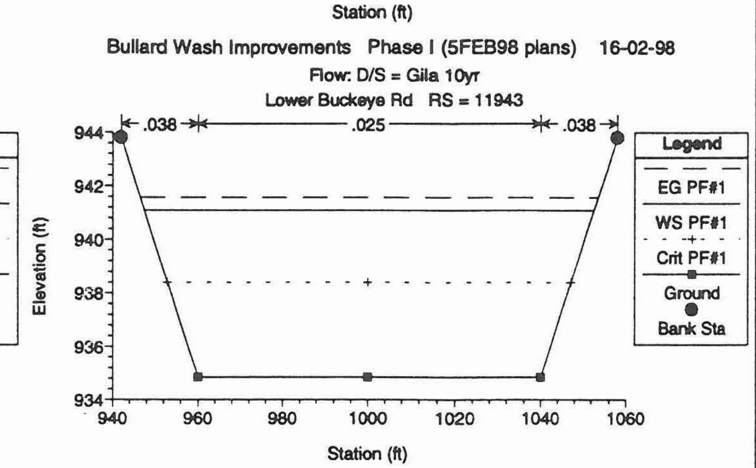
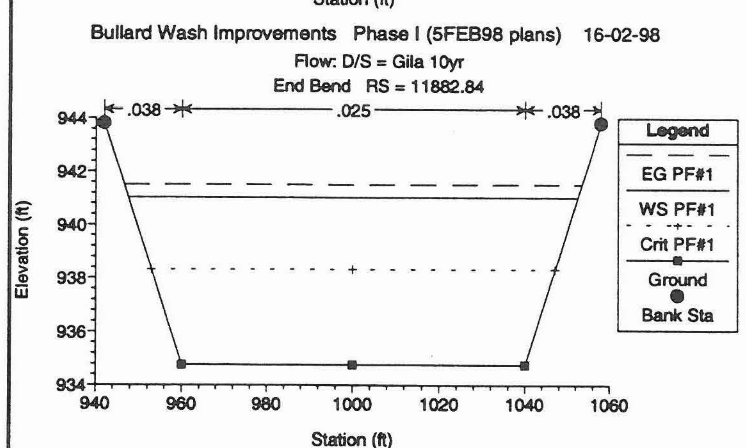
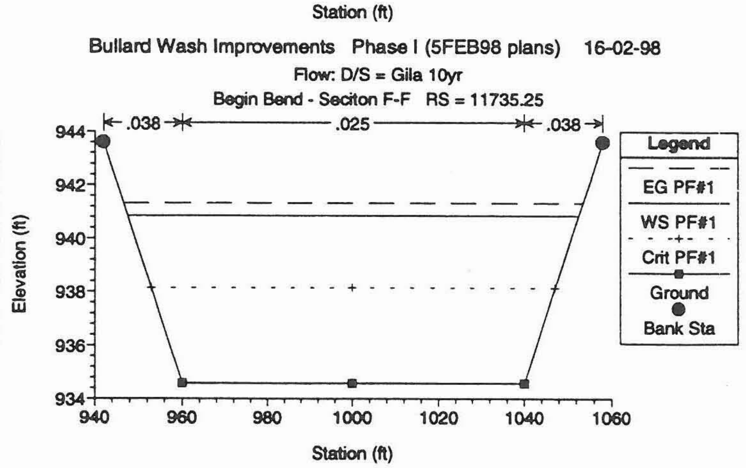
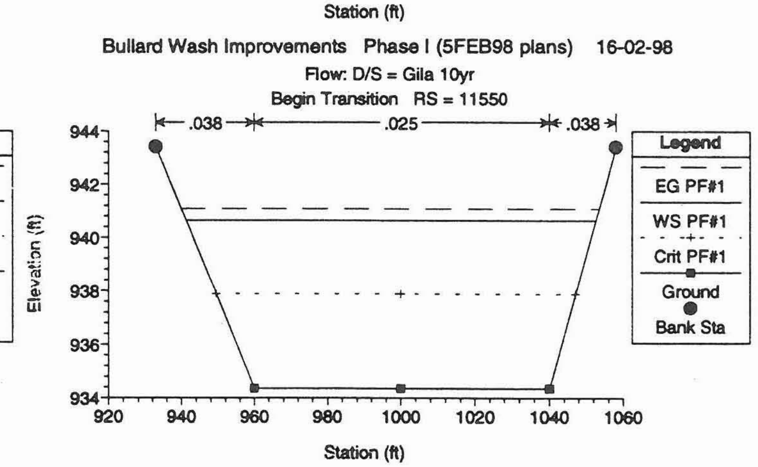
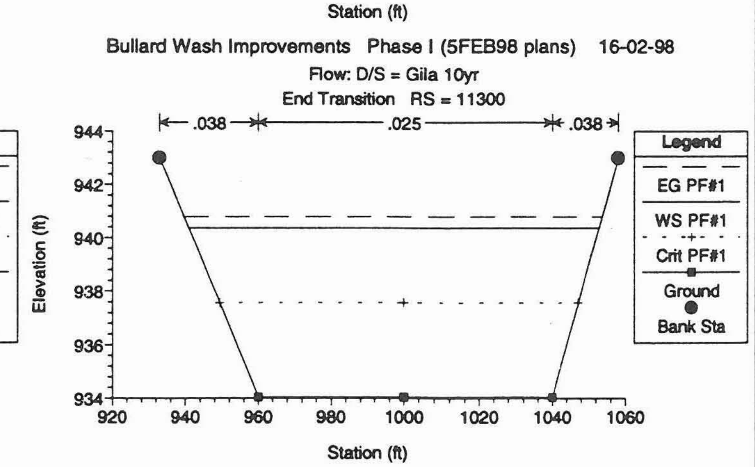
Flow: D/S = Gila 10yr
End Transition RS = 11963
.038
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Bank Sta
Elevation (ft)
Station (ft)

