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Elk River Recovery Assessment: Recovery Framework

PREPARED FOR

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Cover photos: Sediment-laden flow in the mainstem Elk River at Steel Bridge.

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GLOSSARY

Term	Definition
Accretion	The process of growth or increase, typically by the gradual accumulation of additional layers or matter.
Adaptive management	An intentional approach to making decisions and adjustments in response to new information and changes in context.
Aggradation	The increase in land elevation, typically in a river system, due to the deposition of sediment. Aggradation occurs in areas in which the supply of sediment is greater than the amount of material that the system is able to transport.
Alevin	A newly spawned salmon or trout still carrying the yolk.
Allochthonous	Sediment or rock that originated at a distance from its present position.
Alluvium	A deposit of clay, silt, sand, and gravel left by flowing streams in a river valley or delta, typically producing fertile soil.
Anadromous	Anadromous fish are born in freshwater, then migrate to the ocean as juveniles where they grow into adults before migrating back into freshwater to spawn.
Anthropogenic	Resulting from the influence of human beings on nature.
Avulsion	The rapid abandonment of a river channel and the formation of a new river channel.
Backwater	A part of a river in which there is little or no current. May refer to a branch of a main river, which lies alongside it and then rejoins it, or to a body of water in a main river, which is backed up by the tide or by an obstruction such as a dam.
Bankfull	The water level or stage at which a stream, river or lake is at the top of its banks and any further rise would result in water moving into the flood plain.
Basin	An area of land where precipitation collects and drains off into a common outlet, such as into a river, bay, or other body of water.
Bathymetry	The measurement of water depth at various places in a body of water.
Bedload	Particles in a flowing river that are transported along the bed. Erosion and bed shear stress continually remove material from the bed and banks of the stream channel, adding this material to the regular flow of water.
Beneficial uses	The uses of “water of the state” protected against degradation, such as domestic, municipal, agricultural and industrial supply; power generation; recreation; aesthetic enjoyment; navigation and preservation of fish and wildlife, and other aquatic resources or preserves. Beneficial uses are the cornerstone of water quality protection under the RWQCB Basin Plan for the North Coast region. Designated beneficial uses, plus water quality objectives, form the basis of water quality standards. The federal Clean Water Act and California Water Code mandate the development of water quality standards for all waterbodies within the state, including wetlands.
Benthic	Bottom-dwelling.
Biomass	The total mass of organisms in a given area or volume.
Brackish	Water that has more salt than freshwater, but not as much as seawater. It may result from mixing of seawater with fresh water, as in estuaries.
Bulk density	The weight of soil in a given volume.
Channel geometry	The description of the size and shape of the channels in which water flows including channel width, depth, and slope. Changes in the geometry of the channel can impact stream velocity and discharge.
Confluence	The junction of two rivers, especially rivers of approximately equal width.

Term	Definition
Coniferous	Belonging or pertaining to the conifers. Conifers are a division of vascular land plants containing a single class, Pinopsida. Conifers are cone-bearing seed plants. All conifers are perennial woody plants with secondary growth.
Crevasse splays	A sedimentary fluvial deposit which forms when a stream breaks its natural or artificial levees and deposits sediment on a floodplain. A breach that forms a crevasse splay deposits sediments in similar pattern to an alluvial fan deposit.
Critical habitat	A specific geographic area that contains features essential to the conservation of an endangered or threatened species and that may require special management and protection (as defined by the Endangered Species Act).
Crustacean	An arthropod of the large, mainly aquatic group Crustacea, such as a crab, lobster, shrimp, or barnacle.
Depensatory	In population dynamics, depensation is the effect on a population whereby, due to certain causes, a decrease in the breeding population leads to reduced production and survival of eggs or offspring.
Depocenter	The part of a sedimentary basin where a particular rock unit has its maximum thickness.
Discharge	The volumetric flow rate of water that is transported through a given cross-sectional area.
Dissolved Oxygen	The amount of gaseous oxygen (O2) dissolved in water. Oxygen enters the water by direct absorption from the atmosphere, by rapid movement, or as a waste product of plant photosynthesis. Water temperature and the volume of moving water can affect dissolved oxygen levels. Oxygen dissolves easier in cooler water than warmer water. Adequate dissolved oxygen is important for good water quality and is necessary to all forms of life. Dissolved oxygen levels that drop below 5.0 mg/L cause stress to aquatic life. Lower concentrations cause greater stress and dissolved oxygen levels that fall below 1-2 mg/L for a few hours may result in large fish kills.
Ecotone	A transitional area of vegetation between two different plant communities with some of the characteristics of each bordering biological community but generally containing species not found in the overlapping communities.
Entrainment	Fish being transported along with the flow of water and out of their normal river, lake or reservoir habitat into unnatural or harmful environments.
Entrenchment	The vertical containment of a river. An entrenched river or stream flows in a narrow trench or valley cut into a plain or relatively level upland with little modification of the original course. The down-cutting of the river could be the result of the river cutting into bedrock, tectonic uplift, decrease of load, increase of runoff, extension of the drainage basin, river piracy, or change in base level such as from a fall in sea level. The term “entrenchment ratio” has been quantitatively defined by Rosgen (1994) to provide a consistent method for field determination as the ratio of the width of the flood-prone area to the surface width of the bankfull channel. The flood-prone area width is measured at the elevation that corresponds to twice the maximum depth of the bankfull channel as taken from the established bankfull stage.
Epibenthic	Organisms that live on or just above the bottom sediments in a body of water which tend to forage on the creatures that live in or on the sediments.
Escapement	The number of salmon that return to spawn in a river. For species that die after spawning (such as Chinook), escapement can be estimated by counting the number of salmon carcasses found in the spawning grounds.

Term	Definition
Estuary	A partially enclosed, coastal water body where freshwater from rivers and streams mixes with salt water from the ocean. Often called nurseries of the sea (USEPA, 1993), estuaries provide vital nesting and feeding habitats for many aquatic plants and animals.
Eutrophication	When a body of water becomes overly enriched with minerals and nutrients that induce excessive growth of plants and algae, oftentimes resulting in oxygen depletion of the water body.
Eustatic	The eustatic sea level is the distance from the center of the earth to the sea surface. An increase of the eustatic sea level can be generated by decreasing glaciation, slower spreading rates of the mid-ocean ridges or fewer mid-oceanic ridges.
Facies	A body of rock with specified characteristics, which can be any observable attribute such as their overall appearance, composition, or condition of formation, and the changes that may occur in those attributes over a geographic area.
Fingerling	a fish that has reached the stage where the fins can be extended and where scales have started developing throughout the body. At this stage, the fish is typically about the size of a finger.
Fry	Recently hatched fish that have reached the stage where the yolk-sac has almost disappeared and the swim bladder is operational to the point that the fish are capable of feeding themselves.
Geomorphic	Relating to the form of the landscape and other natural features of the earth's surface.
Geomorphic reach	A length of a stream or river, generally suggesting a relatively uniform, uninterrupted stretch. The beginning and end points may be based on changes in the rivers form such as slope, channel geometry, or valley width.
Headwall swales	A geomorphic feature consisting of a concave depression with convergent slopes, typically of 65% or greater steepness that is connected to a watercourse or lake by way of a continuous linear depression and that has been sculpted over geologic time by shallow landslide events. The slope profile is typically smooth and unbroken by benches, but may be interrupted by recent landslide deposits or scars.
Headwater	A tributary stream of a river close to or forming part of its source.
Hydrodynamics	A branch of physics that deals with the motion of fluids and the forces acting on solid bodies immersed in fluids and in motion relative to them. Hydrodynamic models of river systems predict depth, velocity, water surface profile, flow inundation and shear stress.
Hydrogeomorphology	An interdisciplinary science that focuses on the interaction and linkage of hydrologic processes with landforms or earth materials and the interaction of geomorphic processes with surface and subsurface water in temporal and spatial dimensions.
Hydrograph	A graph showing the rate of flow (discharge) versus time past a specific point in a river, channel, or conduit carrying flow.
Hyporheic	An area or ecosystem beneath the bed of a river or stream that is saturated with water and supports invertebrate fauna.
In-channel benches	Level, step-like fluvial deposits occurring at different heights above the channel bed but below the main floodplain surface. In-channel benches are generally constructed to inundate at variable flood exceedances in order to provide fish rearing benefits over a range of low to moderate flow magnitudes.
Indurated	Hardened.
Intertidal	The intertidal zone (sometimes referred to as the littoral zone) is the area that is above water at low tide and underwater at high tide.

Term	Definition
Intrinsic potential	The intrinsic potential of a stream looks at how landscape characteristics affect a particular fish species to define the underlying capacity of a stream to provide high-quality habitat for that species. Intrinsic potential is derived from reach-scale stream attributes (gradient, stream size, and valley constraint) that influence availability of the fine-scale habitat features (e.g., pools, spawning gravel, and large wood) preferred by salmonids.
LiDAR	Light Detection and Ranging surveying or remote sensing method that that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth. Differences in laser return times and wavelengths can then be used to make digital 3-D representations of the target.
Loading capacity	The total amount of sediment a stream is able to transport. Load is the amount of sediment carried by the stream and is generally limited by the amount of sediment available upstream.
Longitudinal profile	A graphic presentation of elevation vs. distance; in channel hydraulics it is a plot of water surface elevation against upstream to downstream distance.
Macroinvertebrates	Organisms that lack a spine and are large enough to be seen with the naked eye, including small aquatic animals and the aquatic larval stages of insects.
Mélange	A large-scale, mappable body of rock characterized by a lack of continuous bedding and the inclusion of fragments of rock of all sizes, contained in a fine-grained deformed matrix.
Mendocino Triple Junction	The point where the Gorda plate, North American plate, and Pacific plate meet in the Pacific Ocean near Cape Mendocino in northern California.
Morphology	A study of structure or form. As applied to rivers, the shapes of river channels and how they change in shape and direction over time.
Natal	Relating to the homing process by which salmonids use geomagnetic imprinting and olfactory cues to return to their birthplace to reproduce.
Nuisance flooding	California Water Code §13050 defines nuisance to mean anything which meets all of the following requirements: 1. Is injurious to the health, or is indecent or offensive to the senses, or an obstruction to the free use of property, so as to interfere with the comfortable enjoyment of life or property. 2. Affects at the same time an entire community or neighborhood, or any considerable number of persons, although the extent of the annoyance or damage inflicted in individuals may be unequal. 3. Occurs during, or as a result of, the treatment or disposal of waste.
Osmoregulation	The maintenance of constant osmotic pressure in the fluids of an organism by the control of water and salt concentrations.
Planform	Channel shape as seen from the air. Planform change can be the result of a straightened course imposed on the river through different channel management activities, or a channel response to other adjustment processes such as aggradation and widening. When a river changes planform and cuts a new channel, a change in channel slope usually results, sometimes initiating another channel evolution in which degradation causes the channel slope to increase, or aggradation causes the slope to decrease.
Porosity	A measure of the void (i.e., empty) spaces in a material.
Reach	A length of a stream or river, generally suggesting a , uninterrupted stretch.
Redd	A nest for spawning built by salmon and steelhead into the gravel of streams or the shoreline of lakes. The redd is formed by the female using her tail to dig a depression in the gravel into which eggs are deposited. The size of a redd depends on the size of the fish making the nest.
Refugia	An area in which a population of organisms can survive through a period of unfavorable conditions.

Term	Definition
Riffle	A shallow landform in a flowing channel with specific topographic, sedimentary, and hydraulic indicators. Riffles are the shallower, faster moving sections of a stream.
Riparian	Plant communities contiguous to and affected by surface and subsurface hydrologic features of perennial or intermittent waterbodies.
Roughness	Hydraulic roughness is the measure of the amount of frictional resistance water experiences when passing over land and channel features.
Salinity	The saltiness or amount of salt dissolved in a body of water.
Salmonid	A fish of the salmon family Salmonidae.
Scrub	A plant community characterized by vegetation dominated by shrubs, often also including grasses, herbs, and geophytes.
Sediment budget	An organizational tool to help understand sediment transport and storage patterns within a system.
Silviculture	The growing and cultivation of trees.
Slough	Part of the estuary, where freshwater flows from creeks and runoff from land mix with salty ocean water transported by the tides.
Smolt	A young salmon (or trout) after the parr stage and about two years old that is at the stage of development when it assumes the silvery color of the adult and is ready to migrate to the sea.
Spatial resolution	The number of pixels utilized to construct a digital image or map. Images with higher spatial resolution are composed with a greater number of pixels than those with lower spatial resolution.
Spawning	The act or process of producing or depositing eggs.
Subsidence	The gradual caving in or sinking of an area of land.
Suspended sediment	The portion of the sediment that is maintained in suspension by the turbulence of flowing water and do not settle/touch the river bed. Generally comprised of fine sand, silt and clay particles.
Substrate	The surface on which the river organisms live. May be inorganic (consisting of boulders, pebbles, gravel, sand or silt), or organic (consisting of fine particles, leaves, wood, moss and plants).
Terrestrial	Living or growing on land.
Thalweg	The line that connects the lowest points in a valley or river channel. The line of fastest flow or deepest water along a river's course.
Tide Gate	An opening through which water may flow freely when the tide moves in one direction, but which closes automatically and prevents the water from flowing in the other direction. Tide gates are typically used to drain tidelands (areas that incoming tides regularly cover) for agricultural or other uses.
Tidal prism	The volume of water in an estuary or inlet between mean high tide and mean low tide, or the volume of water leaving an estuary at ebb tide. It can also be thought of as the volume of the incoming tide plus the river discharge.
Topography	A detailed description or representation on a map of the natural and artificial features of an area.
Tributary	A stream or river that flows into a larger stream or mainstem river or lake. A tributary does not flow directly into a sea or ocean. Tributaries and the main stem river drain the surrounding drainage basin of its surface water and groundwater, leading the water out into an ocean.

Term	Definition
Turbidity	Turbidity is the measure of relative clarity of a liquid. It is an optical characteristic of water and is an expression of the amount of light that is scattered by material in the water when a light is shined through the water sample. The higher the intensity of scattered light, the higher the turbidity. Material that causes water to be turbid include clay, silt, finely divided inorganic and organic matter, algae, soluble colored organic compounds, and plankton and other microscopic organisms.
TMDL	Total Maximum Daily Load (TMDL). The maximum amount of a pollutant that can be discharged into a waterbody from all sources (point and nonpoint) and still maintain water quality standards. Under CWA section 303(d), TMDLs must be developed for all waterbodies that do not meet water quality standards even after application of technology-based controls, more stringent effluent limitations required by a state or local authority, and other pollution control requirements such as Best Management Practices (BMPs).
Understory	A layer of vegetation beneath the main canopy of a forest.
Velocity	The speed of something in a given direction. Velocity will change along the course of a river based on factors such as gradient, water volume, the shape of the river channel, and the amount of friction created by the bed, rocks and plants.
Water quality objectives	Numeric or narrative limits or levels of water quality elements or biological characteristics established to reasonably protect the beneficial uses of water or to prevent pollution problems within a specific area.
Water quality standards	State-adopted and USEPA-approved standards for waterbodies that prescribe the use of the waterbody and criteria that must be met to protect designated beneficial uses. Water quality standards also include the federal and state anti-degradation policy which requires that existing uses are to be maintained.
Water surface elevation	The heights reached by flows of various magnitudes and frequencies at pertinent points in a floodplain.
Width to-depth ratio	The ratio of the bankfull surface width to the mean depth of the bankfull channel. Key to understanding the distribution of available energy within a channel, and the ability of various discharges occurring within the channel to move sediment.
Watershed	A land area that delivers rainfall and snowmelt to creeks, streams, and rivers, and eventually to outflow points such as reservoirs, bays, and the ocean. The size of a watershed (also called a drainage basin or catchment) is defined on several scales—referred to as Hydrologic Unit Codes (HUC)—based on the geography that is most relevant to its specific area.
Young-of-year	Fish born within the past year, which have not yet reached one year of age.

1 INTRODUCTION

Elk River, the largest tributary to Humboldt Bay and natal stream to four species of anadromous salmonids, is undergoing intensive watershed-wide recovery efforts to remediate impairments associated with excessive channel sedimentation. Chronic high turbidity associated with elevated sediment supply and reduced channel conveyance capacity resulting from channel sedimentation have impaired domestic and agricultural water supply, degraded aquatic habitat, and increased nuisance flooding in the 19.2 river miles encompassing the Project area (Figure 1-1).

1.1 Watershed Setting

Elk River drains a 58.3 square mile (mi^2) watershed in Humboldt County, California. The basin drains westward across the seaward slope of the outer Coast Range to the coastal plain and into Humboldt Bay, near the city of Eureka (Figure 1-1). The basin can be divided into four main areas: (1) North Fork Elk River (58.2 km^2), (2) South Fork Elk River (50.4 km^2), (3) Mainstem Elk River downstream of the North Fork Elk River and South Fork Elk River confluence (26.9 km^2), and (4) Martin Slough (15.3 km^2) (Figure 1-1).

The basin is located along the southeastern margin of the actively uplifting and deforming southern Cascadia forearc basin at the leading edge of northward migrating Mendocino triple junction. The present-day Mainstem Elk River valley occupies a deep, structural trough formed within the coastal plain as a result of northwest-trending folding and faulting and regional tectonic uplift and subsidence. The valley is a naturally occurring depocenter filled with thick, unconsolidated Late Pleistocene and younger alluvium deposited during marine transgression related to eustatic sea level rise. The approximately 12 miles of Mainstem Elk River downstream of the North Fork Elk River and South Fork Elk River confluence consist of low-gradient, alluvial channel types with narrow riparian canopy, transitioning to tidally influenced fresh, brackish, and saline slough channels.

Geology in the Elk River basin is predominantly composed of the Wildcat Group, the Yager terrane, and the Franciscan Complex Central Belt (Ogle, 1953; McLaughlin et al. 2000, Marshall and Mendes 2005). The most extensive geologic unit in the basin is the Wildcat Group, a thick overlap assemblage of poorly indurated marine siltstone and fine-grained 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 and inner gorges. The Yager terrane is highly folded and sheared argillite and sandstone turbidites with minor pebbly conglomerate. The sandstone facies commonly form cliffs and exert local base level control where streams have incised through younger, less resistant overlap deposits. The argillite facies are typically deeply weathered, promoting deep-seated flow failures on moderately steep slopes. 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 Franciscan Complex Central Belt. Undifferentiated shallow marine and fluvial deposits of middle to late Pleistocene age cap ridges across the western portion of the watershed.

The Elk River watershed has a maritime coastal climate with mild wet winters and a prolonged summer dry season. Mean air temperatures at the coast fluctuate from 48° F in January to 55° F in June. Mean annual precipitation ranges from 39 inches on the coast near Eureka to 60 inches near Kneeland, located 2,657 feet above sea level and approximately 12 miles inland. Roughly 90 percent of the annual precipitation occurs as rainfall between October and April. Intense rainfall over steep topography composed of erodible parent materials results in high sediment yields. Storm events with rainfall intensity exceeding 3 to 4 inches a day are considered capable of initiating landslides (PALCO 2004). Rainfall exceeding 5 inches per day occurred three times between 1941 and 1998 (water years 1950, 1959, and 1997). The 24-hour rainfall total of 6.8 inches on December 27, 2002 caused widespread landslides and flooding (Tetra Tech 2015).

The majority (82%) of the mountainous upper third of the watershed is zoned as timber production zone (TPZ). Humboldt Redwood Company (HRC) and Green Diamond Resource Company (GDRC) own and manage 75% and 7% of the Upper Elk River watershed, respectively. The remaining portions of the Upper Elk River watershed comprise the Bureau of Land Management's (BLM) Headwaters Forest Reserve established in 1999 (13%) and a combination of non-industrial timberlands, private residences, and agricultural land uses (5%). The Lower Elk River watershed is primarily under grazing and rural residential uses. Martin Slough is urbanizing, and additional residential development is anticipated in the coming decades.

Elk River provides critical habitat for several species of historically abundant anadromous salmonids, including coho salmon (*Oncorhynchus kisutch*), Chinook salmon (O. tshawytscha), steelhead (O. mykiss), and coastal cutthroat trout (*O. clarkii*). Three species (Chinook, coho, and steelhead) are currently listed as threatened under the Federal Endangered Species Act (ESA); coho are listed by the California ESA. Prior to human disturbances, Elk River supported large numbers of coho salmon (CDFG 1994, Weitkamp et al. 1995, HBWAC 2005, NMFS 2014). The upper watershed, tributaries, and Mainstem Elk River provide exceptional potential for restoring salmonid spawning and rearing habitat, and short reaches within the watershed continue to maintain good quality habitat. Tidally influenced freshwater and brackish habitats in the Elk River estuary also provide critical natal and non-natal habitat for juvenile salmonids (Wallace 2011).

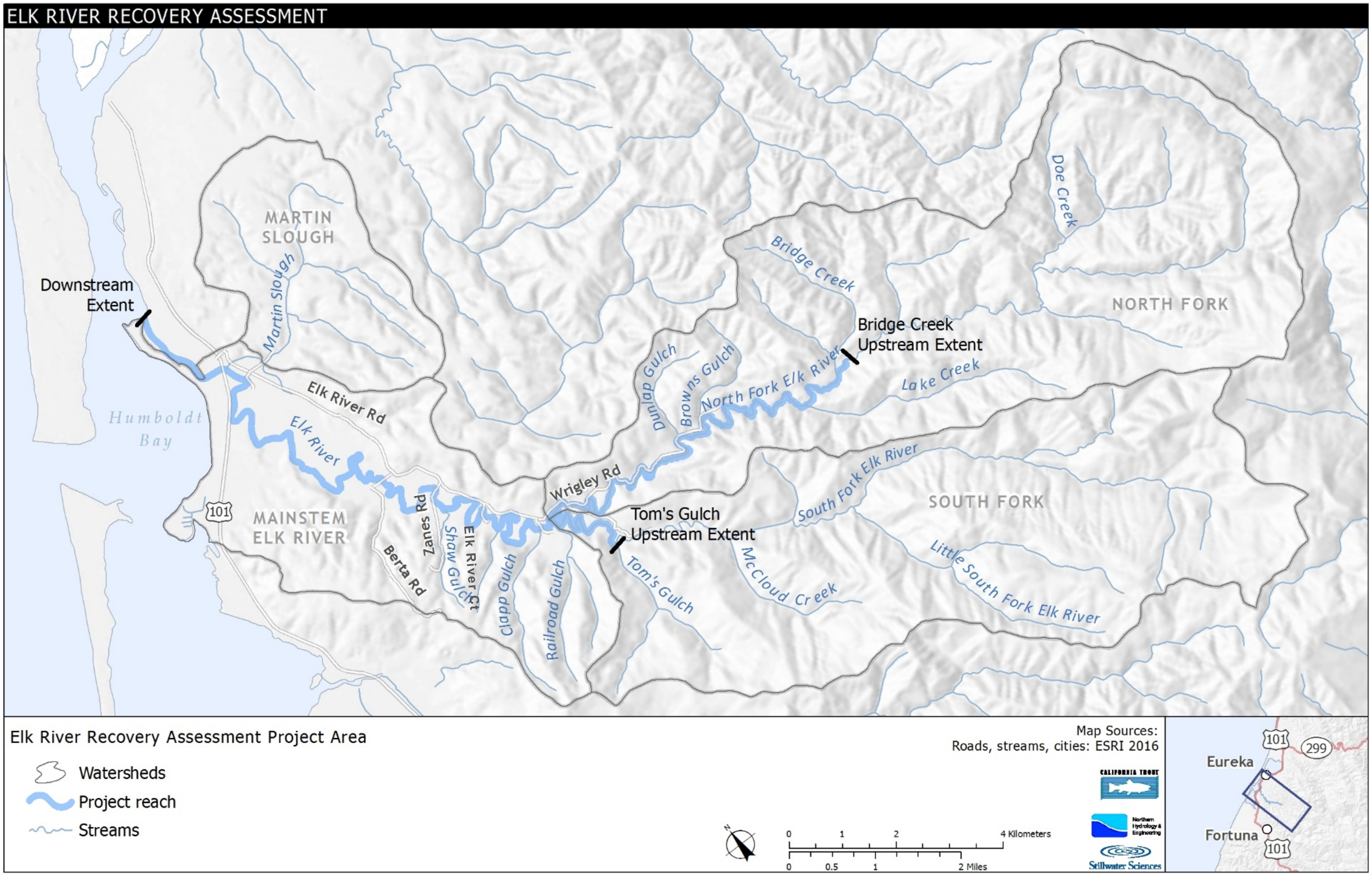

Figure 1-1. Elk River Recovery Assessment Project area.

1.2 Watershed Condition and Impairment

The Elk River watershed has undergone several extensive anthropogenic disturbances over the last century and a half. Commercial timber harvest operations beginning in the late 1800s severely altered natural hillslope erosional processes and significantly changed sediment supply, transport, and depositional processes in stream channels and on floodplains. Stream channels were historically maintained relatively clean of large wood to facilitate transporting logs downstream. Timber harvesting and consequent management-related sediment loading markedly increased from 1988 to 1997 when Maxxam Corporation (Maxxam) owned and managed Pacific Lumber Company (PALCO). During this time, PALCO adopted more aggressive road building and silvicultural practices, accelerating the annual average harvest rate by approximately five times the previous long-term average (Regional Water Board 2013). During this period of accelerated harvest, Elk River experienced several water years with higher than average rainfall. Significant rainfall events that occurred across the highly erodible and recently disturbed landscape during these years resulted in numerous large landslides, historically unprecedented sediment delivery to the upper Elk River and its tributaries, and significant sedimentation in lower-gradient channel reaches. Elevated sediment loading and channel sedimentation continued through the last decade of the twentieth century. Humboldt Redwood Company currently owns these former PALCO lands and is working to mitigate controllable sediment sources.

Changes in floodplain land uses in Lower Elk River, primarily for livestock and dairy operations, have also affected stream channel, riparian vegetation, and salmonid habitat conditions. Estuarine and tidal wetlands were diked and drained to reclaim these lands for agricultural use, reducing the extent and effects of tidal influence in the lower reaches of Elk River. Although land development and infrastructure are relatively limited in Elk River, numerous roads and bridges, rural residential developments, and other infrastructure have also altered watershed conditions.

Discharges of sediment and organic debris to watercourses have aggraded stream channels in the low gradient reaches of Elk River, significantly reducing channel capacity. Prior analysis of available North Fork Elk River, South Fork Elk River, and Mainstem Elk River cross-section data indicated there is approximately 640,000 cubic yards (yd^3) of excess stored sediment impairing the Elk River channel: more than 280,000 yd^3 in the lower North Fork Elk River, nearly 100,000 yd^3 in the lower South Fork Elk River, and nearly 260,000 yd^3 in the upper Mainstem Elk River (Regional Water Board 2013). Uncertainty surrounding these prior estimates prompted additional data collection and modeling studies to refine the estimate.

Channel conditions do not currently meet water quality objectives (i.e., for sediment, suspended material, settleable matter, turbidity, and dissolved oxygen) and adversely impact multiple beneficial uses of water (i.e., municipal [MUN] and agricultural [AGR] water supplies, cold freshwater habitat [COLD], rare, threatened and endangered species [RARE], migration of aquatic organisms [MIGR], spawning, reproduction, and/or early development [SPWN], and water contact recreation [REC-1]). Severe stream channel aggradation has increased the incidence of nuisance flooding, affecting property access and use and increasing the risk to human health and welfare. Fields, roadways, driveways, homes, and septic systems are frequently inundated. Overbank flooding onto roads and private properties in some locations in Elk River now occurs several times a year, depending on the frequency, intensity, and duration of storm events. The impacted reach, as defined by the North Coast Regional Water Quality Control Board, extends from the confluence of Brown's Gulch on the North Fork Elk River and Tom's Gulch on the South Fork Elk River to Berta Road on the Mainstem Elk River (Regional Water Board 2016).

1.3 Elk River Regulatory Program

Resource agencies and stakeholders are resolving the complex ecological and social issues resulting from sediment impairment in Elk River by implementing a multifaceted approach that includes a Total Maximum Daily Load Implementation and Monitoring Plan, Waste Discharge Requirements to reduce future sediment loads, a Recovery Assessment and Implementation Framework to alleviate existing sediment impairments and improve ecosystem function, and a Stewardship Program to coordinate stakeholder participation in recovery planning and implementation.

1.3.1 The Elk River Sediment Total Maximum Daily Load

The North Coast Regional Water Quality Control Board (Regional Water Board) and the U.S. Environmental Protection Agency (USEPA) listed the Elk River watershed as a sediment-impaired waterbody in 1998 under the Clean Water Act Section 303(d). In response to a 2004 petition from residents to dredge the Elk River, the Regional Water Board convened a Technical Advisory Committee (TAC) to guide discussions and identify information needed to understand the effectiveness and potential environmental consequences of dredging, among other sediment remediation alternatives. Based on TAC recommendations, the Regional Water Board concluded that (1) a better understanding of existing channel conditions and physical processes was necessary to evaluate the potential effects of sediment remediation measures and other direct actions designed to hasten recovery of beneficial uses of water in Elk River, and (2) development of appropriate and effective measures would require an integrated, system-wide, and scientifically-based planning effort informed by predictive modeling of hydraulic and geomorphic responses to potential treatment alternatives.

The Regional Water Board released for public review a staff report for a sediment Total Maximum Daily Load (TMDL) for the Upper Elk River in 2013 (Regional Water Board 2013). After additional technical reports and a lengthy public process of amending the Water Quality Control Plan for the North Coast Region (Basin Plain), the Regional Water Board adopted the Action Plan for the Upper Elk River Sediment TMDL (TMDL Action Plan) (Regional Water Board 2016). In the subsequent two years, the State Water Resources Control Board (State Water Board) and Office of Administrative Law approved the Basin Plan amendment, and the Upper Elk River Sediment TMDL became state law under California Code of Regulations Section 3909.6. Likewise, US EPA approved the Upper Elk River TMDL pursuant to Clean Water Act section 303(d) and implementing regulations.

The TMDL Action Plan addresses impairments in the 44.2 square mile (approximately 28,300 acre) Upper Elk River Watershed. The Program of Implementation (associated with the Upper Elk River Sediment TMDL) includes non-regulatory actions that are designed to address sedimentation throughout the watershed but does not establish sediment load allocations for land use in the Martin Slough or Lower Elk River westerly sub-watersheds, nor for activities in the Lower Elk River sub-watershed downstream of Berta Road. The goal of the TMDL Action Plan is to achieve sediment related water quality standards, including the protection of the beneficial uses of water in the upper watershed and prevention of nuisance conditions. The TMDL Action Plan establishes the sediment load consistent with current conditions in the impacted reaches, identifies a process for assessing and implementing necessary and feasible remediation and restoration actions, and describes a program of implementation to be considered and incorporated into regulatory and non-regulatory actions of the Regional Water Board and other stewardship partners in the watershed.

Because capacity for sediment is limited by the ongoing aggradation in the impacted reaches, the loading capacity for additional sediment is defined as zero until the capacity of the impacted reaches can be expanded.

1.3.2 The Elk River Recovery Assessment

In 2013, in part to address the TAC recommendations described above (e.g., better understanding of existing conditions, and a system-wide planning effort), the Regional Water Board received funding from the State Water Board Cleanup and Abatement Account to conduct the *Elk River Recovery Assessment* (Recovery Assessment or ERRA) *and Sediment Remediation Pilot Implementation Project*. The goal of the Recovery Assessment is to test the response of the system to a suite of direct recovery actions, potentially including mechanical channel rehabilitation, sediment detention, vegetation management, floodplain modification, and infrastructure improvements. The Recovery Assessment also satisfies the Regional Water Board's need for a sediment remediation feasibility study. The Program approach is further described in Section 2.0.

1.3.3 The Elk River Watershed Stewardship Program

To accompany the Regional Water Board's regulatory program (TMDL Action Plan and Waste Discharge Requirements [WDRs]) and the Recovery Assessment's technical feasibility studies, the Regional Water Board is also supporting the Elk River Watershed Stewardship Program. The intent of the Stewardship Program is to coordinate stakeholder participation in recovery planning and implementation. The Stewardship Program is more fully described in Section 7.3.

2 ELK RIVER RECOVERY ASSESSMENT

The Regional Water Board contracted with California Trout, Inc. (CalTrout), Northern Hydrology and Engineering, (NHE), and Stillwater Sciences (SWS) in 2014 to conduct the ERRA and Pilot Implementation Program. The ERRA is motivated by the need to better understand if sediment deposited in the Elk River channel since approximately 1988 will remain in storage and continue to impair beneficial uses and cause nuisance flooding[1] even with successful future reduction in watershed sediment delivery that would be achieved under the WDRs and TMDL Action Plan. The ERRA analyzes the system-wide fate and transport of this stored sediment under different management scenarios, including assessing the feasibility of various mechanical channel rehabilitation actions and identifying the extent to which these actions, in combination with reduced sediment load, will lead to sustainable recovery of beneficial uses and water quality, abatement of nuisance conditions, and recovery of ecosystem functions in Elk River. The scope of ERRA analyses was limited to sediment impaired beneficial uses and nuisance flooding, and treatments for recovery of those uses in sediment impaired reaches as defined in previous work by the Regional Water Board.

2.1 Approach

The general approach to assessing potential trends in future channel conditions included three steps:

1. Documenting existing morphology and sediment conditions in the Elk River channel and floodplain from Bridge Creek on the North Fork Elk River and Tom's Gulch on the South Fork Elk River to Humboldt Bay;
2. Developing tools to assess future conditions in response to a range of potential actions that include reduction in sediment load and mechanical rehabilitation of stream channels and floodplains; and
3. Analyzing system trajectory under various management scenarios.

The ERRA utilized a large volume of historical and existing data, analyses, and imagery from past and on-going efforts by HRC, GDRC, Salmon Forever, Regional Water Board, and the County of Humboldt. Most of these prior data collection and monitoring efforts in Elk River occurred near county road bridge crossings, in the vicinity of the North Fork Elk River and South Fork Elk River confluence, and in upstream reaches located within commercial timberlands. Critical data gaps occurred primarily in the South Fork Elk River upstream of the North Fork Elk River and South Fork Elk River confluence and on the Mainstem Elk River downstream of the North Fork Elk River and South Fork Elk River confluence.

Additional data collection and monitoring for the ERRA occurred primarily during Water Years 2014 and 2015 through a joint effort by NHE, SWS, CalTrout, HRC, BLM, the Natural Resource Conservation Service (NRCS), Redwood Community Action Agency (RCAA), and local

[1] California Water Code (CWC) § 13050(m) defines nuisance to mean anything which meets all of the following requirements: (1) Is injurious to health, or is indecent or offensive to the senses, or an obstruction to the free use of property, so as to interfere with the comfortable enjoyment of life or property. (2) Affects at the same time an entire community or neighborhood, or any considerable number of persons, although the extent of the annoyance or damage inflicted upon individuals may be unequal. (3) Occurs during, or as a result of, the treatment or disposal of waste.

landowners. Two primary types of data were collected to inform the ERRA: (1) channel and floodplain geomorphic characteristics, and (2) flow and water quality.

Channel and floodplain data collection included:

- Topographic surveys of the channel thalweg, cross sectional transects, and bridge infrastructure;
- Sampling bed, bank, and floodplain sediment;
- Mapping large woody debris; and
- Mapping bank and floodplain vegetation.

Flow and water quality data collection included:

- Discharge,
- Velocity,
- Water surface elevation,
- Suspended sediment concentration (SSC),
- Salinity, and
- Temperature.

Additional data collection and analyses were tailored to address the specific ERRA project objectives and occurred at a spatial resolution necessary to supplement existing monitoring networks, inform data gaps at the reach scale, and support development of system-wide models.

The ERRA involved developing a conceptual model of hydrogeomorphic processes and a numerical hydrodynamic and sediment transport (HST) model that were used in combination to (1) describe existing conditions and processes, (2) identify site-specific opportunities and constraints to recovery, (3) predict changes in the Elk River channel under existing and future sediment load and mechanical channel rehabilitation scenarios, and (4) identify monitoring priorities that support adaptive management. Integration of the ERRA conceptual model and HST model provides a framework for identifying appropriate recovery strategies and evaluating their potential effectiveness at recovering impaired beneficial uses and reducing nuisance flooding. Given the lack of detectable recovery during recent decades with improved watershed management practices, this overall approach is critical in developing an implementation framework that will cost-effectively accelerate recovery of beneficial uses and ecosystem functions while minimizing any negative effects of rehabilitation actions on sedimentation patterns and aquatic habitat within and between treated reaches.

A Technical Advisory Committee (TAC) consisting of local, state, and federal agency scientists and local landowners was formed as part of the ERRA (Table 2-1). The TAC provided substantial input on ERRA analyses, particularly in developing and analyzing the management scenarios described below.

Table 2-1. Elk River Recovery Assessment Technical Advisory Committee (TAC) members who participated in four TAC meetings from 2015 to 2017.

Name	Affiliation
Eileen Cashman	Humboldt State University (HSU) Engineering
Tom Lisle	Stillwater Sciences
Mary Ann Madej	US Geological Survey (USGS), Retired
Connor Shea	US Fish and Wildlife Service (USFWS)
John Bair	McBain Associates
Sam Flannigan	Bureau of Land Management
Margaret Tauzer	National Marine Fisheries Service (NMFS)
Jack Lewis	Redwood Sciences Lab, Retired
David Manthorne	California Department of Fish and Wildlife (CDFW)
Nick Simpson	California Department of Fish and Wildlife
Hank Seemann	Humboldt County
Mike Miles	Humboldt Redwood Company
Shane Beach	Humboldt Redwood Company
Nick Harrison	Humboldt Redwood Company
Matt Sparacino	Humboldt Redwood Company
Kristi Wrigley	Salmon Forever
Jon Shultz	Natural Resources Conservation Service
Matt House	Green Diamond Resource Company
Jesse Noell	Salmon Forever
Lance Le	North Coast Regional Water Quality Control Board
Chuck Striplen	North Coast Regional Water Quality Control Board
Alydda Mangelsdorf	North Coast Regional Water Quality Control Board
Clayton Creager	North Coast Regional Water Quality Control Board
Adona White	North Coast Regional Water Quality Control Board
Jeff Anderson	Northern Hydrology & Engineering
Bonnie Pryor	Northern Hydrology & Engineering
Jay Stallman	Stillwater Sciences
Darren Mierau	California Trout

2.2 Management Scenarios

The ERRA evaluates future trends in channel and floodplain geomorphic, hydraulic, and water quality conditions under the following three management scenarios:

1. Existing channel conditions with existing sediment loads (referred to as *Existing Condition*). The Existing Condition represents how the system will likely function in the future without sediment remediation and is the baseline for measuring system response under other scenarios.
2. Existing channel conditions with reduced sediment loads (referred to as *Reduced Suspended Sediment Concentration*).
3. A suite of broad recovery actions in combination with existing sediment loads (referred to as *Modified Channel*).

The following considerations helped guide identification of opportunities and constraints, development of proposed actions, and analyses of the three management scenarios.

1. How do channel and floodplain morphology, channel geometry, and bed and bank materials change throughout the channel network?
2. How do flow patterns (i.e., channel capacity, flow velocity, and flood inundation) vary over the channel network?
3. How do suspended sediment concentrations vary longitudinally and laterally (i.e., channel versus floodplain) throughout the channel network?
4. How do sedimentation patterns (e.g., aggradation and incision) vary longitudinally and laterally (i.e., channel versus floodplain) throughout the channel network?
5. How does channel and floodplain morphology affect flow and sedimentation patterns?
6. How does the distribution and size of wood vary throughout the channel network and how do these values compare to published targets?
7. How do vegetation and wood affect flow and sedimentation patterns?
8. What is the upper extent of the tidal zone?

For each of these questions, the ERRA seeks to describe the Existing Condition scenario, and how these patterns are expected to change under the Reduced *S*uspended Sediment Concentration and Modified Channel scenarios.

2.3 Supporting Information and Documentation

Table 2-2 lists the primary information and studies developed as part of the ERRA and used to support the ERRA Framework report.

Table 2-2. Primary Elk River Recovery Assessment (ERRA) information and documentation developed under ERRA and used in the ERRA Framework report.

Information, document	Source	Appendix
Elk River Technical Advisory Committee (TAC) meeting agendas, attendees, and summaries.	CalTrout	Appendix A
Elk River TAC comments for HST model configuration for Modified Channel Scenario	CalTrout, NHE, SWS	Appendix B
Elk River Recovery Assessment: Reduced SSC targets	Regional Water Board	Appendix C
SSC Trend Analysis presentation to TAC by Jack Lewis	Jack Lewis	Appendix D
Elk River Recovery Assessment Data Report (miscellaneous data sets)	NHE and SWS	Appendix E
Elk River Hydrodynamic and Sediment Transport Modeling Study in Support of Recovery Assessment	NHE and SWS	Appendix F

3 CONCEPTUAL MODEL OF EXISTING HYDROGEOMORPHIC PROCESSES

The ERRA conceptual model synthesizes what is known and can reasonably be inferred about the geomorphic and hydraulic (i.e., hydrogeomorphic) functions within the Elk River channel and floodplain based on existing and historical information. The primary objectives of the ERRA conceptual model include the following:

- Describe existing hydrogeomorphic and sedimentologic conditions, processes, and controls within the Project area;
- Identify natural and anthropogenic drivers and likely responses to changes in controlling variables within the river system;
- Support HST modeling of system trajectory under existing channel conditions with current sediment loads, reduced sediment loads, and a suite of process-based recovery actions;
- Guide development of a monitoring program; and
- Communicate key concepts to stakeholders and decision makers.

With these primary objectives in mind, the ERRA conceptual model links the following five components in the Project area:

1. Valley morphology and channel geometry,
2. Sediment supply,
3. Channel change,
4. Channel sediment composition,
5. Channel and floodplain roughness (i.e., vegetation and woody debris), and
6. Sediment oxygen demand of in-channel sediments.

3.1 Geomorphic Reaches

The 19.2-mile Project channel length was stratified into 11 reaches, each with relatively homogenous fluvial geomorphic forms and processes (Figure 3-1). The reach delineation was based on intrinsic and extrinsic factors related to floodplain and channel form, hydraulics, and sediment dynamics (e.g., valley width and confinement; tributary water, sediment, and wood inputs; planform, channel slope, channel top-of-bank and toe widths, and bed surface texture). Representative study sites were selected in each geomorphic reach to collect information necessary for developing the ERRA conceptual model and parameterizing the HST model.

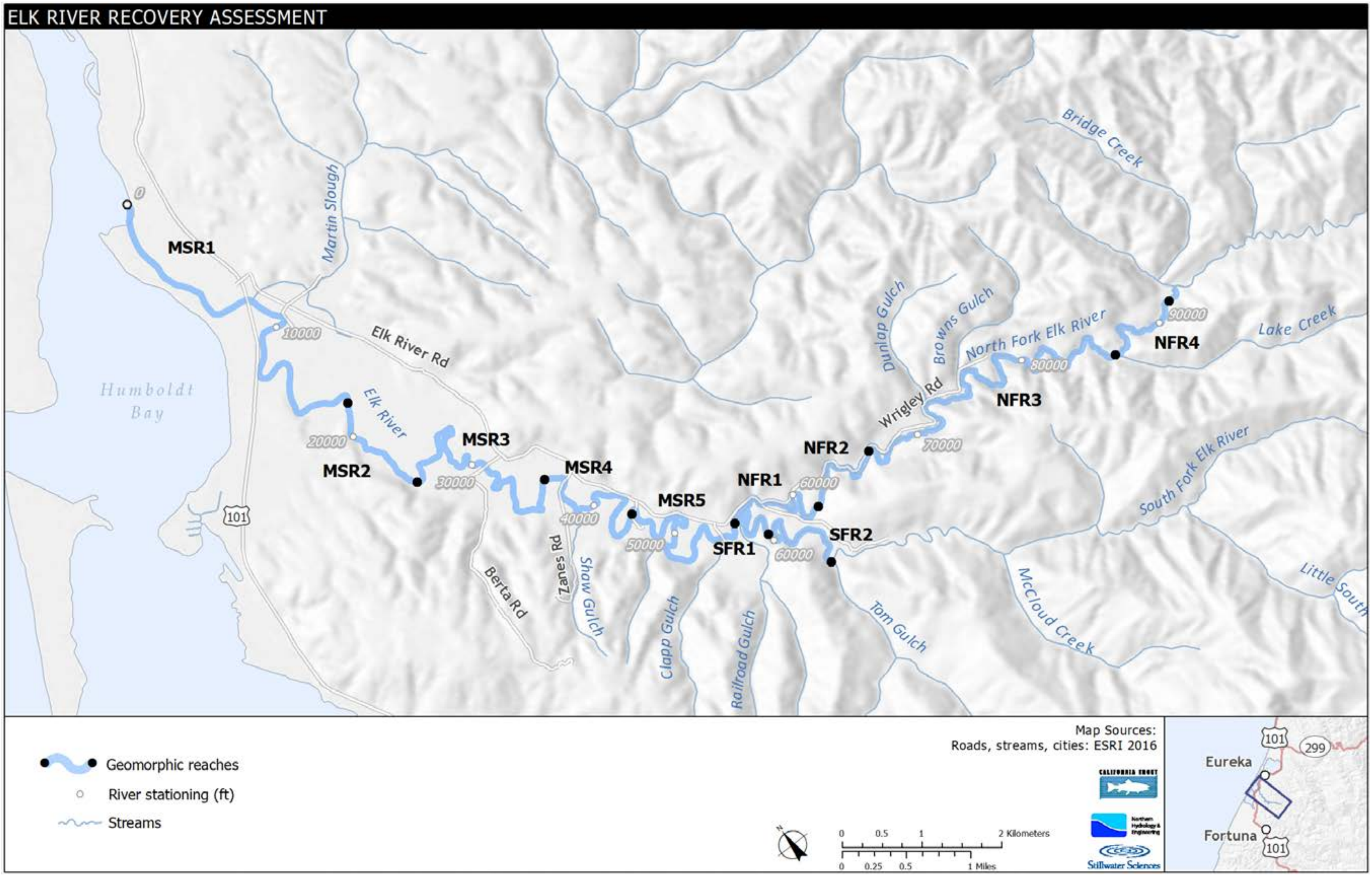

Figure 3-1. Geomorphic reaches in the Elk River Project area.

3.2 Valley Morphology and Channel Geometry

Little information is available describing valley morphology and channel geometry prior to the extensive and persistent changes associated with early Anglo-American settlement, ranching, logging, and railroad development in the Elk River Valley during the late-19th and early-20th centuries. To better understand existing large-scale controls on hydrodynamics and sediment dynamics, we analyzed the relative elevations of valley bottom landforms (e.g., terraces, natural levees, floodplains, and flood basins) above a reference valley floor surface (Figure 3-2). The analysis reveals a locally convex-up section of the Elk River valley floor longitudinal profile compared to the concave-up channel thalweg profile (Figure 3-3). The convex-up valley longitudinal profile in Elk River is a geologic form most likely explained by local deformation (i.e., faulting or folding) across the valley or a transition from a region of long-term tectonic uplift to a region of long-term subsidence. Analogous convex-up longitudinal profiles have been documented in coastal plain reaches of other nearby, relatively pristine watersheds where tectonic deformation and lithologic variability are the controlling factors (Keller et al. 1995).

The separation between the valley floor longitudinal profile and channel thalweg profile describes the degree of channel incision or entrenchment (Figure 3-3 inset). In the convex part of the valley, the channel is entrenched up to 19 feet and the relatively narrow floodplain is confined by older river terraces, resulting in a large-scale hydraulic constriction. This hydraulic constriction is an intrinsic geologic control that helps explain longitudinal trends in channel geometry, grain size, and reach-scale response to increased sediment load. This longitudinal form therefore provides an important basis for defining geomorphic reaches, as follows:

- **North Fork Elk River Reach 1 (NFR1) and South Fork Elk River Reach 1 (SFR1):** Upstream portion of the convex valley profile. The North Fork Elk River and South Fork Elk River channels narrow and become increasingly entrenched.
- **Mainstem Elk River Reach 5 (MSR5):** Central region of the convex valley profile. The Mainstem Elk River channel is deeply entrenched within a valley narrowly confined by Late Pleistocene river terraces, creating a hydraulic control that backwaters this reach, as well as the lower reaches of the North Fork Elk River during high flows. Floodplain inundation within the backwater area has little down valley velocity. See Transect 1 on Figure 3-4 for a representation of typical valley morphology in the entrenched section of MSR5.
- **Mainstem Elk River Reach 4 (MSR4):** Downstream portion of the convex valley profile. Channel entrenchment begins to decrease, and floodplain extent begins to widen, natural levees begin to form in response to overbank flow and sedimentation, and floodplains are bisected by short high flow channels. This is the first reach where a large percentage of the runoff during high flow events moves down the floodplain rather than in the channel. See Transect 2 on Figure 3-4 for a representation of typical valley morphology in MSR4.
- **Mainstem Elk River Reach 3 (MSR3):** Downstream of the convex valley profile. Longitudinally extensive natural levees separate the channel from lower adjacent floodplains, referred to as flood basins. The deepest parts of the flood basins are typically about the same elevations as the nearby channel thalweg. The channel planform is less stable than in upstream and downstream reaches, with a tendency for channel avulsion indicated by natural levee breaches that concentrate out-of-bank flow and create crevasse splays onto the floodplain. A much larger percentage of runoff during high flow events is conveyed down extensive floodplains than in the channel. Return flows from the floodplain to the channel are concentrated near Showers Road. The combination of floodplain return flows, high topography, and other confining features (e.g., constructed levees) near

Showers Road creates a hydraulic control that leads to backwater effects during high flows. See Transect 3 on Figure 3-4 for a representation of typical valley morphology in MSR3.

- **Mainstem Elk River Reach 2 (MSR2):** Fluvial-tidal transition. The channel is located against the south valley toe slopes rather than occurring in a meandering pattern throughout the valley, as in upstream reaches. Natural and constructed levees are built to their highest elevations and the adjacent floodplains maintain a consistent elevation across the valley floor. Channel widths begin to expand after remaining consistent through MSR3. Flow is typically contained within the channel through the reach, in part, because out-of-bank flow in MSR3 conveys a large fraction of the total runoff during floods to the broad floodplain located north of the channel in MSR2. The reach is inundated by high tides (refer to Figure 3-2 showing the 9.5-foot contour associated with the highest tide on record at North Spit). See Transect 4 on Figure 3-4 for a representation of typical valley morphology in MSR2.
- **Mainstem Elk River Reach 1 (MSR1):** Tidal estuary. The Mainstem Elk River through this reach is typical of a tidal slough channel with a large width-to-depth ratio and near vertical banks. The channel is typically confined by constructed levees and adjoined by historical and existing intertidal mudflats and tidal wetlands. Hydrodynamics and sediment transport within the channel are predominantly controlled by tidal action. Floodplain flows in MSR1 occur due to out-of-bank flows conveyed from MSR2. A dense network of relict, highly sinuous channels throughout the valley bottom in MSR1 indicate a once extensive tidal estuary prior to agricultural conversion.

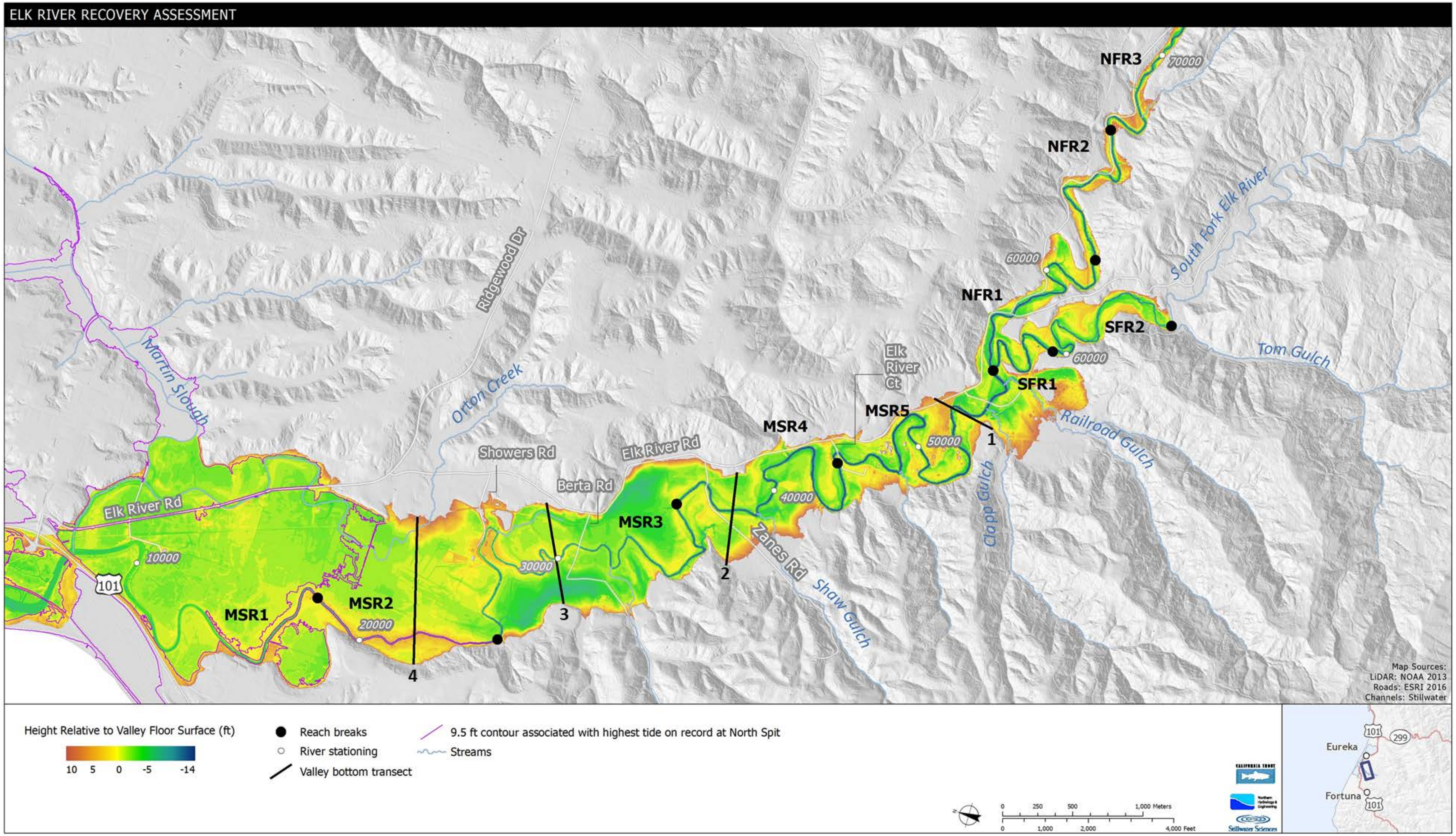

Figure 3-2. Height of geomorphic features relative to the reference valley floor surface.

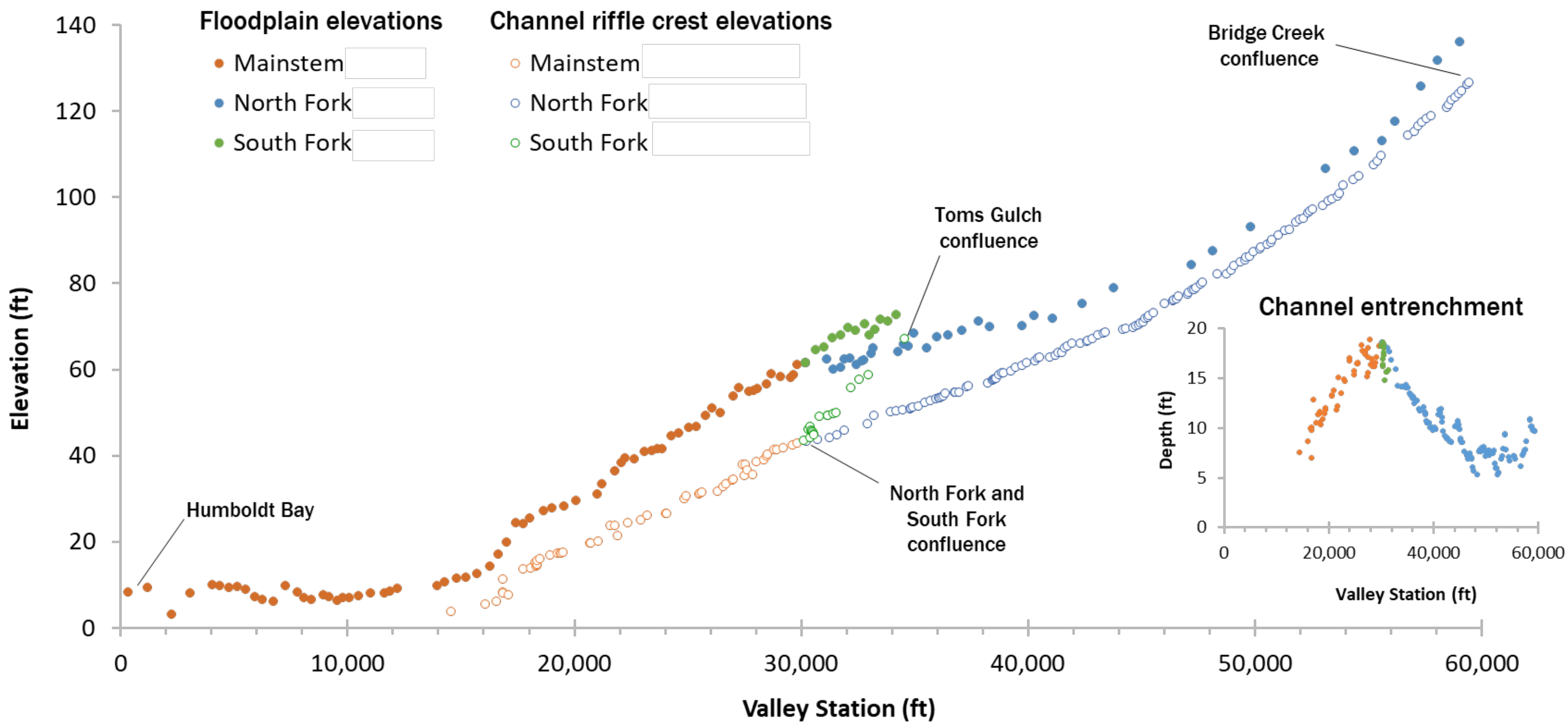

Figure 3-3. Longitudinal profiles of the Elk River valley floor and channel. Inset shows channel entrenchment defined by the separation between the longitudinal profiles.

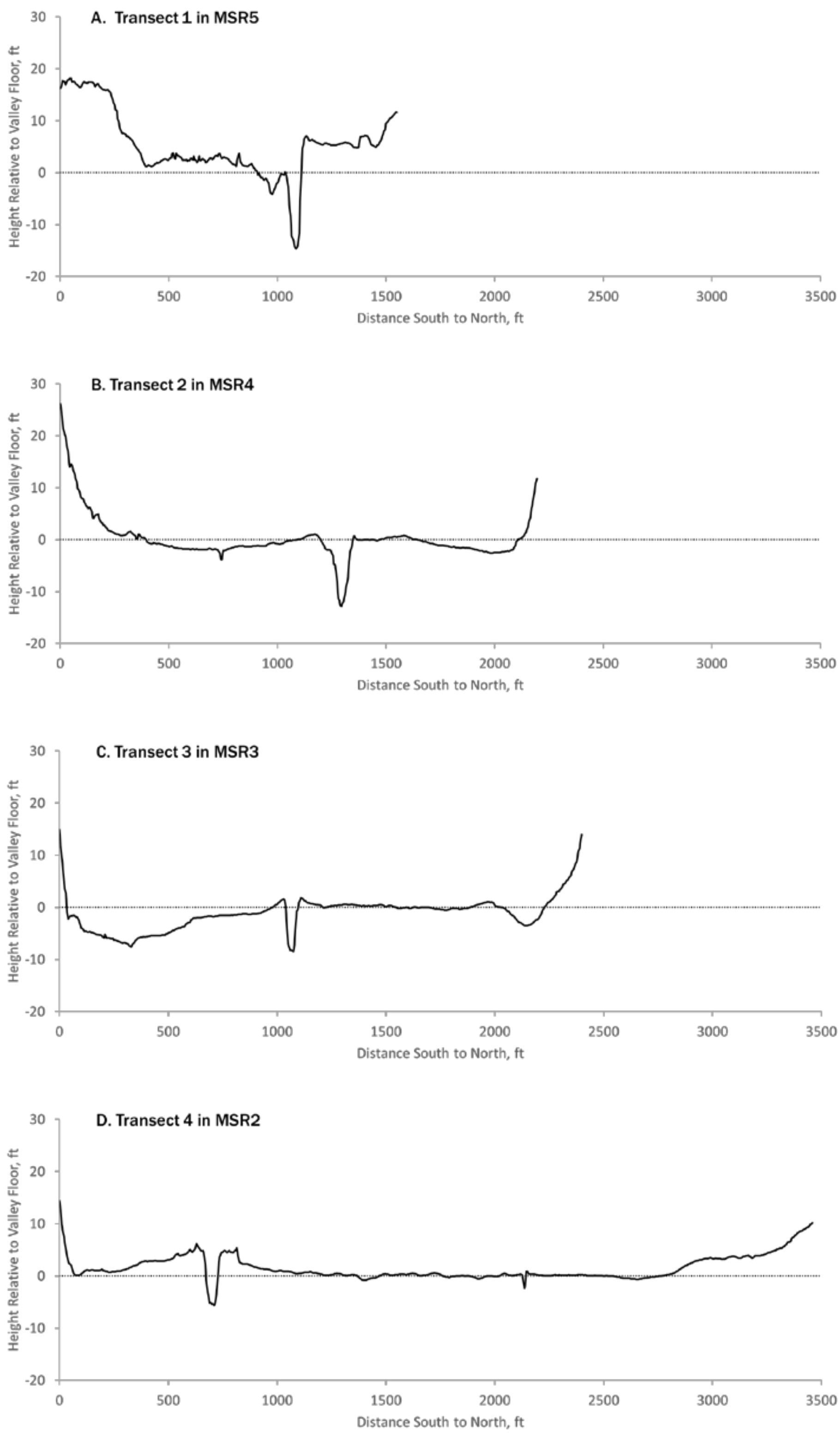

Figure 3-4. Longitudinal changes in cross sectional valley form. Refer to Figure 3-1 for the location of valley transects.

Channel geometry (e.g., width, depth, and slope) changes systematically throughout the Project area in association with patterns in valley morphology. The typical cross section changes from a less entrenched channel with high width-to-depth ratio and more complex active channel features in predominantly gravel-bedded reaches upstream of the convex valley profile (i.e., NFR3 and NFR4) to a progressively more entrenched channel with lower width to-depth ratio and less complex active channel features as the channel descends into the convex portion of the valley profile (i.e., NFR1 and NFR2, SFR1 and SFR2, and MSR5) (Figure 3-5). As the channel exits the convex portion of the valley profile, the channel becomes less entrenched with a progressively larger width-to-depth ratio (MSR4 and MSR3), reaching a maximum width-to-depth in the estuary (MSR1) (Figure 3-5). These general patterns in channel geometry are largely imposed by valley bottom landforms developed in response to tectonic uplift and subsidence, eustatic sea level change, and climate changes over the Late Pleistocene (approximately last 126,000 years). These geologically-derived channel geometries help explain the distribution and magnitude of historical channel sedimentation resulting from increased sediment supply and have important implications for present-day hydrodynamics (e.g., channel conveyance capacity and floodplain inundation) and sediment transport processes affecting channel recovery.

LiDAR data over the 19.2-mile Project channel length indicate pronounced downstream narrowing of channel top-of-bank and toe widths on the North Fork Elk River between approximately station 73,000 and station 57,000, reaching minimum widths near the confluence with the South Fork Elk River (Figure 3-6). This pattern of downstream channel narrowing is atypical of most alluvial river systems, where channel widths typically increase in the downstream direction in response to increasing drainage area and runoff. Channel narrowing in Elk River occurs in association with increasing entrenchment as the channel descends through the upstream portion of the convex valley profile. While top-of bank widths and toe widths typically change proportional to one another, toe widths narrow more in this reach of the Elk River. We attribute the larger reduction in toe widths compared to top-of-bank widths to channel aggradation, particularly through bank accretion. Channel narrowing correlates to other observed channel changes, such as decreasing width-to-depth ratio, fining of the bed material, and an increase in channel aggradation.

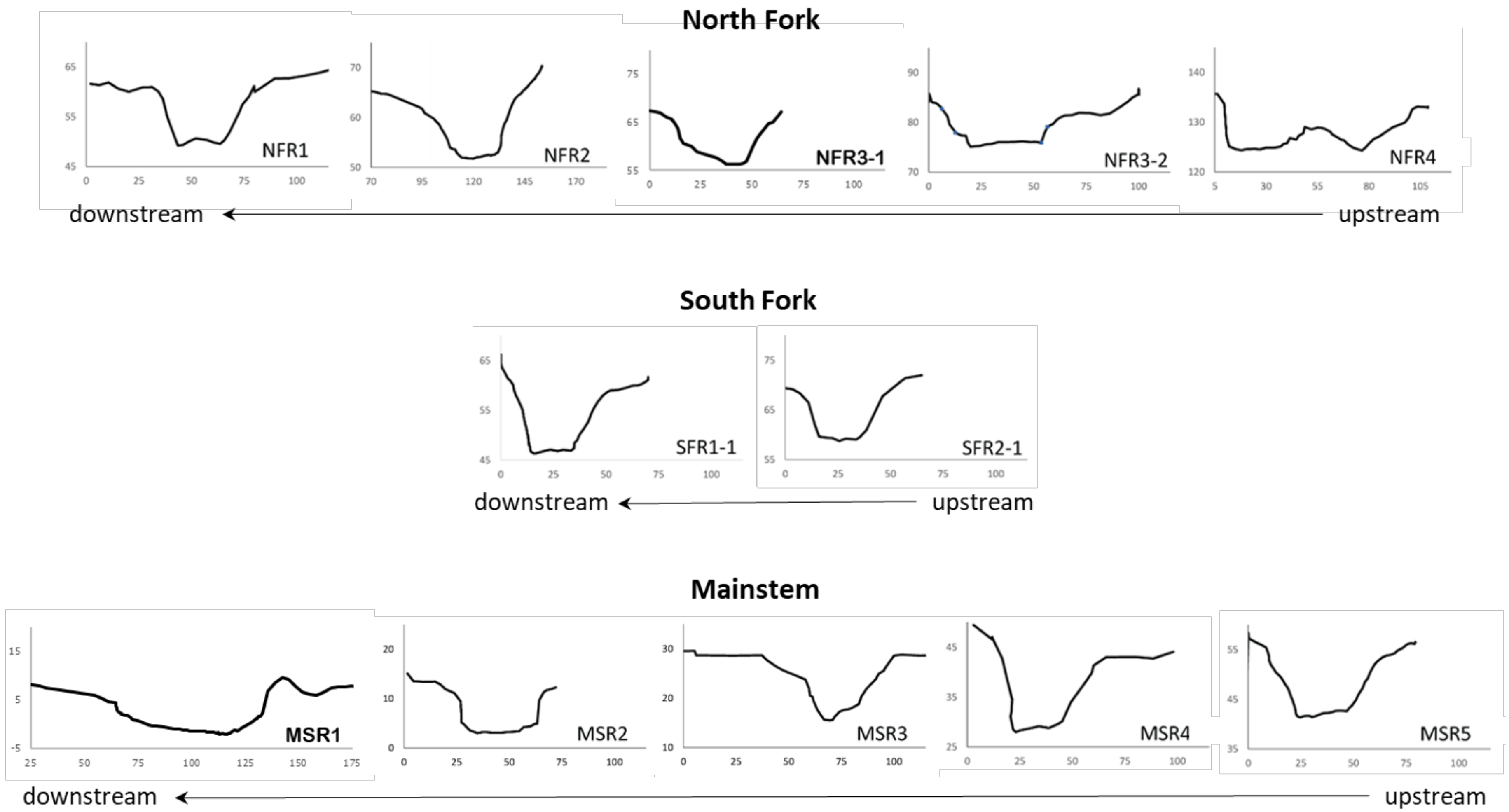

Figure 3-5. Longitudinal changes in typical channel geometry within geomorphic reaches.

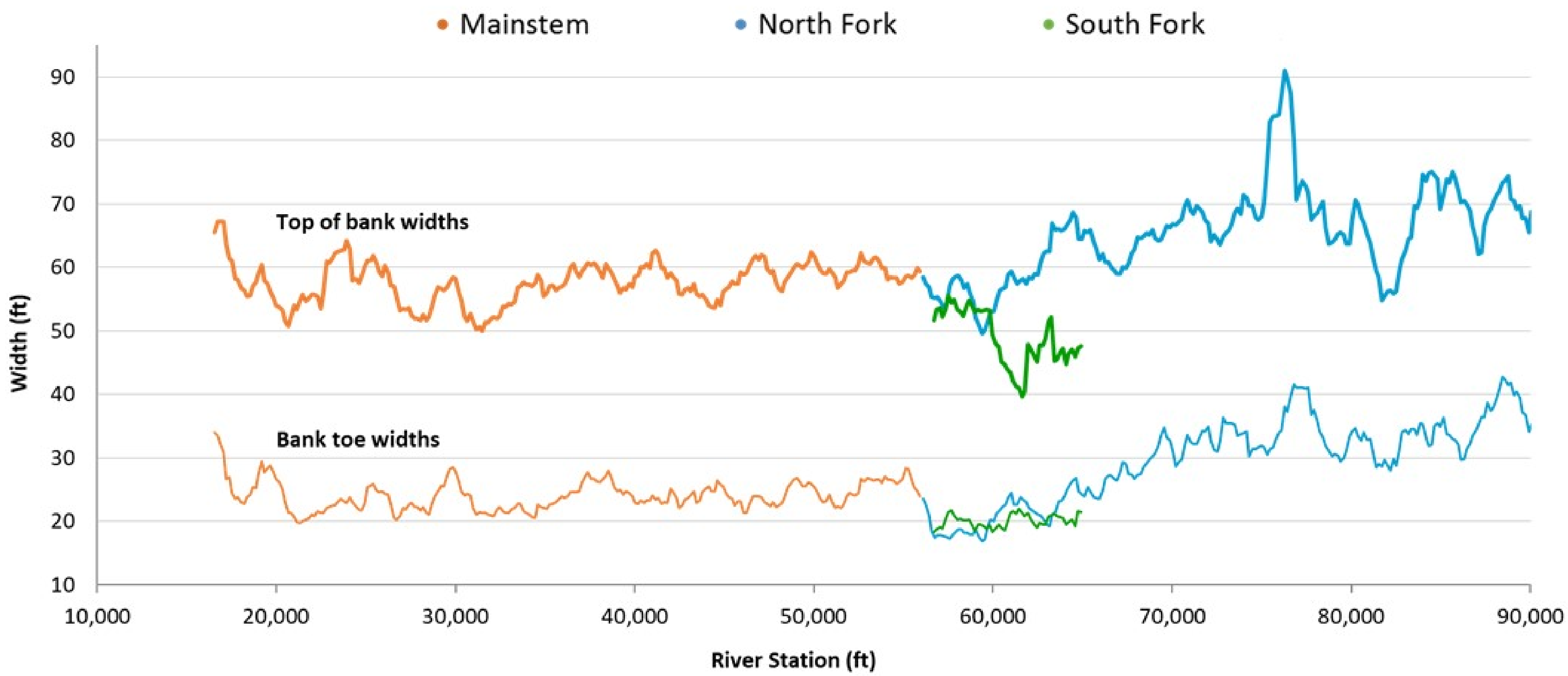

Figure 3-6. Channel top-of-bank and toe widths derived from LiDAR data.

3.3 Sediment Supply

Just as the spatial patterns of channel geometry in the Project area correspond with the valley landforms and associated hydraulic controls described above, the timing and relative magnitude of channel sedimentation corresponds with historical trends in sediment delivery from the upper watershed. Trends in historical and contemporary sediment loading in Elk River from the mid-1950's to present describe two cycles of elevated then diminishing loads (Figure 3-7) corresponding to decadal changes in timber harvest rates and associated road construction. The most recent period of accelerated timber harvest from approximately 1988 to 1997 corresponded with a series of large storm events that significantly increased management-related sediment loading to and increased aggradation in the Elk River within the Project area. The TMDL provides evidence that the rate of sediment production from the upper watershed has declined since 1998, largely in response to 1) a temporary moratorium on new timber harvest plans imposed by CalFire in early 2000, and 2) improved forest management practices and road decommissioning on the part of Humboldt Redwood Company. Despite this decline in sediment production, the Elk River within the Project area continues to aggrade.

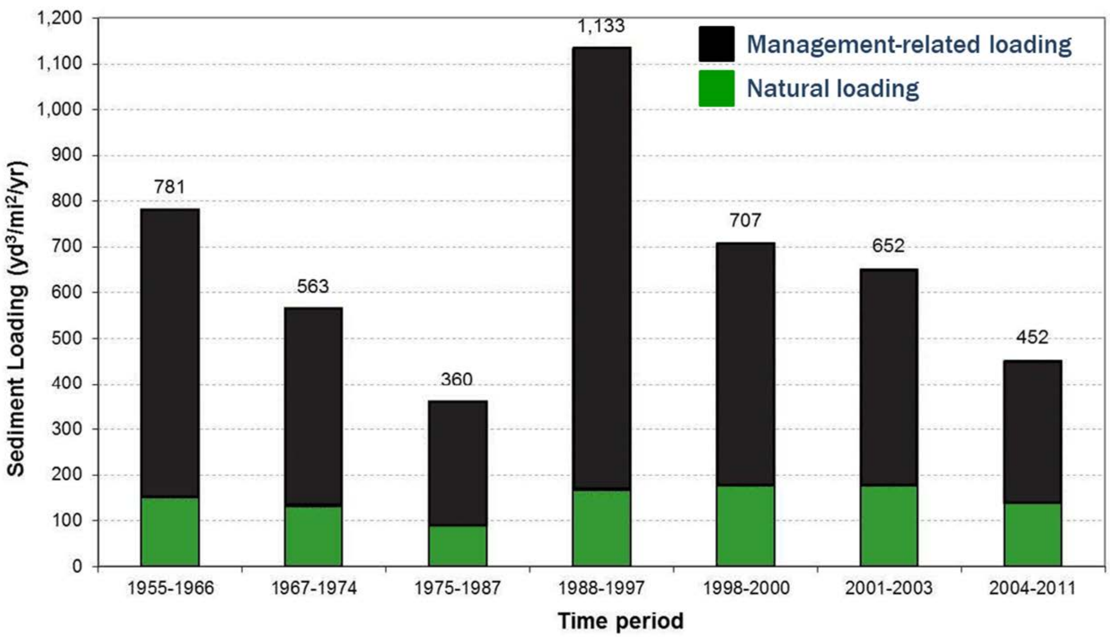

Figure 3-7. Sediment loading by time period, 1955–2011 (Modified from Tetra Tech 2015).

Many of the tributaries that produced the largest amount of sediment from 2004 to 2011 (the most recent period included in the TMDL) contributed a disproportionately high sediment load directly to channels in the Project area: these include Bridge Creek and McWhinney Creek on the North Fork Elk River, Tom's Gulch and McCloud Creek on the South Fork Elk River, and Clapp Gulch and Railroad Gulch (both large producers of relatively coarse sediment) on the Mainstem Elk River (Figure 3-8). Suspended loads in Elk River remained high relative to other Humboldt Bay tributaries during this time period (Figure 3-9), with no significant increasing or decreasing trend in suspended sediment concentration from water year (WY) 2003 to WY2015 (Figure 3-10).

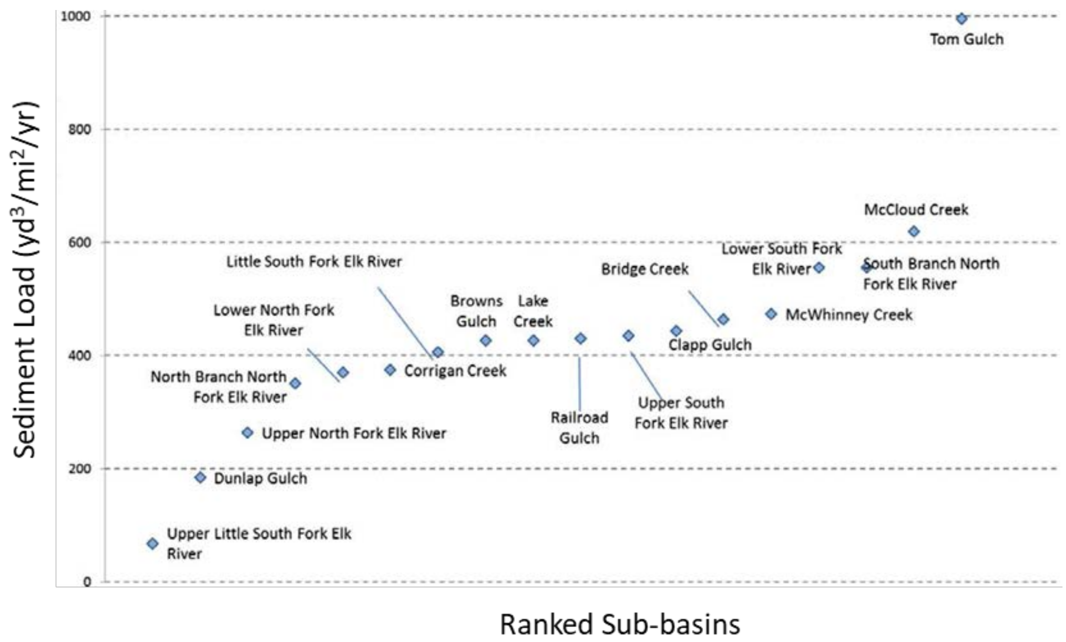

Figure 3-8. Sediment loading during the 2004–2011 time period by subwatershed (Tetra Tech 2015).

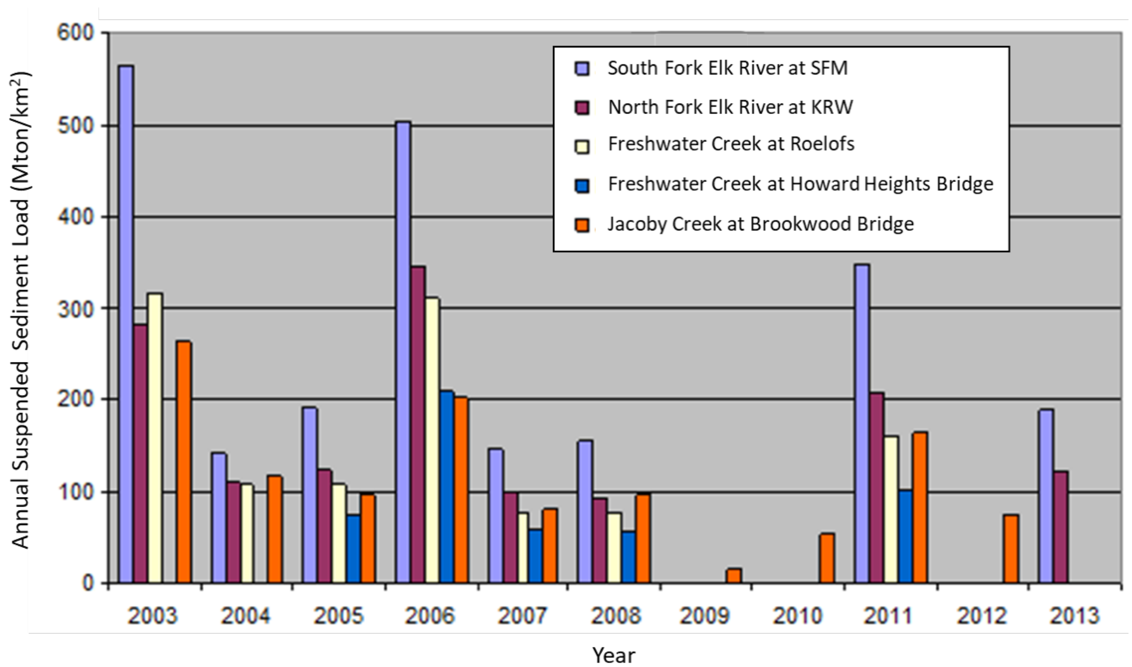

Figure 3-9. Suspended loads in Humboldt Bay tributaries, 2003–2013 (Lewis 2013).

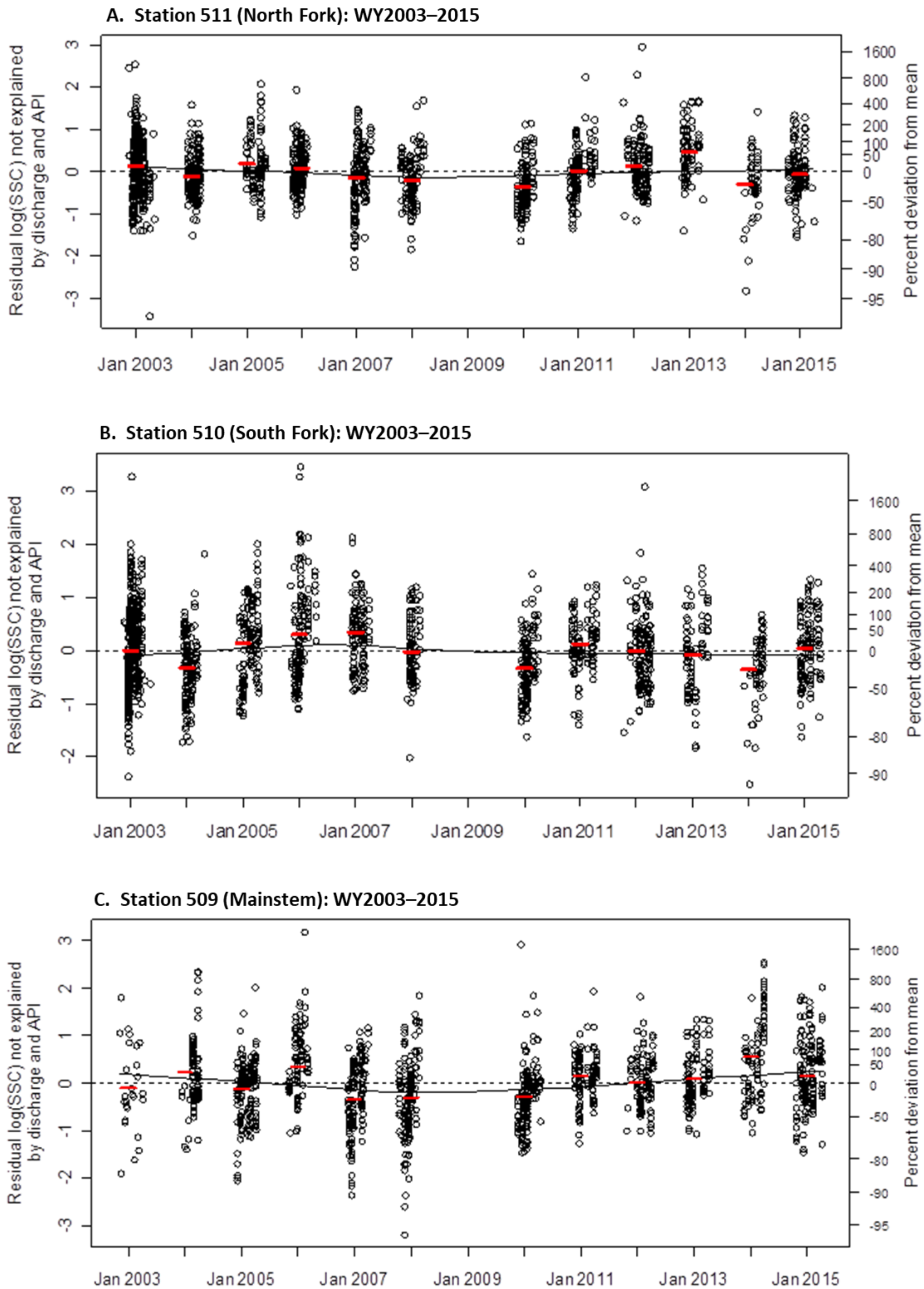

Figure 3-10. Suspended sediment concentrations (SSC) in Elk River, 2003–2015. The figures show the sequence of residuals from bivariate regression models predicting log (SSC) as a linear function of log (discharge) and hourly antecedent precipitation index (API). Red bars show annual means (Appendix D).

3.4 Channel Change

Channel aggradation is the primary driver of impaired beneficial uses and nuisance flooding in the impacted reach by reducing conveyance capacity, lowering velocities, and limiting sediment transport (Regional Water Board 2013). Channel change observed in repeated transect surveys in the Project area indicates an average sedimentation rate of approximately 8,600 m^3/yr (7,300 mT/yr) for the period 2002–2011 (Tetra Tech 2015). Hydrodynamic and sediment transport modeling in the Project area indicates a similar average sedimentation rate of approximately 9,200 m^3/yr (7,800 mT/yr) for the period 2003–2008 (NHE and SWS 2013, Tetra Tech 2015).

Average channel bed elevations increased at four bridge sites (North Fork Bridge, Steel Bridge, Zanes Road, and Berta Road) with long term periods of record (Table 3-1, Figure 3-11). The average aggradation rate of 0.12–0.16 ft/year was similar at Steel Bridge, Zanes Road, and Berta Road. The North Fork Bridge site aggraded more slowly (0.06 ft/year). Cumulative changes in cross-sectional area indicate decreasing channel capacity over time at each bridge site (Figure 3-12). Apart from Zanes Road (where data was limited), most of the reduction in channel area from aggradation occurred prior to 2000, with decreasing aggradation rates thereafter. The timing (post-1990) and magnitude of aggradation at the Elk River bridge, Steel Bridge, and Zanes Road bridge are similar, with the magnitude of change diminishing in the downstream direction. These sites responded similarly to sediment loading. Channel aggradation at Berta Road occurred prior to 1990 and resulted in a larger change in cross-sectional area, suggesting different controls than at upstream sites.

Transect surveys conducted at 23 sites in the North Fork Elk River, South Fork Elk River, and Mainstem Elk River by HRC over a period from 1997 to 2016 indicate consistent trends in reduced cross-sectional area since 1997 (Figure 3-13). There were also typically net decreases in channel cross-sectional area observed at 27 sites surveyed in the North Fork Elk River, South Fork Elk River, and Mainstem Elk River by the ERRA team and partners from 2002 to 2014.

Table 3-1. Changes in bed elevations and cross-sectional areas at bridge sites.

Bridge site	Average bed elevation change		Percent reduction in cross-section area	
	Period	Change, ft	Period	% change
North Fork Bridge	1947–2002	4.2	1971–2016	44
Steel Bridge	1958–2015	6.2	1958–2016	24
Zanes Road	1969–2014	6.3	2006–2016	5
Berta Road	1969–2016	6.5	1969–2016	50

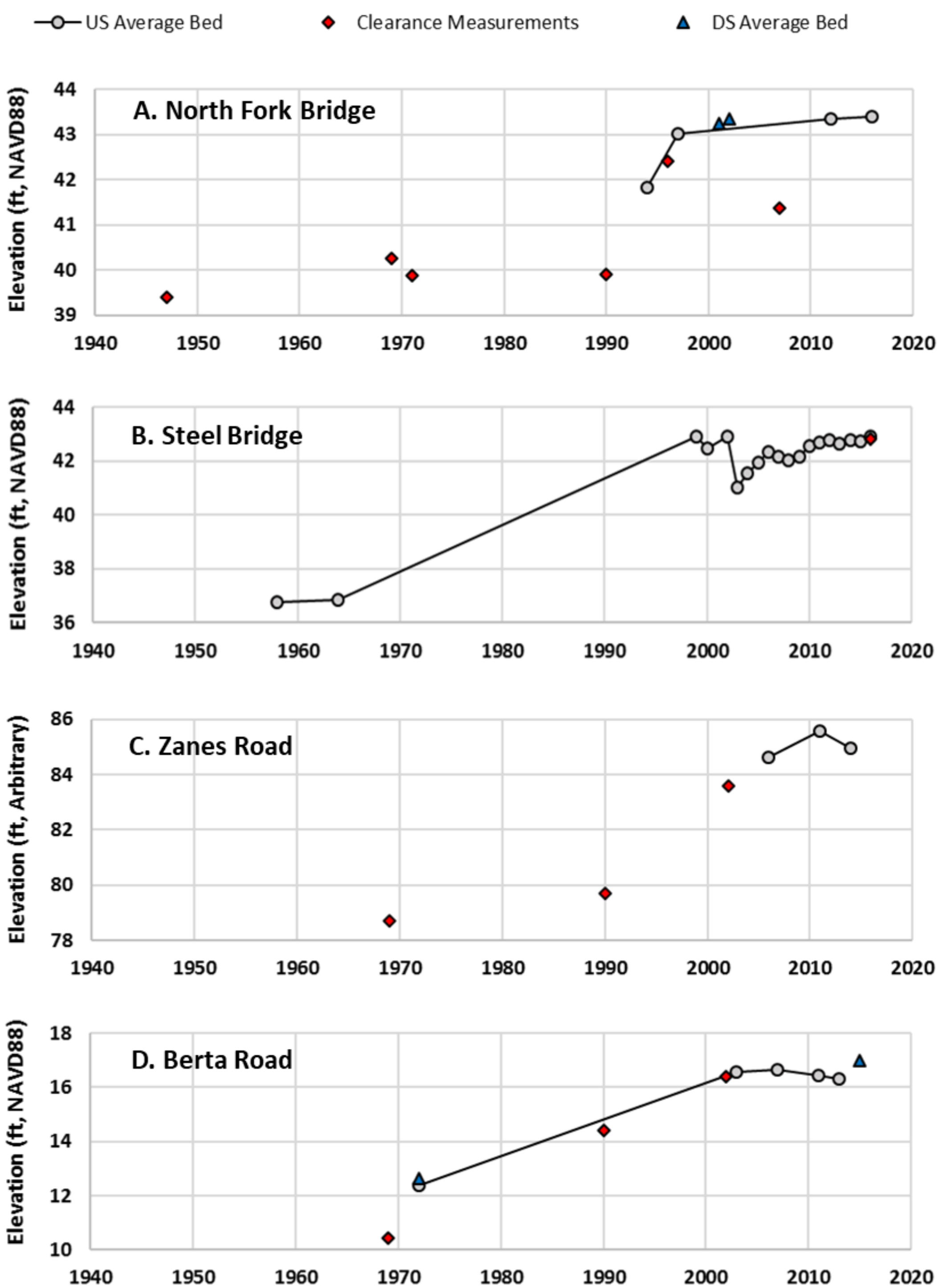

Figure 3-11. Average bed elevation changes at Elk River bridge sites.

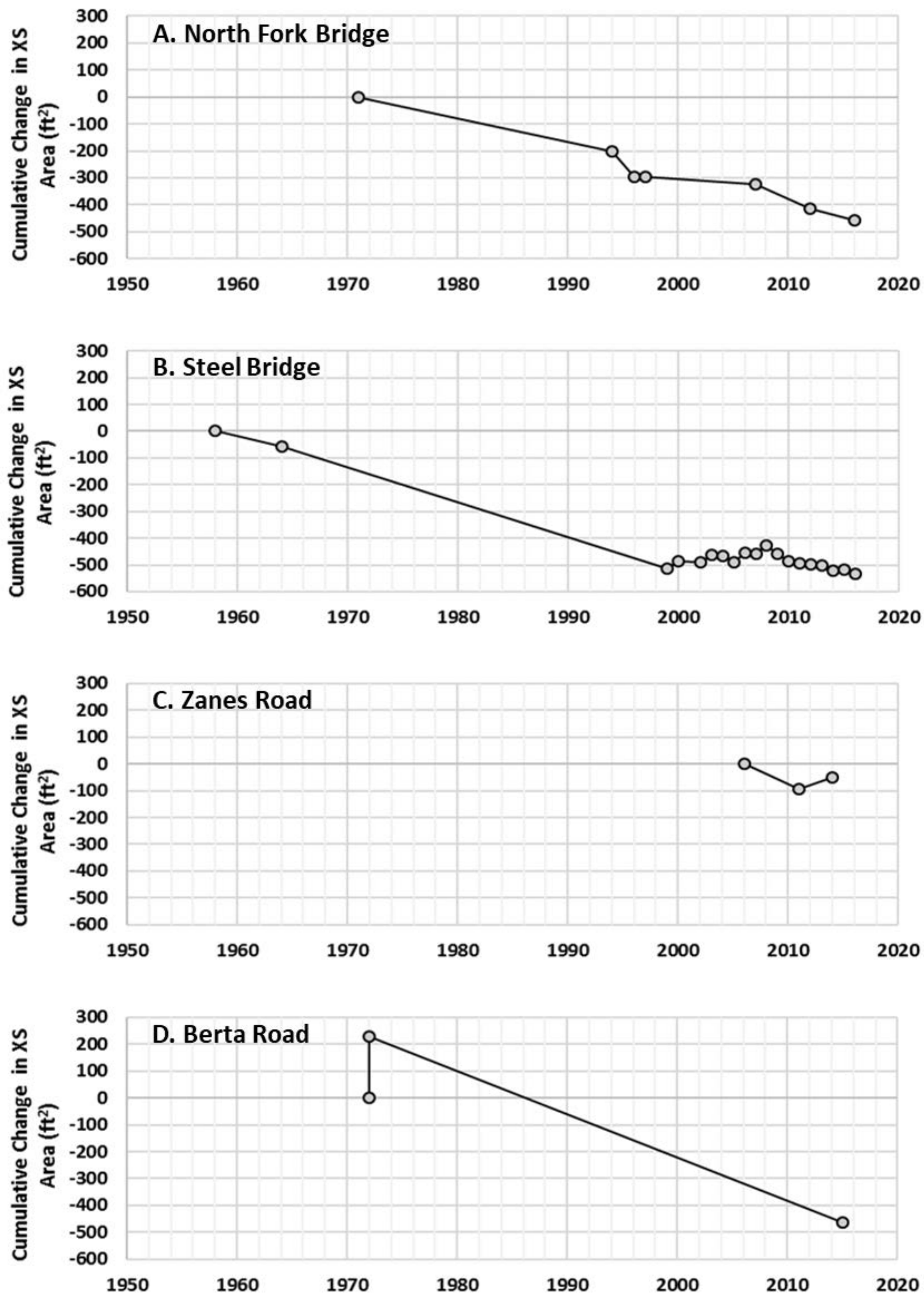

Figure 3-12. Cumulative changes in cross-sectional area at Elk River bridge sites.

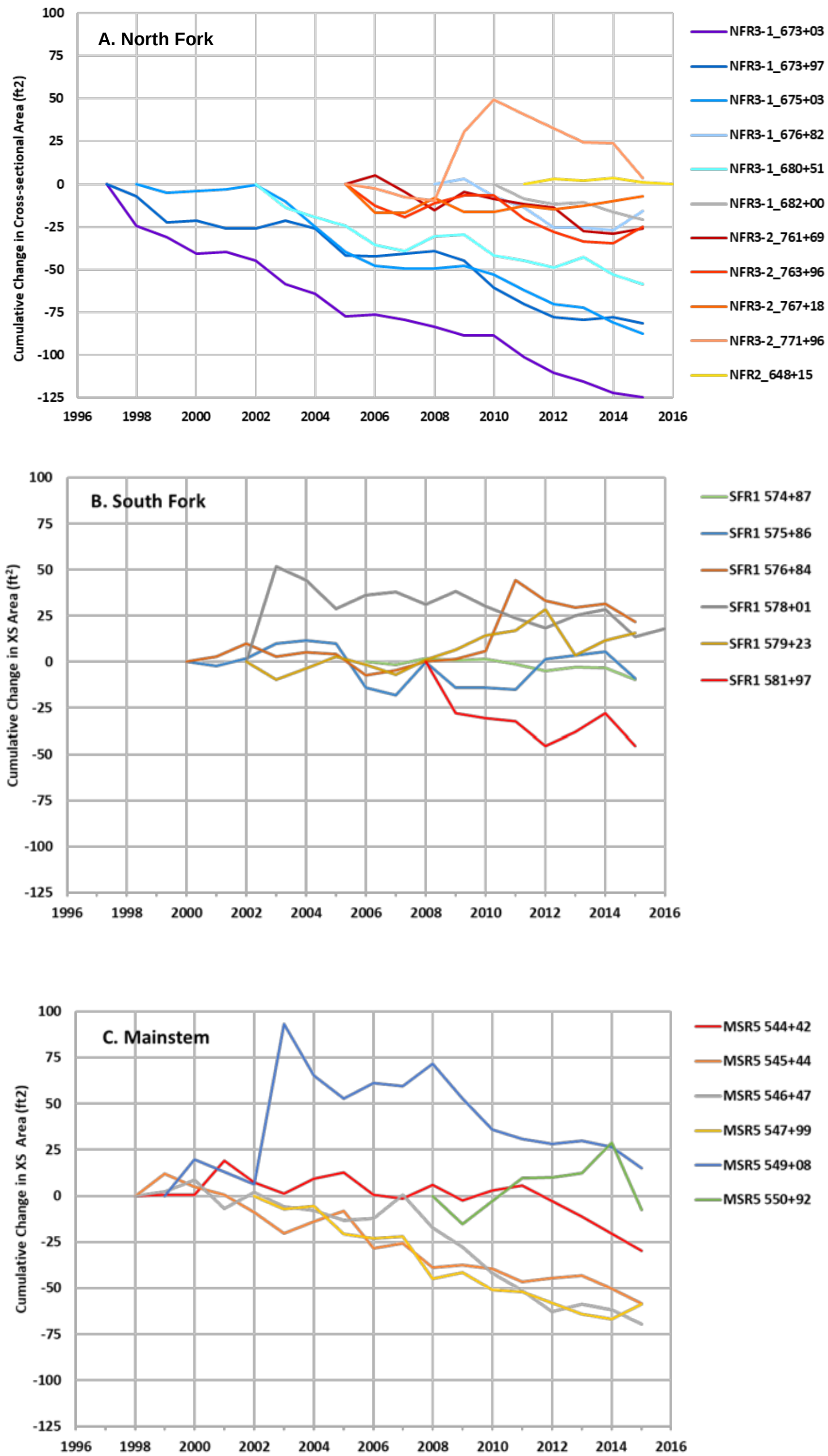

Figure 3-13. Cumulative changes in cross-sectional area at Elk River monitoring transects, 1997–2016.

3.5 Channel Sediment Composition

Channel sediment composition is an intrinsic response variable to the patterns in valley bottom landforms and channel geometry controlling hydrogeomorphic processes in Elk River. An overall trend in the downstream fining of bed material from gravel to sand to silt is interrupted by anomalously fine-bedded channel conditions in the most impacted reaches (i.e., upstream extent of MSR5, NFR1, and SFR1). Deposition and persistent storage of these fine sediments is primarily responsible for impaired beneficial uses, water quality, and nuisance flooding. Sustainable recovery of the Elk River depends, in large part, on erosion and transport of these fine sediments within and through the reach.

The increased valley confinement and channel entrenchment within the locally convex-up section of the Elk River valley floor longitudinal profile, combined with the hydraulics at the North Fork Elk River and South Fork Elk River confluence, create backwater conditions that focuses fine sediment deposition immediately upstream in the most impacted reach. The effects of these reach-scale geomorphic and hydraulic controls on sediment deposition in this reach are further exacerbated by vegetation dynamics that have increased hydraulic roughness of the channel and floodplain in MSR5, and by the abundant supply of relatively coarse sediment from Railroad Gulch and Clapp Gulch. Aggraded fine sediment deposits in the Project reach are unconsolidated, have a large fraction of sand and finer sized particles, low bulk densities, and are anchored by excessive in-channel vegetation.

We characterized sediment composition in the Elk River channel by mapping bed surface textures (i.e., facies) at the Project scale (Figure 3-14) and within intensive study sites (Figure 3-15); and by bulk sampling bed, bank, and floodplain material within intensive study sites. The sediment characterization supported development of this conceptual model of hydrogeomorphic processes, as well as parameterization of the HST model (i.e., sediment grain size distribution and classes, effective diameter, porosity, and bulk density).

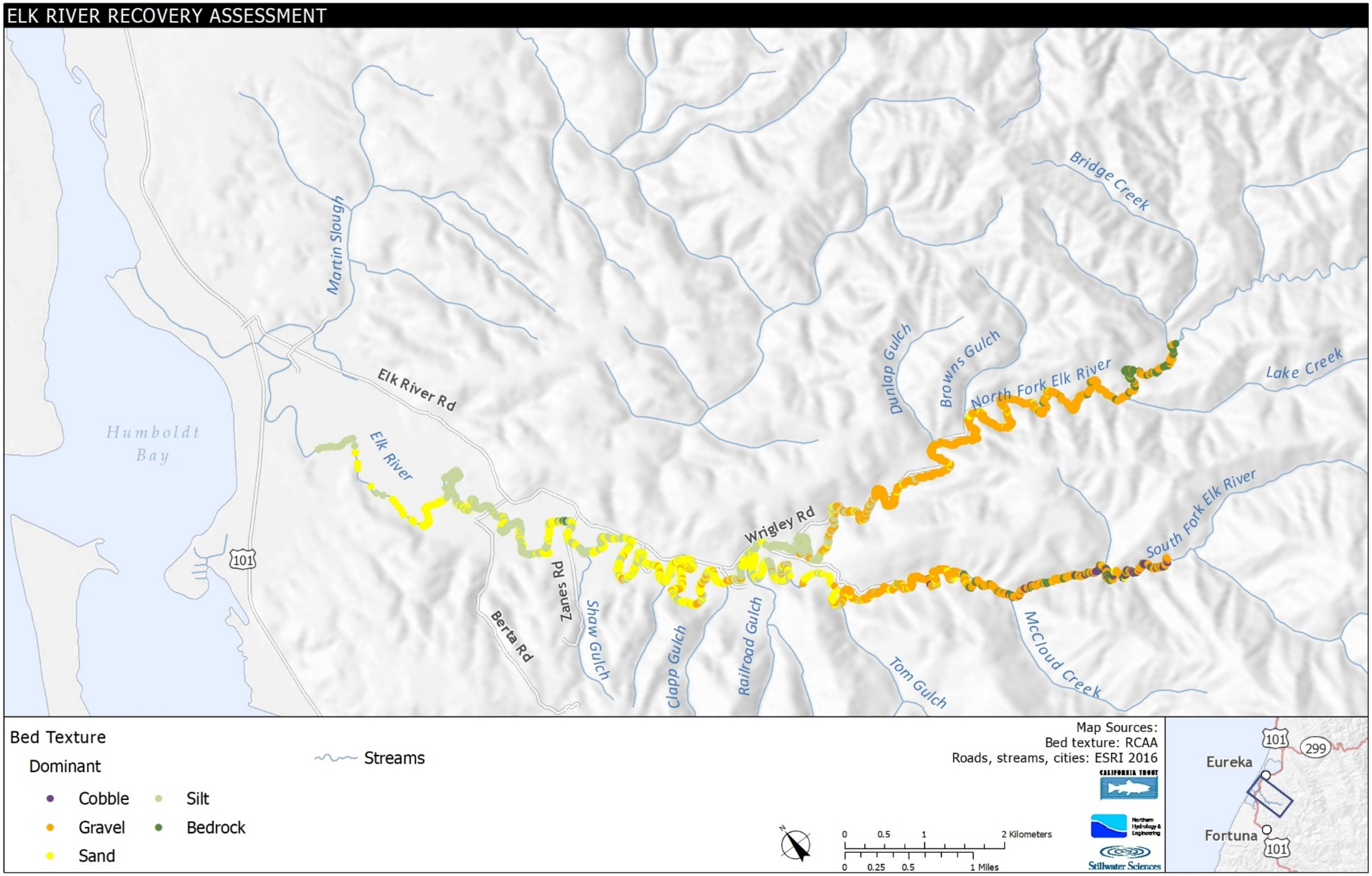

Figure 3-14. Longitudinal changes in bed surface texture mapped during the longitudinal profile survey.

