Technical Memorandum

URS

7720 N. 16th Street
Suite 100
Phoenix, Arizona 85020
602.371.1100 Tel
602.371.1615 Fax

Action	Info	File
Sediment Transport Analysis for Waterman Wash		23445383.08400

From Elliot Silverston, Ph.D., PE
Hui-Ming 'Max' Shih, Ph.D., PE, CFM
Adam Lacey, EIT

Date June 28, 2011

Subject **RVADMP – Waterman Wash Sediment Transport Analysis**

1 – INTRODUCTION

The purpose of this technical memorandum is to present the methodology and analysis results of the Waterman Wash morphology and sediment transport study in Rainbow Valley, Arizona. This study is part of the overall Rainbow Valley Area Drainage Master Plan (RVADMP) for the Flood Control District of Maricopa County (District). The Waterman Wash drainage area is about 450 mi^2. The Waterman Wash study reach begins at the confluence with the Gila River and extends approximately 16.4 miles upstream. Channel bed inverts vary from El. 1,144 feet upstream to El. 858 feet downstream with an average channel slope of 0.3%. **Figure 1-1** shows the general project location and study reach. This memorandum contains the fluvial channel analysis including:

1. Stream Morphology Assessment,
2. Cross Section Geometry Assessment, and
3. Channel Sediment Delivery Rate Analysis for frequency storms and long-term duration.

Historical aerial images were utilized for the channel platform variation analysis. Stream platforms were classified based on the Rosgen Stream Classification System (D.L. Rosgen, CATENA, 1994). Copeland's method (USACE, 1994) and the empirical channel width equations were used to theoretically define the equilibrium channel dimensions – channel width, depth, and slope – for a forming discharge and sediment load. For channel sediment transport analysis, the river hydraulic analysis program, HEC-RAS 4.1, developed by the U.S. Army

Corps of Engineers was utilized for channel hydraulic and sediment transport modeling. Six major tributaries contribute runoff and sediment to the study reach in the Waterman Wash. Due to lack of gauged flow and sediment data, sediment transport rating curves were estimated and used to compute the lateral sediment flows corresponding with tributary flows to Waterman Wash. General sediment transport trends and a long-term sediment transport simulation, were also discussed. The sediment delivery at each computation cross section was compared with the sediment delivery from its upstream cross section to identify incremental channel deposition or scour.

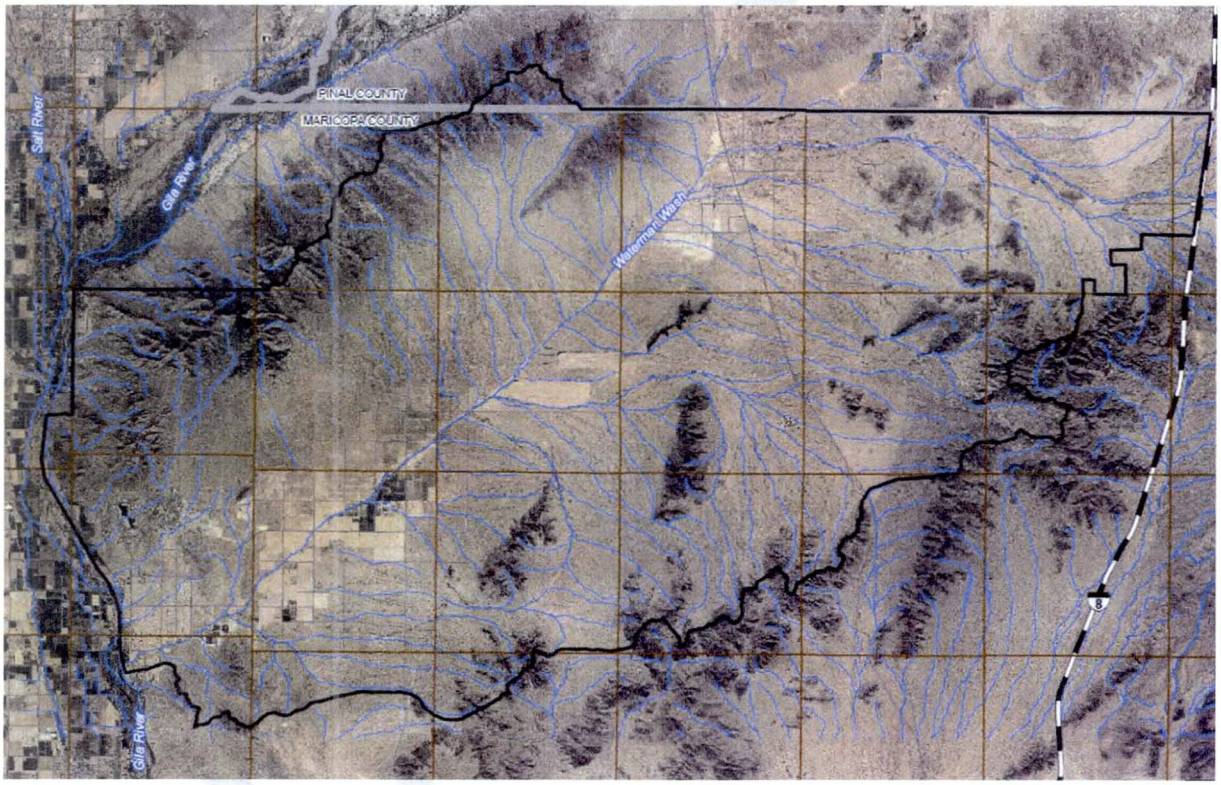


Figure 1-1
Location of the Waterman Wash in Maricopa County, Arizona

This study was implemented and complied with the following study guidelines and regulations.

1. Army Corps. HEC-RAS v.4.1 (2010) User's manual and Hydraulic Reference.
2. Drainage Design Manual, Hydraulics, for Maricopa County, Arizona (June 2010, Draft).
3. Design Manual for Engineering Analysis of Fluvial System, Department of Water Resources, Arizona (1985).

4. U.S. Army Corps of Engineers. (1994). Channel Stability Assessment for Flood Control Projects. EM-1110-2-1418. Washington, D.C.

Select pages of relevant references and documents are provided in **Attachment A**.

The following information/documents were provided by the District or obtained from previous tasks conducted for the RVADMP:

1. Historical aerial photographs from 1937, 1949, 1993, 1999, 2001, 2005, and 2008.
2. HEC-RAS steady flow model for the Waterman Wash.
3. Channel bed sediment samples including particle size and friction.
4. Rainbow Valley – Hydrology Report: Inflow hydrographs of frequency storms, 10-yr, 25-yr, 50-yr and 100-yr, events from upstream study limit and tributaries.
5. Related field information and photographs.

A map showing the sediment sample locations, Figure A-1 is also provided in **Attachment A**.

2 – GEOMORPHIC ANALYSIS

2.1 – Stream Morphology Assessment

The channel from Waterman Wash to the Gila River was separated into five distinct reaches, or segments, based on channel platform constraints which include bridge crossings and roads. The study reaches are shown in **Figures B-1** and **B-2** in **Attachment B**. Historical stream parameters were measured using GIS software and aerial photographs from 1937, 1949, 1993, 1999, 2001, 2005, and 2008. The summarized results are shown in **Table 2-1**. Historical channel platforms indicate that the downstream reaches 4 and 5 have approximately remained in the same pattern since 1937, and the upstream reaches 1, 2, and 3 have been meandering with an approximate maximum meander width of 500 feet.

Stream platforms were classified based on the Rosgen Stream Classification System (D.L. Rosgen, CATENA, 1994). The Rosgen classification system has been widely adopted by water professionals and is a useful tool for evaluating and comparing stream channel conditions. The Rosgen system classifies streams based on channel geomorphology, gradient, sinuosity and function. The classification system is stratified into three progressive levels, based on channel form, dominant substrate, and gradient. In this study, the Level 3 Rosgen classification system

was employed to identify the current conditions of the Waterman Wash reaches. The required variables for the stream evaluation are defined below:

$$\text{Channel Entrenchment, } E = \frac{W_f}{W_b} \qquad \text{Eq. 1}$$

where w_f= floodplain width, and W_b = bankfull width.

$$\text{W/D Ratio} = \frac{W_b}{D_b} \qquad \text{Eq. 2}$$

where D_b = bankfull depth.

$$\text{Channel Sinuosity, } \Omega = \frac{L_c}{\Lambda} \qquad \text{Eq. 3}$$

where L_c = channel length, and Λ = meander length.

A detailed diagram of the Level 3 Rosgen classification system and channel condition evaluations is presented in **Attachment B**. Summarized results of the current channel condition evaluations are presented in **Table 2.2**.

Generally, "A" channels are typically found near the headwaters of mountain streams. Lower gradient "B" channels are characteristic of streams flowing though alluvial plains and broad mountain valleys below the headwaters. "C" and "E" channels tend to be found in lower elevation reaches with broad floodplains and low gradients. The bed slope of Waterman Wash is between 0.26% to 0.4%. The bed material for upstream reaches 1 and 2 is primarily composed of fine gravel, and the downstream reaches 3, 4, and 5 are primarily composed of coarse sand and fine gravel. Commonly, Waterman Wash is wide, and shallow with a relatively straight channel. Sinuosity ranges between 1.02 to 1.06. Reaches 1 and 2 were classified as Rosgen Type C4 and Reaches 3, 4, and 5 were classified as Rosgen Type D5.

Table 2.1
Waterman Wash Evaluation using the Rosgen Stream Classification System

Reach	Year	Channel Length (ft)	Meander Width (ft)	Meander Length (ft)	Sinuosity
Reach 1	2008	14,150	660	13,900	1.02
	2005	14,180	590	13,900	1.02
	2001	14,100	660	13,900	1.01
	1999	14,125	690	13,900	1.02
	1993	N/A	N/A	N/A	N/A
	1949	N/A	N/A	N/A	N/A
	1937	14,200	690	13,900	1.02

Reach	Year	Channel Length (ft)	Meander Width (ft)	Meander Length (ft)	Sinuosity
Reach 2	2008	8,610	1,110	8,200	1.05
	2005	8,550	1,110	8,200	1.04
	2001	8,580	990	8,200	1.05
	1999	8,530	990	8,200	1.04
	1993	8,550	1,110	8,200	1.04
	1949	N/A	N/A	N/A	N/A
	1937	8,700	1,130	8,200	1.06
Reach 3	2008	12,520	575	12,300	1.02
	2005	12,590	570	12,300	1.02
	2001	12,580	590	12,300	1.02
	1999	12,550	570	12,300	1.02
	1993	12,540	550	12,300	1.02
	1949	N/A	N/A	N/A	N/A
	1937	12,700	710	12,300	1.03
Reach 4	2008	18,170	1,290	17,500	1.04
	2005	18,200	1,270	17,500	1.04
	2001	18,280	1,250	17,500	1.04
	1999	18,180	1,142	17,500	1.04
	1993	18,270	1,290	17,500	1.04
	1949	18,280	1,090	17,500	1.04
	1937	18,430	1,150	17,500	1.05
Reach 5	2008	17,990	850	16,700	1.08
	2005	17,670	875	16,700	1.06
	2001	17,700	880	16,700	1.06
	1999	17,700	870	16,700	1.06
	1993	17,680	900	16,700	1.06
	1949	17,670	890	16,700	1.06
	1937	N/A	N/A	N/A	N/A

Table 2.2
Waterman Wash Evaluation using the Rosgen Stream Classification System

Reach	Channel	Entrenchment	W/D Ratio	Sinuosity	Slope	Channel Material	Rosgen Stream Classification
1	Single	Slightly	55	1.02	0.0026	Fine gravel	C4
2	Single	Slightly	23	1.05	0.0031	Fine gravel	C4
3	Multiple (Braided)	Moderate	33	1.02	0.0031	Coarse Sand and Fine Gravel	D5
4	Multiple (Braided)	Moderate	27	1.04	0.0033	Coarse Sand and Fine Gravel	D5
5	Multiple (Braided)	High	67	1.06	0.0040	Coarse Sand	D5

2.2 – Cross Section Geometry Assessment

An equilibrium channel cross section is affected by channel cross section geometry, bed slope, upstream sediment supply, vegetation covers, sediment particles, channel forming discharge, and other hydraulic and physical constraints. Work conducted for other tasks of the RVADMP provided the frequency storm hydrographs, bed material gradation, and a steady flow HEC-RAS model of the Waterman Wash presented herein. Typically, floods with a return periods in the range of 2-year ~ 5-year are measured to be the channel forming discharge for natural channels. According to the field observation and hydraulic analysis, the observed stable cross sections indicate that the estimated 5-year discharge is approximately the bankfull discharge. Consequently, 5-year discharge is assumed as the forming discharge for the Waterman Wash.

The forming discharges at the representative cross sections are shown in **Table 2-3**.

Table 2-3
Channel Forming Discharges at the Representative Cross Sections in the Waterman Wash

Cross-Section	Forming Discharge, Q_5 (cfs)
16.72	389
15.65	398
14.40	543
14.30	497
8.44	933
6.68	974
4.00	983
3.69	989

Sixteen representative cross sections were selected for channel equilibrium assessment along Waterman Wash as shown on Figure C-1 in **Attachment C**. Channel width, channel roughness, and bed slope were approximated from a 2008 aerial image and from the HEC-RAS model developed for the floodplain analysis. The existing bankfull depth was estimated using the forming discharge with a bank side slope of 3H:1V. A summary table for the existing cross section characteristics is presented in **Attachment C**. Currently, the existing channel width varies between 40 feet and 180 feet. The bankfull depth varies between 1.4 feet and 3.1 feet.

The Hydraulic Design – Stable Channel Design module in HEC-RAS was developed based on the Copeland's method (US ACE, 1994). The module is able to calculate the theoretical equilibrium channel dimensions (channel width, depth, and slope) for a forming discharge and sediment load. The output provides dynamic equilibrium curves based on each given cross

section geometry, bed material, and upstream sediment supply. However, these theoretical dynamic equilibrium curves present multiple solutions for a stable channel design. Soar and Thorne (2001) suggests that using the empirical width equations developed from hydraulic geometry attributes of stable natural field channels could enhance the predictions of stable channel geometry along the theoretical equilibrium curves. **Figure 2-1** illustrates the enhanced stable channel geometry range by using the empirical channel width equation.

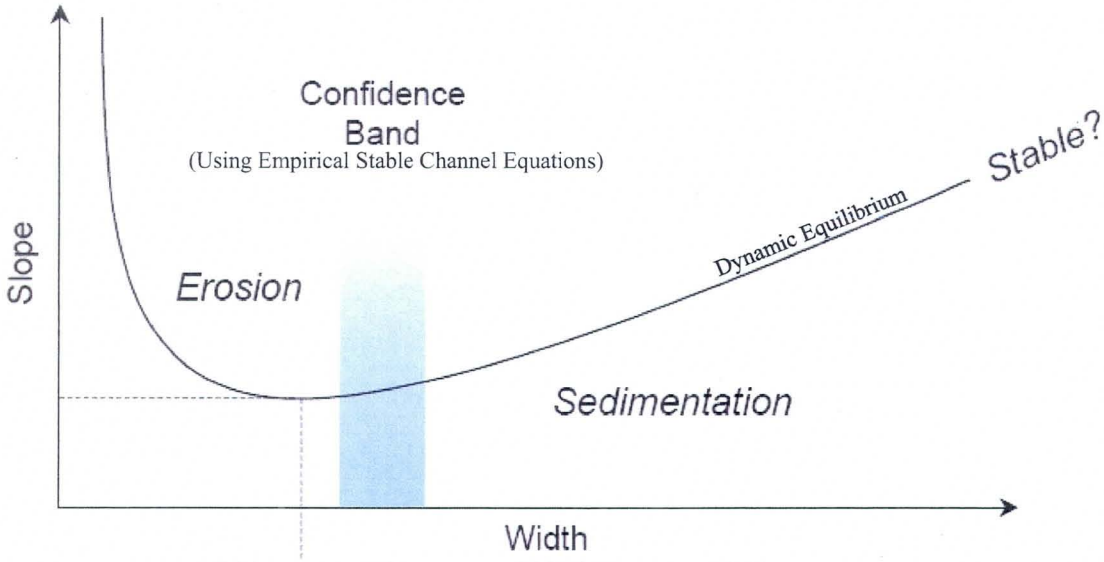


Figure 2-1
Enhanced Stable Channel Geometry on the Theoretically Dynamic Equilibrium Curves

Waterman Wash bed material is primarily comprised of coarse sands and fine gravels. The empirical channel width equation presented in Hey and Thorne (USACE, 2001) for gravel bed channels was coupled with the computed equilibrium curves to indicate a confidence range for predicted stable geometry. Hey and Thorne's 1986 empirical equation developed for natural stable gravel-bed channels with resistant banks is presented as Eq. 4.

$$W_b = a \cdot {Q_b}^b \qquad \text{Eq. 4}$$

Where: W_b = Channel bankfull width; Q_b = bankfull discharge and forming discharge in this study; a = discharge coefficient = 2.45 (2.33-2.58, 95% confidence limits); and B = discharge exponent and 0.57.

Predicted stable channel geometry for the analyzed cross sections under existing conditions is presented in **Attachment C**. These analyzed results describe the possible channel geometry variation for future conditions. Additionally, the changes between the current conditions and possible future stable conditions illustrate the channel evolution sequences.

The Channel Evolution Model (CEM) by Schumm et al. (1981 and 1984) was implemented to define the channel evolution phase for the current reaches. The CEM (**Figure 2-2**) consists of six channel-reach types, which describes the evolutionary phases typically encountered in an incised channel. These evolutionary phases range from strong disequilibrium to a new state of quasi-equilibrium. **Table 2-4** presents the channel evolution phases of the selected cross sections in Waterman Wash. Generally, the upper Waterman Wash reach is a Phase III channel, which implies that bed degradation is the dominant process. The middle Waterman Wash reach is a Phase V channel, meaning that bank erosion and bed aggradation are the dominant processes. The lower Waterman Wash reach is a Phase VI channel or a Phase V channel. This reach is approaching a quasi-equilibrium condition, meaning sediment inflow from the forming discharge is approximately equal to the sediment transport capacity at the selected cross sections and these cross sections are under stable conditions. The detail analysis is presented in **Attachment C**.

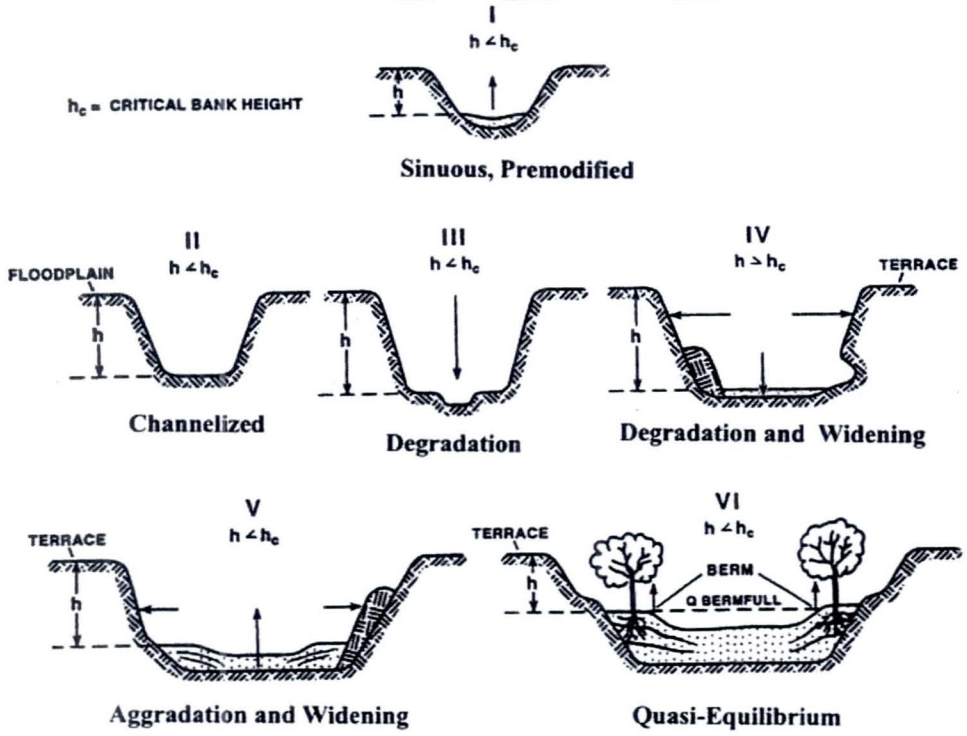


Figure 2-2
Incised Channel Evolution Sequence (Schumm et al., 1984)

Table 2-4
Channel Evolution Phase for the Existing Cross Sections in Waterman Wash

Station	Bankfull Discharge (cfs)	Incised Channel Evolution Phase
15.65	398	III, Degradation
14.49	398	V, Aggradation & Widening
13.53	497	III, Degradation
12.42	497	III, Degradation
11.45	497	V, Aggradation & Widening
10.45	497	IV, Degradation & Widening
9.40	497	V, Aggradation & Widening
8.29	933	V, Aggradation & Widening
7.31	933	V, Aggradation & Widening
6.34	974	V, Aggradation & Widening
5.20	974	V, Aggradation & Widening
4.23	974	III, Degradation
3.31	989	V, Aggradation & Widening
2.17	989	VI, Quasi-Equilibrium
1.24	989	III, Degradation
0.27	989	V, Aggradation & Widening

3 – SEDIMENT TRANSPORT ANALYSIS

HEC-6 (USACE, HEC 1993) is a one-dimensional moveable boundary open channel flow numerical model designed to simulate and predict changes in river profiles resulting from scour and deposition over moderate time periods. HEC-6 was replaced by the US Army Corps of Engineers' HEC-RAS program in 2008. The sediment transport modeling in HEC-RAS is a quasi-unsteady hydraulic computation. A continuous discharge record is partitioned into a series of steady flows of variable discharge and duration. For each discharge, a water-surface profile is calculated, providing energy slope, velocity, depth, and other variables at each cross section. Potential sediment transport rates are then computed at each section. These rates, combined with the duration of the flow, permit a volumetric accounting of sediment within each reach. The amount of scour or deposition at each section is then computed and the cross-section geometry is adjusted for the changing sediment volume. Computations then proceed to the next flow in the sequence and the cycle is repeated using the updated cross-section geometry. Sediment calculations are performed by grain size fractions, allowing the simulation of hydraulic sorting and armoring.

HEC-RAS is a powerful tool that allows the engineers to estimate the channel responses to a predicted series of water and sediment supply. The primary limitation is that HEC-RAS is one-dimensional program. The computed geometry is adjusted only in the vertical direction and average hydraulic parameters are assumed in the computations.

Per aforementioned channel geomorphology and cross section stability assessments, Waterman Wash would be continuously widening and meandering in an effort to reach stable conditions. Due to the application limitation of HEC-RAS, the bed aggradation and degradation is only considered in the vertical direction, as it is not capable of practically simulating the horizontal variation in bed aggradation and degradation. Additionally, the input hydrograph is a combined hydrograph consisting of a series of unit hydrographs over time. The input hydrograph is not based on recorded/gauged flow data. Therefore, it is important to mention that the computed quantity of bed aggradation and degradation would only provide an approximate channel bed variation prediction, excluding changes of platform and widening widths. Generally, the computed sediment delivery rate is recommended to evaluate the bed erosion and deposition in each reach. Sediment delivery is defined as the cumulative amount of sediment that has been delivered passing a certain channel section for a specified period of time. Sediment delivery is widely employed by engineers for watershed management. It is also used to keep track of sediment supply and removal along the channel reach.

In this memorandum, HEC-RAS v.4.1 was used to perform the sediment transport simulations for single storm events and flood series over a long-term duration. No local scour/deposition at specific structures, such as bridges, abutments, peers, and grade controls, was estimated herein. The sediment transport models are attached in **Attachment I**. The sediment transport for single storm events and flood series over a long term duration are summarized in **Attachments F** and **G**, respectively. The input parameters and model schematics are presented in the following sections.

3.1 – Hydrology

Sediment delivery rates in the stream will closely follow the flow pattern since water is the primary agent for channel sediment transport. In order to model fluvial and sedimentation processes in Waterman Wash, the stream flow must be established using flood frequency hydrographs. A hydrograph is a representation of the stream flow over time at a point of interest. In this memorandum, the frequency hydrographs for the 10-, 25-, 50-, and 100-year events in the upstream study reach and tributaries were obtained from the Rainbow Valley – Hydrology Report as a part of the RVADMP.

Figure 3-1 shows the inflow hydrographs for the frequency storms at the Waterman Wash upstream study limit at Station 16.72 (ST. 16.72). These hydrographs were used for the storm event based sediment transport analyses. The frequency storm hydrographs from each of the tributaries are shown in **Attachment D**.

A long-term sediment transport simulation was also conducted as part of this sediment transport study. According to the Maricopa County Drainage Design Manual (2010) and Design Manual for Engineering Analysis of Fluvial Systems (Arizona Department of Water Resources, 1985), a series floods over a 100-year time span is recommended to represent long-term channel flow. Over a 100-year period, it can be statistically expected that the 100-year flood will be exceeded once, two events will exceed the 50-year flood, four events will exceed the 25-year flood, ten events will exceed the 10-year flood, etc. **Figure 3-2** shows a random sequence of events over a 100-year time span at the Waterman Wash upstream study limit, ST. 16.72, used for the flood series analyses, since the sequence of occurrence of the floods is beyond prediction. The peak event near the middle of the flood series is the 100-year hydrograph. The 100-year flood series from tributaries are shown in **Attachment D**. These flood series were used to compute the long-term sediment delivery in the Waterman Wash.

These obtained inflow hydrographs and the simulated sequence flood series from the upstream study limit and tributaries were utilized in HEC-RAS models to compute the correlated equilibrium sediment inflows by using sediment transport rating curves.

DRAFT

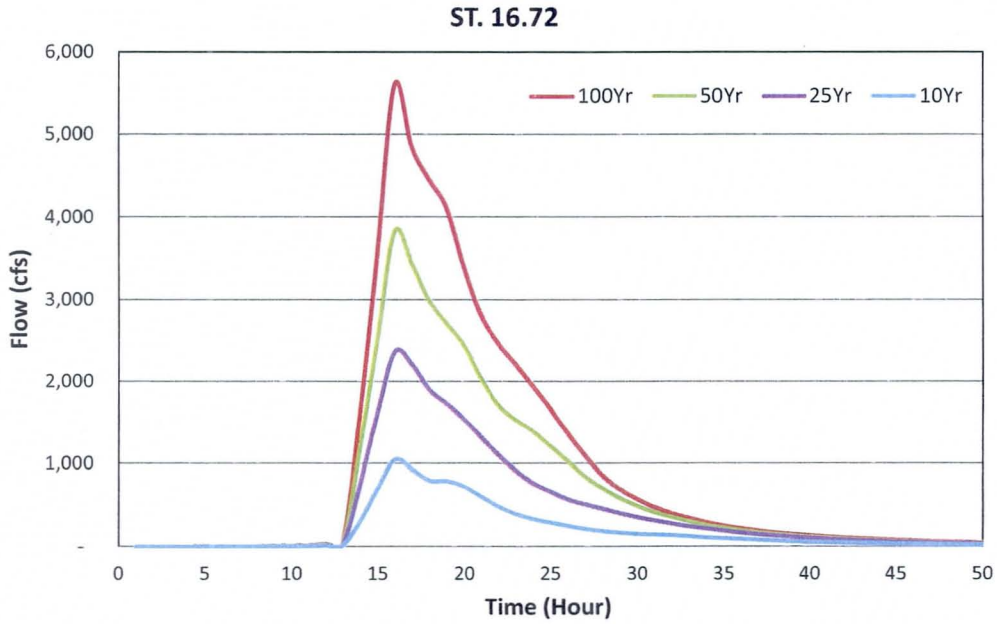


Figure 3-1
Frequency Storm Hydrographs at ST. 16.72,
where the Upstream Study Limit of Waterman Wash

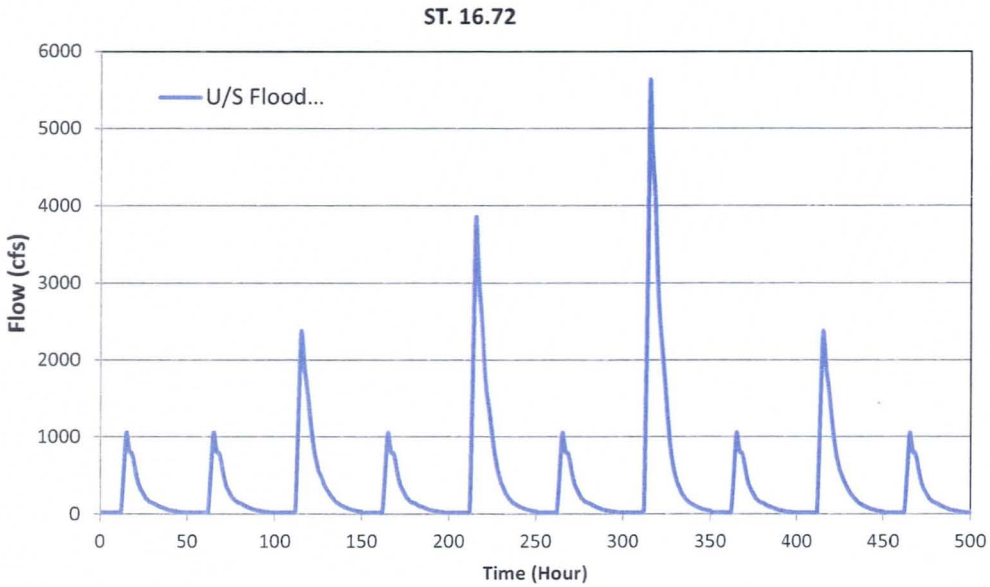


Figure 3-2
100-year Series Flood Hydrographs at the Upstream Study Limit
of the Waterman Wash ST. 16.72

3.2 – Bed Material Gradation & Selection of Sediment Transport Equation

Per the sediment samples obtained from the study area, the channel deposits predominantly consist of fine gravels and coarse sands. The sampling for the gradation analysis was obtained from the channel bed and the channel banks for Waterman Wash and tributaries. The grain size D_{50} ranged between 0.15 to 12.7 mm. Upon reviewing the samples obtained from the channel banks, it was decided that most of the channel bank soil samples were not representative of the material in the channel bed. The grain size distributions were assigned to the appropriate cross sections in the HEC-RAS models. Particle gradations were assigned/calculated using the option in HEC-RAS for a cross section that contained no gradation data. Cross sections were also interpolated in HEC-RAS wherever necessary for modeling purposes. The HEC-RAS default grain classes were used for sediment diameters. Percent finer data was entered if the respective particle sizes fell within the HEC-RAS default range for grain size.

The selection of sediment transport equations was based on the predominant channel bed particles, flow hydraulics, and channel geometries. The average Waterman Wash slope is approximately 0.3%. The dominant bed material for the most of tributaries and upstream reaches is fine gravel and is transported downstream. Based on these channel characteristics, the Meyer Peter Muller equation (1948) was selected for the sediment transport model for the Waterman Wash.

3.3 – Sediment Rating Curve Analogy Analysis

Because there is no stream gauge data or sediment gauge data for the contributing tributaries, the sediment-rating curve analogy was applied to estimate the equilibrium sediment transport capacities from the supply tributaries. This analogy requires the following: grain size distribution for supply reaches, an estimated range of peak flows, and a description of hydraulic characteristics of each supply reach. Hydraulic information is based on normal depth calculations. Sediment transport capacity is calculated for a range of discharges in the supply reaches. The sediment rating curve analogy analysis is suitable for streams where the sediment supply is not limited and consists of an equilibrium sediment transport capacity with its flow discharge.

There are six major tributaries that contribute sediment to Waterman Wash were used for this analysis. A representative cross section was selected for each tributary. Normal flow calculation for a simple trapezoidal cross section with an average channel slope was utilized to compute channel hydraulics for a range of peak flows. As previously stated, the Meyer Peter Muller equation (1948) was selected for computing the transport capacity (q_s).

$$q_s = \frac{RKR^{\frac{3}{2}} \cdot \gamma_w \cdot D \cdot S - 0.047 \cdot \gamma_w \left(G-1\right) \cdot d_s}{0.25 \cdot \left(\frac{\gamma_w}{g}\right)^{\frac{1}{3}} \cdot \left(\gamma_w \frac{G-1}{G}\right)^{\frac{2}{3}}}^{\frac{3}{2}} \cdot B \qquad \text{Eq. 5}$$

Where: G= specific gravity of sediment; r_w=unit weight water in lb/ft^3; g= acceleration of gravity and 32.2 ft/sec^2; D= flow depth in feet; S= channel slope; d_s= median particle diameter in feet; and RKR =Nikaradse roughness ratio and shown as

$$RKR = \frac{\overline{f'}}{8} \cdot \frac{V}{\overline{g \cdot D \cdot S}} \qquad \text{Eq. 6}$$

Where: V= flow velocity in ft/sec; and f'= friction factor duce to particle size and expressed as

$$f' = \frac{2.82843}{BCoeff - 3.75 + 2.5 \cdot ln\ 2 \cdot \frac{D}{d_{90}}}^{2} \qquad \text{Eq. 7}$$

Where: d_{90}= 90% finer particle size in feet; and $BCoeff$= Schlichting's B coefficient and is estimated by using

$$BCoeff = \begin{cases} 5.5 + 2.5 \cdot ln\ R_s & , if\ R_s \leq 5 \\ 0.297918 + 24.8666 \cdot log\ R_s - 22.9885 \cdot log\ R_s^{\ 2} \ldots \\ \quad + 8.5199 \cdot log\ R_s^{\ 3} - 1.10752 \cdot log\ R_s^{\ 4} & , if\ 5 < R_s \leq 70 \\ 8.5, otherwise \end{cases} \qquad \text{Eq. 8}$$

Where: R_s= Shear Reynold's number.

$$R_s = \frac{u_* \cdot d_{90}}{\upsilon} \qquad \text{Eq. 9}$$

Where: v= kinematic viscosity in ft^2/sec; and u_*=Shear velocity in ft/sec.

$$u_* = \overline{g \cdot D \cdot S} \qquad \text{Eq. 10}$$

The HEC-RAS sediment transport module computes the sediment unit discharge and converts it to mass per unit time (tons/day). The selected representative cross sections, tributary profiles, and estimated sediment-rating curves and tables for each tributary are presented in **Attachment E**.

3.4 – Boundary and Initial Conditions, and Parameters in HEC-RAS Models

The cross section geometry and Manning's roughness coefficients used for the sediment transport analysis were obtained from the Waterman Wash HEC-RAS steady flow model developed for the floodplain delineation task. It should be noted that many of the cross sections from the floodplain delineation HEC-RAS model were removed due to the fact that many of the sections were either at or near critical flow. The sediment transport model requires selecting a sorting method to compute the active layer thickness and vertical bed layer tracking assumptions. The Exner 5 method is a three layer active bed model that includes the capability of forming a coarse surface layer that will limit erosion of deeper material, thereby simulating bed armoring (Reference User Manual HEC-RAS). A mobile bed limit is set for each cross section to set limits for the lateral erosion and depositions. Adjusting the limits is an iterative process based on the extents of erosion and deposition along the cross-section. In this study, channel deposition and erosion are allowed to occur only between main channel bank limits. A constant temperature of 60°F was assumed through the entire simulation time.

The Report 12 method, which is a default in HEC-6 is being used to compute the fall velocity. The maximum depth of sediment that can be eroded below the channel invert is set at 10 feet. In order to achieve a numerically stable model, a computation increment of 18 seconds, a maximum interval distance of 500 feet between cross sections, initial discharge, and warm-up computation durations were utilized to perform numerically stable sediment transport models.

3.5 – Sediment Transport Modeling Results

HEC-RAS analyses were performed for the frequency storms and 100-year flood series events for the existing Waterman Wash conditions. The HEC-RAS output files are included on the CD in **Attachment I**. The result outputs were summarized and shown in **Attachments F and G.** The summary output lists the cross section station, initial channel elevation, total accumulated elevation change, sediment delivery, and bed aggradation/degradation.

Spatial variations in sediment delivery along Waterman Wash during the 10-year, 25-year, 50-year, and 100-year frequency storm events, and a long-term scenario based on 100-year series floods are presented as longitudinal profiles along the river station in **Figure 3-3**. A decreasing sediment delivery in the downstream direction (i.e. negative gradient for the sediment delivery-station curve) means that sediment load is partially stored in the channel to result in net deposition in local reach variation. On the other hand, an increasing sediment delivery in the downstream direction (positive gradient for the sediment delivery-station curve) indicates sediment removal from the channel boundary or net scour. A uniform sediment delivery along the channel (horizontal curve) indicates a sediment balance reaching dynamic equilibrium. These

results indicate the downstream segments of the wash approximately reach quasi-equilibrium, which concurs with the geomorphic analysis results in **Section 2**. The estimated total sediment delivery is approximately 15,000 tons after the 100-year flood series, and is about 150 tons per year from the Waterman Wash system. This sediment loading results may be underestimated since the minor storm events were not included in the simulation.

In **Figure 3-3**, the output sediment delivery-station curve under long-term flood conditions indicates that Waterman Wash generally tends to scour sediment from the channel.

In general, the computed local reach variation results show that sedimentation occurs upstream of tributary confluences and decreases bed slopes in the downstream direction. Channel scour happens downstream of tributary confluences and increases bed slopes in the downstream direction. The most prevalent scour conditions are shown in the upstream reaches which corresponds with the geomorphic analysis results in **Section 2**.

Spatial variations in channel bed elevation during the 10-year, 25-year, 50-year, and 100-year frequency storm events, and the long-term scenario based on 100-year flood series are presented as longitudinal profiles along the river station in **Figures 3-4**. The computed maximum scour depth is less than 2ft, and the computed maximum sedimentation height is less than 0.5ft.

A stream gauge, ID #6833, is located on the Rainbow Valley Road bridge over Waterman Wash. The trend of the recorded gauge heights of the approximately same discharges can indicate channel degradation in the period of 1999-2010. The channel degradation at this stream gauge was estimated using the recorded gauge heights and discharges. The computation is shown in **Attachment H**. The estimated bed scour is approximately 0.65ft caused by local bridge scour and channel general scour. According to the 10-year and 25-yr sediment transport analysis outputs, the simulated general scour at the approximate stream gauge location is about 0.25 and shows a good agreement with the site tendency and field observation.

As results indicate, the confluences with tributaries result in deposition immediately upstream and scour immediately downstream along Waterman Wash. An approximate horizontal invert change-station line expresses the downstream reach has approximately reached equilibrium conditions, and most future channel scour would be in the upstream reaches. In addition, the computed bed degradation for the long term event would be considered as general scour for an in-channel structure design, such as bridges and abutments. The estimation of local scour depth due to structures was not considered in this study.

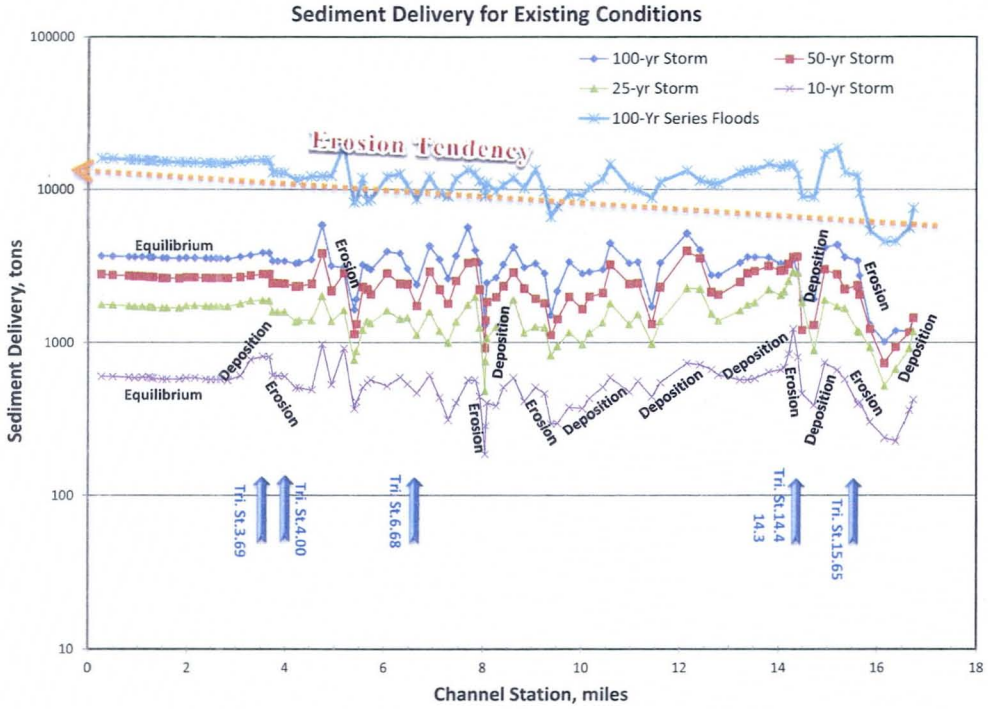


Figure 3-3
Total Sediment Delivery for the Waterman Wash during the Analyzed Events

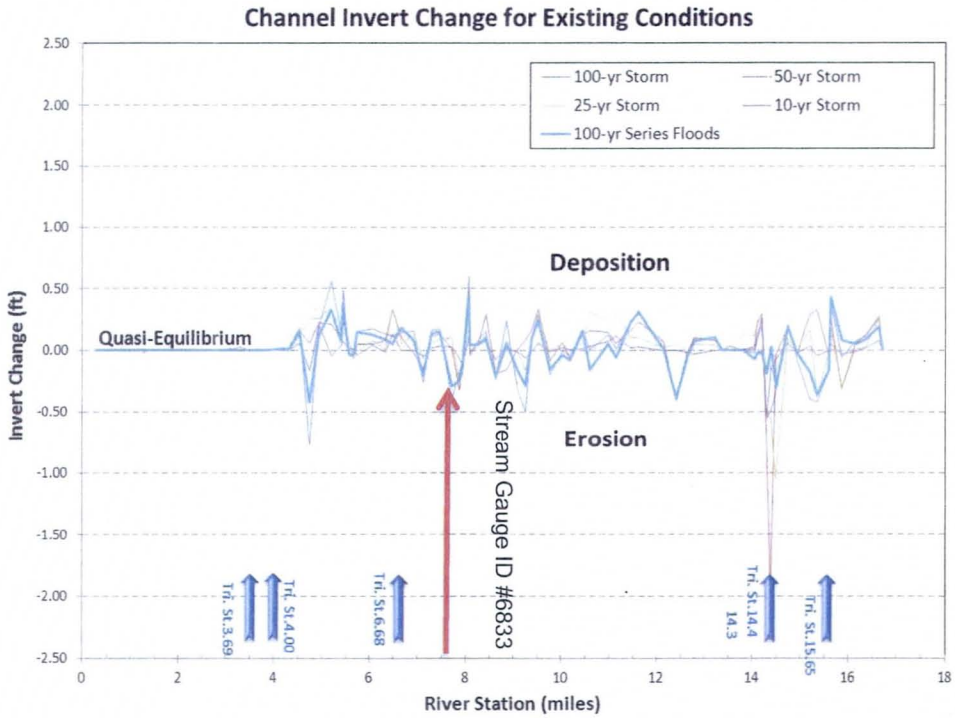


Figure 3-4
Total Channel Invert Change for the Waterman Wash during the Analyzed Events

4 – CONCLUSIONS

Fluvial geomorphology assessments for the channel platform and cross sections were conducted based on field data and historical aerial images. Channel type and stability were estimated and used to indicate future geometry variations. Detailed information are attached to this memorandum in **Attachments B** and **C**. In general, Waterman Wash is a relatively straight channel with small sinuosity. Upstream reaches are classified as an incising channel. Downstream reaches tend to reach dynamic equilibrium conditions. Widening channel cross sections would be the anticipated in the future for most of the middle reaches.

HEC-RAS modeling pertinent to this memorandum analyzed sediment transport trends in Waterman Wash. The primary intent was to determine the sediment delivery and channel invert change based on the existing channel conditions. Simulation results of the Waterman Wash study reach generally tends to scour sediment from the channel during the long-term scenario. The estimated degradation depths could be considered as the possible general scour depth. Frequency

storm scenario outputs pinpoint the critical locations of deposition and scour that could be considered for future management and structure design improvements.

It is important to mention that the computed quantity of bed aggradation and degradation would only provide an approximate channel bed variation prediction, excluding local scours, changes of platform and widening widths. Generally, the computed sediment delivery rate is recommended to evaluate the bed erosion and deposition in reaches. All summarized outputs, maps, and detail information are attached to this memorandum.

DRAFT

REFERENCES

U.S. Army Corps of Engineers. HEC-RAS v.4.1 (2010) User's manual and Hydraulic Reference.

U.S. Army Corps of Engineers. HEC-6 (1993) User's manual.

URS Corporation, *Rainbow Valley Area Drainage Master Plan Contract FCD 2006C029, Technical Data Notebook – Hydrology, Volumes I-IV,* October 2010.

