WATERTOWN, SOUTH DAKOTA
FLOOD RISK MANAGEMENT
GENERAL INVESTIGATIONS STUDY

FINAL INTEGRATED FEASIBILITY REPORT & ENVIRONMENTAL ASSESSMENT

APPENDIX M: SEDIMENT ANALYSIS

OMAHA DISTRICT
NORTHWESTERN DIVISION

July 2026

EXECUTIVE SUMMARY

A general investigation (GI) study was conducted to evaluate potential flood risk reduction measures for the city of Watertown, South Dakota. This report focuses on the sediment modeling efforts to help determine Federal interest in considered alternatives using the HEC-RAS (RAS) two-dimensional (2D) unsteady flow hydraulic modeling conducted for project analysis. The 2D hydraulic model was used to complete a sediment transport capacity analysis to compare two alternatives to the existing conditions. Only the no action (Alternative 1), the channel widening and levee left bank only (Alternative 3), and the channel widening, levee left bank only, and lowering Lake Kampeska to Elevation 1718 ft (Alternative 8) were evaluated in the sediment analysis. Refer to the Hydraulic Analysis for further discussion on the hydraulic model and alternatives.

Sediment transport capacity provides a qualitative comparison of the change in transport that may occur as a result of a modification from the existing condition. Changes in transport capacity may occur due to an expansion of the cross-sectional area, increases in roughness, or increasing the channel length by adding curvature to the alignment. Channel widening is expected to reduce sediment transport for the alternatives relative to the existing condition.

Sediment transport capacity was compared using the channel centerline. Results indicate that the reduction in transport capacity for Alternatives 3 and 8, relative to the existing, is small with low likelihood of impacts to channel capacity. Additional analysis may be necessary during final design.

A statistical analysis was performed with comparison to existing transport capacity and is summarized:

- Alternative 3 has an average capacity percent of Alt 1 of 81% for all events; the 20th percentile of 33% for the 50% Annual Exceedance Probability (AEP), 83% for the 10% AEP, and 88% for the 1% AEP

- Alternative 8 has an average capacity percent of Alt 1 of 74% for all events; the 20th percentile of 30% for the 50% AEP, 78% for the 10% AEP, and 84% for the 1% AEP.

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1.0 INTRODUCTION

This report describes the sediment analysis conducted for the General Investigations (GI) study of the Big Sioux River in Watertown, SD. The GI study's purpose is to address flood risk along the Big Sioux River in the vicinity of Watertown, SD. The sediment analysis will assess if the recommended plan greatly affects sediment conditions as compared to the No Action Alternative.

The hydraulic analysis performed for the project developed a 2D RAS model to design project features. The 2D model was used to conduct a capacity only sediment analysis for three alternatives to assess the relative sediment maintenance needs compared to the no action alternative. Results comparing sediment transport capacity and velocity are illustrated for the existing and alternative conditions. Note that this is a feasibility level assessment; further analysis will be performed during final design.

Figure 1-1, taken from the 2005 Watertown Feasibility Study (2018), shows a map of the Watertown, SD study area.

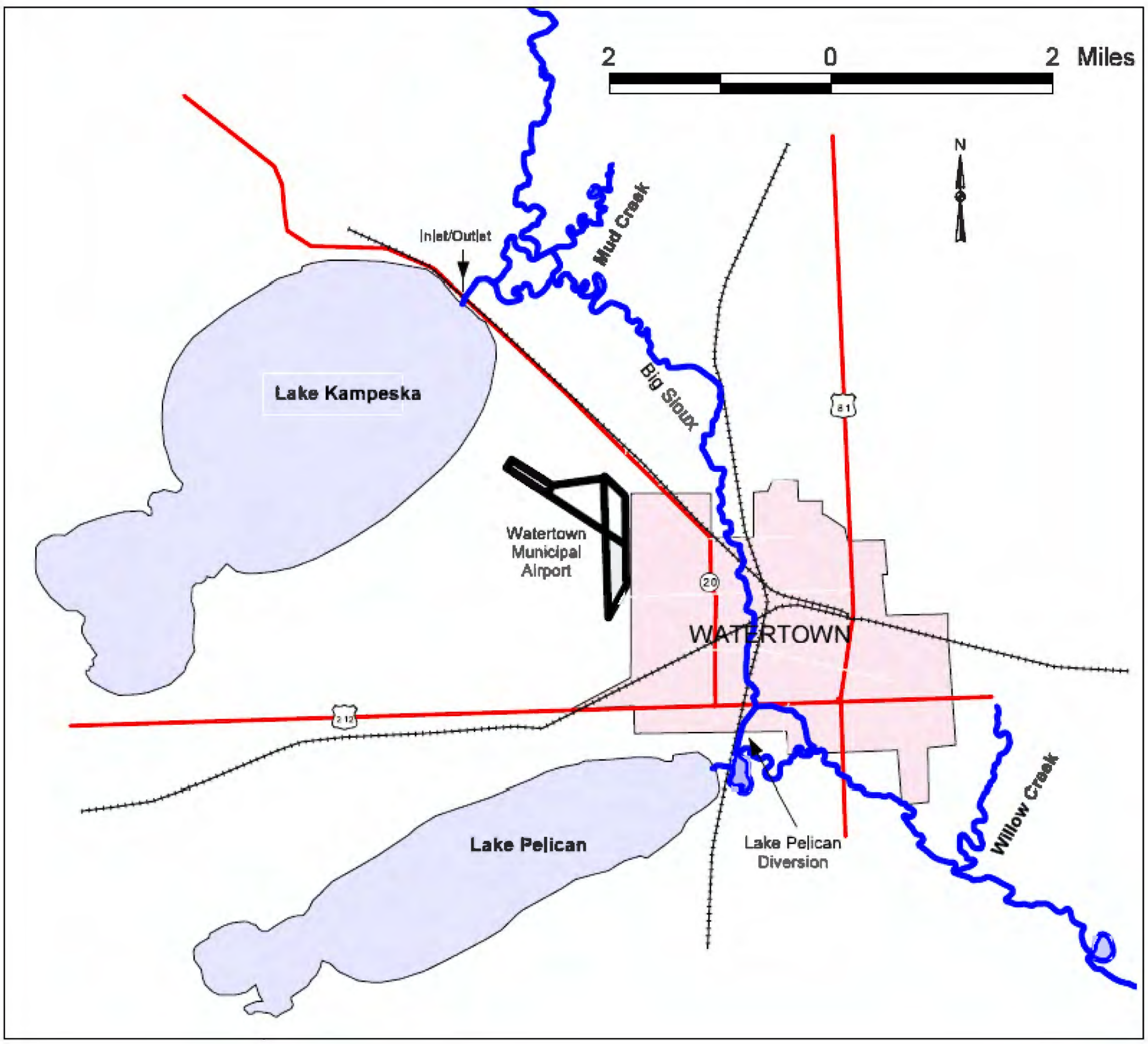


Figure 1-1. Watertown Study Area Map

2.0 SEDIMENT DATA AND OBSERVATIONS

Sparse sediment data exists for the Big Sioux River near Watertown. Only one bed gradation was available from the USGS gage of the Big Sioux River at Watertown, SD (06479500) from 18 October 1966 and is shown in Figure 2-1. The bed material D_{50} is about 2.5 mm (very fine gravel), and the majority of the sample is classified as gravel (54% of the sample). There are no current sediment-related issues reported in the study area.

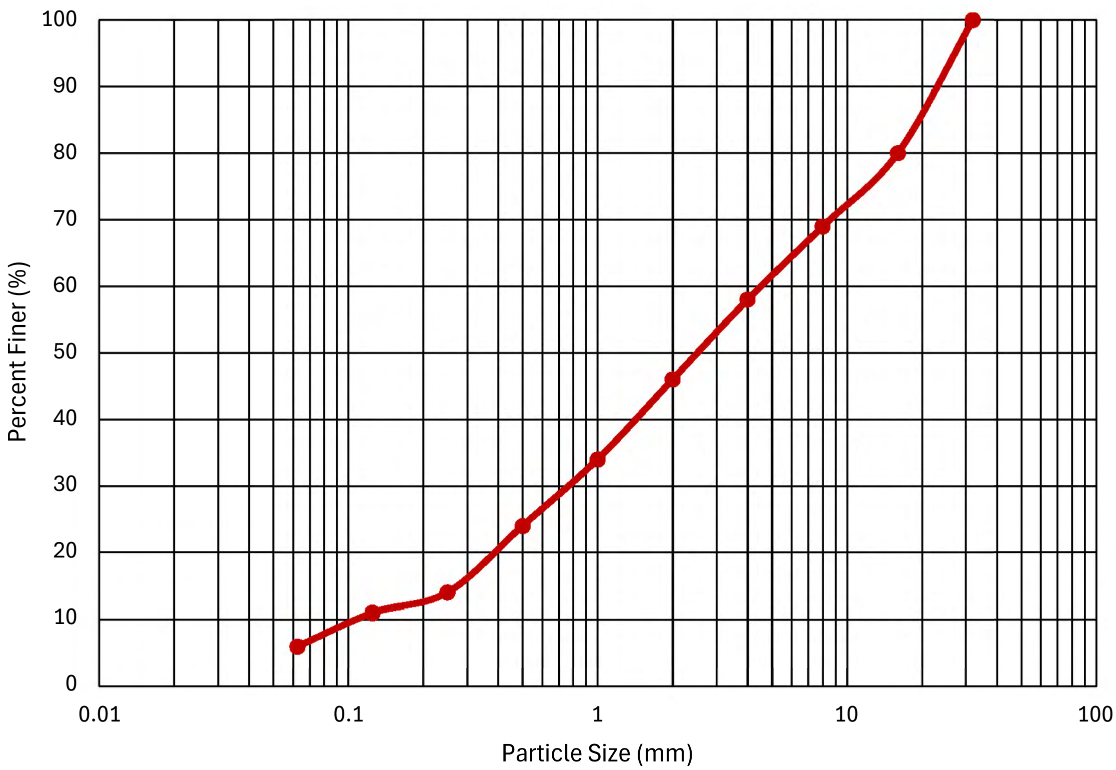


Figure 2-1. 18 Oct 1966 Big Sioux River - Bed Sample

3.0 ALTERNATIVES DESCRIPTION

Three alternatives were evaluated for the purposes of the sediment capacity analysis. A brief summary of the alternatives is provided in the following sections. Refer to the hydraulics Appendix of this study for further details. Not all alternatives were modeled to reduce analysis scope. Modeled alternatives selected for the sediment evaluation consisted of:

- Alternative 1 – No Action
- Alternative 3 – Channel Widening + Levee Left Bank Only (No closure structures)
- Alternative 8 – Lowering Lake Kampeska to Elevation 1718 ft NAVD88 + Channel Widening + Levee Left Bank Only (No closure structures)

3.1 Alternative 1 – No Action

The No Action alternative is hydraulically the same as the existing conditions model. The initial pool elevation assumed for existing conditions at Lake Kampeska was 1718.8 feet NAVD88 based on observed historic data. Due to unknown reliability, remnants of old berms constructed during past flood fights were removed from the terrain for the alternatives modeling.

