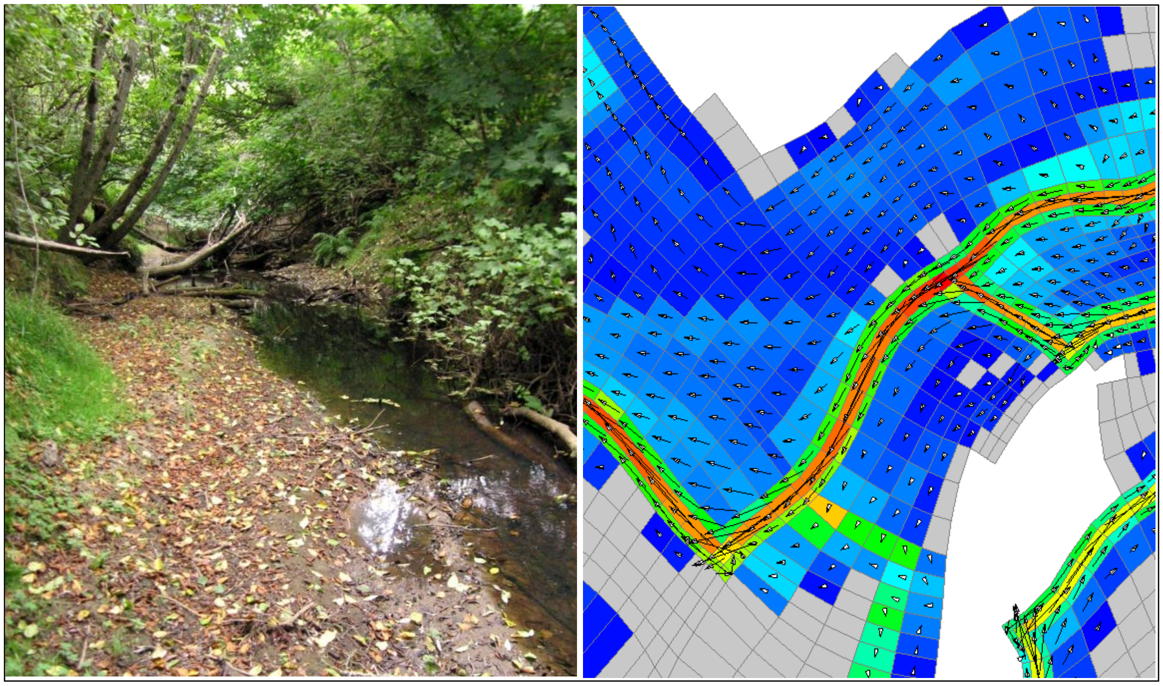
Appendix 3-D

Elk River Hydrodynamic and Sediment Transport Pilot Modeling Report



Elk River Hydrodynamic and Sediment Transport Modeling Pilot Project

Final Report

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1 INTRODUCTION

1.1 Background

The Elk River basin drains westward across the seaward slope of the outer Northern California Coast Range to the coastal plain and into Humboldt Bay, located near the city of Eureka in Humboldt County (Figure 1-1). Elk River is the largest tributary to Humboldt Bay and provides critical habitat for several species of historically abundant anadromous salmonids, including coho salmon (*Oncorhynchus kisutch*), Chinook salmon (*Oncorhynchus tshawytscha*), and steelhead (*Oncorhynchus mykiss*). The basin can be divided into four main areas: (1) North Fork Elk River (58.2 km^2), (2) South Fork (50.4 km^2), (3) the lower Elk River downstream of the North Fork and South Fork confluence (26.9 km^2), and (4) Martin Slough (15.3 km^2). The 19.3 km (12 miles) of mainstem Elk River downstream of the North Fork and South Fork confluence consist of low-gradient, alluvial channel types with dense riparian canopy transitioning to tidally-influenced fresh, brackish, and saline slough channels. These habitats provide summer and winter rearing habitat for young-of-year and juvenile coho salmon and steelhead, promoting high juvenile growth rates and survival (Miller and Sadro 2004).

The mediterranean climate supports a coniferous forest community dominated by redwood (*Sequoia sempervirens*), western hemlock (*Tsuga heterophylla*), Sitka spruce (*Picea sitchensis*), grand fir (*Abies grandis*), and Douglas-fir (*Pseudotsuga menziesii*). Salmonid habitat and water quality conditions in the lower Elk River have been degraded from discharge of waste associated with industrial harvest of these forest species in the upper watershed, domestic and agricultural activities in the middle watershed, and agricultural activities in the lower watershed. Historically extensive tidal marsh areas in lower Elk River have also been diked and converted to pasture, and much of the tidal prism into lower Elk River has been blocked by tide gates.

Geology in the Elk River basin is predominantly comprised of the Franciscan Complex Central Belt, the Yager terrane, and the Wildcat Group (Ogle 1953; McLaughlin et al. 2000, Marshall and Mendes 2005). The dominant geologic unit in the Elk River Basin is the Wildcat Group, a thick sequence of marine siltstone and fine-grained sandstone. The Wildcat Group typically consists of poorly indurated siltstone and fine-grained silty sandstone that weathers to granular, non-cohesive, non-plastic clayey silts and clayey sands. Wildcat Group terrain is characterized by steep and dissected topography sculpted by debris sliding, and is known for historically high erosion rates associated with headwall swales, hollows and inner gorges. Franciscan Complex Central Belt is an accretionary mélange enclosing blocks of more coherent sandstone, greenstone, and chert. Large, deep-seated landslides and earthflows are common in the Central belt Franciscan complex. The Yager terrane is highly folded and sheared argillite and sandstone turbidites with minor pebbly conglomerate. The sandstone facies commonly forms cliff units and exerts local base level control where streams have incised through younger, less resistant overlap deposits. The argillite facies is typically deeply weathered, promoting deep-seated flow failures on moderately steep slopes.

The EPA included Elk River on its 303(d) list of impaired water bodies in 1998 as a result of excessive sedimentation. Accelerated timber harvest rates beginning in 1986, followed by large storm events in 1995–1998, caused voluminous discharge of fine sediment and organic debris that resulted in major channel changes and increased the incidence of routine flooding in the Elk River valley. Sedimentation has reduced channel conveyance in the upper mainstem Elk River by 60% since 1965 (Patenaude 2004).

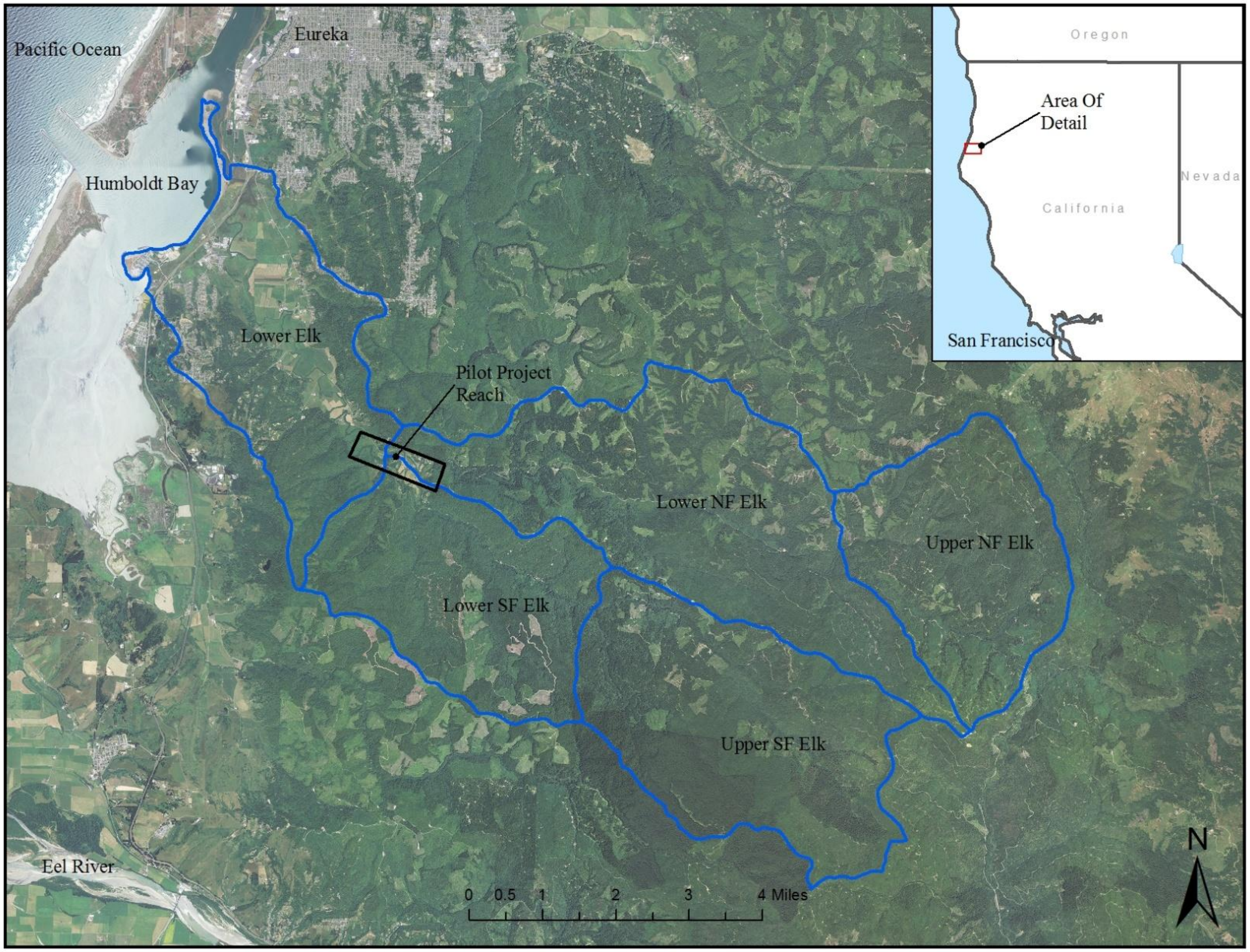


Figure 1-1. Location map of Elk River watershed and pilot project reach.

In addition to increasing the incidence of nuisance flooding, channel aggradation with fine sediment has severely impaired domestic and agricultural water supplies and degraded salmonid habitat by filling pools and burying spawning gravel and large wood. Loss of spawning habitat, channel complexity, rearing habitat, and winter off-channel refugia, combined with excessively high suspended sediment and turbidity, have contributed to listing of Southern Oregon and Northern California Coast (SONCC) coho salmon under State and Federal Endangered Species Acts and listing of Northern California (NC) steelhead under the Federal Endangered Species Act.

Since 1997, the North Coast Regional Water Quality Control Board (RWQCB) has been working with landowners in the upper watershed (e.g., Humboldt Redwood Company [HRC], Bureau of Land Management [BLM], and Green Diamond Resource Company [GDR]) to develop regulatory and non-regulatory programs that prevent new sediment sources and control existing sediment sources. The Elk River Total Maximum Daily Load (TMDL) for Sediment is being established in accordance with Section 303(d) of the Clean Water Act (CWA) to:

1. Identify the major sources of sediment delivery to Elk River and its tributaries,
2. Evaluate the mechanisms that cause sediment impairment in Elk River,
3. Estimate the assimilative capacity of the system by identifying the total loads of sediment that can be delivered to Elk River and its tributaries while still meeting water quality standards, and
4. Develop a strategy to recover Elk River's beneficial uses of water, achieve water quality objectives and abate nuisance conditions.

The TMDL sediment source analysis for Elk River inventoried and described all sources of sediment discharge that are impacting beneficial uses of water in the basin (RWQCB 2011a). The magnitude of the annual average sediment loading was estimated for six analysis periods, including: 1955-1965, 1966-1974, 1975-1987, 1988-1997, 1998-2000, and 2001-2003. The 1988-1997 time period represents the greatest loading over the analysis periods, 1,134 $yd^3/mi^2/yr$, or 1,659% over naturally occurring background (Figure 1-2). Bridge Creek and Lake Creek (tributaries to the North Fork) and Railroad Gulch (tributary to the mains stem Elk River) had the largest cumulative loading during analysis time period (Figure 1-3).

While efforts to control sediment sources from the upper watershed are ongoing, little work has been done to directly restore impaired channel conditions and associated aquatic habitat in the heavily impacted middle reach of Elk River. The middle reach includes the lower North Fork Elk River downstream of approximately the Bridge Creek confluence, Lower South Fork Elk River downstream of approximately the Tom Gulch confluence, and the mainstem Elk River from the confluence of the north and south forks downstream to approximately Elk River Court. Mechanical removal of in-stream sediment deposits was proposed in the middle reach by stakeholders in 1998. Without the information to adequately evaluate the potential effects of mechanical sediment removal, the RWQCB staff considered the approach potentially damaging. In response to RWQCB direction in 2002 and a second petition for dredging of the middle reach from Elk River residents in 2004, Redwood Community Action Agency (RCAA) under contract to the State Board, convened a Technical Advisory Committee (TAC) comprised of experts in fluvial geomorphology and river restoration in July 2008 to guide discussions and identify technical analyses needed to understand the effectiveness and potential environmental consequences of restoration alternatives. The TAC concluded that: (1) a better understanding of aquatic habitat conditions and physical processes is necessary to evaluate the potential effects of sediment reduction measures and other direct actions designed to hasten recovery of beneficial uses of water in the lower Elk River, and (2) development of appropriate and effective measures will require an integrated, system-wide, and scientifically-based planning effort informed by predictive modeling of geomorphic and biological responses to treatment alternatives.

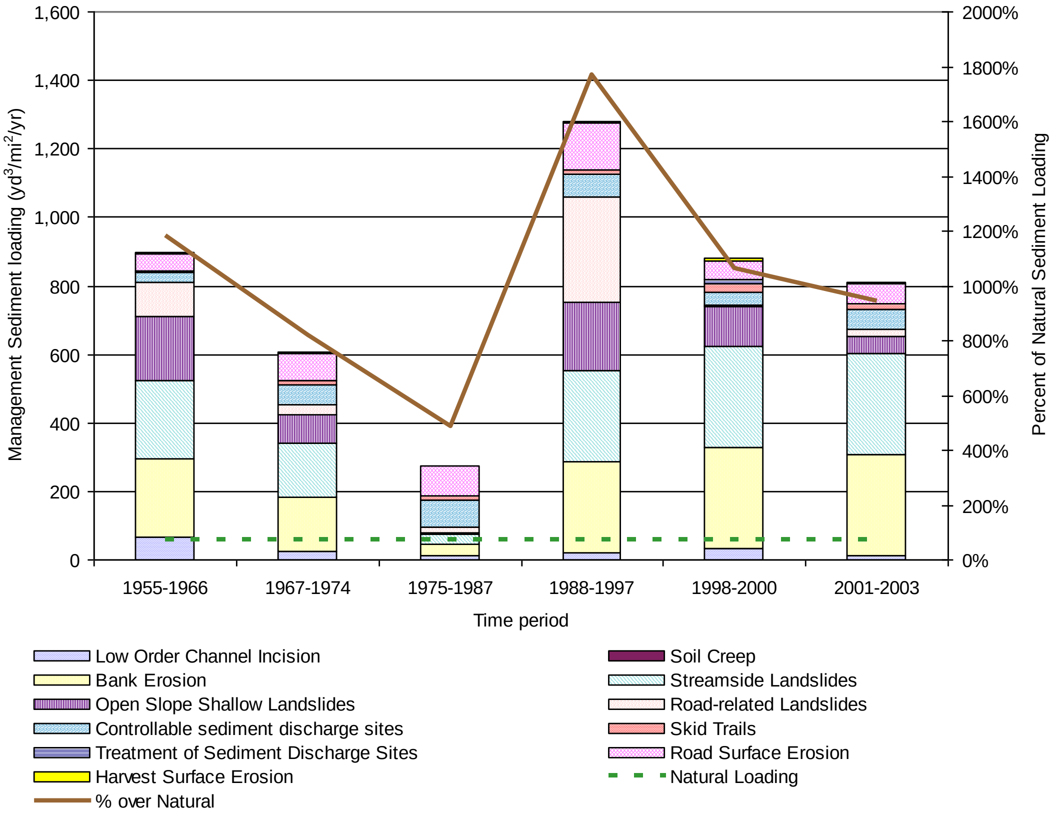


Figure 1-2. Elk River loading by source category for analysis time periods (Figure 3.60 in RWQCB 2011a).

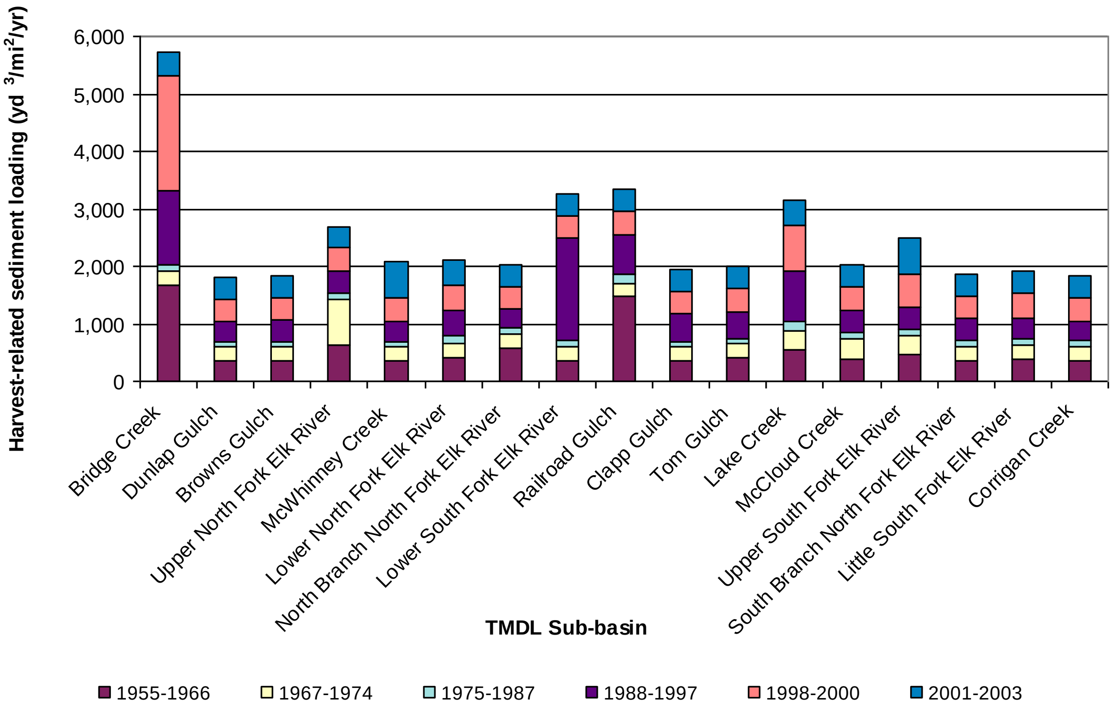


Figure 1-3. Summary of harvest-related sediment loading (yd^3/mi^2/yr) by sub-basin for analysis time periods (Figure 3.62 in RWQCB 2011a).

1.2 Objectives

RCAA, under contract to the State Board, contracted Northern Hydrology and Engineering (NHE) and Stillwater Sciences (SWS) to develop and apply a predictive hydrodynamic and sediment transport model in a pilot reach of the middle Elk River. The pilot reach includes reaches of the North Fork (NF) Elk River, South Fork (SF) Elk River, and mainstem Elk River where detailed monitoring of streamflow, turbidity, suspended sediment load, bed sediment composition, and channel topography (e.g., repeated cross-section surveys) has been conducted since about 2002 (longer for some parameters). The pilot reach includes the NF Elk River from approximately the boundary separating the HRC and Wrigley properties downstream to the confluence with the SF Elk River; the SF Elk River approximately 200 m upstream from the first bridge crossing (located near the Noell property) downstream to the confluence with the NF Elk River; and the mainstem Elk River from the north and south fork confluence to approximately 900 m downstream of the Steel Bridge. The RWQCB anticipates that, once calibrated and validated, the hydrodynamic and sediment transport model may be used as a predictive tool to analyze the potential effects of sediment load reduction, as well as various actions designed to remove in-stream sediment deposits and directly restore channel conditions in the sediment-impaired middle reach of lower Elk River down to Humboldt Bay.

Specific objectives of the pilot study include the following:

- Evaluate existing flow, sediment and cross-section data for use in the hydrodynamic and sediment transport model;
- Describe, sample and analyze the composition of bed, bank and floodplain sediment deposits;
- Generate a topographic surface integrating cross-section and LIDAR data;
- Develop and calibrate a hydrodynamic and sediment transport model;
- Evaluate and compare model predictions to observed conditions (e.g., depositional patterns observed at cross sections, suspended sediment concentrations, bed material grain size); and
- Evaluate the potential effects of reduced sediment loads to the study reach.

2 FIELD AND OBSERVATION DATA USED FOR HYDRODYNAMIC AND SEDIMENT TRANSPORT MODEL CONFIGURATION AND CALIBRATION

Configuration and calibration of a hydrodynamic and sediment transport model requires field and observational data. Data used for model configuration includes topography (e.g., LiDAR) and bathymetry (e.g. cross sections); streamflow or discharge (Q); suspended sediment concentration (SSC); and the physical properties of bed, bank and floodplain sediment deposits (Table 2-1). Calibration data include measurements of model output values for water surface elevation (WSE), velocity (V), SSC, bed elevation and composition. Most of the data outlined in Table 2-1 consist of existing information collected by others and are discussed in later chapters of this report. Data collected as part of this pilot study are discussed below.

Table 2-1. Elk River field and observational data used in HST model configuration and calibration[1]

Data Description	Data Use	Source
LiDAR DEM topography	Project DEM development	RWQCB, SWS
Cross-sections surveys within pilot reach	Project DEM development, measured sediment deposition rates	RWQCB, SFO
Gaging station data (stage, Q, V, rating curves)	Model inflow boundary conditions, model calibration	HRC, SFO, J. Lewis
Elk River WSE	Model calibration	HRC, SFO, RWQCB
TTS stations (turbidity and SSC)	Model SSC boundary conditions, model calibration	HRC, SFO, J. Lewis
Water column sediment sand/fine fraction	Suspended sediment cohesive/non-cohesive class breaks	SFO, J. Lewis
Bed, bank and floodplain sediment bed physical data	Model sediment bed initialization	SWS, NHE, RSL (collected in this study)

1. RWQCB = North Coast Regional Water Quality Control Board; SWS = Stillwater Sciences; SFO = Salmon Forever; NHE = Northern Hydrology & Engineering; HRC = Humboldt Redwood Company; J. Lewis = Jack Lewis; TTS = turbidity threshold sampling

2.1.1 Elk River Pilot Project DEM

A digital elevation model (DEM) for the Elk River pilot project area (Project DEM) was developed by combining an existing LiDAR (Light Detection and Ranging) DEM collected for the RWQCB and cross-sections of the pilot project reach (Figure 2-1) surveyed in 2002 by Graham Matthews & Associates (RWQCB 2011b).

LiDAR data was collected in the Elk River, Freshwater Creek, and Ryan Creek watersheds during March 2005 (Sanborn 2005). A kriging algorithm was used on LiDAR bare earth points (average 2.2 points per m^2) to create a 1-m LiDAR DEM of the Elk River watershed.

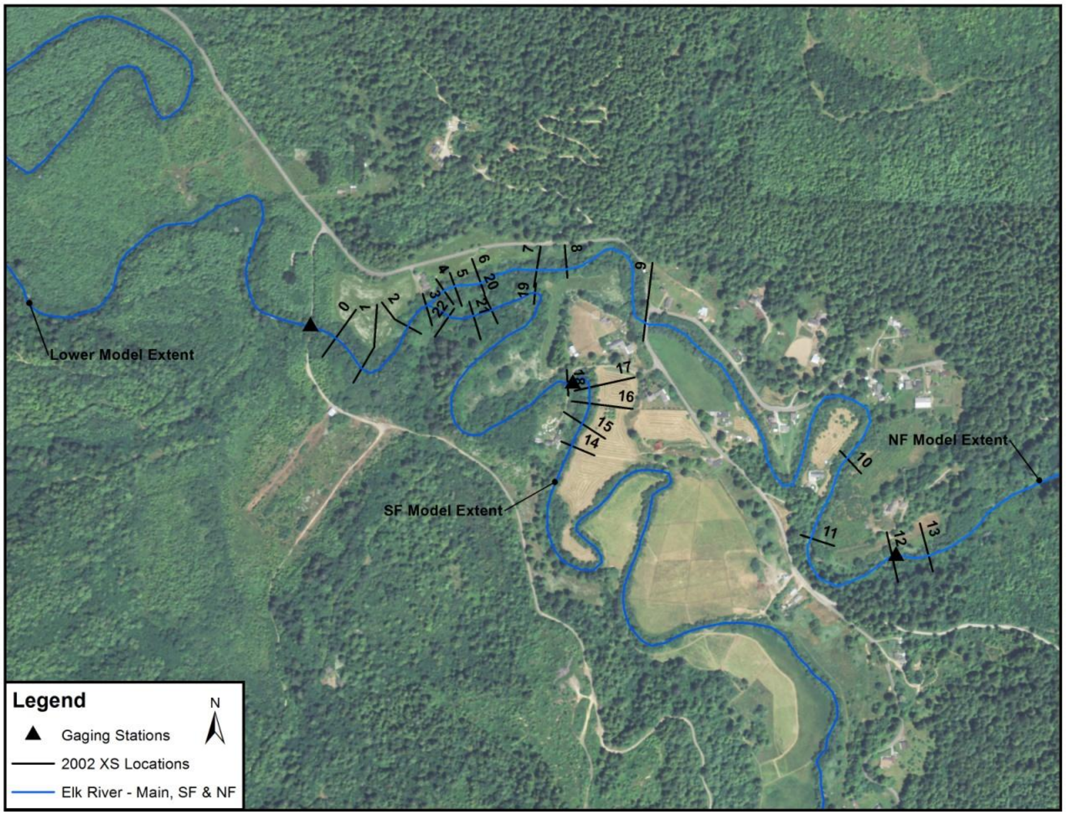


Figure 2-1. Location of cross-sections and gaging stations within the Elk River pilot project reach.

Comparison of the 2002 cross-section data and points extracted from the LiDAR DEM at the same locations indicates that the LiDAR DEM accurately represents bank and floodplain elevations (Figure 2-2 and Figure 2-3). LiDAR cannot penetrate the water surface. Consequently, the LiDAR DEM does not accurately represent bathymetry of the channel bed below the water line. To provide a single Project DEM, the 2002 cross-section data below the water line were burned into the LiDAR DEM. The methodology to integrate the 2002 cross-section data into the LiDAR DEM to form the Project DEM consisted of the following steps in ArcGIS:

1. LiDAR DEM points located within the wetted channel area were clipped and removed.
2. Cross-section points surveyed in 2002 that occur below the water surface were isolated.
3. A series of cross-sections, located between cross-sections surveyed in 2002, were interpolated through the pilot project reach along the channel centerline.
4. A surface representing the area below the water line was created using the surveyed and interpolated cross-section data and then clipped to the same water surface area as in (1).
5. The new surface representing the area below the water line was added to the LiDAR DEM and then re-sampled to form the 1-m Project DEM.

Figure 2-4 and Figure 2-5 show two cross-sections surveyed in 2002 compared to points extracted from the Project DEM at the same cross-section locations. The Project DEM is used to represent bed, bank and floodplain conditions that existed at the start of Water Year (WY) 2003.

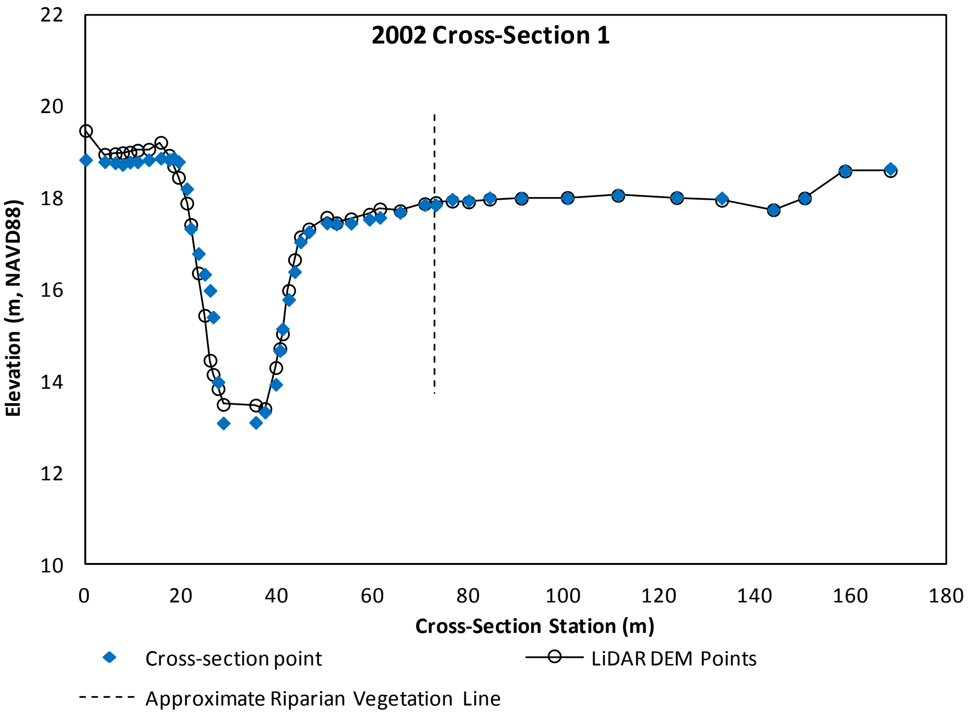


Figure 2-2. Comparison of points surveyed at cross-section 1 in 2002 with points extracted from the LiDAR DEM at the same locations.

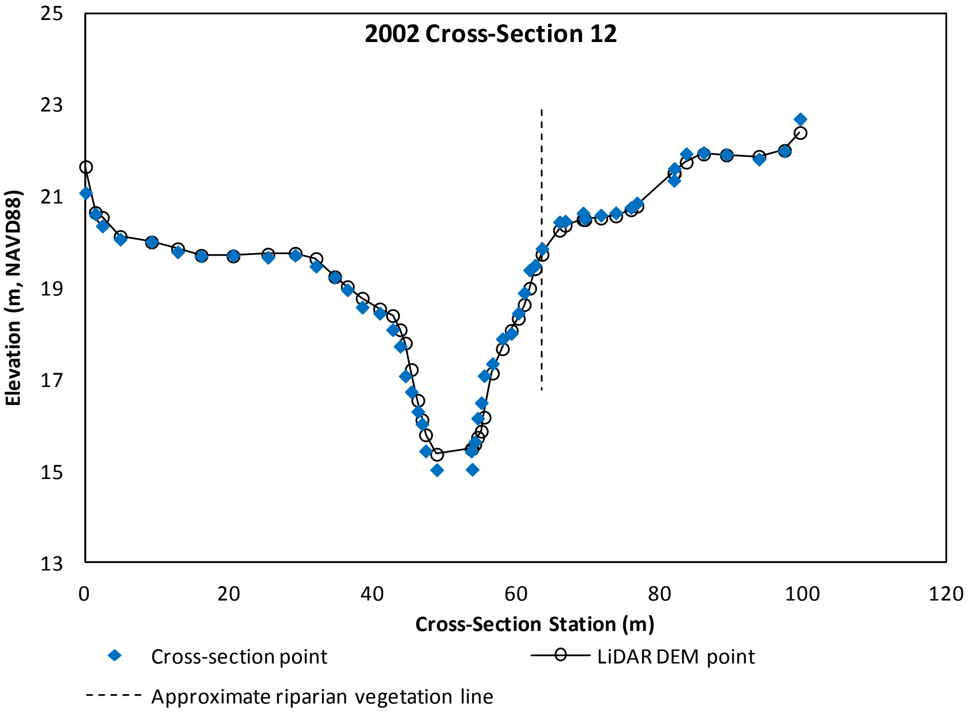


Figure 2-3. Comparison of points surveyed at cross-section 12 in 2002 with points extracted from the LiDAR DEM at the same locations.

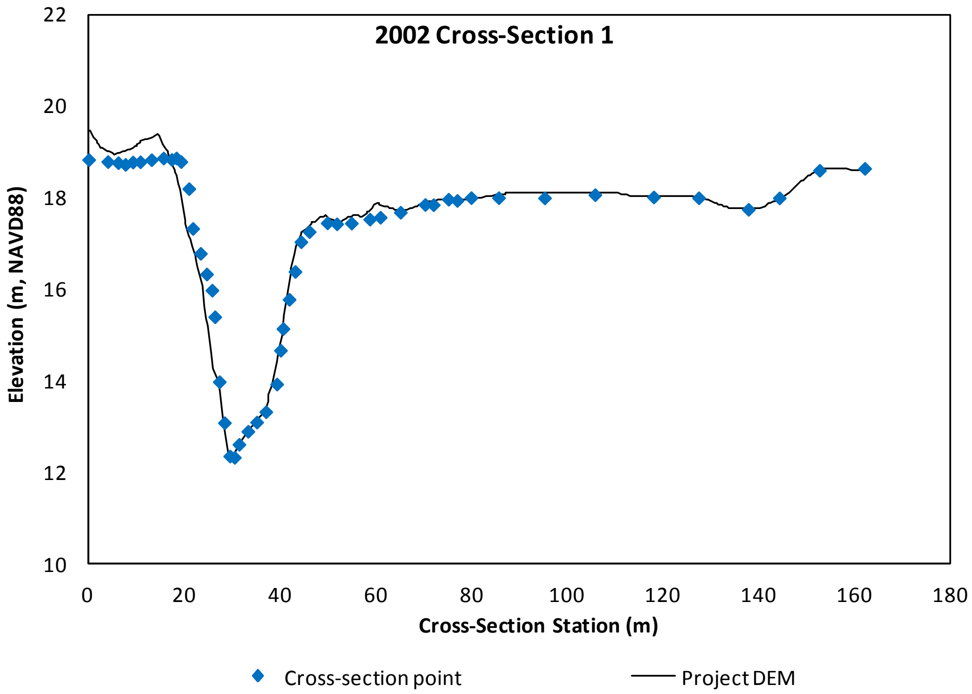


Figure 2-4. Comparison of points surveyed at cross-section 1 in 2002 with points extracted from the Project DEM along the cross-section line.

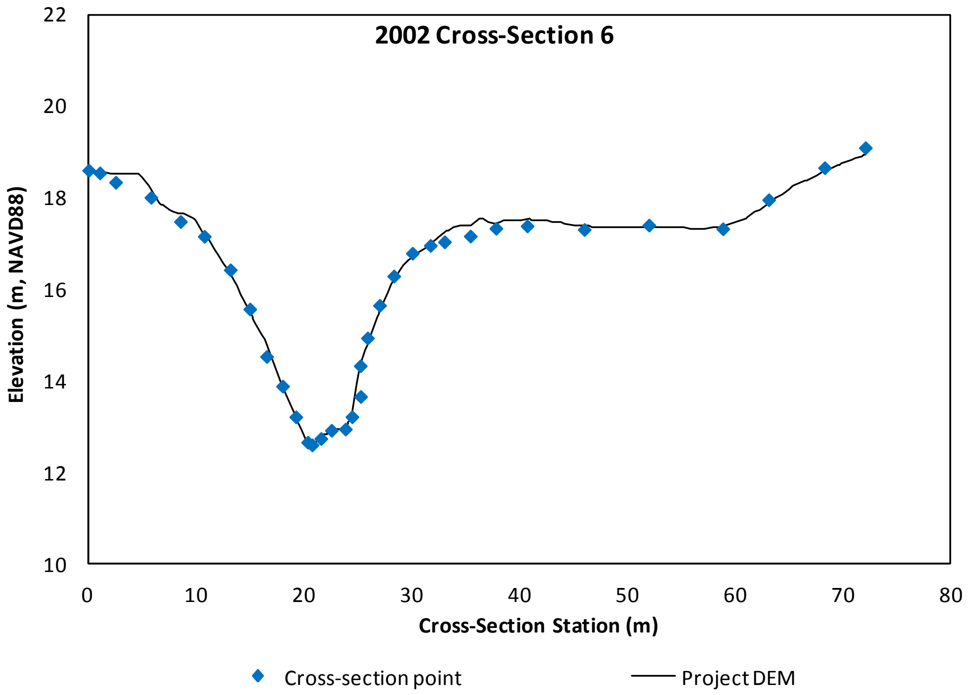


Figure 2-5. Comparison of points surveyed at cross-section 6 in 2002 with points extracted from the Project DEM along the cross-section line.

2.1.2 Characteristics of Channel Bed, Bank and Floodplain Sediment Deposits

The bulk density, porosity, and grain size distribution of channel bed, channel bank, and floodplain sediment deposits in the pilot project area were determined from bulk sampling at 40 locations in the North Fork, South Fork, and mainstem Elk River project reaches. Core samples were also taken from the channel bed at 8 locations in the general vicinity of bulk sample sites to qualitatively assess stratification and thickness of layered bed material deposits.

A reconnaissance field survey of project reaches was first conducted to identify representative sites potentially feasible for bulk sampling and core sampling. The field reconnaissance included identification of typical channel bed and bank morphology, grain size distributions, and roughness elements (e.g., planform curvature, wood jams, and live vegetation) that locally influenced hydraulics and sediment dynamics. Bulk sampling was conducting by shovel sampling coarse bed material deposits and by pushing steel cylinders with a fixed volume into finer surface deposits devoid of significant herbaceous vegetation cover. To assess the effects of sample size on parameter values, bulk sampling of fine sediment deposits involved experimentation with four cylinder sizes (Table 2-2) cut from ANSI Schedule 40 steel pipe. Of the 40 samples collected in the field, 16 were analyzed for bulk density, porosity and grain size distribution (Table 2-3, Figure 2-6).

Table 2-2. Cylinder sizes used for bulk sampling bed, bank and floodplain surface deposits in the Elk River pilot project area.

Diameter (in)	Length (in)
3	3
3	6
6	3
6	6

Table 2-3. Sediment samples analyzed for bulk density, porosity and grain size distribution in the Elk River pilot project area.

Sample	Location	Channel Reach	Type
MS-B-2	HRC Station 509	mainstem	bank
MS-C-1	HRC Station 509	mainstem	channel
MS-C-2	XS-0	mainstem	channel
MS-FP-1	HRC Station 509	mainstem	floodplain
NF-B-4	XS-12	north fork	bank
NF-B-6	XS-12	north fork	bank
NF-C-1	XS-5	north fork	channel
NF-C-2	XS-7	north fork	channel
NF-C-3	XS-12	north fork	channel
NF-C-4	XS-10	north fork	channel
NF-FP-3	XS-5	north fork	floodplain
NF-FP-5	XS-12	north fork	floodplain
SF-B-3	XS-20	south fork	bank
SF-C-1	XS-20	south fork	channel
SF-C-2	XS-14	south fork	channel
SF-FP-4	XS-20	south fork	floodplain

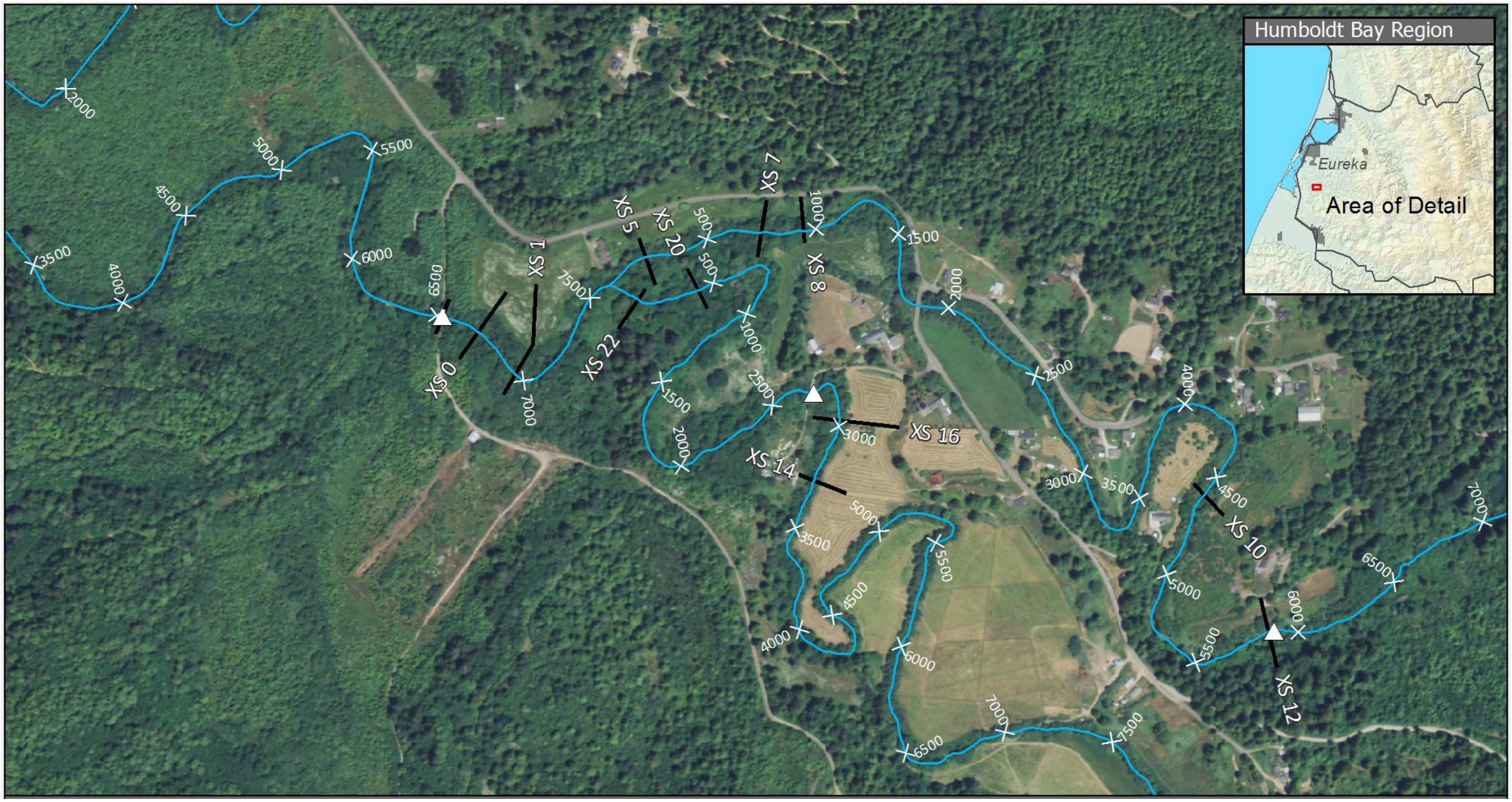


Figure 2-6. Sediment sampling locations in the Elk River pilot project area.