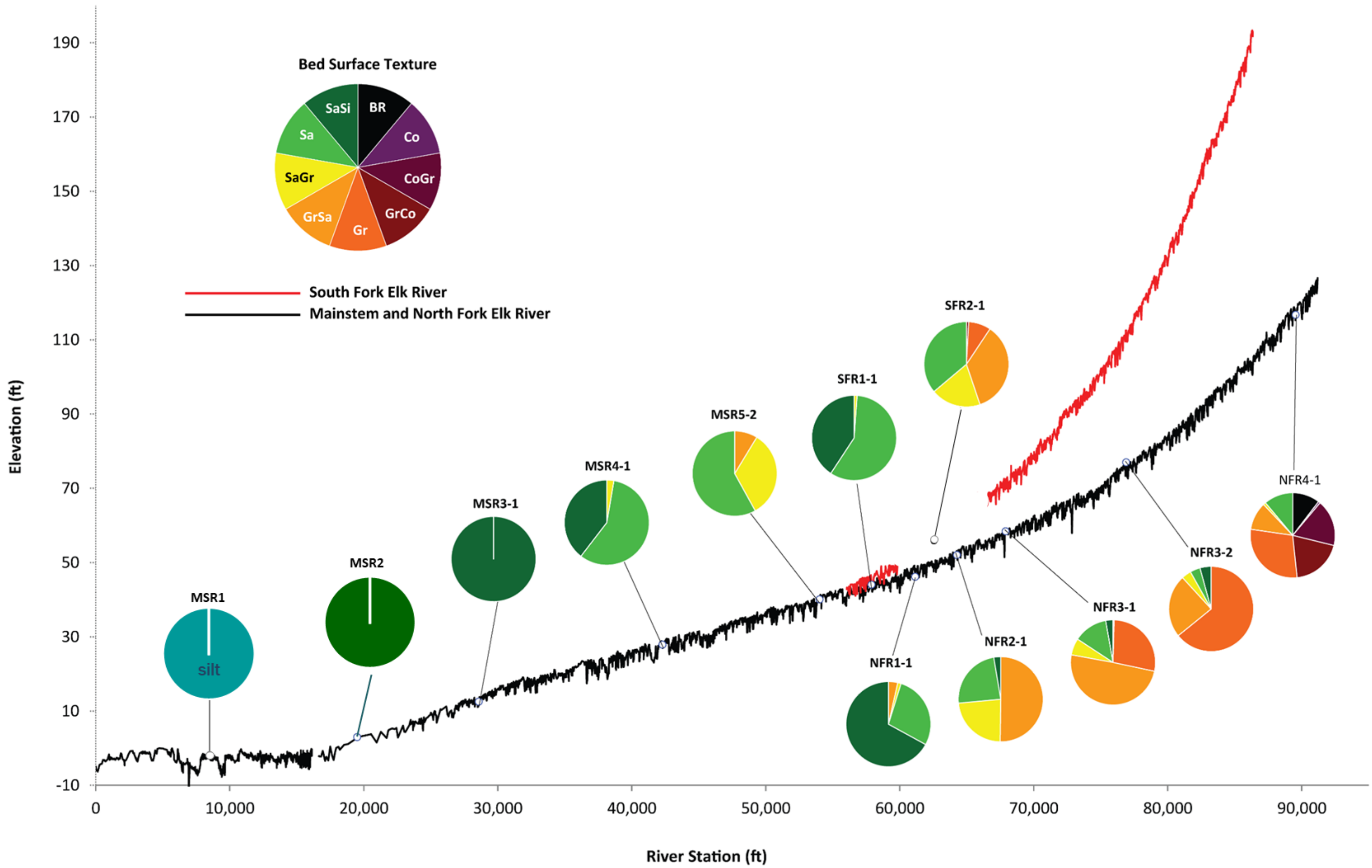

Figure 3-15. Longitudinal changes in bed surface texture mapped within intensive study sites

Facies mapping at a coarse resolution throughout the Project length and at a finer scale within intensive study sites indicate the following general trends in downstream fining of bed texture:

- Heterogeneous patches of cobble, gravel, and sand with intermittent bedrock control in the uppermost reaches of the North Fork Elk River (NFR4) and South Fork Elk River (SFR2),
- Predominantly gravel-sand mixtures in the middle reaches of the North Fork Elk River and South Fork Elk River (NFR3, NFR2, and SFR2),
- Predominantly homogeneous sand with patchy gravel in the middle Mainstem Elk River (MSR5 and MSR4),
- Homogeneous sand-silt mixtures in the lower Mainstem Elk River (MSR3 and MSR2), and
- Silt in the estuary (MSR1).

Within this general downstream fining trend, bed textures anomalously fine to sand-silt and silt in the most impacted reach (upstream extent of MSR5, NFR1 and SFR1) before coarsening back to sand and gravel in the upper Mainstem Elk River (MSR5). We attribute this anomalous fining to hydraulic backwater conditions created by (1) increased valley confinement and channel entrenchment in the locally convex-up section of the Elk River valley floor longitudinal profile (MSR5), (2) hydraulics at the North Fork Elk River and South Fork Elk River confluence, (3) an abundant supply of relatively coarse and less mobile sediment supplied from Railroad Gulch and Clapp Gulch, (4) increased hydraulic roughness imposed by channel and floodplain vegetation in MSR5, and (5) accelerated upstream sediment supply.

The longitudinal change in area-weighted bed grain size distribution from bulk samples illustrates the same pattern observed in bed surface textures, where a general trend in downstream fining is interrupted by anomalously fine bed particle size in the impacted reach (NFR1 and SFR1) (Figure 3-16). The anomalous fining is particularly apparent in the North Fork Elk River (see the intensive study site in NFR1 near station 61,000 on Figure 3-16), where bed material abruptly changes to fine sand and finer.

Dry bulk densities of channel bed material in the impacted reach typically range from 490 to 1,280 kg/m^3, and average porosities range from 0.52 to 0.81. These densities are low compared to densities typically observed in fluvial sediment deposits, in part due to the large fine sediment fraction. In fact, the properties of these sediments are more similar to slough channels in a tidal estuary than a river channel at the inland margin of the coastal plain. This finer material is likely sourced from erosion within portions of the watershed underlain by the Wildcat Group, which Ogle (1953) reported was typically comprised of about 80 to 100 percent silt and finer grain sizes. Deposition of fine sediment with a cohesive fraction and low bulk densities results in aggraded deposits in the impacted reach that are more resistance to erosion than the predominantly cohesionless sediment mixtures comprising the channel in upstream and downstream reaches, and once consolidated, can persist in storage under current conditions. These fine-grained sediment deposits with low-bulk density may also promote growth of in-channel vegetation.

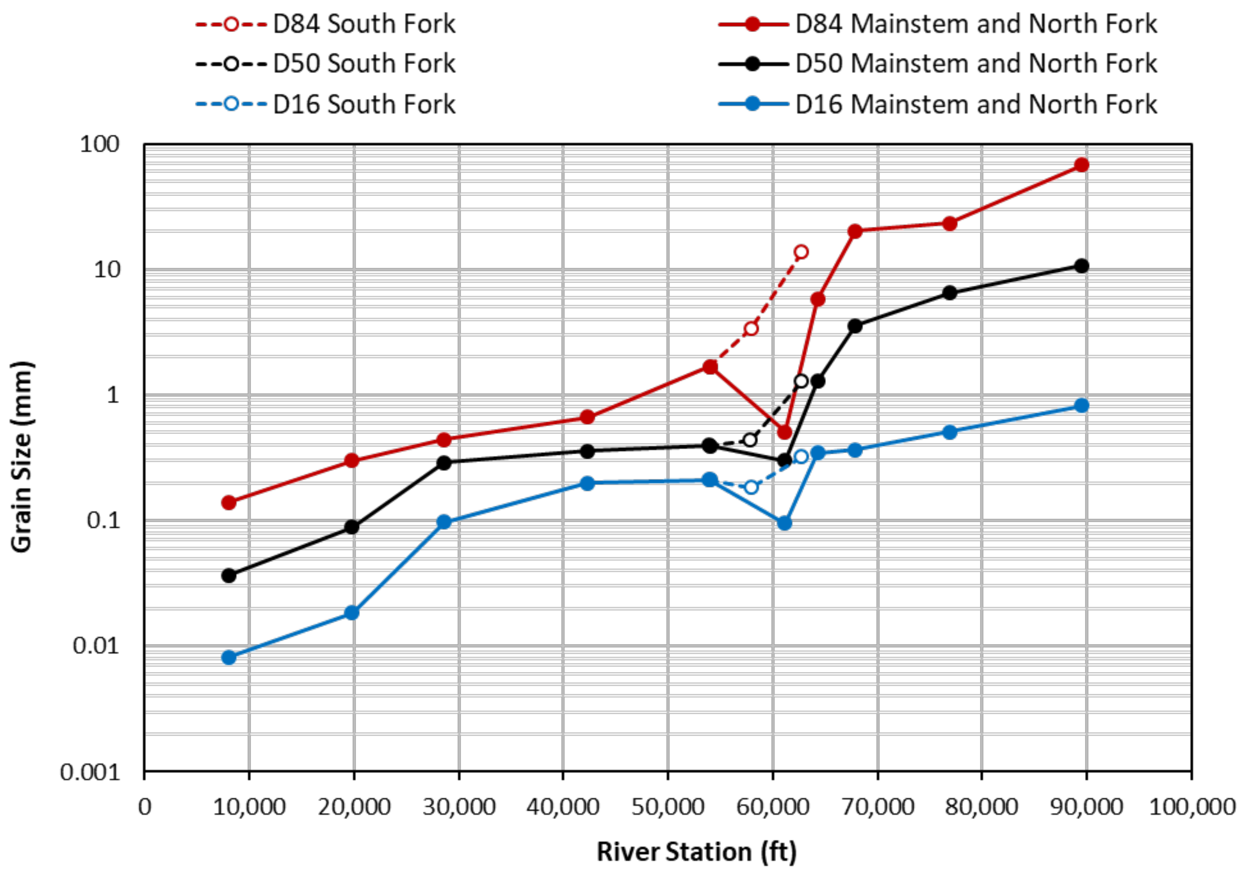

Figure 3-16. Longitudinal change in area-weighted bed grain size distribution parameters.

3.6 Channel and Floodplain Roughness

Resistance to flow imposed by large wood and riparian vegetation in channel and floodplain areas is an important factor influencing hydrodynamics, sediment transport, and aggradation in the Project area. Little is known about the historical vegetation occupying the channel banks and floodplain in Project area. On his map of Humboldt County, Lentell (1914) identified the western extent of the "Redwood Timber Belt" crossing Lower Elk River near the fluvial-tidal transition (MSR2). Lentell's map suggests the valley bottom upstream of this boundary was occupied by an old growth coniferous forest community typical of the maritime coastal climate, including redwood (*Sequoia sempervirens*), Sitka spruce (*Picea sitchensis*), and grand fir (*Abies grandis*). The historian Jerry Rhode summarized early writings of Elk River: "In the 1870s, much of the area was covered with salmon berry, alder, spruce, and wild crab apple" (Rhode pers. comm. 2017). Early settlement and land use in the Lower Elk River valley resulted in lasting, large-scale changes to the historical vegetation patterns. By the early twentieth century, old growth coniferous forests throughout the valley bottom were converted to agricultural land uses. Rhode recounted statements by early settlers: "Once the floodplain had been rid of its early vegetation, including numerous pesky redwoods, the area lent itself to the establishment of many fine dairy farms and stock ranches" (Rhode, pers. comm., 2017). The historically extensive estuary in Lower Elk River, composed of tidal wetlands and a dense network of sinuous slough channels, was diked and converted to pasture. Much of the tidal prism into Lower Elk River was altered by levees and tide gates. Commercial harvest of forest species in the upper basin during the period of initial entry in the late nineteenth century and afterwards resulted in conversion of old-growth redwood forests to young, predominantly even-aged stands.

These changes in historical vegetation patterns by domestic and agricultural land uses dramatically changed the composition and structure of vegetation in the Project area channel and floodplain. The loss of old growth conifers and large deciduous hardwood trees on the channel banks and in floodplain areas resulted in the loss of the old-growth riparian canopy and altered the structure of understory vegetation to a denser assemblage of riparian shrubs and brambles that typically encroaches on the channel. Streamside landowners historically thinned or removed this dense vegetation to improve flow conveyance. During the period of extensive land use conversion and vegetation change, large woody debris was also removed from the channel to facilitate log drives and improve flow conveyance. The current frequency and volume of LWD within the bankfull Elk River channel are below the commonly accepted targets for channels of comparable size in the region (Flosi et al. 2010, Regional Water Board 2004). By 1941, the channel planform became fixed in nearly the identical position that it occurs in today.

Another important change to channel and floodplain vegetation occurred during the 1990s, when a redwood plantation was established from the North Fork Elk River and South Fork Elk River confluence downstream to Elk River Courts (MSR5) (Figure 3-17). The densely stocked plantation hydraulically roughened the floodplain and further exacerbated the hydraulic constriction in MSR5 resulting from the more narrowly confined valley, deeply entrenched channel, and hydraulics at the North Fork Elk River South Fork Elk River confluence.

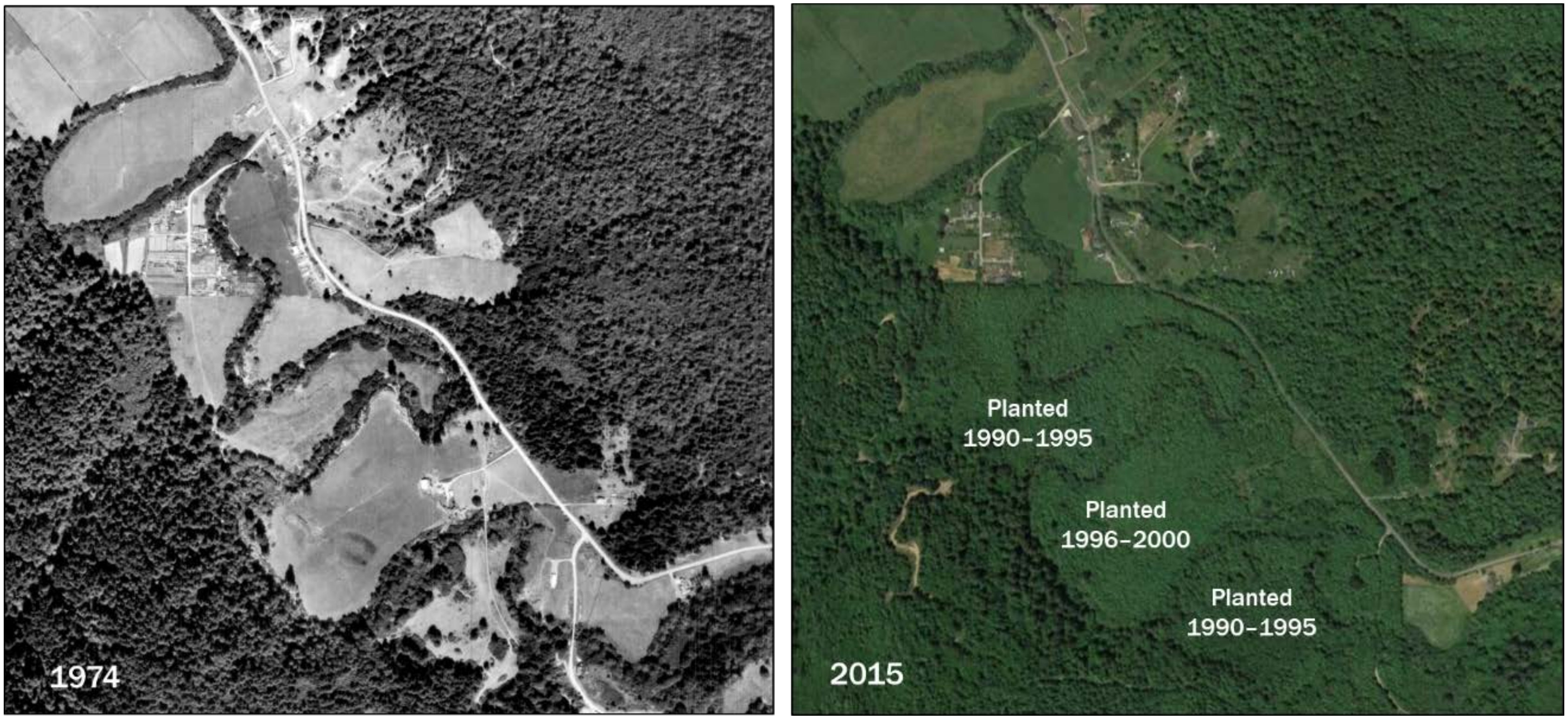

Figure 3-17. Redwood plantation established in MSR5 during the 1990s.

In many reaches, the channel is now occupied by very dense woody riparian shrubs, bramble, and fine woody debris (Figure 3-18). This dense vegetation is often rooted at the bank toe and in the channel bed, especially where riparian vegetation has been mechanically pushed into the channel (e.g., in MSR2) and where bank failures have delivered sediment and vegetation into the channel (e.g., in NFR1, MSR5, and MSR4). In some reaches (e.g., NFR2, NFR1, and MSR5), invasive sedge (*Carex Obnupta*) typical of slough channels anchors fine sediment deposits accreted to the bed and banks, increasing flow resistance, and reducing sediment routing and sorting (Figure 3-19).

Figure 3-18. Hydraulically rough riparian vegetation and fine woody debris within the bankfull channel.

Figure 3-19. The native slough sedge (*Carex obnupta*) growing in fine sediment deposits accreted to the bed and banks.

3.7 Sediment Oxygen Demand of In-Channel Sediments

Dissolved oxygen (DO) measurements in specific reaches of the Elk River indicate low concentrations and impairment well below Regional Water Board minimum DO standards (see Section 4.2). The limited observations indicate DO impairment in reaches NFR2, NFR1, SFR2, SFR1, MSR5 and a tributary to NFR4. Focused water quality monitoring is needed to evaluate potential DO and/or other water quality impairments in other reaches.

Since no known point source discharges exist in the Elk River, and the DO impairments found in NFR1 and NFR2 are above potential inputs from residential onsite wastewater systems, the likely cause of the low DO concentrations is sediment oxygen demand (SOD) from decomposing organic matter in the channel bed sediment deposits. The inability of the Elk River to flush fine sediment and accumulated organic matter from the low bulk density sediment bed (Section 3.5), along with accumulations of small woody debris and dense vegetation rooted at the channel bank toe and in the bed (Section 3.6, Figure 3-18 and Figure 3-19), has created a sediment bed with high organic content that exerts a large SOD impairing water column DO concentrations.

DiToro (2001) developed a conceptual SOD model that helps describe the effects on DO concentrations in the Elk River Project area (Figure 3-20). DiToro (2001) divides the sediment bed into aerobic and anaerobic layers where decomposing organic material creates a SOD to the overlying water column. The processes in DiToro's (2001) SOD model are described below, along with linkages to the Elk River system.

1. Particulate organic matter (POM) from the water column is deposited to the aerobic and anaerobic layers of the sediment bed. Within the Elk River, the POM likely originates from upstream soil erosion and refractory vegetation (allochthonous particles) with relatively low organic content that decays slowly; and from living in-channel vegetation, algae, and leaf litter (autochthonous particles) with high organic content that is more readily decomposed. These sources of POM and the high sedimentation rates create a high organic content sediment bed in the Elk River.
2. The POM decomposes in the anerobic layer (diagenesis) forming soluble methane (CO_4), ammonia (NH_4), and other reduced chemical species. Some of the soluble species are converted to particulate forms. In sediments with high organic content, methane and nitrogen gas bubbles can escape the bed into the water column. Gas bubbles have been visually observed in the Elk River by the ERRA team.
3. The soluble species are transported to the aerobic layer where they can be oxidized, consuming oxygen, and forming a SOD on the overlying water column. Oxidized and reduced species can also be remixed into the anerobic layer for further reaction (e.g. nitrate can be denitrified to nitrogen gas). Residual soluble species (either reduced or oxidized) in the aerobic layer are transferred to the overlying water where they exert a biochemical oxygen demand (BOD). This BOD source can be transported downstream similar to a point source discharge of wastewater, further reducing water column DO levels by oxidation.
4. Particulate and dissolved chemicals can be buried by sedimentation. Given the low bulk-density sediments and the long-term accumulation of POM in the bed, the digenesis process likely extends deep into the existing Elk River sediment bed.

The inability of the Elk River to flush the POM from the system or scour the bed, along with the high sediment deposition rates that annually bury the POM, form a negative feedback that continually creates a high organic content sediment bed. The decomposing organic material in the sediment bed will continue to impair DO levels in the overlying water column by exerting a high SOD and transferring reduced chemicals to the water column creating a BOD. It is anticipated that the above SOD process will worsen into the future.

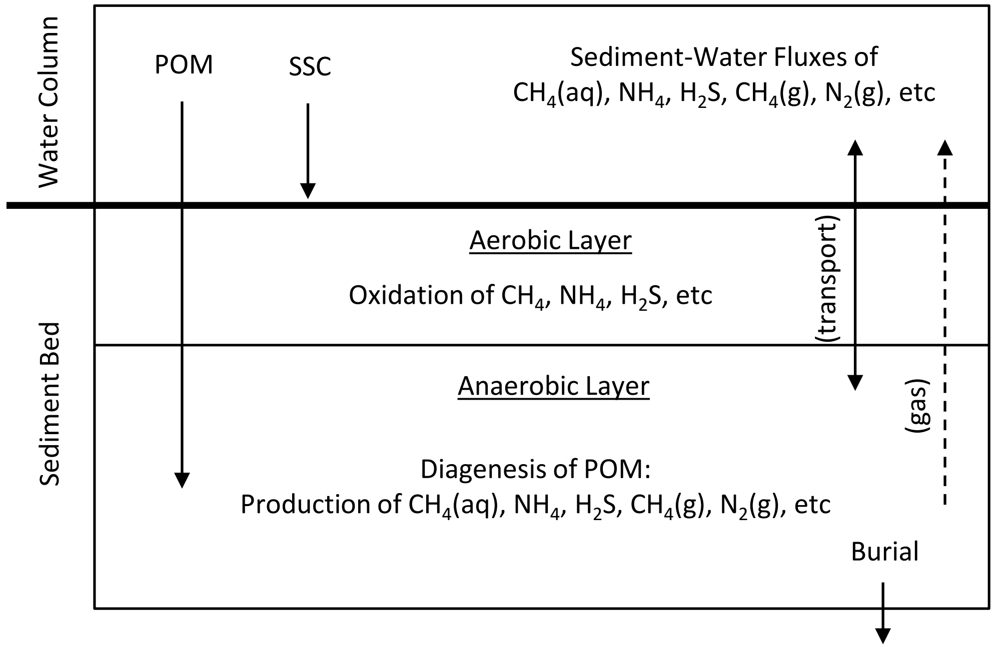

Figure 3-20. Schematic diagram of the sediment oxygen demand model framework (modified from DiToro et al. 1990 and DiToro 2001).

3.8 Synthesis

The channel and floodplains in the Elk River Project area have evolved over the past century in response to a number of interrelated factors, including early Anglo-American settlement, (e.g., ranching, road and railroad development, and logging); increases in management-related sediment loading associated with more recent industrial scale timber harvest; increased hydraulic roughness associated with changes in channel and floodplain riparian vegetation and wood load; and feedback mechanisms between channel aggradation, hydrodynamics, and sediment transport.

Reach-scale valley bottom landforms control floodplain confinement, channel entrenchment, and channel-floodplain connectivity throughout the Project area. A large-scale hydraulic constriction created in MSR5 by these intrinsic geologic conditions, combined with the peak flow timing at the North Fork Elk River and South Fork Elk River confluence, and the coarse particle sizes supplied by Railroad and Clapp Gulch relative to Mainstem Elk River transport competence combine to create hydraulic backwater conditions in adjacent upstream reaches of the North Fork Elk River and South Fork Elk River. HST model simulations of existing conditions using storm hydrographs from WY 2003 to 2015 demonstrate hydrodynamics (e.g., depth, velocity, water surface profile, flow inundation) consistent with predicted responses to valley morphology and associated channel geometry.

Elk River crossed a threshold during the latter part of the twentieth century (i.e. 1988–1997), when accelerated timber harvest and road building in the upper watershed coincided with large storm events, leading to management-related increases in sediment loading and rapid channel aggradation in the Project area. The resulting channel aggradation created an enduring feedback loop, where reduced channel conveyance capacity and slower flow velocities limit sediment transport rates, promote further channel sedimentation under reduced sediment loading, and prolong the residence time of aggraded sediment deposits. The large-scale hydraulic constriction in MSR5 and associated backwater conditions in adjacent upstream reaches were further exacerbated during this time by establishment of a densely stocked redwood plantation throughout the valley floor between Steel Bridge and Elk River Court.

Deposition of fine sediment with a cohesive fraction and low bulk densities results in aggraded deposits in the impacted reach that are more resistance to erosion than the predominantly cohesionless sediment mixtures comprising the channel in upstream and downstream reaches, and once consolidated, can persist in storage under current conditions. These fine-grained sediment deposits with POM content may also promote growth of in-channel vegetation and low DO. Changes in the composition and structure of vegetation on the channel bed and banks have also increased hydraulic resistance and helped anchor these sediment deposits, creating channel forms and processes with limited sediment routing and sorting.

Downstream of MSR5, the channel becomes less entrenched and flow routing across the floodplain increases. Longitudinally extensive natural levees separate the bankfull channel from adjacent large, deep flood basins. Compared to other reaches of Elk River, floodplains in MSR4 and MSR3 convey a large proportion of the total water and sediment flux during storm events. Floodplain sediment storage in these reaches is an important component of the Elk River annual sediment budget. The channel planform in this reach is less stable than in upstream and downstream reaches, with a tendency for channel avulsion. Elevated floodplain topography near the fluvial-tidal transition and confining features (e.g., constructed levees) near Showers Road create a hydraulic control in Lower Elk River that backwaters upstream areas during high flows. The Mainstem Elk River through the most downstream reach is a tidal slough channel confined by levees and adjoined by historical and existing but disconnected intertidal mudflats and tidal wetlands. Hydrodynamics and sediment transport are controlled by tidal action. A dense network of relict, highly sinuous channels throughout the valley bottom in this area indicate a once extensive tidal estuary prior to agricultural conversion.

Other nearby coastal river basins that experienced similar rapid channel and floodplain aggradation due to increased sediment loading (e.g., Bull Creek, Redwood Creek, Freshwater Creek) have recovered or exhibit recovery, where stored sediment evacuates over decades. The most rapid period of recovery in these basins typically occurred within the first decade following disturbance. In the case of Elk River, however, there is no foreseeable period within which sediment impaired beneficial uses will recover without mechanical intervention.

4 AQUATIC HABITAT RESPONSES TO SEDIMENT IMPAIRMENT

Salmonids represent and depend on several impaired beneficial uses of water in Elk River, and the effect of impaired channel conditions and nuisance flooding on native salmonid populations is therefore an important focus of the Elk River Recovery Assessment. Native salmonids (and other aquatic organisms) in Elk River depend on properly functioning stream channels and floodplains; a mature riparian vegetation corridor contributing allochthonous materials, terrestrial invertebrates, and shade; large wood that forms complex in-channel habitat features; cold, clear, and well-oxygenated water; and a healthy stream-estuary ecotone where natal and non-natal migratory fish can transition between freshwater and saltwater. In addition to their freshwater habitat requirements, native salmonids in Elk River depend on diverse life history strategies (including several different juvenile rearing and outmigration pathways) to maintain resilient and abundant populations in temporally variable environments (Schindler et al. 2010, Wallace et al. 2015). Leaving their natal spawning habitat at different times allows fry and juvenile salmonids to interface with a mosaic of non-natal rearing habitats.

Timber harvest and road building in the upper watershed, ranching and residential development in the middle and lower watershed, and other land uses over the past century and a half have cumulatively impaired water quality (i.e., causing high turbidity and suspended sediment concentrations, elevated water temperatures, and low dissolved oxygen) and have degraded stream channels and floodplains that provide critical spawning and rearing habitats for salmonids (Regional Water Board 2013, 2016; NMFS 2014, 2016; Tetra Tech 2015). Large inputs of fine sediment during the 1980s and 1990s accelerated water quality and habitat degradation in the lower 19 miles of Elk River. In turn, habitat degradation has significantly reduced juvenile and adult salmonid abundance in Elk River (NMFS 2014, 2016), and may be impairing critical life history pathways that are essential to the recovery of these species.

This chapter synthesizes available information regarding the salmonid species, life histories, and habitats in Elk River and Humboldt Bay. The synthesis draws strong inferences about the status of salmonids in Elk River based on information from nearby streams, trends in annual abundance and recovery, and the extensive literature on salmonid ecology. We also provide our professional judgment about salmonid life history and habitat conditions where empirical information is not available. More robust water quality monitoring and detailed study of salmonid life history and habitat conditions is warranted in Elk River, particularly in the middle and lower reaches where empirical data are sparse.

4.1 Functional Salmonid Habitat Reaches

The ERRA Project area can be divided into four functional reaches that collectively provide salmonid habitat for all salmonid life stages: (1) the upper reaches of the North Fork Elk River (NFR4 and NFR3) and the North Fork above the Project area, the South Fork Elk River above the Project area, and numerous upper watershed and headwater tributaries; (2) the confined lower North Fork and South Fork Elk River (NFR2 and NFR1, SFR2 and SFR1) and Mainstem Elk River (MSR5); (3) the predominantly unconfined lower Mainstem Elk River valley from Elk River Court downstream to the upper extent of tidal influence (MSR4 and MSR3); and (4) the stream-estuary ecotone extending from the upstream extent of tidally-influenced freshwater to Humboldt Bay (MSR2 and MSR1) (Figure 4-1).

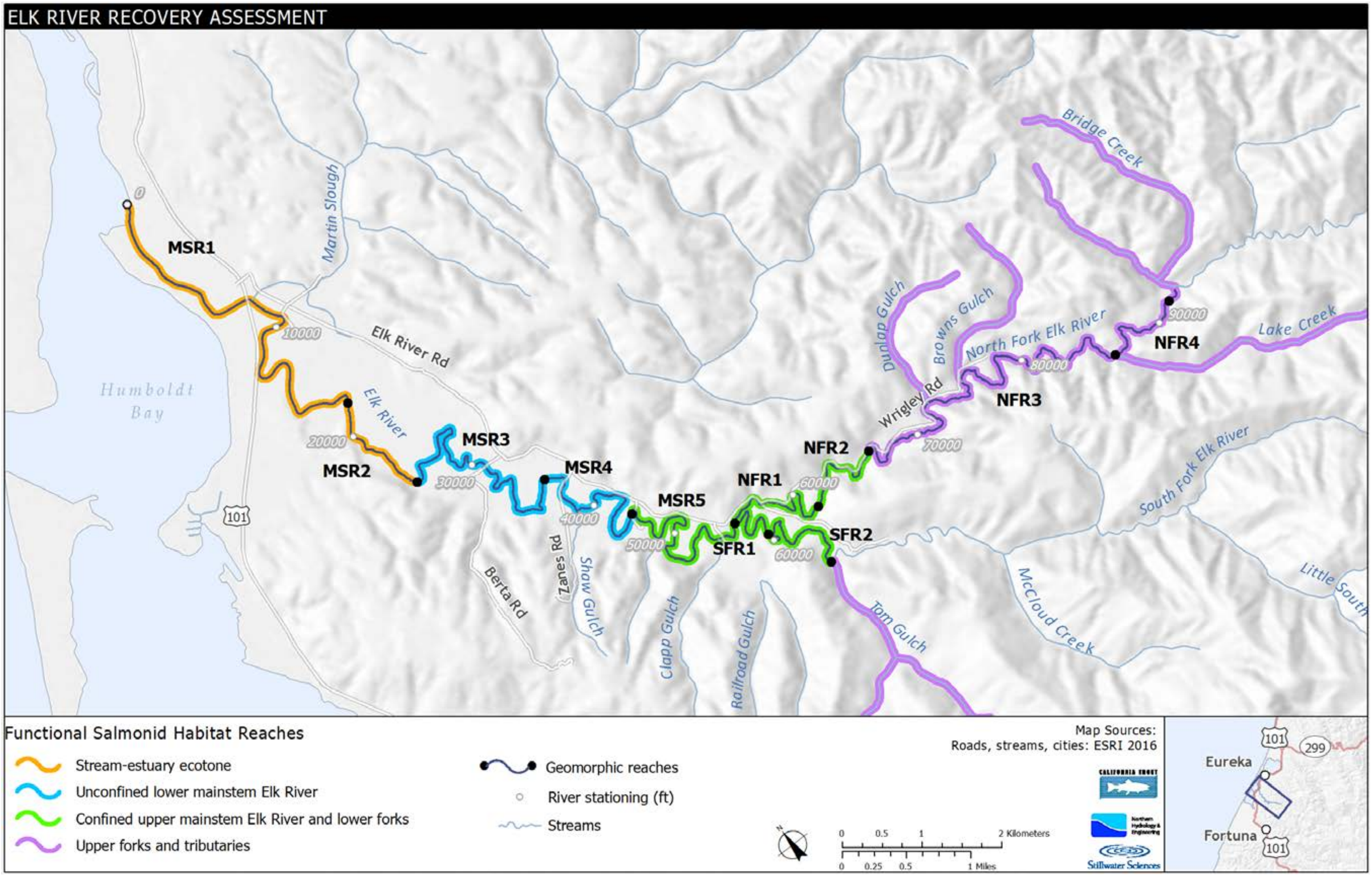

Figure 4-1. Functional salmonid habitat reaches.

4.1.1 Upper forks and tributaries

The upper reaches of the ERRA Project area include the North Fork Elk River from RM 17.2 to RM 11.7 and the South Fork Elk River from RM 12.5 to RM 11.3. Several fish-bearing tributaries enter these reaches, including Tom's Gulch on the South Fork Elk River and Dunlap Gulch, Brown's Gulch, Lake Creek, and Bridge Creek on the North Fork Elk River. There are 6.7 miles of spawning habitat within the ERRA Project area in NFR3 and NFR4, with several miles of additional spawning habitat available in the North Fork Elk River, South Fork Elk River, and in tributaries above the Project area. An upper estimate of spawning habitat in Elk River, based on the total length of blue-line streams, is approximately 46.6 stream miles (28.8 mi in North Fork, 17.8 mi in South Fork).

Historical habitat function

The upper reaches of the ERRA Project area historically provided important spawning habitat for Chinook, coho, and steelhead. The majority of functional spawning reaches in Elk River are upstream of the ERRA Project area and were not surveyed in this study. However, anecdotal evidence indicates spawning habitat was historically available along the entire North Fork and South Fork downstream to their confluence. Spawning habitat was historically not likely available in the mainstem Elk River reaches. The forks and tributaries also historically provided high quality and abundant young-of-year and juvenile rearing habitat.

Current habitat conditions

Based on available information reviewed for the ERRA, spawning habitat in much of upper Elk River forks and tributaries appears to be relatively abundant, is in early to more advanced stages of recovery from sediment and channel impairment, and is currently capable of supporting stable spawning populations of Chinook, coho, and steelhead (HBWAC 2005, Regional Water Board 2013 Fisheries Appendix, HRC 2014). While there has been no comprehensive salmonid population monitoring program in Elk River (as is occurring in nearby Freshwater Creek), several habitat surveys and inventories have been conducted in the Elk River. Redd surveys have been conducted by PALCO, the Institute for River Ecosystems, Natural Resources Management, and the California Department of Fish and Wildlife (CDFW) (HBWAC 2005). CDFW has conducted habitat inventories in numerous tributaries since the early 1980s, and began to document spawning habitat impairments prior to the increased sediment loads of the late 1980s and 1990s (Table 4-1). PALCO conducted redd counts for coho salmon in the North Fork and South Fork Elk River for the period 1986 to 2003 (Figure 4-2). CDFW has conducted spawning ground surveys on several Humboldt Bay tributaries including the North Fork and South Fork Elk River as early as 1986 (HBWAC 2005), and annually since 2008, and have documented all listed salmonid species spawning in the upper forks (Figure 4-3) and in several tributary reaches.

Table 4-1. Summary of CDFW spawning observations in Elk River tributaries (Regional Water Board 2013), indicating existing impairment to spawning habitat in some upper-watershed tributaries prior to the 1986–2000 period.

Year	Location	Surveyor's description
1982	Dunlap Gulch	Gravel too small for spawning
1982	Brown's Gulch	Spawning activity noted
1983	Shaw Gulch	Sand and silt are dominant substrate
1983	Clapp Gulch	Lack of any suitable spawning habitat
1983	Railroad Gulch	Lack of spawning gravel, no gravel retention behind logjams
1983	Lake Creek	Absence of spawning gravel, mud, and silt sources
1983	Bridge Creek	Unsuitable spawning

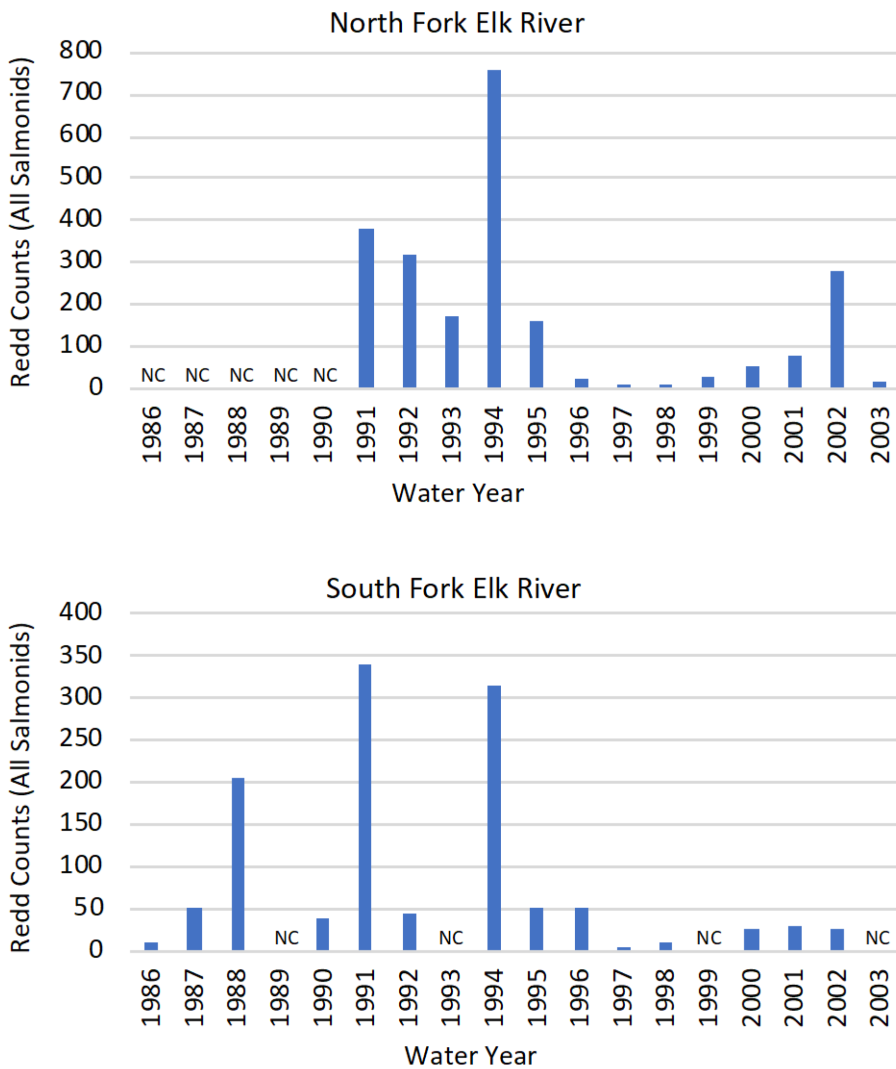

Figure 4-2. Annual redd counts (all salmonids) from PALCO spawning surveys on North Fork Elk River and South Fork Elk River, 1986–2003. NC = No Counts.

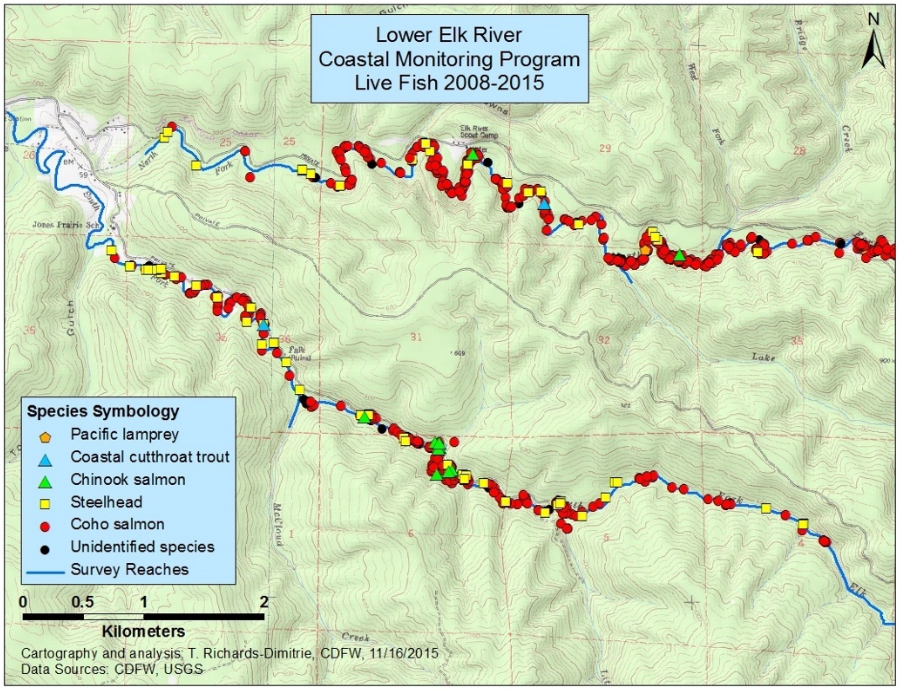

Figure 4-3. Live adult fish observed during CDFW spawning surveys on North Fork Elk River and South Fork Elk River, 2008–2015 (note lack of tributary survey reaches).

Several tributaries remain impaired by high sediment loads (Figure 3-8) which likely results in high percentages of fine sediment in spawning gravels, and alteration to channel morphology and habitat function. Within the ERRA Project area, an important transition from gravel-dominated channel substrates to sand-dominated substrates occurs on the North Fork at the downstream portion of NFR3 (below Brown's and Dunlop Gulch), and on the South Fork at the confluence with Tom's Gulch. These transitions demarcate downstream boundaries of current spawning habitat availability and observed spawning activity (Figure 4-3).

Juvenile salmonid rearing habitat is also likely impaired in many reaches of the forks and tributaries due to sediment aggradation and associated loss of pool habitat, reduction of large wood storage, channel simplification, and lack of habitat complexity. In general, gravel composition in the steeper, upper South Fork Elk River (upstream of the ERRA Project area) has lower percentages of fine sediment than the upper North Fork Elk River (upstream of the ERRA Project area). Some tributaries still have many reaches with good rearing habitat associated with high benthic invertebrate productivity. Aquatic inventories indicate healthy populations of aquatic invertebrates in upper North Fork Elk River (NFR3) but relatively low invertebrate abundance at HRC monitoring sites in the confined upper Mainstem Elk River (MSR5, PALCO 1999, HRC 2015). Water temperatures reported by HRC (2014) generally appear to meet favorable temperature targets in recent years. The riparian canopy is recovering, with good ratings for percent canopy of riparian forest, and somewhat lower ratings for percent canopy over-stream (HRC 2014). HRC monitoring results for the North Fork Elk River (2014) indicated that most reaches did not meet targets for pool depth (HRC 2015), although pool area targets were met. Pools were abundant, and many were associated with adequate large wood, but data collected in this study indicate the ERRA Project reaches did not meet wood loading targets compared to desired conditions for LWD (Regional Water Board 2006) (Figure 4-4). Chronic turbidity levels are high (Klein et al. 2011), turbidity and SSC have not shown a trend toward improvement (Appendix D), and degraded water quality likely continues to impair fish health, rearing success, and survival.

4.1.2 Confined upper Mainstem Elk River and lower forks

The confined lower North Fork Elk River and South Fork Elk River reaches, and the upper Mainstem Elk River extends from RM 11.7 on the North Fork Elk River and 11.3 on the South Fork Elk River downstream to Elk River Court (RM 8.5) (geomorphic reaches NFR2, NFR1, SFR2, SFR1, MSR5) (Figure 4-1). The channel in these reaches is typically narrow and entrenched within steep banks. Stream banks and adjacent floodplain vegetation is dominated by riparian forest (red alder, arroyo willow, bigleaf maple) and coniferous forest (redwood, Sitka spruce, Grand Fir), with little open canopy, and with a dense understory composed of riparian and coastal scrub.

Historical habitat function

The transition from a predominantly gravel bed to predominantly sand bed marks the downstream extent of salmon and steelhead spawning habitat. Historical accounts by local residents describe spawning as far downstream as the North Fork Elk River and South Fork Elk River confluence. Spawning habitat may have historically been confined to the steeper riffles and tributary confluences (e.g., Railroad Gulch and Clapp Gulch), but spawning habitat was not likely available in MSR5 between the North Fork and South Fork confluence and Elk River Court. This reach, however, historically provided high quality and abundant year-round non-natal rearing habitat for young-of-year and juvenile salmonids, and was important during spring outmigration as juveniles and pre-smolts emigrated from upper forks and tributary rearing areas. Large wood recruited to the channel from adjacent floodplains was likely abundant as pieces and jams that provided complex habitat with deep pools, dense cover, coarse substrate, cold water, and abundant food resources. Juvenile salmonids rearing in these reaches during the winter may have been less dependent on high flow refugia in off channel floodplain areas due to low in-channel flow velocities resulting from the low-gradient reaches (NHE and SWS 2013).

Current habitat conditions

Fine sediment accumulation has significantly impacted water quality, channel morphology, and adult holding and juvenile rearing habitat for salmonids in the more confined upper Mainstem Elk River and lower North Fork Elk River and South Fork Elk River reaches. Although NMFS (2014, 2016) identifies Intrinsic Potential for salmonid production in these reaches, CDFW does not conduct spawning surveys downstream of the North Fork Elk River and South Fork Elk River confluence (Anderson and Ward 2015) due to the lack of spawning habitat.

Salmonid rearing habitat in these reaches is currently heavily degraded by numerous factors. The effects of habitat impairment are different during different rearing seasons. In summer, the effects of sediment aggradation and channel simplification have had pronounced detrimental effects on juvenile salmonid rearing habitat. Fine sediment aggradation has buried or embedded riffle substrates, likely reducing benthic invertebrate productivity (in overall biomass and abundance)

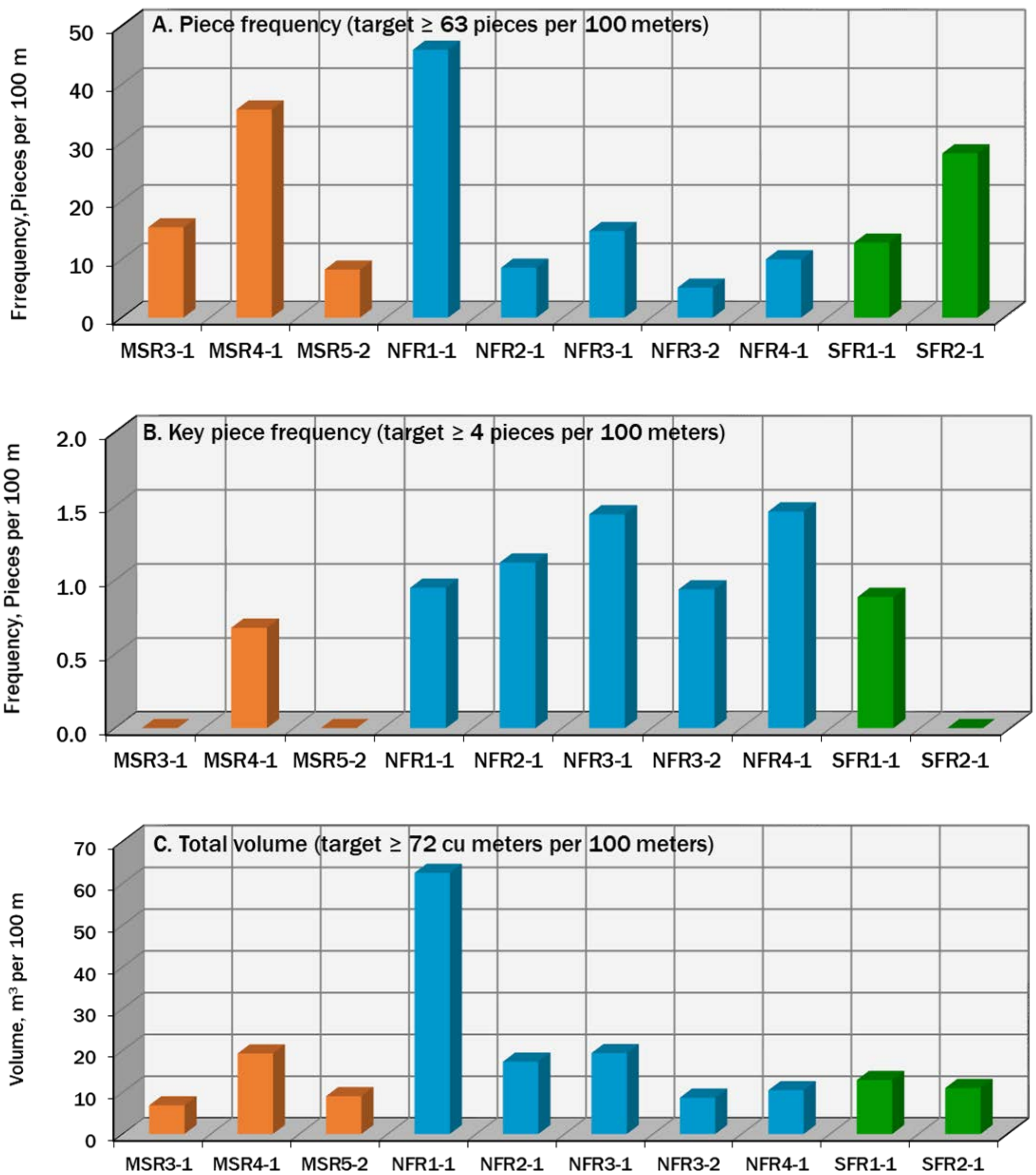

Figure 4-4. LWD piece frequency (A), key piece frequency (B), and volume (C) at intensive study sites in Elk River. LWD was at least 3 feet long and 6 inches in diameter. Key pieces were determined based on stability, function, and volume requirements that vary with bankfull width (Regional Water Board 2004).

and diminishing food resources during critical spring and summer rearing seasons. While benthic invertebrate data were not collected in Elk River for this study, we can surmise low benthic invertebrate productivity based on research reported in the literature. For example, Cover (et al. 2008) found that fine sediment caused an overall reduction in prey availability for salmonids. NMFS (2016) concluded that epibenthic grazer and predator taxa of benthic macroinvertebrates, an important food source for salmonids, were limited or non-existent in channels with high levels of sedimentation. Suttle (et al. 2004) found that increasing concentrations of deposited fine sediment decreased growth and survival of juvenile steelhead trout.

Pool depths and volumes are also significantly reduced, diminishing the overall habitat carrying capacity and habitat quality. The volume of large in-channel wood has been reduced throughout these reaches, with smaller and less-persistent hardwood species (willow and alder) providing the majority of the current volume (Figure 4-4). As a consequence, habitat complexity is significantly diminished. In addition, a large proportion of the current wood volume is deposited above the winter baseflow water surface and does not provide habitat benefits. Much of the in-channel sediment deposits are colonized by dense beds of slough sedge (*Carex obnupta*), possibly obstructing juvenile fish passage between shallow pool units (Figure 3-19). Juvenile salmonids have recently been observed rearing in these conditions in NFR1 and MSR5 in summer, with apparently good condition factor (i.e., length to weight ratio). It is unknown if these summer juveniles remain in this habitat and successfully rear in these reaches during winter, or if juvenile growth rates in spring and summer are adequate to eventually allow recruitment to the adult population.

Winter rearing habitat is considered the likeliest limiting habitat in Elk River, especially for juvenile coho salmon (S. Ricker, CDFW, pers. comm. 2018). These confined reaches of Elk River once provided high quality and abundant winter rearing habitat but are now heavily aggraded by fine sediment and provide very poor winter rearing conditions. Pool volumes are low, large wood providing complex habitat features is scarce, and the natural channel confinement in these reaches reduces access to floodplain rearing refugia. More frequent flooding across road surfaces and pastures may also contribute to stranding mortality. During the winter rearing season, poor water quality resulting from acute and chronic high suspended sediment concentrations and turbidity levels impair fish health and feeding success. Section 4.2 describes water quality impairment resulting from high suspended and bedload sediment, and high turbidity levels.

4.1.3 Unconfined lower Mainstem Elk River

The unconfined lower Elk River valley extends from Elk River Court (RM 8.5) downstream to the upper extent of tidal influence (RM 4.7) (geomorphic reaches MSR4 and MSR3) (Figure 4-1). These reaches are characterized by a low gradient, relatively unconfined channel meandering across a wide valley bottom occupied by ranch lands and mixed residential land uses. The channel typically has sand and silt bed material, steep and erosive channel banks, and a narrow riparian zone.

Historical habitat function

The unconfined lower Mainstem Elk River historically provided high quality non-natal summer and winter rearing habitat for juvenile salmonids. While there is sparse historical data describing these reaches, we surmise these salmonid habitat conditions from comparable stream reaches and their functions observed in nearby Freshwater Creek (e.g., the Middle Mainstem Freshwater Creek at Howard Heights). Relatively low velocities persisting year-round in the Mainstem Elk River channel provided favorable winter rearing, while extensive connected floodplains provided highly productive off-channel habitat. Summer rearing was also likely historically productive due to moderately cool summer water temperatures, frequent large, deep, and shaded pools with large volumes of woody material, and high inputs of allochthonous materials and terrestrial invertebrates from the surrounding dense riparian vegetation. These reaches also likely contained deep holding pools important for migrating adults but did not provide spawning habitat due to the lack of suitable spawning gravel substrate.

Current habitat conditions

Similar to the upstream confined reaches, the unconfined reaches of lower Mainstem Elk River have been impacted by channel and habitat simplification resulting from land uses, large wood removal, and sediment aggradation. Fine sediment aggradation has filled pools and embedded coarse substrates, simplifying the channel, and reducing benthic invertebrate productivity. Although water quality information is limited in these reaches, winter water quality is known to be significantly impaired by high suspended sediment concentration and turbidity. Water quality conditions in these reaches are not well defined, although a few samples exist (see Section 4.2). The riparian corridor in these reaches is constrained to a narrow strip primarily composed of willow and alder located along the streambanks and encroaching onto the stream channel. The riparian understory is dominated by non-native Himalaya blackberry and other riparian and coastal scrub species. Stream banks are degraded by cattle grazing in places. On average, large wood volumes in these reaches are less than 20 percent of the target values recommended by the Regional Water Board (Figure 4-4).

Juvenile salmonid surveys in Elk River suggest that the unconfined reaches of lower Mainstem Elk River are at their juvenile coho salmon carrying capacity, and the densities supported in these reaches may be different than densities in upstream reaches (M. Wallace, CDFW, pers. comm., 2016). These densities appear to depend on water year type. In wetter years, there is apparently enough upstream habitat available that few juvenile coho salmon move down to use the stream-estuary ecotone. In drier years, degraded habitat upstream apparently forces the emigration of juveniles downstream to the stream-estuary ecotone. CDFW noted increased juvenile rearing in the stream-estuary ecotone reaches of Elk River during recent drought years (M. Wallace, CDFW, pers. comm. 2016).

4.1.4 Stream-estuary ecotone

The Elk River stream-estuary ecotone encompasses the lowest channel reach from the limit of tidal influence at approximately RM 4.7 downstream to Humboldt Bay at river mile (RM) 0 (geomorphic reaches MSR2 and MSR1) (Figure 4-1). Figure 3-2 shows the approximate upstream extent of tidal influence indicated by the highest tide on record at North Spit. The stream-estuary ecotone can be subdivided into an upper reach of tidally influenced freshwater (MSR2) and a lower reach of saline/brackish water (MSR1). The upper and lower stream-estuary ecotone reaches are divided at the upper extent of saline/brackish water near RM 3.2. These reaches are characterized by tidal slough channels with large width-to-depth ratios and near vertical banks. The channel is typically confined by constructed levees and adjoined by historical and existing intertidal mudflats and seasonal wetlands currently used for dairy and cattle ranching.

Historical habitat function

The Elk River stream-estuary ecotone historically included over 400 acres of salt marsh and brackish habitats with networks of tidal channels accessible to salmonids and other fish and crustacean species throughout the year during some portion of the tidal cycle. In Elk River, as in other tributaries to Humboldt Bay, the stream-estuary ecotone once offered highly productive rearing habitat for both juvenile and pre-smolt salmonids. Wallace et al. (2015) observed three life history strategies employed by juvenile coho salmon in the stream-estuary ecotone of Humboldt Bay tributaries, including (1) young-of-year (YOY) fish that arrive in the spring and reside primarily in the Mainstem Elk River channel in the summer and early fall; (2) juvenile coho that migrate to the stream-estuary ecotone in the fall after the first large streamflow event and rear extensively in smaller tributary and off-channel habitat during the winter and following spring; and (3) juveniles and pre-smolts that emigrate through the stream-estuary ecotone in spring. Chinook salmon are largely dependent on estuarine and tidal marsh habitats (Healey 1982, NMFS 2016), where they typically feed and grow for extended periods before migrating to sea. Rearing for at least some portion of their juvenile life history confers distinct benefits to growth and survival (Miller and Sadro 2003, Koski 2009). The life-cycle monitoring station on Freshwater Creek operated by CDFW found that approximately 40% of the coho smolts produced from the basin reared in the stream-estuary ecotone, and coho juveniles that reared in the stream-estuary ecotone were larger than their cohorts rearing in stream habitat upstream of the stream-estuary ecotone (Wallace et al. 2015). The ecotone of Elk River historically did not provide salmonid spawning habitat due to the absence of suitable spawning substrate and the presence of saline water during the fall and winter spawning season.

Current habitat conditions

The amount and quality of aquatic habitat in the Elk River stream-estuary ecotone has been significantly reduced by conversion of former tidelands to agricultural land uses. Most of the historically extensive tidal marsh lands in lower Elk River are currently used for cattle and dairy ranching. Remaining habitat is impaired by sediment aggradation, flood control, and tide gates that reduce the tidal prism and impair migration into and out of sloughs and off-channel areas (e.g., Elk River Wildlife Area). Elk River east of US Highway 101 is constricted by levees and the Northwestern Pacific railroad grade and lacks access to off-channel rearing habitats due to floodplain disconnection. Habitat in the stream-estuary ecotone has been further simplified by removal of streamside riparian vegetation. Low dissolved oxygen during the summer and fall (4–5 mg/L range) may limit juvenile rearing habitat quality (M. Wallace, CDFW, pers. comm. 2016). The impairment and loss of productive tidal marsh and estuarine rearing habitat has likely contributed to the acute decline of salmonid population abundance in Humboldt Bay (HBWAC 2005; NMFS 2014, 2016).

4.2 Water Quality

In addition to the physical habitat impairment discussed above, we examined existing water quality data to assess its effect on habitat impairment. Four relevant aspects of water quality are evaluated: turbidity, suspended sediment concentration, temperature, and dissolved oxygen.

4.2.1 Turbidity

Turbidity is a well-studied aspect of salmonid ecology, but specific turbidity thresholds recommended to avoid effects on salmonids remain uncertain (Newcombe and MacDonald 1991, Klein et al. 2008.). While moderate turbidity levels can help salmonids evade predators (Gregory 1993, Gregory and Levings 1998), juvenile salmonids avoid highly turbid waters (Bisson and Bilby 1982). Most studies report negative impacts on fish from high turbidity (Newcombe and Jensen 1996; Chapman et al. 2014; Kjelland et al. 2015; Klein et al. 2008, 2011). Many studies of the effects of turbidity on salmon have been laboratory-based and relatively small scale (i.e., Sweka and Hartman 2011) and are typically based on model simulations of individual fish behavior (i.e., Harvey et al. 2009). However, these studies generally confirm what fish biologists have suspected for decades: that turbidity impairs salmon feeding and growth. The combined findings of the many turbidity studies are also the basis of conceptual models explaining the effects of turbidity on salmon (e.g., Newcombe and Jensen 1996, Klein et al. 2008). Salmonids rearing in turbid water move shorter distances to food items (Sweka and Hartman 2001, Rosenfeld 2002, Hansen et al. 2013), are more active, and switch foraging strategies from drift feeding to active searching (Suttle et al. 2004, Sweka and Hartman 2011). This switch is energetically costly and results in lower growth rates compared with clear water (Henley et al. 2000, Harvey et al. 2009, Sweka and Hartman 2011).

Klein et al. (2008, 2011) assembled annual turbidity data for three water years from 28 streams in the north coast of California, to examine the cumulative effects of turbidity on salmonid populations. Their study estimated the duration in which specific turbidity thresholds were exceeded, then modeled the potential effects on anadromous salmonids. Of the 28 streams studied, the two Elk River stations (KRW and SFM) had the highest turbidity durations (hours above selected turbidity levels) recorded in two of the three water years analyzed (WYs 2004 and 2005). Klein et al. (2008) predicted reduced growth rates resulting from chronic turbidity. Their model of steelhead growth used literature values for fish growth and adult return rates, conservative estimates of turbidity from several Elk River locations, and assumed a relation between reactive distance, feeding efficiency, and growth. Their model of smolt growth and smolt-to-adult-return rates demonstrates that chronic turbidity can greatly reduce productivity of a steelhead population.

A key aspect of the Klein model is understanding that larger smolts are more likely to return as adults, amplifying the importance of growth rates. For example, a 171 mm smolt is over twice as likely to return as an adult than a 160 mm smolt (Klein et al. 2008). When juvenile fish growth rates are reduced by a small amount from turbidity, the effects reduce the number of adults returning in subsequent years. An almost exponential steelhead smolt survival curve between 120 mm and 190 mm and a steeply declining growth curve between 5 Nephelometric Turbidity Unit (NTU) and 70 have a large effect on the model's findings (Klein et al. 2008).

The combination of chronic and acute sub-lethal effects from suspended sediment appears to result in significant detrimental effects in Elk River, but turbidity may in fact be more limiting on a population scale. According to NMFS (2016):

> *"Increased suspended sediment concentration, and resultant increased turbidity, can cause avoidance responses, and physical damage to gills of juveniles, smolts and adults, as well as reduced feeding and growth rates of juveniles and smolts. High levels of fine sediment and embeddedness can also reduce the feeding success, and ultimately growth of 0+ and 1+ fish, because extended periods of high turbidity reduce visibility of prey as well as the type of invertebrate prey available. Epibenthic grazer and predator taxa of benthic macroinvertebrates, an important food source for salmonids, are limited or non-existent in channels with high levels of sedimentation."*

So, while juvenile salmonids may successfully rear and survive in Elk River reaches impaired by high turbidity levels, their growth may be impaired and their subsequent survival to adult recruitment may be diminished.

4.2.2 Suspended sediment concentration

Newcombe and Jensen (1996) developed a severity of ill effects index (SEV) describing the effects associated with excess suspended sediment. Their meta-analysis of existing studies yielded equations describing the biological response to the concentration and duration of suspended sediment. The biological response to suspended sediment range from no effect, to behavioral effects, up to sub-lethal and lethal effects. Behavioral effects to fish from suspended sediment include stress or avoidance, where sublethal effects include reduction in feeding, increased respiration, and habitat degradation. Suspended sediment does more than just alter fish's behavior to adapt less efficient feeding strategies. Michel et al. (2013) observed actual changes to the structure of *O. mykiss* kidney cells and to *O. mykiss* metabolic pathways after exposure to increased sediment. These changes occurred even when gill abrasion was not present, leading them to conclude that turbidity from high suspended sediment concentrations may be more harmful to a fish than the physical damage inflicted by the fine sediment (Michel et al. 2013).

Data analyzed from Elk River monitoring stations in reaches SFR1 and NFR2 from water years (WY) 2003 to 2013 indicate the potential for a suite of sub-lethal effects ranging from 0–90 percent of the time (Lewis 2013, Tetra Tech 2015) (Table 4-2). The Newcombe and Jensen (1996) models assume constant SSC and compute the duration that the constant SSC is exceeded. To apply this model to continuous (non-constant) SSC data for Elk River, Lewis (2013) computed the duration as the longest period in any given year exceeding specified SSC thresholds, then computed the resulting SEV for that period. The result is the maximum SEV for the specified SSC each year, which is an underestimate of SEV because in any period of changing suspended sediment concentration, the average SSC will be higher than the minimum value listed in the table. The water years with differing SSC concentrations and exposure duration inputs illustrate the range of effects on juvenile salmonids and salmonid eggs and larvae.

Table 4-2. Severity of Ill Effects (SEV) for North Fork Elk River and South Fork Elk River.[1] The SEV scores are based on the longest continuous period (duration) in each water year in which suspended sediment concentration exceeds the six SSC thresholds indicated in the table.

Site/WY[2]	Juvenile salmonids only: Suspended sediment concentration (mg/L)						Salmonid eggs + larvae: Suspended sediment concentration (mg/L)					
	SSC 2981	SSC 1097	SSC 403	SSC 148	SSC 55	SSC 20	SSC 2981	SSC 1097	SSC 403	SSC 148	SSC 55	SSC 20
SF 2003	7.7	8.3	7.9	7.9	7.6	7.8	8.2	10	10.1	11	11.3	12.4
NF 2003	0	7.8	7.7	7.3	7.1	7.3	0	9.1	9.8	9.9	10.5	11.6
SF 2004	0	6.8	7.4	7.4	6.9	6.8	0	7.6	9.3	10.1	10.1	10.7
NF 2004	0	6.2	7.3	7.2	6.8	7.2	0	6.7	9.2	9.9	9.9	11.4
SF 2005	0	7.2	7.3	7.4	7.4	7.3	0	8.2	9.3	10.1	10.9	11.6
NF 2005	0	7.2	7	6.8	7.2	7.5	0	8.3	8.8	9.2	10.6	11.9
SF 2006	5.7	7.9	8.3	8.6	8.5	7.9	5	9.4	10.8	12.1	12.6	12.6
NF 2006	0	7.3	7.6	7.4	7.7	7.9	0	8.3	9.6	10.1	11.4	12.5
SF 2007	0	7.6	7.6	7.3	7.5	7.3	0	8.8	9.6	10.1	11.1	11.5
NF 2007	0	6.2	7.2	7	7.5	7.1	0	6.7	9	9.5	11.1	11.2
SF 2008	0	7.6	7.6	7.6	7.5	7.9	0	8.9	9.6	10.5	11.1	12.6
NF 2008	0	6.5	7	6.9	7.4	7.1	0	7.2	8.7	9.3	10.9	11.2
SF 2011	7.4	7.6	8.1	8.2	8.5	8	7.8	8.9	10.4	11.4	12.7	12.6
NF 2011	0	7.3	7.3	7.3	7	7.6	0	8.4	9.2	9.9	10.3	12.1
SF 2013	0	7.6	7.8	7.4	7.2	7.2	0	8.8	9.9	10.1	10.7	11.4
NF 2013	0	7.2	7.1	7.3	7.5	8.5	0	8.2	8.9	10	11.1	13.4

SEV 8–8.9	SEV 9–9.9	SEV 10–0.9	SEV 11–11.9	SEV ≥12
major physio-logical stress	reduced growth, delayed hatching	10–20% mortality	20–40% mortality	40–60% mortality

[1] SEV analysis from Lewis (2013) based on methods of Newcombe and Jensen (1996).
[2] NF = North Fork Elk River at the KRW monitoring site; SF = South Fork Elk River at the SFM monitoring site.

According to Lewis (2013): "Suspended sediment's harshest effects are on the most sensitive but abundant life stages: salmonid eggs and larvae. A maximum SEV score of 12.7 occurred at SFM in WY11. Severities above 12 occurred in 4 of 8 years at SFM and in 3 of 8 years at KRW. A severity of 12 is defined as a lethal effect with 40–60% mortality. A severity of 11, associated with 20–40% mortality, was exceeded at SFM in all years but WY04, and at KRW in all years. Model 4 [salmonid eggs and larvae] SEV scores above 10 occurred every year at all stations, suggesting 0–20% mortality, increased predation, and moderate to severe habitat degradation."

Avoidance of high SSC (e.g., through emigration) likely occurs at SEV scores of 3 and presumably at all higher levels (Newcombe and Jensen 1996). Presumably the sublethal and lethal effects only occur in juveniles that do not manage to find a lower concentration refuge. Newcombe and Jensen (1996) note that "a pollution episode capable of causing high mortality (e.g., of sac fry) or gill damage or starvation or slowed maturation (e.g., of age-0 fingerlings and age-2 juveniles) among caged fish might not cause any of these direct effects in a wild population that is free to move elsewhere in the stream system".

While the SSC data used in the SEV analysis is derived from Salmon Forever monitoring stations, these conditions apply throughout the reaches where the measurements were conducted (NFR2 and SFR1). Assuming a relationship between the average annual concentrations predicted by the HST model and the SEV, similarly impaired conditions also occur in MSR 1–5, NFR1, NFR3, and SFR2, which overall comprise a substantial portion of the habitat in Elk River.

4.2.3 Water temperature

Water temperature affects the behavior and survival of Pacific salmonids throughout each of their freshwater life stages (Berman 1998). Salmonids require cold flowing freshwater to thrive. Water temperatures affect salmonids' metabolism, incubation rates in redds, and adult migration timing, with high temperatures causing stress, susceptibility to disease (Spence and Hughes 1996), and mortality. Despite being a well-studied topic, there is no consensus on exact water temperature thresholds for adverse effects on salmonids.

The EPA has developed TMDL temperature guidelines for nearby South Fork Eel and Navarro rivers, but none specific to Elk River. However, the existing EPA temperature guidelines are broadly applicable to the Elk River. For example, Humboldt Redwood Company uses a Maximum Weekly Average Temperature (MWAT) upper threshold of 62.2 °F on the Elk River to indicate properly functioning aquatic conditions (PALCO 1999, HRC 2015). This is nearly equivalent to the USEPA's MWAT threshold of 62.6 °F between marginal and poor habitat conditions for juvenile coho salmon (Table 4-3) (USEPA 1999, 2000).

Table 4-3. Species-specific stream temperature guidelines for juvenile salmonid cold water habitat. MWAT is "Maximum Weekly Average Temperature."

Cold water habitat descriptor	Stream temperature guidelines (MWAT in °F)	
	Coho salmon[1]	Steelhead[2]
Good	<59°	<63°
Marginal	59–62.6°	63–66°
Poor	62.6–66.2°	>66°
Inadequate	>66.2°	--

[1] MWATs for coho salmon juveniles are from the Navarro River (USEPA 2000) and the South Fork Eel River (USEPA 1999).
[2] MWATs for steelhead juveniles are from the South Fork Eel River (USEPA 1999).

Humboldt Redwood Company conducts routine temperature monitoring on its property in the Elk River (Figure 4-5). Additional water temperature data are available for the stream-estuary ecotone (MSR1) from CDFW (Wallace et al. 2015). The greatest overlap between these efforts was in 2008 and is presented to show the range of temperatures from the Elk's headwaters down to Humboldt Bay (Table 4-4). In this example water year, the HRC data for reach NFR3 shows higher water temperatures than surrounding reaches, with the MWAT slightly exceeding HRC's threshold of 62.2 °F for properly functioning aquatic conditions. Other reaches of Elk River have MWAT's within the temperature guidelines prescribed by the EPA (1999).

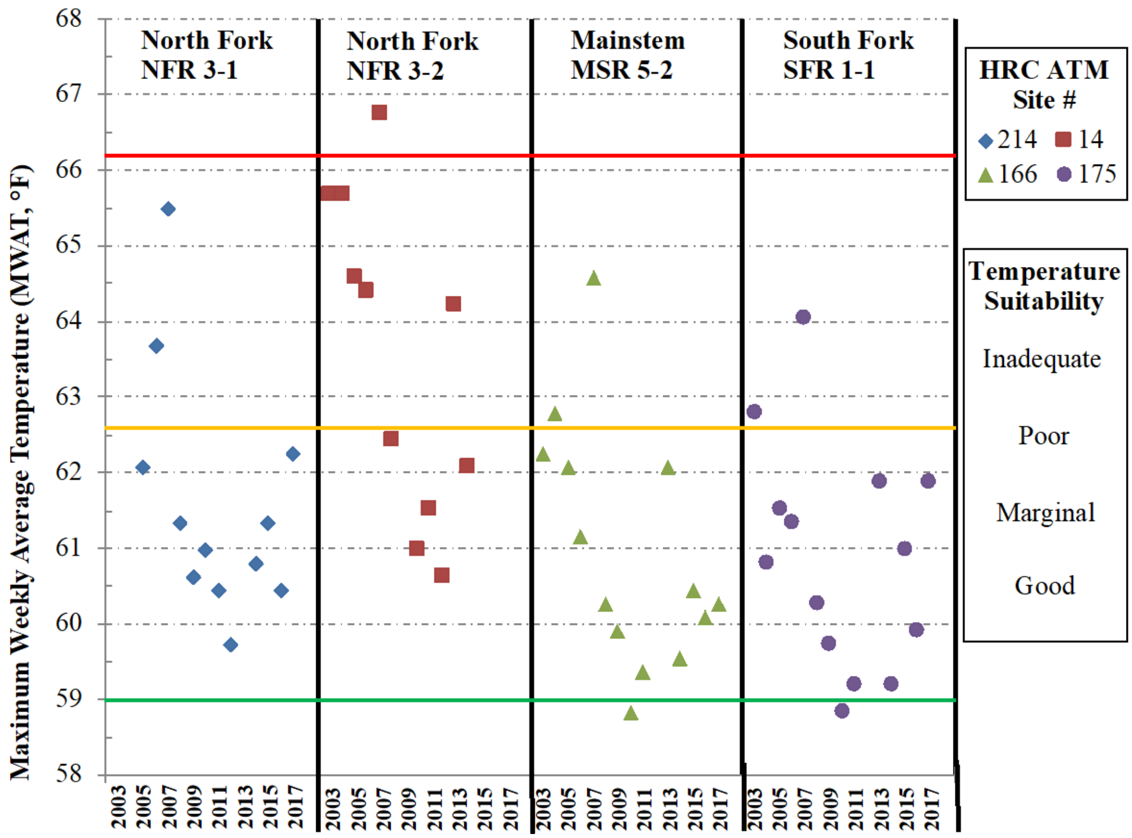

Figure 4-5. Maximum Weekly Average Temperatures (MWAT) for Elk River, with Humboldt Redwood Company Annual Trend Monitoring (ATM) site number and corresponding study reach, years 2003–2014. MWAT ratings for juvenile coho salmon habitat condition adopted from Navarro River (USEPA 2000) and South Fork Eel River (USEPA 1999) temperature TMDLs.

Table 4-4. Maximum Weekly Average Temperature (MWAT) in Elk River from 2008, showing an example of water temperature trends along Elk River.

Habitat reach	Geomorphic reach	Operator	MWAT (°F)
Upper North Fork	NFR3	HRC	61.3–62.4
Lower South Fork	SFR1	HRC	60.3
Confined Upper Mainstem	MSR5	HRC	60.3
Upper Stream Estuary Ecotone	MSR2	CDFW	60.3
Lower Stream Estuary Ecotone	MSR1	CDFW	63.0
Lower Stream Estuary Ecotone	MSR1	CDFW	59.0

Elevated water temperatures in reach NFR3 are also evident when comparing MWAT's across many water years (Figure 4-5). In the four reaches shown, 63% of the MWATs are rated as "marginal" and 27% of the MWATs are rated "poor" for juvenile coho salmon habitat. Only rarely are temperatures in the range of "good" or "inadequate".

4.2.4 Dissolved Oxygen

Based on limited available data, water quality impairment from low dissolved oxygen (DO) concentrations may be occurring in several locations in Elk River, including the stream-estuary ecotone, the confined mainstem reach, and possibly in tributaries to the North Fork Elk River (Regional Water Board, unpubl. data, 2007 and 2008).

CDFW monitored juvenile salmonids rearing in tidal channels and off-channel ponds in the stream-estuary ecotone of several Humboldt Bay tributaries (Wallace 2006; Wallace and Allen 2007, 2009, 2012) including Elk River, and noted DO concentrations below the minimum thresholds set by the Regional Water Board (Table 4-5). Wallace (2006), and Wallace and Allen (2007, 2009, 2012) commonly captured juvenile salmonids in areas where DO levels were 5–7 mg/L, and occasionally captured juvenile coho salmon in areas as low as 3.5 to 5 mg/L. According to Wallace (M. Wallace, CDFW, pers. comm., 2016) low DO in the 4 to 5 mg/L range may limit juvenile rearing opportunities and would improve with greater tidal circulation. Tidal channels were generally less prone to low DO than off-channel ponds, though both provide important rearing habitat (M. Wallace, CDFW, pers. comm. 2016). Bjornn and Reiser (1991) reported that salmonids function without impairment at DO levels near 8 mg/L and are probably limited by levels <5 mg/L. Ruggerone (2000) reported that juvenile coho salmon tolerate lower DO levels than other salmonids, often as low as 4 mg/L.

Table 4-5. Dissolved Oxygen (DO) concentration minimum limits from Regional Water Board for the North Coast Region.

Beneficial use designation	Daily minimum DO objective	7-day moving average DO objective
COLD	6.0 mg/L	8.0 mg/L
SPWN [1]	9.0 mg/L	11.0 mg/L
Humboldt Bay	6.0 mg/L	NA

[1] During critical spawning and egg incubation period (Sept 15–June 4)

In freshwater rearing habitat in Elk River, reduced pool volumes associated with fine sediment aggradation, combined with accumulated organic material and warm summer water temperatures in August and September, may cause low DO concentrations (see Section 3.5), which could impair summer rearing habitat and create physiological barriers to juvenile migration.

Unpublished data from the Regional Water Board for the confined mainstems reach of Elk River in September 2007 and October 2008 suggest the potential for water quality impairment from low DO concentrations in some locations in the late summer months. Data collected in September 2007 in the North Fork Elk River were below the Regional Water Board's 6 mg/L minimum threshold; DO concentrations appeared to rebound in the Mainstem Elk River, with DO concentrations of 7 to 8 mg/L measured at Elk River Courts and Berta Road bridges (Figure 4-6). Data collected by the Regional Water Board from the North Fork Elk River in October 2008 indicated DO concentrations at or just below 8 mg/L (Figure 4-7). DO concentrations measured in the South Fork Elk River during the same sampling events were slightly higher than the North Fork Elk River, ranging from 4 to 8 mg/L in 2007, and 8 mg/L in 2008 (Figure 4-8).

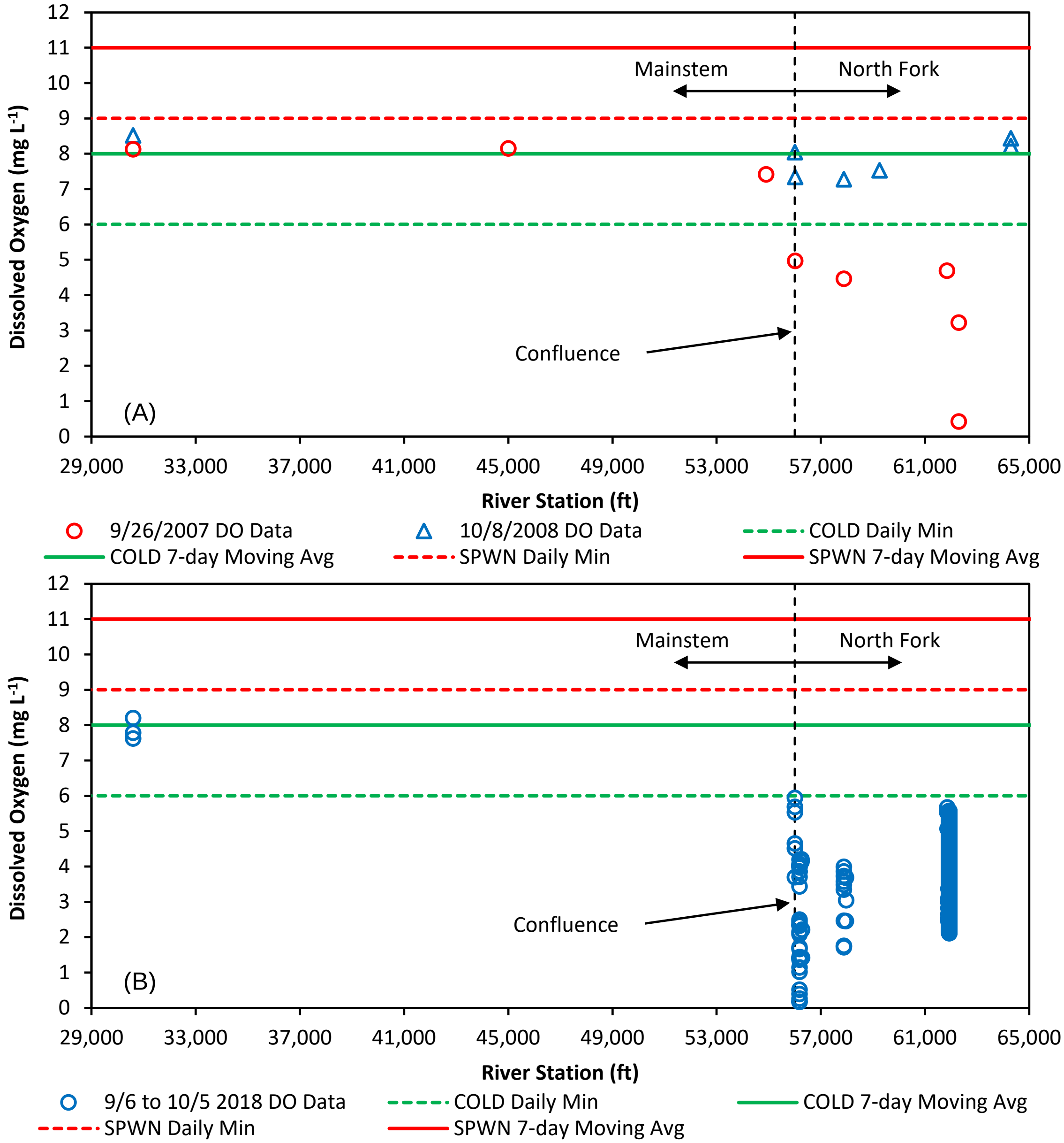

Figure 4-6. Dissolved Oxygen data for select locations in North Fork Elk River and Mainstem Elk River; 2007 and 2008 data collected by Regional Water Board (A), and 2018 data collected by California Trout and Northern Hydrology & Engineering (B).

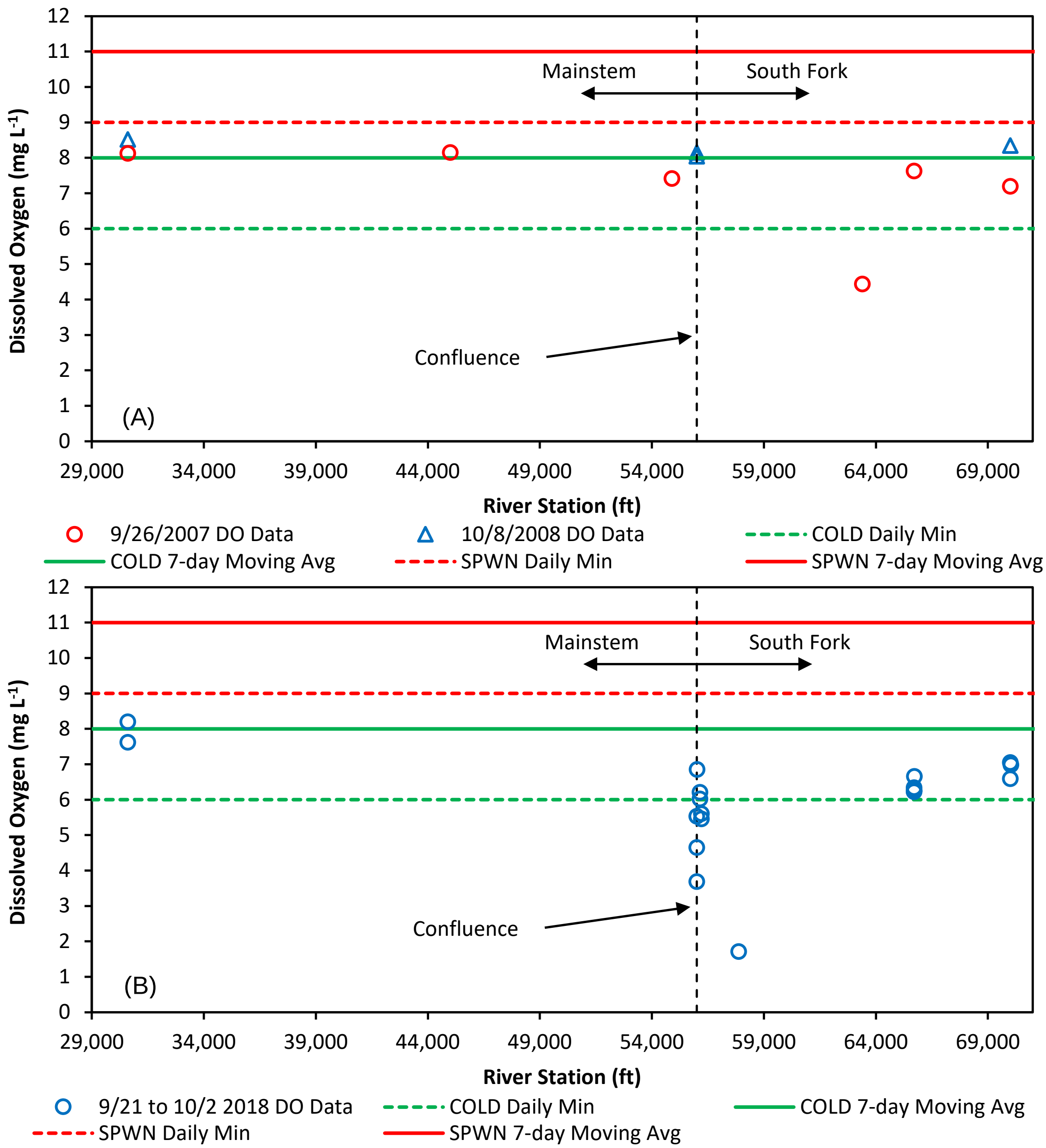

Figure 4-7. Dissolved Oxygen data for select locations in South Fork Elk River and Mainstem Elk River; 2007 and 2008 data collected by Regional Water Board (A), and 2018 data collected by California Trout and Northern Hydrology & Engineering (B).

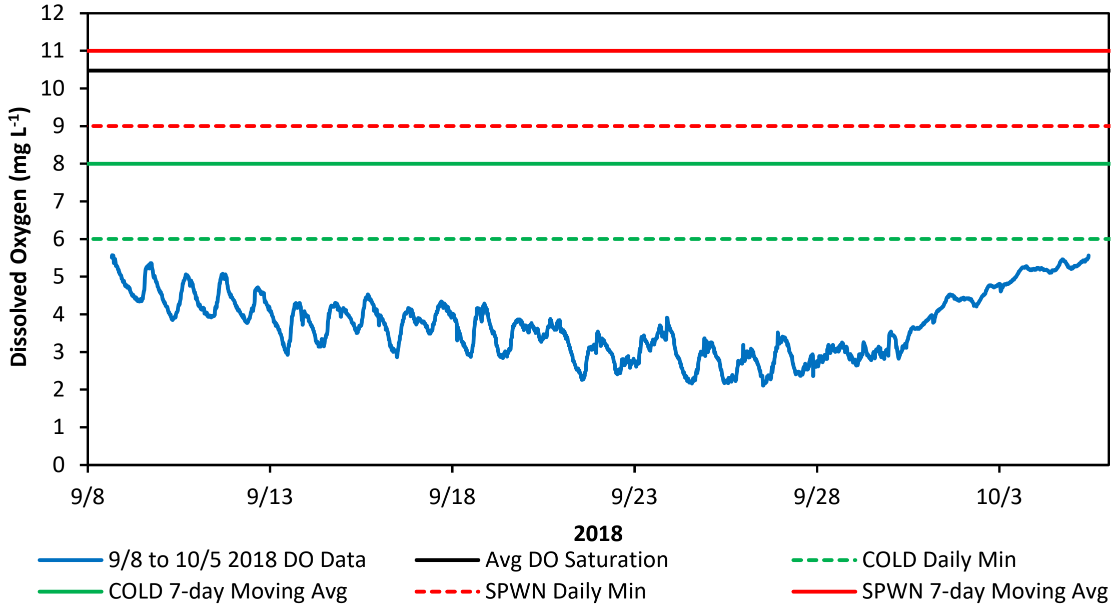

Figure 4-8. Continuous 15-min dissolved oxygen data at KRW monitoring station on North Fork Elk River (reach NFR2). 2018 data collected by Northern Hydrology & Engineering.

CalTrout and NHE measured DO in select locations in the North Fork, South Fork, and Mainstem Elk River in 2018 using a handheld YSI Model 60520-1 DO meter. The most downstream reaches of the North Fork Elk River at the Wrigley Orchard and Flood Curve reaches were characterized by stagnant, shallow pools heavily aggraded by fine sediment, large accumulations of small woody debris, and thick growths of slough sedge, duckweed, and algae covering all flatwater habitat (Figure 3-18 and Figure 3-19). There was very little visible flow in these reaches.

Measurements were collected between September 6 and October 2, 2018. A similar pattern of DO impairment was observed as with the 2007 and 2008 data. The North Fork Elk River had very low DO concentrations, with all DO measurements below the Regional Water Board minimum threshold of 6.0 mg/L (Figure 4-6) and with many measurements below 1 to 2 mg/L. DO concentrations again appeared to rebound in the Mainstem Elk River, although very few locations and samples were collected from the mainstem. DO in the South Fork Elk River was above 6 mg/L, except for samples collected at or just above the confluence, where concentrations ranged from 4 to 7 mg/L (Figure 4-7).

Deep pools (>4 ft water depth) in these reaches had a strong DO gradient, with DO levels of 0.1 to 1.0 mg/L at the bottom, and 3–4 mg/L at intermediate and shallow depths. Despite the low DO and poor water quality, this lower North Fork reach retains some function as summer rearing habitat for salmonids. Fish sampling by CDFW and CalTrout in 2018 found pools in the lower North Fork to be occupied by both coho and steelhead, with DO in the 3.5 to 4.0 mg/L range (CalTrout 2018)

In response to low DO measurements collected in September 2018, NHE installed a YSI Model 6600 EDS V2 data sonde in a shallow pool (>3ft water depth) at the Wrigley Orchard (KRW) site. The datalogger, deployed from September 8 to October 5, 2018, collected continuous DO concentrations at 15-minute intervals. During the entire sampling period DO concentrations never exceeded 6 mg/L, dipped to a period low DO in the 2 to 4 mg/L range in mid-to-late September and gradually increased in late-September, likely in response to cooler ambient air temperatures and a small rain event. Diurnal fluctuations of 1 to 2 mg/L were observed, with lowest DO concentrations in early morning hours.

Because the KRW site is located above any potential sources of residential onsite wastewater input, and no known point sources exist upstream, the low DO concentrations are likely due to sediment oxygen demand from decomposing organic matter in the channel bed sediment deposits. Sediment oxygen demand is also the likely cause of the low DO levels at other locations in Elk River as described above and explains the DO gradient measured near the sediment bed.

4.3 Status of Salmonid Populations in Elk River

The Humboldt Bay watershed, of which Elk River is the largest of four sub-watersheds, hosts three independent populations of anadromous salmonids – Chinook, coho, and steelhead. Each are listed as threatened and are considered to be at high risk of extinction. A fourth species – coastal cutthroat trout (*O. clarkii*) - is not listed but was considered for listing in 1999.

Humboldt Bay, and by extension lower reaches of Elk River, may also provide nursery habitat for green sturgeon (*Acipenser medirostris*). The former tidelands and current stream-estuary ecotone of Elk River likely also provide habitat for the federally endangered tidewater goby (*Eucyclogobius newberryi*).

The following sections summarize information about Humboldt Bay populations of Chinook salmon, coho salmon, and steelhead as described in the NMFS Recovery Plans for these species (NMFS 2014, 2016).

4.3.1 California Coastal Chinook

The Humboldt Bay population of the California Coastal Chinook Evolutionarily Significant Unit (ESU) is considered a "Potentially Independent Population" with a targeted adult spawner abundance of 2,600 adult fish (NMFS 2016). Current estimates of abundance are not available for populations in this (ESU) or the ESU as a whole. The numbers of spawning adult Chinook salmon are low in the Humboldt Bay population relative to historic numbers and recovery targets (NMFS 2016) and counts of adults at the Freshwater Creek weir from 1994 through 2014 indicate the wild population has dramatically declined (Ricker and Anderson 2014). Ricker and Anderson (2014) raised concerns over depensatory population effects in Freshwater Creek, and similar trends can be inferred in Elk River. Low numbers of juveniles also suggest the watershed is not functioning properly. The NMFS (2016) Multispecies Recovery Plan attributed poor ratings to the following conditions in Humboldt Bay tributaries contributing to Chinook impairment:

- significantly altered structure and function of salt marsh, intertidal, and subtidal habitat,
- sediment impairment from road construction and timber harvest;
- impaired winter rearing habitat complexity resulting from lack of large wood;
- reduction in pool frequency and depth, riffle habitat quality;
- loss of floodplain connectivity;

- loss of riparian vegetation and associated shade, wood recruitment, nutrients, and streambank stability; and
- impaired water quality from elevated turbidity and suspended sediment concentration.

4.3.2 Southern Oregon and Northern California Coast (SONC) coho salmon

The Humboldt Bay population within the Southern Oregon and Northern California Coast (SONCC) coho salmon ESU is considered a "Core, Functionally Independent Population" with a targeted adult spawner abundance of 5,700 fish (NMFS 2014). According to Williams et al. (2008), at least 191 coho salmon must spawn in Humboldt Bay tributaries each year to avoid [genetic] effects of extremely low population sizes (NMFS 2014). The Humboldt Bay tributaries population size is unknown, but the most recent redd abundance estimates ranged from 194 redds in 2009–2010 to 2,002 redds in 2010–2011 (NMFS 2014). There are no CDFW estimates available for Elk River, but the trend in Freshwater Creek adult abundance estimates (Table 4-6) indicates adult escapement has declined since 2002–2003, ranging from a high of 1,807 in 2002–2003 to a low of 89 in 2009–2010 (Moore and Ricker 2012). NMFS (2014) concludes that the juvenile life stage is most limited, primarily due to reductions in the quality and quantity of summer and winter rearing habitat. The Coho Recovery Plan (NMFS 2014) lists "lack of floodplain and channel structure" and "altered sediment supply" as very high stresses. The Humboldt Bay Watershed Advisory Committee (HBWAC) report considered excess sediment as the primary limiting factor for salmonids in Elk River (HBWAC 2005). The NMFS (2014) SONC Coho Recovery Plan lists the following limiting stresses contributing to diminished coho abundance:

- increased sediment delivery and deposition,
- lack of channel and floodplain structure,
- impaired mainstem and estuary function and loss of associated non-natal rearing habitat,
- loss of riparian vegetation and associated shade, wood recruitment, nutrients, and streambank stability, and
- impaired water quality from elevated turbidity and suspended sediment concentration.

Table 4-6. Redd abundance estimates in Freshwater Creek, Humboldt Bay, and Prairie Creek (Ricker 2011; Ricker et al. 2014, 2014a, 2014b, 2014c; Anderson and Ward 2015, 2016)[1].

	2009–2010	2010–2011	2011–2012	2012–2013	2013–2014	2014–2015	2015–2016
Coho Salmon							
Humboldt Bay	194	1,099	1,738	763	630	1,183	562
Freshwater Creek		231	420	244	127	453	323
Prairie Creek		344	387	365	538	160	180
Chinook Salmon							
Humboldt Bay		19	0	0	0	1	3
Freshwater Creek		12	0	0	0		
Prairie Creek		262	103	308	151	158	295

	2009–2010	2010–2011	2011–2012	2012–2013	2013–2014	2014–2015	2015–2016
Steelhead							
Humboldt Bay	134	11	19	172	35	170	59
Freshwater Creek		4	7	13	2	72	0
Prairie Creek		19	10	66	57	187	201

[1] The number of returning adults is assumed equal to twice the number of redds. The contribution of Elk River salmonids to the total number of estimated Humboldt Bay redds is unknown. Elk River and Freshwater Creek provide proportionally more salmonid spawning habitat than other, smaller Humboldt Bay watersheds. Prairie Creek is included as a reference site, but is a much smaller watershed than Elk River.

4.3.3 North Coast steelhead

The Humboldt Bay population of the North Coast Steelhead Dependent Population Segment (DPS) is considered a "Functionally Independent Population" with a target spawner population of 4,100 adults (NMFS 2016). Spawning steelhead numbers for the Humboldt Bay population are low relative to historic numbers and recovery targets (NMFS 2016). In Freshwater Creek, there is no statistically significant trend in adult steelhead returns from 2000 through 2014 (Ricker and Anderson 2014, as cited in NMFS 2016), suggesting the steelhead populations in Freshwater Creek and other Humboldt Bay tributaries like Elk River are not recovering. The summer rearing juvenile life-stage is considered to be most limiting, primarily due to altered sediment supply, lack of floodplain and channel structure, and impaired estuary conditions (NMFS 2016). The recovery plan indicates that recovery actions should focus on restoring the natural watershed processes (i.e., the fluvial transport of wood, water, sediment, nutrients, and energy) (NMFS 2016). The NMFS (2016) Multispecies Recovery Plan attributed poor ratings to the following conditions in Humboldt Bay tributaries contributing to steelhead impairment:

- reduced in-stream habitat complexity (LWD, shelter, pool/riffle/flatwater ratio, percent primary pools),
- impaired streamflow hydrology (number, condition, and/or magnitude of diversions),
- impacts to riparian vegetation,
- impaired sediment (gravel quality—bulk, spawning gravels), and
- impacts to water quality (turbidity and suspended sediment).

4.4 Synthesis

The direct and cumulative effects of sediment aggradation, the severe alteration to channel and floodplain structure that contributes to winter and summer rearing habitat, the degraded water quality conditions (e.g., turbidity, suspended sediment, temperature, and DO), and landscape-scale alterations from human land uses in the lower 12 miles of Elk River have left the Elk River watershed and its salmonid populations significantly impaired and at risk. Salmonids currently struggle to survive and persist at nearly every life-stage in all habitat reaches of Elk River, including the headwaters and upper tributaries, the middle Mainstem Elk River reaches, the valley bottomlands, and the estuary. Adult spawning appears impaired by sediment aggradation in many locations in upper reaches of the North Fork Elk River, South Fork Elk River, and a few tributaries, but does not appear to limit fry production in the watershed at current rearing habitat capacities. Juvenile rearing habitat may be a key limiting factor in Elk River and is likely saturated at low densities in the upper watershed. Stream reaches providing non-natal juvenile rearing habitat in the lower forks, the Mainstem Elk River, and the estuary are heavily degraded by sediment aggradation and by acute and chronic turbidity and high suspended sediment concentrations during the winter. Temperature and dissolved oxygen are likely impaired during the lowest summer and fall low-flow conditions in the confined mainstem and lower forks reaches.

Recent modeling of coho salmon life-stage production in nearby Freshwater Creek (Scheer 2017) suggests several factors that would increase adult salmonid abundance in Elk River: (1) increasing the seeding capacity in spawning reaches to improve production of juveniles and smolts from the upper watershed would ensure that abundant young-of-year salmonids are present to utilize restored or rehabilitated habitat in the lower watershed, (2) restoring winter rearing habitat function of middle and lower mainstem reaches of Elk River would provide long-term benefit to coho salmon survival, and (3) increasing overwinter survival and winter rearing habitat capacity in the stream-estuary ecotone would likely have the greatest benefit to the long-term average adult escapement.

These conclusions broadly apply to Elk River. Increasing life-history diversity by restoring non-natal rearing habitat in middle and lower Elk River, and in the stream-estuary ecotone, would improve long-term population stability. The early emigrant life history, which benefits from lower mainstem and stream-estuary ecotone non-natal rearing habitat, is important for population viability. Restoration of the stream-estuary ecotone provides dual benefits of winter habitat refugia during winter, as well as productive habitat for smolt emigrants on their way to the ocean in spring.

Sediment related recommendations for improving salmonid habitat, beneficial uses and water quality in the Elk River Project area include:

1. Reducing SSC in the upper watershed North Fork and South Fork Elk River and tributaries would reduce in-channel SSC and turbidity (with or without conducting mechanical sediment removal).
2. Removing in-channel sediment deposits would allow the high SSC (particularly fine sediments) to flush from system and sediment bed, reduce deposition rates, and scour fine sediments and excessive in-channel vegetation and small woody debris from channel bed. This action would also reduce the sediment impairments (sediment oxygen demand and flux of reduced constituents to water column) to water quality and return DO level to expected levels.