3.2 Alternative 3 – Channel Widening + Levee Left Bank Only (No Closure Structures)

Alternative 3 includes channel widening and a left bank levee. The channel widening used a trapezoidal channel set to the invert of the existing channel. The width of the channel increased by approximately 30 to 50 ft on either side of the existing banks for a total width of approximately 110 to 150 ft for about 4.6 miles to allow for more flow capacity during flood events. The channel widening assumed side slopes of 1V:3H. The left bank levee height was calculated by identifying the lowest road that would require a closure structure. This would allow for no closure structures needed for this alternative.

3.3 Alternative 8 - Lowering Lake Kampeska to Elevation 1718 ft NAVD88 + Channel Widening + Levee Left Bank Only (No closure structures)

Similar to Alternative 3, Alternative 8 includes channel widening and a left bank levee. It also includes initial flow conditions for Lake Kampeska at an elevation 0.8 ft lower than its usual pool elevation (el. 1718 ft).

Figure 3-1 displays an example cross-section of what the widened section would look like. Figure 3-2 shows the location of the left bank levee/floodwall alignment as well as the approximate top width of the widened section (blue polygon).

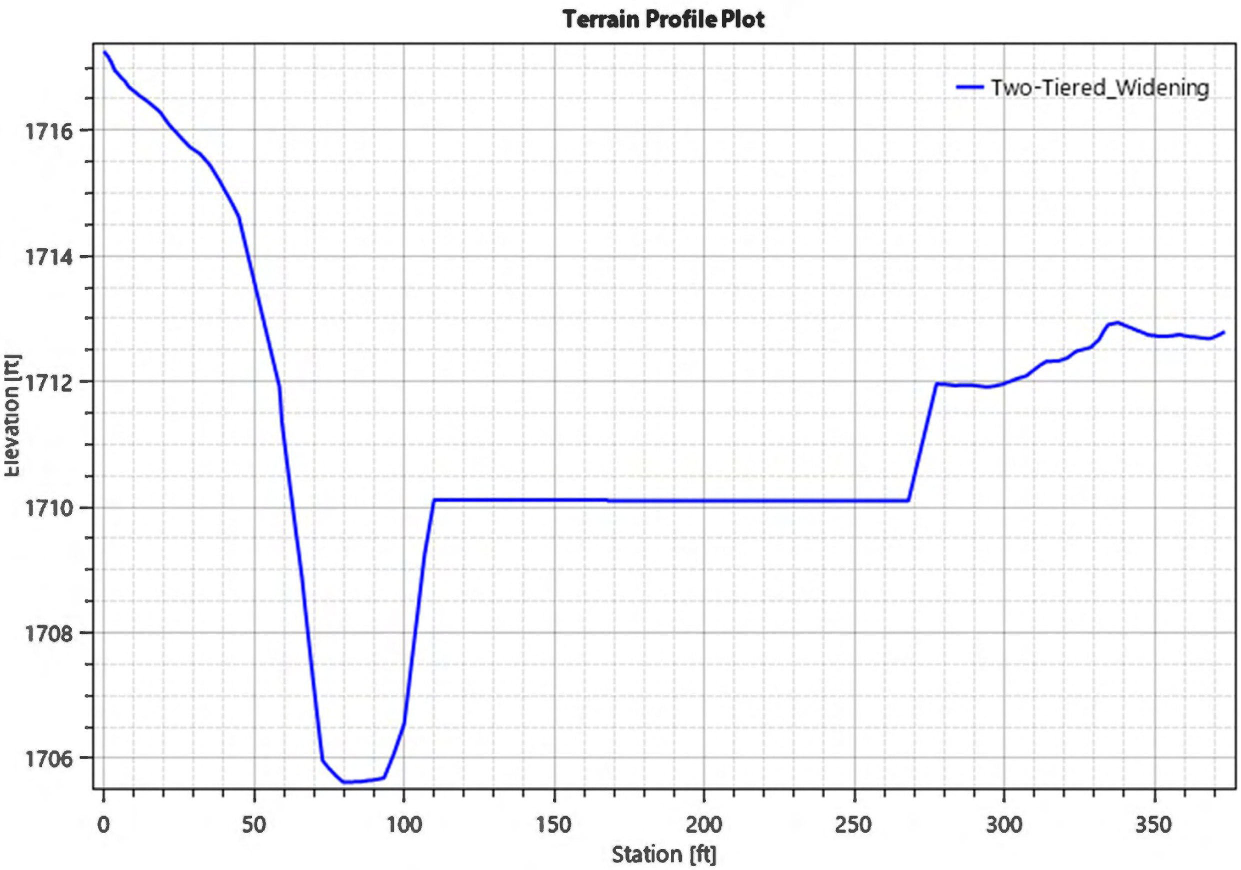


Figure 3-1. Example Alternative 8 Widened Cross-Section

Figure 3-2. Extent of Alternative 8 Levee/Floodwall and Channel Widening

4.0 SEDIMENT TRANSPORT EVALUATION WITH 2D RAS MODEL

The USACE Hydrologic Engineering Center's River Analysis System version 6.7 Beta (RAS) was used to perform an assessment of sedimentation processes for the alternative condition compared to the No Action current condition. Sediment parameters were added to the RAS 2D unsteady flow hydraulic model to perform a Capacity Only sediment analysis. Alternatives 3, and 8 were compared to Alternative 1 (No Action).

4.1 Datum

All elevation data in this report references the North American Vertical Datum of 1988 (NAVD88) in US Survey Feet unless otherwise specified. The horizontal coordinate system used for the hydraulic modeling was NAD 1983 State Plane South Dakota North FIPS 4001 in US Survey Feet.

4.2 Sediment Evaluation with Capacity Only

Accurate sediment transport modeling with RAS requires an extensive array of input parameters and past performance data to calibrate the model. Parameters include the incoming sediment load and gradation, bed material gradation, historic data to calibrate the sediment transport function, repetitive surveys within the model reach, and sedimentation observations and maintenance records for removal volumes.

Sediment computations add run time to hydraulic models, sometimes substantially. The sediment computations for multiple grain classes are computationally expensive, and a detailed sediment model can increase model run time by an order of magnitude or more over a hydraulic model.

RAS includes a range of sediment modeling options that offer tradeoffs between run time and feature richness. HEC added a fixed bed sediment modeling mode as an intermediate analysis option. Because much of the run time in the mobile-bed sediment model is in the bed mixing and elevation updates, a fixed bed sediment capacity tool can provide some of the insight at a fraction of the runtime.

The capacity-only option is a fixed-bed, 2D sediment model that computes capacity without sediment transport while the concentration-only model solves the Advection-Dispersion equations without bed change. Both simplifications can provide some of the value of a 2D sediment model for an intermediate level of effort (and run time) and are useful as good comparison and screening level tools.

Since sparse sediment data exists for the Big Sioux River and time was limited with a compressed schedule, a capacity only modeling effort was conducted. The capacity only analysis allows a qualitative comparison between alternatives and can be used to inform on relative project performance and sediment maintenance requirements.

The sediment analysis compared velocities and sediment transport capacity for existing conditions to with-project conditions. Alternative velocities were compared to Alternative 1 to help identify potential locations of sediment deposition or erosion.

The hydraulic analysis performed for the project design (Appendix B) developed a 2D RAS model to design project features. The same 2D model was used to conduct a capacity only sediment analysis. The RAS capacity only sediment analysis was performed using version 6.7 Beta (USACE n.d.).

4.3 Sediment Model Parameters

A simplified capacity only analysis does not require the full suite of sediment data, however, it does need a bed gradation. Only one bed gradation was found for the USGS gage, Big Sioux at Watertown, SD (06479500) from October 1966. Equilibrium load was used for the upstream sediment boundary conditions.

4.4 Hydrologic Inputs

The same hydrologic inputs as the hydraulic model were used for the sediment modeling. The Hydrology Section developed and provided eight annual exceedance probability (AEP) hydrographs for the Big Sioux River, North Branch of Mud Creek, South Branch of Mud Creek, and Willow Creek. More information on the hydrologic inputs can be found in the hydraulics and hydrology appendices (USACE 2023).

5.0 SEDIMENT EVALUATION RESULTS

Sediment transport capacity results were extracted from the RAS model. Within RAS, transport capacity values are computed for each 2D model cell. Centerlines were created for each alternative and the transport capacity was extracted from RAS along the centerline. Reported values vary with cell size. Graphical and statistical results analysis was performed by comparing all results along the centerline. The analysis was performed for eight AEP events.

5.1 Alternative 1 – No Action

The stationing for the centerline used to extract transport capacity results is shown in Figure 5-1. A reduced area was used for output analysis to focus on the area of alternative actions and just upstream. Centerline RAS computed transport capacity for the eight AEP events is shown in Figure 5-2. The centerline computed peak water surface elevation and velocity is shown in Figure 5-3.