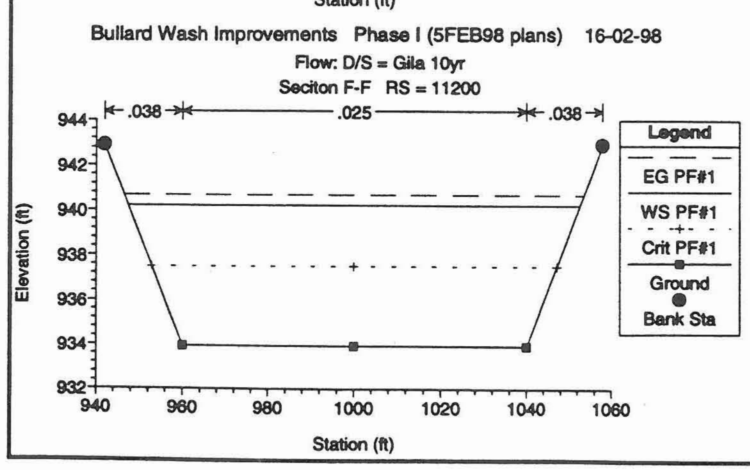

Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
Lower Buckeye Rd RS = 11943
.038
.025
.038
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Bank Sta
Elevation (ft)
Station (ft)

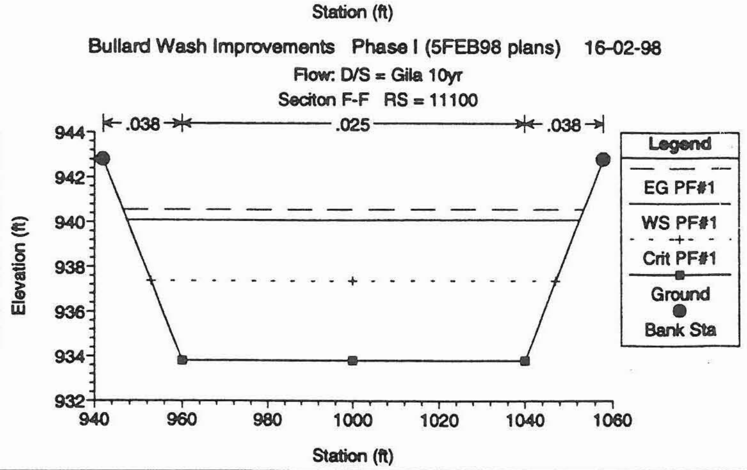

Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
End Bend RS = 11882.84
.038
.025
.038
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Bank Sta
Elevation (ft)
Station (ft)