5 HYDRODYNAMICS AND SEDIMENT TRANSPORT MODEL

A numerical model, referred to as the Elk River Hydrodynamic and Sediment Transport model (HST model), was developed to broaden and deepen the understanding of flow and sedimentation patterns in the impacted reaches of Elk River. The HST model broadly enables a better understanding of (1) existing channel and floodplain sediment impairments and nuisance flooding, (2) the effects of sediment recovery actions at achieving water quality objectives, recovering beneficial uses, and reducing nuisance flooding, and (3) future long-term trends in channel and floodplain sedimentation for a range of recovery actions. Refer to Appendix E for more detailed information regarding the HST model.

While flow and sedimentations patterns are generally understood at long-term channel monitoring sites (Appendix E), data gaps between monitoring sites and over large river reaches severely limit our understanding of system processes, controls, and responses to changes in these controls. The HST model allows a more complete and detailed understanding of flow inundation and sedimentation patterns between monitoring sites and throughout the Project area. HST model simulations help identify the strength of hydraulic and geomorphic controls at different times during a flood hydrograph and across different water year types. The HST model is also used in a predictive capacity to explore the key questions associated with the management scenarios described in Section 2.2. In order to explore these key questions with a numerical model, the management scenarios must be translated from a general description to a quantitative set of actions (e.g., sediment removal, vegetation management, etc.), each with specific parameters (e.g., specific quantity of sediment removed; channel shape following excavation; and target vegetation species, density, diameter and height) that are relevant and consistent with model inputs and outputs. Development of the HST model and the numerical results provides a better understanding of the complex hydrodynamics, sediment transport, and deposition patterns in the Elk River Project area. This information also supported development of the conceptual model of hydrogeomorphic processes.

5.1 Model Development

The ERRA hydrodynamic and sediment transport analyses were implemented using Environmental Fluid Dynamics Code (EFDC). EFDC is a public-domain modeling system for simulating one-, two- and three-dimensional flow, transport, and biogeochemical processes in surface waters. EFDC was originally developed at the Virginia Institute of Marine Science by Dr. John Hamrick. The U.S. Environmental Protection Agency (EPA) continued development of EFDC with support from Tetra Tech. The EFDC model couple’s hydrodynamic, sediment, and other water quality constituent processes by internally linking cohesive and non-cohesive sediment transport, water and sediment toxic contaminant transport and fate, dye transport, and water quality and eutrophication sub-models. EFDC was selected as the modeling framework for the ERRA based, in part, on the success of the HST model at reproducing depth, velocity and sediment observations in a 4.0 km pilot reach of Elk River (NHE and SWS, 2013).

The HST model domain includes approximately 29.5 km (~18 mi) of the Elk River channel. The upstream boundaries of the domain begin just below Lake Creek on the North Fork Elk River and Tom’s Gulch on the South Fork Elk River. Humboldt Bay is the downstream boundary (Figure 5-1). The HST model is configured as a two-dimensional (2D) model. The curvilinear-orthogonal grid consists of 36,296 horizontal segments and one completely mixed, depth-averaged vertical layer. Bank and floodplain grid cell elevations were assigned using the project LiDAR, and channel bed elevations were mapped to the grid cells using the longitudinal profile survey.

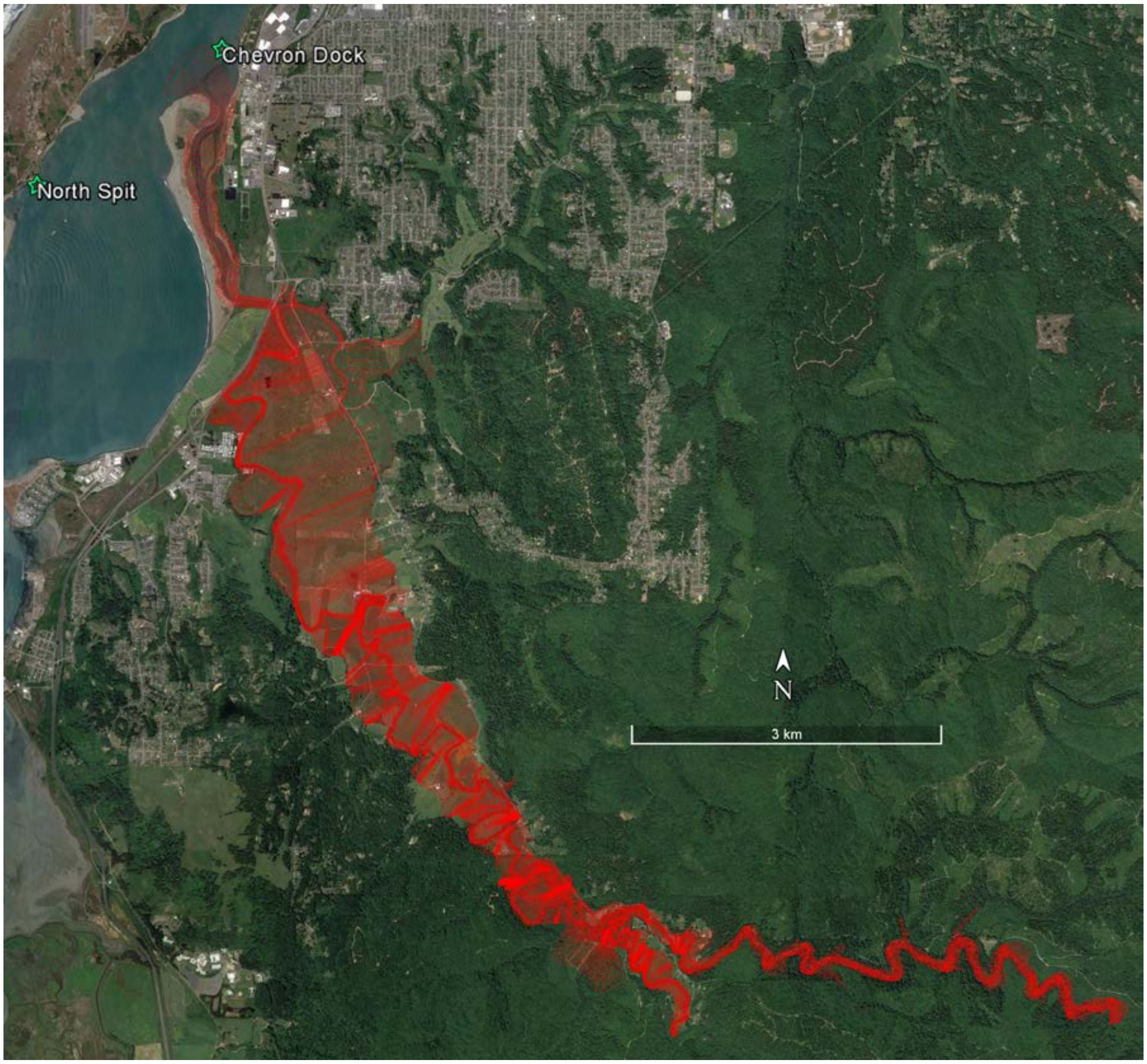

Figure 5-1. HST model domain, grid configuration, and the relative locations of the NOAA North Spit tide station and the Chevron Dock CENCOOS sampling site.

The watershed areas draining into the upstream boundaries of the model domain for the North Fork Elk River and South Fork Elk River are 48.1 and 49.7 km^2, respectively. The area between the upstream and downstream boundaries is 47.0 km^2. The model domain excludes geomorphic reach NFR4 because data was limited or not available to adequately define boundary conditions above NFR3. The domain includes the 10- to 100-year floodplain. Thirteen stream flow boundaries were incorporated into the HST model domain, including the North Fork Elk River and South Fork Elk River, and eleven tributaries. Except for Martin Slough, the tributary channels were not configured into the model domain, and tributary flows discharged directly into the Elk River channel at the tributary confluence locations. The model configuration was based on available data for bathymetry, topography, stream discharge, and sediment concentration.

Infrastructure components incorporated into the HST model domain include tide gate structures, drainage ditch features, bridge crossings, and at-grade floodplain roads. These include the following:

- The four largest tide gate structures and the major drainage ditch features located in the lower agricultural reaches of the domain.
- Six bridge crossings located on the North Fork Elk River (Elk River Road Bridge), South Fork Elk River (South Fork Bridge), and Mainstem Elk River (Elk River Courts Road, Berta Road, Zanes Road, and HWY 101). The topographic constrictions of the bridge crossing (road approaches) were accounted for in the model grid, but the bridge piers and decks were not.
- Five at-grade roads (Elk River Road, Steel Bridge Road, Elk River Courts Road, Berta Road and Zanes Road) that cross the floodplain perpendicular to the direction of flow and are routinely flooded annually.

The configured HST model simulates the following state variables and physical processes:

- Depth and velocity;
- Multiple size classes of cohesive and non-cohesive suspended sediment transport;
- Bedload transport of multiple size classes of non-cohesive sediment;
- Vegetation resistance;
- Wetting and drying of grid cells;
- Multi-layer sediment bed with bed armoring;
- Sediment bed geomechanics for grain size distribution, porosity, and bulk density; and
- Bed morphological change (scour and deposition).

5.1.1 Simulation period

The HST model was configured for long-term simulations that included a 13-year period of record (POR) extending from water year (WY) 2003 through WY 2015. To reduce run times, the simulations were reduced to periods when discharge was greater than or equal to 3 cms (~106 cfs) (Q-threshold of 3 cms) in the North Fork Elk River and South Fork Elk River. This approach proved effective during the pilot project, reducing model run times while demonstrating adequate predictive capability (NHE & SWS, 2013). This approach also fits the goals and objectives of using the HST model to reproduce sedimentation patterns in Elk River, which occurs during higher flows and sediment loads. The reduced suspended sediment load (SSL) during the simulation period is only 2.5 and 2.4 percent less than the SSL for the North Fork Elk River (HRC 511) and South Fork Elk River (HRC 510), respectively (Table 5-1). The focus on modeling high-flow periods is consistent with Elk River monitoring efforts that only collect data during the high-flow periods from October to May of each WY. All HST model results presented in later sections are for this reduced simulation period.

Table 5-1. Comparison of suspended sediment load and number of days that discharge exceeded 3 cms during WY 2003–2015 for the entire period of record (POR) and for the reduced period of record.

Quantity	North Fork Elk River (HRC Station 511)	South Fork Elk River (HRC Station 510)
SSL (MT) for POR[1]	143,025	167,481
SSL (MT) for reduced POR[2]	139,432	163,449
Difference (percent)	2.5	2.4
Days in POR	2,787	2,787
Days in reduced POR	399	399
Difference (days)	2,388	2,388

[1] Suspended sediment load (SSL), period of record (POR), metric tons (MT).
[2] Reduced period of record when discharge was greater than or equal to 3 cms.

5.1.2 Boundary conditions

Model boundary conditions provide the external forcing to the HST model for predictions interior to the model domain. Boundary conditions for the HST model include time-variable discharge and suspended sediment concentrations (SSC) at the upstream boundaries on the North Fork and South Fork Elk River, at three tributaries to the NF Elk River, and eight tributaries to the Mainstem Elk River (Figure 5-2). All boundary conditions were adjusted to the reduced simulation period (discharges over Q-threshold of 3 cms) described in the previous section.

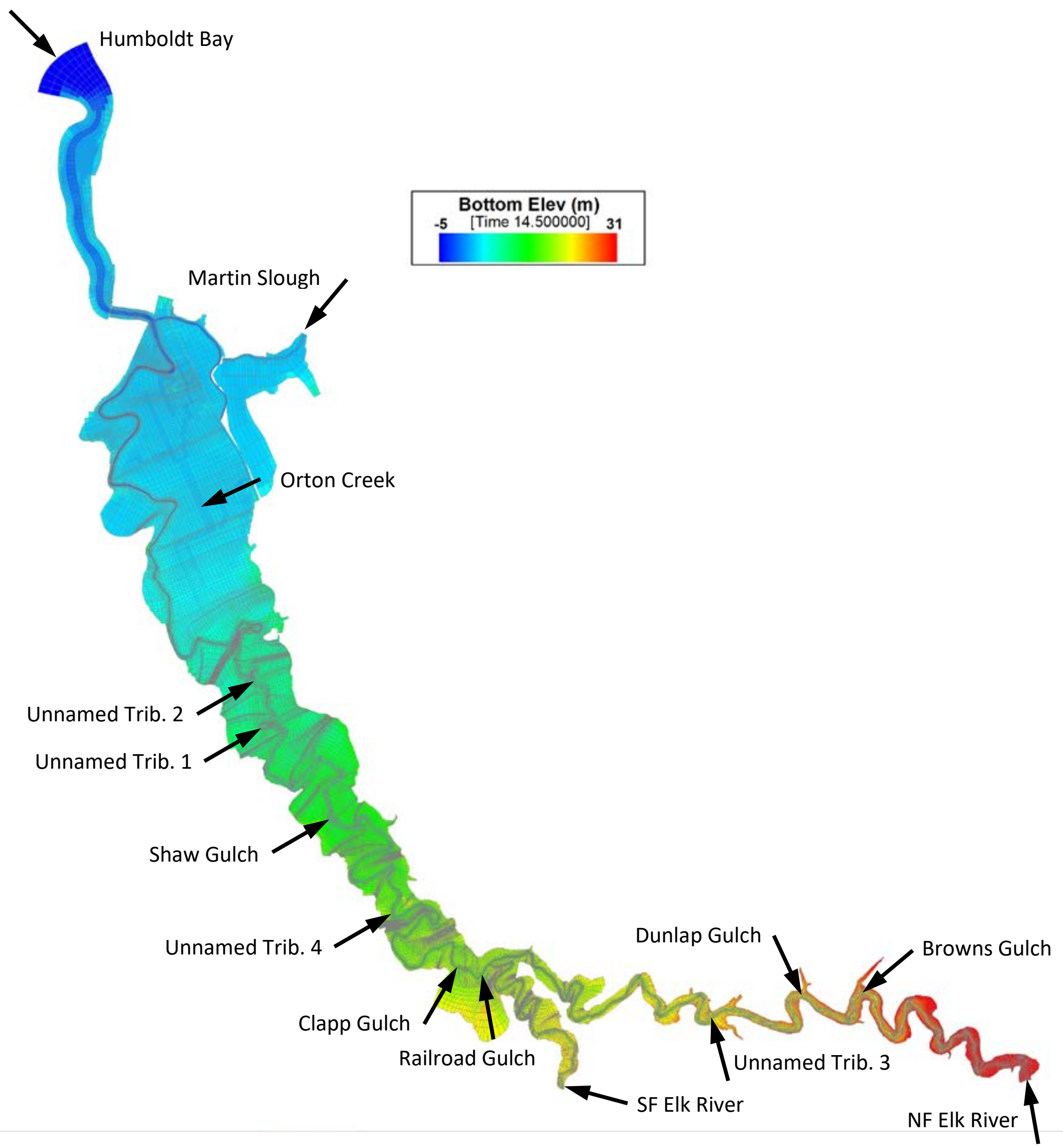

Figure 5-2. ER-HST model grid and boundary conditions.

Discharge

Discharge gauging 15-minute time-series data were available for the North Fork Elk River (HRC 511) and South Fork Elk River (HRC 510) that span the WY 2003–2015 POR, and Railroad Gulch (HRC 683 and 684) only for WY 2014–2015 (Appendix F). The gauged discharge data for NF and SF Elk River and Railroad Gulch were not located at the model boundaries and a combination of flow balancing and/or scaling by drainage area ratios was used to adjust values to the representative locations. The same approach was used to estimate ungauged tributary flows and Railroad Gulch prior to WY 2014. Table 5-2 summarizes assumptions used for all discharge and SSC upstream boundary conditions simulated in the HST model.

Table 5-2. HST model boundary condition summary for WY 2003–2015.

Boundary condition	Parameter	Approach for estimating parameters	Drainage area (km^2)	Drainage area ratio[1]	Time lag (hrs)
NF Elk River	Discharge	Scaled to NF Elk River gauge (HRC 511) and flow balance with Browns Gulch, Dunlap Gulch, Unnamed Trib. 3.	48.07	0.844	2.840
	SSC	Same as NF Elk River gauge (HRC 511).			
Browns Gulch	Discharge	Scaled to NF Elk River gauge (HRC 511).	2.35	0.467	1.455
	SSC	Same as NF Elk River gauge (HRC 511).			
Dunlap Gulch	Discharge	Scaled to NF Elk River gauge (HRC 511).	1.69	0.336	1.066
	SSC	Same as NF Elk River gauge (HRC 511).			
Unnamed Trib. 3	Discharge	Scaled to NF Elk River gauge (HRC 511).	0.99	0.197	0.460
	SSC	Same as NF Elk River gauge (HRC 511).			
SF Elk River	Discharge	Same as SF Elk River gauge (HRC 510).	49.65	1.000	1.579
	SSC	Same as SF Elk River gauge (HRC 510).			
Railroad Gulch	Discharge	Scaled and flow balance with WF (HRC 683) and EF Railroad Gulch (HRC 684) for WY 2014–2015; Scaled to SF Elk River gauge (HRC 510) for WY2003–2013.	3.05	1.116	0
	SSC	Mass balance with WF Railroad Gulch (HRC 683) and EF Railroad Gulch (HRC 684) for WY 2014–2015; SSC-discharge rating for WY2003–2013.			
Clapp Gulch	Discharge	Scaled to Railroad Gulch.	2.72	0.891	0
	SSC	Same as Railroad Gulch.			
Unnamed Trib. 4	Discharge	Scaled to Railroad Gulch.	0.76	0.250	0
	SSC	Same as Railroad Gulch.			
Shaw Gulch	Discharge	Scaled to Railroad Gulch.	1.40	0.460	0
	SSC	Same as Railroad Gulch.			
Unnamed Trib. 1	Discharge	Scaled to Railroad Gulch.	1.79	0.588	0
	SSC	Same as Railroad Gulch.			
Unnamed Trib. 2	Discharge	Scaled to Railroad Gulch.	0.73	0.240	0
	SSC	Same as Railroad Gulch.			
Orton Creek	Discharge	Scaled to Railroad Gulch.	1.62	0.533	0
	SSC	Same as Railroad Gulch.			
Martin Slough	Discharge	Scaled to NF Elk River gauge (HRC 511).	13.55	0.282	0
	SSC	Same as NF Elk River gauge (HRC 511).			

1 Drainage areas for gauged locations are NF Elk River (HRC 511) = 56.97 km^2, SF Elk River (HRC 510) = 50.25 km^2, WF Railroad Gulch (HRC 683) = 1.48 km^2, and EF Railroad Gulch (HRC 684) = 1.25 km^2.

Suspended sediment concentration

Observed SSC 15-minute time-series data were available for the North Fork and South Fork Elk River at the gauged locations for WY 2003–2015, and for Railroad Gulch for WY 2014–2015.

The observed SSC time-series at the gauged locations were determined from turbidity-threshold methodologies as outlined in Appendix F. The WY 2014–2015 SSC values for Railroad Gulch were determined from a mass balance of West Fork and East Fork of Railroad Gulch discharge and SSC data. Estimates of Railroad Gulch SSC for the ungauged period prior to WY 2014 were based on a bias corrected LOWESS-fit curve of log-transformed SSC and discharge data for WY 2014–2015 (Appendix F), that was applied to the scaled Railroad Gulch discharge record. The ungauged tributaries were assigned observed SSC values depending on proximity and orientation of gauged and ungauged sites (Table 5-2).

Time adjustments for discharge and suspended sediment concentrations

Discharge and SSC time-series were adjusted for travel time between the boundary condition location and the gauged location in North Fork and South Fork Elk Rivers. (Table 5-2). An iterative procedure was used to estimate the time-lag adjustments for the North Fork and South Fork Elk River boundary conditions by minimizing the differences between observed and predicted water surface elevations for storm hydrographs in WY 2015. The time-lag adjustment for North Fork Elk River tributaries were estimated by the ratio of channel lengths between the tributary to North Fork Elk River boundary condition locations. No time-lag adjustments were used for the remaining tributaries.

Humboldt Bay tide levels and suspended sediment concentrations

A boundary condition consisting of tidal elevations and SSC in Humboldt Bay was applied along the downstream boundary of the model (Figure 5-2). Tide data from the NOAA North Spit tide station (station number 9418767) was used to provide the tidal elevation time-series. Two different approaches for the tidal elevation boundary conditions were used for the WY 2015 calibration run and the WY 2003–2015 validation or long-term recovery action simulations. A SSC time-series boundary condition was developed from continuous observed and estimated turbidity data and a SSC/turbidity relation using Humboldt Bay data. Additional detail is provided in Appendix F.

Flow withdrawal

The Q-threshold (flow > 3cms) approach for reducing the simulation period allowed discharges in the North Fork and South Fork Elk River boundary conditions to approach or fall below 1 cms. Although this condition happened infrequently, model instabilities occurred in the South Fork Elk River when discharge dropped below 1 cms due to the grid configuration. To overcome this, any flows below 1 cms in the North Fork or South Fork Elk River boundary condition file were set to 1 cms. To prevent excess flow in the estuary portions of the HST model domain (MSR1 and MSR2), a flow withdrawal boundary condition was used at the downstream end of the MSR3 reach. This boundary condition removed any excess flow added to the North Fork or South Fork Elk River boundary conditions to bring the discharge to 1 cms. For the WY 2003–2015 simulation period, only 14 days had flows below 1 cms, and the maximum flow withdrawal was 0.03 cms.

5.1.3 Sediment particle size

Six sediment particle classes were specified for the HST model based on ERRA study objectives, geomorphic field observations, and bed material particle size distributions (PSD) determined from sediment sampling in Elk River intensive study sites (Appendix E). The six classes included one cohesive sediment class and five representative non-cohesive sediment classes (Table 5-3). Following the pilot project work (NHE and SWS, 2013), the effective diameter (d_{eff}) for each sediment class was determined using the average of the weighted geometric mean and weighted critical shear velocity methods, as described by Hayter (2006). The resulting particle size class breaks and average d_{eff} provides a reasonable distribution between the six sediment classes (Figure 5-3). It should be noted, that only geomorphic reach NFR3 and SFR2 had bed material retained on the 31.5 mm sieve (~ 3%). For EFDC sediment bed initiation, the maximum class break for NonCoh5 was set to 38.95 mm to align the bed d_{50} with the d_{eff} size of 17.65 mm.

Table 5-3. Sediment particle size classes, effective diameter (d_{eff}) estimation methods, and the average effective diameter for each sediment class used in the HST model.

Sediment classes	Particle size class name	Particle size range (mm)	Method 1 d_{eff}[1] (mm)	Method 2 d_{eff}[2] (mm)	Average d_{eff} (mm)
Cohesive 1 (Coh1)	Clay to coarse silt	d <= 0.045	NA	NA	0.010
Non-Cohesive 1 (NonCoh1)	Coarse silt to fine sand	0.045 < d <= 0.15	0.082	0.055	0.069
Non-Cohesive 2 (NonCoh2)	Fine to medium sand	0.15 < d <= 0.5	0.307	0.315	0.311
Non-Cohesive 3 (NonCoh3)	Coase to very coarse sand	0.5 < d <= 2	0.957	1.016	0.987
Non-Cohesive 4 (NonCoh4)	Very fine to fine gravel	2 < d <= 8	3.876	4.101	3.988
Non-Cohesive 5 (NonCoh5)	Medium to coarse gravel	8 < d <= 31.5	16.959	18.347	17.653

[1] Method 1 = weighted geometric mean method, NA = not applicable
[2] Method 2 = critical shear velocity method

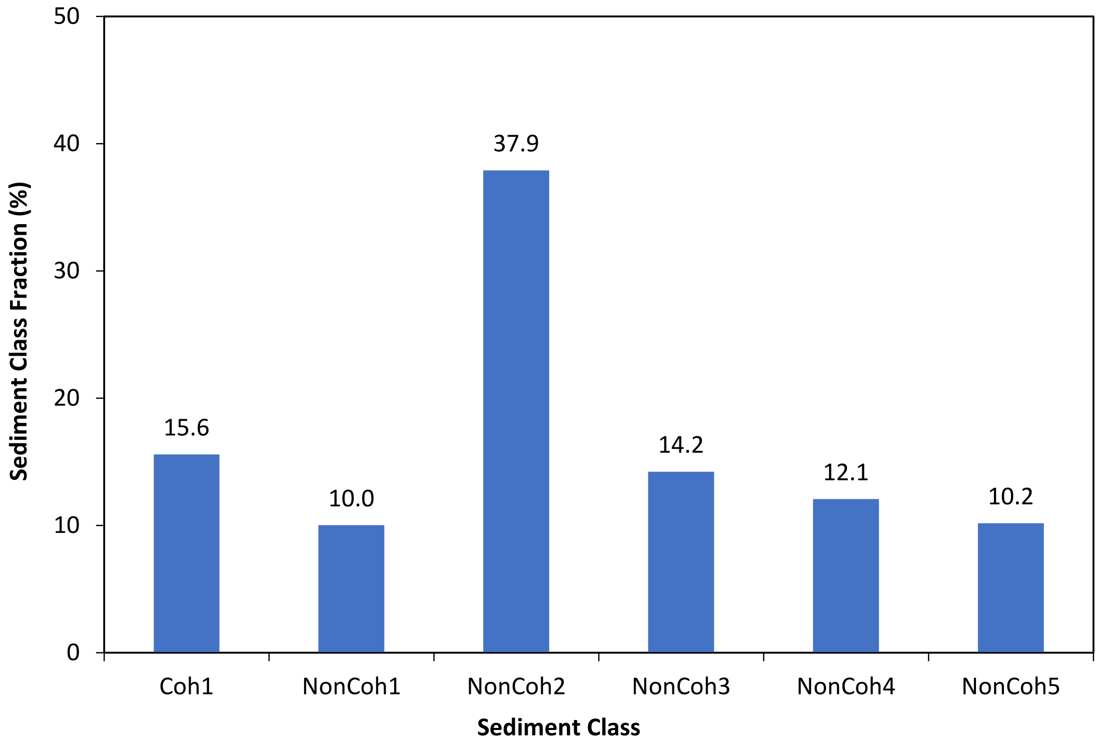

Figure 5-3. Average sediment class particle size distribution for the HST model.

5.1.4 Sediment bulk density and porosity

The Elk River within the project reach has unusually low sediment bed bulk density and high porosity values, as observed through field measurements (Appendix E). A constant wet bulk density of 1,627 kg/m^3 and porosity of 0.62 were used for the sediment bed in the HST model. Using a sediment specific gravity of 2.65 results in a dry bulk density of 1,007 kg/m^3, a value considerably lower than typical dry bulk density values for sand and gravel bedded stream channels (e.g., 1,500–2,000 kg/m^3 [Wu 2008]). The HST model converts the sediment mass eroded or deposited from the sediment bed to a volume lost or gained from the sediment bed using this dry bulk density. Consequently, a lower dry bulk density will change the sediment bed volume from erosion or deposition more than a higher density value.

5.2 Calibration and Validation

The HST model was calibrated to WY 2015, which had the most comprehensive spatial data set spanning most of the Elk River study area. Observational data included water surface elevation (depth), velocity, discharge, suspended sediment concentration, particle size distribution, and channel cross-sections. The general calibration process consisted of developing a set of model coefficients consistent with literature values and adjusting boundary conditions that provided reasonable performance metrics between observed and predicted hydrodynamic and sediment variables. Appendix F provides a detailed description of the model calibration process.

The model was validated from WY 2003 to 2014, which spans the period of available data for the Elk River. However, observations for this period are spatially limited to the upper extents of the ERRA Project area. Observational data for the validation period consisted of water surface elevation (depth), velocity, discharge, suspended sediment concentration, and channel cross-sections. The validation process consisted of using the calibrated HST model to simulate the WY 2003–2014 period, with the objective of having the observed and predicted performance metrics consistent with calibration values. A detailed discussion of model validation is provided in Appendix F.

Several model performance metrics were used to evaluate the ability of the HST model to predict available hydrodynamic and sediment observed datasets. Performance metrics consisted of both qualitative (graphical) and quantitative (statistical) methods that included (1) time-series, correlation, and probability plots; and (2) model error, correlation, and performance statistics. Grid scale model results were compared to observations for water surface elevation (depth), velocity, discharge, and suspended sediment concentration. Predicted particle size distribution, channel change and sedimentation patterns were compared to observations at the reach scale. Overall, the developed HST model provides good to excellent calibration and validation performance metrics for all modeled variables with observational data. A detailed discussion of the HST model calibration and validation is provided in Appendix F.

The Elk River HST model calibration and verification results were compared to a similar comprehensive hydrodynamic and sediment transport study on the Housatonic River that used the EFDC modeling framework (Appendix F). The HST model developed for the Elk River meets all skill performance measures established for depth, discharge, and SSC by the EPA for the Housatonic River study (Beach et al. 2000).

5.3 Boundary Condition Adjustments

During the calibration and validation process issues were identified with the North Fork and South Fork Elk River discharge and SSC data used for the HST model boundary conditions. This section summarizes each issue and if and how it was adjusted for the HST model.

5.3.1 Discharge

Given difficulties in accessing many of the Elk River monitoring stations during flood events, high flow discharge measurements are limited. Physical discharge measurements consist of in-channel flows only with no measurements of out-of-bank flows. Consequently, existing Elk River discharge ratings within the Project area are only accurate for in-channel flood flows that do not go out-of-bank, which was previously identified in the Elk River pilot project effort (NHE and SWS 2013). HRC has attempted to estimate out-of-bank flows and adjust the upper end of the discharge ratings at the HRC 511 and 510 monitoring sites. During hydrodynamic calibration the HST model consistently over and under predicted high-water elevations at HRC 510 and 511, respectively, despite good agreement between observed and predicted stage/discharge estimates at both sites. It was concluded that the HRC 510 and 511 discharge ratings could be improved outside the measurement record, and the HST model was used in a trial-and-error process to adjust the upper ends of both ratings (Figure 5-4). These adjusted discharge ratings were used to represent flows for the North Fork and South Fork Elk Rivers for all HST model simulations.

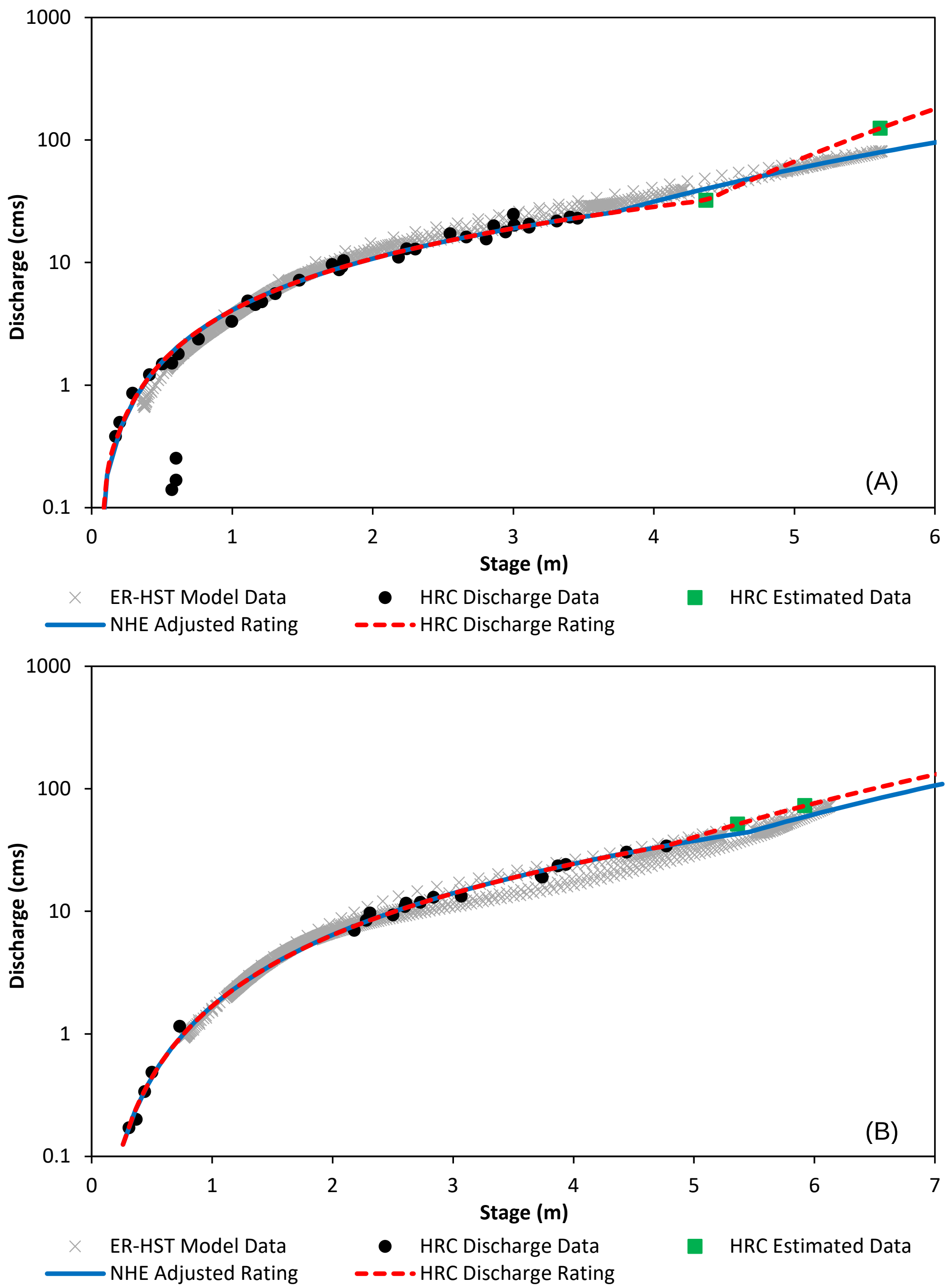

Figure 5-4. Adjusted North Fork Elk River (HRC 511) (A) and South Fork Elk River (HRC 510) (B) discharge ratings.

5.3.2 SSC

During sediment transport calibration of the HST model it became apparent that the SSC boundary conditions were over specified. The SSC data used for the boundary conditions consisted of continuous 15-min SSC data determined by turbidity-threshold approaches for the

HRC 511, HRC 510 and Railroad Gulch monitoring stations (Table 5-2). During WY 2015 sampling efforts, depth integration samples (DIS) for SSC were collected at HRC 509, HRC 510 and HRC 511. Comparison of the these DIS samples to the corresponding ISCO samples demonstrate that the DIS samples have consistently lower SSC than the ISCO samples (Figure 5-5). This is not surprising as the DIS sample represents a cross-sectional average SSC value, and the ISCO sample is a point sample generally collected near the center of the channel. Consequently, the continuous 15-min data used for the SSC boundary conditions overestimates cross-sectional average SSC values at the channel boundaries.

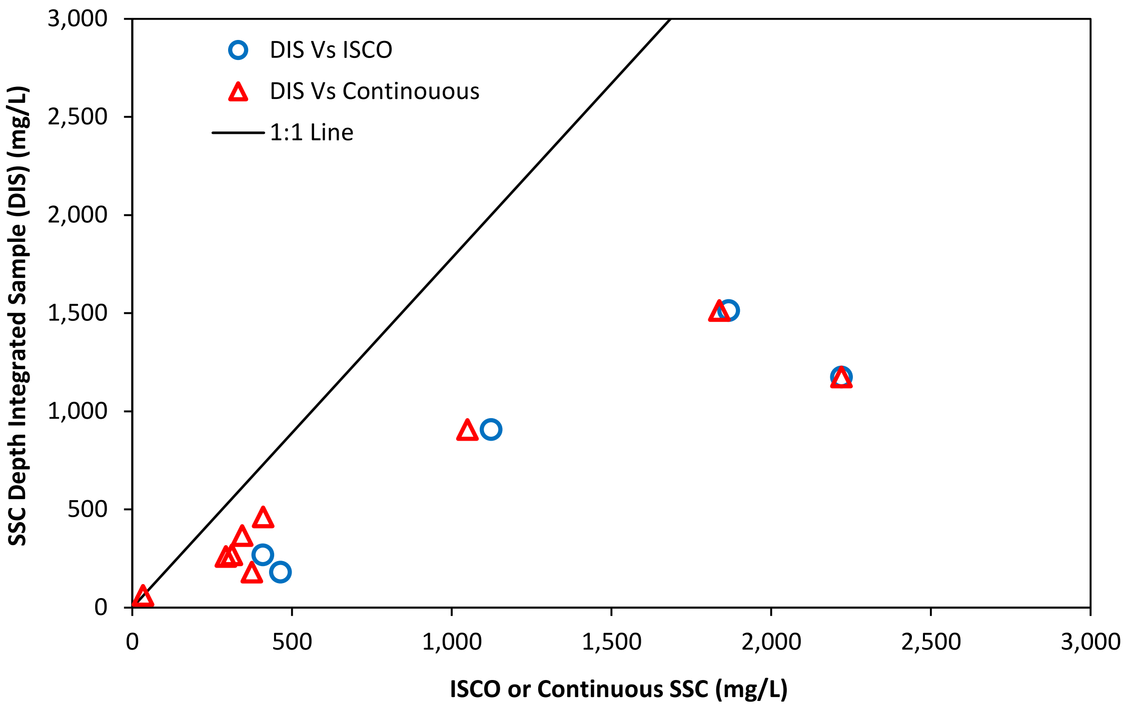

Figure 5-5. Observed ISCO and continuous suspended sediment concentration (SSC) compared to depth integrated sample (DIS) SSC at HRC 509, HRC 510, and HRC 511 monitoring stations for WY 2015.

The HST model appears to resolve the over specified SSC boundary conditions (Figure 5-6), and this correction probably occurs within a short distance in the NFR3 and SFR2 reaches directly below the boundary condition locations as the model adjusts sediment transport to incoming SSC and predicted flow conditions. The HST model underpredicts the ISCO and grab SSC samples (average relative bias of -26%), but does a better job predicting the DIS SSC samples (average relative bias of -7%). This indicates that even with the over specified SSC boundary conditions, the HST model can predict cross-sectional averaged SSC observations with a high level of reliability and accuracy over a range of concentrations. Sediment deposition results are probably overestimated in the upper reaches of NFR3 and SFR2 where the HST model adjusts for the over specified SSC boundary conditions and should be used with caution.

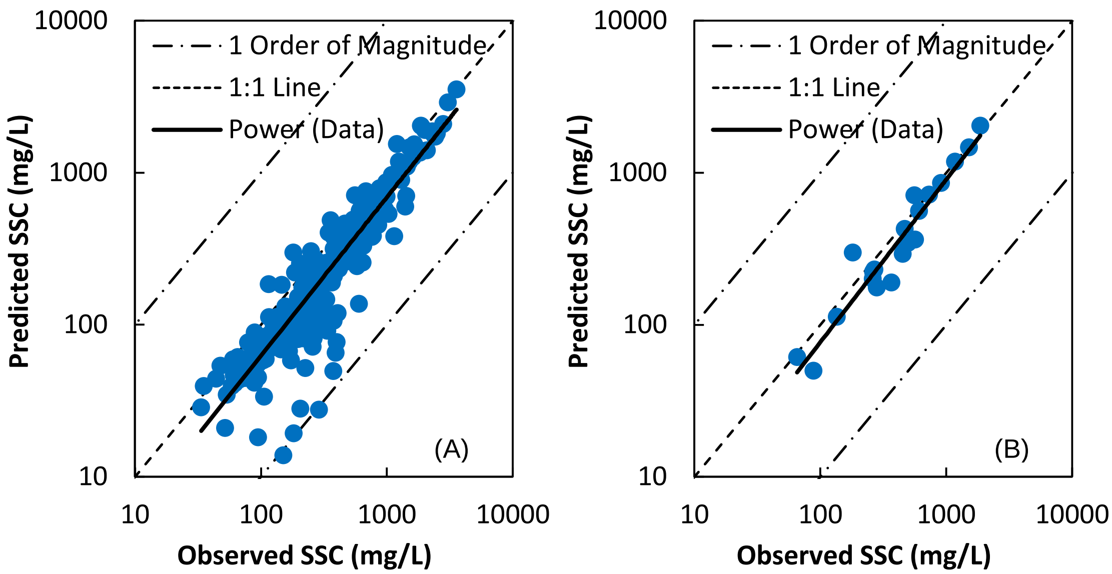

Figure 5-6. Observed suspended sediment concentrations (SSC) for all sample types (A) and observed SSC for depth integrated samples (DIS) only (B) compared to predicted SSC from HST model for all Elk River stations for WY 2015.

5.4 Model Analyses

The HST model was developed as a tool to: (1) describe existing conditions and processes, (2) identify site-specific opportunities and constraints to recovery, (3) predict changes in the Elk River channel under existing and future sediment load and mechanical channel rehabilitation scenarios, and (4) identify monitoring priorities that support adaptive management. The primary analyses conducted under the ERRA include assessing the trajectory of the system for the following scenarios:

1. Existing channel conditions with existing sediment loads (referred to as Existing Condition).
2. Existing channel conditions with reduced sediment loads (referred to as Reduced SSC).
3. A suite of recovery actions in combination with existing sediment loads (referred to as Modified Channel).

These three analyses were conducted with the sediment transport version of the model which predicts hydrodynamics (depth, velocity, shear stress), as well as sediment transport (suspended sediment and bedload) and sedimentation (erosion and deposition) patterns. The model scenarios were selected to evaluate critical questions that would help identify the pathway for Elk River Recovery. At the onset of the ERRA, available data clearly indicated continuing aggradation in intensively monitored channel reaches, but it was uncertain if and where similar responses occur throughout the river system and the degree to which channel aggradation results from incoming sediment load, reduced conveyance capacity due to channel aggradation, vegetation roughness, transportation infrastructure, or other factors. Thus, analysis of existing channel conditions was necessary to expand our understanding of the entire system response.

The response of the system to a reduction in sediment load is critical to determining whether recovery could occur by reducing sediment loads from the upper watershed alone. If reduced sediment loads can shift the system toward recovery, where would the signals of recovery first be detected and what would the system look like through time? Would certain reaches experience more rapid recovery, while others remain chronically impaired and potentially worsen as the existing stored sediment deposits move through the river system? This analysis built upon the findings in the Elk River Pilot Study (NHE and SWS, 2013) that indicated a 75 percent reduction in SSC produced channel scour and incision within the Elk River pilot project reach (includes NFR1, lower portion of NFR2, SFR1, and upstream portion of MSR5).

The third category of ERRA modeling analyses (i.e., the Modified Channel) focused on the effectiveness of potential mechanical channel and floodplain rehabilitation actions (e.g., removing hydraulic constrictions and/or reducing vegetation roughness, removing aggraded channel sediment deposits, and reducing sediment loads through tributary sediment detention) at initiating and accelerating recovery of beneficial uses and reducing nuisance flooding in impacted reaches. The ERRA TAC requested that prior to evaluating any combination of management actions, the modeling analyses first evaluate system-wide hydrodynamic responses (i.e., depth or water surface elevation, velocity, and shear stress) to individual actions. These actions included changes in (1) channel roughness (roughness height, Z_0), (2) channel and bank vegetation (vegetation drag), and (3) channel geometry through sediment removal. These management actions, analyzed as part of the ERRA, have been discussed by resource agencies, scientists, and local landowners for many years (Regional Water Board 2016). One of the most important questions regarding potential mechanical rehabilitation actions is the longevity of the treatments (i.e., at what rate will the channel or floodplain fill back in or aggrade following implementation?). The third category of analyses also provides an understanding of how the system may have generally functioned prior to the 1980’s.

The results of these analyses demonstrate different trajectories in Elk River channel and floodplain conditions; and facilitate a broader discussion about what “recovery” may look like, such as the rates at which recovery may likely occur throughout the ERRA Project area. Because the Regional Water Board defined sediment impairment downstream to Berta Road, potential recovery actions in the estuary (e.g., tidal wetland restoration) were not addressed in the ERRA but could be included in future phases. The ERRA is intended to provide the information necessary for stakeholders to define the preferred recovery strategy and the projects that comprise it during the Stewardship process (Regional Water Board 2016). Important questions regarding how desired channel and floodplain conditions are achieved and the potential impacts of implementation are not addressed in detail in the ERRA. Site specific actions will be identified through the Stewardship process, and impact analyses will be conducted and reported during subsequent regulatory steps.

5.4.1 HST Model configuration

This section provides a brief overview of how the developed HST model was configured for each management scenario simulation. All scenario simulations were for the long-term 13-year reduced simulation period spanning WY 2003–2015. Refer to Appendix F for a more detailed description of the HST model configuration and modifications for each management scenario.

Existing conditions management scenario

The existing conditions management scenario used the calibrated and validated existing conditions HST model using existing sediment loads for the WY 2003–2015 reduced simulation period.

Reduced SSC scenario

The Reduced SSC scenario used the existing conditions HST model with reduced SSC based on reductions identified by the Regional Water Board. SSC is reduced in the HST model by reducing the sediment concentrations at the boundary conditions (Figure 5-2). All other model parameters are identical to the Existing Conditions scenario. The methodology for developing the sediment concentration reduction was developed by the Regional Water Board with input from the TAC and is described in Appendix C. SSC was reduced by 27% at the upstream boundary condition of the North Fork Elk River, all North Fork Elk River tributaries, and Martin Slough. SSC was reduced by 32% at the upstream boundary condition of the South Fork Elk River and all Mainstem Elk River tributaries (except Martin Slough).

Modified Channel scenario

The Modified Channel scenario included altering the channel geometry, slope, vegetation, and roughness parameters. Sediment loads are identical to the Existing Conditions scenario. A set of options were presented to the TAC and written comments were solicited on the model configuration for the Modified Channel scenario. Twelve TAC members provided comments, and the consensus on the configuration included:

- Channel geometry modified to conditions similar to cross-section surveys prior to 1980.
- No change to vegetation on the floodplain.
- Native and more mature vegetation on channel banks (more similar to an old-growth riparian vegetation).
- Removal of vegetation in the active channel.
- Large wood added to the channel with size and frequency that meet published targets.
- Reduce roughness height (Zo) (calibrated Zo values include vegetation growth in the active channel and in-channel woody debris).
- No change to existing sediment supply.

All comments from TAC members are provided in Appendix B: Recommendations for TAC #3 to the Regional Water Board. A summary of the key modifications to the HST model grid and parameters under each model scenario are described below. Appendix E provides a more detailed description of these modifications.

Modified Channel geometry

The Modified Channel scenario included widening the channel banks and/or deepening the channel bed within the HST model domain. Channel adjustments were applied to all geomorphic reaches within the HST model, although only a small section of the upstream portion of MSR1 was modified. The modified channel geometry was based on available cross-section and bridge survey data (Appendix F). Figure 5-7 shows the existing and modified channel profile, and Figure 5-8 includes three example channel cross-sections illustrating the existing and modified channel geometry. The modified channel geometry removed approximately 449,500 cubic meters (587,900 cubic yards) of sediment from the Elk River channel.

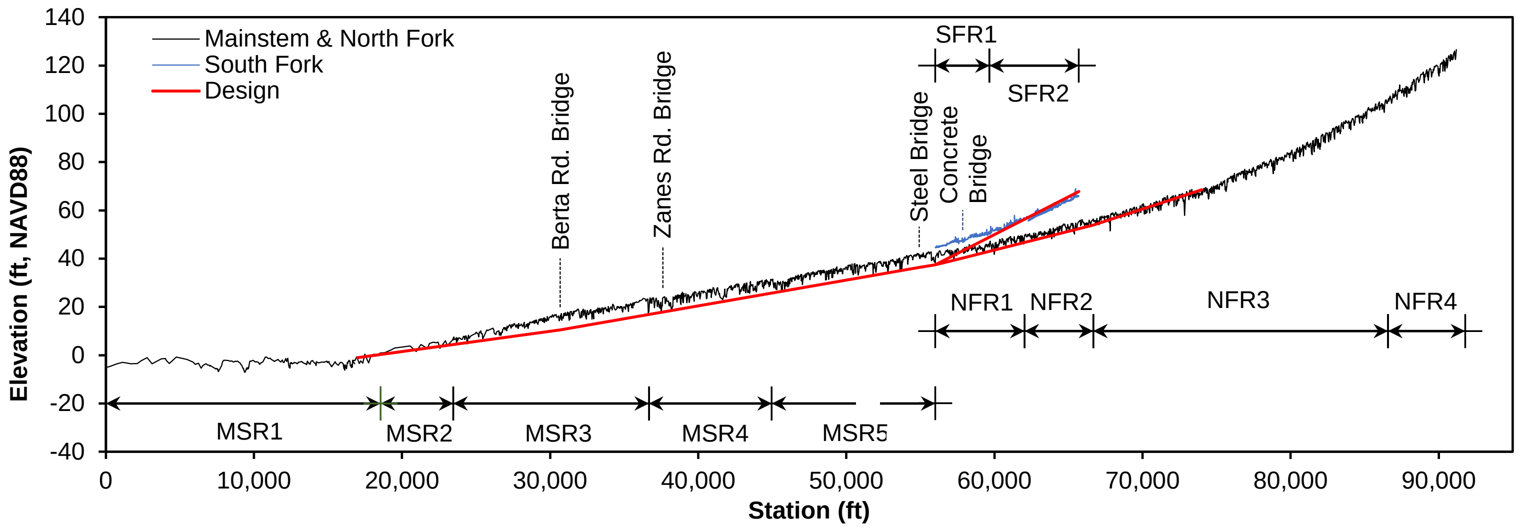

Figure 5-7. Existing Condition and Modified Channel profiles for Mainstem Elk River, North Fork Elk River and South Fork Elk River.

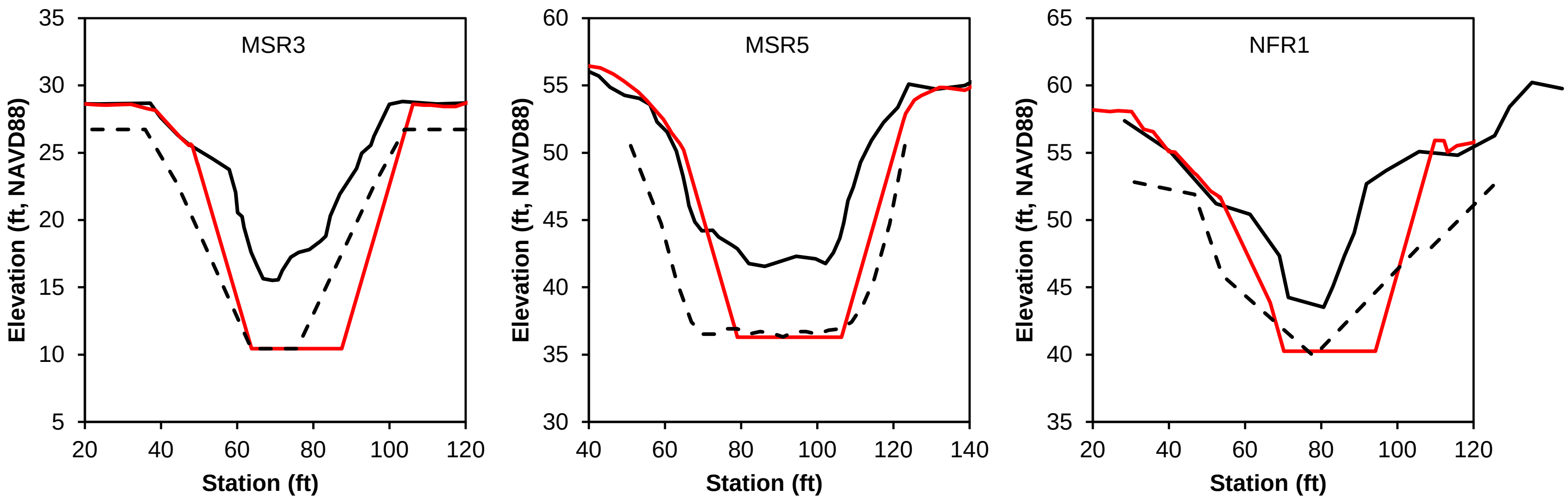

Figure 5-8. Existing and modified channel cross-sections for geomorphic reaches MSR3, MSR5 and NFR1. Dashed black line represents historical (pre-1988) channel survey, solid black line represents existing topography, and red line represents modified channel.

Channel bank vegetation

HST model values corresponding to drag imposed by vegetation on the channel banks were modified from the calibrated values for existing conditions to reflect the characteristics of old-growth riparian vegetation. Drag values estimated for existing conditions and old-growth riparian vegetation were based on observed field data and literature information (Table 5-4). For the HST model domain, channel banks consisted of either riparian vegetation or tidal wetland vegetation.

Table 5-4. Existing condition and modified channel bank vegetation drag values.

HST model configuration	Description	Stem density (#/m2)	Stem diameter (m)	Stem height (m)
Existing Condition	Riparian vegetation	2063	0.007	0.636
Modified Channel		1.920	0.181	1.874
Existing Condition	Tidal wetland	1843	0.006	0.730
Modified Channel		365	0.007	1.219

Channel bed roughness height

HST model values corresponding to the roughness height (Zo) of the channel bed were modified from the calibrated values for existing conditions to reflect more natural channel conditions (Figure 5-9). Calibrated Zo values were relatively high, which accounted for the disturbed channel bed. Disturbed channel conditions consist of dense vegetation growing directly into the channel bed, and numerous small and large wood pieces embedded in the channel sediment deposits. More natural condition Zo values were estimated based on literature values and an exponential-fit curve using existing D_{90} bed material within intensive study sites.

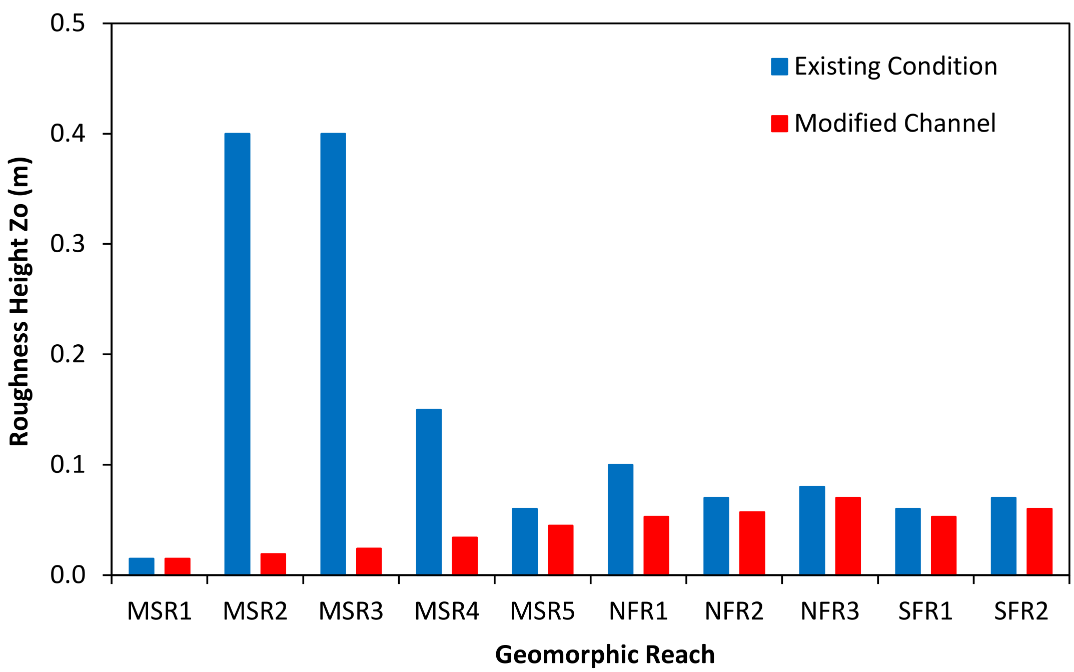

Figure 5-9. Channel bed roughness height (Zo) for the Existing Conditions and Modified Channel scenarios.

6 SYSTEM RESPONSE TO MANAGEMENT SCENARIOS

Three management scenarios (Existing Condition, Reduced SSC and Modified Channel) were analyzed with respect to system response on flood inundation, spatial patterns and magnitudes of sediment transport and storage, channel geometry, bulk density, suspended sediment concentrations, and effect on salmonid habitat. The HST model is the primary tool for numerical predictions of system response, whereas the collective impact on impaired beneficial uses draws upon the conceptual model, literature of aquatic habitat response, previous data collection, and landowner observations.

6.1 Hydrologic Conditions During the Simulation Period

The WY 2003–2015 model simulation period was selected based on the availability of flow and suspended sediment data necessary to populate the model boundary conditions. Flow, stage, and suspended sediment concentrations were measured in the South Fork Elk River, North Fork Elk River, and Railroad Gulch (see Appendix E and Appendix F).

Annual suspended sediment load (SSL) is intrinsically tied to the hydrologic record in that the highest loads typically occur in wet years with high peak flows and/or years with high annual flow volumes. Thus, predicted sediment transport rates and storage changes are affected by the sequence of future water year types (wet or dry years). Lacking a long-term hydrologic record within the Elk River watershed, the Little River near Trinidad (USGS 11481200), located 21.5 mi north of the Project area, was used as a surrogate to evaluate the extent to which hydrologic conditions during the WY 2003–2015 simulation period represent the longer-term range of natural climate variability (e.g., wet versus dry in terms of annual peak flows and flow volumes). Flood-frequency estimates were computed for the Little River station by fitting a Log-Pearson Type III (LP3) probability distribution to the series of annual peak discharge data (WY 1956 to 2017) following guidelines described in Bulletin 17C (England et al. 2018). Flood frequency estimates using the California regional flood-frequency equations (Gotvald et al. 2012) were also applied to the Little River for comparison with the LP3 estimates following Bulletin 17C. The regional equations estimate lower 2-year and 10-year peak flows compared to LP3 estimates (Figure 6-1).

The long-term record in Little River indicates relatively moderate stream flows during the period WY 2003–2015 simulation period compared to the full record (Figure 6-1). Annual peak flows in Little River during the Elk River simulation period were at or below the 2-year recurrence interval flow (LP3 analysis), with the exception of the 10-year recurrence peak flow in 2003. Measured peak flows in North Fork Elk River and South Fork Elk River show a similar pattern to those measured in Little River (Figure 6-2). The highest peak flow in Elk River during the simulation period occurred in 2003, a nearly 10-year flow based on the regional equations. The highest annual flow in Elk River during the simulation period occurred in 2006 consistent with Little River. Annual flow volumes were moderate, with 9 of the 13 years having annual flow volumes less than 50% exceedance probability. There were no extremely wet or dry water year types during the simulation period, and all years were within 5% and 95% exceedance probabilities.

The 13-year simulation period contains an important large peak flow (10-year flow) as well as years with higher flow volumes but, overall, the simulation period is drier than the long-term record. Therefore, HST model simulations may under-predict the long-term system responses (i.e., sediment transport and storage changes).

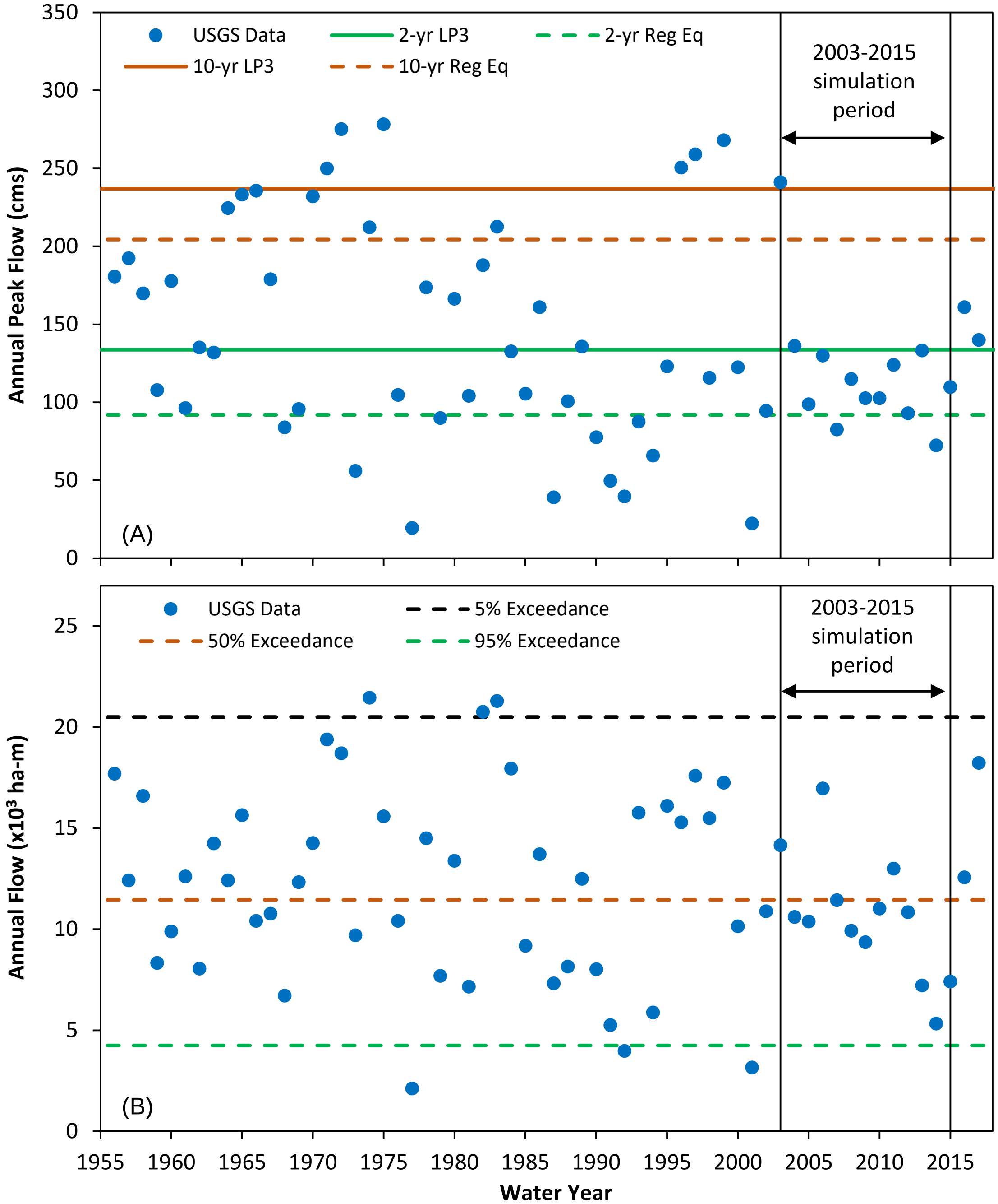

Figure 6-1. Annual peak flow (A) and annual flow (B) for Little River near Trinidad (USGS No. 11481200). Peak flow plot provides the 2- and 10-yr flood-frequency estimates from a LP3 distribution and the California regional equations (Reg Eq). Annual flow plot provides the 5%, 50% (median) and 95% exceedance flow thresholds.

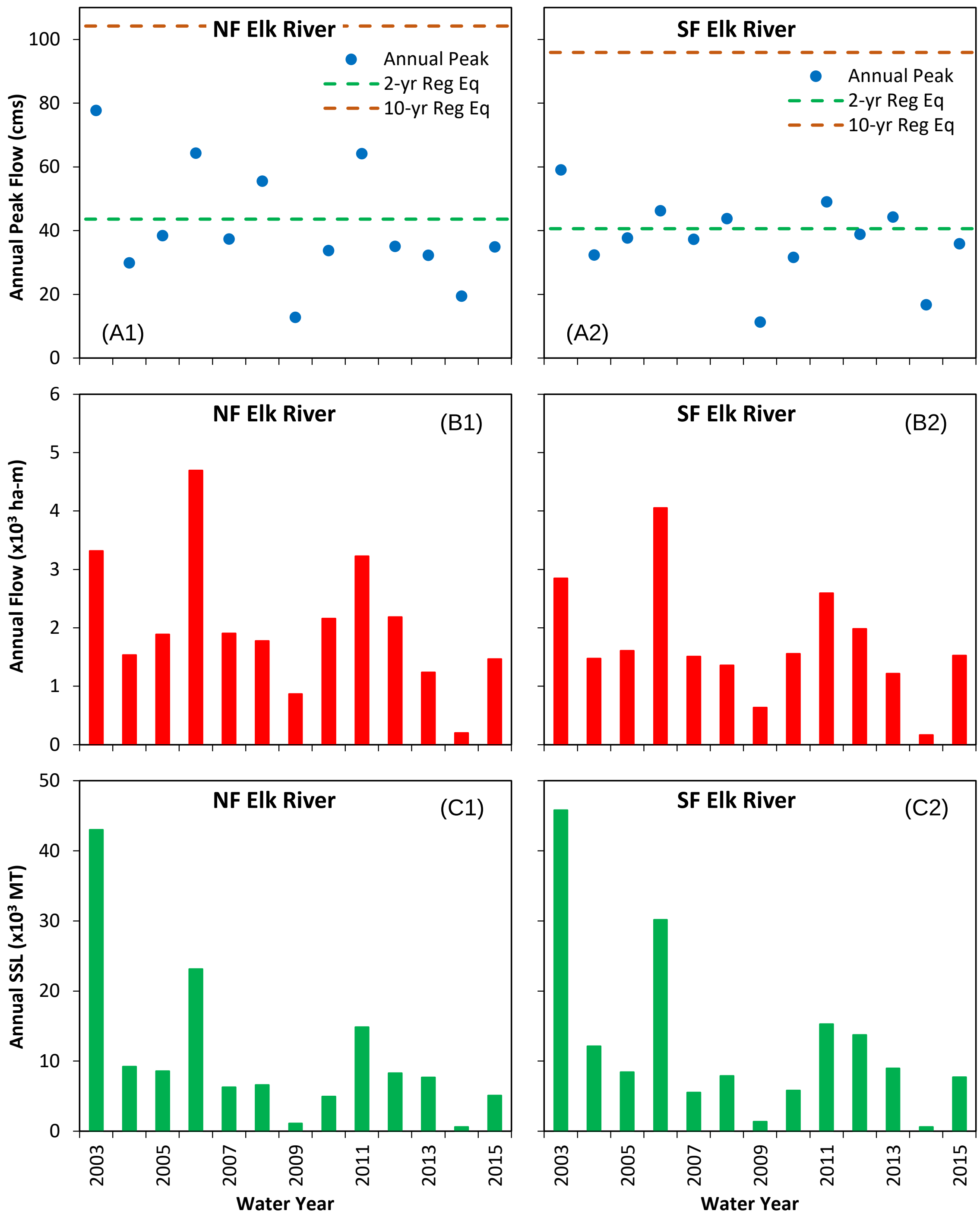

Figure 6-2. Annual peak flow (A1 and A2), annual flow (B1 and B2) and annual suspended sediment load (SSL) (C1 and C2) for the North Fork Elk River (HRC 511) and South Fork Elk River (HRC 510) monitoring stations, respectively. Annual peak flow (A1 and A2) plots provide the 2- and 10-yr recurrence interval flood-frequency estimates from the California regional equations (Reg Eq).

6.2 Annual Flow and Flood Inundation

Downstream flow conveyance and flow patterns were computed for each reach in the Elk River Project area for the Existing Condition, Reduced SSC, and Modified Channel scenarios. Nuisance flooding occurs across floodplains that include a variety of affected land uses (e.g., residential, agricultural, and infrastructure). Road-related flooding is used as an indicator of overall nuisance flooding. Roadway flood inundation was estimated at locations that are routinely flooded.

6.2.1 Annual flow distribution

Annual flow within the channel and across floodplains is similar for the Existing Condition and Reduced SSC scenario (Figure 6-3). The majority of the annual flow is conveyed in the channel through the North Fork Elk River and South Fork Elk River, and MSR5. The floodplains are inundated, but do not contribute substantially to the downstream conveyance of water. In the lower Mainstem Elk River downstream of MSR5 (e.g., MSR4 to MSR2), an increasing proportion of the annual flow is conveyed across the floodplain with less in-channel flow conveyance. Floodplain flow was not computed for MSR1, since much of the floodplain flow entering this tidally influenced reach is either stored for extended periods (i.e., no downstream flow) or exits through tide gates and slough channels.

The Modified Channel scenario decreases floodplain inundation in the North Fork Elk River and South Fork Elk River, and MSR5. The Modified Channel scenario also alters the distribution of channel and floodplain flow fluxes in the Mainstem Elk River reaches (MSR4 to MSR2) because the increased channel capacity largely contains flow within the channel and reduces floodplain inundation (Figure 6-3). The Modified Channel scenario does not substantially alter channel or floodplain flow patterns in MSR1 because substantial channel modification did not occur in this reach and inundated floodplains in this reach do not substantially contribute to the downstream movement of water.

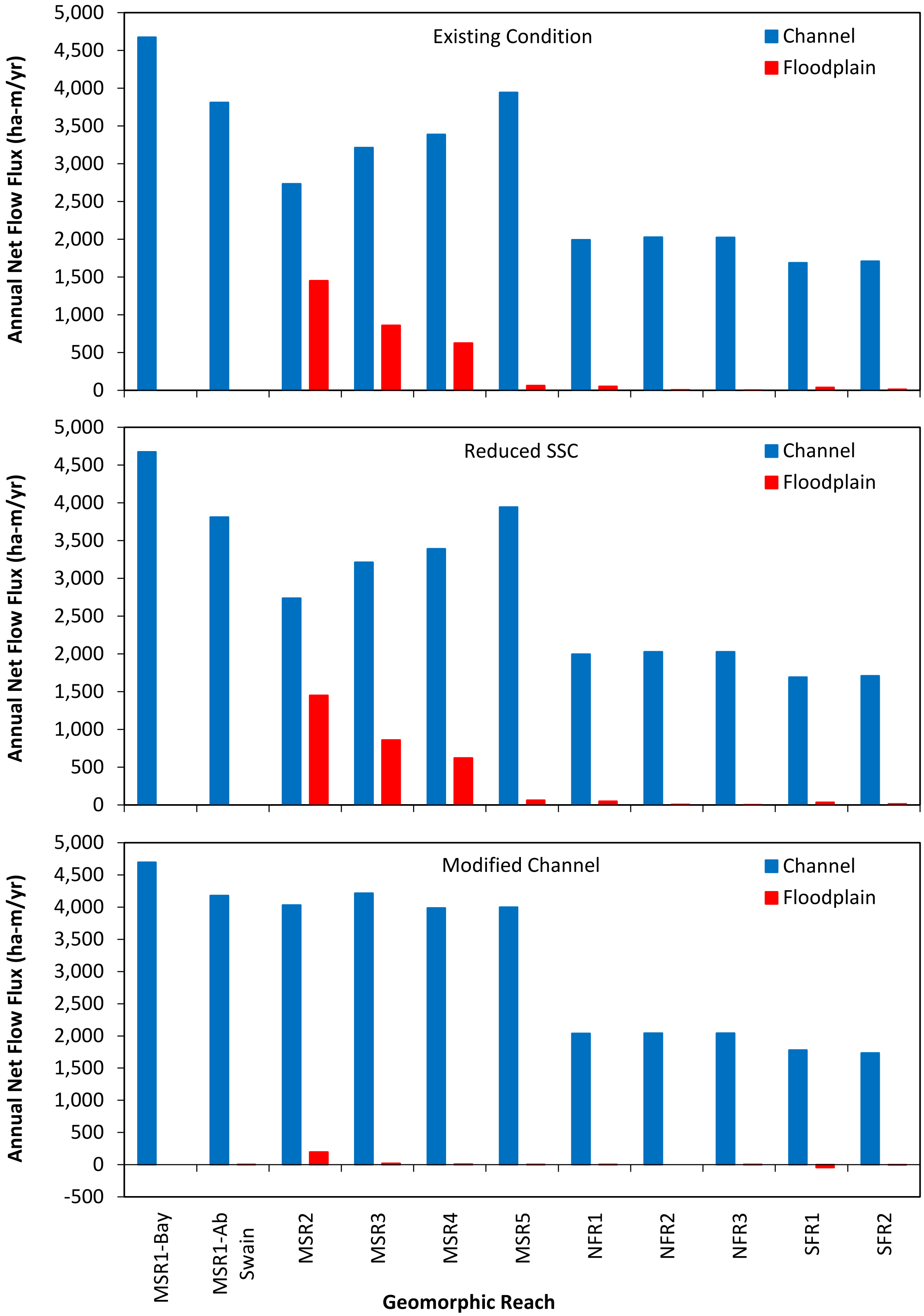

Figure 6-3. Annual net flow flux by geomorphic reach for Existing Condition, Reduced SSC, and Modified Channel scenarios for the 13-yr long-term simulations (WY 2003–2015).

6.2.2 Roadway flood inundation

The frequency of flooding on roads was evaluated at Showers Road, Berta Road, Zanes Road, Elk River Court, and Elk River Road Flood Curve (i.e., Flood Curve, located near the Elk River Road Bridge on North Fork Elk River) for the Existing Condition and Modified Channel scenarios (Table 6-1, Figure 6-4). The average number of flooded days (estimated as an entire calendar day) per year was computed over the 13-year simulation period. Zanes Road and Elk River Court experience the least amount of flooding under the Existing Condition, while Showers Road and Flood Curve have more than twice the number of flooded days. Berta Road is the most frequently inundated roadway, which is flooded for 26 days per year on average. This flooding frequency occurs during a period of relatively moderate stream flows (Figure 6-1). The distribution of flood events across water years shows that because roads are flooding during moderate storms, the years with the most frequent road flooding are not necessarily the same years with the highest peak flows. For example, the Flood Curve was inundated 15 days in 2006 and the peak flow was less than a 2-year recurrence interval, compared to only 10 days of inundation in 2003 when the peak flow was estimated to be closer to a 10-year event.

No flooding is predicted with the Modified Channel scenario at Showers Road, Zanes Road, and Elk River Courts for flows that occurred during WY 2003–2015. Flooding at Flood Curve is reduced from 5.7 days per year to 0.4 days per year, and flooding at Berta Road is reduced from 26 days per year to 2.5 days per year. The Modified Channel scenario reduces Berta Road flooding to nearly the same frequency that Elk River Courts experiences flooding under the Existing Condition.

Table 6-1. Roadway flood frequency (estimated as calendar days each year) for the 13-year simulation period (WY 2003–2015) for Existing Conditions (EC) and Modified Channel (MC) scenarios.

Water year	Showers Road		Berta Road		Zanes Road		Elk River Court		Flood Curve	
	EC	MC	EC	MC	EC	MC	EC	MC	EC	MC
2003	12	0	41	6	6	0	7	0	10	2
2004	10	0	19	0	1	0	2	0	6	0
2005	6	0	29	2	1	0	2	0	8	0
2006	19	0	55	5	7	0	7	0	15	1
2007	3	0	28	4	2	0	2	0	4	0
2008	5	0	20	3	2	0	2	0	4	1
2009	0	0	10	0	0	0	0	0	0	0
2010	5	0	25	0	2	0	2	0	2	0
2011	7	0	38	3	2	0	2	0	7	1
2012	9	0	28	3	1	0	2	0	8	0
2013	5	0	18	5	1	0	3	0	4	0
2014	0	0	3	0	0	0	0	0	1	0
2015	5	0	24	2	3	0	3	0	5	0
Total days	**86**	**0**	**338**	**33**	**28**	**0**	**34**	**0**	**74**	**5**
Avg days/yr	**6.6**	**0.0**	**26.0**	**2.5**	**2.2**	**0.0**	**2.6**	**0.0**	**5.7**	**0.4**

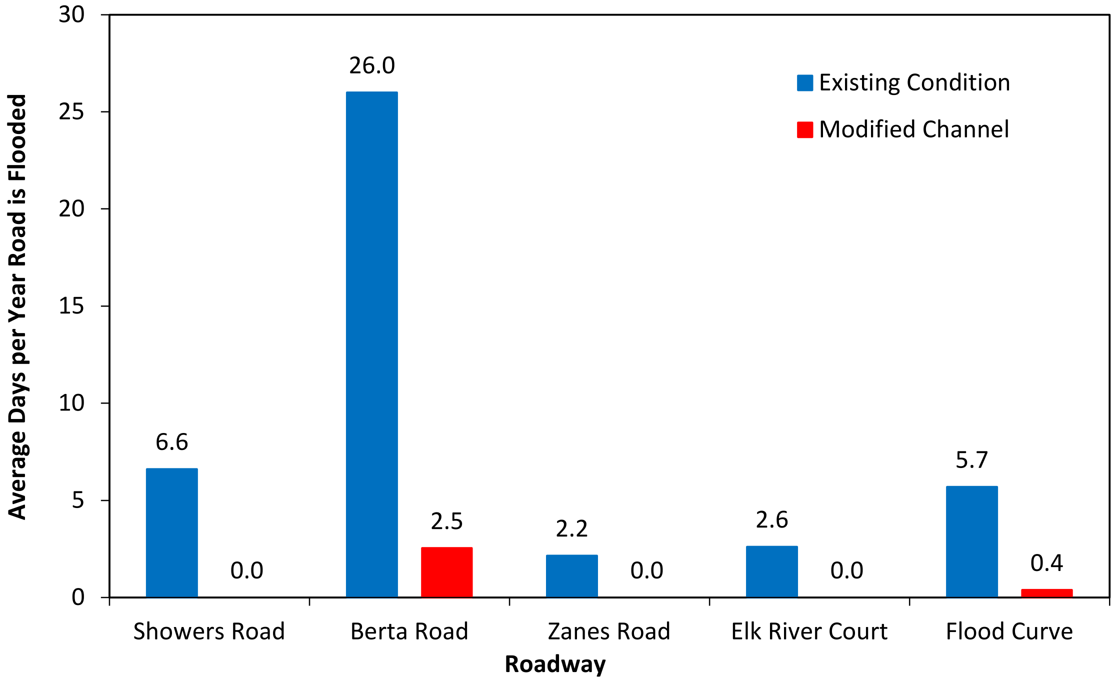

Figure 6-4. Average days per year that the lowest point on a roadway is flooded to a depth greater than 2.5 cm for the Existing Condition and the Modified Channel scenarios for the 13-yr long-term simulations (WY 2003–2015).

6.3 Sediment Budget

Sediment budgets are organizational tools to help understand sediment transport and storage patterns within a system. Sediment budgets can vary substantially in their spatial scale and complexity, but all terms can be simplified to input, output, and storage terms with the following relation:

$$\text{Input} - \text{Change in Storage} = \text{Output}$$

Fluvial sediment budgets were developed in the non-tidal reaches of the Elk River to assess sediment transport and storage patterns at several spatial scales: (1) Project area; (2) the North Fork Elk River, South Fork Elk River, and Mainstem Elk River (downstream of the North Fork Elk River and South Fork Elk River confluence); and (3) for individual geomorphic reaches. Individual geomorphic reaches are the finest resolution of the sediment budget, since they were delineated as generally homogenous fluvial geomorphic forms and processes. Examining the sediment budget at these various spatial scales demonstrates unique responses to potential management actions throughout the Project area and helps inform appropriate strategies for recovering impaired beneficial uses and reducing nuisance flooding.

The sediment budgets were developed from the HST model sediment flux analysis (Appendix F). The simplified sediment budgets aggregate multiple input, output, and storage terms. Terms described in the sediment flux analysis and sediment budget are defined in Table 6-2. The input term includes sediment generated from upstream reaches and tributaries (boundary conditions), and includes sediment generated both in-channel and across the floodplain. Change in storage is computed by differencing the total deposition minus the erosion that occurred in a given area. The outputs were calculated using the equation above (Input – Change in Storage), rather than using the output flux terms extracted from the HST model. The output flux terms from the model are subject to model truncation and rounding errors, and extraction errors related to the location of the flux line and the orientation of the grid cells. The sediment budget excludes the tidal reaches (MSR1 and MSR2). These reaches have more complex routing of tidally-influenced water and sediment through a network of tide gates and slough channels, and do not have dominant downstream fluxes.

Table 6-2. Sediment budget and sediment flux terms.

Flux label	Flux term	Sediment budget term	Definition
Tributary	Source	Input	Includes all sediment from tributaries. These loads may come in at any point within the reach.
Suspended load from upstream reach	Source	Input	Suspended sediment load from upstream reach which may include a boundary condition or a predicted load.
Suspended load from downstream reach	Source	NA	Suspended sediment load from downstream reach which may include a boundary condition or predicted load. Significant sediment sources entering the downstream end of the reach only occur within the tidal reaches.
Bedload from upstream reach	Source	Input	Bedload from upstream reach as a predicted load. No bedload was entered as a boundary condition.
Bedload from downstream reach	Source	NA	Bedload from downstream reach as a predicted load. No bedload was entered as a boundary condition.
Suspended load to downstream reach	Sink	NA	Predicted suspended load transported to downstream reach.
Bedload to downstream reach	Sink	NA	Predicted bedload transported to downstream reach.
Deposition	Sink	Storage Change	Sediment deposited on the channel bed, banks, or floodplain within the reach.
Erosion	Source	Storage Change	Erosion from the channel bed, banks, or floodplain from within the reach.
Floodplain to channel	Source/Sink	NA	Sediment load transferred from the floodplain to the channel.
Channel to floodplain	Source/Sink	NA	Sediment load transferred from the channel to floodplain.

6.3.1 Sediment budget for the fluvial portions of the Project area

The sediment budget for the fluvial portions of the Project area (e.g., upstream of MSR2) describes how much of the Elk River sediment load is transported through or deposited in the channel and on adjacent floodplains at the most aggregated spatial scale (Figure 6-3). Under Existing Conditions, the Elk River transports about 46% of the sediment load to the tidally influenced reaches (MSR1 and MSR2), with approximately 23% of the load stored in the channel and 32% stored on floodplains. Under the Reduced SSC scenario, the Elk River exports about 30% less sediment (roughly equivalent to the upstream load reduction), and sediment is stored in similar distributions to Existing Condition in the channel and on floodplains. These results demonstrate that sediment will continue to accumulate in the channel and on floodplains under the Existing Condition and Reduced SSC scenarios. The river is not expected to incise into or export legacy stored sediment or new sediment that is accumulated annually.

The Modified Channel scenario has the same sediment input as the Existing Condition scenario but has strikingly different sediment transport and depositional patterns. The Modified Channel scenario exports 89% of the sediment load, with 9% of the load stored in the channel and only 2% stored on floodplains. The Modified Channel scenario dramatically reduces the role of floodplain sediment storage due to less frequent inundation.

Table 6-3. Simplified sediment budget for the fluvial portions of the Project area upstream of the tidal reaches for Existing Condition, Reduced SSC, and Modified Channel scenarios.

Sediment budget term	Existing		Reduced SSC		Modified channel	
	Mass MT/yr1	% of input	Mass MT/yr	% of input	Mass MT/yr	% of input
Total Input	34,573		24,046		34,573	
Total Output	15,772	46%	11,585	48%	30,749	89%
Storage in Channel	7,804	22%	5,348	22%	3,078	9%
Storage on Floodplains	10,998	32%	7,114	30%	746	2%

[1] MT = metric tons. yr = year.

6.3.2 Sediment budget for Mainstem Elk River, North Fork Elk River, and South Fork Elk River

The changes demonstrated by the sediment budget for the fluvial portions of the Project area in the previous section are not equally distributed throughout the channel network. Finer scale sediment budgets developed for the North Fork Elk River, South Fork Elk River, and Mainstem Elk River describe inputs, outputs, and storage specific to these areas (Table 6-4, Table 6-5, and Table 6-6). Unit sediment storage in the channel was computed by dividing the total storage in the channel by the length of the channel. Unit sediment storage in the floodplain was computed by dividing the total storage in the floodplain by the length of the floodplain as measured through the center of the valley. This sediment budget illustrates the following:

- Sediment Transport
  - Under the Existing Condition and the Reduced SSC scenario, the North Fork Elk River and South Fork Elk River channels transport the majority of the incoming sediment to the Mainstem Elk River. The Mainstem Elk River channel, in contrast, transmits substantially less of the incoming sediment load.
  - In the Modified Channel scenario, the percentage of incoming sediment that is transported out of the reach increases for all reaches, with the most significant increases occurring in the Mainstem Elk River.

- Sediment Storage
  - Under the Existing Condition and the Reduced SSC scenarios, the majority of the sediment mass entering floodplain storage occurs in Mainstem Elk River reaches.
  - Under both the Reduced SSC and Modified Channel scenarios, the mass of new sediment stored on floodplains during the simulation period is less than under the Existing Condition scenario for all reaches. The most substantial reductions in new sediment accumulation on the floodplains occur within the Mainstem Elk River reach. The Modified Channel scenario accumulates the least amount of new sediment on the floodplains.
  - Channel sediment storage is greater than floodplain sediment storage in both the North Fork Elk River and South Fork Elk River under all scenarios.
  - On a per unit length basis, channel sediment storage is greater in the South Fork Elk River than in the North Fork Elk River and Mainstem Elk River.
  - The amount of new sediment stored in the channel during the simulation period is less under the Reduced SSC and Modified Channel scenarios than under the Existing Condition scenario. The Modified Channel scenario accumulates the least amount of new sediment in the channel.

Table 6-4. Simplified sediment budget for the Existing Condition for North Fork Elk River, South Fork Elk River, and Mainstem Elk River upstream of the tidal reaches.

Sediment budget term	North Fork (NFR 1–3)		South Fork (SFR 1–2)		Mainstem (MSR 3–5)	
	Mass MT/yr[1]	% of input	Mass MT/yr	% of input	Mass MT/yr	% of input
Input	10,726		12,573		28,738	
Output	7,585	71%	9,878	78%	15,772	56%
Storage in Channel	2,407	22%	1,839	15%	3,558	13%
Unit Storage in Channel Based on Channel Length (MT/yr/km)	266		618		359	
Storage on Floodplains	734	7%	856	7%	9,409	33%
Unit Storage on Floodplains Based on Valley Centerline (MT/yr/km)	97		591		2,172	

[1] MT = metric tons. yr = year. km = kilometer

Table 6-5. Simplified sediment budget for Reduced SSC for the North Fork Elk River, South Fork Elk River, and Mainstem Elk River upstream of the tidal reaches.

Sediment budget term	North Fork (NFR 1–3)		South Fork (SFR 1–2)		Mainstem (MSR 3–5)	
	Mass MT/yr[1]	% of input	Mass MT/yr	% of input	Mass MT/yr	% of input
Input	7,830		8,550		20,012	
Output	5,560	71%	6,785	79%	11,585	58%
Storage in Channel	1,746	22%	1,214	14%	2,388	12%
Unit Storage in Channel Based on Channel Length (MT/yr/km)	193		408		209	
Storage on Floodplains	524	7%	551	7%	6,039	30%
Unit Storage on Floodplains Based on Valley Centerline (MT/yr/km)	69		381		1,394	

[1] MT = metric tons. yr = year. km = kilometer

Table 6-6. Simplified sediment budget for Modified Channel scenario for the North Fork Elk River, South Fork Elk River, and Mainstem Elk River upstream of the tidal reaches.

Sediment budget term	North Fork (NFR 1–3)		South Fork (SFR 1–2)		Mainstem (MSR 3–5)	
	Mass MT/yr[1]	% of input	Mass MT/yr	% of input	Mass MT/yr	% of input
Input	10,726		12,573		32,647	
Output	9,647	90%	11,725	93%	30,749	94%
Storage in Channel	908	8%	654	5%	1,516	5%
Unit Storage in Channel Based on Channel Length (MT/yr/km)	100		220		133	
Storage on Floodplains	170	2%	194	2%	382	1%
Unit Storage on Floodplains Based on Valley Centerline (MT/yr/km)	23		134		88	

[1] MT = metric tons. yr = year. km = kilometer

6.3.3 Sediment budget for geomorphic reaches

A sediment budget was developed at the geomorphic reach scale to examine reach-scale transport and storage patterns for the Existing Condition, Reduced SSC, and Modified Channel scenarios (Table 6-7, Table 6-8, Table 6-9, Figure 6-5). The inputs, outputs, and storage are specific to the individual geomorphic reaches. As described in Section 5.3, the input boundary condition SSC values for the North Fork Elk River and South Fork Elk River are over specified and likely affect the sediment transport and deposition patterns (boundary condition affect) in the upper portions of reaches NFR3 and SFR2.

The results of the sediment budget analysis for the geomorphic reaches demonstrate the following:

- Sediment Transport
    - The Existing Condition and Reduced SSC scenarios result in transport of 73–95% of the sediment that enters a geomorphic reach to the next downstream reach.
        - Reaches at the upstream boundary conditions (NFR3 and SFR2) tend to convey a smaller percentage of the incoming sediment load, which is likely a boundary condition affect rather than an indicator of different sediment transport characteristics.
        - The reaches in the North Fork Elk River and South Fork Elk River that are not affected by the SSC boundary condition transmit 93–95% of the incoming sediment load.
        - The percentage of the incoming sediment load that is transported downstream decreases in the downstream direction to a minimum of 73–76% in MSR 3.
    - The Modified Channel scenario results in transport of 92–100% of the sediment that enters a geomorphic reach to the next downstream reach. Excluding the reaches affected by the boundary conditions, all reaches transport 97% of the incoming sediment or more. There is not a decreasing downstream transport trend in the Mainstem Elk River.
- Sediment Storage
    - In both the North Fork Elk River and South Fork Elk River, more sediment is deposited in the channel than on floodplains on a mass and per unit length basis for all management scenarios.
    - Existing Condition and Reduced SSC scenarios:
        - The amount of sediment deposited in the channel per unit length is similar (within the same order of magnitude) in all reaches of the Elk River, with the exception of SFR2. The highest sedimentation rates occur in the South Fork Elk River and upper Mainstem Elk River reaches (MSR5 and MSR4) for Existing Condition and Reduced SSC scenarios.
        - Floodplain sediment storage substantially increases downstream of Elk River Court (MSR4 and MSR3) for the Existing Condition and the Reduced SSC scenario. Floodplain sediment storage in these reaches is a significant part of the sediment budget.
        - Reducing the SSC by 27–32% reduces the magnitude of sedimentation throughout all reaches of the Elk River by an amount similar to the overall reduction (26–35%) (Table 6-10) but does not change the overall patterns of sedimentation compared to Existing Condition scenario.
- The Modified Channel scenario significantly alters storage patterns.
    - Floodplain sediment storage is reduced from 24% and 14% in MSR3 and MSR4, respectively to 1% or less of the incoming sediment load in the Modified Channel scenario.
    - The Modified Channel scenario reduces sediment storage in the channel from 3–18% of the incoming sediment load to <1–7%.
    - Sediment accumulation is substantially reduced for the Modified Channel scenario with reductions of 59–80% (Table 6-10) compared to Existing Condition scenario. The highest reductions occur in the Mainstem Elk River reaches and SFR2.

Table 6-7. Simplified sediment budget for geomorphic reaches for Existing Condition scenario upstream of the tidal reaches.

Sediment budget term[1]	North Fork			South Fork		Forks	Mainstem		
	NFR3	NFR2	NFR1	SFR2	SFR1	NF+SF	MSR5	MSR4	MSR3
Model Channel Reach Length (m)	5,811	1,413	1,836	1,114	1,861	12,035	2,944	3,960	3,013
Valley Centerline Reach Length (m)	5,139	1,227	1,174	409	1,039	8,987	1,190	1,749	1,393
Cumulative Input (MT/yr)	10,726	10,726	10,726	12,573	12,573	23,299	31,089	32,334	34,573
Reach Output (MT/yr)	8,582	8,182	7,585	10,588	9,878	17,463	22,862	19,371	15,772
Storage in Channel (MT/yr)	1,776	299	331	1,214	625	4,246	1,555	1,295	708
Unit Storage in Channel Based on Channel Length (MT/yr/km)	306	212	180	1,090	336	353	528	327	235
Storage on Floodplains (MT/yr)	367	101	266	770	85	1,590	836	3,442	5,131
Unit Storage on Floodplains Based on Valley Centerline (MT/yr/km)	72	82	226	1,885	82	177	702	1,968	3,683
Percent of incoming sediment load transported downstream	80%	95%	93%	84%	93%		91%	80%	73%
Percent of incoming sediment load deposited in the channel	17%	4%	4%	10%	6%		6%	6%	3%
Percent of incoming sediment load deposited in the floodplain	3%	1%	3%	6%	1%		3%	14%	24%
Cumulative Storage in Channel (MT/yr)	1,776	2,076	2,407	1,214	1,839	4,246	5,801	7,096	7,804
Cumulative Storage on Floodplains (MT/yr)	367	468	734	770	856	1,590	2,425	5,867	10,998
Cumulative Storage (MT/yr)	2,144	2,544	3,140	1,985	2,695	5,836	8,226	12,963	18,802
Percent of cumulative sediment load deposited in channel	17%	19%	22%	10%	14%	18%	19%	22%	22%
Percent of cumulative sediment load deposited on floodplains	3%	5%	7%	6%	7%	7%	8%	18%	32%
Percent of cumulative sediment load in storage (channel or floodplain)	20%	24%	29%	16%	21%	25%	27%	40%	54%

[1] MT = metric tons. yr = year. km = kilometer

Table 6-8. Simplified sediment budget for geomorphic reaches for Reduced SSC scenario upstream of the tidal reaches.

Sediment budget term[1]	North Fork			South Fork		Forks	Mainstem		
	NFR3	NFR2	NFR1	SFR2	SFR1	NF+SF	MSR5	MSR4	MSR3
Model Channel Reach Length (m)	5,811	1,413	1,836	1,114	1,861	12,035	2,944	3,960	3,013
Valley Centerline Reach Length (m)	5,139	1,227	1,174	409	1,039	8,987	1,190	1,749	1,393
Cumulative Input (MT/yr)	7,830	7,830	7,830	8,550	8,550	16,379	21,677	22,524	24,046
Reach Output (MT/yr)	6,245	5,962	5,560	7,256	6,785	12,345	16,055	13,726	11,585
Storage in Channel (MT/yr)	1,314	212	220	798	416	2959	1,019	872	497
Unit Storage in Channel Based on Channel Length (MT/yr/km)	226	150	120	716	223	246	346	220	165
Storage on Floodplains (MT/yr)	271	71	182	496	56	1,075	568	2,304	3,166
Unit Storage on Floodplains Based on Valley Centerline (MT/yr/km)	53	58	155	1,213	53	120	477	1,317	2,273
Percent of incoming sediment transported downstream	80%	96%	93%	85%	93%		91%	81%	76%
Percent of incoming sediment deposited in channel	17%	3%	4%	9%	6%		6%	5%	3%
Percent of incoming sediment deposited in floodplain	3%	1%	3%	6%	1%		3%	14%	21%
Cumulative Storage in Channel (MT/yr)	1,314	1,526	1,746	798	1,214	2,959	3,978	4,851	5,348
Cumulative Storage on Floodplains (MT/yr)	271	342	524	496	551	1,075	1,643	3,947	7,114
Cumulative Storage (MT/yr)	1,584	1,867	2,269	1,294	1,765	4,034	5,621	8,798	12,461
Percent of cumulative sediment load deposited in channel	17%	20%	22%	9%	14%	18%	18%	22%	22%
Percent of cumulative sediment load deposited on floodplains	3%	4%	7%	6%	7%	7%	8%	17%	30%
Percent of cumulative sediment load in storage (channel or floodplain)	20%	24%	29%	15%	21%	25%	26%	39%	52%

[1] MT = metric tons. yr = year. km = kilometer

Table 6-9. Simplified sediment budget for geomorphic reaches for Modified Channel scenario upstream of the tidal reaches.

Sediment budget term[1]	North Fork			South Fork		Forks	Mainstem		
	NFR3	NFR2	NFR1	SFR2	SFR1	NF+SF	MSR5	MSR4	MSR3
Model Channel Reach Length (m)	5,811	1,413	1,836	1,114	1,861	12,035	2,944	3,960	3,013
Valley Centerline Reach Length (m)	5,139	1,227	1,174	409	1,039	8,987	1,190	1,749	1,393
Cumulative Input (MT/yr)	10,726	10,726	10,726	12,573	12,573	23,299	31,089	32,334	34,573
Reach Output (MT/yr)	9,849	9,803	9,647	12,103	11,725	21,372	29,007	29,360	30,749
Storage in Channel (MT/yr)	722	41	145	279	375	1,562	126	762	628
Unit Storage in Channel Based on Channel Length (MT/yr/km)	124	29	79	250	201	130	43	192	208
Storage on Floodplains (MT/yr)	154	5	11	191	3	364	29	130	222
Unit Storage on Floodplains Based on Valley Centerline (MT/yr/km)	30	4	10	468	3	41	25	74	160
Percent of incoming sediment transported downstream	92%	100%	98%	96%	97%		99%	97%	97%
Percent of incoming sediment deposited in channel	7%	<1%	2%	2%	3%		<1%	3%	2%
Percent of incoming sediment deposited in floodplain	1%	<1%	<1%	2%	<1%		<1%	<1%	1%
Cumulative Storage in Channel (MT/yr)	722	763	908	279	654	1,562	1,688	2,450	3,078
Cumulative Storage on Floodplains (MT/yr)	154	159	170	191	194	364	394	524	746
Cumulative Storage (MT/yr)	876	922	1,079	470	848	1,926	2,082	2,974	3,825
Percent of cumulative sediment load deposited in channel	7%	7%	8%	2%	5%	7%	6%	7%	9%
Percent of cumulative sediment load deposited on floodplains	1%	2%	2%	2%	2%	1%	1%	2%	2%
Percent of cumulative sediment load in storage (channel or floodplain)	8%	9%	10%	4%	7%	8%	7%	9%	11%

[1] MT = metric tons. yr = year. km = kilometer

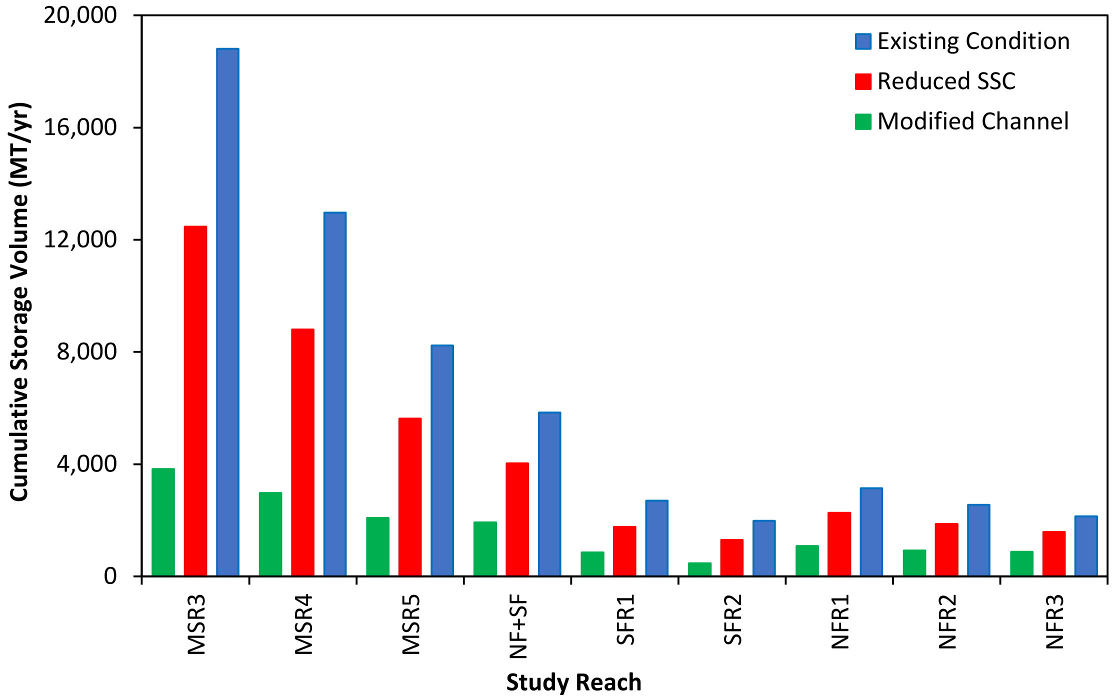

Figure 6-5. Cumulative sediment storage over the 13-yr simulation period (WY 2003–2015) for the Existing Condition, Reduced SSC, and Modified Channel scenarios. NF+SF is the sum of the North Fork Elk River and South Fork Elk River cumulative sediment storage.

Table 6-10. Percent reduction in new sediment accumulation compared to the Existing Condition for Reduced SSC and Modified Channel scenarios.

	MSR3	MSR4	MSR5	NF+SF	SFR1	SFR2	NFR1	NFR2	NFR3
Reduced SSC	34%	32%	32%	31%	35%	35%	28%	27%	26%
Modified Channel	80%	77%	75%	67%	69%	76%	66%	64%	59%

6.4 Sediment Transport

This section is intended to provide a more detailed analysis of sediment transport. Sediments transported in suspension in the water column are differentiated from sediments transported as bedload (Figure 6-6). Bedload is transported along the channel bed by rolling, sliding or saltation. In general, sediments transported in suspension are typically less than 2 mm, while sediment transported as bedload are typically larger than 2 mm; however, the actual mode of transport of a particular grain size depends on the stream hydraulics. Individual grains larger than ~0.13 mm (fine sand) will be at rest on the stream bed until shear velocities are sufficiently high to initiate motion (typically sliding or rolling of a grain). Grains will initially move as bedload until shear velocities are sufficiently high to hold the particle in suspension. As shear velocities decrease, the suspended particle will settle to the bed (according to the settling velocity) and continue moving as bedload until shear velocity drops and the particle comes to rest (Figure 6-6). Sediments that are transported as bedload typically become imbricated once at rest, which increases particle packing, and increases bulk density. Grain sizes less than ~0.13 mm will become suspended directly from being at rest, without being transport as bedload. These particles settle out of the water column directly onto the bed.

