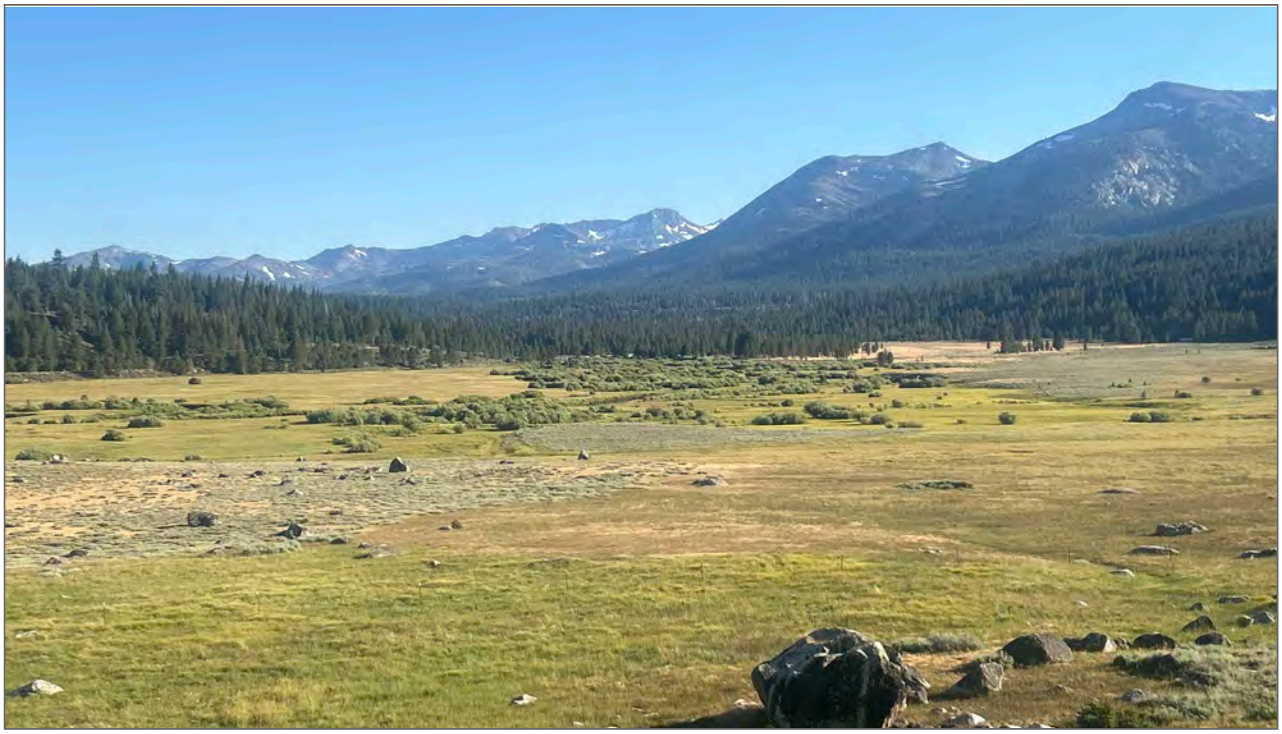
West Fork Carson Prioritization Project

DRAFT Findings and Planning Report



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1.0 INTRODUCTION

The West Fork Carson Prioritization Project (WFCPP) is a basin-scale planning effort designed to improve understanding of the sediment and geomorphologic system of the portion of the West Fork Carson River (WFCR) watershed that is in California (**Figure 1**), and to identify and prioritize stream restoration actions that could improve water quality. The project is led by Alpine Watershed Group (AWG) and funded in full, or in part, by the United States Environmental Protection Agency (EPA) and the State Water Resources Control Board (SWRCB) under the Federal Water Quality Management Planning Program (Clean Water Act Section 205[j]), with a matching contribution from the Carson Water Subconservancy District (CWSD).

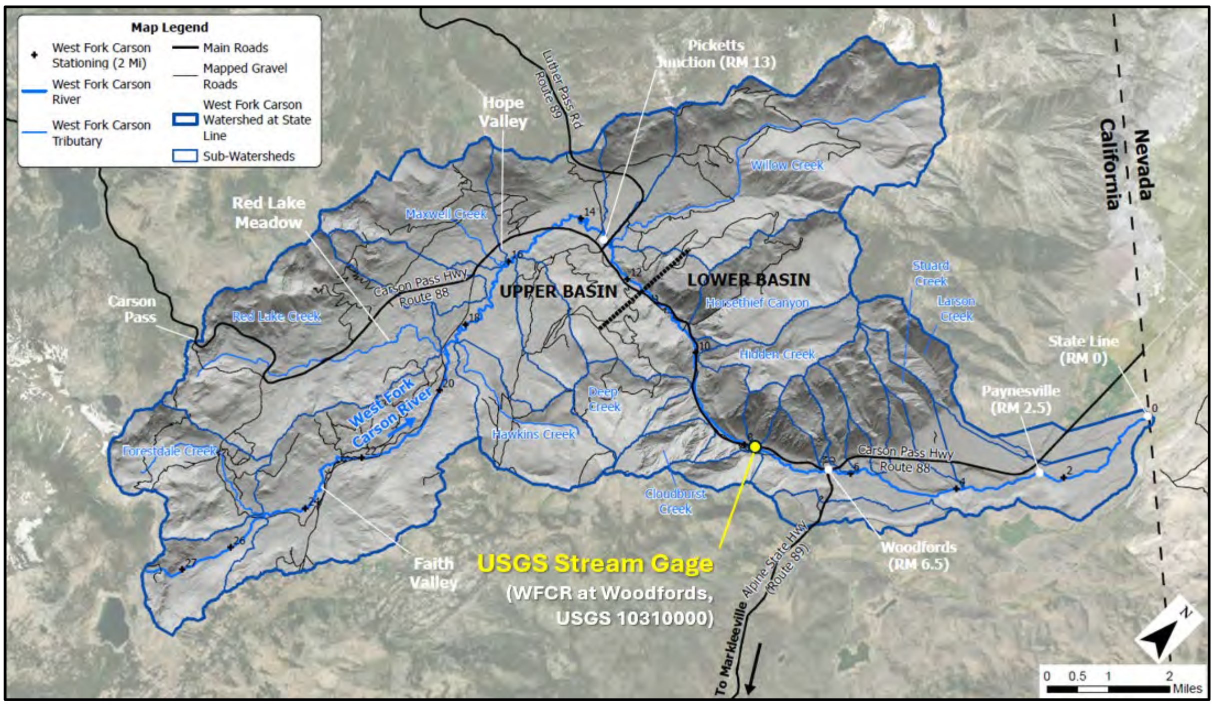


Figure 1. *Map of West Fork Carson River Watershed in Alpine County, California, Showing Subbasins and Some Key Features in the Watershed.*

The WFCR is listed in the 2018 California Integrated Report for Clean Water Act Sections 305(b) and 303(d) as impaired for multiple pollutants, including turbidity and sediment-related constituents such as phosphorus (SWRCB, 2021). In the 2023 West Fork Carson River Vision Plan, the Lahontan Regional Water Quality Control Board (Lahontan) emphasized the need for a “Geomorphologic Model and Prioritization Project” to better understand sediment sources and transport processes in the watershed and to identify which reaches or tributaries would be most beneficial to restore for water quality improvements (Lahontan, 2023).

This project focuses primarily on processes controlling fine sediment and turbidity, sediment-bound constituents, and, to a lesser extent, water temperature. Other water quality impairments, including dissolved nutrients, bacteria, and salts, are largely influenced by non-geomorphic processes and are outside the scope of this project.

1.1 GOALS, OBJECTIVES, AND OVERALL APPROACH TO PROJECT

The overarching goal of the WFCPP, as defined by AWG (2024), is to complete a geomorphological assessment and sediment transport planning model to:

1. Characterize sediment inputs and fluxes within the West Fork Carson River watershed to identify dominant sources and storage areas.
2. Develop a Prioritization Plan that recommends stream restoration and infrastructure projects based on quantified sediment processes, potential benefits to water quality, and feasibility.

Based on these objectives, the project contained two components:

Geomorphologic Model: A synthesis of field observations, topographic analysis, hydraulic modeling, and mapping to describe the physical processes controlling sediment transport in the watershed. This included identifying the key sediment sources, such as upland erosion and streambank erosion, downstream suspended sediment transport, and sediment storage within floodplains. The geomorphologic model includes a basin-scale hydraulic model and a "sediment budget" – a watershed-scale accounting of sediment sources, storage, and export. Results from the sediment budget directly inform project identification and prioritization by highlighting locations where interventions are likely to provide the greatest benefit.

Project identification and Prioritization: This part of the project identifies potential restoration projects in the basin, guided by the geomorphologic model and sediment budget results. Fifteen potential restoration projects were screened for physical feasibility, predicted water quality improvements, and other ecological and social factors. Projects were then evaluated using a multi-criteria scoring approach and stakeholder-informed weighting system called Multiple Accounts Analysis (MAA) to generate a prioritized set of potential restoration sites.