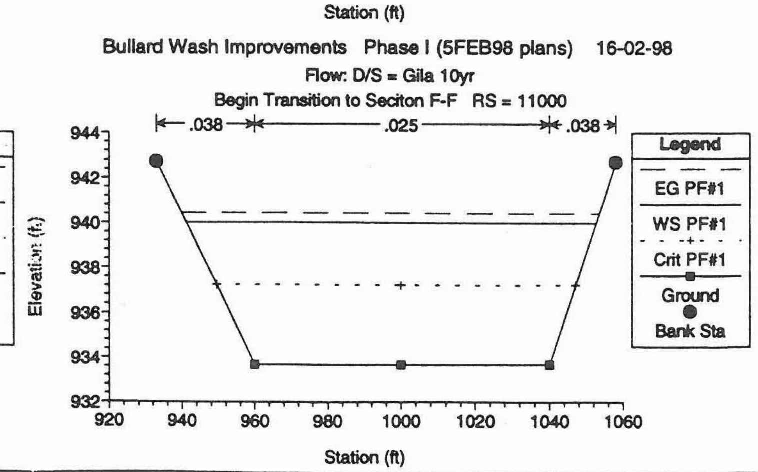

Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
Begin Bend - Seciton F-F RS = 11735.25
.038
.025
.038
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Bank Sta
Elevation (ft)
Station (ft)

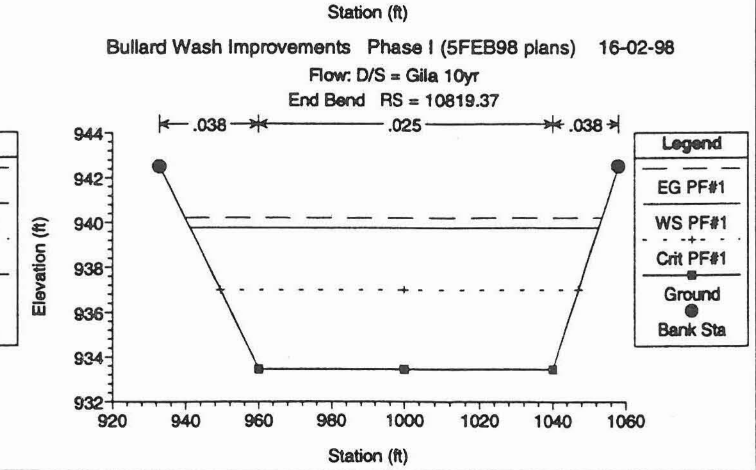

Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
Begin Transition RS = 11550
.038
.025
.038
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Bank Sta
Elevation (ft)
Station (ft)