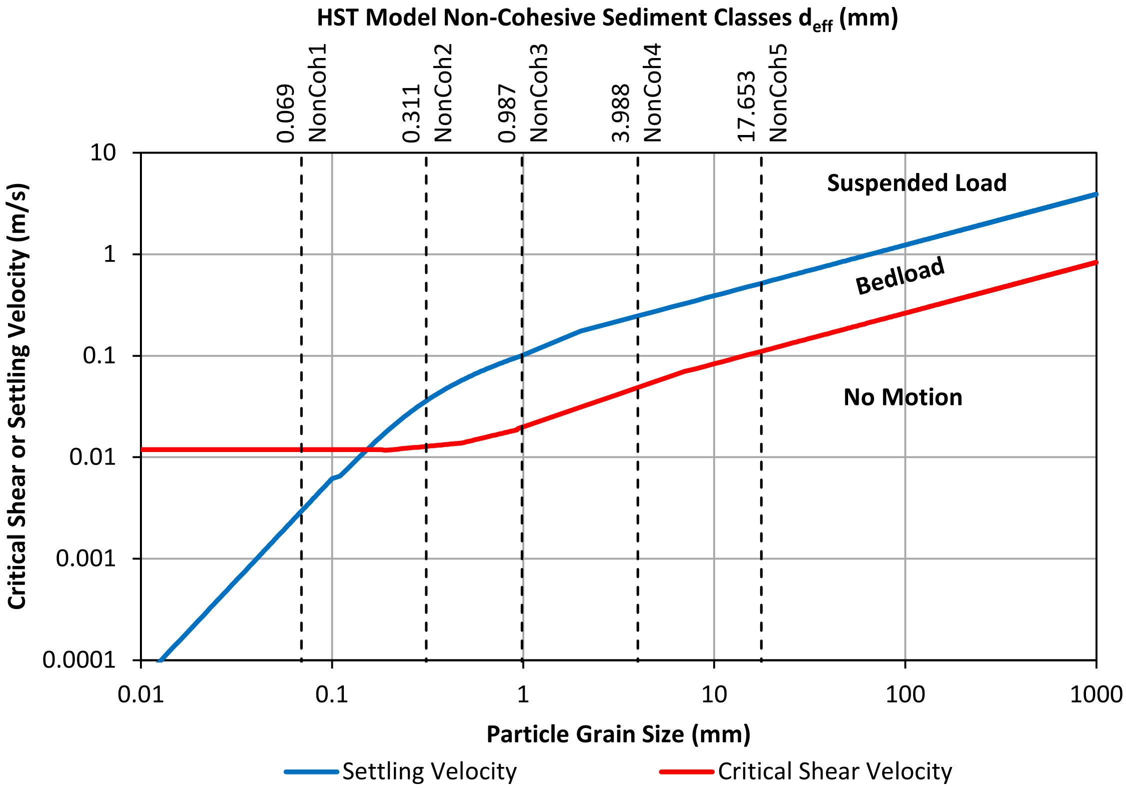

Figure 6-6. Critical shear and settling velocity of particles (adapted from Tetra Tech, 2007). Refer to Table 5-3 for a description of non-cohesive sediment classes used in the HST model.

The total suspended sediment load in the Elk River is made up of different size grains which typically range from silts and clays (<0.062 mm) to very coarse sand (2 mm). These grain sizes are transported at different concentrations depending on local flow hydraulics. Of the five non-cohesive sediment classes in the HST model, four classes (NonCoh2 to NonCoh5) can be transported as suspended or bedload depending on shear velocity (Figure 6-6). NonCoh1 class can only be transported as suspended load, thus, particles in this size class will not become imbricated. It is possible that an excess of this size material in the channel bed contributes to the low bulk densities measured in the Project area (see Section 5.1.4).

Sediment flux describes the mass of material that moves during a given time step. Sediment fluxes are expressed as suspended load (Figure 6-7), bedload (Figure 6-8), and suspended sediment by sediment size class (Figure 6-9). The sediment flux is determined at the downstream end of each geomorphic reach. Note that flow entering the marshplain/floodplain in MSR1 above Swain Slough occurs from the upstream floodplain (MSR2), and to a lesser extent over low areas of the levees. Flow and sediment that enter these areas only exit the floodplain through tide gates. The tide gate and drain fluxes are not directly accounted for in the sediment flux analysis. However, the sediment flux analysis captures the flux from the tide gates back to the channel by accounting for the increase in channel downstream flux between MSR2 and MSR1 above Swain.

The marshplain/floodplain downstream of Swain Slough is effectively leveed from the channel and do not receive significant overbank flows.

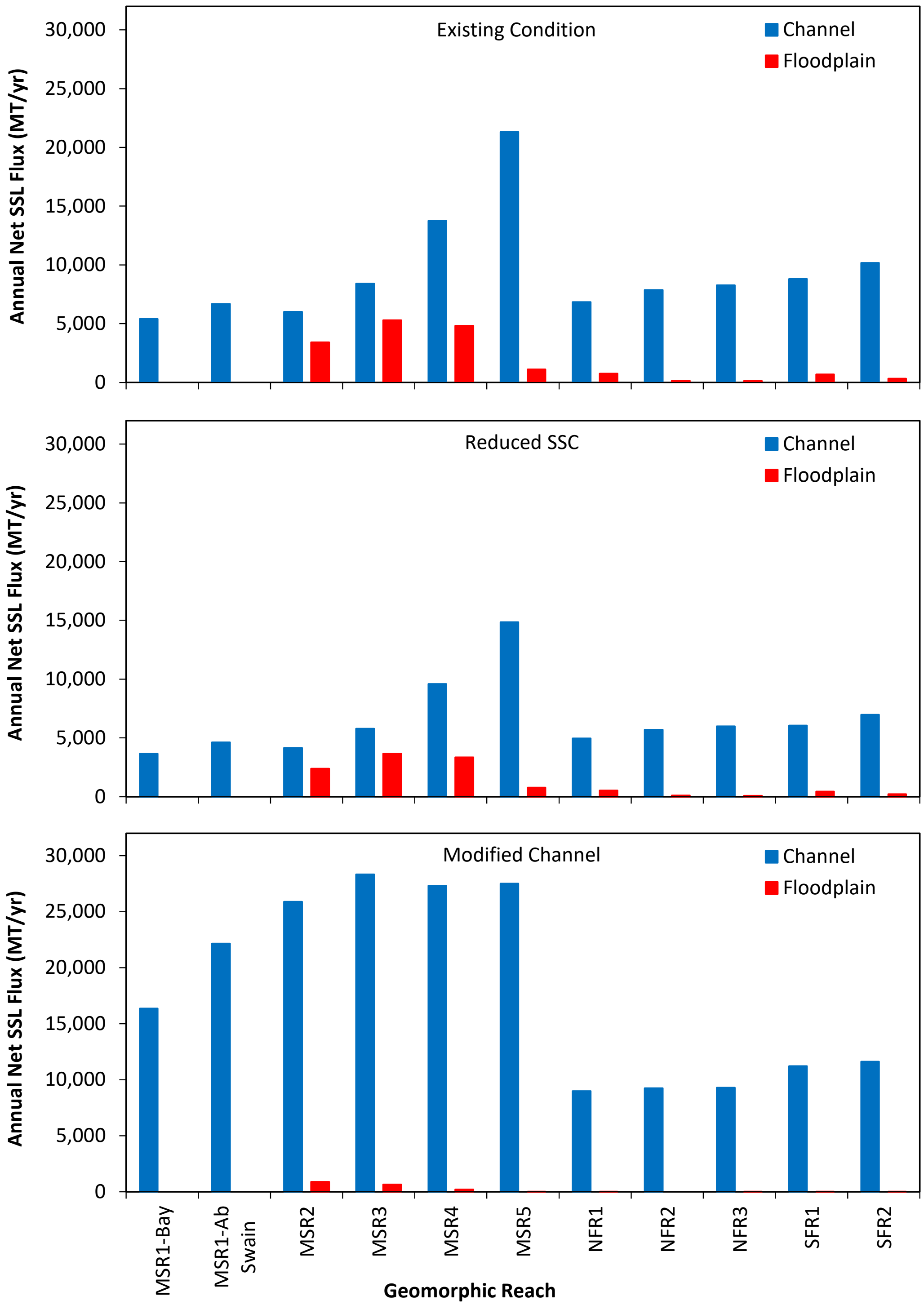

Figure 6-7. Annual net suspended sediment load (SSL) flux by geomorphic reach for Existing Condition, Reduced SSC, and Modified Channel scenarios for the 13-yr long-term simulations (WY2003–2015).

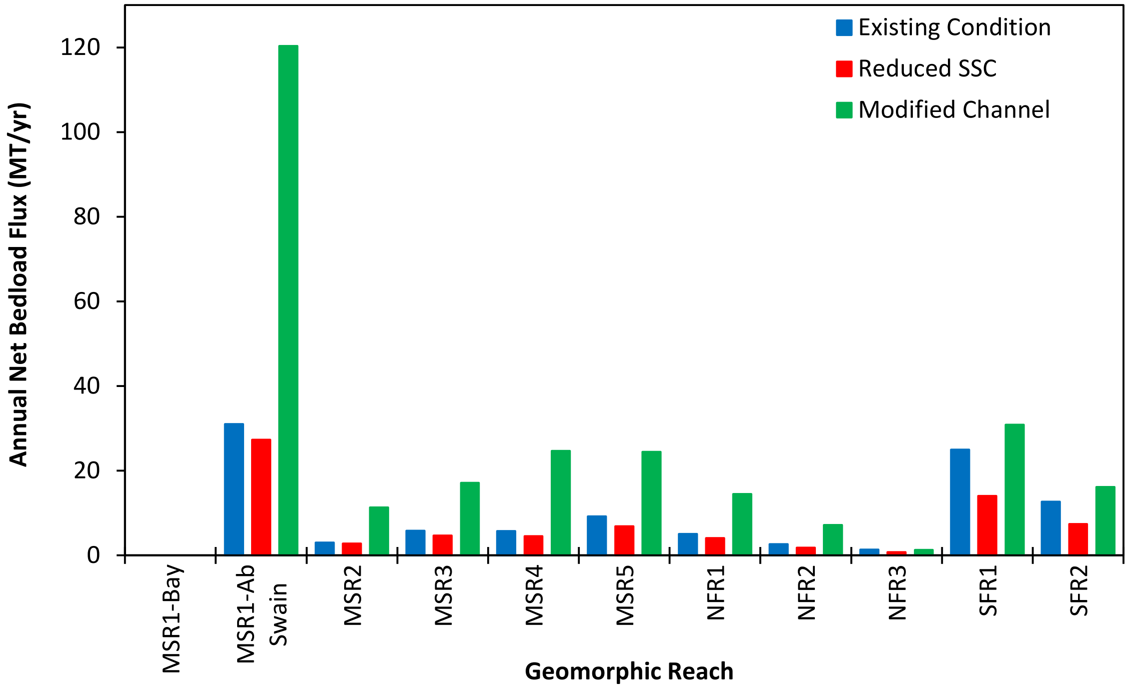

Figure 6-8. Annual net bedload flux by geomorphic reach for Existing Condition, Reduced SSC, and Modified Channel scenarios for the 13-yr long-term simulations (WY 2003–2015).

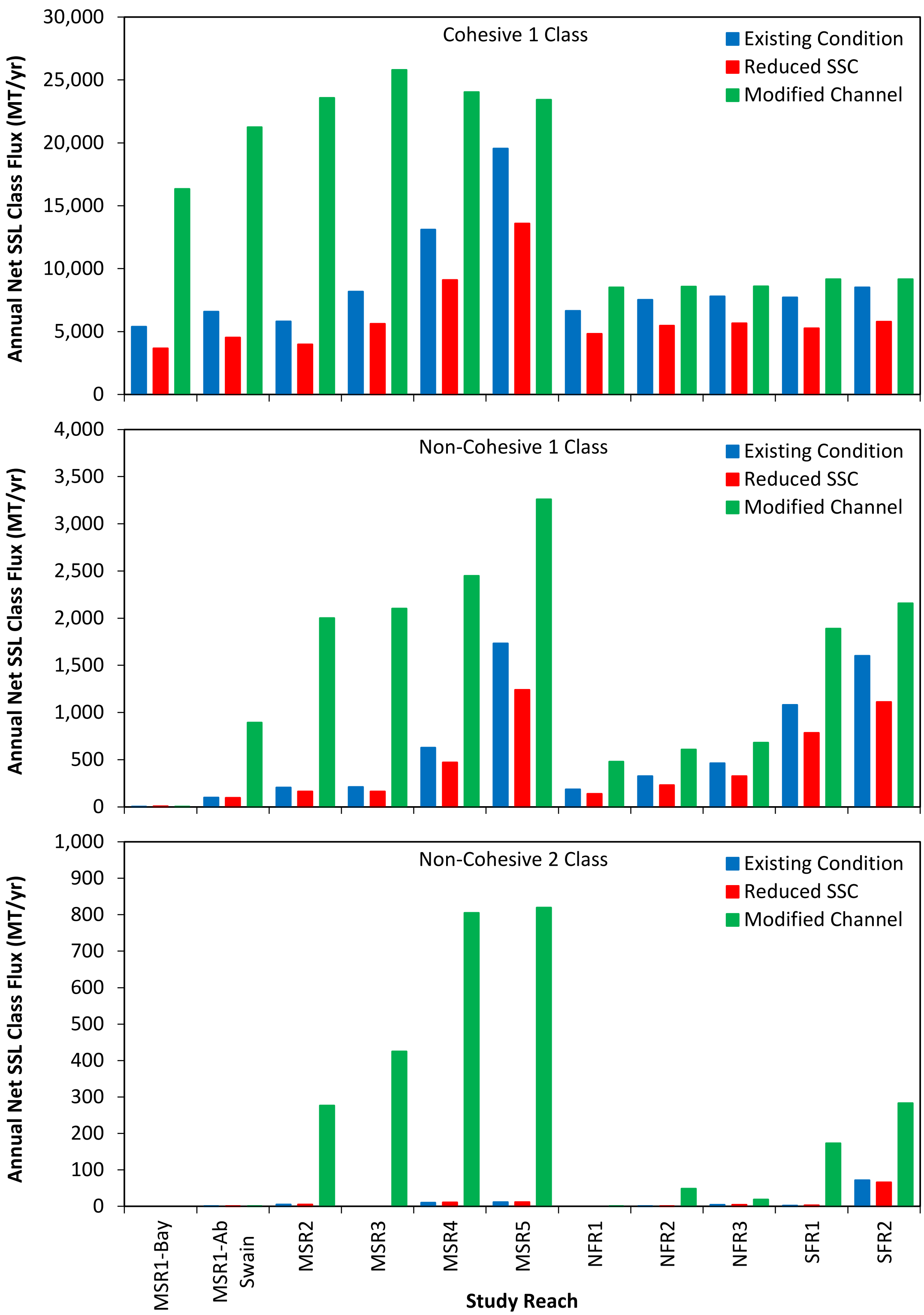

Figure 6-9. Annual average channel suspended sediment load (SSL) flux for Coh1 (d<0.045 mm), NonCoh1 (0.045<d<=0.15 mm), and NonCoh2 (0.15<d<=0.5 mm) classes by geomorphic reach for Existing Condition, Reduced SSC, and Modified Channel scenarios for the 13-yr long-term simulations (WY 2003–2015).

Fluxes are expressed on an average annual basis for the ERRA analyses and computed at the downstream end of each geomorphic reach. A substantial shift in sediment flux occurs in the Modified Channel scenario compared to Existing Condition, particularly in the lower Mainstem Elk River reaches downstream of Elk River Court (Figure 6-7). Sediment fluxes in the lower reaches decline in the downstream direction for Existing Conditions and Reduced SSC scenarios due to floodplain fluxes but are elevated through the fluvial reaches for the Modified Channel scenario due to reduced floodplain flow. Total sediment flux declines in the tidal reaches due to lower SSC floodplain flows re-entering the channel, sedimentation in the channel and adjacent marshplain and floodplain, and mixing with less turbid bay water.

Sediment flux calculations indicate bedload transport is low relative to suspended sediment flux across the channel and floodplain, generally 2 to 3 orders of magnitude less. The general longitudinal pattern of bedload transport is similar for the Existing Condition, Reduced SSC, and Modified Channel scenarios (Figure 6-8). This result differs from suspended sediment flux and storage patterns which are substantially different between Existing Conditions and Modified Channel scenarios. The highest bedload transport rates occur in South Fork Elk River and the tidal reach (MSR1 above Swain). A peak in bedload transport also occurs in MSR5 and declines to a minimum in MSR2. The Modified Channel scenario increases bedload transport across all reaches. This result indicates the channel has a higher capacity to modify the channel bed including scouring pools, building bars, sorting bed material, and imbricating the bed, which collectively would lead to an increase in channel complexity and may increase bulk density throughout the system.

The total suspended sediment load is broken down by sediment class Coh1 (d<0.045 mm), NonCoh1 (0.045<d<=0.15 mm) and NonCoh2 (0.15<d<=0.5 mm) for the three management scenarios (Figure 6-9). The other non-cohesive sediment classes (NonCoh3 to NonCoh5) do not substantially contribute to the suspended sediment load for any management scenario and only move as bedload. These sediment classes are transported at different rates depending on local flow hydraulics. The Existing Condition and Reduced SSC scenarios show similar patterns of transport of different grain size classes, with the Existing Condition having higher loads relative to the Reduced SSC scenario. The Modified Channel scenario has substantially higher loads for all grain sizes including the cohesive load. Grains <0.15 mm (Coh1 and NonCoh1) increase across all reaches. Grains between 0.15–0.5 mm (NonCoh2) generally aren't transported in significant amounts in most reaches for Existing Condition and Reduced SSC scenarios. The Modified Channel scenario substantially increases the transport of this size class in all reaches, except NFR1 and the tidal reaches. The increase in transport of the finer grain sizes (Coh1, NonCoh1 and NonCoh2) in the channel is critical for coarsening of the channel bed, as the Existing Channel bed consists of a high fraction of these finer grain sizes (Figure 5-3).

6.5 Channel Response to Management Scenarios

The channel response to the management scenarios is expressed in changes to the channel substrate (Figure 6-10), erosion and deposition of the channel bed (Figure 6-11 and Figure 6-12), channel geometry changes (Figure 6-13 and Figure 6-14) and rate of channel infilling (Figure 6-15).

The existing channel substrate in the Elk River was mapped as part of the ERRA (see Section 3.5 Channel Sediment Composition and Appendix E). A distinct dip in the substrate size was observed in the North Fork Elk River reaches NFR2 and NFR1 (Figure 3-16). Over the long-term simulation for Existing Condition, fining is predicted in all reaches except NFR2, which is predicted to coarsen (Figure 6-10). The Reduced SSC scenario shows a similar trend in all reaches, with coarsening occurring in both of the upper reaches of the North Fork Elk River (NFR3 and NFR2). The Modified Channel scenario results in coarsening throughout the Mainstem Elk River above the tidal reach (MSR1) and in the North Fork Elk River and South Fork Elk River (Figure 6-10).

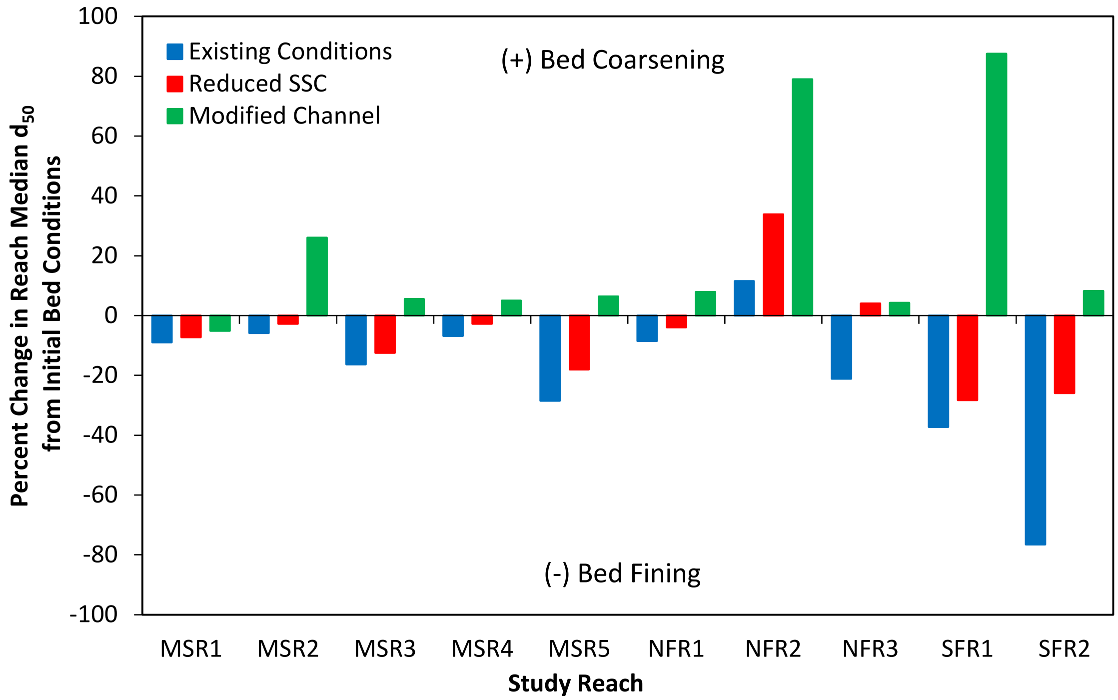

Figure 6-10. Percent change in channel bed d_{50} (top-layer of HST bed grid) from initial conditions by geomorphic reach for Existing Conditions, Reduced SSC, and Modified Channel scenarios for the 13-yr long-term simulations (WY2 2003–2015).

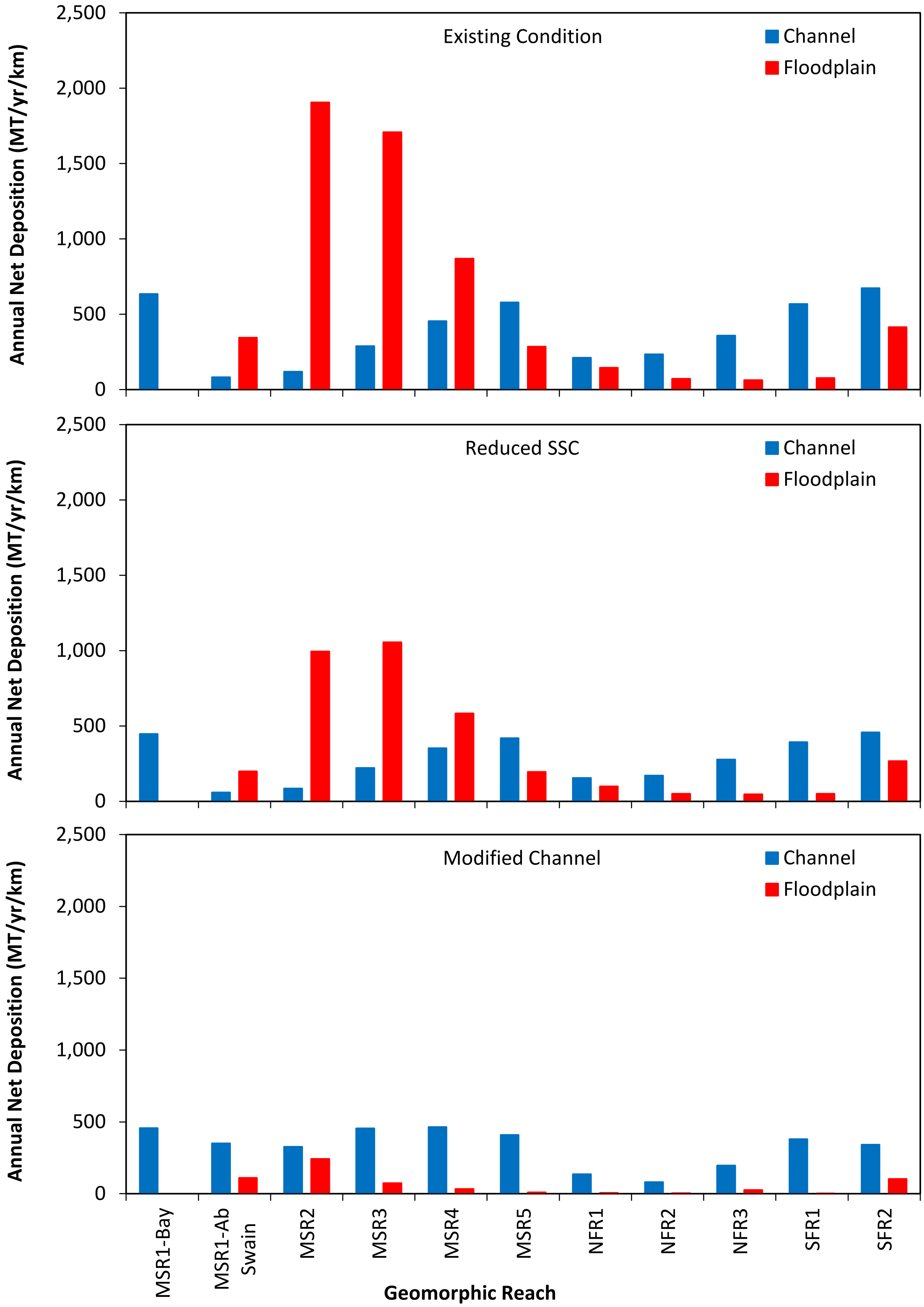

Figure 6-11. Annual net deposition by geomorphic reach (normalized by reach length) for Existing Conditions, Reduced SSC, and Modified Channel scenarios for the 13-yr long-term (WY 2003–2015).

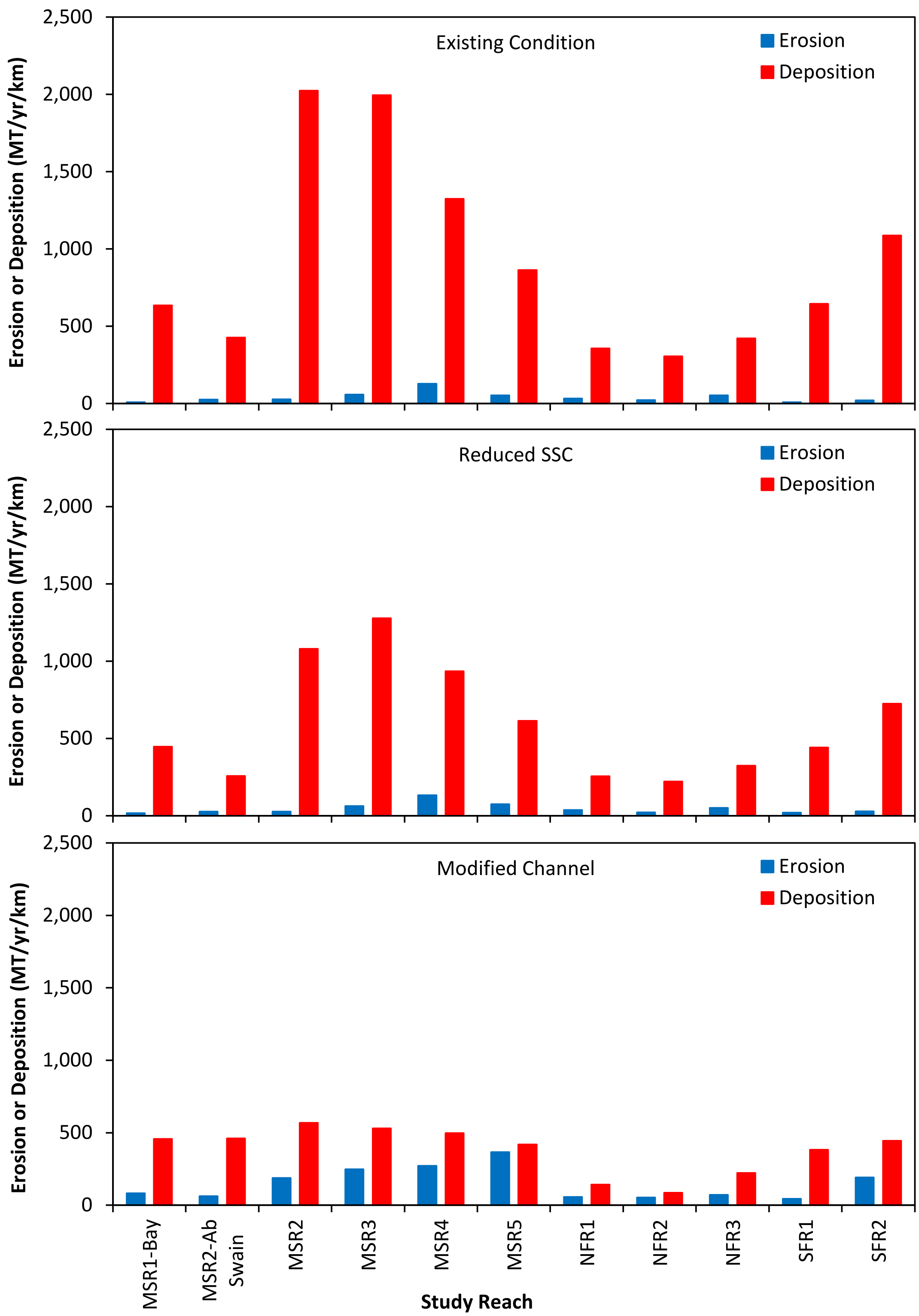

Figure 6-12. Annual channel erosion and deposition by geomorphic reach (normalized by reach length) for the Existing Condition, Reduced SSC, and Modified Channel scenarios for the 13-yr long-term simulations (WY 2003–2015).

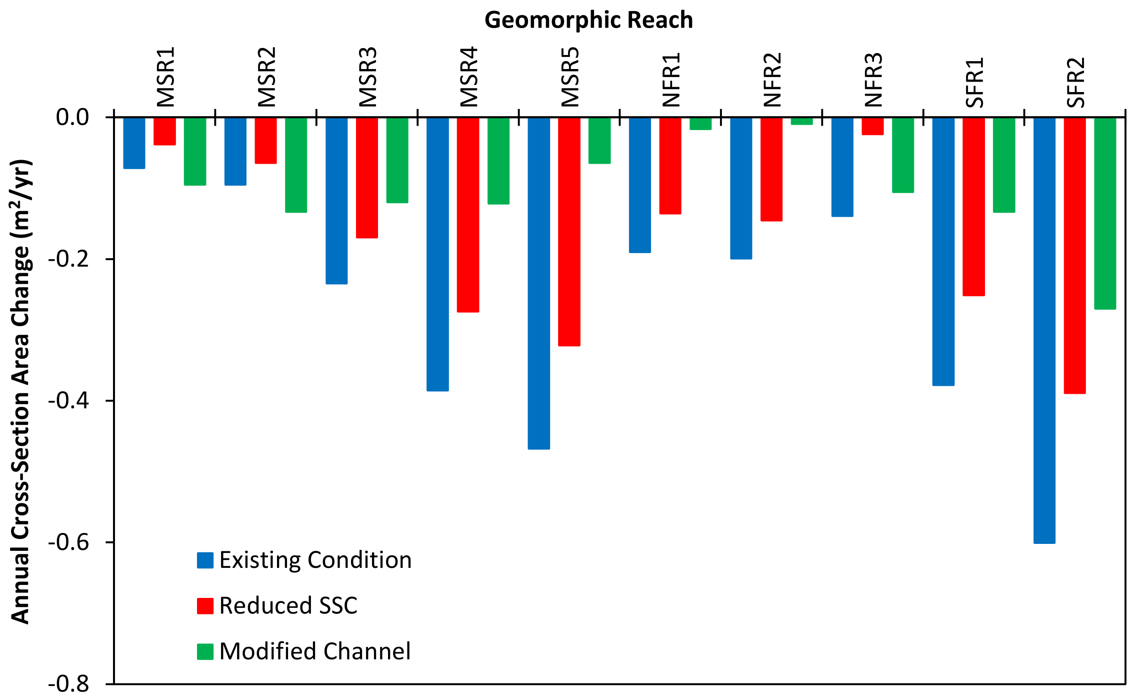

Figure 6-13. Annual average channel cross-sectional area changes by geomorphic reach for Existing Condition, Reduced SSC, and Modified Channel scenarios for the 13-yr long-term simulations (WY 2003–2015).

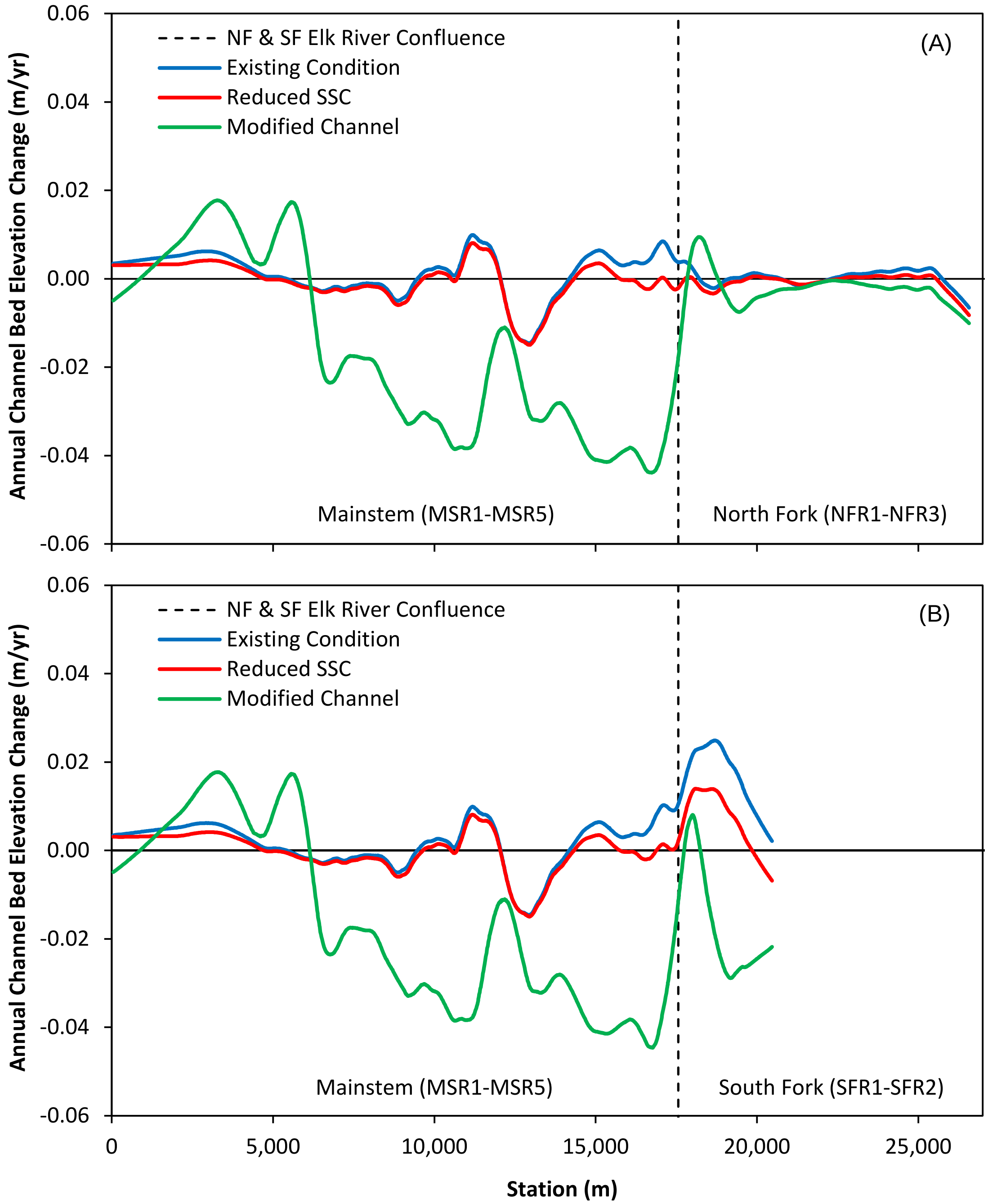

Figure 6-14. Annual average channel bed profile change (LOESS smoothed) for the Mainstem Elk River and North Fork Elk River (A) and Mainstem Elk River and South Fork Elk River (B) for Existing Condition, Reduced SSC, and Modified Channel scenarios for the 13-yr long-term simulations (WY 2003–2015).

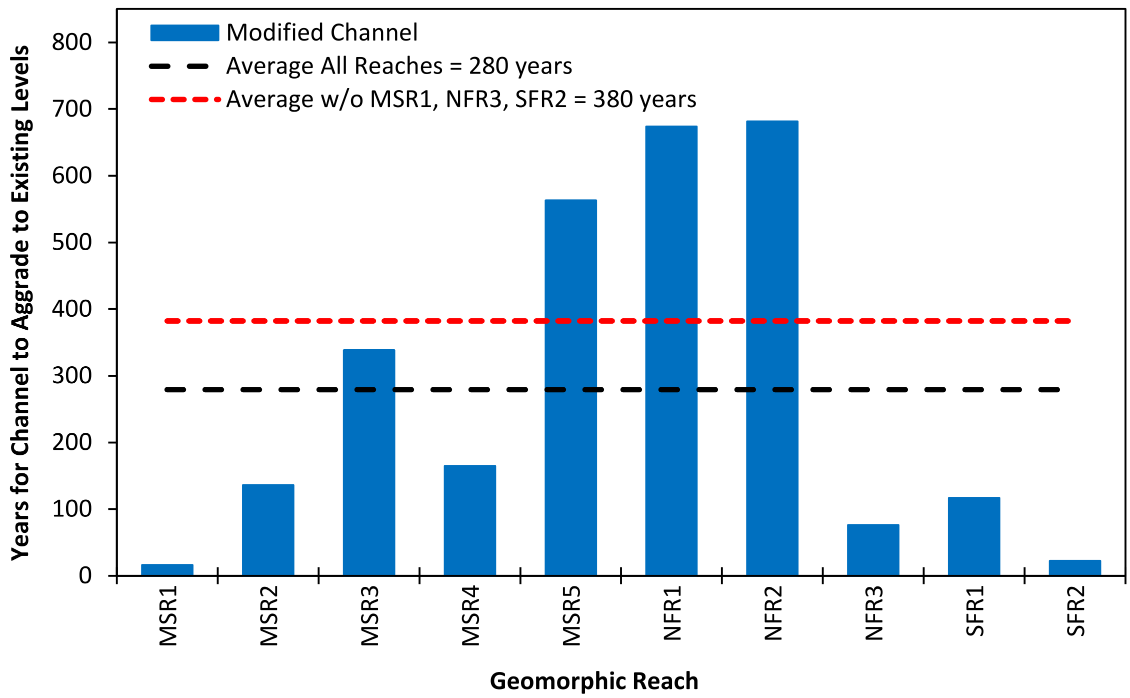

Figure 6-15. Number of years to aggrade the Modified Channel scenario to existing levels, based on the 13-yr long-term simulation (WY 2003–2015). Years to refill based on HST model parameters and assumptions.

Net deposition in the channel and floodplain varies longitudinally with the highest depositional rates occurring in the South Fork Elk River, the upstream end of the Mainstem Elk River (MSR5), and the tidal reach (MSR1) (Figure 6-11). Depositional rates in the Mainstem Elk River channel decline as floodplain deposition increases through MSR2.

Within the channel, a comparison of erosion and deposition rates (Figure 6-12) demonstrates channel bed activity, which indicates potential for development of channel complexity. In areas where there is a lot of deposition relative to scour, low amplitude bar forms may dominate the channel bed. In areas with more balanced erosion and deposition, there exists higher potential for bar forms with greater relief that may be formed through a combination of bar building and pool scour. The Existing Condition and Reduced SSC scenario depositions are high relative to erosion in all reaches (Figure 6-12). The Modified Channel scenario has significantly lower channel deposition rates compared to the Existing Condition and Reduced SSC scenarios (Figure 6-12). Although the Modified Channel scenario has net deposition, erosion increased throughout all reaches (Figure 6-12, which indicates a higher potential for pool development and sediment sorting as more sediment exchange occurs.

Cross-sectional channel change was evaluated using the Existing Condition, Reduced SSC, and Modified Channel scenario model outputs for the 13-year long-term simulation. The results demonstrate that reduction in channel cross-sectional area from sediment aggradation is largest for Existing Conditions in all fluvial reaches of the Elk River (from MSR3 to the upper reaches of the North Fork Elk River and South Fork Elk River) (Figure 6-13). The Modified Channel scenario has the lowest cross-sectional area change in all reaches, except for the tidal reaches

(MSR1 and MSR2), due to the increased downstream channel fluxes from upstream reaches (Figure 6-7, Figure 6-8 and Figure 6-9).

The channel bed changes do not differ substantially between the Existing Condition and Reduced SSC scenarios. However, the Modified Channel scenario has a higher potential for channel bed change with some scour predicted in the MSR3 to MSR5 reaches, and deposition predicted in MSR1 and MSR2 (Figure 6-14). Since the cross-sectional area in the Modified Channel scenario still decreases (Figure 6-13), this indicates that the majority of sediment accumulation is occurring on the channel banks.

The Reduced SSC scenario slows the aggradation rate but does not increase cross-sectional area, resulting in no net export of stored sediment. The channel size will still diminish over time, albeit at a slower rate than under Existing Conditions. The Modified Channel scenario is also aggradational (Figure 6-13). Removing sediment from the channel does not result in scouring or long-term expansion of the channel cross-sectional area, but all the channel reaches upstream of MSR2 return to a slower long-term aggradation rate more typical of a low-gradient coastal floodplain. Increased sediment transport capacity in the reaches results in more sediment routed to the lower-gradient downstream estuary reaches (MSR1 and MSR2), resulting in slightly higher aggradation rates in these reaches than Existing Conditions.

Sediment impaired reaches of Elk River are located within a naturally aggrading coastal floodplain. Thus, one of the key concerns about any action that removes sediment from the channel is how quickly subsequent aggradation would occur. Predicted channel responses (e.g., aggradation rates) to the Modified Channel scenarios over the 13-year long-term simulation period were projected into the future to estimate the likely time required for the channel to evolve back to its current aggraded condition (Figure 6-15). The time varies between reaches depending on sediment loads entering the reach and the amount of channel excavation anticipated under the Modified Channel scenario. Predicted aggradation rates under the Modified Channel scenario indicates the channel would likely require an average of 280 years to evolve from the excavated condition back to the current aggraded condition (Figure 6-15). This average time period increases to 380 years if transitional reaches that have less excavation in the Modified Channel scenario (i.e., NFR3, SFR2, and MSR1) are excluded. NFR1, NFR2, and MSR5 have infill rates of approximately 600 years or more. These estimated time frames for the excavated channel to evolve back to the current aggraded condition will lengthen as TMDL implementation reduces upstream sediment loads. Furthermore, anticipated increases in sediment bulk density for the Modified Channel scenario would also extend these time frames.

6.6 Suspended Sediment Concentration

Suspended sediment concentrations vary throughout the channel network under existing conditions, and the magnitude of response to Reduced SSC and Modified Channel scenarios varies among geomorphic reaches (Figure 6-16, Table 6-11, Figure 6-17). The general longitudinal pattern for both Existing Condition and Reduced SSC scenarios is a downstream decline in suspended sediment concentrations in the North Fork Elk River and South Fork Elk River. SSC are higher in the upper Mainstem Elk River (MSR5) than in the North Fork Elk River and are consistent with concentrations in the South Fork Elk River. Concentrations in the upper Mainstem Elk River (MSR5) are elevated above what would be expected from a mixing of the North Fork Elk River and South Fork Elk River due to sediment inputs from Railroad Gulch and Clapp Gulch. SSC declines in the downstream direction as a result of sediment deposition in the channel and floodplain and lower concentration floodplain return flows (Figure 6-16 and Figure 6-17). The downstream most tidal reach (MSR1) has distinctly lower concentrations due to mixing with less turbid bay water (Figure6-16 and Figure 6-18).

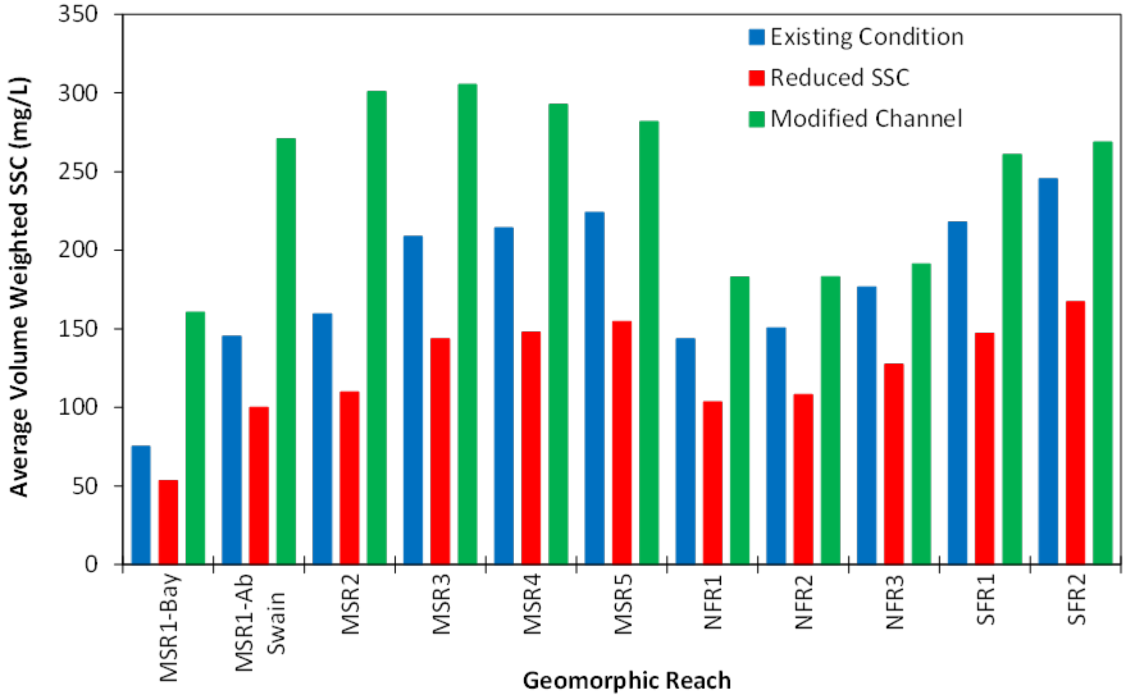

Figure 6-16. Annual average channel volume weighted suspended sediment concentration (SSC) by geomorphic reach for Existing Condition, Reduced SSC, and Modified Channel scenarios for the 13-yr long-term simulations (WY 2003–2015). Average values assume SSC data is lognormally distributed.

Table 6-11. Statistical summary of volume weighted suspended sediment concentration (SSC) by geomorphic reach for Existing Condition, Reduced SSC, and Modified Channel scenarios for the 13-yr long-term simulations (WY 2003–2015).

Parameter	Management scenario	SSC (mg/L) by geomorphic reach										
		MSR1-Bay	MSR1-Ab Swain	MSR2	MSR3	MSR4	MSR5	NFR1	NFR2	NFR3	SFR1	SFR2
Assumed data is lognormally distributed												
Average	Existing Condition	75.2	145	160	209	214	224	144	151	176	218	245
	Reduced SSC	53.5	100	110	144	148	155	103	108	128	147	167
	Modified Channel	161	271	301	305	293	282	183	183	191	261	269
Standard Deviation	Existing Condition	91.3	151	166	255	269	263	176	188	217	279	324
	Reduced SSC	60.3	104	114	176	188	184	128	137	158	191	220
	Modified Channel	293	352	373	381	377	360	234	240	246	392	388
Median	Existing Condition	47.8	101	110	132	133	145	91.0	94.1	111	134	148
	Reduced SSC	35.5	69.3	75.9	90.9	91.5	99.5	65.0	67.0	80.1	90.0	101
	Modified Channel	77.2	165	189	191	180	174	113	111	117	144	153
Based on ranked data												
Minimum	Existing Condition	5.0	8.8	14.6	16.3	17.1	18.5	12.7	12.4	14.9	11.1	12.0
	Reduced SSC	4.3	6.1	10.4	11.5	11.9	12.7	9.1	8.8	10.6	7.5	8.3
	Modified Channel	5.4	11.4	19.4	20.7	19.0	18.2	14.7	13.9	15.2	9.2	10.6
Quartile 1 (25%)	Existing Condition	23.1	55.2	59.2	65.4	64.8	74.0	44.4	45.1	54.0	66.0	71.4
	Reduced SSC	17.6	37.8	40.6	44.7	44.1	50.2	31.5	31.9	38.7	44.1	48.5
	Modified Channel	30.0	79.6	92.1	92.1	85.0	83.0	53.4	51.7	55.4	64.9	69.9
Quartile 2 (50%, median)	Existing Condition	48.5	101	106	116	114	127	78.4	81.5	96.4	122	135
	Reduced SSC	35.3	69.4	72.4	79.2	78.0	86.5	55.8	57.9	69.0	81.3	92.0
	Modified Channel	68.1	154	168	171	160	155	97.5	95.7	100	130	140
Quartile 3 (75%)	Existing Condition	88.3	171	191	247	248	259	162	170	203	246	278
	Reduced SSC	63.2	118	132	171	171	179	116	121	146	166	189
	Modified Channel	191	326	355	358	344	329	207	207	219	296	308
Maximum	Existing Condition	2014	3,267	3,899	4,326	5,242	5,474	5,163	5,382	5,779	7,015	7,811
	Reduced SSC	1446	2,219	2,629	2,982	3,633	3,839	3,768	3,926	4,220	4,772	5,315
	Modified Channel	2592	4,009	4,847	5,867	6,254	6,262	5,531	5,584	5,932	7,345	8,095

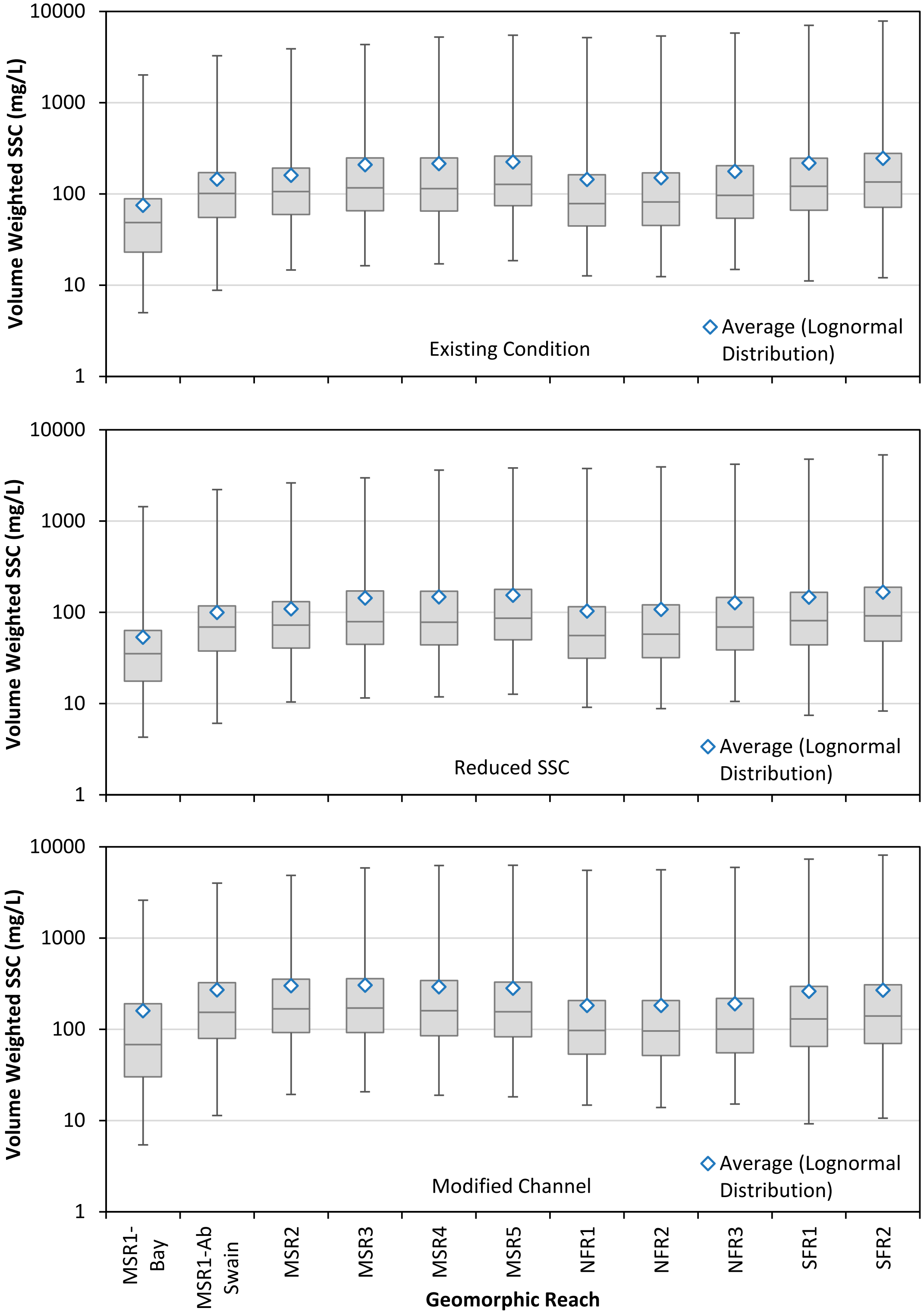

Figure 6-17. Box plot of volume weighted suspended sediment concentration (SSC) by geomorphic reach for Existing Condition, Reduced SSC, and Modified Channel scenarios for the 13-yr long-term simulations (WY 2003–2015). Average value assume SSC data is lognormally distributed.

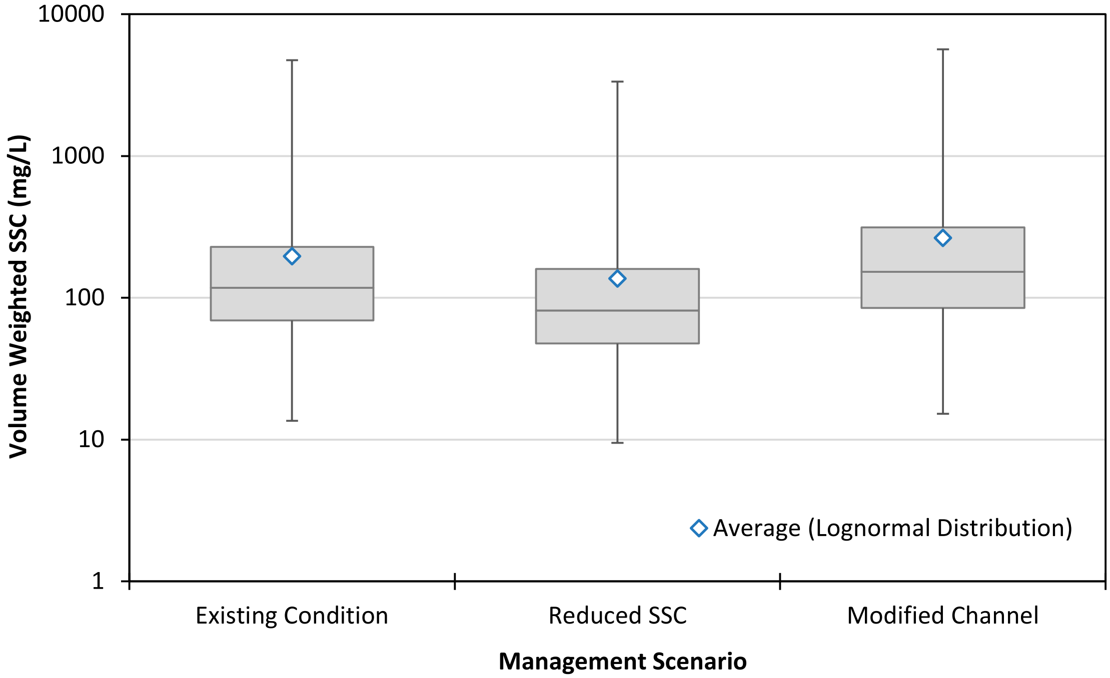

Figure 6-18. Box plot of volume weighted suspended sediment concentration (SSC) for all reaches except MSR1 for Existing Condition, Reduced SSC, and Modified Channel scenarios for the 13-yr long-term simulations (WY 2003–2015). Average value assume SSC data is lognormally distributed.

The magnitude of the sediment reduction at the boundary conditions (Figure 5-2) for the Reduced SSC scenario (roughly 30%) translated to a similar magnitude reduction across all reaches in the Project area (Figure 6-16, Figure 6-17 and Figure 6-18). This result indicates that for the existing channel geometry, concentration reductions can improve SSC in all downstream reaches. This result is consistent with the prediction that existing sediment stored in the channel is stagnate and will not scour for the Reduced SSC scenario, and the amount of new aggradation that occurs in the Project area is dependent on the sediment supply at the boundary conditions.

The lowest concentrations that occur in a given reach indicate whether the river tends to clear between storm events. The model results are limited to SSC predictions for flows greater than approximately 1 to 3 cms (35 to 106 cfs). The trends observed for minimum SSC (decreases in the downstream direction) are similar to those observed for peak SSC for Mainstem Elk River (Table 6-11 and Figure 6-17). However, the minimum SSC in Mainstem Elk River above the tidal reaches (MSR3 to MSR5) are higher than in the North Fork Elk River and South Fork Elk River. Although the South Fork Elk River has the higher concentrations throughout the majority of the storm period, the South Fork reaches a lower minimum concentration than Mainstem Elk River and consistent with the lower North Fork Elk River (Table 6-11). These results suggest that the minimum concentrations in Mainstem Elk River are being further elevated by tributaries entering the Mainstem Elk River (e.g., Railroad Gulch and Clapp Gulch), and both forks of the Elk River may be cleaner between storm periods than Mainstem Elk River. These results are based on model predictions only. Data collected at stream gauges on the North Fork Elk River, South Fork Elk River and Mainstem Elk River could help to better inform this question; however, the current gauge on the mainstem at Steel Bridge is upstream of Clapp Gulch, and thus, would only capture the influence of Railroad Gulch. The lower flow gauge data was not evaluated as part of this study.

The Modified Channel scenario generally increases SSC throughout the channel network, likely due in part to tributary inputs. The magnitude of decline in SSC in the downstream direction in the North Fork Elk River and South Fork Elk River is muted. Contrary to Existing Conditions, a small increase in concentration occurs in the downstream direction from MSR5 to MSR3, followed by a slight decline through the upper tidal reaches (MSR2 and MSR1 above Swain). A pronounced decline occurs in the downstream most tidal reach, due to dilution with lower SSC bay water. The average SSC for the Modified Channel scenario is higher than Existing Conditions in all reaches. The difference in concentrations between the Modified Channel scenario and Existing Conditions decline for the minimum and maximum concentrations in the reach (Table 6-11 and Figure 6-17).

The overall higher concentrations in the Modified Channel scenario (Figure 6-18 and Figure 6-19) are attributed to increased transport capacity of the stream to route sediment (particularly fine sediment) through the Project area. The Modified Channel scenario does not shift the channel to an erosive channel that produces more sediment. Rather, the channel remains depositional (absorbing more sediment than is produced from erosion) and simply conveys the delivered sediment from the boundary conditions (i.e., upstream watershed SSC) through the Project area. However, the increased conveyance reduces deposition rates in the channel and adjacent floodplains compared to Existing Conditions.

The primary way to reduce SSC throughout the Project area is to reduce sediment concentrations entering at the boundary conditions of the HST model from the upper watersheds and tributaries. SSC reductions at the boundary conditions produced lower concentrations across all flows (Figure 6-18 and Figure 6-19). Within the Project area, sediment deposition zones that are frequently flooded and return lower concentration water to the channel can reduce concentrations in the main channel as shown by trends of reduced SSC in the downstream direction for Existing Conditions and Reduced SSC scenario. Reducing the in-channel and floodplain sedimentation rates results in higher SSC in the channel throughout the Project area.

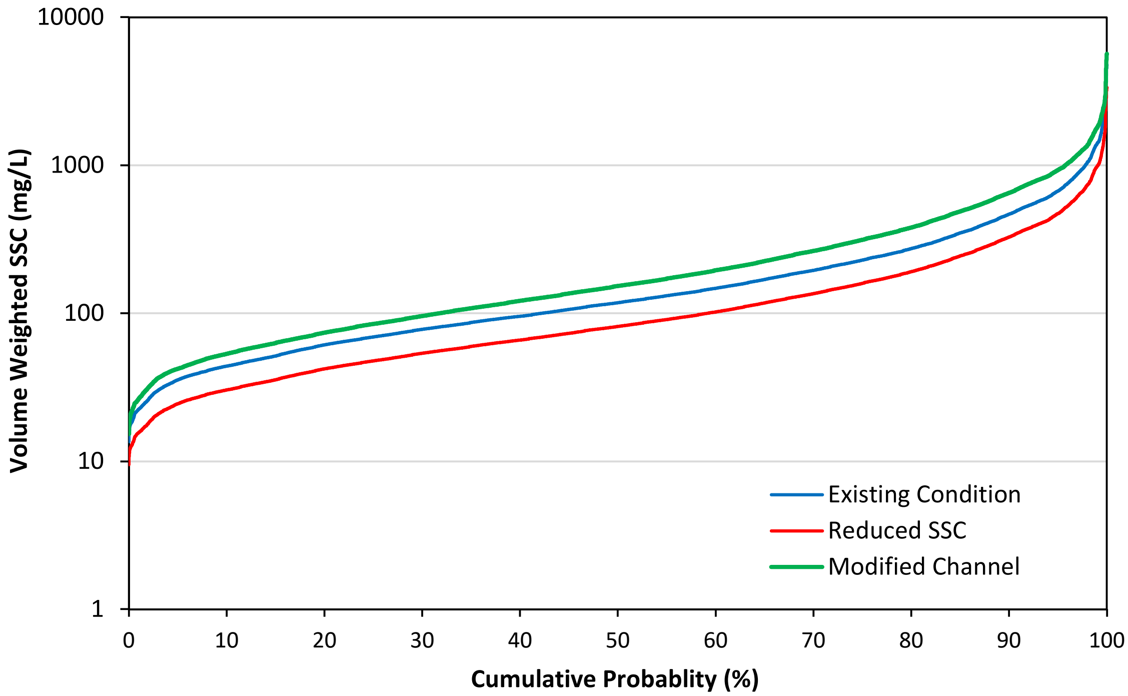

Figure 6-19. Cumulative frequency plot of volume weighted suspended sediment concentration (SSC) for all reaches except MSR1 for Existing Condition, Reduced SSC, and Modified Channel scenarios for the 13-yr long-term simulations (WY 2003–2015). Average value assume SSC data is lognormally distributed.

6.7 Salmonid Habitat

The effects of high suspended sediment concentrations and aggraded channel conditions on the physiology, behavior, and habitat conditions of salmonids were not directly studied, but are based on measurements of channel substrate; pool frequency and depth; wood size and frequency; channel geometry; stream temperature in the intensive study reaches (see Appendix E); channel and floodplain connectivity; and measured and predicted SSC. These predicted habitat effects resulting from impaired water quality conditions are inferred from the extensive literature on salmonid ecology. Habitat conditions may have been historically more uniform within the functional habitat reaches in the Project area outlined in Section 4, which were the upper forks and tributaries (NFR3, NFR4), upper Mainstem Elk River and lower forks (MSR5, SFR1, SFR2, NFR1, NFR2), lower Mainstem Elk River (MSR3, MSR4), and the stream-estuary ecotone (MSR1, MSR2), but habitat impairments have affected portions of these functional habitat reaches differently.

The SEV analysis presented in Section 4.2.2 was repeated for each modeling scenario with SSC data generated from the hydrodynamic model. These data differ slightly from the data used in the Lewis (2013) SEV analysis: Lewis used Salmon Forever KRW and SFM data, whereas the ERRA used data predicted from the HST model for flows greater than 1 to 3 cms (Q-threshold) at those locations. Recall that the exceedance durations used in the SEV analyses represent the *maximum continuous durations* above the given SSC that occurred in any given year, not the total duration. In summary, the SEV analysis based on Newcombe and Jensen (1996) and HST model predicted SSC included the following comparisons:

1. Existing Condition scenario (HST model predicted SSC data),
2. Reduced SSC scenario vs. Existing Condition scenario, and
3. Modified Channel scenario vs. Existing Condition scenario.

To evaluate SEV scores from modeling scenarios and observed data, we used the paired Student's t-test (Hsu & Lachenbruch 2005), Wilcoxon signed-rank test (Wilcoxon 1945), the R_V coefficient (Robert and Escoufier 1976), and estimates from ordinary linear regression. Both the Student's t-Wilcoxon signed-rank test compares the differences in the mean between paired samples (i.e. the SEV scores between scenarios and the observations). Student's t assumes differences are normally distributed, while Wilcoxon compares the sample ranks and is thus non-parametric. R_V is a multivariate generalization of the squared Pearson's correlation, and the statistic's usage assumes SEV scores for each SSC threshold are independent; in other words, RV measures the closeness of two matrices. Finally, regressing SEV scores from one scenario to another or to the observations can indicate the magnitude of the differences via the regression intercept and slope coefficient.

Based on the analysis of sediment impairment and consequent nuisance flooding, and degradation of physical habitat and water quality presented in previous sections of this report, we evaluated these findings to better understand if the three management scenarios will enable salmonid-related beneficial uses to be supported in Elk River.

6.7.1 Existing conditions scenario

Under the Existing Conditions management scenario, salmonids and other native aquatic species inhabiting Elk River are severely affected by impaired aquatic habitat conditions resulting from high suspended sediment concentrations and aggraded channel conditions. Effects on salmonid physical habitat include reduced pool volumes and depths; reduced large wood material (LWM) volumes; embedded and buried riffle substrates with low food production rates; changes in hyporheic flows affecting egg incubation, alterations to water temperature regimes; low dissolved oxygen concentrations; and overall reduction in habitat area. These impaired habitat conditions generally affect incubating eggs, newly emergent alevins and young-of-year parr, and juvenile life stages. Adult salmonid life stages may also be affected, but likely less so than immature fish. Years of cumulative sediment aggradation have resulted in changes to channel confinement and access to floodplain refugia. These changes include reduced access to in-channel benches that have become aggraded, and increased potential for fish entrainment in flood flows onto floodplains in the lower mainstem and estuary reaches. Entrainment here could result in fish stranding and mortality where return flows are intercepted by tile drains, roads, ditches, and tide gates. Physiological and behavioral effects are also severe under Existing Conditions and may include gill abrasion; effects on blood physiology; disruption to osmoregulation during smolting; avoidance of adverse conditions through emigration; impaired foraging success; and reduced growth rates that ultimately may result in reduced marine survival (Bash et al. 2001).

The Severity of Ill Effects analysis based on Newcombe and Jensen (1996) presented in Section 4.3 predicted sub-lethal effects on juvenile salmonids, and sub-lethal and lethal effects (20–40% mortality) on salmonid eggs and larvae in most hydrologic years of the simulation period. These water quality conditions, measured at KRW and SFM monitoring stations, presumably apply throughout the reaches (i.e., NFR2, NFR1 and SFR1) where stations were located. Assuming a relationship between the average annual concentrations predicted by the HST model (Figure 6-16) and the Severity of Ill Effects Index, similarly impaired conditions also occur in all reaches of Elk River.

The maximum continuous hours above the specified SSC for the observed SSC (Section 4.2.2) was computed for the Existing Conditions scenario. The SEV analysis for Existing Conditions using ERRA SSC data (comparable to the SEV analysis presented in Table 4-2) is presented in Table 6-12. SEV was computed for the same water years as in Lewis (2013) to accommodate more direct comparisons.

Comparison of Observed SEV (Lewis 2013) (Table 4-2) to ERRA Existing Conditions SEV (Table 6-12) shows very similar SEV scores despite using different data sets. There was a slight shift toward lower SEV scores in the Existing Conditions using predicted SSC data. But changes in the SEV scores (comparing predicted SSC to observed SSC) had absolute values less than one in nearly all SSC thresholds and WY's; thus, the response category of the SEV score (the expected salmonid response) did not significantly change. Therefore, for a description of the SEV results (impacts to salmonid functions) for Existing Conditions, refer to Section 4.2.2.

Under the Existing Conditions scenario, the sediment oxygen demand from the decomposing organic matter in the aggraded sediment deposits would continue to impair DO concentrations in specific reaches of the Elk River during critical summer juvenile rearing life stages. The low DO conditions could potentially worsen in the future with continued aggradation.

6.7.2 Reduced SSC scenario

The Reduced SSC scenario relieves some of the physiological and behavioral effects of high SSC, and may slightly improve growth rates and survival of young-of-year and juvenile life stages, but does not alleviate impaired habitat conditions. The Reduced SSC scenario is not likely to increase juvenile abundance and smolt production, and is therefore, alone, not likely to promote recovery of listed salmonid species.

If high SSC and turbidity increases juvenile salmonid migration as an avoidance response, one possible benefit resulting from the Reduced SSC Scenario would be a potential reduction in migration, allowing emergent fry and juveniles to potentially avoid emigration and utilize higher quality rearing habitat in the upper watershed. This outcome could be beneficial to newly emergent fry and juvenile coho salmon and steelhead in the upper forks and tributaries reaches where pool habitat is less degraded than in the middle, confined reaches of Elk River.

Another potential benefit of reduced SSC to juvenile salmonids would be more rapid clearing of water from peak SSC and turbidity levels during winter storm recessions. Improvement of post-peak flood water quality would enable juvenile salmonids to resume feeding during winter baseflows, and thus potentially counterbalance some of the effects of high SSC on salmonids. The HST model analysis was not able to estimate the rate of SSC and turbidity reduction following peak storm events for individual storm hydrographs below 1 to 3 cms.

The SEV analysis with Reduced SSC had a predictable response of reduced maximum durations above each SSC threshold and reduced SEV scores (Table 6-13). However, the very small change in magnitude of the SEV scores was notable: SEV scores were reduced by less than one in nearly all SSC thresholds and WY's; thus the response category of the SEV score didn't change. The implication we surmise is that altering SSC during storm flows (either high or low) doesn't alter the SEV very much. The high SEV numbers are primarily controlled by SSC during the lower flows (< 3 cms) because those values are the same in all model scenarios (Existing Condition, Reduced SSC, and Modified Channel). Much larger reductions than approximately 30% in SSC are needed to reduce SEV by one unit or more.

The SSC values necessary to improve the SEV response (in the positive direction) occur in the Elk River watershed in Little South Fork (station ESL). Lewis computed SEV scores for Little South Fork for WY's 2004 and 2005 (Table 6-14). According to Lewis (Jack Lewis, Personal Communication 2018):

> "While the sediment loads [in Little South Fork (ESL)] in years other than 2004 are not known precisely it is absolutely clear that they must be very small. In 2004, sampling used the TTS method which preferentially samples storm events and high turbidities. Using the same TTS sampling algorithm, 118 of 207 samples at Salmon Forever's SFM (South Fork main stem) station on South Fork Elk River exceeded 100 mg/L, while *none* (of about 50 points) exceeded that value at ESL. The maximum turbidity recorded in 2004 at ESL was 62 NTU on Feb. 16. In contrast, the SFM station reached over 1500 NTU that day and exceeded 200 NTU during 12 different storm events that year. In 2005, the maximum turbidity at ESL was 125, while SFM reached 1600 NTU and exceeded 200 NTU in 20 different events. Chronic turbidity is less variable than the maxima and yet HRC's data (Sullivan et al. 2013) show that on all three of their measures of chronic turbidity, ESL has the lowest of all monitored streams every single year. That includes several subwatersheds that have similar or higher percentages of Yager formation and one watershed (Bridge Creek) that like ESL is apparently without deep-seated landslides. Differences of such a magnitude cannot be explained by the variation in topography, bedrock, or rainfall within the Elk River."

The Reduced SSC scenario would not improve impairments to DO from the decomposing organic matter in the aggraded sediment deposits (sediment oxygen demand), during the critical summer juvenile rearing life stages. The low DO conditions could potentially worsen in the future with continued aggradation.

6.7.3 Modified Channel scenario

The Modified Channel scenario would likely improve channel morphology resulting in better physical habitat conditions for incubating eggs; newly emergent alevins and young-of-year parr; and 1+ and 2+ juvenile life stages. Rearing conditions during non-flood periods (i.e., winter baseflows, spring recession, and summer low-flows) benefit from increased pool habitat and overall rearing habitat capacity; increased volumes of LWM adding to habitat complexity; coarser riffle substrates in some reaches with consequent higher food production rates (Cover et al. 2008, Suttle et al. 2004, NMFS 2016); and colder summer water temperatures resulting from deeper water, more hyporheic flow, and increased shading from an expanded riparian canopy. The Modified Channel scenario would dramatically increase rearing habitat capacity and rearing productivity in the Mainstem Elk River reaches as well as in the stream-estuary ecotone, which provide critical non-natal rearing habitat for juvenile salmonids. Improving habitat for this life-stage would likely release the current winter rearing habitat bottleneck and increase smolt production and average smolt size from Elk River. Wallace et al. (2015) found that about 40% of the coho salmon smolt production from Freshwater Creek originated from the stream-estuary ecotone, and that these fish were larger than their cohorts rearing upstream.

The Modified Channel scenario would also likely maintain connectivity to off-channel and floodplain habitat refugia, but potentially at different flood-flow or high-flow frequencies for different off-channel features. Reconstructing in-channel benches would provide young-of-year and juvenile salmonids access to off-channel habitat during low-to-moderate flood flows in areas that could have lower SSC exposure. Those benches could be constructed to inundate at variable flood exceedances to provide rearing benefits over a range of low to moderate flow magnitudes. During higher flood flows, there would be less frequent connectivity to floodplains, but mortality associated with fish access to floodplain refugia could be reduced by modifying flood-flow pathways and upgrading infrastructure.

The Modified Channel scenario results in higher SSC (Figure 6-16) and duration during storm flows although it is unknown if SSC concentrations recover more quickly after storms pass because modeled flows were truncated at 1–3 cms. The predicted SSC for the Modified Channel scenario indicate that minimum concentrations for flows above 1–3 cms are higher in the North Fork Elk River and Mainstem Elk River and lower in the South Fork. But with higher SSC, the SEV scores also increase under the Modified Channel scenario (Table 6-15). Again, however, the change (increase) is very modest and most increases had absolute values less than one in nearly all SSC thresholds and WY's; thus, the category of the SEV score didn't change.

The net effect of increased SSC on rearing salmonids is difficult to predict when considering the potential mitigating effects of improved rearing habitat. Given that current SSC impairment is high, a marginal increase in SSC concentration and duration during winter flood events may not substantially worsen the existing sub-lethal effects on egg and alevin, young-of-year, and juvenile life stages. Increased SCC predicted by the Modified Channel scenario could be reduced by other recovery actions, such as trapping sediment from tributaries (e.g., Tom's Gulch, Railroad Gulch, Clapp Gulch), building sediment basins within the Project area, or by providing rearing juveniles with better access to floodplain refugia during flood flows, where lower SSC concentrations could persist. Smaller intermittent tributaries and drainages may exist throughout the Project area that have lower SSC that could be developed as refugia areas. These smaller features were not evaluated as part of the ERRA but could be explored with landowners during the Elk River Stewardship Program.

Under the Modified Channel scenario, the aggraded sediment conditions would be remediated throughout the Elk River, which could potentially improve DO concentrations in the confined mainstems reaches during critical summer juvenile rearing life stages. Without aggraded sediment filling pools and burying riffles, organic materials would not become trapped in the bed sediments, the sediment oxygen demand would be alleviated, and DO concentrations would be expected to return to concentrations in the 8–10 mg/L range.

Table 6-12. Severity of Ill Effects (SEV) for North Fork Elk River and South Fork Elk River for Existing Conditions using SSC output from the HST model.

Site/WY[2]	Juvenile salmonids only						Salmonid eggs + larvae					
	Suspended sediment conc. (mg/L)						Suspended sediment conc. (mg/L)					
	SSC 2981	SSC 1097	SSC 403	SSC 148	SSC 55	SSC 20	SSC 2981	SSC 1097	SSC 403	SSC 148	SSC 55	SSC 20
SF 2003	8.3	8.3	7.8	7.8	7.6	7.8	9.1	9.9	10	10.7	11.3	12.4
NF 2003	8.1	8.2	7.7	7.7	7.1	7.3	8.9	9.8	9.8	10.6	10.5	11.6
SF 2004	0	7.6	7.9	7.4	6.9	6.8	0	8.8	10	10.1	10.1	10.7
NF 2004	0	6.8	7.3	7.2	6.7	7.2	0	7.6	9.2	9.8	9.9	11.4
SF 2005	0	6.9	7	6.9	7	7.3	0	7.8	8.7	9.3	10.3	11.6
NF 2005	0	6.8	7	6.8	7.2	7.5	0	7.6	8.7	9.2	10.7	11.9
SF 2006	7.3	7.5	7.7	8.3	8.5	7.9	7.6	8.7	9.9	11.5	12.6	12.6
NF 2006	0	7.3	7.1	7.1	7.1	7.9	0	8.3	8.9	9.7	10.5	12.5
SF 2007	0	6.5	7.3	7	7	7.3	0	7.2	9.1	9.5	10.3	11.5
NF 2007	0	5.4	7.2	6.9	6.6	7.1	0	5.5	9.1	9.4	9.6	11.2
SF 2008	0	7.5	7.3	7	7.4	7.9	0	8.8	9.2	9.5	11	12.6
NF 2008	0	6.8	7	6.7	6.9	7.1	0	7.6	8.8	9.1	10.1	11.2
SF 2011	7.2	7.6	7.6	7.5	7.6	8.1	7.4	8.8	9.7	10.3	11.3	12.9
NF 2011	0	7.6	7.4	7.1	6.9	7.6	0	8.8	9.3	9.7	10.2	12.1
SF 2013	0	7.4	7.2	7.3	7	7.2	0	8.6	9	9.9	10.3	11.4
NF 2013	0	7.2	7.2	7.4	7.5	8.5	0	8.3	9.1	10.1	11.1	13.4

SEV 8–8.9	SEV 9–9.9	SEV 10–10.9	SEV 11–11.9	SEV ≥12
major physio-logical stress	reduced growth, delayed hatching	10–20% mortality	20–40% mortality	40–60% mortality

[1] SEV analysis from Lewis (unpublished) based on methods of Newcombe and Jensen (1996).
[2] NF = North Fork Elk River at the KRW monitoring site; SF = South Fork Elk River at the SFM monitoring site.

Table 6-13. Severity of Ill Effects (SEV) for North Fork Elk River and South Fork Elk River for Reduced SSC Scenario using SSC output from the HST model.

Site/WY[2]	Juvenile salmonids only						Salmonid eggs + larvae					
	Suspended sediment conc. (mg/L)						Suspended sediment conc. (mg/L)					
	SSC 2981	SSC 1097	SSC 403	SSC 148	SSC 55	SSC 20	SSC 2981	SSC 1097	SSC 403	SSC 148	SSC 55	SSC 20
SF 2003	8	8.2	7.7	7.7	7.6	7.8	8.7	9.8	9.8	10.6	11.3	12.4
NF 2003	7.9	8.1	7.6	7.2	7	7.3	8.5	9.7	9.7	9.7	10.4	11.6
SF 2004	0	6.9	7.7	7.3	6.9	6.8	0	7.8	9.9	9.9	10.1	10.7
NF 2004	0	6.3	7	7.1	6.6	7.2	0	6.9	8.7	9.6	9.7	11.4
SF 2005	0	6.7	6.8	6.6	6.8	7.3	0	7.5	8.5	8.9	10	11.6
NF 2005	0	6.2	6.9	6.6	6.7	7.5	0	6.6	8.5	8.9	9.8	11.9
SF 2006	0	7.2	7.6	7.6	8.5	7.9	0	8.2	9.7	10.4	12.6	12.6
NF 2006	0	7.1	7	7	6.8	7.9	0	8.1	8.7	9.5	10	12.5
SF 2007	0	4.5	7	6.9	7	7.3	0	4	8.7	9.3	10.3	11.5
NF 2007	0	0	7	6.8	6.5	6.7	0	0	8.7	9.2	9.5	10.7
SF 2008	0	7	7.1	6.9	6.9	7.7	0	8	8.9	9.3	10.2	12.2
NF 2008	0	6.3	6.9	6.6	6.5	7.1	0	6.8	8.6	8.8	9.6	11.2
SF 2011	0	7.2	7.3	7.2	7.6	8.1	0	8.2	9.1	9.8	11.3	12.9
NF 2011	0	7.2	7.3	7	6.8	7.3	0	8.3	9.1	9.5	10.1	11.5
SF 2013	0	7.2	7	7.2	7	7.1	0	8.2	8.7	9.8	10.3	11.3
NF 2013	0	6.3	7.1	7.2	6.9	8.5	0	6.8	8.8	9.9	10.1	13.4

SEV 8–8.9	SEV 9–9.9	SEV 10–10.9	SEV 11–11.9	SEV ≥12
major physio-logical stress	reduced growth, delayed hatching	10–20% mortality	20–40% mortality	40–60% mortality

[1] SEV analysis from Lewis (unpublished) based on methods of Newcombe and Jensen (1996).
[2] NF = North Fork Elk River at the KRW monitoring site; SF = South Fork Elk River at the SFM monitoring site).

Table 6-14. Severity of Ill Effects (SEV) for South Fork Elk River (SF) and Little South Fork Elk River (ESL). Suffixes on the water year identify the party or entity responsible for estimating SSC: L = Jack Lewis, M = Peter Manka, H = Humboldt Redwood Company.

Site/WY[2]	Juvenile salmonids only						Salmonid eggs + larvae					
	Suspended sediment conc. (mg/L)						Suspended sediment conc. (mg/L)					
	SSC 2981	SSC 1097	SSC 403	SSC 148	SSC 55	SSC 20	SSC 2981	SSC 1097	SSC 403	SSC 148	SSC 55	SSC 20
SF 2004	0	6.8	7.4	7.4	6.9	6.8	0	7.6	9.3	10.1	10.1	10.7
ESL 2004M	0	0	0	0	4	4.6	0	0	0	0	5.7	7.4
ESL 2004H	0	0	0	0	3.8	4.2	0	0	0	0	5.3	6.8
SF 2005	0	7.2	7.3	7.4	7.4	7.3	0	8.2	9.3	10.1	10.9	11.6
ESL 2005H	0	0	0	4.7	4.7	5.1	0	0	0	5.9	6.8	8.2

SEV 8–8.9	SEV 9–9.9	SEV 10–10.9	SEV 11–11.9	SEV ≥12
major physio-logical stress	reduced growth, delayed hatching	10–20% mortality	20–40% mortality	40–60% mortality

[1] SEV analysis from Lewis (unpublished) based on methods of Newcombe and Jensen (1996).
[2] NF = North Fork Elk River at the KRW monitoring site; SF = South Fork Elk River at the SFM monitoring site).

Table 6-15. Severity of Ill Effects (SEV) for North Fork Elk River and South Fork Elk River for Modified Channel scenario using SSC output from the HST model.

Site/WY[2]	Juvenile salmonids only						Salmonid eggs + larvae					
	Suspended sediment conc. (mg/L)						Suspended sediment conc. (mg/L)					
	SSC 2981	SSC 1097	SSC 403	SSC 148	SSC 55	SSC 20	SSC 2981	SSC 1097	SSC 403	SSC 148	SSC 55	SSC 20
SF 2003	8.3	8.3	7.8	7.8	7.6	7.8	9.1	9.9	10	10.7	11.3	12.4
NF 2003	8.2	8.2	7.7	7.7	7.2	7.3	9	9.8	9.8	10.6	10.6	11.6
SF 2004	0	7.9	7.9	7.4	6.9	6.8	0	9.3	10.1	10.1	10.1	10.7
NF 2004	0	7	7.4	7.2	6.7	7.2	0	7.9	9.3	9.8	9.9	11.4
SF 2005	0	7	7.1	6.9	7	7.3	0	7.9	8.8	9.3	10.3	11.6
NF 2005	0	6.9	7.1	6.8	7.3	7.5	0	7.8	8.8	9.2	10.7	11.9
SF 2006	7.4	7.6	7.7	8.3	8.5	7.9	7.7	8.8	9.9	11.5	12.6	12.6
NF 2006	0	7.3	7.1	7.2	7.6	7.9	0	8.4	8.9	9.7	11.2	12.5
SF 2007	0	7.1	7.3	7	7	7.3	0	8	9.2	9.5	10.3	11.5
NF 2007	0	6.6	7.3	7	6.9	7.1	0	7.3	9.2	9.4	10.1	11.2
SF 2008	6.6	7.6	7.4	7	7.4	7.9	6.6	8.8	9.3	9.5	11	12.6
NF 2008	0	7.3	7.1	6.7	6.9	7.1	0	8.4	8.9	9.1	10.2	11.2
SF 2011	7.5	7.6	7.7	7.5	7.6	8.1	7.8	8.9	9.8	10.3	11.3	12.9
NF 2011	0	7.7	7.4	7.1	6.9	7.6	0	9	9.4	9.7	10.2	12.1
SF 2013	0	7.5	7.2	7.3	7	7.2	0	8.7	9.1	9.9	10.3	11.4
NF 2013	0	7.4	7.3	7.4	7.5	8.5	0	8.5	9.1	10.1	11.1	13.4

SEV 8–8.9	SEV 9–9.9	SEV 10–10.9	SEV 11–11.9	SEV ≥12
major physio-logical stress	reduced growth, delayed hatching	10–20% mortality	20–40% mortality	40–60% mortality

[1] SEV analysis from Lewis (unpublished) based on methods of Newcombe and Jensen (1996).
[2] NF = North Fork Elk River at the KRW monitoring site; SF = South Fork Elk River at the SFM monitoring site).

SEV scores for the Reduced SSC scenario differ markedly ($R_V < 0.5$) from observations and other scenarios, where the latter group are greatly correlated ($R_V > 0.9$) with each other (Table 6-16, Table 6-17). From the Student's t-test and at an α=0.05 significance level, mean SEV scores from observations versus scores from both Existing Condition and Modified Channel scenarios are not significant. Modified Channel mean score is significantly greater than both Existing Condition and Reduced SSC. Reduced SSC mean SEV score is significantly lower than observations and other scenarios. Wilcoxon test results show a different picture where mean ranks of SEV scores are significantly different between any dataset pair; however, the general conclusions are similar: Modified Channel scores' mean rank is higher than other scenarios, and Reduced SSC scores' mean rank are lowest overall. Regression results show a similar result: Reduced SSC scores trend lower than scores from observations and other scenarios—over one SEV score (i.e. intercept > 1) lower in all comparisons. While regression intercepts for the other pairs are not significant, the slopes are significant, and they all differ by less than one percent.

Differences in SEV scores between observations, Existing Condition, and Modified Channel are small enough to consider the three datasets as one group. Whereas Reduced SSC scores are different in enough measures to be another group. The story emerging from these multiple lines of statistical evidence suggests that lower SSC concentrations are the driving factor in lowering SEV scores.

Table 6-16. Results from two tests of statistical significance between scenarios and observations.

	Wilcoxon Signed-Rank Test p-values			Student t's Test p-values		
Hypotheses†	**Two-Sided**	**Greater**	**Lower**	**Two-Sided**	**Greater**	**Lower**
Existing: Observed	<0.001	>0.999	<0.001	0.744	0.628	0.372
Modified: Observed	0.009	0.995	0.005	0.164	0.082	0.918
Modified: Existing	<0.001	<0.001	>0.999	0.004	0.002	0.998
Reduced: Modified	<0.001	>0.999	<0.001	<0.001	>0.999	<0.001
Reduced: Observed	<0.001	>0.999	<0.001	<0.001	>0.999	<0.001
Reduced: Existing	<0.001	>0.999	<0.001	<0.001	>0.999	<0.001

† E.g. for the alternative hypothesis that existing SEV scores are greater than existing SEV scores at significance level $\alpha=0.05$

Table 6-17. R_V coefficients, p-values, and simple linear regression coefficients and p-values.

	R_V Coefficient	**R_V Coefficient p-value**	**Regression Slope**	**Slope p-value**	**Regression Intercept**	**Intercept p-value**
Existing: Observed	0.980	<0.001	1.002	<0.001	0.012	0.947
Modified: Observed	0.983	<0.001	1.008	<0.001	-0.184	0.418
Modified: Existing	0.999	<0.001	1.005	<0.001	-0.182	0.170
Reduced: Modified	0.485	0.003	0.834	<0.001	1.770	<0.001
Reduced: Observed	0.472	0.004	0.894	<0.001	1.226	<0.001
Reduced: Existing	0.441	0.006	0.887	<0.001	1.252	<0.001

6.8 Synthesis

The following sections summarize the results of the three management scenarios (Existing Condition, Reduced SSC, and Modified Channel), with a specific focus on the effects of the management scenarios on beneficial uses, water quality, and nuisance flooding.

6.8.1 Existing Condition scenario

The Existing Condition management scenario is intended to demonstrate the future trajectory of the system if no actions are taken and sediment concentrations remain the same as observed during the WY 2003–2015 period.

The Elk River sediment source assessment (Tetra Tech 2015) concluded from analyses of available sediment sources and delivery information that the magnitude of sediment discharged during 1988–2000 period greatly exceeded that during any other time period (e.g., see Table 6, pg. 51 of Tetra Tech 2015). The high sediment loads during this period corresponded with extensive land disturbance; poor road construction and maintenance practices; significant rainfall (WY 1996, 1997, 1999); and a significant earthquake event (1992) (Regional Water Board 2013). The observed channel aggradation and sediment storage are consistent with system responses anticipated under the elevated loads documented in the Elk River TMDL.

Aggradation during the 1988–2000 period occurred at higher rates than the period of analysis (WY 2003–2015) (Figure 3-11). The ERRA analyses (e.g., cross section and longitudinal profile surveys, historical bridge surveys, and HST model predictions) corroborate the prior estimate of approximately 640,000 cu yds of “cumulative excess sediment deposits” currently stored in the Elk River channel (Regional Water Board 2013). Aggradation rates are currently lower than during the 1988–2000 period but remain higher than the period prior to 1988 due to altered channel conditions. All reaches of the Elk River are predicted to be aggradational, which is consistent with available data. The majority of sediment entering storage is confined to the channel in the low gradient portions of lower North Fork Elk River, lower South Fork Elk River, and upper Mainstem Elk River (NFR1, NFR2, NFR3, SFR1, SFR2, MSR5). The lower Mainstem Elk River reaches upstream of tidal influence (MSR3 and MSR4) have a substantial amount of sediment entering storage in both the channel and floodplains. Currently SSC in the estuary reaches (MSR1 and MSR2) are the lowest in the watershed, and aggradation in the estuary occurs at a lower rate than in upstream reaches, likely as a combined result of sediment storage in the upstream channel and floodplains, lower SSC floodplain return flows, and mixing with low SSC water from Humboldt Bay.

Channel vegetation patterns are likely affected by the ongoing sediment impairment. Channel sediment deposits have low bulk density, which encourages vegetation establishment on the channel bed and may be partially responsible for colonization of fine sediment deposits by the native slough sedge (*Carex obnupta*) that is more common in wetland than riverine environments. The lack of large woody debris present in the existing channel has been identified as a major impairment that occurred prior to 1988. Recovery of large wood storage and recruitment of wood to the channel is critical to salmonid habitat and ecosystem recovery.

The ongoing sediment impairment and the inability of the system to flush fine sediment and accumulated organic matter from the sediment bed has created a bed with high organic content that exerts a sediment oxygen demand and drives down dissolved oxygen concentrations in the water column. Under the existing condition scenario, this condition will continue or worsen in the future.

Under current fluvial processes and without more significant sediment source reduction and/or channel rehabilitation efforts, the aggraded condition of the Elk River channel will not recover to pre-1988 channel conditions. Thus, the following nuisance flood conditions, and the beneficial uses and water quality impaired by the 1988–2000 sediment impacts will worsen:

- Channel and floodplain sediment aggradation will continue and could accelerate into the future.
- Nuisance flooding will increase due to accelerated aggradation.

- Water supply for municipal and agricultural uses will not improve due to ongoing fine sediment accumulation and high SSC and turbidity in the water column.
- Cold freshwater habitat will continue to be impaired due to high SSC and turbidity in the water column and fine sediment deposition that causes pool infilling, reduces channel complexity, and fines the channel bed. Spawning habitat will continue to be impaired due to fine sediment deposition and high SSC and turbidity. Riparian vegetation dominated by willow and alder, and lacking in mature conifer species, will not enable recruitment of large wood into the channel for habitat-forming features. Off-channel habitat will continue to be accessible primarily on the broad floodplains in the lower Elk River where stranding risk is high, but variably-inundated in-channel benches remain heavily aggraded.
- Low dissolved oxygen concentrations in some reaches of Elk River will remain below water quality standards, will continue to impair cold freshwater habitat, and could worsen into the future.
- Recreation (e.g., swimming and fishing) will continue to be impaired due to low fish populations, pool filling and on-going fine sediment deposition on the bed and banks.

6.8.2 Reduced SSC scenario

The Reduced SSC scenario reduces the SSC of all model inputs (tributaries and upstream boundary conditions at NFR3 and SFR2) by 27–32%. Since SSC has not changed significantly over the period of record (WY 2003–2015) (Lewis 2013, Appendix D), reducing SSC to the levels identified in the Reduced SSC scenario will likely require more sediment reduction measures than are currently in place. Reducing SSC in the upper reaches of the North Fork Elk River, South Fork Elk River, and other tributaries reduces SSC throughout the Project area and results in lower aggradation rates system wide, but does not result in channel incision necessary to reverse the aggradation that has occurred since the 1980’s. The HST model under the Reduced SSC scenario predicts coarsening of the bed in the upper reaches of the North Fork Elk River, but the channel bed in the South Fork Elk River and Mainstem Elk River reaches continues to fine.

The following beneficial uses, water quality conditions, and nuisance flooding will continue to worsen under the Reduced SSC scenario, but at a slower rate than the Existing Condition scenario:

- Channel and floodplain sediment aggradation will continue and could accelerate into the future, but at a lower rate than Existing Conditions.
- Nuisance flooding will increase due to accelerated aggradation, but at a lower rate than Existing Conditions.
- Cold freshwater habitat will continue to be impaired due to existing and continued aggradation of pools and fine sediment remaining in the channel bed resulting in less channel complexity. Riparian vegetation dominated by willow and alder, and lacking in mature conifer species, will not enable recruitment of large wood into the channel for habitat-forming features. Off-channel habitat will continue to be accessible primarily on the broad floodplains in the lower Elk River where stranding risk is high, but variably-inundated in-channel benches remain heavily aggraded.
- Low DO concentrations in some reaches of Elk River will remain below water quality standards, will continue to impair cold freshwater habitat, and could worsen into the future.

- Recreation including swimming, fishing and aesthetic enjoyment is not expected to improve in the lower North Fork Elk River, South Fork Elk River and Mainstem Elk River reaches due to continued fining of the channel bed and on-going aggradation.

Some beneficial uses will improve under the Reduced SSC scenario:

- Salmonid spawning habitat may improve in upstream reaches of the North Fork Elk River, where coarsening is predicted, and fine sediment deposition rates are lower. The coarsening could shift the gravel/sand transition further downstream, increasing spawning habitat area and improve the quality of existing spawning habitat.
- Cold freshwater habitat will be improved by lowering of SSC and turbidity in the water column in all reaches.
- Water supply for municipal and agricultural uses will improve in all reaches due to less fine sediment accumulation around intake structures and lower SSC and turbidity in the water column.

6.8.3 Modified Channel scenario

The Modified Channel scenario includes an altered channel geometry that is similar to the pre-1980s channel, with mature vegetation along the channel banks; existing vegetation on the floodplains; reduced roughness associated with removing invasive vegetation and dense small and live wood accumulations in the channel bed; and large wood storage similar to a healthy forested stream. The Modified Channel scenario substantially alters sediment transport and storage patterns in all reaches of the Elk River. The majority of sediment that is currently deposited in the channel and floodplains is transported through the system to the estuary and bay. Although channel and floodplain aggradation still occur with the Modified Channel scenario, the rate of aggradation in the channel is lower, and the rate of aggradation in the floodplains is significantly lower than the Existing Condition and Reduced SSC scenarios. The model predicts that it would take at least 280 years to return the Modified Channel scenario to existing conditions (i.e., channel sediment storage following the 1988–2000 period), averaged over all reaches. As recovery progresses, reductions in SSC and changes in bulk density will further extend the period of time required for the channel bed to reach this existing condition.

The Modified Channel scenario substantially reduces nuisance flooding throughout the Project area due to an increase in flow conveyance and reduced aggradation rates. This higher transport regime of the Modified Channel scenario has both positive and negative implications for beneficial uses and water quality. The higher transport rate will flush fine sediment and organic matter from the system and channel bed, creating a sediment bed with lower organic content and a lower sediment oxygen demand than existing conditions.

The Modified Channel scenario does not improve some beneficial uses or water quality over the Existing Condition scenario. Improvement of these beneficial uses requires additional actions that reduce SSC:

- Cold freshwater habitat will continue to be impaired due to higher SSC and turbidity that will occur during winter storm periods.
- Water supply for municipal and agricultural uses in all reaches will not improve during winter storm periods due to high SSC and turbidity. The duration of high SSC and turbidity may be the same as, or longer, then the Existing Condition scenario during storm periods.

Additional analyses are required to determine the SSC and turbidity effects during low flows.

The Modified Channel scenario improves the following beneficial uses, water quality, and nuisance flooding conditions:

- Channel and floodplain sediment aggradation rates are significantly reduced compared to Existing Conditions.
- Nuisance flooding is significantly improved in all reaches.
- Spawning habitat may improve in the North Fork Elk River and South Fork Elk River, where coarsening is predicted, and fine sediment deposition rates are lower. The coarsening could shift the gravel/sand transition further downstream, increasing spawning habitat area and improving the quality of existing spawning habitat.
- Cold freshwater habitat will be improved in all reaches by channel coarsening; increased capacity to scour bed sediments (erosion); increased large wood storage and loading that meets generally accepted targets for forested streams; less fine sedimentation of pools and spawning gravels; and old-growth riparian vegetation on the channel banks.
- Water supplies for municipal and agricultural uses will improve due to less fine sediment accumulation around intake structures.
- DO concentrations would be expected to improve due to less fine sediment and organic matter accumulation in the channel bed resulting in a lower sediment oxygen demand. DO concentrations would be expected to meet water quality standards and support cold freshwater habitat and other beneficial uses into the future.
- Recreation including swimming, fishing and aesthetic enjoyment may improve due to increased scour of pools, lower rate of fine sediment deposition, and stream bed coarsening.

7 RECOVERY FRAMEWORK

Recovering beneficial uses and reducing nuisance flooding in the Elk River requires a combination of sediment source reduction, sediment remediation, and restoration of other hydraulic, geomorphic, and ecological impairments. The management scenarios are limited to addressing sediment remediation and selected impairments that directly affect sediment remediation, such as vegetation in the channel and floodplains and large wood recruitment and storage in the channel. The understanding gained by analyzing these management scenarios was combined with information about other known impairments to develop a list of reach-specific recovery actions. These actions are not exhaustive but are those most likely to promote recovery in the Elk River. Additional and/or more site-specific actions to address impairments may be identified through Stewardship, or future project phases.

7.1 Relative Benefits of Different Recovery Scenarios in Elk River

The Existing Condition and Modified Channel scenarios show substantially different river systems in terms of sediment transport and storage. The Modified Channel scenario is an informative surrogate for how the system likely functioned prior to the high sediment loadings in the 1980s and 1990s. The Modified Channel scenario was built with a channel bed elevation and bottom width based on measured cross-sections prior to this period of rapid channel aggradation. Although high sediment loading also aggraded the floodplains and active channel benches were aggraded substantially, it is possible that the former channel had more complex connections to the floodplain and had lower adjacent surfaces that were more frequently inundated and stored more sediment than occur in the Modified Channel scenario. The Modified Channel scenario includes old-growth vegetation on the channel banks and no vegetation in the channel bed, creating channel roughness characteristics that are different than the channel that existed prior to the 1980s. The Modified Channel scenario has large woody debris throughout the channel network at a frequency and volume typical of healthy forested streams. This channel characteristic is known to be absent from the system due to land-use changes that reduced the density of trees in the riparian corridor, upslope logging activities that reduced large wood supply, and direct wood removal from the channel. However, these differences likely do not change the conclusion that the channel historically transported more sediment to the estuary and bay than it does under current conditions.

Sedimentation that occurs in the channel and floodplain in the upstream reaches under Existing Conditions results from settling of material out of the water column, and thus contributes to the trend of declining SSC in the downstream direction. The Modified Channel scenario reduces in-channel sedimentation by increasing transport of material through the system. Sedimentation on the floodplain is also reduced as a result of decreased frequency of flooding. Thus, the impacts of implementing recovery actions designed to remediate sediment-impaired channel and floodplain conditions (e.g., fine sediment deposition and aggradation of the bed, pool infilling, channel narrowing and simplification, and increased flooding) results in higher in-channel SSC concentrations. Duration generally increases for a given concentration, but these increases are generally small, and in some cases duration decreases. The higher SSC of the Modified Channel scenario results in minor increases to the SEV, with a median change in juvenile salmonids and salmonid eggs and larvae of 0 to 0.2 compared to Existing Conditions.

Under Existing Conditions, the impacts to the channel from fine sediment accumulation on the bed and banks persist throughout the year, affecting spawning, emergence, rearing habitat, and sedimentation of water supplies, whereas impacts from elevated in-channel SSC are limited to storm periods in the winter months.

Reducing the impact of increased SSC during the winter storm periods is an important part of the Recovery Framework. The Reduced SSC scenario demonstrates that a reduction in upslope SSC (or sediment load) reduces in-channel SSC throughout the channel network. Similarly, maintaining floodplain inundation reduces SSC concentrations as well as provide refuge for juvenile salmonids during higher winter flows when SSC is elevated. Reducing SSC alone does not improve impairments from fine sediment accumulation in the channel that persist throughout the year.

Mechanical channel rehabilitation is sufficient for reducing nuisance flooding and would improve habitat; however, it is insufficient for full recovery of beneficial uses for winter rearing habitat and water supply. Suspended sediment concentrations (or sediment loads) must also be reduced through additional upslope measures and may be further reduced on the Mainstem Elk River by maintaining or creating broad zones of floodplain inundation that can effectively trap and store sediment, and by trapping sediment delivered directly to the Mainstem Elk River from tributaries. Transitioning the channel back toward a system that is aggrading at a slower rate results in additional sediment delivered to the estuary and bay. To avoid potential impacts to the estuary, actions should be taken to expand the tidal prism (e.g., tidal marsh restoration) to better distribute sediment across the tidal marsh plains and help flush sediment from and maintain the tidal channels.

Important components of the recovery of beneficial uses, water quality, and reduction of nuisance flooding include:

- Suspended sediment concentration (or sediment load) reduction from upslope sources.
- Mechanical channel rehabilitation includes sediment removal, pool formation, bank complexity, localized enhancement of substrate, vegetation management, and addition of large wood.
- Mechanical channel rehabilitation will remove the decomposing organic matter from the sediment bed causing the sediment oxygen demand impairment to DO levels.
- Retention and improvement of floodplain connectivity integrated within a working landscape.
- Infrastructure improvements.
- Estuary enhancement.

7.2 Recommended Actions for Elk River Recovery: A Framework

This section summarizes the recommended actions that when combined describes the Framework for recovery of beneficial uses, water quality, and reduces nuisance flooding in the Elk River. Table 7-1 and Table 7-2 summarize the recommended actions by reach for the North Fork Elk River and South Fork Elk River, and the Mainstem Elk River, respectively. Table 7-3 summarizes interdependencies between recommended recovery actions.

Table 7-1. Recommended recovery actions for North Fork Elk River and South Fork Elk River.