1.2 SCOPE OF REPORT

This report, and accompanying Appendices, document the methods and outcomes of the project and include:

- A discussion of watershed and reach-scale geomorphology and sediment processes,
- An explanation of the methods and findings of the sediment budget, including conclusions relevant to management and restoration,
- Identification of potential restoration projects to reduce fine sediment and provide other environmental and social benefits,
- Detailed descriptions and feasibility level evaluations of 15 potential projects,
- Landowner engagement and stakeholder input,
- The results of the prioritization and rankings of potential projects, and
- Discussion of the results of the rankings and recommendations for watershed-scale restoration planning.

To allow readers to review methods, analyses, and detailed results, much of the supporting information, including maps, hydraulic analyses, and detailed descriptions of potential projects, is provided in the Appendices. The Appendices are subdivided into two sections, corresponding to the two main components of the report:

Geomorphologic Model:

- **Appendix G-1:** A 21-page map book of the main stem WFCR and tributaries that shows the geomorphology of the streams in detail.
- **Appendix G-2:** Two, 21-page map books showing the extent and intensity of bank erosion along the WFCR and tributaries using two separate methods: the Bank Erosion Hazard Index (BEHI) (Rosgen, 2001), and a more subjective Bank Erosion Severity Index based on field observations from Summer 2024.
- **Appendix G-3:** A 21-page map book showing the modeled inundation extents of the 2-year, 10-year and 100-year recurrence interval floods along the mainstem WFCR and key tributaries.

Prioritization Plan:

- **Appendix P-1:** Detailed descriptions, information, evaluations and scoring for each of 15 potential projects.
- **Appendix P-2**: Results of a stakeholder engagement process, led by AWG, to understand the relative importance of different societal values (costs, benefits, risks, feasibility, recreational and aesthetic impacts) of restoration projects to key stakeholders in the watershed.
- **Appendix P-3**: An annotated slideshow presenting and explaining the MAA process, along with the results.

2.0 GEOMORPHOLOGIC MODEL

The geomorphologic model developed for the WFCR watershed is not a single, quantitative computer model, but rather an integrated synthesis of observations, measurements, analyses, and interpretations designed to explain how sediment is generated, transported, stored, and exported from the watershed. Based on field observations, data, and geological inference, a working hypothesis behind the geomorphologic model is that natural erosional and depositional processes that predominated in the upper WFCR basin have been modified by land use and/or geological changes, leading to changed patterns of erosion and deposition, and a major shift in the importance of different fine sediment sources in the watershed-scale sediment budget. The prevalence of thick deposits of fine sediment in the large glacial and structural valleys, such as Hope Valley, Faith Valley, Red Lake Creek, and other meadows, indicate that they were once major sediment sinks on the landscape. Presently, given the widespread prevalence of bank erosion in these valleys today, it seems clear that there was some kind of a shift from depositional to erosional conditions in these valleys.

The geomorphologic model aims to understand the current sources of fine sediment in the basin and combines several lines of evidence, including geologic mapping, topographic analysis, hydraulic modeling, field-based erosion assessments, historical aerial imagery, and long-term streamflow and sediment data. These lines of evidence are brought together to identify dominant geomorphic processes, constrain sediment sources and sinks, and explain observed patterns of erosion, deposition, and channel change throughout the basin – the central questions underlying whether and where stream restoration actions could be used to benefit water quality. A central element of this framework is the sediment budget (Section 2.4), which provides a quantitative accounting of the primary sediment sources, transport rates, and storage elements, and serves as the primary bridge between geomorphic understanding and restoration planning.

In addition to the analyses presented in the main body of this report, several components of the geomorphologic model are provided as standalone appendices intended to support future planning, design, and implementation efforts in the WFCR watershed (**Appendices G-1** through **G-3**).

2.1 GEOLOGIC OVERVIEW OF THE BASIN

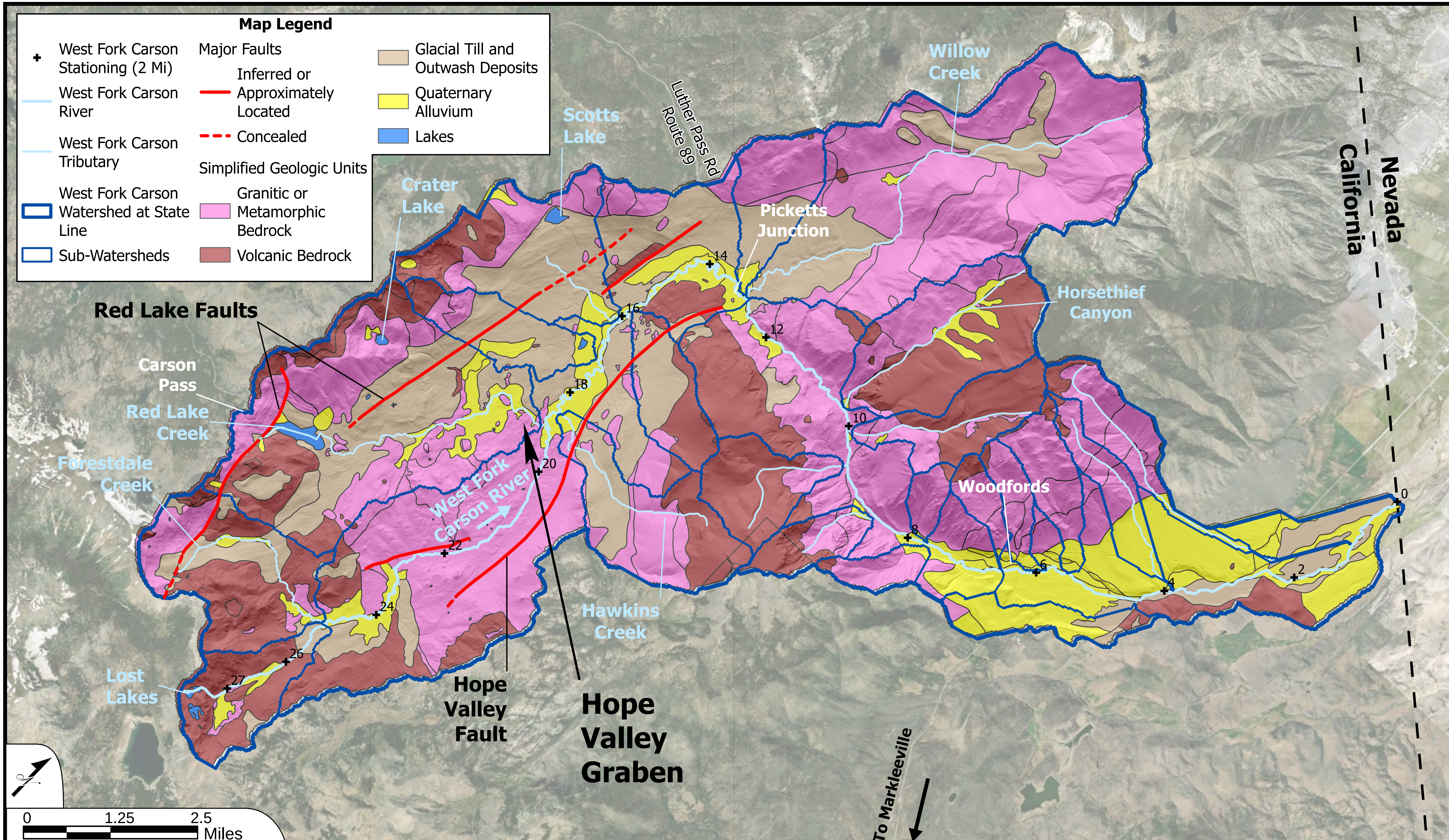
The geomorphic processes operating in the WFCR watershed, as well as the sediment budget, are fundamentally controlled by its geologic framework. **Figure 2** presents a modified geologic map of the basin based on mapping by Armin and John (1983) and Armin et al. (1984). For the purposes of this study, the numerous mapped geologic units were consolidated into four generalized categories, listed below in order of relative age (oldest first):

1. **Granitic and metamorphic rocks**
2. **Volcanic rocks**
3. **Glacial till and outwash deposits**
4. **Alluvial deposits**

The oldest rocks in the basin are crystalline **Mesozoic metasedimentary and granitic rocks**, primarily Cretaceous granitic rocks of the Sierra Nevada batholith. These crystalline rocks are relatively resistant to erosion and tend to produce coarse sediment (sand and gravel) where exposed. **Volcanic rocks**, including Miocene (10–15-million-year-old) volcanic flows and associated deposits, are also present in upland portions of the watershed, including high peaks such as Red Lake Peak, Stevens Peak, Round Top, and Little Round Top, which are all part of the Carson Pass volcanic center (Armin and John, 1983). These rocks have a range of erodibility depending on lithology and can weather to produce both coarse (gravel and larger) and finer grained sediment (silt and clay).

Overlying and inset into these bedrock units in the upper basin are extensive Quaternary **glacial till and outwash deposits**, particularly within Hope Valley and other broad valley bottoms. These deposits consist of poorly sorted material ranging from clay and silt to boulders, derived from glacial transport and deposition primarily during the Tioga and Tahoe glaciations (170,000 to 14,000 years old). Glacial till is generally more erodible than the underlying bedrock and contains abundant fine sediment that can be mobilized through gullying and bank erosion; whereas glacial outwash in the lower basin contains large boulders that line the channel bed and banks and prevent bank erosion. Therefore, the distribution of glacial till and outwash deposits is an important control on sediment supply in the basin.