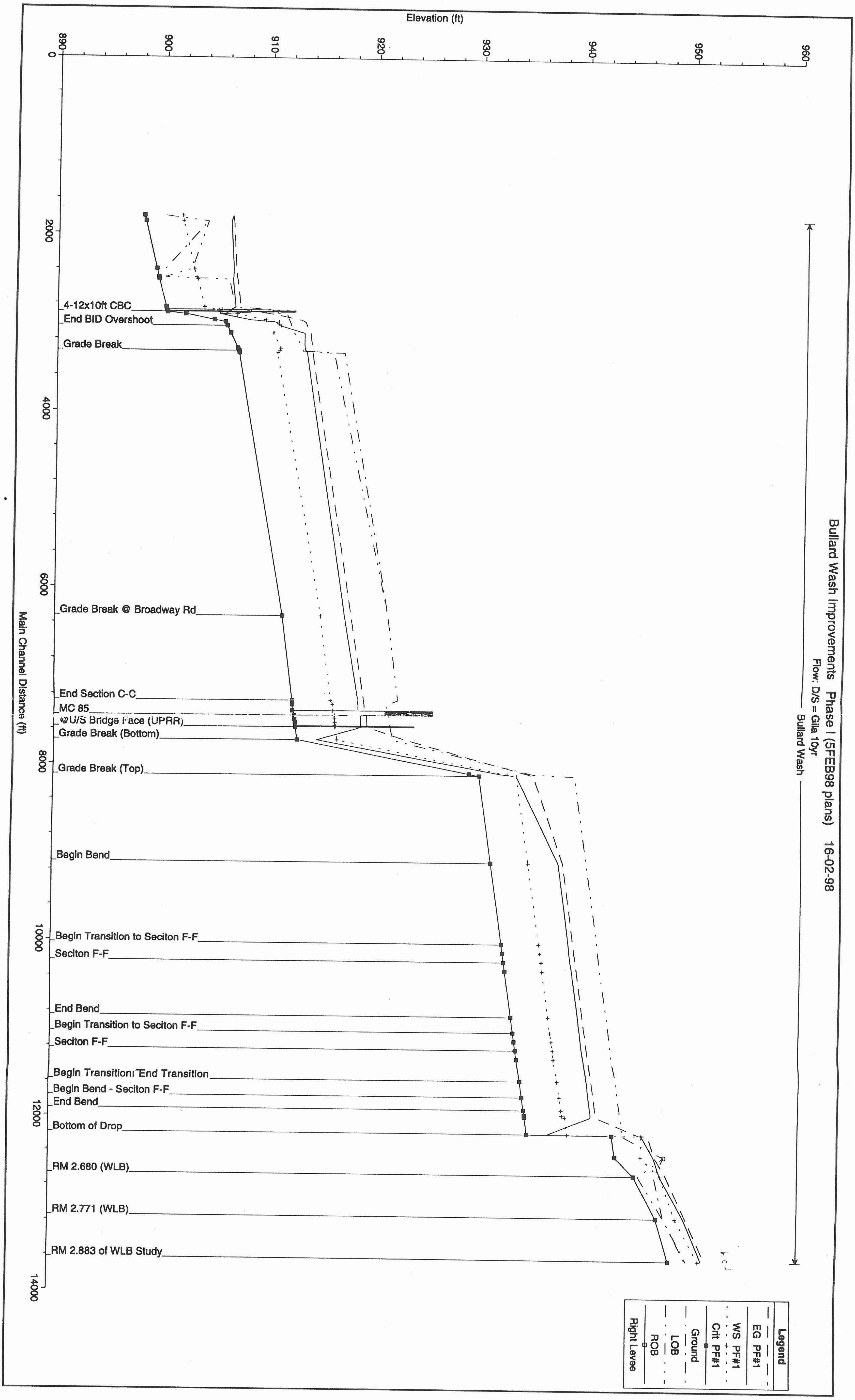

Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
End Transition RS = 11300
.038
.025
.038
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Bank Sta
Elevation (ft)
Station (ft)


Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
Seciton F-F RS = 11200
.038
.025
.038
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Bank Sta
Elevation (ft)
Station (ft)


Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
Seciton F-F RS = 11100
.038
.025
.038
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Bank Sta
Elevation (ft)
Station (ft)


Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
Begin Transition to Seciton F-F RS = 11000
.038
.025
.038
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Bank Sta
Station (ft)


Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
End Bend RS = 10819.37
.038
.025
.038
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
Bank Sta
Elevation (ft)
Station (ft)



Bullard Wash Improvements Phase I (5FEB98 plans) 16-02-98
Flow: D/S = Gila 10yr
Bullard Wash
Elevation (ft)
890
900
910
920
930
940
950
960
Main Channel Distance (ft)
0
2000
4000
6000
8000
10000
12000
14000
4-12x10ft CBC
End BID Overshoot
Grade Break
Grade Break @ Broadway Rd
End Section C-C
MC 85
@U/S Bridge Face (UPRR)
Grade Break (Bottom)
Grade Break (Top)
Begin Bend
Begin Transition to Seciton F-F
Seciton F-F
End Bend
Begin Transition to Seciton F-F
Seciton F-F
Begin Transition‾End Transition
Begin Bend - Seciton F-F
End Bend
Bottom of Drop
RM 2.680 (WLB)
RM 2.771 (WLB)
RM 2.883 of WLB Study
Legend
EG PF#1
WS PF#1
Crit PF#1
Ground
LOB
ROB
Right Levee

Don Rerick - FCDX

From: Don Rerick - FCDX
Sent: Tuesday, April 28, 1998 9:08 AM
To: 'olbertbd@sverdrup.com'
Cc: Don Rerick - FCDX
Subject: FW: Bullard Wash Project - Review of Sediment Transport & Scour Analysis Report

Brad, Kofi and Scott Ogden have reviewed the subject report. Kofi's response to his review was that the sedimentation analysis is "adequate to support the channel design".

Scott's comments follow below, and pertain to the application of the 1.3 safety factor. After reviewing his comments, it appears that they are consistent with the direction provided earlier by Kofi.

Therefore, please have Ash make the indicated changes to the report and make the final submittal. The revised and slightly deeper toedown depths will need to be incorporated into the 60% plans.

Please let me know that you received this e-mail. Thanks.