Dry bulk density and porosity were calculated from the fixed sampler volumes and the dry sample weights (Table 2-4), using an assumed sediment specific gravity of 2.65. Dried samples were then processed through nested sieves larger than 0.25 mm. For each sample, material passing the 0.25 mm sieve was split and processed through nested sieves ranging from 0.18 thru 0.062 mm. The sample fraction passing the 0.062 mm sieve was sent to the U.S. Forest Service's Redwood Sciences Laboratory (RSL) in Arcata, California to be analyzed with a LS13-320 Particle Size Analyzer (hereafter referred to as the particle counter). A particle counter analyzes the number of particles in different size classes based on changes in the electrical resistance of a sample suspended in electrolytes. Samples analyzed with RSL's particle counter were first baked in a muffle furnace at 550 °C to burn off organics. Weight of the sample used in analysis was calculated by subtraction (in weight – out weight). Tare weight of the tin used to measure sample weight was used as a check for cross-contamination. Garnet control samples were run at the beginning and end of each day and every 4 hours at a minimum. All garnet controls conformed to size specifications recommended by the manufacturer. Particle counter analyses were repeated at least three times for each sample. Results from the laboratory analysis of material >0.062 mm and particle counter analysis of material <0.062 mm were combined to determine the grain size distribution of each bulk sediment sample (Table 2-5, Figure 2-7 and Figure 2-8).

Table 2-4. Porosity and bulk density of channel bed, channel bank and floodplain sediment deposits in the Elk River pilot project area.

Channel	Location	Average Porosity	Average Wet Bulk Density (g/l)	Average Dry Bulk Density (g/l)
Mainstem	channel	0.484	1,851	1,367
	bank	0.551	1,741	1,190
	floodplain	0.600	1,661	1,061
North Fork	channel	0.769	1,380	611
	bank	0.537	1,764	1,227
	floodplain	0.599	1,662	1,063
South Fork	channel	0.699	1,497	798
	bank	0.575	1,701	1,126
	floodplain	0.602	1,656	1,054
Combined	Channel	0.681	1,527	847

Table 2-5. Grain size distribution of channel bed, channel bank and floodplain deposits in the Elk River pilot project area.

Sieve Size (mm)	**Cumulative % Passing**														
	MS-B-2	**MS-C-1**	**MS-C-2**	**MS-FP-1**	**NF-B-4**	**NF-B-6**	**NF-C-1**	**NF-C-3**	**NF-C-4**	**NF-FP-3**	**NF-FP-5**	**SF-B-3**	**SF-C-1**	**SF-C-2**	**SF-FP-4**
16	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.09	100.00
8	100.00	96.39	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	81.98	100.00
4	100.00	68.44	99.65	100.00	100.00	100.00	100.00	100.00	99.85	100.00	100.00	100.00	100.00	59.55	100.00
2	100.00	41.06	96.92	100.00	100.00	100.00	100.00	99.51	99.78	100.00	100.00	100.00	100.00	44.55	100.00
1	100.00	29.87	88.79	100.00	100.00	100.00	99.40	98.66	99.65	100.00	100.00	100.00	100.00	33.52	100.00
0.5	99.62	23.61	73.52	95.19	95.19	94.89	98.65	92.33	99.18	86.58	91.47	94.70	99.89	25.57	95.84
0.25	75.42	10.31	33.59	83.76	83.76	84.05	91.03	58.72	94.89	77.48	77.76	84.91	89.54	11.11	88.38
0.125	45.73	1.65	3.69	68.99	68.99	65.01	46.47	24.01	48.00	70.34	62.39	68.41	32.69	3.08	75.93
0.062	26.47	0.94	1.98	50.02	50.02	40.93	25.90	11.41	23.58	61.76	44.55	42.86	13.46	1.76	54.59
0.031	12.62	0.26	0.40	29.67	29.67	22.26	8.25	3.10	6.27	49.30	25.93	23.43	3.15	0.53	30.13
0.016	6.26	0.11	0.14	17.30	17.30	12.45	3.40	1.26	2.50	38.85	14.03	14.12	1.27	0.25	16.05
0.008	3.34	0.06	0.07	11.32	11.32	7.43	1.64	0.61	1.30	32.44	7.72	9.67	0.64	0.13	9.58
0.004	2.06	0.04	0.05	8.96	8.96	5.20	1.04	0.40	0.85	29.61	5.03	7.75	0.43	0.09	7.07
0.002	1.18	0.02	0.04	7.53	7.53	3.76	0.66	0.25	0.56	27.95	3.43	6.53	0.29	0.05	5.53
0.001	0.55	0.01	0.02	6.51	6.51	2.81	0.31	0.12	0.28	26.91	2.38	5.68	0.14	0.02	4.41
0.0005	0.09	0.00	0.00	5.75	5.75	2.14	0.05	0.02	0.04	26.16	1.59	5.05	0.02	0.00	3.56
0.00024	0.00	0.00	0.00	5.60	5.60	2.01	0.00	0.00	0.00	26.02	1.43	4.92	0.00	0.00	3.40

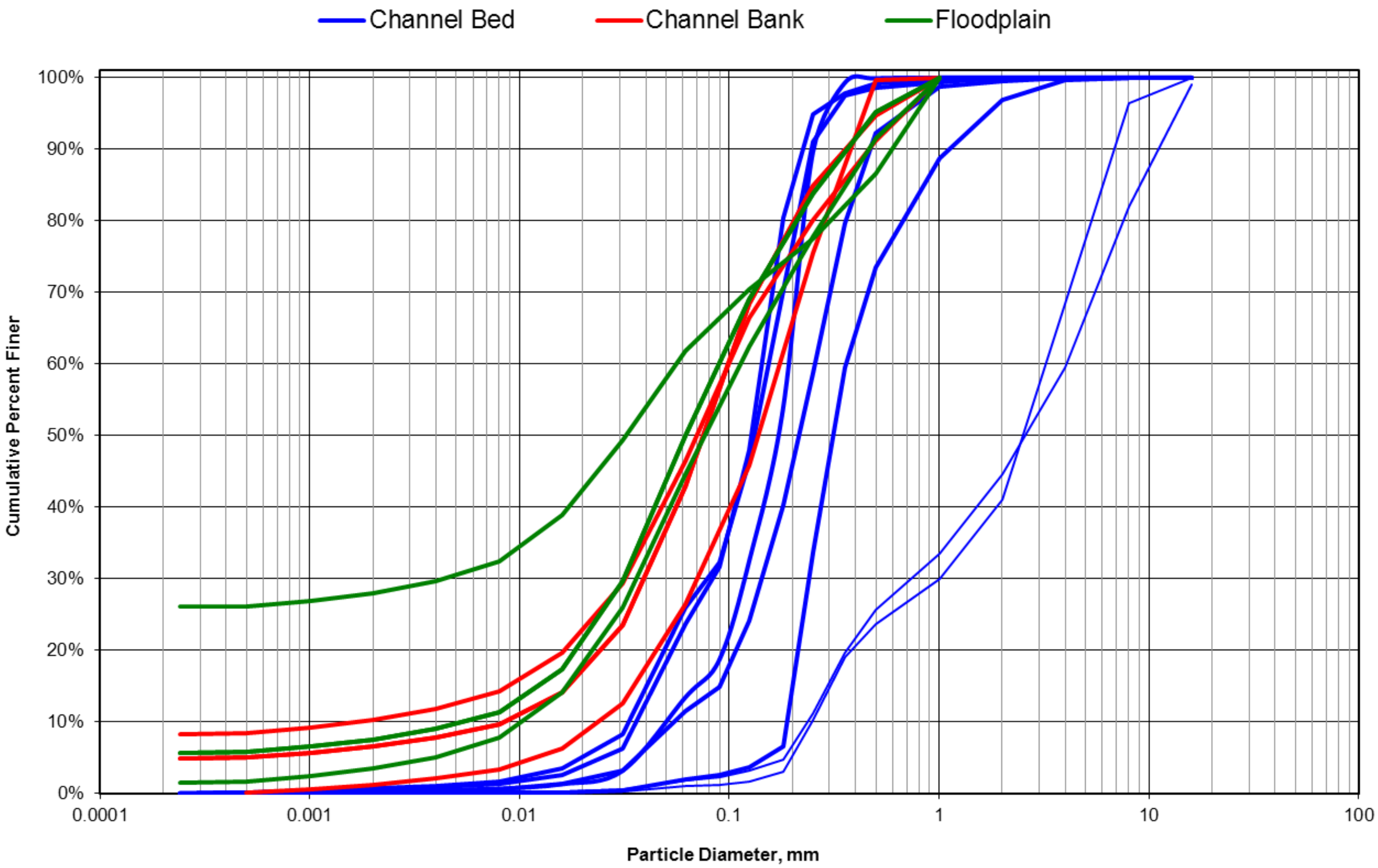
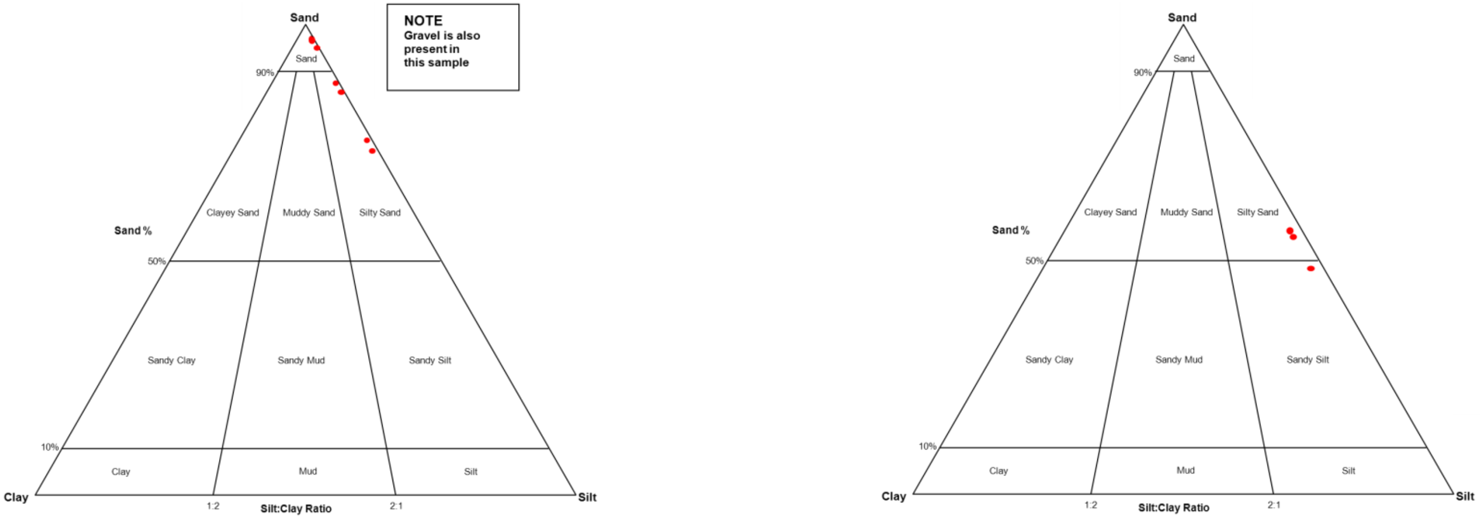
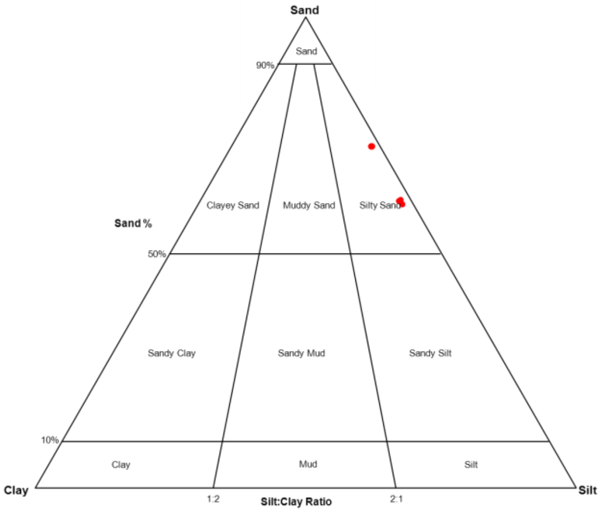


Figure 2-7. Particle size distributions of bulk samples from channel bed, channel bank and floodplain sediment deposits.



(A) Channel bed deposits

(C) Floodplain deposits



(B) Channel bank deposits

Figure 2-8. Sand-silt-clay diagrams for bulk sediment samples of (A) channel bed, (B) channel bank and (C) floodplain deposits.

3 HYDRODYNAMIC AND SEDIMENT TRANSPORT MODEL CONFIGURATION

A properly calibrated and tested hydrodynamic and sediment transport (HST) model of the sediment impaired Elk River could provide a valuable tool for evaluating existing conditions, sediment source control strategies, TMDL allocation alternatives, system trajectory, and informing decisions regarding large scale restoration actions. This chapter summarizes the development of the HST model and observational data used for boundary conditions, model parameters and calibration. Results of this pilot project study will also inform the feasibility of extending the HST modeling domain to include a larger reach of the sediment impaired Elk River.

3.1 Modeling Framework

The HST model developed for use in the Elk River pilot project reach is based on the Environmental Fluid Dynamics Code (EFDC) modeling system. EFDC is a public-domain, Environmental Protection Agency (EPA) supported modeling system for simulating three-dimensional, two-dimensional, or one-dimensional flow, transport and biogeochemical processes in surface waters. The EFDC model dynamically couples hydrodynamics and salinity and temperature transport, and can internally link to dye transport, cohesive and non-cohesive sediment transport, water and sediment toxic contaminant transport and fate, and water quality and eutrophication sub-models. EFDC uses a curvilinear-orthogonal grid in the horizontal domain, and a sigma grid in the vertical. The numerical scheme uses second-order accurate finite differencing in both space and time. EFDC was originally developed at the Virginia Institute of Marine Science by Dr. John Hamrick (Hamrick 1992), and full documentation of the EFDC model can be found in Tetra Tech (2007a, 2007b, and 2007c). The Windows-based EFDC_Explorer6 (Craig 2011) was used for a majority of the pre and post processing of the EFDC model.

The HST model developed for the Elk River pilot project reach is currently configured to simulate hydrodynamics and sediment transport via the sediment transport sub-model. The HST model simulates the following state variables and physical processes:

- water levels,
- velocity,
- vegetation resistance,
- wetting and drying of grid cells,
- multiple size classes of cohesive and non-cohesive suspended sediment transport,
- bedload transport of multiple size classes of non-cohesive sediment,
- sediment bed geomechanics with multiple sediment layers for multiple size classes of cohesive and non-cohesive sediments, and
- bed morphology (scour and deposition).

The remainder of this chapter describes the HST model grid, assumptions regarding the simulation period, and general information regarding upstream and downstream boundary conditions. More detailed information regarding boundary condition adjustments, initial conditions, parameters, sediment classes, sediment bed and other assumptions are discussed in the HST model calibration sections.

3.2 HST Model Grid

The Elk River pilot project HST model was configured as a two-dimensional (2D) model. The curvilinear-orthogonal grid for the model (Figure 3-1) consists of 3,505 horizontal segments, with an average grid cell size of approximately 12.1 by 12.9 m. Grid resolution consisted of 1 cell for the channel bed, 1 cell for each bank, and multiple cells on the floodplain. The model grid domain was configured to accommodate the pilot reach, but was extended upstream and downstream of the pilot reach to offset the effects of boundary condition assumptions. The model grid covered approximately 3.42 km of the mainstem and NF Elk River, and approximately 1.11 km of the SF Elk River. Bed, bank and floodplain elevations were assigned to the model grid cells using the Project DEM described in Section 2.1.1 (Figure 3-2).

The location of the model grid inflow and downstream boundary conditions are shown on Figure 3-3, and are defined as follows:

- North Fork Elk River inflow = NF_Elk_BC,
- South Fork Elk River inflow = SF_Elk_BC,
- Railroad Gulch inflow = RRGulch_BC,
- Clapp Gulch inflow = CLGulch_BC, and
- downstream mainstem Elk River = DS_M-Elk_BC.

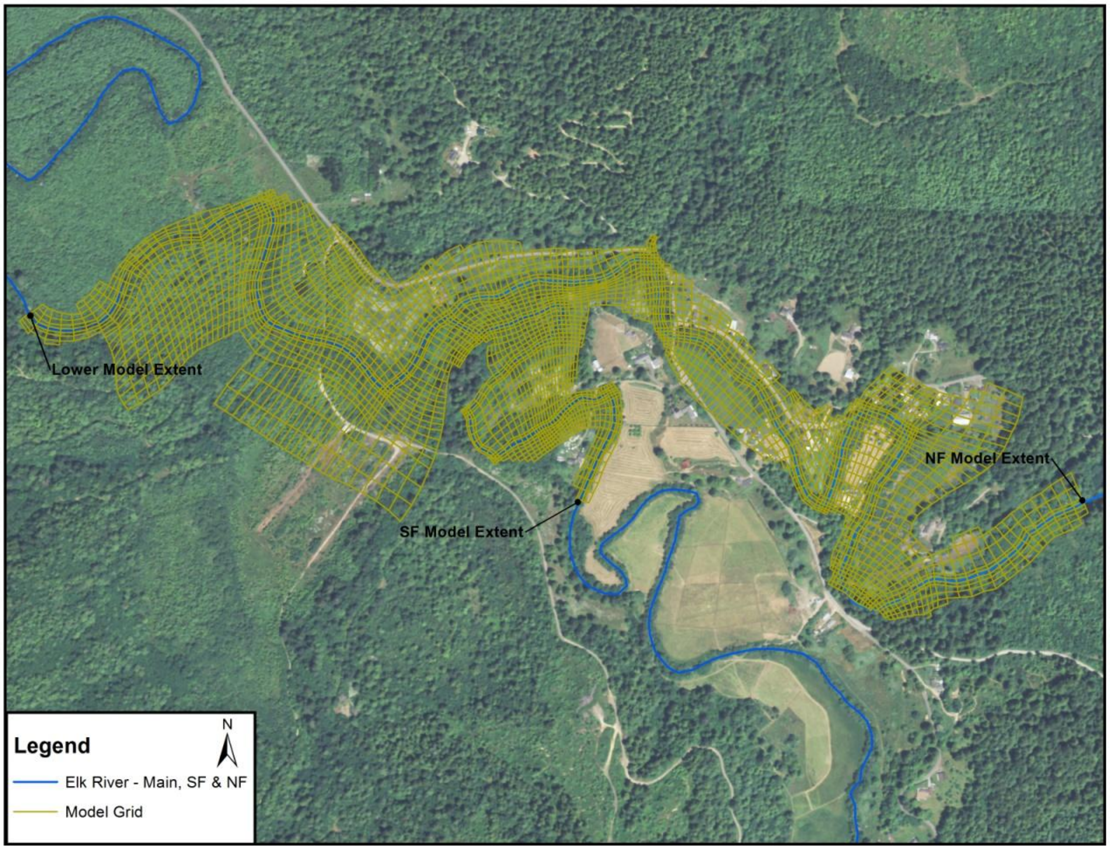


Figure 3-1. Elk River pilot project HST model grid.

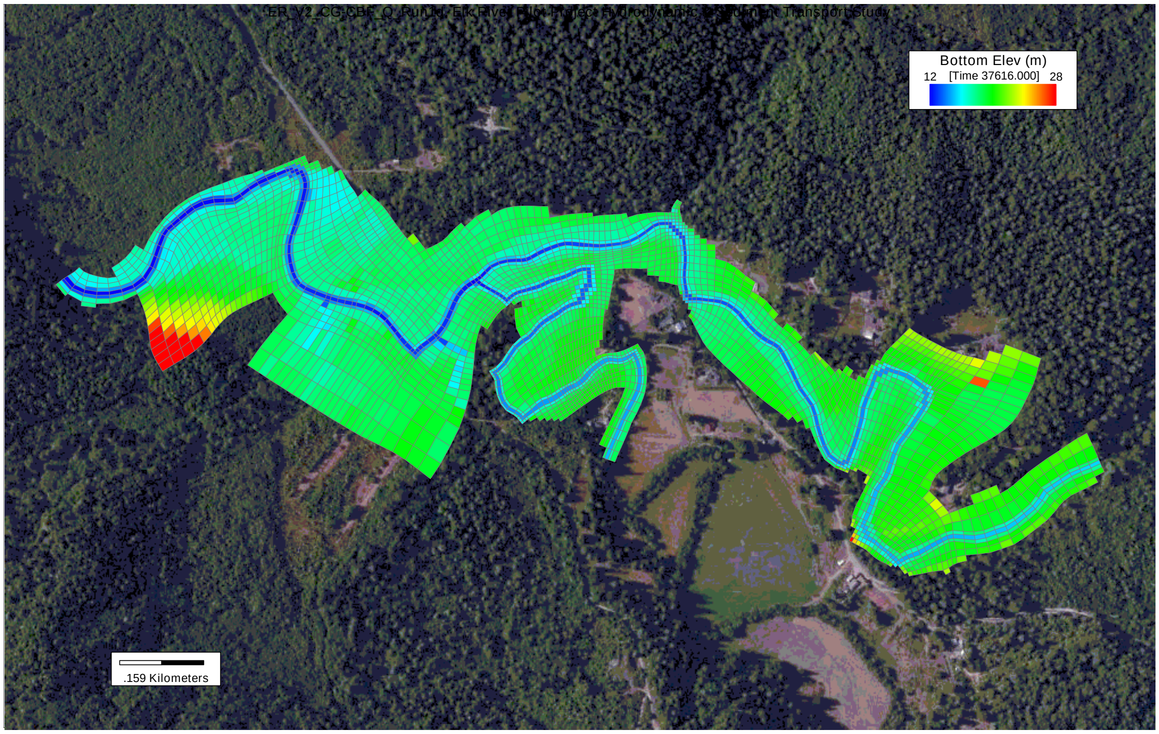


Figure 3-2. Elk River pilot project HST model grid elevations.

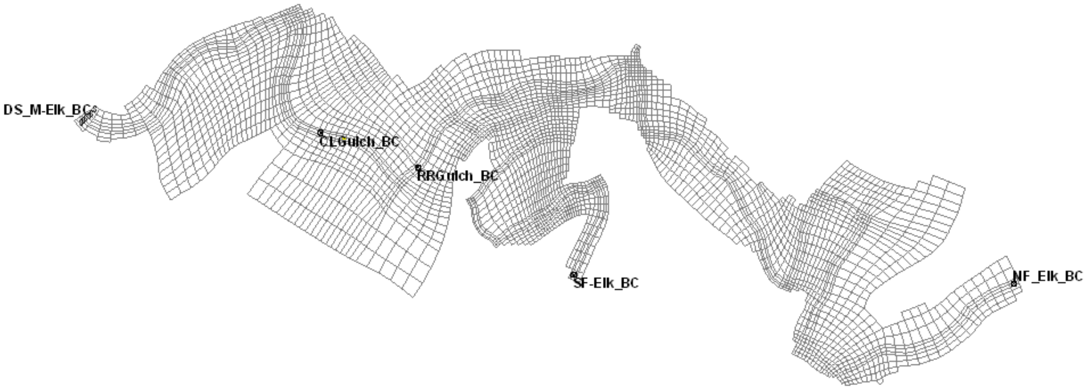


Figure 3-3. Elk River pilot project HST model grid boundary condition locations.

3.3 HST Model Simulation Period

The HST model was configured for a 6-year simulation period from water year (WY) 2003 to 2008 (a water year spans the period October 1 to September 30). Shorter periods were used for model calibration (discussed below). In general, the available gaging station Q and SSC data were not collected for the entire WY, with the collection focused during the winter/spring period (approximately October to May). To help reduce overall model run times, the 6-year simulation period was further reduced to discharges over a Q threshold of 3 cms in the NF Elk River (Table 3-1). This approach fits the project focus of assessing the ability of the HST model to reproduce sediment deposition patterns in the impaired Elk River reach, which only occurs at the higher flows and sediment loads.

Table 3-1 summarizes total suspended sediment load (SSL) for the period of record (POR) versus the SSL for the reduced WY 2003-08 period that includes only flows over the Q threshold of 3 cms at the two upstream gaging stations within the pilot project reach. The reduced SSL during the simulation period is only 4.1 to 4.2 percent (%) less than the total SSL for the entire WY 2003-08 POR for the NF and SF Elk River, respectively (Table 3-1). The reduced simulation period significantly reduces the total number of days (297 days) required for HST model simulation for the WY 2003-08 run, with only a minor reduction in the total SSL. For the reduced WY 2003-08 simulation period, the starting time is arbitrarily set at 2003.0 days and extends to 2300.0 days.

Table 3-1. Comparison of suspended sediment load (SSL) and number of days for WY 2003-08 for the entire period of record (POR) and the reduced POR for Q > 3cms in the NF Elk River.

Gaging Station	NF Elk River gaging station KRW (SFO)	SF Elk River gaging station KRW (SFO)
SSL for POR (MT)	60,283.7	85,189.5
SSL for reduced POR for Q > 3 cms (MT)	57,794.5	81,578.1
Difference (%)	**-4.1**	**-4.2**
Number of days for POR	1,445	Same as NF Elk River
Number of days for reduced POR for Q > 3 cms in NF Elk River	297	Same as NF Elk River
Difference (days)	**-1,148**	**Same as NF Elk River**

The current grid resolution requires a 0.5 second time step to satisfy the Courant-Friedrich-Levy (CFL) criterion. The HST model required 84.8 CPU hours of simulation time and generated approximately 12.9 GB of output data for the six-year simulation period.

3.4 Q and SSC Model Inflow Boundary Conditions

North Fork and SF Elk River Q and SSC inflows are at the upstream boundaries of the model domain (Figure 3-3) and are based on the Salmon Forever (SFO) gaging station 10-min data (SFO 2011). The NF Elk River Q boundary condition uses the KRW station data, and the SF Elk River uses the SFM station data. Figure 3-4 and Figure 3-5 show the continuous reduced Q and

SSC record (Q > 3 cms for NF Elk River) for the NF and SF Elk River, respectively, with the arbitrary start time of 2003.

The discharge record for Clapp and Railroad Gulch boundary conditions (Figure 3-3) are based on the watershed area ratio for each gulch and the SF Elk River data. In 2002, measurements of Q and SSC were made in Railroad Gulch (data provided by Adona White, RWQCB, 2012 personal communication). Estimates of SSC for Railroad and Clapp Gulch were based on a simple SSC/Q power equation (uncorrected for bias) for the Railroad Gulch 2002 data (Figure 3-6), and then applied to the scaled discharge record for each gulch. The estimated SSC record for Railroad and Clapp Gulch was constrained to an upper limit of 4,479 mg/l, which is the maximum value in the SF Elk River 10-minute SSC record.

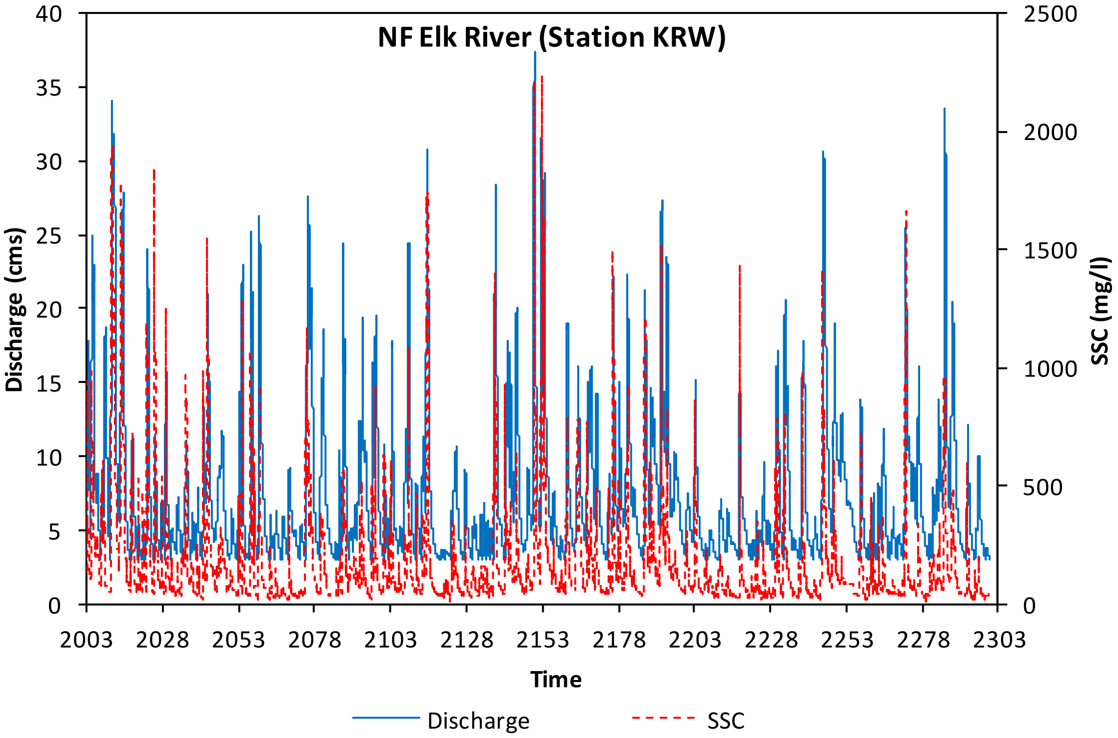


Figure 3-4. NF Elk River (Station KRW) 10-minute Q and SSC measurements for reduced WY 2003-08 (Q > 3cms in NF Elk River) with arbitrary start date of 2003 (time is in days).

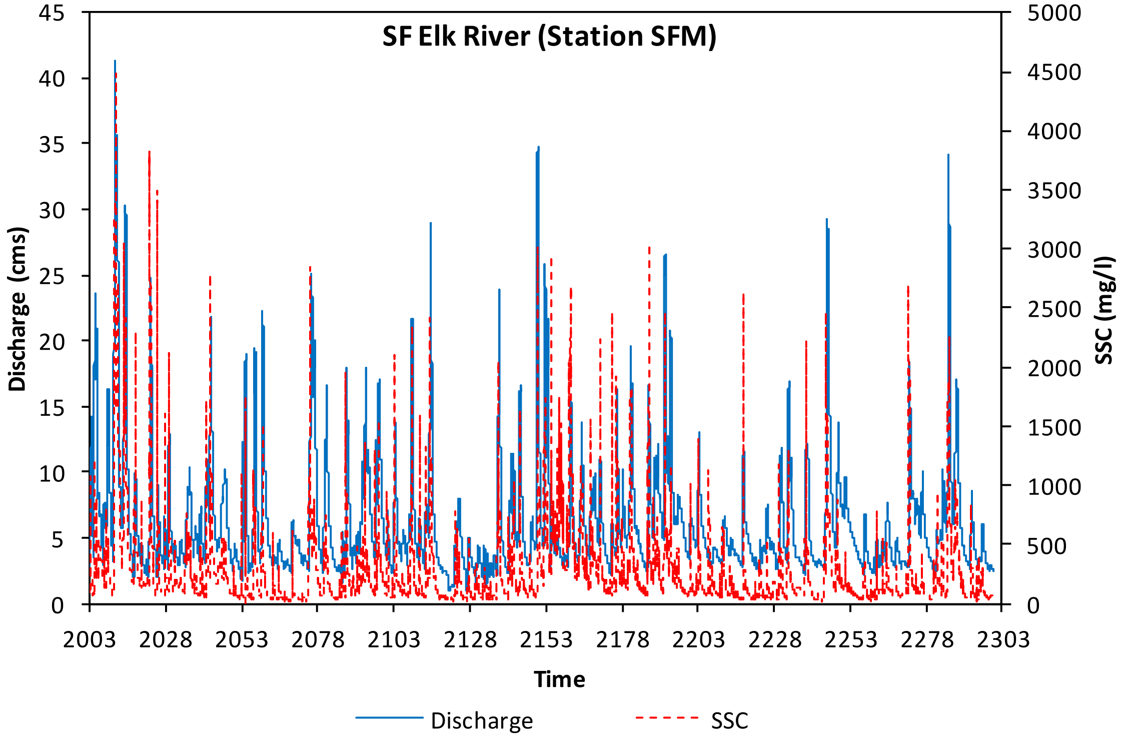


Figure 3-5. SF Elk River (Station SFM) 10-minute Q and SSC measurements for reduced WY 2003-08 (Q > 3cms in NF Elk River) with arbitrary start date of 2003 (time is in days).

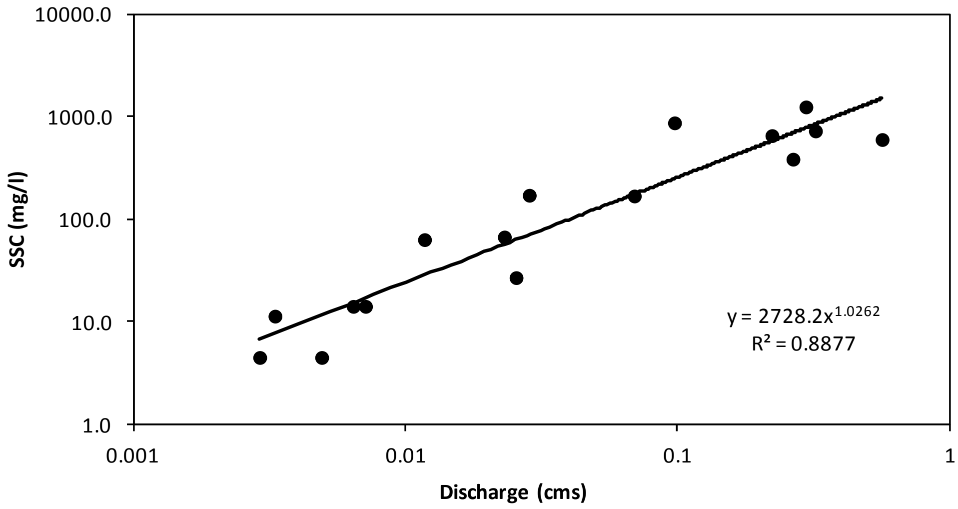


Figure 3-6. SSC rating curve (unadjusted for bias) for 2002 Railroad Gulch SSC and Q measurements.

3.5 Water Surface Elevation Downstream Boundary Condition

Water surface elevation data is not available at the downstream end of the HST model grid (Figure 3-3). To provide an approximation of the downstream WSE for the WY 2003-08 simulations the following approach was used.

1. A simple steady-state HEC-RAS model was developed of the lower HST model domain, with a cross-section located at the downstream end of the HST model grid.
2. A series of steady-state discharges were run through the HEC-RAS model and a rating curve (Figure 3-7) was developed for the cross-section located at the downstream end of the HST model grid.
3. Using the rating curve and the sum of the NF and SF Elk River and Railroad and Clapp Gulch discharges at a particular time, a WSE versus time series was developed.
4. The WSE time series was then lagged 92.23 minutes to accommodate the travel time from the gaging stations to the end of the HST model grid. The travel time was estimated by dividing the approximate length of channel from the NF Elk River gaging station (2,274 m) by the average gaged velocity (0.411 m/s).
5. The final WSE time series (Figure 3-8) was used as the downstream boundary condition for the HST model grid.

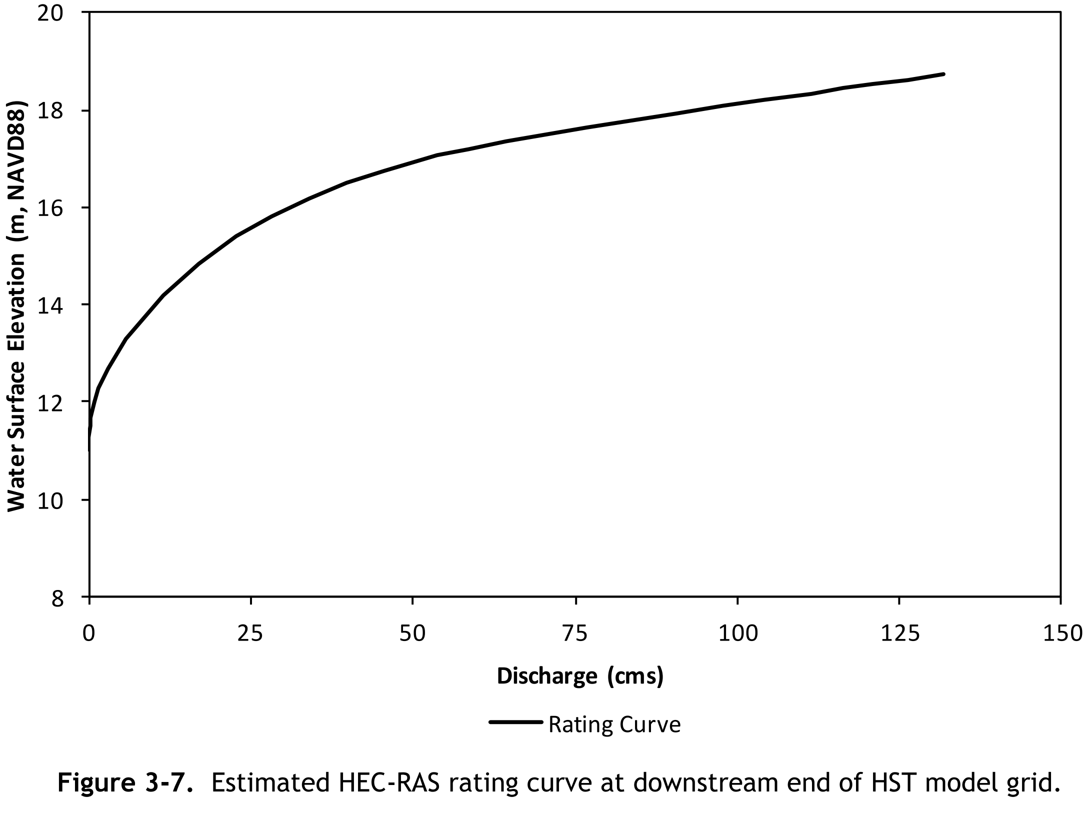


Figure 3-7. Estimated HEC-RAS rating curve at downstream end of HST model grid.

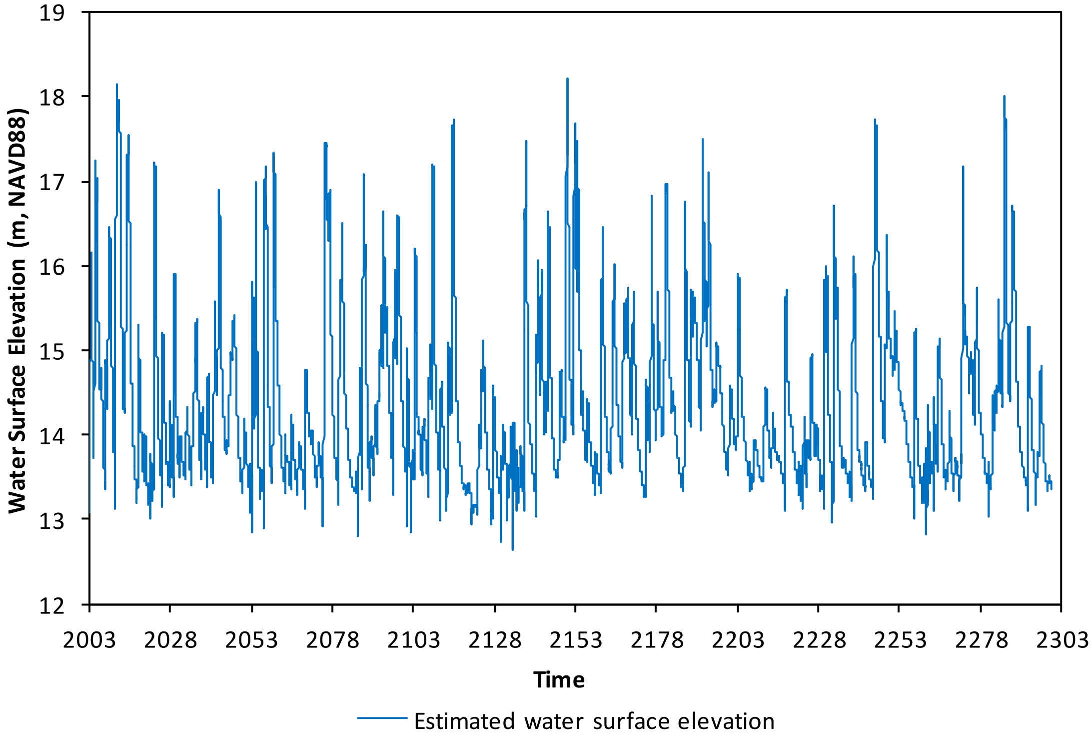


Figure 3-8. Estimated WSE at downstream boundary condition for HST model (time is in days).