The youngest geologic units are Holocene **alluvial deposits**, consisting of fluvial sand, gravel, and fine overbank sediments that form modern channel, floodplains, and terraces. These deposits are directly associated with active channel processes, mostly since the last glacial retreat, and represent both potential sources as well as long term storage reservoirs for fine sediment.



Simplified Geologic Map of the West Fork Carson River Watershed

(modified from Armin and John, 1983; Armin et. al, 1984)

West Fork Carson River Prioritization Project

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FIGURE 2

2..1 Tectonic Setting and Structural Controls

The WFCR watershed lies within the eastern Sierra Nevada–western Basin and Range transition zone, an area influenced by extensional tectonics. Hope Valley occupies a structurally controlled depression interpreted as a **graben**, bounded by normal faults (Hagan et al., 2009). Down-dropping of this structural block created accommodation space that was later modified by glaciers and filled with glacial and fluvial sediments. The graben structure helps explain both the broad valley morphology and the thick accumulation of unconsolidated sediment that now forms the eroding meadow banks.

Structural controls also influence channel gradient and base level. Downstream of Hope Valley, the river transitions into narrower, confined reaches that locally coincide with resistant bedrock or boulder-controlled valley constrictions. These controls limit lateral migration, prevent significant sediment storage, and influence upstream channel adjustments.

2.1.2 Paleocanyon Features

Hagan et al. (2009) describe evidence for an ancestral paleocanyon system within the region, carved into bedrock prior to glaciation and later partially filled with volcanic and sedimentary deposits. Portions of the modern WFCR occupy segments of this paleocanyon system. The presence of paleocanyon topography influences valley alignment, gradient transitions, and the distribution of unconsolidated deposits.

The bedrock framework, tectonic setting, paleocanyon development, and glacial history provide the geologic template upon which modern geomorphic processes operate. Differences in erodibility among granitic bedrock, volcanic units, glacial till, and alluvium directly influence patterns of bank erosion, sediment supply, and floodplain storage evaluated in the sediment budget (Section 2.4).

2.2 HYDROLOGY AND HYDRAULIC ANALYSIS

For the purposes of this report, *hydraulic analysis* includes two closely related components. The first is hydrology, which describes how much water enters the river system and when—ranging from large flood events to lower flows during dry periods. The second component is two-dimensional (2D) hydraulic modeling, which is used to understand where that water goes on the landscape, including the extent of flooding, water depths, and flow velocities within the channel and across floodplains. The 2D model is confined to the channels and adjacent floodplain areas and helps identify existing flow patterns in the WFCR watershed, where floodplain topography allows overbank flooding and sediment storage, and where it may be possible to influence these conditions to provide potential benefits.

This section begins with a summary of the high flow hydrology of the WFCR based on presently available data, followed by a description of the development and results of the basin-scale 2D hydraulic model.

2.2.1 Hydrology

For this assessment, the hydrology analysis mainly focused on higher flows in the WFCR watershed. Large flood events are particularly important in the geomorphic and sediment context of the WFCR.

High-magnitude flows mobilize large volumes of suspended sediment, drive bank erosion, allow floodplain sedimentation, and can produce significant channel adjustments. Flood events contribute disproportionately to long-term sediment export and channel changes.

Information on historic floods are available from long-term records at the U.S. Geological Survey (USGS) stream gage 10310000 – West Fork Carson River at Woodfords, CA. The gage is located approximately 8 miles upstream of the California–Nevada state line (**Figure 1**) and captures runoff and sediment contributions from the upper basin, including Hope Valley. The period of record includes the following active years: 1890–1891, 1901–1920, and 1937 to present, providing more than a century of peak flow data (**Figure 3**). This long record allows for a reliable analysis of flood magnitude, variability, and recurrence intervals relevant to sediment transport and floodplain inundation.

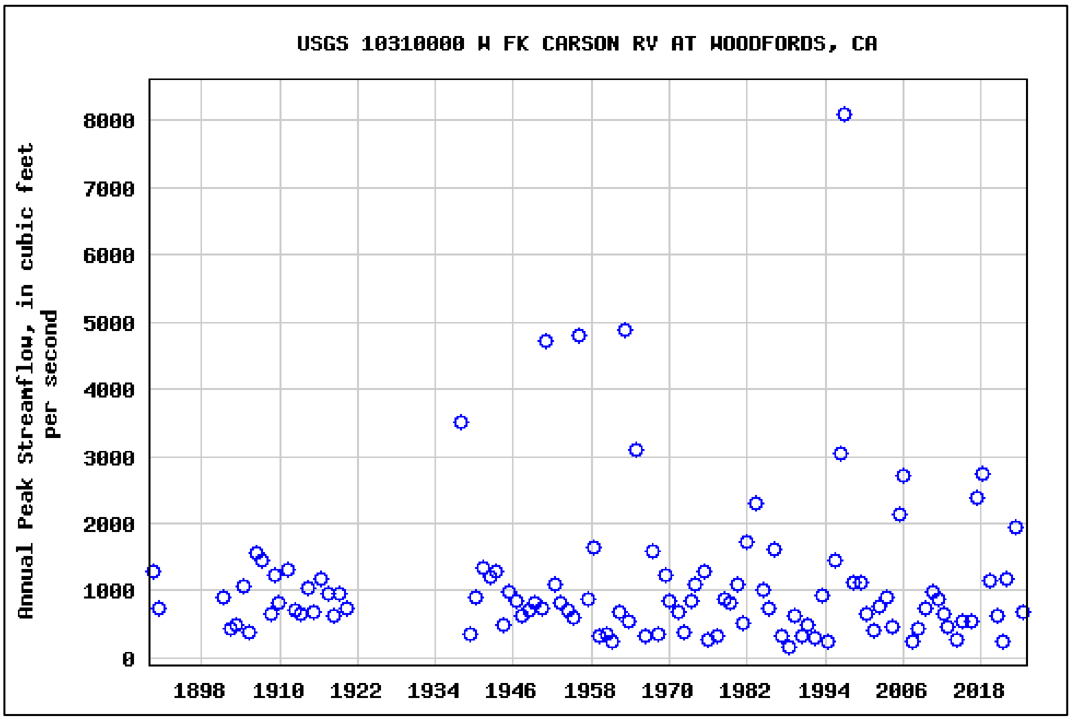


Figure 3. *Historic Water Year Peak Flows at the West Fork Carson River at Woodfords Gage (from USGS website)*

Table 1 lists the highest recorded peak flows during the period of record. The largest flood on record occurred on December 31, 1996, with a peak discharge of 8,100 cubic feet per second (cfs). This event was almost twice as large as the second-highest recorded flood (4,890 cfs in 1963). Notably, the seventh-largest flood in the record occurred earlier that same year, in May 1996, making calendar year 1996 an unusually extreme hydrologic year in the context of the full period of record.

Table 1. *Highest Historic Flow Peaks at USGS Gage on West Fork Carson at Woodfords (Active Years: 1890 – 1891, 1901 – 1920, 1937 - present)*

Date	Peak Flow(cfs)
12/31/1996	8,100
1/31/1963	4,890
12/22/1955	4,810
11/19/1950	4,730
12/10/1937	3,500
12/22/1964	3,100
5/15/1996	3,040
4/7/2018	2,750
12/30/2005	2,720
5/5/2017	2,380
5/28/1983	2,290

Peak flow frequency analysis was conducted using the U.S. Army Corps of Engineers Hydrologic Engineering Center Statistical Software Package (HEC-SSP). Results are presented in **Table 2**. Based on this analysis the estimated 100-year recurrence interval peak flow is close to 6,000 cfs, and the 2-year recurrence interval flow is around 800 cfs. The 2-year discharge was used in this study to delineate floodplain inundation areas for hydraulic modeling and sediment storage analyses (**Appendix G-3**).

Table 2. *Estimated Peak Flow Frequency in West Fork Carson River at Woodfords Gage*

Recurrence Interval	Peak Flow at USGS Gage[1]
1.25-yr	450
1.5-yr	550
2-yr	790
5-yr	1,510
10-yr	2,190
20-yr	3,030
50-yr	4,460
100-yr	5,840

Peak flows in the primary tributaries were evaluated using two methods (**Table 3**). The first method, referred to as the basin transfer method, uses the peak flows at the Woodfords gage, and applies a simple drainage area ratio adjustment to estimating peak flows on tributaries. The second method used regional regression equations developed by the USGS (Gotvald et al., 2012) in the StreamStats program (Ries et al., 2024). StreamStats estimates peak flood discharges based on watershed characteristics, with drainage area and mean annual precipitation serving as key input parameters.

Table 3 compares peak flow estimates generated using StreamStats with flows generated using the drainage-area-scaled flows derived from the Woodfords gage. The comparison shows the StreamStats estimates are significantly higher, typically by a factor of two, compared with those developed from the basin transfer method. StreamStats regression equations are based on statistical analyses of multiple gaged basins and represent average hydrologic behavior across a broad region. As such, they may not fully reflect local watershed conditions. The study area is primarily snowmelt-driven and includes meadow and floodplain storage that can attenuate peak flows. In contrast, the regional regression datasets used by StreamStats often include basins influenced by rainfall-driven runoff, which typically produce sharper and higher peak discharges. Consequently, StreamStats may overestimate peak flows for this type of watershed. Because the Woodfords gage is located within the basin and represents similar watershed conditions and local hydrology, and has a long period of record, the basin transfer method was used for this planning-level hydraulic model.