-----Original Message-----
From: Scott Ogden - FCDX
Sent: Friday, April 24, 1998 12:14 PM
To: Don Rerick - FCDX
Cc: Pedro Calza - FCDX
Subject: RE: Bullard Wash Project - Review of Sediment Transport & Scour Analysis Report

On page 7, Section 4.1, the safety factor could be changed to 1.3 thereby reducing the toe down depths a minor amount. However, the calculation of the total toe down depth at the specific locations susceptible to local scour in Section 4.2 are calculated incorrectly. They should be as follows:

Middle Reach at STA 119+53:

Toe Down Depth = [1.21 + 0.38 + 1.0 + 2.8(bend scour) + 3.4(sill scour)]x1.3 = 11.4 feet

Downstream Reach at STA 73+00:

Toe Down Depth = [2.12 + 0.54 + 1.0 + 5.5(sill scour)]x1.3 = 11.9 feet

There are also a few typos that need cleaning up in the report.

Hope this helps. Call me if you need to discuss further.
Scott Ogden

-----Original Message-----
From: Don Rerick - FCDX
Sent: Thursday, April 23, 1998 1:34 PM
To: Scott Ogden - FCDX
Cc: Pedro Calza - FCDX; Don Rerick - FCDX
Subject: Bullard Wash Project - Review of Sediment Transport & Scour Analysis Report

Scott I have reviewed the report and have Kofi's e-mail message response to his review. He found the report to be acceptable.

I have only one comment of interest, and it pertains to the use of the safety factor.

We had discussed with Kofi that if a combined scour depth calculation was used, then the SF would be 1.3 rather than 1.5. On page 7 of the report, Ash Patel uses 1.5. This doesn't make much of a difference, though the for Downstream reach, it would change the depth from 5.5' to about 4.75', or say 5' even. Over the length of the channel, times two sides, this would amount to a goodly volume of gabion baskets.

So, please take a look at the report, and give me some input on the use of 1.3 versus 1.5 SF.

And, keep the report handy, as when we receive the 60% plans in about two weeks, I would like you to take a look at the plan/profile sheets to verify that the channel invert and top of bank profiles agree with the report HEC-RAS results.

Thanks.

Don Rerick - FCDX

From: Don Rerick - FCDX
Sent: Thursday, April 23, 1998 1:34 PM
To: Scott Ogden - FCDX
Cc: Pedro Calza - FCDX; Don Rerick - FCDX
Subject: Bullard Wash Project - Review of Sediment Transport & Scour Analysis Report

Scott I have reviewed the report and have Kofi's e-mail message response to his review. He found the report to be acceptable.

I have only one comment of interest, and it pertains to the use of the safety factor.

We had discussed with Kofi that if a combined scour depth calculation was used, then the SF would be 1.3 rather than 1.5. On page 7 of the report, Ash Patel uses 1.5. This doesn't make much of a difference, though the for Downstream reach, it would change the depth from 5.5' to about 4.75', or say 5' even. Over the length of the channel, times two sides, this would amount to a goodly volume of gabion baskets.

So, please take a look at the report, and give me some input on the use of 1.3 versus 1.5 SF.

And, keep the report handy, as when we receive the 60% plans in about two weeks, I would like you to take a look at the plan/profile sheets to verify that the channel invert and top of bank profiles agree with the report HEC-RAS results.

Thanks.

SEND MEMO TO ASH/BRAD AFTER
RESPONSE FROM SCOTT. 4/23

Don Rerick - FCDX

From: Kofi Awumah - FCDX
Sent: Wednesday, April 22, 1998 2:50 PM
To: Don Rerick - FCDX
Cc: Scott Ogden - FCDX
Subject: Bullard Wash - Sediment Analysis

A review of the above report submitted by Wood-Patel & Associates indicates that the sedimentation analysis is adequate to support the channel design.
You may therefore issue the consultant a letter approving this portion of the design work.