U.S. Army Corps of Engineers. (1994). Channel Stability Assessment for Flood Control.

Projects. EM-1110-2-1418. Washington, D.C.

Drainage Design Manual, Hydraulics, for Maricopa County, Arizona (June 2010, Draft).

Design Manual for Engineering Analysis of Fluvial System, Department of Water Resources, Arizona (1985).

DRAFT

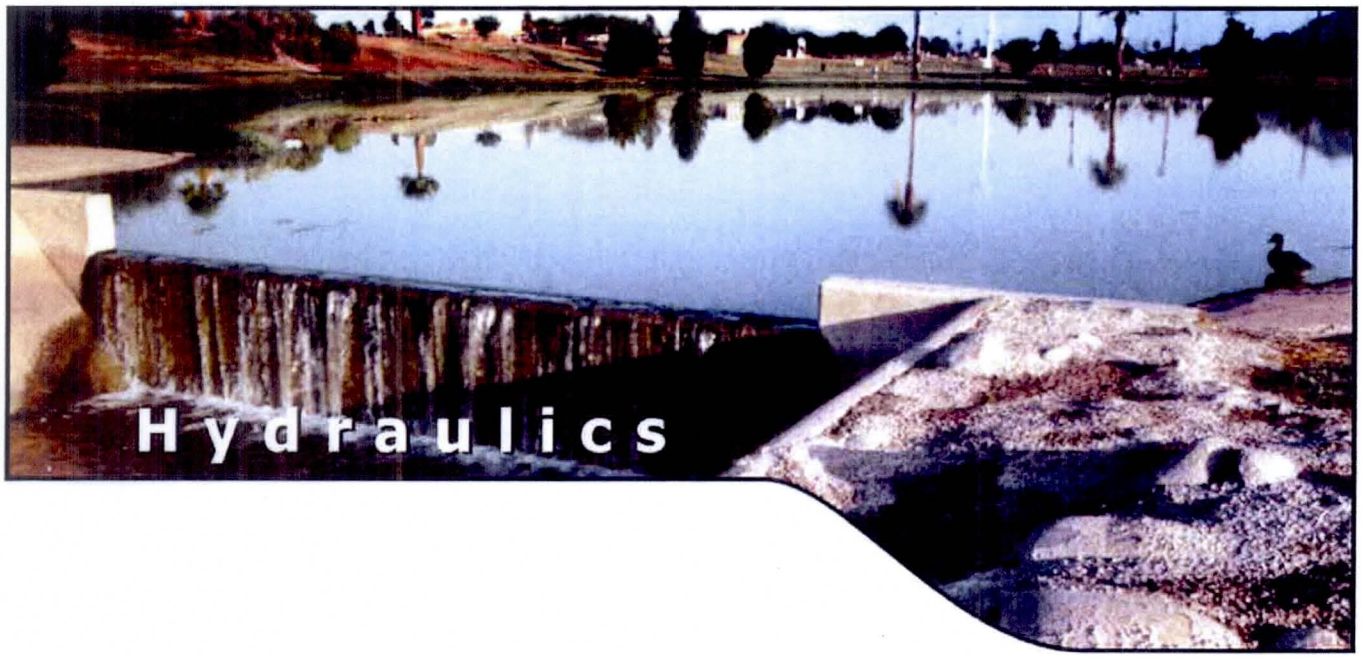
Attachment A

Relevant References

(Select Pages)

Drainage Design Manual

for Maricopa County, Arizona



2801 West Durango Street, Phoenix, Arizona 85009 (602) 506-1501

11.8.2.1 Long-Term Scour (Degradation)

Long-term degradation can be estimated by the following methods:

1. *A trend analysis of historic bed elevation data.*
2. *Simulation by use of sediment transport modeling such as HEC-6 (USACE, 1991), HEC-6T (MBH, 2002), FLUVIAL-12 (Chang, 2006), or other sediment transport modeling software subject to the District's approval prior to the modeling.*
3. *Application of equilibrium slope analyses.*
4. *Level I Analysis from Arizona State Standard 5-96 (ADWR, 1996).*

Trend Analysis

A trend analysis of historic bed elevation data is limited by the availability of adequate, long-term data for the watercourse. Therefore, such an analysis may be possible only for some of the major watercourses in Maricopa County. In addition, factors such as instream gravel mining and channelization of the watercourse may complicate such historic analyses.

Sediment Transport Modeling

Simulation modeling such as HEC-6, HEC-6T, FLUVIAL-12 or other District-approved software may provide useful results; however, whichever method chosen is dependent upon entering appropriate hydraulic data for the watercourse (hydraulic geometry and sediment characteristics). Furthermore, the results are highly sensitive to hydrologic input (flood magnitude-frequency relations, flow duration, shape of hydrograph, etc.). Simulation modeling may only be appropriate for regional studies of major watercourses, especially those for which structural flood control alternatives are being considered. Whenever data are available, site-specific calibration should be performed to calibrate the parameters in the model such that it can reproduce the historical scour/deposition. When applying the modeling approach to evaluating the scour/deposition hazard, the maximum scour or deposition during the entire simulation time period must be used as the design parameters. The flow hydrograph can be generated from historical flow records if they are available. Ideally, records for a period of one hundred years should be used. When there is no historical flow record, a synthetic long-term hydrograph can be generated. As indicated by Chang (2006), "In the time span of 100 years, one may expect statistically one flood event exceeding the 100-year flood, two events exceeding the 50-year flood, four events exceeding the 25-year flood, ten events exceeding the 10-yr flood, etc." Therefore, the following is a potential group of events that may be used for 100-year time span long-term simulation: one 100-year flood hydrograph, one 50-year flood hydrograph, two 25-year flood hydrographs, and six 10-year flood hydrographs. The sequence of flood events is subject to engineering judgment. Before the synthetic long-term hydrograph is used in the model, the FCDMC must approve the hydrograph.

The bed material sediment sampling should be based on Pemberton and Lara (1984). The inflowing sediment load for various discharges for the study reach may be estimated by (1) field

ARIZONA
DEPARTMENT OF WATER RESOURCES

DESIGN MANUAL FOR ENGINEERING ANALYSIS OF FLUVIAL SYSTEMS

1985

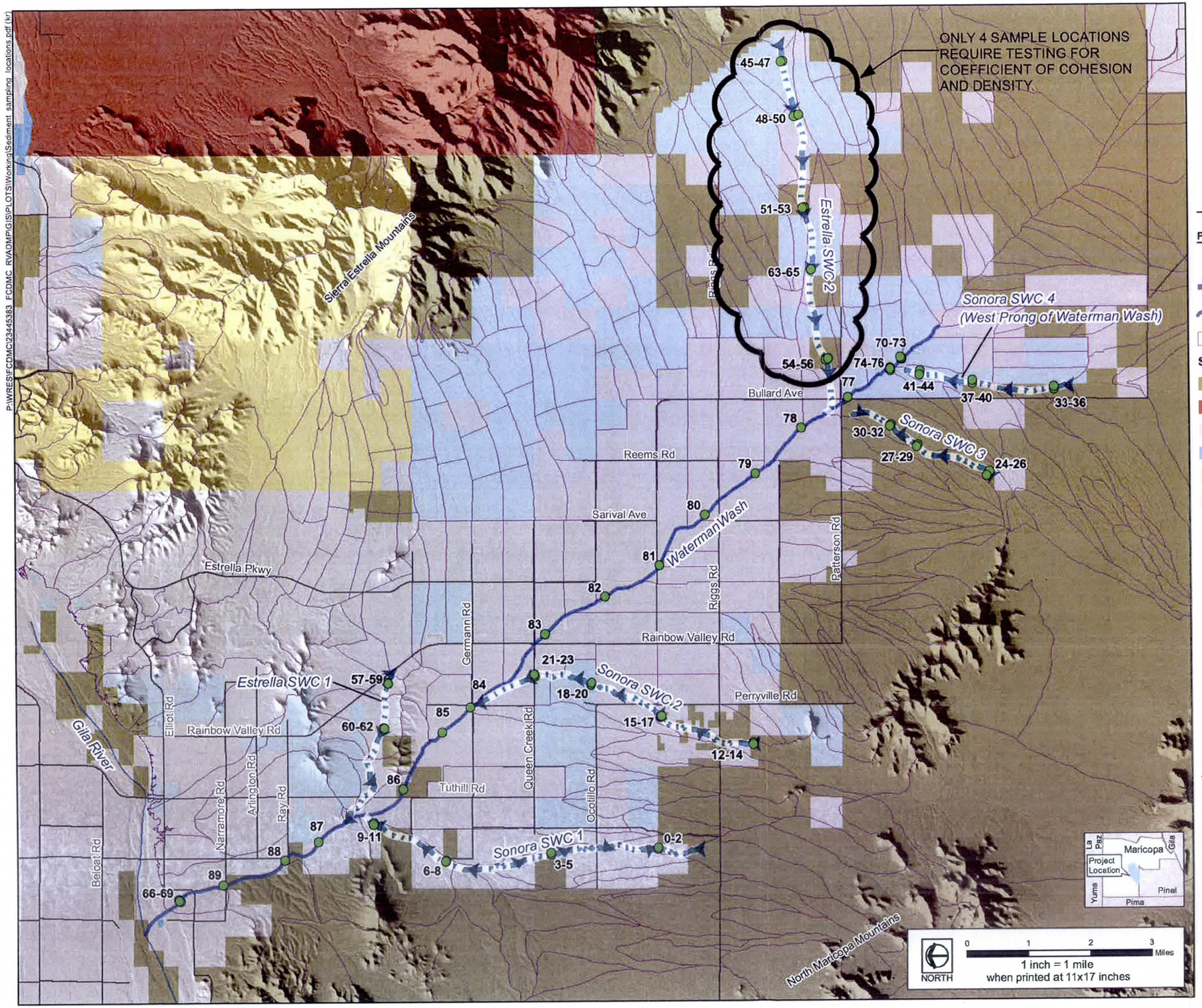
tial not only of a single event, such as a 100-year flood, but also the cumulative impact of a series of smaller flows. One approach to evaluating long-term erosion impacts is to develop a "representative" annual storm and then to extrapolate in time the effect of this storm. This concept is similar to the practice in hydrology of adopting the two-year flood as being representative of the annual event; however, for purposes of long-term erosion analysis the representative annual event can be more accurately defined by a probability weighting of the erosion resulting from several single storms (see Section 3.4). With this approach the long-term analysis of erosion potential accounts for the probability of occurrence of various flood events during any one year.

After establishing the representative annual storm for evaluating long-term erosion (lateral migration) potential, the duration in years defining the "long term" must be determined. For example, based on both the limitations of the probability weighting approach and the single-event probability of occurrence of a 100-year flood in a 25-year period (22 percent), a reasonable definition of the "long term" for an urban area might be 25 years. Thus the boundaries of an erosion and flooding buffer zone could represent the envelope established by the reach-by-reach calculation of the erosion and flooding potential of either the 100-year flood (short term) or the cumulative erosion impact of a series of smaller events over a 25-year period (long term), whichever is greater.

The buffer zone is then plotted by consideration of the controlling factor (100-year flooding, 100-year erosion, or long-term erosion) for each cross section used in the analysis. The boundary of the buffer zone between cross sections can be drawn as a smooth curve or as a series of tangent lines that can be easily referenced to existing survey data and readily compared with existing survey plats. The buffer zone so defined goes one step further than the conventional 100-year flood plain boundary by considering potential changes in channel configuration from lateral migration. The selection of this definition of the buffer zone is supported by the legal and policy precedents of the National Flood Insurance Program, the short- and long-term degree of risk associated with the 100-year return period event, and the accuracy of the methodology used for estimating long-term erosion impacts [i.e. by limiting the extrapolation to reasonable length in time (e.g., 25 years)]. For detailed discussion of the methodology and its application the reader is referred to Lagasse, et al. (1984).

Rainbow Valley
Area Drainage Master Plan
Sediment Sample Location

Figure A-1



Project Features

- Sediment Sample Locations
- Significant Wash Corridor
- Waterman Wash
- HEC-1 Drainage Sub-Basin

Surface Management

- Bureau of Land Management
- Gila River Indian Reservation
- State Trust Land
- Arizona Game and Fish Department (State Land)
- County, Park and Outdoor Recreation Area
- Private Land

Reference Features

- Gila River
- Major Road

Data Sources

Sediment Sampling Locations: URS 2010
Base: Flood Control District of Maricopa County 2008

P:\WRES\FCDMC\23445383 FCDMC RVADMP\GIS\PLOTS\Working\Sediment sampling locations.pdf (kc)

Waterman Wash Sediment Gradation Data - HEC RAS Sediment Transport Model

Class[1]	Diameter (mm)[2]	Percentage Finer by Weight (%)															
		Sample 69	Sample 72 (2)	Sample 76 (2)	Sample 77 (2)	Sample 78 (2)	Sample 79 (2)	Sample 80 (2)	Sample 81 (2)	Sample 82	Sample 83 (2)	Sample 84	Sample 85 (2)	Sample 86 (2)	Sample 87 (2)	Sample 88 (2)	Sample 89 (2)
Clay	0.004		1.82			15.99		0.9	9.02	0.89	2.26	8.34	2.26	17.13	13.26	3.01	3.72
VFM	0.008		2.15			17.01		1.11	9.88	1.47	2.44	8.72	4.94	18.63	18.25	3.31	4.25
FM	0.016		2.35			17.53		1.33	9.89	1.47	2.6	9.09	4.94	19.01	18.86	3.91	4.78
MM	0.032		2.35			18.05		1.55	10.09	1.48	2.6	9.29	4.94	22.43	29.98	4.51	4.78
CM	0.0625		2.54		32.58	18.05		1.55	10.3	1.48	2.75	9.67	4.94	22.43	29.98	5.11	4.78
VFS	0.125	37.44	2.73	0.81	32.58	18.42	12.42	1.85	10.51	1.74	2.82	10.09	7.35	29.76	55.6	5.97	5.06
FS	0.25	45.83	3.25	1.33	38.85	20.09	15.94	2.3	11.37	2.38	4.3	11.17	11.57	34.29	71.89	8.48	6.57
MS	0.5	65.12	9.75	7.87	52.42	34.25	21.56	9.83	17.63	12.55	7.96	21.74	47.43	52.67	85.79	19.99	22.76
CS	1	71.13	14.31	14.37	58.65	45.39	24.21	19.21	22.99	21.2	9.88	28.3	66.44	59.67	88.88	28.29	39.93
VCS	2	88.99	44.46	65.31	81.51	86.09	60.9	58.17	42.08	58.72	34.97	45.52	94.24	81.12	96.32	61.71	82.95
VFG	4	90.72	50.5	70.98	85.69	89.35	68.23	64.94	45.23	65.19	40.42	48.96	95.15	84.44	97.04	66.19	85.2
FG	8	97.5	84.17	92.92	97.02	98.02	94.96	91.42	77.7	93.44	82.14	74.55	98.39	97.29	99.37	90.34	94.11
MG	16	99.51	92.71	98.76	99.61	99	99.31	98.8	93.98	98.99	97.24	94.07	99.7	99.45	99.95	97.6	96.53
CG	32	100	97.69	100	100	100	100	100	100	100	100	99.05	100	100	100	100	98.98
VCG	64		100	100								100		100		100	100

Notes :

1. The sediment particle size classification is based of the HEC-RAS Hydraulic Reference Manual.
2. The diameter was based of the geometric mean of the grain class as described in HEC-RAS Hydraulic Reference Manual.
3. The percentage finer by weight for each grain class were obtained from the sediment samples for Waterman Wash.

Sediment Grain Size Distribution - Waterman Wash (Channel Sample)

Grain Size (mm)	TP-66 (1)*	TP-69*	TP-70 (1)	TP-72 (1)	TP-77 (1)*	TP-78 (1)*	TP-79 (1)*	TP-80 (1)*	TP-81 (1)*	TP-82	TP-83 (1)*
	1.0 ft**	1.0 ft**	1.0 ft**	1.0 ft**	0.7 ft**	1.1 ft**	1.0 ft**	1.0 ft**	1.1 ft**	2.8 ft**	1.2 ft**
76.2								100.00			
50.8								98.26			100.00
38.1	100.00		100.00		100.00	100.00	100.00	98.26	100.00		98.61
31.75	99.24		98.34		98.78	99.65	99.58	98.26	98.92		98.61
25.4	99.05	100.00	97.84		97.85	99.65	99.58	98.26	98.71		98.61
19.1	98.97	99.73	97.09	100.00	96.14	99.13	99.41	98.05	98.55	100.00	98.16
12.7	98.35	99.51	96.49	99.14	92.52	97.76	98.07	97.12	97.71	98.99	97.07
9.5	97.65	99.04	95.77	98.32	88.90	95.61	96.17	95.85	96.47	97.35	95.83
6.35	95.46	97.50	93.63	96.39	81.88	90.87	91.38	92.72	93.74	93.44	90.79
4.75	93.34	96.11	91.50	94.24	76.16	85.45	86.84	89.19	90.99	86.11	86.68
2.38	79.30	90.72	79.73	83.87	59.49	66.27	70.51	75.07	78.45	65.19	67.46
2	72.83	88.99	74.48	79.30	55.91	57.80	64.61	70.21	72.38	58.72	60.12
1.19	53.62	81.69	53.73	56.84	41.37	36.64	44.77	48.25	51.09	40.14	34.87
0.59	27.79	71.13	25.04	18.05	24.80	18.75	25.96	25.61	25.44	21.20	14.37
0.42	14.97	65.12	14.26	9.15	19.04	10.82	16.12	15.71	13.67	12.55	8.22
0.297	7.55	58.20	6.81	4.66	15.06	5.31	7.41	5.57	6.23	6.45	3.75
0.149	2.65	45.83	2.92	1.39	12.26	0.99	0.95	0.60	1.29	2.38	1.07
0.075	1.69	37.44	2.43	0.90	11.53	0.39	0.34	0.22	0.58	1.74	0.77
0.0369											
0.0364				0.83							
0.0363			2.29								
0.036											
0.0359											
0.0356										1.48	
0.0355											
0.0353											
0.0332											
0.0329											
0.0328											
0.0318											
0.0305											
0.0233											
0.0231				0.83							
0.023			2.29								
0.0228											
0.0227											
0.0225										1.48	
0.0211											
0.0209											
0.0208											
0.0206											
0.0197											
0.0135											
0.0133			2.28	0.83							
0.0132											
0.0131											
0.013										1.47	
0.0122											
0.0121											
0.012											
0.0115											
0.0096											
0.0094			2.27	0.43							
0.0093											
0.0092										1.47	
0.0087											
0.0086											
0.0085											
0.0082											
0.0068											
0.0067			2.27	0.42							
0.0066											
0.0065										1.47	
0.0062											
0.0061											
0.006											
0.0058											
0.0033			1.80	0.19							
0.0032										0.89	
0.0031											
0.003											
0.0029											
0.0014			1.38	0.04						0.84	
0.0013											
0.0012											

* No Hydrometer readings available for the sample. Only sieve readings.

** Sediment Sample depth.

Sediment Grain Size Distribution - Waterman Wash (Channel Sample)

Grain Size (mm)	Percent Passing (Center of Wash)										
	TP-84	TP-85 (1)*	TP-86 (1)*	TP-87 (1)*	TP-88 (1)*	TP-89 (1)	TP-66 (2)*	TP-70 (2)	TP-72 (2)	TP-77 (2)*	TP-78 (2)
	3.1 ft**	1.0 ft**	0.9 ft**	1.3 ft**	1.1 ft**	0.5 ft**	1.9 ft**	2.8 ft**	2.6 ft**	3.0 ft**	2.6 ft**
76.2											
50.8									100.00		
38.1	100.00							100.00	97.69		
31.75	99.05				100.00			99.54	97.69		
25.4	98.33				99.49	100.00	100.00	99.35	97.46		100.00
19.1	97.39	100.00	100.00	100.00	99.49	99.61	99.78	99.13	95.81	100.00	99.25
12.7	94.07	99.78	99.36	99.31	98.84	98.40	99.20	97.33	92.71	99.61	99.00
9.5	87.41	99.43	98.65	98.50	97.92	97.37	98.39	95.05	89.98	98.96	98.82
6.35	74.55	98.50	96.35	95.51	94.57	93.32	96.01	89.67	84.17	97.02	98.02
4.75	65.93	97.27	93.14	93.31	91.46	89.00	93.94	84.02	77.28	95.20	96.69
2.38	48.96	90.04	75.55	84.61	82.13	71.20	83.92	66.91	50.50	85.69	89.35
2	45.52	66.91	69.69	82.01	78.63	66.41	81.47	63.27	44.46	81.51	86.09
1.19	36.47	73.84	45.16	71.11	69.00	50.03	70.90	50.01	26.59	70.22	68.60
0.59	28.30	50.59	22.92	57.71	54.97	31.97	56.36	33.72	14.31	58.65	45.39
0.42	21.74	36.03	17.91	50.94	42.92	20.32	47.88	23.55	9.75	52.42	34.25
0.297	15.77	25.74	14.85	44.23	30.77	10.19	39.40	15.29	6.18	46.77	26.65
0.149	11.17	14.47	11.67	34.28	15.37	2.80	31.14	9.02	3.25	38.85	20.09
0.075	10.09	7.70	9.56	24.50	7.98	1.67	28.48	7.87	2.73	32.58	18.42
0.0369									2.54		
0.0364											
0.0363											
0.036						1.67					
0.0359											
0.0358											
0.0355											
0.0353								7.66			
0.0332	9.67										
0.0329											
0.0328											18.05
0.0318											
0.0305											
0.0233									2.35		
0.0231											
0.023											
0.0228						1.34					
0.0227											
0.0225								7.11			
0.0211	9.29										
0.0209											
0.0208											17.53
0.0206											
0.0197											
0.0135									2.35		
0.0133											
0.0132						1.01					
0.0131											
0.013								6.85			
0.0122	9.09										
0.0121											
0.012											17.53
0.0115											
0.0096									2.15		
0.0094						0.34					
0.0093											
0.0092								6.58			
0.0087											
0.0086	8.90										
0.0085											17.01
0.0082											
0.0068									1.99		
0.0067						0.33					
0.0066											
0.0065								6.34			
0.0062											
0.0061	8.72										
0.006											17.01
0.0058											
0.0033						0.33			1.82		
0.0032								6.10			
0.0031											
0.003	8.34										15.99
0.0029											
0.0014						0.33		5.54	1.43		
0.0013	7.97										
0.0012											15.93

* No Hydrometer readings available for the sample. Only sieve readings.

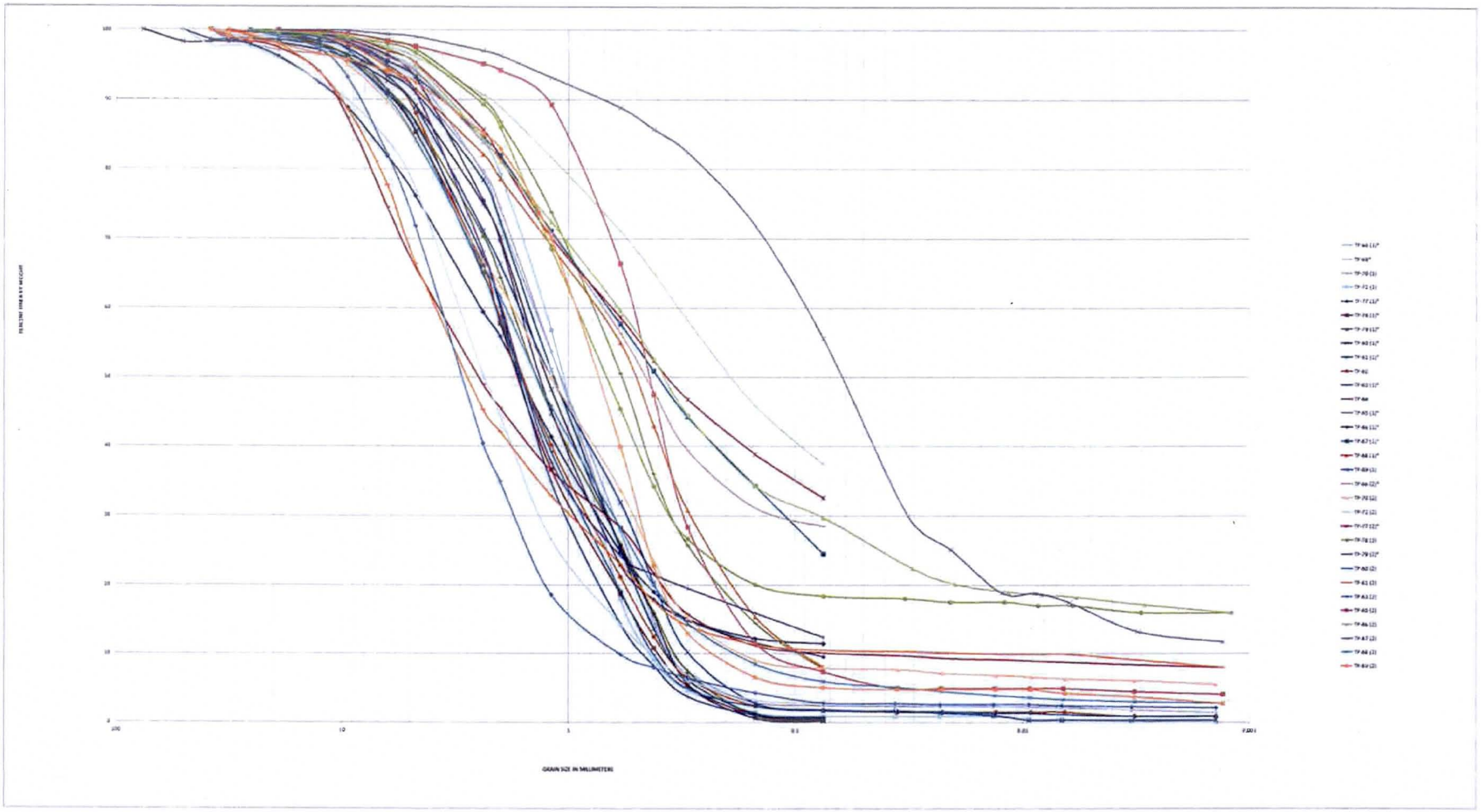
** Sediment Sample depth.

Sediment Grain Size Distribution - Waterman Wash (Channel Sample)

Grain Size (mm)	TP-79 (2)*	TP-80 (2)	TP-81 (2)	TP-83 (2)	TP-85 (2)	TP-86 (2)	TP-87 (2)	TP-88 (2)	TP-89 (2)
	3.0 ft**	2.7 ft**	3.0 ft**	2.5 ft**	2.7 ft**	3.3 ft**	3.0 ft**	3.5 ft**	2.6 ft**
76.2									
50.8									
38.1									100.00
31.75			100.00						98.98
25.4		100.00	99.02	100.00		100.00		100.00	98.52
19.1	100.00	99.70	97.96	99.36	100.00	99.67	100.00	98.96	97.96
12.7	99.31	98.80	93.98	97.24	99.70	99.45	99.95	97.60	96.53
9.5	98.23	97.11	88.67	93.23	99.42	99.07	99.84	95.84	95.71
6.35	94.96	91.42	77.70	82.14	98.39	97.29	99.37	90.34	94.11
4.75	91.07	85.62	66.49	71.88	97.64	95.03	99.03	84.31	92.53
2.38	68.23	64.94	45.23	40.42	95.15	84.44	97.04	66.19	85.20
2	60.90	58.17	42.08	34.97	94.24	81.12	96.32	61.71	82.95
1.19	37.73	39.23	32.90	18.61	89.30	72.43	93.23	45.78	70.07
0.59	24.21	19.21	22.99	9.88	66.44	59.67	88.88	28.29	39.93
0.42	21.56	9.83	17.63	7.96	47.43	52.67	85.79	19.99	22.76
0.297	19.54	4.91	14.11	6.42	28.33	44.52	82.42	14.44	13.00
0.149	15.94	2.30	11.37	4.30	11.57	34.29	71.89	8.48	6.57
0.075	12.42	1.85	10.51	2.82	7.35	29.76	55.60	5.97	5.06
0.0369									
0.0364									
0.0363				2.75					
0.036		1.55							
0.0359					4.94				
0.0356									
0.0355									4.78
0.0353								5.11	
0.0332									
0.0329			10.30						
0.0328									
0.0318							29.99		
0.0305						22.43			
0.0233									
0.0231									
0.023				2.60					
0.0228									
0.0227		1.55			4.94				
0.0225								4.51	4.78
0.0211									
0.0209			10.09						
0.0208									
0.0206							25.12		
0.0197						20.14			
0.0135									
0.0133				2.60					
0.0132		1.33							
0.0131					4.94			3.91	
0.013									4.78
0.0122							18.86		
0.0121			9.89						
0.012									
0.0115						19.01			
0.0096									
0.0094				2.60					
0.0093		1.33			4.94			3.61	
0.0092									4.78
0.0087							18.86		
0.0086									
0.0085			9.89						
0.0082						18.63			
0.0068									
0.0067				2.44					
0.0066		1.11			4.94			3.31	
0.0065									4.25
0.0062							17.46		
0.0061			9.88						
0.006									
0.0058						18.25			
0.0033				2.26					
0.0032		0.90			4.49			3.01	3.72
0.0031							13.26		
0.003			9.02						
0.0029						17.13			
0.0014		0.88		2.10					
0.0013			7.96		4.07		11.75	2.73	2.73
0.0012						15.96			

* No Hydrometer readings available for the sample. Only sieve readings.

** Sediment Sample depth.


PERCENT FINER BY WEIGHT
100
90
80
70
60
50
40
30
20
10
0
100
10
1
0.1
0.01
0.001
GRAIN SIZE IN MILLIMETERS

Attachment B

Waterman Wash Morphology Assessment

URS CALCULATION COVER SHEET Quality

Project Name:	RVADMP Sediment Yield/Transport	**Project Number:**	23445383
Project Location:	Goodyear, AZ	**Client Name:**	FCDMC
PM Name:	Elliot Siverston	**PIC Name:**	Pascal Hinnen

IDENTIFYING INFORMATION

(This section is to be completed by the Originator.)

Calculation Medium: ☐ Electronic File Name:

(Select as appropriate) ☒ Hard-copy Unique Identification:

Number of pages *(including cover sheet)*:

Discipline: Sediment Yield Analysis

Title of Calculation: Stream Classification and Historical channel parameter comparison

Calculation Originator: Adam Lacey

Calculation Contributors:

Calculation Checker: Max Shih

DESCRIPTION & PURPOSE

Compare stream parameter changes from 1937 - 2008; Stream classification

BASIS / REFERENCE / ASSUMPTIONS

Rosgen Stream Classification; Parameters measured using aerial photography and GIS

ISSUE / REVISION RECORD

Checker comments, if any, provided on: ☐ hard-copy ☐ electronic file ☐ Form 3-5 (MM)

No.	Description	P	S	F	Originator Initials	Date	Checker Initials	Date
0	Initial Issue	☐	☐	☒	AJL	6/7/11	MK.S.	06.16.2011
1		☐	☐	☐				
2		☐	☐	☐				
3		☐	☐	☐				

Note: For a given Revision No. Check off either P (Preliminary), S (Superseding) or F (Final). If there are no revisions to the Initial Issue check off F (Final). Comments may be provided on the hard-copy calculations, electronic file or on Form 3-5 (MM).

APPROVAL and DISTRIBUTION

☒ The calculations associated with this Cover Sheet have been checked.

Adam Lacey — Originator Signature — Date: 6/7/2011

Checker Signature — Date: 06.16.2011

Project Manager Signature — Date: 6-27-11

Distribution:

Project Central File – Quality file folder

Other Specify: ____

Objective

1. Determine historical channel parameters of Waterman Wash from 1937 to 2008.
2. Classify Waterman Wash using Rosgen stream classification methods.
3. Compare current stream parameters to predicted future parameters.

Given

- Stable Channel calculations (URS 2011) by Adam Lacey
- Aerial Photography of Waterman Wash from 1937 – 2008

References

Rosgen, Dave (2006). *Watershed Assessment of River Stability and Sediment Suppl.* Wildland Hydrology. (selected pages attached)

Files

T:\Projects\23445383_Rainbow_Sed_Study\Sub_00\10.0_Calculations_Analysis_Data\10.01_Hydraulics\Stream_Classification

- Calc_Stream_Parameters.docx
- Stream_Parameters.xlsx
- CCS_Stream_Parameters.doc

Procedure

Waterman Wash was divided into 5 reaches based on the bridge crossings for the analysis, because bridges constrain the meandering channel. This will allow the reaches to start and end in the same position for future studies. Stream parameters were traced and measured using GIS software and aerial photography from 1937, 1949, 1993, 1999, 2001, 2005, and 2008. A summary table is shown in **Table 1**. Maps of the study reaches are attached.

Each reach was given a stream classification using Rosgen methods (Rosgen, 2006). A summary is shown in **Table 2.**

Additionally, **Table 3** compares the current conditions to the predicted future conditions for each reach. Predicted equilibrium conditions were calculated in "Stable Channel Design" calculations (URS, 2011). It should be mentioned that channel meandering could be constrained by future development including (but not limited to) levees, bridges, channel grade controls, commercial, residential, agricultural, and mining activities.

Definition:

$$\Omega = \frac{L}{\Lambda} = \frac{\Delta h/_{s}}{\Lambda}$$

Where: Ω= sinuosity, L =Channel Length, Λ= Meander Length, Δh = elevation change, s = slope

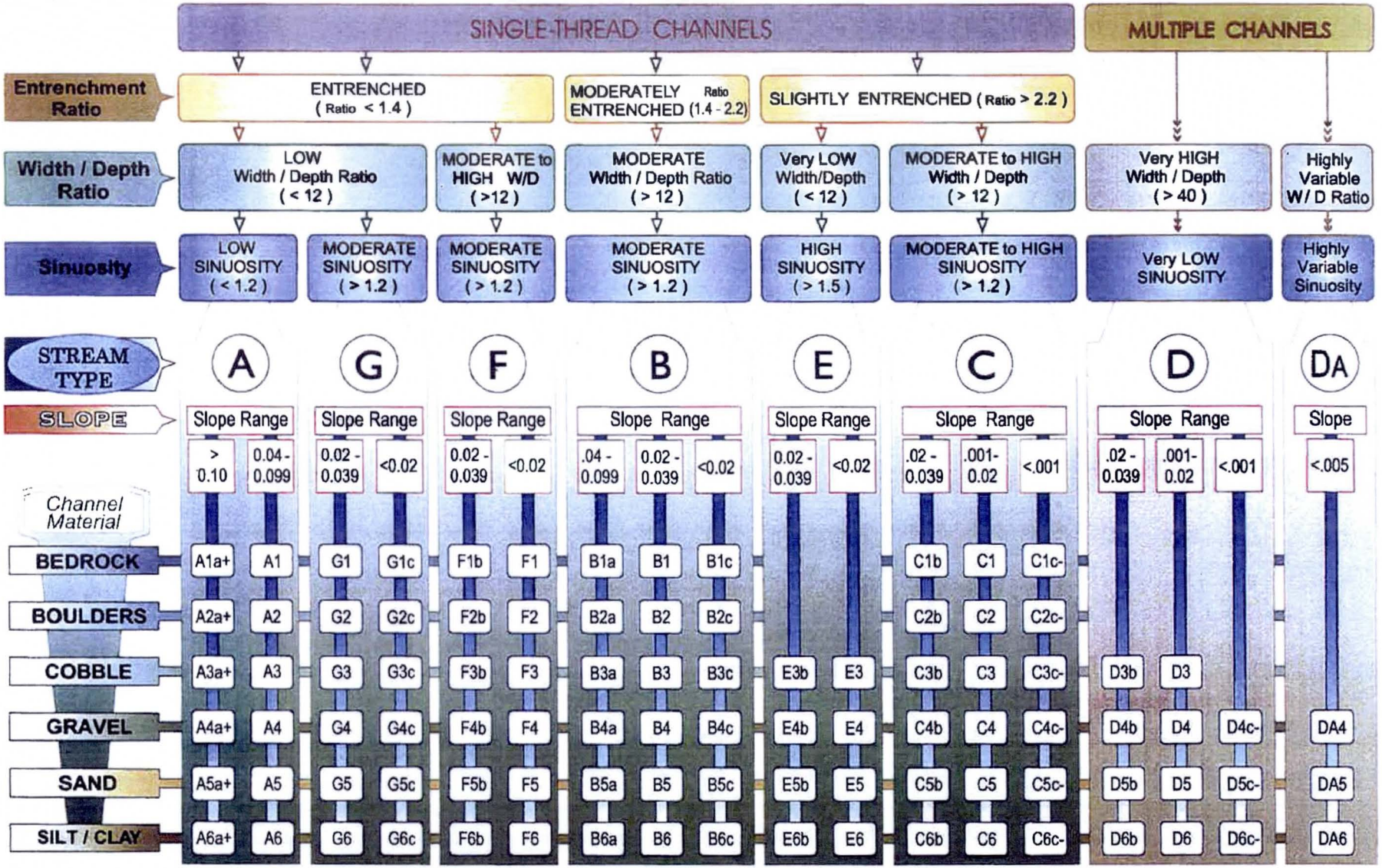
Table 1. Historical Channel Parameters					
Reach	Year	Channel Length (ft)	Meander Width (ft)	Meander Length (ft)	Sinuosity
Reach 1	2008	14,150	660	13,900	1.02
	2005	14,180	590	13,900	1.02
	2001	14,100	660	13,900	1.01
	1999	14,125	690	13,900	1.02
	1993	N/A	N/A	N/A	N/A
	1949	N/A	N/A	N/A	N/A
	1937	14,200	690	13,900	1.02
Reach 2	2008	8,610	1,110	8,200	1.05
	2005	8,550	1,110	8,200	1.04
	2001	8,580	990	8,200	1.05
	1999	8,530	990	8,200	1.04
	1993	8,550	1,110	8,200	1.04
	1949	N/A	N/A	N/A	N/A
	1937	8,700	1,130	8,200	1.06
Reach 3	2008	12,520	575	12,300	1.02
	2005	12,590	570	12,300	1.02
	2001	12,580	590	12,300	1.02
	1999	12,550	570	12,300	1.02
	1993	12,540	550	12,300	1.02
	1949	N/A	N/A	N/A	N/A
	1937	12,700	710	12,300	1.03
Reach 4	2008	18,170	1,290	17,500	1.04
	2005	18,200	1,270	17,500	1.04
	2001	18,280	1,250	17,500	1.04
	1999	18,180	1,142	17,500	1.04
	1993	18,270	1,290	17,500	1.04
	1949	18,280	1,090	17,500	1.04
	1937	18,430	1,150	17,500	1.05
Reach 5	2008	17,990	850	16,700	1.08
	2005	17,670	875	16,700	1.06
	2001	17,700	880	16,700	1.06
	1999	17,700	870	16,700	1.06
	1993	17,680	900	16,700	1.06
	1949	17,670	890	16,700	1.06
	1937	N/A	N/A	N/A	N/A

Table 2. Waterman Wash 2008: Rosgen Stream Classification							
Reach	Channel	Entrenchment	W/D Ratio	Sinuosity	Slope	Channel Material	Rosgen Stream Classification
1	Single	Slightly	55	1.02	0.0026	Coarse Sand and gravel	C4
2	Single	Slightly	23	1.05	0.0031	Coarse Sand and gravel	C4
3	Multiple (Braided)	Moderate	33	1.02	0.0031	Coarse Sand and gravel	D5
4	Multiple (Braided)	Moderate	27	1.04	0.0033	Coarse Sand and gravel	D5
5	Multiple (Braided)	High	67	1.06	0.0040	Coarse Sand and gravel	D5

Table 3. Comparison Summary						
Reach	Current Conditions (2008)			Predicted Equilibrium Conditions		
	Length (ft)	Slope (ft/ft)	Sinuosity	Length (ft)	Slope (ft/ft)*	Sinuosity
1	14,150	0.0026	1.02	16,261	0.0023	1.17
2	8,610	0.0031	1.05	8,548	0.0031	1.04
3	12,520	0.0031	1.02	12,300	0.0036	1.00
4	18,170	0.0033	1.04	17,500	0.0041	1.00
5	17,990	0.0039	1.08	19,014	0.0037	1.14

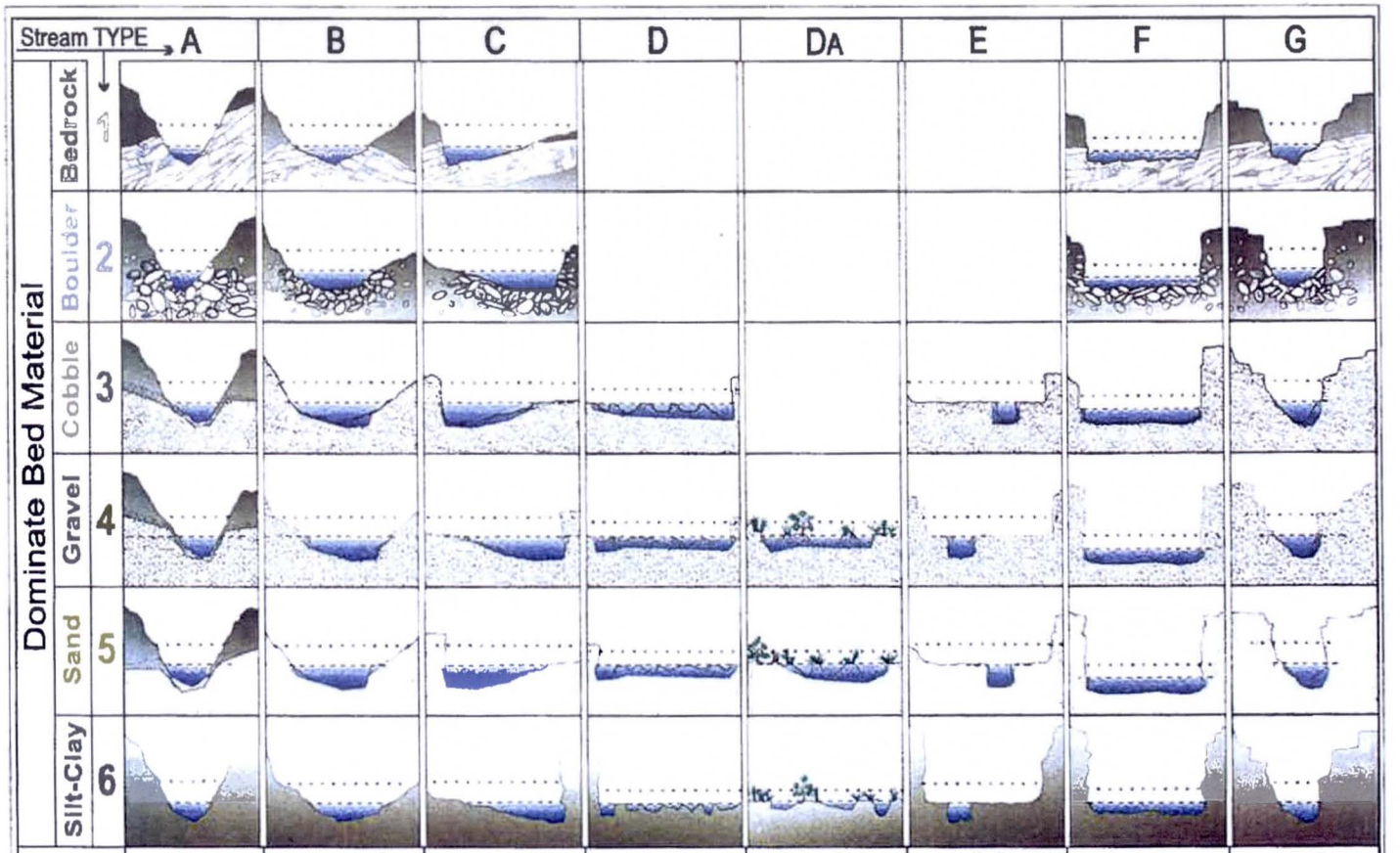
*Equilibrium slopes were taken from the Stable Channel calculation package (URS, 2011)

The Key to the Rosgen Classification of Natural Rivers



KEY to the *ROSGEN* CLASSIFICATION of NATURAL RIVERS. As a function of the *"continuum of physical variables"* within stream reaches, values of ***Entrenchment*** and ***Sinuosity*** ratios can vary by +/- 0.2 units; while values for ***Width / Depth*** ratios can vary by +/- 2.0 units.