Figure 5-1. Plan View Centerline for Output

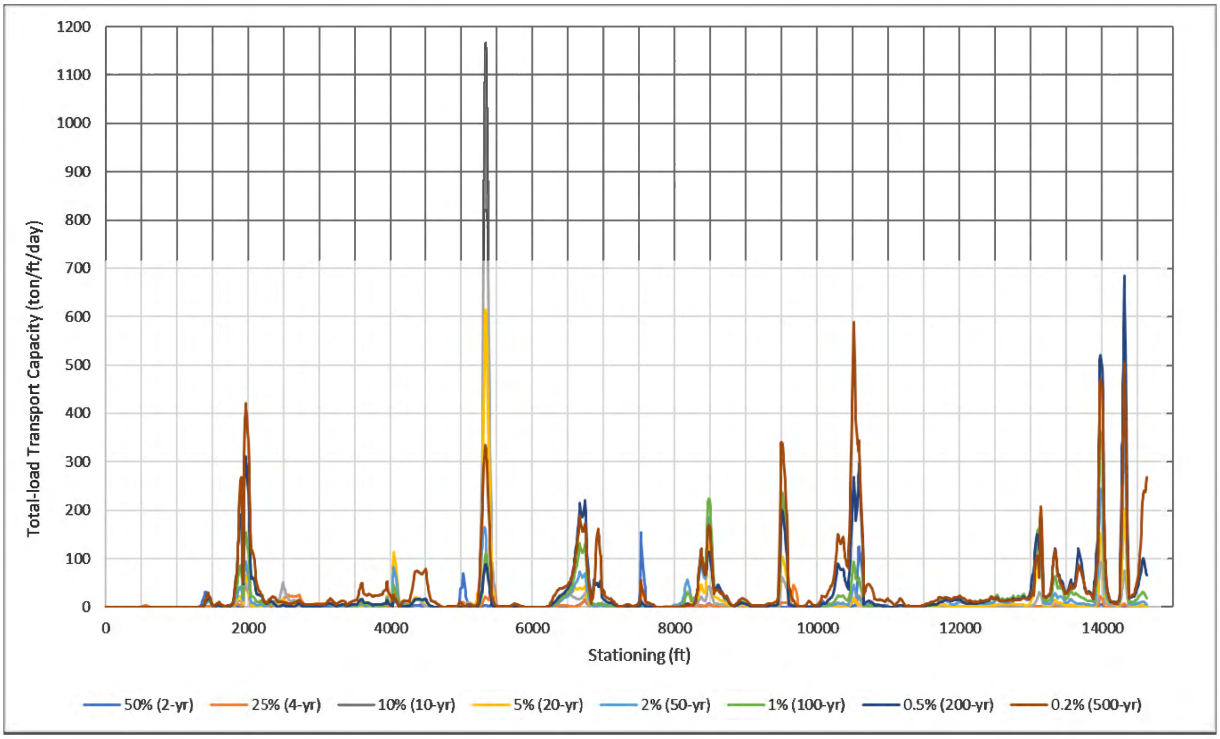


Figure 5-2. Alternative 1 Centerline Transport Capacity

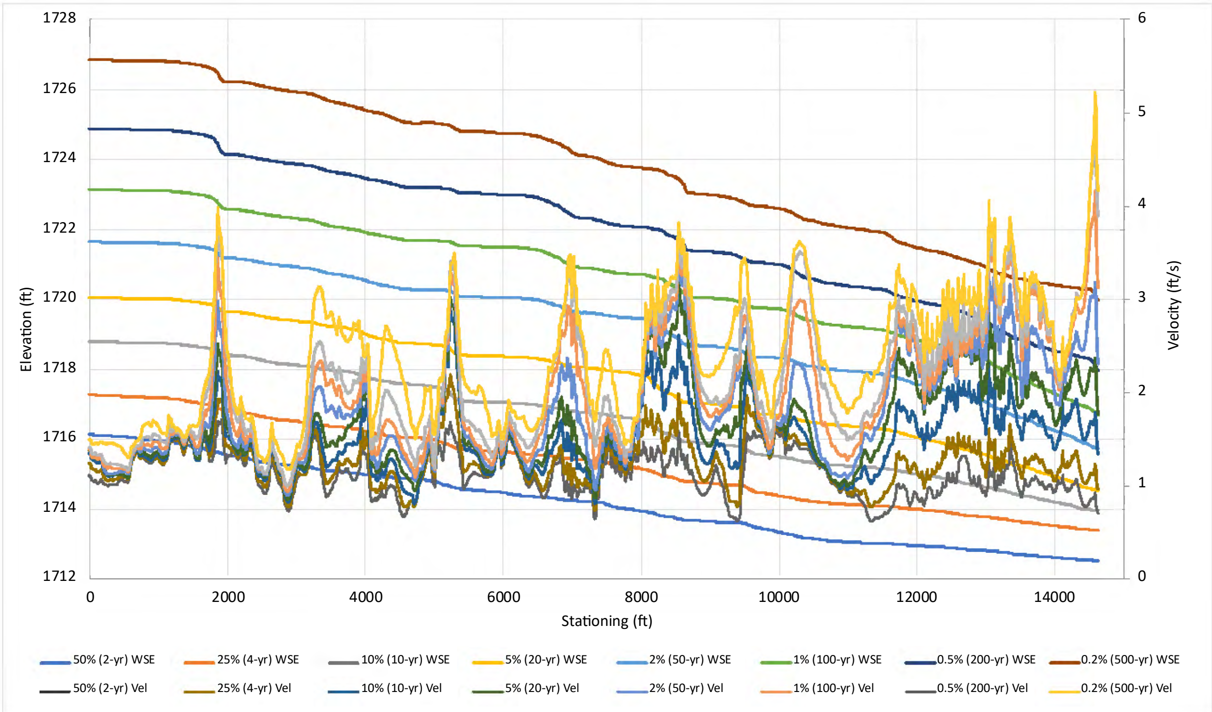


Figure 5-3. Alternative 1 Centerline Water Surface Elevation and Velocity

5.2 Alternative 3 – Channel Widening + Levee Left Bank Only (No Closure Structures)

Centerline RAS computed transport capacity for the eight AEP events is shown in Figure 5-4. The centerline computed peak water surface elevation and velocity is shown in Figure 5-5.

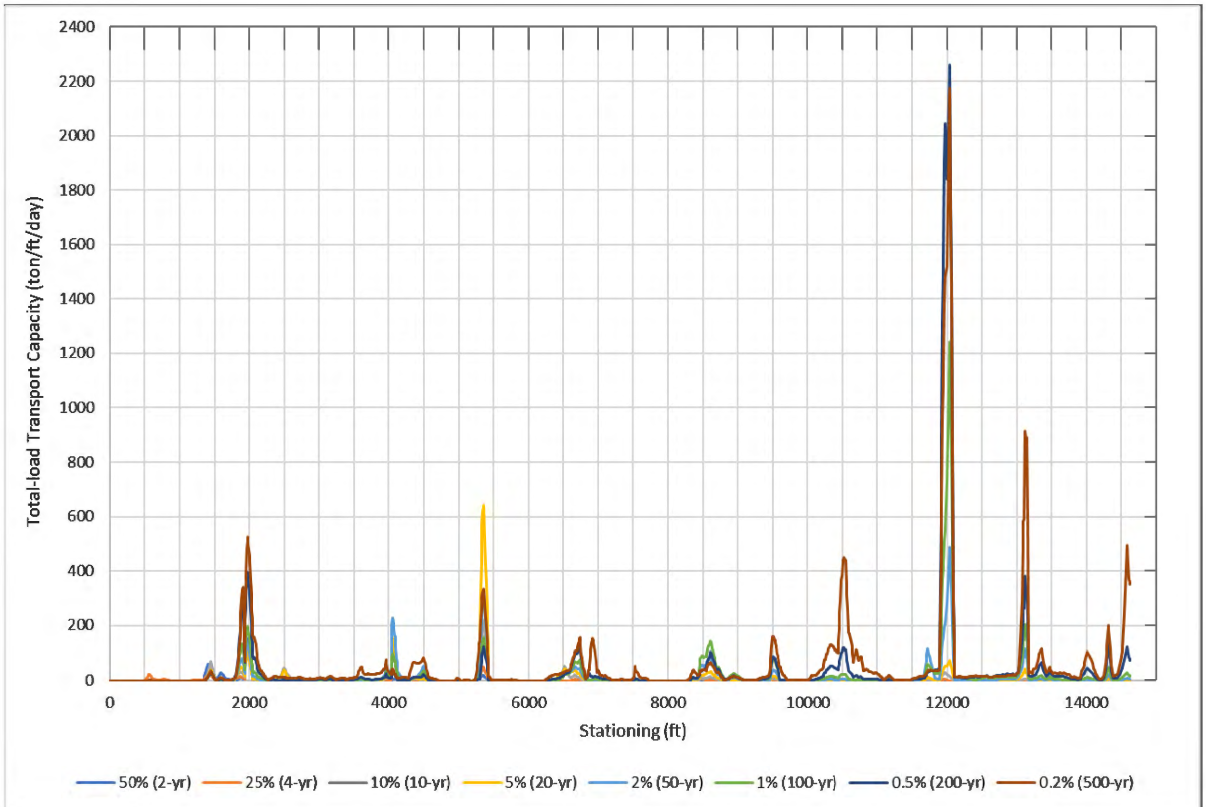


Figure 5-4. Alternative 3 Centerline Transport Capacity

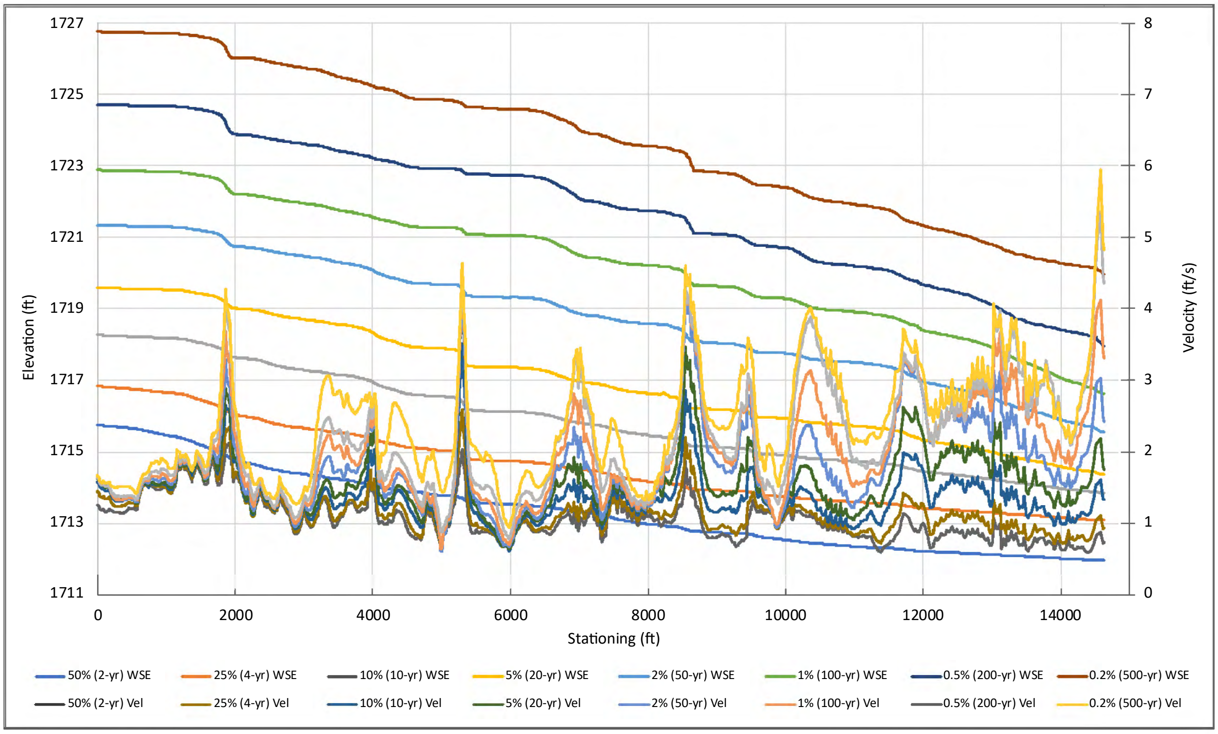


Figure 5-5. Alternative 3 Centerline Water Surface Elevation and Velocity

5.3 Alternative 8 – Lowering Lake Kampeska to Elevation 1718 ft NAVD88 + Channel Widening + Levee Left Bank Only (No closure structures)

Centerline RAS computed transport capacity for the eight AEP events is shown in Figure 5-6. The centerline computed peak water surface elevation and velocity is shown in Figure 5-7.

The geometric changes to the model are the same for Alternatives 3 and 8 with only lake elevation changes, so the results are very similar.