Geomorphic reach	Recommended actions					
	Sediment load reduction		Channel rehabilitation	Floodplain rehabilitation	Infrastructure	Vegetation management
	Tributary	Main				
NFR4	Bridge Creek source reduction	na	Add large wood	na	na	Maintain and/or promote growth of conifer-dominated riparian community.
NFR3	Lake, Browns, Dunlap source reduction	na	Transition excavated channel geometry and slope to existing conditions, add large wood. Construct/maintain appropriate channel morphology (e.g., bar/pool).	na	na	Maintain and/or promote growth of conifer-dominated riparian community, discourage vegetation in active channel.
NFR2	na	na	Transition excavated channel geometry and slope to existing conditions, add large wood. Construct/maintain appropriate channel morphology (e.g., bar/pool).	na	na	Maintain and/or promote growth of conifer-dominated riparian community, discourage vegetation in active channel.
NFR1	na	na	Remove stored sediment and restore channel geometry (width, depth, and slope) to pre-1988 conditions using historical survey data at Elk River Road bridge. Add large wood. Construct appropriate channel morphology (e.g., bar/pool).	Selective near channel floodplain lowering to historical elevations to reestablish floodplain sediment dynamics and connectivity with channel.	Evaluate flood capacity and potential for improving flow conveyance and large wood passage at Elk River Road Bridge. Selective modification of railroad grade in conjunction with floodplain improvements.	Maintain and/or promote growth of conifer-dominated riparian community, discourage vegetation in active channel.
SFR2	Tom's Gulch source reduction and detention	Create/enhance features that route sediment laden water into/across floodplains. Recontour floodplains into low-lying floodplain areas (flood basins).	Transition excavated channel geometry (slope) to existing conditions, add large wood. Construct/maintain appropriate channel morphology (e.g., bar/pool).	Selective near channel floodplain lowering to historical elevations to reestablish floodplain sediment dynamics and connectivity with channel.	Evaluate SF HRC bridge for passage of large wood.	Maintain and/or promote growth of conifer-dominated riparian community, discourage vegetation in active channel.
SFR1	na	na	Remove stored sediment and restore channel geometry (width, depth, and slope) to pre-1988 conditions using empirical relationships. Add large wood. Construct appropriate channel morphology (e.g., bar/pool).	Selective near channel floodplain lowering to historical elevations to reestablish floodplain sediment dynamics and connectivity with channel.	Evaluate flood capacity and potential for improving flow conveyance and large wood passage at residential bridge (SFM gage).	Maintain and/or promote growth of conifer-dominated riparian community, discourage vegetation in active channel.

Table 7-2. Recommended recovery actions for Mainstem Elk River.

Geomorphic reach	Recommended Actions					
	Sediment load reduction		Channel rehabilitation	Floodplain rehabilitation	Infrastructure	Vegetation management
	Tributary	Main				
MSR5	Railroad and Clapp source reduction and detention (Jones Prairie).	Create/enhance features that route sediment laden water into/across floodplains. Recontour floodplains into low-lying floodplain areas (flood basins).	Remove stored sediment and restore channel geometry (width, depth, and slope) to pre-1988 conditions using historical survey data at Steel Bridge. Add large wood. Construct appropriate channel morphology (e.g., bar/pool).	Selective near channel floodplain lowering to historical elevations to reestablish floodplain sediment dynamics and connectivity with channel.	Evaluate flood capacity and potential for improving flow conveyance and large wood passage at Elk River Court Bridge. Removal of Steel Bridge and abandoned railroad trestle. Selective modification of railroad grade.	Maintain and/or promote growth of conifer-dominated riparian community, discourage vegetation in active channel.
MSR4	Unknown	Create/enhance features that route sediment laden water into/across floodplains. Recontour floodplains into low-lying floodplain areas (flood basins).	Remove stored sediment and restore channel geometry (width, depth, and slope) to pre-1988 conditions using historical survey data at Berta, Zanes, and Steel bridges. Add large wood. Construct appropriate channel morphology (e.g., bar/pool).	Selective near channel floodplain lowering to historical elevations to reestablish floodplain sediment dynamics and connectivity with channel.	Evaluate flood capacity and potential for improving flow conveyance and large wood passage at Elk River Courts, and Zanes Road. Removal of abandoned bridge.	Maintain and/or promote growth of conifer-dominated riparian community, discourage vegetation in active channel.
MSR3	Unknown	Create/enhance features that route sediment laden water into existing flood basins. Recontour floodway and flood basins, in conjunction with infrastructure modifications, to reduce nuisance flooding.	Remove stored sediment and restore channel geometry (width, depth, and slope) to pre-1988 conditions using historical survey data at Berta Road bridge. Add large wood. Construct appropriate channel morphology (e.g., bar/pool).	Selective near channel floodplain lowering to historical elevations to reestablish floodplain sediment dynamics and connectivity with channel.	Evaluate flood capacity and potential for improving flow conveyance and large wood passage at abandoned bridge and Berta Road. Modify drainage infrastructure to provide fish passage and reduce stranding.	Maintain and/or promote growth of conifer-dominated riparian community, discourage vegetation in active channel.
MSR2	Unknown	Maintain existing floodplain sediment storage functions.	Transition excavated channel geometry and slope to existing conditions. Construct appropriate channel morphology (e.g., bar/pool).	Selective near channel floodplain lowering to historical elevations to reestablish floodplain sediment dynamics and connectivity with channel; selective improvement of secondary flow paths and modification of levees.	Modify drainage infrastructure to provide fish passage and reduce stranding in conjunction with floodplain enhancement.	Maintain and/or promote growth of conifer-dominated riparian community, discourage vegetation in active channel.
MSR1	Unknown		na		Modify drainage infrastructure to provide fish passage and reduce stranding in conjunction with estuary restoration. Modify drainage infrastructure to provide fish passage in conjunction with floodplain enhancement.	na

Table 7-3. Interdependencies between recommended recovery actions.

Recommended action	Interdependent actions				
	Sediment load reduction	**Channel rehabilitation**	**Floodplain rehabilitation**	**Infrastructure**	**Vegetation management**
Sediment load reduction		Channel enlargement and lower roughness will result in higher SSC in the channel and therefore potentially reduce the benefits of sediment load reduction in the lower mainstem reaches. Channel rehabilitation will require concurrent floodplain rehabilitation to maximize the benefits of sediment load reduction.	Floodplain rehabilitation will help maximize the benefits of sediment load reduction by capturing and retaining sediment in floodplain areas.	Negligible	Where roughness is decreased within the channel, higher SSC in the channel will potentially reduce the benefits of sediment load reduction (e.g., in the lower mainstem reaches). Vegetation management will require concurrent floodplain rehabilitation to maximize the benefits of sediment load reduction. Thinning the redwood tree plantation to reduce upstream backwater effects could result in less channel and floodplain sedimentation and higher SSC in the channel. Requires concurrent floodplain rehabilitation to capture and retain sediment in other floodplain areas.
Channel rehabilitation	Sediment load reduction will extend the longevity of channel rehabilitation by reducing channel sedimentation.		To maximize the benefits of channel rehabilitation, floodplain rehabilitation should not reduce channel sediment transport capacity.	To maximize the benefits of channel rehabilitation, infrastructure improvements should be designed to pass large wood and minimize backwater conditions during high flows.	Channel bed vegetation management will enhance benefits of channel rehabilitation by improving sediment transport capacity. Channel bank and floodplain vegetation management will provide a long-term source of wood to the channel, as well as other benefits to aquatic habitat.
Floodplain rehabilitation	Sediment load reduction will extend the longevity of floodplain rehabilitation by reducing floodplain sedimentation.	Channel rehabilitation could disconnect floodplain flow. Therefore, channel rehabilitation should be designed in coordination with floodplain rehabilitation to maintain and increase floodplain connectivity.		Floodplain rehabilitation may require modifying existing infrastructure.	Floodplain vegetation management will improve sediment capture and retention in floodplain areas, as well as provide benefits to off-channel riparian habitat.
Infrastructure	Sediment load reduction will extend the longevity of infrastructure improvements by reducing channel and floodplain sedimentation.	Channel rehabilitation will substantially decrease flooding of infrastructure and property. Channel rehabilitation will need to be designed to accommodate existing infrastructure (e.g., bridges, levees, road prisms).	Floodplain rehabilitation will need to be designed to accommodate existing infrastructure (e.g., bridges, levees, road prisms).		Channel vegetation management will improve flood conveyance capacity in the vicinity of infrastructure.
Vegetation management	Sediment load reduction may discourage vegetation establishment on the channel bed.	Channel rehabilitation may result in the short-term loss of riparian vegetation in the channel, which would be recovered through revegetation. Channel rehabilitation may discourage vegetation establishment on the channel bed.	Floodplain rehabilitation may result in the short-term loss of riparian vegetation in floodplain areas, which would be recovered through revegetation. Floodplain rehabilitation actions could consider inundation frequency and duration that promote natural regeneration of floodplain riparian vegetation communities.	Bridge and road improvements that result in greater flow and sediment transport continuity and improve wood passage may require less vegetation management.	

7.2.1 Sediment load reduction

The timber landowners in the upper watershed, including HRC, GDRC, and BLM have been implementing sediment load reduction efforts for many years, and will continue to do so through the Regional Water Board's WDR regulatory programs. HRC and GDRC operate timber management activities under watershed-specific WDR's to reduce road and management related sediment discharge sources (Tetra Tech 2015). However, managed timber lands in the Elk River still yield significantly higher quantities of sediment than undisturbed lands in the Elk River (Jack Lewis, Personal communication 2018) despite rigorous implementation of best management practices. In Elk River, large volumes of sediment were deposited and stored in tributary channels during the 1988–1997 time-period (Tetra Tech 2015), and high sediment loads will continue to be delivered to the Project area for the foreseeable future.

To reduce tributary sediment loads and protect the downstream investment in mechanical sediment remediation, sediment trapping is the most immediate and effective means available. Sediment trapping can be accomplished by creating localized geomorphic features, such as in-channel sediment detention basins or low-elevation floodplain surfaces, that reduce the velocity of water containing high suspended sediment concentrations and allow sediment to settle out of suspension. Sediment deposited in winter when concentrations are high can routinely be removed later during the low-flow season to maintain the sediment trapping capacity of the site. Trapping sediment before it is delivered to the Elk River could help to reduce the rate of in-channel sediment aggradation, and significantly improve water quality conditions if implemented at appropriate scale and locations.

The Elk River TMDL analysis (TetraTech 2015) quantified sediment loads for fourteen Elk River sub-basins (TetraTech 2015, Table 7, pg. 57) and ranked each sub-basin on a unit-area basis (Figure 8, pg. 58). Based on this analysis and combined with results of the Recovery Assessment HST model, we recommend sediment detention basins be considered on the following tributaries that contribute disproportionately high sediment loads to the impacted reaches: Tom's Gulch, Railroad Gulch, and Clapp Gulch. Other tributaries, such as Lake Creek, Browns Gulch, and Bridge Creek on the North Fork Elk River, and various tributaries on Mainstem Elk River with limited or no monitoring data should also be accessed for sediment trapping opportunities. Furthermore, opportunities for sediment trapping and subsequent removal in the North Fork Elk River, South Fork Elk River, and Mainstem Elk River could be considered.

Sediment detention basins can be designed to mimic natural salmonid habitat features and provide valuable winter juvenile salmonid rearing habitat. Such habitat features should consider the following concepts in their design:

- In-channel roughness elements (e.g., large wood structures) to encourage deposition on floodplains, coupled with routine sediment removal during the dry season.
- In-channel pools that allow accumulation of sediment, with routine sediment removal.
- Large in-channel sediment detention basins.
- Off-channel wetland features that can serve as a sediment basin and provides habitat benefits and sediment trapping with periodic removal.

7.2.2 Channel rehabilitation

A primary focus of the Recovery Assessment has been to document the extensive impairment to the channel bed and banks, the sediment composition, water quality, and aquatic habitat that has resulted from large-scale sediment aggradation in Elk River. Currently the Elk River channel bed and banks are covered by deep sediment accumulations that are masked by a thin veneer of poorly functioning aquatic and riparian habitat.

The singularly most important finding of more than 13 years of field observations, and the conceptual model and hydrodynamic and sediment transport modeling analysis conducted as part of the ERRA, is the conclusion that the large volume of accumulated sediment stored in the Elk River will not mobilize and transport out of the system. Even with reduced upslope sediment loads (i.e., reduced upslope suspended sediment concentrations) the existing aggraded sediment will remain in the system, and the impairment to beneficial uses and water quality, and nuisance flooding conditions will continue and possibly worsen into the future.

Given that the Elk River is not expected to export stored sediment even under a hypothetical reduced loading scenario, mechanical intervention is required to remediate stored sediment in the existing channel to reduce nuisance flooding and recover some beneficial uses and water quality improvements. The ERRA evaluated the two book-ends of possible approaches. No action (Existing Condition scenario) and full sediment remediation which returns the channel geometry to the pre-1980 configuration, increases mature vegetation on the stream banks, and increases wood loading (Modified Channel scenario) relative to existing conditions. The amount of mature vegetation and wood loading in the Modified Channel scenario is likely higher than vegetation conditions which existed prior to the rapid sediment aggradation that occurred in the late 1980s and 1990s.

Mechanical sediment remediation is expected to be the most expedient and effective approach to minimize nuisance flooding and recover some beneficial uses and water quality improvements. Mechanical sediment remediation should enlarge the channel width and depth to approximate cross-section dimensions that would convey flood flows at rates and magnitudes similar to the conditions that existed prior to the rapid sediment aggradation that occurred in the late 1980's and 1990's. Sediment transport rates and depositional rates are likely different than the pre-1980's because sediment supply has been altered. Thus, the depositional patterns resulting from a restored channel are also expected to be different.

The Modified Channel scenario approximately restored channel dimensions to pre-1980 conditions. In the lower reaches of the Mainstem Elk River (MSR4, MSR3, and MSR2), the sediment deposition that occurred along the large natural levees were not completely accounted for in developing the restored channel dimensions. Consequently, the channel dimensions developed for these reaches (MSR4, MSR3, and MSR2) may have a larger cross-sectional area that conveyed more in-channel flow than occurred for the pre-1980 channel conditions. This condition will be assessed as part of the Elk River Stewardship Program and future modeling and design phases.

Hydrodynamic model analyses of intermediate actions such as widening the channel by excavation of the banks alone but not deepening the channel, or managing vegetation alone indicate that these types of action would provide only modest improvement over existing conditions. Alternatives that altered the channel planform (e.g., adding meander cutoffs), were not evaluated as part of the ERRA, because these features would need to be designed in coordination with specific in-channel actions. The selection of the in-channel actions drastically alters the sediment transport, storage, and floodplain connectivity. Therefore, the objective of the floodplain channel could vary substantially. Specific designs within the floodplain may have an impact on private landowners, and therefore, must be developed in conjunction with landowners.

These types of site-specific actions will be explored and potentially developed with private landowners as part of the Elk River Stewardship Program.

Mechanical sediment remediation will likely rely on the use of heavy equipment (excavators and dump trucks) to dig the sediment out of the channel and transport it to nearby sediment disposal sites. This action will cause temporary disturbance to aquatic and riparian habitats, as well as the fish and wildlife species that rely on those habitats, and thus should be implemented in multiple phases over a timespan of several years. Voluntary landowner cooperation will be essential to implement this action.

7.2.3 Floodplain rehabilitation/modification

With the exception of vegetation along the stream banks and wood loading, no other impairments related to historical land use or infrastructure development prior to the 1980's impairment were included in the Modified Channel scenario, such as floodplain modifications. The selection of actions included in this scenario was made in conjunction with the Elk River TAC, with the intention of understanding the effects of a set of actions that would not require substantial land use changes. Impacts and potential alterations to infrastructure (e.g., levee building, drainage alterations) that occurred on the landscape prior to the 1980's are intended to be discussed with private landowners as part of the Stewardship process.

Potential floodplain rehabilitation and modifications include:

- Regrading and removal of deposited sediment to pre-1980s levels.
- Better connectivity to channel.
- Creating or restoring localized off-channel or backwater features.

These floodplain actions should be conceptualized and designed in conjunction with mechanical sediment rehabilitation of the channel and/or upslope sediment load (or suspended sediment concentration) reduction. Conducting floodplain actions without incorporating these critical additional actions will lead to floodplain improvements that will likely not persist and return to existing levels since these floodplain actions will also function as sediment traps.

7.2.4 Infrastructure

The ERRA quantified the increase in flood-frequency since 2003 at Elk River Flood Curve near the Elk River Road Bridge, Elk River Court, Zanes Road, Berta Road, and Showers Road. Full mechanical sediment rehabilitation of the Elk River channel would change flooding conditions at these locations to roughly the pre-1980 flood-frequency conditions. These conditions may or may not be an acceptable target for infrastructure that meets current standards and the needs of the community.

Potential modifications to infrastructure could include:

- Acceptable flood-frequency based on current standards, use, and community needs.
- Allow for the passage of woody debris including whole trees.
- Consider the site-specific long-term aggradation.
- Consider fish and other species passage.

These modifications should consider the larger goals of Elk River Recovery to ensure that infrastructure modifications do not reduce or constrain opportunities for future recovery.

7.2.5 Vegetation management

Vegetation within the Elk River Project area consists of native and non-native riparian and floodplain species, and land-use practices have significantly altered channel and floodplain vegetation composition. Sediment aggradation has affected channel conditions allowing dense riparian vegetation to establish on the channel banks and bed, significantly affecting channel hydraulics, geomorphology, and sediment transport.

Vegetation along the stream corridor of Elk River consists of native riparian forest biohabitats along the stream banks, and conifer forest biohabitats on upper slopes and floodplain surfaces adjacent to the riparian corridor. Riparian vegetation is composed of mostly young age-classes of native hardwood species (willow, alder, bigleaf maple, and elderberry) forming a tree canopy, with a dense understory of various willow species, native and non-native blackberries, stinging nettle, elderberry, and other native species. Conifer biohabitats are composed primarily of redwood and Sitka spruce, with smaller patches of western red cedar and grand fir. Collectively this band of vegetation surrounding the stream channel provides habitat for numerous wildlife and bird species, shades the stream channel from solar radiation, and provides invertebrate food sources and allochthonous organic material (leaves and wood) to the stream channel. Channel conditions have allowed dense riparian shrubs, bramble, willow, and a wetland sedge to establish along the bank toe and channel bed in many reaches of the Elk River.

In a healthy and mature riparian stream corridor, the stream contains in-channel large wood and recruits large wood directly from the riparian corridor. In-channel large wood provides geomorphic and hydraulic controls that sort and store sediment and create complex flow paths that scour pools. Large wood also provides high quality instream habitat for juvenile salmonids and other aquatic species. In most reaches of the Elk River Project area the channel and riparian corridor is generally devoid of large wood.

Vegetation also provides hydraulic “roughness” along the stream channel and floodplains, which alters flow patterns. Dense, channel spanning vegetation can slow water velocities and raise water surface elevations. Immature riparian vegetation generally has higher densities of understory species and thus higher roughness compared to more mature riparian forests with larger trees, taller canopies, less dense understories, and thus lower hydraulic roughness.

To ameliorate the effects of flooding, the riparian vegetation along Elk River channel corridor should be treated in selected locations to remove non-native invasive plants and encourage more mature age-classes of trees with a higher proportion of large and maturing hardwood and conifer species. In specific reaches, it may be necessary to thin or remove the dense shrubs and willows that have colonized along the channel banks and bed and remove the sedge that is growing on the in-channel stored sediment deposits. Conifer species should be planted along the banks and channel corridor to enhance tree species diversity, slowly increase shade to the stream and understory vegetation, and eventually provide mature trees for natural recruitment of large wood into the stream channel. Long-term vegetation management of the Elk River riparian corridor should focus on large native conifer and hardwood trees and native understory species. The management for large trees will help to control the existing dense shrubs, bramble, willow, and sedge that currently occupy the channel bank toes and bed over the long-term.

The 107-acre redwood tree plantation located on the floodplain in MSR5 from the North Fork Elk River and South Fork Elk River confluence downstream to Elk River Court is a unique vegetation feature along Elk River. Prior to being planted in dense rows of redwood, this floodplain surface was open pasture used for cattle grazing. Historically it was likely a redwood forest with mixed riparian vegetation along the stream channel. The increase in floodplain vegetative roughness associated with the redwood tree plantation (planted in 1979–82) contributes to increased backwater flood levels in NFR2, NFR1, SFR1 and MSR5, and with the increased sediment loads cumulatively increased in-channel sediment aggradation in these reaches. It is recommended to thin the redwood trees from the floodplain and along the channel in the MSR5 reach. Riparian hardwoods should also be replanted along the channel corridor for diversity. This action would enhance the riparian forest quality, reduce vegetative roughness along the channel and floodplain, promote native understory, and provide a supply of large logs for instream wood recruitment to support geomorphic and habitat function.

7.2.6 Habitat enhancement

Concurrent with the implementation of the channel and floodplain remediation actions outlined above, additional complementary actions should be implemented to enhance salmonid habitat in Elk River. These actions, while not entirely resulting from sediment impairment, can nevertheless contribute to improving habitat conditions for listed salmon and steelhead. Habitat enhancement should focus on improving winter and spring rearing habitat for juvenile and pre-smolt life stages, especially along the Mainstem Elk River reaches (MSR2 through MSR5, NFR1 and SFR1). The actions listed below are not independent of other proposed actions, but rather can be integrated with the full set of actions described in Table 7-1 and Table 7-2.

Specific habitat enhancement actions should include:

1. Rehabilitate pool habitat by mechanical excavation of excess stored sediment, increasing pool surface area and residual pool depth, and increasing pool frequency along the length of restored reaches. Pool reconstruction should target conditions providing suitable winter rearing habitat with adequate instream cover objects for refugia for juvenile salmonids, and summer rearing habitat with suitable depths and large wood pieces to create complex and diverse habitat.
2. Create complex juvenile and adult salmonid habitat through the addition of numerous large wood structures, increased large wood volume, and number of key pieces stored in-channel, emphasizing whole trees and large logs where feasible. Large wood augmentation should focus on MSR3 to MSR5, NFR1 to NFR4, and SFR1 to SFR2. Wood loading volumes and specific targets for individual reaches should be developed based on evaluation of local reference sites and from published literature on salmonid habitat restoration, targeting a minimum of 85 pieces/mile (SONCC Coho Recovery Plan wood loading rates). Large wood structures should be placed at meander bends and interact with flow from the baseflow to bankfull water surface elevations, as well as be included in backwater channels. Large wood will provide cover, hydraulic complexity, increase hyporheic exchange, and sorting of bed material to produce a diversity of substrates for a variety of aquatic organisms.
3. Maintain and promote the expansion of riparian habitat area and vegetation diversity, by: (1) expanding the riparian corridor width to a minimum 100 ft from top of stream banks, and wider where feasible, (2) increasing tree and plant species diversity through selective thinning and removal of dense hardwood trees and understory shrubs, (3) through planting of conifer species, and (4) removal of invasive and non-native plant species.
4. Construct complex, multi-elevation floodplain benches to create off-channel habitat available over a range of flows during winter baseflows, winter floods, and spring recession. Floodplain surfaces should be constructed to create low-velocity areas inundated for long-durations and should be gently sloped to direct water to backwater areas and

valley walls. Floodplain surfaces should also provide roughness elements (large and small wood pieces) to create complex flow hydraulics.

5. Construct off-channel ponds and backwater features that are connected to surface flow only during high flow events, especially in the less confined valley reaches (MSR2 to MSR4).
6. Improve channel and floodplain connectivity for fish movement into and out of existing topographically low floodplain areas. Rehabilitate drainage structures to improve fish passage and enhance access during the winter months.
7. Enhance existing wetlands and expand wetland areas where possible.
8. Expand the estuary through selective removal of levees, improvement of tide gate infrastructure, and the enhancement of the drainage and tidal channel network. Where those actions might affect agricultural lands, conservation easements, land swaps, or acquisitions with willing landowners should be considered during Stewardship.

7.2.7 Monitoring

A framework for monitoring should be developed that specifies monitoring goals, objectives, parameters, and evaluates the sufficiency of the current monitoring network for monitoring long-term trends and effectiveness of remediation actions. This monitoring framework should also identify how existing and new data will be assessed, shared, and used to guide projects and activities, and adaptively manage the Elk River recovery.

The monitoring framework should address the following monitoring components:

- Water quality data collection (temperature, dissolved oxygen, pH, salinity).
- Discharge and continuous turbidity and SSC.
- Channel and floodplain geomorphic conditions.
- Aquatic habitat conditions (riffle-pool frequency, large wood volumes, food resources).
- Adult and juvenile salmonid population information (abundance, growth, survival, life history diversity).

7.3 Developing and Implementing an Elk River Recovery Action Plan

The Elk River Recovery Assessment and this Recovery Framework report represent a critical step toward identifying *technical* solutions to the sediment impairment, nuisance flooding, and impacts to beneficial uses and water quality in the Elk River. For an implementation program to proceed at a scale and timeline needed for full recovery of beneficial uses, several additional planning, environmental compliance, and permitting phases are still needed. The first next step is a pro-active outreach program to ensure the community fully understands and supports proposed remediation actions. The second planning step entails a full suite of regulatory compliance documents and permits. This regulatory program would ensure compliance with the California Environmental Quality Act or CEQA, the National Environmental Policy Act or NEPA, federal and state endangered species acts, and a host of other state and local permits. Each of those regulatory statutes requires full and transparent input from stakeholders and the public.

Actions proposed and implemented on private property are entirely voluntary in terms of landowner participation, unless under specific regulatory jurisdiction.

To complement ongoing technical studies (Recovery Assessment), and regulatory program (Elk River TMDL and WDRs), the Regional Water Board is proposing a community and stakeholder-driven Elk River Watershed Stewardship Program (Stewardship Program) to coordinate multi-stakeholder participation in the recovery of Elk River beneficial uses of water. The Stewardship Program will:

- Coordinate directly with watershed residents, local, state, and federal resource agency staff, and other stakeholders to solicit input and transmit information on recovery program activities that are ongoing throughout the watershed.
- Provide a broad umbrella under which specific working groups form to coordinate resource management issues in a collaborative and transparent way.
- Seek to build partnerships, interpret technical studies for stakeholders, landowners, and the public, and identify pilot projects and future remediation actions that are feasible, fundable, and broadly supported by stakeholders.

The Stewardship Program will host community meetings, working group meetings, one-on-one meetings with individual landowners, a website, and occasional newsletters to disseminate information. The Program will facilitate two working groups to focus on Sediment Remediation/Science and Monitoring; and Community Health & Safety (i.e., Agriculatural and drinking water and road flooding). The Sediment workgroup will identify (1) potential remediation strategies and actions to reduce impacts from sediment and water quality impairment, including mechanical sediment trapping or removal, riparian vegetation management, and salmonid habitat enhancement; (2) a strategy for scientific monitoring; and (3) potential remediation areas, project types, and individual projects. The Health & Safety workgroup will identify potential actions to (4) address drinking water and agricultural water needs where water supply is challenged, and (5) to reduce impacts from nuisance flooding on Elk River Road, Wrigley Road, Elk River Courts, Berta Road, and Zanes Road.

The outcome of the Stewardship Program will result in an *Action Plan for the Recovery of Beneficial Uses of Water in Elk River.* The action plan will provide a detailed and formal project description to be used in developing a Programmatic Environmental Impact Report required by CEQA and during federal Endangered Species Act consultation.

8 REFERENCES CITED

Anderson, C. and D. Ward. 2015. Results of regional spawning ground surveys and estimates of total salmonid redd construction in the Humboldt Bay, Humboldt County California, 2014–2015. California Department of Fish and Wildlife Coastal Salmonid Monitoring Program.

Arauho, H. A. 2011. Population responses of coho and Chinook salmon to sedimentation associated with forest roads in a coastal watershed of the Lower Fraser River. Master's thesis, Simon Fraser University, British Columbia, Canada.

Bash, J., C. Berman, and S. Bolton. 2001. Effects of turbidity and suspended solids on salmonids. Center for Streamside Studies, University of Washington.

Beach, R., J. Clough, P. Craig, A. Donigian, R. McGrath, R. Park, A. Stoddard, S. Svirsky, and C. Wallen. 2000. Modeling Study of PCB Contamination in the Housatonic River. Prepared for U.S. Army Corps of Engineers New England District Concord, Massachusetts and U.S. Environmental Protection Agency Region 1 Boston, Massachusetts. October.

Benda, L. and P. Bigelow. 2014. On the patterns and processes of wood in northern California streams. Geomorphology 209: 79–97.

Berg, L. 1982. The effect of exposure to short-term pulses of suspended sediment on the behavior of juvenile salmonids. Pages 177–196 *in* G.F. Hartman et al. editors. Proceedings of the Carnation Creek workshop: a ten-year review. Department of Fisheries and Oceans, Pacific Biological Station, Nanaimo, Canada.

Berman, C. 1998. Oregon Temperature Standard Review. U.S. EPA, Region 10. Seattle, WA.

Bisson, P. A., and Bilby, R. E. 1982. Avoidance of suspended sediment by juvenile coho salmon. North American Journal of Fisheries Management,2: 371–374.

Bjornn, T., and D. Reiser. 1991. Habitat requirements of salmonids in streams. American Fisheries Society Special Publication 19: 83-138.

Buchanan, T. J., and W. P. Somers. 1969. Techniques of water resource investigations of the United States Geological Survey: discharge measurements at gaging stations book 3 application of hydraulics. United States Government Printing Office, Washington.

Buffington, J. M., and D. R. Montgomery. 1999. Effects of hydraulic roughness on surface textures of gravel-bed rivers. Water Resources Research 35: doi: 10.1029/1999WR900138. issn: 0043-1397.

Buffington, J., and D. Montgomery. 1999. A procedure for classifying textural facies in gravel-bed rivers. Water Resources Research 35:1,903–1,914.

Buffington J. M., T. E. Lisle, R. D. Woodsmith, and S. Hilton. 2002. Controls on the size and occurrence of pools in coarse-grained forest rivers. River Research and Applications 18: 507–531.

California Department of Fish and Game (CDFG). 1994. Petition to the California Board of Forestry to list coho salmon (*Oncorhynchus kisutch*) as a sensitive species. Calif. Dep. Fish Game Rep., 35 p. plus appendices. (Available from California Board of Forestry, 1416 Ninth, Sacramento, CA 95814.)

California Trout. 2018. Field Note: Fish sampling and dissolved oxygen monitoring North Fork Elk River and Elk River, tributary to Humboldt Bay. California Trout North Coast Region, Arcata, CA.

Chapman, D. W. 1988. Critical review of variables used to define effects of fines in redds of large salmonids. Transactions of the American Fisheries Society 117: 1–21.

Chapman, J. M., C. L. Proulx, M. A. Veilleux, C. Levert, S. Bliss, M. È. André, N. W. Lapointe, and S. J. Cooke. 2014. Clear as mud: a meta-analysis on the effects of sedimentation on freshwater fish and the effectiveness of sediment-control measures. Water Research 56: 190–202.

Collins, A. L., P. S. Naden, D. A. Sear, J. I. Jones, I. D. L. Foster, and K. Morrow. 2011. Sediment Targets for Informing River Catchment Management: International Experience and Prospects. Hydrological Processes 25: 2,112–2,129.

Cover, M. R., C. C. May, W. E. Dietrich, and V. H. Resh. 2008. Quantitative linkages among sediment supply, streambed fine sediment, and benthic macroinvertebrates in northern California streams. Journal of the North American Benthological Society 27: 135–149.

DiToro, D. M., P. R. Paquin, K. Subburamu, and D. A. Gruber. 1990. Sediment oxygen demand model: methane and ammonia oxidation. Journal Environmental Engineering, ASCE 116: 945–986.

DiToro, D. M. 2001. Sediment Flux Modeling. Wiley-Interscience, New York.

Edwards, T. K., and G. D. Glysson. 1999. Field methods for measurement of fluvial sediment: U.S. Geological Survey techniques of water-resources investigations, book 3, chap. c2.

England, J.F., Jr., T.A. Cohn, B.A. Faber, J.R. Stedinger, W.O. Thomas Jr., A.G. Veilleux, J.E. Kiang, and R.R. Mason Jr. 2018. Guidelines for determining flood flow frequency—Bulletin 17C: U.S. Geological Survey Techniques and Methods, book 4, chap. B5, 148 p.

Fay, M.P. & Proschan, M.A. (2010). "Wilcoxon–Mann–Whitney or t-test? On assumptions for hypothesis tests and multiple interpretations of decision rules." Statistics Surveys. 4: 1–39

Flosi, G., S. Downie, J. Hoelain, M. Bird, R. Coey, B. Collins. 2010. California Stream Habitat Restoration Manual. Fourth Edition. California Department of Fish and Game.

Gotvald, A.J., N.A. Barth, A.G. Veilleux, and C. Parrett. 2012. Methods for determining magnitude and frequency of floods in California, based on data through water year 2006: U.S. Geological Survey Scientific Investigations Report 2012–5113, 38 p.

Gregory, R. S. 1993. Effect of turbidity on the predator avoidance behavior of juvenile chinook salmon (Oncorhynchus tshawytscha). Canadian Journal of Fisheries and Aquatic Sciences 50: 241–246.

Gregory, R. S., and C. D. Levings. 1998. Turbidity reduces predation on migrating juvenile Pacific salmon. Transactions of the American Fisheries Society 127: 275–285.

Humboldt Redwood Company. 2015. Class I Stream Aquatic Trends Monitoring 2014 Annual Report. Scotia, California.

Hansen, A. G., D. A. Beauchamp, and E. R. Schoen. 2013. Visual prey detection responses of piscivorous trout and salmon: effects of light, turbidity, and prey size. Transactions of the American Fisheries Society 142: 854–867.

Harvey, B. C., J. L. White, and R. J. Nakamoto. 2009. The effect of deposited fine sediment on summer survival and growth of rainbow trout in riffles of a small stream. North American Journal of Fisheries Management 29: 434–440.

Healey MC. 1982. Catch, escapement and stock-recruitment for British Columbia Chinook salmon since 1951. Can Tech Rep Fish Aquat Sci 1107:1–77

Henley, W. F., M. A. Patterson, R. J. Neves, and A. D. Lemly. 2000. Effects of sedimentation and turbidity on lotic food webs: a concise review for natural resource managers. Reviews in Fish. Sci. 8: 125–139.

Hsu, H., & Lachenbruch, P. A. (2005). Paired t test. In Encyclopedia of Biostatistics. Hoboken, NJ: John Wiley & Sons.

Humboldt Bay Watershed Advisory Committee (HBWAC). 2005. Humboldt Bay Watershed Salmon and Steelhead Conservation Plan. Available at:http://www.nrsrcaa.org/nrs/projcurr/pdfs/EnhancePlanComplete.pdf

Humboldt Redwood Company. 2014. Elk River Salmon Creek Watershed Analysis Revisited.

Keller, E., A. MacDonald, T. Tully, and N. Merrit. 1995. Effects of large organic debris on channel morphology and sediment storage in selected tributaries of Redwood Creek, Northwestern California. *In* Geomorphic Processes and Aquatic Habitat in the Redwood Creek Basin, Northwestern California. K. Nolan, H. Kelsey, and D Marron *Editors*. U.S. Geological Survey Professional Paper 1454.

Kelsey, H. M. 1980. A sediment budget and an analysis of geomorphic process in the Van Duzen River basin, north coastal California, 1941–1975: Geological Society of America Bulletin 91: 1,119–1,216.

Kjelland, M. E., C. M. Woodley, T. M. Swannack, and D. L. Smith. 2015. A review of the potential effects of suspended sediment on fishes: potential dredging-related physiological, behavioral, and transgenerational implications. Environment Systems and Decisions 35: 334–350.

Klein, R, W. Trush, and M. Buffleben. 2008. Watershed condition, turbidity, and implications for anadromous salmonids in north coastal California streams. Report to California North Coast Regional Water Quality Control Board. Santa Rosa, California.

Klein, R.D., Lewis, J., and M.S Buffleben. 2011. Logging and turbidity in the coastal watersheds of northern California, Geomorphology (2011), doi:10.1016/j.geomorph.2011.10.011

Koski, K. V. 1966. The survival of coho salmon (*Oncorhynchus kisutch*) from egg deposition to emergence in three Oregon coastal streams. Master's thesis. Oregon State University, Corvallis.

Koski, K. 2009. The fate of coho salmon nomads: the story of an estuarine-rearing strategy promoting resilience. *Ecology and Society*, *14*(1).

Kemp, P., D. Sear, A. Collins, P. Naden, and I Jones. 2011. The Impacts of fine sediment on riverine fish. Hydrological Processes 25: 1,800–1,821.

Knighton, A.D. 1991. Channel bed adjustment along mine-affected rivers of northeast Tasmania. Geomorphology 4: 205–219.

Lentell, J. N. 1914. Map of Humboldt County.

Lewis, J. 2013. Salmon Forever’s 2013 Annual Report on Suspended Sediment, Peak Flows, and Trends in Elk River and Freshwater Creek, Humboldt County, California. Submitted to Redwood Community Action Agency. SWRCB Agreement No. 07-508-551-1. June 2013.

Lewis, J. 2017. Elk River Recovery Assessment: Suspended Sediment Concentration Trend Analysis. Powerpoint presentation to the Elk River Technical Advisory Committee. December 2017.

Lisle, T. E. 1982. Effects of aggradation and degradation on riffle-pool morphology in natural gravel channels, northwestern California. Water Resources Research 18: 1,643–1,651.

Lisle, T. E. 1989. Sediment transport and resulting deposition in spawning gravels, north coastal California. Water resources research, 25: 1,303–1,319.

Ogle, B. A. 1953. Geology of Eel River Valley area. Bulletin No. 164. California Division of Mines, San Francisco.

Marshall, G. J., and E. Mendes. 2005. Geologic and geomorphic features related to landsliding and landslide potential in the Elk River watershed. State of California, Department of Conservation, California Geological Survey, Sacramento, California.

McLaughlin, R. J., S. D. Ellen, Jr. M. C. Blake, A. S. Jayko, W. P. Irwin, K. R. Aalto, G. A. Carver and S. H. Clarke, Jr. 2000. Geology of the Cape Mendocino, Eureka, Garberville, and southwestern part of the Hayfork 30 x 60 minute quadrangles and adjacent offshore area, northern California. Pamphlet to accompany Miscellaneous Field Studies Map MF-2336, Version 1.0. U. S. Geological Survey.

Michel, C., H. Schmidt-Posthaus, and P. Burkhardt-Holm. 2013. Suspended sediment pulse effects in rainbow trout (*Oncorhynchus mykiss*)—relating apical and systemic responses. Canadian Journal of Fisheries and Aquatic Sciences 70: 630–641.

Miller, B. A., and S. Sadro. 2003. Residence time and seasonal movements of juvenile coho salmon in the ecotone and lower estuary of Winchester Creek, South Slough, Oregon. Transactions of the American Fisheries Society 132: 546–559.

Montgomery D. R., B. D. Collins, J. M. Buffington, T. B. Abbe. 2003. Geomorphic effects of wood in rivers. Pages 21–47 *in* S. V. Gregory, K. L. Boyer, A. M. Gurnell, editors. The ecology and management of wood in world rivers. American Fisheries Society Symposium 37.

Moore, T., and S. Ricker. 2012. Escapement, spawning distribution, and migration patterns of adult salmonids in Freshwater Creek, 2011-2012. California Department of Fish and Game, Anadromous Fisheries Resource Assessment and Monitoring Program, 50 Ericson Ct., Arcata, CA 95521.

Mueller, D., and C. Wagner. 2006. Application of the loop method for correcting acoustic doppler current profiler discharge measurements biased by sediment transport. USGS Scientific Investigations Report 2006-5079.

National Marine Fisheries Service. 2016. Coastal Multispecies Recovery Plan. National Marine Fisheries Service, West Coast Region, Santa Rosa, California.

Newcombe, C. P., and J. O. T. Jensen. 1996. Channel suspended sediment and fisheries: a synthesis for quantitative assessment of risk and impact. North American Journal of Fish. Management 16: 693–727.

Newcombe, Charles P., and Donald D. MacDonald. 1991. Effects of suspended sediments on aquatic ecosystems. North American Journal of Fisheries Management 11.1: 72–82.

NHE and Stillwater Sciences (Northern Hydrology Engineering and Stillwater Sciences). 2013. Elk River Hydrodynamic and Sediment Transport Modeling Pilot Project. Final Report.

NMFS (National Marine Fisheries Service). 2014. Final Recovery Plan for the Southern Oregon/Northern California Coast Evolutionarily Significant Unit of Coho Salmon (*Oncorhynchus kisutch*). National Marine Fisheries Service. Arcata, California.

NMFS. 2016. Coastal Multispecies Final Recovery Plan: California Coastal Chinook Salmon ESU, Northern California Steelhead DPS and Central California Coast Steelhead DPS. West Coast Region, Santa Rosa, California. October.

North Coast Regional Water Quality Control Board. 2004. Salmonid freshwater habitat targets for sediment-related parameters. State Water Resources Control Board North Coast Region, Santa Rosa, California

North Coast Regional Water Quality Control Board (NCRWQCB). 2013. Peer Review Draft: Staff report to support the technical sediment total maximum daily load for the Upper Elk River.

North Coast Regional Water Quality Control Board (NCRWQCB). 2013b. Appendix 3-B Fisheries Information for Upper Elk River *in* Peer Review Draft: Staff report to support the technical sediment total maximum daily load for the Upper Elk River.

PALCO (Pacific Lumber Company). 1999. Habitat conservation plan and associated documents for PALCO lands. Section 3. Habitat conservation plan for the properties of the Pacific Lumber Company, Scotia Pacific Holding Company, and Salmon Creek Corporation.

PALCO. 2004. Elk River/Salmon Creek Watershed Analysis. Pacific Lumber Company, Scotia, CA.

Patenaude, J. R. 2004. Preliminary Assessment of Flooding in Lower Elk River. Staff Report of the North Coast Regional Water Quality Control Board, Crescent City, California.

Reeves G. H., F.H. Everest, and T.E. Nickelson. 1989. Identification of physical habitats limiting the production of coho salmon in western Oregon and Washington. US Forest Service General Technical Report PNW 245.

Regional Water Board (North Coast Regional Water Quality Control Board). 2006. Desired Salmonid Freshwater Habitat Conditions for Sediment-Related Indices. July 28, 2006

Regional Water Board. 2013. Peer Review Draft Staff Report to Support the Technical Sediment Total Maximum Daily Load for the Upper Elk River. March 4, 2013.

Regional Water Board. 2016. Action Plan for the Upper Elk River Sediment TMDL. Adopted by the Regional Water Board as an amendment to the Water Quality Control Plan for the North Coast on May 12, 2016. https://www.waterboards.ca.gov/northcoast/water_issues/programs/tmdls/elk_river/pdf/180319/ACTION_PLAN_FOR_THE_UPPER_ELK_RIVER_SEDIMENT_TMDL.pdf

Ricker, S. J., and C. W. Anderson. 2014. Freshwater Creek salmonid life cycle monitoring station. Annual report. California Department of Fish and Game, Anadromous Fisheries Resource Assessment and Monitoring Program. 50 Ericson Ct., Arcata, CA. 42p plus appendices.

Rinne, J. N. 2001. Effects of substrate composition on Apache Trout fry emergence. Journal of Freshwater Ecology 16: 355–365.

Robert, P., & Escoufier, Y. (1976). A unifying tool for linear multivariate statistical methods: the RV-coefficient. Applied Statistics. 25 (3): 257-265.

Roberts, R. G., and M. Church. 1986. The sediment budget in severely disturbed watersheds, Queen Charlotte Ranges, British Columbia. Canadian Journal of Forest Resources 16: 1,092–1,106.

Rosenfeld, J. 2002. Modelling the effects of changes in turbidity and channel structure on growth of juvenile salmonids. Final 2002–2003 Project Report, Forestry Innovation Investment Research Program, FII R2003-183, B.C. Ministry of Water Land and Air Protection.

Rosenfeld, J. S., and L. Huato. 2003. Relationship between large woody debris characteristics and pool formation in small coastal British Columbia streams. North American Journal of Fisheries Management 23: 928–938.

Ruggerone, G.T. 2000. Differential survival of juvenile sockeye and coho salmon exposed to low dissolved oxygen during winter. Journal of Fish Biology 56: 1013-1016.

Ryan P. A. 1991. Environmental effects of sediment on New Zealand streams: a review. New Zealand Journal of Marine and Freshwater Research 25: 207–221.

Sanborn. 2005. Freshwater Creek Watershed and Elk River Watershed Tributaries of Humboldt Bay, California. LIDAR Campaign Final Report.

Sanborn. 2005. Freshwater Creek Watershed and Elk River Watershed Tributaries of Humboldt Bay, California. LIDAR Campaign Final Report.

Scheer, G. 2017. A population model for Coho salmon (*Onchorhynchus kisutch*) in freshwater creek: evaluating the effects of life history variation and habitat restoration. (MS thesis, Humboldt State University). https://digitalcommons.humboldt.edu/etd/105

Schindler, D. E., R. Hilborn, B. Chasco, C. P. Boatright, T. P. Wuinn, L. A. Rogers, and M. S. Webster. 2010. Population diversity and the portfolio effect in an exploited species. Nature 465: 609–612.

Sedell, J. R., P. A. Bisson, E J. Swanson, and S. V. Gregory. 1988. What we know about large trees that fall into streams and rivers. Pages 47–81 *in* C. Maser, R. F. Tarrant, J. M. Trappe, and J. E Franklin, editors. From the forest to the sea: a story of fallen trees. U.S. Forest Service General Technical Report PNW-GTR-229.

Sparkman, M. D. 2003. Negative influences of predacious egg-eating worms, Haplotaxis ichthyophagous, and fine sediments on coho salmon, *Oncorhynchus kisutch*, in natural and artificial redds. Master's thesis. Humboldt State University, Arcata, California.

Spence, B.C. and Hughes, R.M. 1996. An ecosystem approach to salmonid conservation. ManTech Environmental Research Services, Corporation.

Solinst Canada Ltd. 2017. Solinst Levelogger Model 3001. Retrieved February 2017, from User Guide: Levelogger Series - Software Version 4.3.0: https://www.solinst.com/products/dataloggers-and-telemetry/3001-levelogger-series/operating-instructions/user-guide/3001-user-guide.pdf

Suttle, K. B., M. E. Power, J. M. Levine, and C. McNeely. 2004. How fine sediment in riverbeds impairs growth and survival of juvenile salmonids. Ecological Applications 14: 969–974.

Sweka, J. A., and Hartman, K.J., 2001. Influence of turbidity on brook trout reactive distance and foraging success. Transactions of the American Fisheries Society 130: 138–146.

Sweka, J., and K.Hartman. 2011. Effects of turbidity on prey consumption and growth in Brook trout and implications for bioenergetics modeling. Canadian Journal of Fisheries and Aquatic Sciences 58: 386–393.

Tetra Tech Inc. 2007. The Environmental Fluid Dynamics Code, Theory and Computation, Volume 2: Sediment and Contaminant Transport and Fate. Tetra Tech, Inc., Fairfax, VA.

Tetra Tech Inc. 2015. Upper Elk River: Technical Analysis for Sediment. Prepared for the Environmental Protection Agency, Region 9 and North Coast Regional Water Quality Control Board.

USDA Forest Service. 1981. CALVEG: A Classification of California Vegetation. Pacific Southwest Region, Regional Ecology Group, San Francisco California.

United States Environmental Protection Agency. 1999. South Fork Eel River total maximum daily loads for sediment and temperature. Region 9, Water Division, San Francisco, CA.

United States Environmental Protection Agency. 2000. Navarro River total maximum daily loads for sediment and temperature. Region 9, Water Division, San Francisco, CA.

Wallace, M., and S. Allen. 2007. Juvenile Salmonid Use of the Tidal Portions of Selected Tributaries to Humboldt Bay, California. Prepared for the California Department of Fish and Game and the Pacific States Marine Fisheries Commission.

Wallace, M. 2011. Juvenile salmonid use of the tidal portions of selected tributaries to Humboldt Bay, California. 2009–2011. Final report for contract P0810517 to California Department of Fish and Game Fisheries Restoration Grants Program.

Wallace, M., S. Ricker, J. Garwood, A. Frimodig, and S. Allen. 2015. Importance of the stream-estuary ecotone to juvenile coho salmon (*Oncorhynchus kisutch*) in Humboldt Bay, California. California Fish and Game 101: 241–266.

Weitkamp, L. A., T. C. Wainwright, G. J. Bryant, G. B. Milner, D. J. Teel, R. G. Kope, and R. S. Waples. 1995. Status review of coho salmon from Washington, Oregon, and California. US Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northwest Fisheries Science Center.

Wilcoxon, F. (1945). Individual comparisons by ranking methods. Biometrics Bulletin. 1 (6): 80-83.

Williams, T. H., Bjorkstedt, E. P., Duffy, W. D., Hillemeier, D., Kautsky, G., Lisle, T. E., McCain, M., Rode, M., Szerlong, R. G., Schick, R. S., Goslin, M. N., and Agrawal, A. 2006. Historical population structure of coho salmon in the southern Oregon / northern California coasts evolutionarily significant unit. National Marine Fisheries Service, Santa Rosa, CA. 85 pp. U.S. Department of Commerce, NOAA Technical Memorandum SWFSC-390.

YSI Incorporated. 2012. 6-Series Multiparameter Water Quality Sondes User Manual. Retrieved February 2017, from https://www.ysi.com/File%20Library/Documents/Manuals/069300-YSI-6-Series-Manual-RevJ.pdf

Appendices

Appendix A

Elk River Technical Advisory Committee (TAC) Meeting Attendees, Notes, and Presentation Materials

Summary Memorandum of Elk River Recovery Assessment Technical Advisory Committee Meeting #1

Date: December 7, 2015
Time: 10:00 AM to 1:00 PM
Location: Humboldt Bay Aquatic Center, Eureka, CA

CalTrout, the Regional Water Board, and the Elk River Recovery Assessment (ERRA) project team - Northern Hydrology and Engineering, Stillwater Sciences, and Jack Lewis - convened a Technical Advisory Committee meeting to seek technical input and expert peer-review of the ERRA. This brief document provides a summary of the ERRA TAC Meeting #1.

Meeting Objectives

- Introduce the Elk River Recovery Assessment and Project Team
- Describe the broader watershed context for the Recovery Assessment
- Describe our objectives for engaging with the Elk River Technical Advisory Committee

Agenda

- Welcome and Introductions
- Overview of Elk River Recovery Assessment and ongoing watershed activities: presentations by Darren Mierau of CalTrout and Alydda Mangelsdorf of the Regional Water Board.
- Recovery Assessment: watershed overview project set-up, data collection, modeling recovery scenarios: presentations by Bonnie Pryor of NHE and Jay Stallman of Stillwater Science.
- Questions-Answers; TAC Next Steps.

Summary

The Elk River Recovery Assessment is a focused planning effort informed by empirical data and predictive modeling, with the goal to develop a collaborative, scientifically-based restoration strategy composed of a set of actions designed to hasten recovery of beneficial uses of water and related aquatic ecosystem functions. Collaborators include the Elk River Assessment Project Team, the Elk River TAC, and the Elk River Stewardship Program.

Elk River is impaired by fine sediment that originated primarily from discharge of waste primarily contributed from the upper watershed. Impairments include fine sediment with turbidity and channel deposits degrading fisheries habitat, domestic and agricultural supply. Nuisance flooding conditions have resulted from reduced channel capacity associated with stored instream sediment deposits.

The Recovery Assessment includes: documenting existing conditions, developing a set of desired future conditions, and analyzing potential recovery actions. Several pilot implementation projects are being developed to demonstrate remediation approaches.

Modeling; both numerical and conceptual models are being developed to guide recovery planning in Elk River. The Recovery Assessment will address several key questions:

- If loads are reduced, will the Elk River recover?
- If load reductions are insufficient, what additional actions may be required to achieve desired conditions?

Attendees

The Technical Advisory Committee attendees included:

Attendees:	
Name	**Organization**
Darren Mierau, Debbie Marshall, Matthew Metheny	CalTrout
Alydda Mangelsdorf, Adona White, Lance Le, Clayton Creager	North Coast Regional Water Quality Control Board
Jay Stallman, Tom Lisle	Stillwater Sciences
Jeff Anderson, Bonnie Pryor	Northern Hydrology & Engineering
David Manthorne	California Department of Fish & Wildlife
Connor Shea	U.S. Fish And Wildlife Service
Kristi Wrigley	Salmon Forever Sediment Lab/Elk River Resident's Assoc.
Jesse Noell	Salmon Forever
Margaret Tauzer	NOAA Fisheries
Peggy Wilzbach	USGS California Cooperative Fish Research Unit
Mary Ann Madej	U.S. Geological Survey
Matt House	Green Diamond Resource Company
Shane Beach, Nick Harrison	Humboldt Redwood Company
Yana Valachovic, Dan Stark, Brendon Twig	University of California Cooperative Extension
Jack Lewis	Independent
Sam Flanagan	Bureau Of Land Management
John Bair	McBain Associates
Hank Seemann, Cybelle Immitt	County Of Humboldt Natural Resource Planning

If you have any questions, please contact the Project Director at any time.
Sincerely,

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Elk River Recovery Assessment
Technical Advisory Committee
Agenda: Informational Meeting #1

Date: December 7, 2015
Time: 10:00 AM to 1:00 PM
Location: Humboldt Bay Aquatic Center, Waterfront Drive, Eureka, CA

Meeting Objectives

- Introduce the Elk River Recovery Assessment and Project Team
- Describe the broader watershed context for the Recovery Assessment
- Describe our objectives for engaging with the Elk River Technical Advisory Committee

Agenda: Elk River Watershed Stewardship Meeting #1

	Agenda
10:00	Welcome and Introductions
10:15 – 10:45	Overview of Elk River Recovery Assessment and ongoing watershed activities
10:45 – 11:30	Recovery Assessment Part I: watershed overview project set-up, data collection
11:30 – 11:45	*Break*
11:45 – 12:15	Recovery Assessment Part II: modeling recovery scenarios
12:15 – 1:00	Questions-Answers; TAC Next Steps.

Attendance:

NAME	ORGANIZATION
Darren Mierau	CalTrout
Alydda Mangelsdorf	North Coast Regional Water Quality Control Board
Jay Stallman	Stillwater Sciences
Jeff Anderson	Northern Hydrology & Engineering
Bonnie Pryor	Northern Hydrology & Engineering
Tom Lisle	Stillwater Sciences
Adona White	North Coast Regional Water Quality Control Board
David Manthorne	California Department of Fish & Wildlife
Lance Le	North Coast Regional Water Quality Control Board
Matthew Metheny	CalTrout/USGS California Cooperative Fish Research Unit
Kristi Wrigley	Salmon Forever Sediment Lab/Elk River Resident's Assoc.
Margaret Tauzer	NOAA Fisheries
Peggy Wilzbach	USGS California Cooperative Fish Research Unit
Debbie Marshall	CalTrout
Mary Ann Madej	U.S. Geological Survey
Matt House	Green Diamond Resource Company
Shane Beach	Humboldt Redwood Company
Dan Stark	University of California Cooperative Extension
Nick Harrison	Humboldt Redwood Company
Connor Shea	U.S. Fish and Wildlife Service
Jack Lewis	Independent
Sam Flanagan	Bureau of Land Management
John Bair	McBain Associates
Cybelle Immitt	County of Humboldt Natural Resource Planning
Clayton Creager	Regional Water Board
Hank Seemann	Humboldt County Public Works
Brendon Twig	University of California Cooperative Extension
Yana Valachovic	University of California Cooperative Extension
Jesse Noell	Salmon Forever

Summary Memorandum of Elk River Recovery Assessment Technical Advisory Committee Meeting #2

Date: November 10th, 2016
Time: 9:00 AM to 4:00 PM
Location: Humboldt County Ag Center, Eureka, CA

CalTrout, the Regional Water Board, and the Elk River Recovery Assessment (ERRA) project team - Northern Hydrology and Engineering, Stillwater Sciences, and Jack Lewis - convened a Technical Advisory Committee meeting to seek technical input and expert peer-review of the ERRA. This brief document provides a summary of the ERRA TAC Meeting #2.

Meeting Objectives

- Develop a shared understanding of the function of the Elk River TAC and participation in the Recovery Assessment.
- Develop a clear understanding of the Recovery Assessment Technical Team's Conceptual Model of Elk River existing morphologic, hydrodynamic, and sediment conditions.
- Begin to develop a technical framework and draft set of numerical values for "Targeted Conditions" in the sediment impaired middle reaches and lower valley reaches of Elk River

Agenda

- Review agenda and goals for today's TAC #2 meeting, discuss expectations of the TAC process; Review of TAC #1 meeting content
- Presentation of draft Conceptual Model of existing conditions (Jay Stallman of Stillwater Science.).
- TAC feedback to conceptual model. Does the model provide a reasonable interpretation of the system?
- Presentation of "Targeted Conditions" (Bonnie Pryor and Darren Mierau)
- Review of meeting. Questions-Answers; discussion of plans for next TAC meeting.

Summary

Draft Conceptual Model of Current Conditions – Key concepts include; 1) Valley geomorphology and channel geometry. 2) Channel/Floodplain sediment size. 3) Vegetation and Woody Debris. 4) Reach-scale hydrodynamics. 5) Sediment supply. 6) Channel change.

TAC Feedback on Conceptual Model:
Q: How much were channels affected by splash dams after 1950s?
A: 600 cfs, coming out of bank; SWRCB target is 2200 cfs channel capacity. Recovery Program considers current conditions and will develop desired/target conditions
Q: How do human influences (bridges, levees) affect natural function?
A: Studied infrastructure constraints (Steel Bridge), will look at Berta; need detailed map of levees and other constraints from Lidar; finer scale analysis
Q: Need subsidence and uplift discussion.
Q: Rate of runoff associated with peak flow – how much and timing.

Q: Accuracy of historical channel maps questionable.
Q: Hydraulic control between R2 & R1 – role in lower basin; constriction of velocity
A: tidal control

Desired Conditions – Current impacted beneficial uses include; Recreation, Municipal, Agriculture, Cold freshwater habitat, and Preservation of rare and endangered species. Based on current conditions – develop a physical description of each channel; dimension/slope, vegetation type, distribution, bed grain size, wood storage. Review and edit "desired conditions" Based on assumptions for geomorphic reaches. Desired conditions modeled with EFDC; evaluate: Channel changes (primarily vertical change), Sediment concentrations (maintenance of targets through the system), Grain size changes (coarsening or fining), Flood inundation frequency and extent, Identification of areas more prone to rapid sedimentation, Evaluate role of selected infrastructure on sedimentation patterns.

Attendees
The Technical Advisory Committee attendees included:

Attendees:	
Name	**Organization**
Sam Flannigan	Bureau of Land Management
Darren Mierau, Dave Heaton, Debbie Marshal, Matt Metheny	CalTrout
David Manthorn	California Department of Fish and Wildlife
Matt House	GDRC
Nick Harrison, Shane Beach	Humboldt Redwoods Co.
Eileen Cashman	HSU Engineering
Peggy Wilsbach	HSU Fisheries Co-op
Hank Seeman	Humboldt County
John Bair	McBain Associates
Bonnie Pryor, Jeff Anderson	Northern Hydrology & Engineering
Margaret Tauzer	National Marine Fisheries Service
Jon Shultz	NRCS
Adona White, Alydda Mangelsdorff, Chuck Striplin, Lance Le	Regional Water Board
Marian Madej	Retired USGS
Kristi Wrigley, Jesse Noell	Salmon Forever
Jay Stallman, Tom Lisle	Stillwater Sciences
Yana Valachovic	UC Extension
Connor Shea	USFWS

If you have any questions, please contact the Project Director at any time.
Sincerely,

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Elk River Recovery Assessment TAC Meeting #2
November 10 2016 – Humboldt County Ag Center Eureka

Attendance: Eileen Cashman (HSU Engineering); Tom Lisle (Stillwater Sciences); Marian Madej (Retired USGS); Connor Shea (USFWS); Sam Flannigan (BLM); Margaret Tauzer (NMFS); David Manthorn (CDFW); Hank Seeman (Humboldt County); Nick Harrison (HRC); Shane Beach (HRC); Kristi Wrigley (Salmon Forever); Jon Shultz (NRCS); Matt House (GDRC); Yana Valachovic (UC Extension); Lance Le (Regional Water Board); Chuck Striplin (Regional Water Board); Alydda Mangelsdorff (Regional Water Board); Jeff Anderson (NHE); Bonnie Pryor (NHE); Jay Stallman (Stillwater); Darren Mierau (CalTrout); Dave Heaton (CalTrout); Matt Metheny (CalTrout)

Time	Agenda Item
8:30-9:00 (30 min.)	Refreshments and pre-meeting discussions
9:00-9:30 (30 min.)	Review the Elk TAC process; Describe ongoing Recovery Assessment and Stewardship integration; Review meeting agenda and expected outcomes
9:30-10:30 (60 min.)	Presentation of draft Conceptual Model of existing conditions (Jay Stallman)
10:30-10:45 (15 min.)	Break
10:45-11:15 (30 min.)	Continue presentation of Conceptual Model (Jay Stallman)
11:15-12:00 (45 min.)	TAC feedback to conceptual model, focusing on these three questions: 1. Have we made reasonable interpretations with the available information? 2. Can you identify other linkages between processes that were not identified in the conceptual model? 3. Do you have alternative hypotheses that should be considered in the conceptual model?
12:00-1:00 (60 min.)	Catered Lunch
1:00-1:45 (45 min.)	Presentation of "Targeted Conditions" (Bonnie Pryor and Darren Mierau)
1:45-2:45 (60 min.)	Break-out groups ("World Café" model)
2:45-3:15 (30 min.)	Break-out groups "report back" and discussion (group facilitators with Bonnie and Jay);
3:15-4:00 (60 min.)	Wrap-up; discuss overall observations/feedback on the day's information; plans for December TAC #3 meeting; meeting review and wrap-up (handout questionnaire for homework)

TAC Overview (Darren Mierau):
- Project scoping started 4 years ago with the Regional Water Board; implementation began in 2014 to describe current conditions and develop desired outcomes; the contract requires two TAC meeting, with the amount of data to review, the Steering Committee is requesting 4 meetings.
  - First meeting, Dec. 7th, 2015, included the project background.
  - Second meeting, Nov 10th, 2016, to solicit input regarding the conceptual model.
  - Third meeting, Dec 9th, 2016, focus on hydraulic and sediment transport.
  - Fourth meeting, Spring 2017, review modeling results and develop recovery actions for sediment reduction.
- Relationship with Stewardship Program: Technical information from Assessment Team will be provided to the public; Steering Committee, headed by the County and UCCE, conducting 15 meetings to organize the Program.

Meeting Outcomes (Yana Valachovic):

- A shared understanding of the function of the Elk River TAC and participation in the Recovery Assessment.
- A clear understanding of the Recovery Assessment Technical Team's Conceptual Model of Elk River existing morphologic, hydrodynamic, and sediment conditions.
- A technical framework and draft set of numerical values for "Desired Future Conditions" in the sediment impaired middle reaches and lower valley reaches of Elk River

Draft Conceptual Model of Current Conditions (Jay Stallman):

- Foundations of Model - identification of drivers within the system
- Framework – strategies and effect of achieving desired outcomes
- Key Concepts

1. Valley Geomorphology and Channel Geometry
    - Convex bottom morphology
        - Geologic feature, not anthropogenic – 4-6' aggradation; first floodplain elevations to center valley line
        - Valley bottom landforms confined by terrace; confined channel responding to landforms
        - Valley profile:
    - Cross sections:
        - MSR5 – confined reach; maximum separation; greatest convexity; most entrenched – 18'
        - MSR5 to 4 – channel starting to develop; natural levees forming; increasing proportions of flood flow
        - MSR3 – higher levees; lateral flood plain
        - MSR2 – fluvial tidal transition zone; flood plain constant elevation; anthropogenic influence; natural levee on right bank
    - Geomorphic Reaches:
        - NFR2 – upstream limb begins trenching into floodplain; expand into wider floodplain; upper limb to convexity; invasive sedge
        - NFR1 – backwater effects; 3 major factors 1) confined reach, 2) confluence of north and south forks, 3) anthropogenic effects of steel bridge and vegetation; little velocity; channel aggradation
        - SFR2 – coarser grain
        - SFR1 –entrenching, sediment fining;
        - SFR5 – entrenched
        - SFR4 – flood plain storage; high flow paths, conveying flood flow
        - MSR 3 – large flood basin; backwater effect; channel toward evulsion, defined high flow channel, out of bank flow
        - MSR2 – fluvial tidal transition zone
        - MSR1 – tidal influence reach
    - Historical maps: splash dams – 1886 railroad transporting logs; tidal influence to Berta Road
    - Thumbnail – channel geometry; 25' elevation, 100' horizontal change; showing entrenchment
    - TOB and toe widths – narrowing of top and toe widths channel entrench
2. Channel and Floodplain Sediment Size
    - Sediment size – bed surface texture
    - cobble gravel; gravel/sand; sand/gravel; sand; fine (sand/silt)
    - Top to downstream – fine trend
    - Bed particle size – D84, D50, D16
3. Vegetation and woody debris
    - Redwood timber belt historically, valley floor forest cover; 1941 - agricultural reclamation; 1990 – phased redwood planting

- Vegetation mapping, variables for modeling (stem density, height, diameter); invasive sedge anchors sediment deposits; live and dead willows trap sediment; rough channel
- Total large wood debris (LWD) frequency and volume below SWRCB guidelines – indices for cold water fish; HCP identify target conditions for salmon

4. Reach-scale hydrodynamics
   - valley form, channel geometry, valley morphology
   - EFDC model – incorporates vegetation
   - Grid cell resolution
   - model 2002 and 2014 floods – flow and velocity is accurate compared to HRC data; compartmentalization of flood capacity
5. Sediment supply
   - Summarize existing information – TMDL
6. Channel change
   - Elevation narrowing, aggradation
   - Bridge locations, bed elevations – changes at bridges; 1990 hinge point at Elk River, Zanes and Steel

TAC Feedback on Conceptual Model:

Q: How much were channels affected by splash dams after 1950s?

A: 600 csf, coming out of bank; SWRCB target is 2200 csf channel capacity. Recovery Program considers current conditions and will develop desired/target conditions

Q: How do human influences (bridges, levees) affect natural function?

A: Studied infrastructure constraints (Steel Bridge), will look at Berta; need detailed map of levees and other constraints from Lidar; finer scale analysis

Q: Need subsidence and uplift discussion.

Q: Rate of runoff associated with peak flow – how much and timing.

Q: Accuracy of historical channel maps questionable.

Q: Hydraulic control between R2 & R1 – role in lower basin; constriction of velocity

A: tidal control

Desired Conditions (Bonnie Pryor):

- "What would a recovered Elk River look like?"
  - If loads are reduced, will the Elk River recover beneficial uses?
  - If load reductions are insufficient, what addition actions may be required to recover beneficial uses?
- Impacted beneficial uses:
  - Recreation
  - Municipal
  - Agriculture
  - Cold freshwater habitat
  - Preservation of rare and endangered species
- Goal – Develop physical description of each channel; dimension/slope, vegetation type, distribution, bed grain size, wood storage. Review and edit "desired conditions"
  - Based on assumptions for geomorphic reaches
  - Desired conditions modeled with EFDC; evaluate:
  - Channel changes (primarily vertical change)
  - Sediment concentrations (maintenance of targets through the system)
  - Grain size changes (coarsening or fining)
  - Flood inundation frequency and extent

- Identification of areas more prone to rapid sedimentation
- Evaluate role of selected infrastructure on sedimentation patterns

- 10 reaches = 10 visions: reach specific, long-term, quantitative

- Break-out Groups: Example Desired Conditions:
  - Channel dimensions prior to 1990 were generally adequate for achieving bankfull targets and a reasonable frequency and flooding extent.
    - Need off channel habitat information
    - Is 1990 condition appropriate for NR SF MS5 MS4 geometry to Zanes Road – variability in lower system; conveyance varies downstream, agree that the transition is around Zanes Road
    - Single thread channel may not be applicable, especially in lower reaches
    - Bankfull vs recurrence interval vs conveyance capacity; flow containment/conveyance should vary by reach
    - How do we portray/account for importance of floodplain for conveyance, habitat, etc.?
    - Do not prioritize beneficial uses; one use may be easier to restore than another
    - Reduce nuisance issues
    - Fish population data lacking
    - Riparian forests in lower reaches inconsistent with land management goals
    - Did gravel deposit in Humboldt Bay? Affect in velocity close to bay, MSR1 and MSR2 - what controls this?
    - Should Elk River function as other coastal streams do?
    - Subsidence and uplift?
    - Sea level rise
    - Incorporate importance of floodplain conveyance, potentially as an additional assumption][static nature of statement may not be appropriate to describe spatially varying channel conveyance characteristics
  - Grain sizes were sufficient to support spawning throughout the North Fork and South Fork with fining in the downstream direction.
  - Grain sizes in mainstem were too fine to support spawning, but a mixture of gravel and sand persisted in the reach to Showers Road. Some areas were sand dominated and others were gravel dominated depending on local sources of gravels (tributaries, bedrock outcrops, etc.).
  - Large wood has been in deficit for a long time due to wood removal, clearing of streamside forests, reduced delivery from upstream.
  - Riparian forests must be re-established for wood recruitment.
    - Consistent with site potential
    - Multiple functions rather than solely wood recruitment functions
  - Non-native invasive species should be eliminated.
    - Vegetation should be managed to minimize effects on conveyance capacity and sediment transport
  - Winter base flow channel should be free of dense vegetation.
  - Infrastructure should not alter water surface elevations.
    - Minimize effect of infrastructure
    - Consider how wood interacts with channel form and vegetation
    - Don't address spatial variability by reach
    - Infrastructure changes could be considered to minimize effects on water surface elevations
  - The estuary it critically important to increase fish populations

Overall thoughts:
Is dead wood all redwood?
Vocabulary is important – need definitions
Constraints come later
Develop a set of conditions to game with
Infrastructure assumption is hard to remove – why is this included?
Consider language changes

December TAC Meeting:

- Outcome:
  - Concurrence on "desired conditions" for reaches
  - Introduce fisheries and habitat information
- Provide feedback prior to Dec. meeting
- New information distributed before Dec meeting: summary of conditions, landowner surveys
- Constraints as goals/opportunities
- Need comprehensive map of infrastructures; model can identify issues to check hypothesis

November 10, 2016

Questionnaire Requesting Written Responses NAME: ______________________

1. Has our Elk River Conceptual Model made reasonable interpretations with the available information? Please explain your perspective or other interpretations.

2. Are there important additional linkages between processes that can and should be identified in the conceptual model to better inform the recover assessment?

3. Do you have alternative hypotheses to those presented by the technical team today that should be considered in the conceptual model to better inform the recovery assessment?

4. The hydrologic time-series that the Recovery Assessment Team has selected for hydrodynamic model runs spans a 16 year period of record for Elk River using water years 2001-2015. Given the representative water year classification for Bull Creek (Table 1), is this 16 year record an adequate representation of varying hydrologic conditions; including wet, dry, successive wet and successive dry years?

5. The sediment concentration data used for model Scenario-2 (existing conditions with reduced sediment loads) is being developed and recommended by the Regional Water Board staff. Is a generic percentage reduction (e.g., 50% or 75% reduction) in existing sediment loads an adequate approach to represent future sediment conditions, or should boundary conditions for different sediment load sources (e.g., Tom, Railroad, Clapp, NF, etc.) vary based on assumptions of different localized management actions/responses?

6. At least two "pilot" sediment reduction actions will be tested in Elk River in the first phase of project implementation: (1) mechanical sediment removal (with varying channel/floodplain dimensions and configurations), and (2) mechanical vegetation suppression/removal. What other small-scale implementation projects do you recommend in this pilot phase in Elk River?

7. If you have any other comments, please let us know

Summary Memorandum of Elk River Recovery Assessment Technical Advisory Committee Meeting #3

Date: December 9th, 2016
Time: 9:00 AM to 4:00 PM
Location: Humboldt County Ag Center, Eureka, CA

CalTrout, the Regional Water Board, and the Elk River Recovery Assessment (ERRA) project team - Northern Hydrology and Engineering, Stillwater Sciences, and Jack Lewis - convened a Technical Advisory Committee meeting to seek technical input and expert peer-review of the ERRA. This brief document provides a summary of the ERRA TAC Meeting #3.

Meeting Objectives

- Continue to solicit input (written or oral) from the Elk River TAC in the Recovery Assessment
- Review questions and comments regarding the Recovery Assessment Technical Team's Conceptual Model of Elk River existing morphologic, hydrodynamic, and sediment conditions.
- Discuss Hydrodynamic Modeling scenarios proposed by Recovery Assessment Team and scenario(s) proposed/refined by Stewardship Program
- Solicit input on Targeted Conditions and Broad Recovery Actions to be evaluated/interpreted by the hydrodynamic model and conceptual model in the sediment impaired middle reaches and lower valley reaches of Elk River

Agenda

- Follow-up discussion of Conceptual Model (Jay Stallman and Team)
- Discussion of hydrodynamic model scenarios (Bonnie Pryor and Team)
- Discussion of Desired Future Conditions (Bonnie Pryor and Team)
- Wrap-up and review

Summary

Intro and review of comments /questions from TAC #2 Meeting

Follow-up Discussion of Conceptual Model

Current conditions vs. pre-settlement conditions inherent to the modeling process were discussed. Model uses pre 1990 conditions as a baseline for functionality. The model reflects shorter term geomorphologic equilibrium as opposed to longer term geologic equilibrium. Restoration of channel geometry leading to a self maintaining state that supports beneficial uses is desired. The Elk River has likely always been transport limited, but we did enter a negative feedback loop that increased aggradation and flooding. There is a geologic valley convexity present in this reach of the river but the impairment of beneficial uses is not driven by convexity, but rather by land-use. Pre logging stream morphology (multi-thread vs. single-thread channel) is problematic to discern - Log drives favored making streams into a single channel to convey logs. Vegetation is included in the model. A forested area would have less pronounced levees. Our frame of reference is a deciduous riparian zone. The original floodplain function was Spruce forest. The way sediment moves through the trees in a Spruce

swamp is very different from willow/crab apple. Type of riparian vegetation and size of trees are all very important to levee building in the conceptual model.
Stewardship is currently working on a condensed version of conceptual model should be developed and be made available to the stakeholders and public. Modeling parameters were discussed.

Discussion on Hydrodynamic Model Scenarios
It was presumed that remediation was necessary, and we wanted to confirm this. The HST model was developed to test this hypothesis. If all management was controlled there would be a reduction of 75% of sediment, (75% reduced sediment scenario). It seems that scenario 2A is necessary. We want to see if the larger channel will fill in the same way it did in 1997 or change considering restoration and reduced sediment. Existing conditions results from 1A and 1B to set reduced loads in 2A and 2B will be used. Three model runs are required but we intend to do four runs that model 15 years of data. Model runs take a long time to process (~two weeks) so the number of runs of differing scenarios is limited.

Discussion of Desired Future Conditions

- Qualitative comparisons, not numeric
- Evolving attributes (coarsening of bed) are evaluated
- Desired Future Conditions are unique to reaches, and target beneficial uses.
- DFCs are intended to guide restoration actions.

Wrap-up and review

Attendees

The Technical Advisory Committee attendees included:

ERRA TAC #3 Attendees		
Name	**Organization**	**Group**
Sam Flannigan	BLM	Biological
Darren Mierau, Matt Metheny	CalTrout	Biological
David Manthorn	CDFW	Biological
Matt House	GDRC	Biological
Nick Harrison, Shane Beach	HRC	Physical
Eileen Cashman	HSU Engineering	Physical
Hank Seeman	Humboldt County	Physical
Tom Lisle	Stillwater Sciences	Physical
John Bair	McBain Associates	Biological
Bonnie Pryor, Jeff Anderson	NHE	Physical
Margaret Tauzer	NMFS	Physical
Jon Shultz	NRCS	Biological
Adona White, Alydda Mangelsdorff, Chuck Striplin	Regional Water Board	Biological/Physical
Marian Madej	Retired USGS	Physical
Jesse Noell, Kristi Wrigley	Salmon Forever	Physical/Biological
Jay Stallman	Stillwater	Biological
Yana Valachovic	UC Extension	Biological
Connor Shea	USFWS	Physical

If you have any questions, please contact the Project Director at any time.
Sincerely,

Darren Mierau
North Coast Director
California Trout Inc.
Office: 707.825.0420 / Cell: 707.845.7810
email: dmierau@caltrout.org
615 11th Street, Arcata, CA 95521
www.caltrout.org

Elk River Recovery Assessment TAC Meeting #3

Date: December 9, 2016
Time: 8:30 AM to 4:00 PM
Location: Humboldt County Ag Center (5630 South Broadway, Eureka)

Desired Outcomes:

1. Continue to solicit input (written or oral) from the Elk River TAC in the Recovery Assessment
2. Review questions and comments regarding the Recovery Assessment Technical Team's Conceptual Model of Elk River existing morphologic, hydrodynamic, and sediment conditions.
3. Discuss Hydrodynamic Modeling scenarios proposed by Recovery Assessment Team and scenario(s) proposed/refined by Stewardship Program
4. Solicit input on Targeted Conditions and Broad Recovery Actions to be evaluated/interpreted by the hydrodynamic model and conceptual model in the sediment impaired middle reaches and lower valley reaches of Elk River

Agenda: Elk River TAC Meeting #3

Time	Agenda Item
8:30-9:00	Refreshments and pre-meeting discussions (Ramones treats…come early!)
9:00-10:45	Follow-up discussion of Conceptual Model (Jay and Team) • Review questions and comments on Conceptual Model received from TAC • Revisit "clicker" questions on Conceptual Model components (have we improved our understanding of CM?) • Additional TAC Questions/Comments on Conceptual Model (are we ready to move on?)
10:45-11:00	Break
11:00-12:15	Discussion of hydrodynamic model scenarios (Bonnie and Team)
12:15-1:15	Catered Lunch (Ramones again…sandwiches this time!)
1:15-3:15	Discussion of Desired Future Conditions (Bonnie and Team) • Review questions and comments on Desired Future Conditions from TAC • Solicit input on Broad-Scale Restoration Actions
3:15-4:00	Wrap-up: • discuss overall observations/feedback on the day's information • plans for next TAC4 meeting • meeting review and wrap-up

Memory is motion. It glides upon the river like the canoes of twenty decades past. It rustles through the tops of vanished redwoods marked now only by their monumental stumps. All places sing their own story, but here, in the quietude of Elk River valley, the song is more easily heard.

Elk River TAC Participants

Name	**Organization**
Peggy Wilsbach	HSU Fisheries Co-op
Eileen Cashman	HSU Engineering
Tom Lisle	Stillwater Sciences
Mary Ann Madej	Retired USGS
Connor Shea	USFWS
John Bair	McBain Associates
Sam Flannigan	BLM
Margaret Tauzer	NMFS
Jack Lewis	Retired Redwood Sciences Lab
David Manthorne	CDFW
Hank Seemann	Humboldt County
Nick Harrison	HRC
Shane Beach	HRC
Kristi Wrigley	Salmon Forever
Jon Shultz	NRCS
Matt House	GDRC
Yana Valachovic	UC Extension
Jesse Noell	Salmon Forever
Lance Le	Regional Water Board
Chuck Striplin	Regional Water Board
Alydda Mangelsdorff	Regional Water Board
Adona White	Regional Water Board
Jeff Anderson	NHE
Bonnie Pryor	NHE
Jay Stallman	Stillwater
Darren Mierau	CalTrout
Dave Heaton	CalTrout
Matt Metheny	CalTrout

Elk River Recovery Assessment (ERRA)

Technical Advisory Committee (TAC) Meeting #4

Date/Time: December 6, 2017 (9- 1 pm)

Location: Humboldt Bay Aquatic Center

Desired Outcome:

- **Solicit input on the set of actions that will be analyzed as part of the ERRA.**

Wednesday, December 6th 9:00-1:00 PM

Time	Agenda Item
9:00–9:15	Welcome, Introductions, Review (Darren)
9:15-10:15	Summary of calibration and validation of the model (Jeff Anderson/Bonnie Pryor)
10:15-10:30	Reduced Sediment Load and SSC Trend Analysis (Lance Le)
10:30-10:45	SSC Trend Analysis (Jack Lewis)
10:45-11:00	Break
11:00-12:45	Analysis of selected actions (Jeff Anderson)
12:45-1:00	Questions, Recap, Next Steps, Adjourn (Darren Mierau)

Elk River TAC Participants

Name	Affiliation
Eileen Cashman	HSU Engineering
Tom Lisle	Stillwater Sciences
Mary Ann Madej	US Geological Survey (USGS), Retired
Connor Shea	US Fish and Wildlife Service (USFWS)
John Bair	McBain Associates
Sam Flannigan	Bureau of Land Management (BLM)
Margaret Tauzer	NOAA Fisheries/NMFS
Jack Lewis	Redwood Sciences Lab, Retired
David Manthorne	California Department of Fish and Wildlife (CDFW)
Hank Seemann	Humboldt County
Matt Sparacino	Humboldt Redwoods Company
Shane Beach	Humboldt Redwoods Company
Kristi Wrigley	Salmon Forever
Jon Shultz	Natural Resource Conservation Service (NRCS)
Matt House	Green Diamond Resource Company (GDRC)
Jesse Noell	Salmon Forever
Lance Le	North Coast Regional Water Quality Control Board (NCRWQCB)
Chuck Striplen	North Coast Regional Water Quality Control Board (NCRWQCB)
Alydda Mangelsdorff	North Coast Regional Water Quality Control Board (NCRWQCB)
Clayton Craeger	North Coast Regional Water Quality Control Board (NCRWQCB)
Jeff Anderson	Northern Hydrology & Engineering (NHE)
Bonnie Pryor	Northern Hydrology & Engineering (NHE)
Jay Stallman	Stillwater Sciences
Darren Mierau	California Trout
Marissa Adams	California Trout

Appendix B

Elk River TAC Comments for HST Model Configuration for Modified Channel Scenario

January 11, 2018

Lance Le, Water Resources Control Engineer
North Coast Regional Water Quality Control Board
5550 Skylane Blvd, Suite A
Santa Rosa, CA 95403-1072

RE: Progress Report and ERRA TAC HST Model Recommendations

The objective of the recovery assessment is to develop a set of actions that will recover beneficial uses and reduce nuisance flooding in the Elk River. The budget and scope are limited to demonstrating the response of the system with:

- No mechanical action in the project area with existing sediment supply delivered from the upper watershed,
- No mechanical action within the project area with a reduced sediment supply from the upper watershed, and
- <u>One</u> restoration strategy with mechanical actions in the project area either with existing or a reduced sediment supply.

On December 6, 2017, the Elk River Recovery Assessment (ERRA) team convened the fourth and final meeting of the ERRA Technical Advisory Committee (TAC) under SWRCB ERRA grant agreements 13-087-110 and D15-16003. A key objective of TAC meeting #4 was to present the results of the hydrodynamic and sediment transport modeling, including model calibration and validation, and integration of other empirical data (sediment load and Suspended Sediment Concentrations (SSC) trend analysis) to present a picture of how the existing hydrological and sediment system is functioning in order to better understand the relationship between form and process. A primary goal of TAC meeting #4 was to solicit input on the "set of actions" to be analyzed in the final Hydrodynamic and Sediment Transport (HST) model run and to establish the basis for agreement regarding the configuration of the final HST model run.

Based on responses of the TAC to options for different action scenarios presented in a survey form distributed at the meeting (attached), the ERRA team is providing the following recommendations for the final model run to be conducted under the grant agreement. The individual survey responses of TAC participants are summarized and provided in *Table 1: Summary of TAC Action Scenario Preferences to Run with Final ERRA HST Model*. The deadline for completing the final model run is Spring 2016, therefore we are submitting the TAC responses and recommendation of the technical team for RWQCB direction on the configuration of the next model run as soon as possible (the model will require approximately one month to run).

ERRA Team Recommendations

The restoration strategy that the majority of TAC members supported exploring has a modified channel, existing vegetation on the floodplain, modified vegetation on the bed and banks, modified roughness height, modified large woody debris, and the existing sediment supply. The areas where the least agreement occurred were large woody debris (six TAC members support increased frequency of large woody debris, five support existing conditions), bank vegetation (seven support modified vegetation, five support existing vegetation), and the modified channel (eight support a modified channel, and four support existing channel).

The ERRA team concurs with the majority recommendation provided by the members of the TAC.

The absence of a recommendation to modify a given parameter should not be viewed as a recommendation that a given parameter should not be considered as an action to facilitate recovery. For instance, the ERRA team and TAC recommends modeling the selected mechanical actions with the existing sediment supply for several reasons that are unrelated to the clear benefit that a reduced sediment supply will have on recovery and sustainability. The project team would like to isolate the effects of mechanical actions alone; apart from potential reductions in sediment supply. Given that no reductions of sediment supply have been observed during the monitoring period, the most pressing question to the ERRA team is how well a combination of mechanical actions will perform under the existing sediment supply.

Table 1: Summary of TAC Action Scenario Preferences to Run with Final ERRA HST Model

Action	TAC Consensus	Reasons for Selection	TAC Minority Opinion and Reasons for Selection
Action Scenario: CHANNEL TOPOGRAPHY			
Modified (1, 3, 4, 8, 9, 10, 11, 12)		▪ Channel will require some level of modification. ▪ Multi-channel scenario should be included below the constriction to the mainstem. It is likely unpermittable to dredge the entire mainstem. ▪ Immediate resolution of nuisance flooding. Answers question of if an excavated channel would be self-sustaining. ▪ Consider limiting excavation to reaches where flooding is of greatest concern (MSR3-5, NFRI, SFR1). ▪ Most likely to reduce water surface elevation and improve capacity and transport. Most likely to impact beneficial uses in short term (25 years). ▪ Establishing bed slopes paired with vegetation management might sustain recovery under existing sediment conditions. ▪ Don't want designer channel with 1 ½:1 slopes etc. Lower the bottom and dig out the	Existing (2, 5, 6, 7) ▪ Existing best to see impact of increased velocity on sediment transport. ▪ Unrealistic to dredge miles of stream. Site specific excavations more likely. Unclear if model being run on reach-by-reach basis. Test to see if goals can be met without costly and disruptive channel dredging.

	"secondary channel" that has filled in (see fence along downriver side of Wrigley ranch property). ▪ Interested in effect of increased flood conveyance with addition of overflow channels through MS5 reach, multiple channel outlets, and areas for tidal inundation. Focus on increased channel conveyance from downstream to upstream. ▪ Would be incredibly difficult to implement and raises a number of issues on impacts, longevity, ongoing geologic trends, seal level rise, etc. See as more of an end-member in the modeling exercise to understand where could get to with a comprehensive set of actions. ▪ Will action expose coarser bed? Potentially allow for fish habitat enhancement as part of action. Most interested in magnitude and effectiveness of channel modifications and channel clearing on nuisance flood reduction. Would help evaluate questions about if the habitat disturbance and construction cost are justified by potential benefits. If not, explore other options.	
Action Scenario: VEGETATION ON FLOODPLAIN		
Existing (2, 3, 4, 5, 6, 7, 9, 10, 11, 12)	▪ Modification and management on the floodplain is unlikely without land acquisition. ▪ Existing land uses and existing vegetation are likely to be maintained. ▪ Best to assume current land use will continue. Maybe landowners would convert to planting. ▪ Retains existing land uses. No influence of flood frequency. Limited potential to influence flood height. ▪ Less effect on in-channel dynamics? ▪ Model existing vegetation if looking for cause of degradation. ▪ Not likely to establish old-growth vegetation on floodplain. ▪ Not practical to restore old-growth vegetation within project's planning period.	Old Growth (1, 8) ▪ Reduction needed to prevent unnaturally large levee production associates with excess bank/floodplain roughness. ▪ Thick vegetation needs to go. Slow water areas are made even slower by vegetation.
Action Scenario: VEGETAION ON BANKS		

Old Growth (1, 5, 7, 8, 9, 10, 11)	▪ Model native vegetation on banks. ▪ Less likely to cause channel to contract after excavation. ▪ Reduction needed to prevent unnaturally large levee production associates with excess bank/floodplain roughness. ▪ Appreciable change in accretion/aggradation dynamics. ▪ Implementable through management over time. ▪ Vegetation needs to get here ASAP. Never had the berry vines etc. until heavy sediment deposits. ▪ Appreciable change in accretion/aggradation dynamics.	Existing (2, 3, 4, 6, 12) ▪ Bank vegetation may be modified, but will regrow and long-term management is unlikely. ▪ Don't expect a big change in the short-term (25 years). Transition to be obvious in 25-50 years. Old growth might be possible after 100 years. ▪ Conversion to mature forest strands would take longer than our management window. ▪ Not likely to establish old-growth vegetation on floodplain (esp. within project planning period).
Action Scenario: VEGETATION IN THE CHANNEL BED		
None (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12)	▪ Vegetation in the channel will need to be removed under any scenario and will have best effect on velocity. ▪ Vegetation will be removed if channel is excavated. Remove vegetation from non-excavated reaches too. ▪ Questionable whether this is sustainable. ▪ Remove willows and other vegetation in channels to sustain changes in channel topography. ▪ Implies some level of channel topography action ▪ How does vegetation removal affect dissolved oxygen in the lower reaches? ▪ Effective way to reduce form roughness in channel. ▪ Channel vegetation needs to be cleared. It depletes oxygen and slows down water if there is any movement in summer, contributing to algae growth etc.	Existing (MSR 2-3)
Action Scenario: LARGE WOODY DEBRIS		
Old Growth Values Applied to All Cells (3, 5, 6, 7, 10, 11)	▪ Jams of smaller wood would be removed and augmentation of LWD would improve conveyance while maintaining fish habitat.	Existing (Mapped jams only) (1, 2, 4, 9, 12) ▪ (Old growth) complicates interpretations and has limited potential to influence flooding.

	▪ OR no values applied – any LWD in channel would be physically installed, plus existing jams could be easily manipulated when doing work. ▪ LWD value should change as move downstream with change in topography and associated native vegetation. ▪ Easily coupled with channel topography? Implementable. ▪ Good for habitat but adds form roughness. May need another model run without LWD.	▪ Unlikely could change wood loading or restore old growth vegetation in the short- to mid-term. ▪ Velocity is already low and roughness is high, so adding more LWD for hydrodynamics doesn't make seem useful. ▪ Remove willows and other vegetation in channels to sustain changes in channel topography. ▪ Existing IF goal is to limit nuisance flooding. Increase LWD if goal is to increase fish habitat.
	1 participant not sure. States need some LWD strategically placed to enhance flow and pool development.	
Action Scenario: ROUGHNESS HEIGHT		
Reduced (1, 3, 5, 6, 7, 9, 10, 11, 12)	▪ Roughness will need to be decreased in a restoration project, but will regrow without management. ▪ If channel is excavated, roughness will be reduced anyway. ▪ This is biggest increase in velocity and probably biggest bang for the buck. ▪ Remove willows and other vegetation in channels to sustain changes in channel topography. ▪ Seems somewhat coupled with channel bed vegetation. ▪ Assuming that this is from other vegetation in channel.	Existing (2, 4) ▪ How much could we change over existing conditions. Don't believe we could affect this. ▪ Site-specific reduction may be realistic but not for miles of stream.
	1 participant not sure what this is. States river in most places needs to be lowered not necessarily widened except for directly above the North Fork concrete bridge. Banks need to be steepened and bottom dug down (aware difficult to impossible at this point).	
Action Scenario: SEDIMENT SUPPLY		
Existing (1, 4, 5, 6, 7, 9, 12)	▪ No sign of reductions to-date and no prospect of reduced harvest rates. ▪ Modeling based on existing sediment supply helps answer question of sustainability of improved channel under high loading.	Reduced (8, 10, 11). ▪ Some level of sediment reduction should occur. Would prefer a smaller reduction (15%) which may be achievable within this project timeframe.

	▪ Skeptical will see SCC reduction in the short-term. Jack Lewis analysis shows no change (or very little) in 10 years. ▪ Will see better results if use the larger sediment input. Reduced values may not be attainable. ▪ Want to see how recovery proceeds with increased transport capacity achieved through the composite results without including the confounding factor of decreasing sediment supplies.	Don't believe 30% reduction will be achieved in the next 10 years and may be unrealistic to model without sediment trapping. ▪ We already know aggradation is occurring under existing sediment loads. Will reduced sediment loads make a significant difference? ▪ Focused reduction (retention, ponds?) in select, high-volume tributaries. ▪ Needs to be reduces to values before MAXXAM when old PL logged 75-150 acres/year. Previously, river got muddy but cleared without leaving sediment deposits. ▪ Model reduced sediment supply to look for cause of degradation

Other Comments:

- Recommend being conservative in estimation. Short term=25 years, Mid-Term=50 years, Long-term=100 years.
- Most interested in seeing how increase in velocity will affect sediment transport, aggradation, etc. Would like model run to test hypothesis that increased velocity will decrease aggradation rates. Most helpful would be knowing the maximum velocity can be achieved while holding aggradation at zero, or as close to zero as possible with existing conditions.
- Is the objective of the modeling to look for the cause of channel degradation or the solution to channel restoration. Modeling to find the cause should include adding in features that were lost (natural tidal prism), versus only what is feasible.
- Preliminary results seem to show that reductions in SCC alone will not halt observed bed aggradation and bank accretion. A critical objective is setting hydraulic parameters that promote bed/bank scour and eliminate the observed bed aggradation and bank accretion. Through a series of physical manipulations, the effects of nuisance flooding can be abated by reducing water surface elevations. Thus a series of actions can be taken to relatively quickly reduce flooding frequency in areas of concern. The next step is to determine if a combination of changes in V, Q, and WSE could change the sediment transport dynamics in such a way to increase scour and promote a more self-sustaining channel configuration. Barring that, some estimate of aggradation rate after implementation would be useful to estimate the maintenance needs of these efforts. For example, implementation of the old growth parameter shows

an increase in velocity of 0.14m/sec at MS5. IS this alone sufficient to significantly alter sediment transport dynamics in the reach? IS it possible to scour out the cohesive fraction of sediment and radically change the sediment transport dynamics through vegetation changes alone?
- For modeling purposes, implementation of the modified parameters (vegetation, channel excavation) would occur over the entire study reach. In each of the response scenarios, some level of flooding is still observed (i.e. water still flowing across Berta Road at the north end of the road). This would suggest the need to define target areas of nuisance flooding as well as an acceptable flood frequency at these areas. Could reductions in WSE be expressed as inundation frequency or exceedance probability? Also, there may be specific areas of continues nuisance flooding (e.g. MS5 and Berta Road) that might warrant more specific actions at a finer scale or accomplished through infrastructure improvements.
- Do we know what grin size distribution is at depth? Does excavation of the channel expose coarse sediment? How does this affect the calculations form sediment transport (i.e. loss of cohesive sediment)? This may also have implications for fish populations if a coarser-bedded channel is exposed (gravel).