© Wildland Hydrology 1481 Stevens Lake Road Pagosa Springs, CO 81147 (970) 731-6100 e-mail: wildlandhydrology@pagosa.net



	A	B	C	D	DA	E	F	G
Entrchmnt.	< 1.4	1.4 - 2.2	> 2.2	n/a	> 4.0	> 2.2	< 1.4	< 1.4
W/D Ratio	< 12	> 12	> 12	> 40	< 40	< 12	> 12	< 12
Sinuosity	1 - 1.2	> 1.2	> 1.2	n/a	variable	> 1.5	> 1.2	> 1.2
H_2O Slope	.04-.099	.02-.039	< .02	< .04	<.005	< .02	< .02	.02-.039

© Wildland Hydrology 1481 Stevens Lake Road Pagosa Springs, CO 81147
(970) 731-6100 e-mail: wildlandhydrology@pagosa.net

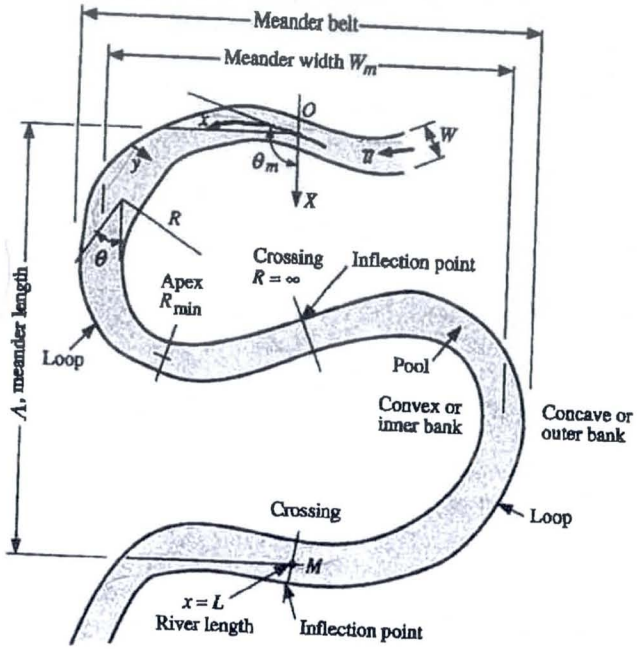


Figure 6.11. Definition sketch of a meandering river.

When plotting the orientation angle θ as a function of downstream distance x, Langbein and Leopold (1966) found that θ is a function of the maximum angle θ_m set at the origin, the downstream distance x and the river length L:

$$\theta = \theta_m \cos \frac{2\pi x}{L}. \tag{6.30}$$

This sine-generated curve is compared with an observed meandering pattern in Fig. 6.12.

The meander length Λ is computed from the following relationship:

$$\Lambda = \int_0^L \cos\theta \, dx = \int_0^L \cos\left[\theta_m \cos\left(\frac{2\pi x}{L}\right)\right] dx. \tag{6.31}$$

The sinuosity Ω, defined as $\Omega = L/\Lambda$, increases gradually with θ_m in radians,

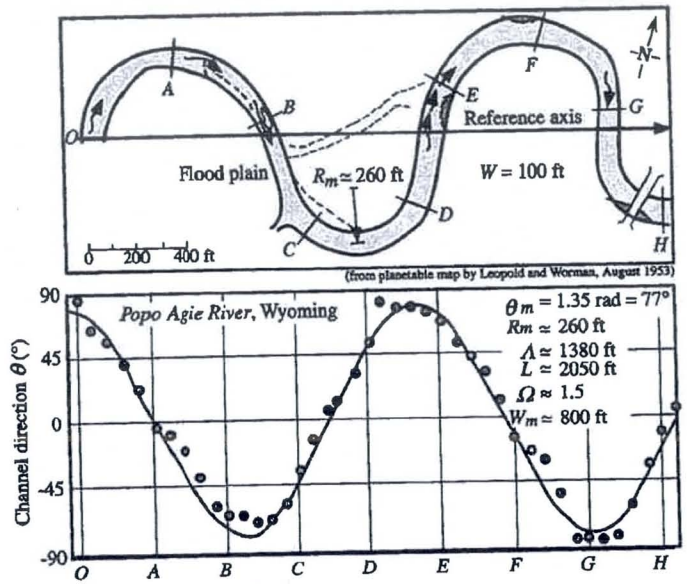


Figure 6.12. Meandering planform geometry (after Langbein and Leopold, 1966).

as illustrated in Fig. 6.13:

$$\Omega \equiv \frac{L}{\Lambda} = \frac{L}{\int_0^L \cos\theta \, dx} \cong 1 + \left(\frac{2\theta_m}{\pi}\right)^5 = 1 + 0.1\theta_m^5. \tag{6.32}$$

The radius of curvature R can be obtained from $dx = R d\theta$; thus combining this with Eq. (6.30) gives

$$R = \frac{L}{2\pi\theta_m} \csc\left(\frac{2\pi x}{L}\right). \tag{6.33}$$

The minimum radius of curvature R_m at the apex is obtained when csc $[(2\pi x)/L] = 1$ or

$$R_m = \frac{L}{2\pi\theta_m}. \tag{6.34}$$

For a given meander length Λ, the minimum radius of curvature (which obviously corresponds to the maximum value of Λ/R_m) varies with θ_m as

$$\frac{\Lambda}{R_m} = \frac{2\pi\theta_m \Lambda}{L} = \frac{2\pi\theta_m}{\Omega}. \tag{6.35}$$

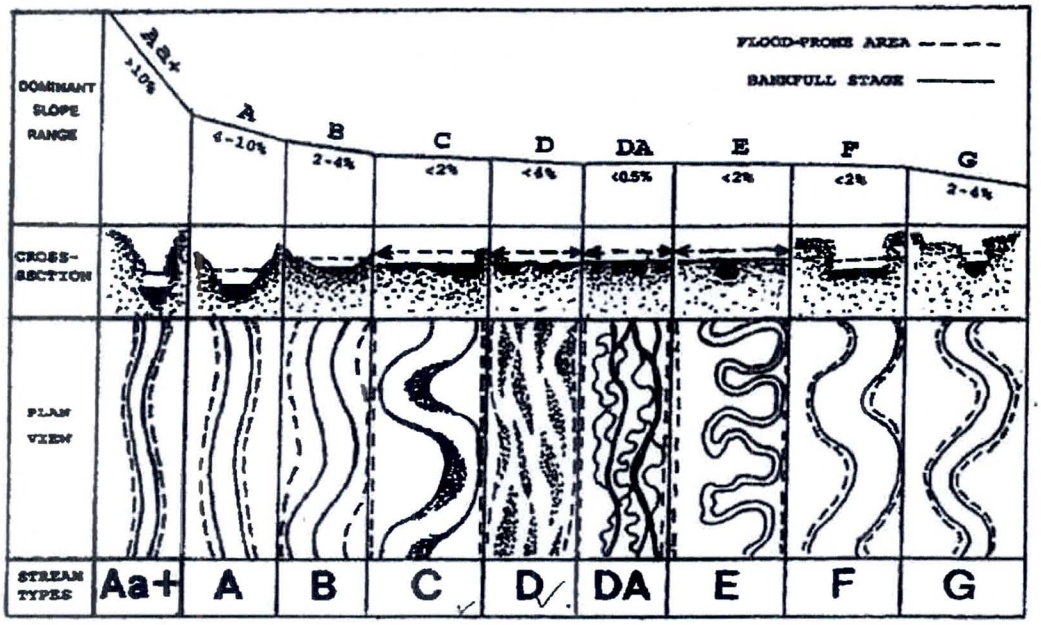


Fig. 1. Longitudinal, cross-sectional and plan views of major stream types.

pattern, shape, and dimension. Level I combines the influences of climate, depositional history, and life zones (desert shrub, alpine, etc.) on channel morphology.

The presence, description, and dimensions of floodplains, terraces, fans, deltas and outwash plains are a few examples of valley features identified. Depositional and erosional history overlay channel patterns at this level. Generalized categories of "stream types" initially can be delineated using broad descriptions of longitudinal profiles, valley and channel cross-sections, and plan-view patterns (see Fig. 1 and Table 2).

Longitudinal profiles

The longitudinal profile, which can be inferred from topographic maps, serves as the basis for breaking the stream reaches into slope categories that reflect profile morphology. For example, the stream types of Aa + (Fig. 1) are very steep, (greater than 10%), with frequently spaced, vertical drop/scour-pool bed features. They tend to be high debris transport streams, waterfalls, etc. Type A streams are steep (4–10% slope), with steep, cascading, step/pool bed features. Type B streams are riffle-dominated types with "rapids" and infrequently spaced scour-pools at bends or areas of constriction. The C, DA, E and F stream types are gentle-gradient riffle/pool types. Type G streams are "gullies" that typically are step/pool channels. Finally, the D type streams are braided channels of convergence/divergence process that lead to localized, frequently spaced scour/depositional bed forms.

Bed features are consistently found to be related to channel slope. Grant et al. (1990) described bed features of pools, riffles, rapids, cascades, and steps as a function

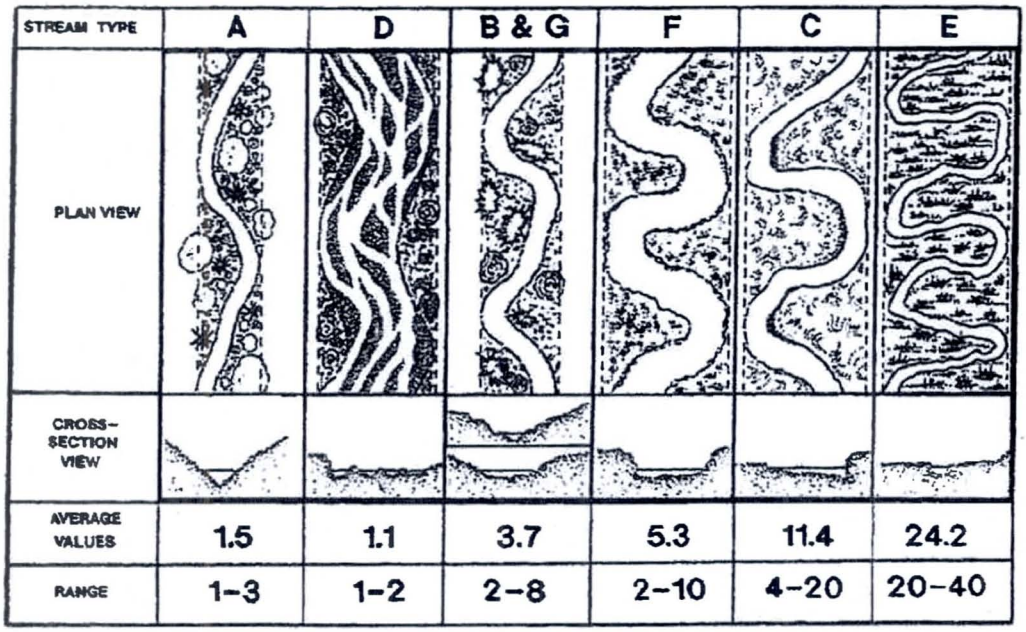


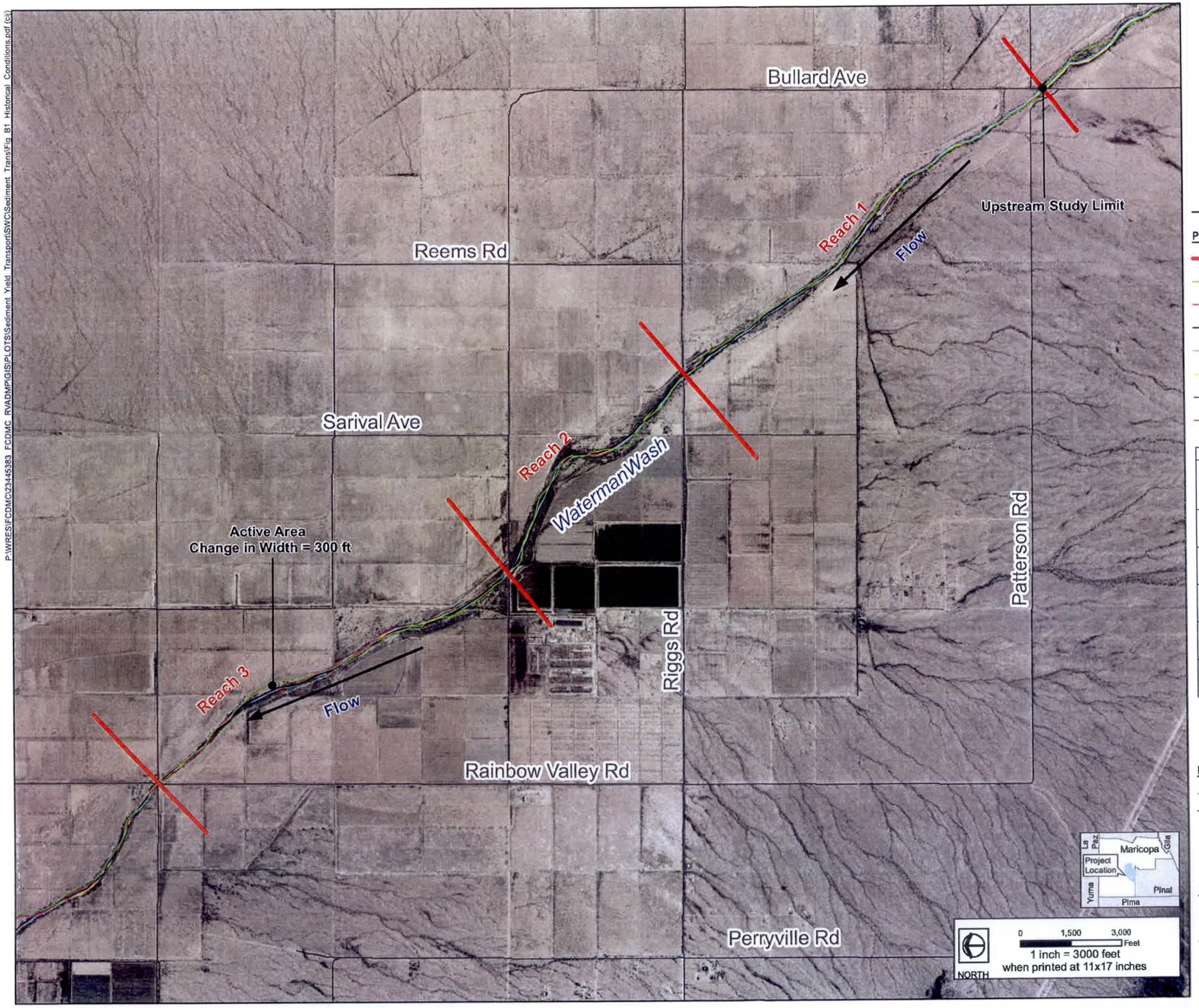
Fig. 3. Meander width ratio (belt width/bankfull width) by stream type categories.

(E stream types). Complex stream patterns are found in the multiple channel, braided (D) and anastomosed (DA) stream types. Sinuosity can be calculated from aerial photographs and often, like slope, serves as a good initial delineation of major stream types. These river patterns have integrated many processes in deriving their present form and thus, provide interpretations of their associated morphology.

Even at this broad level. of delineation, consistency of dimension and associated pattern can be observed by broad stream types. Meander width ratio (belt width/ bankfull surface width) was calculated by general categories of stream types for a wide variety of rivers. Measured mean values and ranges by stream type are shown in Fig. 3. Early work by Inglis (1942) and Lane (1957) discussed meander width ratio but the values were so divergent among rivers that the ratio appeared to have little value. When stratified by general stream types, however, the variability appears to be explained by the similarities of the morphological character of the various stream types. This has value not only for classification and broad-level delineations, but also for describing the most probable state of channel pattern in stream restoration work.

Discussion

Interpretations of mode of adjustment — either vertical, lateral, or both — and energy distribution can often be inferred in these broad types. Many variables that are not discrete delineative variables integrate at this level to produce an observable morphology. A good example of this is the influence of a deep sod-root mass on type E streams that produces a low width/depth ratio, low meander length, low radius of curvature, and a high meander width ratio. Vegetation is not singled out for mapping at this level, but is implicit in the resulting morphology. If this vegetation is changed, the width/depth ratio and other features will result in adjustments to the



P:\WRES\FCDMC\23445383_FCDMC_RVADMP\GIS\PLOTS\Sediment_Yield_Transport\SWC\Sediment_Trans\Fig_B1_Historical_Conditions.pdf (ci)

Rainbow Valley
Area Drainage Master Plan
Waterman Wash
Historical Conditions

Figure B-1

Project Features

- Reach
- 1939 Stream
- 1949 Stream
- 1993 Stream
- 1999 Stream
- 2001 Stream
- 2005 Stream
- 2008 Stream

Waterman Wash 2008: Rosegen Stream Classification

Reach	Channel	Entrenchment	W/D Ratio	Sinuosity	Slope	Channel Material	Rosgen Stream Classification
1	Single	Slightly	55	1.02	0.0026	Coarse Sand and Gravel	C4
2	Single	Slightly	23	1.05	0.0031	Coarse Sand and Gravel	C4
3	Multiple (Braided)	Moderate	33	1.02	0.0031	Coarse Sand and Gravel	D5
4	Multiple (Braided)	Moderate	27	1.04	0.0033	Coarse Sand and Gravel	D5
5	Multiple (Braided)	High	67	1.06	0.0040	Coarse Sand and Gravel	D5

Reference Features

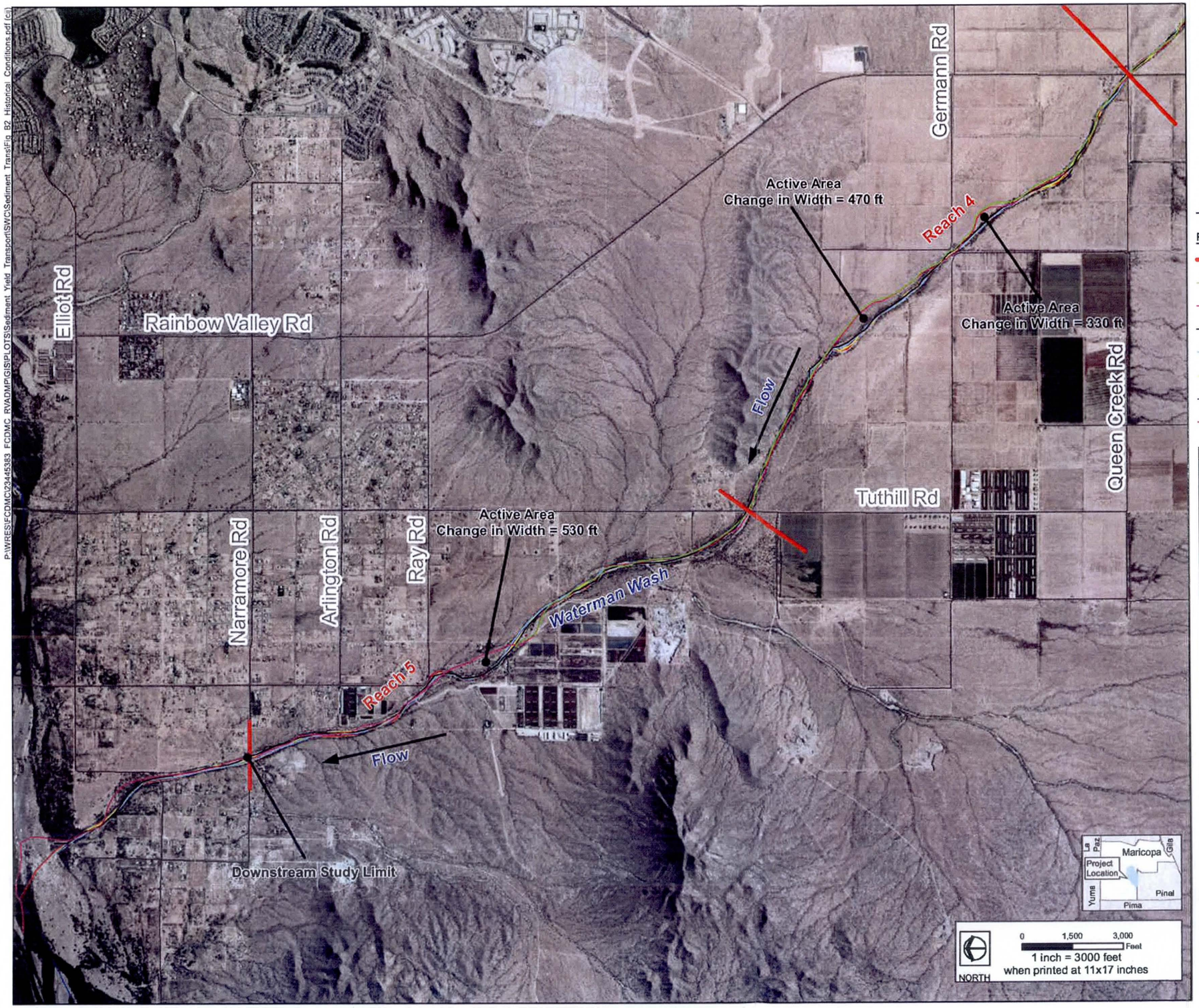
- River/Stream
- Major Road

Data Sources

Historical Data Locations: Flood Control District of Maricopa County 2008
Aerial Imagery: Bing 2011

Rainbow Valley
Area Drainage Master Plan
Waterman Wash
Historical Conditions

Figure B-2



Project Features

- Reach
- 1939 Stream
- 1949 Stream
- 1993 Stream
- 1999 Stream
- 2001 Stream
- 2005 Stream
- 2008 Stream

Waterman Wash 2008: Rosegen Stream Classification

Reach	Channel	Entrenchment	W/D Ratio	Sinuosity	Slope	Channel Material	Rosgen Stream Classification
1	Single	Slightly	55	1.02	0.0026	Coarse Sand and Gravel	C4
2	Single	Slightly	23	1.05	0.0031	Coarse Sand and Gravel	C4
3	Multiple (Braided)	Moderate	33	1.02	0.0031	Coarse Sand and Gravel	D5
4	Multiple (Braided)	Moderate	27	1.04	0.0033	Coarse Sand and Gravel	D5
5	Multiple (Braided)	High	67	1.06	0.0040	Coarse Sand and Gravel	D5

Reference Features

- River/Stream
- Major Road

Data Sources

Historical Data Locations: Flood Control District of Maricopa County 2008
Aerial Imagery: Bing 2011

P:\WRES\FCDMC\23445383_FCDMC_RVADMP\GIS\PLOTS\Sediment Yield_Transport\SW\Sediment Trans\Fig_B2_Historical_Conditions.pdf (cj)

Attachment C

Cross Section Geometry Assessment

URS CALCULATION COVER SHEET Quality

Project Name:	**RVADMP Sediment Yield/Transport**	**Project Number:**	**23445383**
Project Location:	**Goodyear, AZ**	**Client Name:**	**FCDMC**
PM Name:	**Elliot Silverston**	**PIC Name:**	**Pascal Hinnen**

IDENTIFYING INFORMATION

(This section is to be completed by the Originator.)

Calculation Medium: ☐ Electronic File Name:

(Select as appropriate) ☒ Hard-copy Unique Identification:

Number of pages *(including cover sheet)*:

Discipline: Sediment Yield Analysis

Title of Calculation: Evaluation of Channel Equilibrium

Calculation Originator: Adam Lacey

Calculation Contributors:

Calculation Checker: Max Shih

DESCRIPTION & PURPOSE

Determine an equilibrium channel for a 16 mile reach on Waterman Wash

BASIS / REFERENCE / ASSUMPTIONS

An unsteady sediment analysis was performed using USACE's HEC-RAS v4.1.0

ISSUE / REVISION RECORD

Checker comments, if any, provided on: ☐ hard-copy ☐ electronic file ☐ Form 3-5 (MM)

No.	Description	P	S	F	Originator Initials	Date	Checker Initials	Date
0	Initial Issue	☐	☐	☒	AJL	6/3/11	MS	06/15/2011
1		☐	☐	☐				
2		☐	☐	☐				
3		☐	☐	☐				

Note: For a given Revision No. Check off either P (Preliminary), S (Superseding) or F (Final). If there are no revisions to the Initial Issue check off F (Final). Comments may be provided on the hard-copy calculations, electronic file or on Form 3-5 (MM).

APPROVAL and DISTRIBUTION

☒ The calculations associated with this Cover Sheet have been checked.

Adam Lacey — **Originator Signature** — 6/3/2011 — **Date**

Shih — **Checker Signature** — 06.15.2011 — **Date**

Project Manager Signature — 6-27-11 — **Date**

Distribution:

Project Central File – Quality file folder

Other Specify: ____

Objective

To evaluate the equilibrium state for study reaches on Waterman Wash.

Given

HEC-RAS Model by Max Shih
T:\Projects\23445383_Rainbow_Sed_Study\Sub_00\10.0_Calculations_Analysis_Data\10.01_Hydraulics\HecRas_Sediment Models\100_Yr_Sed_MPM

- Sed_Rev_Max.prj

Flood Frequency Analysis (URS Phoenix Office, 2011)

Files

T:\Projects\23445383_Rainbow_Sed_Study\Sub_00\10.0_Calculations_Analysis_Data\10.01_Hydraulics\Excel

- Stable_Channel_Design.xlsx

T:\Projects\23445383_Rainbow_Sed_Study\Sub_00\10.0_Calculations_Analysis_Data\10.01_Hydraulics\HecRas_Sediment Models\Sed_AJL

- Sed_Rev_Max.prj

T:\Projects\23445383_Rainbow_Sed_Study\Sub_00\10.0_Calculations_Analysis_Data\10.01_Hydraulics\Word

- Calc_Stable Channel.docx
- CCS_Stable_Channel.doc

T:\Projects\23445383_Rainbow_Sed_Study\Sub_00\10.0_Calculations_Analysis_Data\10.01_Hydraulics

- Waterman_Wash.fm8 (FlowMaster)

References

- USACE HEC-RAS Version 4.1.0 computer software
- USACE (USACE, 2001). *Channel Restoration Design for Meandering Rivers, Chapter 5*. September, 2001. (selected pages attached)
- Incised Channel Evolution Sequence (Schumm et al., 1984) (selected pages attached)

Procedure

USACE's HEC-RAS (version 4.1.0) computer program was used to evaluate channel equilibrium statistics for Waterman Wash study reaches. The Copeland Method was used for computations. Input values for the stable channel design model in HEC-RAS include the forming discharge, channel geometry, manning's "n", and channel gradation. The 5-year discharge was considered the forming discharge for the analyzed reaches. The results are shown below. Gradation and Manning's "n" values were obtained from a HEC-RAS model created by Max Shih (URS, 2011). The existing channel widths were measured

using GIS software and aerial photography from 2008, and side slopes were assumed to be 3H:1V for the entire channel.

In addition, the evolution phase of the channel at each reach was determined using Schumm's (1984) Incised Channel Evolution Sequence chart (attached).

The study reach is approximately 16 miles long and was divided into 16 reaches for analysis. Equilibrium channel widths were calculated using a regression equation by Hey and Thorne (USACE, 2001).

$$W = aQ^b$$

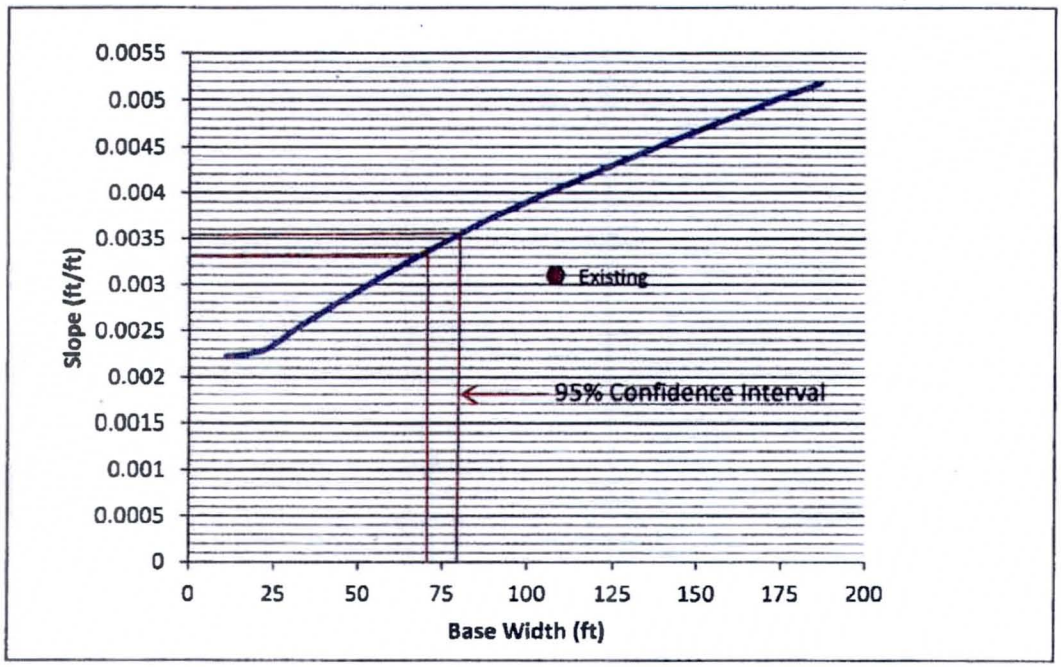
Where:
W = Channel Bankfull Width
Q = Forming Discharge (5-year flood for this study)
a = discharge coefficient (2.33 – 2.58: 95% Confidence)
b = discharge exponent (0.57)

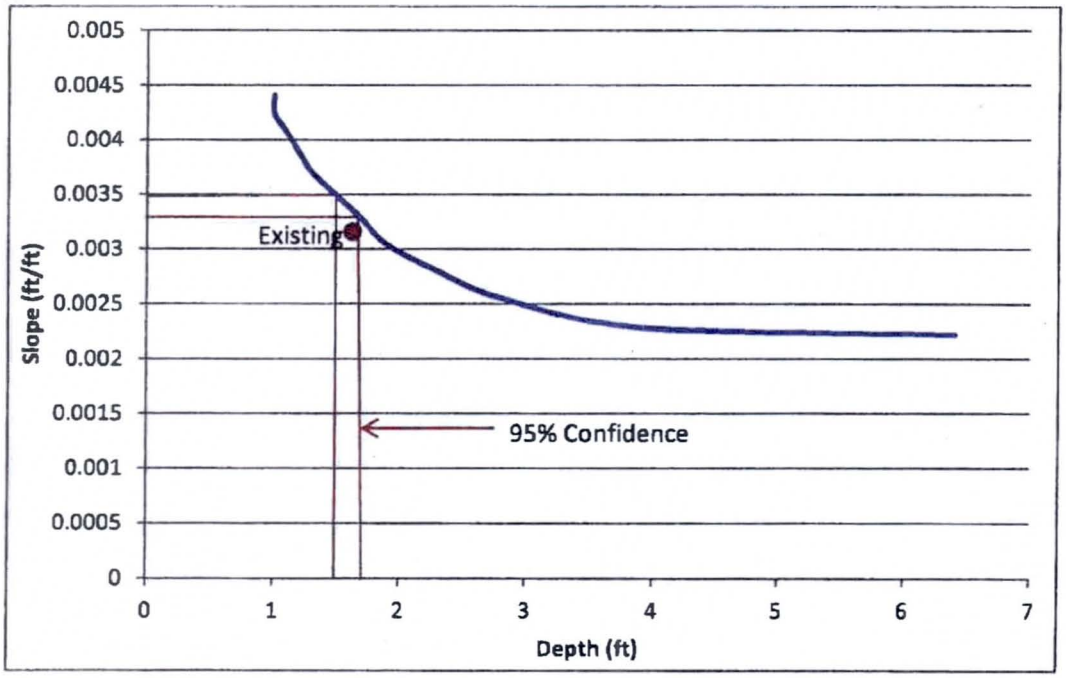
A summary of the results are shown below.

Analyzed Cross-Sections at Channel Forming Discharges

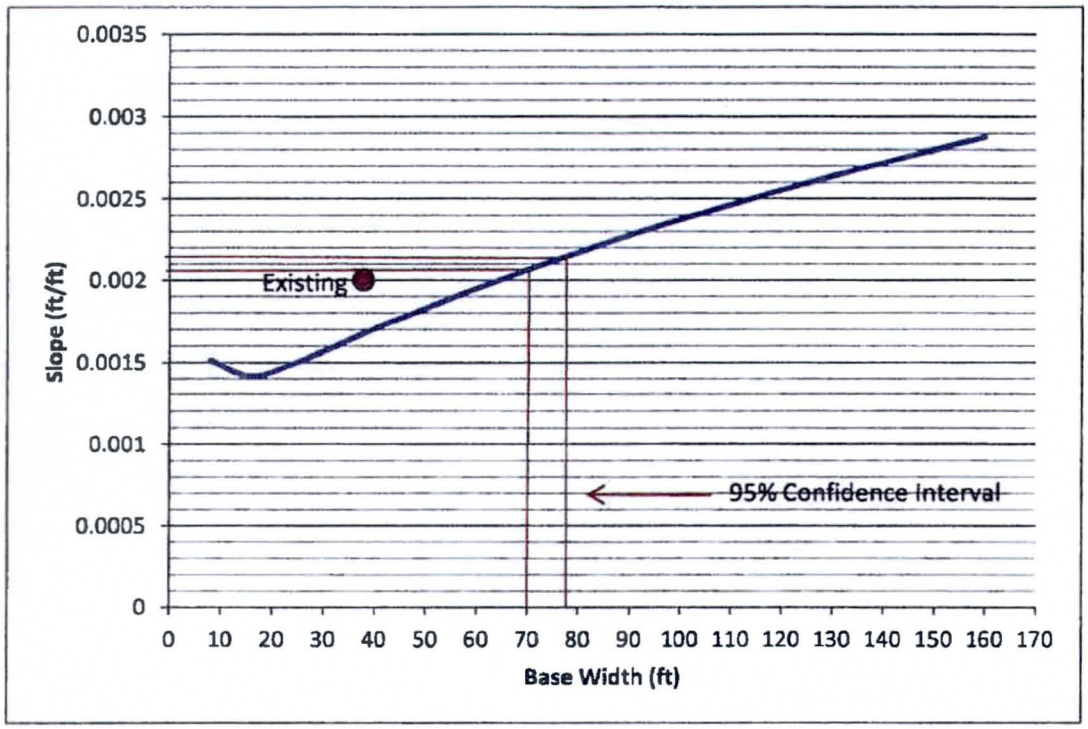
Cross-Section	5-year Discharge (cfs)	Widths (ft, 95% Confidence)	
		Lower Bound	Upper Bound
16.72	389	69.8	77.2
15.65	398	70.7	78.3
14.40	543	84.4	93.4
14.30	497	80.2	88.8
8.44	933	114.9	127.2
6.68	974	117.7	130.3
4.00	983	118.3	131.0
3.69	989	118.7	131.5

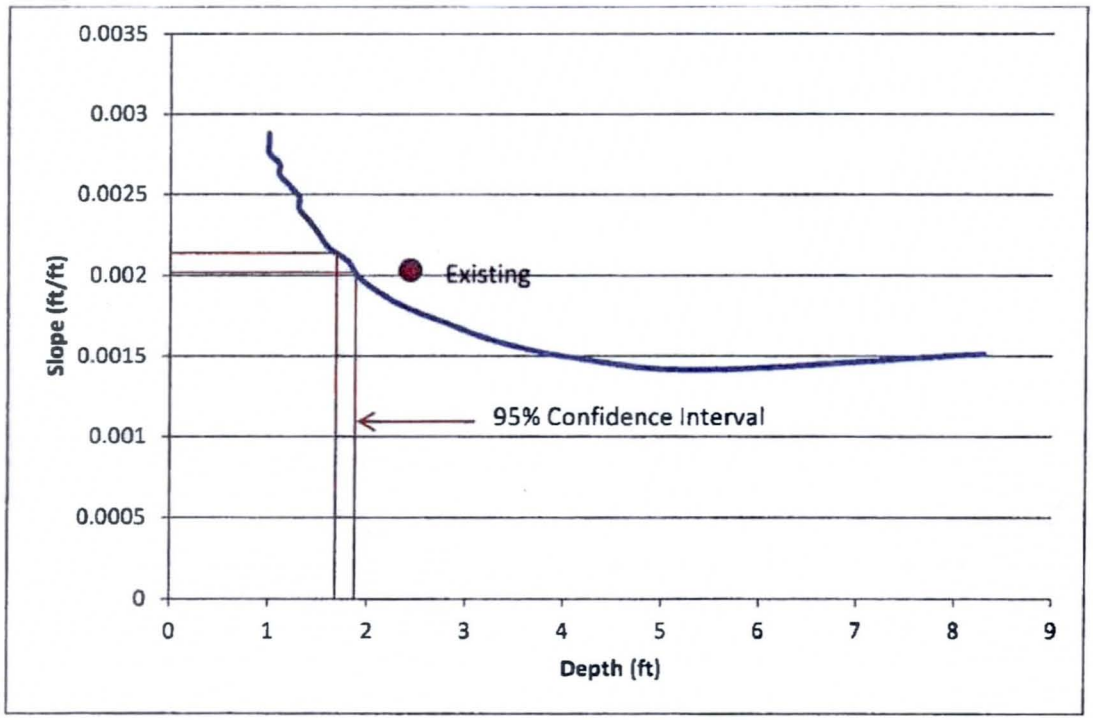
Station 15.65 (Phase III)



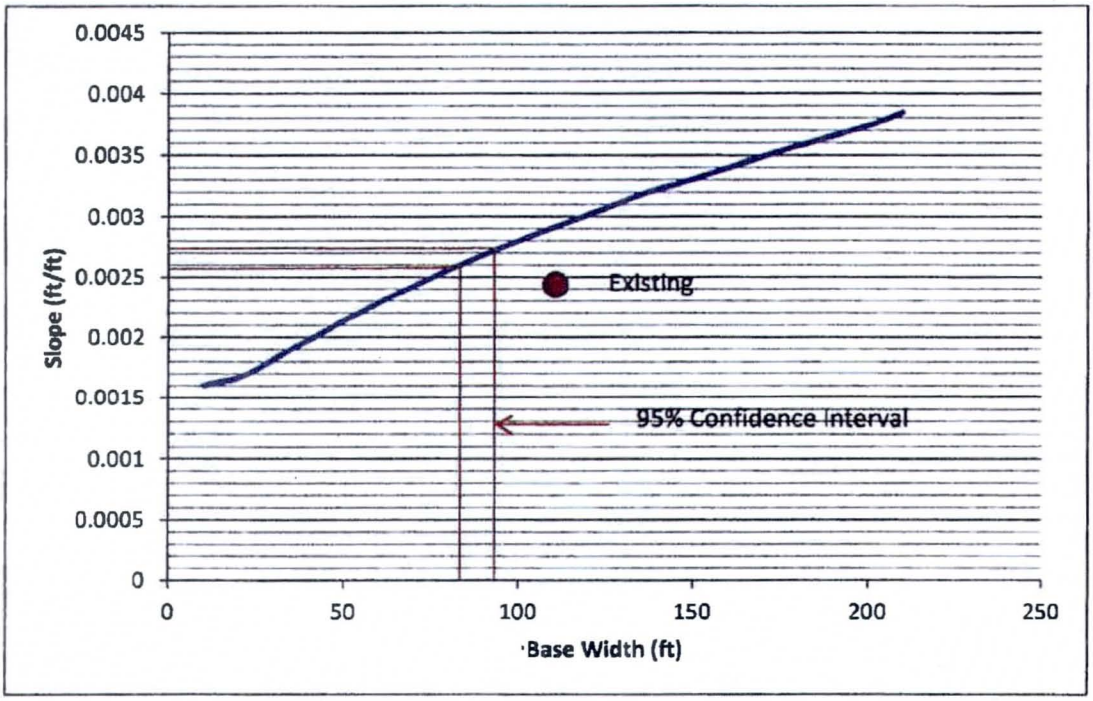


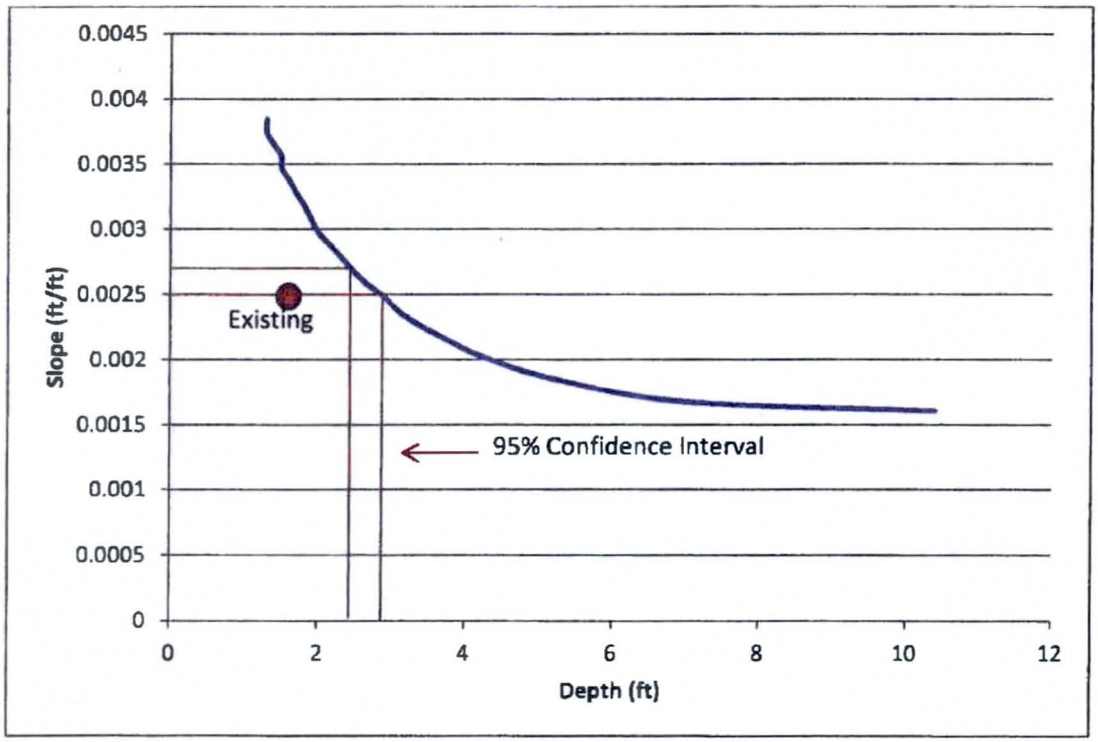
Station 14.49 (Phase V)



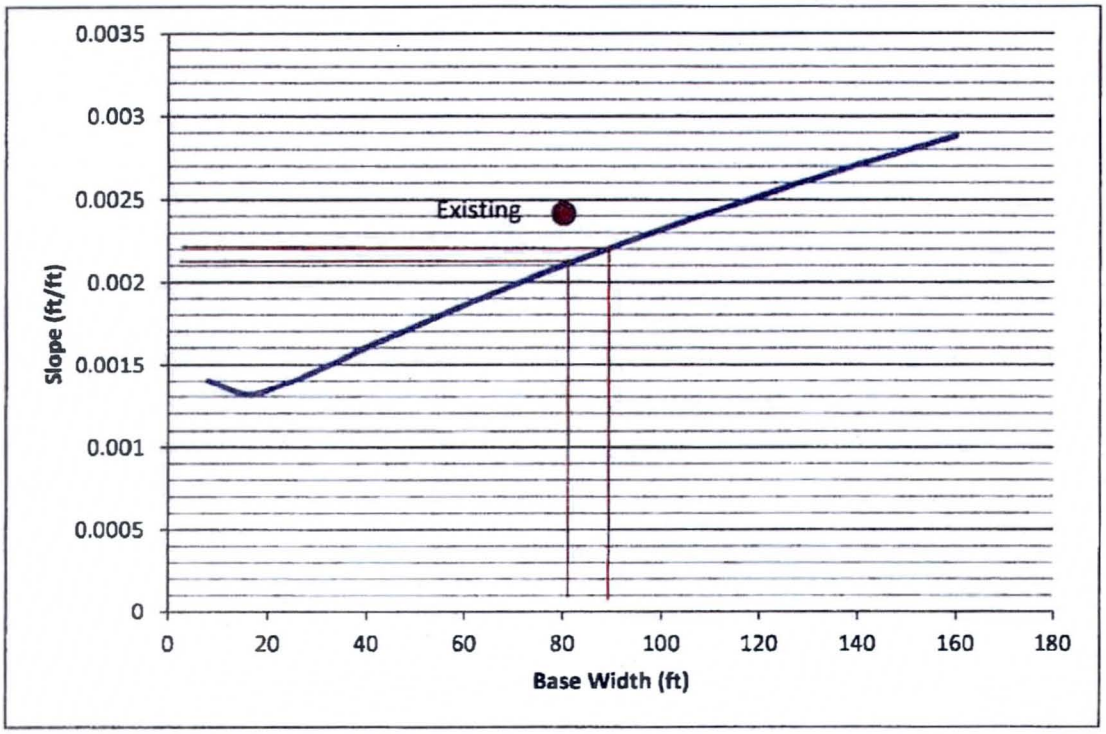


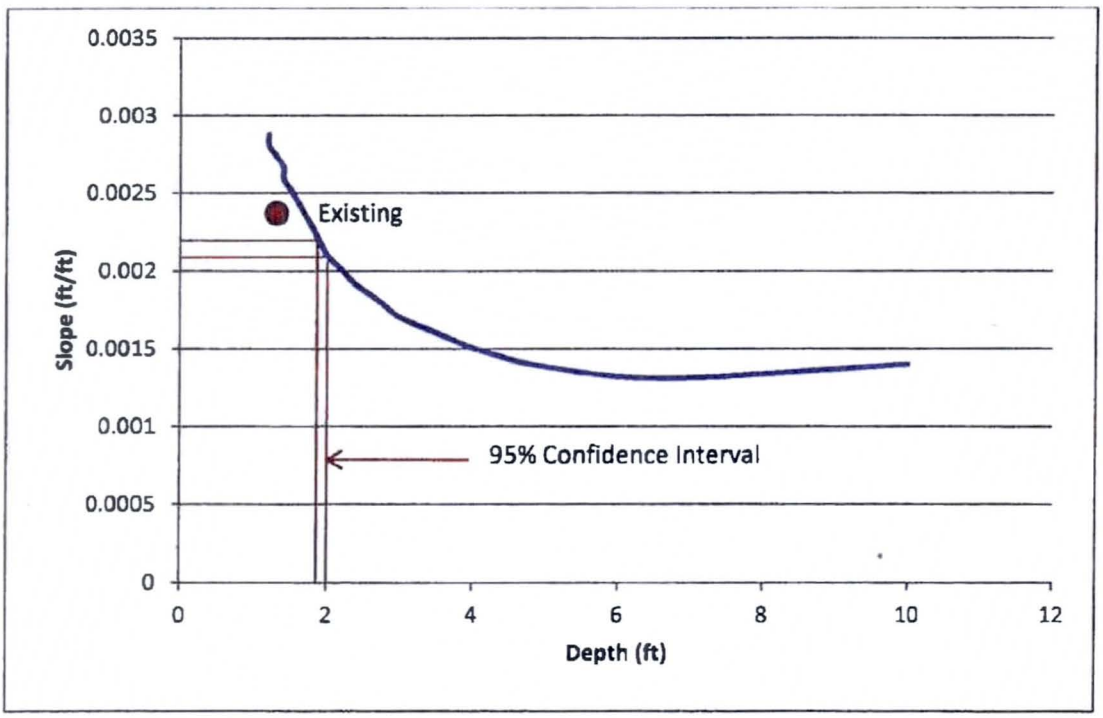
Station 13.53 (Phase III)