4 HYDRODYNAMIC AND SEDIMENT TRANSPORT MODEL CALIBRATION

The following sections describe calibration of the hydrodynamic and sediment transport model components. Numerous combinations of model parameters and assumptions were evaluated during the calibration process. Only the final calibrated parameters, boundary condition adjustments, and predicted calibration results are described herein. However, recommendations for additional data collection included in a later chapter were influenced by the overall HST model calibration process and assumptions.

4.1 Hydrodynamic Model Calibration

4.1.1 General Approach

The general approach used in calibrating the hydrodynamic model was to adjust inflow boundary conditions and model parameters so that predicted Q, V and WSE reasonably matched observations of peak flood elevations and measured relationships in the NF and mainstem Elk River. The hydrodynamic model calibration period included 5 days spanning 25 - 30 December 2002. The period included the 28 December 2002 flood event, the largest flood event during the WY 2003-08 simulation period.

4.1.2 Inflow Boundary Condition Adjustments

During the hydrodynamic model calibration the model consistently underestimated observed high water elevations during the 28 December flood. This underestimate occurred despite good agreement between observed and predicted stage/discharge estimates at two streamflow measurement sites. Ultimately, it was concluded that the NF and SF Elk River 10-minute discharge record (Figure 3-4 and Figure 3-5) underestimate out-of-bank flood events. This conclusion is supported by the SFO rating curves for both the NF and SF Elk River that contain only in-channel measurements. No attempt has been made to account for out-of-bank flows at these stations.

To better account for the out-of-bank flows, a trial and error process was followed whereas the NF and SF Elk River boundary condition discharges were increased until they agreed reasonably well with peak flood elevation observations. The following equations were used to increase the NF and SF Elk River 10-minute discharge records:

<u>NF Elk River</u>

$$Qadj = Q, \qquad if\ Q < 16.677\ cms$$
$$Qadj = Q + (1.3Q - 21.680), \qquad if\ 16.677\ cms < Q$$

<u>SF Elk River</u>

$$Qadj = Q, \qquad if\ Q < 30.15\ cms$$
$$Qadj = Q + (0.6Q - 18.090), \qquad if\ 30.15\ cms < Q$$

where *Qadj* = adjusted discharge. The flow thresholds of 16.677 cms (~589 cfs) for the NF Elk River and 30.15 cms (~1,065 cfs) for the SF Elk River are the approximate maximum in-channel Q measurements obtained at each gaging station by SFO.

The adjusted NF and SF Elk River 10-minute discharge records compared to the original records are provided in Figure 4-1 and Figure 4-2, respectively.

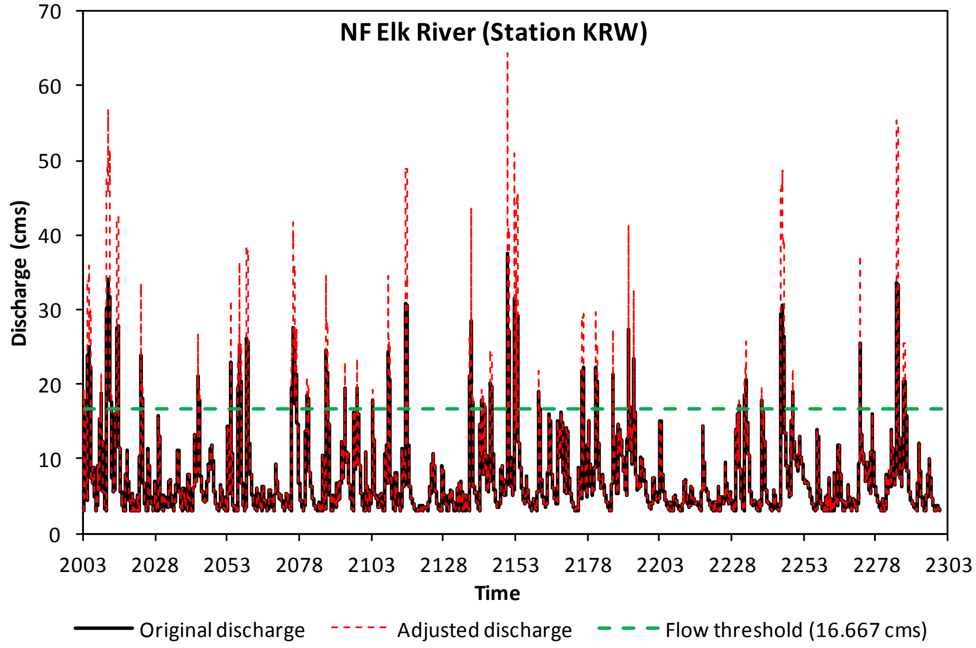


Figure 4-1. Original and adjusted NF Elk River (Station KRW) 10-minute Q record for reduced WY 2003-08 (Q > 3cms) period (time is in days).

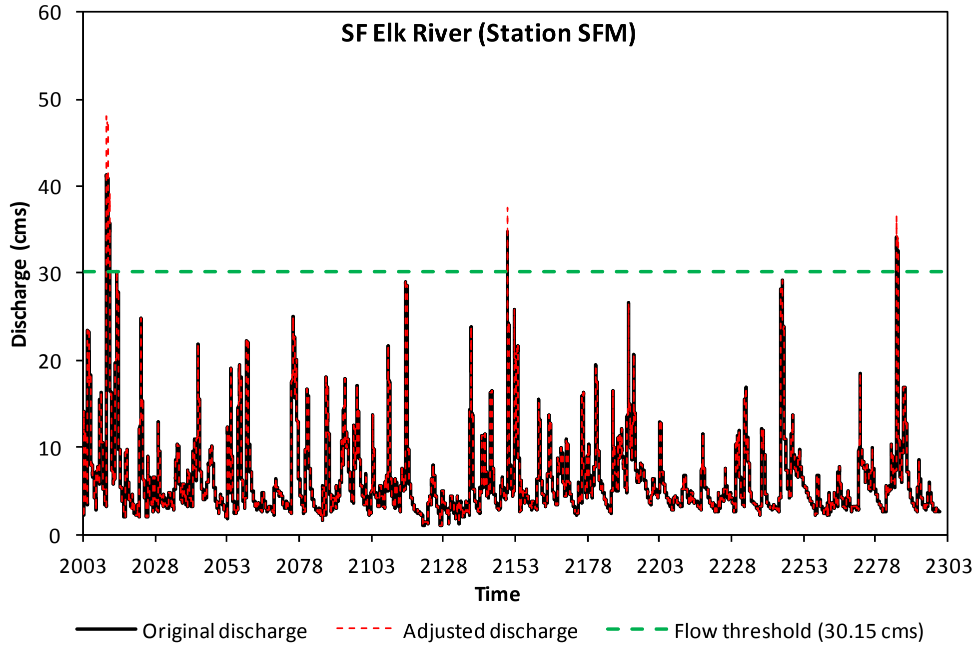


Figure 4-2. Original and adjusted SF Elk River (Station KRW) 10-minute Q record for reduced WY 2003-08 (Q > 3cms) period (time is in days).

4.1.3 Bottom Roughness and Vegetation Drag

To better predict water velocity and depth (and ultimately shear stress) compared to available data, it was necessary to incorporate vegetative drag (in addition to bottom friction) into the HST model.

Effective Roughness Height

The adjusted parameter for bottom friction is the effective bed roughness height (Z_0), which represents the total roughness due to skin friction and form drag, and is generally represented by bed physical properties. Based on the bed physical data described in Section 2.1.2 and literature values (Ji 2008, Tetra Tech 2007a and 2007b), four different Z_0 zones were differentiated for the Elk River pilot project reach (Table 4-1). These four Z_0 zones were then assigned to the model grid in the appropriate areas within the model domain (Figure 4-3).

Table 4-1. Bottom effective roughness height (Z_0) by zones used in the calibrated hydrodynamic model.

Roughness Zones	Z_0 (m)	Source
Coarse channel bed	0.04	Calibration, bed physical data, literature
Fine channel bed	0.02	Calibration, bed physical data, literature
Bank and floodplain	0.01	Physical data, literature
Paved and gravel road, driveway	0.005	Calibration, literature

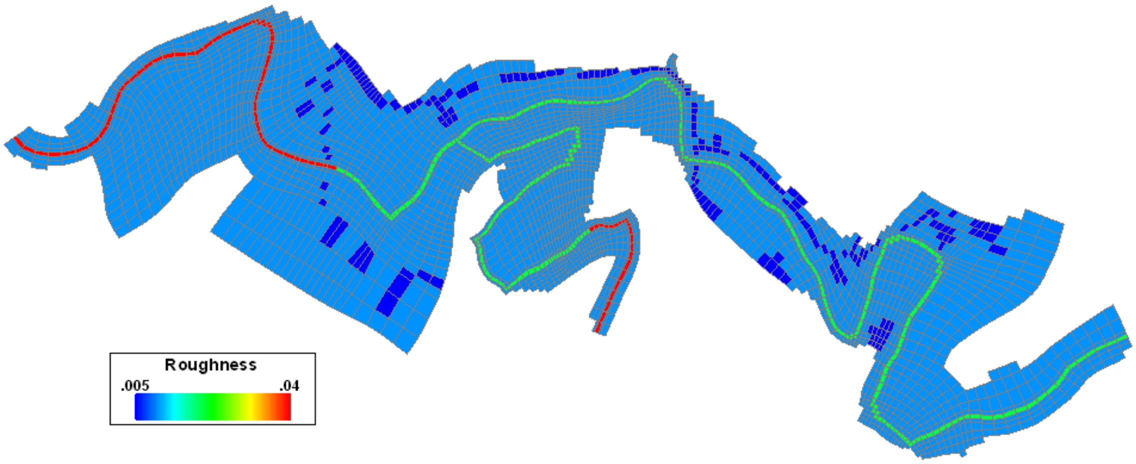


Figure 4-3. Model grid bottom effective roughness height (Z_0) designation.

Vegetative Resistance Parameters

To accommodate frictional resistance effects on the flow field from the vegetated banks and floodplain, the vegetation resistance formulation in EFDC was used (Moustafa and Hamrick

2000). Data required to incorporate the EFDC vegetation resistance formulation includes plant density, stem diameter and stem height. As these data were not available for the Elk River pilot project reach, initial values were taken from the literature (Weston 2004) and then adjusted during calibration. Six vegetation community types were assumed for this assessment and digitized as polygons using the 2009 NAIP imagery. The plant density, stem diameter and stem height of the six communities (Table 4-2) were then assigned to the model grid via the vegetation polygons (Figure 4-4). The alpha depth factor was set to the default value of 0.7854, and the drag coefficient factor was set to 0.5.

Table 4-2. Vegetation community type and physical characteristics used in the calibrated hydrodynamic model.

Vegetation Type	HST Model Code	Plant Density (#/m^2)	Stem Diameter (m)	Stem Height (m)
Bank	1	100	0.01	1
Riparian	2	5	0.1524	5
Forest	3	0.14	0.2658	20.4
Pasture	4	564	0.0031	0.3
Orchard	5	0.1	0.3	6
Channel	0	0	0	0

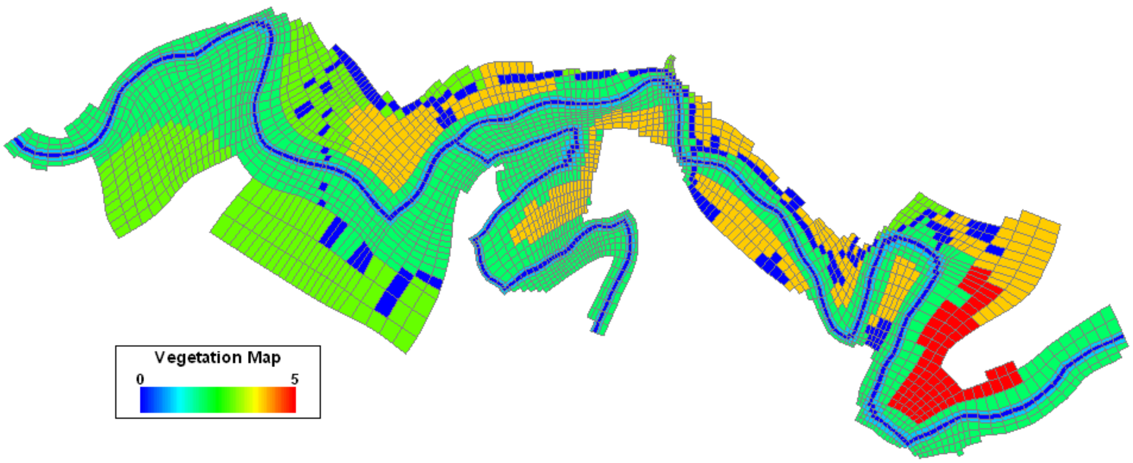


Figure 4-4. Model grid vegetation community type designation.

4.1.4 Horizontal Eddy Viscosity and Diffusivity Coefficient

A constant horizontal eddy viscosity and diffusivity coefficient of 0.1 m^2/s was used for the HST model in the Elk River pilot project work.

4.1.5 Initial Conditions

The hydrodynamic model was run for 2-days prior to the hydrodynamic calibration period of 25 - 30 December 2012. Water depth and velocity results of the 2-day simulation period were then used as initial conditions for the hydrodynamic model simulation run.

4.1.6 Hydrodynamic Model Calibration Results

Hydrodynamic model results were compared to measured data used to construct the rating curves for Station KRW run by SFO and Station 509 run by HRC. Streamflow measurements for Station KRW are taken in the NF Elk River from the Concrete Bridge, and Station 509 measurements are taken in the mainstem Elk River from the Steel Bridge. Predicted WSE are compared to the continuous stage record at Station KRW on the NF Elk River for the 5-day calibration run. Finally, predicted maximum WSE for the 28 December 2002 flood event is compared to observed peak flood elevations at two locations in the project reach; the Red House and the Steel Bridge on the mainstem Elk River. Figure 4-5 show the locations of the observational sites used for hydrodynamic model comparisons.

Model results were not compared to the rating curve data for SFO Station SFM located on the SF Elk River due to its close proximity to the model grid boundary. Furthermore, modeled WSE could not be compared to the continuous stage record at Station SFM since the NAVD88 elevation of the staff plate was not available to convert stage to WSE.

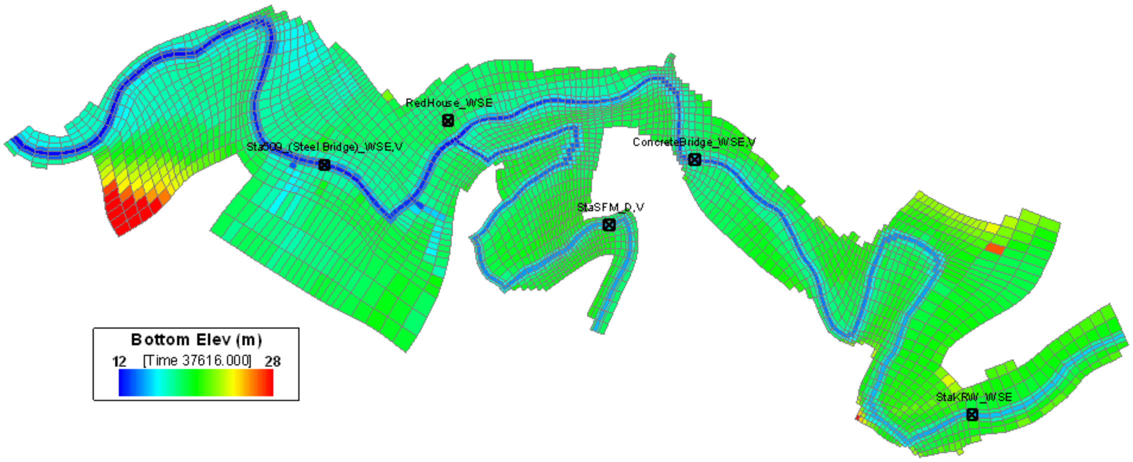
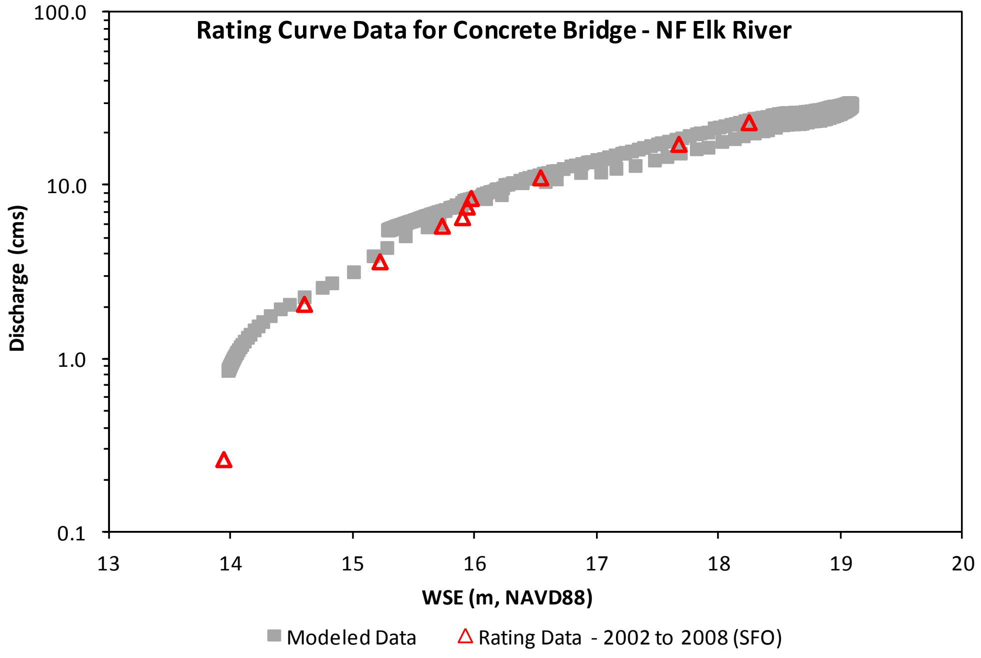


Figure 4-5. Monitoring station locations on model grid with elevations.

Rating Curve Comparisons

Figure 4-6 and Figure 4-7 show model predictions for the 25 – 30 December 2002 calibration period compared to observed rating curve data at two locations: Concrete Bridge and Station 509 (Steel Bridge). These figures show that the model adequately predicts in-channel WSE and V over a wide range of flows at these two locations.



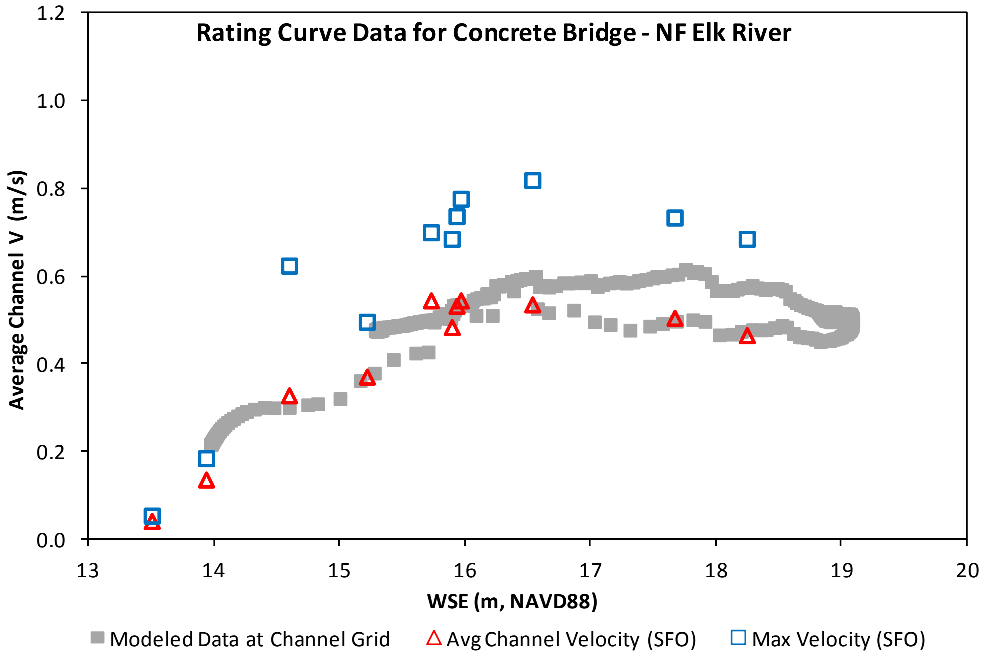
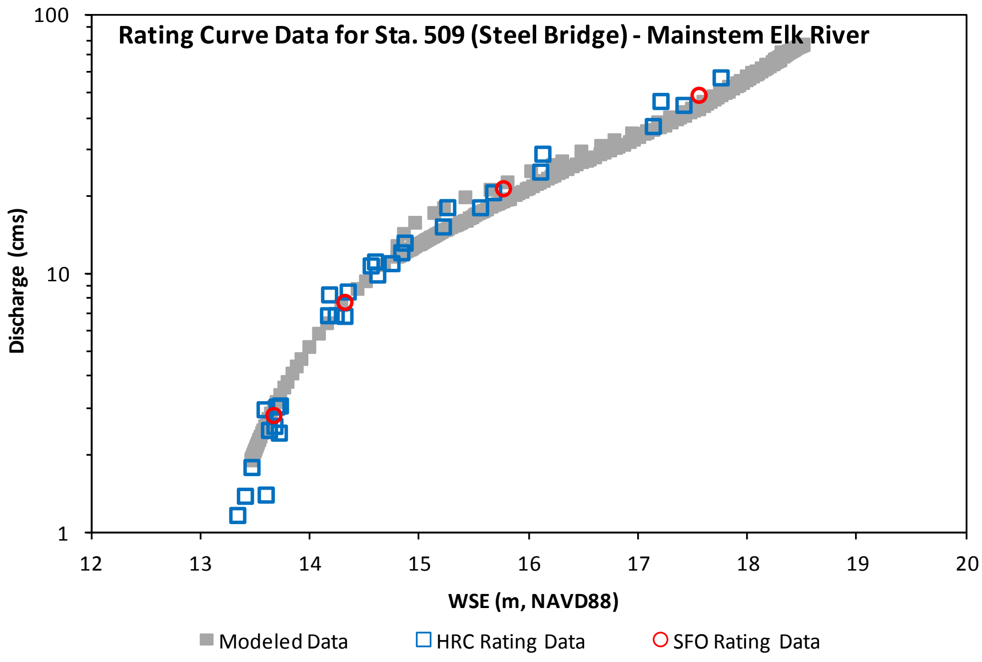


Figure 4-6. Hydrodynamic model predictions compared to observed rating curve data at the NF Elk River SFO Concrete Bridge discharge measurement stations.



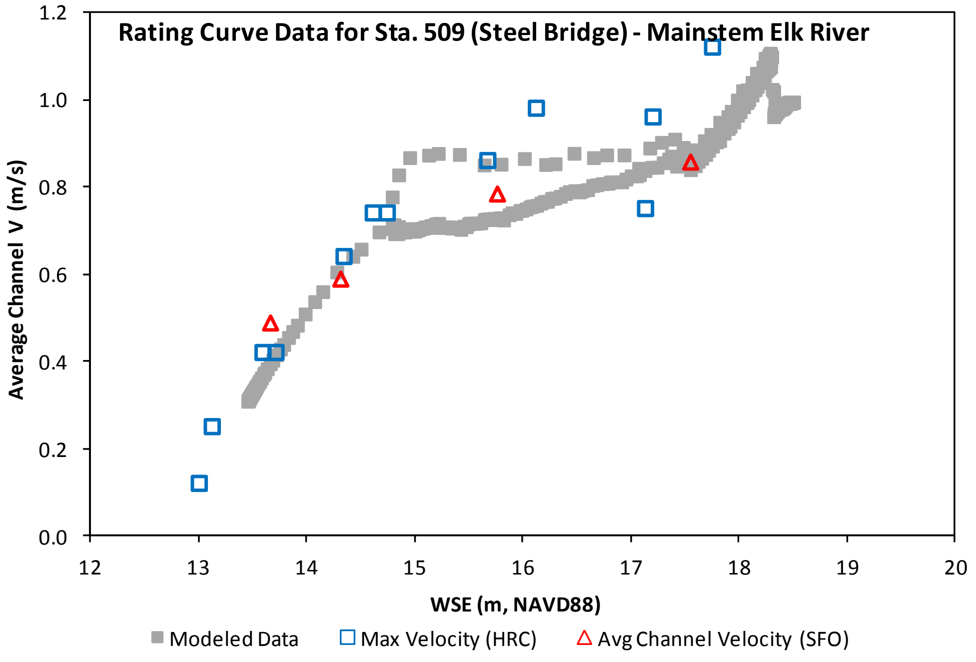


Figure 4-7. Hydrodynamic model predictions compared to observed rating curve data at the mainstem Elk River HRC Station 209 (Steel Bridge) discharge measurement station.

Water Surface Elevation Comparisons

Figure 4-8 shows the 5-day predicted WSE compared to the continuous stage record at Station KRW on the NF Elk River. The predicted maximum WSE during the 28 December 2002 flood event is shown on Figure 4-9 for the entire modeling domain, and comparison with observed peak flood elevations are provided in Table 4-3.

Overall, the calibration results indicate that the hydrodynamic model adequately simulates Q, V and WSE in the Elk River pilot project reach compared to observed data, despite the necessary assumptions and boundary condition adjustments.

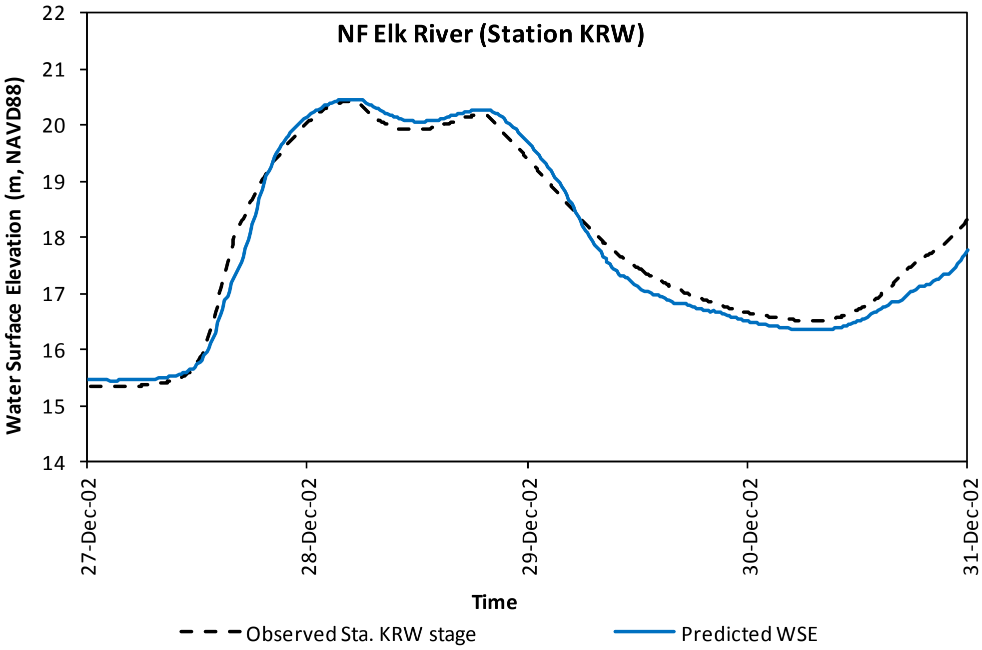


Figure 4-8. Hydrodynamic model predictions of WSE compared to observed continuous stage data in the NF Elk River (Station KRW).

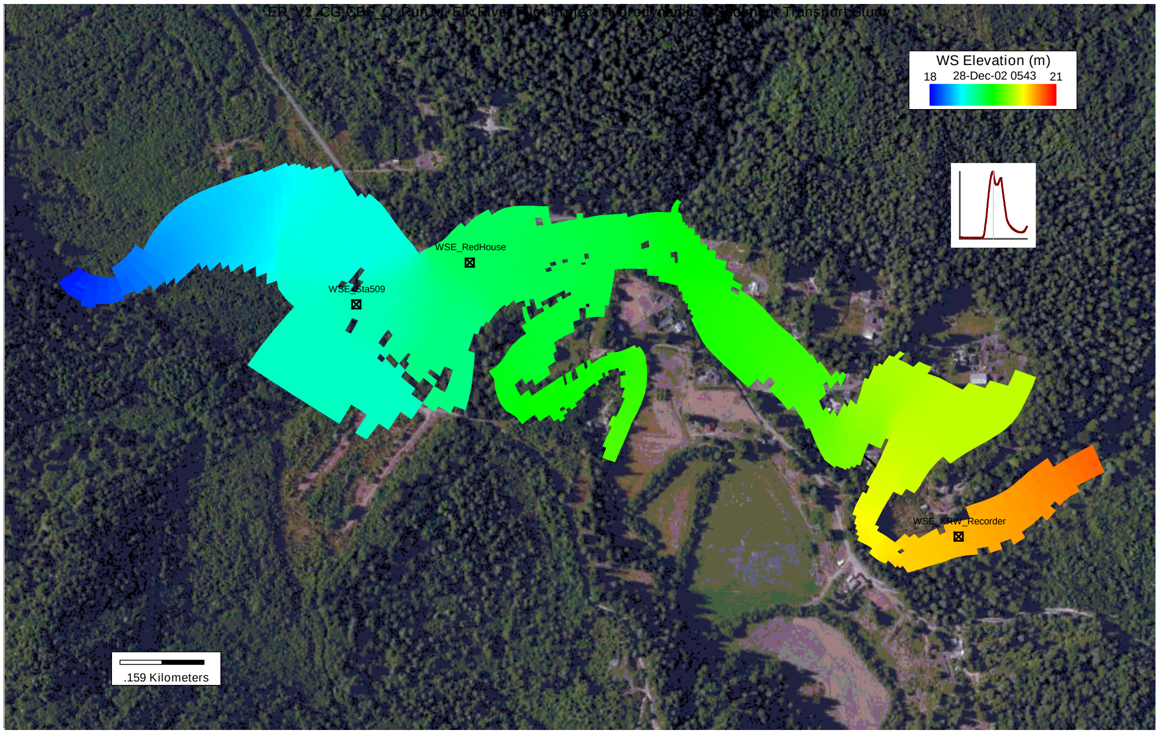


Figure 4-9. Hydrodynamic model predictions of maximum WSE and inundation extend during the 28 December 2002 flood event.

Table 4-3. Observed peak flood elevations compared to predicted maximum WSE for the 28 December 2002 flood event at three locations within the Elk River pilot project reach.

Observation Location	Observed Peak Flood Elevation (m)	Predicted Maximum WSE (m)
Station KRW (SFO) on NF Elk River	20.4	20.5
Red House (SFO) at Confluence of NF and SF Elk River	19.4	19.3
Station 509 – Steel Bridge (HRC) on mainstem Elk River	19.1	19.0

4.2 Sediment Transport Model Calibration

4.2.1 General Approach

Following hydrodynamic model calibration, the sediment transport model was calibrated for the reduced WY 2003 period that included 50 days with flows above the 3 cms threshold. Limited sediment data is available for calibrating the sediment transport model within the Elk River pilot project reach. Suspended sediment concentrations are measured at three locations (Figure 4-5): Station KRW on the NF Elk River, Station SFM on the SF Elk River, and Station 509 (Steel Bridge) on the mainstem Elk River. Since SSC data at the KRW and SFM stations are used for boundary conditions, only the SSC measurements at Station 509 on the mainstem Elk River can be used for calibration of the sediment transport model.

A number of cross-sections that have been repeatedly surveyed within the Elk River pilot project reach can be used to estimate channel bed, bank and floodplain elevation changes due to erosion and/or sedimentation. However, the cross-section resurveys have been sporadic since 2002, and no data exists for assessing sediment deposition rates for WY 2003.

Since the focus of the Elk River pilot project study was to assess the ability of the HST model to predict channel erosion and depositional patterns in the pilot project reach, a more qualitative approach was used to calibrate the sediment transport model. First, model parameters, sediment bed physical characteristics and inflow SSC gradations were adjusted so that the model generally predicted qualitative (visual) sediment aggradation and depositional patterns in the Elk River pilot project reach for WY 2003. Predicted SSC were then compared to observations at Station 509 on the mainstem Elk River near the downstream end of the pilot reach, which provides an overall assessment of how well the sediment transport model performs.

4.2.2 Sediment Classes

Based on the sediment grain size distributions discussed in Section 2.1.2, five sediment classes were defined for the sediment transport model (Table 4-4): one cohesive class, and four non-cohesive classes. The effective diameters (d_{eff}) for each class were determined using the average of the weighted geometric mean and weighted critical shear velocity methods based on the sediment grain size distributions, as described by Hayter (2006).

Table 4-4. Sediment particle size classes used in sediment transport model[1].

Sediment Classes	Particle Size Range (mm)	Geometric Mean Approach d_{eff} (mm)	Critical Shear Velocity Approach d_{eff} (mm)	Mean d_{eff} used in Model (mm)
Cohesive 1 (medium silt to clay)	$0.00024 < d_{eff} <= 0.031$	0.012	NA	0.0122
Non-Cohesive 1 (coarse silt to very fine sand)	$0.031 < d_{eff} <= 0.125$	0.069	0.069	0.069
Non-Cohesive 2 (fine to medium sand)	$0.125 < d_{eff} <= 0.5$	0.230	0.242	0.236
Non-Cohesive 3 (coarse to very coarse sand)	$0.5 < d_{eff} <= 2.0$	0.957	1.015	0.986
Non-Cohesive 4 (very fine to medium gravel)	$2.0 < d_{eff} <= 16.0$	4.938	5.261	5.099

1. NA = not applicable

4.2.3 Sediment Bed Initial Conditions

The bed sediment input requirements for the sediment transport model include:

- number of bed layers and bed layer thickness,
- initial bed fraction of each sediment class for each layer,
- porosity or void ratio for each layer, and
- bulk density for each layer.

These input data are applied to each grid cell, and can be constant or spatially varied. The remainder of this section summarizes the sediment bed input parameters and overall process of initializing the sediment bed.

The sediment data described in Section 2.1.2 were used to establish five distinct sediment bed zones within the Elk River pilot project reach:

- coarse channel bed mainstem Elk River,
- coarse channel bed SF Elk River,
- fine channel bed (rest of river),
- channel banks, and
- floodplains.

Each of the five sediment bed zones was digitized as polygons onto the model grid. Wet bulk density and porosity were assigned to each sediment zone (Table 4-5), and sediment gradations were established for each sediment zone (Figure 4-10) using Section 2.1.2 data. The five sediment layers and thicknesses assumed for the sediment bed, which were applied uniformly over the entire model grid, are as follows:

1. top surface layer = 0.1 m,
2. first subsurface layer = 0.15 m,
3. second subsurface layer = 0.25 m,
4. third subsurface layer = 0.5 m thick, and
5. fourth subsurface layer = 2.0 m.

All bed layers were assigned the same sediment bed properties within the sediment bed zones. The above bed sediment properties were mapped to the model grid using the Digital Sediment Model approach available in EFDC_Explorer6 (Craig 2011). Figure 4-11 shows the sediment bed initial conditions for porosity. Figure 4-12 through Figure 4-14 show the sediment fraction initial conditions for cohesive 1, non-cohesive 1 and non-cohesive 3 sediment classes (Table 4-4), respectively. Figure 4-15 shows the initial condition sediment bed d_{50} following model grid initialization.

Table 4-5. Wet bulk density and porosity for each sediment bed zone.

Sediment Bed Zone	Wet Bulk Density (kg/m^3)	Porosity
Coarse channel bed mainstem Elk River	2195	0.275
Coarse channel bed SF Elk River	1549	0.667
Fine channel bed (rest of river)	1412	0.750
Channel bank	1735	0.555
Floodplain	1660	0.600

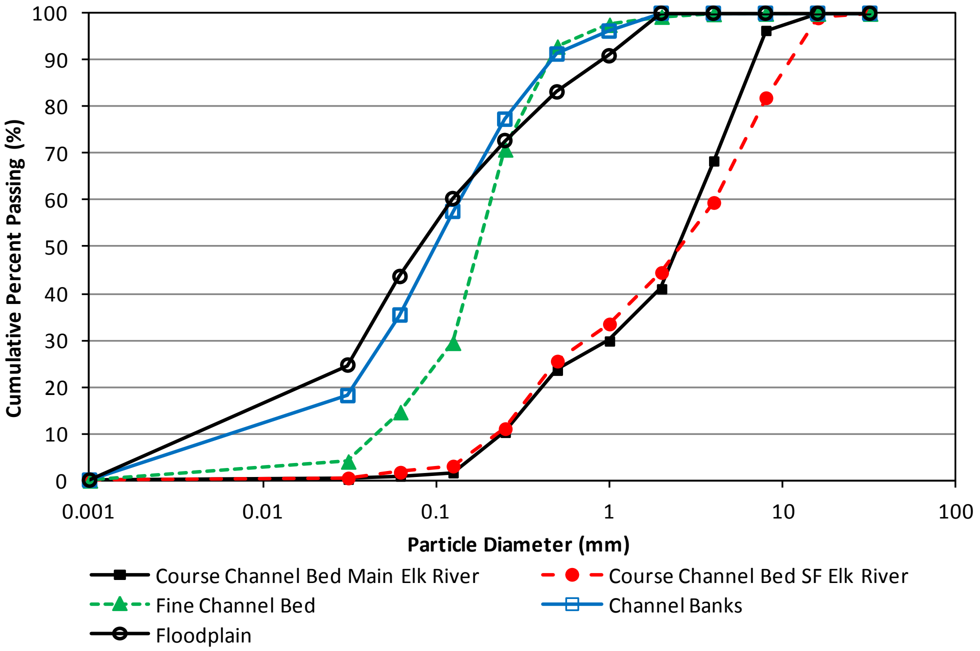


Figure 4-10. Sediment grain size distributions for each sediment bed zone.

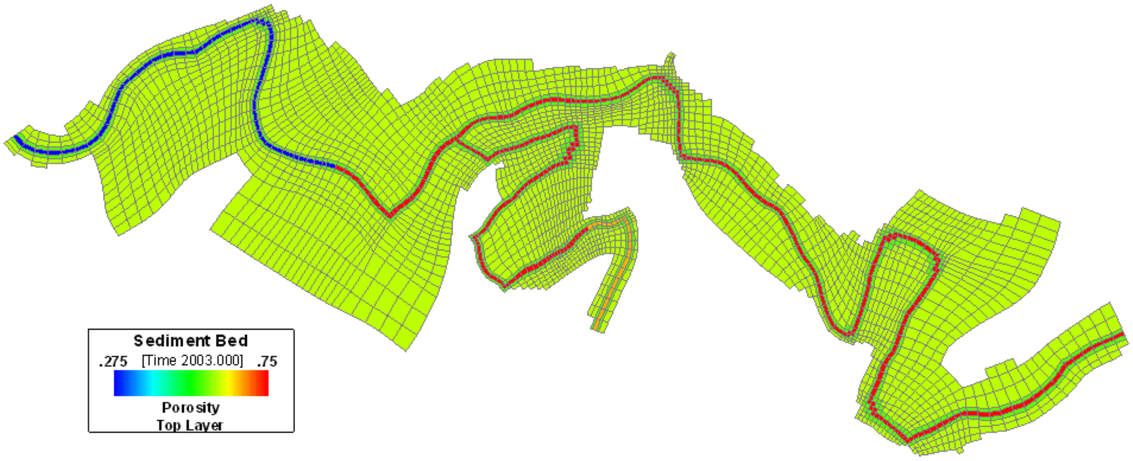


Figure 4-11. Sediment bed porosity used for model grid initialization.