1, Matt Sparacino, HRC 2, Mary Ann Madej, USGS Retired 3. David Manthorne, CDFW 4. John Bair, McBain Associates	5. Jon Shultz, NRCS 6. Tom Lisle, Stillwater Sciences 7. Matt House, Green Diamond Resource Company 8. Kristi Wrigley, Salmon Forever	9. Jack Lewis, Redwood Sciences Lab, Retired 10. Sam Flannigan, BLM 11. Margaret Tauzer, NOAA Fisheries/NMFS 12. Conor Shea, USFWS

The following TAC members were not in attendance and did not submit a summary sheet regarding their preferred modeling approach:

- Eileen Cashman, HSU Engineering
- Hank Seemann, Humboldt County
- Shane Beach, Humboldt Redwoods Company
- Jesse Noell, Salmon Forever

If you have any questions, please contact the Project Director at any time.
Sincerely,

Darren Mierau
North Coast Director
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Appendix C

Elk River Recovery Assessment: Reduced SSC Targets

Sediment Reduction Scenario

Lance Le

December 6, 2017

Regional Water Board

Background

- Supplies SSC reduction for Scenario 1B & 2B
  - Applies % reduction at boundary conditions of South and North Fork Elk River
- Trend analysis for HRC SSC data originally basis for reduction recommendation
  - No trends detected in data (Lewis, pers. comm.)
- Need for different approach

Data

- Sediment source analysis from Technical Report, Table 8 pg 59-60 (Tetra Tech, 2015)
- Summarized in Table 9 (pg 61)

	Sediment Source Category	1955-1966	1967-1974	1975-1987	1988-1997	1998-2000	2001-2003	2004-2011
Natural	Natural Bank Erosion	9	9	9	9	9	9	9
	Natural Streamside Landslides	26	26	26	26	26	26	26
	Shallow Hillslope Landslides	30	30	30	30	30	30	30
	Deep seated Landslides	3	3	3	3	3	3	3
	Deep Seated Influence on Bank Erosion and Streamside Landslides	84	64	25	99	108	108	76
	Natural Loading	**152**	**132**	**93**	**167**	**176**	**176**	**144**
Land Use	In-Channel: Low Order Channel Incision	67	23	14	21	32	12	14
	In-Channel: Management-Related Bank Erosion & Streamside Landslides	186	141	54	219	240	240	160
	Road-Related Landslides	99	29	15	307	3	20	25
	Open Slope shallow landslides	189	82	6	201	118	51	5
	Land Use-related Sediment Discharge Sites	30	60	80	65	39	73	39
	Post-Treatment Sediment Discharge Sites	0	0	0	0	13	4	24
	Skid Trails	4	12	11	12	26	15	15
	Road surface erosion	52	78	87	137	55	56	22
	Harvest Surface Erosion	2	6	2	5	6	5	4
	Land Use Loading	**629**	**431**	**268**	**966**	**531**	**476**	**308**
Total	**Total Loading**	**781**	**563**	**360**	**1,133**	**707**	**652**	**452**
	Percent of total attributable to land use activities	*81%*	*77%*	*74%*	*85%*	*75%*	*73%*	*68%*

Methods

- In general, considers changes in sediment loading through different periods as compared to contemporary (2004-2011) loads
- 4 “options” on approach:
  1. Minimum anthropogenic loads
  2. Selective based on watershed processes
  3. Reduction relative to highest loading period, 1988-1997
  4. Generalization of option 1 to all periods and loads
- Average results from four options to arrive at percent reduction for each fork

Option 1

Equation 1 $$\%\,Reduction_{fork} = 100 \cdot \left(1 - \frac{\bar{L}_{natural} + \sum_{category\ i} L_{min,i}}{L_{T,2004}}\right)$$

- $\bar{L}_{natural}$ = mean of natural loads
- $L_{min,i}$ = minimum load for a source category
- $\bar{L}_{T,2004}$ = total load from 2004-2011 period
- Most restrictive option leading to greatest percent reduction

Option 2

Source Category	Action
In-Channel: Low Order Channel Incision	Minimum
In-Channel: Management-Related Bank Erosion and Streamside Landslides	50% reduction from 2004-2011
Road-Related Landslides	Minimum
Road Surface Erosion	Zero
Land Use-related Sediment Discharge Sites	Minimum
Post-Treatment Sediment Discharge Sites	Zero
Open Slope Landslides	2004-2011
Harvest Surface Erosion	Minimum
Natural Loading	Average from all periods

- Uses Equation 1, but instead of minimums for all categories, follows the above table

Option 3

Equation 2 $$\% \, Reduction_{fork} = 100 \cdot \left(1 - \frac{\sum_{subbasin\ i} w_i L_{2004,i} \cdot \frac{L_{T,i}}{L_{1988,i}}}{L_{T,2004}} \right)$$

- L_T = total loads from a reference period
- w = area fraction of a subbasin for a given fork
- Systematically excludes different source categories when summing loads
- Also switches out reference periods
- 9 source categories; 6 reference periods = 3066 percent reduction values

Option 4

- Generalization of Option 1
  - Utilizes Equation 1; relative to 2004-2011 loads
- Considers all loads and not just minimums for each source category
  - Mixes loads from different time periods
- >40 million combinations and reduction numbers
  - Omit results that negative reduction (i.e. increase in sediment load)

Recommendation

	South Fork	North Fork	Action
Option 1	49%	30%	Minimum anthropogenic + average natural
Option 2	40%	28%	Selective based on TMDL and WDRs + average natural
Option 3	26%	40%	Mean of possibility space using Equation 2
Option 4	11%	8%	Mean of sampled possibility space via Equation 1
Average	**32%**	**27%**	**To be applied to boundary conditions**

- Mean of results from different options
- Option 4's mean is from sampled results due to long computation time

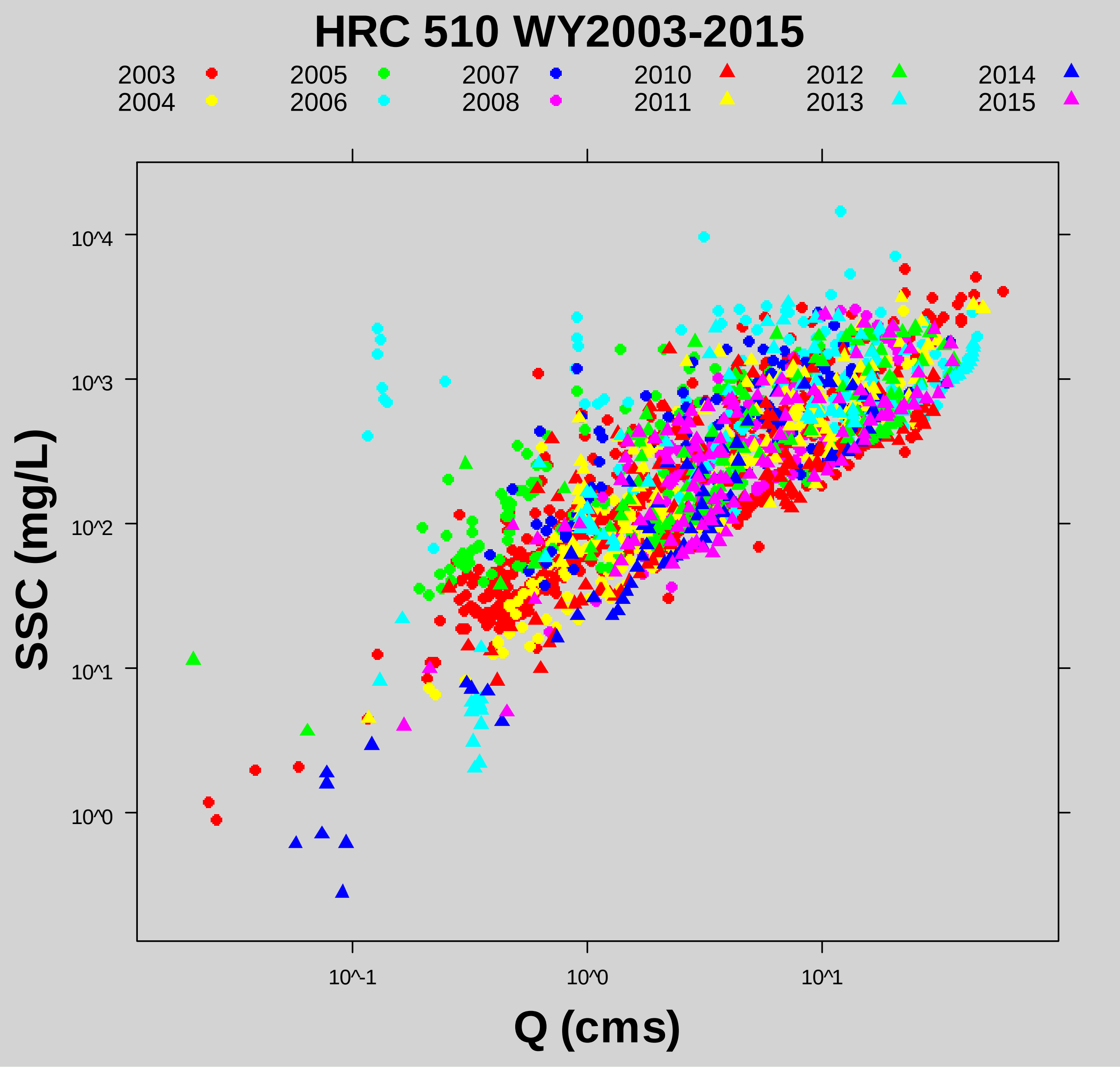
Appendix D

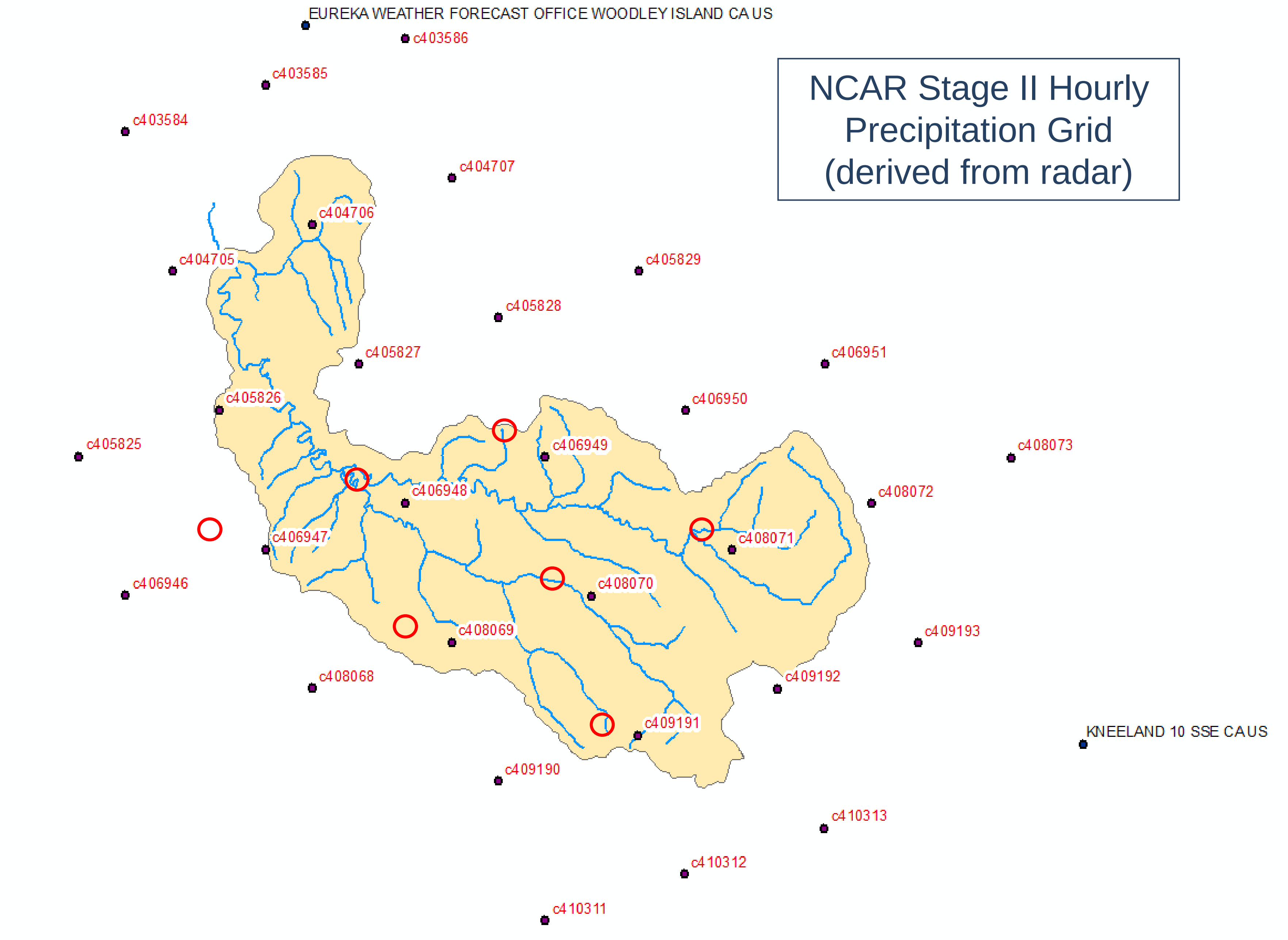
SSC Trend Analysis Presentation to TAC by Jack Lewis

ELK RIVER RECOVERY ASSESSMENT
SUSPENDED SEDIMENT CONCENTRATION (SSC) TREND ANALYSIS

SSC Trend Analysis, conducted by Jack Lewis

- Analyze SSC trends at HRC 509, 510 and 511 stations
- Use same methodology as SSC trend analysis conducted for Salmon-Forever at KRW and SFM stations
- Compare SSC trend analysis between HRC and Salmon-Forever data

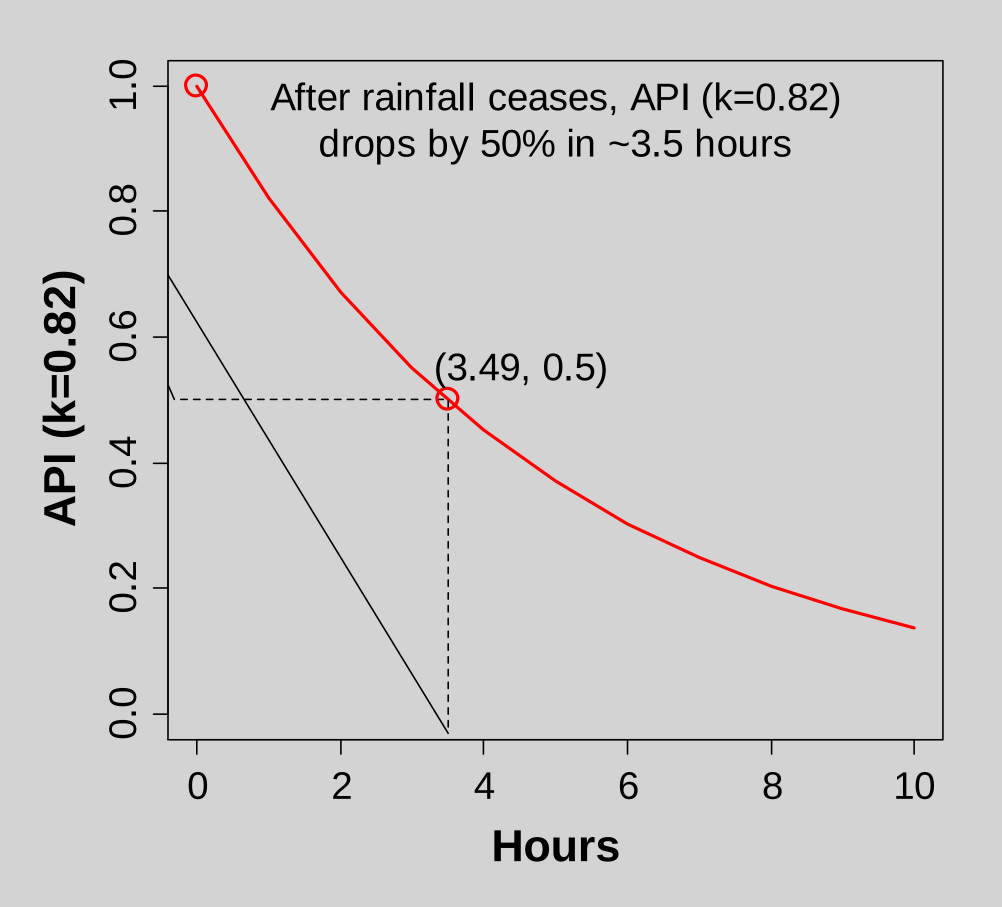

HRC 510 WY2003-2015
2003
2004
2005
2006
2007
2008
2010
2011
2012
2013
2014
2015
10^4
10^3
10^2
10^1
10^0
SSC (mg/L)
10^-1
10^0
10^1
Q (cms)



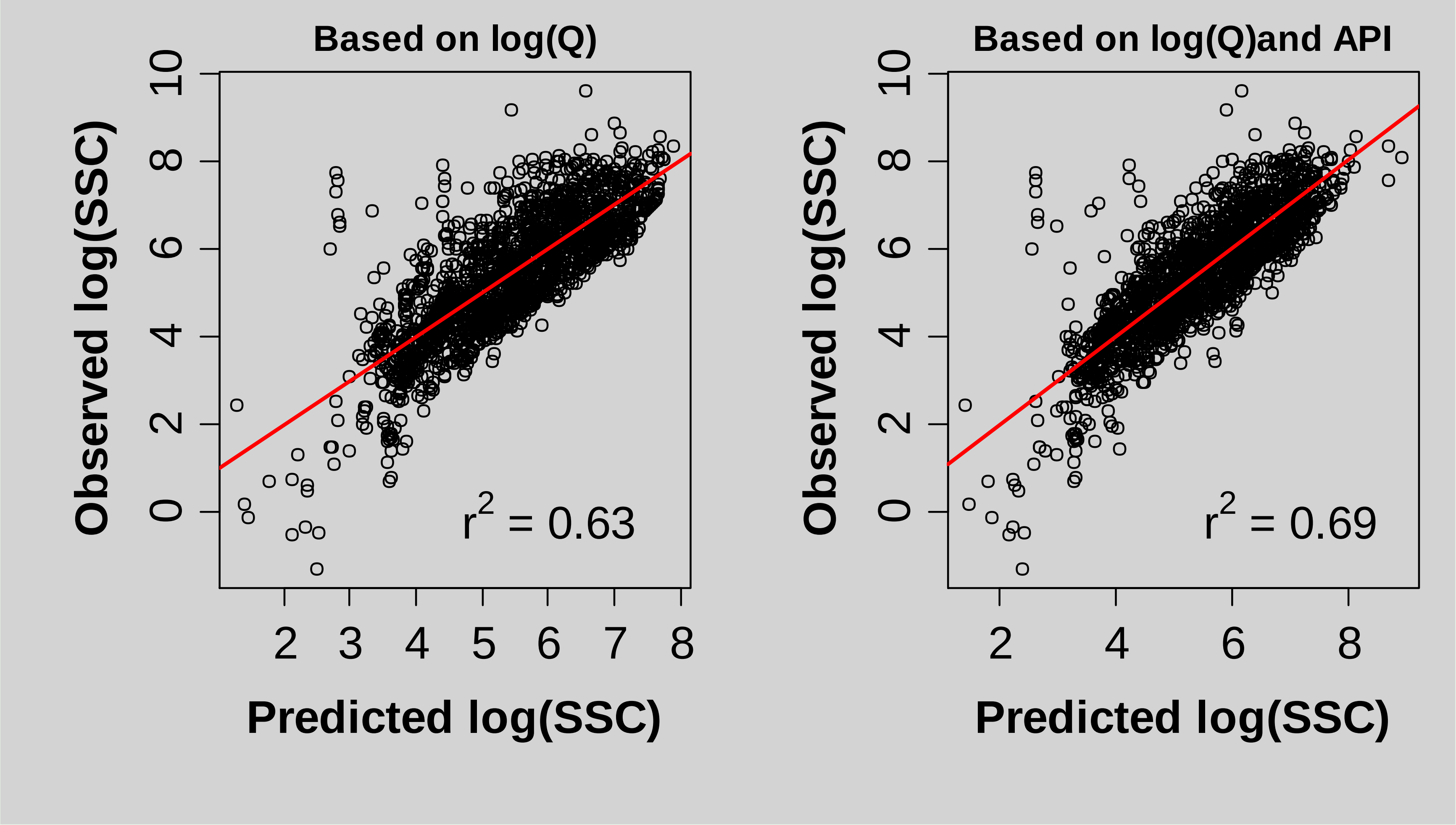
NCAR Stage II Hourly Precipitation Grid (derived from radar)

Antecedent Precipitation Index

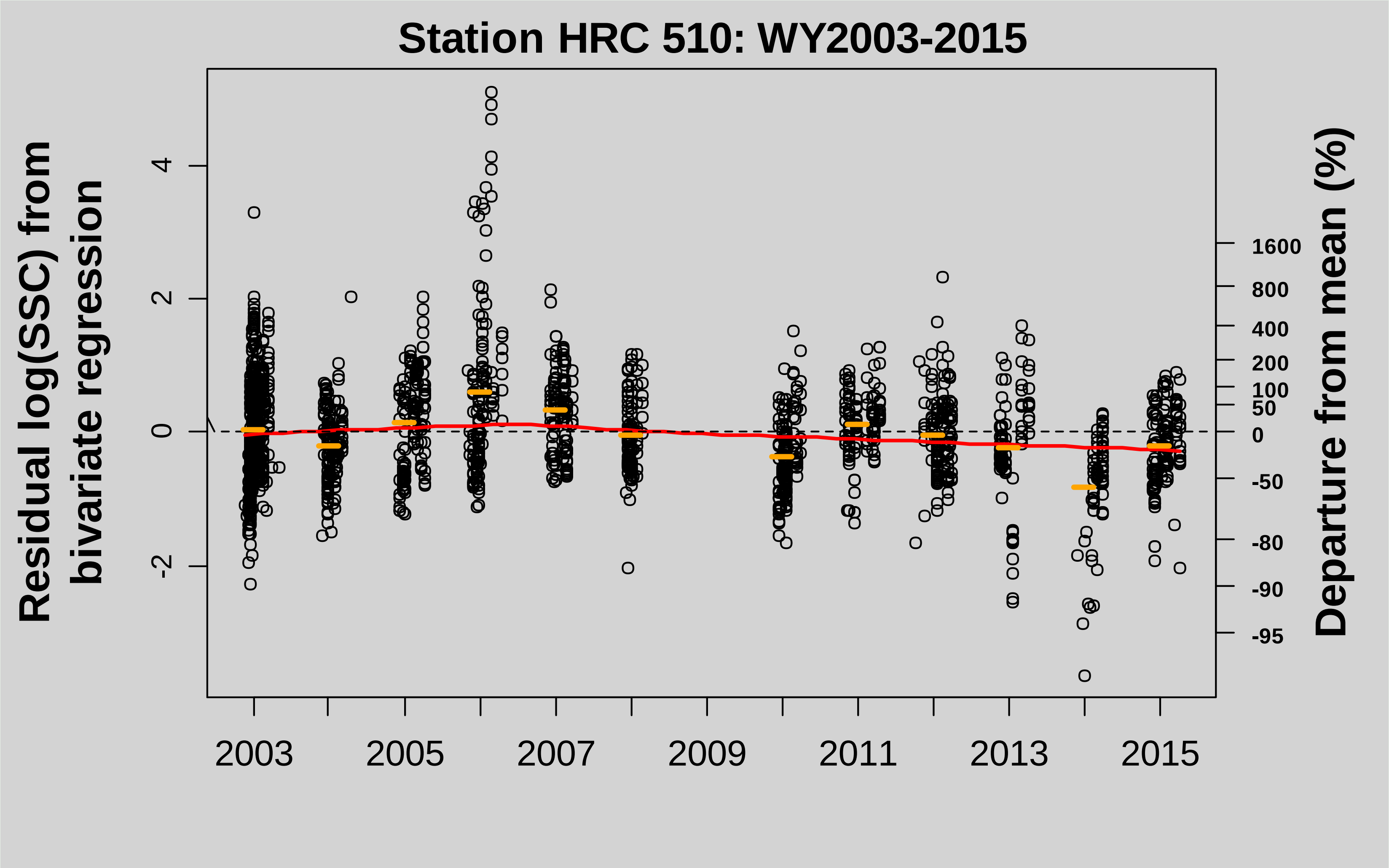
$$API_t = k\ API_{t-1} + PPT_t$$

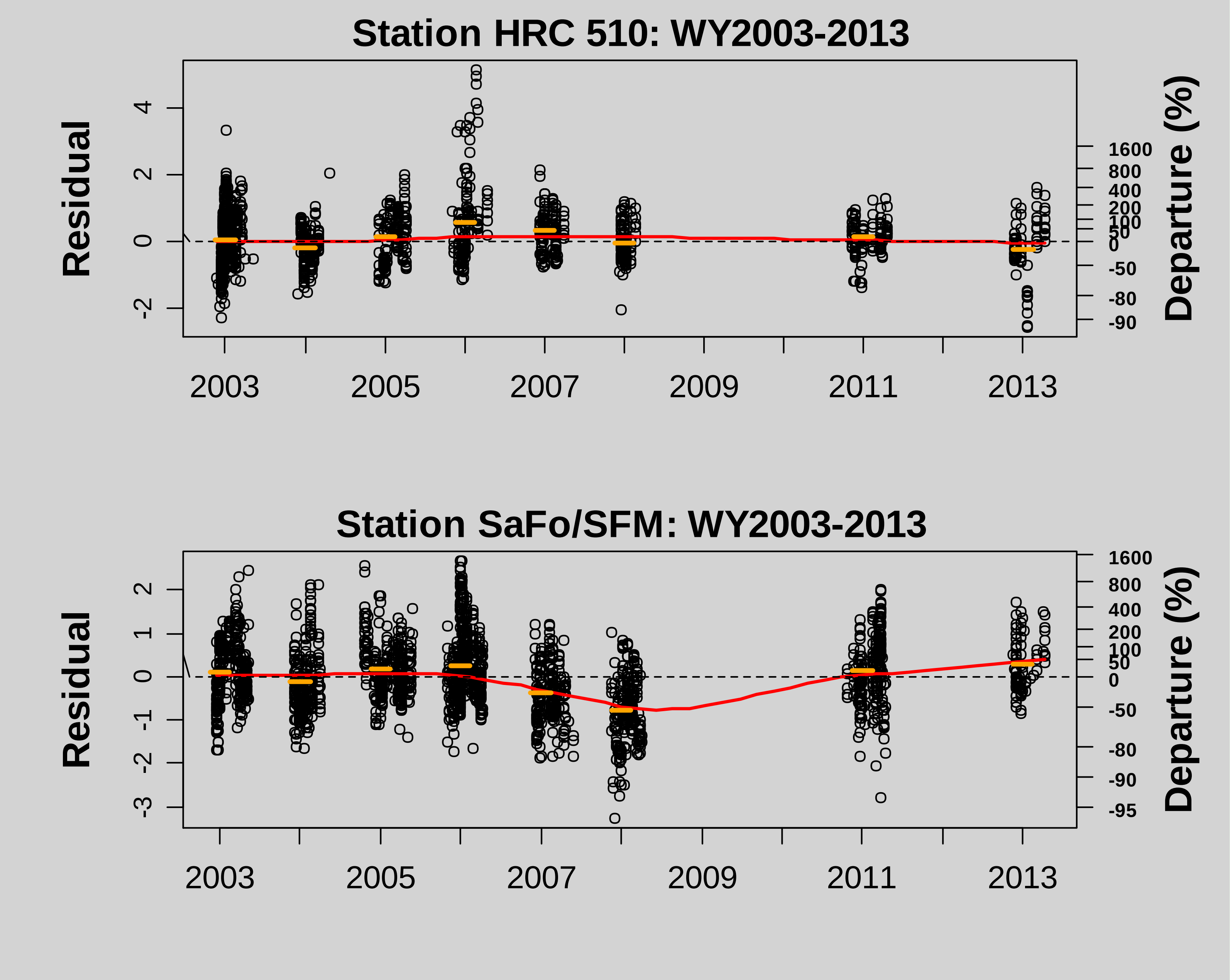


Two Regression Models for HRC 510

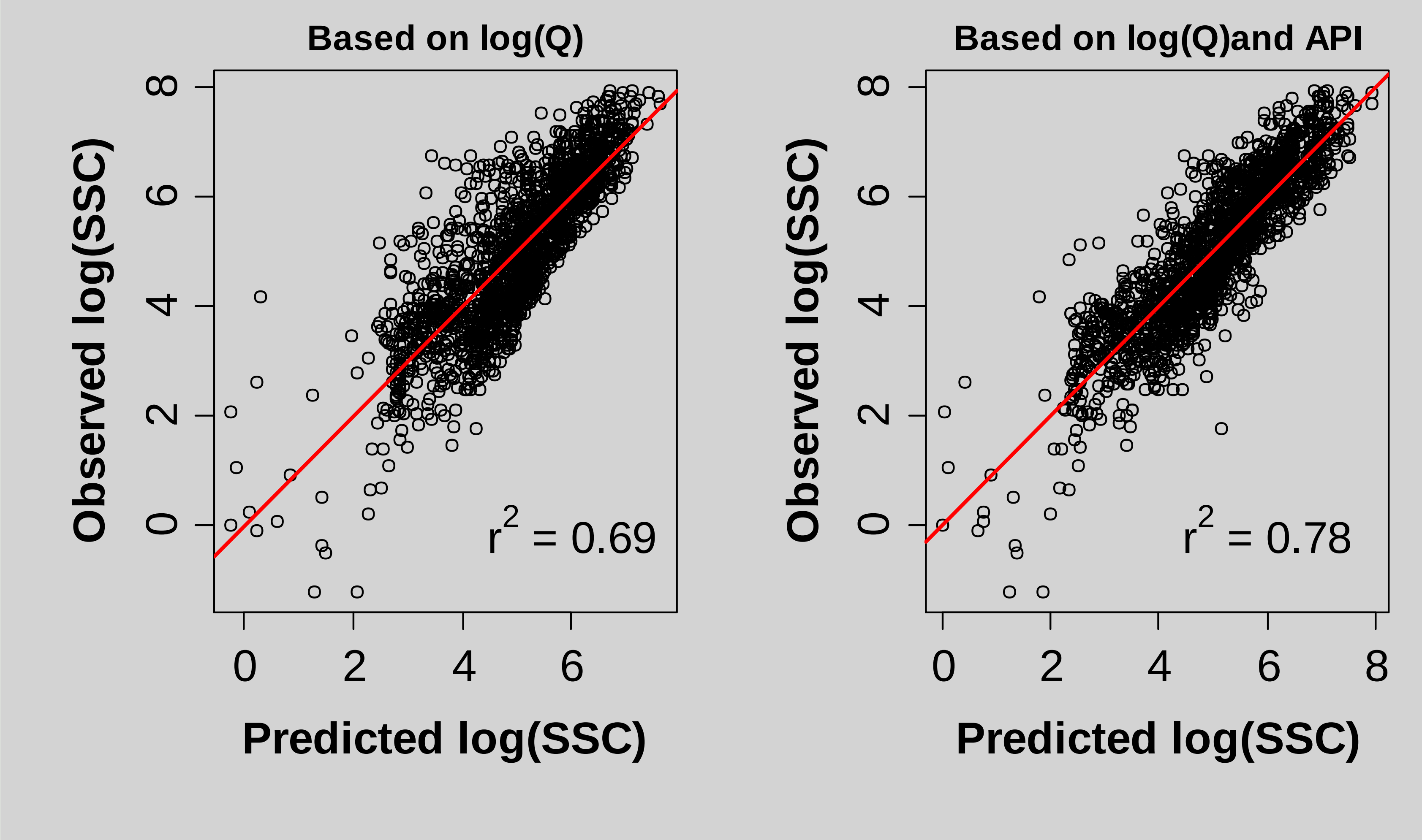


Trend in Regression Residuals: HRC 510

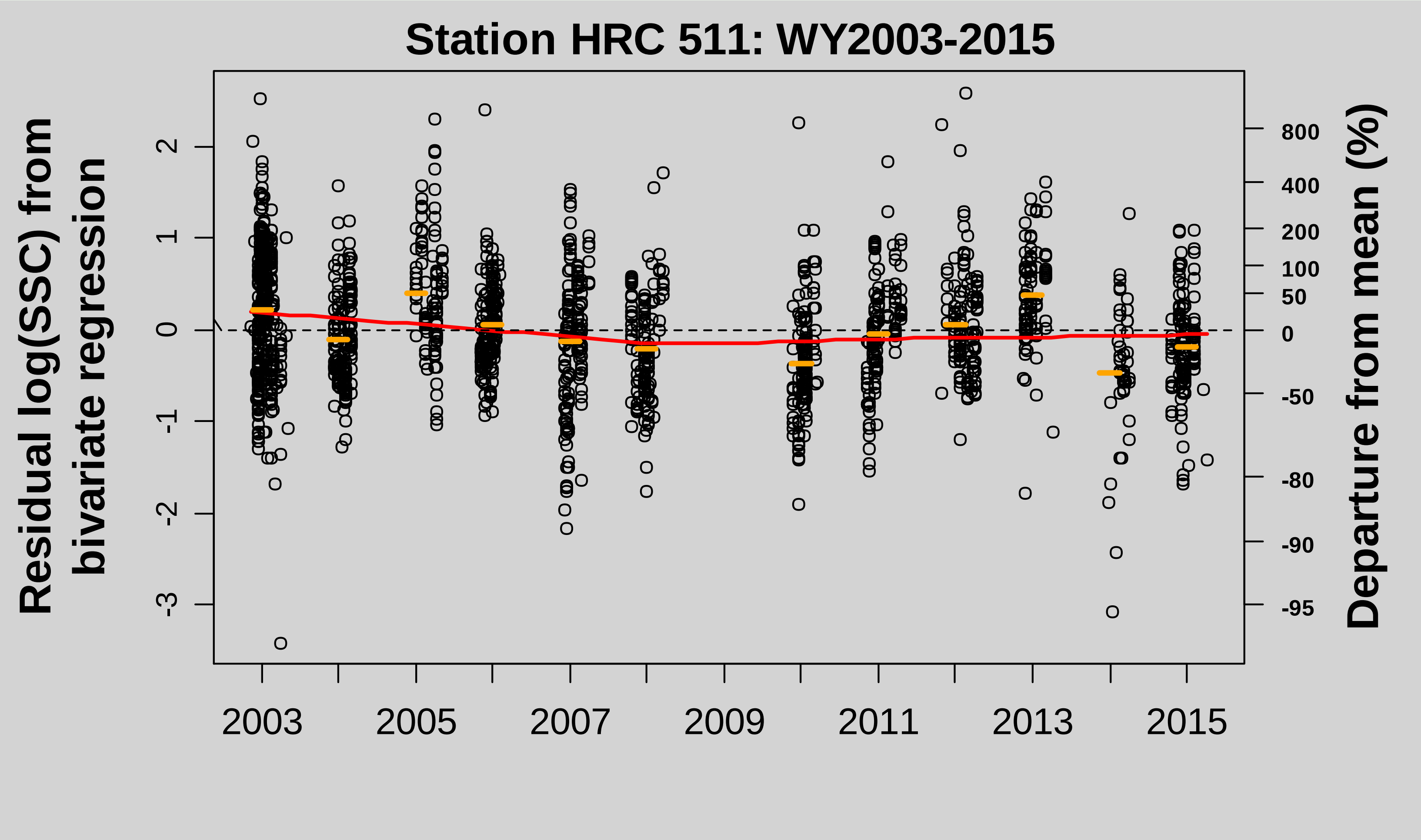


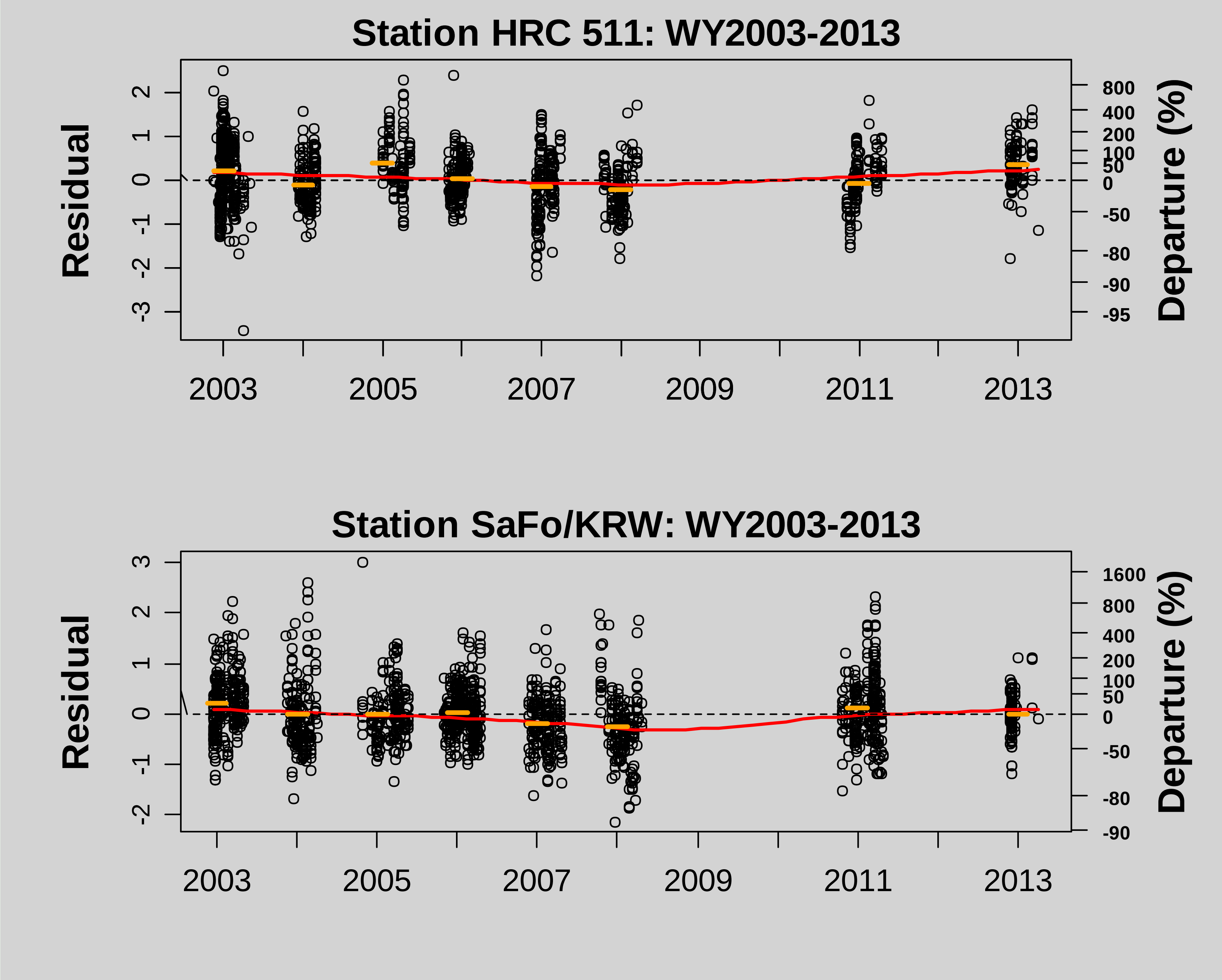

Station HRC 510: WY2003-2013
Residual
Departure (%)
4
2
0
-2
1600
800
400
200
100
50
0
-50
-80
-90
2003
2005
2007
2009
2011
2013
Station SaFo/SFM: WY2003-2013
Residual
Departure (%)
2
1
0
-1
-2
-3
1600
800
400
200
100
50
0
-50
-80
-90
-95
2003
2005
2007
2009
2011
2013

Two Regression Models for HRC 511

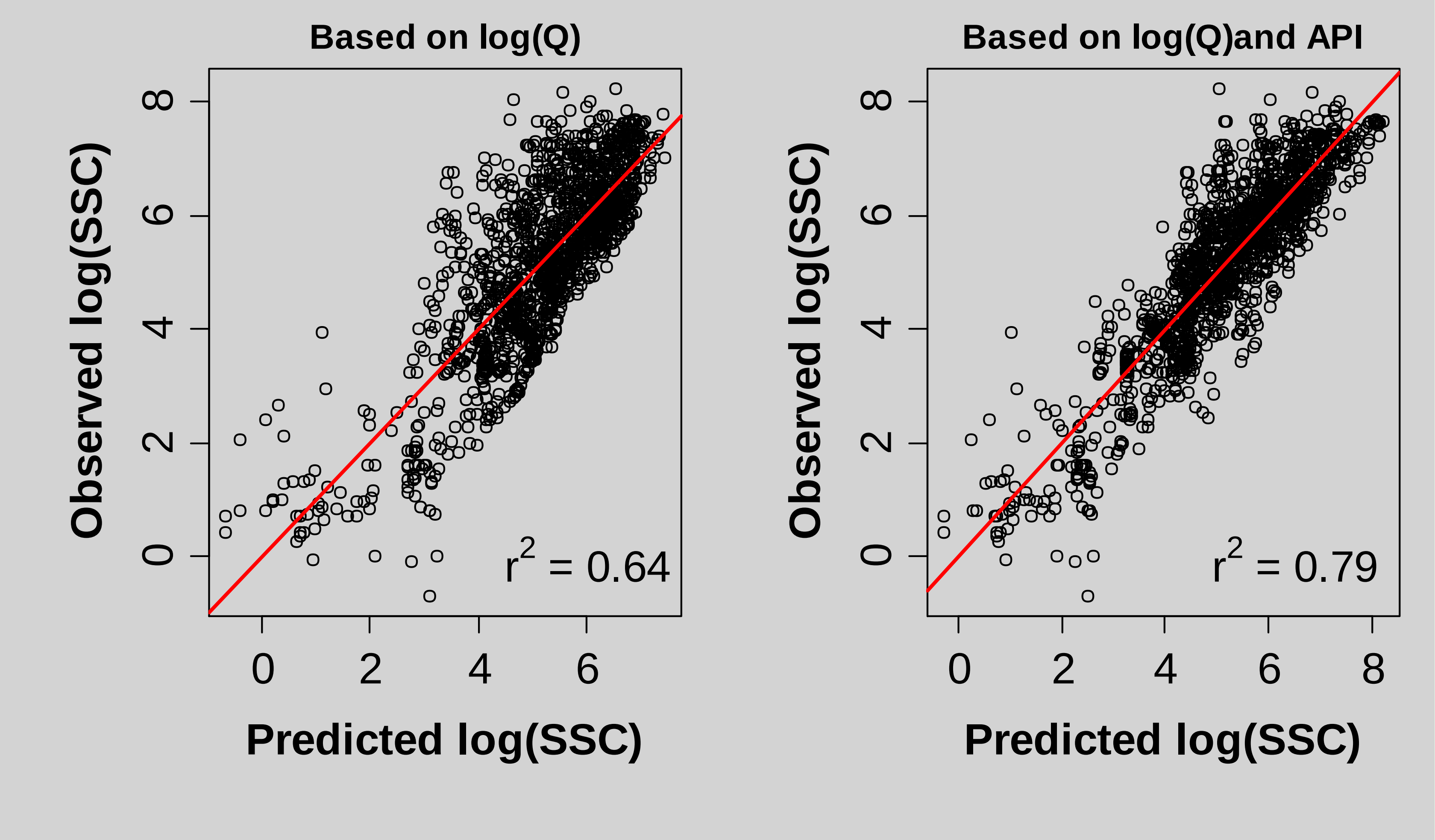


Trend in Regression Residuals: HRC 511

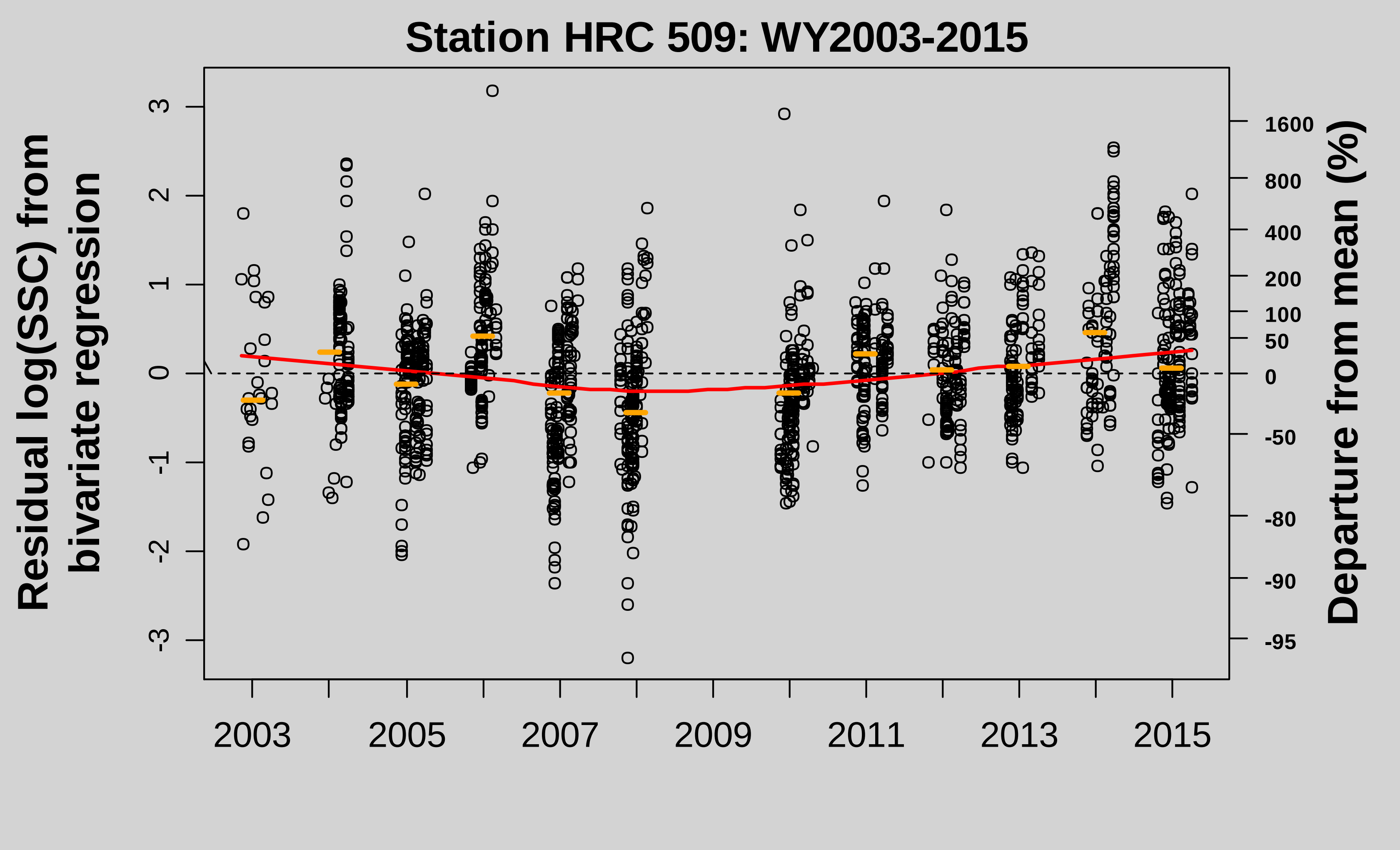



Station HRC 511: WY2003-2013
Residual
Departure (%)
2003
2005
2007
2009
2011
2013
Station SaFo/KRW: WY2003-2013
Residual
Departure (%)
2003
2005
2007
2009
2011
2013

Two Regression Models for HRC 509



Trend in Regression Residuals: HRC 509



Summary of Trends

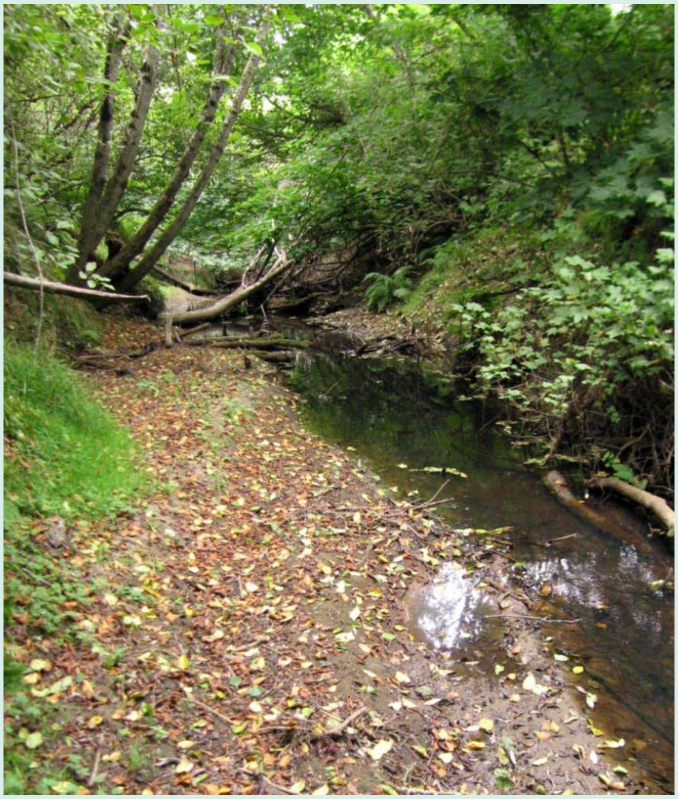
- No declining trends found in SSC for a given discharge and rainfall condition at the lower stations run by HRC and Salmon-Forever.
- If discharge has changed, there may be associated changes in SSC. In my work for SaFo, I did not find good evidence for changes in storm peaks or flow volumes.
- Lack of SSC trends *may* reflect the abundant sediment supply in these low gradient reaches
- Trend analyses like this should be done for stations higher in the watershed

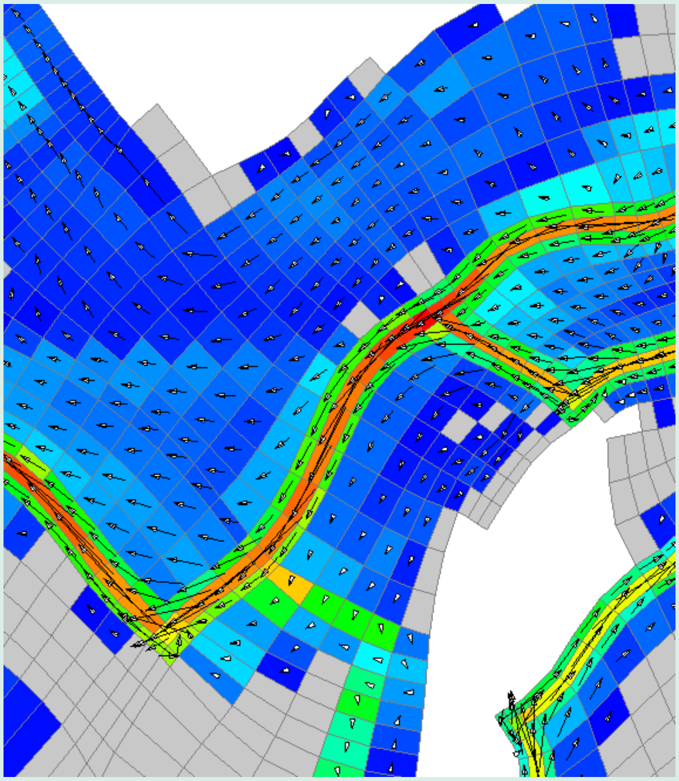
Appendix E

Elk River Recovery Assessment Data Report
(miscellaneous data sets)

DRAFT REPORT ◦ DECEMBER 2017

Elk River Recovery Assessment Data Report





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Northern Hydrology & Engineering

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Stillwater Sciences and Northern Hydrology & Engineering. 2017. Elk River Recover Assessment Data Report. Prepared by Stillwater Sciences, Arcata, California and Northern Hydrology & Engineering, McKinleyville, California for California Trout, Arcata, California.

Cover photo: Lower South Fork Elk River.
Cover graphic: Hydrodynamic and sediment transport model results near the confluence of the North Fork and South Fork.

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Tables

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Attachments

1 INTRODUCTION

Elk River, the largest tributary to Humboldt Bay and natal stream to four species of anadromous salmonids, is undergoing intensive watershed-wide recovery efforts to remediate impairments associated with excessive channel sedimentation that occurred between 1986 and 1998. Elevated fine sediment supply, chronic high turbidity, and reduced channel capacity due to increased channel sediment storage have impaired domestic and agricultural water supply, degrading aquatic habitat, and increased nuisance flooding in the Middle Reach of the watershed. 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.

Resource agencies and stakeholders are addressing the complex ecological and social issues resulting from sediment impairment by implementing a multifaceted approach developed in tandem with the Total Maximum Daily Load Implementation and Monitoring Plan for Elk River. The approach includes: (1) Waste Discharge Requirements to reduce future sediment loads from timberlands, (2) a Recovery Assessment and Implementation Framework to alleviate existing sediment impairments and improve ecosystem function through mechanical channel rehabilitation, and (3) a Stewardship Program to coordinate stakeholder participation in recovery planning and implementation. The Recovery Assessment and Implementation Framework, underway since May 2014, is describing existing conditions, identifying site-specific opportunities and constraints, and predicting system trajectory under existing and future sediment load and mechanical channel rehabilitation scenarios. Given the large amount of stored sediment that may be affected by recovery efforts, this overall approach is critical in addressing the potential effects of rehabilitation actions on sedimentation patterns and aquatic habitat within and between treated reaches.

In 2012, a two-dimensional hydrodynamic and mobile-bed sediment transport model was developed to assess sediment load reduction on channel recovery in a 2.5-mile pilot reach of Elk River. The Recovery Assessment and Implementation Framework is expanding this modeling approach and associated field data collection to assess channel and aquatic habitat conditions and evaluate the effectiveness of potential restoration actions along 19.2 miles of the North Fork, South Fork, and mainstem Elk River (**Figure 2-1**). The approach will be used to assess reach-specific recovery rates, effects of restoration actions in treated and untreated reaches, and data collection priorities supporting adaptive management.

2 ERRA TEAM AND PARTNERS

Data collection for the Elk River Recovery Assessment (ERRA) during the focused monitoring period (2014-2015) was conducted through a joint effort between Northern Hydrology and Engineering (NHE), Stillwater Sciences (SWS), California Trout, Humboldt Redwood Company (HRC), the Bureau of Land Management (BLM), the Natural Resource Conservation Service (NRCS) and local landowners. Additional imagery, data and analyses from earlier and on-going monitoring were contributed by Redwood Community Action Agency (RCAA), HRC, Green Diamond Resource Company, Salmon Forever, the Regional Water Quality Control Board (RWQCB), and the County of Humboldt.

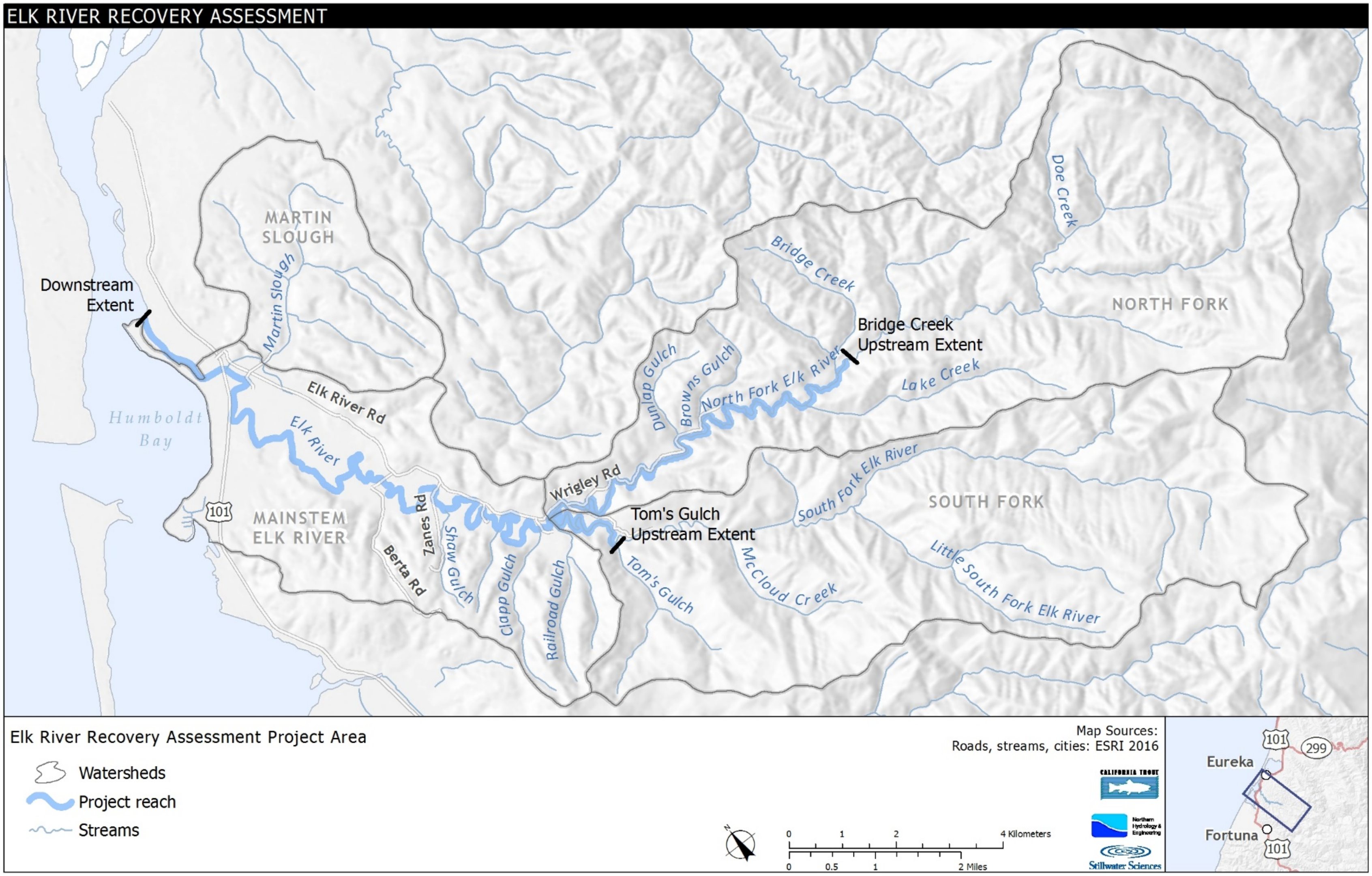

Figure 2-1. Elk River Recovery Assessment Project Area.

3 GOALS AND OBJECTIVES

The goals of the ERRA are to analyze the fate and transport of sediment, assess the effects of potential sediment removal and restoration activities, and develop an implementation framework that will lead to recovery of beneficial uses and ecosystem functions in the Elk River.

Specific objectives of the Project include the following:

- Document existing channel morphology and sediment conditions from Bridge Creek on the North Fork and Tom's Gulch on the South Fork to Humboldt Bay;
- Develop tools to assess future conditions over a range of scenarios that include changes in sediment loads and physical stream conditions that affect flow and sediment patterns. These tools include a conceptual model and a hydrodynamic and sediment transport (HST) model; and
- Conduct analyses to assess the trajectory of the system under (1) existing channel conditions with sediment loads, (2) existing channel conditions with reduced sediment loads, and (3) a suite of broad recovery actions in combination with existing or reduced sediment loads based on the results of the first two analyses.

Data collected as part of the ERRA focused on understanding sediment impairment and recovery potential in the Elk River. These data supplement existing information (collected by county and state agencies, non-profits, landowners, etc.) and are tailored to address the specific Project objectives discussed above. Data collection was designed to describe existing conditions on the Elk River and support development of tools to help answer key questions about the current state of the Elk River and potential future conditions over a range of flow and sediment conditions.

Relevant questions include:

- How do channel and floodplain morphology, channel geometry, and bed and bank materials change throughout the channel network?
- How does the distribution and size of wood vary throughout the channel network?
- How do flow patterns (i.e., channel capacity, flow velocity, and flood inundation vary over the channel network?
- How do suspended sediment concentrations vary longitudinally and laterally (i.e., channel versus floodplain) throughout the channel network?
- How do sedimentation patterns (e.g., aggradation and incision) vary longitudinally and laterally (i.e., channel versus floodplain) throughout the channel network?
- How does channel and floodplain morphology affect flow and sedimentation patterns?
- How do vegetation and wood affect flow and sedimentation patterns?
- What is the upper extent of the tidal zone?

The purpose of this report is to describe data collected as part of the ERRA. A sub-set of these questions that can be directly answered as part of the data collection effort and are addressed within this data report. Questions that require additional or more integrated analyses across multiple data sets and resource areas will be addressed in the ERRA report.

4 METHODOLOGY AND RESULTS

Prior to the ERRA, the bulk of site-specific data collection in the Elk River watershed occurred in the vicinity of the North Fork and South Fork confluence and in upstream reaches. Long-term monitoring of channel conditions occurs on timber property and within other private property on the North Fork and South Fork. Project partners provided data from existing monitoring networks to support the ERRA. These data and methods are reported, when available. In some cases, it was necessary to transform these data (e.g., change the projection, datum, or units). The ERRA team focused on collecting critical data in reaches that are outside of the existing monitoring networks and supplementing the existing monitoring networks with additional data (Table 4-1). Critical data gaps occur primarily upstream of the existing monitoring network in the South Fork and on the mainstem downstream of HRC monitoring station 509 (Steel Bridge), located near the confluence with the North Fork and South Fork confluence.

This report is organized into two primary categories of data collection: (1) channel and floodplain geomorphic characteristics and (2) flow and water quality.

Channel and floodplain data collection included:

- Topographic surveys of the channel thalweg, cross sectional transects, and bridge infrastructure;
- Sampling bed, bank and floodplain sediment;
- Mapping large woody debris; and
- Mapping bank and floodplain vegetation.

Flow and water quality data collection included:

- Discharge,
- Water surface elevation,
- Suspended sediment concentration,
- Salinity, and
- Temperature.

Data collection occurred at a spatial resolution adequate to inform data gaps at the reach scale and support development of the conceptual model and HST model.

4.1 Geomorphic Reaches

The 19.2-mile channel length in the study area was stratified into 11 reaches with similar fluvial geomorphic forms and processes (**Figure 4-1**). The delineation was based on intrinsic and extrinsic factors that influence and/or are influenced by hydraulics, sediment dynamics, and channel form. These factors include valley width and confinement, tributary inputs (e.g., water, sediment, and wood), planform, channel slope, channel top of bank and toe widths, and preliminary point observations of bed surface texture. Representative study reaches were selected in each geomorphic reach for the purpose of collecting stream channel information necessary for developing a conceptual model and parameterizing the HST model (**Figure 4-1**, Attachment A). Potential study sites were identified primarily based on attributes obtained from aerial imagery, estimates of channel slope and cross sectional channel geometry derived from Light Detection and Ranging (LiDAR), and bed surface texture representative of the overall geomorphic reach. Access from willing landowners was also a critical factor in selecting intensive study sites.

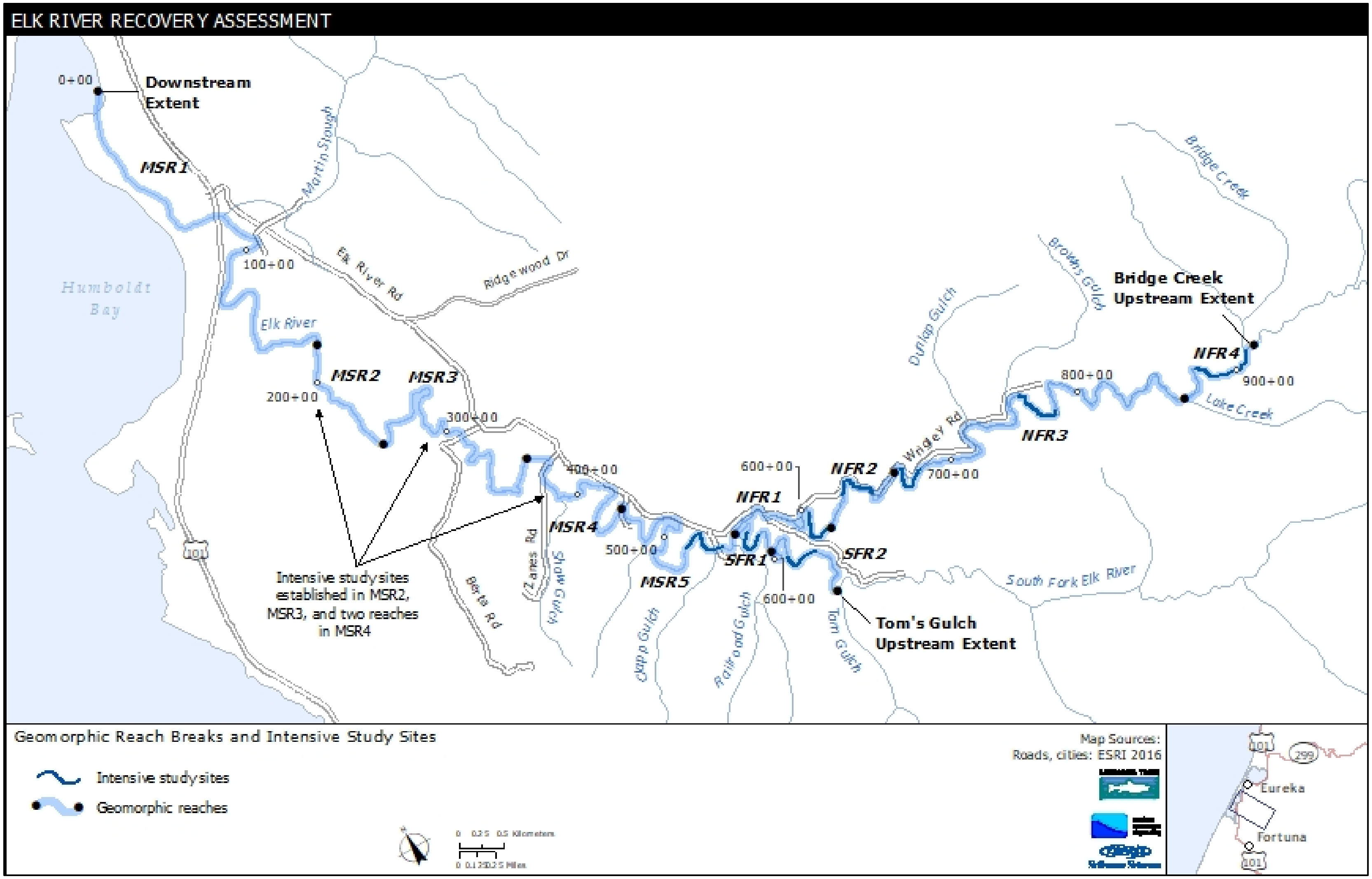

Figure 4-1. Geomorphic reaches and intensive study sites in the Elk River Project area. Intensive study sites in reaches MSR2, MSR3, and MSR4 are not shown per landowner access agreements.

Table 4-1. Summary of data collected as part of the Elk River Recovery Assessment.

Data type	Geomorphic reach										
	MSR1	**MSR2**	**MSR3**	**MSR4**	**MSR5**	**SFR1**	**SFR2**	**NFR1**	**NFR2**	**NFR3**	**NFR4**
Longitudinal Profile[1]	x	x	x	x	x	x	x	x	x	x	x
Transect[2]	x	x	x	x	x	x	x	x	x	x	x
Bed Material	x	x	x	x	x	x	x	x	x	x	x
Bank Material		x	x	x	x	x	x	x	x	x	x
Floodplain Material		x	x	x	x	x	x	x	x	x	x
Vegetation Mapping	x	x	x	x	x	x	x	x	x	x	x
Large Woody Debris		x	x	x	x	x	x	x	x	x	x
Discharge		x	x	x	x						
Water Surface Elevation (15-min)	x	x	x	x	x	x	x	x	x		
Water Surface Elevation (spot)	x	x	x	x	x	x	x	x	x		
Suspended Sediment Concentration	x	x	x	x	x	x	x	x	x		
Salinity	x	x									
Temperature	x	x	x	x			x				

[1] The longitudinal profile surveys of the South Fork and mainstem Elk River were conducted by RCAA with assistance from BLM, USFWS, NOAA, and the ERRA team. The longitudinal survey of the North Fork was led by HRC.
[2] Transect surveys in MSR5, SFR1, NFR2, NFR3 and NFR4 were conducted in coordination with HRC in 2014/2015. Historical transect data was collected by HRC.

4.2 Topography

Topographic data was derived from LiDAR data collected during March 2005 (Sanborn 2005). LiDAR data capture in the Elk River watershed occurred using an OPTEC Airborne Laser Terrain Mapping system referencing two airborne GPS base stations. Table 4-2 shows the planned LIDAR acquisition parameters.

Table 4-2. LIDAR acquisition parameters.

Average altitude	1,000 meters above ground level
Airspeed	~100 knots
Scan frequency	40 hertz
Scan width half angle	16 degrees
Pulse rate	50000 hertz

The LiDAR survey effort was designed to collect mass points at approximately 4.5 points per m^2 over an approximately 300 km^2 area. A kriging algorithm was used on filtered last return LiDAR data in a pilot area to create different size digital elevation model (DEM) grids representing the bare earth surface (average 2.2 points per m^2)(Sanborn 2005). Comparison of curvature, elevation differences, and contour patterns from the various grid sizes (1 to 5 m) indicated that a 4-m grid substantially reduced variance in curvature over short length scales while minimizing elevation change relative to the 1-m grid, maintained the definition of unchanneled valleys apparent in 5-m contours, and reduced computation time required for model applications and spatial analyses. A 4-m DEM grid was created for the entire Project Area using kriging (linear variogram, radius of 200 m, and maximum of 64 points) (Stillwater Sciences 2007).

4.2.1 Project coordinate system and survey control

Sixteen survey control points were established in the Project area in January 2008 (**Figure 4-2**) by Points West Surveying (PWS). The Project coordinate system in California State Plane Zone 1 (NAD 83 [2007], U.S. Survey Feet) was derived from GPS observations holding the HPGN-D monument at Spruce Point fixed (PID AC9253). Distances calculated from coordinates are grid. Elevations are reported in U.S. Survey Feet relative to the North American Vertical Datum of 1988 (NAVD88) based on a GPS tie to the NGS Vertical Control Monument PID LV1183. Data collected prior to the ERRA that was referenced to National Geodetic Vertical Datum of 1929 (NGVD29) were converted to NAVD88 using the National Geodetic Survey tool VERTCON. Additional control points beyond the PWS network were established in the North Fork by Kolstad Land Surveyors and in the South Fork by BLM. The ERRA team established additional temporary control points in intensive study sites using a Trimble R8 Model 2 GNSS system provided by the U.S. Forest Service Redwood Sciences Laboratory.

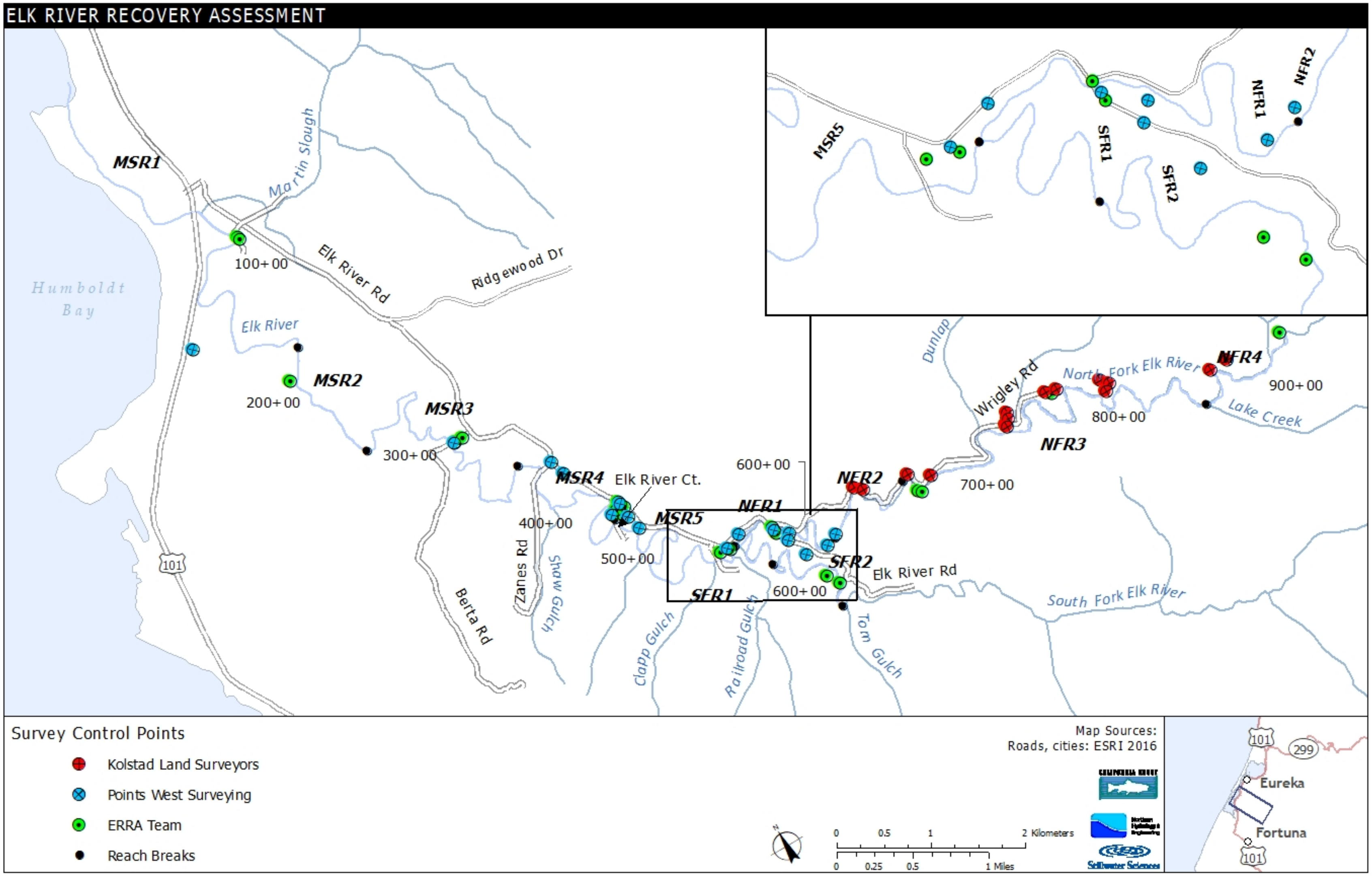

Figure 4-2. Survey control network in the Elk River Project area.

4.2.2 Longitudinal profile survey

A longitudinal profile survey was conducted over the Project length (Humboldt Bay upstream to approximately Bridge Creek on the North Fork and Tom's Gulch on the South Fork) to support analyses, planning, and design. The consultant team developed a guidance document for the surveyors. Guidance included identification of survey boundaries, point density, ancillary data collection methods, photographic documentation, QAQC protocols, and file delivery formats.

Surveys were conducted in phases over the Project length, with each survey closing on common control points to verify consistency. The mainstem Elk River survey from the Trailer Park near Humboldt Hill to the North Fork and South Fork confluence and 1.5 miles up the North Fork to approximately the HRC property boundary was conducted by Redwood Community Action Agency (RCAA) in coordination with Project partners during August through October, 2012. The survey was conducted using a conventional total station. The profile survey was extended up the North Fork to the confluence with Bridge Creek by HRC and up the South Fork by BLM during July through August 2015. These surveys were also conducted using a conventional total station.

The surveys were completed as a series of networks, each beginning from two known points and closing on a known point. Survey data from each network was individually adjusted using a least squares adjustment to equally distribute errors. The unadjusted closure error on ranged from 9.0-25.9 feet in the horizontal and -0.3 to -0.7 feet in the vertical. Survey point density largely depended on capturing major breaks in slope. The maximum point density was expected to be approximately 1 to 2 bankfull channel widths apart. Pools shorter than half the channel width were defined with three points located at the upstream end of the pool, the maximum pool depth and the riffle crest at the downstream end of the pool. Pools longer than a channel width included additional points to define the pool shape. In addition to breaks in slope, all tributary confluences were surveyed.

During the longitudinal profile survey, ancillary data (Table 4-3) and photos were collected to support subsequent more detailed surveys and analyses. Ancillary data included geotagged photography looking upstream and downstream at each station setup and descriptions of the following:

- Channel reach morphology;
- Dominant bed surface texture (i.e., facies) at each thalweg point;
- Large woody debris (pieces and accumulations that altered channel morphology or were greater than half of the channel bankfull width).
- Bank erosion (larger than half of the channel bankfull width), length and height of the failure were recorded.
- Entrance and exits of any side channels (high or low flow) and drainage ditches.
- Structures (e.g., bridges, tide gates, culverts, artificially hardened banks)

Table 4-3. Ancillary data collected during longitudinal profile survey.

Thalweg	
RC	Riffle crest
M-POOL	Maximum pool depth
POOL	Point in pool
THW	No significant break in slope
Facies	
F	Fines: <0.25 mm
S	Sand (0.25 - 2mm)
G	Gravel (> 2mm)
Reach morphology	
R-P	Riffle-pool, contains bars, pools, riffles
R-P-V	Vegetated riffle-pool
PLANE	Plane bed
PLANE-V	Vegetated plane bed
Channel width	
<1 : less than 1 channel width	
1-3: 1-3 channel widths	
>3: greater than 3 channel widths	
Structures	
BRG	Bridge
RSP	Rock slope protection
*Write in any others	
Other	
LWD	Large woody debris
BF	Bank failure
LEW	Left edge water
REW	Right edge water
TRB	Top right bank
TLB	Top left bank
TRP	Top right pin
TLP	Top left pin
CP	Control point

On December 7, 2012, the USFWS conducted a bathymetric survey of the 3.2 miles of the mainstem from the Trailer Park (where the conventional survey began) to the river mouth (defined by pilings in the Elk River at approximately -124 degrees 46' 20.685" and 40 degrees 46' 20.685"). The survey was conducted using a Trimble R-8 RTK/GPS system and a Sonarmite depth sounder on a jet boat. An additional wading rover was used where depths were too shallow for the boat. The GPS base station was set on the Spruce Point BM #1 and the data was collected to Trimble TSC3 data collectors, downloaded to Trimble Business Center software and exported to a csv file for import into AutoCAD. For those points collected using the depth sounder, the point code is the depth from the sounder to the river bed. Horizontal precision ranged from 0.01-0.11, and vertical precision ranged from 0.02-0.15 feet. Submerged wood and vegetation may result in larger error than reported. The bathymetric survey generally described the thalweg, but due to lack of visibility, may not have always captured the deepest portion of the channel and the riffle crest elevations.

Figure 4-3 depicts the longitudinal profile. Reach-average channel slope generally increases in the upstream direction (Table 4-4), with zero slope in MSR1 (tidally influenced reach), a maximum slope of 0.0041 in the North Fork, and a maximum slope of 0.0028 in the South Fork. Intensive study sites are subsets of each geomorphic reach.

Pool statistics were computed from longitudinal profile data in fluvial reaches (MSR 3-5, NFR 1-4, SFR 1-2) (Table 4-5). A pool was defined as having a depth greater than 3 feet relative to the downstream riffle crest. Pool frequency in mainstem reaches varied from 0.12 to 0.55 pools/100 meters, while pool frequency in the North Fork steadily increased in the upstream direction from a low of 0.27 pools/100 meters to a high of 0.85 pools/100 meters. In the South Fork, pool frequency was higher in SFR1 than in SFR 2. Pool frequency in SFR 2 was the second lowest in the project area with the lowest pool frequency occurring in MSR 3. Mean pool lengths in MSR 3 and MSR4 were similar, with lower values in MSR 5. Mean pool length increased substantially in NFR 1, representing the longest pools (726 feet), then steadily declined in the upstream direction to a minimum value of 228 feet in NFR 4. Mean pool length in the South Fork was lower in the downstream reach, and higher in the upstream reach. The portion of the channel that was occupied by pools greater than 3 feet deep varied from a low of 20% in MSR 3 to a high of 90% in MSR 4. MSR 4 had the third highest pool frequency and the second highest mean pool length. MSR 3 had very few pools, with length similar to that in MSR 4.

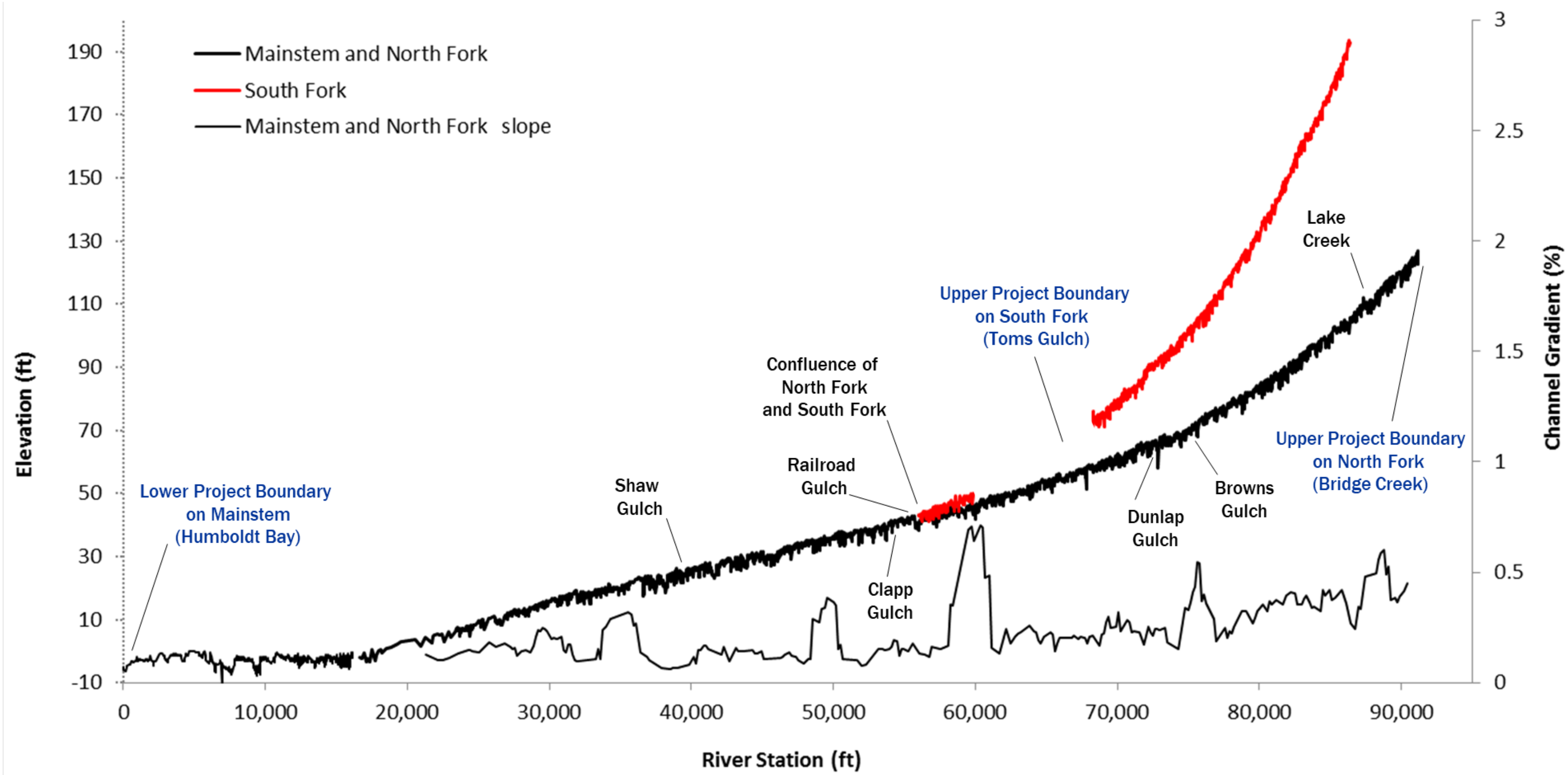

Figure 4-3. Longitudinal profile of the Elk River within the Project Area.

Table 4-4. Average slope in geomorphic reaches and intensive study sites.

Reach	Intensive study reach	Average slope	
		Geomorphic reach	Intensive study site
MSR1	-	0	-[1]
MSR2	MSR2-1	0.0009	0.0011
MSR3	MSR3-1	0.0014	0.0013
MSR4	MSR4-1	0.0010	0.0009
MSR5	MSR5-2	0.0010	0.0016
NFR1	NFR1-1	0.0012	0.0015
NFR2	NFR2-1	0.0016	0.0018
NFR3	NFR3-1	0.0024	0.0015
	NFR3-2	0.0024	0.0024
NFR4	NFR4-1	0.0041	0.0041
SFR1	SFR1-1	0.0019	0.0022
SFR2	SRF2-1	-[2]	0.0028

[1] An intensive study site was not established in MSR1.
[2] Slope is not reported due to an unresolved error in the longitudinal survey of the South Fork.

Table 4-5. Frequency and depth of pools in the Project area.[1]

Reach	Reach length (ft)	Number of pools	Max pool depth (ft)	Mean pool length (ft)	Number of pools per 100 meters	Ratio of pool length to reach length
MSR3	13212	5	4.20	519	0.12	20%
MSR4	8280	14	6.01	531	0.55	90%
MSR5	11050	11	5.06	382	0.33	38%
NFR1	6024	5	5.44	726	0.27	60%
NFR2	4638	5	4.44	301	0.35	32%
NFR3	19899	35	9.07	275	0.58	48%
NFR4	4610	12	5.10	228	0.85	59%
SFR1	3657	6	4.81	257	0.54	42%
SFR2	6037	4	3.78	412	0.22	27%

[1] Includes pools greater than 3 feet deep.

4.2.3 Longitudinal changes in channel width and depth

The LiDAR DTM was used to extract Project-wide information about valley bottom geomorphic features and channel geometry (i.e., width and depth). Top-of-bank widths and toe widths were extracted throughout the Project channel length by mapping top-of-bank and toe elevations along both channel margins. Mapping was conducted on-screen using the 2005 LiDAR DTM. Surveyed cross section transects and transects cut from the LiDAR DTM helped inform and calibrate mapping of top-of-bank and toe elevations. The distance between the top-of-bank and toe lines was used to calculate top-of bank and toe widths (Figure 4-4). Channel toe width narrows in the downstream direction between approximately station 73,000 and station 57,000, an atypical pattern for most river systems. We attribute narrowing in toe width largely to channel aggradation. Narrowing in channel width correlates to other observed changes in grain size distribution and valley bottom geomorphology.

To better understand valley morphological controls on geomorphic and hydrologic processes, we analyzed the relative elevations of valley bottom geomorphic features (e.g., flood basins, natural levees and channel avulsion points, high flow channels, and terraces) above a reference floodplain (or valley bottom) surface. The process involved defining a reference floodplain surface developed from elevations adjacent to the channel top-of-banks and then subtracting the original LiDAR DTM from this surface. The resulting difference between the two topographic grids reflects the relative elevation of a given geomorphic feature above or below the reference surface. The process is equivalent to removing the overall trend in down valley slope from a topographic surface (also referred to as "detrending"). Figure 4-5 shows the heights of geomorphic features relative to the reference floodplain surface. Figure 4-6 shows longitudinal profiles of the reference floodplain surface and the channel thalweg defined by surveyed riffle crests throughout the Project area. Figure 4-7 show the depth of channel incision below the reference floodplain. The results of this analysis reveal a convex up valley profile compared to a concave up thalweg profile. The longitudinal distribution in the profile separation (i.e., channel incision or entrenchment) correlates to other longitudinal trends in confining geomorphic features, channel width and depth, channel avulsion, bed grain size distribution, and overall floodplain connectivity and flow paths. These results are discussed in more detail within the context of the conceptual model of hydrogeomorphic processes.

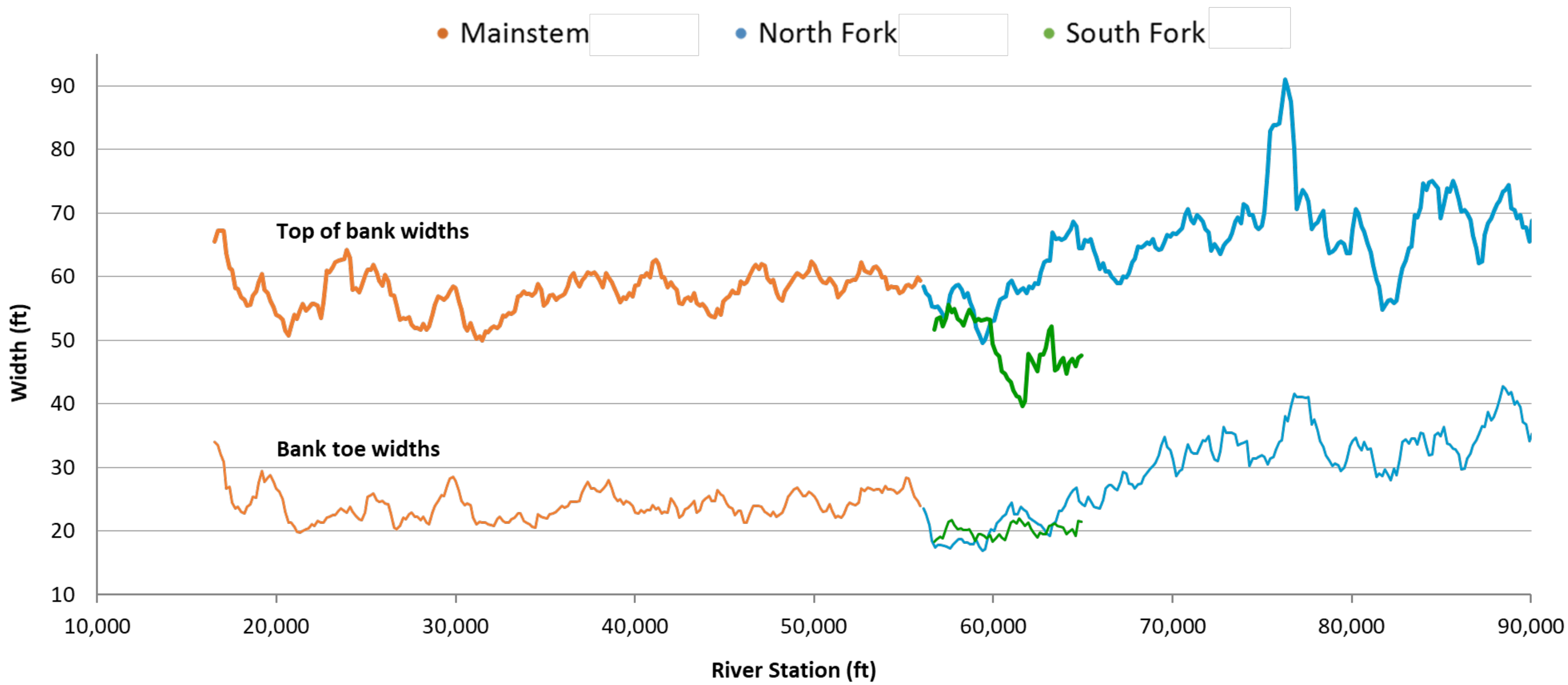

Figure 4-4. Channel top-of-bank and toe widths derived from LiDAR data.

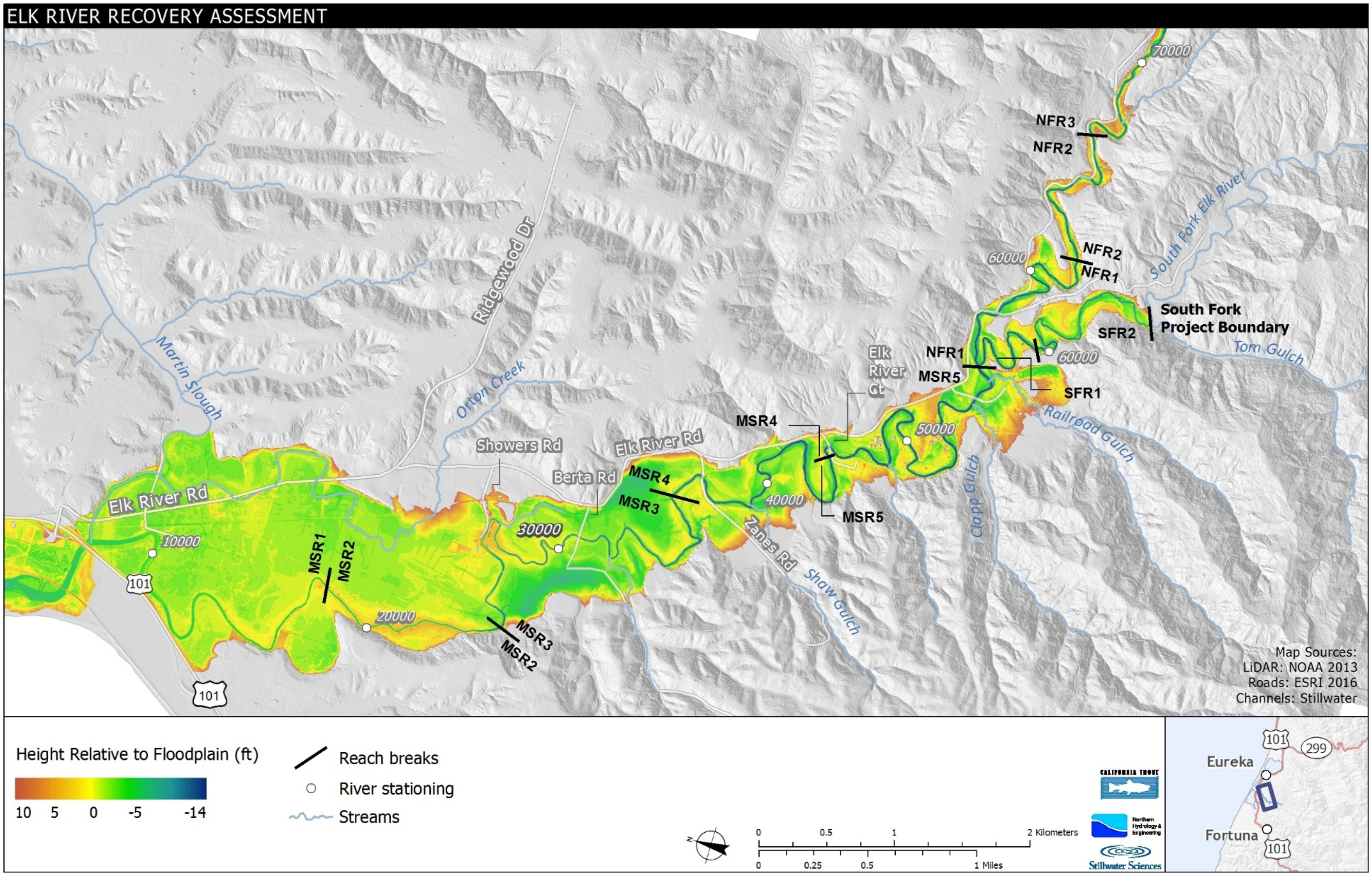

Figure 4-5. Height of geomorphic features relative to the reference floodplain surface.

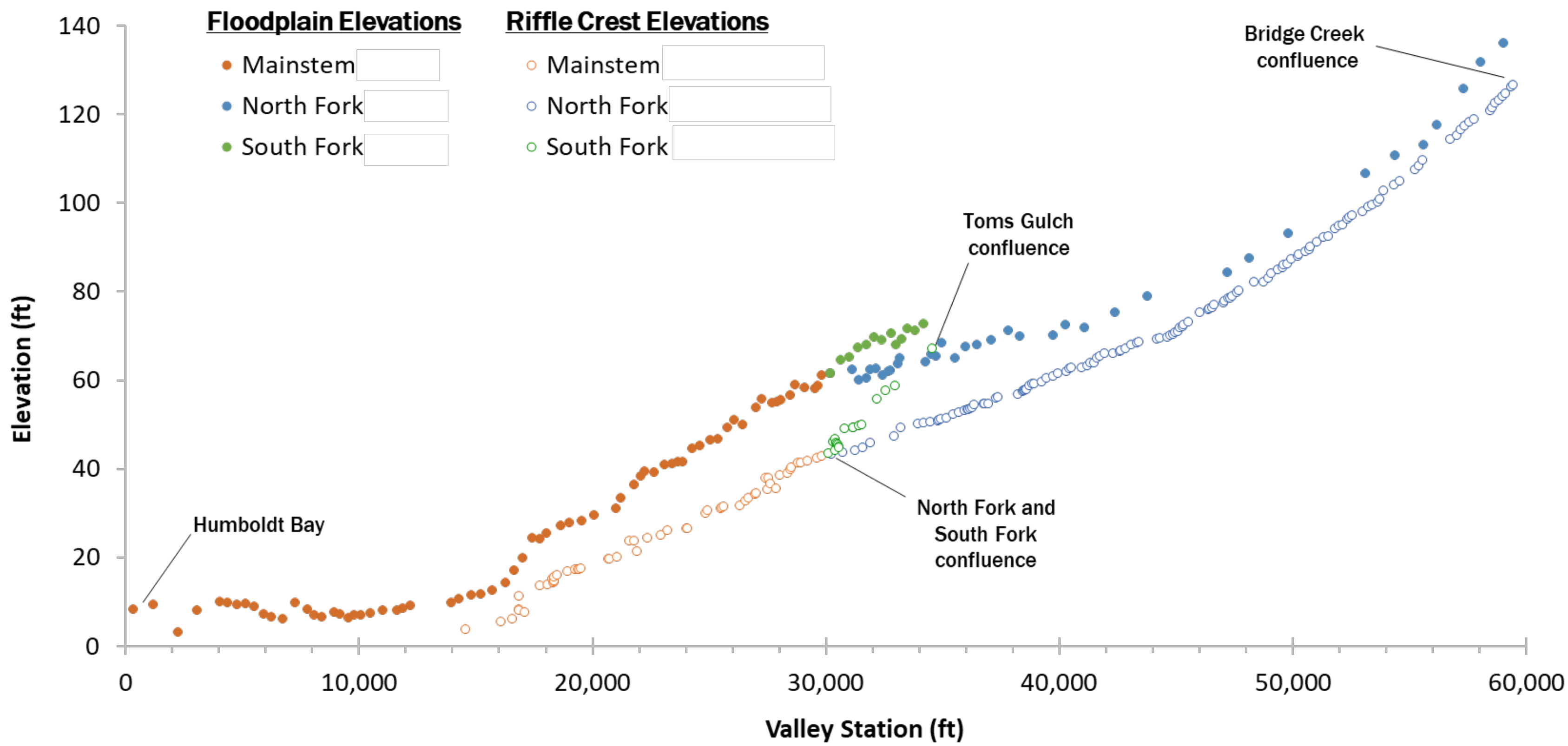

Figure 4-6. Floodplain and thalweg riffle crest longitudinal profiles.

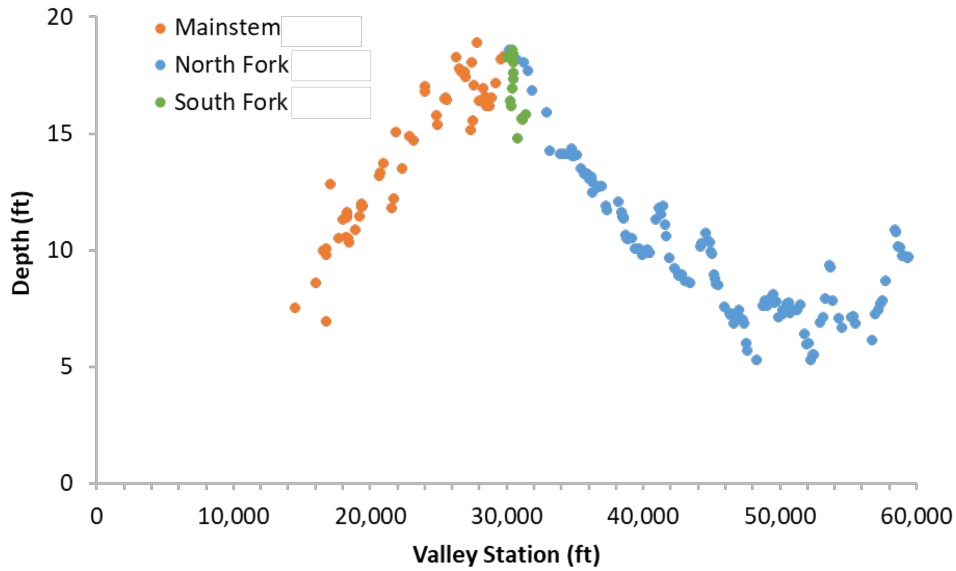

Figure 4-7. Channel depth relative to the reference floodplain surface.

4.2.4 Transect surveys

A total of 81 transects (new and previously established) comprise the ERRA network (**Figure 4-8** and **Figure 4-9**). The transect network contributes to the ERRA in several ways:

- Surveyed transects were compared to the LiDAR DTM to evaluate potential biases when estimating longitudinal changes in channel geometry (top widths and toe widths) from LiDAR data,
- Repeat surveys in 2015 and 2016 were used to calibrate the HST model, and
- Surveyed transects provide baseline data from which to measure future channel change.

The County of Humboldt, HRC, Salmon Forever, RWQCB, and Randy Klein provided historical survey data to assess changes in channel geometry (i.e., cross-sectional area and average bed elevation) over time (Figure 4-8). Previously established transects within the ERRA Project area date back to 1947 in the form of bridge reports containing channel cross sections sketched within a scaled bridge schematic. The number and extent of transects established for monitoring channel conditions in the Elk River increased after 1997. Previously established transects occur within the ERRA Project area in reaches MSR5, SFR1, NFR1, NFR2, and NFR3.

HRC data

Survey data was provided by HRC at 37 transects within MSR5, SFR1, NFR2, NFR3, NFR4, and ATM162 (upstream of ERRA Project area) (Figure 4-8). HRC surveys were conducted between 1997 and 2016, with specific periods of record varying between transects.

Salmon Forever data

Channel survey data was provided by Salmon Forever (SF) at 25 transects within the MSR3, MSR4, MSR5, SFR1, NFR1, and NFR2 reaches (**Figure 4-8**). Surveys were conducted by SF between 2001 and 2011, with specific periods of record varying between transects. Data reports may be found online at the Natural Resources Services website (http://www.naturalresourcesservices.org/projects/elk-river-and-freshwater-creek-sediment-monitoring-project).

County/Caltrans data

Historical documents issued by the County of Humboldt and the California Department of Transportation were reviewed to assess channel changes at three bridge locations: Berta Road Bridge (1969–2015), Zanes Road Bridge (1969-2015), and North Fork Elk River Bridge (1947–2015). Historical documentation consisted of bridge reports, bridge file updates, public meeting notes, and survey data. Several documents contained bridge schematics, bridge-to-channel-bed clearance measurements, and channel transect data which were used to assess changes in channel geometry over time. Qualitative observations were also presented within these historical documents, including bed material types, vegetation patterns, incidences of flooding, and perceived scour and erosion near bridge piers and along the channel banks.

Other data

Additional transect data was obtained from Randy Klein for the North Fork Elk River Bridge surveyed by Conroy in 1996 and 1997 and Schillinger in 2001. Transects at Steel Bridge (HRC Stations 509) surveyed by USGS 1958 and 1964 and by Rossen/Smith in 2002 are also included. ERRA surveys included the collection of data points located on the bridge infrastructure, which were used to adjust historical channel elevation measurements to the Project datum (NAVD88).

Transects were established and/or resurveyed in 2014–2016 (Figure 4-9). The ERRA team surveyed new and previously established transects in reaches MSR1, MSR2, MSR3, MSR4, SFR2, and NFR4; while HRC surveyed new and previously established transects in MSR5, NFR2, NFR3, and SFR1. A minimum of three new transects were established in each intensive study site, generally at riffle crests. Additional transects were also established near existing transects where it was necessary to improve spatial coverage within a reach. New transects were typically monumented with ½” rebar 3 to 4 feet in length, except for MSR1. Surveying was conducted with a total station, except at MSR1. Survey methods at MSR1 are described in the section below describing the bathymetric survey. Surveyed transect data are provided in the Project geodatabase, as well as in excel spreadsheets in the electronic attachment.

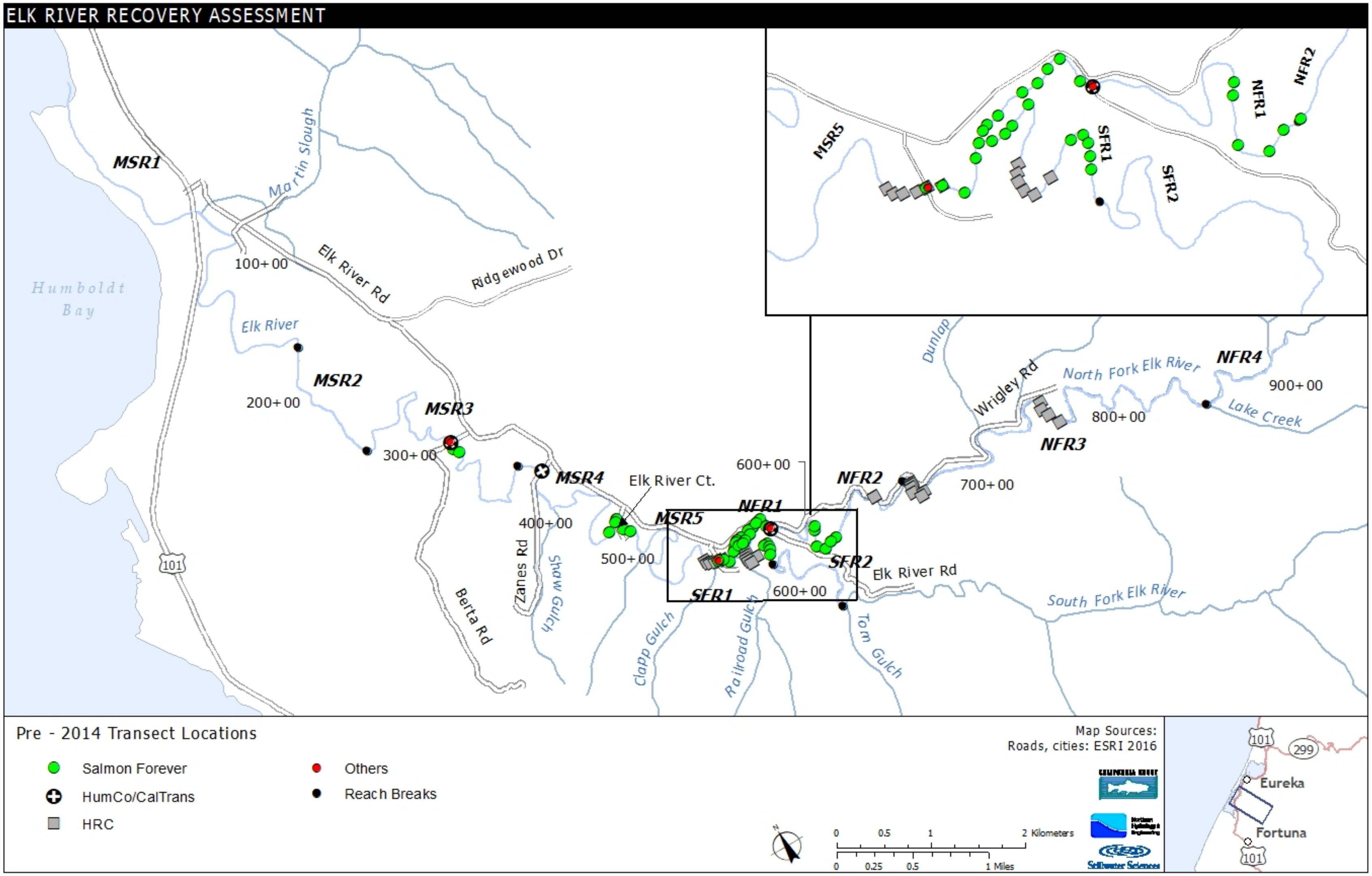

Figure 4-8. Transect locations with historical data prior to 2014 in ERRA Project area.

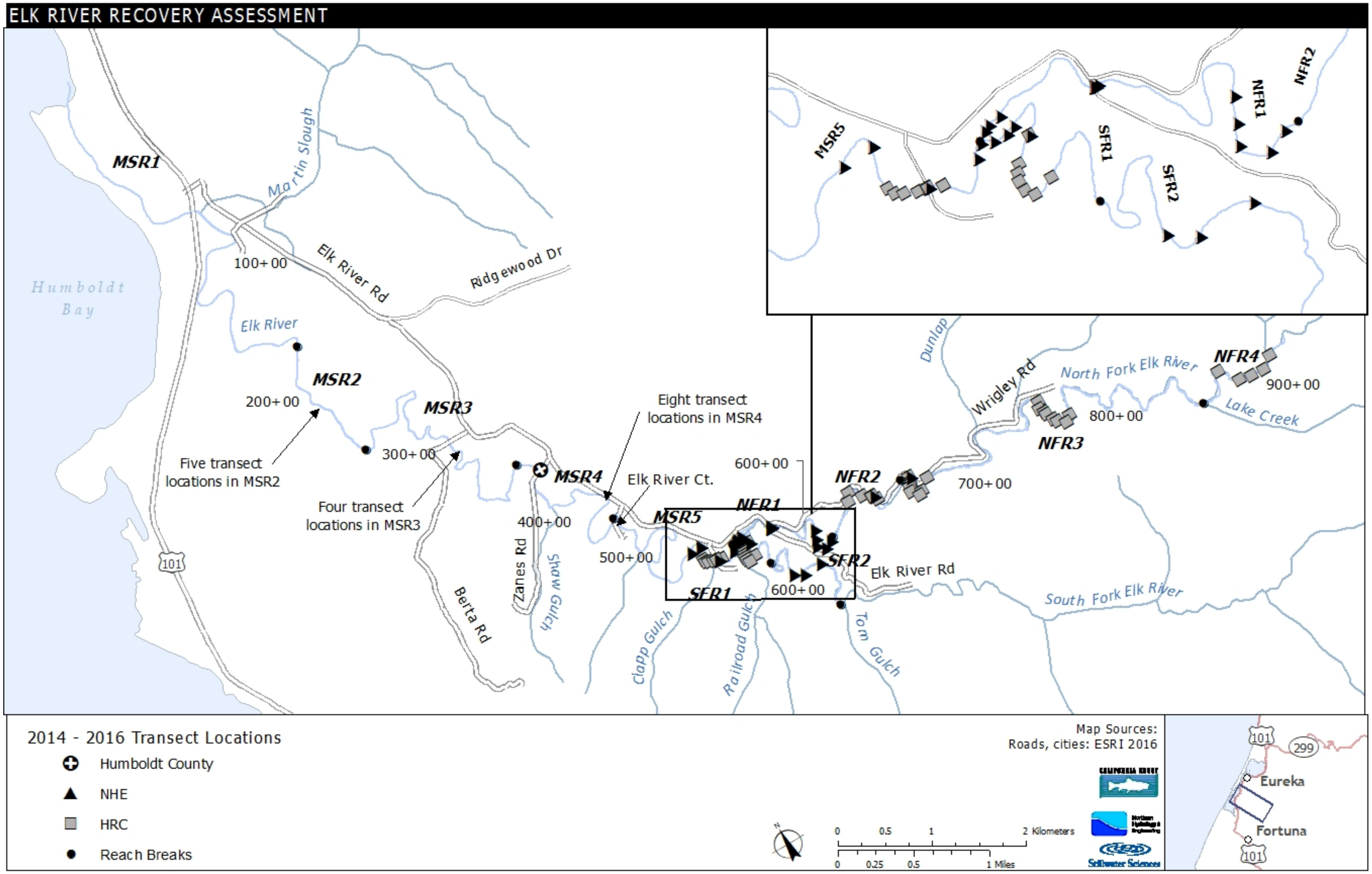

Figure 4-9. 2014–2016 transect locations in the ERRA Project area.