Table 3. *Estimated Tributary Flows for Hydraulic Model Input*

Percent Chance Exceedance			80	50	10	2	1
Return Int.			1.25	2	10	50	100
Location	Drainage Area (Sq-Mi)	Analysis	Flow (cfs)				
West Fork Carson at Woodfords, CA (USGS 10310000)	65.4	Bulletin 17B	449	789	2186	4459	5841
Headwaters to Below Willow Creek							
Upper West Fork Carson River	1.91	DA Ratio	13	23	64	130	171
		StreamStats	39	68.6	206	405	501
Forestdale Creek	3.6	DA Ratio	25	43	120	245	322
		StreamStats	64	112	336	660	816
Red Lake Creek	9.09	DA Ratio	62	110	304	620	812
		StreamStats	120	210	628	1230	1520
Hawkins Creek	2.94	DA Ratio	20	35	98	200	263
		StreamStats	46	81.4	244	480	595
Unnamed 1L	1.68	DA Ratio	12	20	56	115	150
		StreamStats	26	46.5	140	275	342
Maxwell Creek	3.63	DA Ratio	25	44	121	247	324
		StreamStats	57	101	303	596	738
Willow Creek	10.87	DA Ratio	75	131	363	741	971
		StreamStats	89	157	470	925	1150
Willow Creek to Woodfords Gage							
Horsethief Canyon	3.76	DA Ratio	26	45	126	256	336
		StreamStats	45	78.3	235	462	574
Hidden Creek	1.77	DA Ratio	12	21	59	121	158
		StreamStats	25	44.8	134	265	330
Deep Creek	1.68	DA Ratio	12	20	56	115	150
		StreamStats	28	49.4	148	292	363

2.2.2 Hydraulic Model Set Up

A two-dimensional (2D) hydraulic model was developed to simulate floodplain inundation patterns and flow dynamics throughout the WFCR watershed. The model domain and boundary conditions are shown in **Figure 4**. The model extends from the upper basin past the California-Nevada state line and includes the mainstem WFCR and major tributaries.

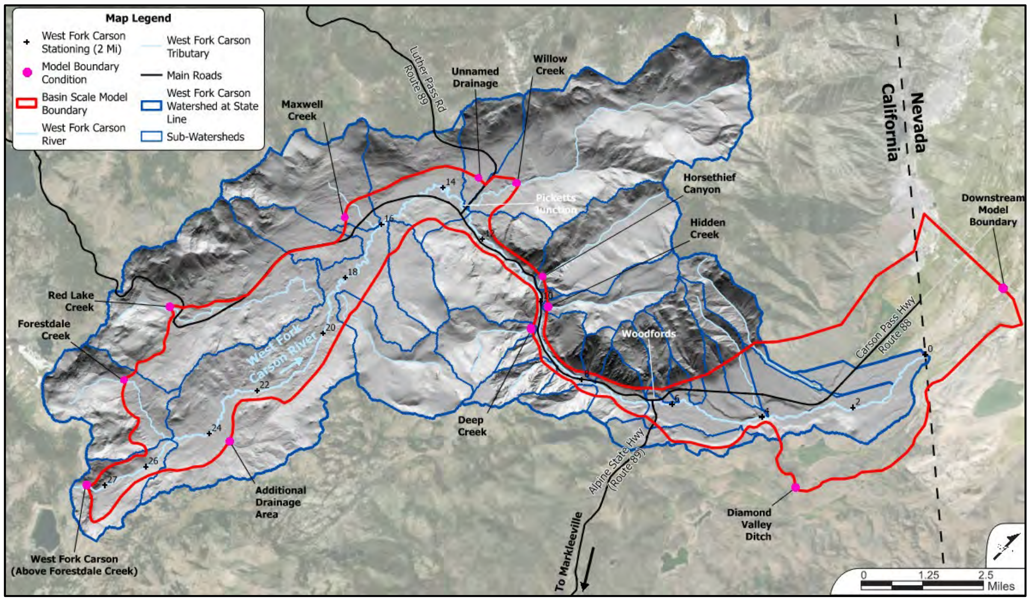


Figure 4. Basin-Scale Hydraulic Model Extent and Boundary Conditions

Topographic input for the hydraulic model was obtained from Sierra Nevada Work Unit 8 LiDAR data collected by NV5 Geospatial for the USGS. LiDAR acquisition occurred over two days in November 2021 and during multiple collection periods from June through August 2022. The 2022 dataset was used as the primary basis for terrain development. Minor terrain modifications were performed at select roadway crossings to hydraulically connect upstream and downstream flow paths where culvert information was unavailable. These edits were limited in scope and intended solely to prevent artificial flow obstructions in the model. Given the scope of the current project and the scale of the watershed, no supplemental ground survey data were incorporated into the modeling terrain. While this is appropriate for a planning-scale model, it is anticipated that site-scale modeling to support design work will require collection of ground-based survey data.

A two-dimensional computational mesh was developed with breaklines along channel banks to improve representation of channel geometry and hydraulic gradients. Finer mesh elements were applied within the active channel where hydraulic variability is greatest, while coarser elements were used across the overbank and floodplain areas to enhance computational efficiency without materially affecting model accuracy.

Boundary conditions consisted of flow hydrographs applied at the upstream limits of the mainstem and principal tributaries. Peak discharges for tributary inflows were estimated using a basin transfer method (**Table 3**). This approach assumes similar hydrologic response characteristics among subwatersheds and is considered appropriate for basin-scale planning analyses of this nature.

2.2.3 Hydraulic Model Results

Results of the basin-wide 2D hydraulic model are presented in **Appendix G-3** as a map book showing inundation extents for the 1-year, 2-year, and 10-year recurrence interval peak flows. These maps provide a spatial representation of where water spreads across the valley bottom under progressively larger flood events and were used to evaluate floodplain connectivity and restoration potential throughout the watershed.

Figure 5 presents two examples from the hydraulic modeling results map book. In this first example (**Figure 5A**), between Diamond Valley Road and the California-Nevada State Line, the modeled 1-year and 2-year flows are relatively confined to the existing channel and adjacent low surfaces. Except at a fan channel in the lower end of this reach, the 10-year flow does not spread extensively across the valley bottom. This pattern indicates that the reach is very incised relative to the adjacent floodplain, and efforts to reconnect the floodplain will require substantial "lift," raising the grade of the channel by 8 to 10 feet using boulders. In the second example (**Figure 5B**), Forestdale Creek and the West Fork Carson River converge in a narrow, bedrock-confined reach. Here, the channel is geologically confined and there is no floodplain. Below this, where the valley opens to upper Faith Valley, the model shows as the most upstream significant floodplain storage area in the watershed. In these areas, with a rise in the base level of 2 to 3 feet, the floodplain would more frequently inundate, capture fine sediment, temporarily store floodwater, and promote groundwater recharge.

Areas such as those identified with green arrows in **Figure 5** immediately identify potential restoration opportunities. Where the 10-year flood inundates large portions of the valley bottom, but smaller floods do not, relatively modest increases in channel bed elevation (e.g., on the order of 2–3 feet) could increase the frequency of overbank flow from once per decade to annual or near-annual events. Such changes would be expected to increase floodplain sediment deposition, improve hydrologic connectivity with the floodplain, and reduce bank erosion.

At the basin scale, these modeling results provided a screening-level tool for identifying reaches with the potential for increasing floodplain connectivity.

In addition to the basin-scale model, the hydraulic model was applied at a finer, site-specific scale to evaluate initial feasibility of specific restoration concepts. Smaller models were developed focusing on several areas of interest where multiple existing and proposed model runs were used to evaluate potential project opportunities. These site-specific models have higher resolution and shorter run times than the basin scale model, allowing multiple scenarios to be evaluated. These site-scale hydraulic analyses were used to estimate the amount of channel bed aggradation might be required to reconnect floodplains and to assess potential interactions with infrastructure or other constraints. The results of those site-scale evaluations are included in **Appendix P-1**.