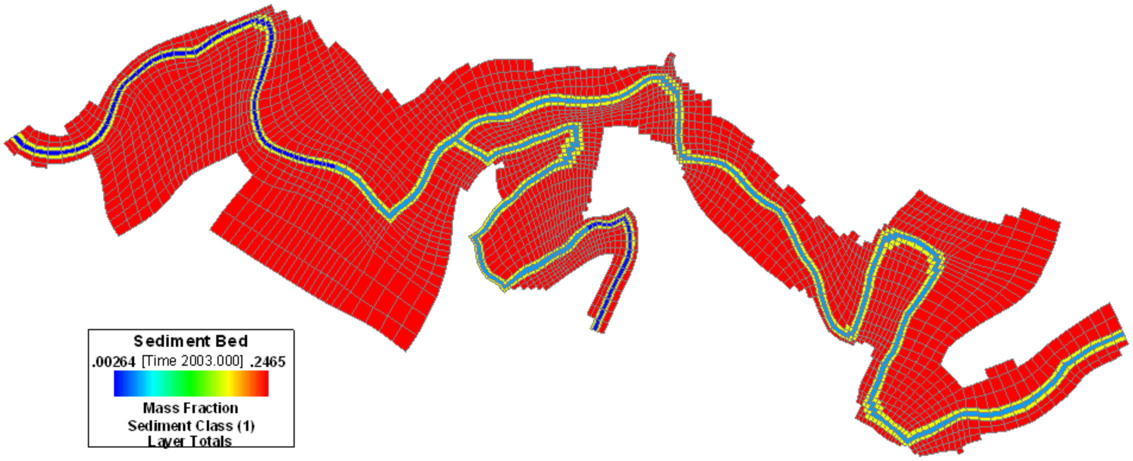


Figure 4-12. Fraction of Cohesive 1 sediment (d_{eff} < 0.031 mm) in the sediment bed used for model grid initialization.

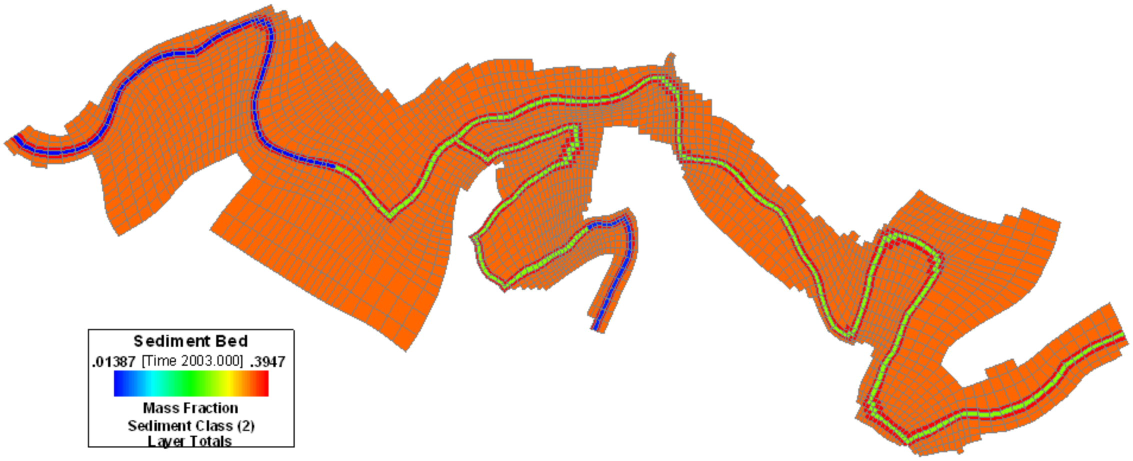


Figure 4-13. Fraction of Non-Cohesive 1 sediment (0.031 mm < d_{eff} <= 0.125 mm) in the sediment bed used for model grid initialization.

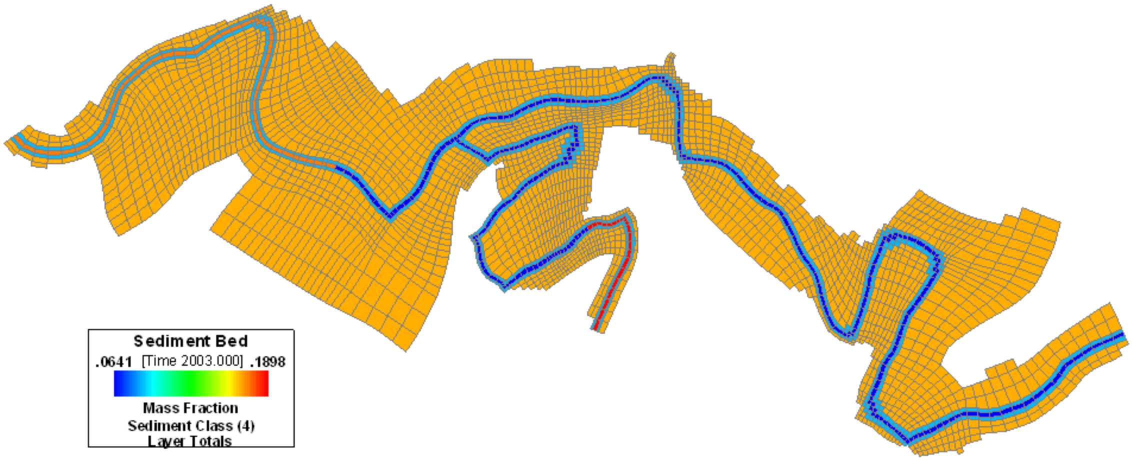


Figure 4-14. Fraction of Non-Cohesive 3 sediment (0.5 mm < d_{eff} <= 2 mm) in the sediment bed used for model grid initialization.

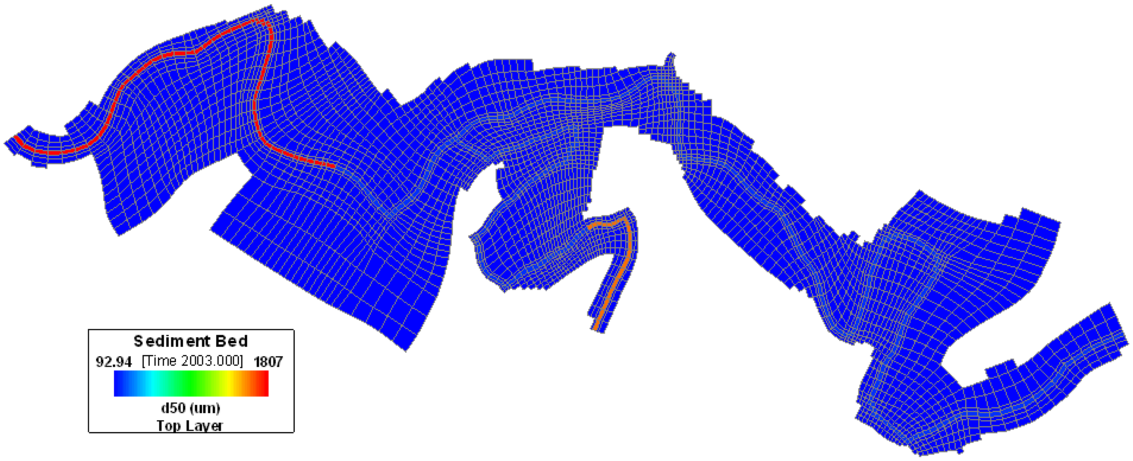


Figure 4-15. Sediment bed d_{50} following model grid sediment initialization.

4.2.4 Inflow Total Suspended Sediment Load

The incoming SSL at the upstream boundary in the NF and SF Elk Rivers, Railroad Gulch and Clapp Gulch were estimated using the adjusted inflows (Section 4.1.2), SFO 10-min continuous SSC records and estimated SSC records for the Gulch's (Section 3.4). Table 4-6 summarizes the estimated total SSL for each inflow by water year, along with the total SSL for the pilot project reach. Variations in the annual total SSL for WY 2003 to 2008 are shown in Figure 4-16, with the average SSL for this six-year period being 30,114 MT/yr. Significant sediment loads occurred in WY 2003 and WY 2008.

Table 4-6. NF and SF Elk River, Railroad Gulch, Clapp Gulch and total pilot project reach estimated SSL for the reduced WY 2003-08 simulation period.

Water Year	NF Elk River Total SSL (MT/yr)	SF Elk River Total SSL (MT/yr)	Railroad Gulch Total SSL (MT/yr)	Clapp Gulch Total SSL (MT/yr)	Total Pilot Project Reach SSL (MT/yr)
2003	19,550	27,808	4,147	3,028	54,533
2004	7,017	6,749	1,997	1,380	17,143
2005	7,853	9,146	2,066	1,436	20,501
2006	23,727	24,530	4,630	3,231	56,118
2007	6,259	6,683	1,823	1,284	16,048
2008	5,824	7,564	1,725	1,228	16,340
Average	**11,705**	**13,747**	**2,731**	**1,931**	**30,114**

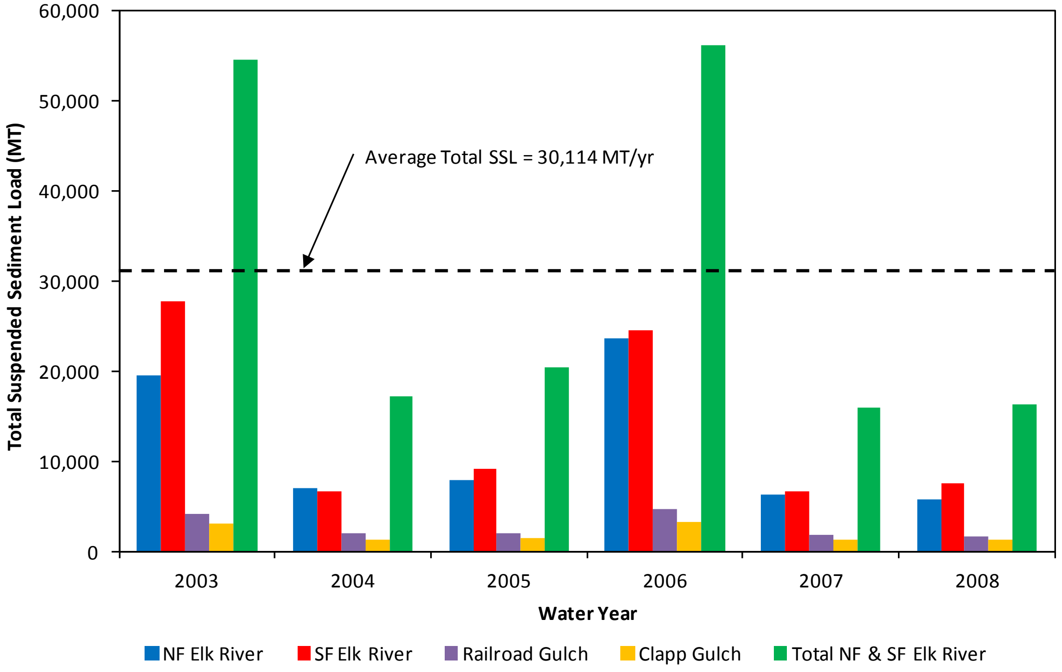


Figure 4-16. Estimated SSL for NF and SF Elk River, Railroad and Clapp Gulch, and total SSL to pilot project reach for the reduced WY 2003-08 simulation period.

4.2.5 Inflow SSC Boundary Condition Particle Size Distribution

The boundary condition SSC 10-min continuous inflow records described in Section 3.4 need to be specified into the five sediment classes (Table 4-4). Detailed particle size distributions of suspended sediment in the Elk River pilot project reach have not been collected or analyzed/described. However, SFO has analyzed the fine sediment/sand fraction break (fine sediment < 0.063 mm) of suspended sediment samples collected at Stations KRW (NF Elk River) and SFM (SF Elk River), which are the data sources for the SSC boundary conditions. SFO (2011) concluded that no apparent relationship between sand fraction and SSC or discharge exists at the KRW and SFM stations.

The following approach was used to estimate the composition of the incoming SSC at the four boundary conditions:

1. The average fine sediment fraction was determined for Stations KRW and SFM using available data (SFO 2011): Station KRW (NF Elk River) = 85.09 %, and Station SFM (SF Elk River) = 90.27 %. For Railroad Gulch and Clapp Gulch a fine sediment fraction of 85 % was assumed.
2. The cohesive 1 sediment class (Table 4-4) was assumed equal to the fine sediment fraction. The total percent of the 4 non-cohesive classes were assumed equal to the difference between 100 % and the fine sediment fraction.
3. Based on the collected bed sediment data (Section 2.1.2) and model calibration (trial-and-error), each of the 4 non-cohesive classes was assigned a percentage of the total percentage of the 4 non-cohesive classes.
4. Results from steps 2 and 3 were then combined to create the sediment particle size class breakdown for each SSC input boundary condition (Table 4-7), which was applied to the entire 10-minute SSC record.

Figure 4-17 to Figure 4-20 show the WY 2003-08 simulation period concentrations of total SSC for each sediment class based on the approach described above for each inflow boundary condition. These figures are plotted on a logarithmic vertical axis for clarity.

Table 4-7. Estimated total SSC breakdown per sediment particle size class at each inflow boundary condition.

Sediment Classes	**Fraction (%) of Total SSC**			
	NF Elk River	**SF Elk River**	**Railroad Gulch**	**Clapp Gulch**
Cohesive 1 (medium silt to clay)	85.09	90.27	85.00	85.00
Non-Cohesive 1 (coarse silt to very fine sand)	10.44	6.81	9.00	7.50
Non-Cohesive 2 (fine to medium sand)	3.73	2.43	4.50	6.00
Non-Cohesive 3 (coarse to very coarse sand)	0.67	0.44	1.05	1.05
Non-Cohesive 4 (very fine to medium gravel)	0.07	0.05	0.45	0.45

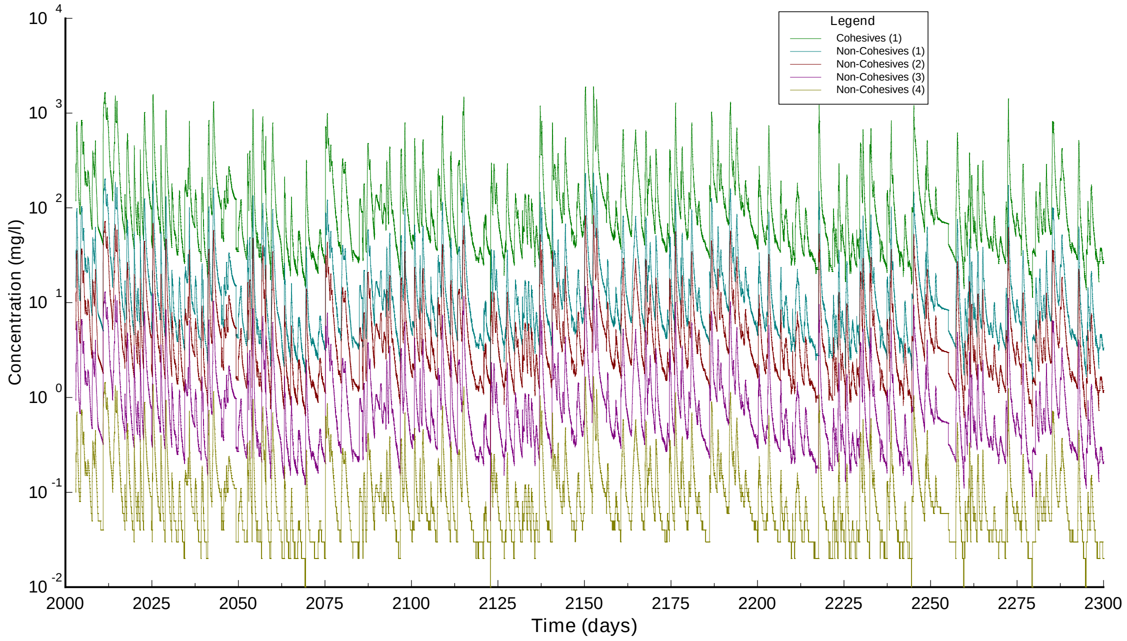


Figure 4-17. NF Elk River SSC sediment particle class breakdown.

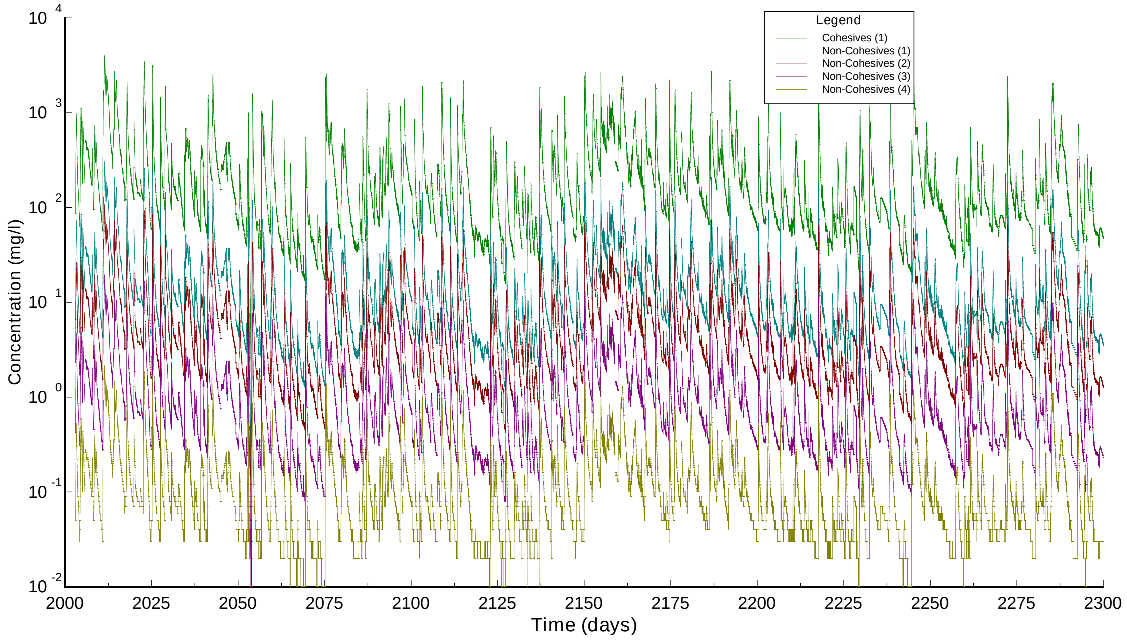


Figure 4-18. SF Elk River SSC sediment particle class breakdown.

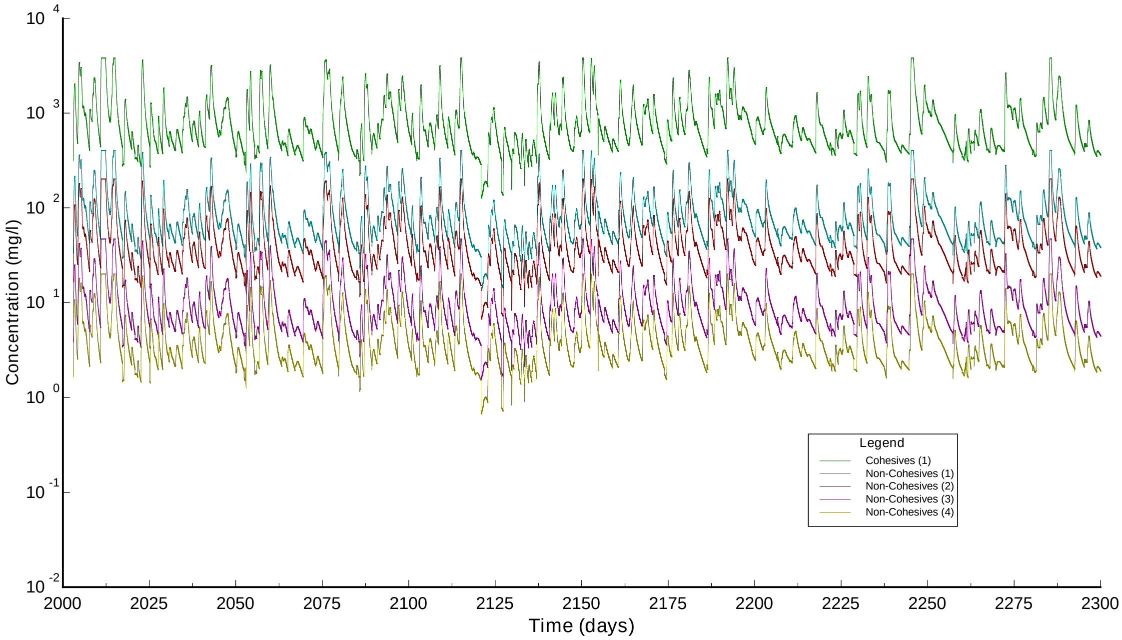


Figure 4-19. Railroad Gulch SSC sediment particle class breakdown.

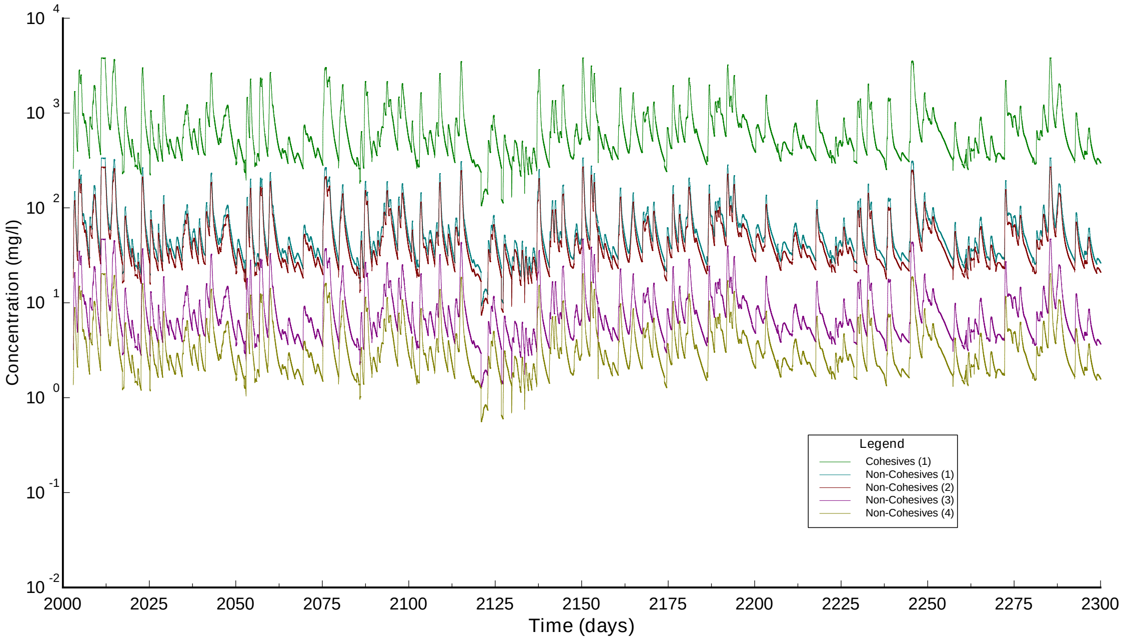


Figure 4-20. Clapp Gulch SSC sediment particle class breakdown.

4.2.6 Sediment Transport Model Parameters and Numerical Options

Key sediment transport model parameters (Table 4-8) were determined through model calibration or from literature values. A number of EFDC sediment transport model options were implemented for this simulation, and the key options are outlined below.

Bed shear stress was separated into cohesive and non-cohesive fractions within the EFDC model. The Krone (1963) probability of deposition approach using the cohesive grain stress was used for cohesive suspended sediment transport within the EFDC model. The Van Rijn (1984) near-bed equilibrium concentration formulation was used for non-cohesive suspended sediment transport. Non-cohesive settling velocity, critical shear stress and critical shields stress were determined internal to the EFDC model using the approach of Van Rijn (1984). The Wu et al. (2000) bedload function was used for non-cohesive bedload transport using default parameters.

To reduce computation time, the sediment transport model was computed every fourth time steps of the hydrodynamic model.

Table 4-8. Key parameters and EFDC model options used in the sediment transport model for the Elk River pilot project.

Model Parameter/Option	Value/Description	Source
Anti-diffusion correction/flux limitation option in EFDC	Off/off	EFDC option
Maximum sediment bed layer thickness before new layer added to sediment bed model	0.5 m	Calibration, estimate
Non-cohesive roughness grain size for stress separation	$2d_{50}$	Calibration, EFDC option
Cohesive 1 settling velocity	0.0001 m/s	Calibrated within range of literature values (Ji 2008, Tetra Tech 2007b)
Cohesive 1 critical shear stress for deposition	0.1 N/m^2	Calibrated within range of literature values (Ji 2008, Tetra Tech 2007b)
Cohesive 1 critical shear stress for erosion	0.1 N/m^2	Calibrated within range of literature values (Ji 2008, Tetra Tech 2007b)
Reference surface erosion rate	0.005 g/m^2/s	Calibrated within range of literature values (Ji 2008, Tetra Tech 2007b)
Constant bed porosity (θ) for depositing non-cohesive sediment	0.605	Average of all measured sediment porosity values (Section 2.1.2)
Void ratio (ε) of depositing cohesive sediment	1.532	Estimated based on bed porosity by equation: $\varepsilon = \theta/(1-\theta)$
Non-cohesive bed armoring	Not used	EFDC option
Maximum adverse slope for bedload transport	0.05	Calibration

4.2.7 Initial Conditions and Model Spin-Up

The same water depth and velocity initial conditions used in the hydrodynamic model calibration were used for the sediment transport model calibration. The initial SSC concentrations were assumed equal to 5 mg/l for the cohesive sediment (cohesive 1 sediment class), and 0 mg/l for the four non-cohesive sediment classes. Since the WY 2003 model run began at a relatively low-flow of 3 cms, any effects of the initial SSC concentrations quickly dissipated during the first storm peak.

The bed sediment initial conditions were described in Section 4.2.3. Adjustment of the initial bed conditions, which were developed from data collected over a large spatial domain, requires a longer period to adjust to local velocity, depth, shear stress and incoming SSC. Thus, the entire WY 2003 calibration run was used as the model spin-up period for sediment bed characteristics such as d_{50} and porosity. Sediment bed characteristics and changes from initial conditions were not assessed during the calibration period, but are assessed for the long-term simulations (WY 2003-08) (see Section 5 and 6). Cumulative sedimentation patterns at the end of WY 2003 calibration run were assessed.

4.2.8 Sediment Transport Model Calibration Results

Results of the sediment transport model runs for WY 2003 were compared to qualitative (visual) sediment depositional patterns observed in the Elk River pilot project reach during WY 2003 (Adona White, RWQCB, 2012 personal communication). Predicted SSC were compared to depth integrated SSC samples at the HRC Station 509 (Steel Bridge) on mainstem Elk River.

Overall Sediment Depositional Patterns

Figure 4-21 and Figure 4-22 show model predictions of cumulative sedimentation (elevation changes) at the end of the WY 2003 simulation period at different figure scales. Figure 4-21 shows results with an elevation change scale of 0 to 0.1 m, which provides better overall resolution of sedimentation patterns, particularly on the floodplains. The scale on Figure 4-22 is from -0.1 to 0.3 m, which better illustrates overall in-channel sedimentation patterns. It should be noted that net sediment deposition and scour estimates occurred at various locations within the model grid that were greater or less than the selected scales on these figures.

Reach Scale Sedimentation (Elevation Changes)

Average, minimum and maximum cumulative sedimentation (elevation changes) at the end of the WY 2003 simulation period (Table 4-9) were extracted from the model domain within the established vegetative zones (Table 4-2, Figure 4-4), and the fine and coarse channel bed designations (Table 4-5). Overall cumulative sedimentation values appear reasonable and are consistent with visual sediment deposition patterns in the pilot project reach following WY 2003 (Adona White, RWQCB, 2012 personal communication).

Table 4-9. Reach scale cumulative sedimentation (elevation change) at the end of WY 2003 simulation period extracted from the model grid within the different channel and vegetation zones.

Model Grid Zone	Average Sedimentation (m)	Minimum Sedimentation (m)	Maximum Sedimentation (m)
Total channel bed	0.157	-0.589	1.006
Coarse channel bed	0.090	-0.589	0.731
Fine channel bed (rest of river)	0.176	-0.479	1.006
Channel banks	0.101	-0.222	0.521
Riparian area on floodplain	0.019	-0.019	0.258
Pasture area on floodplain	0.008	-0.015	0.045
Forest area on floodplain	0.013	-0.016	0.056

SSC Comparisons at Station 509

Predicted SSC values for the WY 2003 simulation were compared to depth integrated SSC values collected by HRC at Station 509 (Steel Bridge) on the mainstem Elk River (SSC values provided by RWQCB 2011). Only four of the SSC observations for WY 2003 included day and time of sampling. The remaining SSC measurements only had the day of sampling, which precluded developing rigorous statistics between model predictions and observations.

Figure 4-23 shows the predicted SSC compared to the observed depth integrated SSC values for the entire WY 2003 simulation period at Station 509 (Steel Bridge) on mainstem Elk River. Figure 4-24 shows a correlation plot between predicted and observed SSC at Station 509. Although only four SSC data points were available with a complete time stamp, the measured and predicted data still plot along the 1:1 line.

Calibration results indicate that the sediment transport model appears to reasonably reproduce sediment deposition patterns and cumulative sedimentation within the Elk River pilot project reach, and SSC at Station 509 within the mainstem Elk River.

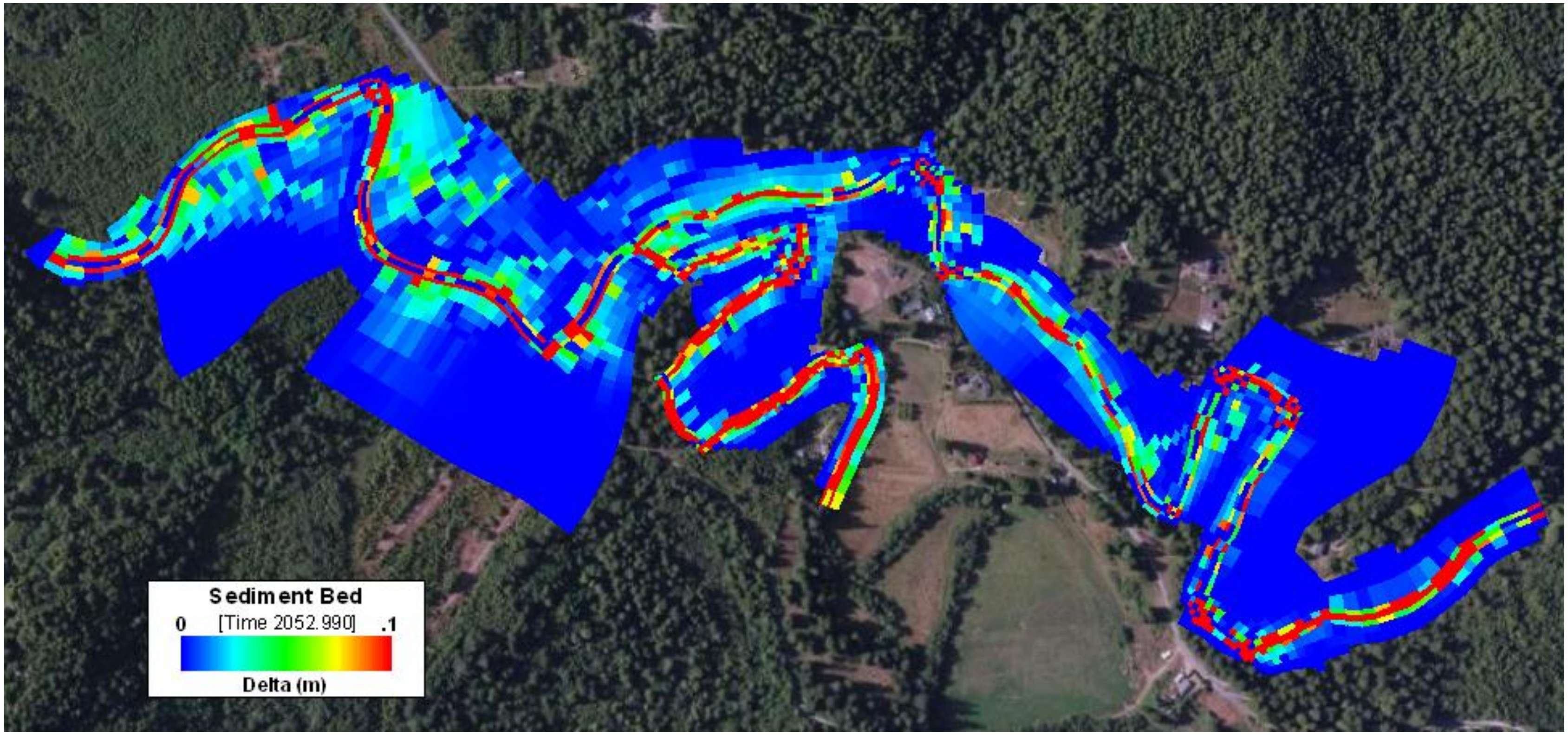


Figure 4-21. Predicted WY 2003 cumulative sedimentation (elevation change) in Elk River pilot project reach. Scale of figure shows 0 to 0.1 m of sedimentation, which best illustrates overall sediment deposition patterns in channel, channel bank and floodplain locations.

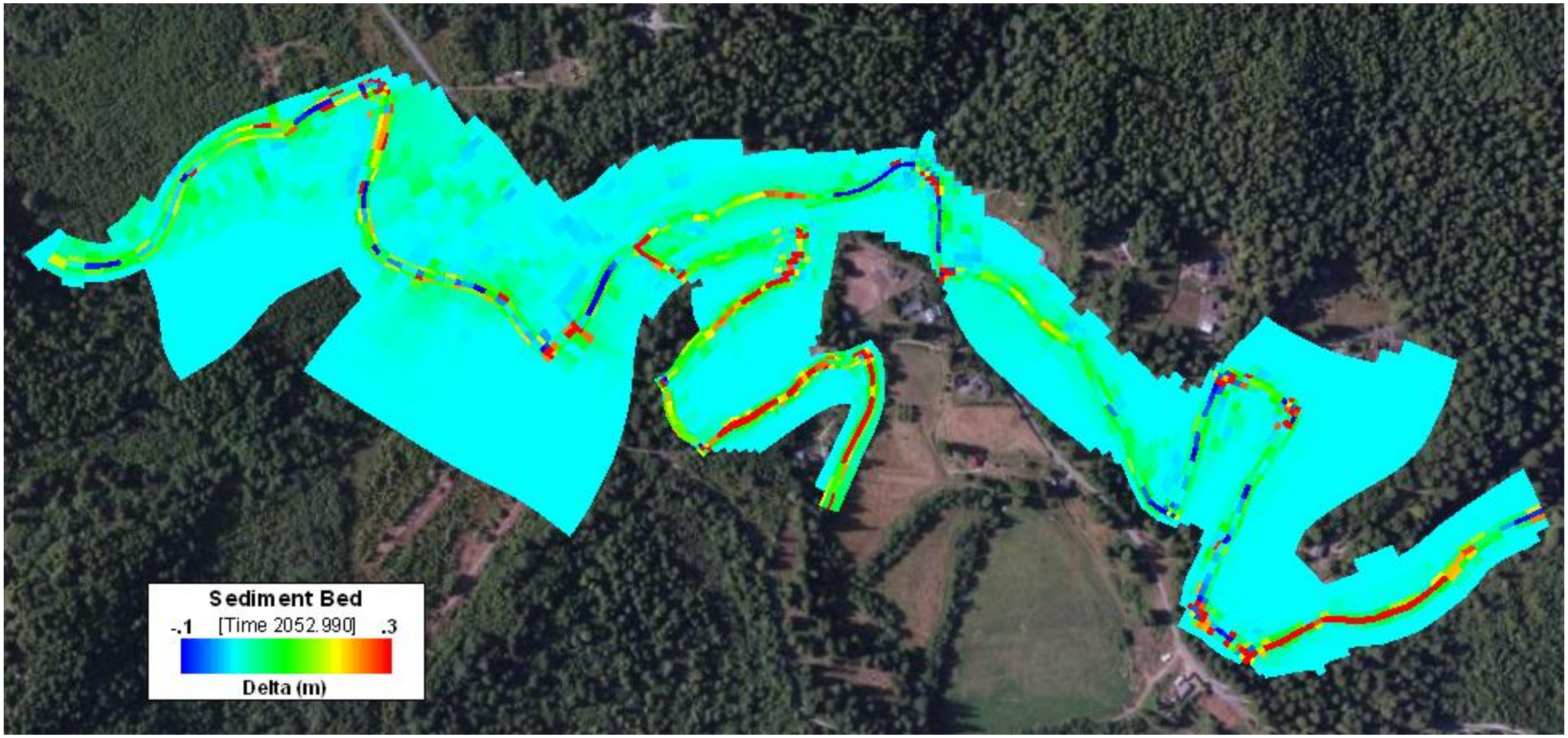


Figure 4-22. Predicted WY 2003 cumulative sedimentation (elevation change) in Elk River pilot project reach. Scale of figure shows -0.1 to 0.3 m of sedimentation, which best illustrates overall sediment deposition patterns in channel and channel bank locations.

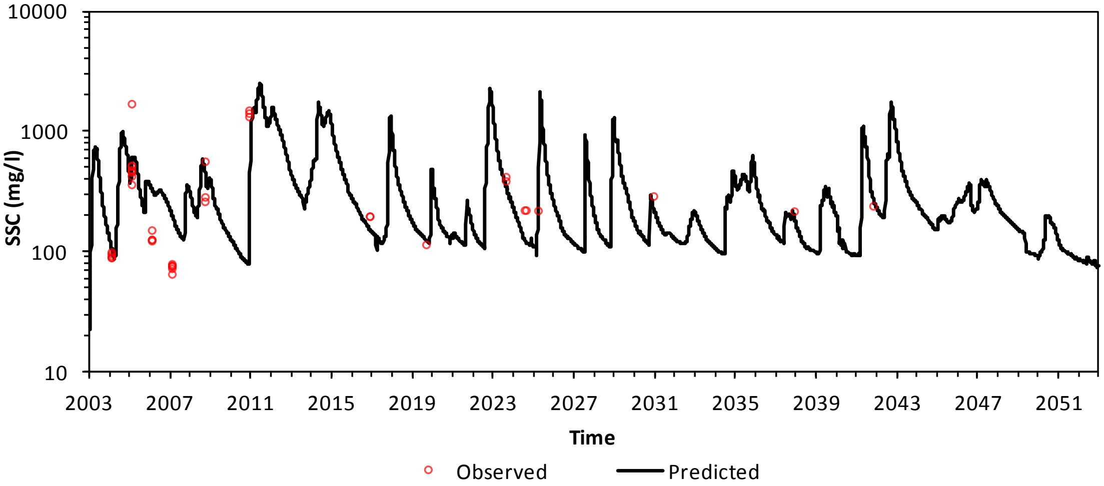


Figure 4-23. Time series of SSC for reduced WY 2003 simulation period at HRC Station 509 (Steel Bridge) on mainstem Elk River (time is in days).

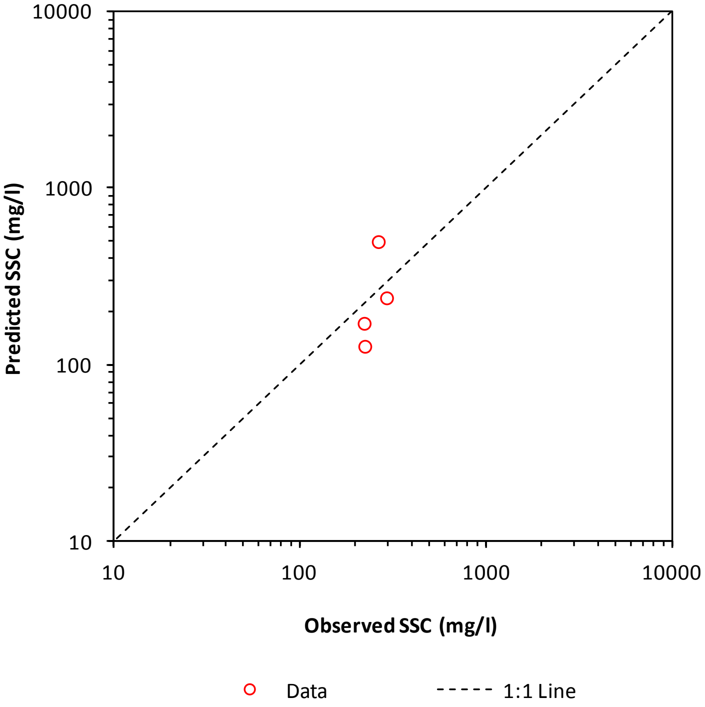


Figure 4-24. Correlation plot of observed and predicted SSC at Station 509 (Steel Bridge) for reduced WY 2003 simulation period.

5 RESULTS OF SIX-YEAR (WY 2003-08) HST MODEL SIMULATIONS FOR EXISTING SEDIMENT SUPPLY CONDITIONS

This chapter describes results for the six-year long (WY 2003-08) simulations for existing sediment conditions using the calibrated HST model. Results for the existing sediment supply conditions run were compared to elevation changes (also referred to as cumulative sedimentation or sedimentation for the remainder of this report) estimated from cross-section surveys over available time periods. Model results for Q, WSE and V for WY 2003-08 were compared to the rating curve data at the NF Elk Concrete Bridge and mainstem Elk River Station 509 (Steel Bridge) stations. Predicted Q, WSE and SSC were also compared to observations at Station 509 for WY 2004-08. Section 7 provides suggestions for improving future HST modeling efforts on the Elk River.