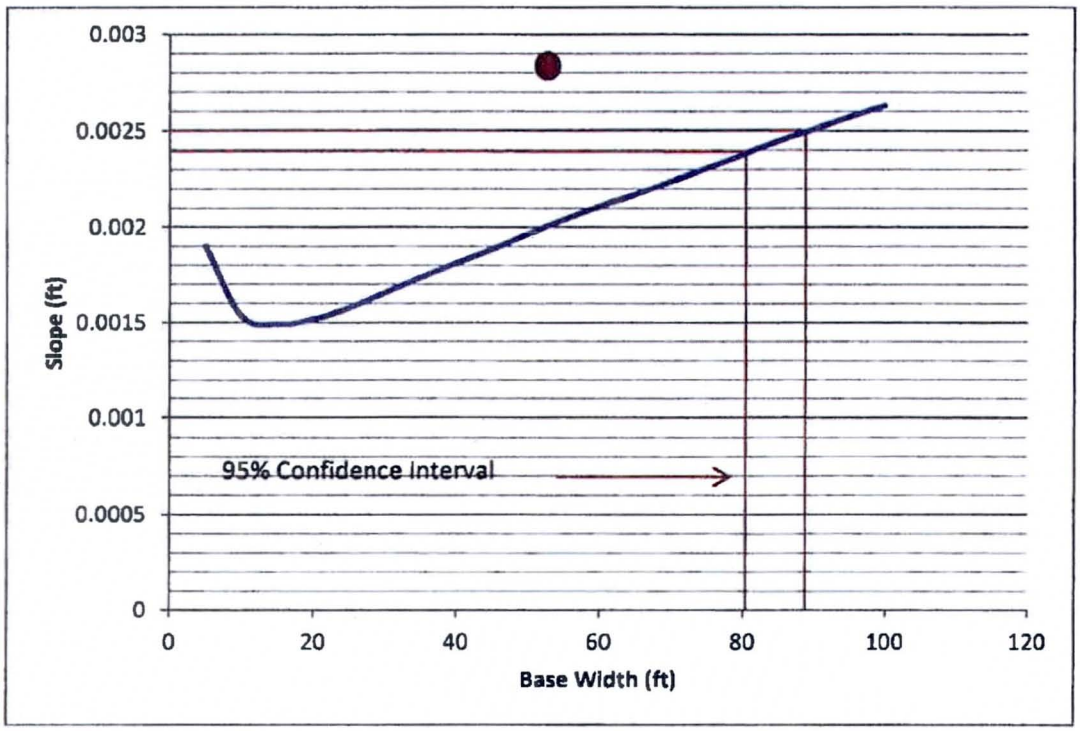


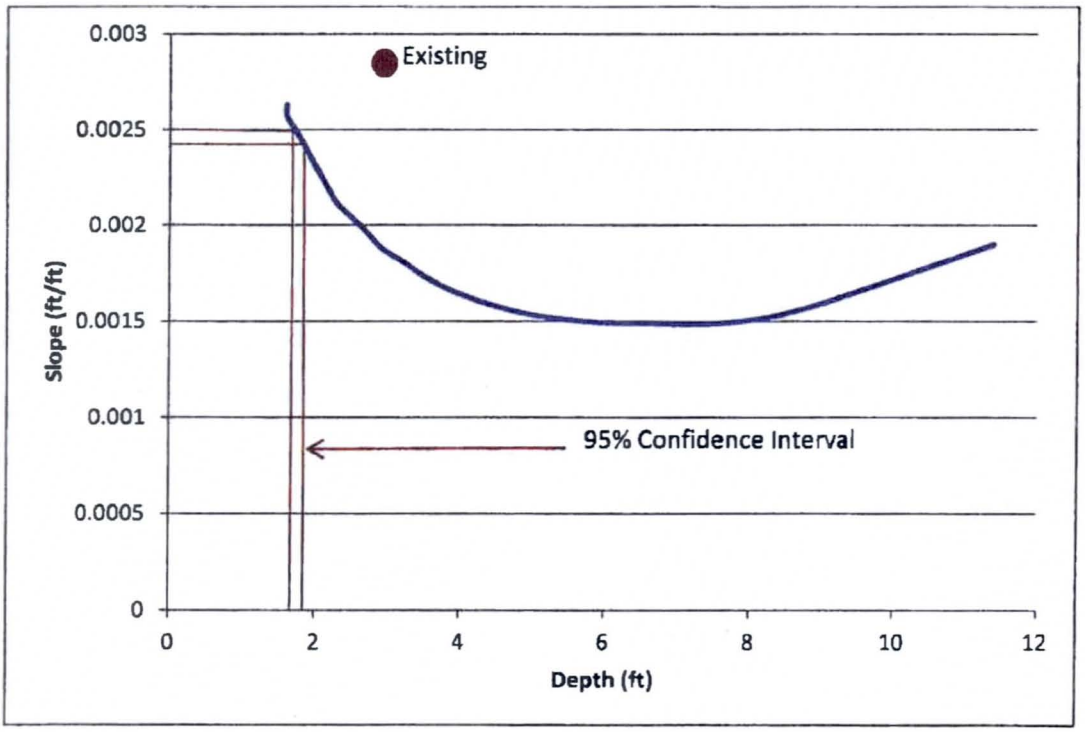
Station 12.42 (Phase III)



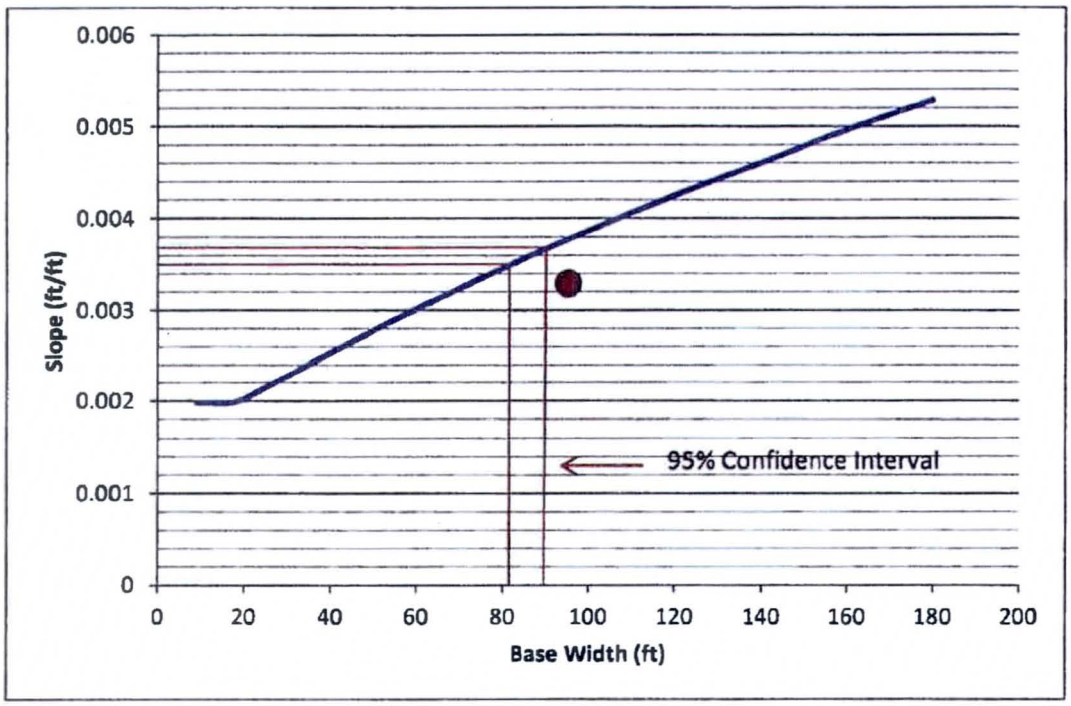


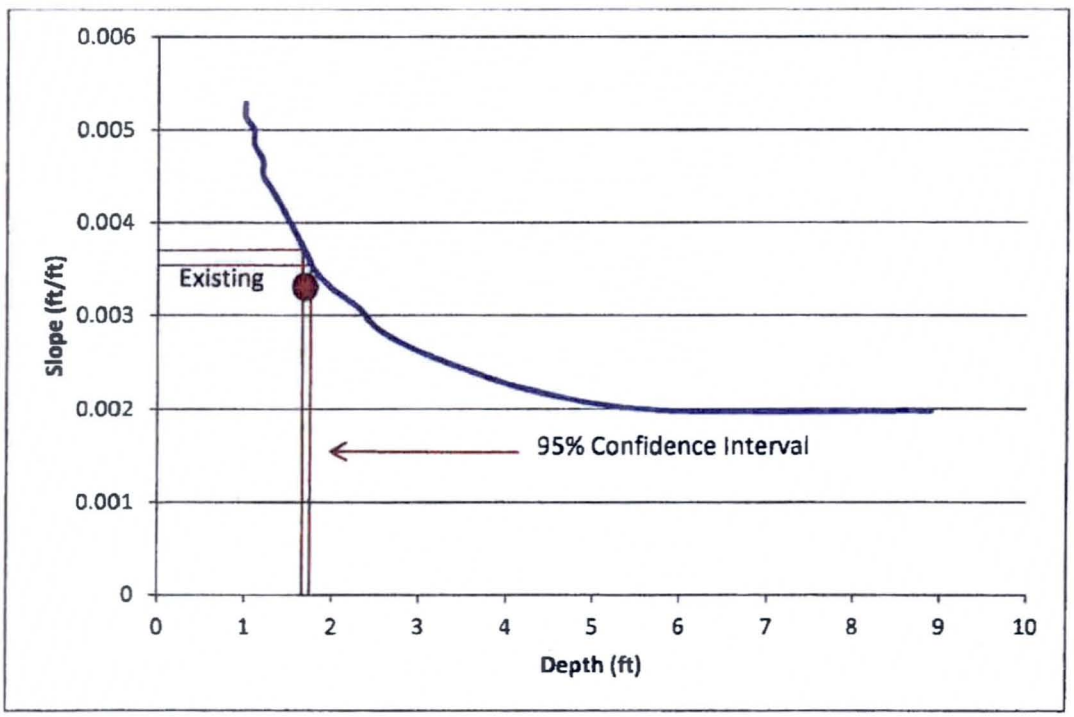
Station 11.45 (Phase V)



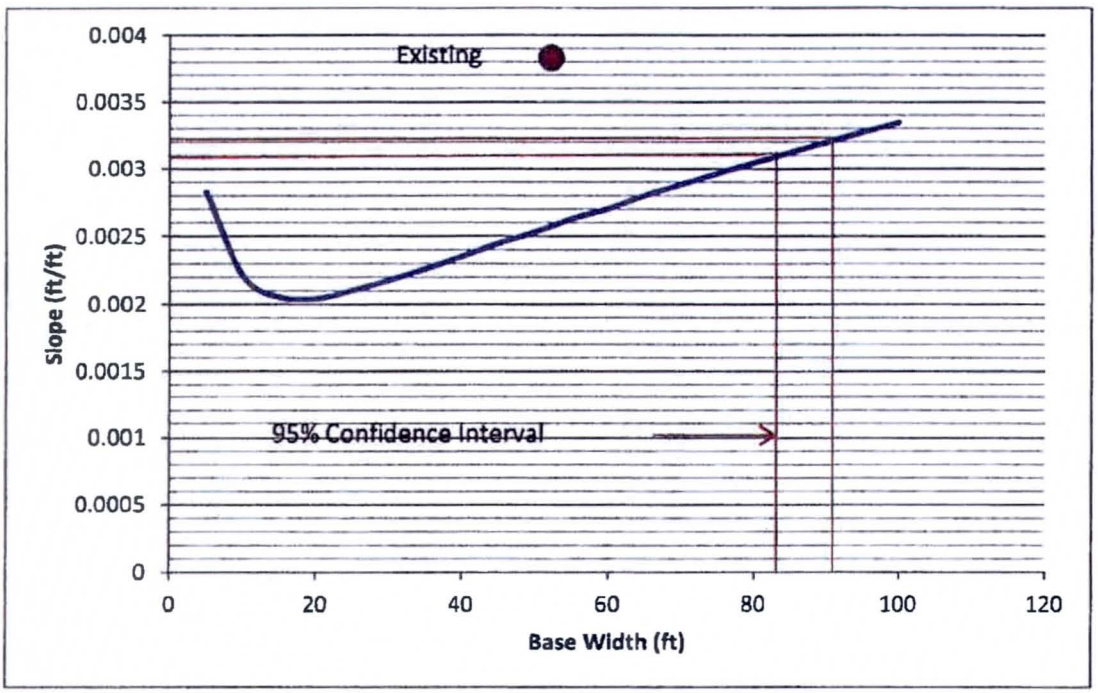


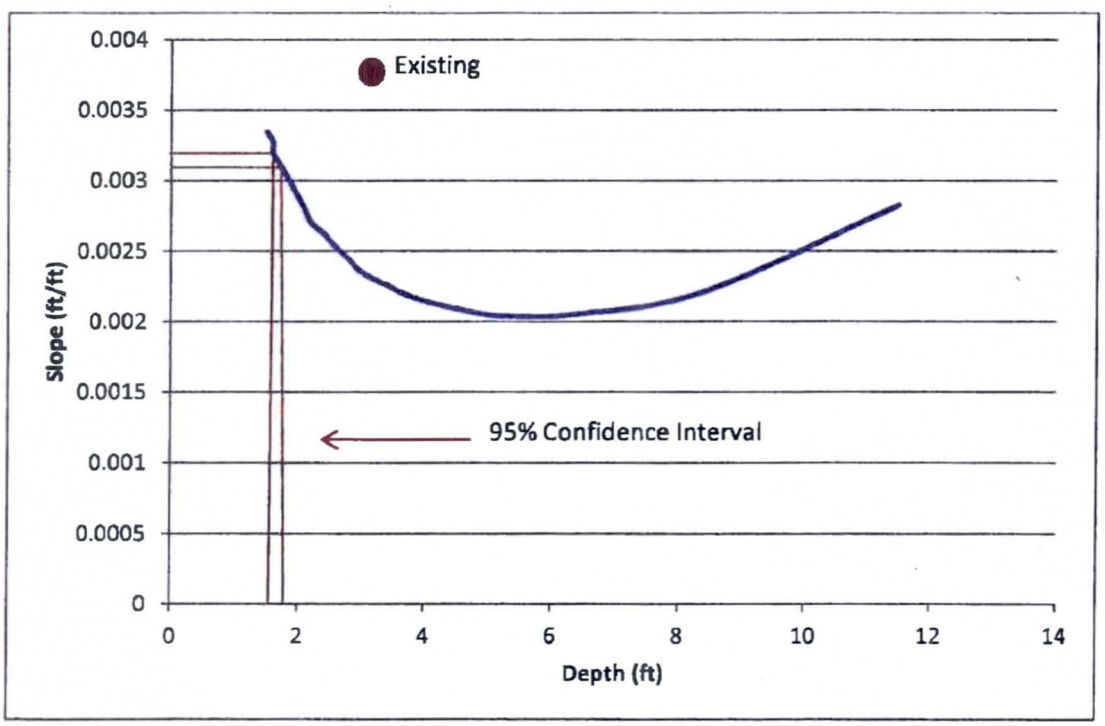
Station 10.45 (Phase IV)



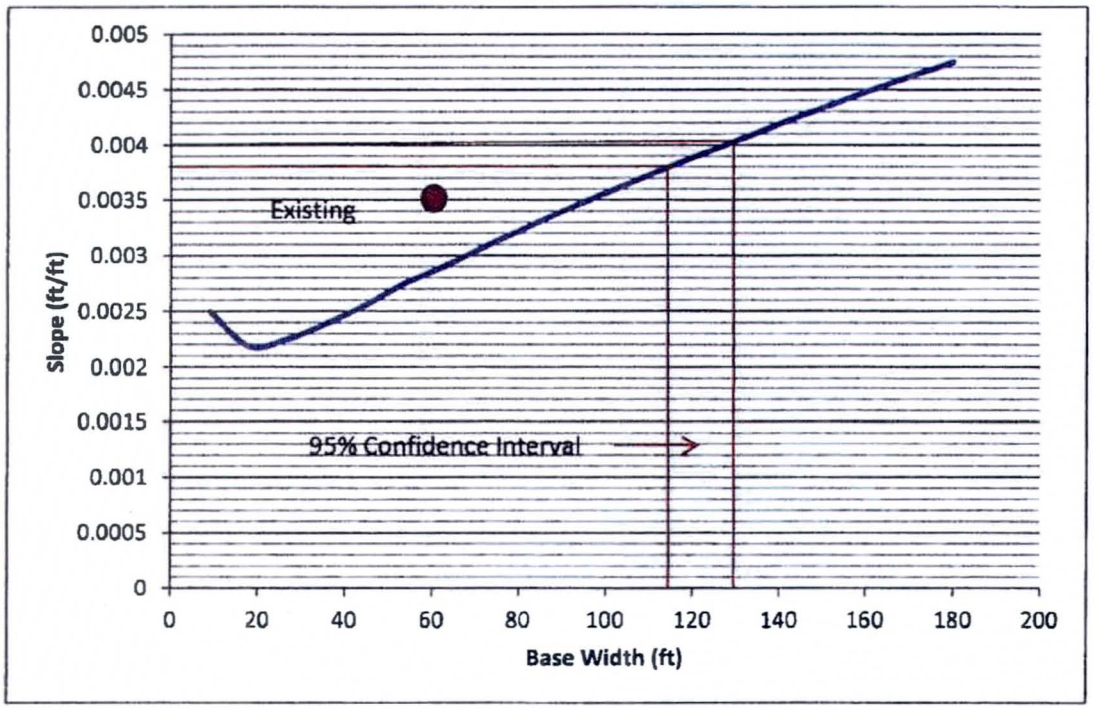


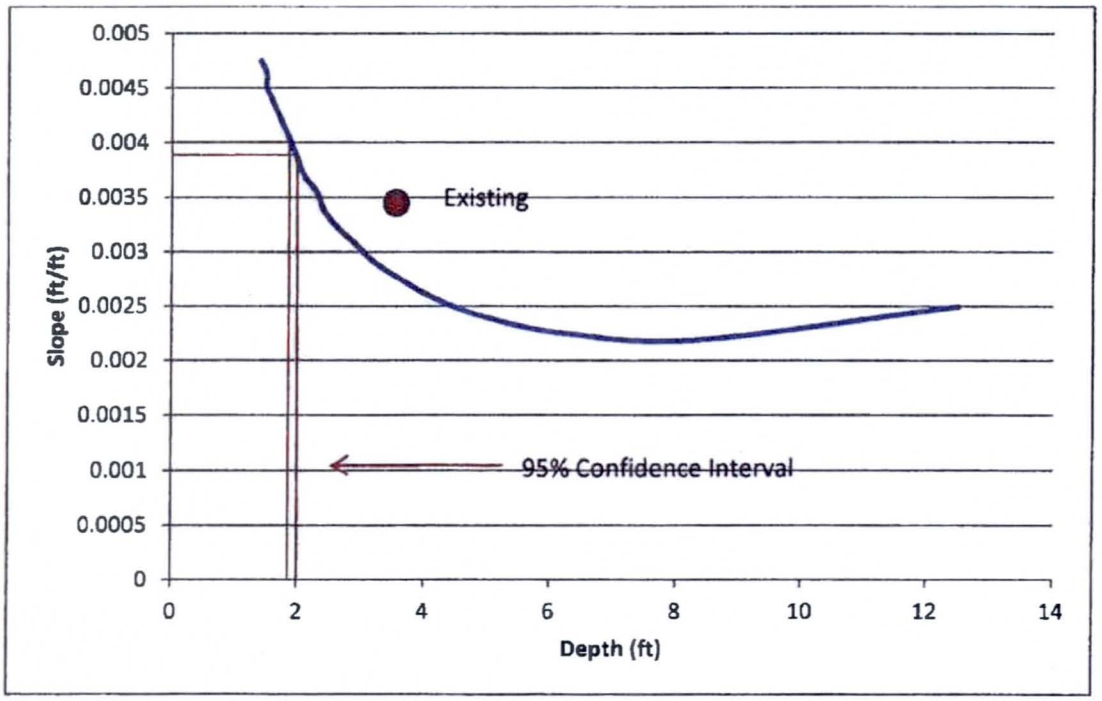
Station 9.40 (Phase V)



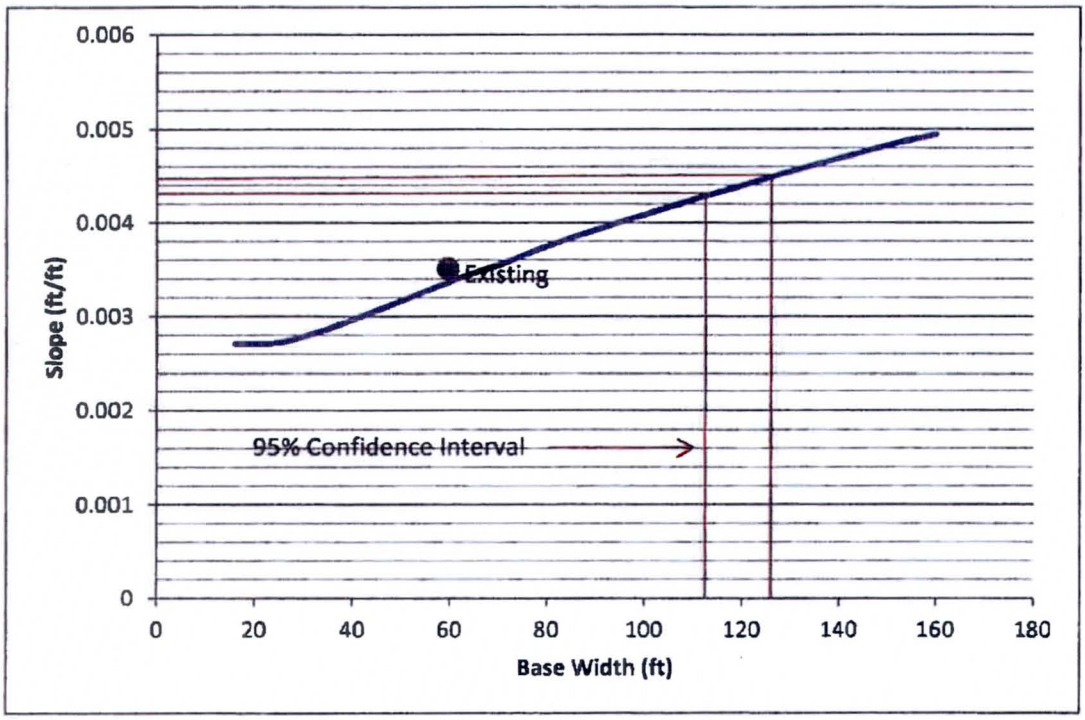


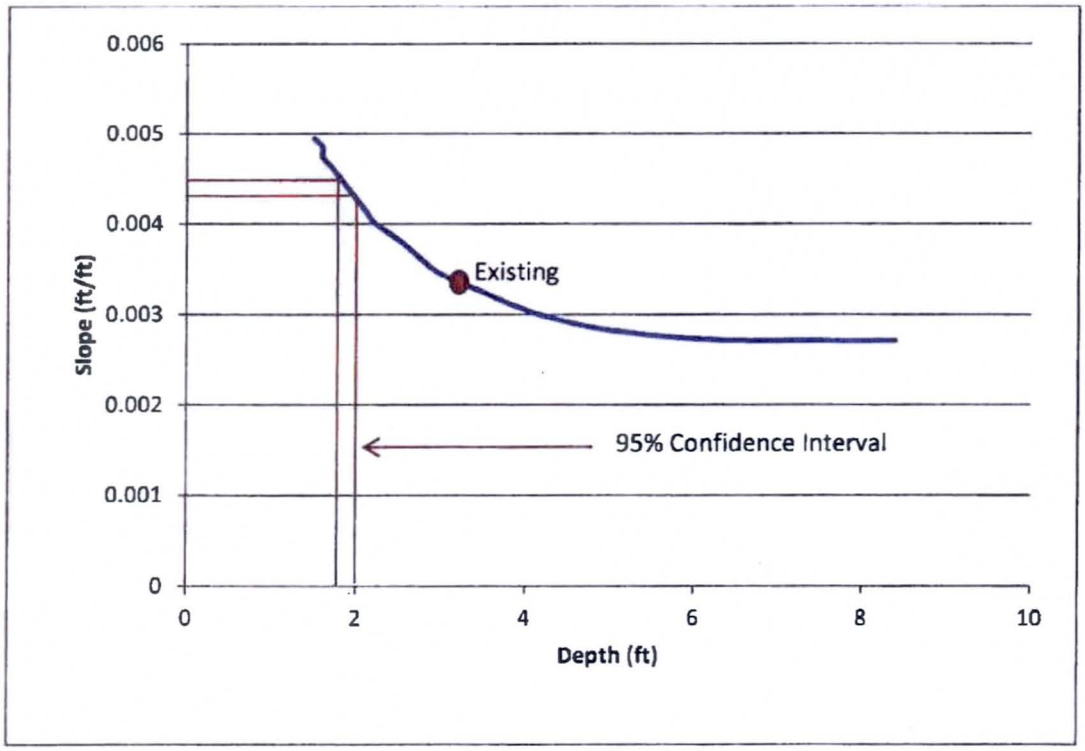
Station 8.29 (Phase V)



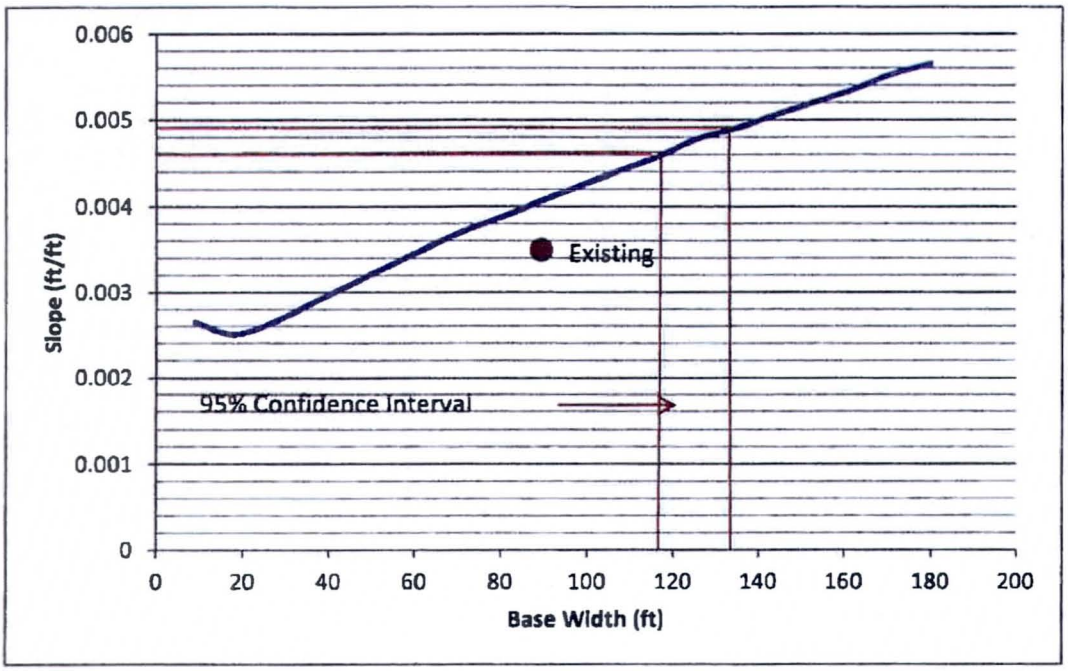


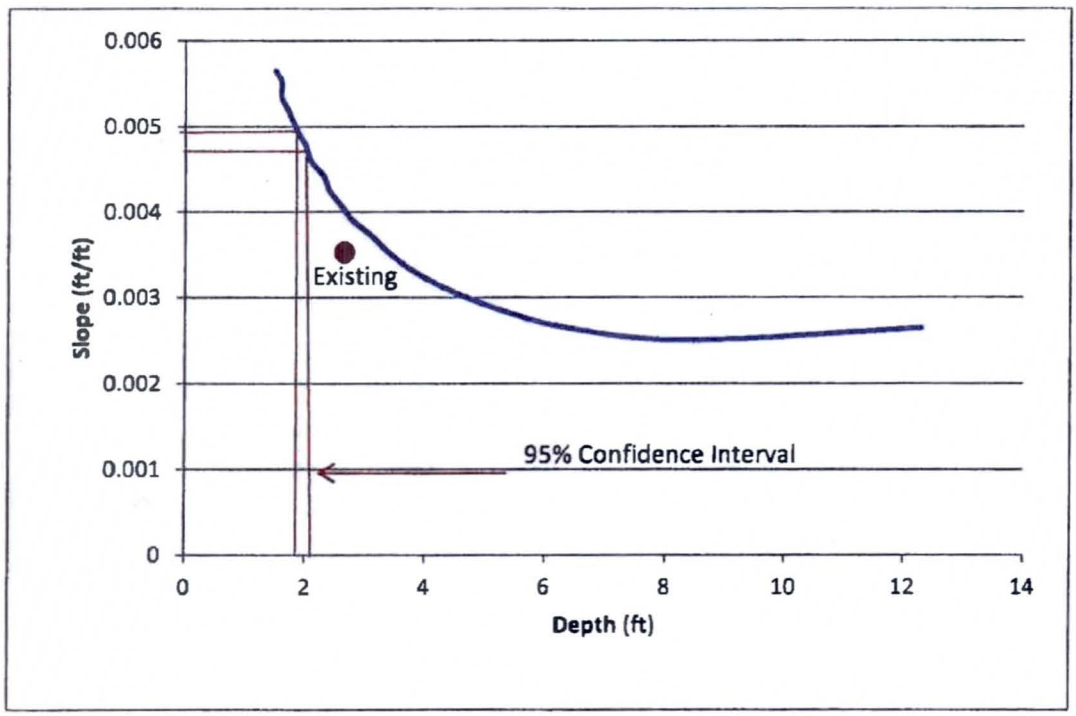
Station 7.31 (Phase V)



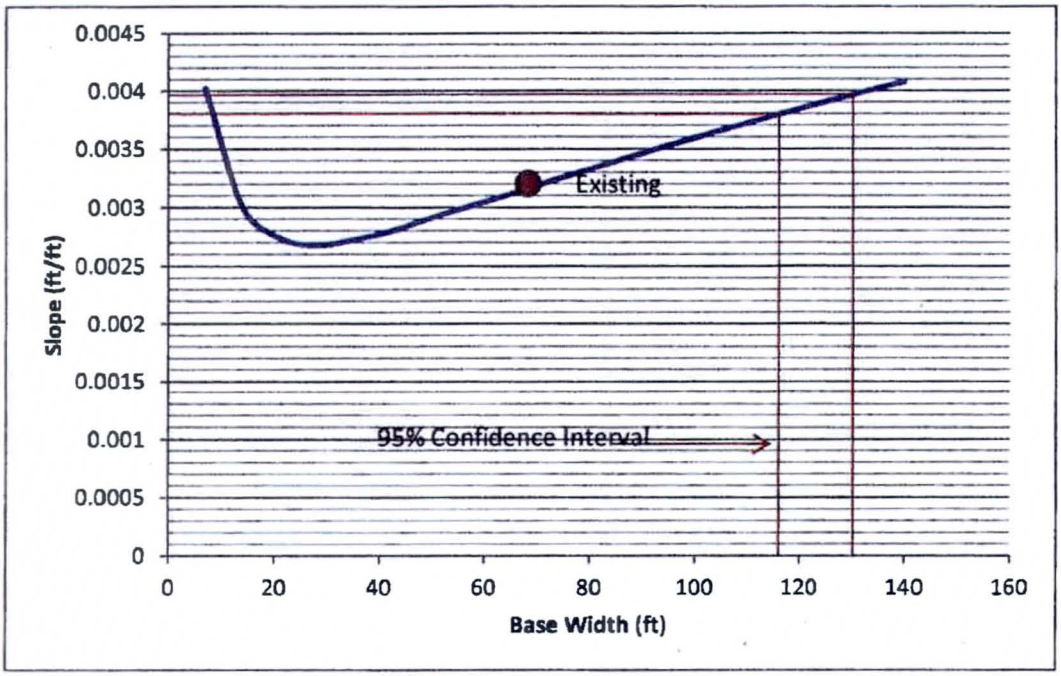


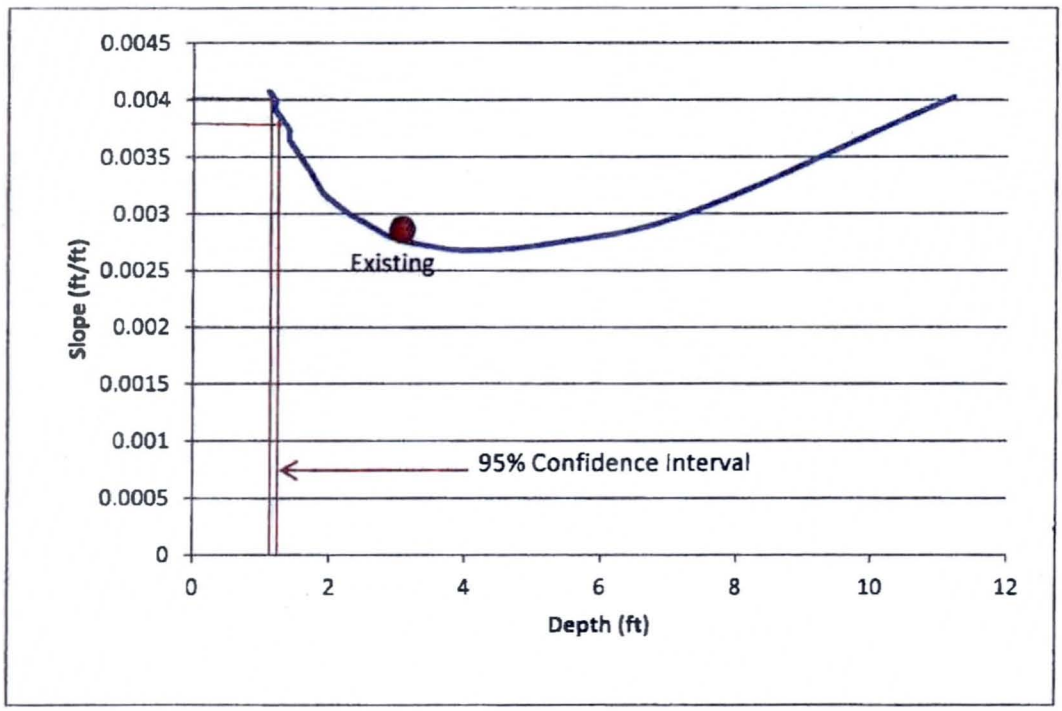
Station 6.34 (Phase V)



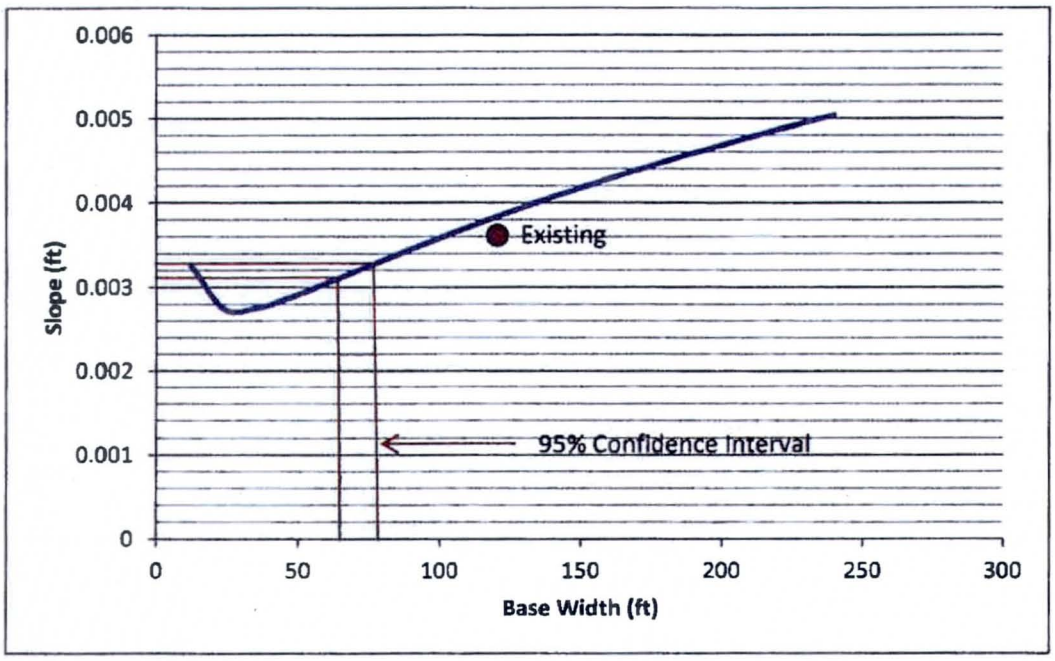


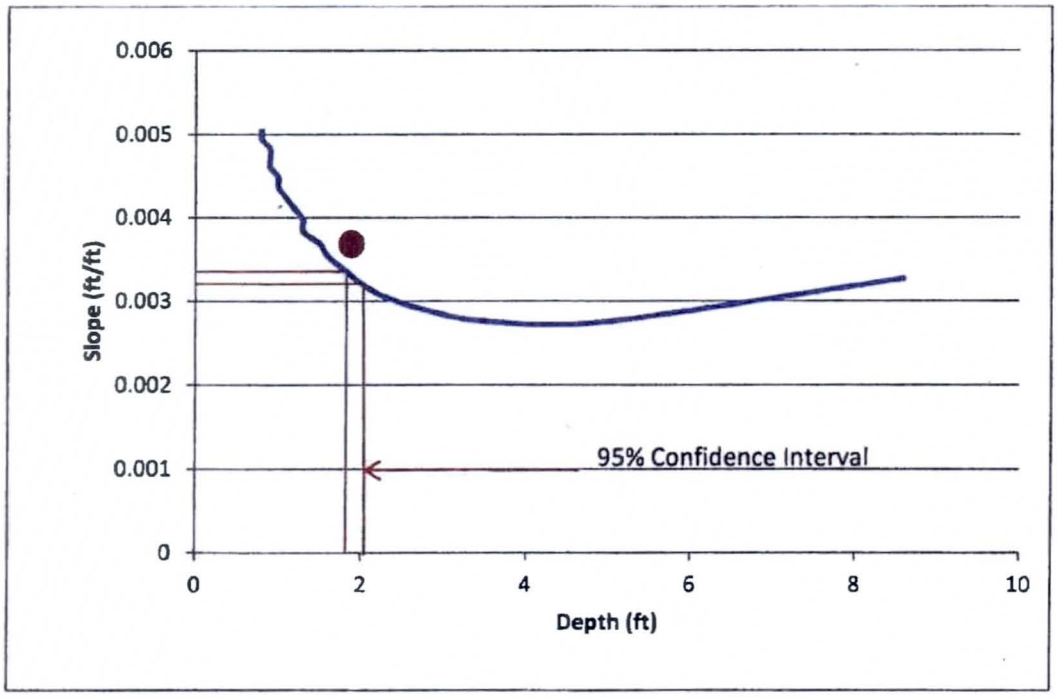
Station 5.20 (Phase V)



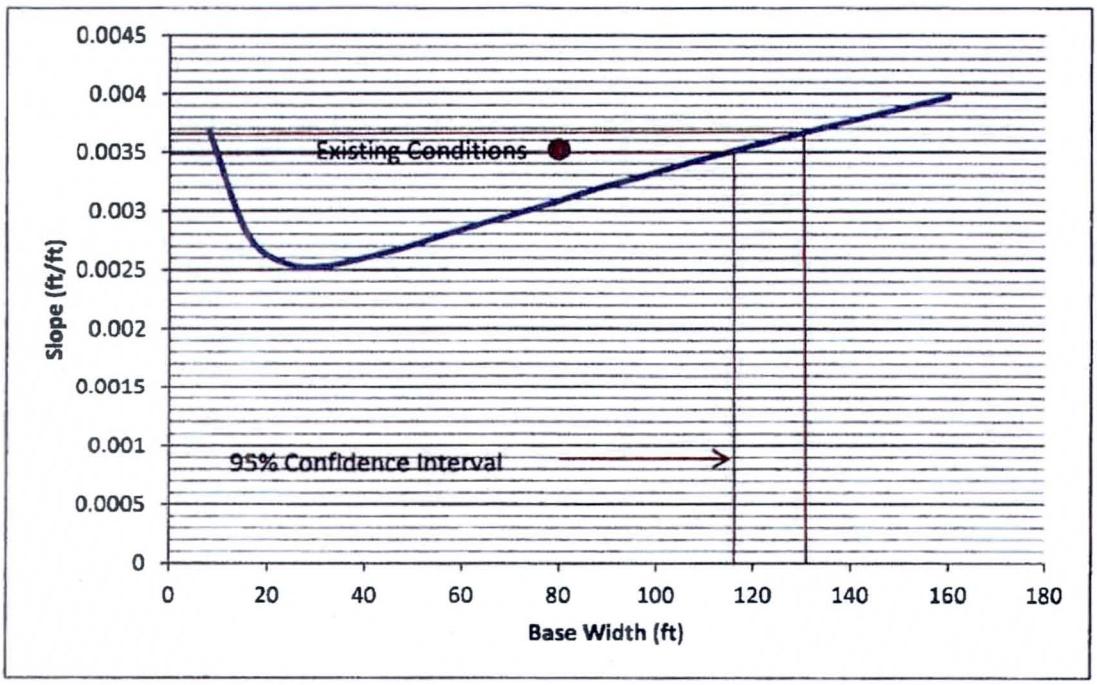


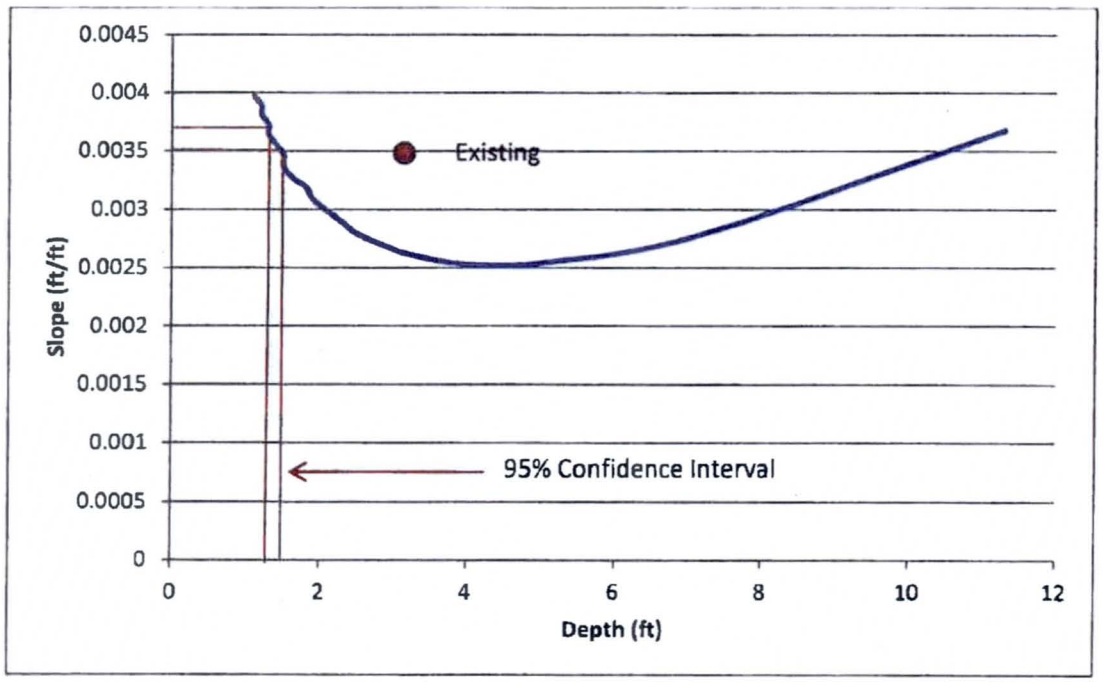
Station 4.23 (Phase III)