WOOD/PATEL
CIVIL ENGINEERS • HYDROLOGISTS • LAND SURVEYORS
Wood, Patel & Associates, Inc.
1550 East Missouri, Suite 203
Phoenix, Arizona 85014
(602) 234-1344
FAX 234-1322

LETTER OF TRANSMITTAL

FLOOD CONTROL DISTRICT
RECEIVED
APR 1 ? 1998
DJR

TO FCDMC

DATE 4/10/98 JOB NO. 96464
ATTENTION Don Rerick P.E.
RE:
Ballard Wash Outfall Channel
Sed. Transport & Scour Analysis

WE ARE SENDING YOU ☒ Attached ☐ Under separate cover via ____ the following items:

☐ Shop drawings ☐ Prints ☐ Plans ☐ Samples ☐ Specifications
☐ Copy of letter ☐ Change order ☒ Report

COPIES	DATE	NO.	DESCRIPTION
2	4/10/98		Sed. Transport & Scour Analysis Report

THESE ARE TRANSMITTED as checked below:

☒ For approval ☐ Approved as submitted ☐ Resubmit ____ copies for approval
☐ For your use ☐ Approved as noted ☐ Submit ____ copies for distribution
☐ As requested ☐ Returned for corrections ☐ Return ____ corrected prints
☐ For review and comment ☐ ____
☐ FOR BIDS DUE ____ 19 ____ ☐ PRINTS RETURNED AFTER LOAN TO US

REMARKS Don,
Brad Olbert & myself met with Kofi today to discuss sedimentation issue. Based on our discussions, the report is updated and section 3.5 "Watershed Load Estimation" is modified. Kofi's comments are incorporated & discussion is included about siltation.
Hopefully, this modification will satisfy all previous & recent comments.
Your approval letter will be sincerely appreciated.
Thanks for your assistance.

COPY TO Brad Olbert P.E., Sverdrup

SIGNED: [signature]

If enclosures are not as noted, kindly notify us at once.

MEETING MINUTES

Sverdrup Civil, Inc.

Date: April 13, 1998

LOCATION AND DATE:	Flood Control District April 10, 1998; 9:00 am
PARTICIPANTS:	Kofi Awumah, Flood Control District of Maricopa County (FCDMC) Ash Patel, Wood Patel and Associates, Inc. Brad Olbert, Sverdrup Civil, Inc.
SUBJECT:	**Contract FCD 95-39** **Flood Control District of Maricopa County** **Bullard Wash Channel Improvements - Final Design** **Sediment Transport/Yield Meeting**

SUMMARY:

The above participants met to discuss review comments on the Sediment Transport & Scour Analysis Report prepared by Wood Patel and Associates.

Mr. Awumah presented his concerns on sediment transport issues based primarily on the clogging problems associated with the existing railroad and MC 85 bridges. Mr. Patel stated that the problems at that location is primarily caused by downstream conditions (ponding effect at bridges during storm events is caused by farmers dikes used to capture tailwater flows) that will not be present on the proposed channel design. Mr. Olbert said that the new channel will also incorporate a shallow concrete lined ditch designed specifically to convey tailwater flows and its sediment load to an irrigation outlet structure located upstream of the new bridges. This will help reduce long term maintenance for the channel and keep the tailwater flows from blocking access to the channel.

Mr. Awumah was unaware of the conditions causing the sediment problem at the bridges and agreed that a sediment yield calculation would be unnecessary. Mr. Awumah requested that additional information on the existing sediment transport conditions and information on the tailwater ditch in the main channel be included in the report. Mr. Patel said that the information will be added to the report in Section 3.5 and a revised report will be submitted Monday next week.

Please review these meeting minutes and call me (231-8999) if you have comments.

Signed: Bradford D. Olbert

Bradford D. Olbert, P.E.

Distribution: 013884-2B
Meeting Attendees

Flood Control District of Maricopa County
2801 West Durango Street
Phoenix, Arizona 85009-6399
(602) 506-1501
FAX: (602) 506-4601
TT: (602) 506-5859

March 31, 1998

MEMO TO Don Rerick to be forwarded to Wood-Patel & Assoc.

FROM: Kofi Awumah Via Pedro Calza
SUBJECT: Bullard Wash Sediment Analysis

General Comments:

1. The equation used (Equation 5.8b of the referenced book) to determine the sediment discharge for the equilibrium slope analysis is not applicable to the representative sediment size found in this channel. The D_{50} of the bed material must be greater than 0.1mm but in this channel, it is between 0.03mm and 0.06mm. Equation 5.8a or others in the same reference may be more appropriate.

2. There was no documentation of how sediment entering the channel from the watershed at the upstream segment was obtained. FEMA likes to see an analysis of how the inflowing sediment load used was derived.

3. The consultant may apply a safety factor of 1.3 instead of 1.5 to the scour depths that considered multiple scour components.