For this report, positive bed elevation change (or sedimentation) refers to deposition. Negative bed elevation changes refer to scour.

5.1 Elevation Change Measured at Cross-Sections within the Elk River Pilot Project Reach

To provide a quantitative assessment of predicted sedimentation, HST model results were compared to elevation changes determined from cross-section surveys located within the pilot project reach (Figure 2-1). Specific cross-sections were surveyed within the pilot project reach at different times between 2002 and 2007:

1. In 2002, all 23 cross-sections shown on Figure 2-1 were surveyed.
2. In 2006, four cross-sections (XS 10, 11, 12 and 13) were surveyed on the NF Elk River above the Concrete Bridge near Station KRW.
3. In 2007, three cross-sections (XS 4, 6, 8) were surveyed on the NF Elk River between the Concrete Bridge and confluence; two cross-sections (XS 18 and 22) were surveyed on the SF Elk River between Station SFM and confluence; and three cross-sections (XS 1, 2 and 3) were surveyed on the mainstem Elk River downstream of the confluence.

The RWQCB (Adona White, RWQCB, 2012 personal communication) provided a summary of bed, bank and floodplain elevation changes determined from the cross-section surveys (SFO 2011) within the pilot project reach (Table 5-1). A sub-reach median cumulative sedimentation value for the period between cross-section surveys is provided in the table, along with an estimated annual sedimentation rate which is equal to the elevation change divided by the time period. To provide a reach scale comparison between predicted and measured sedimentation, time-weighted reach average sedimentation rates are also provided in Table 5-1. The measured bed, bank and floodplain sedimentation rates were compared to predicted values at the grid (cross-section scale), sub-reach and reach scale.

Table 5-1. Summary of elevation changes measured at surveyed cross-sections for different time periods within the Elk River pilot project reach.

Location (upstream to downstream)	Cross-Section No.	Channel (m or m/yr)	Left Bank (m or m/yr)	Right Bank (m or m/yr)	Left Floodplain (m or m/yr)	Right Floodplain (m or m/yr)
NF Elk River above Concrete Bridge (WY 2003-06)	XS 13	0.049	-0.182	-0.082		
	XS 12	0.263	0.114	0.185	0.035	
	XS 11	0.305	0.176	0.089		
	XS 10	0.021	0.162	0.082		
Sub-Reach Median		**0.156**	**0.138**	**0.085**	**0.035**	
Sub-Reach Med. Rate		**0.039**	**0.035**	**0.021**	**0.009**	
NF Elk River between Concrete Bridge and confluence (WY 2003-07)	XS 8	0.074	0.149	0.125		
	XS 6	0.662	0.203	1.116		0.093
	XS 4	0.409	0.153	0.152		
Sub-Reach Median		**0.409**	**0.153**	**0.152**		**0.093**
Sub-Reach Med. Rate		**0.082**	**0.031**	**0.030**		**0.019**
SF Elk River between Sta. SFM and confluence (WY 2003-07)	XS 18	-0.021	0.259	0.335		
	XS 22	-0.020	0.077	0.305		
Sub-Reach Median		**-0.021**	**0.168**	**0.320**		
Sub-Reach Med. Rate		**-0.004**	**0.034**	**0.064**		
mainstem Elk River below confluence (WY 2003-07)	XS 3	0.450	0.728	0.113		
	XS 2	-0.053	0.285	0.037		
	XS 1	0.246	0.268	0.168		0.104
Sub-Reach Median		**0.245**	**0.285**	**0.113**		**0.104**
Sub-Reach Med. Rate		**0.049**	**0.057**	**0.023**		**0.021**
Weighted Reach Average[1]		**0.201**	**0.209**	**0.229**		**0.081**
Weighted Reach Average Rate[1]		**0.043**	**0.043**	**0.047**		**0.017**

1) The weighted reach average value and rate for the floodplain are for the combined right and left floodplains.

5.2 Grid Scale (Cross-Section) Sedimentation Assessment

Channel bed, bank and floodplain elevation changes were extracted from the model grid at the location of each cross-section in Table 5-1. Figure 5-1, Figure 5-2, Figure 5-3 and Figure 5-4 show the measured and predicted cumulative sedimentation at each cross-section and associated grid cell for the channel bed, left channel bank, right channel bank and floodplain, respectively. The HST model generally predicts the overall net sediment deposition pattern for the channel bed and banks, and floodplain, but significant variability exists between measured and predicted sedimentation values. The model also predicts some grid cell scour in the channel bed compared to measured deposition at the corresponding cross-section (Figure 5-1).

Measured (cross-section values) and predicted longitudinal bed elevation change within the NF and mainstem Elk River channel for WY 2003-06 and WY 2003-07, and SF Elk River channel for WY 2003-07 are shown on Figure 5-5, Figure 5-6 and Figure 5-7, respectively. For these figures, the predicted bed elevation changes were extracted at each channel grid cell. At the grid cell spatial scale the model appears to reasonably predict net bed elevation change (sedimentation) compared to available cross-section data. However, significant channel bed variability exists at this spatial scale. The extreme (0.5 to 1.0 meter) high and low spikes in the bed profile may be an artifact of the model grid resolution at the meander bend cross-over cells. Grid resolution or reconfiguration in these areas should be investigated in future Elk River modeling phases.

These results indicate that significant variability exists in the predictive capability of the model at the grid cell scale, which is not surprising as the sediment transport model was developed for larger spatial scale predictions.

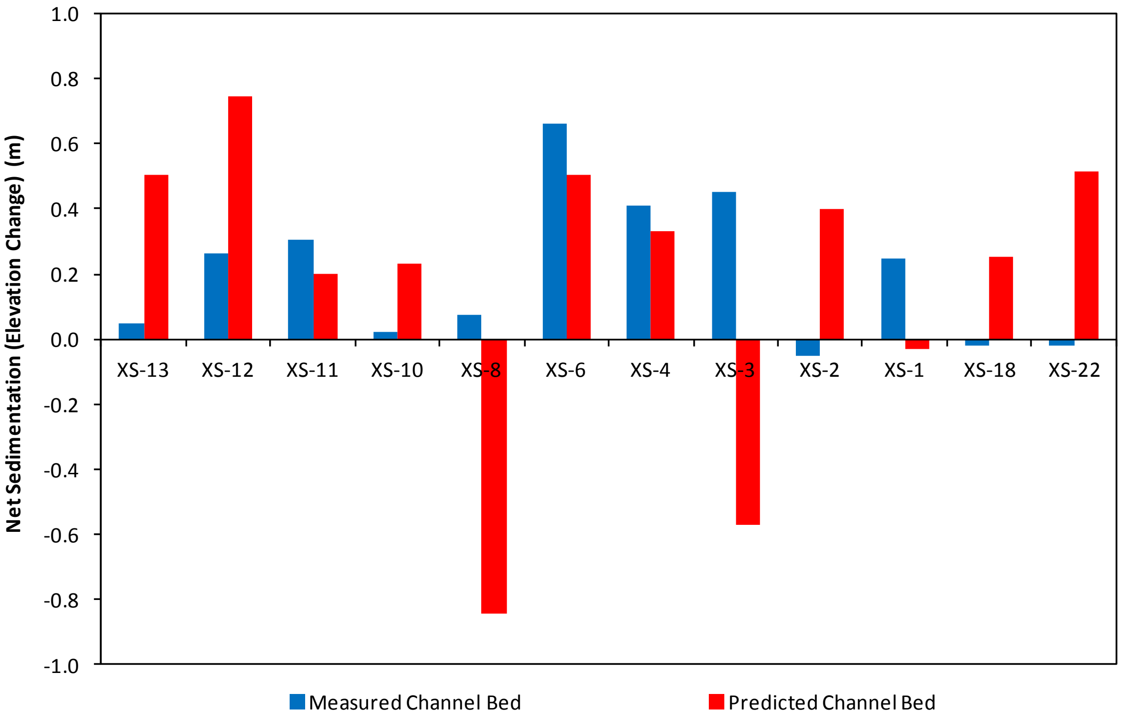


Figure 5-1. Measured and predicted channel bed cumulative sedimentation at cross-section and associated grid cell locations (grid scale) within the Elk River pilot project reach.

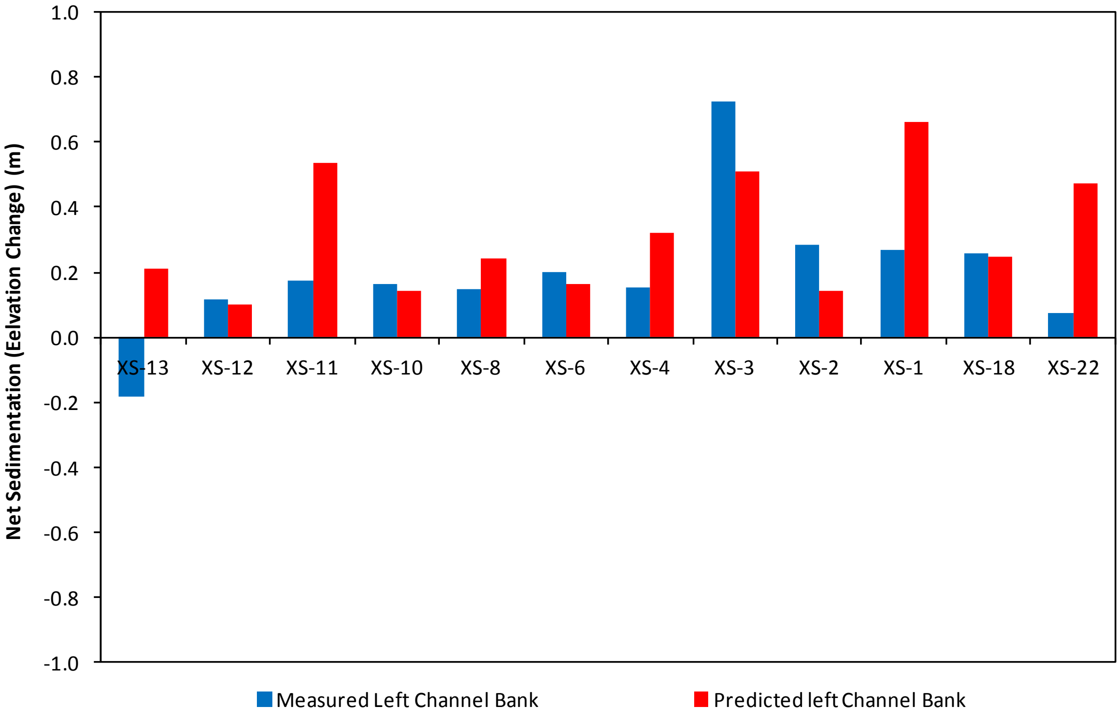


Figure 5-2. Measured and predicted left channel bank cumulative sedimentation at cross-section and associated grid cell locations (grid scale) within the Elk River pilot project reach.

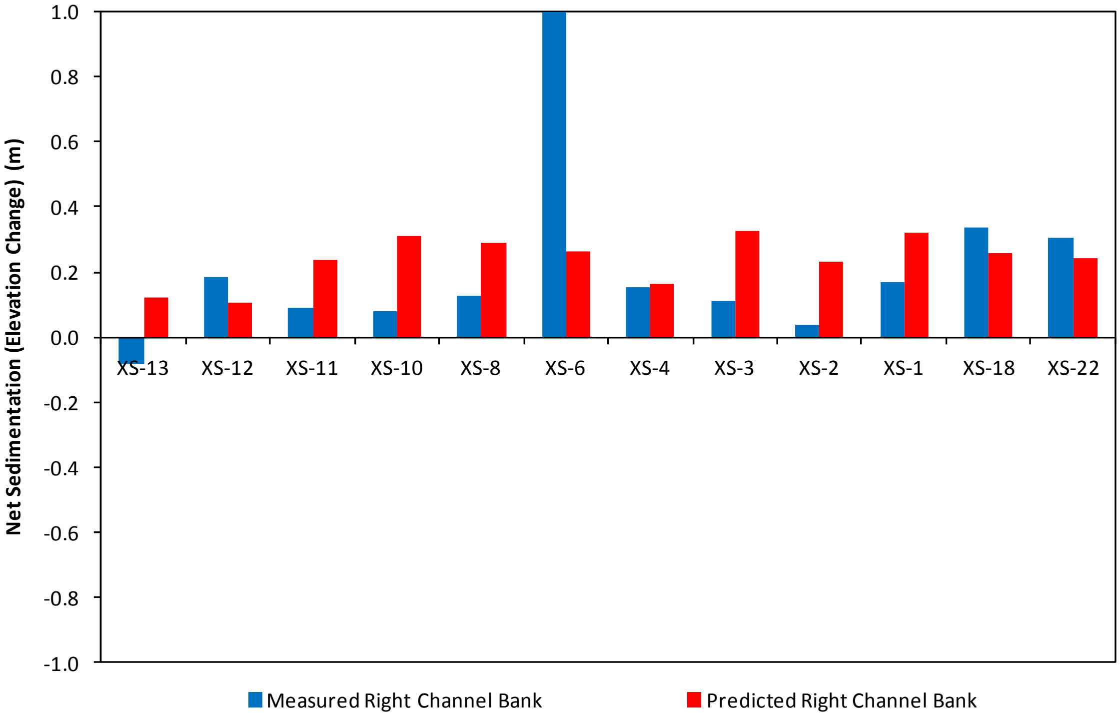


Figure 5-3. Measured and predicted right channel bank cumulative sedimentation at cross-section and associated grid cell locations (grid scale) within the Elk River pilot project reach.

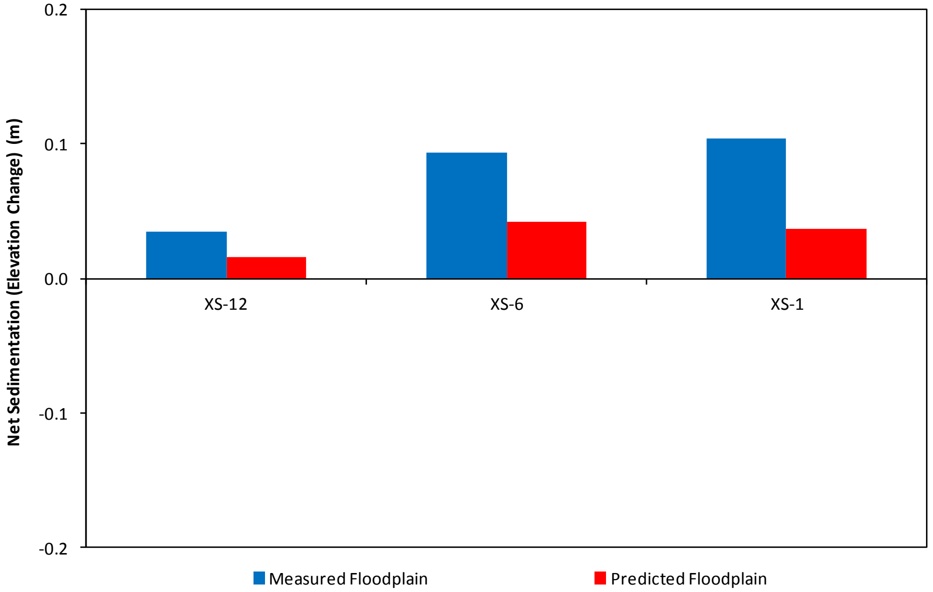


Figure 5-4. Measured and predicted floodplain cumulative sedimentation at cross-section and associated grid cell locations (grid scale) within the Elk River pilot project reach.

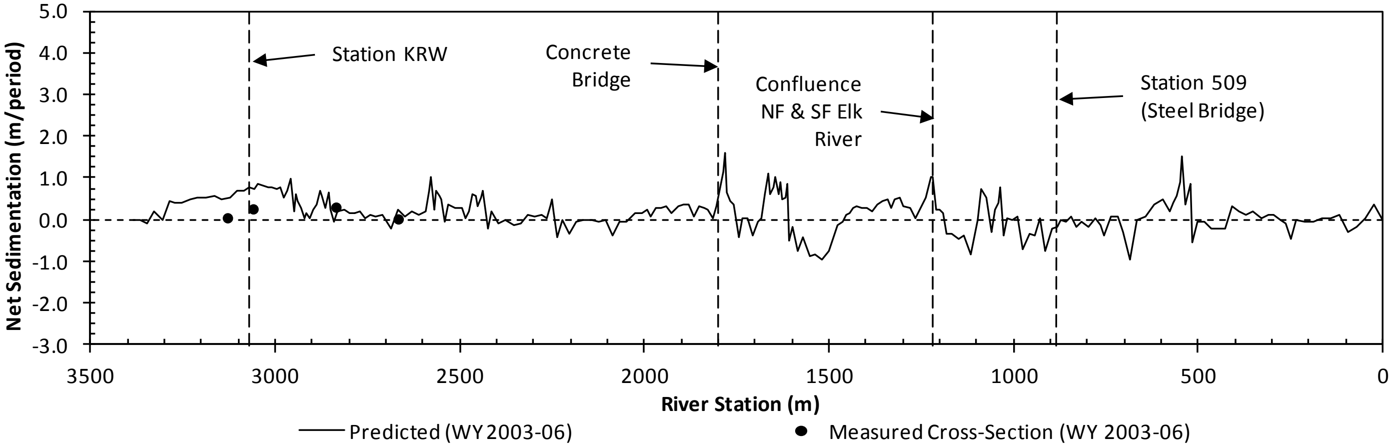


Figure 5-5. Measured and predicted bed elevation change at the grid scale for NF and mainstem Elk River for WY 2003-06.

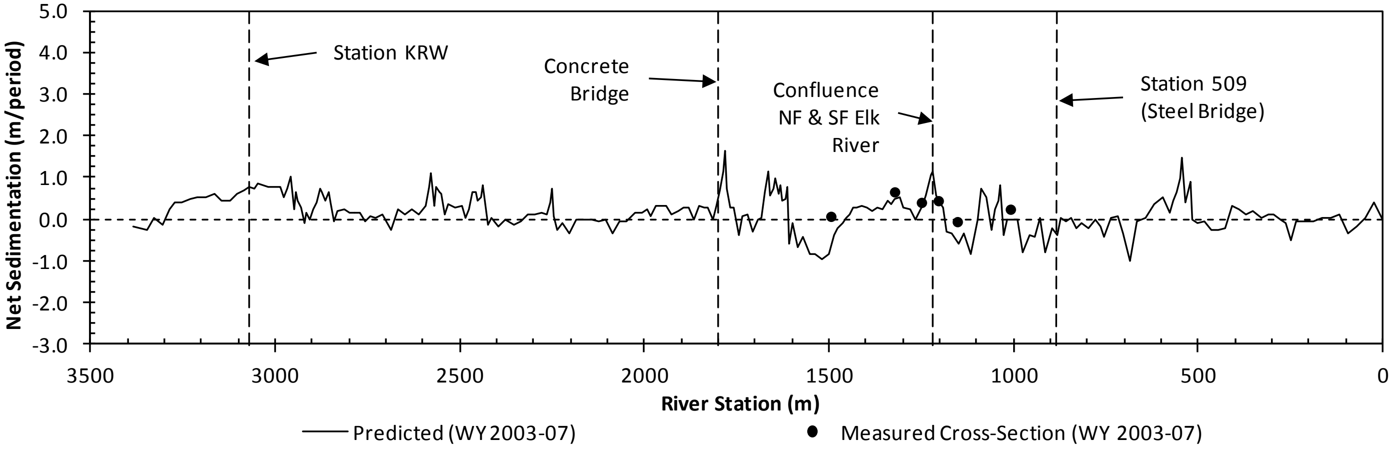


Figure 5-6. Measured and predicted bed elevation change at the grid scale for NF and mainstem Elk River for WY 2003-07.

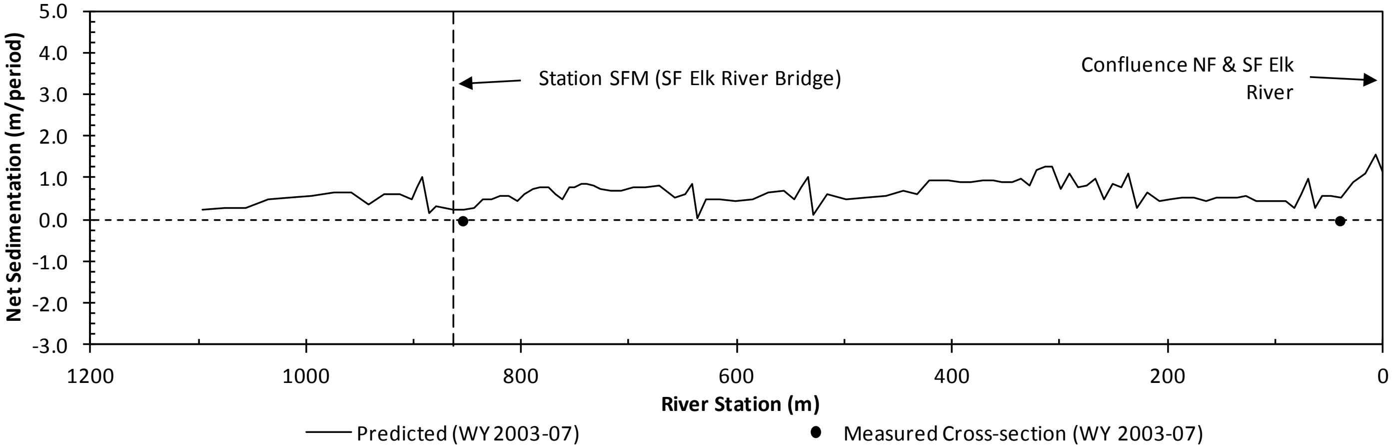


Figure 5-7. Measured and predicted bed elevation change at the grid scale for SF Elk River for WY 2003-07.

5.3 Sub-Reach Scale Sedimentation Assessment

Predicted channel bed and bank sedimentation values were extracted from the model grid at the sub-reach scale as defined in Table 5-1. The grid extraction was done using channel and bank polygons that spanned the cross-sections within each sub-reach area. Since limited measured floodplain data was available, this procedure was not conducted for floodplains. Figure 5-8, Figure 5-9 and Figure 5-10 show the measured (median values in Table 5-1) and predicted cumulative sedimentation for each sub-reach for the channel bed, left channel bank and right channel bank, respectively. Floodplain sedimentation at the sub-reach scale is the consistent with the grid scale sedimentation plot (Figure 5-4).

At the sub-reach spatial scale the HST model adequately simulates sedimentation patterns and change within the channel bed, banks and floodplain with less variability compared to the grid scale estimates. However, some variability still exists between predicted and measured values, particularly in the channel bed (Figure 5-8), where the HST model over predicted sedimentation in the SF Elk River. At the sub-reach scale it appears the HST model has over predicts cumulative sedimentation on the left and right channel banks. The use of a limited number of cross-sections within the sub-reach scale, particularly on the SF Elk River and floodplain, may help to explain some of the observed variability between measured and predicted sedimentation.

To provide a sub-reach estimate of the longitudinal channel bed sedimentation, the extracted channel grid cell values (Figure 5-5 to Figure 5-7) were smoothed by averaging over 9 grid cells (approximately 122 m average length). Figure 5-11, Figure 5-12 and Figure 5-13 show the measured (cross-section values) and the smoothed predicted longitudinal sedimentation profile within the NF and mainstem Elk River channel for WY 2003-06 and WY 2003-07, and SF Elk River channel for WY 2003-07, respectively. The smoothed bed elevation profile removes much of the variability and model grid effects that was observed at the grid cell scale, and provides a better visual match to the available cross-section bed elevation change data.

The measured and predicted comparisons on Figure 5-8 to Figure 5-13 demonstrate that the HST model adequately simulates variations in sedimentation at the sub-reach spatial scale. It is recommended that predicted channel profiles be smoothed (averaged) over approximately 9 grid cells for presentation purposes.

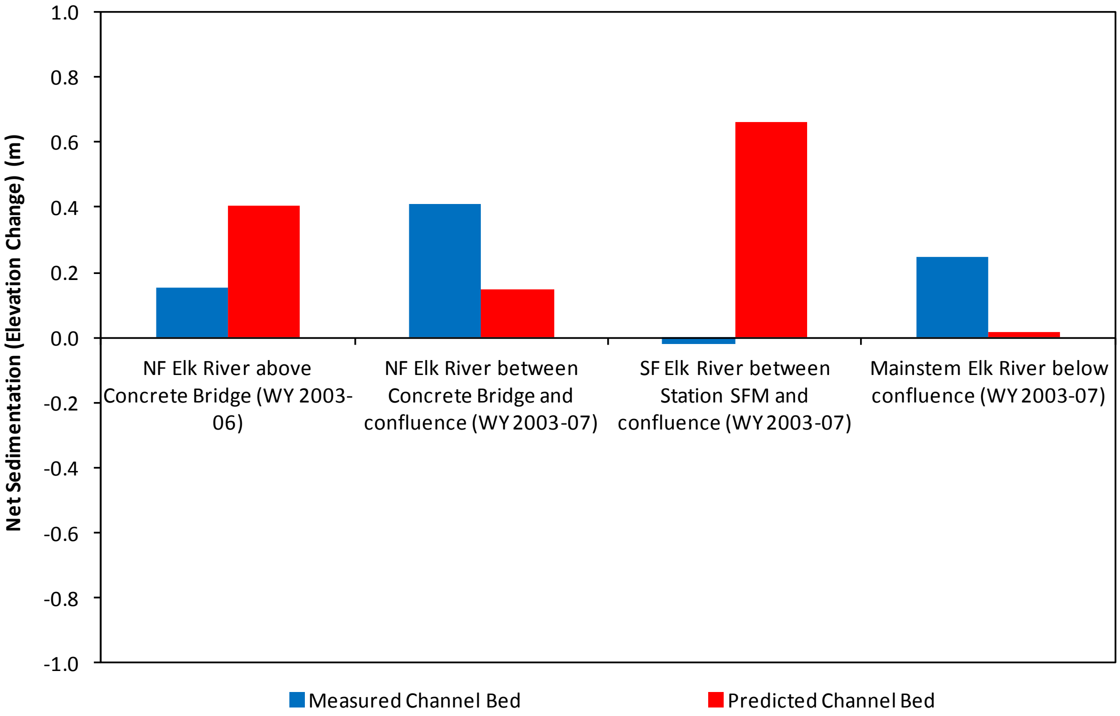


Figure 5-8. Measured and predicted channel bed cumulative sedimentation at the sub-reach scale within the Elk River pilot project reach.

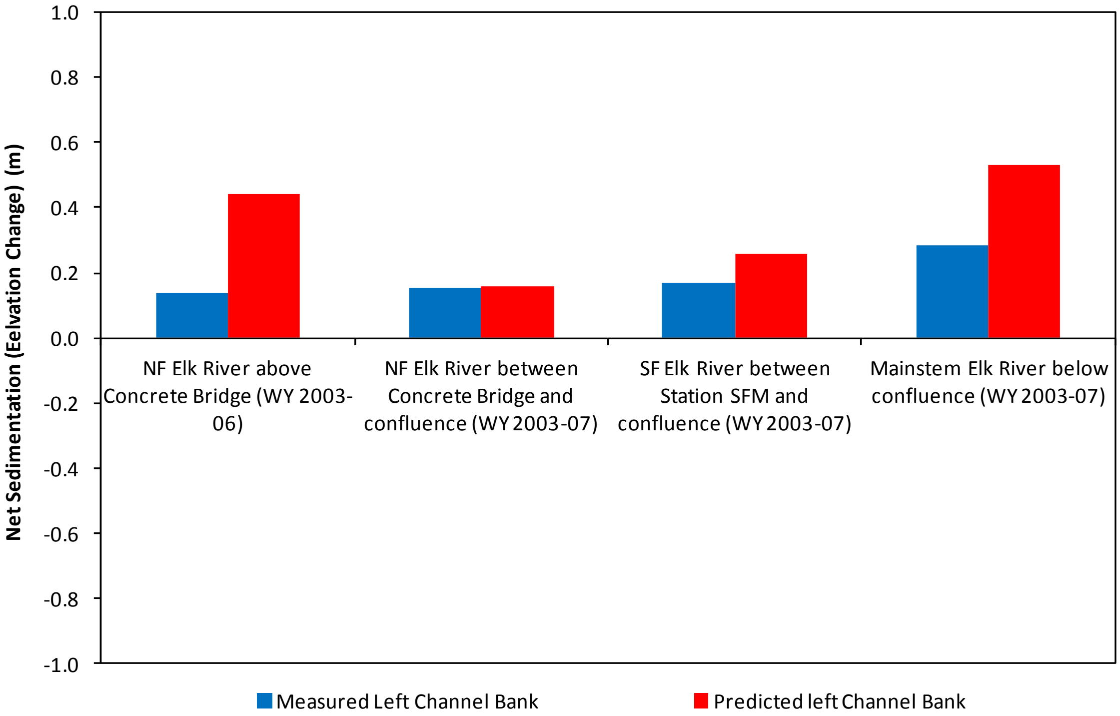


Figure 5-9. Measured and predicted left channel bank cumulative sedimentation at the sub-reach scale within the Elk River pilot project reach.

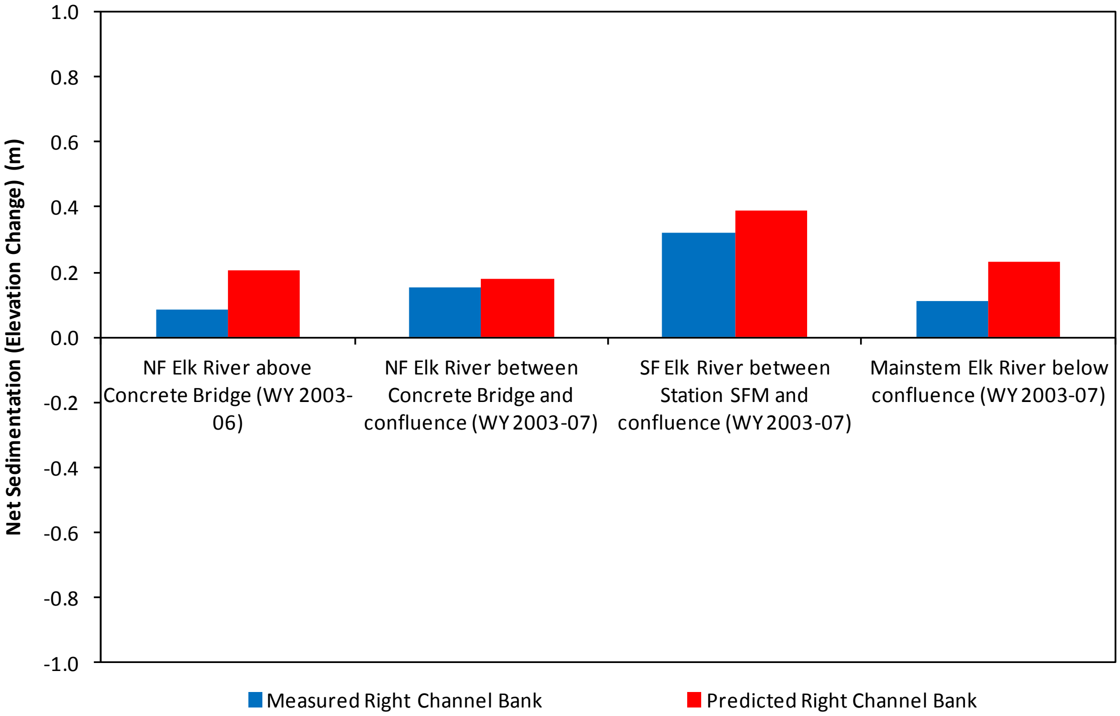


Figure 5-10. Measured and predicted right channel bank cumulative sedimentation at the sub-reach scale within the Elk River pilot project reach.

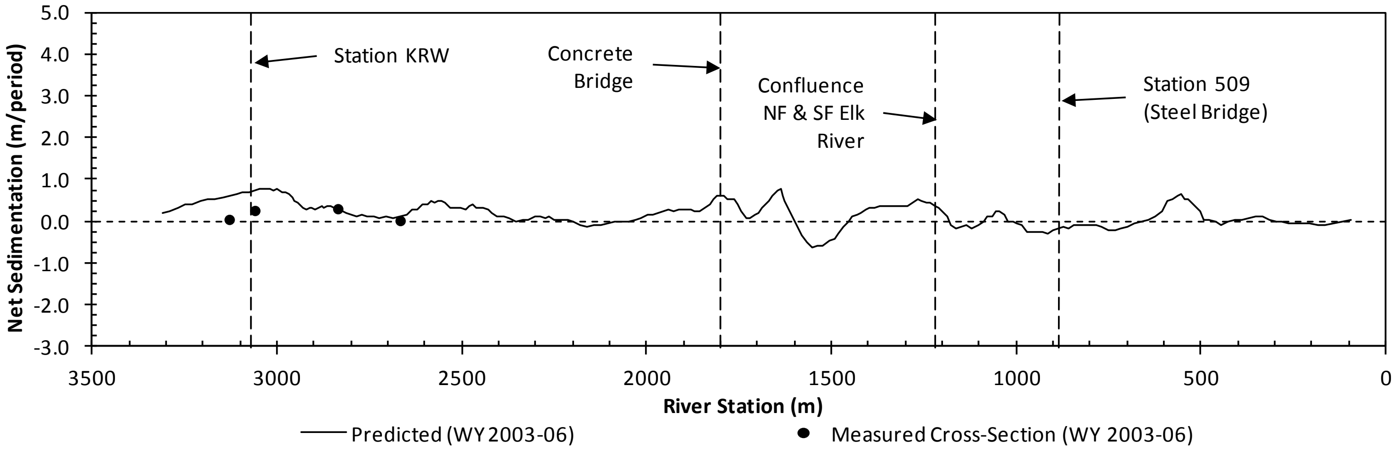


Figure 5-11. Measured and predicted bed elevation change (9 grid cell avg.) for NF and mainstem Elk River for WY 2003-06.

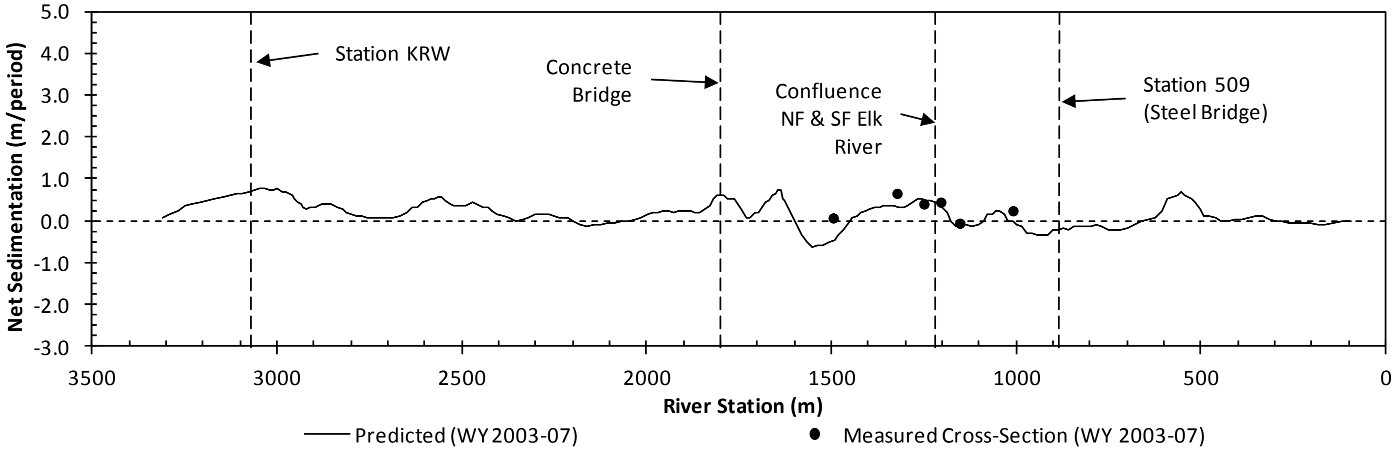


Figure 5-12. Measured and predicted bed elevation change (9 grid cell avg.) for NF and mainstem Elk River for WY 2003-07.

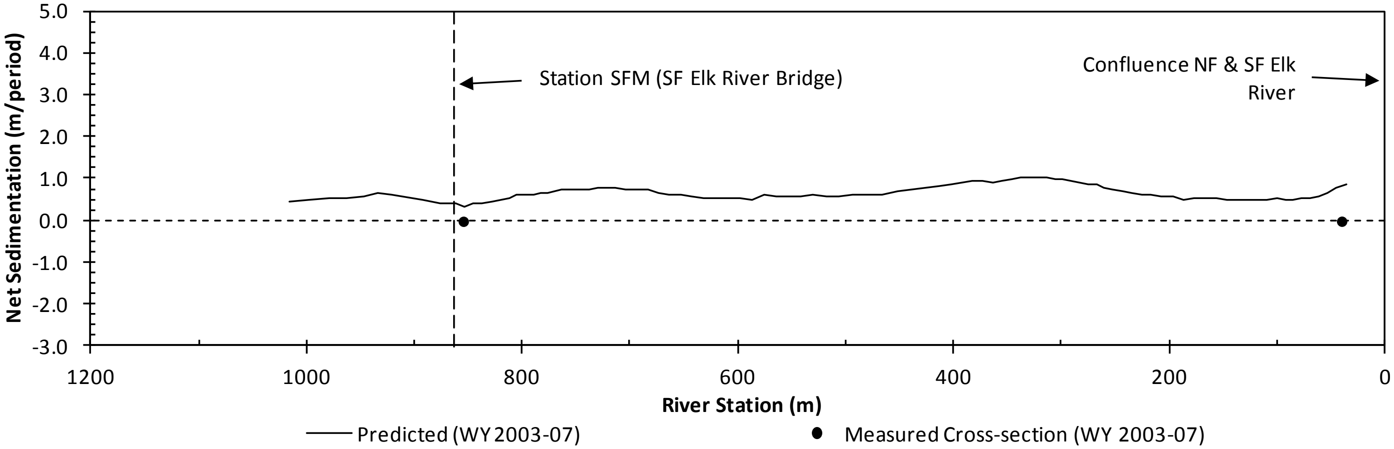


Figure 5-13. Measured and predicted bed elevation change (9 grid cell avg.) for SF Elk River for WY 2003-07.

5.4 Reach Scale Sedimentation Assessment

To provide an assessment of the overall predictive capability of the HST model at the reach scale, results for the channel bed, banks and floodplain sedimentation were extracted from the model grid for the entire pilot project reach. Since the measured bed elevation changes covered two time periods (WY 2003-06 and WY 2003-07) and multiple model grid zones (e.g. riparian and pasture floodplain), the reach scale sedimentation values were assessed as time or area weighted averages. Figure 5-14 shows the measured (weighted averages in Table 5-1) and predicted sedimentation for the channel bed, banks and floodplain at the reach scale. This figure demonstrates the overall predictive capability of the HST model at the pilot project reach scale.

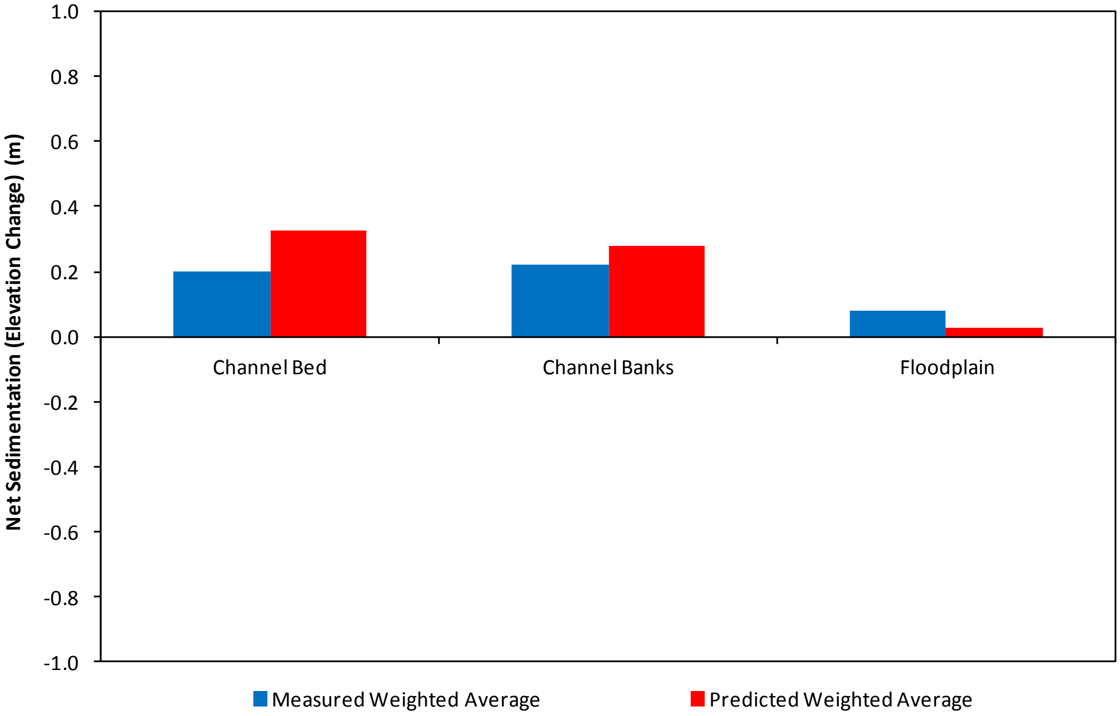


Figure 5-14. Measured and predicted weighted average channel bed, banks and floodplain cumulative sedimentation at the reach scale within the Elk River pilot project reach.