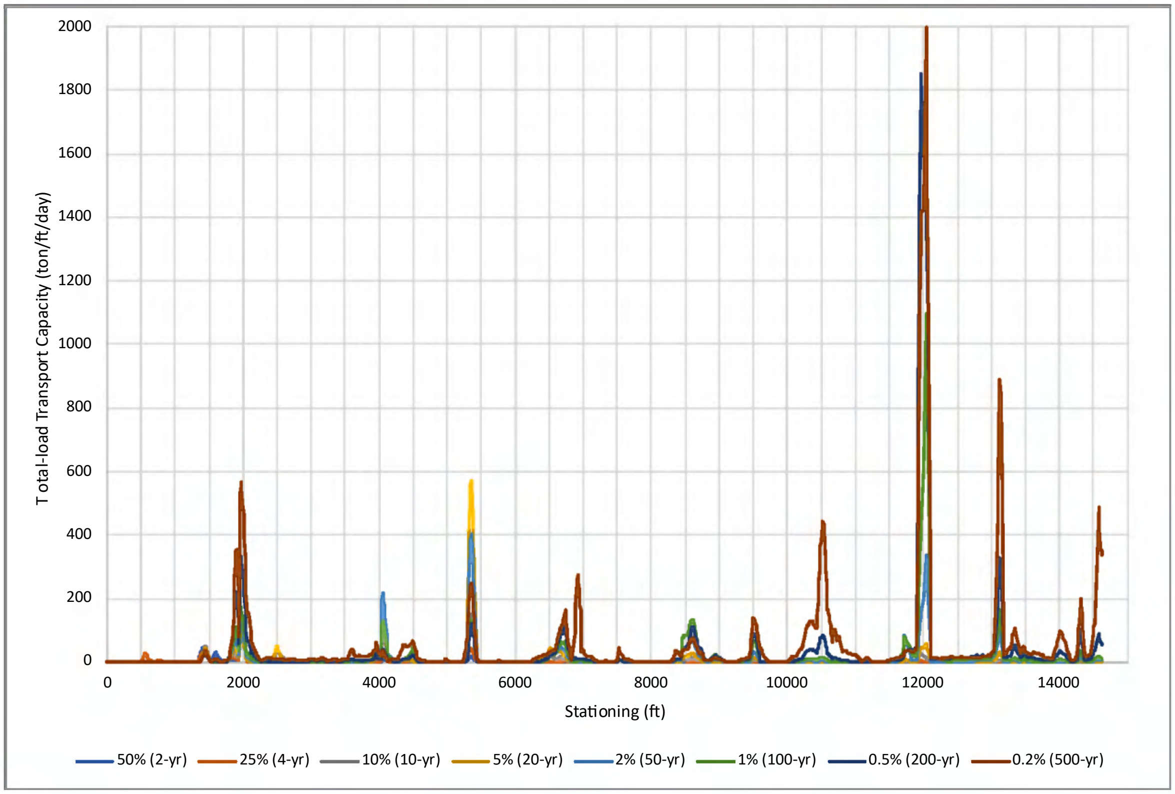


Figure 5-6. Alternative 8 Centerline Transport Capacity

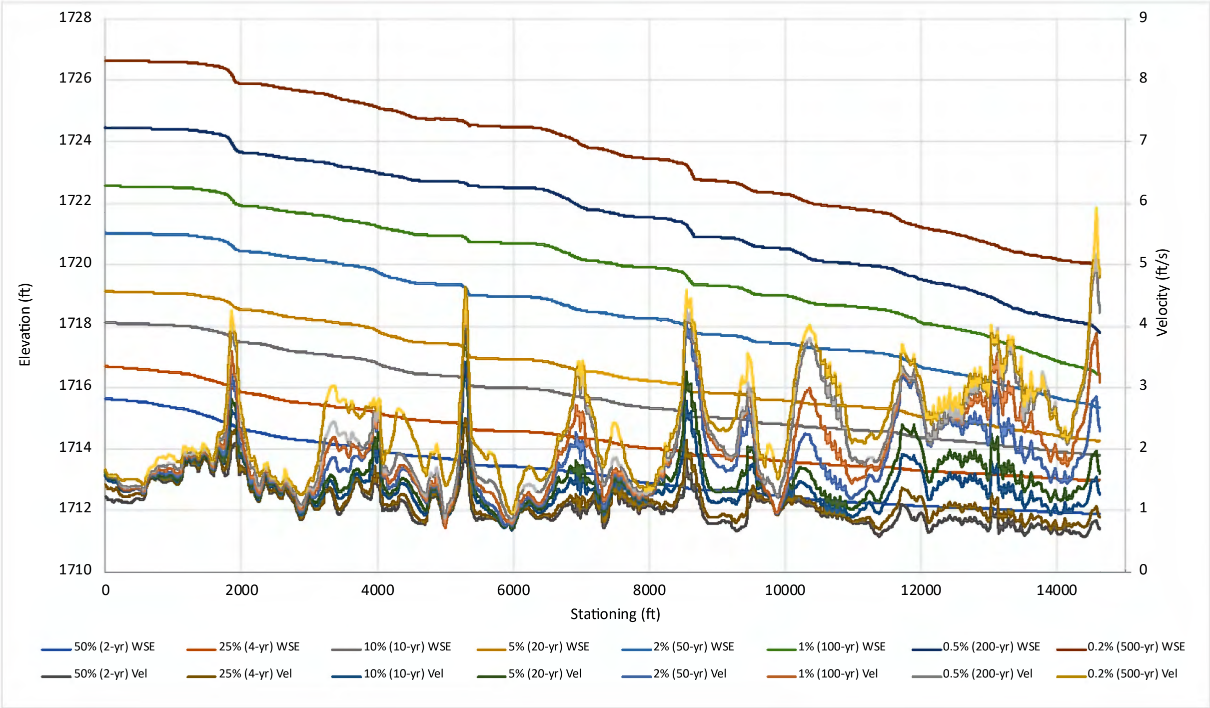


Figure 5-7. Alternative 8 Centerline Water Surface Elevation and Velocity

5.1 Statistical Summary

Statistics (e.g. minimum, maximum, etc.) were determined from analyzing all RAS reported centerline results within the model. For instance, the percentile 10% corresponds to the value for which 10% of the values are less and 90% greater. The percentile statistic was used to better illustrate the variation of transport capacity along the centerline. The transport capacity results are summarized in Table 5-1.

Table 5-1. Transport Capacity (ton/ft/day) Statistical Summary

Statistic	50% (2-yr)	20% (5-yr)	10% (10-yr)	4% (25-yr)	2% (50-yr)	1% (100-yr)	0.5% (200-yr)	0.2% (500-yr)
Alterative 1 – Existing Transport Capacity								
Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Maximum	153.6	58.1	1166.9	613.7	405.0	553.2	684.1	588.6
Average	3.3	3.3	12.9	13.1	15.2	20.3	28.9	39.7
Percent Rank 10%	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.2
Percent Rank 20%	0.0	0.1	0.1	0.1	0.1	0.1	0.2	1.9
Percent Rank 50%	0.2	0.5	0.9	1.6	2.8	3.5	4.7	12.2
Percent Rank 80%	2.5	3.9	7.7	9.6	14.1	20.1	30.1	43.9
Percent Rank 90%	5.2	10.1	18.4	25.4	38.2	46.4	80.8	111.0
Alterative 3 Transport Capacity								
Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Maximum	152.4	111.5	219.1	640.5	489.3	1242.8	2259.0	2174.9
Average	2.4	2.5	5.5	10.0	12.5	16.6	29.1	45.2
Percent Rank 10%	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3
Percent Rank 20%	0.0	0.0	0.1	0.1	0.1	0.1	0.2	1.3
Percent Rank 50%	0.1	0.2	0.3	0.6	1.0	2.1	4.1	11.7
Percent Rank 80%	0.6	1.9	3.4	5.4	8.1	13.9	20.9	41.1
Percent Rank 90%	4.0	5.7	11.4	20.3	32.2	36.0	48.2	98.1
Alterative 8 Transport Capacity								
Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Maximum	156.6	111.8	150.8	570.8	403.6	1096.9	1853.2	1997.2
Average	2.2	2.5	4.4	9.2	11.5	14.9	25.6	43.5
Percent Rank 10%	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2
Percent Rank 20%	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.9
Percent Rank 50%	0.1	0.1	0.3	0.5	1.0	1.7	3.4	10.1
Percent Rank 80%	0.6	1.7	2.9	5.2	7.1	11.9	19.4	38.2
Percent Rank 90%	3.8	5.8	10.1	18.6	29.1	36.5	42.1	96.6

5.2 Capacity Percent of Alternative 1

The sediment transport capacity percent of Alternative 1 was calculated for Alternative 2 and 6. The calculation was (Alt 3 or Alt 8/Alt 1), such that a value less than 100% means that the alternative transport capacity is lower than existing, with a higher risk of deposition. Results are provided in Table 5-2.

Table 5-2. Transport Capacity As A Percent of Alternative 1

Statistic[1]	50% (2-yr)	25% (4-yr)	10% (10-yr)	5% (20-yr)	2% (50-yr)	1% (100-yr)	0.5% (200-yr)	0.2% (500-yr)
Alterative 3 Transport Capacity								
Minimum								73%
Maximum	99%	192%	19%	104%	121%	225%	330%	369%
Average	73%	77%	42%	76%	82%	82%	101%	114%
Percent Rank 10%	17%	21%	158%	153%	141%	113%	123%	116%
Percent Rank 20%	33%	27%	83%	116%	99%	88%	68%	70%
Percent Rank 50%	52%	31%	33%	38%	35%	59%	86%	96%
Percent Rank 80%	25%	49%	44%	57%	57%	69%	70%	94%
Percent Rank 90%	76%	57%	62%	80%	84%	78%	60%	88%
Alterative 8 Transport Capacity								
Minimum								63%
Maximum	102%	192%	13%	93%	100%	198%	271%	339%
Average	68%	74%	34%	70%	76%	73%	88%	110%
Percent Rank 10%	17%	18%	156%	153%	142%	104%	106%	96%
Percent Rank 20%	30%	24%	78%	114%	105%	84%	60%	50%
Percent Rank 50%	48%	27%	30%	33%	34%	49%	72%	83%
Percent Rank 80%	23%	44%	38%	55%	51%	59%	64%	87%
Percent Rank 90%	73%	58%	55%	73%	76%	79%	52%	87%
1 – Percent of Alt 1 for each statistic computed as (Alt 3 or Alt 8)/ Alt 1 values in Table 5-1, such that a number below 100% is less transport capacity than existing (higher risk of deposition).								

A bar chart illustrating the percent of Alternative 1 for each percentile is shown in Figure 5-8.