From:	Don Rerick - FCDX
Sent:	Wednesday, April 01, 1998 12:19 PM
To:	'woodpatl@netzone.com'; 'olbertbd@sverdrup.com'
Cc:	Don Rerick - FCDX; Ed Raleigh - FCDX; Pedro Calza - FCDX
Subject:	FW: Bullard Wash Sediment/Scour Analysis

Attached for your use is a memo from Kofi outlining the last (I hope) design issues for the CLOMR; i.e., sediment analysis and scour safety factors. The use of either 1.3 or 1.5 SF is explained, as was done in Kofi's e-mail to Brad on March 30. I don't expect any further changes to the SF. Ed, I need to know immediately if this is incorrect.

Ash, the referenced "book" in Kofi's memo is an ADWR Technical publication. If you have any questions, contact Kofi directly, and document the telecon accordingly. Kofi will be leaving us on April 21, so lets resolve any outstanding concerns ASAP.

Thanks.

-----Original Message-----

From:	Kofi Awumah - FCDX
Sent:	Tuesday, March 31, 1998 3:58 PM
To:	Don Rerick - FCDX
Cc:	Pedro Calza - FCDX; Ed Raleigh - FCDX
Subject:	Bullard Wash Sediment/Scour Analysis

Attached is my comments to Wood-Patel. Note that we did not request any Hec-6 modeling to be performed.

bullard2.doc

Don Rerick - FCDX

From: Don Rerick - FCDX
Sent: Thursday, April 02, 1998 9:43 AM
To: Kofi Awumah - FCDX
Cc: Pedro Calza - FCDX; Don Rerick - FCDX; 'olbertbd@sverdrup.com'
Subject: Bullard Wash - Sediment & Scour Draft Analysis

Kofi, I have forwarded to you an original of the subject analysis provided by Ash Patel.

Please review this as soon as you can and provide me and Ash with your written comments.

Your particular concern about the need for a "sediment yield" analysis of the contributing watershed because of its primarily agricultural usage at this time must be discussed with Ash to get his response and indication if he believes this is within his original scope of work. I will review the original scope to see if this was specifically or by implication included as part of their work effort. If necessary, I guess we will at worst have to issue another C.O.

Please get me your comments by April 10 at the latest. Thanks.

WOOD/PATEL
CIVIL ENGINEERS • HYDROLOGISTS • LAND SURVEYORS
Wood, Patel & Associates, Inc.
1550 East Missouri, Suite 203
Phoenix, Arizona 85014
(602) 234-1344
FAX 234-1322

LETTER OF TRANSMITTAL

DATE: 4/2/98 JOB NO.:

ATTENTION: Kofi Awumah

RE: Bullard Wash Outfall Channel Sediment Transport

TO: FCDMC

WE ARE SENDING YOU ☒ Attached ☐ Under separate cover via ______ the following items:

☐ Shop drawings ☐ Prints ☐ Plans ☐ Samples ☐ Specifications

☐ Copy of letter ☐ Change order ☒ Report

COPIES	DATE	NO.	DESCRIPTION
1	4/2/98		Sediment Transport & Scour Analysis

THESE ARE TRANSMITTED as checked below:

☒ For approval ☐ Approved as submitted ☐ Resubmit ____ copies for approval

☐ For your use ☐ Approved as noted ☐ Submit ____ copies for distribution

☐ As requested ☐ Returned for corrections ☐ Return ____ corrected prints

☒ For review and comment ☐ ______

☐ FOR BIDS DUE ______ 19____ ☐ PRINTS RETURNED AFTER LOAN TO US

REMARKS

Kofi,

Per your input & guidelines on 4/1/98, we have updated the Sediment/Scour Analysis report.

Hopefully, all your past comments have now been incorporated. Please review and if you agree with our calculation approach, an approval letter will be appreciated.

Thank you for your prompt response.

COPY TO Don Rerick P.E. (FCDMC)
Brad Olbert P.E. (Sverdrup)

SIGNED: [signature]

If enclosures are not as noted, kindly notify us at once.

From: Kofi Awumah - FCDX
Sent: Monday, April 13, 1998 8:21 AM
To: Don Rerick - FCDX
Subject: RE: Bullard Wash & Sediment Transport/Yield

We had the discussion and the Consultants explained why sediment load into the channel will be minimal. I asked them to include their explanation in the report and they agreed to do so. Their explanation appear to be reasonable to me, at this point.