The HST model captures the cumulative sedimentation well at the reach scale within the channel bed, banks and floodplain. The variability between predicted and measured sedimentation has further been reduced at the reach spatial scale compared to the grid and sub-reach spatial scales. The HST model appears to slightly over predict the cumulative sedimentation for the channel bed and banks, and under predict for the floodplain. As explained earlier, one potential explanation for the over and under prediction is the use of a limited number of cross-sections within the pilot project reach to estimate bed elevation change. Another potential cause of over prediction on the channel bed and banks is the use of a high porosity (0.605) value in the HST model (Table 4-8) for the deposition of non-cohesive sediment, which was based on the average of all collected sediment samples (Section 2.1.2). The high porosity value results in a low dry bulk density which gives a thicker bed change for a given mass of depositing sediment compared to a lower porosity value. The use of a lower porosity for the depositing non-cohesive sediment should be investigated in future modeling efforts.

5.5 Reach Scale Sedimentation at Different Temporal Scales

Cumulative sedimentation within the pilot project reach occurred at different temporal scales depending on the model grid zones (Table 5-2, Figure 5-15 and Figure 5-16). Based on HST model simulations it appears that in-channel and floodplain sediment deposition patterns respond somewhat differently to annual sediment loads. Large in-channel (bed and banks) sediment deposition occurred during WY 2003 and WY 2006, which correspond to large sediment load years (Section 4.2.4). In between large sediment load years (WY 2003 and WY 2006), in-channel sedimentation occurred on the bed and banks at a more gradual rate. This type of in-channel sedimentation response may indicate that a sediment load threshold condition exists within the Elk River pilot project reach.

It is worth noting that the coarse channel bed also showed some minor reduction in cumulative sedimentation following the large WY 2003 and WY 2006 sedimentation years, while the fine channel bed did not show any reduction in sedimentation over the six-year simulation period. However, the channel banks had larger cumulative sedimentation each year than the coarse channel bed. These sedimentation trends indicate that the EFDC model vegetation drag algorithm and assumptions appear to be affecting the hydrodynamics and sediment transport correctly.

Net sediment deposition in the floodplain appears to be somewhat more consistent year to year within the riparian and forest zones than in the channel zone (Table 5-2, Figure 5-16). However, the pasture zones did appear to accumulate most of the cumulative sedimentation during the WY 2003 and WY 2006 large sediment loads. The riparian zones, which are predominantly along the top of the channel banks, properly accumulate the largest cumulative sedimentation of any of the floodplain zones as they are closest to the channel and have the greatest vegetation drag. Likewise, the pasture floodplain zones have the smallest cumulative sedimentation as these zones have less vegetation drag. This further indicates that the EFDC model hydrodynamics and sediment transport appear to be accurately accounting for the effects of vegetation drag.

Table 5-2. Average cumulative sedimentation at the end of each water year for the six-year simulation extracted from the model grid within the different channel and vegetation zones.

Model Grid Zone	**Sediment Deposition (m)**					
	WY 2003	**WY 2004**	**WY 2005**	**WY 2006**	**WY 2007**	**WY 2008**
Total Channel bed	0.157	0.165	0.199	0.319	0.329	0.344
Coarse channel bed	0.090	0.086	0.103	0.177	0.169	0.179
Fine channel bed (rest of river)	0.176	0.186	0.225	0.358	0.373	0.389
Channel banks	0.099	0.136	0.171	0.278	0.283	0.317
Riparian area on floodplain	0.018	0.023	0.025	0.035	0.038	0.048
Pasture area on floodplain	0.008	0.008	0.008	0.013	0.013	0.015
Forest area on floodplain	0.013	0.015	0.018	0.021	0.024	0.027

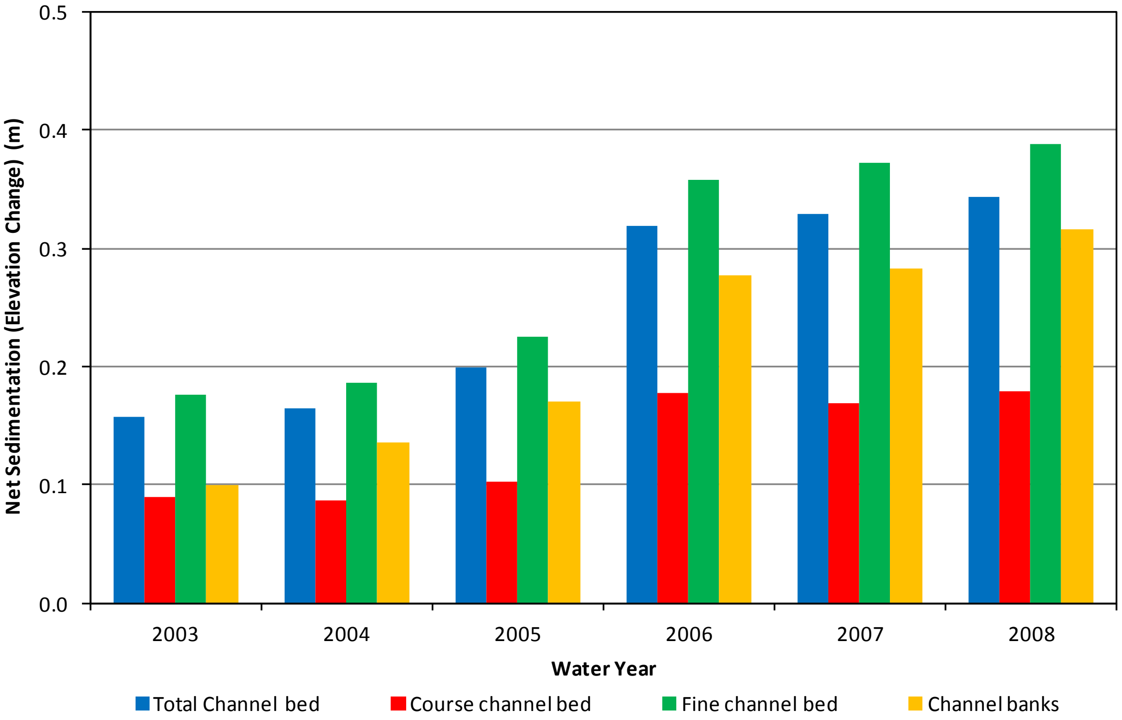


Figure 5-15. Predicted end of year average cumulative sedimentation within the Elk River channel and banks by channel bed types.

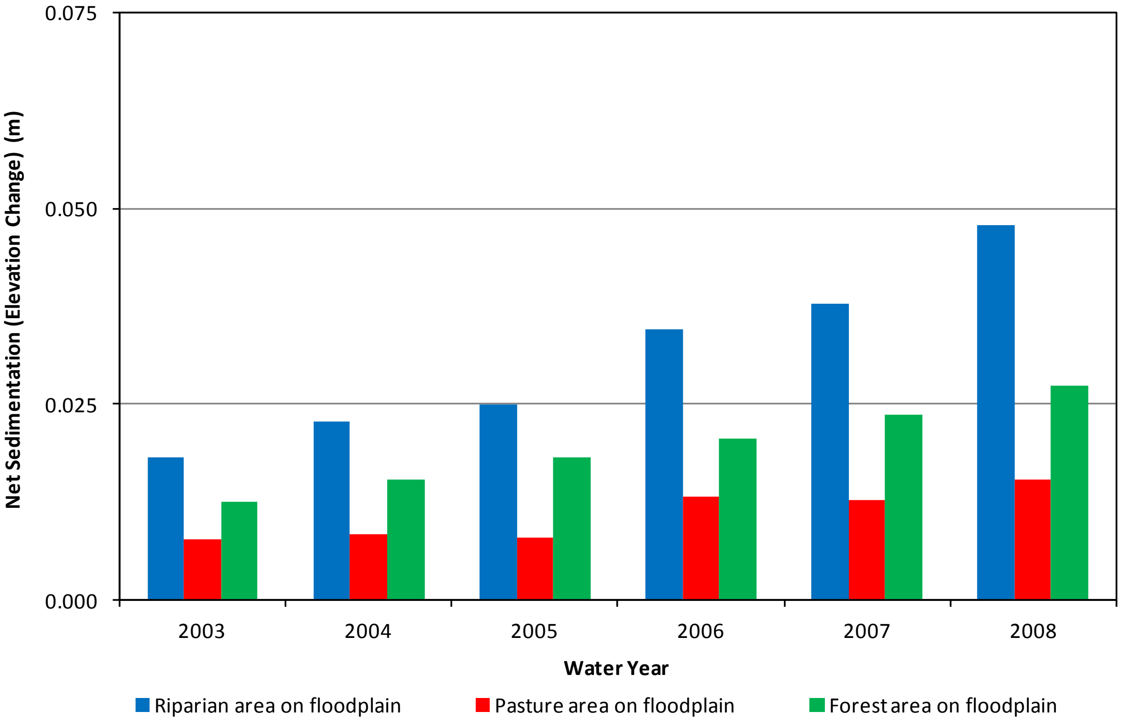


Figure 5-16. Predicted end of year average cumulative sedimentation within the Elk River floodplain by vegetation zone types.

5.6 Overall Sedimentation Patterns, Sediment Transport and Trajectory of the Pilot Project Reach

The average, minimum and maximum cumulative sedimentation values within the channel and vegetative zones at the end of the six-year simulation period (WY 2003-08) are provided in Table 5-3.

To provide an assessment of overall sediment transport predictive capability within the pilot project reach, total SSL and bedload flux were extracted from the model grid near the end of the pilot project reach. The SSL was extracted across a flux line that accounted for the total flow over the channel and floodplain, while the bedload flux was extracted from the channel bed only. The predicted SSL and bedload flux were then subtracted from the total inflow sediment load for the pilot project reach (NF and SF Elk River, Railroad Gulch, Clapp Gulch, Table 4-7) to provide estimates of annual sediment flux and storage within the pilot project reach. Table 5-4 and Figure 5-17 summarizes the total SSL inflow, sediment outflow, and cumulative sedimentation within the Elk River pilot project reach. On average, the pilot project reach tends to transport approximately 82 %, or store approximately 18 %, of the delivered sediment load (Table 5-4). Model results show that sediment load inflow exceeds outflow for each simulated water year, indicating that the pilot project reach retains sediment each year, with more sediment being retained for the large inflow years (WY 2003 and WY 2006). Based on model results, bedload makes up a very small fraction of the total sediment load within the pilot project reach.

Predicted cumulative sedimentation at the end of the six-year simulation period (WY 2003-08) is shown in Figure 5-18 and Figure 5-19 at different figure scales. Cumulative sedimentation occurred within the model grid that is greater or less than the scales shown on these figures. Figure 5-18 provides better resolution of the overall sediment depositional patterns in the pilot project reach, while Figure 5-19 provides a better picture of in-channel sedimentation.

Figure 5-20 and Figure 5-21 show the starting channel bed elevation (initial condition) and the predicted bed elevation (9 grid cell average) at the end of the six-year simulation (WY 2008) for the NF and mainstem Elk River and SF Elk River, respectively. The predicted bed elevation profiles at the end of the simulation period (WY 2008) seem reasonable, with no apparent deviation in overall bed slope. The upper end of the NF Elk River reach and entire SF Elk River reach had a net elevation gain due to sedimentation (Figure 5-21), which could be a result of the estimated SSC gradations (Table 4-7) and particularly the assumed non-cohesive 3 and 4 sediment fractions. These assumed coarser sediments in the inflow SSC may have been over specified and are not being effectively transported as suspended sediment or bedload. It is worth noting the predicted sediment deposit downstream of the Station 509 (Steel Bridge) on the mainstem Elk River (Figure 5-20), which has an effect on model predictions described in a later section.

To further assess assumptions regarding the inflow SSC gradations and other model parameters, the change in the sediment bed d_{50} over the six-year simulation period was extracted from the model grid and summarized in Table 5-5 and Figure 5-22. In general the sediment bed fined over the six-year simulation compared to initial conditions. However, the fine channel bed, which represents the majority of the channel bed in the pilot project reach, initially fined in WY 2003 and then coarsened over the remaining water years and ended at a d_{50} value close to the initial condition. Potential causes of the sediment bed fining include assumptions related to the initial sediment bed and the inflow SSC gradations. For example, the incoming SSC may contain a large fraction of fines that essentially acts as wash load and does not readily settle within the pilot project reach. Likewise, the SF Elk River and Railroad and Clapp Gulches may contain much coarser material than assumed. This assessment of sediment bed d_{50} is based on initial d_{50} values derived from sediment bed samples collected in 2011. Sediment bed d_{50} values at the beginning of the simulation periods (WY 2003) may have been finer and have coarsened with time, a process the HST model would have generally reproduced.

The HST model results for the six-year simulation indicate that the entire pilot project reach is depositional, and the overall sedimentation patterns at the end of the six-year simulation period (WY 2003-08) are consistent with the general sedimentation patterns described by the RWQCB (Adona White, RWQCB, 2012 personal communication).

Based on the six-year long HST model simulations, the trajectory of the Elk River pilot project reach under existing sediment supply conditions will continue to be a depositional environment.

Table 5-3. Reach scale cumulative sedimentation at the end of the six-year simulation period (WY 2003-08) extracted from the model grid within the different channel and vegetation zones.

Model Grid Zone	Average Sedimentation (m)	Minimum Sedimentation (m)	Maximum Sedimentation (m)
Total Channel bed	0.344	-1.005	1.660
Coarse channel bed	0.179	-1.005	1.473
Fine channel bed (rest of river)	0.389	-0.964	1.660
Channel banks	0.317	-0.993	1.356
Riparian area on floodplain	0.048	-0.021	1.101
Pasture area on floodplain	0.015	-0.013	0.096
Forest area on floodplain	0.027	-0.016	0.119

Table 5-4. Predicted total sediment load flux and storage within the Elk River pilot project reach for the reduced WY 2003-08 simulation period.

Water Year	Total Pilot Project Reach SSL Inflow (Table 4-6) (MT/yr)	Total SSL Outflow at end of Pilot Project Reach (MT/yr)	Total Bedload Outflow at end of Pilot Project Reach (MT/yr)	Total Sediment Load Outflow at end of Pilot Project Reach (MT/yr)	Net Sediment Storage within Pilot Project Reach (MT/yr)	Percent of SSL Inflow Stored within Pilot Project Reach
2003	54,533	41,841	3.3	41,844	12,689	23.2
2004	17,143	14,348	1.7	14,349	2,794	16.3
2005	20,501	16,939	1.6	16,940	3,561	17.4
2006	56,118	45,713	3.6	45,716	10,402	18.5
2007	16,048	13,733	1.5	13,734	2,314	16.8
2008	16,340	13,683	1.4	13,684	2,656	16.3
Average	**30,114**	**24,376**	**2.2**	**24,378**	**5,736**	**18.1**

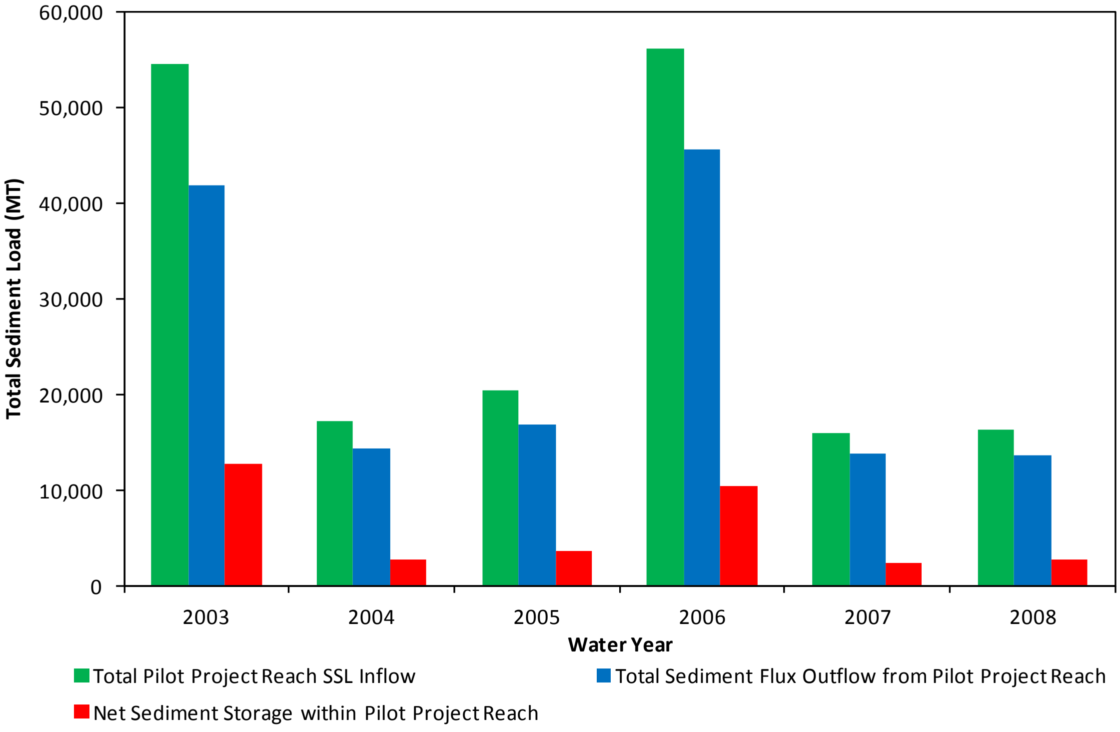


Figure 5-17. Total SSL inflow, predicted sediment load outflow and net sediment storage within the Elk River pilot project reach for the reduced WY 2003-08 simulation period.

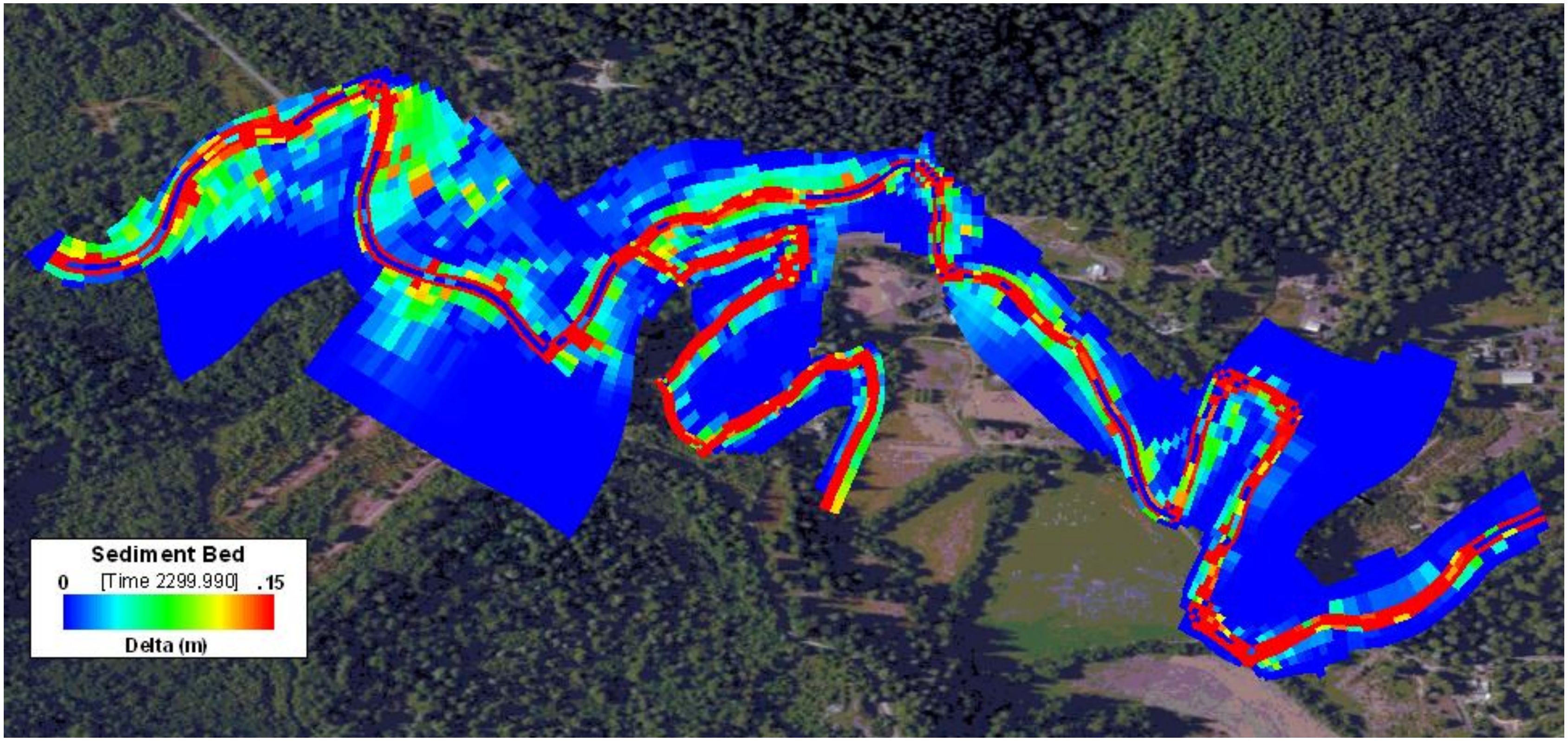


Figure 5-18. Predicted end of WY 2008 cumulative sedimentation in Elk River pilot project reach for the six-year simulation for existing sediment conditions. Scale of figure shows 0 to 0.15 m of sedimentation, which best illustrates overall sediment deposition patterns in channel, channel bank and floodplain locations.

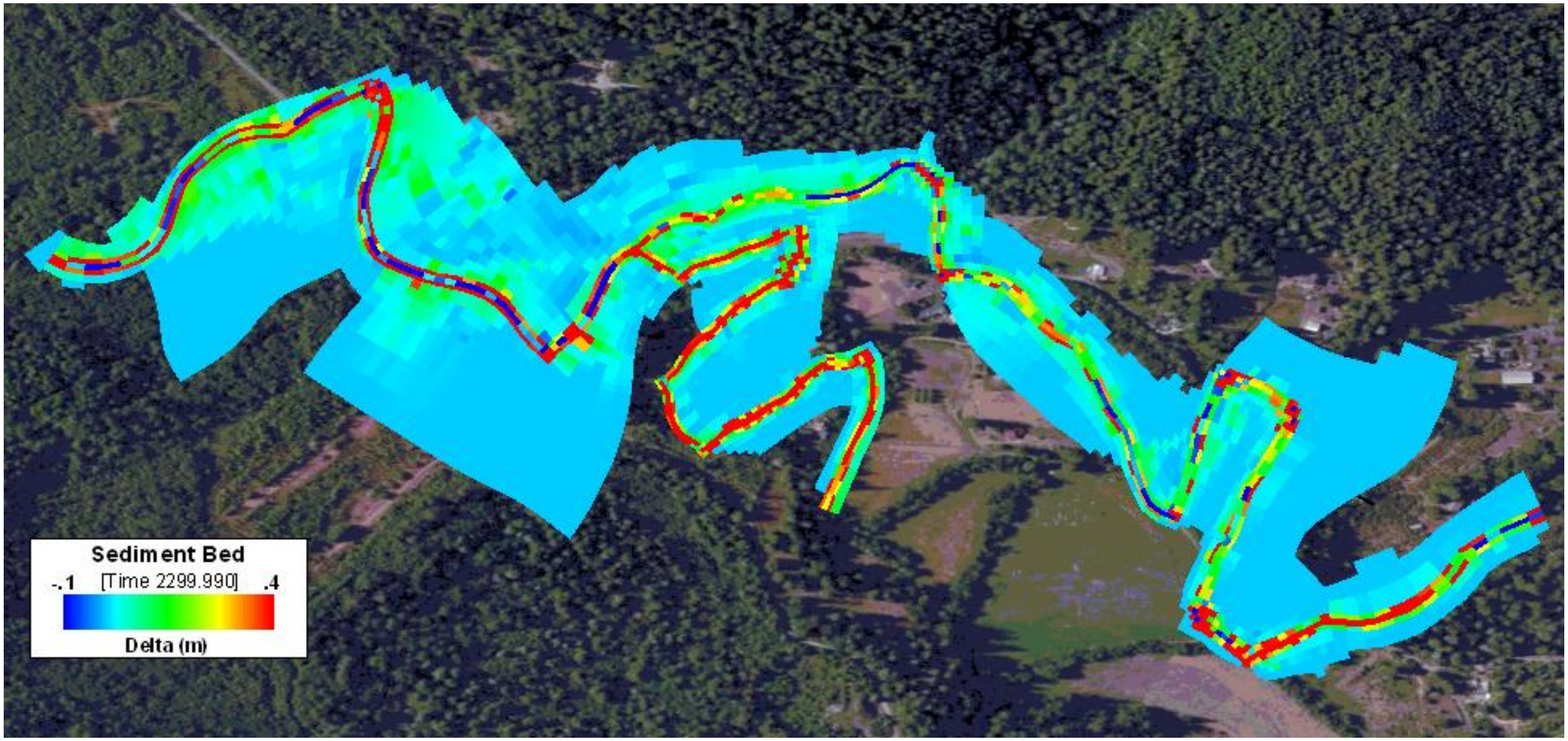


Figure 5-19. Predicted end of WY 2008 cumulative sedimentation in Elk River pilot project reach for the six-year simulation for existing sediment conditions. Scale of figure shows -0.1 to 0.4 m of sedimentation, which best illustrates overall sediment deposition patterns in channel and channel bank locations.

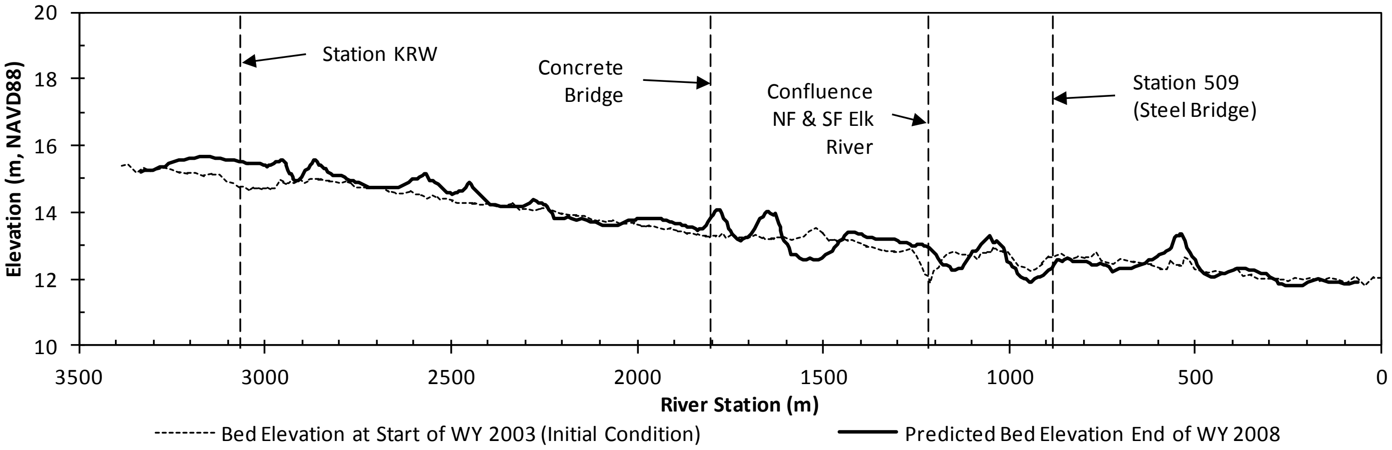


Figure 5-20. Initial condition bed elevation (start of WY 2003) and predicted bed elevation (9 grid cell average) at end of simulation period (WY 2008) for NF and mainstem Elk River.

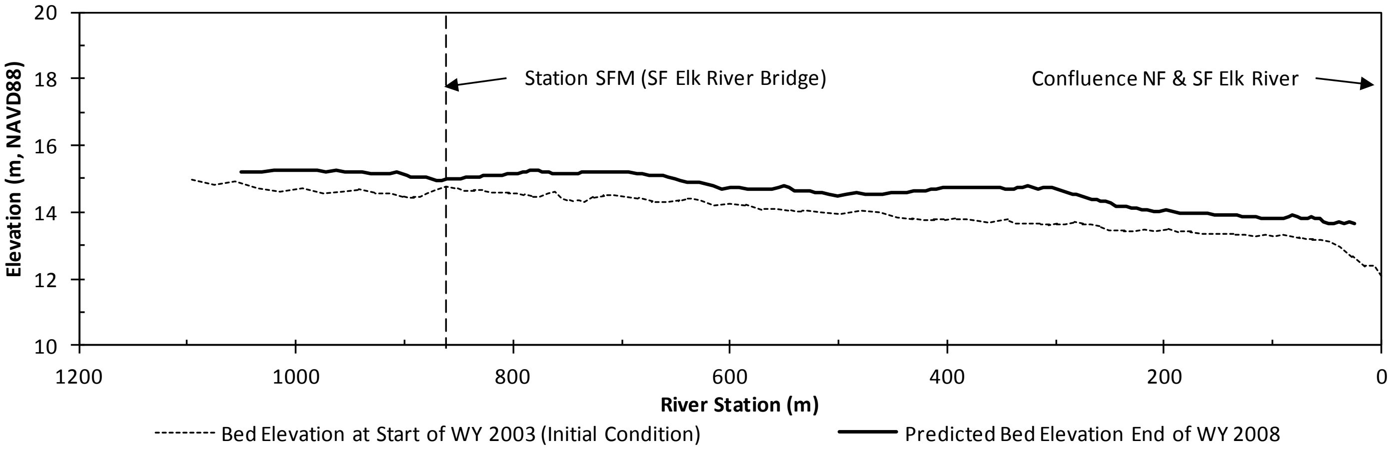


Figure 5-21. Initial condition bed elevation (start of WY 2003) and predicted bed elevation (9 grid cell average) at end of simulation period (WY 2008) for SF Elk River.

Table 5-5. Initial condition sediment bed d_{50} and predicted bed surface layer d_{50} for different model grid zones at end of each water year for the six-year simulation (WY 2003-08) within the Elk River pilot project reach.

Model Grid Zone	**d_{50} (um)**						
	Initial Cond.	**WY 2003**	**WY 2004**	**WY 2005**	**WY 2006**	**WY 2007**	**WY 2008**
Coarse channel bed mainstem Elk River	1,807	698	704	667	563	700	747
Coarse channel bed SF Elk River	1,623	165	191	182	108	126	133
Fine channel bed (rest of river)	171	86.2	113	115	113	133	147
Channel bank	96.0	56.7	53.7	51.5	46.7	51.4	52.7
Floodplain (Riparian Area)	92.9	73.7	71.3	69.8	65.8	63.8	61.8

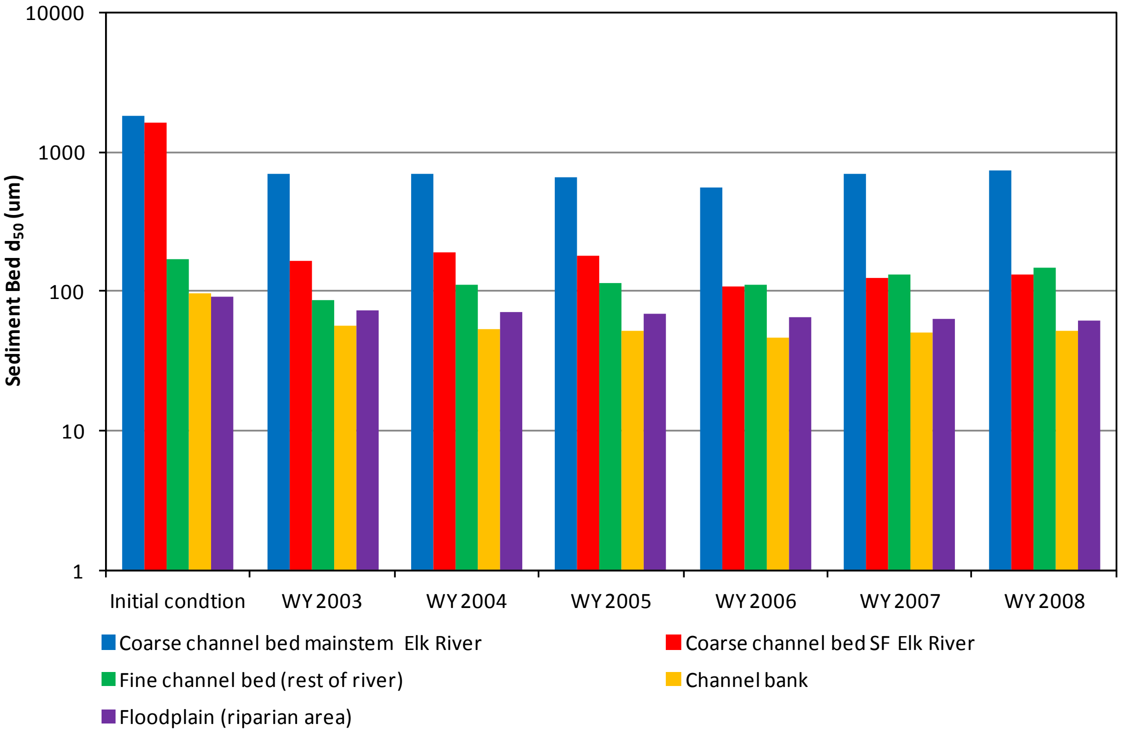


Figure 5-22. Change in the upper layer sediment bed d_{50} for different model grid zones at the end of each water year for the six-year simulation period (WY 2003-08) within the Elk River pilot project reach. Figure plotted on log scale to provide better resolution of change.

5.7 Rating Curve, Q, WSE and SSC Comparisons

5.7.1 Rating Curve Comparisons

Part of the hydrodynamic model calibration process was comparing model predictions to rating curves developed for the Concrete Bridge and Station 509 (Steel Bridge) for the 25 – 30 December 2002 calibration period. To further assess the overall predictive ability of the HST model, results for the six-year simulation (WY 2003-08) were again compared to the rating curves (Figure 5-23 and Figure 5-24). Despite the sediment bed composition and bed elevation changes associated with the six-year simulation, results show that the HST model still reasonably predicts in-channel WSE, V and Q at the rating curve locations. The most apparent difference is that the HST model appears to slightly over predict average channel V and Q at a given stage, compared to the hydrodynamic calibration run. It's not clear if this is an effect of the sediment transport model or changes to the sediment bed during the simulation.

5.7.2 Q, WSE and SSC Comparisons at Station 509 (Steel Bridge)

As part of ongoing monitoring requirements, HRC has measured continuous stage, estimated continuous Q (via rating curve), and sampled SSC as part of turbidity threshold sampling at Station 509 (Steel Bridge) on the mainstem Elk River. This data is available for WY 2004 to 2008, but not WY 2003.

Figure 5-25 to Figure 5-29 show continuous time-series plots of measured and predicted Q, WSE and SSC data, and Figure 5-30 to Figure 5-35 show correlation and probability distribution plots for measured and predicted Q, WSE and SSC for WY 2004 to 2008 at Station 509. A statistical summary of the HST model performance for Q, WSE and SSC is presented in Table 5-6. Overall results indicate that the HST model accurately predicts Q, WSE and SSC on the mainstem Elk River at Station 509, with high coefficient of determination (R^2) values, and good mean absolute error (MAE), root mean square (RMS) error, relative MAE error, and relative RMS error values for all variables.

Table 5-6. Statistical analysis of measured and predicted Q, WSE and SSC for WY 2004-08 at Station 509 (Steel Bridge) on mainstem Elk River (statistics defined in Ji (2008)).

Variable	Number of Data Points	Measured Mean	Predicted Mean	Mean Absolute Error	Root Mean Square (RMS) Error	Relative Mean Absolute Error (%)	Relative RMS Error (%)
Q (cms)	23,485	13.2	14.2	1.5	2.3	11.2	1.9
WSE (m)	19,602	14.792	14.987	0.223	0.271	1.5	5.3
SSC (mg/l)	401	489.8	349.1	164.6	296.9	33.6	7.9

The HST model slightly over predicts the lower discharges compared to measured values. This difference could be due to HRC discharge estimates and the low end of the Station 509 rating curve, or inherent differences between SFO and HRC discharges as SFO values were used for upstream boundary conditions. Likewise the HST model over predicts low WSE compared to measured continuous stage. This difference is likely due to the sediment deposit that formed on the channel bed over time downstream of Station 509 (Figure 5-20), which backwaters lower flow stages. However, the HST model does a very good job reproducing the higher Q and WSE values. The Q and WSE correlation plots (Figure 5-30 and Figure 5-32) have high R^2 values of 0.97, and the probability distributions (Figure 5-31 and Figure 5-33) show that model predictions have slightly less variability than the measured lower values, due to the likely causes described above.

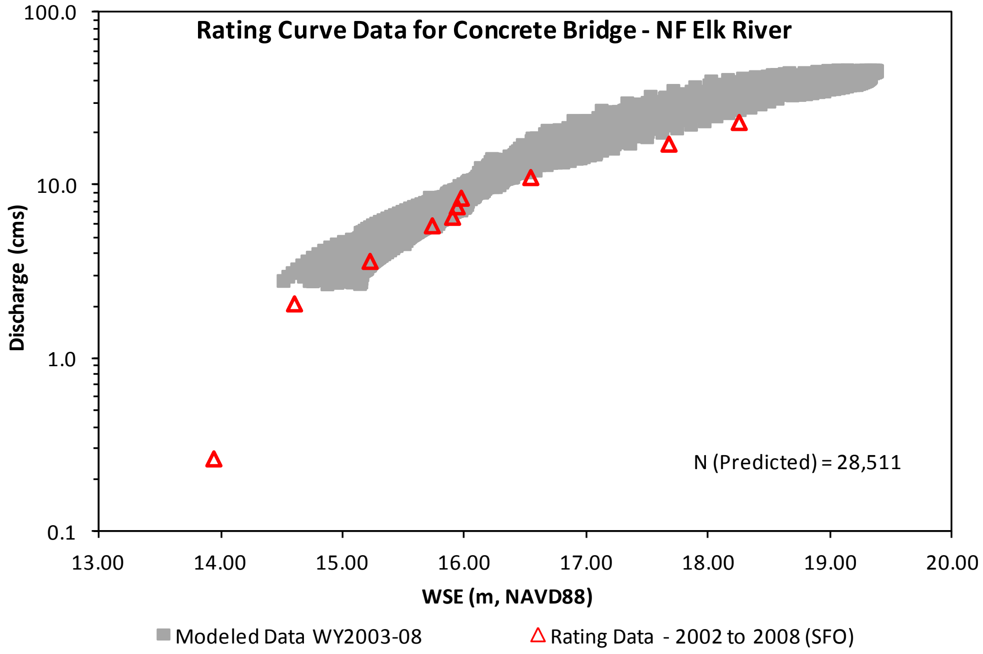
The HST model does a good job predicting SSC compared to measured values for the WY 2004-08 simulation period at Station 509. The model simulates and tracks the observed increasing and decreasing SSC values well during the rising and falling storm hydrographs (Figure 5-25 to Figure 5-29). The HST model accurately predicts SSC values over approximately two-orders of magnitude ($R^2 = 0.79$), and a considerable number of the SSC data-model pairs follow the 1:1 line, with simulated values within one-order of magnitude (Figure 5-34). The model over predicts the lower measured SSC values, and this small cloud of data influences the regression line. The HST model occasionally under predicts the higher SSC values, which could be a function of numerical diffusion caused by the finite difference solution of the mass transport equation in EFDC. An anti-diffusion option is available in the EFDC model, but was not used in the current HST model to save time during the six-year simulation. Another cause of the over and under model predictions of SSC could be related to the nature of SSC sampling during low and high flow events. The SSC probability distribution (Figure 5-35) shows that the HST model predictions have less variability than measured values, and slightly under predicts 75 to 80% of the SSC data, and slightly over predicts the remaining lower 20 to 25%.

5.7.3 Sediment Load Comparison at Station 509 (Steel Bridge)

The final metric used to evaluate the HST model performance was to compare estimated (based on HRC measured values) to predicted SSL at Station 509 on the mainstem Elk River for WY 2004-08 (Table 5-7 and Figure 5-36). The predicted SSL was extracted from the model grid across a flux line that accounted for the total flow in the channel and floodplain. In general, the HST model reproduced the measured SSL reasonably well at Station 509, with model predictions under estimating measured values by approximately 8,000 MT/yr (29 %) on average.

Table 5-7. Measured and predicted SSL at Station 509 (Steel Bridge) on mainstem Elk River for WY 2004-08.