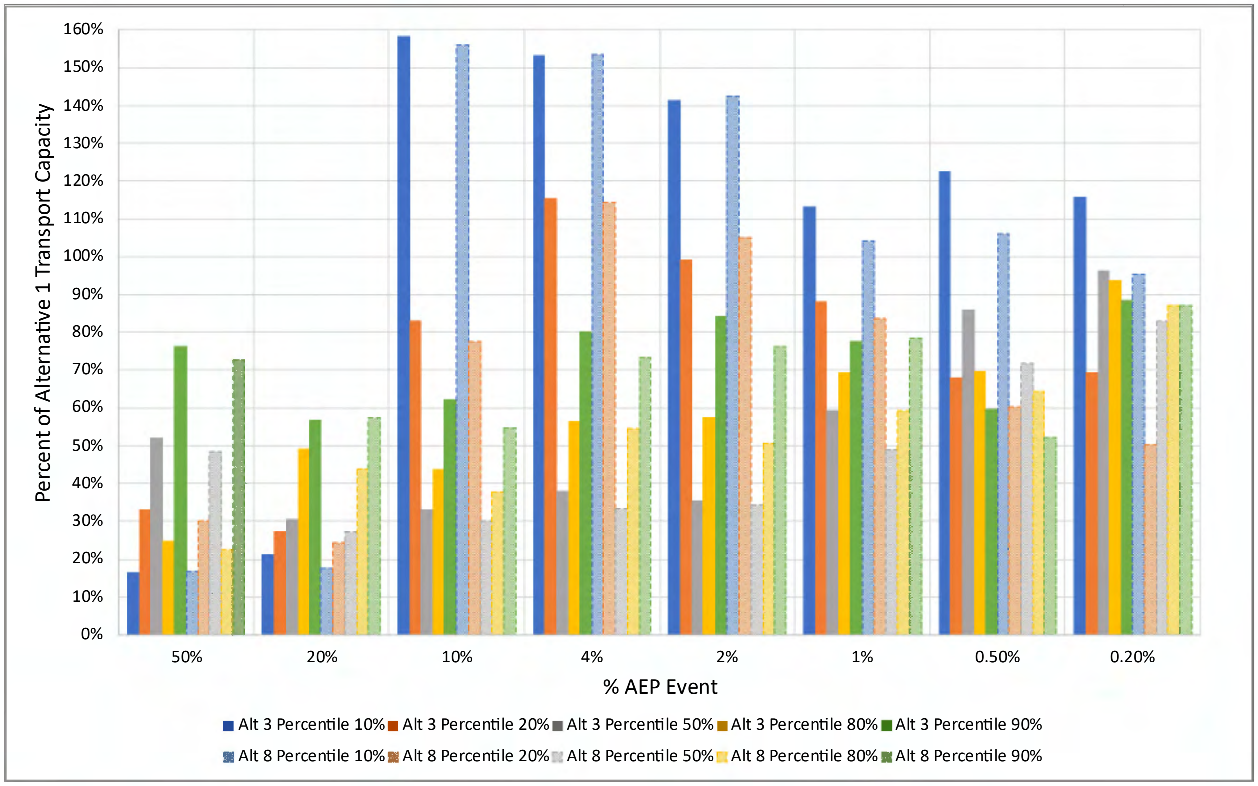


Figure 5-8. Transport Capacity Change by Percentile from Existing

6.0 STABILITY ANALYSIS

A stability analysis was performed to evaluate the existing condition channel. To define a stable channel configuration, the following two methods were applied: (1) hydraulic geometry relationships, and (2) shear stress method. The hydraulic geometry and shear stress methods are quantitative methods used to evaluate channel stability.

6.1 Hydraulic Geometry Method (Width-Discharge)

The hydraulic geometry method is an empirical design approach, based on the premise that natural streams and rivers tend to “develop in a predictable way, producing an approximate equilibrium between the channel and the inflowing water and sediment” (Leopold and Maddock, 1953 in Copeland et al., 2001, page 55). Hydraulic geometry relationships relate bankfull channel dimensions such as width, depth, and slope to discharge or watershed drainage area, and serve as useful tools for the preliminary selection of stable channel dimensions and planform parameters.

Hydraulic geometry relationships that express average bankfull width as a function of bankfull discharge are typically used to determine channel width in restoration design. References included Copeland et al (2001), Soar and Thorne (2001), USACE (1994), and Hey and Thorne (1986).

Hydraulic geometry relationships for width versus discharge are most applicable when developed from data collected from regions with similar physiographic characteristics. Hydraulic geometry equations that express average bankfull width as a function of bankfull discharge are typically used to determine channel width in restoration design.

The general hydraulic geometry width predictor equation is as follows:

$$W = aQ^b \quad \text{(eq. 6-1)}$$

where:

W = bankfull channel top width, (ft)

Q = bankfull discharge, assumed 50% AEP (910 cfs)

a = discharge coefficient

b = discharge exponent

The hydraulic geometry width predictors (i.e. coefficient "a" and exponent "b") are presented in Table 6-1 for stable, gravel-bed streams in North America (Copeland et al., 2001). Copeland et al. (2001, page 79) found that the exponent value could be fixed at 0.50 without compromising statistical significance. The range of discharge coefficients for Copeland et al (2001, page 79) is for the 95% mean response limit as shown in Figure 6-1. The width from USACE (1994) was selected as shown in Figure 6-2 and Table 6-1. Table 6-1 also includes a range of widths measured from the RAS model. The width varied widely throughout the model at the 50% AEP (2-yr) flow from a minimum of approximately 55 ft all the way to a maximum of approximately 400 ft. The bankfull width for most of the model seems to be below the 50% AEP flow, however this was the lowest flow modeled and available for comparison. All values are for the existing condition.

EM 1110-2-1418 has been rescinded due to the publication of EM 1110-2-4000. It was assumed that pertinent information from EM 1110-2-1418 was included in EM 1110-2-4000, however, the figure and accompanying discussion that is the basis for the information in Table 6-1 was not transferred. This information on stable channel top widths is still considered valid, valuable, and applicable to this analysis and can only be found in the above-mentioned Engineer Manual.

Table 6-1. Average Bankfull Width

Source	Description	*a*	*b*	r^2	Computed Width[1] (ft)
Copeland et al. (2001, pg 79)	North America, gravel bed	1.90 to 2.18	0.5	0.8	57 to 66
USACE (1994, pg 5-8)	Curve 2 (Figure 6-2)	2.10	0.5	NA	63
Estimated Range of Widths from the RAS Model					55 to 400

1 - Values based on bankfull discharge of the 50% AEP (2-yr) flow of 910 cfs.

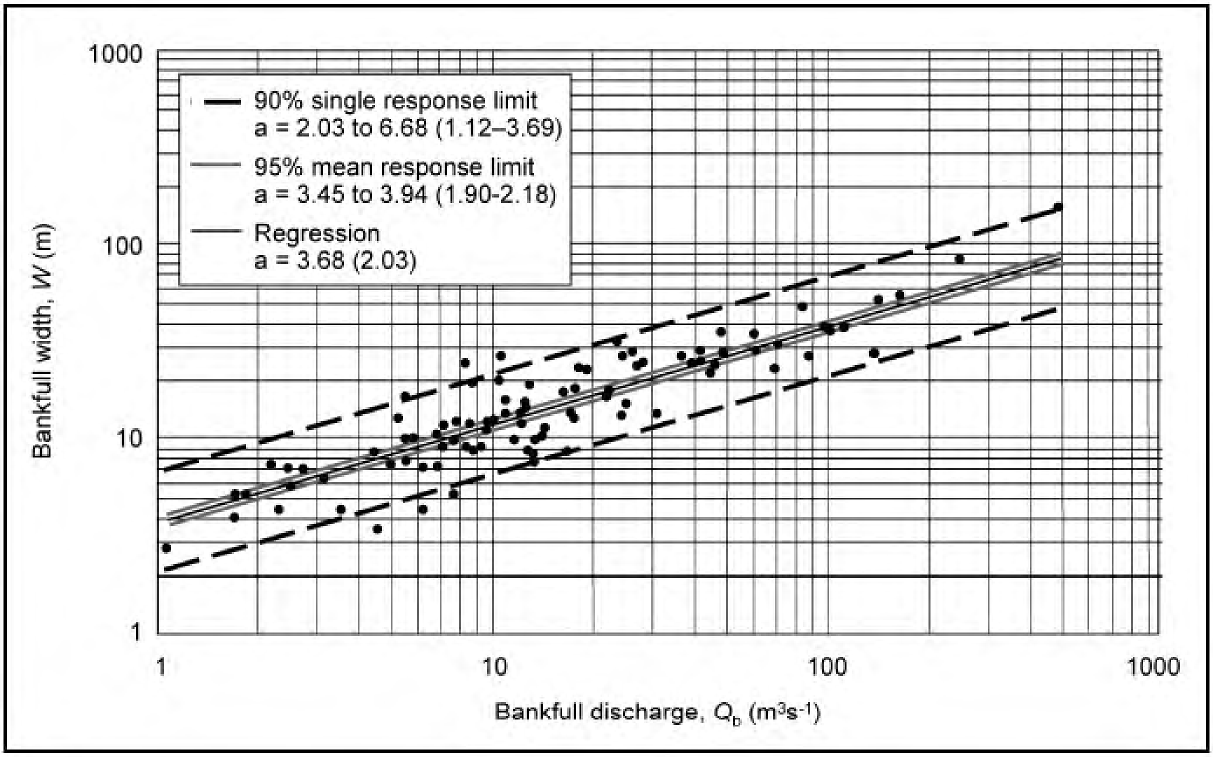
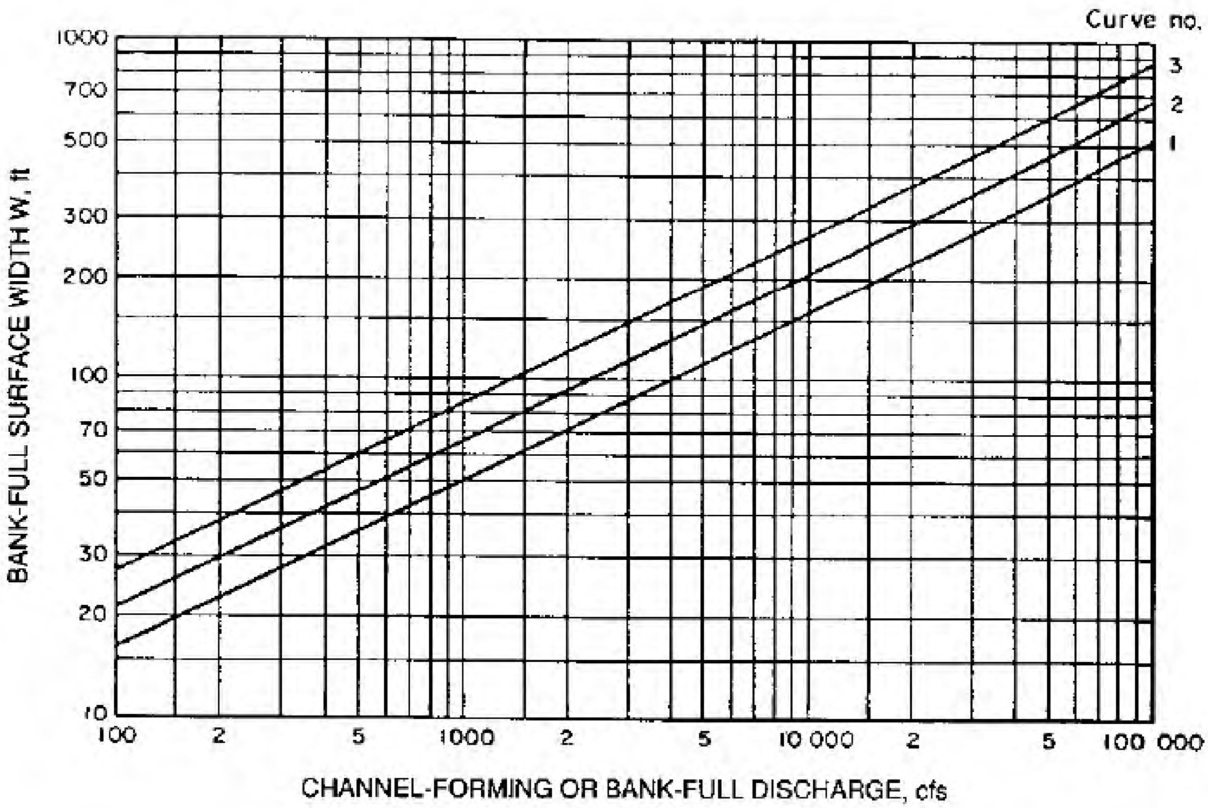


Figure 6-1. Width-Discharge Relationships with Confidence Bands (TR 1-28, Figure 40)



TENTATIVE GUIDANCE: CURVE 1: STIFF COHESIVE OR VERY COARSE GRANULAR BANKS.
CURVE 2: AVERAGE COHESIVE OR COARSE GRANULAR BANKS.
CURVE 3: SANDY ALLUVIAL BANKS.