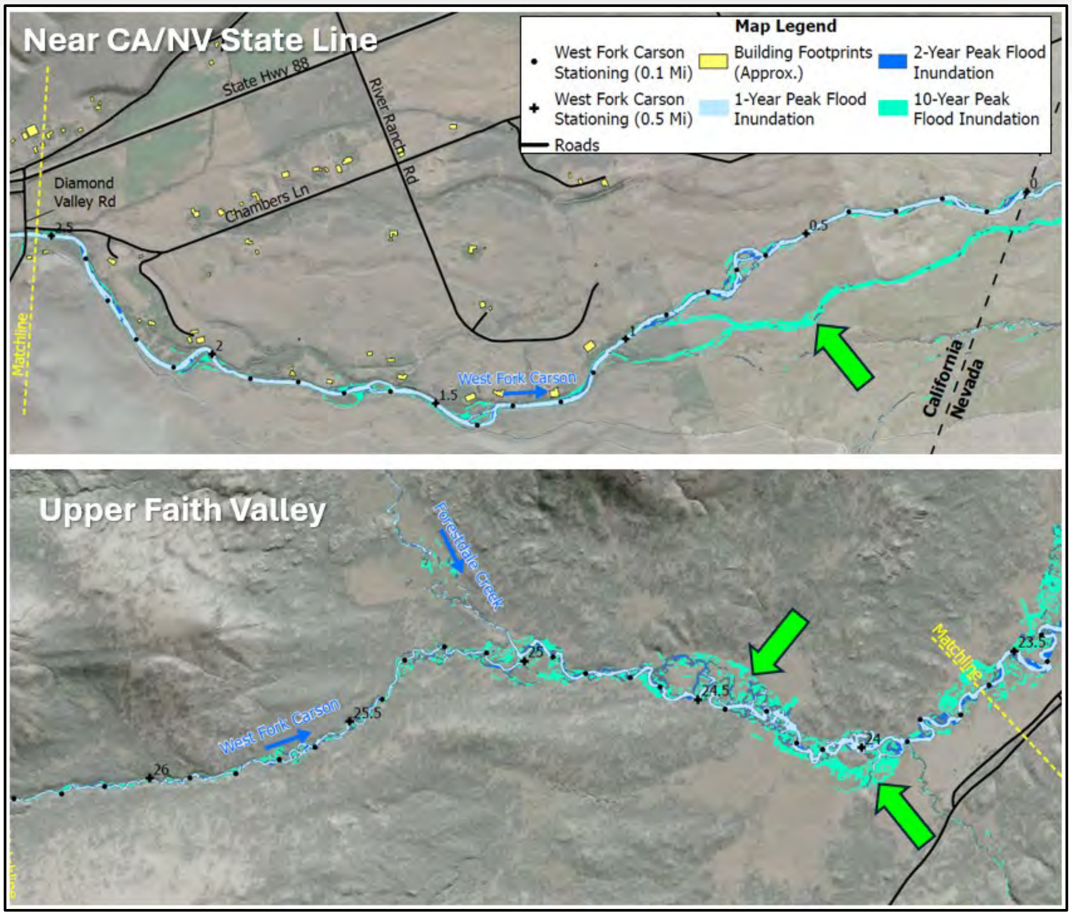


***Figure 5**. Hydraulic Model Results Showing Extent of the 1-Year, 2-Year and 10-Year Recurrence Interval Flows. (A) Near the California/Nevada State Line (B) Below the Confluence of Forestdale Creek and West Fork Carson River. Green arrows identify accessible floodplains that are inundated by the 10-year but not the 2-year floods.*

2.3 SEDIMENT BUDGET

A ***sediment budget*** is a quantitative accounting of sediment sources, storage, and transport within a defined spatial domain (like a watershed) over a specified time period (Dietrich and Dunne, 1978). A sediment budget provides a framework for evaluating how sediment is supplied to, stored within, and removed from a landscape, and for identifying which processes dominate sediment dynamics (Reid and Dunne, 2016). Sediment budgets can be useful as comparative and diagnostic tools, allowing managers to distinguish between dominant and secondary sediment sources of sediment, even if individual components of the sediment budget are not precisely known (Reid and Dunne, 1996).

A sediment budget for fine sediment was developed for the portion of the WFCR watershed in California. The sediment budget quantifies the sources, transport, and storage of fine sediment in the system (**Figure 6**). For this project, the purpose of the sediment budget is to provide a process-based foundation for identifying and prioritizing restoration actions that would reduce fine sediment delivery to the WFCR, and in turn, benefit water quality.

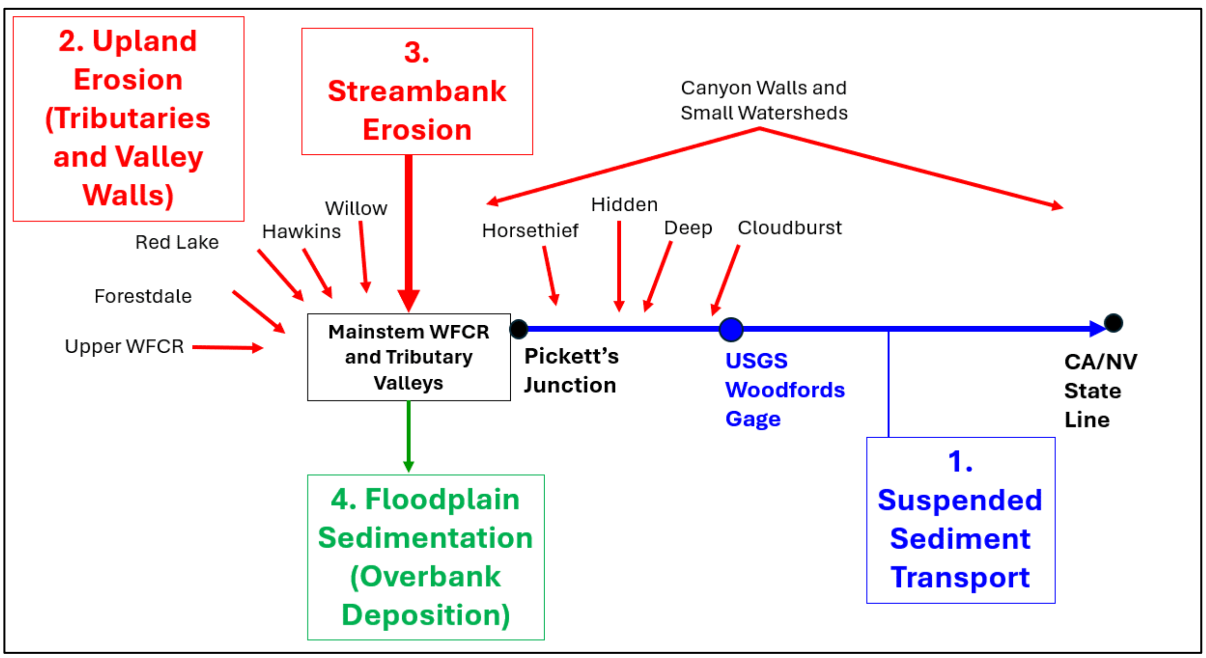


***Figure 6**. Sediment Budget Schematic for Fine Sediment in the West Fork Carson River. Red arrows are sediment sources, green arrow is sediment storage, and blue arrow represents sediment export from the basin via suspended load transport.*

The sediment budget in this study addresses fine_sediment (fine sand, silt, and clay) in the WFCR above the California/Nevada State Line and integrates four primary components (**Figure 6**):

(1) instream suspended sediment transport,
(2) upland erosion,
(3) streambank erosion, and

(4) overbank floodplain sedimentation[1].

Each of these components was estimated using methods appropriate for a basin-scale assessment, including regional empirical studies, local field observations, hydraulic modeling, historical aerial imagery, and long-term stream gaging records.

Uncertainties in the Sediment Budget. The objective of the sediment budget is not to produce a precise annual mass balance, but to constrain the relative magnitude and spatial distribution of sediment sources and sinks. Consistent with the guidance of Dietrich and Dunne (1978) and Reid and Dunne (1996), high levels of uncertainty are explicitly acknowledged for the sediment budget. For this project, the main purpose is to identify dominant processes rather than quantify exact fluxes.

2.3.1 Suspended Sediment Transport

The long-term suspended sediment transport in the WFCR was estimated using flow and sediment sampling data from the USGS gage at Woodfords (USGS Gage 10310000), supplemented with water quality monitoring from the Surface Water Ambient Monitoring Program (SWAMP), a program administered by the California State Water Resources Control Board to track trends in surface water health (SWRCB, 2023). The Woodfords gage provides a continuous record of streamflow and sediment downstream of Hope Valley, with data extending back to the late 1800s (see **Figure 3**). As is normally the case, suspended sediment concentrations (SSC) increase with flow, though considerable scatter exists, particularly during high-flow events (**Figure 7**).

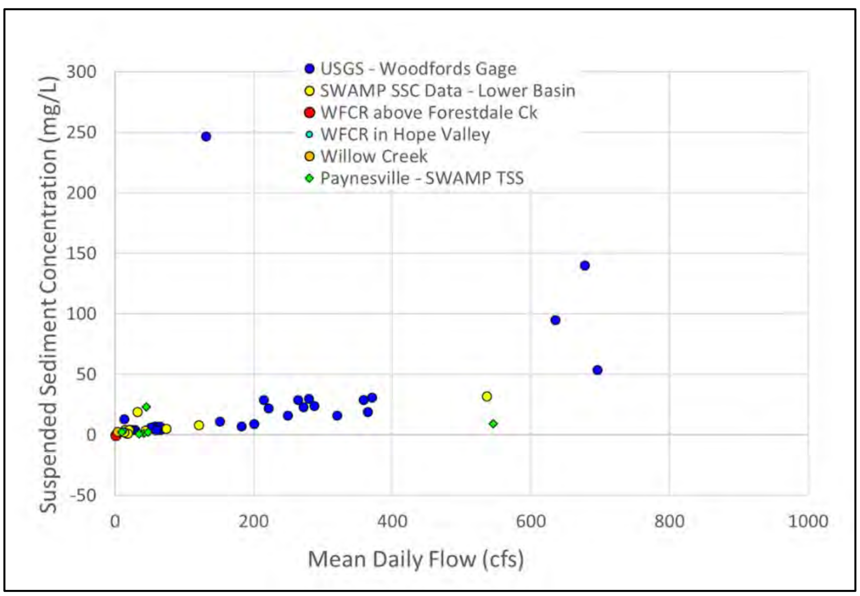


***Figure 7**. Suspended Sediment Concentration Data from Different Locations Around the WFCR Watershed*

[1] Component #4 (floodplain sedimentation or overbank deposition) was the most uncertain of the four components and the most time consuming to estimate in practice. Therefore, overbank deposition was not estimated independently but instead was solved from the other three components and reality checked with a simple calculation.