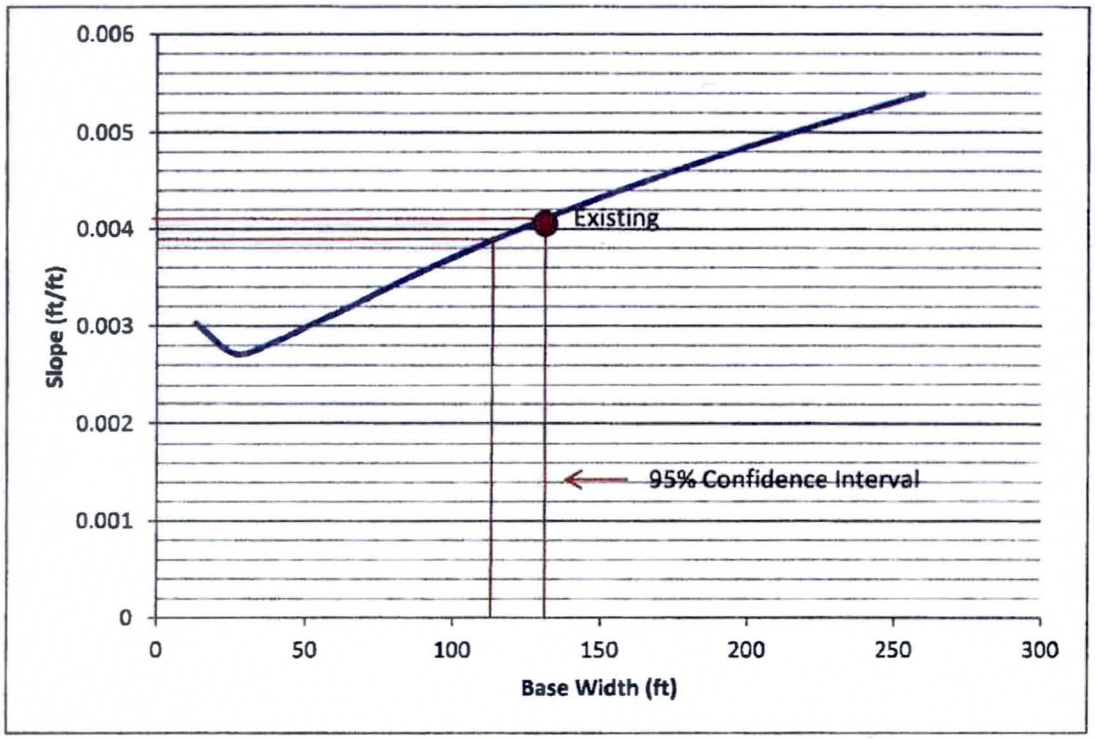


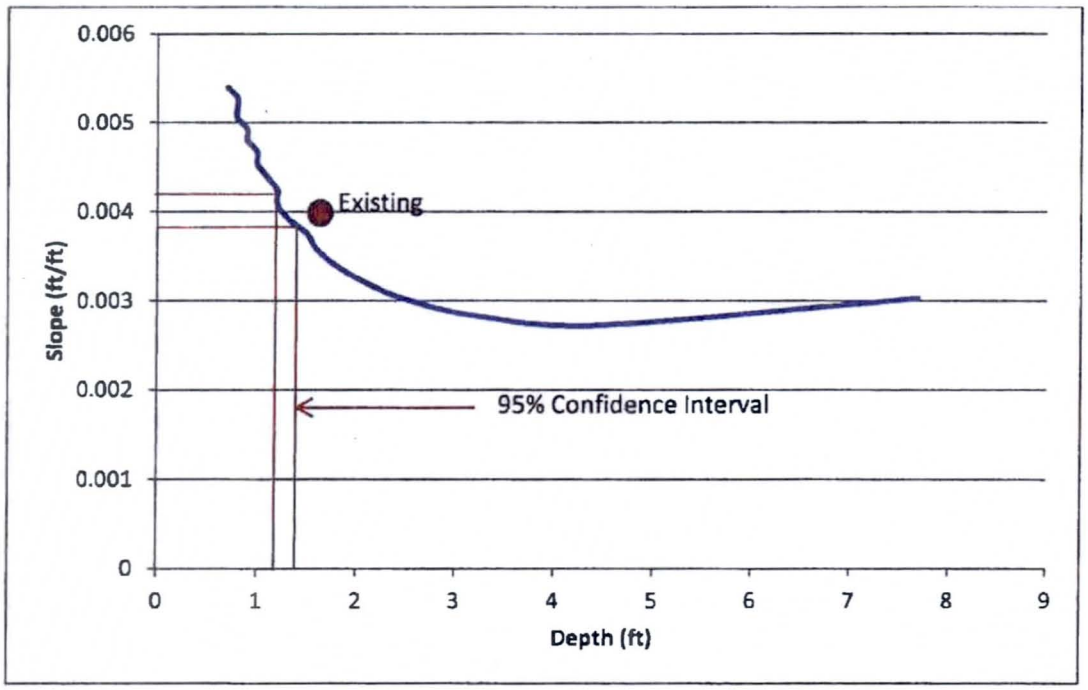
Station 3.31 (Phase V)



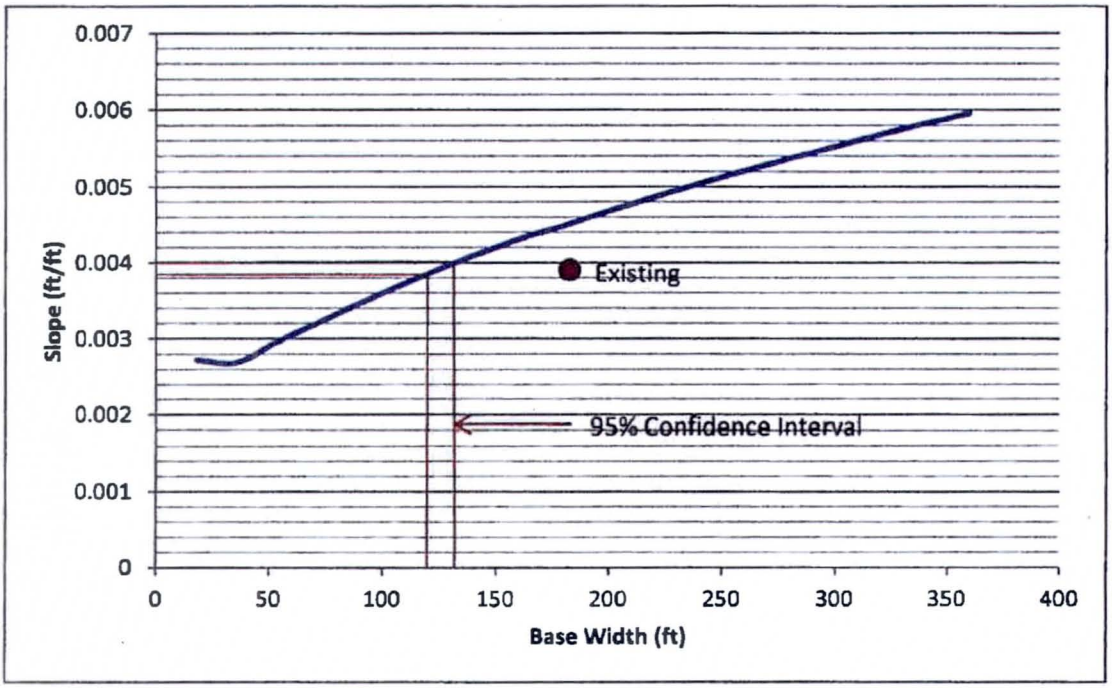


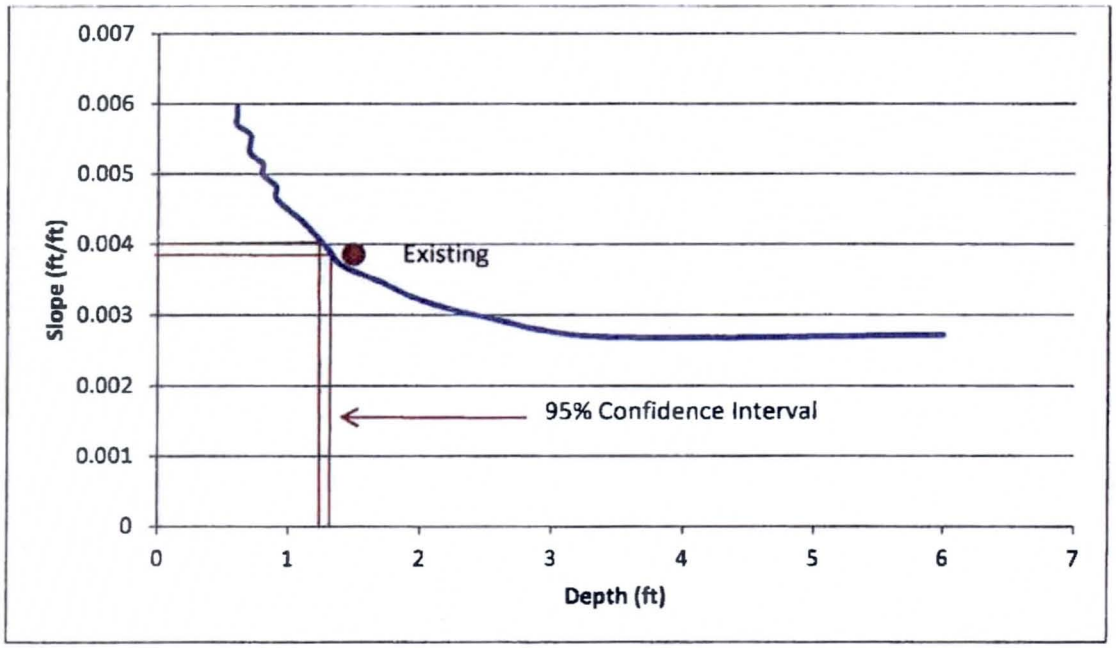
Station 2.17 (Phase VI)



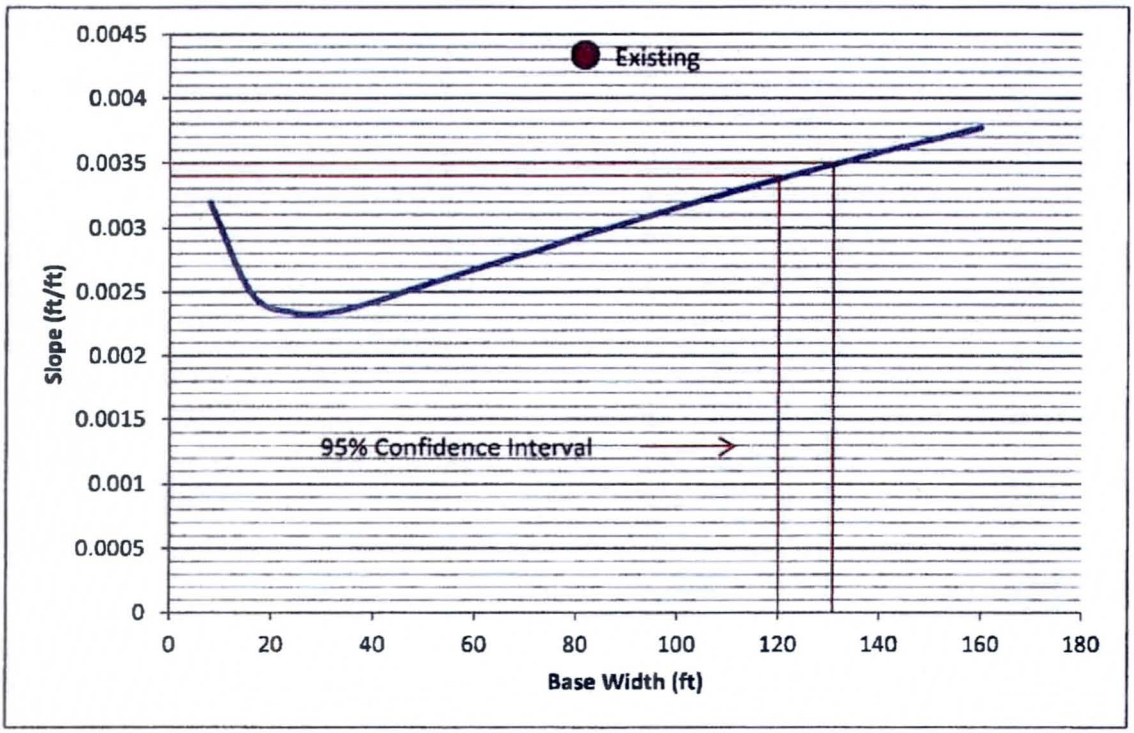


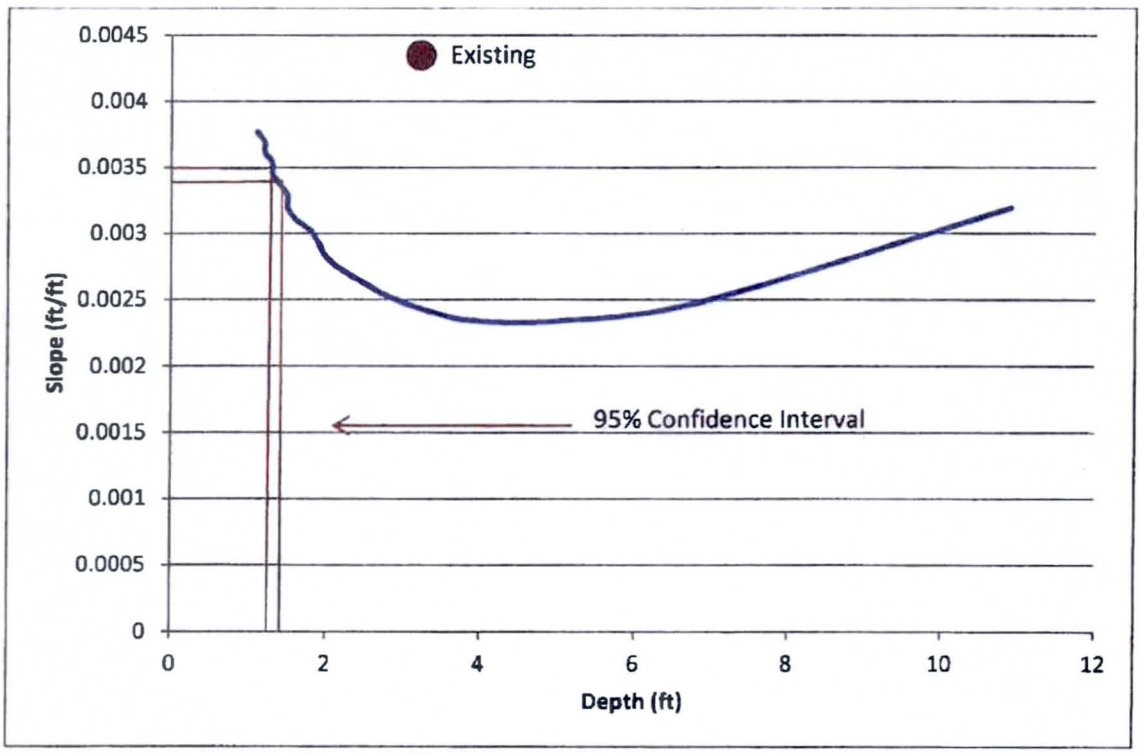
Station 1.24 (phase III)





Station 0.27 (Phase V)





Thorne data were reclassified for this analysis using two distinct groups, since it was considered that the original typing system was difficult to apply in practice because of the subjectivity in distinguishing between four ranges of bank vegetation density. This revised classification also improves the significance of width-discharge equations because sample sizes are larger and enables better comparison with the equations derived from the data compiled by Charlton et al. (1978) and Andrews (1984). The bank typing systems are given in Table 5.8 and the width-discharge relationships for discharges in the range 1 m^3s^{-1} to 1000 m^3s^{-1} based on these systems are defined in Table 5.9.

	Bank Type	
Reference	**Erodible**	**Resistant**
Charlton et al. (1978)	Grass-lined	Tree-lined
Andrews (1984, 1999 pers. comm.)	Thin: almost entirely grass with a light to moderate coverage	Thick: predominantly trees and bushes with 100 percent coverage
Hey and Thorne (1986)*	Less than 5 percent tree/shrub cover, grassy banks or incised into floodplain	At least 5 percent tree/shrub cover

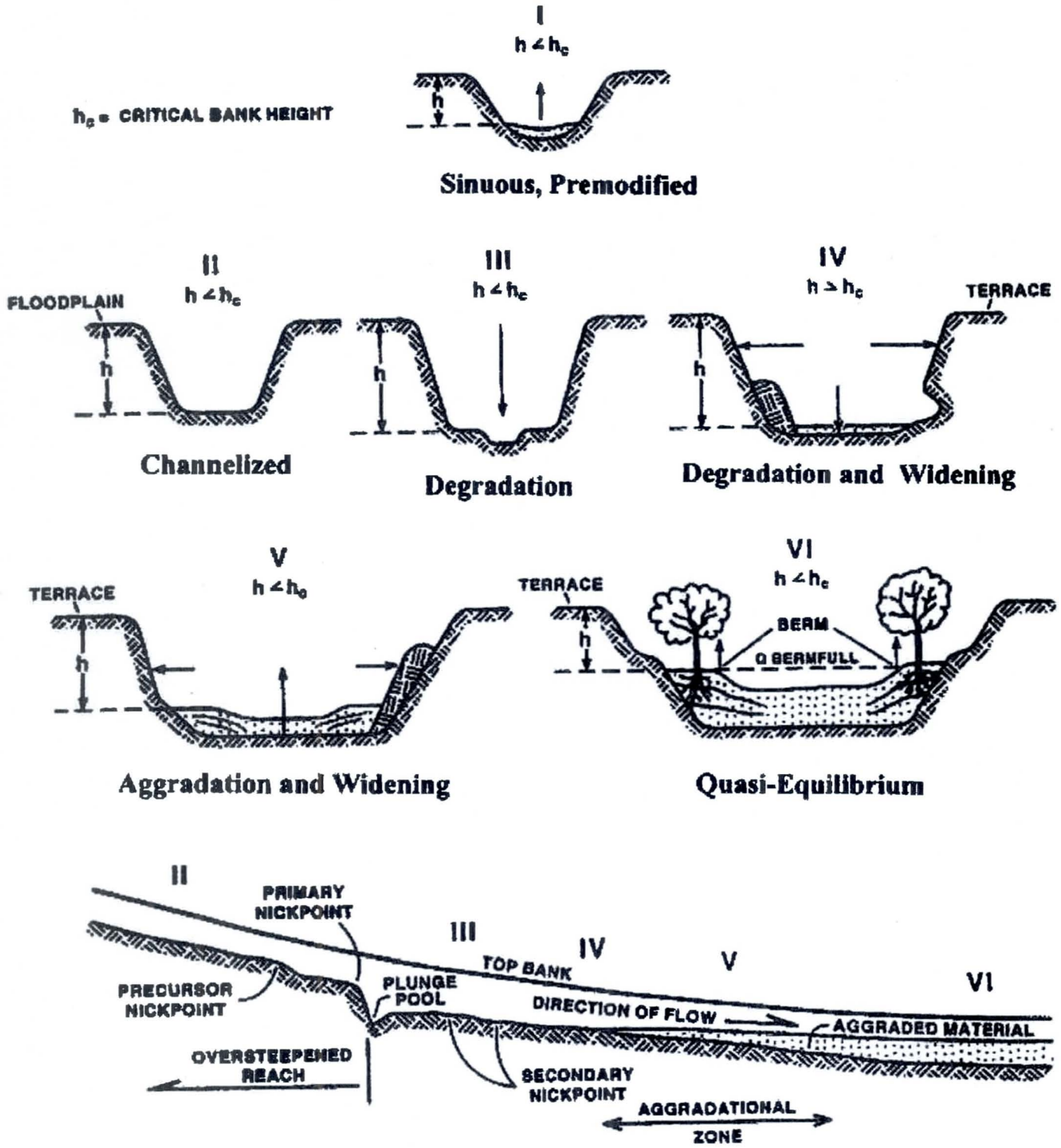
Note: * modified from original definitions by combining the original bank types

Table 5.8 Definitions of erodible and resistant bank types based on categories of riparian vegetation from three data sets.

Data Source	n	a	b	R^2	$P_{b\neq0.5}$ (percent)	a*
Erodible Banks						
Charlton et al. (1978)	10	4.25	0.46	0.91	43.6	3.74 (3.09-4.51)
Andrews (1984)	9	4.18	0.50	0.95	7.2	4.13 (3.78-4.51)
Hey and Thorne (1986)	29	4.25	0.46	0.92	86.4	3.69 (2.46-5.55)
Resistant Banks						
Charlton et al. (1978)	7	2.76	0.48	0.85	25.8	2.51 (2.27-2.77)
Andrews (1984)	14	3.88	0.46	0.96	61.5	3.66 (3.43-3.91)
Hey and Thorne (1986)	33	1.85	0.57	0.93	98.0	2.45 (2.33-2.58)

Note: n = samples in data set; a = discharge coefficient when exponent is not fixed; b = discharge exponent; R^2 = coefficient of determination; $P_{b\neq0.5}$ = significance level of rejecting the null hypothesis that the exponent equals exactly 0.5; a^* = discharge coefficient when exponent is fixed at 0.5 (values in parentheses are 95 percent confidence limits on the mean coefficient value).

Table 5.9 Width-discharge relationships derived from different gravel-bed data sets with typed bank vegetation.


I
h < hc
hc = CRITICAL BANK HEIGHT
h
Sinuous, Premodified
II
h < hc
FLOODPLAIN
h
Channelized
III
h < hc
h
Degradation
IV
h > hc
TERRACE
h
Degradation and Widening
V
h < hc
TERRACE
h
Aggradation and Widening
VI
h < hc
TERRACE
h
BERM
Q BERMFULL
Quasi-Equilibrium
II
PRIMARY NICKPOINT
III
IV
V
VI
TOP BANK
PRECURSOR NICKPOINT
PLUNGE POOL
DIRECTION OF FLOW
AGGRADED MATERIAL
OVERSTEEPENED REACH
SECONDARY NICKPOINT
AGGRADATIONAL ZONE

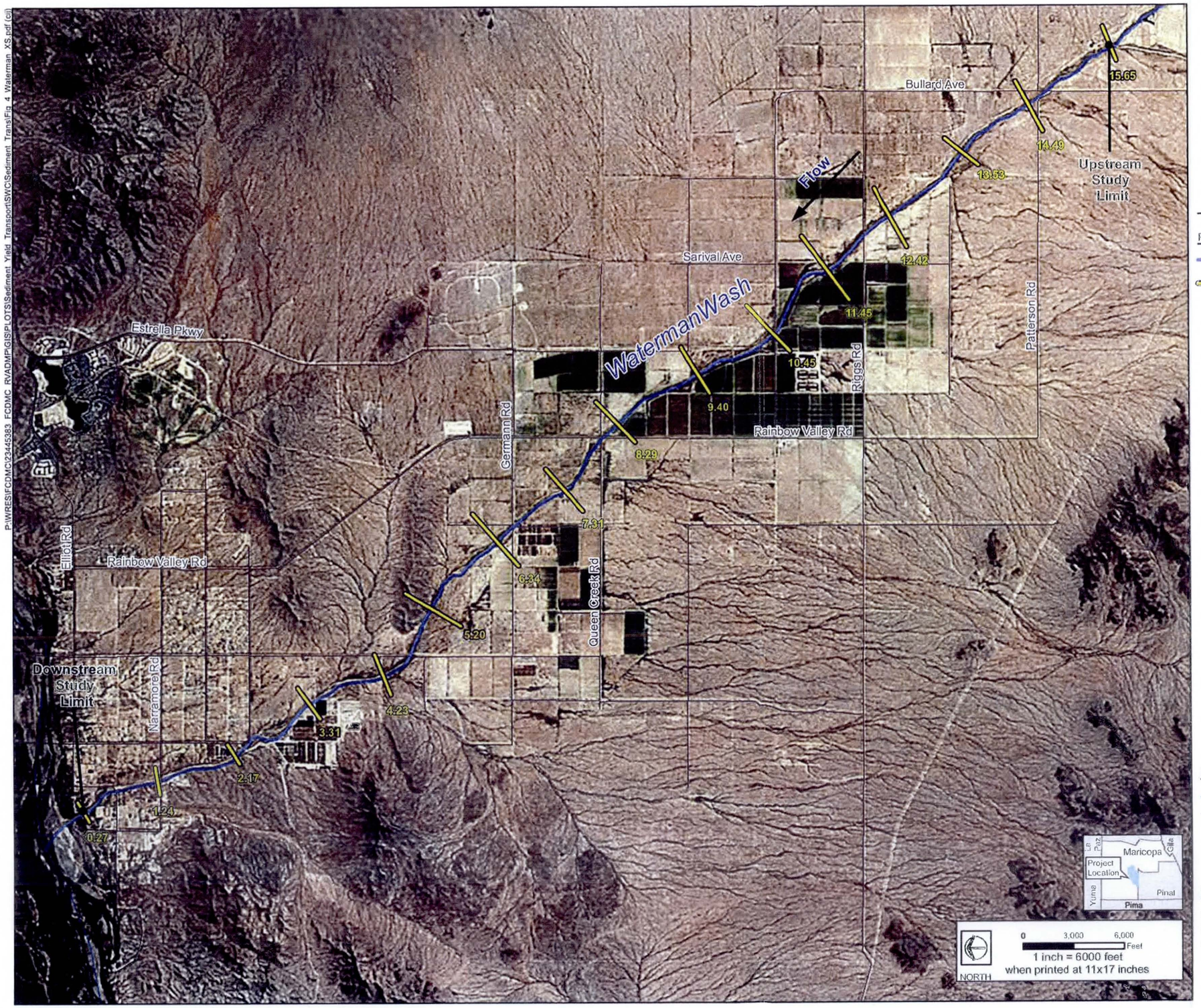
Stable Channel Design for Waterman Wash														
Reach	Q (cfs)	Existing Bankfull Geometry					Predicted Equilibrium-Low			Predicted Equilibrium-High			Future Conditions	
		Width (ft)*	Depth (ft)**	Manning's n	d50 (mm)	Slope (ft/ft)	Width (ft)	Depth (ft)	Slope (ft/ft)	Width (ft)	Depth (ft)	Slope (ft/ft)	Phase	Sinuosity
15.65	398	110	1.5	0.032	1.60	0.0032	70.7	1.6	0.0033	78.3	1.5	0.0035	III, Degradation	No Change
14.49	398	40	2.4	0.028	0.45	0.0020	70.7	1.8	0.0020	78.3	1.6	0.0021	V, Aggradation & Widening	No Change
13.53	497	105	1.5	0.031	1.10	0.0024	80.2	2.7	0.0025	88.8	2.5	0.0027	III, Degradation	More
12.42	497	80	1.7	0.028	1.70	0.0024	80.2	2.0	0.0021	88.8	1.9	0.0022	III, Degradation	Less
11.45	497	50	2.2	0.028	1.70	0.0028	80.2	1.9	0.0024	88.8	1.7	0.0025	V, Aggradation & Widening	Less
10.45	497	90	1.5	0.030	4.50	0.0032	80.2	1.8	0.0035	88.8	1.7	0.0037	IV, Degradation & Widening	More
9.40	497	50	2.4	0.037	1.70	0.0037	80.2	1.8	0.0031	88.8	1.6	0.0032	V, Aggradation & Widening	Less
8.29	933	60	3.1	0.035	4.60	0.0034	114.9	2.0	0.0038	127.2	1.9	0.0040	V, Aggradation & Widening	No Change
7.31	933	60	3.1	0.035	1.60	0.0033	114.9	2.0	0.0043	127.2	1.8	0.0045	V, Aggradation & Widening	More
6.34	974	90	2.5	0.030	4.20	0.0035	117.8	2.1	0.0046	130.3	1.9	0.0049	V, Aggradation & Widening	More
5.20	974	70	2.8	0.032	0.55	0.0032	117.8	1.3	0.0038	130.3	1.2	0.0040	V, Aggradation & Widening	More
4.23	974	120	2.0	0.035	0.45	0.0036	117.8	2.1	0.0031	130.3	2.0	0.0033	III, Degradation	Less
3.31	989	80	2.6	0.035	0.45	0.0035	118.7	1.4	0.0035	131.5	1.3	0.0037	V, Aggradation & Widening	No Change
2.17	989	130	1.7	0.030	0.12	0.0040	118.7	1.3	0.0039	131.5	1.2	0.0041	VI, Quasi-Equilibrium	No Change
1.24	989	180	1.4	0.030	0.12	0.0039	118.7	1.3	0.0038	131.5	1.2	0.0040	III, Degradation	No Change
0.27	989	80	2.3	0.030	0.12	0.0044	118.7	1.4	0.0034	131.5	1.3	0.0035	V, Aggradation & Widening	Less

* Width measured using GIS software

** Normal Depth calculated in Flowmaster, side slopes assumed to be 3:1

Rainbow Valley
Area Drainage Master Plan
Waterman Wash
Channel Equilibrium Evaluation

Figure C-1



Project Features

- Waterman Wash
- Cross Sections

Reference Features

- River/Stream
- Major Road

Data Sources

Historical Data Locations: Flood Control District of Maricopa County 2008
Aerial Imagery: Bing 2011

P:\WRES\FCDMC\2445383_FCDMC_RVADMP\GIS\PLOTS\Sediment Yield Transport\SWC\Sediment Trans\Fig 4 Waterman XS.pdf (cl)

Attachment D

Inflow Hydrographs

Table D-1. Station 16.72 – Inflow Hydrographs

ST. 16.72				
Time	Flow (cfs)			
Hour	100Yr	50Yr	25Yr	10Yr
0	-	-	-	-
1	-	-	-	-
2	-	-	-	-
3	0	-	-	-
4	1	1	1	0
5	1	1	1	1
6	2	2	2	1
7	4	4	3	3
8	7	6	5	4
9	11	9	8	7
10	17	14	12	10
11	28	23	18	13
12	46	38	30	20
13	1,615	1,186	751	314
14	3,539	2,502	1,610	705
15	5,602	3,824	2,361	1,048
16	4,846	3,426	2,204	925
17	4,453	2,978	1,900	799
18	4,113	2,702	1,727	793
19	3,393	2,430	1,539	727
20	2,810	2,025	1,315	601
21	2,468	1,705	1,105	485
22	2,214	1,529	920	395
23	1,948	1,382	771	333
24	1,671	1,207	670	290
25	1,367	1,022	573	249
26	1,096	842	513	212
27	865	706	461	187
28	700	584	405	166
29	576	491	357	153
30	481	414	318	146
31	404	356	279	137
32	346	305	245	123
33	295	259	219	108
34	251	224	192	100
35	219	194	168	91
36	190	168	149	81

ST. 16.72				
Time	Flow (cfs)			
Hour	100Yr	50Yr	25Yr	10Yr
37	166	148	133	71
38	149	131	119	63
39	134	116	106	55
40	119	104	95	50
41	107	93	86	47
42	97	84	77	42
43	87	75	69	38
44	78	67	61	35
45	70	60	55	31
46	62	54	50	28
47	56	48	44	25
48	51	43	41	23
49	46	40	37	21
50	42	37	34	19

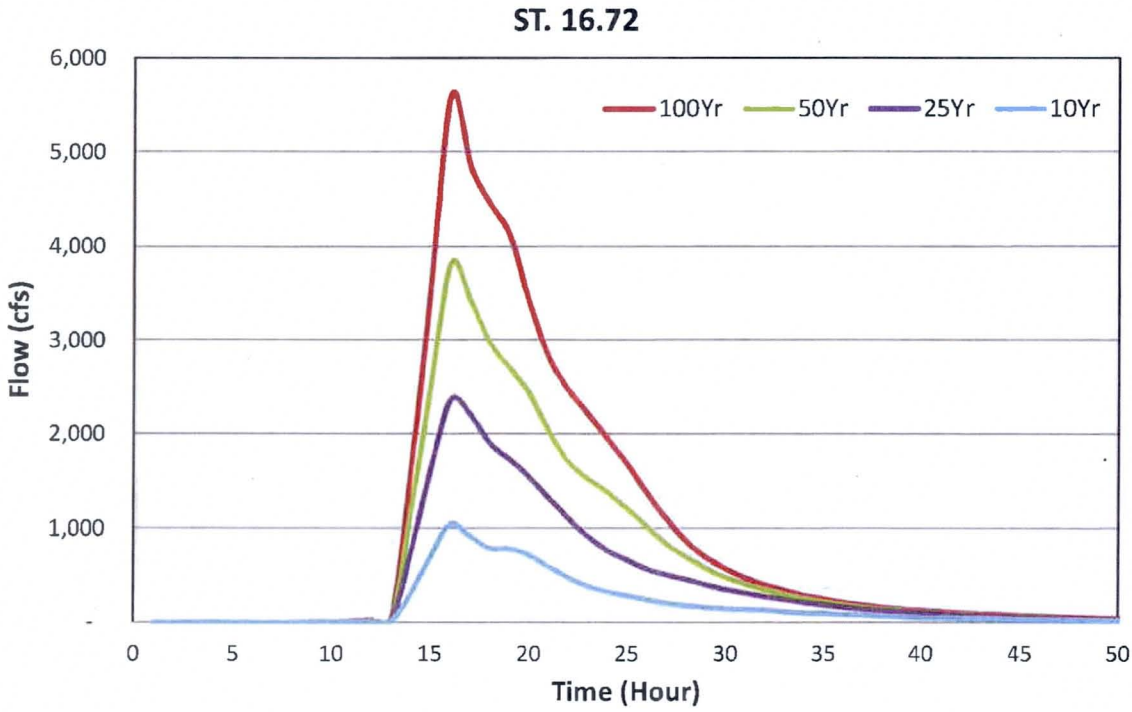


Figure B-1. Station 16.72 – Frequency Storm Hydrographs

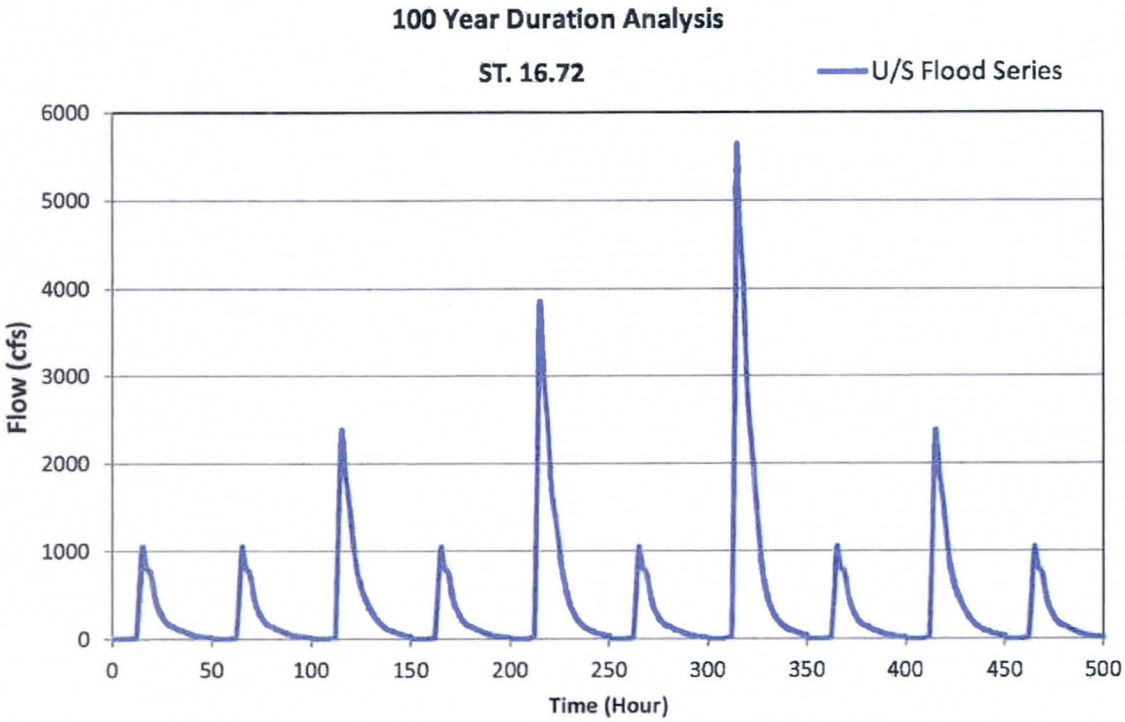


Figure B-2. Station 16.72 – 100-Year Series Floods

Table D-2. Station 15.65 – Inflow Hydrographs

ST. 15.65				
Time	Flow (cfs)			
Hour	100Yr	50Yr	25Yr	10Yr
0	-	-	-	-
1	-	-	-	-
2	-	-	-	-
3	-	-	-	-
4	-	-	-	-
5	-	-	-	-
6	-	-	-	-
7	-	-	-	-
8	-	-	-	-
9	-	-	-	-
10	-	-	-	-
11	-	-	-	-
12	2	2	1	-
13	469	302	177	68
14	2,466	1,558	781	222
15	2,225	1,514	959	337
16	3,917	2,412	1,355	461
17	3,982	2,750	1,674	558
18	2,228	1,611	977	342
19	1,095	783	480	156
20	547	432	298	88
21	327	276	194	57
22	220	194	145	45
23	159	139	117	39
24	116	103	88	35
25	86	75	65	31
26	64	56	52	27
27	51	46	42	23
28	42	38	36	18
29	36	32	30	15
30	31	26	25	13
31	26	22	21	11
32	21	18	18	9
33	18	15	15	7
34	15	12	12	5
35	13	9	9	3
36	10	7	7	2

ST. 15.65				
Time	Flow (cfs)			
Hour	100Yr	50Yr	25Yr	10Yr
37	8	5	5	1
38	6	3	3	1
39	5	2	2	0
40	4	1	1	-
41	3	1	1	-
42	2	0	-	-
43	1	-	-	-
44	1	-	-	-
45	1	-	-	-
46	1	-	-	-
47	-	-	-	-
48	-	-	-	-
49	-	-	-	-
50	-	-	-	-

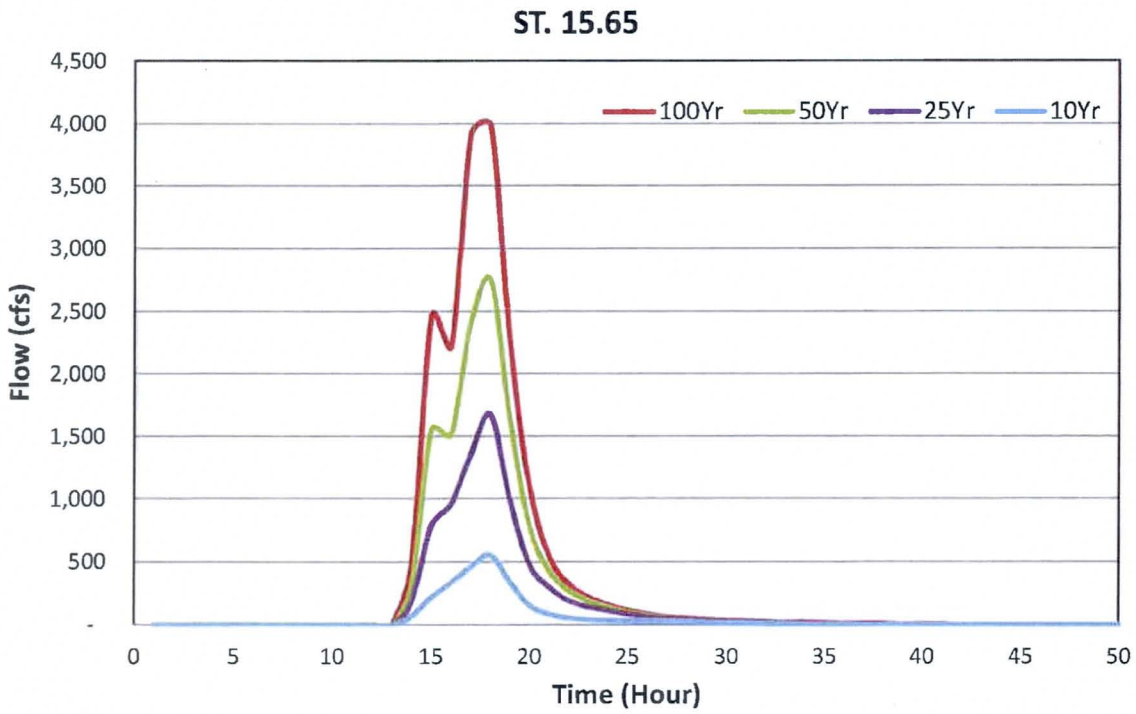


Figure B-3. Station 15.65 - Frequency Storm Hydrographs

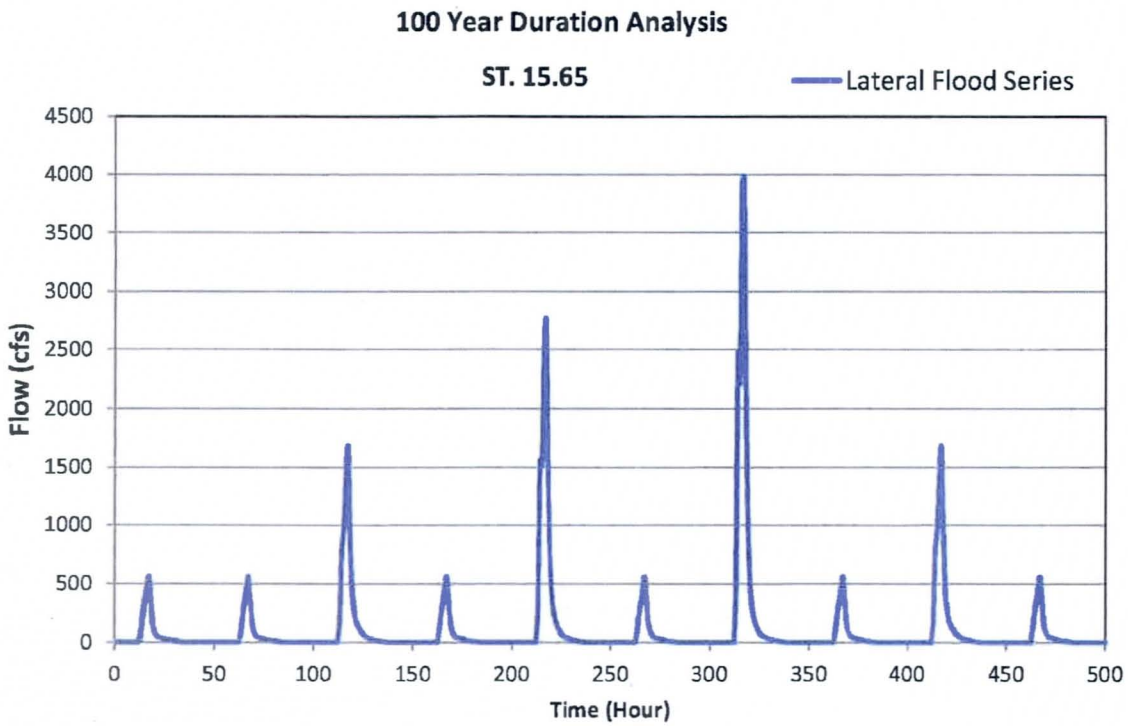


Figure B-4. Station 15.65 - 100-Year Series Floods

Table D-3. Station 14.40 – Inflow Hydrographs

ST. 14.4				
Time	Flow (cfs)			
Hour	100Yr	50Yr	25Yr	10Yr
0	-	-	-	-
1	-	-	-	-
2	-	-	-	-
3	-	-	-	-
4	-	-	-	-
5	-	-	-	-
6	-	-	-	-
7	3	1	0	-
8	16	12	8	4
9	21	18	15	11
10	25	21	18	14
11	28	25	21	16
12	51	40	31	19
13	487	391	294	156
14	297	247	197	135
15	501	398	305	191
16	828	630	484	314
17	637	557	451	308
18	210	173	134	86
19	58	53	49	43
20	45	41	37	32
21	38	34	31	25
22	32	29	26	22
23	28	25	23	20
24	25	23	20	18
25	22	20	19	16
26	20	18	17	15
27	19	17	16	13
28	18	17	15	13
29	16	14	13	11
30	12	11	10	9
31	8	8	7	7
32	6	6	5	5
33	4	4	4	3
34	3	3	3	2
35	2	2	2	2
36	2	2	2	2