SEE PARAGRAPH 5-5 FOR LIMITATIONS.

FORMULA: $W = C Q^{0.5}$ WITH C = 1.6, 2.1, 2.7

Figure 6-2. Tentative Guide to Width-Discharge Relationships for Erodible Channels (USACE, 1994, Fig 5-9)

6.2 Planform Geometry (Meander Wavelength)

Relationships for meander wavelength based upon bankfull width were developed by Soar and Thorne (2001, page 307). A composite relationship was derived from nine data sets consisting of 438 sites.

Meander wavelength is given by:

$L_m = F^* a^* W_{bf}$ (eq 6-2)

where:

L_m = meander wavelength (ft)

F^* = correction factor to account for bias = 1.158

a^* = coefficient in the fixed exponent model = 10.23

W_{bf} = bankfull width (ft)

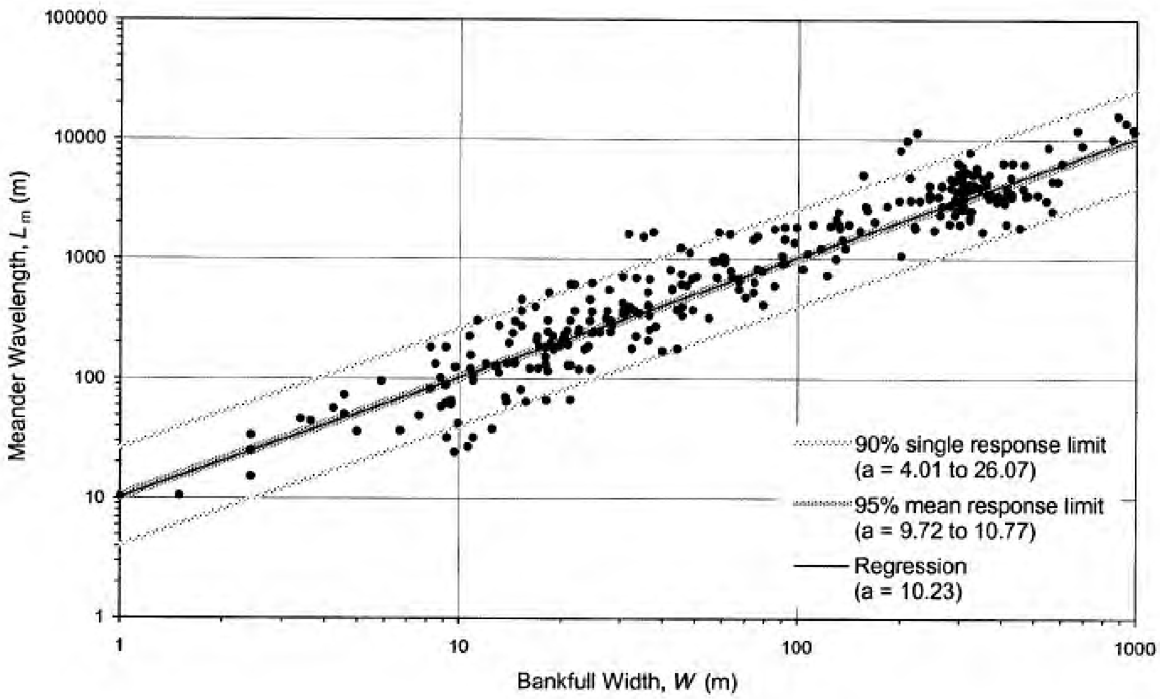


Figure 6-3. Bankfull Width vs Meander Wavelength (ERDC/CHL CR-01-1, Fig 7.2, pg 305)

A plot of the data used to create the meander wavelength equation is shown in Figure 6-3 which demonstrates the large range of appropriate values. Meander wavelengths based on the bankfull widths previously calculated in Table 6-1 range from approximately 650 ft to 4750 ft.

6.3 Allowable Velocity

The allowable or permissible velocity approach can be used for channel lining with natural or manufactured materials. The average channel velocity is calculated for the proposed channel and compared to published allowable velocities for the channel lining material. Computed velocity within a nearby reference reach can be used if applicable.

Allowable velocities have been determined for a large variety of materials and are provided in many texts and manuals. However, these tables have primarily been applied to the design of irrigation and drainage canals and were developed from data in relatively straight, uniform channels with depths less than 3 feet. Allowable velocities can be increased or decreased to account for such irregularities as meandering alignments and increased sediment concentrations, using applicable charts. Allowable velocities are somewhat less than critical velocities so that a factor of safety is generally included in presented values.

6.3.1 Allowable Velocity Estimated Range

Allowable velocities from the Natural Resources Conservation Service (NRCS) that are presented in the National Engineering Handbook (NRCS 2007) are provided in Table 6-2, Figure 6-4, and Figure 6-5.

Table 6-2. Allowable Velocity for Various Materials (NRCS 2007, Table 8-3)

Table 8–3 Maximum permissible canal velocities

	Mean velocity, for straight canals of small slope, after aging with flow depths less than 3 ft (0.9 m)					
	Clear water, no detritus		Water transporting colloidal silts		Water transporting noncolloidal silts, sands, gravels, or rock fragments	
Original material excavated for canals	ft/s	m/s	ft/s	m/s	ft/s	m/s
Fine sand (noncolloidal)	1.5	0.46	2.5	0.76	1.5	0.46
Sandy loam (noncolloidal)	1.75	0.53	2.5	0.76	2.0	0.61
Silt loam (noncolloidal)	2.0	0.61	3.0	0.91	2.0	0.61
Alluvial silt (noncolloidal)	2.0	0.61	3.5	1.07	2.0	0.61
Ordinary firm loam	2.5	0.76	3.5	1.07	2.25	0.69
Volcanic ash	2.5	0.76	3.5	1.07	2.0	0.61
Stiff clay (very colloidal)	3.75	1.14	5.0	1.52	3.0	0.91
Alluvial silt (colloidal)	3.75	1.14	5.0	1.52	3.0	0.91
Shales and hardpans	6.0	1.83	6.0	1.83	5.0	1.52
Fine gravel	2.5	0.76	5.0	1.52	3.75	1.14
Graded, loam to cobbles (when noncolloidal)	3.75	1.14	5.0	1.52	5.0	1.52
Graded silt to cobbles (when colloidal)	4.0	1.22	5.5	1.68	5.0	1.52
Coarse gravel (noncolloidal)	4.0	1.22	6.0	1.83	6.5	1.98
Cobbles and shingles	5.0	1.52	5.5	1.68	6.5	1.98

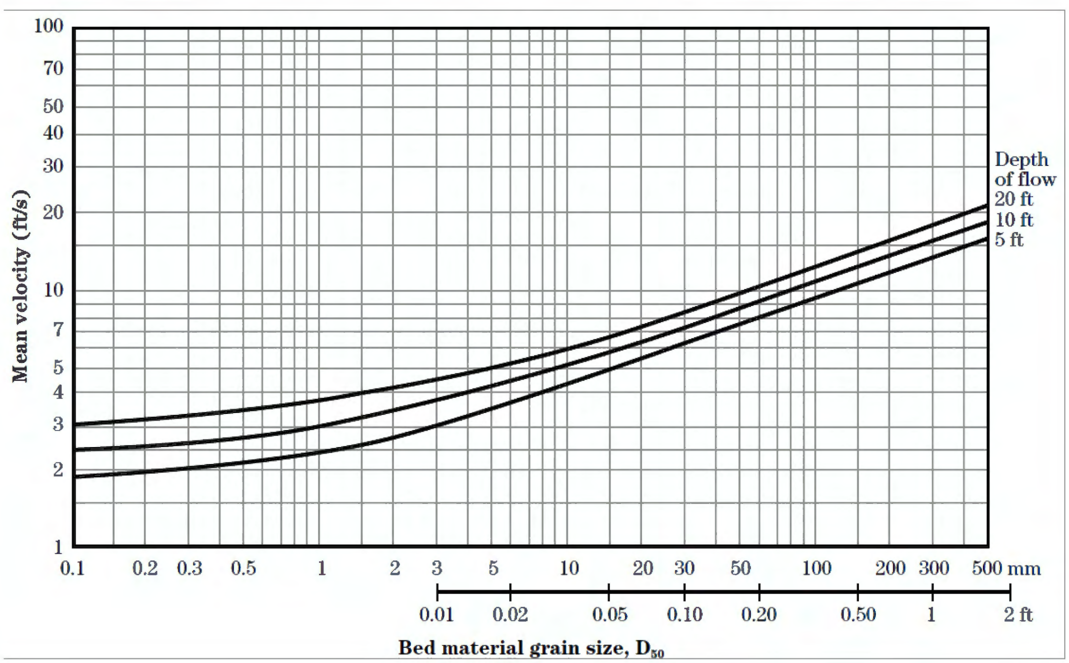
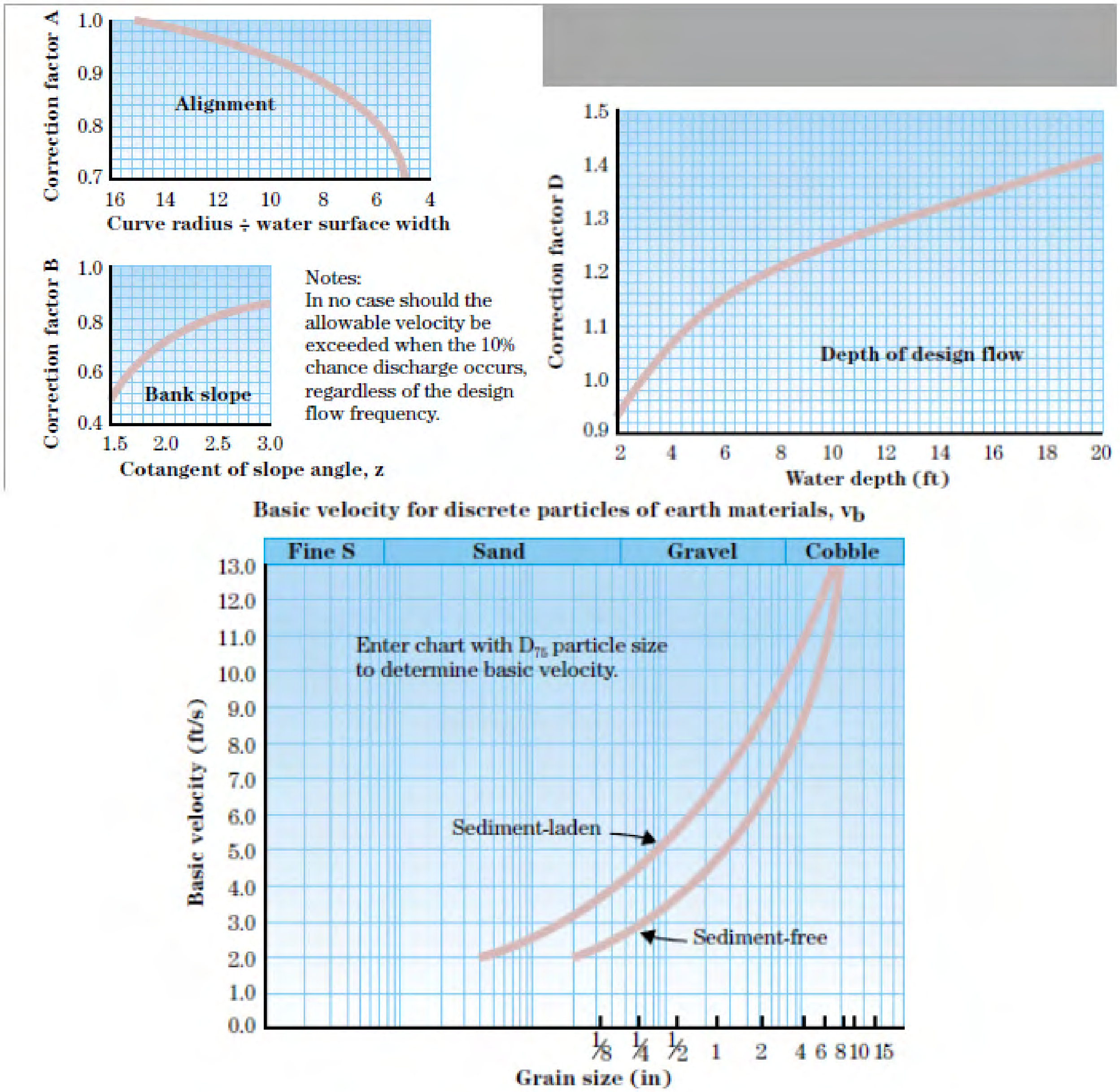