Water Year	Total Measured SSL at Station 509 (MT/yr)	Total Predicted SSL at Station 509 (MT/yr)	Difference in SSL Estimates (MT/yr)	Percent Difference in SSL Estimates
2004	18,173	14,035	4,138	22.8
2005	24,018	16,677	7,341	30.6
2006	59,812	45,572	14,240	23.8
2007	22,289	13,339	8,950	40.2
2008	18,772	13,474	5,298	28.2
Average	**28,613**	**20,619**	**7,994**	**29.1**



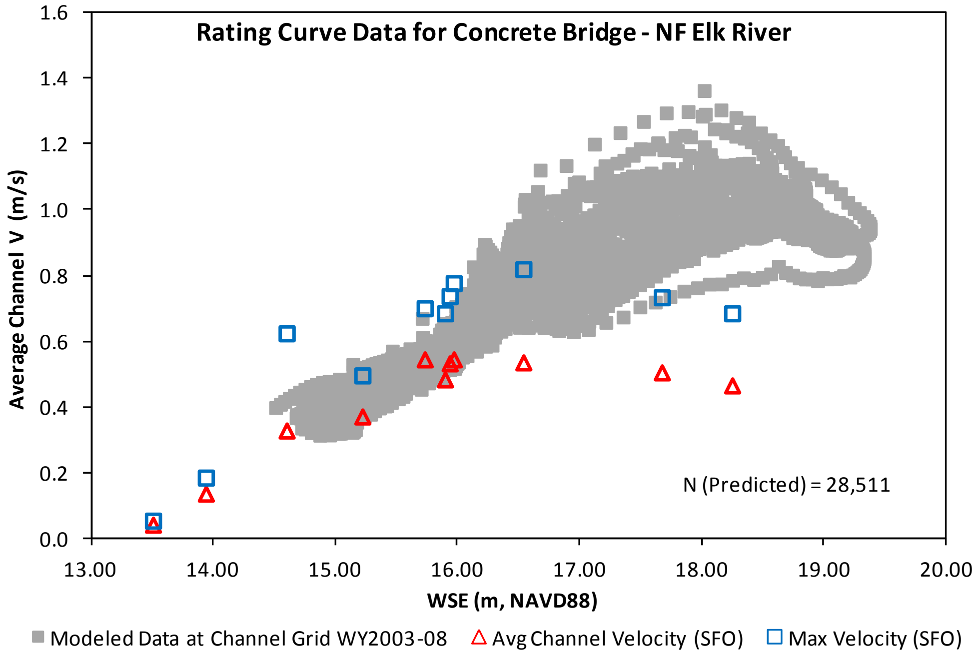
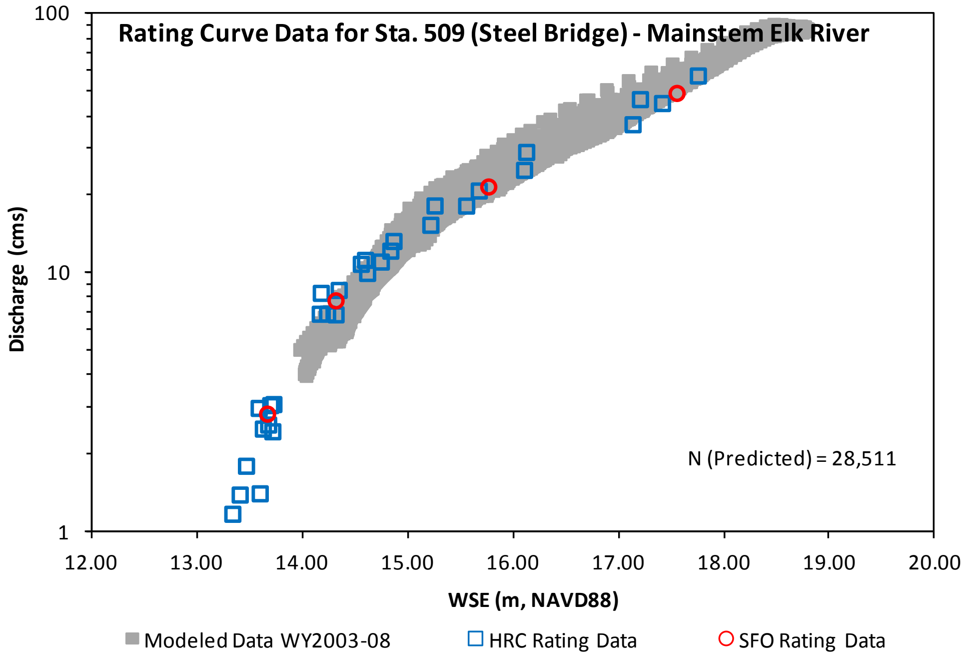


Figure 5-23. Hydrodynamic model predictions compared to observed rating curve data at the NF Elk River SFO Concrete Bridge discharge measurement site for WY 2003-08.



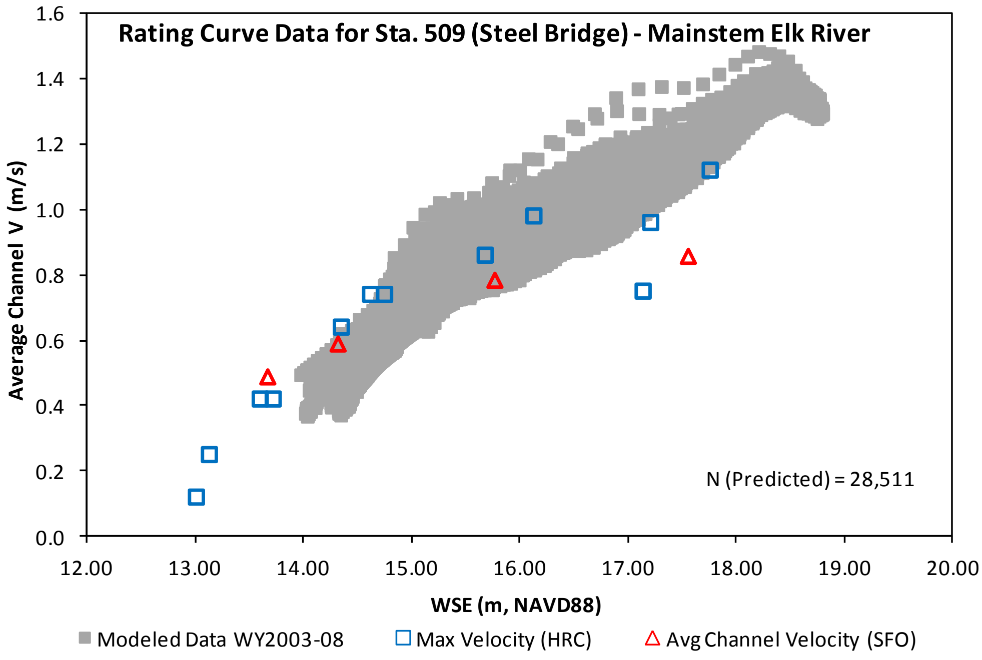


Figure 5-24. Hydrodynamic model predictions compared to observed rating curve data at the mainstem Elk River HRC Station 209 (Steel Bridge) discharge measurement site for WY 2003-08.

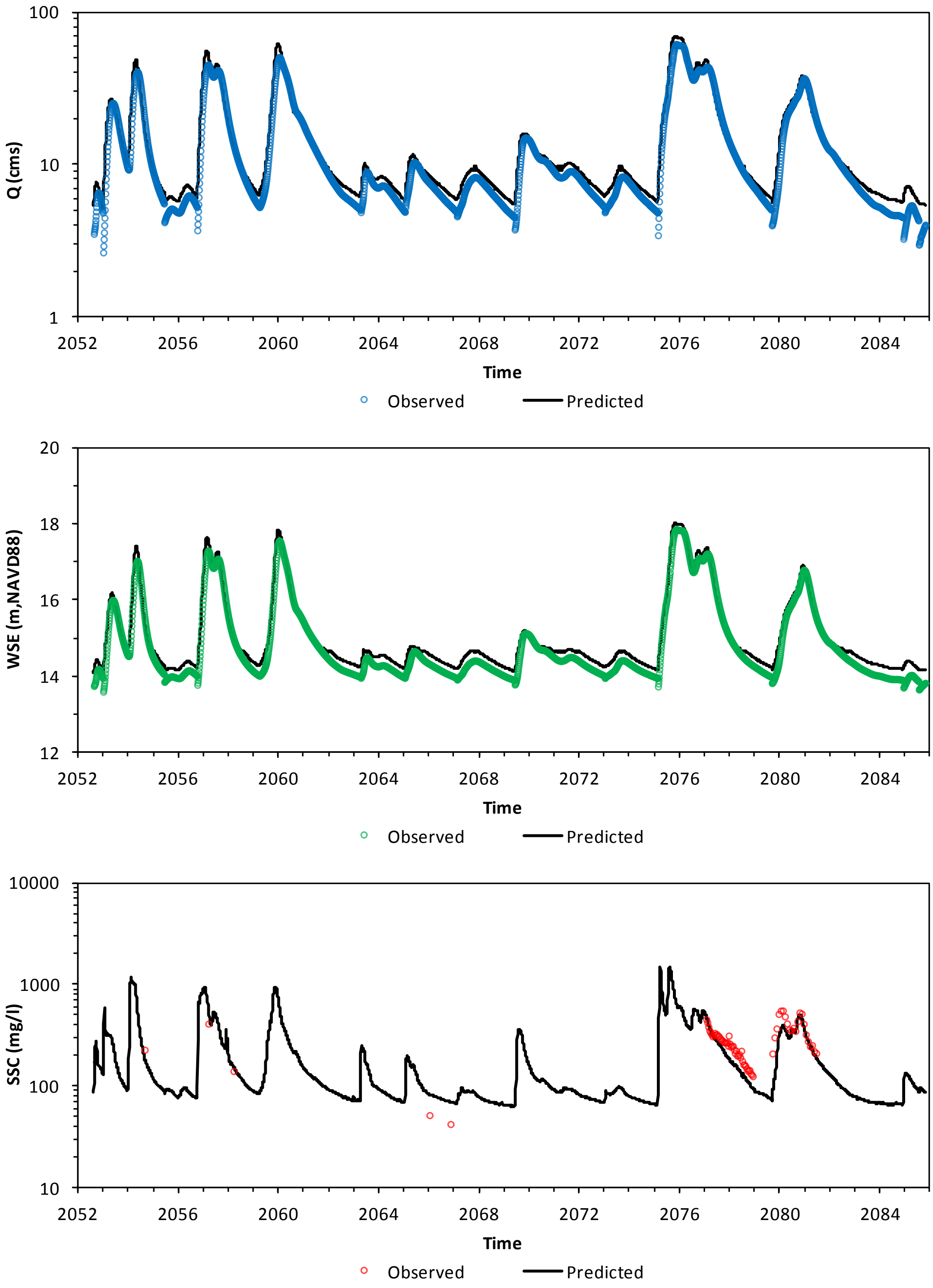


Figure 5-25. Time series of Q, WSE and SSC at Station 509 (Steel Bridge) for WY 2004 reduced period simulation (time is in days).

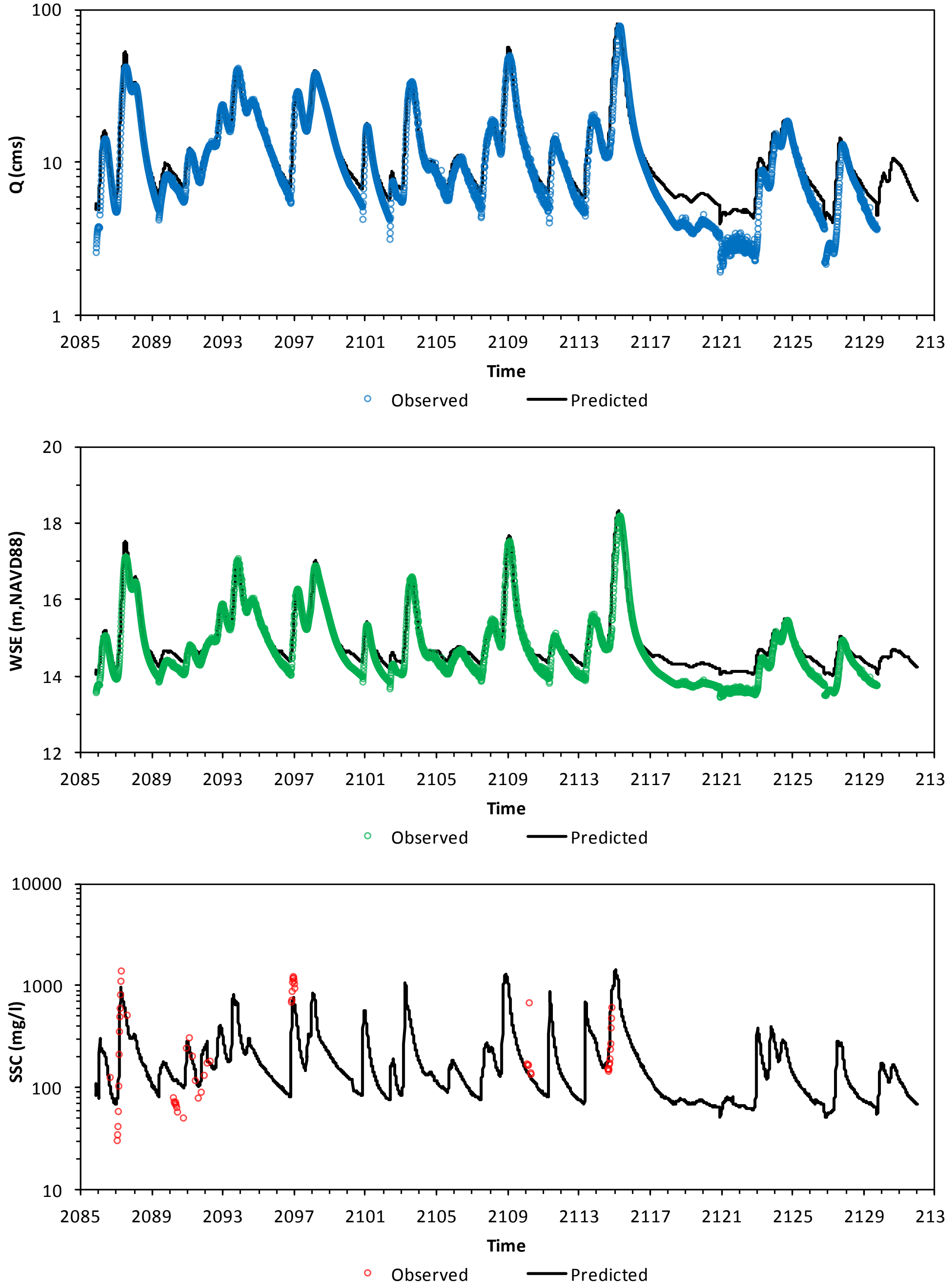


Figure 5-26. Time series of Q, WSE and SSC at Station 509 (Steel Bridge) for WY 2005 reduced period simulation (time is in days).

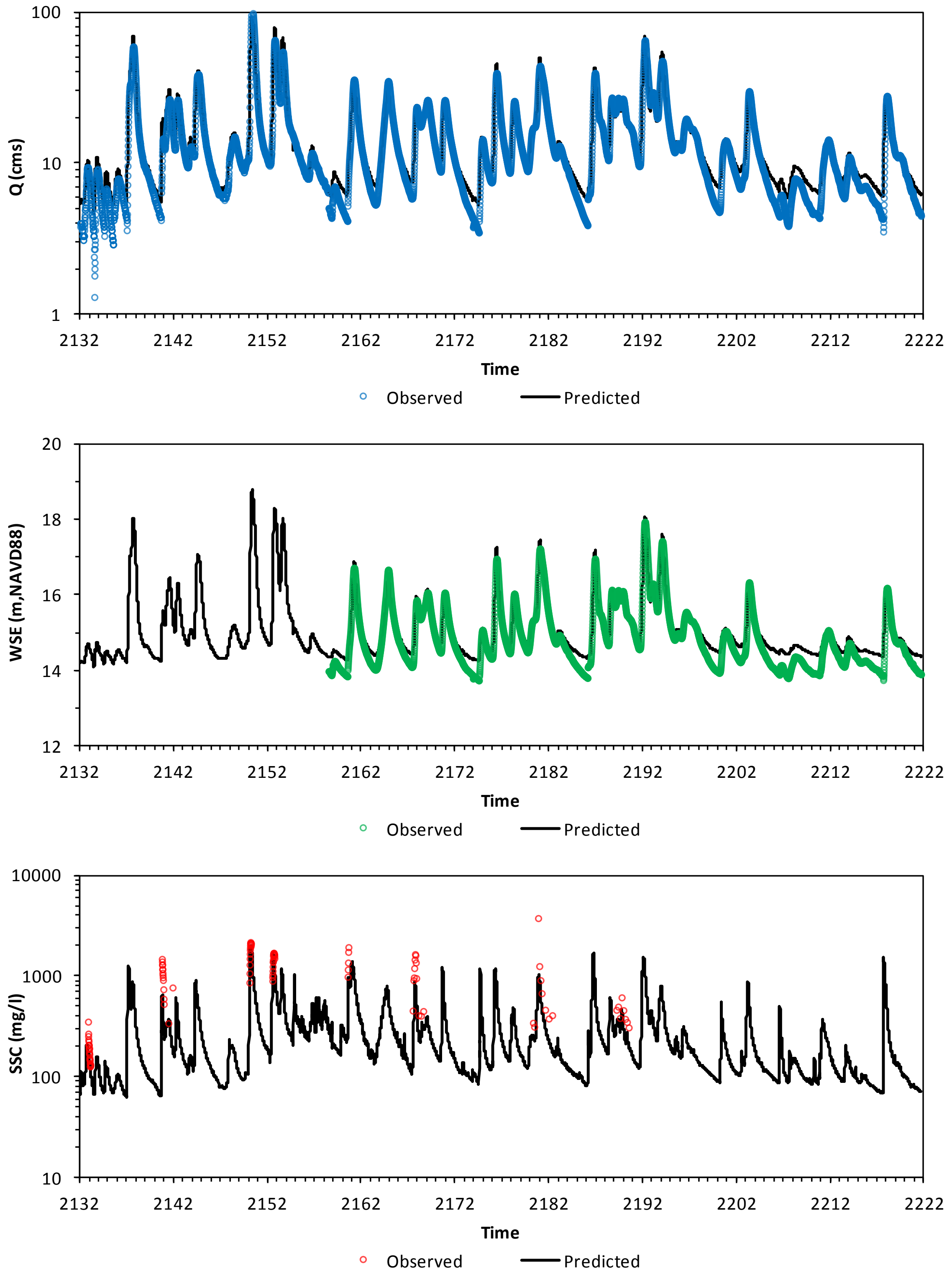


Figure 5-27. Time series of Q, WSE and SSC at Station 509 (Steel Bridge) for WY 2006 reduced period simulation (time is in days).

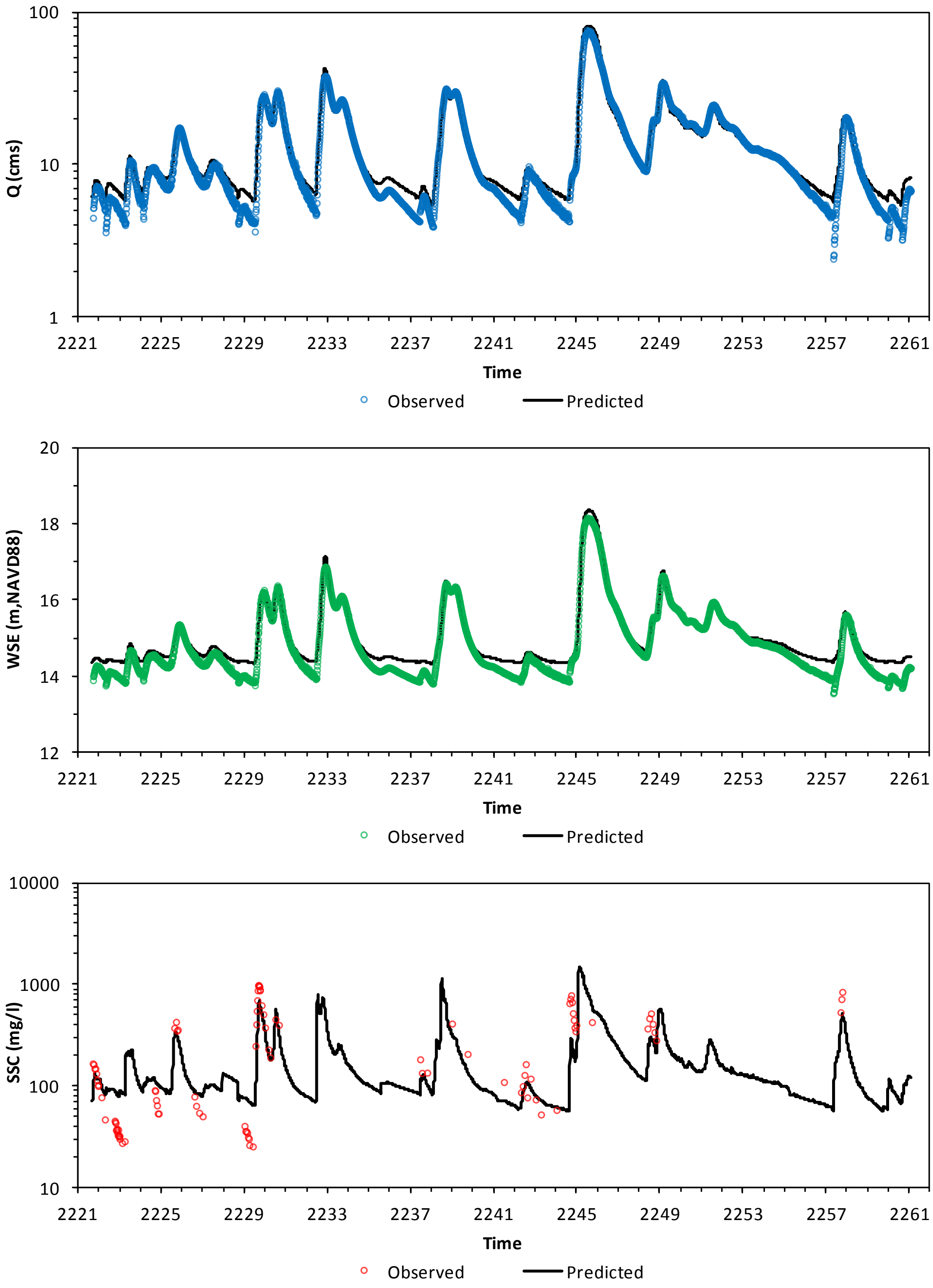


Figure 5-28. Time series of Q, WSE and SSC at Station 509 (Steel Bridge) for WY 2007 reduced period simulation (time is in days).

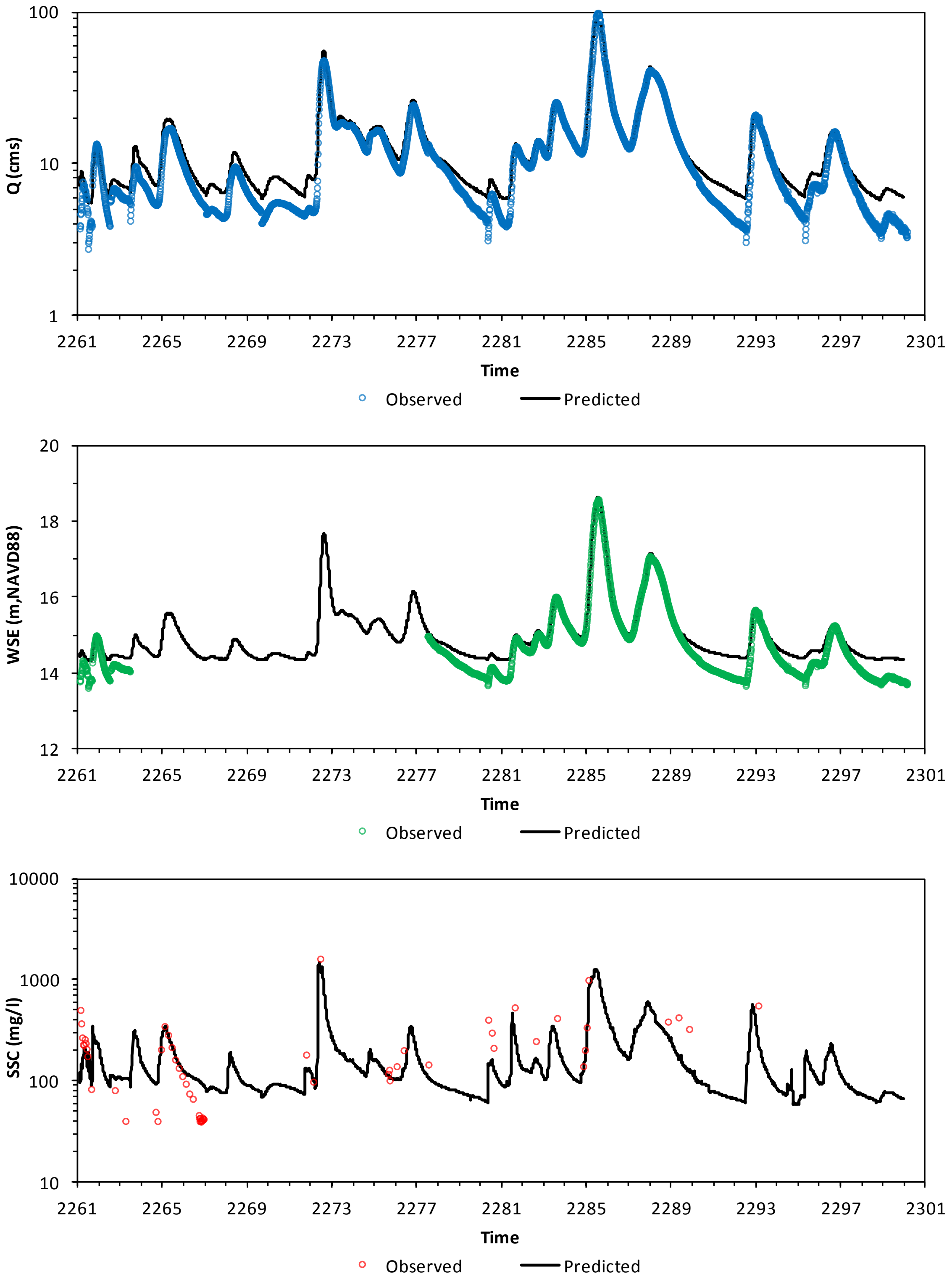


Figure 5-29. Time series of Q, WSE and SSC at Station 509 (Steel Bridge) for WY 2008 reduced period simulation (time is in days).

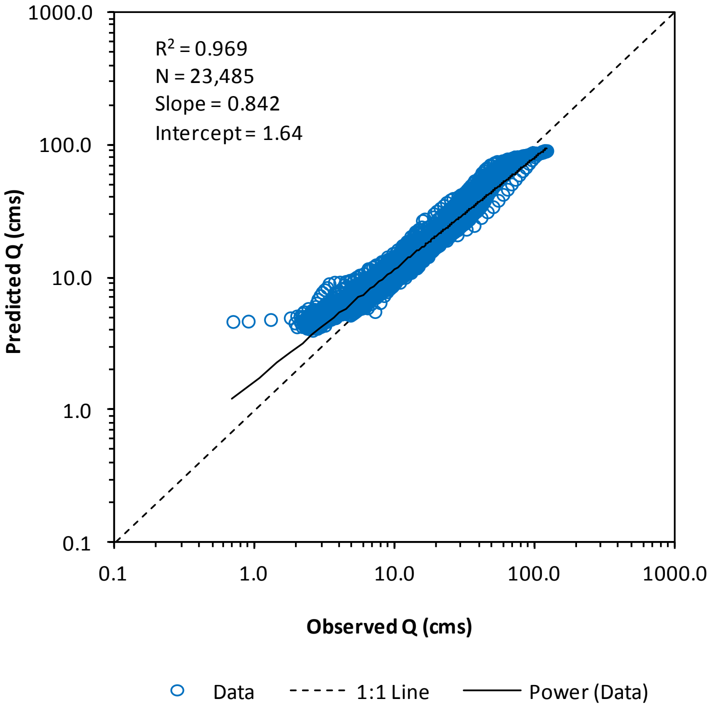


Figure 5-30. Correlation plot of observed and predicted Q at Station 509 (Steel Bridge) for WY 2004-08 reduced simulation period.

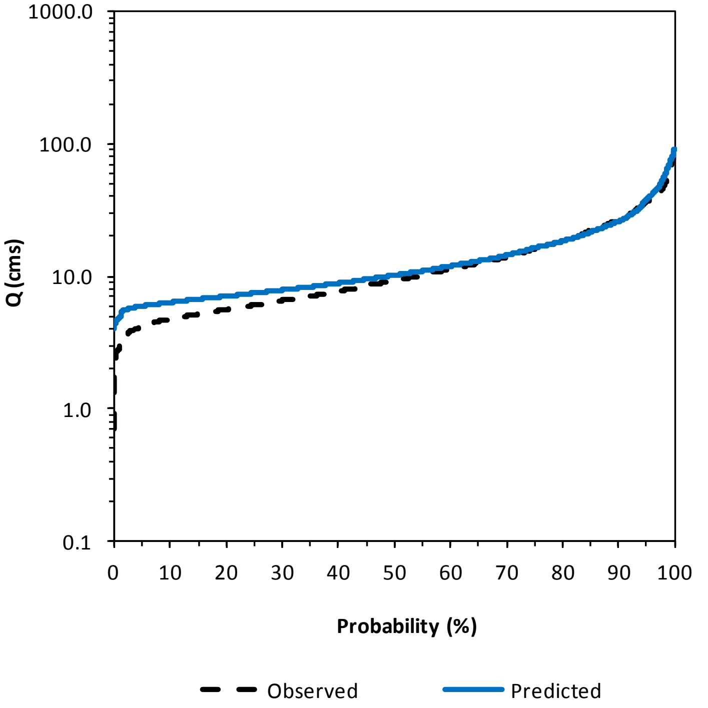


Figure 5-31. Probability distribution of observed and predicted Q at Station 509 (Steel Bridge) for WY 2004-08 reduced simulation period.

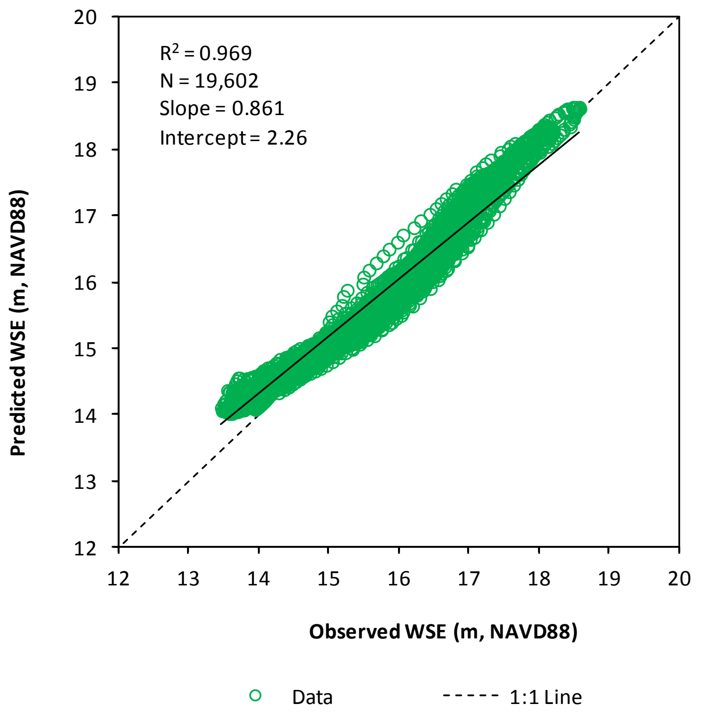


Figure 5-32. Correlation plot of observed and predicted WSE at Station 509 (Steel Bridge) for WY 2004-08 reduced simulation period.

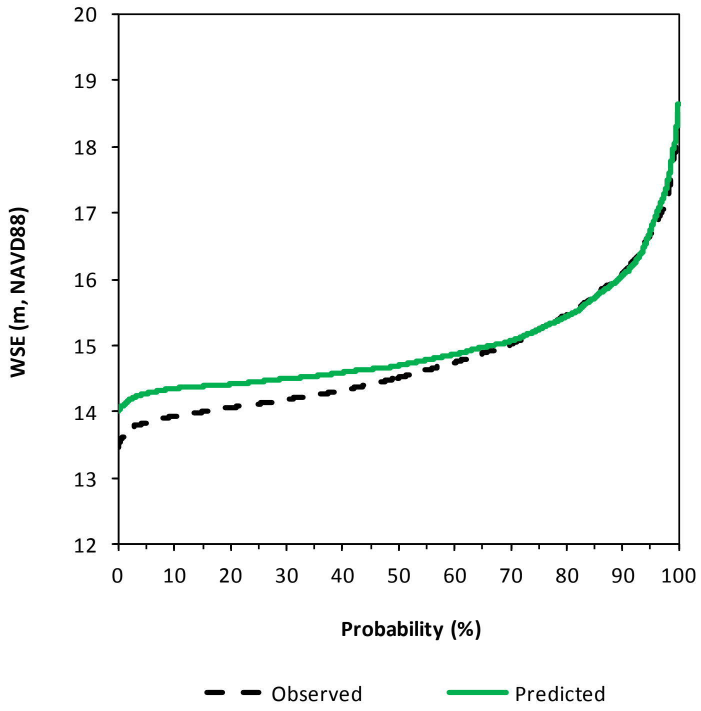


Figure 5-33. Probability distribution of observed and predicted WSE at Station 509 (Steel Bridge) for WY 2004-08 reduced simulation period.

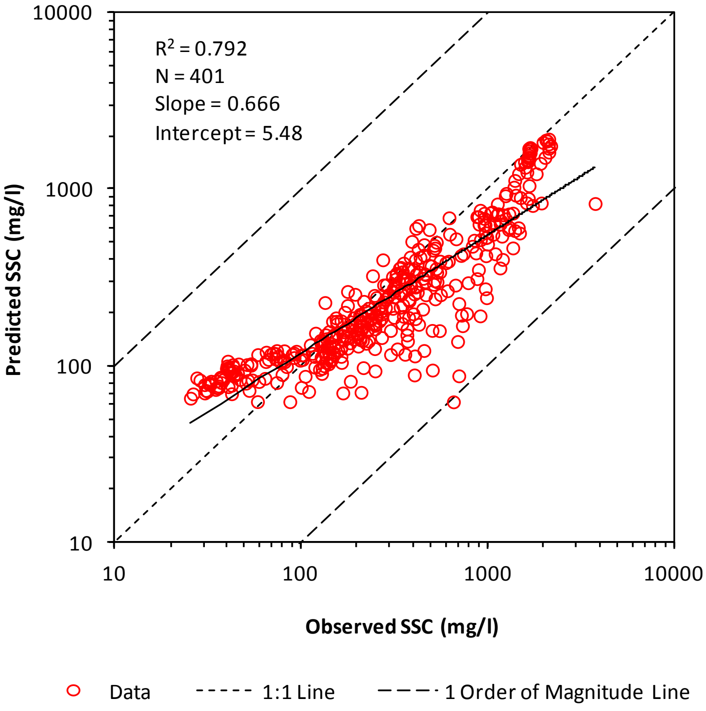


Figure 5-34. Correlation plot of observed and predicted TSS at Station 509 (Steel Bridge) for WY 2004-08 reduced simulation period.

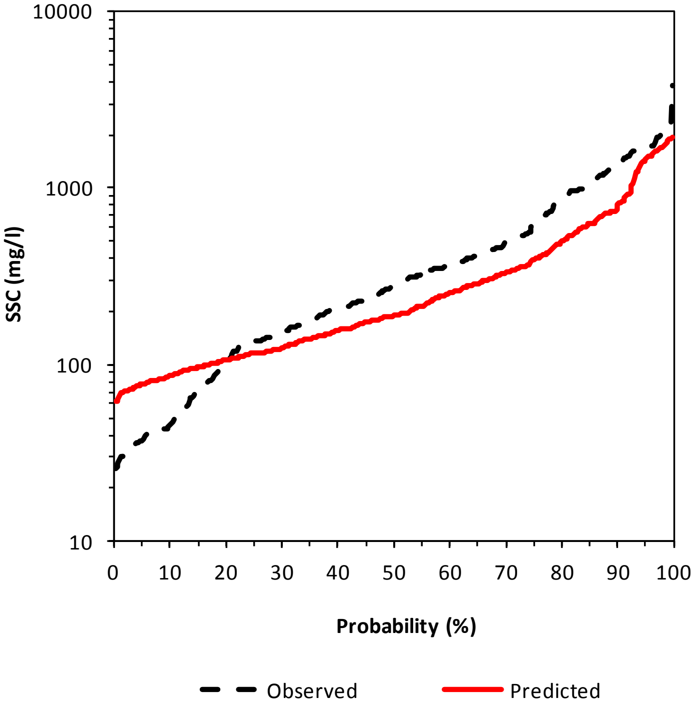


Figure 5-35. Probability distribution of observed and predicted SSC at Station 509 (Steel Bridge) for WY 2004-08 reduced simulation period.

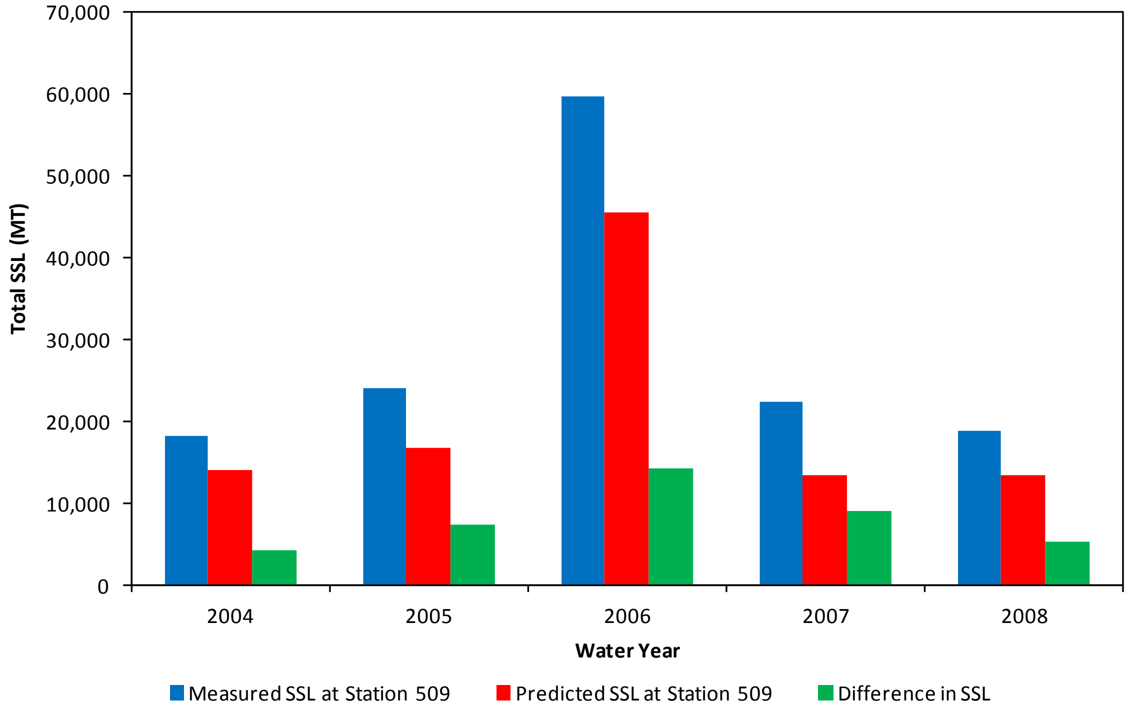


Figure 5-36. Measured and predicted SSL at Station 509 (Steel Bridge) on mainstem Elk River for WY 2004-08 simulation period.

5.8 Summary of HST Model for Existing Sediment Conditions

In summary, the HST model predictive capability was evaluated over a range of spatial scales (grid scale, sub-reach scale and reach scale) within the Elk River pilot project reach. Analysis of model results indicated that:

- Significant variability exits between predicted and measured sediment deposition and erosion, and channel bed profile elevation change (cumulative sedimentation) at the grid scale.
- The HST model adequately simulates larger scale sediment deposition and erosion processes at the sub-reach and reach spatial scales, and the bed elevation changes (cumulative sedimentation) at the sub-reach scale (9 grid cell average).
- The HST model adequately simulates Q, V and WSE compared to rating curves for the entire six-year simulation period (WY 2003-08) at two measuring stations: Concrete Bridge on NF Elk River, and Station 509 (Steel Bridge) on mainstem Elk River.
- The HST model accurately predicts Q, WSE, SSC, and reasonably predicts SSL when compared to measured and/or estimated values at Station 509 (Steel Bridge) on mainstem NF Elk River for WY 2004-08.

In conclusion, the HST model was successfully calibrated and applied to the Elk River pilot project reach for a six-year simulation (WY 2003-08) under existing sediment supply conditions. With additional data collection efforts, the HST model could be refined and applied to the larger sediment impaired reaches of the Elk River.