ST. 14.4				
Time	Flow (cfs)			
Hour	100Yr	50Yr	25Yr	10Yr
37	2	2	2	1
38	1	1	1	1
39	1	1	1	1
40	0	0	0	-
41	-	-	-	-
42	-	-	-	-
43	-	-	-	-
44	-	-	-	-
45	-	-	-	-
46	-	-	-	-
47	-	-	-	-
48	-	-	-	-
49	-	-	-	-
50	-	-	-	-

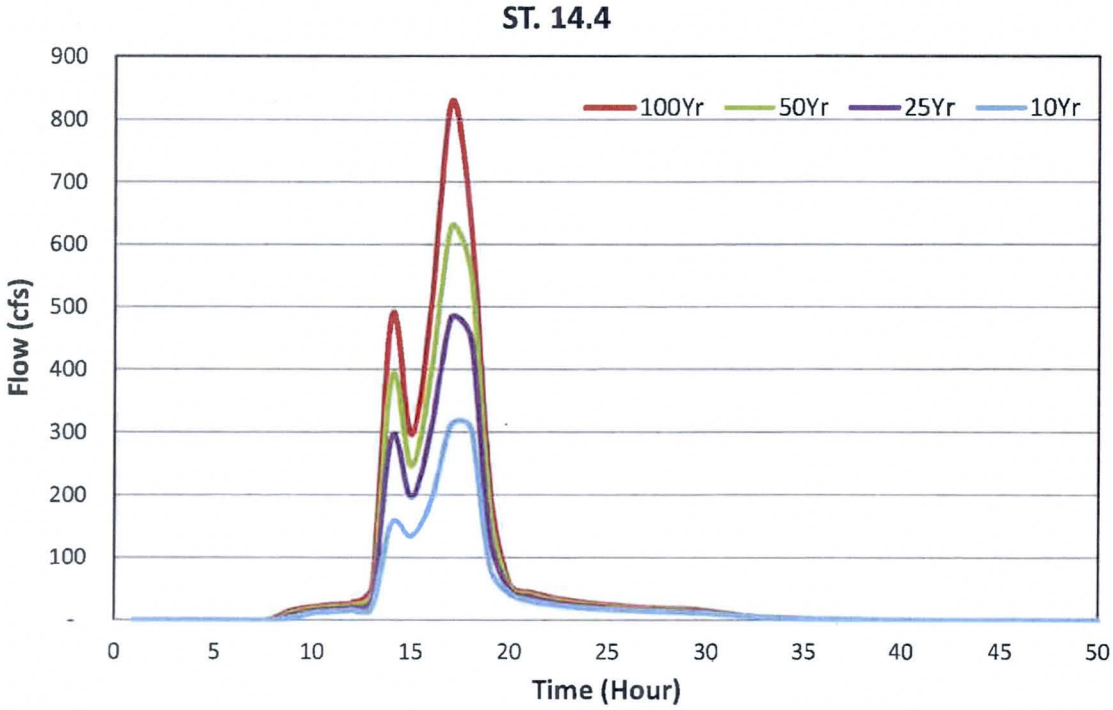


Figure B-5. Station 14.40 - Frequency Storm Hydrographs

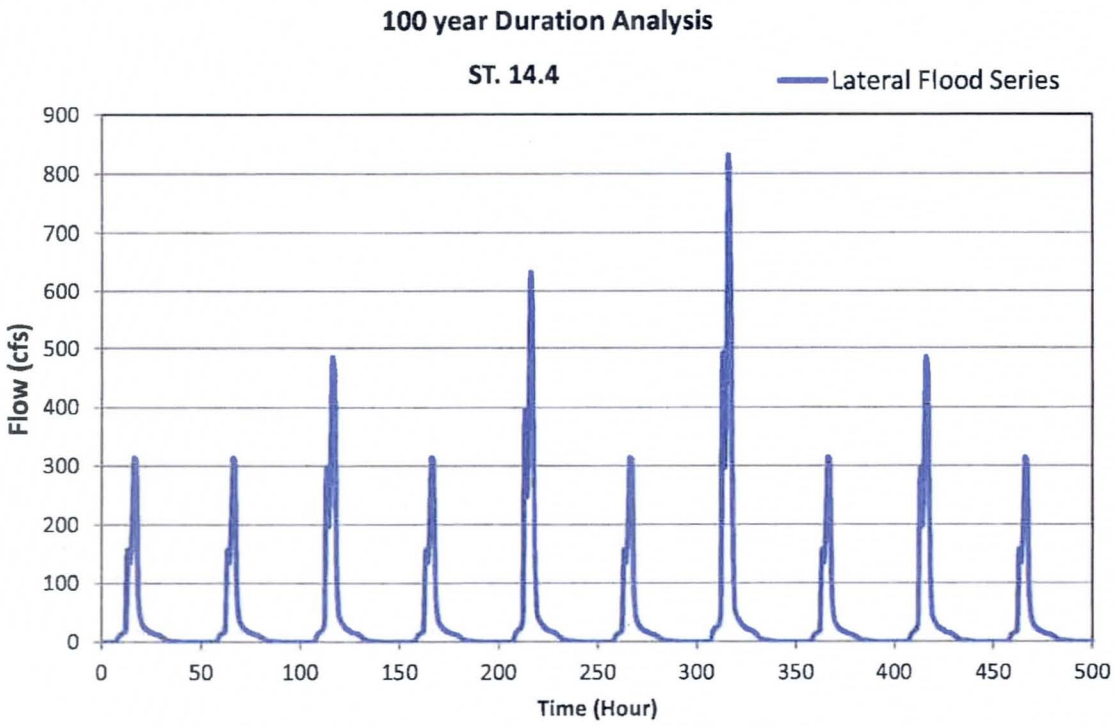


Figure B-6. Station 14.40 - 100-Year Series Floods

Table D-4. Station 14.30 – Inflow Hydrographs

ST. 14.3				
Time	Flow (cfs)			
Hour	100Yr	50Yr	25Yr	10Yr
0	-	-	-	-
1	-	-	-	-
2	-	-	-	-
3	-	-	-	-
4	-	-	-	-
5	-	-	-	-
6	-	-	-	-
7	-	-	-	-
8	-	-	-	-
9	-	-	-	-
10	-	-	-	-
11	-	-	-	-
12	7	4	3	0
13	532	410	295	147
14	272	146	69	16
15	958	622	244	39
16	1,087	655	383	71
17	355	247	190	89
18	218	135	97	60
19	142	99	60	37
20	90	73	45	24
21	58	51	37	15
22	38	36	31	11
23	28	27	23	10
24	20	19	17	9
25	14	14	13	7
26	12	12	11	6
27	11	11	11	5
28	10	10	10	4
29	9	9	9	4
30	8	8	7	3
31	6	6	6	3
32	5	4	4	2
33	3	3	3	2
34	2	2	2	1
35	2	2	2	1
36	1	1	1	1

ST. 14.3				
Time	Flow (cfs)			
Hour	100Yr	50Yr	25Yr	10Yr
37	1	1	1	1
38	1	1	1	-
39	0	-	-	-
40	-	-	-	-
41	-	-	-	-
42	-	-	-	-
43	-	-	-	-
44	-	-	-	-
45	-	-	-	-
46	-	-	-	-
47	-	-	-	-
48	-	-	-	-
49	-	-	-	-
50	-	-	-	-

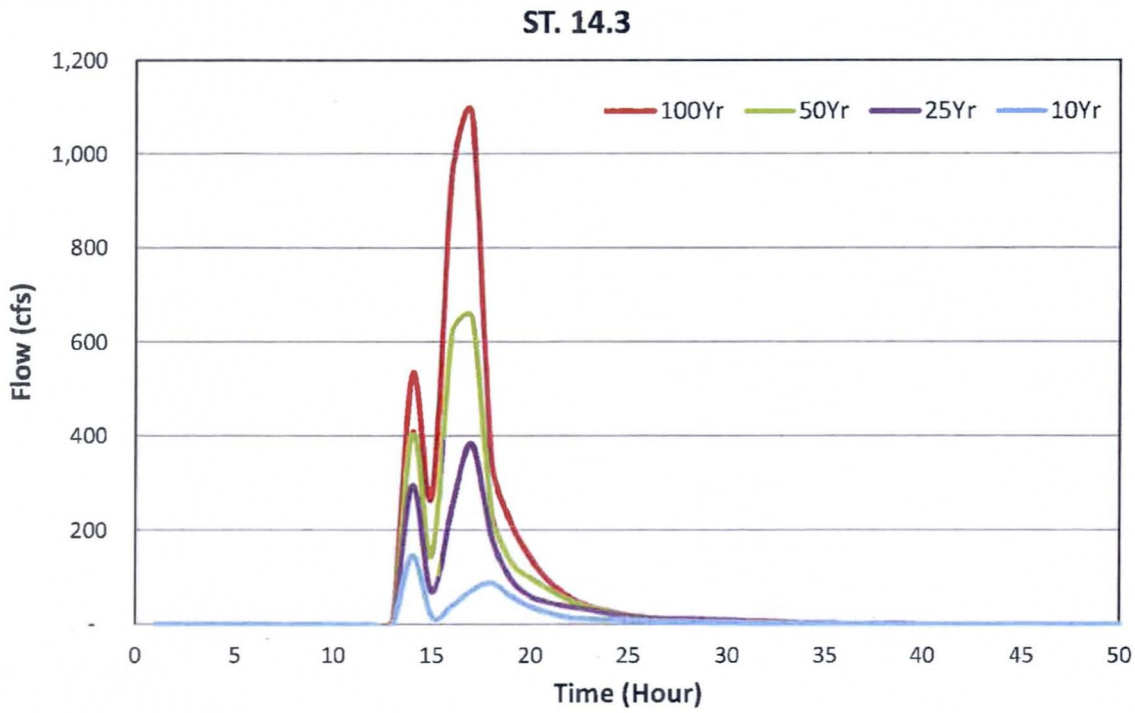


Table B-7. Station 14.30 - Frequency Storm Hydrographs

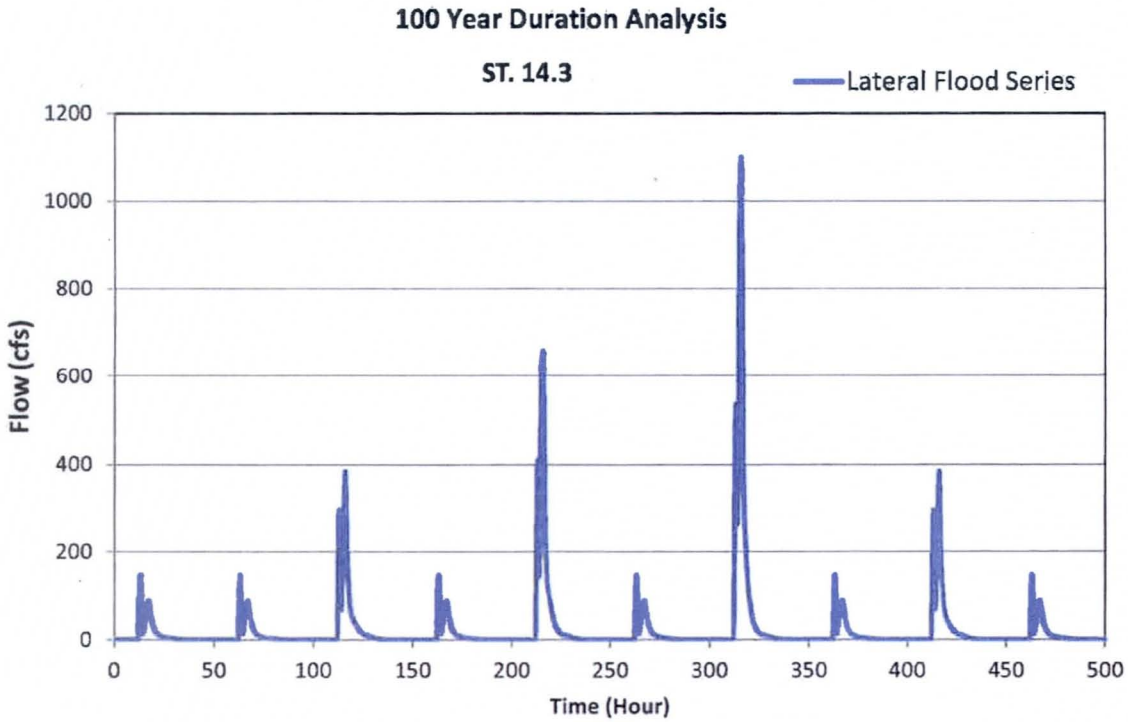


Table B-8. Station 14.30 - 100-Year Series Floods

Table D-5. Station 6.68 – Inflow Hydrographs

ST. 6.68				
Time	Flow (cfs)			
Hour	100Yr	50Yr	25Yr	10Yr
0	-	-	-	-
1	-	-	-	-
2	-	-	-	-
3	1	0	-	-
4	1	1	1	-
5	1	1	1	1
6	1	1	1	1
7	1	1	1	1
8	2	2	1	1
9	2	2	2	1
10	3	2	2	2
11	3	3	2	2
12	36	26	16	9
13	531	390	273	150
14	777	591	427	225
15	303	249	211	150
16	188	132	91	75
17	183	108	63	37
18	142	106	52	25
19	90	82	52	21
20	61	58	47	17
21	42	41	37	15
22	30	29	27	14
23	24	24	23	13
24	20	19	19	13
25	16	16	15	13
26	14	14	14	12
27	13	12	12	11
28	11	11	11	10
29	9	9	9	8
30	7	7	7	6
31	5	5	5	4
32	4	3	3	3
33	2	2	2	2
34	1	1	1	1
35	1	1	1	1
36	0	0	0	-

ST. 6.68				
Time	Flow (cfs)			
Hour	100Yr	50Yr	25Yr	10Yr
37	-	-	-	-
38	-	-	-	-
39	-	-	-	-
40	-	-	-	-
41	-	-	-	-
42	-	-	-	-
43	-	-	-	-
44	-	-	-	-
45	-	-	-	-
46	-	-	-	-
47	-	-	-	-
48	-	-	-	-
49	-	-	-	-
50	-	-	-	-

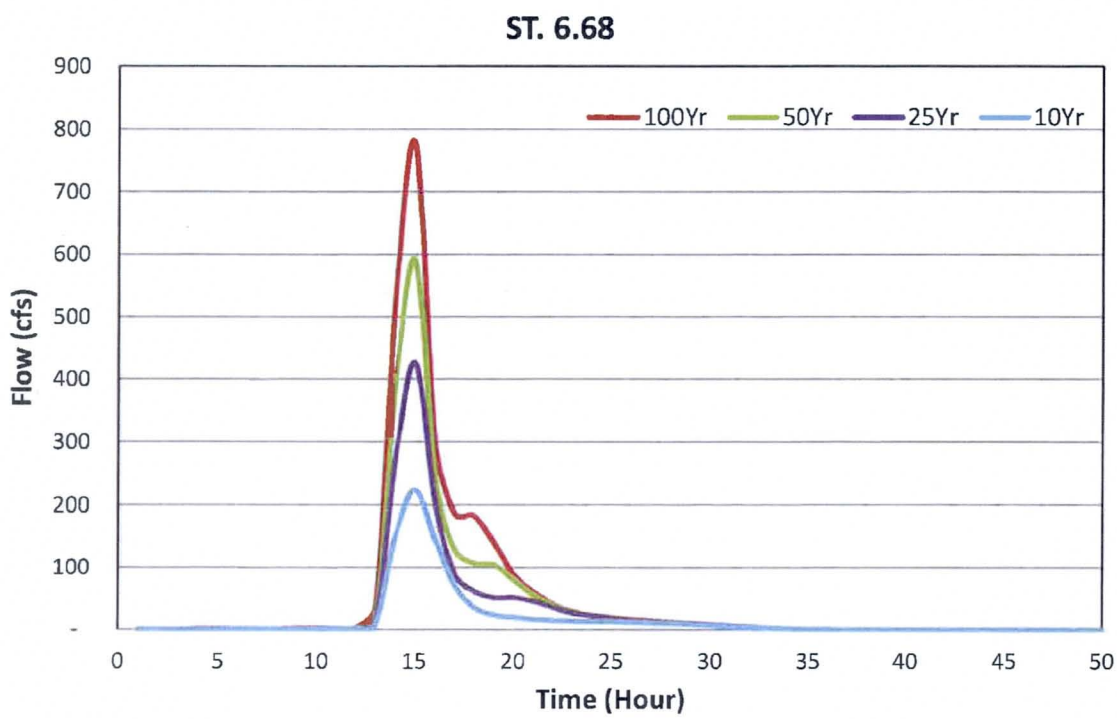


Figure B-9. Station 6.68 - Frequency Storm Hydrographs

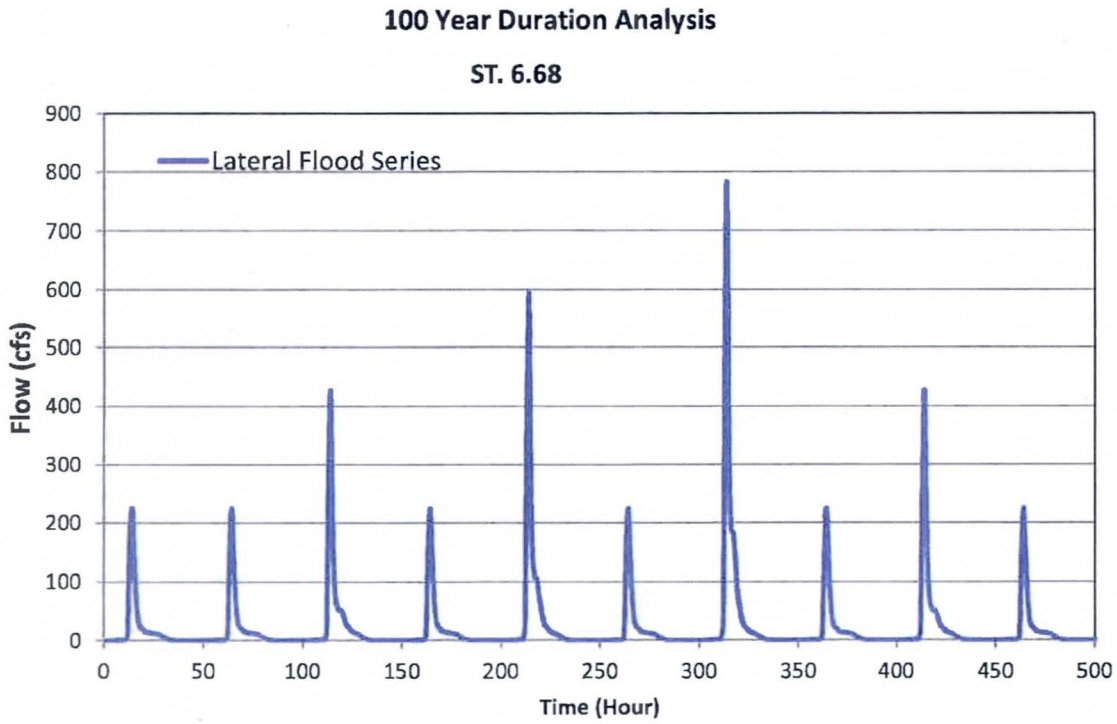


Figure B-10. Station 6.68 - 100-Year Series Floods

Table D-6. Station 4.00 – Inflow Hydrographs

ST. 4.00				
Time	Flow (cfs)			
Hour	100Yr	50Yr	25Yr	10Yr
0	-	-	-	-
1	2	2	1	1
2	6	5	5	4
3	6	5	5	4
4	6	5	5	4
5	7	6	6	5
6	8	7	6	5
7	9	8	7	6
8	11	9	8	7
9	12	11	9	8
10	16	14	13	10
11	21	18	16	13
12	56	46	39	29
13	855	682	523	316
14	1,206	707	373	106
15	1,422	1,054	702	280
16	828	625	434	214
17	583	394	250	138
18	408	304	195	91
19	303	226	161	66
20	227	157	118	55
21	147	111	85	46
22	97	81	62	37
23	68	61	52	30
24	55	52	44	24
25	43	41	35	19
26	31	30	26	15
27	24	24	21	13
28	19	19	18	11
29	16	16	15	9
30	13	13	13	7
31	11	11	10	5
32	8	8	8	4
33	6	6	6	4
34	5	5	5	3
35	4	4	4	3
36	3	3	3	3

ST. 4.00				
Time	Flow (cfs)			
Hour	100Yr	50Yr	25Yr	10Yr
37	3	3	3	2
38	3	3	3	2
39	3	3	2	2
40	2	2	2	1
41	2	2	2	1
42	2	2	2	1
43	1	1	1	1
44	1	1	1	1
45	1	1	1	0
46	1	1	1	-
47	1	1	1	-
48	-	1	0	-
49	-	-	-	-
50	-	-	-	-

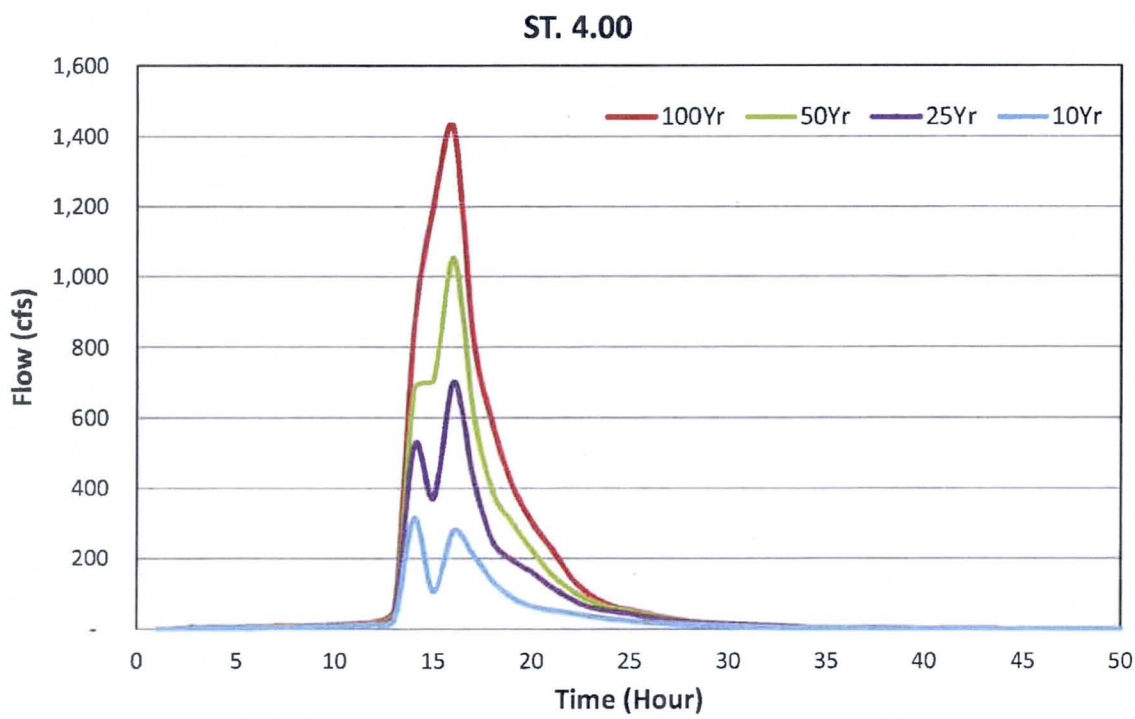


Figure B-11. Station 4.00 - Frequency Storm Hydrographs

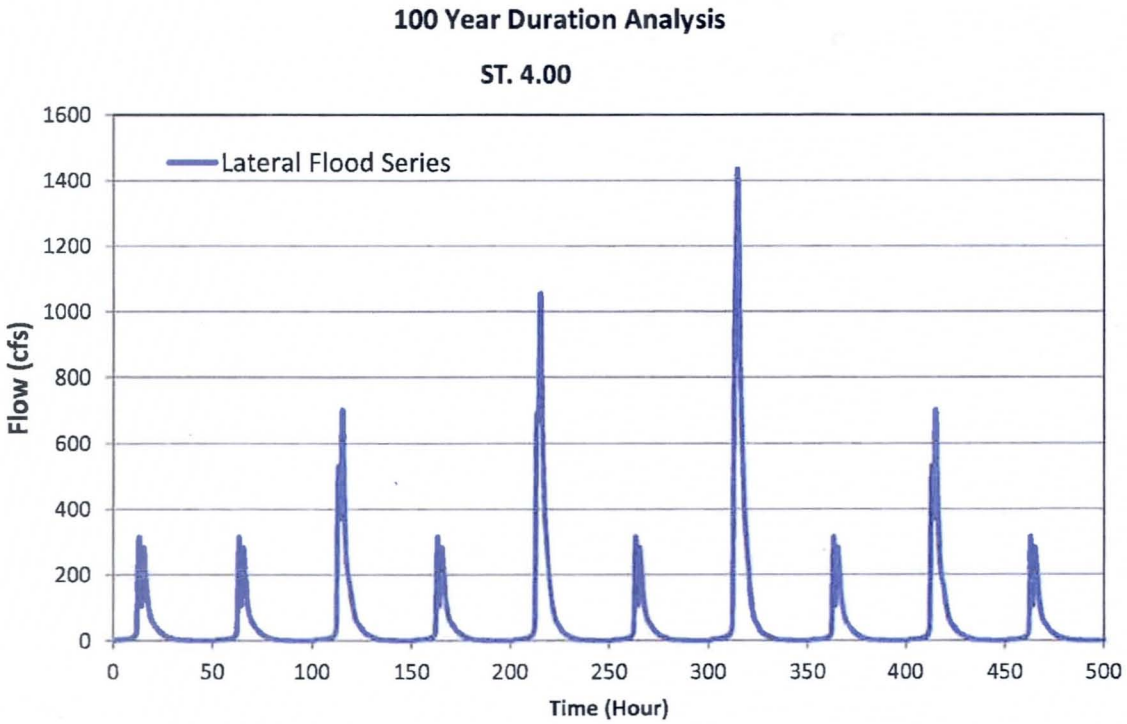


Figure B-12. Station 4.00 - 100-Year Series Floods

Table D-7. Station 3.69 – Inflow Hydrographs

ST. 3.69				
Time	Flow (cfs)			
Hour	100Yr	50Yr	25Yr	10Yr
0	-	-	-	-
1	1	1	1	1
2	3	3	3	2
3	5	4	4	3
4	7	6	5	4
5	13	11	9	7
6	21	18	15	11
7	28	25	21	16
8	33	30	26	21
9	39	34	30	25
10	47	41	35	29
11	58	51	43	34
12	116	92	75	56
13	1,230	958	727	443
14	1,199	953	733	479
15	1,063	871	696	478
16	637	538	448	330
17	415	352	281	191
18	294	244	186	116
19	187	162	133	90
20	122	113	103	76
21	94	89	82	64
22	75	70	64	54
23	59	55	51	43
24	48	44	41	36
25	38	35	33	30
26	31	29	27	24
27	25	23	21	18
28	18	17	15	14
29	13	12	12	10
30	10	9	8	7
31	7	6	6	5
32	5	5	4	4
33	4	4	4	3
34	3	3	3	3
35	2	2	2	2
36	2	2	2	2

ST. 3.69				
Time	Flow (cfs)			
Hour	100Yr	50Yr	25Yr	10Yr
37	1	1	1	1
38	1	1	1	1
39	1	1	1	1
40	1	1	0	-
41	-	-	-	-
42	-	-	-	-
43	-	-	-	-
44	-	-	-	-
45	-	-	-	-
46	-	-	-	-
47	-	-	-	-
48	-	-	-	-
49	-	-	-	-
50	-	-	-	-

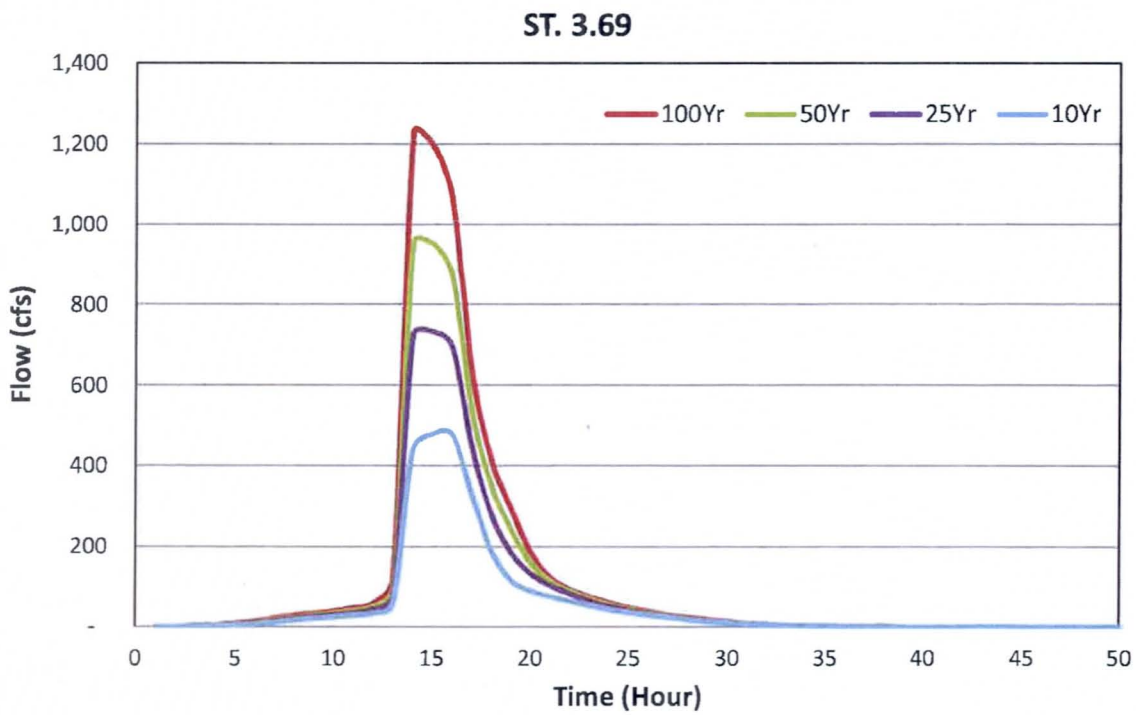


Figure B-13. Station 3.69 - Frequency Storm Hydrographs

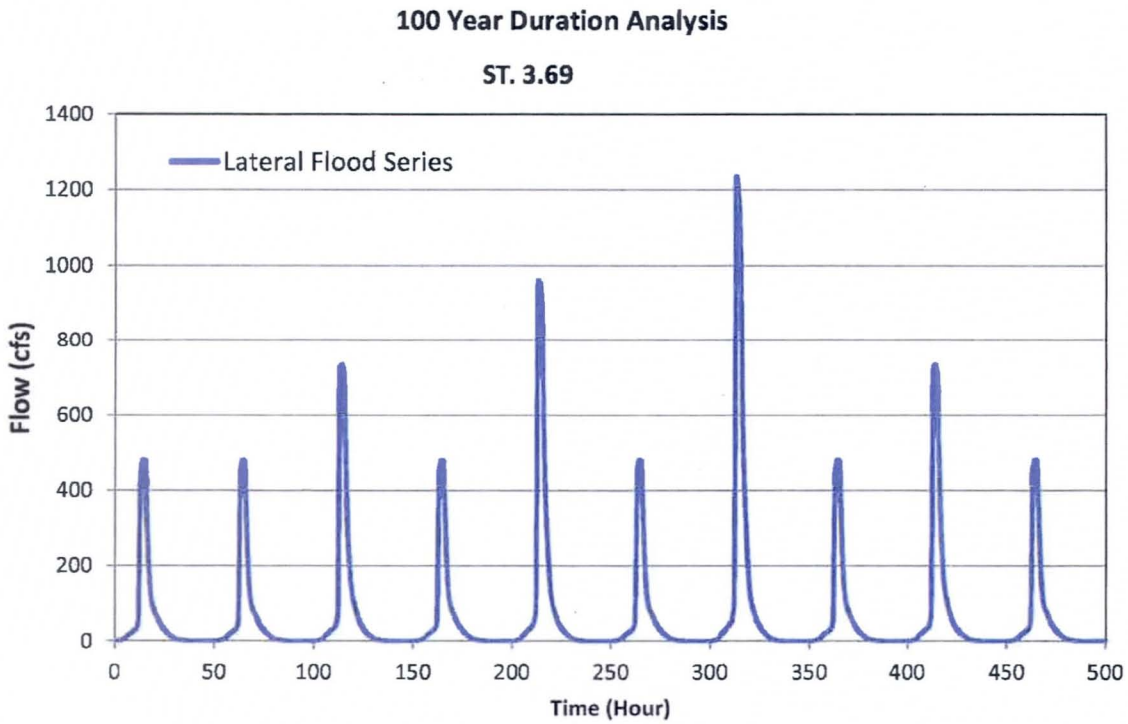
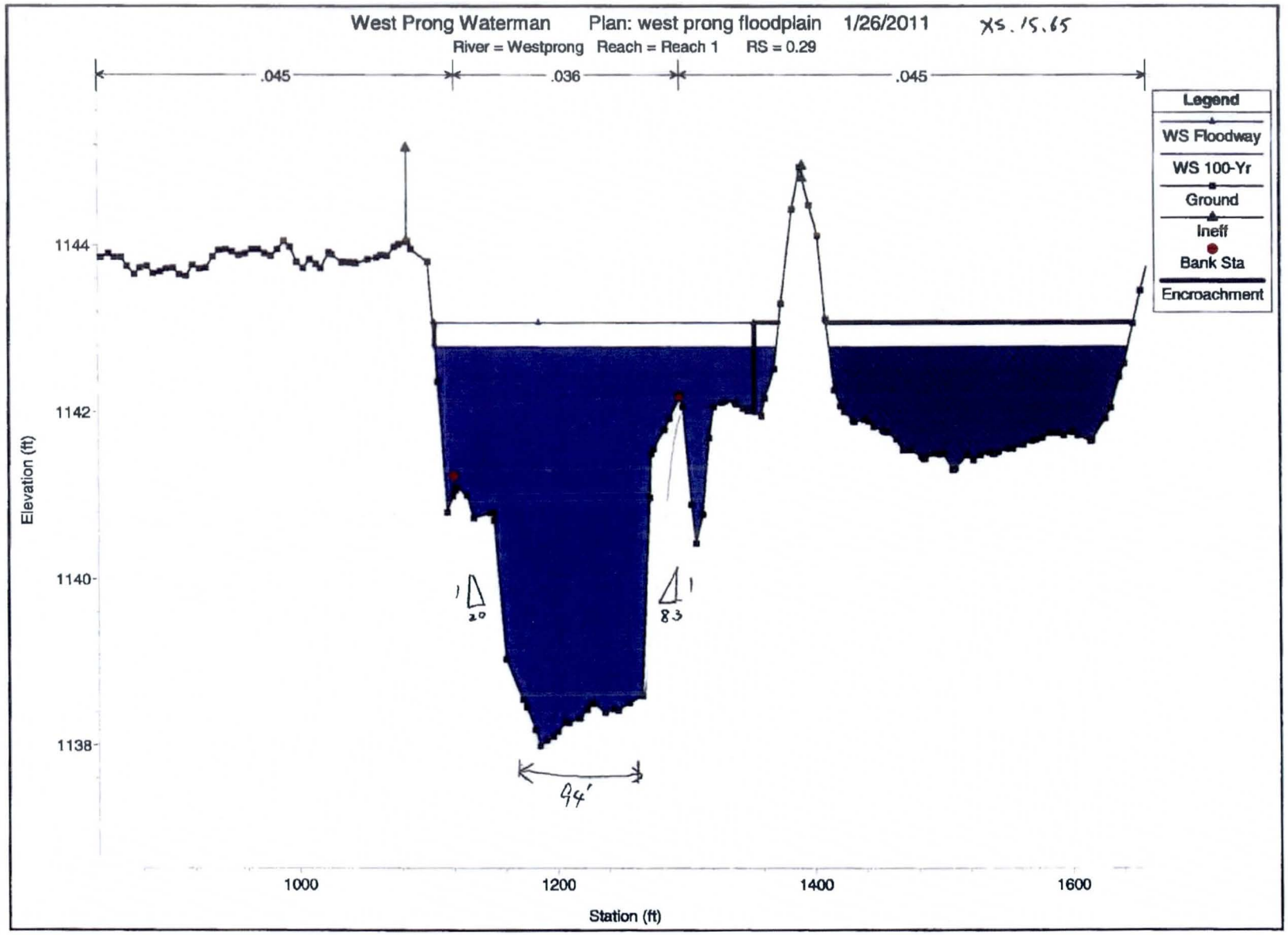


Figure B-14. Station 3.69 - 100-Year Series Floods

Attachment E

Sediment Rating Tables


West Prong Waterman
Plan: west prong floodplain
1/26/2011
XS. 15.65
River = Westprong
Reach = Reach 1
RS = 0.29
.045
.036
.045
Legend
WS Floodway
WS 100-Yr
Ground
Ineff
Bank Sta
Encroachment
Elevation (ft)
1144
1142
1140
1138
1000
1200
1400
1600
Station (ft)
1
20
1
8.3
94'

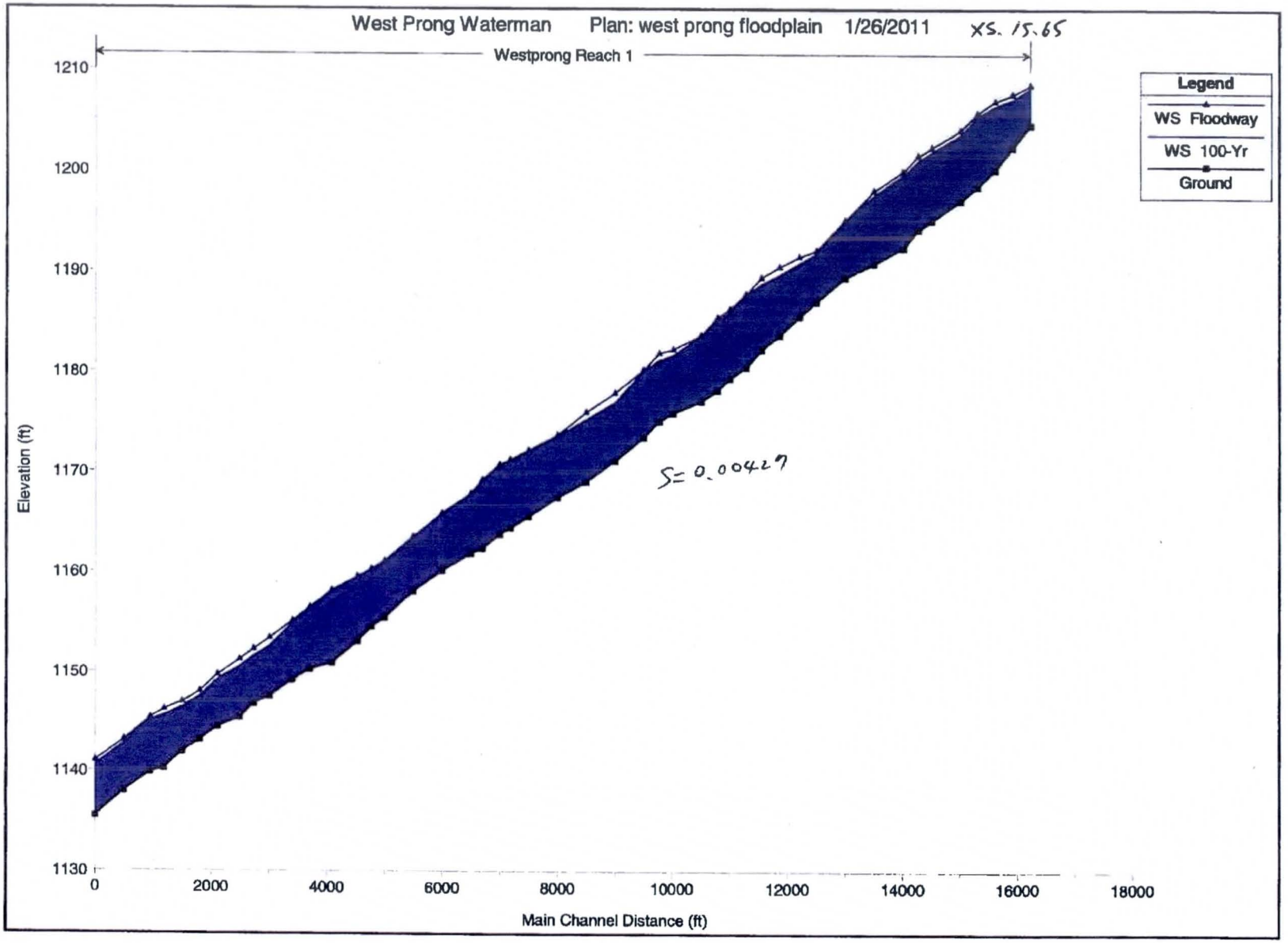

West Prong Waterman
Plan: west prong floodplain 1/26/2011
XS. 15.65
Westprong Reach 1
Legend
WS Floodway
WS 100-Yr
Ground
S= 0.00427
Elevation (ft)
1210
1200
1190
1180
1170
1160
1150
1140
1130
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
Main Channel Distance (ft)

Table E-1. Cross-Section 15.65 - Sediment Rating Table (PMP 1948 Equation)

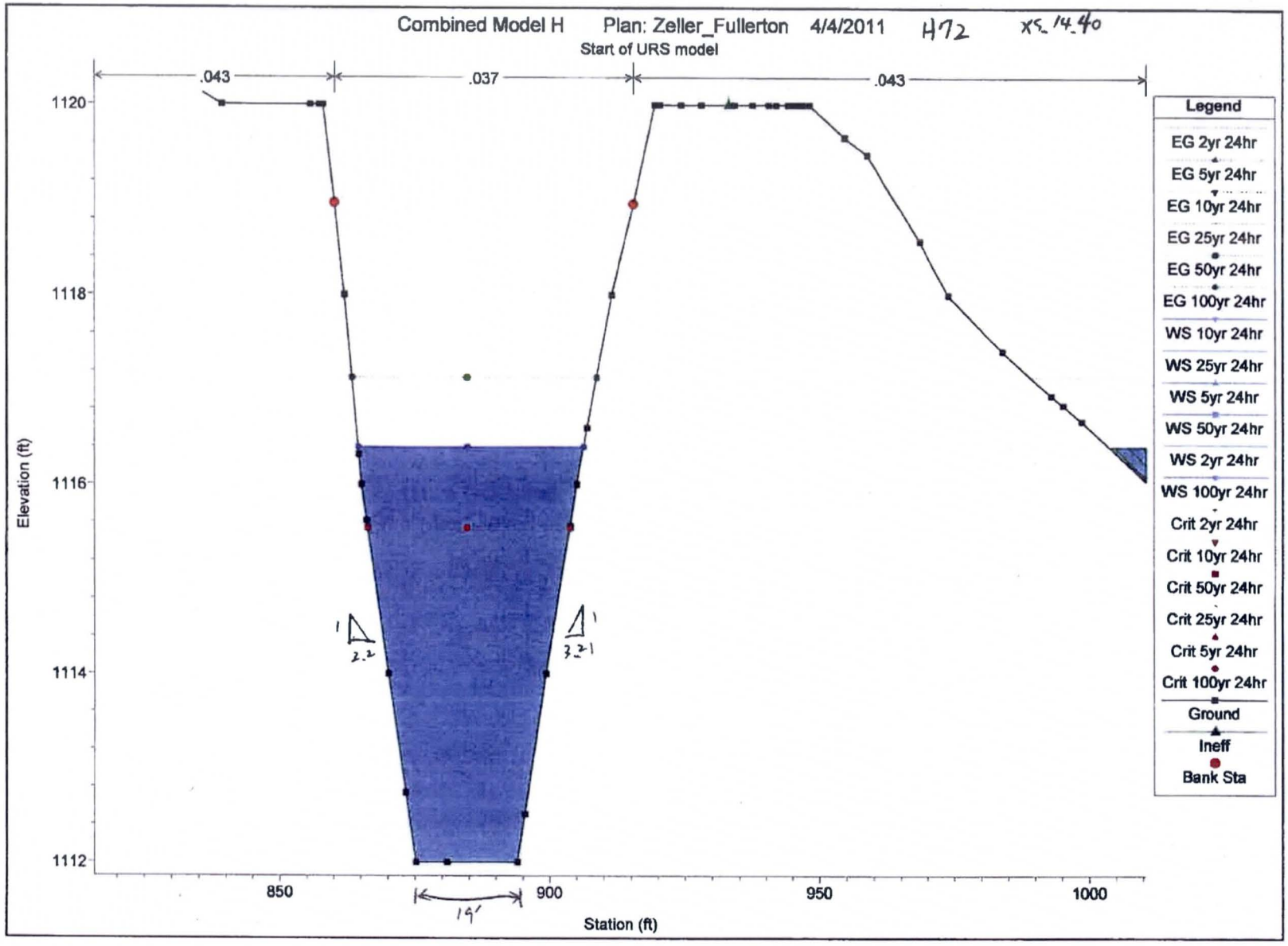
Cross-Section 15.65

Kinematic viscosity, ft^2/s, v=	0.0000122	60 degree	
d50, in ft=	0.0025	=	0.76 mm
d90, in ft=	0.015	=	4.57 mm
G=	2.65		
Unit Weight Water, lb/ft^3=	62.385		3.2051282
Gravity Acceleration, ft/s^2=	32.2		