Figure 6-4. Allowable Velocity Grain Chart (NRCS 2007, Figure 8-3)



Allowable velocities for unprotected earth channels	
Channel boundary materials	Allowable velocity
Discrete particles	
Sediment-laden flow	
D_{75} >0.4mm	Basic velocity chart value x D x A x B
D_{75} <0.4mm	2.0 ft/s
Sediment-free flow	
D_{75} >0.2mm	Basic velocity chart value x D x A x B
D_{75} <0.2mm	2.0 ft/s
Coherent earth materials	
PI >10	Basic velocity chart value x D x A x F x C_e
PI <10	2.0 ft/s

Figure 6-5. USDA-SCS Method for Allowable Velocity (NRCS 2007, Figure 8-4)

The allowable velocity was determined for the D_{50} bed material size on the Big Sioux River of 2.5 mm. Estimated range:

- 3.75 ft/sec (Table 6-2)
- 2.5 to 4.5 ft/sec (Figure 6-4)
- 3 to 5 ft/sec (Figure 6-5)

6.3.2 Computed Velocity

Like the sediment transport capacity, the RAS model computed velocities were extracted along the channel centerline for the alternatives. Model results are shown in Figure 6-6.

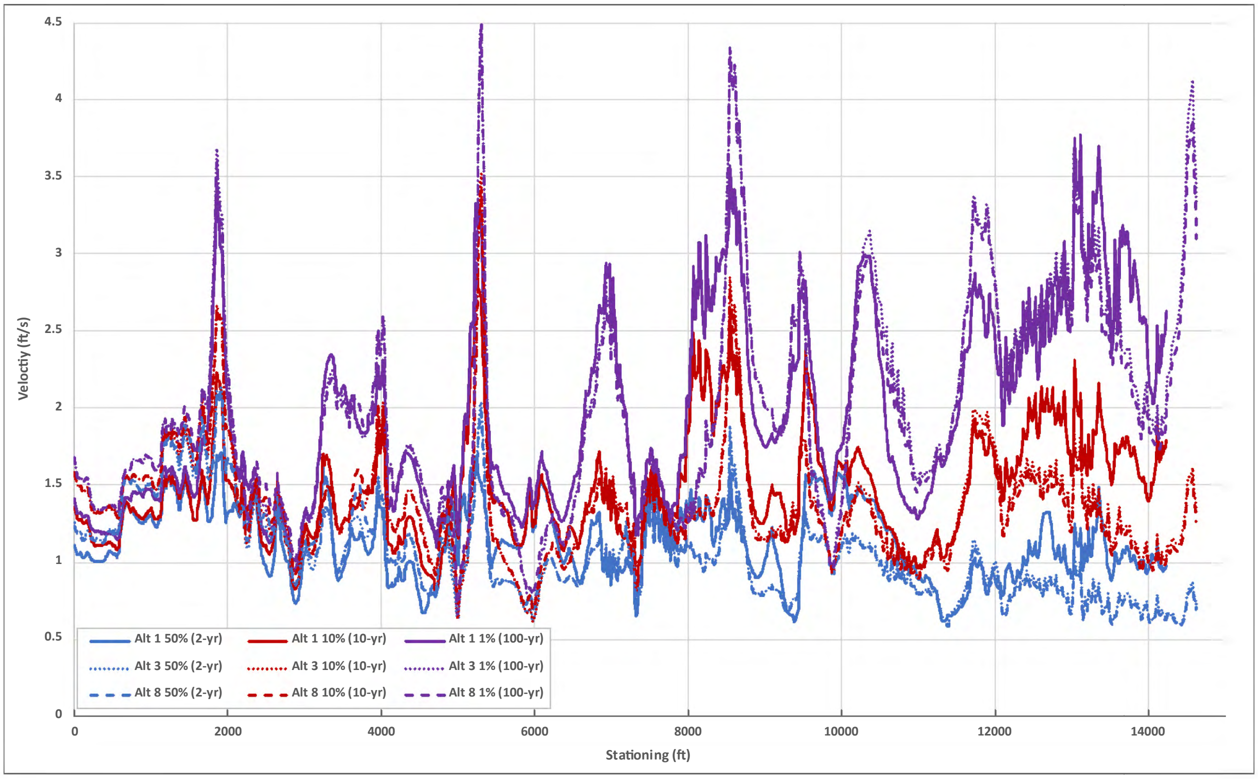


Figure 6-6. Computed Velocity

6.3.3 Allowable Velocity Summary

Velocity computation results are summarized as follows:

- Values taken from the RAS model are generally in the range of recommended values.
- Alternative 1, 3, and 8 velocity range of 1 to 3 ft/s for the 50% AEP (2-year) and 10% AEP (10-year) events. Reasonable performance of the channel is predicted for this range of event magnitude.
- Alternative 1, 3, and 8 velocity range of 1 to 4 ft/s for the 1% AEP (100-year) events.

6.4 Shear Stress

The 2D RAS model computed channel shear stress was used to compare stability of the alternatives. The shear stress terms used in this section are defined below:

- Computed shear stress – Shear stress calculated based on the hydraulic characteristics of the stream for a particular peak discharge (e.g., the bankfull discharge). Types of computed shear stress include average boundary shear stress, maximum bed shear stress, average bank shear stress, and the maximum shear stress in a bend.

- Permissible shear stress – Average shear stress that the bed or bank can withstand before a significant amount of material begins to move or erode. Permissible shear stress is a function of the bed/bank material size, the presence of cohesive soils, and bank slope and vegetation.

6.4.1 Permissible Shear Stress

Table 6-3 (Fischenich 2001) lists recommended values of permissible shear stress and velocity over a wide array of bed material types. The values presented in Table 6-3 relate to average values of shear stress or velocity. Velocity and shear stress are neither uniform nor steady in natural channels. Short term pulses in the flow can give rise to instantaneous velocities or stresses of two to three times the average; thus, erosion may occur at stresses much lower than predicted. Because limits presented in the table were developed empirically, they implicitly include some off this variability. However, natural channels typically exhibit much more variability than the flumes from which these data were developed. The table also provides insights into the sorts of stabilization measures which may be appropriate should they be integrated into any of the alternatives.

The D_{50} bed material size on the Big Sioux River is 2.5 mm, movement of bed material may be expected to occur at shear stress values of 0.75 lb/sq ft or velocities above 2.5 ft/sec.

Table 6-3. Permissible Shear and Velocity for Selected Lining Materials (Fischenich, 2001).

Boundary Category	Boundary Type	Permissible Shear Stress (lb/sq ft)	Permissible Velocity (ft/sec)	Citation(s)
Soils	Fine colloidal sand	0.02 - 0.03	1.5	A
	Sandy loam (noncolloidal)	0.03 - 0.04	1.75	A
	Alluvial silt (noncolloidal)	0.045 - 0.05	2	A
	Silty loam (noncolloidal)	0.045 - 0.05	1.75 – 2.25	A
	Firm loam	0.075	2.5	A
	Fine gravels	0.075	2.5	A
	Stiff clay	0.26	3 – 4.5	A, F
	Alluvial silt (colloidal)	0.26	3.75	A
	Graded loam to cobbles	0.38	3.75	A
	Graded silts to cobbles	0.43	4	A
	Shales and hardpan	0.67	6	A
Gravel/Cobble	1-in.	0.33	2.5 – 5	A
	2-in.	0.67	3 – 6	A
	6-in.	2.0	4 – 7.5	A
	12-in.	4.0	5.5 – 12	A
Vegetation	Class A turf	3.7	6 – 8	E, N
	Class B turf	2.1	4 - 7	E, N
	Class C turf	1.0	3.5	E, N
	Long native grasses	1.2 – 1.7	4 – 6	G, H, L, N
	Short native and bunch grass	0.7 - 0.95	3 – 4	G, H, L, N
	Reed plantings	0.1-0.6	N/A	E, N
	Hardwood tree plantings	0.41-2.5	N/A	E, N
Temporary Degradable RECPs	Jute net	0.45	1 – 2.5	E, H, M
	Straw with net	1.5 – 1.65	1 – 3	E, H, M
	Coconut fiber with net	2.25	3 – 4	E, M
	Fiberglass roving	2.00	2.5 – 7	E, H, M
Non-Degradable RECPs	Unvegetated	3.00	5 – 7	E, G, M
	Partially established	4.0-6.0	7.5 – 15	E, G, M
	Fully vegetated	8.00	8 – 21	F, L, M
Riprap	6 – in. d_{50}	2.5	5 – 10	H
	9 – in. d_{50}	3.8	7 – 11	H
	12 – in. d_{50}	5.1	10 – 13	H
	18 – in. d_{50}	7.6	12 – 16	H
	24 – in. d_{50}	10.1	14 – 18	E
Soil Bioengineering	Wattles	0.2 – 1.0	3	C, I, J, N
	Reed fascine	0.6-1.25	5	E
	Coir roll	3 - 5	8	E, M, N
	Vegetated coir mat	4 - 8	9.5	E, M, N
	Live brush mattress (initial)	0.4 – 4.1	4	B, E, I
	Live brush mattress (grown)	3.90-8.2	12	B, C, E, I, N
	Brush layering (initial/grown)	0.4 – 6.25	12	E, I, N
	Live fascine	1.25-3.10	6 – 8	C, E, I, J
	Live willow stakes	2.10-3.10	3 – 10	E, N, O
Hard Surfacing	Gabions	10	14 – 19	D
	Concrete	12.5	>18	H

[1] Ranges of values generally reflect multiple sources of data or different testing conditions.