To estimate the long term suspended sediment flux, we combined the USGS SSC data along with SWAMP SSC data from the lower basin (**Figure 8**). These data show a clear steep increasing trend with discharge. This strong trend reflects that there must be a non-linear increase in the intensity in the processes supplying the fine sediment during higher flows.

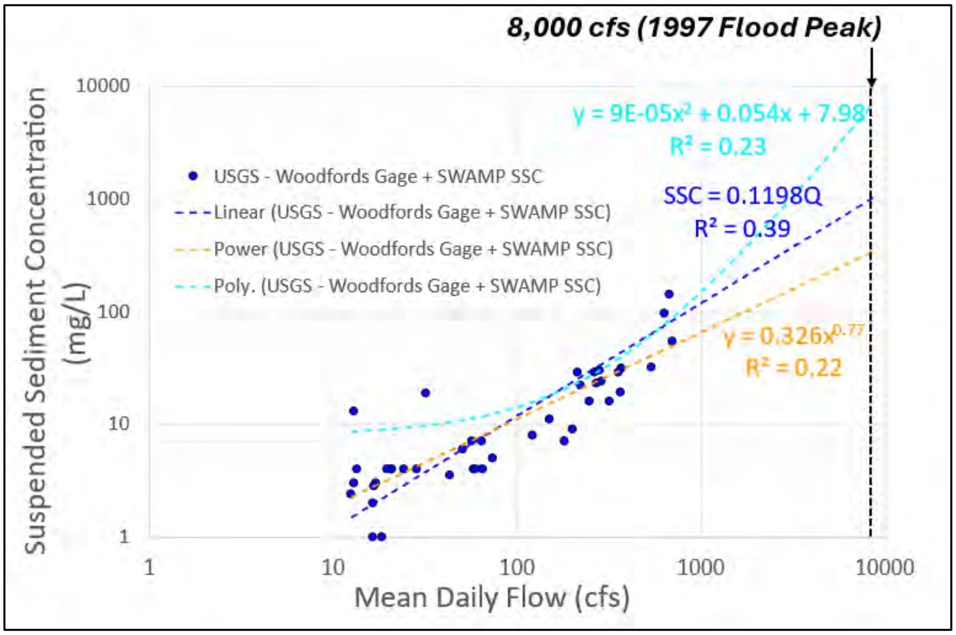


***Figure 8**. Suspended Sediment Rating Curves Versus Mean Daily Flow (data points are the combined data from USGS Woodfords gage and SWAMP SSC data from the Lower Basin)*

Several regression approaches were evaluated to quantify the SSC–flow relationship for estimating sediment flux. Power-law regressions are commonly used for rating curves, but this regression appears to underestimate the limited SSC data available for high flows (orange line, **Figure 8**). A second order polynomial regression (cyan line, **Figure 8**) increases more steeply with discharge and goes through the data at moderately high flows, but likely overestimates SSC during extreme events for which we have no data. The best fit ($R^2 = 0.39$) was found to be a linear regression with the intercept set to zero (blue line, **Figure 8**). The resulting equation (SSC [mg/L] = 0.1198 × Q [cfs]) appears to provide a more reasonable fit to the available data across the range of flow.

The three equations were applied to the mean daily streamflow data for the Woodfords gage, and the daily sediment fluxes were aggregated into water year sediment fluxes for more than century of record. Computed this way, the range of estimates for the long-term fine sediment flux at Woodfords spans approximately 3,000 to 6,000 tons per year (**Figure 9**, next page). The power-law model yields the lowest estimate (~3,000 T/yr) and, as explained in the previous paragraph, likely underestimates transport during high flows. For example, with that model the water year with by far the largest flood (WY 1997) only ranks as the fourth-largest water year in terms of sediment flux (**Figure 9A**), which is not realistic based on the expectation that sediment mobilizes disproportionately during the highest flows. In contrast, the polynomial model (~5,715 T/yr) may overestimate flux during extreme floods, resulting in a sediment flux for WY 1997 that is far outside the scale of the graph (**Figure 9C**). The linear model provides an intermediate estimate of 4,554 T/yr (**Figure 9B**). Based on these comparisons, **a reasonable round-number estimate for the long-term average fine sediment flux is approximately <u>5,000 tons per year</u>**, recognizing substantial uncertainty.

This estimate is considered more reliable than upland and bank erosion predictions because it is based on direct, long-term, local measurements of sediment transport, rather than the more indirect empirical models as discussed in the following sections. Thus, the estimate of 5,000 tons per year provides a reasonable, well-grounded estimate of the amount of sediment leaving the watershed, capturing the integrated effects of all upstream sources and storage reservoirs.

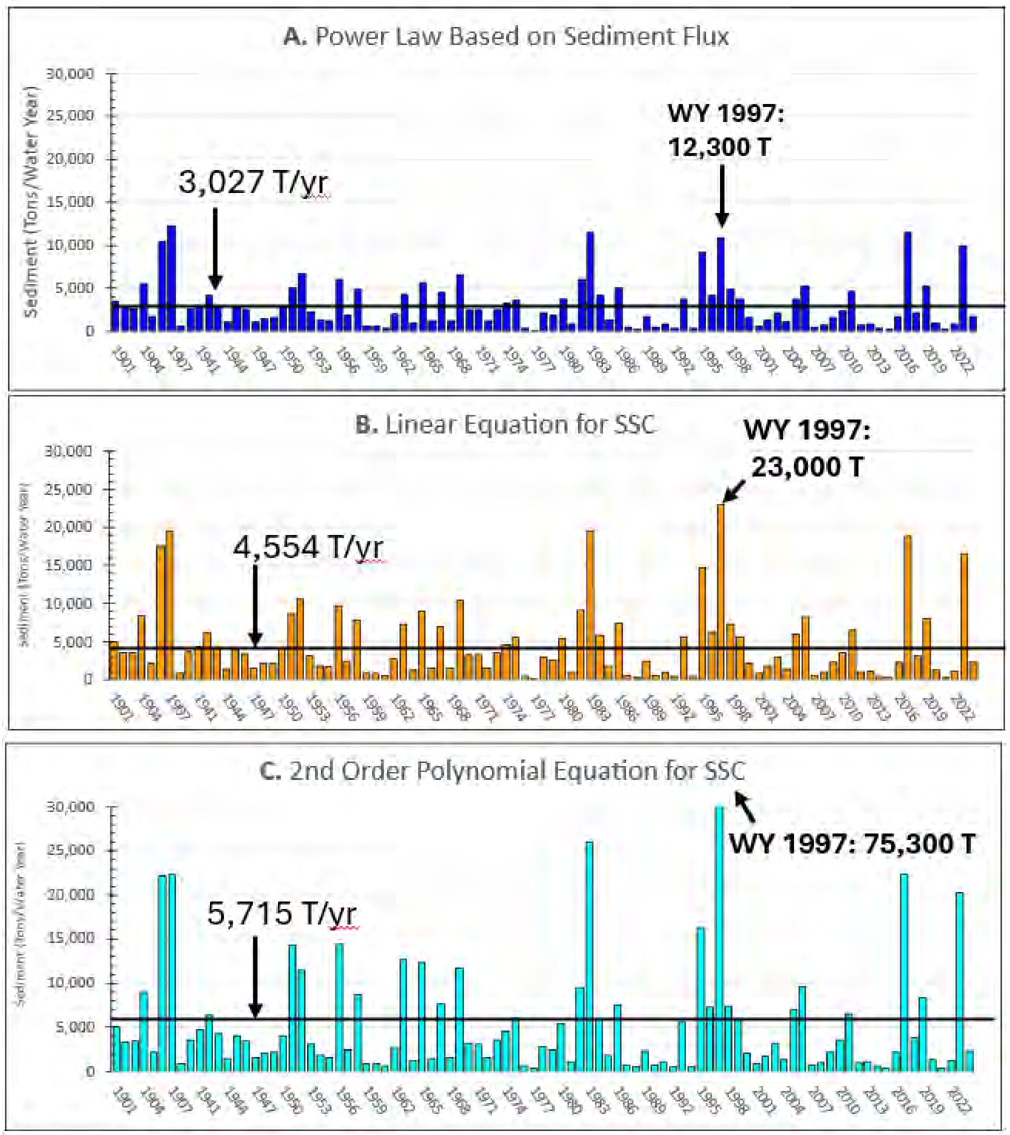


***Figure 9**. Annual Sediment Fluxes Computed Using Three Different Rating Equations: (A) Power Law Regression of Discharge Versus Sediment Flux; (B) Linear Regression Through 0,0 of Discharge Versus Suspended Sediment Concentration; (C) Second Order Polynomial for Discharge Versus Sediment Concentration*

2.3.2 Upland Erosion

Upland erosion represents the portion of the sediment budget derived from hillslopes, unchannelized drainage features, and headwater areas upstream of the actively incising and eroding stream network. Upland erosion consists of hillslope processes like gullying, landslides, rainsplash, rill erosion, wind erosion, and other processes (**Figure 10**). The upland erosion component of the sediment budget would be the primary part of the sediment budget affected by human and other perturbations, including logging, road building, and increased wildfire frequency. The upland-sourced sediment is transported downstream and delivered to the WFCR as tributary inflows and direct erosion from canyon walls (**Figure 6**).