Channel Bottom Width, ft=	94	
Left Bank Side Slope=	20	: 1(H:V)
Right Bank Side Slope=	8.3	: 1(H:V)
Manning's n=	0.036	

Comput Channel Hydraulics

			Rating Table :	1	2	3	4	5	6	7	8	9	10
			Slope=	0.00427	0.00427	0.00427	0.00427	0.00427	0.00427	0.00427	0.00427	0.00427	0.00427
			Discharge, cfs=	5000	50	100	500	750	1000	1500	2000	3000	4000	5000
	(ft)	Total Load (tons/day)		9094	66	174	1022	1524	2011	2957	3876	5658	7393	9094
Clay	1.31E-05	0.004			3.07	3.07	3.07	3.07	3.07	3.07	1.55	1.55	1.55	1.55
VFM	2.62E-05	0.008			0.59	0.59	0.59	0.59	0.59	0.59	0.47	0.47	0.47	0.47
FM	5.25E-05	0.016			2.35	2.35	2.35	2.35	2.35	2.35	1.83	1.83	1.83	1.83
MM	1.05E-04	0.032			1.95	1.95	1.95	1.95	1.95	1.95	1.45	1.45	1.45	1.45
CM	2.05E-04	0.0625			11.59	11.59	11.59	11.59	11.59	11.59	8.79	8.79	8.79	8.79
VFS	4.10E-04	0.125			6.64	6.64	6.64	6.64	6.64	6.64	5.36	5.36	5.36	5.36
FS	8.20E-04	0.25			5.89	5.89	5.89	5.89	5.89	5.89	6.85	6.85	6.85	6.85
MS	0.0016	0.5			11.02	11.02	11.02	11.02	11.02	11.02	15.01	15.01	15.01	15.01
CS	0.0033	1			15.5	15.5	15.5	15.5	15.5	15.5	17.21	17.21	17.21	17.21
VCS	0.0066	2			13.14	13.14	13.14	13.14	13.14	13.14	13.8	13.8	13.8	13.8
VFG	0.0131	4			16.43	16.43	16.43	16.43	16.43	16.43	16.42	16.42	16.42	16.42
FG	0.0262	8			3.45	3.45	3.45	3.45	3.45	3.45	3.99	3.99	3.99	3.99
MG	0.0525	16			0.8	0.8	0.8	0.8	0.8	0.8	0.96	0.96	0.96	0.96
CG	0.1050	32			0.18	0.18	0.18	0.18	0.18	0.18	0.17	0.17	0.17	0.17
VCG	0.21	64												
SC	0.42	128												
LC	0.84	256												
SB	1.68	512												
MB	3.36	1024												
LB	6.72	2048												


Combined Model H
Plan: Zeller_Fullerton
4/4/2011
H72
xs 14.40
Start of URS model
.043
.037
.043
1120
1118
1116
1114
1112
Elevation (ft)
850
900
950
1000
Station (ft)
19'
1
2.2
1
3.21
Legend
EG 2yr 24hr
EG 5yr 24hr
EG 10yr 24hr
EG 25yr 24hr
EG 50yr 24hr
EG 100yr 24hr
WS 10yr 24hr
WS 25yr 24hr
WS 5yr 24hr
WS 50yr 24hr
WS 2yr 24hr
WS 100yr 24hr
Crit 2yr 24hr
Crit 10yr 24hr
Crit 50yr 24hr
Crit 25yr 24hr
Crit 5yr 24hr
Crit 100yr 24hr
Ground
Ineff
Bank Sta

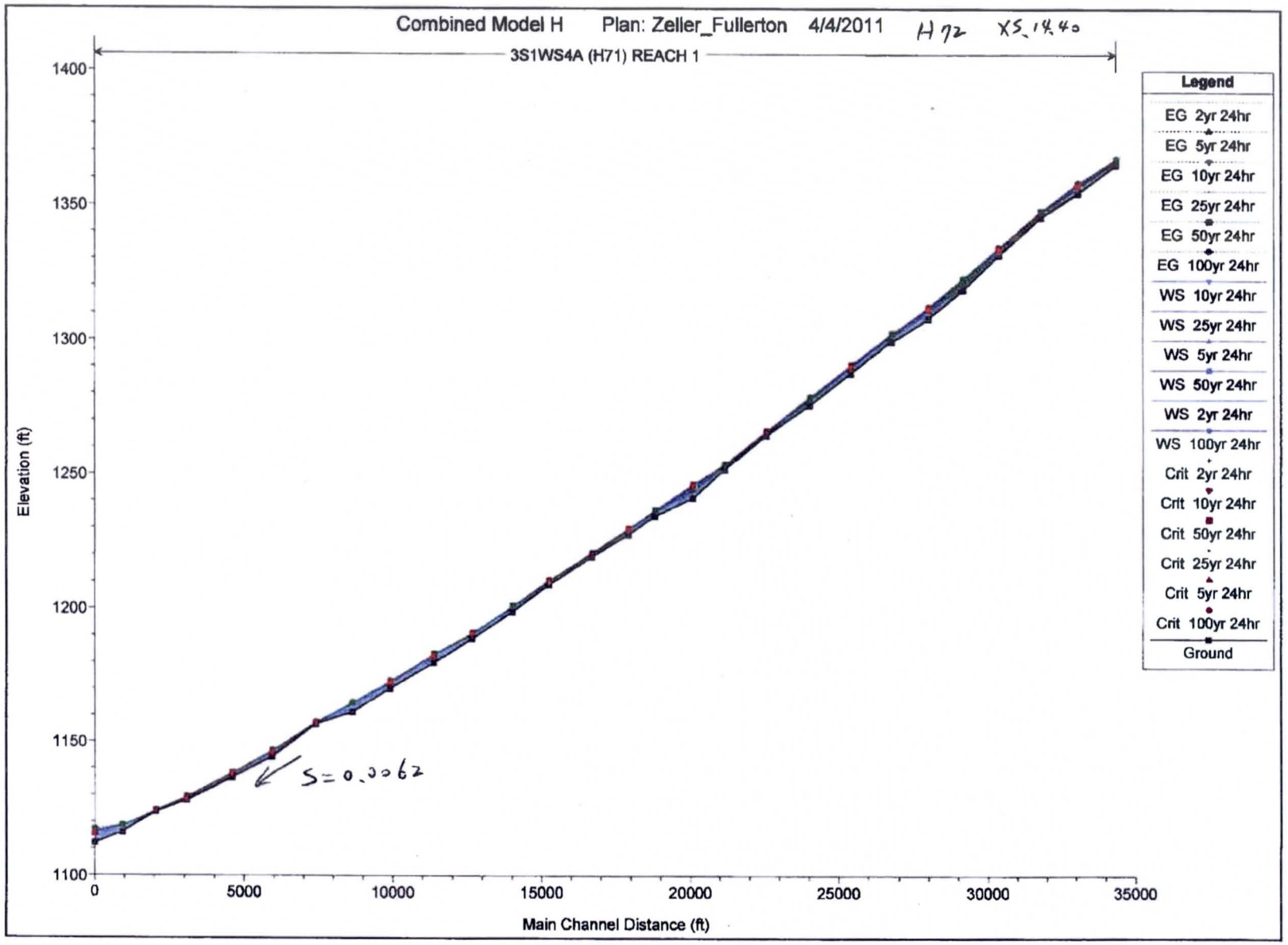

Combined Model H Plan: Zeller_Fullerton 4/4/2011
H72 XS 14.40
3S1WS4A (H71) REACH 1
Elevation (ft)
1400
1350
1300
1250
1200
1150
1100
0
5000
10000
15000
20000
25000
30000
35000
Main Channel Distance (ft)
S=0.0062
Legend
EG 2yr 24hr
EG 5yr 24hr
EG 10yr 24hr
EG 25yr 24hr
EG 50yr 24hr
EG 100yr 24hr
WS 10yr 24hr
WS 25yr 24hr
WS 5yr 24hr
WS 50yr 24hr
WS 2yr 24hr
WS 100yr 24hr
Crit 2yr 24hr
Crit 10yr 24hr
Crit 50yr 24hr
Crit 25yr 24hr
Crit 5yr 24hr
Crit 100yr 24hr
Ground

Table E-2. Cross-Section 14.40 – Sediment Rating Table (PMP 1948 Equation)

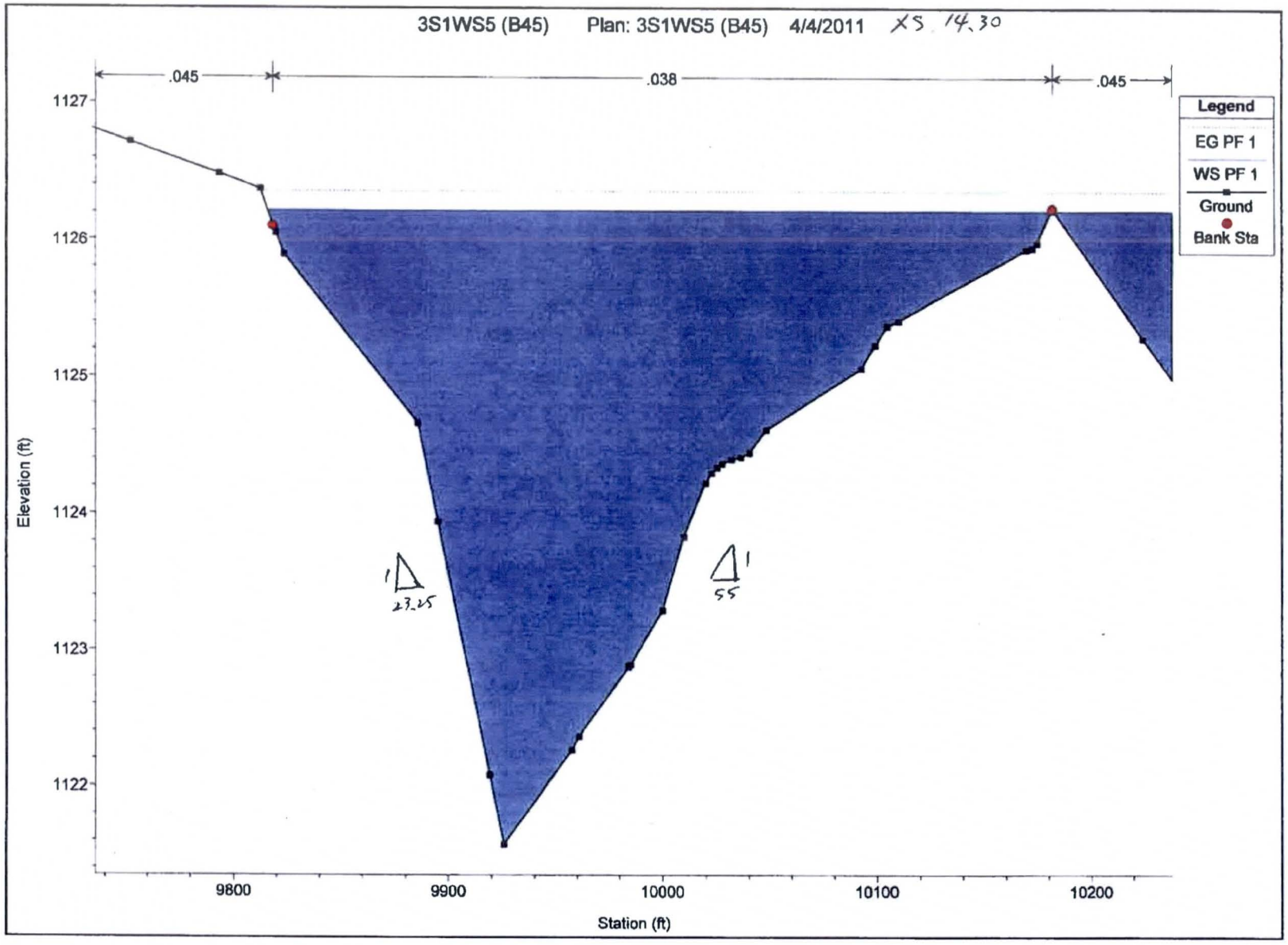
Cross-Section 14.40

Kinematic viscosity, ft^2/s, v=	0.0000122	60 degree	
d50, in ft=	0.00082	=	0.25 mm
d90, in ft=	0.013	=	3.96 mm
G=	2.65		
Unit Weight Water, lb/ft^3=	62.385		
Gravity Acceleration, ft/s^2=	32.2		

Channel Bottom Width, ft=	19	
Left Bank Side Slope=	2.2	: 1(H:V)
Right Bank Side Slope=	3.21	: 1(H:V)
Manning's n=	0.037	

Comput Channel Hydraulics

			Rating Table :	1	2	3	4	5	6	7	8	9	10
		Slope=	0.0062	0.0062	0.0062	0.0062	0.0062	0.0062	0.0062	0.0062	0.0062	0.0062	0.0062
		Discharge, cfs=	5000	10	30	60	100	200	500	1250	1000	1250	1500
	(ft)	Total Load (tons/day)	11052	37	107	203	324	606	1375	3124	2557	3124	3683
Clay	1.31E-05	0.004		3.06	3.06	3.06	3.06	3.06	3.06	3.06	3.06	3.06	3.06
VFM	2.62E-05	0.008		1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04
FM	5.25E-05	0.016		2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81
MM	1.05E-04	0.032		2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56
CM	2.05E-04	0.0625		12.72	12.72	12.72	12.72	12.72	12.72	12.72	12.72	12.72	12.72
VFS	4.10E-04	0.125		11.28	11.28	11.28	11.28	11.28	11.28	11.28	11.28	11.28	11.28
FS	0.00082	0.25		18.87	18.87	18.87	18.87	18.87	18.87	18.87	18.87	18.87	18.87
MS	0.0016	0.5		19.71	19.71	19.71	19.71	19.71	19.71	19.71	19.71	19.71	19.71
CS	0.0033	1		11.05	11.05	11.05	11.05	11.05	11.05	11.05	11.05	11.05	11.05
VCS	0.0066	2		4.61	4.61	4.61	4.61	4.61	4.61	4.61	4.61	4.61	4.61
VFG	0.0131	4		3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
FG	0.0262	8		1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51
MG	0.0525	16		0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91
CG	0.1050	32		0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81
VCG	0.21	64		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
SC	0.42	128											
LC	0.84	256											
SB	1.68	512											
MB	3.36	1024											
LB	6.72	2048											


3S1WS5 (B45) Plan: 3S1WS5 (B45) 4/4/2011 XS 14.30
.045
.038
.045
Legend
EG PF 1
WS PF 1
Ground
Bank Sta
1127
1126
1125
1124
1123
1122
Elevation (ft)
9800
9900
10000
10100
10200
Station (ft)
1
23.25
1
55

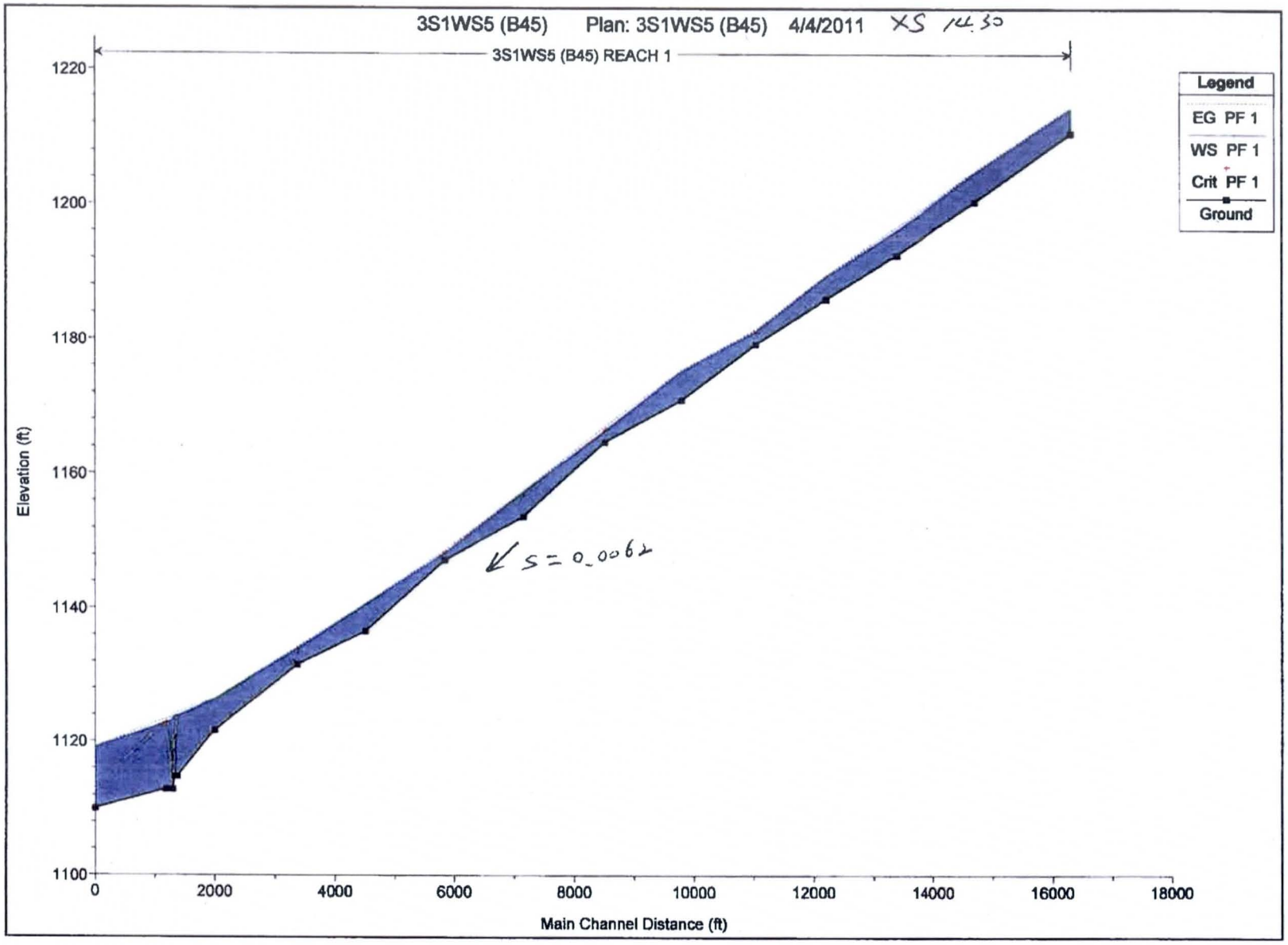

3S1WS5 (B45) Plan: 3S1WS5 (B45) 4/4/2011 XS 14.30
3S1WS5 (B45) REACH 1
Legend
EG PF 1
WS PF 1
Crit PF 1
Ground
S = 0.0062
Elevation (ft)
1220
1200
1180
1160
1140
1120
1100
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
Main Channel Distance (ft)

Table E-3. Cross-Section 14.30 – Sediment Rating Table (PMP 1948 Equation)

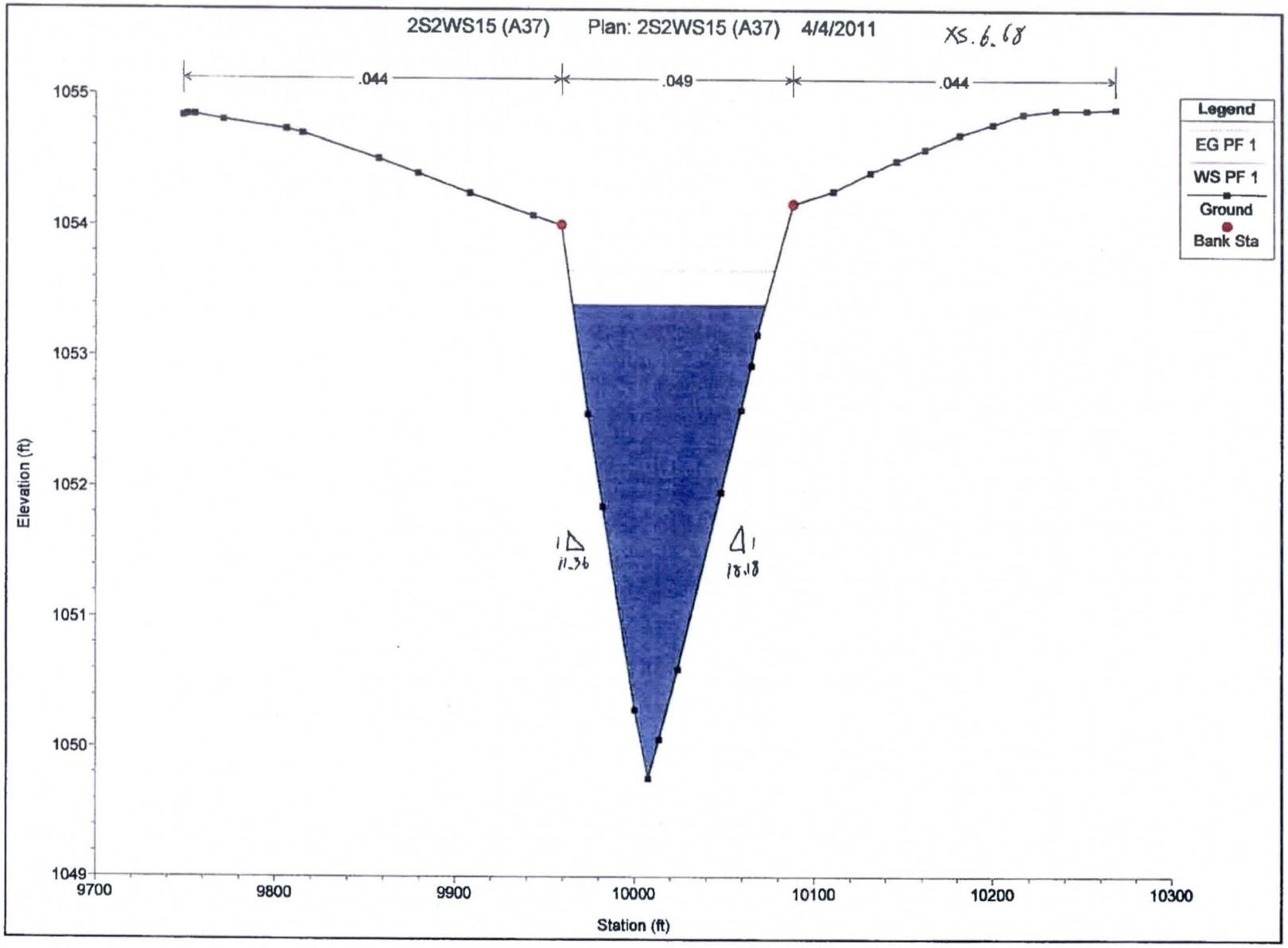
Cross-Section 14.30

Kinematic viscosity, ft^2/s, v=	0.0000122	60 degree	
d50, in ft=	0.0041	=	1.25 mm
d90, in ft=	0.0262	=	7.99 mm
G=	2.65		
Unit Weight Water, lb/ft^3=	62.385		
Gravity Acceleration, ft/s^2=	32.2		

Channel Bottom Width, ft=	0	
Left Bank Side Slope=	23.25	: 1(H:V)
Right Bank Side Slope=	55	: 1(H:V)
Manning's n=	0.038	

Comput Channel Hydraulics

			Rating Table :	1	2	3	4	5	6	7	8	9	10
		Slope=	0.0062	0.0062	0.0062	0.0062	0.0062	0.0062	0.0062	0.0062	0.0062	0.0062	0.0062
		Discharge, cfs=	5000	10	30	60	100	200	500	1250	1000	1250	1350
	(ft)	Total Load (tons/day)	10475	4	32	82	156	350	959	2526	2001	2526	2737
Clay	1.31E-05	0.004		5.38	5.38	5.38	5.38	5.38	5.38	5.38	5.38	5.38	5.38
VFM	2.62E-05	0.008		2	2	2	2	2	2	2	2	2	2
FM	5.25E-05	0.016		6.66	6.66	6.66	6.66	6.66	6.66	6.66	6.66	6.66	6.66
MM	1.05E-04	0.032		5.97	5.97	5.97	5.97	5.97	5.97	5.97	5.97	5.97	5.97
CM	2.05E-04	0.0625		24.66	24.66	24.66	24.66	24.66	24.66	24.66	24.66	24.66	24.66
VFS	0.00041	0.125		7.97	7.97	7.97	7.97	7.97	7.97	7.97	7.97	7.97	7.97
FS	0.00082	0.25		3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75
MS	0.0016	0.5		5.63	5.63	5.63	5.63	5.63	5.63	5.63	5.63	5.63	5.63
CS	0.0033	1		7.14	7.14	7.14	7.14	7.14	7.14	7.14	7.14	7.14	7.14
VCS	0.0066	2		7.48	7.48	7.48	7.48	7.48	7.48	7.48	7.48	7.48	7.48
VFG	0.0131	4		10.01	10.01	10.01	10.01	10.01	10.01	10.01	10.01	10.01	10.01
FG	0.0262	8		4.24	4.24	4.24	4.24	4.24	4.24	4.24	4.24	4.24	4.24
MG	0.0525	16		1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44
CG	0.1050	32											
VCG	0.21	64											
SC	0.42	128											
LC	0.84	256											
SB	1.68	512											
MB	3.36	1024											
LB	6.72	2048											


2S2WS15 (A37) Plan: 2S2WS15 (A37) 4/4/2011
XS. 6.68
.044
.049
.044
Legend
EG PF 1
WS PF 1
Ground
Bank Sta
1
11.36
1
18.18
Elevation (ft)
1055
1054
1053
1052
1051
1050
1049
9700
9800
9900
10000
10100
10200
10300
Station (ft)

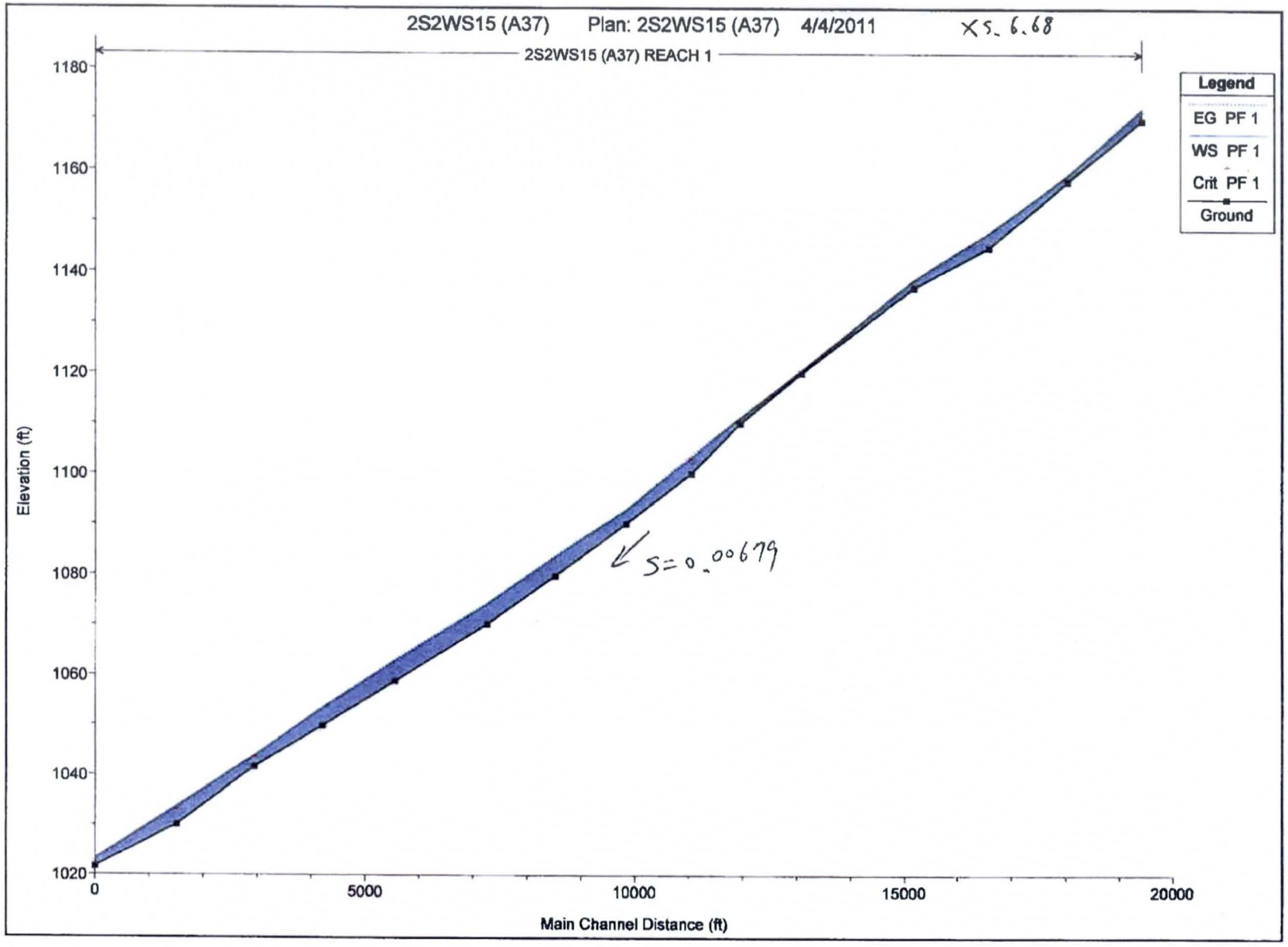

2S2WS15 (A37) Plan: 2S2WS15 (A37) 4/4/2011
XS. 6.68
2S2WS15 (A37) REACH 1
Legend
EG PF 1
WS PF 1
Crit PF 1
Ground
S=0.00679
Elevation (ft)
1180
1160
1140
1120
1100
1080
1060
1040
1020
0
5000
10000
15000
20000
Main Channel Distance (ft)

Table E-4. Cross-Section 6.68 – Sediment Rating Table (PMP 1948 Equation)

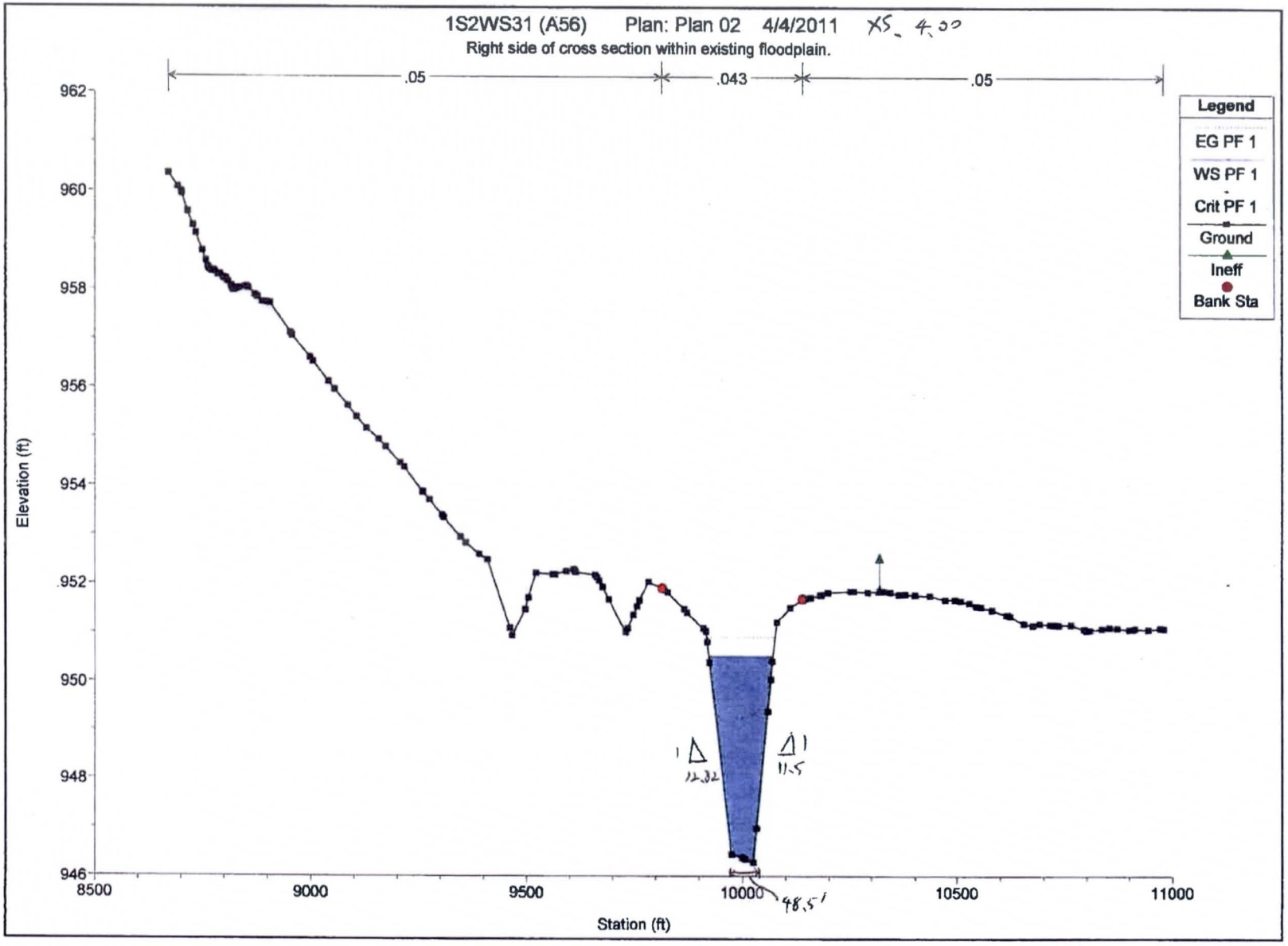
Cross-Section 6.68

Kinematic viscosity, ft^2/s, v=	0.0000122	60 degree	
d50, in ft=	0.014	=	4.27 mm
d90, in ft=	0.0262	=	7.99 mm
G=	2.65		
Unit Weight Water, lb/ft^3=	62.385		18.181818
Gravity Acceleration, ft/s^2=	32.2		

Channel Bottom Width, ft=	0	
Left Bank Side Slope=	11.36	: 1(H:V)
Right Bank Side Slope=	18.18	: 1(H:V)
Manning's n=	0.049	

Comput Channel Hydraulics

		Rating Table :	1	2	3	4	5	6	7	8	9	10
		Slope=	0.00679	0.00679	0.00679	0.00679	0.00679	0.00679	0.00679	0.00679	0.00679	0.00679
		Discharge, cfs=	5000	100	200	250	300	400	500	800	850	900	1000
	(ft)	Total Load (tons/day)	6476	5	66	107	151	248	352	694	753	814	936
Clay	1.31E-05	0.004											
VFM	2.62E-05	0.008											
FM	5.25E-05	0.016											
MM	1.05E-04	0.032											
CM	2.05E-04	0.0625											
VFS	0.00041	0.125		13.62	13.62	13.62	13.62	13.62	13.62	13.62	13.62	13.62	13.62
FS	0.00082	0.25		9.66	9.66	9.66	9.66	9.66	9.66	9.66	9.66	9.66	9.66
MS	0.0016	0.5		8.65	8.65	8.65	8.65	8.65	8.65	8.65	8.65	8.65	8.65
CS	0.0033	1		6.55	6.55	6.55	6.55	6.55	6.55	6.55	6.55	6.55	6.55
VCS	0.0066	2		5.32	5.32	5.32	5.32	5.32	5.32	5.32	5.32	5.32	5.32
VFG	0.0131	4		5.66	5.66	5.66	5.66	5.66	5.66	5.66	5.66	5.66	5.66
FG	0.0262	8		2.04	2.04	2.04	2.04	2.04	2.04	2.04	2.04	2.04	2.04
MG	0.0525	16		0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83
CG	0.1050	32											
VCG	0.21	64											
SC	0.42	128											
LC	0.84	256											
SB	1.68	512											
MB	3.36	1024											
LB	6.72	2048											


1S2WS31 (A56) Plan: Plan 02 4/4/2011 XS 4.00
Right side of cross section within existing floodplain.
.05
.043
.05
Legend
EG PF 1
WS PF 1
Crit PF 1
Ground
Ineff
Bank Sta
Elevation (ft)
962
960
958
956
954
952
950
948
946
8500
9000
9500
10000
10500
11000
Station (ft)
12.32
11.5
48.5'

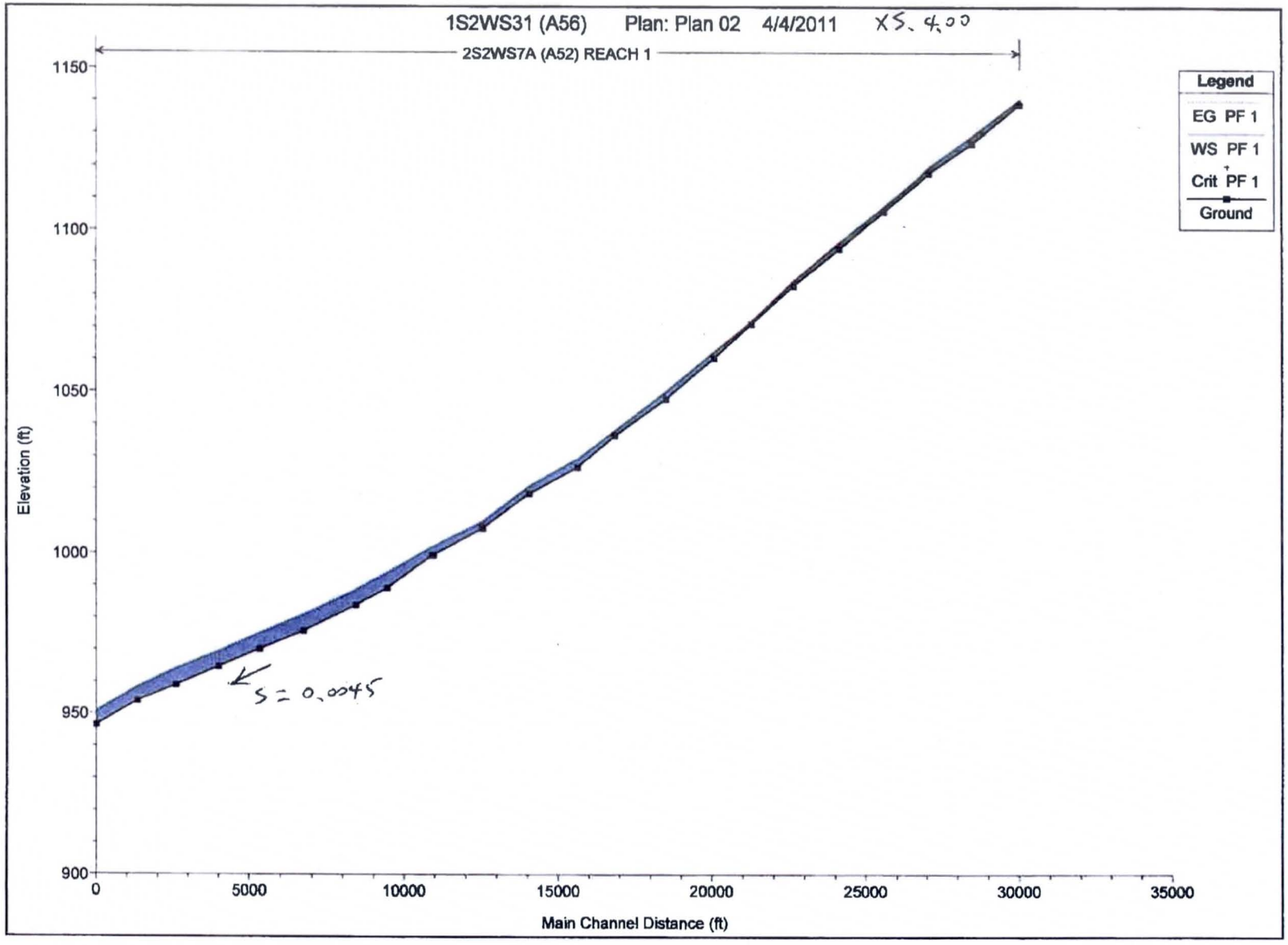

1S2WS31 (A56) Plan: Plan 02 4/4/2011 XS. 4.00
2S2WS7A (A52) REACH 1
Legend
EG PF 1
WS PF 1
Crit PF 1
Ground
S = 0.0045
Elevation (ft)
1150
1100
1050
1000
950
900
0
5000
10000
15000
20000
25000
30000
35000
Main Channel Distance (ft)

Table E-5. Cross-Section 4.00 – Sediment Rating Table (PMP 1948 Equation)

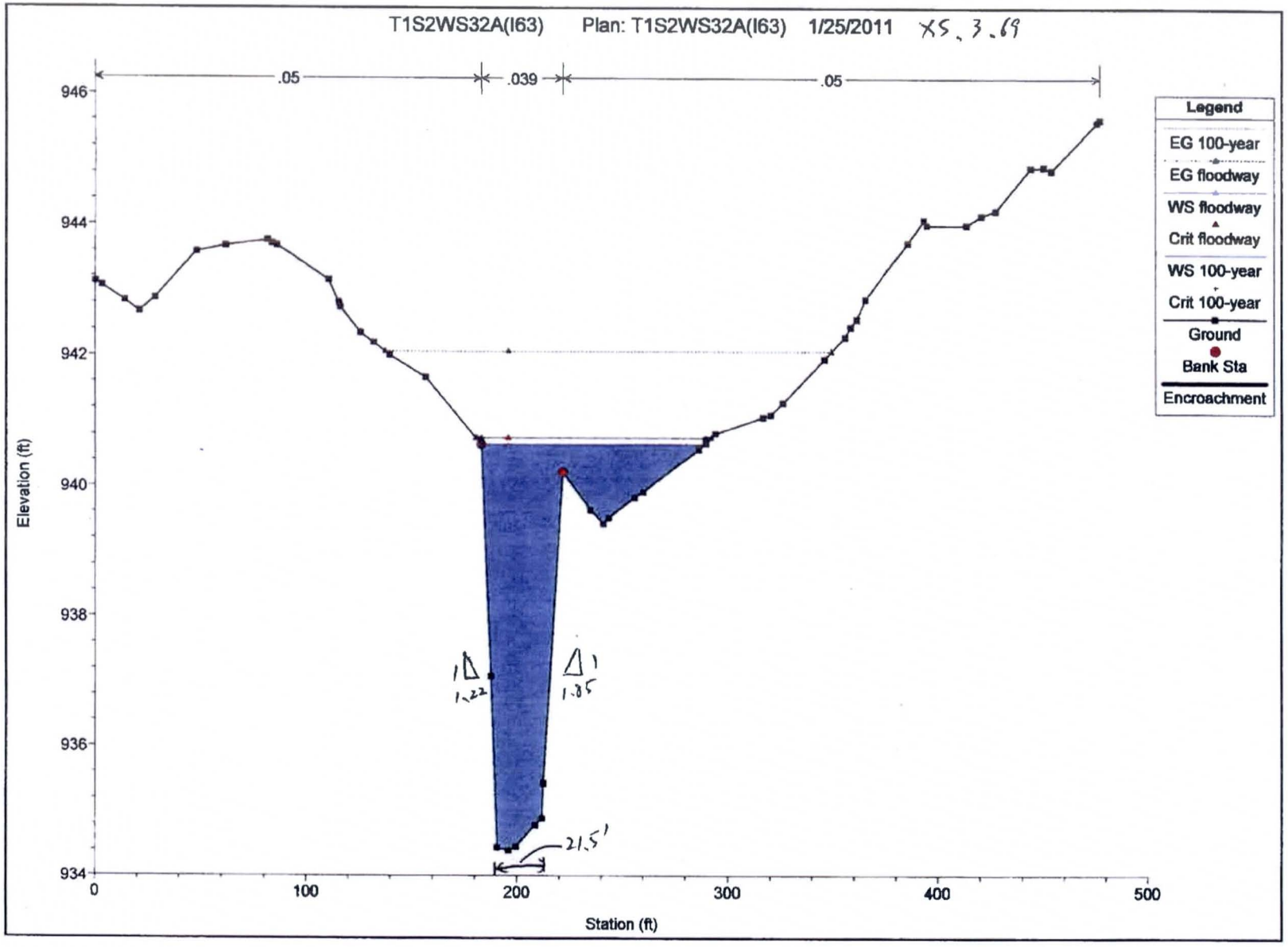
Cross-Section 4.00

Kinematic viscosity, ft^2/s, v=	0.0000122	60 degree	
d50, in ft=	0.0033	=	1.01 mm
d90, in ft=	0.0262	=	7.99 mm
G=	2.65		
Unit Weight Water, lb/ft^3=	62.385		11.50748
Gravity Acceleration, ft/s^2=	32.2		