A. Chang, H.H. (1988).
B. Florineth. (1982)
C. Gerstgraser, C. (1998).
D. Goff, K. (1999).
E. Gray, D.H., and Sotir, R.B. (1996).
F. Julien, P.Y. (1995).
G. Kouwen, N.; Li, R. M.; and Simons, D.B., (1980).
H. Norman, J. N. (1975).
I. Schiechtl, H. M. and R. Stern. (1996).
J. Schoklitsch, A. (1937).
K. Sprague, C.J. (1999).
L. Temple, D.M. (1980).
M. TXDOT (1999)
N. Data from Author (2001)
O. USACE (1997).

6.4.2 Computed Shear Stress

Shear stress values based on the RAS model results are provided in Figure 6-7.

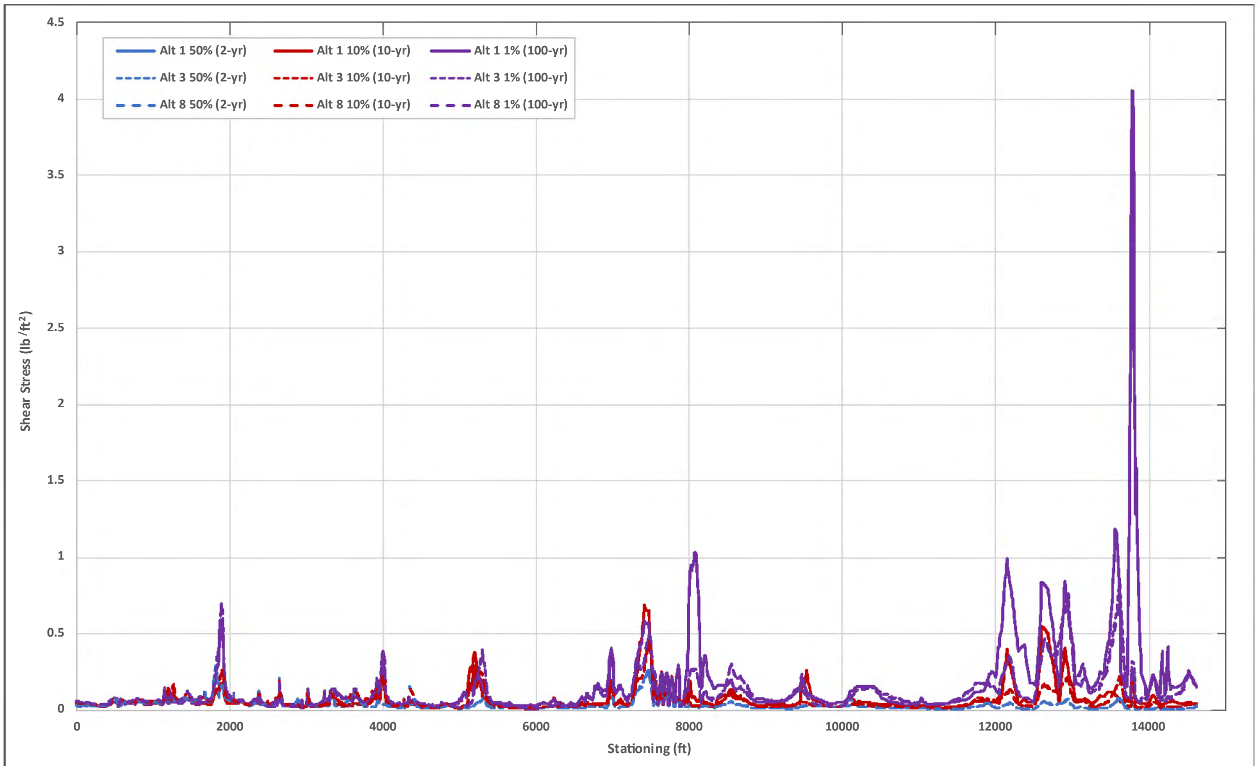


Figure 6-7. Computed Shear Stress

6.4.3 Shear Stress Summary

Shear stress computation results are summarized as follows:

- Values taken from the RAS model are generally in the range of recommended values.
- Alternative 1 shear stress range of 0 to 0.7 lb/sq ft for the 50% AEP (2-year) and 10% AEP (10-year) events. Alternative 3 and 8, shear stress range of 0 to 0.4 lb/sq ft for the 50% AEP (2-year) and 10% AEP (10-year) events. Reasonable performance of the channel is predicted for this range of event magnitude.
- Alternative 1 shear stress range of 0 to 4 lb/sq ft for the 1% AEP (100-year) event. Alternative 3 and 8, shear stress range of 0 to 0.9 lb/sq ft.

6.5 Stability Analysis Summary

A geomorphic stability analysis was performed to evaluate the existing channel. To define a stable channel configuration, the following two methods were applied: (1) hydraulic geometry relationships, and (2) shear stress method. The hydraulic geometry and shear stress methods are quantitative methods used to evaluate channel stability.

The allowable velocity was determined for the D_{50} bed material size on the Big Sioux River of 2.5 mm (0.1 inches). Estimated range:

- 3.75 ft/sec (Table 6-2)
- 2.5 to 4.5 ft/sec (Figure 6-4)

- 3 to 5 ft/sec (Figure 6-5)

Permissible shear stress:

- The D_{50} bed material size on the Big Sioux River is 2.5 mm (0.1 inches), movement of bed material may be expected to occur at shear stress values of 0.75 lb/sq ft or velocities above 2.5 ft/sec.

7.0 SUMMARY

This report focuses on the sediment modeling efforts to evaluate various considered alternatives. A two-dimensional (2D) unsteady flow hydraulic model was used to compare alternatives to the existing condition and two alternatives were chosen to move forward to evaluate with a sediment transport capacity analysis. Only the no action (Alternative 1), the channel widening and levee left bank only (Alternative 3), and the channel widening, levee left bank only, and lowering Lake Kampeska to Elevation 1718 ft (Alternative 8) were evaluated in the sediment analysis. Refer to the Hydraulic Analysis for further discussion on the hydraulic model and alternatives.

Sediment transport potential provides a qualitative comparison of the change in transport potential that will occur as a result of any modification from the existing condition. Sediment transport capacity was compared using the channel centerline. Results indicate that the reduction in transport capacity for Alternative 3 and 8, relative to the existing, is small with low likelihood of impacts to channel capacity. Additional analysis may be necessary during final design.

A statistical analysis was performed with comparison to existing and is summarized as:

• Alternative 3 has a sediment transport capacity percent of existing of:

o the average of 81% for all events.

o the 20th percentile of 33% for the 50% (2-year) event.

o the 20th percentile of 83% for the 10% (10-year) event.

o the 20th percentile of 88% for the 1% (100-year) event.

• Alternative 8 has a sediment transport capacity percent of existing of:

o the average of 74% for all events.

o the 20th percentile of 30% for the 50% (2-year) event.

o the 20th percentile of 78% for the 10% (10-year) event.

o the 20th percentile of 84% for the 1% (100-year) event.

A geomorphic analysis was performed to evaluate the existing channel. To define a stable channel configuration for each alternative, the following methods were applied: (1) hydraulic geometry relationships and (2) shear stress method. The hydraulic geometry and shear stress methods are quantitative methods used to evaluate channel stability.

The allowable velocity was determined for the D_{50} bed material size on the Big Sioux River of 2.5 mm. Estimated range:

- 3.75 ft/sec (Table 6-2)
- 2.5 to 4.5 ft/sec (Figure 6-4)
- 3 to 5 ft/sec (Figure 6-5)

Calculated velocities for Alternatives 1, 3, and were in the range of 1 to 4 ft/s.

Permissible shear stress:

- The D_{50} bed material size on the Big Sioux River is 2.5 mm, movement of bed material may be expected to occur at shear stress values of 0.75 lb/sq ft or velocities above 2.5 ft/sec.

Calculated shear stress for Alternative 1 were in the range of 0 to 4 lb/sq ft while for Alternatives 3 and 8, the shear stress ranged from 0 to 0.9 lb/sq ft.

8.0 REFERENCES

Copeland, R. R., McComas, D. N., Thorne, C. R., Soar, P. J., Jonas, M. M., and Fripp, J. B. 2001. *Hydraulic Design of Stream Restoration Projects*. Technical Report ERDC/CHL TR-01-28, U.S. Army Corps of Engineers: Engineer Research and Development Center; Vicksburg, MS, September 2001.

Fischenich, C. 2001. *Stability Thresholds for Stream Restoration Materials.* Ecosystem Management and Restoration Research Program (EMRRP) Technical Notes Collection ERDC TN-EMRRP-SR-29. USACE - ERDC. Vicksburg, MS, May 2001.

Hey, R. D., and Thorne, C. R. 1986. *Stable Channels with Mobile Gravel Beds*, Journal of Hydraulic Engineering, American Society of Civil Engineers, Vol 112, No. 8, pp 671-689.

NRCS 2007. *Part 654 Stream Restoration Design, National Engineering Handbook*, Natural Resources Conservation Service, U.S. Department of Agriculture, August 2007.

Soar, P. J. and Thorne, C. R. (2001). *Channel Restoration Design for Meandering Rivers.* ERDC/CHL CR-01-1, U.S. Army Corps of Engineers, Engineer Research and Development Center, Vicksburg, MS, September 2001.

USACE n.d. *HEC-RAS 2D Sediment User Manual*, U.S. Army Corps of Engineers, Hydrologic Engineering Center, https://www.hec.usace.army.mil/confluence/rasdocs/h2sd/ras2dsed/6.7_beta, accessed 19 September 2025.

USACE 2025. HEC-RAS 6.7 [Computer Software]. U.S. Army Corps of Engineers, Hydrologic Engineering Center (HEC), Davis, CA. April 2025.

USACE 2023. *AEP Inflow Hydrographs.* Omaha, NE, U.S. Army Corps of Engineers, Omaha District, Hydrologic Engineering Branch, Hydrology Section, April 2023.

USACE 1994. *Channel Stability Assessment for Flood Control Projects.* Engineer Manual 1110-2-1418. Washington, DC: Headquarters, U.S. Army Corps of Engineers, October 1994.