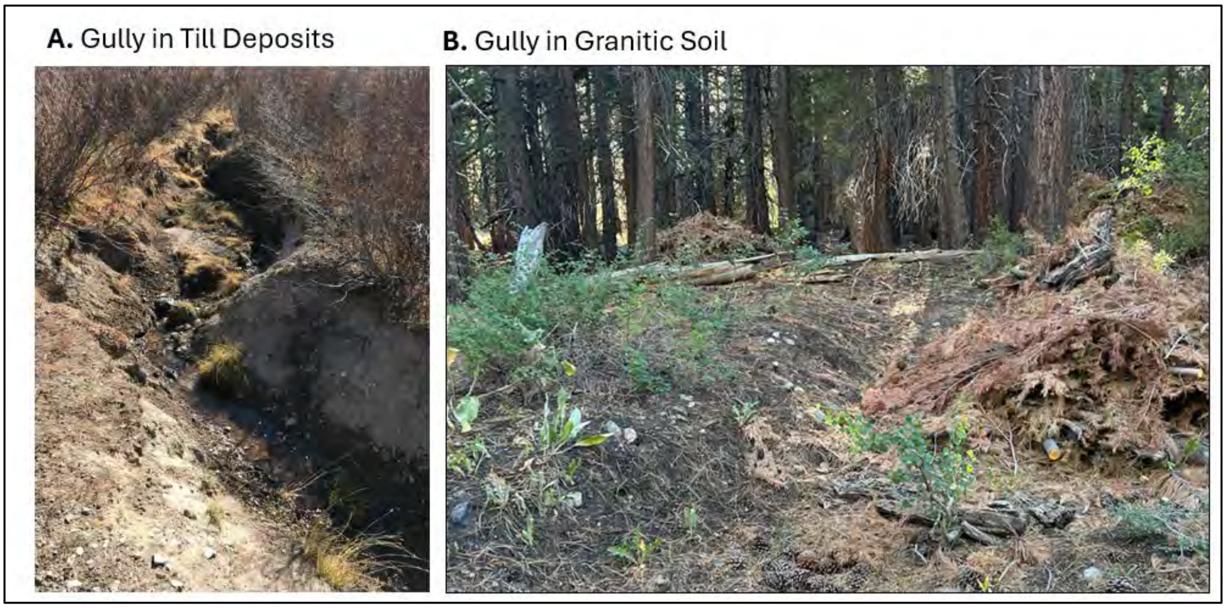


Figure 10*. Photos of Upland Erosion in the West Fork Carson River Watershed*

Estimates of upland erosion are based on an extensive study by Simon et al. (2004), which estimated fine sediment yields for watersheds in the Lake Tahoe region (**Figure 11**, next page). In that study, long-term streamflow and suspended sediment concentration data from a set of "index basins" were used to compute annual sediment yields, expressed as mass of suspended sediment (tons/yr). These basins span a range of basin size, but experience broadly similar climate, geology, precipitation regime, and relief as in the WFCR basin, making them suitable analogs for the current study.

Waterways conducted additional analyses of the Simon et al. (2004) dataset to better understand the factors controlling differences in upland sediment yield among the index basins. The index basins were grouped into three categories—high, medium, and low erosion—based on their reported sediment yields (**Table 4;** also see **Figure 2**). Comparison of basin characteristics suggested that geology may be a dominant control on erosion rates among these watersheds, given the relatively uniform climate and relatively similar topographic relief across the Lake Tahoe region (with exceptions).

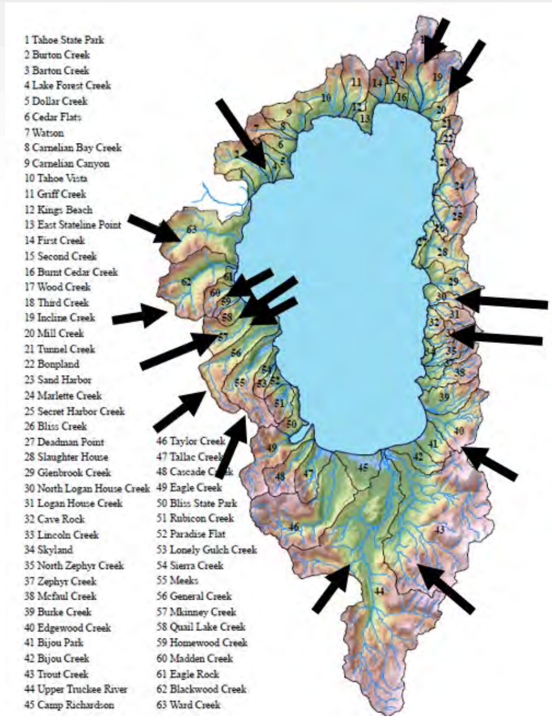


***Figure 11**. Tahoe Basin Watersheds from Simon et al. (2004). Black arrows added by Waterways identify the "index watersheds" in **Table 4**.*

To test this hypothesis, Waterways performed a GIS-based analysis of the geology of the index watersheds using the digital geology compilation of the Lake Tahoe basin (Saucedo, 2005; **Table 5**). The analysis grouped mapped units into four generalized categories: granitic rocks, volcanic rocks, glacial till, and alluvium. The relative proportion of these geologic units was calculated for each index basin and compared to the estimated sediment yields. Basins with a higher percentage of glacial till typically had higher sediment yields, while basins dominated by granitic or volcanic lithologies had lower erosion rates (**Table 4**). There were some exceptions and variations, typically related to land use and topographic features of the index basins. The index basins were grouped into three categories – high, medium, and lower eroding basins.

A parallel analysis was conducted for subwatersheds within the WFCR basin using the same geologic groupings. Based on the similarity of geologic composition, basin size, and topography between WFCR subwatersheds and the Lake Tahoe index basins, sediment yield values were assigned to each WFCR subwatershed by analogy (**Table 5**). These assigned yields, shown in **Figure 12**, represent long-term average upland sediment inputs and are intended to capture relative differences among subwatersheds, rather than precise annual loads. The resulting upland erosion estimates amount to **a long-term average upland fine sediment yield of about 1,400 tons/yr at the CA/NV State Line**. Importantly, **80 percent of this amount originates in the upper basin** (**Table 5**). These estimates provide a basin-scale characterization of sediment sources derived from hillslopes and headwater areas. While these estimates are subject to uncertainty, they use regional empirical data and provide a consistent framework for comparing upland sediment contributions across the WFCR watershed.

Table 4. *Geology and Sediment Yields in Tahoe Basin Index Watersheds (Simons et al., 2004)*