The HST model was developed and calibrated using existing flow and sediment data, and channel bed, bank and floodplain sediment data collected as part of this study. The overall model performance and predictive capabilities could be improved if additional Elk River data collection efforts focused on the following:

- Depth integrated SSC samples and particle size distribution analysis at a number of targeted locations.
- Bedload measurements and particle size distribution analysis at a number of targeted locations.
- Collect and analyze cohesive sediment properties, such as settling velocity, and critical shear stress for erosion and deposition.
- Improvements to the existing discharge rating curves by improving high discharge estimation techniques.
- Additional WSE and V measurements at a number of targeted locations.
- Expand the spatial distribution of channel bed, bank and floodplain sediment data collection.
- Map/define geomorphic reaches with similar characteristics controlling hydrodynamic and sediment transport processes.
- Increase the vertical depth of channel bed sediment samples.
- Expand the cross-section monitoring network, and resurvey cross-sections on a more frequent basis.

Future Elk River HST modeling efforts should consider the following recommendations for model development and calibration efforts:

- Modify the model grid resolution to provide a coarser overall grid to improve computation times. Consider the following: (1) use longer channel grid cells in straight reaches, and provide smooth transition to smaller channel grid cells at meander cross-over locations; and (2) try using a one i or j dimension grid to represent channel and banks, which could use longer grid cells to allow better floodplain cell transitions.
- Modify and improve the inflow SSC gradations. Consider using 2 cohesive classes (e.g. clay and fine silt, and medium to coarse silts), and 3 to 4 non-cohesive classes.
- Use a physically based approach to estimate inflow water column SSC composition based on, for example, Q, WSE, V and shear stress relations.
- Investigate using other options for separating cohesive and non-cohesive grain shear stress (e.g. the $2d_{90}$ option).
- Test the anti-diffusion and flux-limitation options within the EFDC model to improve peak SSC predictions.
- Use the effective diameter of coarse silt and sand fractions as calibration parameters.

6 RESULTS OF SIX-YEAR (WY 2003-08) HST MODEL SIMULATIONS FOR REDUCED SEDIMENT SUPPLY CONDITIONS

The calibrated HST model was used to simulate sediment conditions for WY 2003-08 within the pilot project reach under assumed reduced sediment supply conditions. The RWQCB (Adona White, RWQCB, 2012 personal communication) provided the reduced sediment condition scenario of a 75% reduction in SSL for all inflows (NF and SF Elk River, and Railroad and Clapp Gulch) into the pilot project reach. The reduced sediment scenario was applied to the calibrated HST model by simply reducing all inflow SSC boundary conditions by 75%. The following sections describe the various metrics used to demonstrate the effects of the reduced sediment supply scenario on the Elk River pilot project reach.

6.1 Overall Cumulative sedimentation Patterns

Reach scale cumulative sedimentation values (average, minimum and maximum) at the end of the six-year simulation period (WY 2008) for the reduced sediment supply condition are provided in Table 6-1 within the channel and vegetative zones. Predicted cumulative sedimentation at the end of the six-year simulation period (WY 2008) for the reduced sediment condition is shown in Figure 6-1 and Figure 6-2 at different figure scales. It should be noted that cumulative sedimentation occurred within the model grid that is greater or less than the scales shown on these figures. Table 6-2, Figure 6-3 and Figure 6-4 provide a temporal summary of cumulative sedimentation within the different model grid zones at the reach spatial scale. Finally, Figure 6-5 and Figure 6-6 show the starting channel bed elevation (initial condition) and the predicted bed elevation (9 grid cell average) at the end of the six-year simulation (WY 2008) for the reduced sediment condition for the NF and mainstem Elk River and SF Elk River, respectively.

Based on the HST model results, it appears that the channel bed scours at the reach and sub-reach spatial scales (Table 6-1, Table 6-2 and Figure 6-3) under the reduced sediment supply scenario, while the channel banks and floodplain still aggraded (Figure 6-3 and Figure 6-4), albeit at a much lower rate than the existing sediment supply condition (Table 5-2 and Table 5-3). Under the reduced sediment supply condition the channel bed scours at a relatively constant rate over the simulation period (Figure 6-3) and does not appear to be affected by the large sediment flux years (WY 2003 and WY 2006). However, the channel banks, and riparian and forest floodplain zones (Figure 6-3 and Figure 6-4) appear to be affected by the WY 2003 and WY 2006 sediment load years. This overall cumulative sedimentation trend is a shift from the modeled conditions under the existing sediment supply simulation (Figure 5-15 and Figure 5-16).

The predicted channel bed elevation profile (9 grid cell average) at the end of WY 2008 (Figure 6-5) for the NF and mainstem Elk River demonstrates that overall channel bed scour occurs in the reach due to the reduced sediment load. The overall channel slope does not appear to change significantly from initial conditions. The same channel bed elevation peaks at the model grid cross-over cells are still apparent in the reduced sediment supply simulation. The SF Elk River channel bed elevation profile (Figure 6-6) did not scour as significantly as the NF and mainstem Elk River. Some localized channel bed scour occurs in the upstream reaches of the SF Elk River. However, channel bed deposition is apparent on the lower reach of the SF Elk River, which could be caused by channel bed elevation conditions at the confluence with NF Elk River, or assumptions regarding input sediment conditions (Section 4.2.3) similar to the existing conditions run. Overall, the SF Elk River channel bed elevation profile and slope did not significantly change from initial conditions.

Table 6-1. Reach scale cumulative sedimentation at the end of the six-year simulation period (WY 2003-08) extracted from the model grid within the different channel and vegetation zones for the reduced sediment supply simulation (negative values indicate degradation/scour).

Model Grid Zone	Average Sedimentation (m)	Minimum Sedimentation (m)	Maximum Sedimentation (m)
Total Channel bed	-0.062	-1.604	1.436
Coarse channel bed	-0.021	-1.005	1.220
Fine channel bed (rest of river)	-0.074	-1.641	1.436
Channel banks	0.086	-1.191	0.826
Riparian area on floodplain	0.013	-0.029	0.539
Pasture area on floodplain	0.004	-0.026	0.045
Forest area on floodplain	0.014	-0.033	0.107

Table 6-2. Average cumulative sedimentation at the end of each water year for the six-year simulation period extracted from the model grid within the different channel and vegetation zones for the reduced sediment supply simulation (negative values indicate degradation/scour).

Model Grid Zone	Sediment Deposition (m)					
	WY 2003	WY 2004	WY 2005	WY 2006	WY 2007	WY 2008
Total Channel bed	-0.020	-0.034	-0.041	-0.049	-0.053	-0.062
Coarse channel bed	-0.016	-0.017	-0.019	-0.022	-0.022	-0.021
Fine channel bed (rest of river)	-0.021	-0.038	-0.047	-0.057	-0.062	-0.074
Channel banks	0.037	0.048	0.046	0.069	0.070	0.086
Riparian area on floodplain	0.006	0.006	0.007	0.011	0.011	0.013
Pasture area on floodplain	0.002	0.003	0.003	0.003	0.004	0.004
Forest area on floodplain	0.006	0.007	0.007	0.010	0.013	0.014

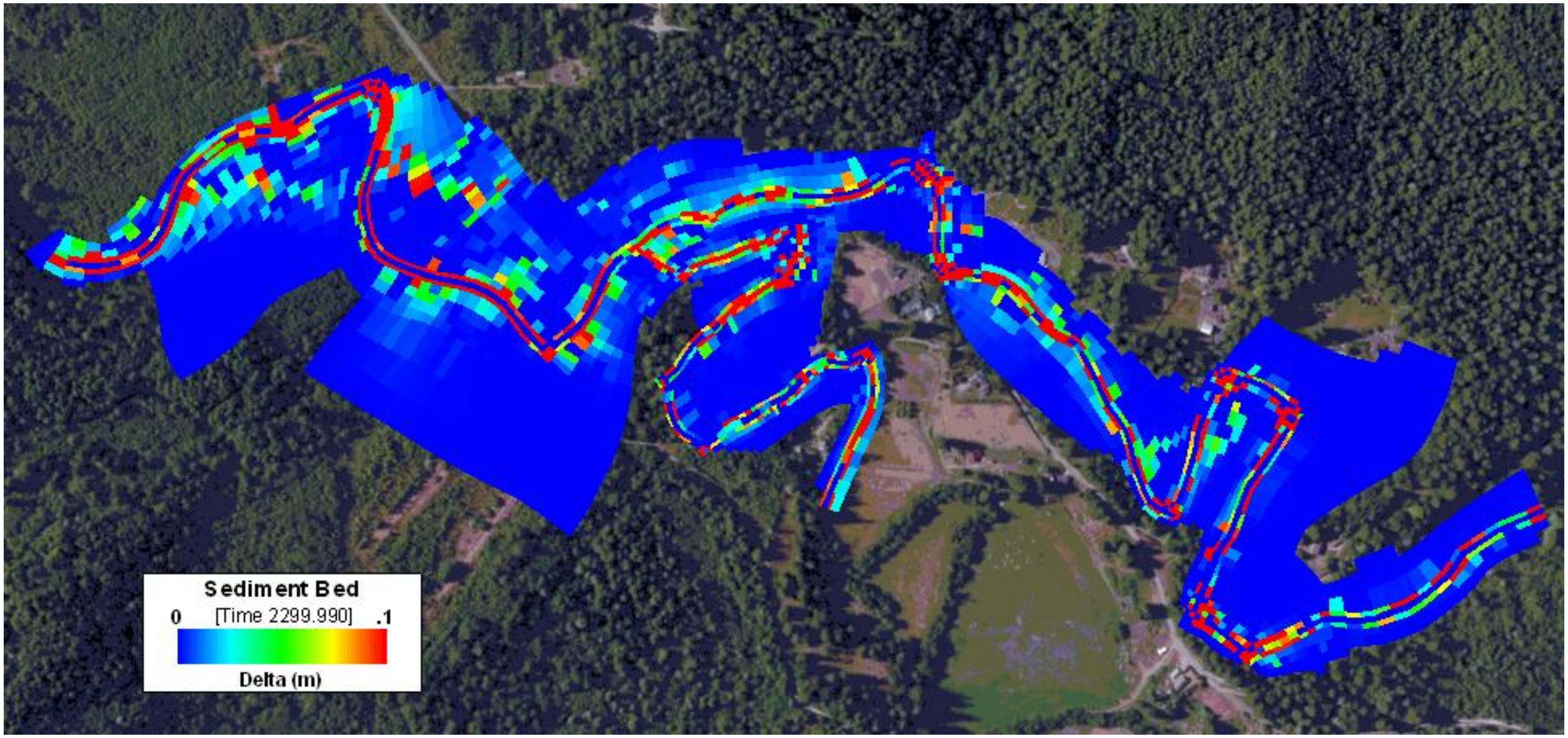


Figure 6-1. Predicted end of WY 2008 cumulative sedimentation in Elk River pilot project reach for the six-year simulation for reduced sediment supply conditions. Scale of figure shows 0 to 0.1 m of sedimentation, which best illustrates overall sediment deposition patterns in channel, channel bank and floodplain locations.

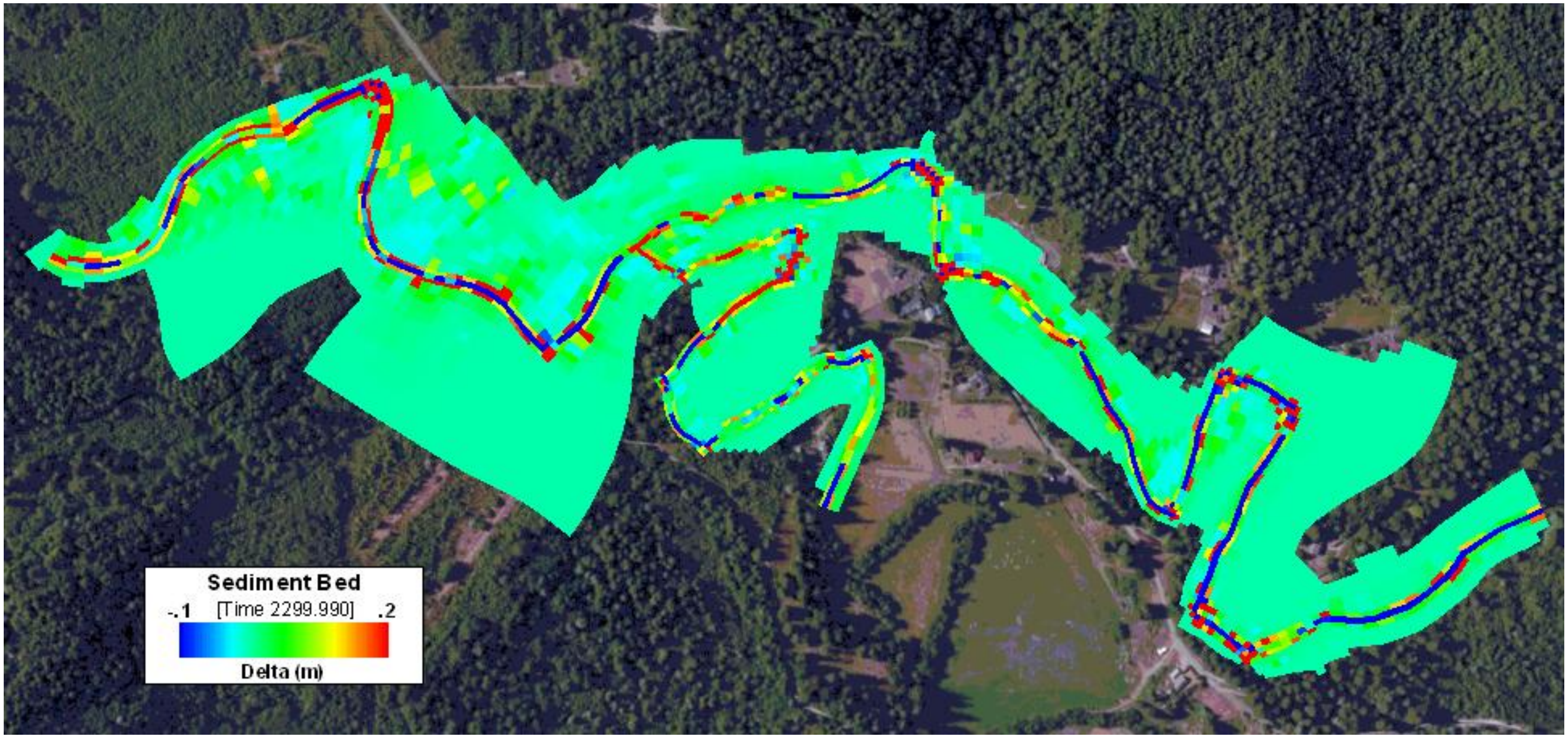


Figure 6-2. Predicted end of WY 2008 cumulative sedimentation in Elk River pilot project reach for the six-year simulation for reduced sediment supply conditions. Scale of figure shows -0.1 to 0.2 m of sedimentation, which best illustrates overall sediment deposition patterns in channel and channel bank locations.

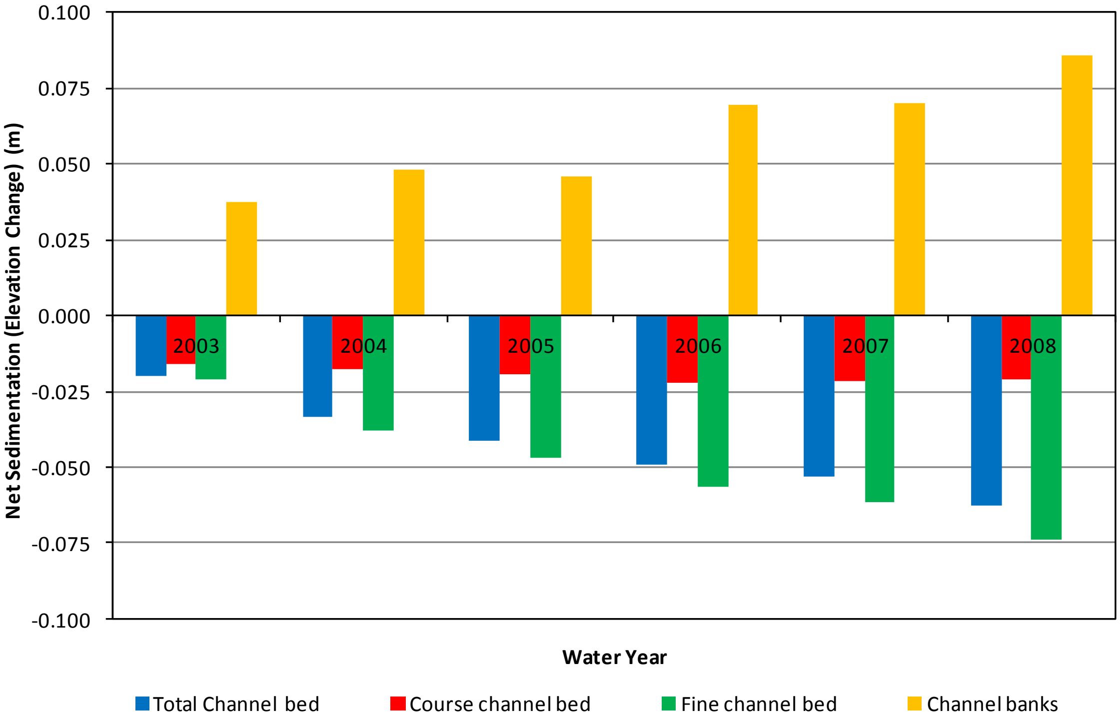


Figure 6-3. Predicted end of water year cumulative sedimentation within the Elk River channel and banks by channel bed types for the reduced sediment supply condition simulation.

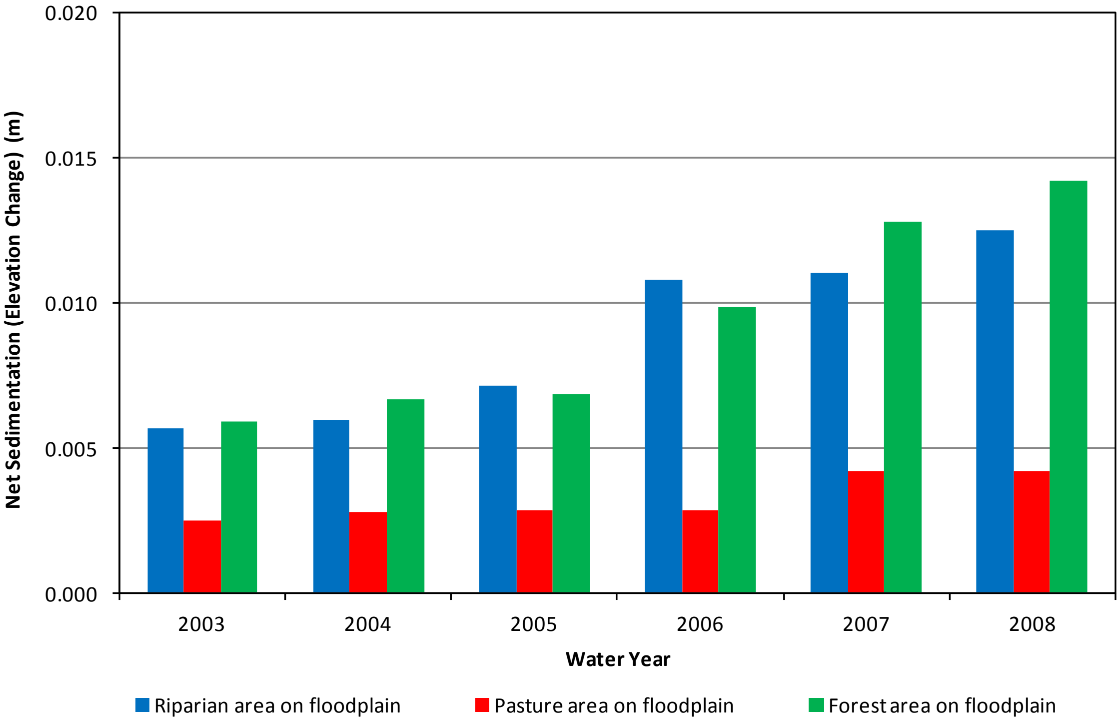


Figure 6-4. Predicted end of water year cumulative sedimentation within the Elk River floodplain by vegetation zone types for the reduced sediment supply condition simulation.

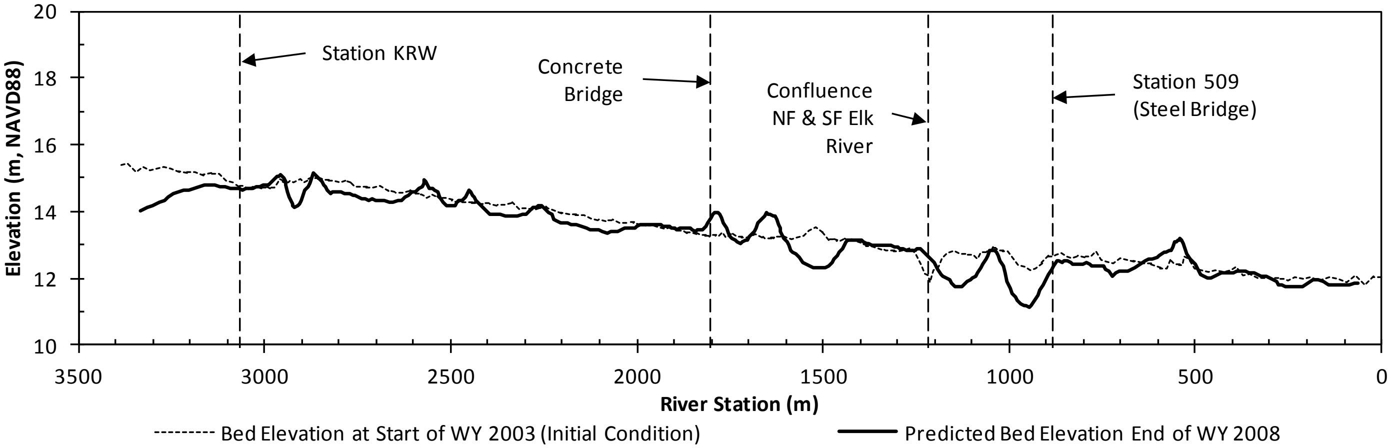


Figure 6-5. Initial condition bed elevation (start of WY 2003) and predicted bed elevation (9 grid cell average) at end of six-year simulation period (WY 2003-08) for NF and mainstem Elk River for reduced sediment supply condition.

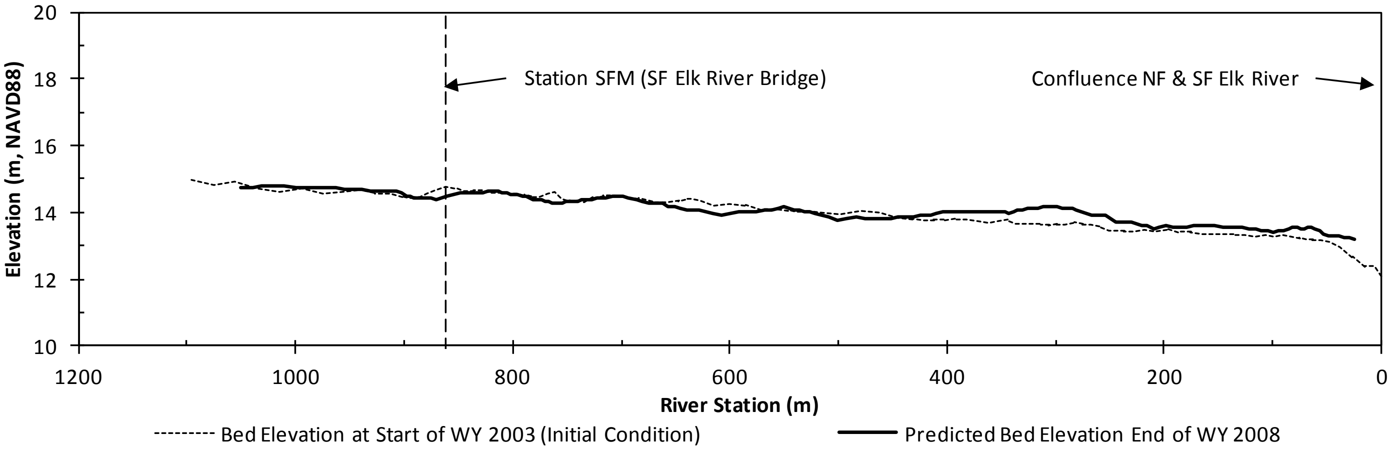


Figure 6-6. Initial condition bed elevation (start of WY 2003) and predicted bed elevation (9 grid cell average) at end of six-year simulation period (WY 2008) for SF Elk River for reduced sediment supply condition.

6.2 Sediment Load Flux and Storage within the Pilot Project Reach

The net sediment flux and storage within the Elk River pilot project reach was reassessed for the reduced sediment supply simulation. The SSL was extracted from the downstream end of the model grid across a flux line that accounts for channel, bank and floodplain flow, while the bedload flux was extracted from the channel cell only. Table 6-3 and Figure 6-7 summarizes the total 75% reduced SSL inflow, sediment outflow and cumulative sedimentation within the Elk River pilot project reach. Even with reduced sediment loads, HST model results indicate that the pilot project reach will retain sediment each, although at a much lesser rate compared to existing sediment conditions (Table 5-4). On average, approximately 12 % of the supplied sediment (Table 6-3) is stored within the pilot project reach for the reduced sediment supply simulation, compared to 18 % (Table 5-4) for the existing sediment conditions. Likewise, more of the supplied sediment is transported through the pilot project reach compared to existing conditions. The total sediment inflow and outflow flux for the reduced sediment supply condition (Figure 6-7) is about the same as the cumulative sediment retained in the pilot project reach for existing sediment conditions (Figure 5-17). Model results indicate that bedload continues to be a small fraction of the total sediment load within the pilot project reach under reduced sediment loads.

Table 6-3. Predicted total sediment load flux and storage within the Elk River pilot project reach for WY 2003-08 for the reduced sediment supply simulation.

Water Year	Total Pilot Project Reach SSL Inflow Reduced 75% (MT/yr)	Total SSL Outflow at end of Pilot Project Reach (MT/yr)	Total Bedload Outflow at end of Pilot Project Reach (MT/yr)	Total Sediment Load Outflow at end of Pilot Project Reach (MT/yr)	Net Sediment Storage within Pilot Project Reach (MT/yr)	Percent of SSL Inflow Stored within Pilot Project Reach
2003	13,633	11,406	3.5	11,410	2,224	16.3
2004	4,286	3,931	1.7	3,933	353	8.2
2005	5,125	4,502	1.2	4,503	622	12.1
2006	14,029	12,010	2.8	12,012	2,017	14.4
2007	4,012	3,622	1.2	3,623	389	9.7
2008	4,085	3,592	1.2	3,593	492	12.0
Average	**7,528**	**6,510**	**2.0**	**6,512**	**1,016**	**12.1**

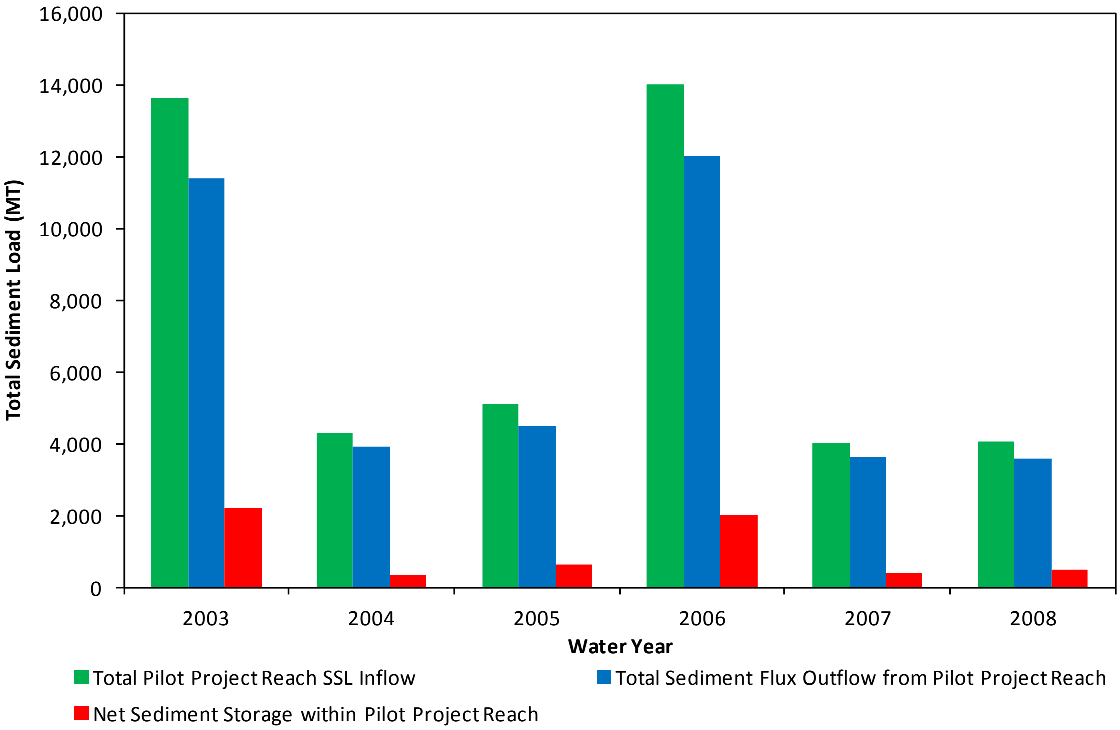


Figure 6-7. Total SSL inflow, predicted sediment load outflow and cumulative sediment load within the Elk River pilot project reach for WY 2003-08 for the reduced sediment supply simulation.

6.3 Sediment Bed d_{50} Change within the Pilot Project Reach

The final variable assessed for the reduced sediment supply condition is the change in the sediment bed d_{50} over the six-year simulation period (Table 6-4 and Figure 6-8). Unlike the existing sediment conditions (Table 5-5 and Figure 5-22), the channel sediment bed surface layer d_{50} coarsened for all channel grid zones for the reduced sediment scenario over time. However, the channel banks and floodplain still fined with time, but at a slower rate than for existing sediment supply conditions. The channel coarsening likely indicates that less of the finer sediment fraction materials (i.e. cohesive 1 and non-cohesive 1, Table 4-7) are being retained in the channel bed.

6.4 Summary of Reduced Sediment Supply Condition within the Elk River Pilot Project Reach

Model results for the six-year simulation indicate that reduced sediment loads into the Elk River pilot project reach (75% reduction in SSC provided by RWQCB) produced channel bed scour and incision. However, the channel banks and floodplain continued to aggrade. Based on HST model predictions and the inherent assumptions, the proposed reduced sediment loads could lead to some form of channel recovery (e.g. channel widening and erosion of banks) within the Elk River pilot project reach by transporting existing sediment deposits downstream.

Table 6-4. Initial condition and predicted sediment bed surface layer d_{50} for different model grid zones at the end of each water year for the six-year simulation period (WY 2003-08) within the Elk River pilot project reach for reduced sediment supply condition.

Model Grid Zone	**d_{50} (um)**						
	Initial Cond.	**WY 2003**	**WY 2004**	**WY 2005**	**WY 2006**	**WY 2007**	**WY 2008**
Coarse channel bed mainstem Elk River	1,807	1,541	1,758	1,786	1,798	1,924	1954
Coarse channel bed SF Elk River	1,623	1,602	1,704	1,580	1,604	1,714	1649
Fine channel bed (rest of river)	171	200.0	226	237	251	266	278
Channel bank	96.0	80.2	84.9	90.2	83.2	85.4	88.9
Floodplain (Riparian Area)	92.9	87.5	86.7	86.3	83.7	83.0	82.2

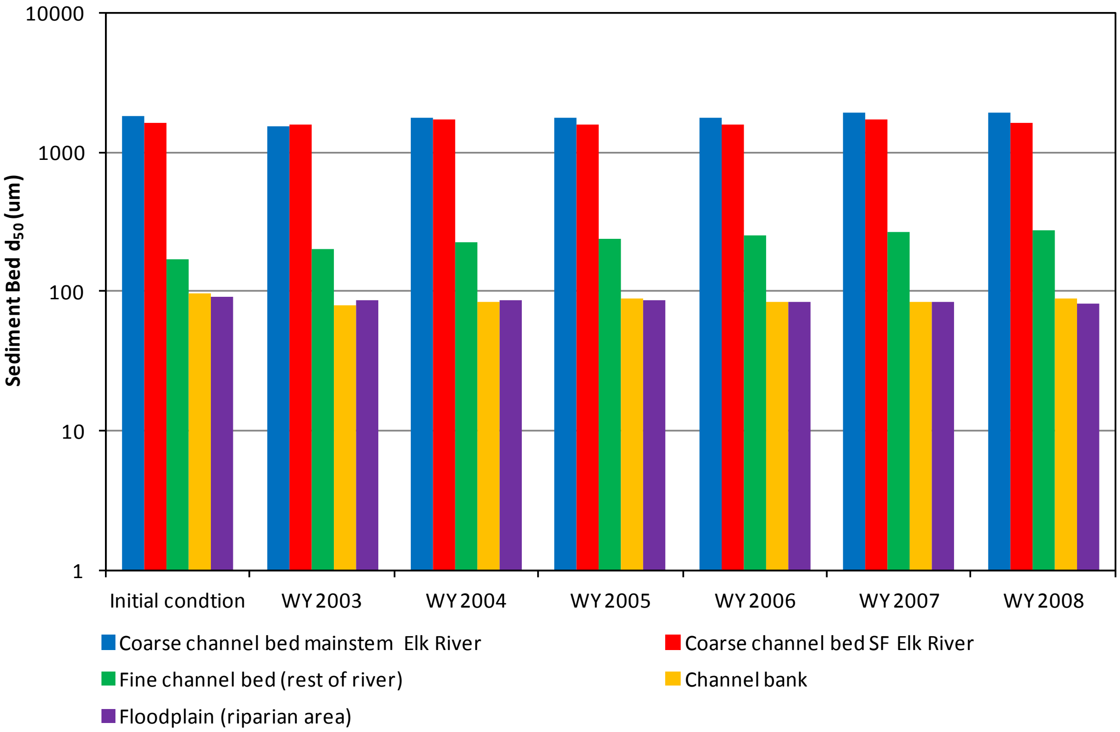


Figure 6-8. Change in the upper layer sediment bed d_{50} for different model grid zones at the end of each water year for the six-year simulation period (WY 2003-08) within the Elk River pilot project reach for reduced sediment supply condition. Figure plotted on log scale to provide better resolution of change.

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 HST Modeling Effort Conclusions

This pilot modeling effort demonstrated that a HST model can be developed for the Elk River pilot project reach that adequately predicts water depth and velocity, general sediment deposition patterns, and in-stream SSC values compared to available data. Provided that the identified data gaps are addressed, the model could be extended over a longer reach (e.g. 32 km or 20 miles) of the sediment impaired Elk River.

7.2 Suitability of Existing Data to Support HST Modeling

The monitoring network within the Elk River pilot project reach was established to document sediment loads and general deposition rates. The monitoring network was not established for HST modeling purposes, and therefore, there are numerous data gaps. However, we were able to use the existing data sets in conjunction with reasonable assumptions to develop a HST model. The following list summarizes the existing data sets and identified data gaps that would improve HST model development and results.

1. The LiDAR DEM covers the entire Elk River watershed and appears suitable for defining bank and floodplain topography. However, these data represent topography in 2005 and may not adequately describe future topography as erosion and/or sedimentation continues.
2. Detailed in-channel below water bathymetry is limited to cross-sections within the pilot reach. Cross-sections within the pilot reach are periodically resurveyed. Limited bathymetry data is available downstream of station 509.
3. Discharge records have been collected continuously since 2002 at Station KRW, SFM and 509. These data appear to be good quality within the range of the rating curve measurements. However, records appear to underestimate discharges for periods when flows are above rating curve measurements.
4. Water surface elevations are available at monitoring station locations and/or streamflow measurement sites. No water surface elevation data is available downstream of station 509.
5. Water velocity measurements are available at streamflow measurement sites. No velocity data is available downstream of station 509.
6. SSC and turbidity measurements have been collected continuously since 2002 at Stations KRW, SFM and 509, and appear to be good quality.
7. SSC sand fraction has been periodically measured at Station KRW and SFM. However, the complete particle size distribution of SSC has not been measured.
8. No bedload data exists for the Elk River.
9. No data exists on location, size and extent of large woody debris jams and in-channel vegetation for characterizing in-channel roughness.
10. Aerial photographs are adequate to delineate vegetation zones. However, no information exists regarding vegetation diameter, height, number of plants per area, large woody debris accumulations, and specific types of vegetation on banks and floodplain for defining vegetative drag.
11. Sediment grain size distributions on bed, bank and floodplain were collected as part of this effort over a large spatial area. However, the spatial location, extent and depth of individual deposits have not been mapped.

12. Data required to assess the hydraulic effects of structures, such as bridges and large woody debris jams, are not available.

7.3 Predicted Trajectory of Elk River Pilot Project Reach to Reduced Sediment Loads

Model results indicate that reduced sediment loads in the NF and SF Elk River, and Railroad and Clapp Gulch (75% reduction in SSC provided by RWQCB) produced channel scour and incision within the Elk River pilot project reach. Based on the HST model predictions and inherent assumptions, the proposed reduced sediment loads could lead to some form of channel recovery within the Elk River pilot project reach by transporting existing sediment deposits downstream. However, the fate of these sediment deposits on downstream reaches could not be assessed with the pilot project model as currently configured. Likewise, the response to predicted bed degradation/scour (e.g. bank erosion) in erosional reaches is unknown. An expanded HST model that extends, for example, from the Middle Reach to Humboldt Bay, could inform fate and transport of stored sediment over a longer reach of the Elk River.

7.4 Recommendations for Modifying or Expanding Existing Monitoring Programs to Support Future HST Modeling

Following are recommendations for modifying or expanding the existing Elk River monitoring programs to support future HST modeling efforts.

1. Conduct a detailed thalweg survey from Humboldt Bay upstream to the top of the Middle Reach Elk River.
2. Expand the existing channel cross-section network both upstream and downstream of the pilot project reach. The cross-sections, or sub-set of the cross-sections, should extend into the floodplain. The established cross-section network should be resurveyed on a routine schedule. Survey at appropriate detail to capture elevation changes at appropriate temporal scales.
3. Extend (update) NF and SF Elk River discharge rating curves at select discharge monitoring locations using slope-area methods for past and future estimates. Update past continuous discharge estimates using the updated rating curves.
4. Recalculate HRC sediment loads using the storm-based sediment load procedure and updated continuous discharge records. Recalculate SFO sediment loads using updated continuous discharge records.
5. Collect additional water surface elevation and velocity data at a number of locations upstream and downstream of pilot project reach. Priority should be on obtaining continuous stage records (stage recorder) and Acoustic Doppler Current Profiler (ADCP) velocity measurements across the channel.
6. Collect Railroad Gulch and Clapp Gulch discharge and sediment load data.
7. Obtain depth integrated SSC samples at existing monitoring stations and additional locations and analyze for particle size distribution.
8. Collect bedload measurements at a number of locations and analyze for particle size distribution.
9. Collect water surface elevation, temperature and salinity data in the tidal reach of lower Elk River.
10. Expand the spatial distribution of channel bed, bank and floodplain sediment deposit sampling and analysis for particle size distribution, bulk density, porosity, specific gravity, etc.
11. Increase the vertical depth of channel bed sediment sampling.

12. Map the location, size and extent of large woody debris jams and in-channel vegetation for characterizing in-channel roughness from Humboldt Bay to the top of the Middle Reach Elk River.
13. Collect data regarding vegetation diameter, height, number of plants per area, large woody debris accumulations, and specific types of vegetation on banks and floodplain for defining vegetative drag within defined vegetation zones from Humboldt Bay to the top of the middle reach.
14. Map the spatial location, extent and depth of the different sediment deposits from Humboldt Bay to top of Middle Reach.
15. Adopt standardized data reporting formats (e.g. state if local standard time or daylight savings time).

7.5 Recommendations for Future HST Model Development and Calibration

Future Elk River HST modeling efforts should consider the following recommendations for model development and calibration efforts:

1. Modify and/or improve the model grid resolution to provide coarser overall grid to improve computation times. Consider the following: (A) use longer channel grid cells in straight reaches, and provide smooth transition to smaller channel grid cells at meander cross-over locations; and (B) try using a one-dimension grid (in i or j direction) to represent channel and banks, which could use longer grid cells that allow better floodplain cell transitions.
2. Modify and improve the inflow SSC gradations. Consider using 2 cohesive sediment classes (e.g. clay and fine silt, and medium to coarse silts), and 3 to 4 non-cohesive sediment classes.
3. Use a physically based approach to estimate inflow water column SSC composition based on, for example, discharge, WSE, velocity and shear stress relations.
4. Collect and analyze cohesive sediment properties, such as settling velocity, and critical shear stress for erosion and deposition.
5. Investigate using $2d_{90}$ to separate cohesive and non-cohesive grain shear stress.
6. Test the anti-diffusion and flux-limitation options within the EFDC model to improve peak SSC predictions.
7. Use the effective diameter of coarse silt and/or sand fractions as calibration parameters.

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