4.2.5 Bathymetric survey

A bathymetric survey was conducted in the lower Elk River tidal reach downstream of RM 3.37 on September 23 and September 25, 2014 to characterize channel bed elevations in the tidal reach and parameterize the HST model. Bathymetry data are georeferenced to California State Plane Zone 1, NAD83 (NSRS2007) U.S. Survey Feet as described in section 5.1.2. Elevations are reported in U.S. Survey Feet relative to NAVD88 (approximate).

Two survey vessels and data acquisition systems were utilized for the bathymetric survey reach. A 15-foot aluminum work boat outfitted with a 12-horsepower outboard was used to survey from the Elk River mouth at Humboldt Bay to RM 3.01. Depth soundings were measured with a Teledyne RDI 1,200 kHz Workhorse Rio Grande Acoustic Doppler Current Profiler (ADCP). Position and elevation were simultaneously measured with a Trimble R8 Model 3 RTK-GNSS rover antenna. The ADCP and GNSS instruments were connected to a laptop computer running WinRiver II software used to visualize and record survey transects. The ADCP was attached to the bow of the vessel using an adjustable boom and mast mount. The ADCP was deployed approximately 1.5 feet below the water surface and the GNSS antenna was mounted to the top of the mast approximately 5 feet above the ADCP.

From RM 3.01 to RM 3.37 the Elk River is heavily vegetated and unnavigable by a typical survey vessel with an outboard motor. In this reach the survey instrumentation was mounted to a small tethered trimaran and pulled along survey transects by field staff from inflatable float-tubes.

4.2.6 Levees

A cursory delineation of constructed levees was attempted through an analysis of LiDAR data. While levee locations were detectable on the LiDAR in some locations, many locations were inconclusive due to dense vegetation cover that resulted in gaps in the LiDAR or inaccurate ground locations. Constructed levees were also difficult to delineate where they are built upon natural levees. Comprehensive delineation of levees within the Elk River requires ground mapping, which was beyond the scope of this work.

4.2.7 Bridges

Bridges in the Project area include the Elk River Concrete Bridge (NFR 1), two private bridges in SFR1, Steel Bridge (also known as Iron Bridge or Elk River Timber Bridge) and a private bridge in MSR5, Elk River Court Bridge and a private bridge in MSR4, Zanes Road Bridge (MSR4), Berta Road Bridge (MSR3), a private bridge in MSR2, and the Railroad Crossing and California State Route 1 crossing in MSR1. Private bridges are difficult to identify from aerial photography and may occur in other locations within the Project area.

Bridges upstream of MSR1 were surveyed using a Trimble M3 Total Station. Surveys focused on documenting the bridge geometry and included surveys of piers, abutments, pilings, railing, deck, beam, and joist locations (where applicable). The stream channel was surveyed at the bridge where access was granted.

4.3 Stream Flow and Water Quality

Long term streamflow gaging records in Project area are concentrated near the confluence and in the lower reaches of the North Fork and South Fork. HRC maintains stations in MSR5, SFR 1, and NFR 2 and Salmon Forever maintains station in MSR 5, SFR 1, and NFR 1. This monitoring network was expanded to include point measurements of discharge and velocity. The measurements were collected over a range of flow and tidal conditions. These measurements are used to calibrate and validate the HST model.

Water quality measurements consisted of suspended sediment concentrations (SSC) (mg/L), salinity concentrations (ppt), and water temperatures (°C). SSC measurements were collected by HRC and Salmon Forever as part of their respective monitoring networks in the North Fork, South Fork in NFR 1, NFR 2, SFR 1 and MSR 5. This monitoring network was expanded to include spot measurements of SSC as well as salinity and temperature.

4.3.1 Discharge and velocity

Discharge and velocity measurements were collected over a range of flows as part of the ERRA (Table 4-6, Table 4-7). Discharge was measured during low flow with a Price AA and pygmy vertical axis current meter and Aquacalc Pro Plus discharge computer following USGS protocols described in Buchanan and Somers (1969). High flow measurements of discharge and velocity profiles were collected with a 1,200 kHz Acoustic Doppler Current Profiler (ADCP) deployed in a small tethered boat that was manually pulled across measurement transects. A minimum of four transects were collected per discharge measurement and reviewed in the field for quality assurance. ADCP measurements can be biased by a moving bed condition (Mueller and Wagner 2006); therefore, a Trimble ProXT differentially corrected Global Positioning System (DGPS) receiver was integrated into the ADCP measurement setup to provide position and velocity reference information and eliminate a moving bed bias. When thick canopy cover or proximity to covered bridges led to unreliable GPS data, stationary or loop-method moving bed tests were conducted and used to correct the ADCP discharge measurements if necessary. Water temperature was verified at the time of measurement with a calibrated thermometer. Velocity profile and discharge measurements were processed in WinRiver II software. Velocity profiles were measured with a stationary boat for 30-90 seconds.

Table 4-6. Discharge measurements during Water Year 2015.

Reach	Date	Start time	End time	Method	Width (ft)	Mean depth (ft)	Area (sq ft)	Mean velocity (ft/s)	Discharge (cfs)
MSR2	11/22/2014	11:57	12:10	BOAT	53.54	6.5	349.7	0.7	254
MSR2	12/12/2014	10:31	10:47	BOAT	67.71	6.7	451.7	0.7	312
MSR2	12/21/2014	15:25	15:38	BOAT	72.65	6.8	491.8	0.6	317
MSR2	2/7/2015	17:10	17:15	BOAT	58.95	7.4	434.2	0.7	325
MSR2	2/10/2015	12:20	12:30	BOAT	58.27	6.9	403.4	0.8	312
MSR3	12/12/2014	12:32	12:44	BOAT	55.74	6.3	349.9	1.3	446
MSR3	12/21/2014	11:16	11:25	BOAT	65.18	6.4	415.2	1.3	547
MSR3	2/7/2015	15:50	16:05	BOAT	56.14	7	390.6	1.3	498
MSR3	2/10/2015	16:15	16:22	BOAT	42.4	6.1	260.1	1.4	371
MSR3	5/19/2015	10:29	11:07	WADING	12.5	1.3	16.7	0.4	6
MSR4 (Upper)	11/22/2014	9:11	9:19	BOAT	64.12	8.8	562.9	1	549
MSR4 (Upper)	12/12/2014	13:46	14:10	BOAT	57.2	7.4	422.7	0.8	347
MSR4 (Upper)	12/21/2014	9:02	9:10	BOAT	110.03	10.1	1115	1.3	1500
MSR4 (Upper)	2/7/2015	14:40	14:50	BOAT	65.77	10.7	703.7	1.2	836
MSR4 (Upper)	2/10/2015	15:30	15:40	BOAT	53.75	6.6	356.3	0.9	308
MSR4 (Upper)	5/5/2015	11:44	12:52	WADING	23.1	1	22.2	0.4	8
MSR5	2/7/2015	12:30	12:40	BOAT	51.25	8.9	456.2	2.1	950

Table 4-7. Thalweg velocity measurements collected with a stationary ADCP.

Reach	Date/Time (LST)	Velocity (ft/s)
MSR2	12/12/14 11:53	1.3
MSR2	2/7/15 17:09	1.0
MSR3	12/12/14 13:47	1.9
MSR3	12/21/14 12:13	1.9
MSR3	2/7/15 15:54	1.8
MSR4 (Upper)	11/22/14 9:24	1.6
MSR4 (Upper)	11/22/14 9:29	1.8
MSR4 (Upper)	12/12/14 15:14	1.3
MSR4 (Upper)	12/21/14 10:52	3.3
MSR4 (Upper)	2/7/15 14:37	2.2
MSR5	2/7/15 12:30	3.0

4.3.2 Water surface elevation

Continuous and spot measurements of water surface elevation were measured in the channel and floodplain to calibrate the HST model and confirm the overall flow field predicted by the numerical model.

4.3.2.1 Continuous measurements

Stage and water temperature were continuously measured with Solinst Leveloggers at MSR1, MSR2, MSR3, MSR4, and SFR 2 (

Table 4-8, **Figure 4-10** through **Figure 4-16**). Leveloggers were housed in PVC stilling wells and secured to t-posts in the channel. Stage data was recorded at six-minute intervals. A barologger was installed near the confluence of the North and South Fork, and was used to compensate the levelogger stage data for barometric pressure using Solinst Levelogger Software. Stage data were converted to water surface elevations in the Project datum (NAVD88). Results indicate that MSR1 and MSR2 are tidally influenced (Figure 4-17). Tidal fluctuations in the MSR3 and upstream reaches are not observed in the record. Continuous water surface elevation measurements were used to calibrate the HST model.

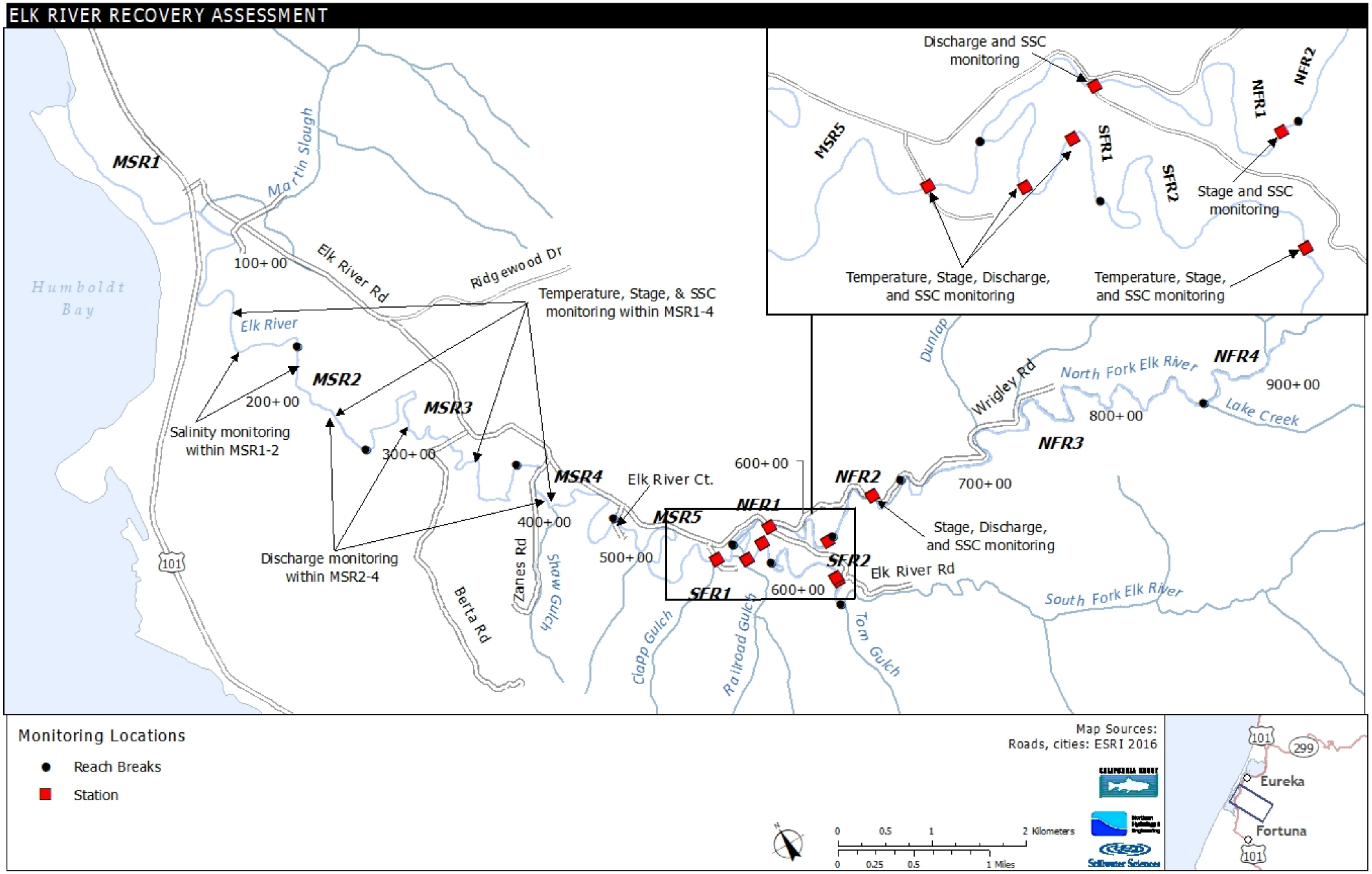

Figure 4-10. Stream flow, stage, and water quality monitoring locations within the ERRA Project area.

Table 4-8. WSE, salinity, and temperature monitoring equipment and periods of record within six reaches of the ERRA Project area.

Reach	Parameter	Equipment	Period of Record*
MSR1	Salinity	YSI 6600EDS V2	Nov. 4, 2014–May 19, 2015
	Temperature		
	WSE	Solinst Levelogger LT F30/M10	Oct. 6, 2014–May 19, 2015
MSR2	Salinity	YSI 6600EDS V2	Nov. 4, 2014–May 19, 2015
	Temperature		
	WSE	Solinst Levelogger LT F30/M10	Oct. 21, 2014–May 19, 2015
MSR3	Temperature	Solinst Levelogger LT F30/M10	Dec. 10, 2014–July 22, 2015
	WSE		
MSR4 (Lower)	Temperature	Solinst Levelogger LT F30/M10	Dec. 10, 2014–June 9, 2015
	WSE		
MSR4 (Upper).	Temperature	Solinst Levelogger LT F30/M10	Oct. 21, 2014–May 12, 2015
	WSE		
SFR2	Temperature	Solinst Levelogger LT F30/M10	Dec. 2, 2014–May 11, 2015
	WSE		

* Periods of record may include brief periods when equipment was being serviced.

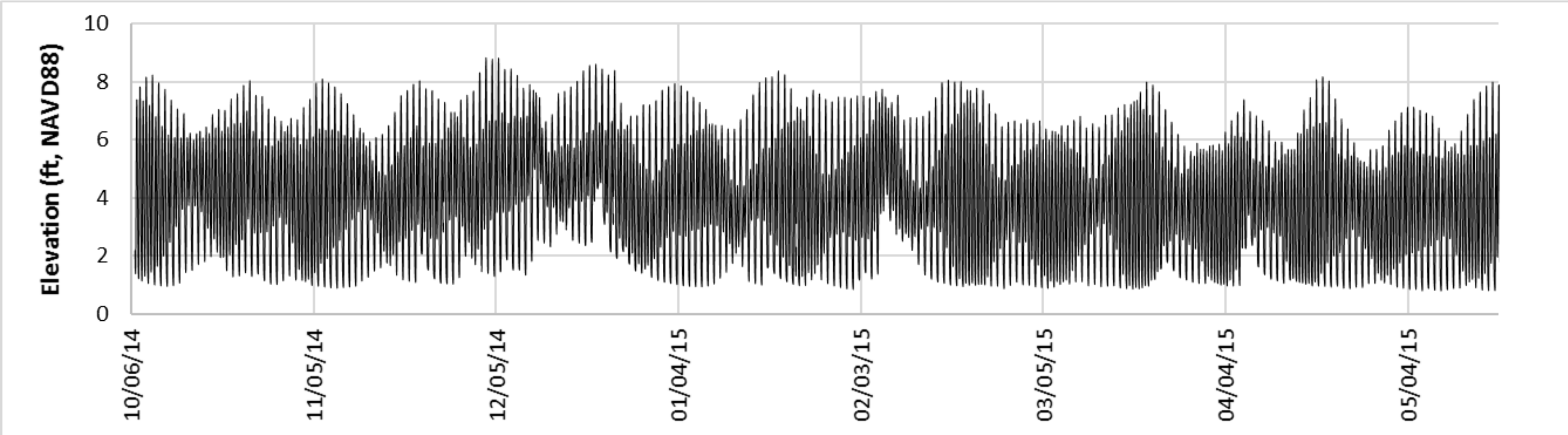

Figure 4-11. Continuous water surface elevation measurements for MSR1 (Oct. 6, 2014–May 19, 2015).

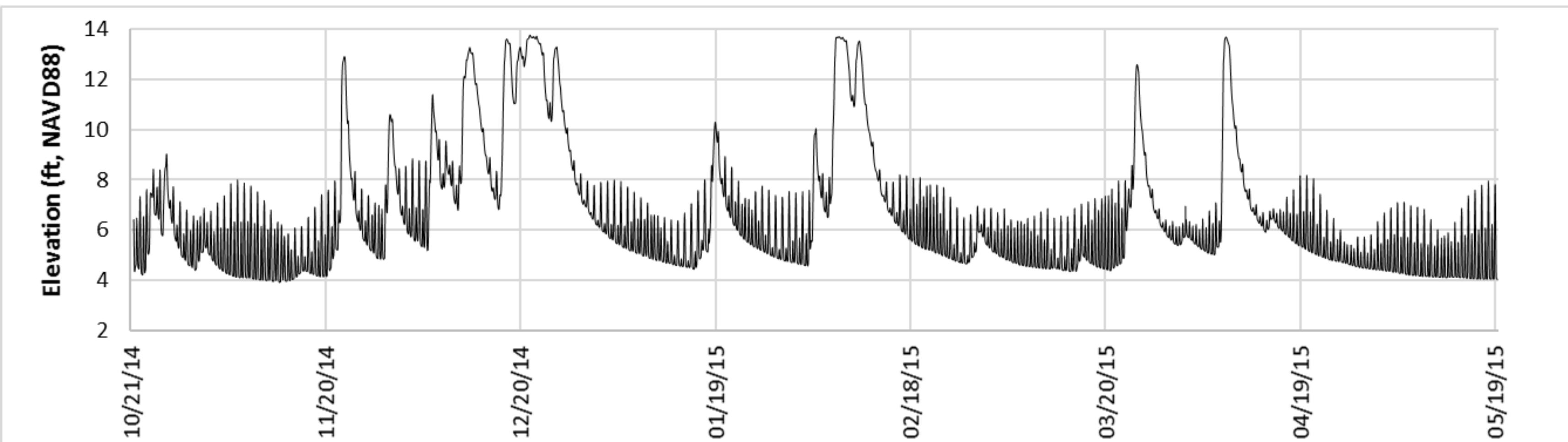

Figure 4-12. Continuous water surface elevation measurements for MSR2 (Oct. 21, 2014–May 19, 2015).

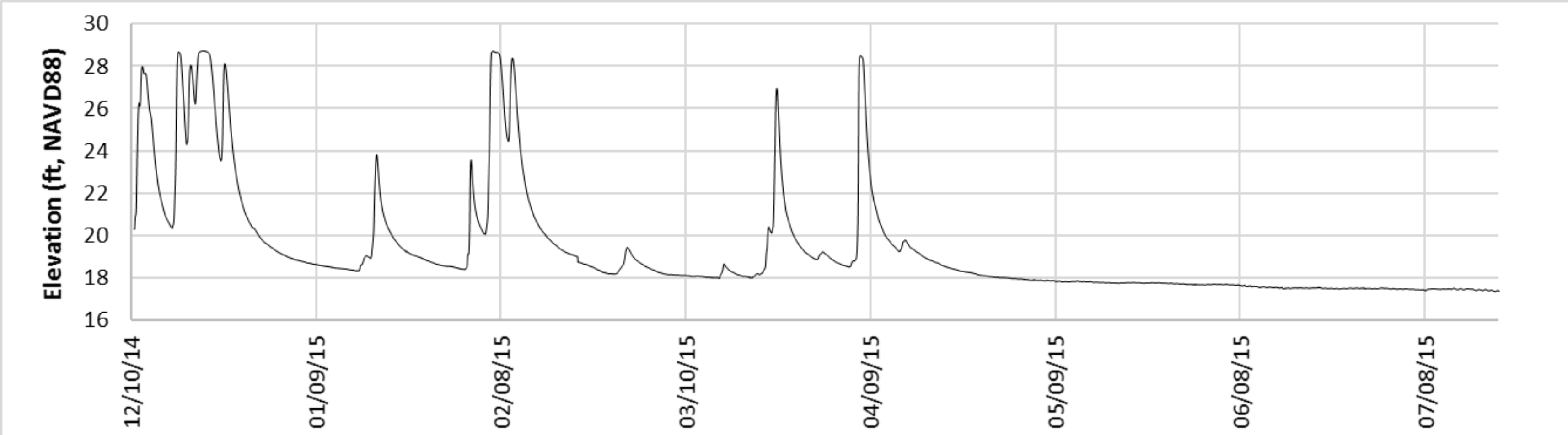

Figure 4-13. Continuous water surface elevation measurements for MSR3 (Dec. 10, 2014–July 22, 2015).

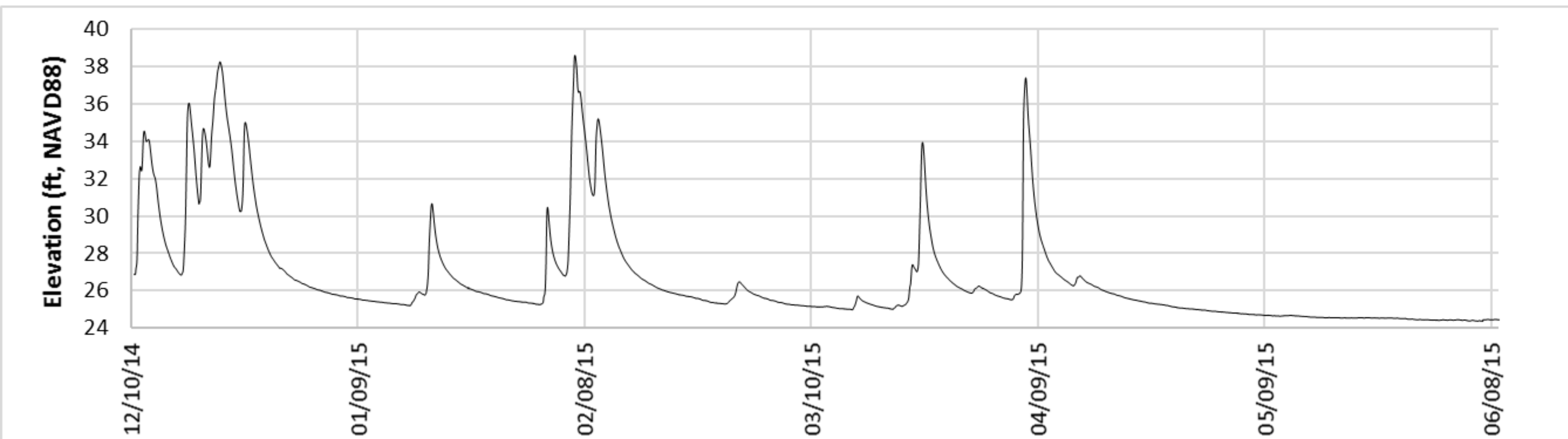

Figure 4-14. Continuous water surface elevation measurements for MSR4 (Dec. 10, 2014–June 9, 2015).

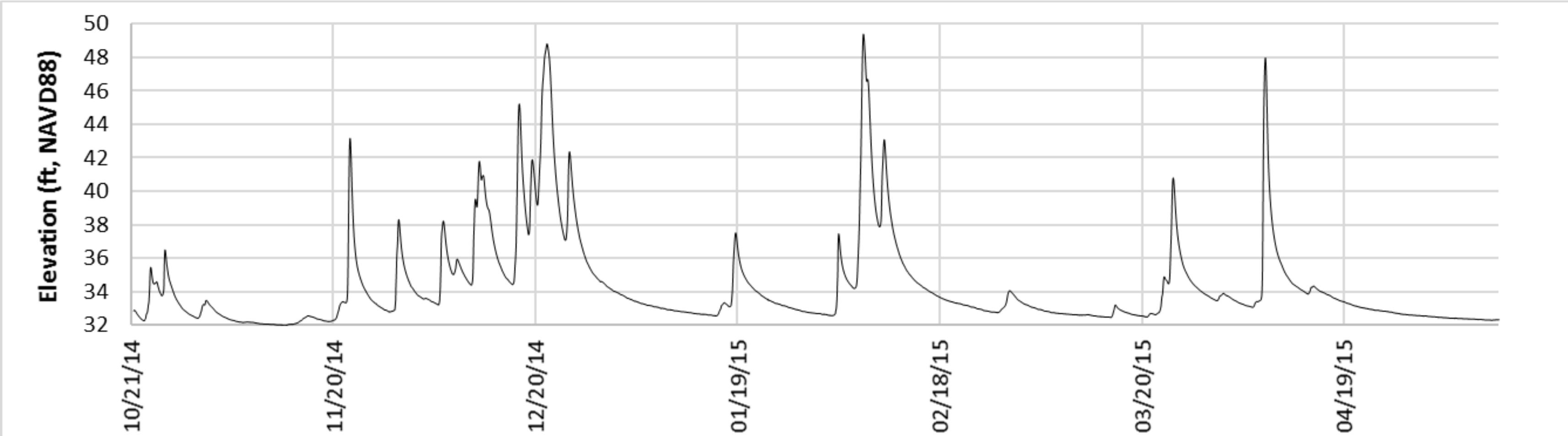

Figure 4-15. Continuous water surface elevation measurements for MSR4 (Elk River Ct. reach) (Oct. 21, 2014—May 12, 2015).

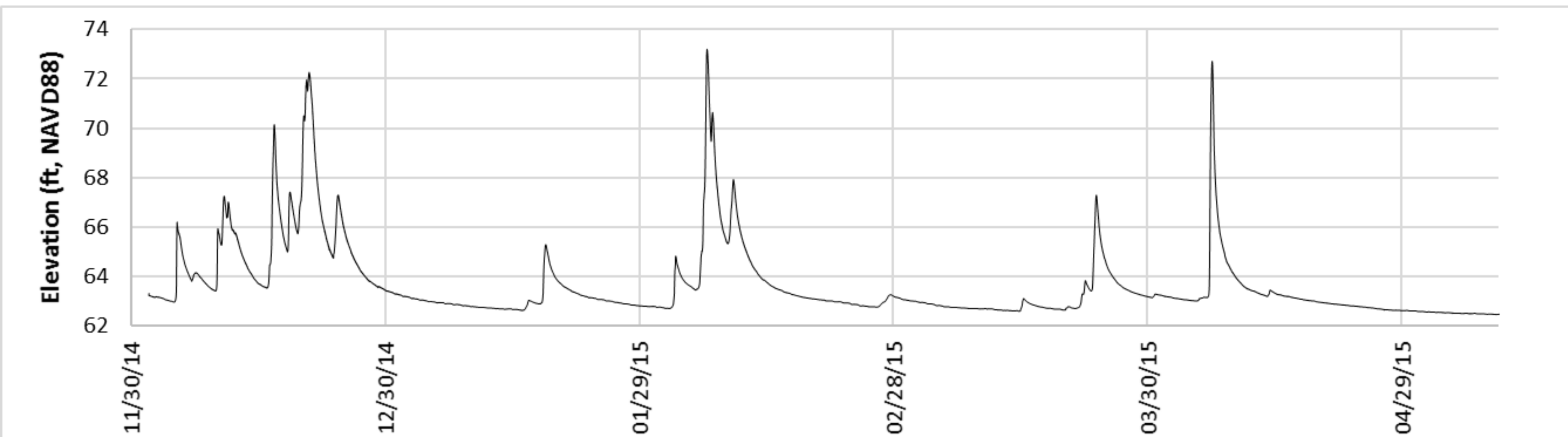

Figure 4-16. Continuous water surface elevation measurements for SFR2 (Dec. 2, 2014–May 11, 2015).

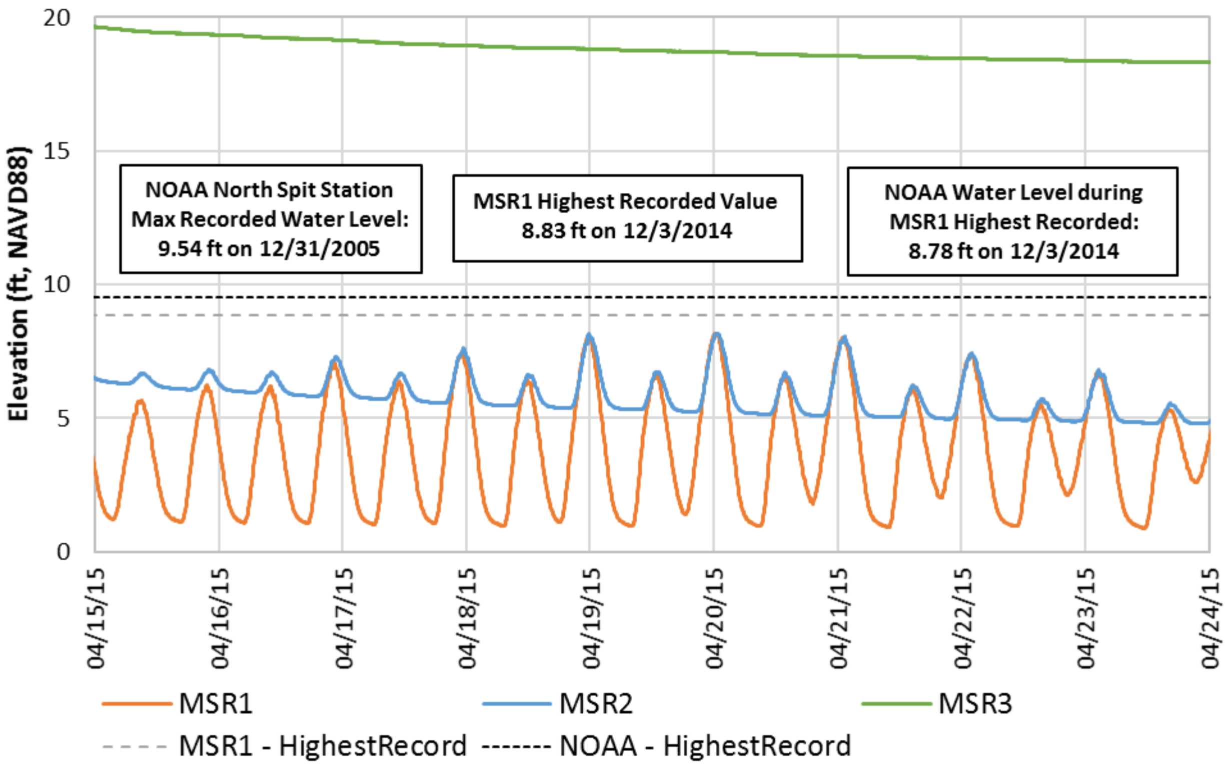

Figure 4-17. Continuous water surface elevation data for MSR1 to MSR3.

4.3.2.2 High flow mapping

Inundation patterns, general flow directions and water surface elevations were mapped during the December 2014 and February 2015 high flows by the ERRA team (MSR 1, 2, 3, 4, SFR2) and by Kristi Wrigley and Jesse Noell (NFR 1, SFR 1). The edge of water was flagged and time and date recorded by Kristi Wrigley between the Concrete Bridge and the upstream end of her property on the North Fork (STA 578+62 to 620+74) and by Jesse Noell on the mainstem upstream of the Steel Bridge and on the South Fork to the upstream end of his property STA (549+08 to 592+82). Flags placed by landowners were surveyed by the ERRA team. The flood extents in the lower mainstem (Elk River Courts to Pine Hill Road) were sketched on aerial photographs, and the water surface elevations and edge of water points were mapped in the field using a Trimble R8 Model 2 RTK-GNSS rover antenna. Substantial portions of the floodplain were not mapped due to lack of property access and limitations Project resources.

4.3.3 Salinity

Salinity was measured in the tidally influenced reaches (MSR1 and MSR2) to calibrate the HST model. Salinity was measured using a YSI 6600EDS V2 Series Multi-Parameter Water Quality Sonde in MSR 1 (Pine Hill Road) and MSR2 from November 4, 2014 to May 19, 2015. Data were recorded in six-minute intervals. The probe was calibrated prior to deployment and checked with a standard 10.0 mS/cm solution during monthly maintenance. An instrument accuracy of ±1.0% of the salinity reading or 0.1 ppt (whichever is greater) is reported by the manufacturer (YSI Incorporated, 2012).

Table 4-8 within Section 4.3.2.1 presents the equipment utilized and periods of record for monitoring salinity at the two Project locations.

Salinity levels in the MSR1 reach range from 0-33 ppt and are tidally influenced, with fresh to brackish conditions during low tides and saline conditions during high tides (Figure 4-18). During high flows, the stream flows overwhelm the tidal influence and fresh water conditions persist regardless of the tide. Salinity levels in MSR 2 are near zero for most of the winter period and less than 5ppt during the low flow period in the fall and late spring (Figure 4-19).

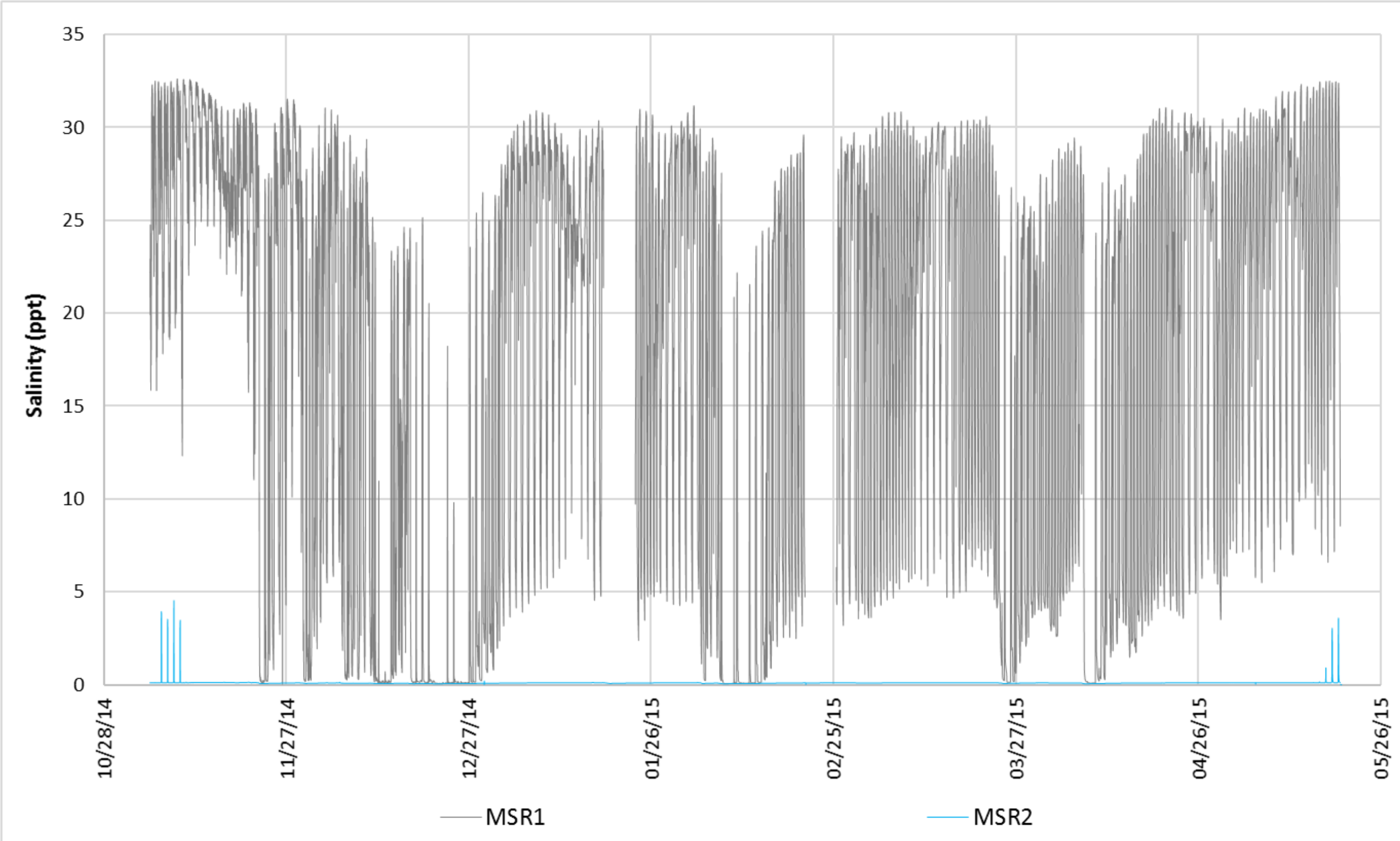

Figure 4-18. Salinity measurements for MSR1 and MSR2. Device was out of water for servicing in mid-January and late February.

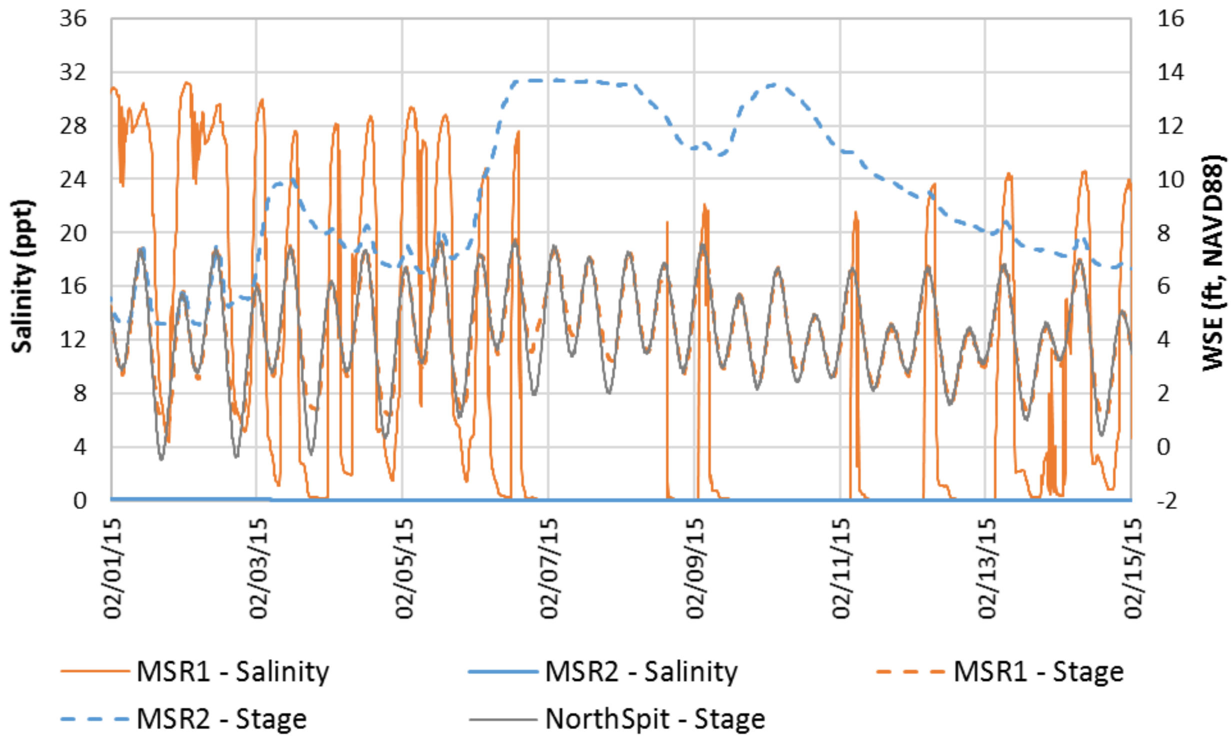

Figure 4-19. Salinity and stage levels for MSR1 and MSR2 from February 1 to February 15, 2015.

4.3.4 Temperature

Temperature was measured at six sites in the late fall of 2014 to the late spring of 2015 (Table 4-8; Figure 4-20 through Figure 4-25). Temperature was recorded in MSR1 and MSR2 by a YSI 6600EDS V2 Series Multi-Parameter Water Quality Sonde, and in MSR3 and MSR4 and SFR2 by a Solinst Levelogger LT F30/M10 Instrument precision of ±0.05ºC and ±0.15ºC are reported, respectively, by Solinst and YSI (Solinst Canada Ltd., 2017) (YSI Incorporated, 2012). Temperature was recorded as a secondary parameter and were not calibrated. Therefore, differences in the reported temperatures may be larger than the reported accuracies of the instruments.

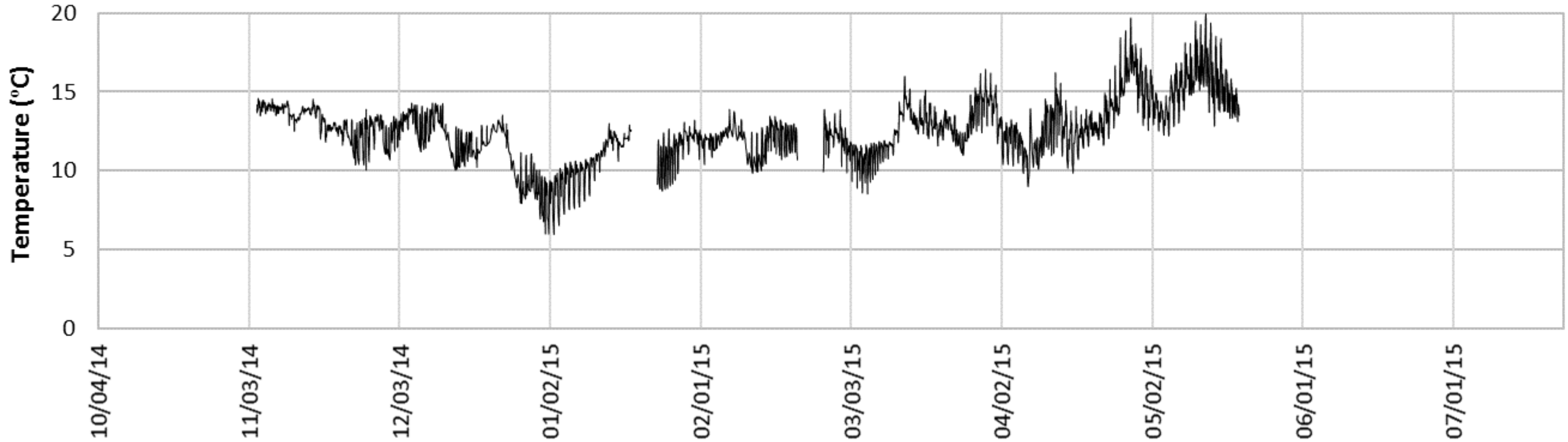

Figure 4-20. Temperature measurements within MSR1 (Nov. 4, 2014 to May 19, 2015).

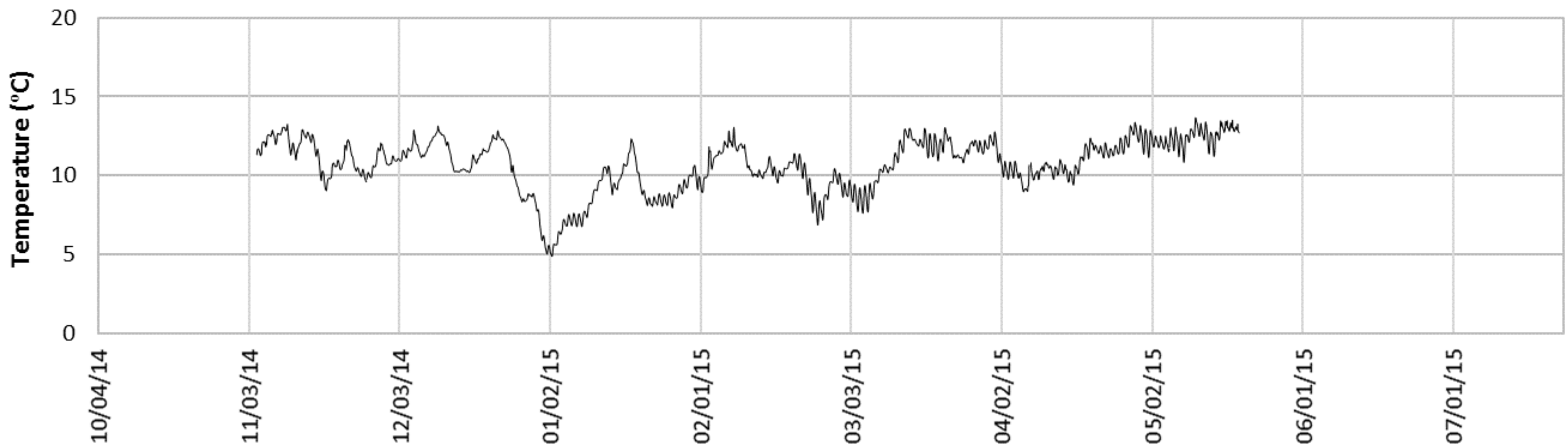

Figure 4-21. Temperature measurements within MSR2 (Nov. 4, 2014 to May 19, 2015).

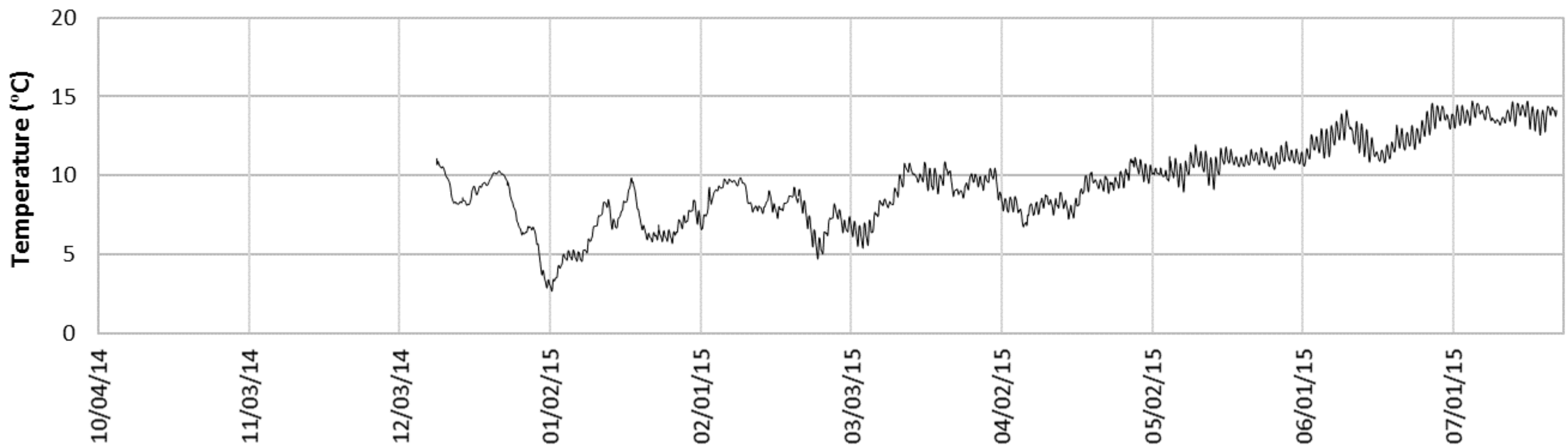

Figure 4-22. Temperature measurements within MSR3 (Dec. 10, 2014 to July 22, 2015).

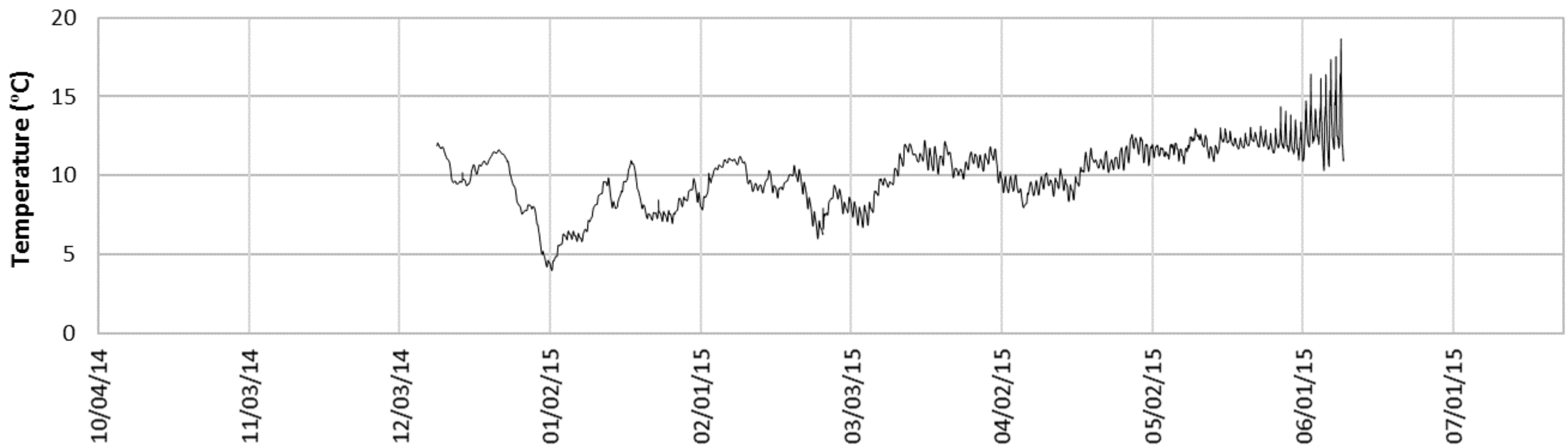

Figure 4-23. Temperature measurements within MSR4 (Zanes Rd.)(Dec. 10, 2014 to June 9, 2015).

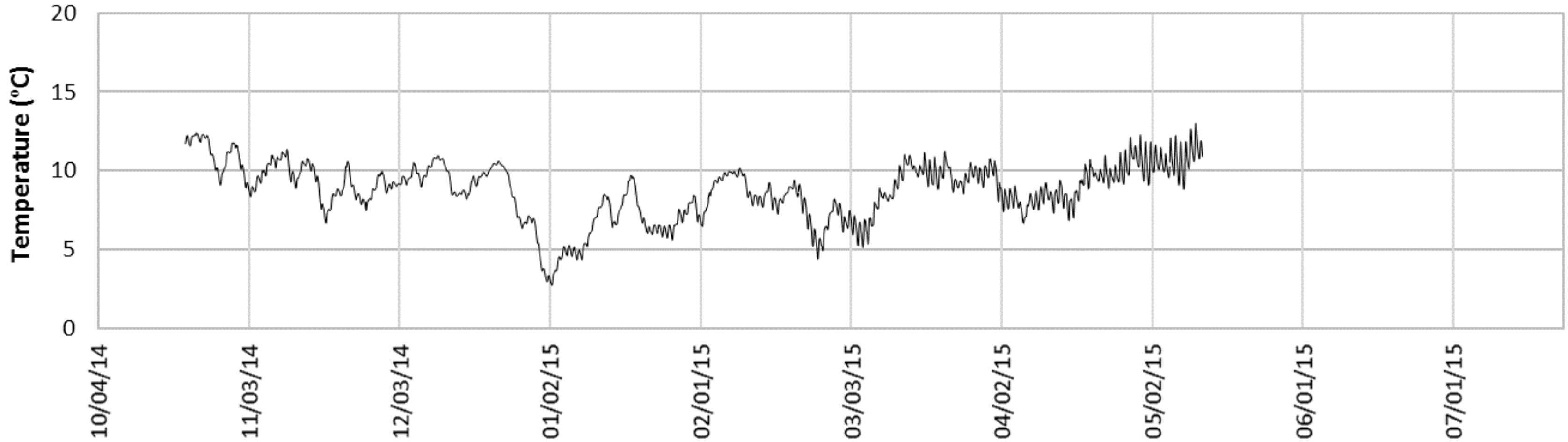

Figure 4-24. Temperature measurements within MSR4 (Elk River Ct.)(Oct. 21, 2014 to May 12, 2015).

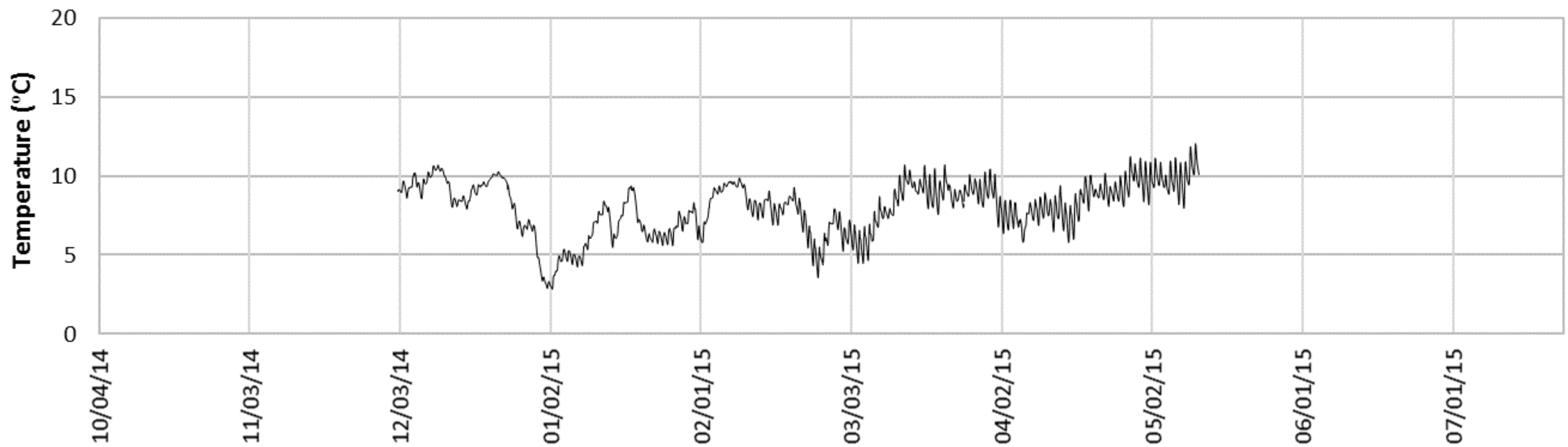

Figure 4-25. Temperature measurements within SFR2 reach (Dec. 2, 2014 to May 11, 2015).

4.3.5 Suspended sediment

Suspended sediment samples were collected to parameterize and calibrate the HST model. Suspended sediment samples are collected by HRC and Salmon Forever as part of their monitoring network in MSR5, NFR1, NFR2, and SFR1. Suspended sediment samples were collected in MSR1, MSR2, MSR3, MSR4, SFR2, and NFR1 by the ERRA team. Samples were not collected in NFR3 and NFR4 due to budget and access constraints. Samples were analyzed for suspended sediment concentration (SSC) and particle size distribution. The size class breaks are 0.032, 0.062, 0.125, 0.25, 0.5, 1, and 2 mm. Samples were collected during high flow events (> 3 m^3/s) that occurred on November 22, 2014, December 11-12, 2014, December 21–24 2014, Feb 7–12, 2015, March 25, 2015 and April 7, 2015. Sampling methods are described in Edwards, T.K., and Glysson, G.D. (1999).

4.3.5.1 Grab samples

Grab samples were collected at sites without a bridge suitable for collection of depth-integrated samples and/or during regularly scheduled maintenance of other equipment at the site. These sites included those within MSR1, MSR2, MSR3, MSR4, and SFR2.

Grab samples were obtained by wading as closely to the thalweg as possible, facing upstream, and plunging the bottle into the water into the water column, targeting a position as close to the center of the water column as possible and avoiding contact with the bed. Flows were often to deep to wade (> 4 feet) and sampling occurred from the bank at a depth of 1-2 feet below the water surface (arm's length). The sample bottle was filled with the opening pointed slightly upward, into the current and until it was ½–¾ full. The date and time was recorded for each sample and the water surface elevation at the site was recorded immediately before and after each sample was collected.

Site conditions such as color and clarity of water, size of particulate visible in waters, recent disturbances (bank erosion/failure, new or modified wood jams), presence or absence of vegetation in the water, and bottom substrate type were recorded.

4.3.5.2 Depth-integrated samples

Depth-integrated (DI) samples were obtained using a DH-48 hand-held depth-integrating sampler with a ¼" nozzle during high flows in MSR2 and MSR 4. Samples were collected at regular intervals (up to 10 verticals) and composited into a single sample. The transit rate was established at the deepest/fastest location and maintained at a constant rate for all verticals in the section. The number of verticals collected at MSR4 was typically limited to 1 vertical due to heavy vehicular traffic. Measurements from the water surface to monumented elevations were typically taken before and after DI sample procurement.

Total suspended sediment concentration results from samples collected between November 2014 and April 2015 are presented in

Table **4-9** through Table 4-17. Suspended sediment concentration results classified by grain size are presented in Table 4-18 through Table 4-27.

Table 4-9. Total suspended sediment concentrations collected in MSR1.

Date/Time (LST)	Reporting limit (mg/L)	Total SSC (mg/L)
12/11/2014 17:08	50.0	1030
12/22/2014 14:37	50.0	150
12/24/2014 8:20	0.5	52
3/25/2015 13:05	0.5	95
4/7/2015 14:06	0.5	378

Table 4-10. Total suspended sediment concentrations collected at two sites in MSR2.

Date/Time (LST)	Site	Reporting limit (mg/L)	Total SSC (mg/L)
12/11/2014 16:16	Site 1	50.0	ND
4/7/2015 14:54	Site 1	0.5	269
11/22/2014 11:20	Site 2	50.0	250
12/12/2014 11:00	Site 2	50.0	134
12/21/2014 15:50	Site 2	50.0	256
12/22/2014 12:50	Site 2	50.0	ND
2/7/2015 16:20	Site 2	0.5	135
2/10/2015 11:46	Site 2	0.5	65.3

Table 4-11. Total suspended sediment concentrations collected at two sites in MSR3.

Date/Time (LST)	Site	Reporting limit (mg/L)	Total SSC (mg/L)
12/11/2014 13:57	Site 1	50.0	150
12/12/2014 13:04	Site 1	50.0	1030
12/24/2014 11:40	Site 1	0.5	69
2/7/2015 15:03	Site 1	0.5	204
3/25/2015 14:45	Site 1	0.5	89
4/7/2015 14:30	Site 1	0.5	389
12/21/2014 11:40	Site 2	50.0	241
12/22/2014 N/A	Site 2	50.0	ND

Table 4-12. Total suspended sediment concentrations collected at three sites in MSR4.

Date/Time (LST)	Site	Reporting limit (mg/L)	Total SSC (mg/L)
12/11/2014 13:33	Site 1	50.0	132
12/21/2014 14:10	Site 1	50.0	348
12/22/2014 13:30	Site 1	50.0	ND
12/24/2014 11:20	Site 1	0.5	106
2/7/2015 12:30	Site 1	0.5	238
3/25/2015 10:39	Site 1	0.5	95
11/22/2014 9:55	Site 2	50.0	258
12/11/2014 13:03	Site 2	50.0	98.8
12/24/2014 12:20	Site 2	0.5	141
3/25/2015 15:21	Site 2	0.5	82
4/7/2015 13:48	Site 2	0.5	345
12/12/2014 13:35	Site 3	50.0	157
12/21/2014 10:20	Site 3	50.0	315
12/21/2014 14:00	Site 3	50.0	354
12/22/2014 11:12	Site 3	50.0	245
2/7/2015 12:45	Site 3	0.5	450
2/10/2015 15:15	Site 3	0.5	88.3
2/12/2015 17:00	Site 3	0.5	58.6

Table 4-13. Total suspended sediment concentrations collected in MSR5.

Date/Time (LST)	Reporting limit (mg/L)	Total SSC (mg/L)
12/11/2014 15:12	50.0	ND
12/21/2014 12:16	50.0	392
12/22/2014 10:56	50.0	199
2/6/2015 12:30	0.5	1863
2/7/2015 9:35	0.5	249
2/7/2015 9:50	0.5	181
2/9/2015 17:29	0.5	367
2/12/2015 17:40	0.5	62.7
4/7/2015 13:30	0.5	643

Table 4-14. Total suspended sediment concentrations collected in NFR1.

Date/Time (LST)	Reporting limit (mg/L)	Total SSC (mg/L)
12/11/2014 13:10	50.0	187
12/22/2014 9:45	50.0	381
2/6/2015 10:05	0.5	730
2/12/2015 16:34	0.5	37.3
4/7/2015 13:20	0.5	263

Table 4-15. Total suspended sediment concentrations collected in NFR2.

Date/Time (LST)	Reporting limit (mg/L)	Total SSC (mg/L)
12/11/2014 12:30	50.0	138
2/7/2015 10:05	0.5	269
2/7/2015 13:18	0.5	260

Table 4-16. Total suspended sediment concentrations collected at three sites in SFR1.

Date/Time (LST)	Site	Reporting limit (mg/L)	Total SSC (mg/L)
12/11/2014 14:18	Site 1	50.0	ND
2/7/2015 11:20	Site 1	0.5	462
12/11/2014 11:12	Site 2	50.0	202
12/21/2014 13:30	Site 2	50.0	564
12/21/2014 20:30	Site 2	50.0	487
12/22/2014 8:30	Site 2	50.0	129
2/6/2015 10:03	Site 2	0.5	907
2/6/2015 12:00	Site 2	0.5	1175
2/6/2015 13:19	Site 2	0.5	1514
2/6/2015 18:30	Site 2	0.5	558
2/6/2015 21:46	Site 2	0.5	607
2/7/2015 12:02	Site 2	0.5	498
2/9/2015 12:20	Site 2	0.5	280
2/9/2015 16:55	Site 2	0.5	262
2/12/2015 14:10	Site 2	0.5	55.2
4/7/2015 13:00	Site 3	0.5	563

Table 4-17. Total suspended sediment concentrations collected at two sites in SFR2.

Date/Time (LST)	Site	Reporting limit (mg/L)	Total SSC (mg/L)
12/11/2014 12:08	Site 1	50.0	ND
12/21/2014 12:20	Site 1	50.0	586
12/22/2014 11:54	Site 1	50.0	ND
2/7/2015 8:25	Site 1	0.5	467
11/22/2014 7:48	Site 2	50.0	50.0

Table 4-18. Classified suspended sediment concentrations collected in MSR1.

Sample ID	1010	1097	1067	1210	1217
# Bottles	1	1	1	1	1
Sample Date	12/11/2014	12/22/2014	12/24/2014	3/25/2015	4/7/2015
Sample Time	17:08	14:37	8:20	13:05	14:06
Tot. Sample Wt.	NA	NA	NA	NA	NA
Tot. Sediment Wt.	NA	NA	NA	NA	NA
<0.032mm Fine (mg/L)	NA	NA	NA	NA	NA
>0.032mm Fine (mg/L)	NA	NA	NA	NA	NA
>0.062mm Sand (mg/L)	NA	NA	NA	NA	NA
>0.125mm Sand (mg/L)	NA	NA	NA	NA	NA
>0.25mm Sand (mg/L)	NA	NA	NA	NA	NA
>0.5mm Coarse (mg/L)	NA	NA	NA	NA	NA
>1.0mm Coarse (mg/L)	NA	NA	NA	NA	NA
>2.0mm Coarse (mg/L)	NA	NA	NA	NA	NA
Total SSC (mg/L)	1030	150	52	95	378
Reporting Limit (mg/L)	50.0	50.0	0.5	0.5	0.5
<0.032mm % Finer	NA	NA	NA	NA	NA
<0.062mm % Finer	NA	NA	NA	NA	NA
<0.125mm % Finer	NA	NA	NA	NA	NA
<0.25mm % Finer	NA	NA	NA	NA	NA
<0.5mm % Finer	NA	NA	NA	NA	NA
<1.0mm % Finer	NA	NA	NA	NA	NA
<2.0mm % Finer	NA	NA	NA	NA	NA

Table 4-19. Classified suspended sediment concentrations collected at two sites in MSR2.

Sample ID	1013	1219	1034	1000	1054–1059	1098–1105	1113–1121	1152–1158
# Bottles	1	1	1	1	6	8	9	7
Sample Date	12/11/2014	4/7/2015	11/22/2014	12/12/2014	12/21/2014	12/22/2014	2/7/2015	2/10/2015
Sample Time	16:16	14:54	11:20	11:00	~15:50	12:50	16:20	11:46
Site	Site 1	Site 1	Site 2	Site 2	Site 2	Site 2	Site 2	Site 2
Tot. Sample Wt.	NA	NA	NA	NA	NA	NA	2558.15	2488.54
Tot. Sediment Wt.	NA	NA	NA	NA	NA	NA	0.3456	0.1625
<0.032mm Fine (mg/L)	NA	NA	NA	NA	NA	NA	114	54.4
>0.032mm Fine (mg/L)	NA	NA	NA	NA	NA	NA	11.3	8.04
>0.062mm Sand (mg/L)	NA	NA	NA	NA	NA	NA	3.67	2
>0.125mm Sand (mg/L)	NA	NA	NA	NA	NA	NA	3.64	0.64
>0.25mm Sand (mg/L)	NA	NA	NA	NA	NA	NA	1.8	0.2
>0.5mm Coarse (mg/L)	NA	NA	NA	NA	NA	NA	0.63	0
>1.0mm Coarse (mg/L)	NA	NA	NA	NA	NA	NA	0	0
>2.0mm Coarse (mg/L)	NA	NA	NA	NA	NA	NA	0	0
Total SSC (mg/L)	ND	269	250	134	256	ND	135	65.3
Reporting Limit (mg/L)	50.0	0.5	50.0	50.0	50.0	50.0	0.5	0.5
<0.032mm % Finer	NA	NA	NA	NA	NA	NA	84.41	83.34
<0.062mm % Finer	NA	NA	NA	NA	NA	NA	92.79	95.65
<0.125mm % Finer	NA	NA	NA	NA	NA	NA	95.50	98.71
<0.25mm % Finer	NA	NA	NA	NA	NA	NA	98.20	99.69
<0.5mm % Finer	NA	NA	NA	NA	NA	NA	99.53	100.00
<1.0mm % Finer	NA	NA	NA	NA	NA	NA	100.00	100.00
<2.0mm % Finer	NA	NA	NA	NA	NA	NA	100.00	100.00

Table 4-20. Classified suspended sediment concentrations collected at two sites in MSR3.

Sample ID	1011	1001	1066	1112	1211	1218	1035	1096
# Bottles	1	1	1	1	1	1	1	1
Sample Date	12/11/2014	12/12/2014	12/24/2014	2/7/2015	3/25/2015	4/7/2015	12/21/2014	12/22/2014
Sample Time	13:57	13:04	11:40	15:03	14:45	14:30	11:40	UNK
Site	Site 1	Site 1	Site 1	Site 1	Site 1	Site 1	Site 2	Site 2
Tot. Sample Wt.	NA	NA	NA	322.46	NA	NA	NA	NA
Tot. Sediment Wt.	NA	NA	NA	0.0657	NA	NA	NA	NA
<0.032mm Fine (mg/L)	NA	NA	NA	179	NA	NA	NA	NA
>0.032mm Fine (mg/L)	NA	NA	NA	20.2	NA	NA	NA	NA
>0.062mm Sand (mg/L)	NA	NA	NA	4.03	NA	NA	NA	NA
>0.125mm Sand (mg/L)	NA	NA	NA	0.62	NA	NA	NA	NA
>0.25mm Sand (mg/L)	NA	NA	NA	0	NA	NA	NA	NA
>0.5mm Coarse (mg/L)	NA	NA	NA	0	NA	NA	NA	NA
>1.0mm Coarse (mg/L)	NA	NA	NA	0	NA	NA	NA	NA
>2.0mm Coarse (mg/L)	NA	NA	NA	0	NA	NA	NA	NA
Total SSC (mg/L)	150	1030	69	204	89	389	241	ND
Reporting Limit (mg/L)	50.0	50.0	0.5	0.5	0.5	0.5	50.0	50.0
<0.032mm % Finer	NA	NA	NA	87.82	NA	NA	NA	NA
<0.062mm % Finer	NA	NA	NA	97.72	NA	NA	NA	NA
<0.125mm % Finer	NA	NA	NA	99.70	NA	NA	NA	NA
<0.25mm % Finer	NA	NA	NA	100.00	NA	NA	NA	NA
<0.5mm % Finer	NA	NA	NA	100.00	NA	NA	NA	NA
<1.0mm % Finer	NA	NA	NA	100.00	NA	NA	NA	NA
<2.0mm % Finer	NA	NA	NA	100.00	NA	NA	NA	NA

Table 4-21. Classified suspended sediment concentrations collected at Sites 1 and 2 in MSR4.

Sample ID	1015	1093	1094	1069	1111	1208	1029	1012	1068	1212	1216
# Bottles	1	1	1	1	1	1	1	1	1	1	1
Sample Date	12/11/2014	12/21/2014	12/22/2014	12/24/2014	2/7/2015	3/25/2015	11/22/2014	12/11/2014	12/24/2014	3/25/2015	4/7/2015
Sample Time	13:33	14:10	13:30	11:20	12:30	10:39	9:55	13:03	12:20	15:21	13:48
Site	Site 1	Site 1	Site 1	Site 1	Site 1	Site 1	Site 2	Site 2	Site 2	Site 2	Site 2
Tot. Sample Wt.	NA	NA	NA	NA	434.44	NA	NA	NA	NA	NA	NA
Tot. Sediment Wt.	NA	NA	NA	NA	0.1036	NA	NA	NA	NA	NA	NA
<0.032mm Fine (mg/L)	NA	NA	NA	NA	199	NA	NA	NA	NA	NA	NA
>0.032mm Fine (mg/L)	NA	NA	NA	NA	27.6	NA	NA	NA	NA	NA	NA
>0.062mm Sand (mg/L)	NA	NA	NA	NA	9.2	NA	NA	NA	NA	NA	NA
>0.125mm Sand (mg/L)	NA	NA	NA	NA	2.76	NA	NA	NA	NA	NA	NA
>0.25mm Sand (mg/L)	NA	NA	NA	NA	0	NA	NA	NA	NA	NA	NA
>0.5mm Coarse (mg/L)	NA	NA	NA	NA	0	NA	NA	NA	NA	NA	NA
>1.0mm Coarse (mg/L)	NA	NA	NA	NA	0	NA	NA	NA	NA	NA	NA
>2.0mm Coarse (mg/L)	NA	NA	NA	NA	0	NA	NA	NA	NA	NA	NA
Total SSC (mg/L)	132	348	ND	106	238	95	258	98.8	141	82	345
Reporting Limit (mg/L)	50.0	50.0	50.0	0.5	0.5	0.5	50.0	50.0	0.5	0.5	0.5
<0.032mm % Finer	NA	NA	NA	NA	83.38	NA	NA	NA	NA	NA	NA
<0.062mm % Finer	NA	NA	NA	NA	94.97	NA	NA	NA	NA	NA	NA
<0.125mm % Finer	NA	NA	NA	NA	98.84	NA	NA	NA	NA	NA	NA
<0.25mm % Finer	NA	NA	NA	NA	100.00	NA	NA	NA	NA	NA	NA
<0.5mm % Finer	NA	NA	NA	NA	100.00	NA	NA	NA	NA	NA	NA
<1.0mm % Finer	NA	NA	NA	NA	100.00	NA	NA	NA	NA	NA	NA
<2.0mm % Finer	NA	NA	NA	NA	100.00	NA	NA	NA	NA	NA	NA

Table 4-22. Classified suspended sediment concentrations collected at Site 3 in MSR4.

Sample ID	1002	1036	1060–1064	1070–1074	1127–1134	1146–1151	1202–1203
# Bottles	1	1	5	5	8	6	2
Sample Date	12/12/2014	12/21/2014	12/21/2014	12/22/2014	2/7/2015	2/10/2015	2/12/2015
Sample Time	13:35	10:20	~14:00	11:12	12:45	15:15	17:00
Site	Site 3	Site 3	Site 3	Site 3	Site 3	Site 3	Site 3
Tot. Sample Wt.	NA	NA	NA	NA	4864.75	3490.02	1246.79
Tot. Sediment Wt.	NA	NA	NA	NA	2.1881	0.3083	0.0731
<0.032mm Fine (mg/L)	NA	NA	NA	NA	179	50.8	38.2
>0.032mm Fine (mg/L)	NA	NA	NA	NA	45.8	25.5	13.8
>0.062mm Sand (mg/L)	NA	NA	NA	NA	216	7.68	4.89
>0.125mm Sand (mg/L)	NA	NA	NA	NA	5.9	2.61	1.68
>0.25mm Sand (mg/L)	NA	NA	NA	NA	2.57	0.95	0.08
>0.5mm Coarse (mg/L)	NA	NA	NA	NA	0	0.75	0
>1.0mm Coarse (mg/L)	NA	NA	NA	NA	0	0	0
>2.0mm Coarse (mg/L)	NA	NA	NA	NA	0	0	0
Total SSC (mg/L)	157	315	354	245	450	88.3	58.6
Reporting Limit (mg/L)	50.0	50.0	50.0	50.0	0.5	0.5	0.5
<0.032mm % Finer	NA	NA	NA	NA	39.94	57.54	65.10
<0.062mm % Finer	NA	NA	NA	NA	50.12	86.42	88.65
<0.125mm % Finer	NA	NA	NA	NA	98.12	95.12	97.00
<0.25mm % Finer	NA	NA	NA	NA	99.43	98.07	99.86
<0.5mm % Finer	NA	NA	NA	NA	100.00	99.15	100.00
<1.0mm % Finer	NA	NA	NA	NA	100.00	100.00	100.00
<2.0mm % Finer	NA	NA	NA	NA	100.00	100.00	100.00

Table 4-23. Classified suspended sediment concentrations collected in MSR5.

Sample ID	1091	1048–1053	1037–1041	1159–1166	1135	1122–1126	1195–1200	1201	1215
# Bottles	1	6	5	8	1	5	6	1	1
Sample Date	12/11/2014	12/21/2014	12/22/2014	2/6/2015	2/7/2015	2/7/2015	2/9/2015	2/12/2015	4/7/2015
Sample Time	15:12	12:16	10:56	12:30	9:35	9:50	17:29	17:40	13:30
Tot. Sample Wt.	NA	NA	NA	5468.48	NA	3273.69	3680.57	898.31	NA
Tot. Sediment Wt.	NA	NA	NA	10.1899	NA	0.594	1.3492	0.0563	NA
<0.032mm Fine (mg/L)	NA	NA	NA	1528	NA	101	81.2	30.7	NA
>0.032mm Fine (mg/L)	NA	NA	NA	236	NA	55.4	105	15.7	NA
>0.062mm Sand (mg/L)	NA	NA	NA	52.7	NA	15.4	89.6	10.6	NA
>0.125mm Sand (mg/L)	NA	NA	NA	28.2	NA	6.54	72.2	5.68	NA
>0.25mm Sand (mg/L)	NA	NA	NA	14.7	NA	2.47	18.2	0	NA
>0.5mm Coarse (mg/L)	NA	NA	NA	3.58	NA	0.61	0	0	NA
>1.0mm Coarse (mg/L)	NA	NA	NA	0	NA	0	0	0	NA
>2.0mm Coarse (mg/L)	NA	NA	NA	0	NA	0	0	0	NA
Total SSC (mg/L)	ND	392	199	1863	249	181	367	62.7	643
Reporting Limit (mg/L)	50.0	50.0	50.0	0.5	0.5	0.5	0.5	0.5	0.5
<0.032mm % Finer	NA	NA	NA	82.01	NA	55.57	22.34	49.00	NA
<0.062mm % Finer	NA	NA	NA	94.68	NA	86.18	50.95	74.04	NA
<0.125mm % Finer	NA	NA	NA	97.51	NA	94.69	75.37	90.94	NA
<0.25mm % Finer	NA	NA	NA	99.02	NA	98.30	95.04	100.00	NA
<0.5mm % Finer	NA	NA	NA	99.81	NA	99.66	100.00	100.00	NA
<1.0mm % Finer	NA	NA	NA	100.00	NA	100.00	100.00	100.00	NA
<2.0mm % Finer	NA	NA	NA	100.00	NA	100.00	100.00	100.00	NA

Table 4-24. Classified suspended sediment concentrations collected in NFR1.

Sample ID	1016–1022	1045–1047	1177–1186	1204	1214
# Bottles	7	3	10	1	1
Sample Date	12/11/2014	12/22/2014	2/6/2015	2/12/2015	4/7/2015
Sample Time	~13:00-13:20	9:45	10:05	16:34	13:20
Tot. Sample Wt.	NA	NA	4126.78	787.98	NA
Tot. Sediment Wt.	NA	NA	3.0105	0.0294	NA
<0.032mm Fine (mg/L)	NA	NA	557	23.1	NA
>0.032mm Fine (mg/L)	NA	NA	118	8.25	NA
>0.062mm Sand (mg/L)	NA	NA	40	4.7	NA
>0.125mm Sand (mg/L)	NA	NA	11.3	1.78	NA
>0.25mm Sand (mg/L)	NA	NA	2.52	0	NA
>0.5mm Coarse (mg/L)	NA	NA	1.07	0	NA
>1.0mm Coarse (mg/L)	NA	NA	0	0	NA
>2.0mm Coarse (mg/L)	NA	NA	0	0	NA
Total SSC (mg/L)	187	381	730	37.3	263
Reporting Limit (mg/L)	50.0	50.0	0.5	0.5	0.5
<0.032mm % Finer	NA	NA	76.32	60.51	NA
<0.062mm % Finer	NA	NA	92.48	82.63	NA
<0.125mm % Finer	NA	NA	97.96	95.23	NA
<0.25mm % Finer	NA	NA	99.51	100.00	NA
<0.5mm % Finer	NA	NA	99.85	100.00	NA
<1.0mm % Finer	NA	NA	100.00	100.00	NA
<2.0mm % Finer	NA	NA	100.00	100.00	NA

Table 4-25. Classified suspended sediment concentrations collected in NFR2.

Sample ID	1089	1136	1138
# Bottles	1	1	1
Sample Date	12/11/2014	2/7/2015	2/7/2015
Sample Time	12:30	10:05	13:18
Tot. Sample Wt.	NA	712.54	593.84
Tot. Sediment Wt.	NA	0.1915	0.1546
<0.032mm Fine (mg/L)	NA	207	186
>0.032mm Fine (mg/L)	NA	40.3	44.5
>0.062mm Sand (mg/L)	NA	15.9	19.7
>0.125mm Sand (mg/L)	NA	4.07	4.72
>0.25mm Sand (mg/L)	NA	1.54	2.36
>0.5mm Coarse (mg/L)	NA	0	3.54
>1.0mm Coarse (mg/L)	NA	0	0
>2.0mm Coarse (mg/L)	NA	0	0
Total SSC (mg/L)	138	269	260
Reporting Limit (mg/L)	50.0	0.5	0.5
<0.032mm % Finer	NA	77.02	71.22
<0.062mm % Finer	NA	92.00	88.34
<0.125mm % Finer	NA	97.91	95.92
<0.25mm % Finer	NA	99.43	97.73
<0.5mm % Finer	NA	100.00	98.64
<1.0mm % Finer	NA	100.00	100.00
<2.0mm % Finer	NA	100.00	100.00

Table 4-26. Classified suspended sediment concentrations collected at three sites in SFR1.

Sample ID	1090	1137	1023-1028	1084-1085	1080-1083	1042-1044	1140	1139	1141	1167–1171	1172–1176	1187–1189	1190–1192	1193–1194	1205	1213
# Bottles	1	1	6		6	3	1	1	1	5	5	3	3	2	1	1
Sample Date	12/11/2014	2/7/2015	12/11/2014	12/21/2014	12/21/2014	12/22/2014	2/6/2015	2/6/2015	2/6/2015	2/6/2015	2/6/2015	2/7/2015	2/9/2015	2/9/2015	2/12/2015	4/7/2015
Sample Time	14:18	11:20	11:00 -11:24	13:30	20:30	8:30	10:03	12:00	13:19	18:30	21:46	12:02	12:20	16:55	14:10	13:00
Site	Site 1	Site 1	Site 2	Site 2	Site 2	Site 2	Site 2	Site 2	Site 2	Site 2	Site 2	Site 2	Site 2	Site 2	Site 2	Site 3
Tot. Sample Wt.	NA	689.36	NA	NA	NA	NA	769.37	787.2	701.12	3790.63	3435.48	2104.71	2089.42	1736.26	597.32	NA
Tot. Sediment Wt.	NA	0.3187	NA	NA	NA	NA	0.6975	0.925	1.0612	2.1139	2.0838	1.0473	0.5849	0.4549	0.033	NA
<0.032mm Fine (mg/L)	NA	303	NA	NA	NA	NA	609	775	1268	338	357	269	83	178	26.5	NA
>0.032mm Fine (mg/L)	NA	105	NA	NA	NA	NA	208	272	182	161	164	142	103	59.2	11.9	NA
>0.062mm Sand (mg/L)	NA	42.6	NA	NA	NA	NA	70.4	83.8	43.5	42.9	61.4	63.1	61.2	19.8	6.53	NA
>0.125mm Sand (mg/L)	NA	9.28	NA	NA	NA	NA	14.4	35.6	16.4	11.6	17.8	19.2	24.1	3.63	7.87	NA
>0.25mm Sand (mg/L)	NA	2.61	NA	NA	NA	NA	4.03	9.15	3.42	3.77	6.03	4.99	7.04	1.04	2.51	NA
>0.5mm Coarse (mg/L)	NA	0	NA	NA	NA	NA	0	0	0	0	0	0	1.87	0	0	NA
>1.0mm Coarse (mg/L)	NA	0	NA	NA	NA	NA	0	0	0	0	0	0	0	0	0	NA
>2.0mm Coarse (mg/L)	NA	0	NA	NA	NA	NA	0	0	0	0	0	0	0	0	0	NA
Total SSC (mg/L)	ND	462	202	564	487	129	907	1175	1514	558	607	498	280	262	55.2	563
Reporting Limit (mg/L)	50.0	0.5	50.0	50.0	50.0	50.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
<0.032mm % Finer	NA	65.48	NA	NA	NA	NA	67.27	65.91	83.80	60.70	58.94	53.96	29.57	68.06	47.81	NA
<0.062mm % Finer	NA	88.21	NA	NA	NA	NA	90.21	89.06	95.82	89.56	85.96	82.47	66.35	90.66	69.37	NA
<0.125mm % Finer	NA	97.43	NA	NA	NA	NA	97.97	96.19	98.69	97.25	96.07	95.14	88.21	98.22	81.20	NA
<0.25mm % Finer	NA	99.44	NA	NA	NA	NA	99.56	99.22	99.77	99.32	99.01	99.00	96.82	99.60	95.45	NA
<0.5mm % Finer	NA	100.00	NA	NA	NA	NA	100.00	100.00	100.00	100.00	100.00	100.00	99.33	100.00	100.00	NA
<1.0mm % Finer	NA	100.00	NA	NA	NA	NA	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	NA
<2.0mm % Finer	NA	100.00	NA	NA	NA	NA	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	NA

Table 4-27. Classified suspended sediment concentrations collected at two sites in SFR2.

Sample ID	1014	1092	1095	1110	1031
# Bottles	1	1	1	1	1
Sample Date	12/11/2014	12/21/2014	12/22/2014	2/7/2015	11/22/2014
Sample Time	12:08	12:20	11:54	8:25	7:48
Site	Site 1	Site 1	Site 1	Site 1	Site 2
Tot. Sample Wt.	NA	NA	NA	466.86	NA
Tot. Sediment Wt.	NA	NA	NA	0.2179	NA
<0.032mm Fine (mg/L)	NA	NA	NA	300	NA
>0.032mm Fine (mg/L)	NA	NA	NA	94	NA
>0.062mm Sand (mg/L)	NA	NA	NA	43.9	NA
>0.125mm Sand (mg/L)	NA	NA	NA	21	NA
>0.25mm Sand (mg/L)	NA	NA	NA	6	NA
>0.5mm Coarse (mg/L)	NA	NA	NA	2.14	NA
>1.0mm Coarse (mg/L)	NA	NA	NA	0	NA
>2.0mm Coarse (mg/L)	NA	NA	NA	0	NA
Total SSC (mg/L)	ND	586	ND	467	50
Reporting Limit (mg/L)	50.0	50.0	50.0	0.5	50.0
<0.032mm % Finer	NA	NA	NA	64.23	NA
<0.062mm % Finer	NA	NA	NA	84.36	NA
<0.125mm % Finer	NA	NA	NA	93.76	NA
<0.25mm % Finer	NA	NA	NA	98.26	NA
<0.5mm % Finer	NA	NA	NA	99.54	NA
<1.0mm % Finer	NA	NA	NA	100.00	NA
<2.0mm % Finer	NA	NA	NA	100.00	NA

4.4 Bed, Bank and Floodplain Material

Bed, bank and floodplain material in the Elk River Project area were characterization by (1) mapping bed surface textures (i.e., facies) at the Project scale and within intensive study sites; and (2) bulk sampling bed, bank, and floodplain material within intensive study sites. Facies and bulk sampling data describing bed material within intensive study site were used to calculate area-weighted bed material grain size distributions for geomorphic reaches. This process supported development of a conceptual model of hydrogeomorphic processes within the Project area, as well as parameterization (e.g., sediment grains size distribution and classes, effective diameter, porosity, and bulk density) of the HST model.

4.4.1 Bed surface texture

Information about channel bed surface texture (i.e., facies) in the mainstem Elk River, North Fork, and South Fork was collected at a coarse resolution throughout the Project length during the longitudinal profile survey and at finer spatial resolution within intensive study sites.

4.4.1.1 Bed texture data associated with the longitudinal profile survey.

Ancillary data collection during the longitudinal profile survey of the Project channel length included visually identifying bed surface textural facies in the vicinity of each thalweg survey point. The dominant facies over a several square-meter area surrounding the survey point was identified as cobble, gravel, sand, or silt. Notes also described any sediment facies that was substantially different than identified at the thalweg point and was greater than 1 channel width in length. Point spacing during the survey was approximately 1 to 2 bankfull channel widths apart. Figure 4-26 illustrates the longitudinal pattern in bed surface texture as characterized during the longitudinal profile survey. More detailed information about bed surface texture was collected within intensive study sites.

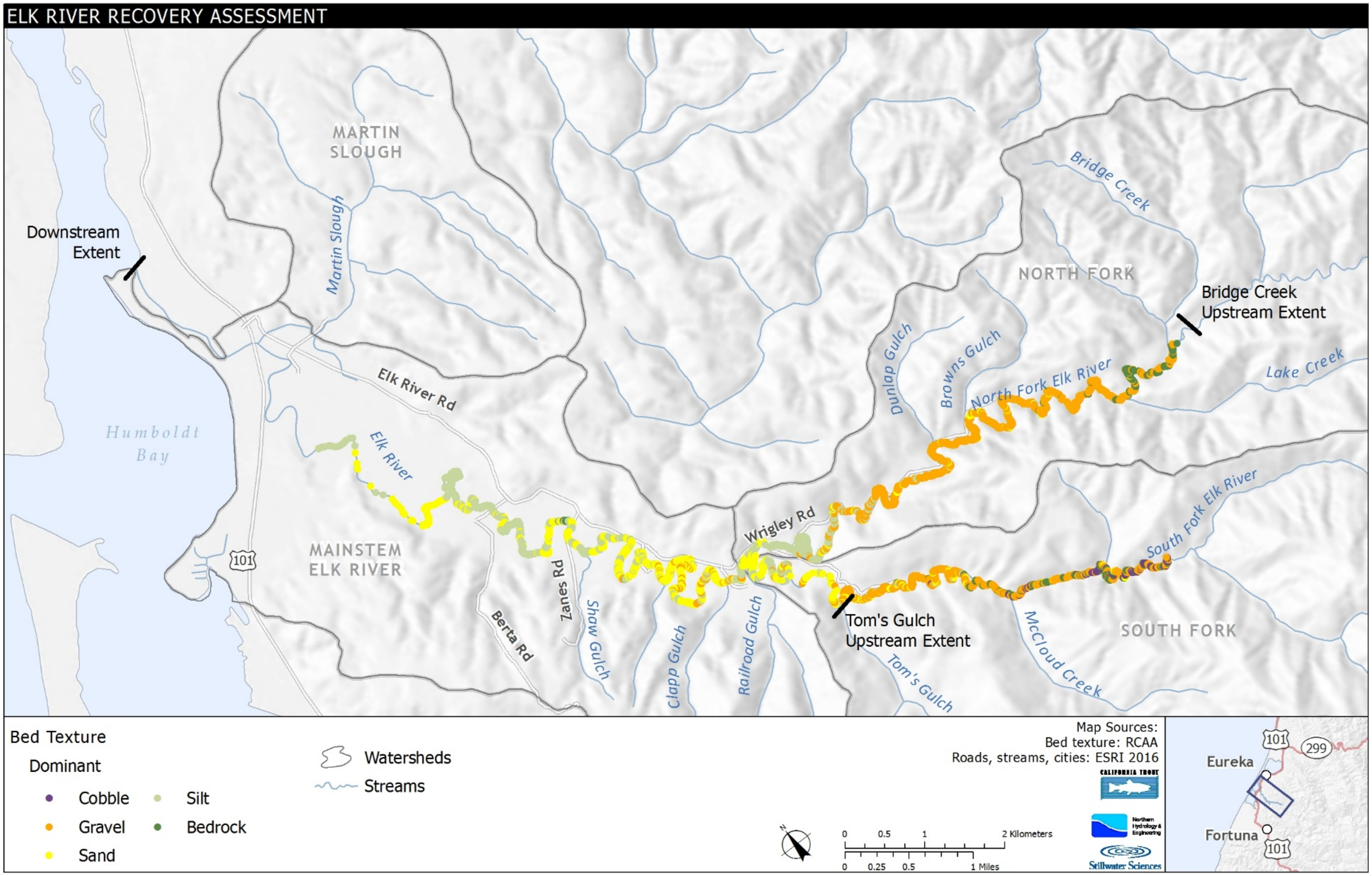

Figure 4-26. Bed surface texture points collected during the longitudinal profile survey.

4.4.1.2 Facies mapping within intensive study sites

At each intensive study site, polygons representing bed surface sedimentary facies within the approximate bank toe elevations were mapped onto field tiles at a scale of 1:480 (1 inch [in] = 40 ft). The minimum mapping area for a facies polygon was approximately 2 square meters (m^2; 22 square feet [ft^2]). Base information on map tiles included 2-foot contours from the LiDAR DTM, top-of-bank and toe lines, survey monuments and surveyed cross sections, and points defining the thalweg riffle crests and maximum pool depths surveyed during the longitudinal profile survey. Attachment A includes sample data sheets used to collection information about bed surface sedimentary facies and geomorphic feature types, as well as related information about bank materials and vegetation.

Facies mapping followed conventions modified from Buffington and Montgomery (1999). The length of a particle's b-axis was used to delineate facies into the following five classes: sand (Sa), less than 2 millimeters (mm); gravel (Gr), 2–64 mm; cobble (Co), 64–256 mm; and boulder (Bo), greater than 256 mm. Each sediment facies was assigned a substrate designation consisting of the dominant and subdominant particle size classes. Subdominant designations were applied when a facies texture occupied at least 5% of the channel bed. For each sediment facies, the median particle size (D_{50}), the D_{84} (that particle size at which 84% of the grain size distribution is finer), and the D_{16} (that particle size at which 16% of the grain size distribution is finer) were estimated. Facies mapping was calibrated with particle measurements, as needed.

Facies polygons were broadly classified into geomorphic feature types that included mid-channel bar, lateral bar, point bar, channel bed, side-channel bed, tributary delta, floodplain, terrace, and colluvium. The activity level (or relative residence time) was described for each geomorphic feature. Activity level relates to multiple factors including height above the thalweg, degree of vegetative cover, and particle characteristics (e.g., roundness, brightness, and sorting). In general, residence time decreases as activity level increases. Information was also collected regarding the relative influence of large wood and other roughness elements on facies types and geomorphic features.

Table 4-28 summarizes the facies areas mapped in each intensive study site. Figure 4-27 through Figure 4-36 illustrate facies polygons and bulk sediment sample locations within intensive study sites. Figure 4-37 illustrates how facies mapped within intensive study sites changes longitudinally within the Project area. Attachment A includes sample data sheets used to collection information about bed surface sedimentary facies and geomorphic feature types.

Table 4-28. Summary of facies areas mapped within intensive study sites.

Facies	Facies Area by Study Site, ft^2										
	MSR 3-1	MSR 4-1	MSR 5-2	NFR 1-1	NFR 2-1	NFR 3-1	NFR 3-2	NFR 4-1	SFR 1-1	SFR 2-1	Total
BR								12,455			12,455
Co								872			872
CoGr								21,134			21,134
GrCo						195		23,316		244	23,755
Gr						13,589	62,318	34,597		2,409	112,914
GrSa			4,601	1,455	22,921	24,110	23,299	12,719		10,043	99,148
SaGr		1,644	17,537	517	10,659	3,087	3,576	1,152	318	5,405	43,894
Sa		35,138	30,638	11,524	10,865	6,316	3,755	13,274	16,363	10,233	138,107
SaSi	35,676	24,058		27,461	1,213	1,359	4,146		11,462		105,375
Si						144					144
Total	**35,676**	**60,839**	**52,776**	**40,958**	**45,658**	**48,799**	**97,094**	**119,519**	**28,143**	**28,334**	**557,797**

Figure 4-27. Facies mapping at intensive study site MSR3-1.

Figure 4-28. Facies mapping at intensive study site MSR4-1.

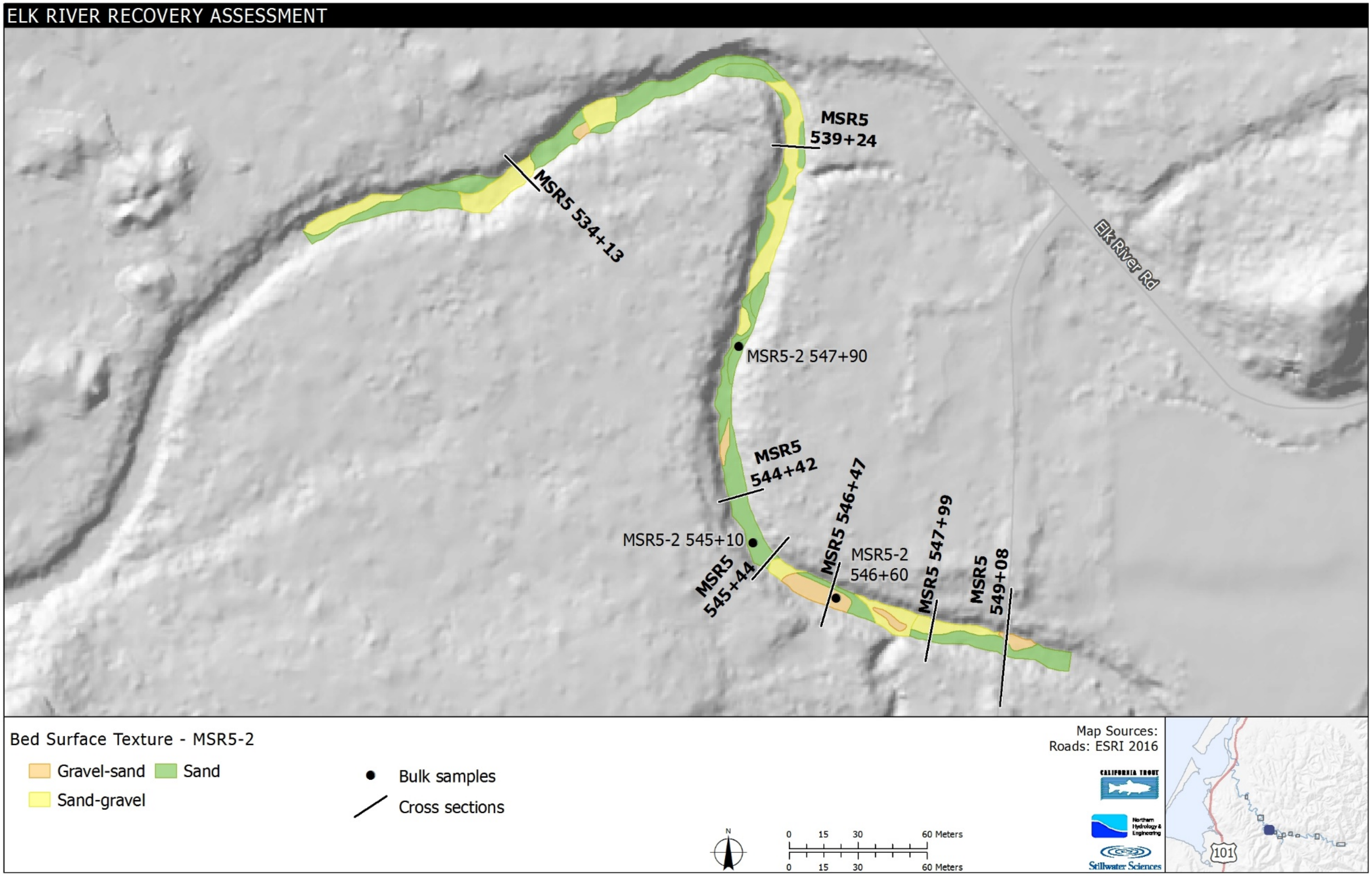

Figure 4-29. Facies mapping at intensive study site MSR5-2.

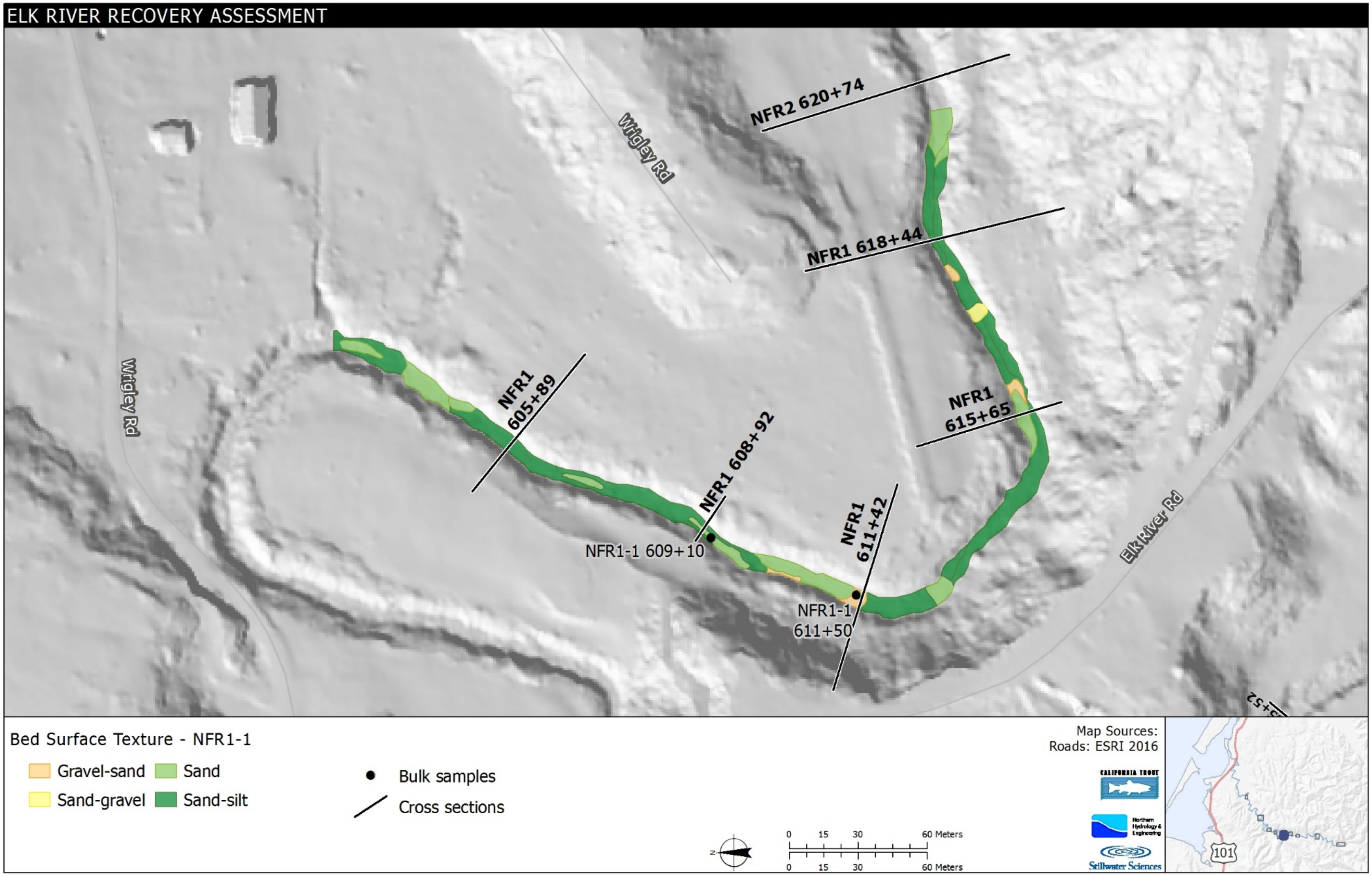

Figure 4-30. Facies mapping at intensive study site NFR1-1.