-----Original Message-----
From: **Don Rerick - FCDX**
Sent: Monday, April 13, 1998 8:16 AM
To: Kofi Awumah - FCDX
Subject: Bullard Wash & Sediment Transport/Yield

How did the meeting go on Friday, and did we reach agreement on the methods, etc. And, have you passed this along to Pedro and Steve? Let me know, thanks.

Don Rerick - FCDX

Final Design Criteria on S.F.

From: Kofi Awumah - FCDX
Sent: Monday, March 30, 1998 8:35 AM
To: 'olbertbd@sverdrup.com'
Cc: Don Rerick - FCDX; Pedro Calza - FCDX; Michael Lopez - FCDX
Subject: Safety Factor for scour

The safety factor for computed scour depth is 1.5 if a single scour component is calculated (e.g., local scour only). It is 1.3 if multiple scour components are computed, (e.g., local, general, long-term degradation, bed forms, bend etc.) applied to the sum of all the scour components.

Don Rerick - FCDX

From: Don Rerick - FCDX
Sent: Thursday, March 26, 1998 5:49 PM
To: Pedro Calza - FCDX; Michael Lopez - FCDX; Kofi Awumah - FCDX
Cc: Don Rerick - FCDX; 'OLBERTBD@SVERDRUP.COM'
Subject: RE: Bullard Wash Project - CLOMR Requirements and Channel Design

Thanks for the response. Is Ash comfortable with your suggestions? If so, he can move forward. If not, then he needs to let us know if he will be looking for more man-hours. As for the safety factor, it is purely a question of FCD being consistent in whatever number we want them to use. Please decide in Engineering what that is to be, 1.3 or 1.5, and pass this directly to Ash. This can be done by e-mail as a way to document what you tell him. Please be sure to copy me and the prime consultant - OLBERTBD@SVERDRUP.COM. Brad, please be sure and check with Ash on this too. Thanks for the assistance.

-----Original Message-----
From: Pedro Calza - FCDX
Sent: Thursday, March 26, 1998 5:01 PM
To: Michael Lopez - FCDX; Don Rerick - FCDX; Kofi Awumah - FCDX
Subject: RE: Bullard Wash Project - CLOMR Requirements and Channel Design

Kofi and I met with Ash Patel yesterday to discuss the sediment transport problem. It appears that Ash underestimated the time required for this task and is suggesting that maintenance will handle any problems that may arise. We pointed out that this would not be sufficient for FEMA and that he must address the watershed sediment yield and total scour in any way he feels is adequate. We suggested several equations with which he agreed. The question of safety factor did not arise. If he is still not clear I suggest that Don call a meeting so that this can be settled. Let me know whatever you decide to do. Thanks

-----Original Message-----
From: **Michael Lopez - FCDX**
Sent: Thursday, March 26, 1998 1:36 PM
To: Don Rerick - FCDX; Kofi Awumah - FCDX
Cc: Pedro Calza - FCDX
Subject: RE: Bullard Wash Project - CLOMR Requirements and Channel Design

I defer to Kofi on the FS. The sediment analysis is in PAC's court. Thanks.

-----Original Message-----
From: Don Rerick - FCDX
Sent: Thursday, March 26, 1998 1:04 PM
To: Kofi Awumah - FCDX; Michael Lopez - FCDX
Cc: 'OLBERTBD@SVERDRUP.COM'; 'WOODPATL@NETZONE.COM'; Pedro Calza - FCDX; Don Rerick - FCDX
Subject: Bullard Wash Project - CLOMR Requirements and Channel Design

I received a call from the consultant asking some questions regarding a very recent memo from Kofi (which I have not seen) outlining certain criteria to be used in analyses to be done to support the channel design and the CLOMR. Some clarification is needed so that the consultant can move forward with design.

1. What safety factors are to be used for scour calcs; 1.3 (as provided by Shapiro and Lopez(?)or 1.5 as provided by Kofi.

2. What method is to be used for the sediment analysis. At our meeting on the CLOMR tasks held Dec. 11, this subject was discussed, and my notes indicate that no direction was given then, but that the FCD was to provide direction to the consultant. Apparently this has been done in this recent memo, stating that the HEC-6 analysis is required. This is apparently more than Wood/Patel was expecting to do.

3. Also, there is some question about how conservative to be in the analysis for the sediment versus O&M requirements, "back-to-back" storms, etc.

Please respond to these concerns, and if necessary we may need to have a conference call, or only if that doesn't work, maybe a meeting to clarify these concerns so the design can move forward.

Thanks.