Channel Bottom Width, ft=	48.5	
Left Bank Side Slope=	12.82	: 1(H:V)
Right Bank Side Slope=	11.5	: 1(H:V)
Manning's n=	0.043	

Comput Channel Hydraulics

			Rating Table :	1	2	3	4	5	6	7	8	9	10
		Slope=	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045
		Discharge, cfs=	5000	20	50	150	300	500	800	1000	1500	2000	2200
	(ft)	Total Load (tons/day)	7746	11	63	248	516	860	1357	1681	2474	3251	3558
Clay	1.31E-05	0.004											
VFM	2.62E-05	0.008											
FM	5.25E-05	0.016											
MM	1.05E-04	0.032											
CM	2.05E-04	0.0625											
VFS	0.00041	0.125		2.78	2.78	2.78	2.78	2.78	2.78	2.78	2.78	2.78	2.78
FS	0.00082	0.25		10.03	10.03	10.03	10.03	10.03	10.03	10.03	10.03	10.03	10.03
MS	0.0016	0.5		18.38	18.38	18.38	18.38	18.38	18.38	18.38	18.38	18.38	18.38
CS	0.0033	1		18.83	18.83	18.83	18.83	18.83	18.83	18.83	18.83	18.83	18.83
VCS	0.0066	2		14.55	14.55	14.55	14.55	14.55	14.55	14.55	14.55	14.55	14.55
VFG	0.0131	4		17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15
FG	0.0262	8		10.53	10.53	10.53	10.53	10.53	10.53	10.53	10.53	10.53	10.53
MG	0.0525	16		3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45
CG	0.1050	32		0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56
VCG	0.21	64											
SC	0.42	128											
LC	0.84	256											
SB	1.68	512											
MB	3.36	1024											
LB	6.72	2048											


T1S2WS32A(I63) Plan: T1S2WS32A(I63) 1/25/2011 XS. 3.69
.05
.039
.05
Legend
EG 100-year
EG floodway
WS floodway
Crit floodway
WS 100-year
Crit 100-year
Ground
Bank Sta
Encroachment
Elevation (ft)
Station (ft)
946
944
942
940
938
936
934
0
100
200
300
400
500
1
1.22
1
1.85
21.5'

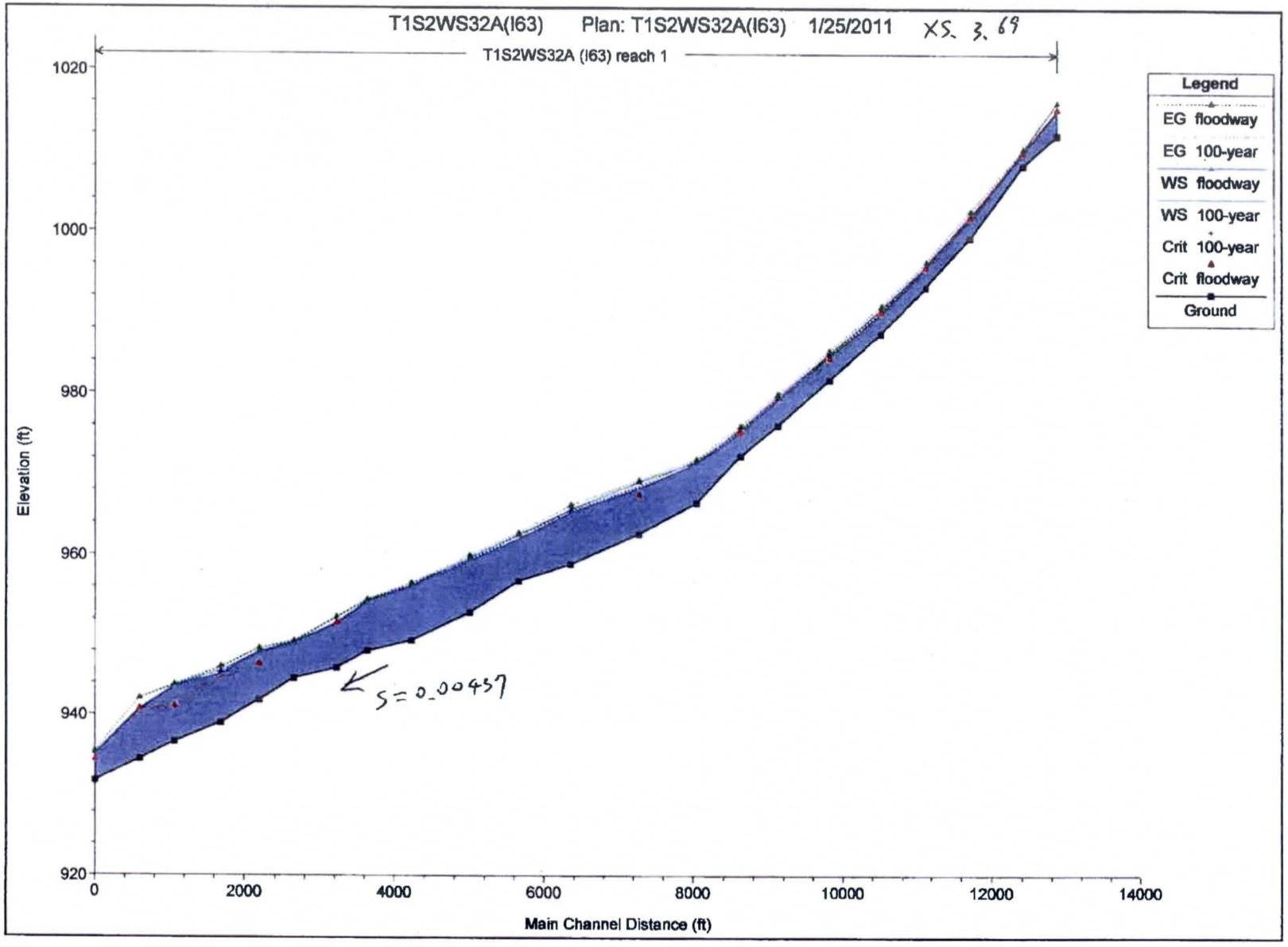

T1S2WS32A(I63) Plan: T1S2WS32A(I63) 1/25/2011
XS. 3.69
T1S2WS32A (I63) reach 1
Legend
EG floodway
EG 100-year
WS floodway
WS 100-year
Crit 100-year
Crit floodway
Ground
Elevation (ft)
1020
1000
980
960
940
920
0
2000
4000
6000
8000
10000
12000
14000
Main Channel Distance (ft)
S=0.00457

Table E-6. Cross-Section 3.69 – Sediment Rating Table (PMP 1948 Equation)

Cross-Section 3.69

Kinematic viscosity, ft^2/s, v=	0.0000122	60 degree	
d50, in ft=	0.0045	=	1.37 mm
d90, in ft=	0.02	=	6.10 mm
G=	2.65		
Unit Weight Water, lb/ft^3=	62.385		
Gravity Acceleration, ft/s^2=	32.2		

1.8518519

Channel Bottom Width, ft=	21.5	
Left Bank Side Slope=	1.22	: 1(H:V)
Right Bank Side Slope=	1.85	: 1(H:V)
Manning's n=	0.039	

Comput Channel Hydraulics

			Rating Table :	1	2	3	4	5	6	7	8	9	10
		Slope=	0.00437	0.00437	0.00437	0.00437	0.00437	0.00437	0.00437	0.00437	0.00437	0.00437	0.00437
		Discharge, cfs=	5000	20	50	150	300	500	800	1000	1500	1800	2000
	(ft)	Total Load (tons/day)	7737	18	76	277	563	925	1440	1772	2574	3042	3350
Clay	1.31E-05	0.004											
VFM	2.62E-05	0.008											
FM	5.25E-05	0.016											
MM	1.05E-04	0.032											
CM	2.05E-04	0.0625											
VFS	0.00041	0.125		0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46
FS	0.00082	0.25		2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9
MS	0.0016	0.5		13.62	13.62	13.62	13.62	13.62	13.62	13.62	13.62	13.62	13.62
CS	0.0033	1		23.53	23.53	23.53	23.53	23.53	23.53	23.53	23.53	23.53	23.53
VCS	0.0066	2		17.69	17.69	17.69	17.69	17.69	17.69	17.69	17.69	17.69	17.69
VFG	0.0131	4		24.78	24.78	24.78	24.78	24.78	24.78	24.78	24.78	24.78	24.78
FG	0.0262	8		12.89	12.89	12.89	12.89	12.89	12.89	12.89	12.89	12.89	12.89
MG	0.0525	16		3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3
CG	0.1050	32		0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
VCG	0.21	64											
SC	0.42	128											
LC	0.84	256											
SB	1.68	512											
MB	3.36	1024											
LB	6.72	2048											

Attachment F

Sediment Transport Analysis for Frequency Storms

Table F-1. 100 Year Event – Sediment Transport Table

* Sediment erosion and deposition can occur at channel bed and bank. Upstream bed change is defined based on the sediment delivery difference between upstream section and downstream section.

U/S Deposition: Total Sediment Inflow > Total Sediment Outflow

U/S Erosion: Total Sediment Inflow < Total Sediment Outflow

Station	Ch Invert El (ft)	Invert Change (ft)	Mass Out Cum: All (tons)	U/S Reach Bed Change*	Notes
16.72	1144.40	0.00	1467		
16.64	1142.73	0.26	1188	Deposition	
16.38	1139.01	0.11	1191	Erosion	
16.15	1135.81	0.07	1006	Deposition	
15.86	1131.72	-0.06	1309	Erosion	
15.65	1130.57	0.38	2731	Erosion	
15.61	1129.69	-0.16	3407	Erosion	
15.35	1124.97	-0.42	3598	Erosion	
15.2	1122.55	-0.39	4338	Erosion	
14.95	1119.33	-0.08	4157	Deposition	
14.73	1114.64	0.21	1929	Deposition	
14.49	1110.23	-0.35	1895	Deposition	
14.4	1108.85	-0.49	2764	Erosion	
14.3	1107.22	-0.56	3490	Erosion	
14.21	1105.80	0.20	3279	Deposition	
14.12	1105.13	0.09	3198	Deposition	
14.05	1103.27	-0.02	3247	Erosion	
13.81	1101.15	0.00	3575	Erosion	
13.53	1098.25	0.00	3598	Erosion	
13.38	1095.79	0.00	3607	Erosion	
13.23	1093.74	0.08	3314	Deposition	
12.79	1086.71	0.11	2741	Deposition	
12.65	1083.77	-0.03	2750	Erosion	
12.42	1081.07	-0.37	4016	Erosion	
12.16	1078.42	0.01	5151	Erosion	
11.62	1070.35	0.32	3301	Deposition	
11.45	1067.45	0.22	1712	Deposition	
11.16	1062.18	0.01	3352	Erosion	
10.99	1059.62	0.12	3288	Deposition	
10.6	1052.94	0.01	4436	Erosion	
10.45	1050.71	0.16	2992	Deposition	
10.18	1046.72	-0.04	2881	Deposition	
10.04	1044.49	0.00	2809	Deposition	
9.77	1040.02	-0.19	3348	Erosion	

Station	Ch Invert El (ft)	Invert Change (ft)	Mass Out Cum: All (tons)	U/S Reach Bed Change*	Notes
9.53	1037.50	0.29	2171	Deposition	
9.4	1035.56	0.11	1505	Deposition	
9.27	1032.81	-0.49	2822	Erosion	
9.09	1028.69	-0.31	3271	Erosion	
8.86	1024.63	0.24	3085	Deposition	
8.64	1021.74	-0.24	4176	Erosion	
8.44	1017.91	0.15	3224	Deposition	
8.29	1015.40	0.08	2643	Deposition	
8.1	1010.48	-0.02	2448	Deposition	
8.07	1011.86	0.60	1895	Deposition	
8.06	1011.46	0.46	1293	Deposition	
7.95	1008.22	-0.08	3304	Erosion	
7.86	1007.31	-0.18	3989	Erosion	
7.71	1003.67	-0.40	5623	Erosion	
7.47	1000.98	0.18	3661	Deposition	
7.31	998.16	0.16	2612	Deposition	
7.14	995.11	-0.26	3484	Erosion	
6.94	991.68	0.15	4256	Erosion	
6.68	987.76	0.15	2382	Deposition	
6.49	983.82	0.12	3026	Erosion	
6.34	980.12	0.13	3810	Erosion	
6.08	977.47	0.17	3912	Erosion	
5.75	971.84	0.16	2986	Deposition	
5.68	969.53	-0.04	3094	Erosion	
5.59	967.00	-0.03	3208	Erosion	
5.46	964.59	0.49	1930	Deposition	
5.42	964.04	0.14	1644	Deposition	
5.2	961.51	0.56	3080	Erosion	
4.95	955.44	0.20	3159	Erosion	
4.76	954.08	-0.78	5829	Erosion	
4.55	949.75	0.18	3465	Deposition	
4.3	944.35	0.00	3319	Deposition	
4.23	942.76	0.00	3269	Deposition	
4	938.51	0.00	3387	Erosion	
3.86	936.14	0.00	3391	Erosion	
3.76	934.50	0.00	3398	Erosion	
3.69	932.49	0.00	3841	Erosion	
3.56	929.80	0.00	3849	Erosion	
3.31	924.58	0.00	3710	Deposition	

Station	Ch Invert El (ft)	Invert Change (ft)	Mass Out Cum: All (tons)	U/S Reach Bed Change*	Notes
3.1	920.78	0.00	3621	Deposition	
2.85	915.61	0.00	3507	Deposition	
2.7	911.27	-0.01	3522	Erosion	
2.61	909.84	0.00	3526	Erosion	
2.5	908.20	0.00	3526	Erosion	
2.4	906.10	0.00	3534	Erosion	
2.17	900.04	0.00	3556	Erosion	
1.99	895.10	0.00	3563	Erosion	
1.85	893.90	0.00	3536	Deposition	
1.6	889.68	0.00	3548	Erosion	
1.51	887.67	0.00	3551	Erosion	
1.32	883.81	-0.01	3580	Erosion	
1.28	882.68	-0.01	3592	Erosion	
1.24	880.98	0.00	3604	Erosion	
1.1	878.04	0.00	3611	Erosion	
0.95	875.46	0.00	3614	Erosion	
0.83	873.00	0.00	3626	Erosion	
0.5	863.80	0.00	3653	Erosion	
0.27	858.40	0.00	3666	Erosion	

Table F-2. 50 Year Event – Sediment Transport Table

* Sediment erosion and deposition can occur at channel bed and bank. Upstream bed change is defined based on the sediment delivery difference between upstream section and downstream section.

U/S Deposition: Total Sediment Inflow > Total Sediment Outflow

U/S Erosion: Total Sediment Inflow < Total Sediment Outflow

Station	Ch Invert El (ft)	Invert Change (ft)	Mass Out Cum: All (tons)	U/S Reach Bed Change*	Notes
16.72	1144.40	0.00	1460.6		
16.64	1142.75	0.28	1170.3	Deposition	
16.38	1139.03	0.13	940.2	Deposition	
16.15	1135.79	0.05	735.0	Deposition	
15.86	1131.47	-0.31	1231.3	Erosion	
15.65	1130.46	0.27	2077.7	Erosion	
15.61	1129.80	-0.05	2369.5	Erosion	
15.35	1125.72	0.33	2254.7	Deposition	
15.2	1123.23	0.29	2803.1	Erosion	
14.95	1119.39	-0.02	3018.6	Erosion	
14.73	1114.61	0.18	1308.6	Deposition	
14.49	1110.55	-0.03	1213.4	Deposition	
14.4	1107.36	-1.98	3663.6	Erosion	
14.3	1107.13	-0.65	3613.2	Deposition	
14.21	1105.90	0.30	3275.8	Deposition	
14.12	1105.25	0.21	2982.6	Deposition	
14.05	1103.33	0.04	2953.6	Deposition	
13.81	1101.15	0.00	3167.7	Erosion	
13.53	1098.29	0.04	2931.6	Deposition	
13.38	1095.79	0.00	2849.2	Deposition	
13.23	1093.74	0.08	2486.9	Deposition	
12.79	1086.70	0.10	2073.0	Deposition	
12.65	1083.78	-0.02	2154.8	Erosion	
12.42	1081.04	-0.41	3554.9	Erosion	
12.16	1078.48	0.08	3973.7	Erosion	
11.62	1070.26	0.23	2312.2	Deposition	
11.45	1067.38	0.16	1330.1	Deposition	
11.16	1062.22	0.06	2451.9	Erosion	
10.99	1059.65	0.15	2423.5	Deposition	
10.6	1053.09	0.16	3232.6	Erosion	
10.45	1050.68	0.13	2123.9	Deposition	
10.18	1046.69	-0.07	2014.3	Deposition	
10.04	1044.56	0.07	1660.4	Deposition	
9.77	1040.13	-0.08	2004.0	Erosion	

Station	Ch Invert El (ft)	Invert Change (ft)	Mass Out Cum: All (tons)	U/S Reach Bed Change*	Notes
9.53	1037.55	0.34	1427.7	Deposition	
9.4	1035.62	0.17	1120.6	Deposition	
9.27	1033.39	0.09	1814.2	Erosion	
9.09	1029.01	0.01	1946.4	Erosion	
8.86	1024.24	-0.15	2268.5	Erosion	
8.64	1021.79	-0.19	2868.8	Erosion	
8.44	1018.05	0.29	2341.0	Deposition	
8.29	1015.39	0.07	1994.2	Deposition	
8.1	1010.48	-0.02	1853.2	Deposition	
8.07	1011.75	0.49	1401.0	Deposition	
8.06	1011.38	0.38	921.2	Deposition	
7.95	1008.19	-0.11	2222.7	Erosion	
7.86	1007.17	-0.32	3357.2	Erosion	
7.71	1004.09	0.02	3303.7	Deposition	
7.47	1000.93	0.13	2527.1	Deposition	
7.31	998.11	0.11	1801.7	Deposition	
7.14	995.22	-0.15	2227.8	Erosion	
6.94	991.50	-0.03	2918.0	Erosion	
6.68	987.71	0.10	1744.7	Deposition	
6.49	984.03	0.33	2418.5	Erosion	
6.34	980.07	0.08	2431.3	Erosion	
6.08	977.35	0.05	2836.4	Erosion	
5.75	971.73	0.05	2084.0	Deposition	
5.68	969.50	-0.07	2241.5	Erosion	
5.59	967.00	-0.03	2323.5	Erosion	
5.46	964.35	0.25	1328.4	Deposition	
5.42	964.00	0.10	1141.0	Deposition	
5.2	961.16	0.21	2849.7	Erosion	
4.95	955.46	0.22	2193.4	Deposition	
4.76	954.92	0.06	3832.9	Erosion	
4.55	949.72	0.15	2427.8	Deposition	
4.3	944.35	0.00	2336.8	Deposition	
4.23	942.76	0.00	2335.8	Deposition	
4	938.51	0.00	2436.8	Erosion	
3.86	936.14	0.00	2440.8	Erosion	
3.76	934.50	0.00	2445.7	Erosion	
3.69	932.49	0.00	2802.4	Erosion	
3.56	929.80	0.00	2807.2	Erosion	
3.31	924.61	0.03	2748.2	Deposition	

Station	Ch Invert El (ft)	Invert Change (ft)	Mass Out Cum: All (tons)	U/S Reach Bed Change*	Notes
3.1	920.78	0.00	2682.6	Deposition	
2.85	915.61	0.00	2640.2	Deposition	
2.7	911.27	-0.01	2652.4	Erosion	
2.61	909.84	0.00	2651.1	Deposition	
2.5	908.20	0.00	2649.9	Deposition	
2.4	906.10	0.00	2654.2	Erosion	
2.17	900.04	0.00	2675.6	Erosion	
1.99	895.10	0.00	2676.9	Erosion	
1.85	893.90	0.00	2635.8	Deposition	
1.6	889.68	0.00	2641.1	Erosion	
1.51	887.67	0.00	2647.4	Erosion	
1.32	883.81	-0.01	2682.8	Erosion	
1.28	882.68	-0.01	2693.3	Erosion	
1.24	880.98	-0.01	2707.7	Erosion	
1.1	878.04	0.00	2715.3	Erosion	
0.95	875.45	-0.01	2725.2	Erosion	
0.83	873.00	0.00	2741.3	Erosion	
0.5	863.80	0.00	2773.7	Erosion	
0.27	858.40	0.00	2797.5	Erosion	

Table F-3. 25 Year Event – Sediment Transport Table

* Sediment erosion and deposition can occur at channel bed and bank. Upstream bed change is defined based on the sediment delivery difference between upstream section and downstream section.

U/S Deposition: Total Sediment Inflow > Total Sediment Outflow

U/S Erosion: Total Sediment Inflow < Total Sediment Outflow

Station	Ch Invert El (ft)	Invert Change (ft)	Mass Out Cum: All (tons)	U/S Reach Bed Change*	Notes
16.72	1144.40	0	1173.8		
16.64	1142.73	0.26	907.6	Deposition	
16.38	1138.93	0.03	663.0	Deposition	
16.15	1135.75	0.01	514.7	Deposition	
15.86	1131.46	-0.32	924.9	Erosion	
15.65	1130.39	0.20	1160.7	Erosion	
15.61	1129.84	-0.01	1184.5	Erosion	
15.35	1125.01	-0.38	1662.3	Erosion	
15.2	1123.11	0.17	1717.2	Erosion	
14.95	1119.40	-0.01	1894.5	Erosion	
14.73	1114.52	0.09	878.8	Deposition	
14.49	1109.53	-1.06	1828.0	Erosion	
14.4	1108.76	-0.58	2812.8	Erosion	
14.3	1107.30	-0.48	2871.6	Erosion	
14.21	1105.88	0.28	2498.9	Deposition	
14.12	1105.28	0.24	2149.4	Deposition	
14.05	1103.41	0.12	2034.4	Deposition	
13.81	1101.27	0.12	2213.7	Erosion	
13.53	1098.28	0.03	1819.1	Deposition	
13.38	1095.79	0.00	1762.6	Deposition	
13.23	1093.70	0.04	1606.3	Deposition	
12.79	1086.65	0.05	1381.8	Deposition	
12.65	1083.79	-0.01	1525.5	Erosion	
12.42	1081.50	0.05	2236.3	Erosion	
12.16	1078.43	0.03	2256.2	Erosion	
11.62	1070.14	0.11	1370.7	Deposition	
11.45	1067.32	0.10	969.0	Deposition	
11.16	1062.45	0.29	1524.8	Erosion	
10.99	1059.73	0.23	1307.7	Deposition	
10.6	1053.25	0.32	1798.2	Erosion	
10.45	1050.61	0.06	1346.4	Deposition	
10.18	1046.76	0.00	1145.4	Deposition	
10.04	1044.55	0.06	962.0	Deposition	
9.77	1040.20	-0.01	1156.2	Erosion	

Station	Ch Invert El (ft)	Invert Change (ft)	Mass Out Cum: All (tons)	U/S Reach Bed Change*	Notes
9.53	1037.49	0.28	938.5	Deposition	
9.4	1035.53	0.08	814.9	Deposition	
9.27	1033.14	-0.16	1249.4	Erosion	
9.09	1029.00	0.00	1262.2	Erosion	
8.86	1024.40	0.01	1150.7	Deposition	
8.64	1021.75	-0.24	1901.5	Erosion	
8.44	1017.88	0.12	1442.6	Deposition	
8.29	1015.38	0.06	1262.0	Deposition	
8.1	1010.50	0.00	1062.5	Deposition	
8.07	1011.60	0.34	748.5	Deposition	
8.06	1011.22	0.22	475.2	Deposition	
7.95	1008.10	-0.20	1242.7	Erosion	
7.86	1007.24	-0.25	1987.0	Erosion	
7.71	1004.17	0.10	1761.5	Deposition	
7.47	1000.89	0.09	1362.2	Deposition	
7.31	998.06	0.06	985.9	Deposition	
7.14	995.31	-0.06	1183.0	Erosion	
6.94	991.65	0.12	1587.4	Erosion	
6.68	987.67	0.06	1113.3	Deposition	
6.49	984.04	0.34	1447.5	Erosion	
6.34	979.99	0.00	1419.8	Deposition	
6.08	977.38	0.08	1606.4	Erosion	
5.75	971.68	0.00	1332.7	Deposition	
5.68	969.53	-0.04	1377.9	Erosion	
5.59	967.10	0.07	1201.9	Deposition	
5.46	964.25	0.15	868.8	Deposition	
5.42	963.98	0.08	761.4	Deposition	
5.2	961.30	0.35	1614.8	Erosion	
4.95	955.49	0.25	1371.2	Deposition	
4.76	955.12	0.26	2016.1	Erosion	
4.55	949.69	0.12	1391.4	Deposition	
4.3	944.35	0.00	1395.8	Erosion	
4.23	942.76	0.00	1361.2	Deposition	
4	938.51	0.00	1578.2	Erosion	
3.86	936.14	0.00	1582.1	Erosion	
3.76	934.50	0.00	1587.1	Erosion	
3.69	932.49	0.00	1883.4	Erosion	
3.56	929.80	0.00	1885.8	Erosion	
3.31	924.58	0.00	1879.9	Deposition	

Station	Ch Invert El (ft)	Invert Change (ft)	Mass Out Cum: All (tons)	U/S Reach Bed Change*	Notes
3.1	920.78	0.00	1789.3	Deposition	
2.85	915.61	0.00	1715.3	Deposition	
2.7	911.28	0.00	1720.3	Erosion	
2.61	909.84	0.00	1719.3	Deposition	
2.5	908.20	0.00	1719.5	Erosion	
2.4	906.10	0.00	1722.4	Erosion	
2.17	900.04	0.00	1735.1	Erosion	
1.99	895.10	0.00	1727.5	Deposition	
1.85	893.90	0.00	1673.1	Deposition	
1.6	889.68	0.00	1675.7	Erosion	
1.51	887.67	0.00	1677.4	Erosion	
1.32	883.82	0.00	1692.6	Erosion	
1.28	882.68	-0.01	1702.4	Erosion	
1.24	880.98	0.00	1709.2	Erosion	
1.1	878.04	0.00	1713.0	Erosion	
0.95	875.46	0.00	1716.0	Erosion	
0.83	873.00	0.00	1727.0	Erosion	
0.5	863.80	0.00	1756.8	Erosion	
0.27	858.40	0.00	1766.8	Erosion	

Table F-4. 10 year Event – Sediment Transport Table

* Sediment erosion and deposition can occur at channel bed and bank. Upstream bed change is defined based on the sediment delivery difference between upstream section and downstream section.

U/S Deposition: Total Sediment Inflow > Total Sediment Outflow

U/S Erosion: Total Sediment Inflow < Total Sediment Outflow

Station	Ch Invert El (ft)	Invert Change (ft)	Mass Out Cum: All (tons)	U/S Reach Bed Change*	Notes
16.72	1144.40	0.00	420.2		
16.64	1142.55	0.08	359.0	Deposition	
16.38	1138.92	0.02	223.2	Deposition	
16.15	1135.74	0.00	233.2	Erosion	
15.86	1131.75	-0.03	302.3	Erosion	
15.65	1130.24	0.05	404.1	Erosion	
15.61	1129.85	0.00	392.6	Deposition	
15.35	1125.35	-0.04	573.2	Erosion	
15.2	1122.97	0.03	659.7	Erosion	
14.95	1119.39	-0.02	736.8	Erosion	
14.73	1114.49	0.06	386.1	Deposition	
14.49	1110.51	-0.07	461.5	Erosion	
14.4	1109.20	-0.14	801.7	Erosion	
14.3	1107.22	-0.56	1228.0	Erosion	
14.21	1105.86	0.26	843.1	Deposition	
14.12	1105.15	0.11	683.6	Deposition	
14.05	1103.31	0.01	663.5	Deposition	
13.81	1101.16	0.01	640.1	Deposition	
13.53	1098.26	0.01	578.6	Deposition	
13.38	1095.80	0.01	567.4	Deposition	
13.23	1093.66	0.00	567.0	Deposition	
12.79	1086.57	-0.03	612.6	Erosion	
12.65	1083.79	-0.02	663.5	Erosion	
12.42	1081.44	0.00	715.7	Erosion	
12.16	1078.40	0.00	730.8	Erosion	
11.62	1070.06	0.03	544.0	Deposition	
11.45	1067.24	0.02	438.7	Deposition	
11.16	1062.27	0.11	556.8	Erosion	
10.99	1059.58	0.08	472.9	Deposition	
10.6	1052.97	0.04	588.1	Erosion	
10.45	1050.56	0.01	510.4	Deposition	
10.18	1046.77	0.01	428.6	Deposition	

Station	Ch Invert El (ft)	Invert Change (ft)	Mass Out Cum: All (tons)	U/S Reach Bed Change*	Notes
10.04	1044.51	0.02	367.2	Deposition	
9.77	1040.20	-0.01	374.2	Erosion	
9.53	1037.27	0.06	295.5	Deposition	
9.4	1035.44	-0.01	292.8	Deposition	
9.27	1033.24	-0.06	461.1	Erosion	
9.09	1028.99	-0.01	506.8	Erosion	
8.86	1024.41	0.02	409.7	Deposition	
8.64	1021.91	-0.07	584.0	Erosion	
8.44	1017.83	0.07	506.7	Deposition	
8.29	1015.37	0.05	381.9	Deposition	
8.1	1010.47	-0.04	398.5	Erosion	
8.07	1011.39	0.13	282.2	Deposition	
8.06	1011.09	0.09	182.7	Deposition	
7.95	1008.18	-0.12	439.8	Erosion	
7.86	1007.43	-0.06	566.8	Erosion	
7.71	1004.10	0.03	562.9	Deposition	
7.47	1000.84	0.04	399.8	Deposition	
7.31	998.02	0.02	310.6	Deposition	
7.14	995.33	-0.04	432.3	Erosion	
6.94	991.53	0.00	607.0	Erosion	
6.68	987.61	0.00	463.6	Deposition	
6.49	983.83	0.13	533.1	Erosion	
6.34	979.97	-0.02	590.1	Erosion	
6.08	977.34	0.04	517.5	Deposition	
5.75	971.65	-0.03	567.7	Erosion	
5.68	969.58	0.01	544.5	Deposition	
5.59	967.05	0.02	508.1	Deposition	
5.46	964.17	0.07	406.2	Deposition	
5.42	963.94	0.04	364.6	Deposition	
5.2	960.91	-0.05	914.3	Erosion	
4.95	955.45	0.21	528.2	Deposition	
4.76	954.70	-0.16	975.6	Erosion	
4.55	949.63	0.06	487.0	Deposition	
4.3	944.35	0.00	501.2	Erosion	
4.23	942.76	0.00	503.1	Erosion	
4	938.51	0.00	599.4	Erosion	
3.86	936.14	0.00	602.4	Erosion	
3.76	934.50	0.00	604.9	Erosion	
3.69	932.49	0.00	809.5	Erosion	

Station	Ch Invert El (ft)	Invert Change (ft)	Mass Out Cum: All (tons)	U/S Reach Bed Change*	Notes
3.56	929.80	0.00	810.6	Erosion	
3.31	924.59	0.01	773.8	Deposition	
3.1	920.80	0.02	603.1	Deposition	
2.85	915.61	0.00	563.7	Deposition	
2.7	911.28	0.00	569.8	Erosion	
2.61	909.84	0.00	570.0	Erosion	
2.5	908.20	0.00	569.9	Deposition	
2.4	906.10	0.00	572.9	Erosion	
2.17	900.04	0.00	585.9	Erosion	
1.99	895.10	0.00	585.3	Deposition	
1.85	893.90	0.00	573.2	Deposition	
1.6	889.68	0.00	573.5	Erosion	
1.51	887.67	0.00	574.3	Erosion	
1.32	883.82	0.00	581.3	Erosion	
1.28	882.68	-0.01	585.5	Erosion	
1.24	880.98	0.00	590.6	Erosion	
1.1	878.04	0.00	590.7	Erosion	
0.95	875.46	0.00	584.8	Deposition	
0.83	873.00	0.00	590.6	Erosion	
0.5	863.80	0.00	597.8	Erosion	
0.27	858.40	0.00	597.5	Deposition	

Attachment G

Sediment Transport Analysis

100-year Series Floods

Table G-1. Sediment Transport Table – 100 Year Duration

*Sediment erosion and deposition can occur at channel bed and bank. Upstream bed change is defined based on the sediment delivery difference between upstream section and downstream section.

U/S Deposition: Total Sediment Inflow > Total Sediment Outflow

U/S Erosion: Total Sediment Inflow < Total Sediment Outflow

Station	Ch Invert El (ft)	Invert Change (ft)	Mass Out Cum: All (tons)	U/S Reach Bed Change*	Notes
16.72	1144.40	0.00	7,487		
16.64	1144.59	2.12	5,583	Deposition	
16.38	1140.33	1.43	4,544	Deposition	
16.15	1135.32	-0.42	4,529	Deposition	
15.86	1130.20	-1.58	5,323	Erosion	
15.65	1130.16	-0.03	9,421	Erosion	
15.61	1129.02	-0.83	12,134	Erosion	
15.35	1126.94	1.55	12,765	Erosion	
15.2	1120.82	-2.12	18,558	Erosion	
14.95	1118.10	-1.31	16,859	Deposition	
14.73	1115.86	1.43	8,865	Deposition	
14.49	1108.74	-1.84	8,943	Erosion	
14.4	1108.73	-0.61	12,444	Erosion	
14.3	1107.41	-0.37	14,243	Erosion	
14.21	1105.63	0.03	14,361	Erosion	
14.12	1105.28	0.24	14,005	Deposition	
14.05	1103.45	0.16	13,841	Deposition	
13.81	1101.14	-0.01	14,490	Erosion	
13.53	1098.25	0.00	13,217	Deposition	
13.38	1095.79	0.00	13,079	Deposition	
13.23	1093.75	0.09	12,677	Deposition	
12.79	1086.99	0.39	10,823	Deposition	
12.65	1083.83	0.03	10,856	Erosion	
12.42	1081.36	-0.08	11,367	Erosion	
12.16	1078.33	-0.07	13,099	Erosion	
11.62	1070.65	0.62	11,087	Deposition	
11.45	1067.58	0.36	8,786	Deposition	
11.16	1062.25	0.09	9,796	Erosion	
10.99	1059.41	-0.09	10,251	Erosion	
10.6	1052.14	-0.79	14,562	Erosion	
10.45	1050.74	0.19	11,608	Deposition	
10.18	1046.96	0.20	10,215	Deposition	
10.04	1044.88	0.39	9,098	Deposition	

Station	Ch Invert El (ft)	Invert Change (ft)	Mass Out Cum: All (tons)	U/S Reach Bed Change*	Notes
9.77	1040.29	0.08	9,294	Erosion	
9.53	1038.06	0.85	7,667	Deposition	
9.4	1035.72	0.27	6,548	Deposition	
9.27	1033.18	-0.12	9,689	Erosion	
9.09	1027.28	-1.72	13,362	Erosion	
8.86	1026.79	2.40	10,132	Deposition	
8.64	1022.50	0.52	11,788	Erosion	
8.44	1019.29	1.53	10,564	Deposition	
8.29	1017.65	2.33	9,670	Deposition	
8.1	1010.82	0.31	10,936	Erosion	
8.07	1013.29	2.03	9,048	Deposition	
8.06	1009.57	-1.43	10,344	Erosion	
7.95	1007.39	-0.91	11,245	Erosion	
7.86	1007.44	-0.05	12,663	Erosion	
7.71	1004.01	-0.06	13,300	Erosion	
7.47	1001.17	0.37	11,636	Deposition	
7.31	998.30	0.30	9,025	Deposition	
7.14	995.83	0.46	9,414	Erosion	
6.94	991.88	0.35	12,021	Erosion	
6.68	988.24	0.63	8,562	Deposition	
6.49	983.83	0.13	10,478	Erosion	
6.34	979.69	-0.30	12,472	Erosion	
6.08	978.67	1.37	12,015	Deposition	
5.75	972.11	0.43	8,593	Deposition	
5.68	969.67	0.10	8,344	Deposition	
5.59	965.92	-1.11	11,734	Erosion	
5.46	965.15	1.05	8,569	Deposition	
5.42	963.93	0.03	8,151	Deposition	
5.2	956.19	-4.76	19,166	Erosion	
4.95	955.31	0.07	12,187	Deposition	
4.76	956.54	1.68	12,068	Deposition	
4.55	950.19	0.62	12,007	Deposition	
4.3	944.33	-0.02	11,501	Deposition	
4.23	942.75	-0.01	11,485	Deposition	
4	938.51	0.00	12,714	Erosion	
3.86	936.12	-0.02	12,737	Erosion	
3.76	934.48	-0.02	12,771	Erosion	
3.69	932.47	-0.02	15,364	Erosion	

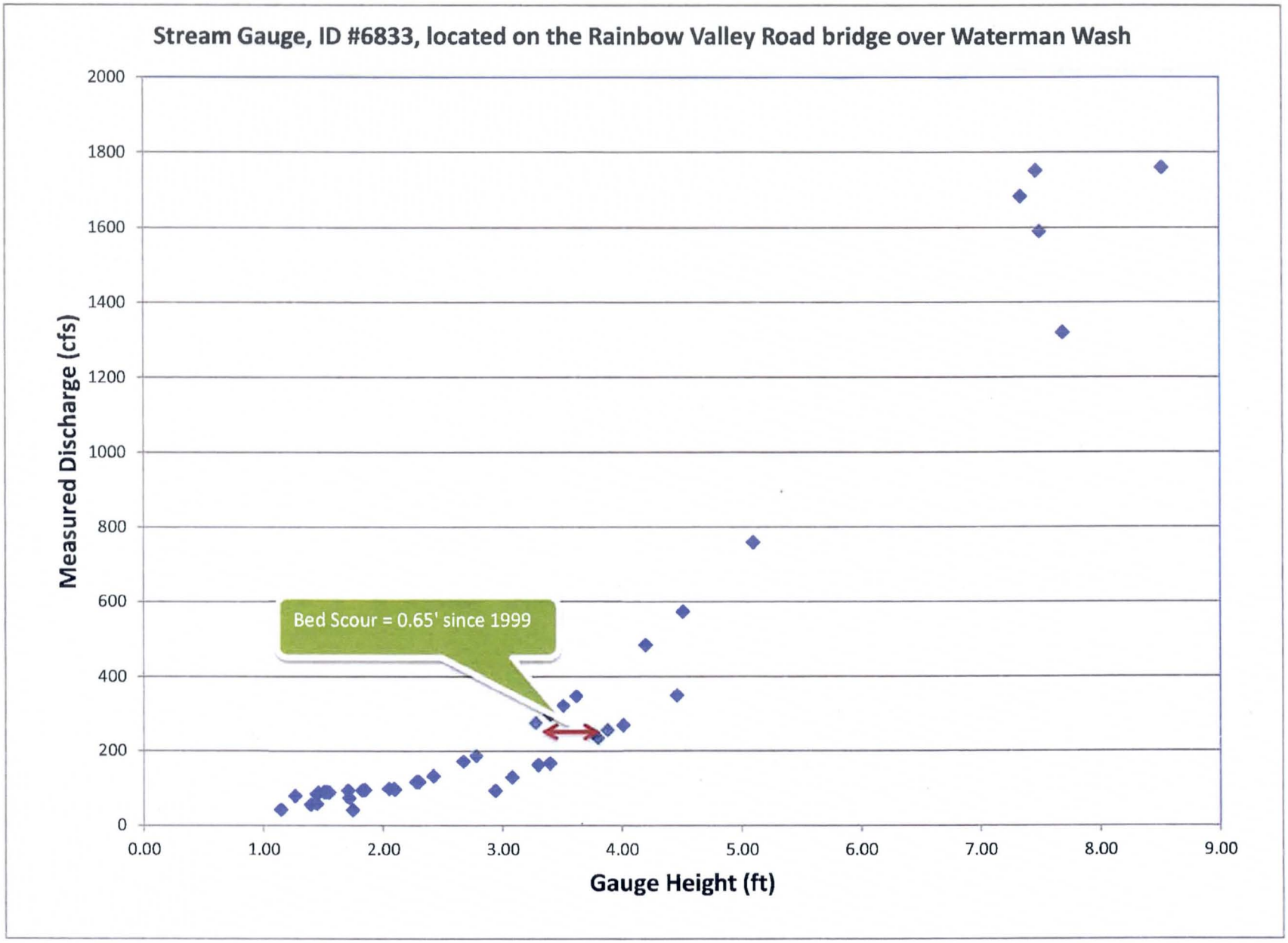
Station	Ch Invert El (ft)	Invert Change (ft)	Mass Out Cum: All (tons)	U/S Reach Bed Change*	Notes
3.56	929.77	-0.03	15,385	Erosion	
3.31	924.61	0.03	15,358	Deposition	
3.1	920.84	0.06	15,114	Deposition	
2.85	915.59	-0.02	14,692	Deposition	
2.7	911.24	-0.04	14,724	Erosion	
2.61	909.84	0.00	14,736	Erosion	
2.5	908.17	-0.03	14,733	Deposition	
2.4	906.06	-0.04	14,753	Erosion	
2.17	900.02	-0.02	14,877	Erosion	
1.99	895.09	-0.01	14,882	Erosion	
1.85	893.88	-0.02	14,962	Erosion	
1.6	889.67	-0.01	15,029	Erosion	
1.51	887.66	-0.01	15,048	Erosion	
1.32	883.76	-0.06	15,216	Erosion	
1.28	882.60	-0.09	15,299	Erosion	
1.24	880.93	-0.05	15,383	Erosion	
1.1	878.03	-0.01	15,451	Erosion	
0.95	875.43	-0.03	15,519	Erosion	
0.83	872.97	-0.03	15,592	Erosion	
0.5	863.76	-0.04	15,786	Erosion	

Attachment H

Bed Scour at the Stream Gauge, ID #6833, located on the Rainbow Valley Road bridge over Waterman Wash since 1999

Table H-1. Gauged Data observed from the gauge station, ID #6833, located on the Rainbow Valley Road bridge over Waterman Wash

Data	Time	Gauge Height (ft)	Measured Discharge (cfs)
08/27/2010	14:27	2.78	187
2/28/2010	9:40	1.75	41
1/22/2010	2:16	7.50	1590
1/20/2010	3:51	3.42	302
8/22/2009	4:26	5.10	759
7/4/2009	0:23	3.40	298
8/29/2008	1:18	7.47	1752
8/26/2008	2:27	1.85	96
8/8/2008	1:34	3.62	347
5/23/2008	9:37	1.83	95
11/30/2007	19:26	1.55	89
8/17/2007	2:41	1.45	85
7/31/2007	0:36	2.28	117
7/25/2007	23:22	2.05	99
9/3/2006	2:11	3.51	321
8/24/2006	20:38	1.71	94
8/12/2006	3:30	3.28	276
8/11/2006	0:35	7.34	1683
7/26/2006	3:27	4.51	573
8/9/2005	21:09	2.09	99
8/2/2005	22:32	1.46	88
7/23/2005	23:38	1.53	90
7/23/2005	2:32	1.51	90
2/24/2005	4:45	2.67	172
2/19/2005	19:33	1.27	80
2/26/2003	13:27	1.72	74
2/14/2003	2:18	4.20	484
1/8/2003	15:13	1.15	42
11/29/2002	19:58	1.40	56
10/27/2002	1:32	1.45	58
9/8/2002	6:37	2.42	133
7/30/2001	6:46	2.10	97
7/6/2001	13:17	2.30	118
11/6/2000	15:19	3.88	257
10/27/2000	18:28	3.08	130
10/24/2000	4:27	3.30	162
10/21/2000	19:06	8.52	1760
2/10/2000	8:36	2.94	94
8/31/1999	15:13	7.69	1320
7/28/1999	22:19	4.46	349
7/15/1999	8:18	3.40	167
7/14/1999	20:38	4.01	270
7/8/1999	10:03	3.80	235


Stream Gauge, ID #6833, located on the Rainbow Valley Road bridge over Waterman Wash
Measured Discharge (cfs)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
Gauge Height (ft)
Bed Scour = 0.65' since 1999

Attachment I

Sediment Transport Analysis

HEC-RAS Models