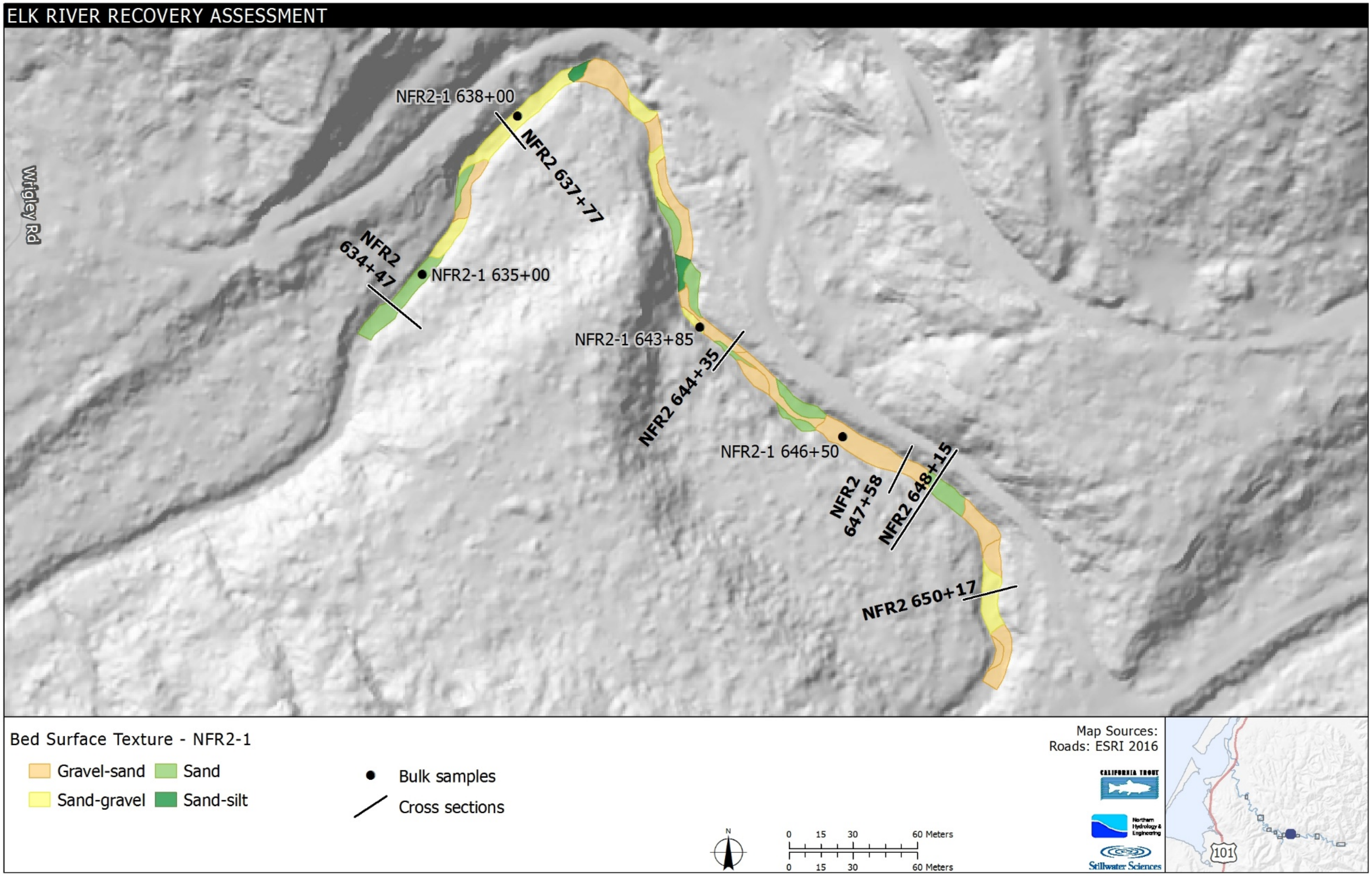

Figure 4-31. Facies mapping at intensive study site NFR2-1.

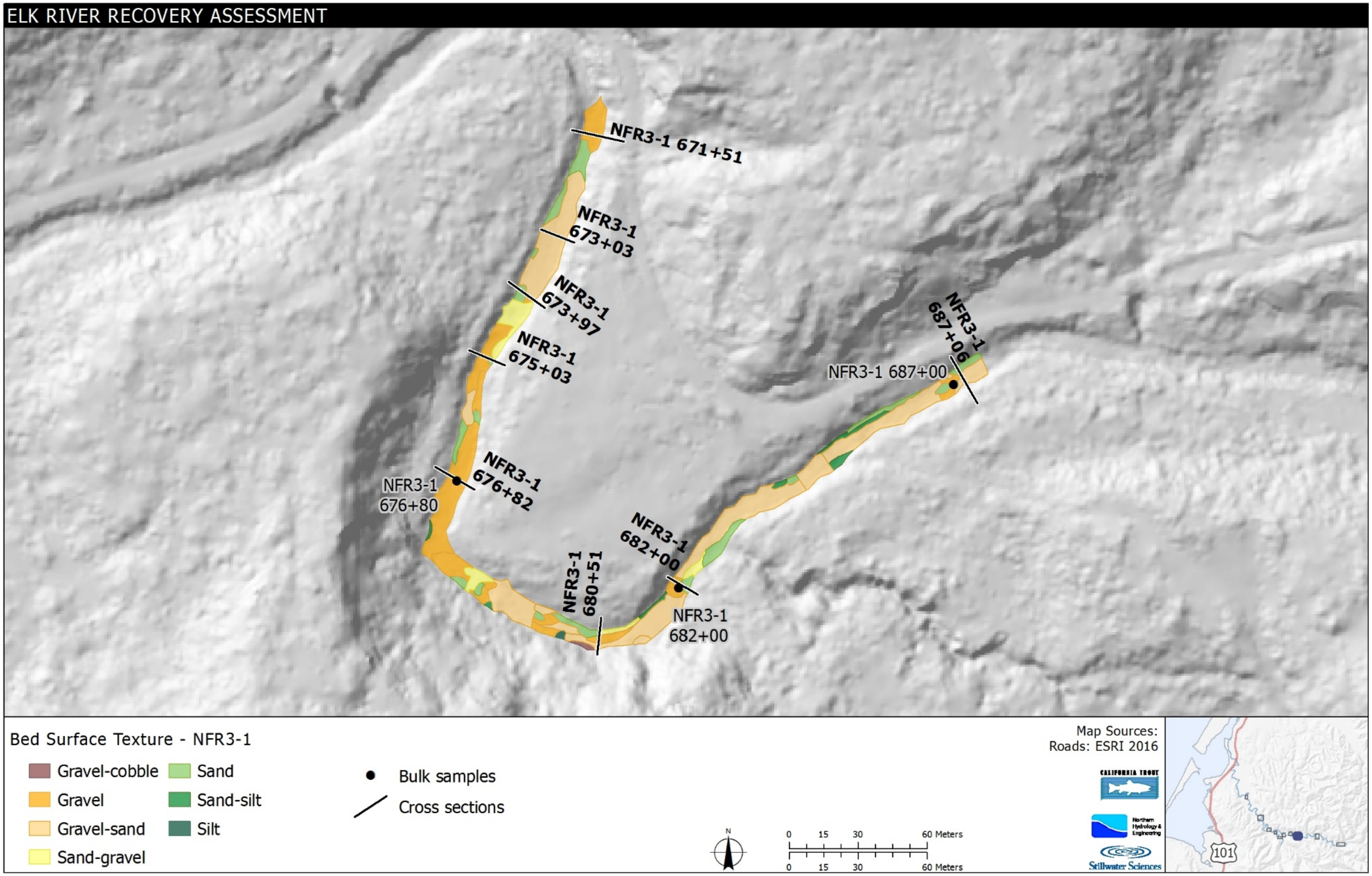

Figure 4-32. Facies mapping at intensive study site NFR3-1.

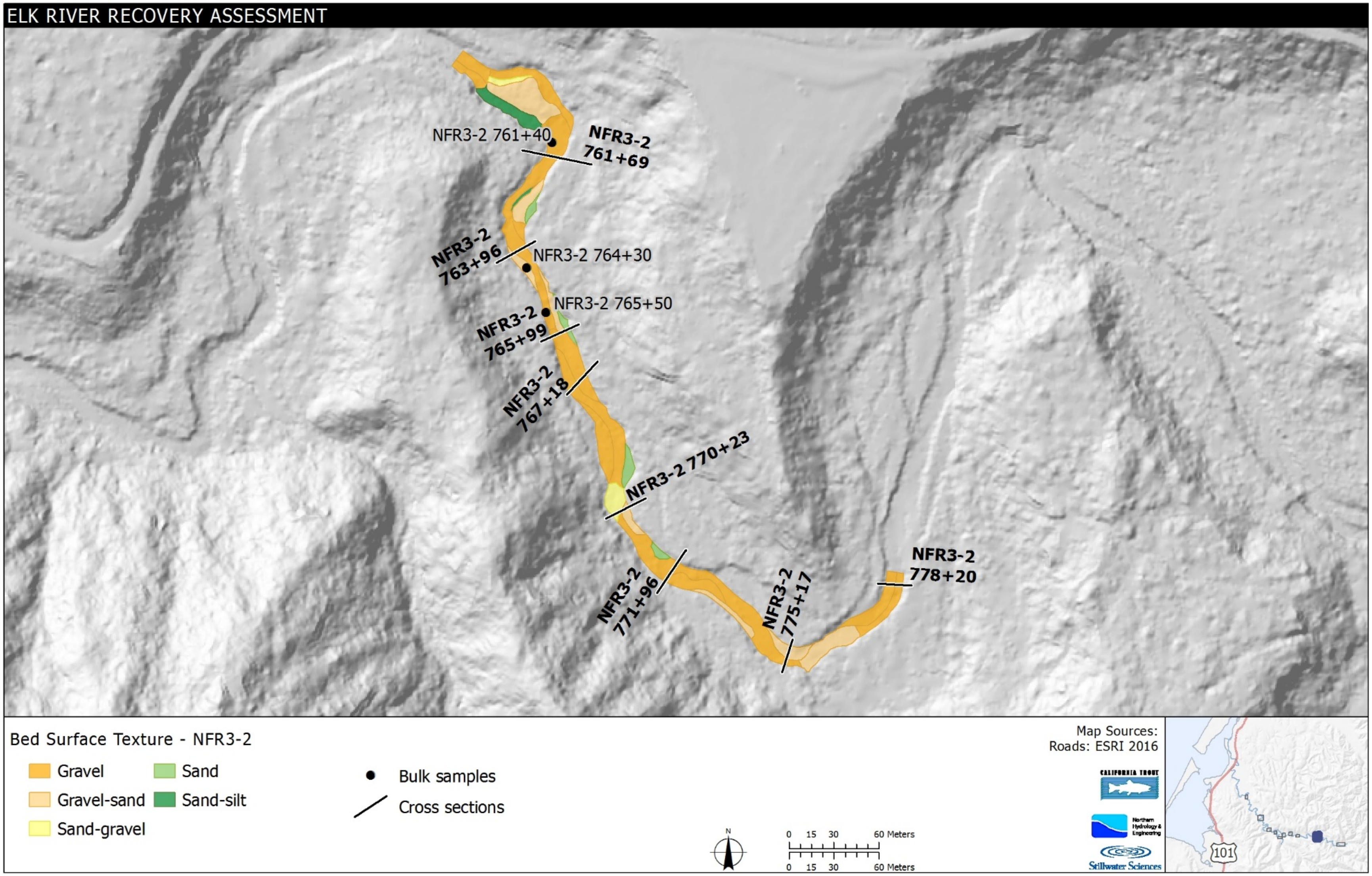

Figure 4-33. Facies mapping at intensive study site NFR3-2.

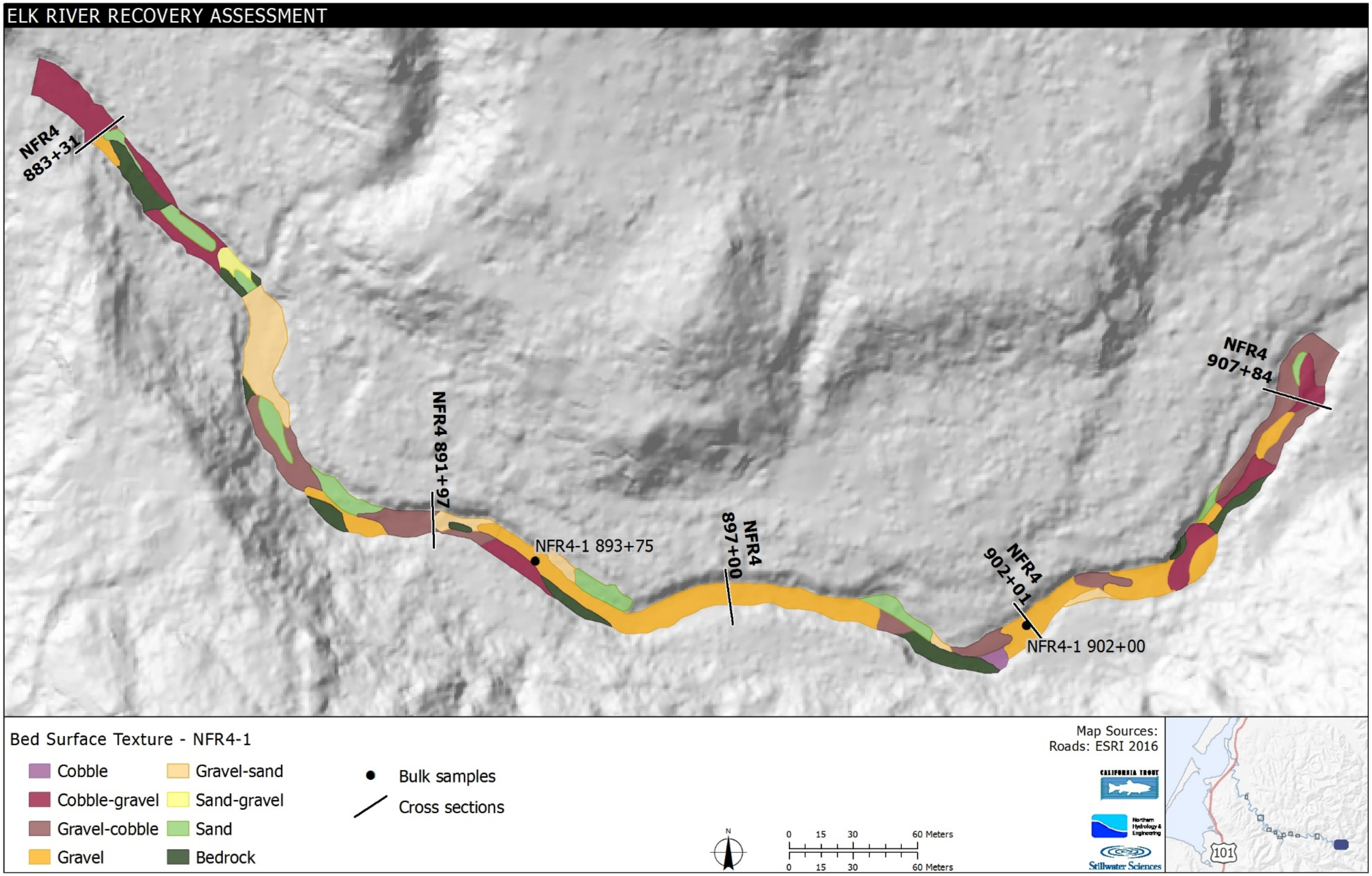

Figure 4-34. Facies mapping at intensive study site NFR4-1.

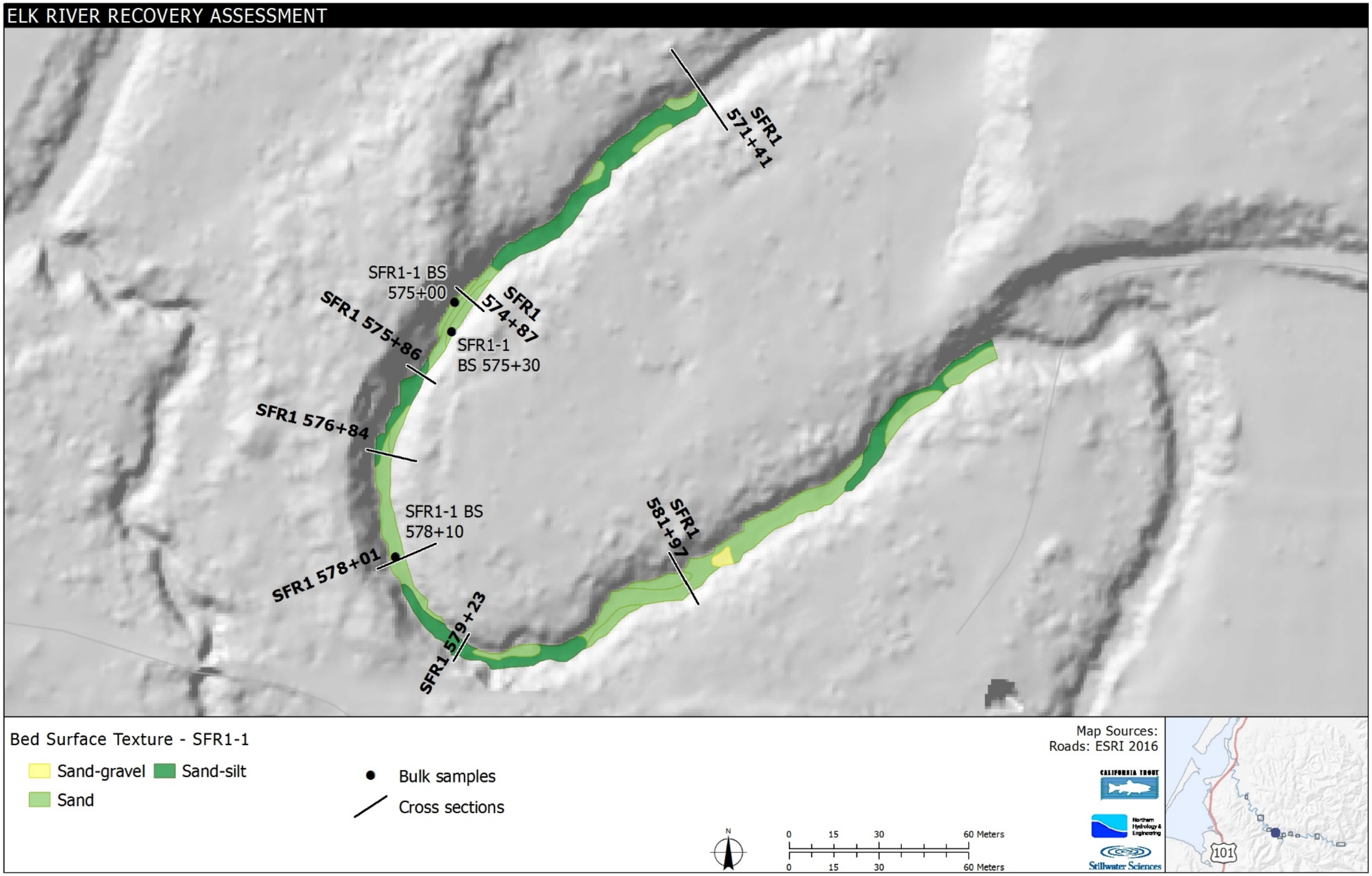

Figure 4-35. Facies mapping at intensive study site SF1-1.

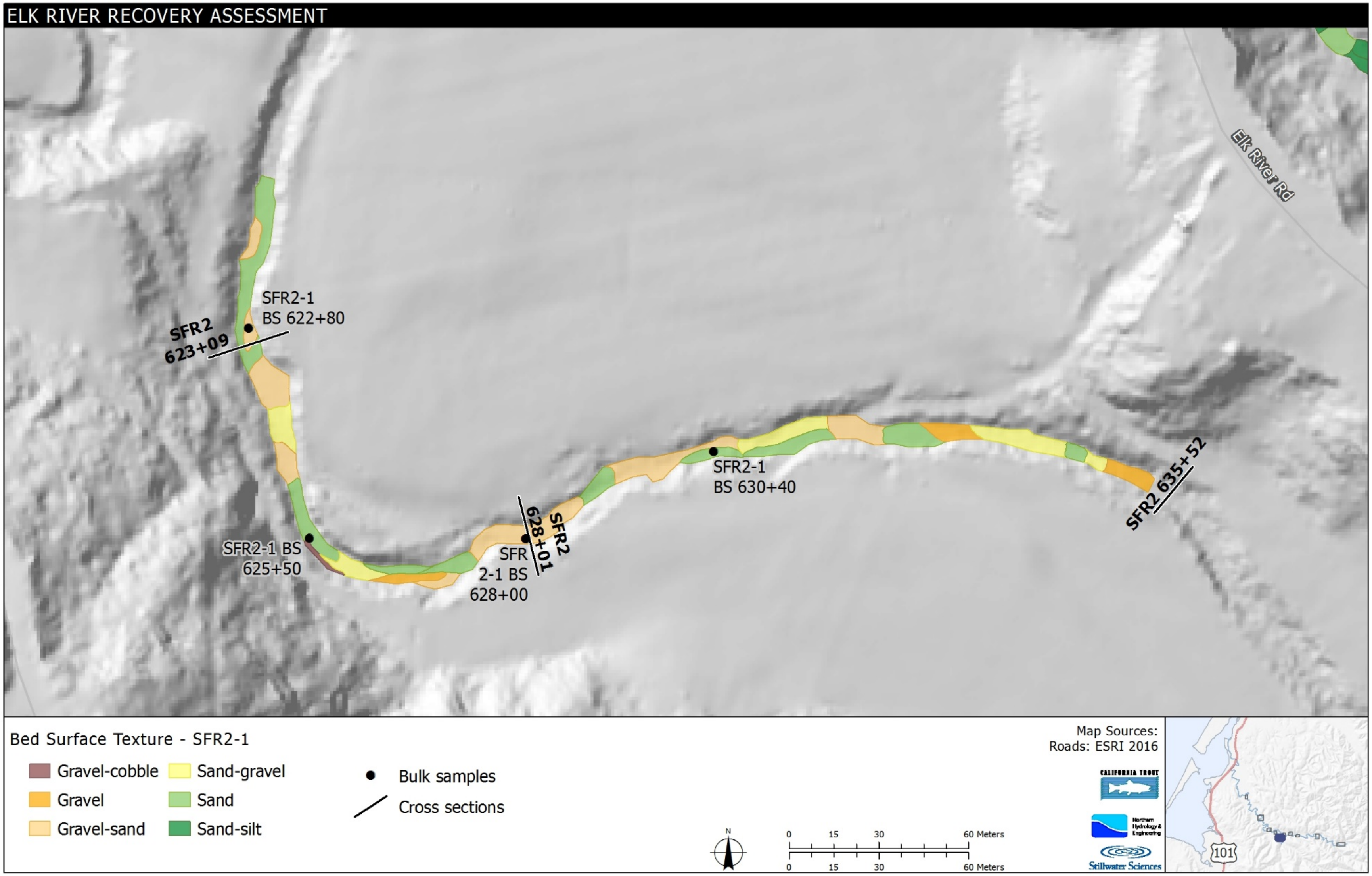

Figure 4-36. Facies mapping at intensive study site SF2-1.

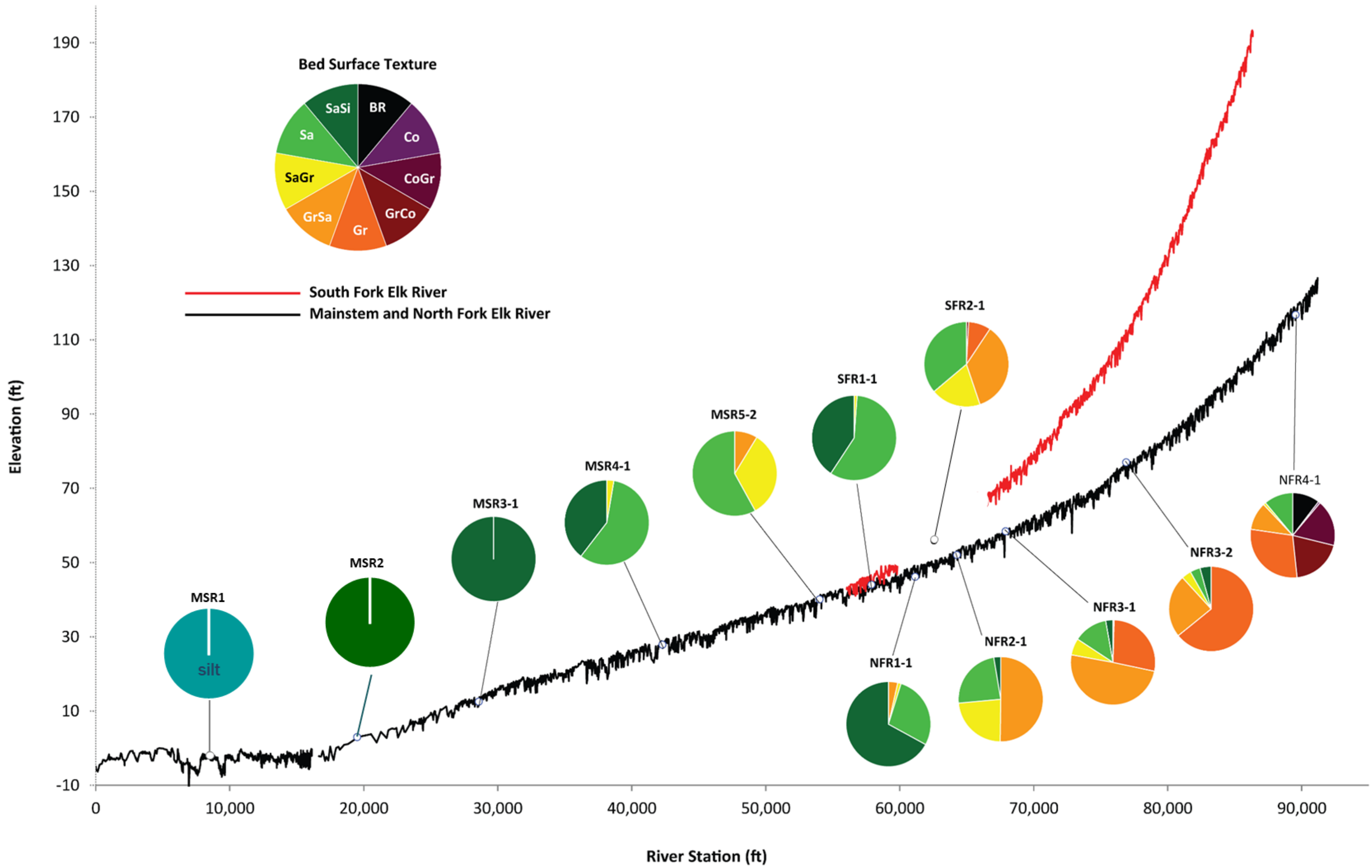

Figure 4-37. Longitudinal change in facies mapped within intensive study sites.

4.4.2 Grain size distribution

The bulk density, porosity, and grain size distribution of channel bed, bank, and floodplain sediment deposits were determined from bulk sampling at 108 locations (61 bed samples, 23 bank samples, and 24 floodplain samples) in the North Fork, South Fork, and mainstem Elk River Project reaches.

Representative sites potentially feasible for bulk sediment sampling were identified during facies mapping at each intensive study site. Bulk sample locations were selected to represent the dominant (i.e., most aerially extensive) facies types within the study site. Some facies types representing a small fraction of the total area within the study site were not sampled due to limited Project resources. Bulk sample site selection also considered typical channel bed and bank morphology and roughness elements (e.g., planform curvature, wood jams, and live vegetation) that locally influenced hydraulics and sediment transport. Coarse bed material (gravel sand mixtures and coarser) was sampled using a McNeil sampler or shovel. Sand and finer bed, bank, and floodplain deposits were sampled using steel cylinders with a fixed volume. Three different cylinder sizes cut from ANSI Schedule 40 steel pipe were used during sampling (**Table 4-29**).

Table 4-29. Cylinder sizes used for bulk sampling bed, bank, and floodplain surface sediment deposits in the Elk River Project area.

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

All but three samples were processed at Humboldt Redwood Company's sediment laboratory in Scotia. Three samples collected in estuary reaches (MSR1 and MSR2) were processed at SHN's sediment laboratory in Eureka. Sample particle size distributions were determined by processing dried samples through nested sieves at whole phi intervals down to 0.045 mm. Dry bulk density and porosity were calculated from fixed sample volumes and dry sample weights. Figure 4-37 summarizes bulk sediment samples collected within the Project area.

Area-weighted average bed particle size distributions were calculated from facies areas and bulk sample results. The particle size distribution representing a specific facies type mapped within an intensive study was calculated as the cumulative percent by mass. Where multiple samples were collected from the same facies type within a study site, a particle size distribution was calculated for the facies type based on the sum of the masses by size class. A single average bed particle size distribution was then calculated for the entire study site by weighting the cumulative percent size distribution for each facies type according to the total mapped area occupied by that facies type. Table 4-30 through Table 4-33 and Figure 4-38 through Figure 4-40 summarize the area-weighted grain size distributions of bed, bank, Table 4-30 and floodplain sediments at intensive study sites. The longitudinal change in area-weighted bed grain size distribution is shown in Figure 4-41.

Table 4-30. Summary of bulk sediment samples collected within the Project area.

Geomorphic reach	Intensive study site	River station	Sample type	Facies	Method[1]	Dry weight, g	Dry density, g/cm^3	Porosity
MSR1	na	6,610	bed	SiSa	3	na	na	na
	na	9,510	bed	SiSa	3	na	na	na
MSR2	MSR2-1	19,800	bed	SaSi	3	na	na	na
MSR3	MSR3-1	28,250	bank	na	2	921.90	1.22	0.54
		28,250	bed	SaSi	3	1321.30	0.46	0.83
		28,250	floodplain	na	2	960.00	1.27	0.52
		28,810	bed	1SaSi	3	1940.90	0.67	0.75
		29,120	bed	1SaSi	3	1600.00	0.55	0.79
MSR4	MSR4-1	42,290	bank	na	2	930.00	1.23	0.53
		42,290	bed	14Sa	4	1870.00	na	na
		42,290	floodplain	na	2	1020.00	1.35	0.49
		43,250	bank	na	2	830.00	1.10	0.58
		43,250	bed	5Sa	4	1770.00	na	na
		43,250	floodplain	na	2	870.00	1.15	0.56
		43,500	bank	na	2	620.00	0.82	0.69
		43,500	bed	2Sa	4	1830.00	na	na
		43,500	floodplain	na	2	820.00	1.09	0.59

Geomorphic reach	Intensive study site	River station	Sample type	Facies	Method[1]	Dry weight, g	Dry density, g/cm³	Porosity
MSR5	MSR5	55,084	bank	na	2	753.20	1.00	0.62
		55,088	bed	na	4	na	na	na
		55,092	bed	na	3	2357.70	0.81	0.69
		55,349	bank	na	2	924.10	1.23	0.54
		55,364	bank	na	2	na	na	na
	MSR5-2	54,235	bank	na	2	770.00	1.02	0.61
		54,235	bed	11Sa	4	1080.80	na	na
		54,235	floodplain	na	2	800.00	1.06	0.60
		54,510	bed	9Sa	4	3517.30	na	na
		54,660	bank	na	2	880.00	1.17	0.56
		54,660	bed	7GrSa	4	3469.90	na	na
		54,660	floodplain	na	2	680.00	0.90	0.66
		54,734	bank	na	2	1014.60	1.35	0.49
		54,760	floodplain	na	1	387.20	1.01	0.62
		54,949	bed	Sa	3	5562.20	1.92	0.28
		54,956	bed	Sa	4	na	na	na

Geomorphic reach	Intensive study site	River station	Sample type	Facies	Method[1]	Dry weight, g	Dry density, g/cm³	Porosity
NFR1	NFR1	56,225	floodplain	na	2	807.70	1.07	0.60
		56,226	bank	na	2	941.20	1.25	0.53
		56,244	bed	na	4	na	na	na
		56,257	bed	na	3	1422.90	0.49	0.81
		56,742	bed	na	4	na	na	na
		56,752	bed	na	3	2265.00	0.78	0.70
		56,937	bank	na	2	963.50	1.28	0.52
		56,939	floodplain	na	2	840.10	1.11	0.58
	NFR1-1	60,574	bed	SaSi	4	na	na	na
		60,582	bed	SaSi	3	1788.10	0.62	0.77
		60,600	bank	na	2	931.00	1.23	0.53
		60,910	bank	na	2	860.00	1.14	0.57
		60,910	bed	7Sa	4	1319.70	na	na
		60,910	floodplain	na	2	820.00	1.09	0.59
		61,150	bank	na	2	900.00	1.19	0.55
		61,150	bed	10GrSa	4	2928.70	na	na
		61,150	floodplain	na	2	780.00	1.03	0.61
		61,867	bed	SaSi	3	1605.00	0.55	0.79
		61,877	bed	SaSi	4	na	na	na
		61,878	bank	na	2	865.30	1.15	0.57
		61,894	floodplain	na	2	747.10	0.99	0.63
NFR2	NFR2-1	63,500	bed	28Sa	4	3120.00	na	na
		63,525	bed	28Sa	3	2280.00	0.79	0.70
		63,800	bed	24SaGr	3	2220.00	0.77	0.71
		63,800	bed	24SaGr	4	2700.00	na	na
		63,800	floodplain	na	2	779.80	1.03	0.61
		64,385	bed	14SaGr	4	2120.00	na	na
		64,650	bed	7GrSa	3	4950.00	1.71	0.36
		64,675	bed	7GrSa	4	2570.00	na	na
		64,675	floodplain	na	2	510.00	0.68	0.74

Geomorphic reach	Intensive study site	River station	Sample type	Facies	Method[1]	Dry weight, g	Dry density, g/cm³	Porosity
NFR3	NFR3-1	67,680	bed	40Gr	3	5330.00	1.84	0.31
		67,680	bed	40Gr	4	3051.10	na	na
		68,200	bed	17Gr	3	5210.00	1.80	0.32
		68,200	bed	17Gr	4	5080.00	1.99	0.25
		68,200	bed	17Gr	4	5164.00	na	na
		68,200	floodplain	na	2	760.00	1.01	0.62
		68,700	bed	4Gr	3	2250.00	0.78	0.71
		68,700	bed	4Gr	4	2213.80	na	na
		68,700	floodplain	na	2	720.00	0.95	0.64
	NFR3-2	76,140	bed	7Gr	4	3060.00	na	na
		76,150	bed	7Gr	4	4740.00	1.90	0.28
		76,430	bed	12GrSa	4	2550.90	na	na
		76,430	floodplain	na	2	750.00	0.99	0.62
		76,440	bed	12GrSa	4	5250.00	1.92	0.27
		76,550	bed	7Gr	4	5220.00	2.22	0.16
		76,550	bed	7Gr	4	2390.00	na	na
NFR4	NFR4-1	89,375	bed	20Gr	4	5500.00	na	na
		89,440	bed	20Gr	4	3730.00	0.98	0.63
		89,440	floodplain	na	2	360.00	0.48	0.82
		90,200	bed	14Gr	4	4920.00	na	na
		90,200	floodplain	na	2	390.00	0.52	0.80
		90,220	bed	14Gr	4	2610.00	0.72	0.73

Geomorphic reach	Intensive study site	River station	Sample type	Facies	Method[1]	Dry weight, g	Dry density, g/cm^3	Porosity
SFR1	SFR1	56,147	bank	na	2	na	na	na
		56,166	bank	na	2	932.50	1.24	0.53
		56,402	bed	na	4	na	na	na
		56,411	floodplain	na	2	820.30	1.09	0.59
		56,413	bed	na	3	2072.00	0.72	0.73
		56,431	bank	na	2	851.50	1.13	0.57
		58,985	bank	na	2	814.90	1.08	0.59
		59,006	floodplain	na	2	709.00	0.94	0.65
		59,429	bed	na	3	2553.40	0.88	0.67
		59,439	bed	na	4	na	na	na
		59,444	bank	na	2	798.20	1.06	0.60
		59,454	floodplain	na	2	808.00	1.07	0.60
	SFR1-1	57,500	bank	na	2	490.00	0.65	0.75
		57,500	bed	6Sa	3	2130.00	0.74	0.72
		57,500	floodplain	na	2	760.00	1.01	0.62
		57,530	bed	7Sa	3	1560.00	0.54	0.80
		57,810	bed	10Sa	3	4720.00	1.63	0.39
SFR2	SFR2-1	62,280	bank	na	2	690.00	0.91	0.65
		62,280	bed	3GrSa	3	1490.00	0.51	0.81
		62,280	floodplain	na	2	575.10	0.76	0.71
		62,550	bed	7Sa	3	2160.00	0.75	0.72
		62,800	bed	14GrSa	4	6195.40	0.44	0.83
		63,040	bed	17Sa	4	1412.90	0.10	0.96

[1] Method: 1=3x3 inch cylinder, 2=3x6 inch cyllinder, 3=6x6 inch cylinder, 4=shovel or McNeil sampler.

Table 4-31. Area-weighted bed grain size distributions at intensive study sites.

Study reach	Midpt station	Slope	Width, ft		Bed grain size, mm											
			TOB	Toe	D_{95}	D_{90}	D_{84}	D_{75}	D_{65}	D_{50}	D_{35}	D_{25}	D_{16}	D_{10}	D_{5}	Graphic mean
MSR1	9,275	na	na	na	0.40	0.25	0.14	0.07	0.05	0.04	0.02	0.02	0.01	0.00	0.00	0.03
MSR2-1	19,735	0.0011	57	27	0.72	0.37	0.30	0.22	0.15	0.09	0.05	0.03	0.02	0.01	0.01	0.08
MSR3-1	28,605	0.0013	53	22	0.57	0.47	0.44	0.39	0.35	0.29	0.23	0.17	0.10	0.04	0.02	0.23
MSR4-1	42,300	0.0009	59	23	1.65	0.88	0.66	0.48	0.43	0.36	0.30	0.26	0.20	0.15	0.04	0.36
MSR5-2	54,005	0.0016	59	27	3.97	2.64	1.69	0.93	0.49	0.39	0.31	0.27	0.21	0.16	0.08	0.52
NFR1-1	61,165	0.0015	58	24	1.84	0.83	0.51	0.44	0.38	0.30	0.23	0.16	0.10	0.04	0.02	0.24
NFR2-1	64,270	0.0018	68	24	11.58	7.75	5.79	3.82	2.45	1.28	0.71	0.50	0.34	0.27	0.15	1.37
NFR3-1	67,905	0.0015	63	27	35.04	26.29	20.19	13.62	8.83	3.56	1.16	0.55	0.37	0.54	0.17	2.98
NFR3-2	76,900	0.0024	83	38	37.14	28.16	23.16	17.28	11.92	6.47	2.62	1.21	0.51	0.31	0.17	4.24
NFR4-1	89,545	0.0041	70	38	126.31	95.32	68.00	44.16	24.05	10.71	3.61	1.58	0.82	0.80	0.37	8.44
SFR1-1	57,890	0.0022	53	20	5.38	4.34	3.35	2.27	0.91	0.44	0.32	0.27	0.18	0.11	0.03	0.65
SRF2-1	62,825	0.0028	47	19	29.61	20.62	13.73	7.90	3.75	1.26	0.61	0.42	0.32	0.52	0.17	1.77

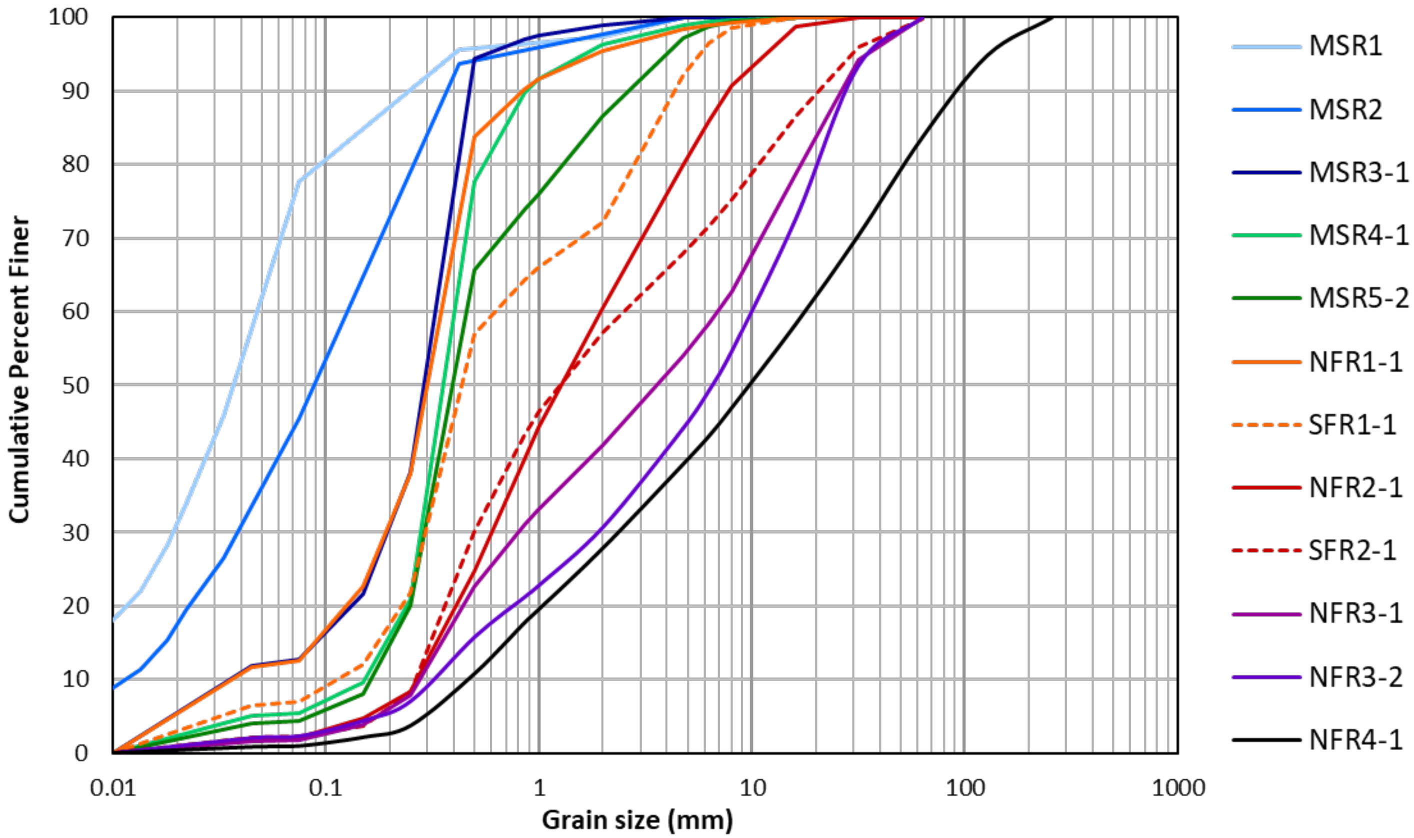

Figure 4-38. Area-weighted bed grain size distributions at intensive study sites.

Table 4-32. Area-weighted bank grain size distributions at intensive study sites.

Study reach	Midpoint station	Slope	Width		Bank grain size, mm											
			TOB	Toe	D_{95}	D_{90}	D_{84}	D_{75}	D_{65}	D_{50}	D_{35}	D_{25}	D_{16}	D_{10}	D_{5}	Graphic mean
MSR1	9,275	na	58	na	na	na	na	na	na	na	na	na	na	na	na	na
MSR2-1	19,735	0.0011	57	27	na	na	na	na	na	na	na	na	na	na	na	na
MSR3-1	28,605	0.0013	53	22	na	na	na	na	na	na	na	na	na	na	na	na
MSR4-1	42,300	0.0009	59	23	15.14	10.07	6.43	3.70	1.82	0.32	0.18	0.12	0.04	0.02	0.02	0.45
MSR5-2	54,005	0.0016	59	27	0.79	0.46	0.37	0.28	0.23	0.18	0.15	0.10	0.04	0.02	0.02	0.14
NFR1-1	61,165	0.0015	58	24	14.78	12.25	9.77	6.75	2.97	0.18	0.08	0.03	0.02	0.02	0.01	0.23
NFR2-1	64,270	0.0018	68	24	na	na	na	na	na	na	na	na	na	na	na	na
NFR3-1	67,905	0.0015	63	27	na	na	na	na	na	na	na	na	na	na	na	na
NFR3-2	76,900	0.0024	83	38	na	na	na	na	na	na	na	na	na	na	na	na
NFR4-1	89,545	0.0041	70	38	na	na	na	na	na	na	na	na	na	na	na	na
SFR1-1	57,890	0.0022	2.67	1.38	0.69	0.32	0.21	0.14	0.09	0.06	0.03	0.02	0.01	0.14	2.67	1.38
SRF2-1	62,825	0.0028	10.5	6.9	4.4	2.1	0.4	0.2	0.1	0.0	0.0	0.0	0.0	0.3	10.5	6.9

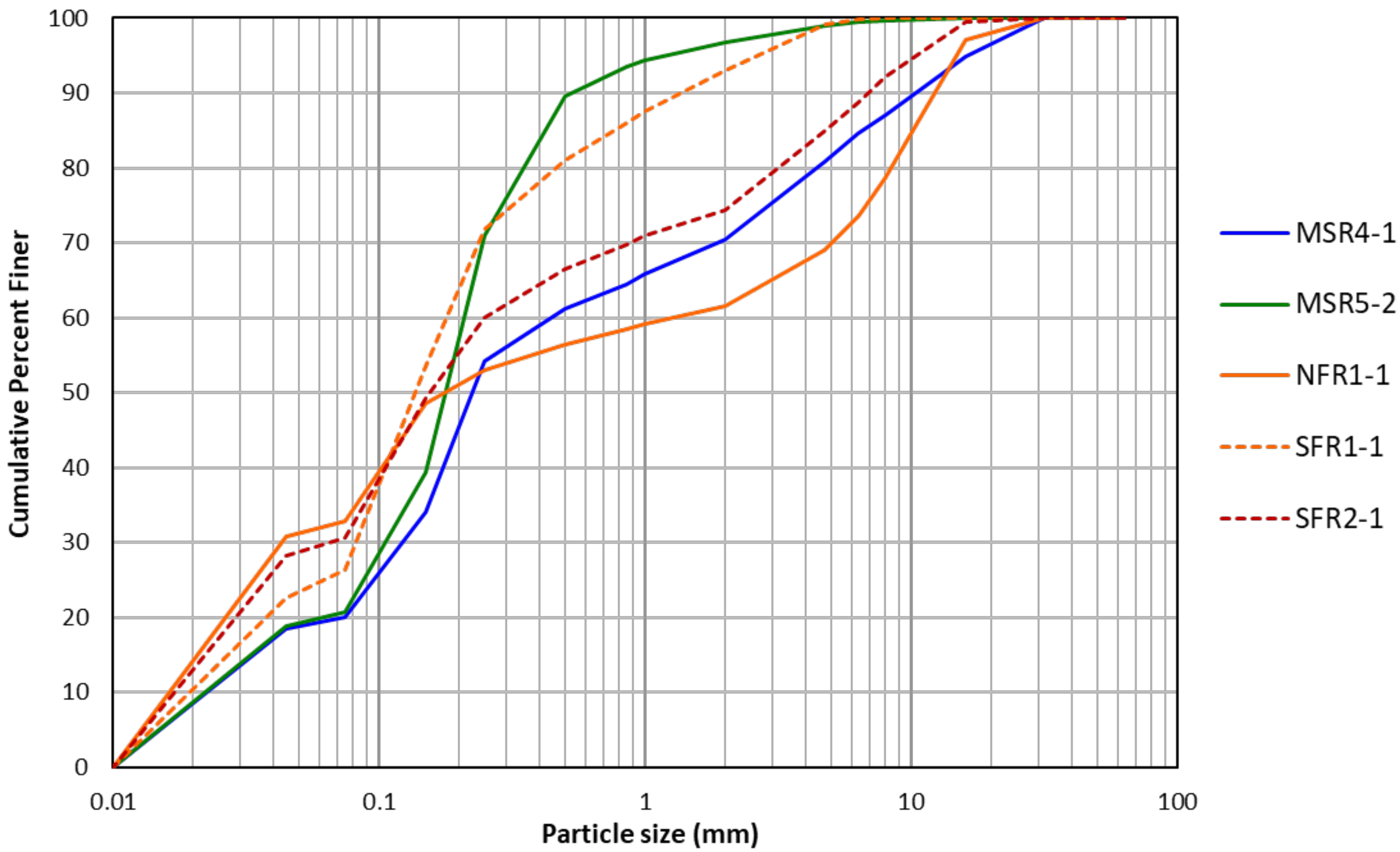

Figure 4-39. Area-weighted bank grain size distributions at intensive study sites.

Table 4-33. Area-weighted floodplain grain size distributions at intensive study sites.

Study reach	Midpoint station	Slope	Width		Floodplain grain size, mm											
			TOB	Toe	D_{95}	D_{90}	D_{84}	D_{75}	D_{65}	D_{50}	D_{35}	D_{25}	D_{16}	D_{10}	D_{5}	Graphic mean
MSR1	9,275	na	58	na	na	na	na	na	na	na	na	na	na	na	na	na
MSR2-1	19,735	0.0011	57	27	na	na	na	na	na	na	na	na	na	na	na	na
MSR3-1	28,605	0.0013	53	22	na	na	na	na	na	na	na	na	na	na	na	na
MSR4-1	42,300	0.0009	59	23	17.96	11.13	7.01	4.18	2.32	0.58	0.19	0.12	0.05	0.03	0.02	0.58
MSR5-2	54,005	0.0016	59	27	17.72	11.42	7.24	4.30	2.50	0.86	0.24	0.10	0.03	0.02	0.01	0.58
NFR1-1	61,165	0.0015	58	24	12.21	8.18	5.71	3.49	2.02	0.57	0.17	0.10	0.04	0.02	0.01	0.33
NFR2-1	64,270	0.0018	68	24	12.52	7.97	5.97	4.16	2.88	1.53	0.64	0.25	0.08	0.03	0.02	0.90
NFR3-1	67,905	0.0015	63	27	9.28	6.57	4.61	2.73	1.35	0.34	0.11	0.08	0.03	0.02	0.01	0.01
NFR3-2	76,900	0.0024	83	38	7.68	6.14	4.64	2.96	1.72	0.53	0.13	0.08	0.03	0.02	0.01	0.43
NFR4-1	89,545	0.0041	70	38	4.30	3.14	2.15	1.15	0.60	0.27	0.14	0.09	0.04	0.02	0.02	0.28
SFR1-1	57,890	0.0022	53	20	3.76	2.61	1.68	0.89	0.39	0.11	0.04	0.03	0.02	0.01	0.01	0.15
SRF2-1	62,825	0.0028	47	19	0.23	0.09	0.04	0.04	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.02

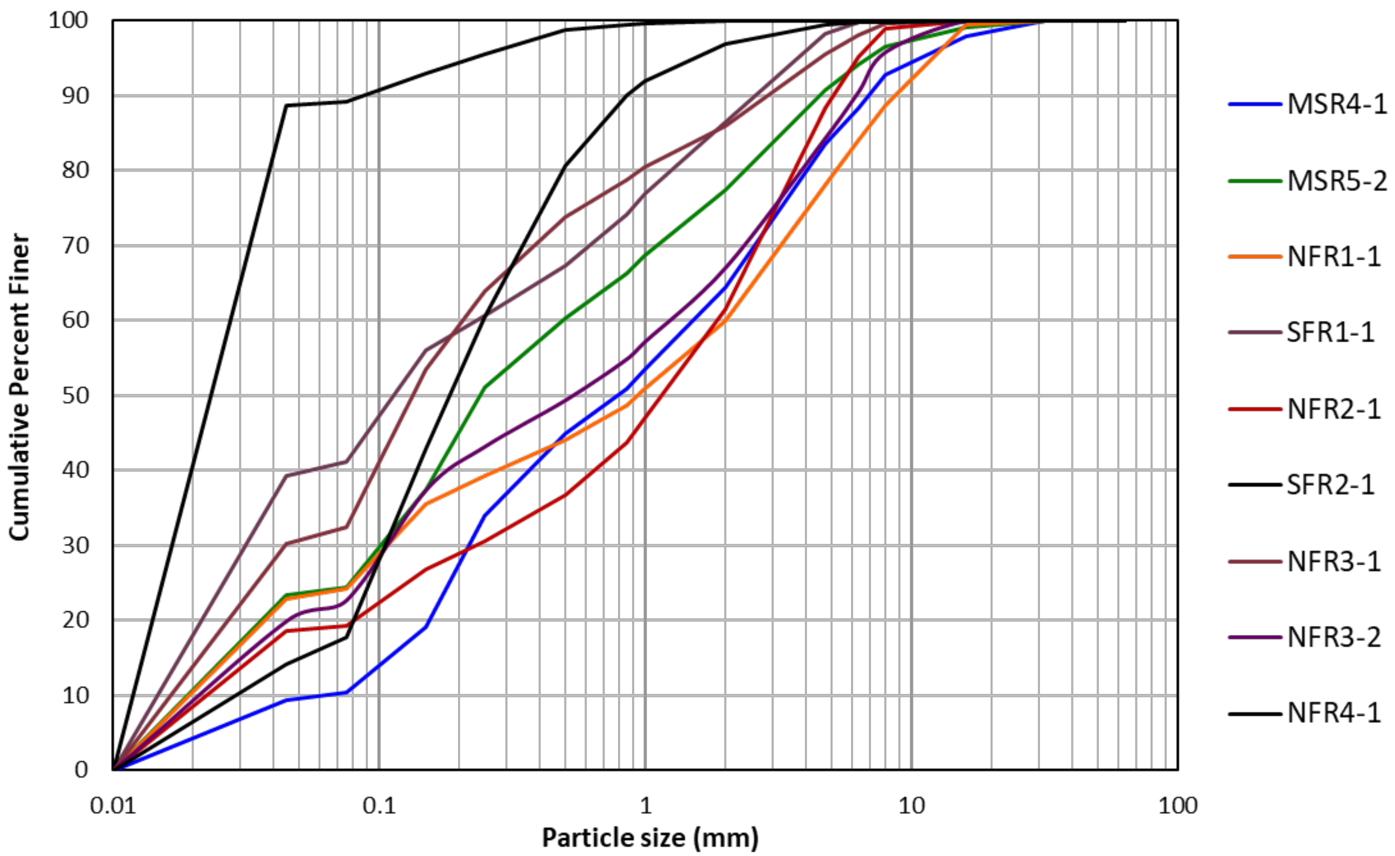

Figure 4-40. Area-weighted floodplain grain size distributions at intensive study sites.

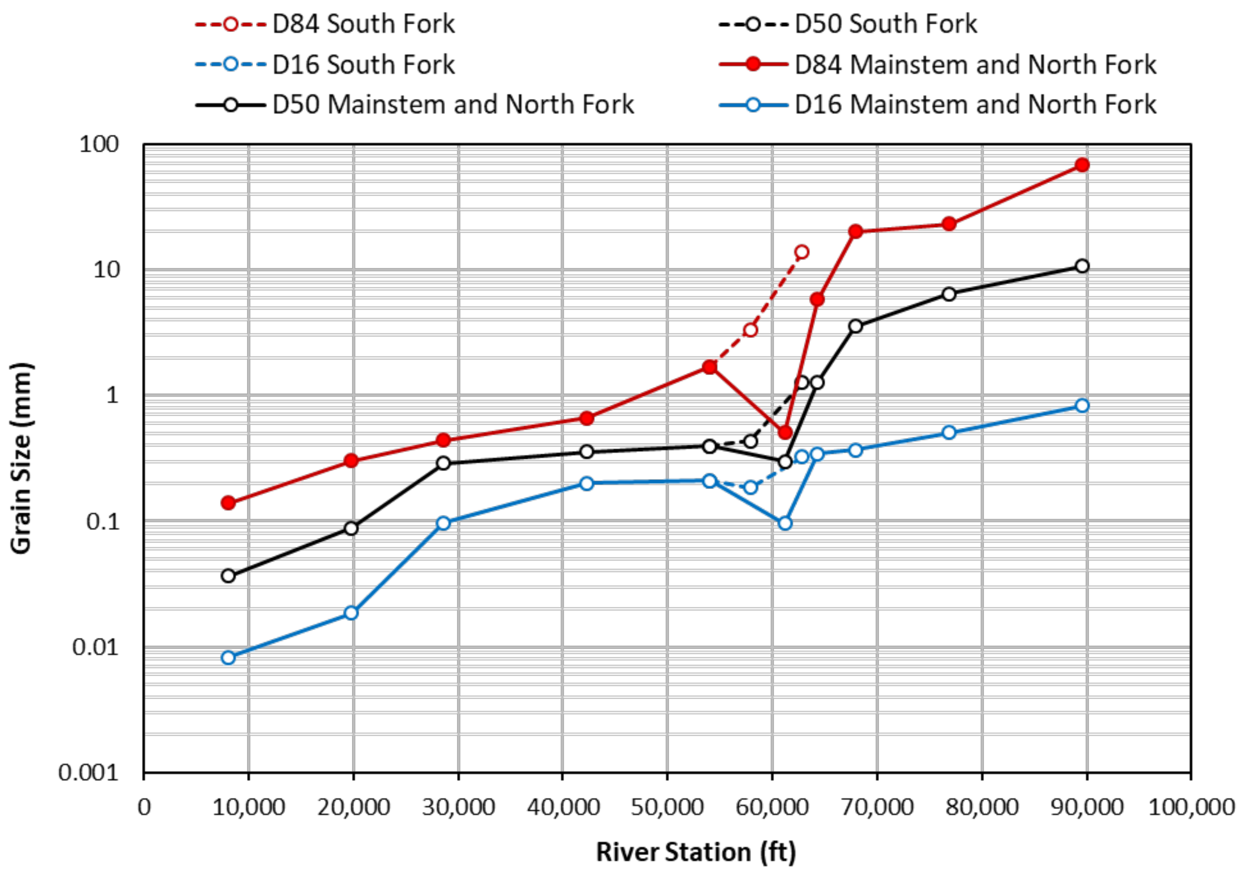

Figure 4-41. Longitudinal change in area-weighted bed grain size distribution parameters.

4.5 Woody Debris

A complete count of all LWD and all LWD jams that occurred within the bankfull channel width was conducted at each intensive study site. Pieces longer than 0.9 m (3 ft) and greater than 15 centimeters (cm; 6 in) diameter were recorded. Pieces that met the minimum size criteria were recorded if any portion of their length occurred within the bankfull channel width.

Detailed descriptions were taken for all recorded pieces including:

- piece location (mapped on sediment facies maps);
- total piece length (within and outside of bankfull channel);
- piece diameter,
- presence of a rootwad;
- tree species or type (e.g., conifer or hardwood);
- degree of decay;
- piece orientation (i.e., perpendicular, angled upstream, angled downstream, or parallel);
- position relative to the channel;
- associated with a jam (defined as three or more pieces of LWD) and the number of pieces within the jam meeting the minimum size threshold;
- recruitment mechanism (i.e., windthrow, bank undercutting, debris, flow, landslide, tree mortality, fluvial, or unknown); and
- geomorphic function.

A description of the geomorphic function of each piece included one or more of the following:

- forming pool habitat (either dammed, plunge, lateral scour, or backwater pool);
- associated with pool habitat but not creating a pool;
- associated with LWD jam;
- acting as a sediment storage site;
- stability in stream channel; and/or
- located in bankfull channel but not influencing channel morphology.

Pieces and jams were located on the sediment facies maps and were tallied into 20 unique size classes based on five length classes (0.9–3 m, 3.1–7.5 m, 7.6–15 m, 15.1–23 m, and >23 m) and four diameter classes (15–30 cm, 31–61 cm, 62–91 cm, and >91 cm). The midpoint of each length and width size class was used to calculate volumes from the tally data. The total volume of each length and diameter class was calculated based on the equation for the volume of a cylinder:

$$Volume = \pi \frac{{D_{mp}}^{2}}{2} L_{mp}$$

where D_{mp} is the diameter at the midpoint of the size class and L_{mp} is the piece length at the midpoint of the size class. Because reach lengths varied between study sites, LWD frequency and volume were normalized to a 100 m (328 ft) stream length.

Table 4-34 summarizes the results of LWD collection at intensive study sites. Figure 4-42 through Figure 4-51show the distribution of wood pieces by length and diameter class at each intensive study site. Figure 4-52 through Figure 4-55 show longitudinal trends in total piece frequency and volume at intensive study sites. Attachment A includes sample data sheets.

Table 4-34. Summary of LWD at intensive study sites.

Intensive study site	Length, m	TOB width, m	Pieces		Frequency				Volume				# pieces forming pools	# jams
			Total	Key	Pieces per TOB width		Pieces per 100 m		M^3 per TOB width		M^3 per 100 m			
					total	key	total	key	total	key	total	key		
MSR3-1	485	16	75	0	2.5	0	15.5	0	1.1	0	6.9	0	0	6
MSR4-1	738	18	263	5	6.4	0.1	35.7	0.7	3.5	2.0	19.3	10.9	18	14
MSR5-2	558	18	46	0	1.5	0	8.2	0.0	1.6	0	9.1	0	14	2
NFR1-1	527	18	242	5	8.1	0.2	45.9	0.9	11.1	2.1	62.5	11.8	20	4
NFR2-1	536	21	46	6	1.8	0.2	8.6	1.1	3.6	4.3	17.3	20.7	24	1
NFR3-1	485	19	72	7	2.9	0.3	14.9	1.4	3.7	4.7	19.4	24.5	13	1
NFR3-2	640	25	33	6	1.3	0.2	5.2	0.9	2.2	3.3	8.7	13.0	21	1
NFR4-1	820	21	82	12	2.1	0.3	10.0	1.5	2.2	5.1	10.5	24.1	19	1
SFR1-1	451	16	58	4	2.1	0.1	12.9	0.9	2.1	2.2	12.9	13.7	24	2
SFR2-1	430	14	121	0	4.0	0	28.2	0	1.6	0	11.0	0	24	8

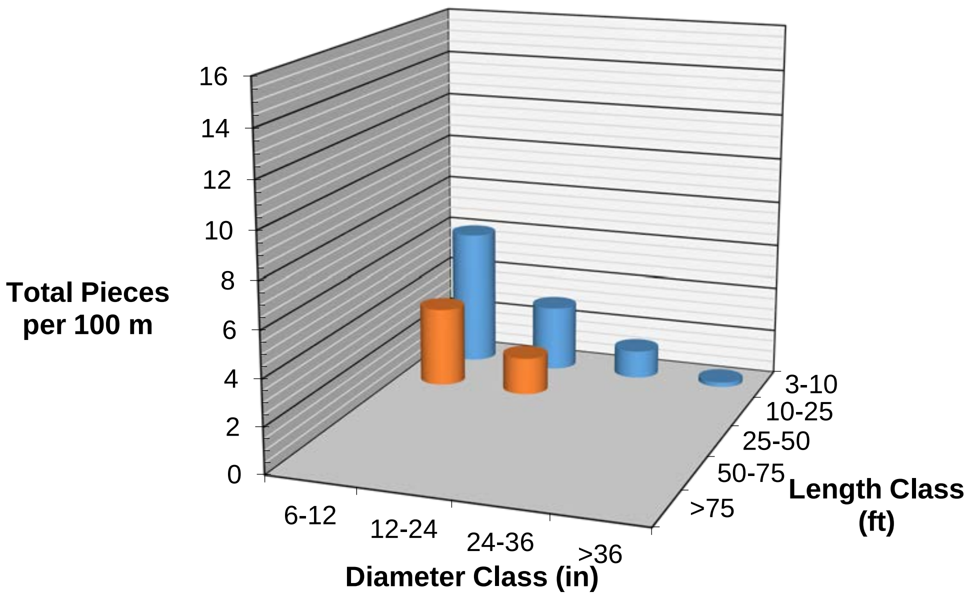

Figure 4-42. Distribution of wood pieces by length and diameter class at intensive study site MSR3-1.

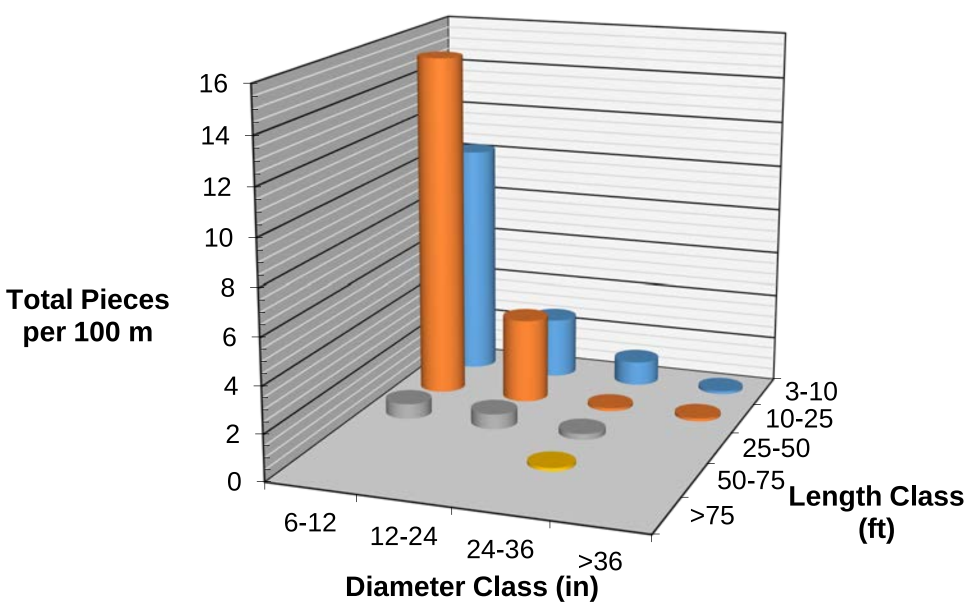

Figure 4-43. Distribution of wood pieces by length and diameter class at intensive study site MSR4-1.

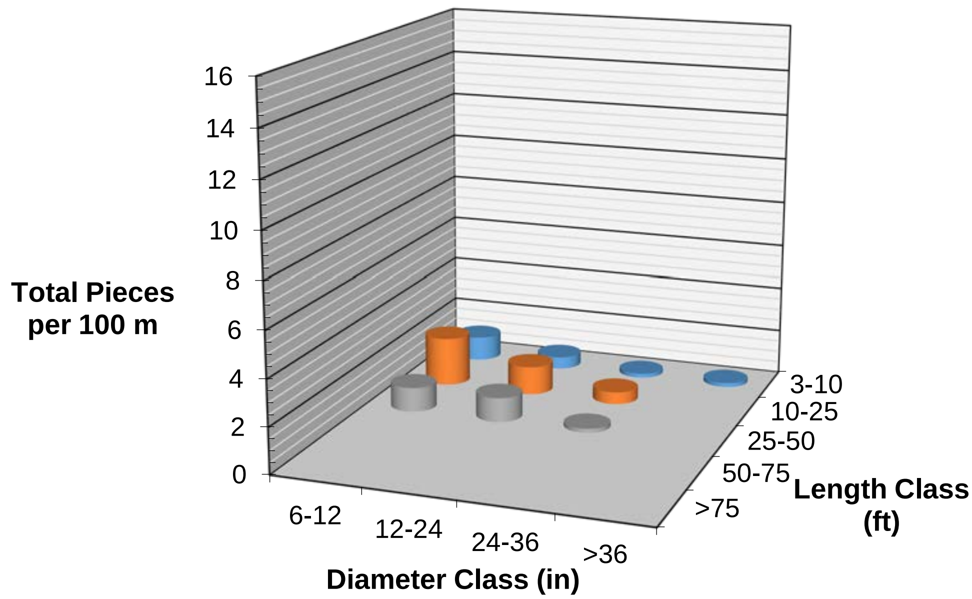

Figure 4-44. Distribution of wood pieces by length and diameter class at intensive study site MSR5-2.

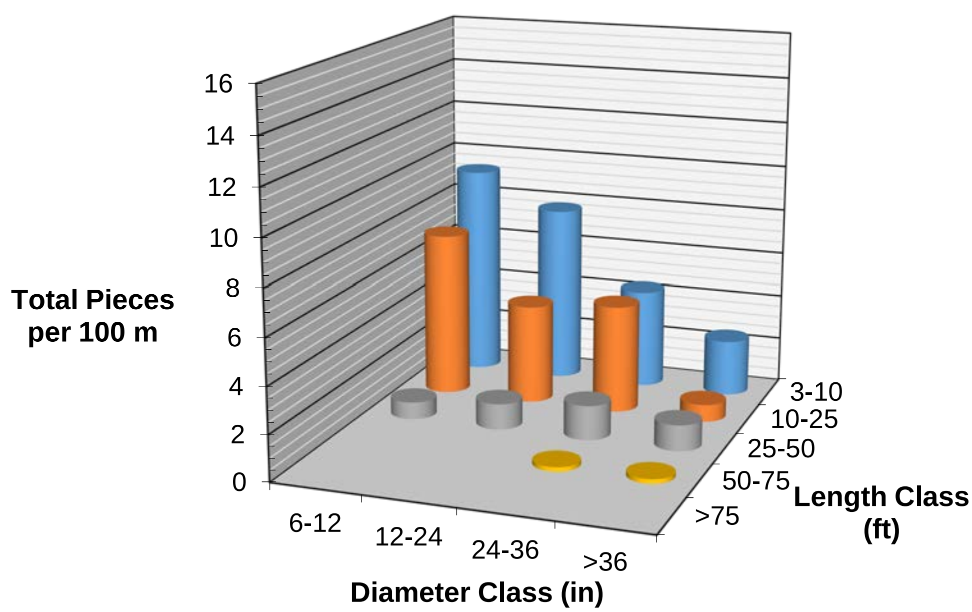

Figure 4-45. Distribution of wood pieces by length and diameter class at intensive study site NFR1-1.

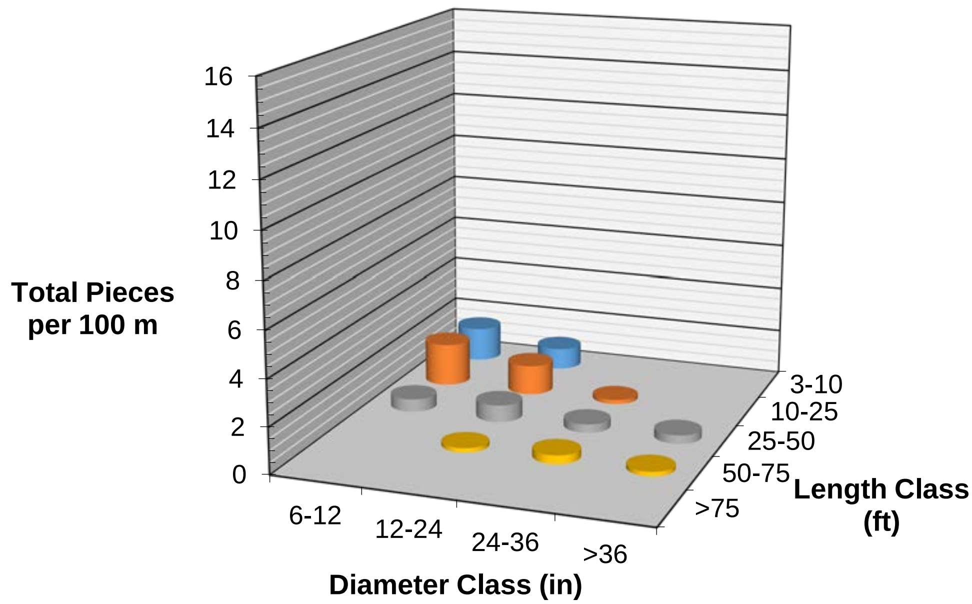

Figure 4-46. Distribution of wood pieces by length and diameter class at intensive study site NFR2-1.

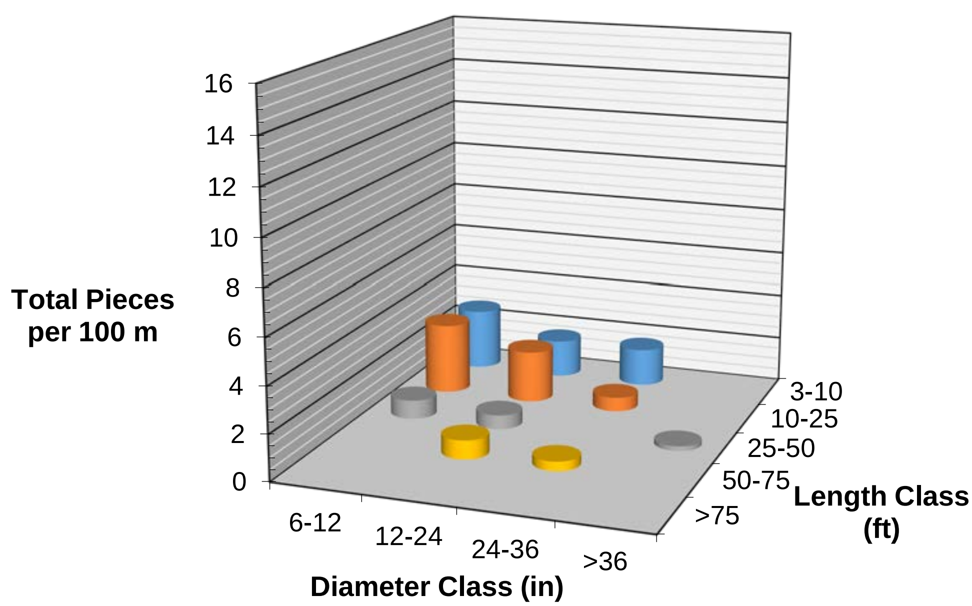

Figure 4-47. Distribution of wood pieces by length and diameter class at intensive study site NFR3-1.

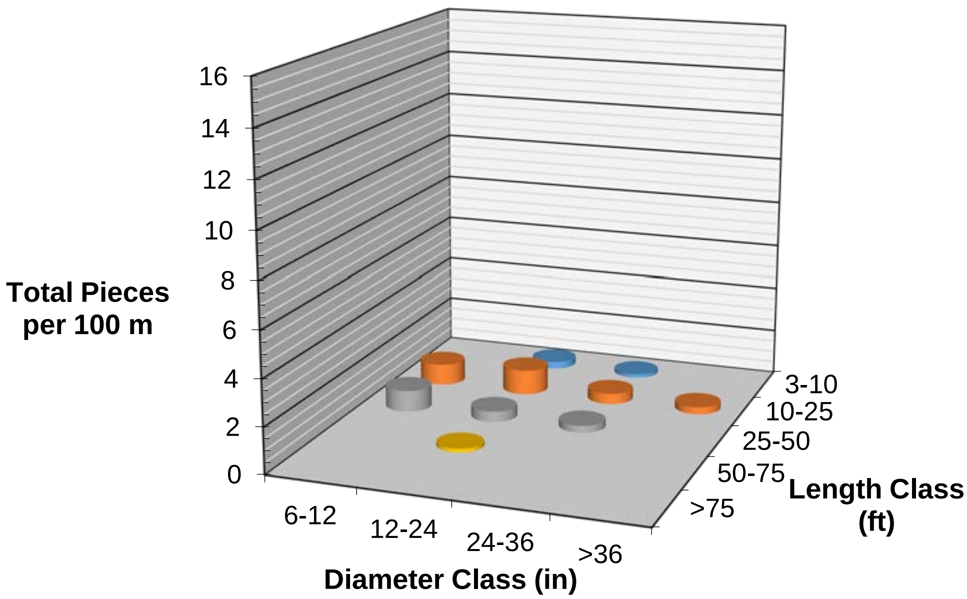

Figure 4-48. Distribution of wood pieces by length and diameter class at intensive study site NFR3-2.

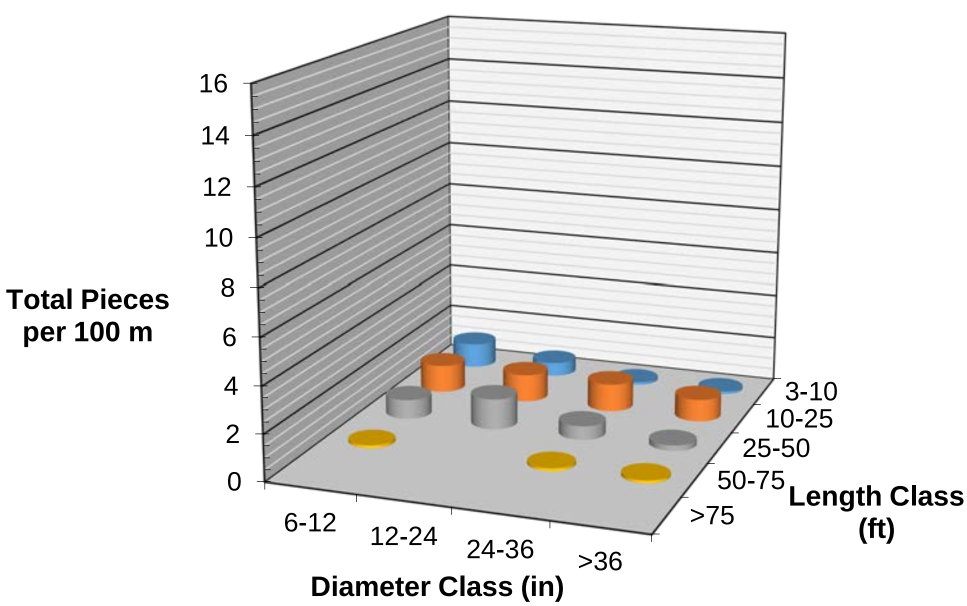

Figure 4-49. Distribution of wood pieces by length and diameter class at intensive study site NFR4-1.

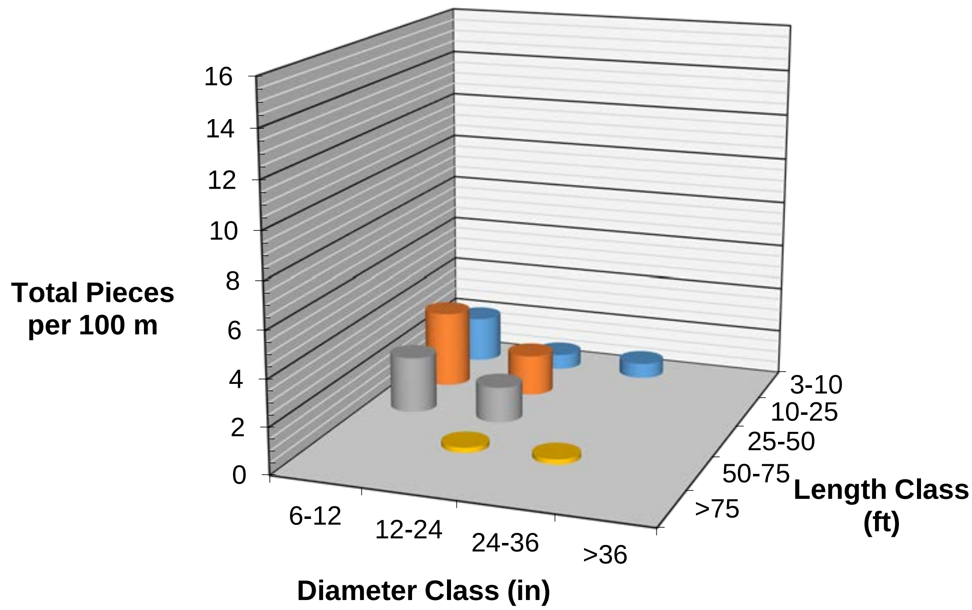

Figure 4-50. Distribution of wood pieces by length and diameter class at intensive study site SFR1-1.

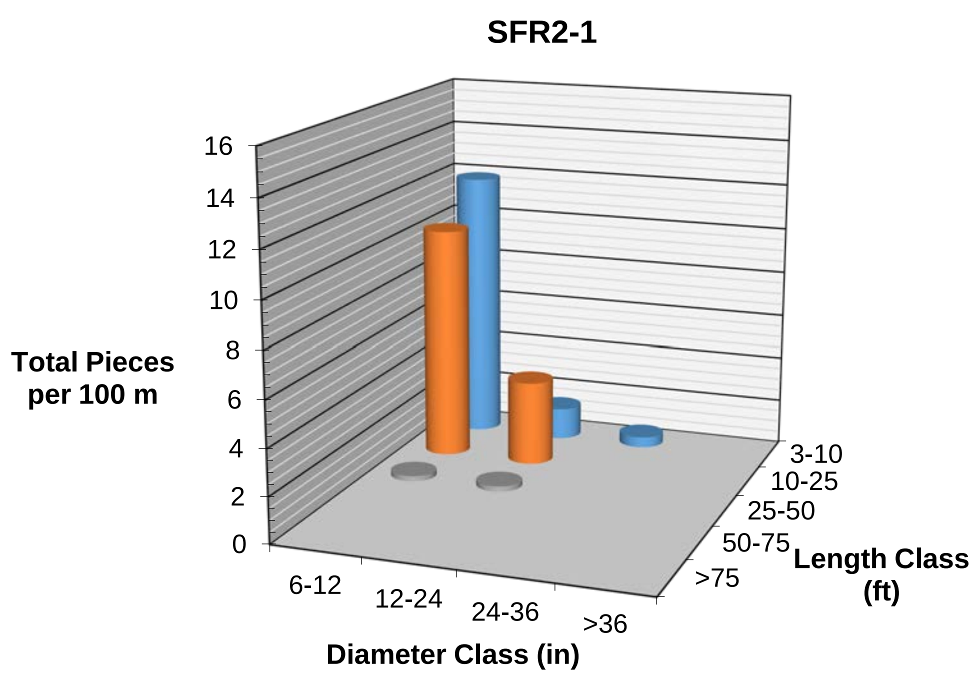

Figure 4-51. Distribution of wood pieces by length and diameter class at intensive study site SFR2-1.

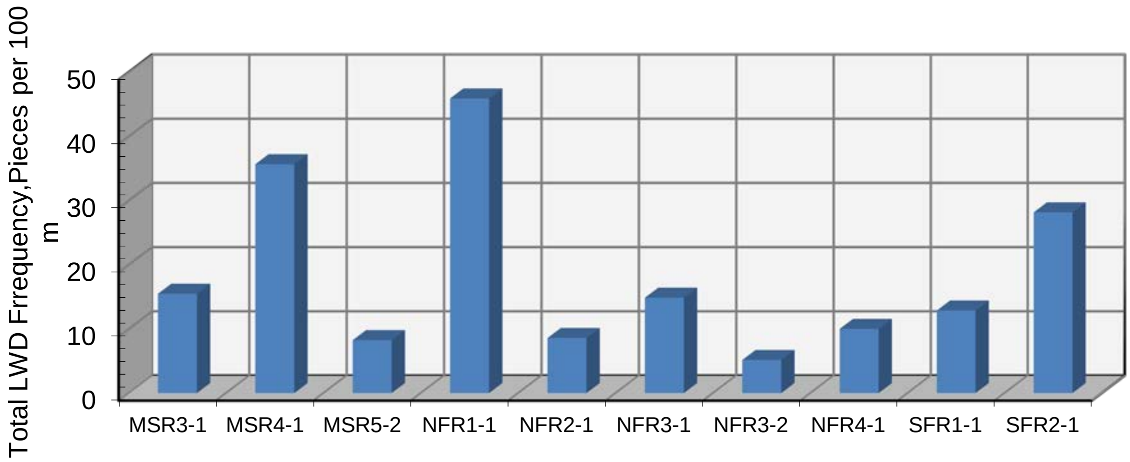

Figure 4-52. LWD frequency at intensive study sites.

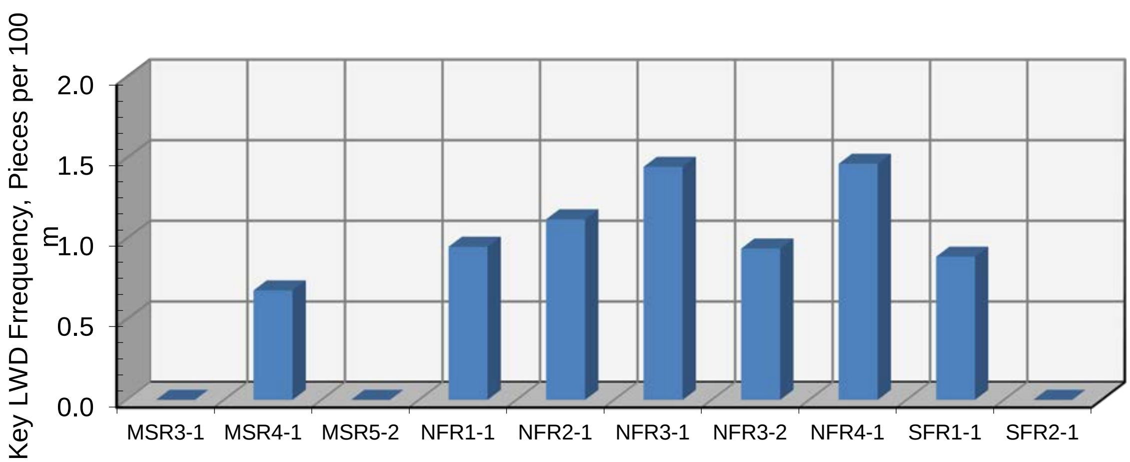

Figure 4-53. Frequency of key LWD pieces at intensive study sites.

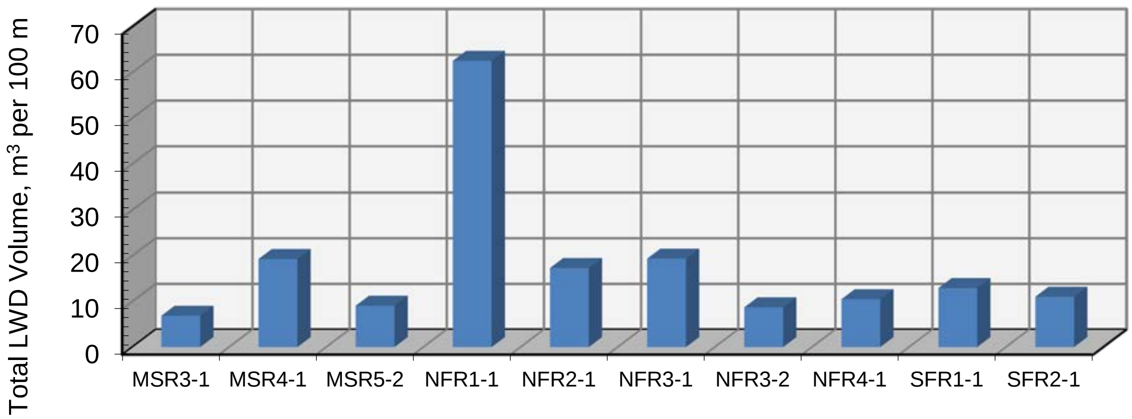

Figure 4-54. LWD volume at intensive study sites.

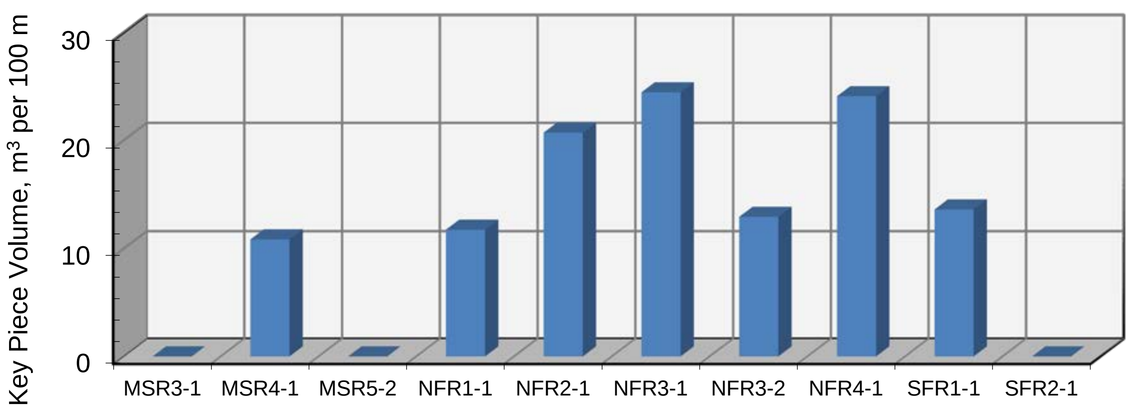

Figure 4-55. Volume of key LWD pieces at intensive study sites.

4.6 Vegetation

The type, distribution, and structure of vegetation was mapped within the model domain for the purpose of parameterizing vegetation resistance in the EFDC hydrodynamic and sediment transport model. The work included characterizing the weighted average stem diameter, height, and density of 31 vegetation types within the Project area.

After reviewing publicly available vegetation mapping data sets (LCMMP, NLCD, and CALVEG)[1], the 2007 CalVeg data set (USFS 1981) was identified as the best available coverage to initially define and map existing vegetation types within the Project area. CalVeg (2007) data includes polygons (minimum mapping unit of 2.5 acres) of different vegetation types delineated based using imagery from 2001 through 2007 using the National Vegetation Classification Standard hierarchy. Minor updates and refinements to the 2007 CalVeg spatial data included adjustments to vegetation polygon classes and boundaries based on aerial imagery (NAIP 2012, and NAIP 2014 where available) viewed at a scale of 1:3,000. Additional edits were made based on field observations conducted during January 2015.

A total of 30 polygons were ground truthed in January 2015 by two Stillwater Sciences botanists (Table 4-35). Sites were selected to ensure that the most common vegetation types were sampled, with priority given to vegetation types that occur within frequently flooded areas and that have the greatest potential effect on hydraulic roughness. Field sites were also selected in part, based on available access to private property and coincidence with geomorphic, hydraulic, and sediment transport data collection components of the Project. At each site visited, the field crew recorded information on vegetation type, stem number, stem size, percent cover of large woody debris that was over 4 inches in diameter and over two feet long, and percent plant cover. Crews also collected information on percent of bare ground in each site visited, as well as percent cover of large woody debris. Stems were defined as main stems as well as large to small branches. Stem density plots were selected to represent the variation in percent cover of these vegetation groups, so this variation is inherently incorporated into the stem density, size and height data.

Vegetation type was divided into four groups:

- Herbaceous plants (including grasses and weeds),
- Ferns (sword ferns, which are larger and stiffer than grasses and forbs),
- Brambles (including blackberry thickets which are woody but flexible and often grow horizontally), and
- Shrubs and Trees (ranging from willows to redwoods).

The number of stems in eight diameter classes observed in each of six height categories was recorded (see attached data sheet). Data were collected using a tablet with a downloaded datasheet for 20 out of a total of 31 mapped vegetation types in the updated CalVeg base map. Since three of these types are bare, vegetation parameters were assumed to be '0' and these types were not sampled in the field; these types are barren, reservoir, and beach sand.

[1] LCMMP is the Land Cover Mapping and Monitoring by the USDA Forest Service Region 5 Remote Sensing Lab and the California Department of Forestry and Fire Protection's Fire and Resource Assessment Program (FRAP). See more detailed description here: http://frap.cdf.ca.gov/projects/land_cover/.

NLCD is the National Land Cover Database (2001), a 16-class land cover classification scheme based on circa 2001 Landsat satellite data applied at a spatial resolution of 30 meters. See more detailed description here: http://www.mrlc.gov/nlcd2001.php.

CALVEG (Classification and Assessment with LANDSAT of Visible Ecological Groupings) is a map product from a scale of 1:24,000 to 1:100,000 produced by the USDSA Forest Service Remote Sensing Lab. See more detailed description here: http://www.fs.fed.us/r5/rsl/projects/gis/data/vegcovs/ncoast/ExistingVegNorCoastWest_2000_2007_v1.html.

Field data were downloaded from the tablet directly to an excel spreadsheet. Data from each field day were then compiled into a single worksheet and reviewed for errors and irregularities. We used pivot tables and standard excel formulas to calculate vegetation parameters by vegetation group (herbaceous, fern, bramble, and shrub/tree), and by vegetation type. All diameter and height numbers are reported as vegetation group averages (averages weighted by stem count) for each vegetation type. The vegetation group values were then combined into summary values for each mapped vegetation type (e.g., stem density as number of stems per square meter, stem diameter [weighted average], and stem height [weighted average]). Products include two shapefiles with vegetation types mapped for the Project area and two files with associated tabular data in Excel format. Attributes for each shapefile include vegetation type, acreage, average stem density (stems/m^2), average stem diameter (m^2), and average vegetation height (m).

Some vegetation types with shrubby understories have very dense networks of small diameter branches that contribute to hydraulic roughness. In summarizing these data into a single stem diameter value, these small, dense branches bring down the weighted average diameter for the whole site. In some cases, this analytical approach may misrepresent the actual dominant diameter of a site. For example, the average tree/shrub stem diameter comes out to 0.2 m in mature redwood stands with dense small shrub understories. Therefore, we report a second analytical approach in which we include only the number of main stems and large branches in calculating parameters for the Tree/shrub vegetation group. Comparison of the two approaches shows that densities decrease and diameters increase with ‘pruning.’ Vegetation types with a mix of trees and shrubs show the greatest difference in these two reporting methods.

The files named ‘Veg Full’ include stem density, diameter, and height based upon field measures of the all large to small diameter stems, including tree and shrub trunks, branches and twigs that contribute to hydraulic roughness. The files named ‘Veg Pruned’ include only measurements of main trunks and large branches in calculating parameters for the Tree/shrub vegetation groups. The two complete sets of data based upon slightly different sampling approaches offer flexibility in parameterizing the hydrodynamic model. In reviewing the scientific literature, we found both approaches applied and the difference not clearly articulated.

Table 4-35. Floodplain vegetation types mapped and field sampled within the Elk River Project area during January 2015.

Vegetation type	Acres mapped in 600 ft buffer of Project Area	Acres mapped in full Project Area	Percent of full Project Area	Number of field polygons sampled	Vegetation type to use where field data are absent
Agriculture (General)	40.69	108.16	3.67	1	
Annual Grasses and Forbs	70.50	217.54	7.39	2	
Apple Orchard	4.83	4.83	0.16	1	
Barren	1.19	14.44	0.49	0	Use ‘0’
Beach Sand	9.39	65.28	2.22	0	Use ‘0’
Big-Leaf Maple	0.40	0.40	0.01	1	
Black Cottonwood	17.90	18.05	0.61	0	Use Mixed riparian
Coyote Brush	1.57	1.81	0.06	1	
Evergreen Tree	0.38	0.38	0.01	0	Use Sitka spruce

Vegetation type	Acres mapped in 600 ft buffer of Project Area	Acres mapped in full Project Area	Percent of full Project Area	Number of field polygons sampled	Vegetation type to use where field data are absent
Mixed Riparian (Alder/Willow/Elderberry)	3.76	3.76	0.13	1	
Mixed Riparian (Cottonwood/willow/alder)	27.33	27.33	0.93	1	
North Coast Mixed Shrub	0	40.11	1.36		Use 'Coyote Brush'
Pastures and Crop Agriculture	325.13	1270.53	43.15	2	
Perennial Grasses and Forbs	0	0.81	0.03		Use 'Annual Grasses and Forbs'
Perennial Lake or Pond	0	11.32	0.38		Use 'Reservoir'
Pickleweed - Cordgrass	3.73	4.24	0.14	1	
Red Alder	134.47	167.62	5.69	3	
Red Alder-Elderberry	5.28	5.28	0.18	1	
Redwood	122.30	185.63	6.30	4	
Redwood - Douglas-Fir	27.25	47.13	1.60	1	
Reservoir	6.45	19.65	0.67	0	Use '0'
Riparian Tree	41.27	41.27	1.40	0	Use 'Mixed Riparian (Alder Willow/Elderberry)'
River/Stream/Canal	77.64	112.24	3.81	1	
Sitka Spruce	3.85	30.52	1.04	1	
Sitka Spruce - Grand Fir	4.28	41.53	1.41	1	
Sitka Spruce - Redwood	134.42	357.35	12.14	2	
Urban/Developed (General)	34.85	40.20	1.37	1	Use 'Pastures and Crop Agriculture'
Urban-related Bare Soil	0	18.07	0.61		Use 'Urban/Developed (General)'
Willow	27.38	38.63	1.31	3	
Willow (Shrub)	1.56	27.57	0.94	1	
Young Redwood	22.62	22.62	0.77	1	
Total	**1150.41**	**2944.33**	**100.0%**	**30**	

5 REFERENCES

Buchanan, T.J. and W.P. Somers. 1969. Techniques of Water Resource Investigations of the United States Geological Survey: Discharge Measurements at Gaging Stations Book 3 Application of Hydraulics. United States Government Printing Office, Washington 65 pp

Buffington, J., and D. Montgomery. 1999. A procedure for classifying textural facies in gravel-bed rivers. Water Resources Research 35:1,903–1,914.

Edwards, T.K., and G.D. Glysson. 1999. Field Methods for Measurement of Fluvial Sediment: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. c2, 89 pp

Mueller, D., and C. Wagner. 2006. Application of the loop method for correcting acoustic doppler current profiler discharge measurements biased by sediment transport. USGS Scientific Investigations Report 2006-5079. 18 pp.

Sanborn. 2005. Freshwater Creek Watershed and Elk River Watershed Tributaries of Humboldt Bay, California. LIDAR Campaign Final Report.

Solinst Canada Ltd. (2017, January 25). Solinst Levelogger Model 3001. Retrieved February 2017, from User Guide: Levelogger Series - Software Version 4.3.0: https://www.solinst.com/products/dataloggers-and-telemetry/3001-levelogger-series/operating-instructions/user-guide/3001-user-guide.pdf

USDA Forest Service (USFS). 1981. CALVEG: A Classification of California Vegetation. Pacific Southwest Region, Regional Ecology Group, San Francisco CA. 168 pp.

YSI Incorporated. (2012, March). 6-Series Multiparameter Water Quality Sondes User Maunal. Retrieved February 2017, from https://www.ysi.com/File%20Library/Documents/Manuals/069300-YSI-6-Series-Manual-RevJ.pdf

Attachments

Attachment A

Sample Data Sheets

CHANNEL SEDIMENT STORAGE AND BED SURFACE TEXTURE Page ______ of ________

Study site: ____ **Date:** ______________ **Crew:** ____________________________________
Reach endpoints: **Upstream** _________ **Downstream** _________ **Survey length:** _______________(ft)

#ID	Geom Feat	Strat	Surf Text		D_{16}	D_{50}	D_{84}	Ht abv thalw, ft	Activity	Wood Infl	Indicators of residence time				Notes
			Dom	Sub							veg	round	bright	sorting	

Geomorphic feature: mid-channel bar (MB), lateral or transverse bar (LB), point bar (PB), main channel bed (CB), side channel bed (HB), tributary delta (TD), floodplain (FB_1, FB_2, …), terrace (T_1, T_2, …), colluvium (C).

Stratified: If deposit is stratified, indicate strata from top to bottom (e.g., sa/gr/cbgr).

Surface texture: boulder (Bo), Cobble (Cb), Gravel (Gr), Sand (Sa), Silt (Si).

Activity: active (A) – moves RI 1-5 yr, no or sparse woody veg, low relief, bed material to annual scour depth; semiactive (SA) - moves RI 5-20 y, predom. woody rip. shrubs and small trees; inactive (IA) – moves w/RI 20-100, woody rip. trees and few upland species, Stable (S) – terrace deposits w/ no historical movement, upland veg.

Influenced by wood: indicate yes or no, upstream and/or downstream.

Vegetation: (1) bare, (2) predominantly herbaceous w/ limited woody riparian species, (3) young woody riparian encroachment, (4) dense/mature woody riparian w/ few upland species, (5) predominantly upland conifers and broadleaf trees and shrubs.

Ptx roundness: (1) angular, (2) subangular, (3) subrounded, (4) rounded. **Ptx brightness:** (1) light, (2) dark, (3) algae, (4) moss/lichen. **Ptx sorting:** (1) well sorted, (2) mod. sorted, (3) poorly sorted.

Additional comments:

____

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____

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Figure A-1. Blank data sheet used to describe sediment storage and bed surface texture at intensive study site inventory.

Bank Erosion and Vegetation

Page ___ of ___

Study Reach Name: _________________________. **Crew:** ___________________. **Date:** _________________.

Bank Conditions	**Bank A**	**Bank B**	**Bank C**	**Bank D**	**Bank E**
Bank height					
Bankfull height					
Bank material*					
Root depth					
Root density (%)					
Bank angle (degrees)					
Vegetation types					
Vegetation cover (%)					
Erosion activity level					
% of total study reach					
Notes					

*Bank material: bedrock (BR), boulder (Bo), cobble (Co), gravel (Gr), sand (Sa), silt and finer (Si). Indicate dominant and subdominant where appropriate (e.g., GrSa). Indicate stratification where appropriate (e.g., sand over gravel =Sa/Gr).

Bank Erosion Sites

Site ID#	**Height, ft**	**Length, ft**	**Composition**	**Mechanism**	**Delivery**	**Notes**

Figure A-2. Blank data sheet used to describe bank conditions and vegetation at intensive study sites.

LARGE WOOD

Page ______ of ________

Study site: ______________________ **Date:** ____________ **Crew:** ______________________

#ID	L ft	D, in	RW	Spec	Decay	Orient	Jam	Block	Stab	Input Mech	Pool Form	Sed Stor	Notes

Rootwad: indicate yes (Y), no (N).

Species: conifer (C), deciduous (D), unknown (U)

Decay: decay class: (1) sound, limbs present; (2) bark loose or absent, limbs absent, surface slightly rotted; (3) surface extensively rotted, center solid or rotted.

Orientation: perpendicular (P), angled downstream (D), angled upstream (U), bank parallel (B).

Jam association (3 or more key pieces): no jam (N), jam without racked material (J), jam with racked material (R). If jam, fill out

Blockage: indicate % of TOB width.

Stability: unstable (U) or stable (S) if rootwad present, banks or channel obstructions at more than one point, end anchored by streambed or bank burial, pegged by standing trees, and/or spanning.

Input mechanism: windthrow (W),bank undercutting (B), debris flow (D), landslide (L), tree mortality (M), unknown (U).

Pool formation: no influence (N), plunge pool (P), lateral scour pool (L), backwater pool (B)

Sediment storage: none (N), upstream (U), downstream (D). Indicate left bank (LB) vs right bank (RB).

Additional comments:

Figure A-3. Blank data sheets used to describe large wood pieces at intensive study sites.

Large Wood Jam

Page ______ of ________

Study Site: ________________________ **Crew**: ___________________________ **Date**: _____/______/______

ID# on Large Wood data sheet: ________.

Average height of jam above thalweg: _______ft.

Permeability (ratio of void area to overall jam area expressed as percent: ___________percent.

Tally "R" if rootwad is attached

Diameter	**Length**				
	3–10 ft (0.9–3.0 m)	**10–25 ft (3.1–7.6 m)**	**25–50 ft (7.7–15.2 m)**	**50–75 ft (15.3–22.9 m)**	**>75 ft (>23 m)**
6–12 in (10–30 cm)					
12–24 in (31–60 cm)					
24–36 in (61–90 cm)					
>36 in (>90 cm)					

Comments (include sketch below as needed):

Figure A-4. Blank data sheets used to describe large wood jams at intensive study sites.

Appendix F

Elk River Hydrodynamic and Sediment Transport Modeling Study in Support of Recovery Assessment