Index Watersheds	Generalized Geology by Watershed Area (computed by Waterways using geologic compilation by from Saucedo, 2005)							Sediment yields reported by Simon et al. (2004)					Computed by Waterways				Notes on Sediment Sources
	Drainage Area (mi2)	Drainage Area (km2)	Granitic and Meta-morphic	Volcanic	Till	Alluvium	Dominant Lithologies	Median Annual Total Suspended Load	Median Annual Fines Load	Total Suspended Sediment Yield	Total Fines Yield	Contributions from Streambanks to Fines Yield	Fines as a % of Sediment Yield	Upland Fines Yield (Total minus Banks)	Upland Sand Yield (Computed from % Fines in Total Load)	Upland Total Sediment Yield (Fines + Sand)	
(Sorted by Total Suspended Sediment Yield)								metric tons/yr	metric tons/yr	T/km2-yr	T/km2-yr	%	%	T/km2-yr	T/km2-yr	T/km2-yr	
Group A - Very High Upland Sediment Yields - Extensive Till and Gullying in Volcanics, Heavy Logging and Roads																	
Blackwood Creek	11.3	29.19	8%	57%	28%	7%	V, T	1930	846	66.55	29.17	51%	44%	**14.31**	**18.34**	**32.65**	Bank erosion and gullying in volcanic lithology
Third Creek	6.1	15.85	35%	13%	44%	7%	T, G	880	318	56.05	20.25	10%	36%	**18.23**	**32.22**	**50.45**	Extensive till deposits in lower watershed
Ward Creek	9.5	24.70	2%	39%	52%	7%	T, V	855	412	34.06	16.41	25%	48%	**12.31**	**13.24**	**25.55**	Extensive till deposits in lower watershed
Group A Average	*9.0*	23.25	15%	37%	41%	7%	T and V	*1,222*	*525*	*52*	*21.95*	*29%*	*43%*	***14.95***	***21.26***	***36.21***	
Group B - Moderately High Upland Sediment Yields - Extensive Till in Granitic Watersheds, Generally Larger Drainage Basins																	
Upper Truckee River	53.8	139.34	49%	9%	28%	13%	G, T	2200	1010	15.49	7.11	63%	46%	**2.61**	**3.08**	**5.69**	Major bank erosion, lots of till and alluvial deposits
Trout Creek	36.7	95.09	67%	0%	28%	5%	G, T	1190	462	12.51	4.86	2%	39%	**4.74**	**7.47**	**12.22**	Lot of till deposits
Incline Creek	6.6	17.17	61%	23%	8%	8%	G, V	217	129	11.99	7.13	4%	59%	**6.87**	**4.68**	**11.55**	Lot of till deposits
General Creek	7.6	19.68	54%	0%	37%	8%	G, T	176	53.3	9.12	2.76	45%	30%	**1.52**	**3.51**	**5.03**	Major bank erosion, lots of till and alluvial deposits
Meeks Creek*	8.2	21.36	76%	0%	21%	0%	G	79.8	19.1	3.59	0.86	0%	24%	**0.86**	**2.73**	**3.59**	Short data set - maybe should have a higher yield
Group 2 Average	*22.6*	58.53	61%	7%	25%	7%	G and T	*773*	*335*	*11*	*4.54*	*23%*	*40%*	***3.32***	***4.30***	***7.62***	
Group C - Low Upland Sediment Yields - Granitic Watersheds, Relatively Little Till																	
Eagle Creek*	7.0	18.05	93%	0%	2%	1%	G	69.9	21.8	3.43	1.07	69%	31%	**0.34**	**0.74**	**1.08**	Very low sed yield (granite)
Edgewood Creek	3.1	7.92	95%	0%	0%	5%	G	21.3	11.4	2.63	1.41	18%	54%	**1.15**	**1.00**	**2.15**	Very low sed yield (granite), relatively high % bank erosion
Quail Lake*	1.2	3.19	14%	29%	52%	3%	T	6.4	3.2	1.52	0.76	0%	50%	**0.76**	**0.76**	**1.52**	Small watershed domninated by till, but low yield
Dollar Creek*	1.1	2.96	0%	100%	0%	0%	V	4.6	2.6	0.98	0.55	4%	57%	**0.53**	**0.41**	**0.94**	
Glenbrook Creek	4.3	11.07	47%	49%	0%	4%	G/V	8.9	7	0.85	0.67	46%	79%	**0.36**	**0.10**	**0.46**	Very low sed yield, high % bank erosion
Logan House	2.1	5.42	99%	0%	0%	1%	G	3	2.3	0.56	0.43	1%	77%	**0.42**	**0.13**	**0.55**	
Group 3 Average	*3.1*	8.10	58%	30%	9%	2%	G and V	*19*	*8*	*2*	*0.81*	*23%*	*58%*	***0.59***	***0.52***	***1.12***	

* denotes watersheds with only 3 years of data (the rest are all > 11 years of data)

Table 5. Sediment Yields from Upper West Fork Carson River Watershed

Watershed	Drainage Area	Drainage Area	Granitic/ Metamorphic	Volcanic	Till	Alluvium	Water	Dominant Lithologies	Index Watershed(s) with Similar Geology	Index Upland Fines Yield	Index Upland Sand Yield	Index Upland Total Yield	Upland Fines Loading	Upland Sand Loading	Total Upland Suspended Sediment Supply	Total Upland Suspended Sediment Supply	Percent of Overall Upland Fine Sediment Supply at State Line
	(mi^2)	(km^2)	*Percentage of Drainage Basin*							T/(km^2-yr)	T/(km^2-yr)	T/(km^2-yr)	T/yr	T/yr	T/yr (1,000 kg)	tons/yr (2,000 lb)	
Headwaters to Below Willow Creek																	
West Fork Carson River ab Forestdale	1.91	4.94	4%	77%	8%	9%	2.3%	V	Group B average	3.32	4.30	7.62	16.42	21.23	37.65	**42**	3%
Forestdale	3.60	9.31	21%	55%	20%	4%	0.2%	V	Group B average	3.32	4.30	7.62	30.93	40.00	70.93	**78**	6%
Red Lake Creek	9.09	23.54	37%	20%	33%	9%	1.6%	G,T	Group B average	3.32	4.30	7.62	78.17	101.09	179.25	**198**	14%
Hawkins Creek	2.94	7.62	42%	28%	26%	3%	0.0%	G,V,T	Group B average	3.32	4.30	7.62	25.31	32.73	58.04	**64**	5%
Stevens Creek	1.64	4.26	16%	13%	58%	12%	0.6%	T	Group B average	3.32	4.30	7.62	14.14	18.29	32.44	**36**	3%
Unnamed 1L	1.68	4.34	61%	1%	34%	4%	0.0%	G, T	Group B average	3.32	4.30	7.62	14.43	18.66	33.08	**36**	3%
Maxwell	3.63	9.40	25%	22%	47%	6%	1.1%	T,G,V	Group B average	3.32	4.30	7.62	31.21	40.36	71.57	**79**	6%
Unnamed 2R	1.49	3.86	10%	37%	53%	0%	0.0%	T,V	Group B average	3.32	4.30	7.62	12.83	16.59	29.42	**32**	2%
Willow	10.87	28.14	78%	0%	21%	1%	0.0%	G,T	Group B average	3.32	4.30	7.62	93.48	120.88	214.36	**236**	17%
Additional Drainage Area	13.50	34.96						G, T	Group B average	3.32	4.30	7.62	116.10	150.14	266.24	**293**	22%
	50.34	130.38	45%	20%	28%	6%	0.5%	G, T	**Above Mouth of Willow Creek**				**433**	**560**	**993**	**1,095**	**80%**
Willow Creek to Woodfords Gage																	
Horsethief	3.76	9.75	38%	53%	0%	8%	0.0%	V,G	Group C average	0.59	0.52	1.12	5.78	5.09	10.87	**12**	0.9%
Hidden	1.77	4.60	28%	72%	0%	0%	0.0%	V,G	Group C average	0.59	0.52	1.12	2.73	2.40	5.13	**6**	0.4%
Deep	1.68	4.35	14%	86%	0%	0%	0.0%	V,G	Group C average	0.59	0.52	1.12	2.58	2.27	4.85	**5**	0.4%
Cloudburst	0.90	2.34	45%	52%	0%	3%	0.0%	V,G	Group C average	0.59	0.52	1.12	1.39	1.22	2.61	**3**	0.2%
Unnamed 3R	0.58	1.51	84%	9%	0%	7%	0.0%	G	Group C average	0.59	0.52	1.12	0.90	0.79	1.69	**2**	0.1%
Unnamed 4L	0.43	1.11	93%	5%	0%	1%	0.0%	G	Group C average	0.59	0.52	1.12	0.66	0.58	1.24	**1**	0.1%
Additional Drainage Area	6.01	145.95						V, G	Group C average	0.59	0.52	1.12	86.57	76.20	162.77	**179**	13.2%
	65.48	169.61	46%	26%	22%	6%	0.4%	V,G	**Willow Creek to Woodfords**				**101**	**89**	**189**	**209**	**15%**
Woodfords to Paynesville																	
Unnamed 5L	0.53	1.36	75%	24%	0%	1%	0.0%	G	Group C average	0.59	0.52	1.12	0.81	0.71	1.52	**2**	0.1%
Unnamed 6L	0.68	1.75	84%	8%	0%	8%	0.0%	G	Group C average	0.59	0.52	1.12	1.04	0.91	1.95	**2**	0.2%
Unnamed 7L	1.20	3.11	82%	9%	0%	9%	0.0%	G	Group C average	0.59	0.52	1.12	1.84	1.62	3.47	**4**	0.3%
Unnamed 8R	1.09	2.81	7%	6%	17%	70%	0.0%	Alluvium	Group B average	3.32	4.30	7.62	9.34	12.08	21.42	**24**	1.7%
Stuard	1.13	2.94	62%	6%	0%	33%	0.0%	G	Group C average	0.59	0.52	1.12	1.74	1.53	3.27	**4**	0.3%
Additional Drainage Area	4.15	10.76						V, G	Group C average	0.59	0.52	1.12	6.38	5.62	12.00	**13**	1.0%
	74.26	192.33	45%	24%	20%	11%	0.3%	G	**Woodfords to Paynesville**				**21**	**22**	**44**	**48**	**4%**
Paynesville to State Line																	
Larson	1.13	2.93	76%	12%	1%	11%	0%	G	Group C average	0.59	0.52	1.12	1.74	1.53	3.27	**4**	0.3%
Additional Drainage Area	2.79	7.23						V, G	Group C average	0.59	0.52	1.12	4.29	3.77	8.06	**9**	0.7%
	78.18	202.49	44%	23%	20%	12%	0.3%		**Paynesville to State Line**				**6**	**5**	**11**	**12**	**1%**
													Fines	**Sand**	**Total**		
									Entire Watershed above State Line				**561**	**676**	**1,237**	**1,364**	**100%**
													T/yr	**T/yr**	**T/yr**	**tons/yr**	

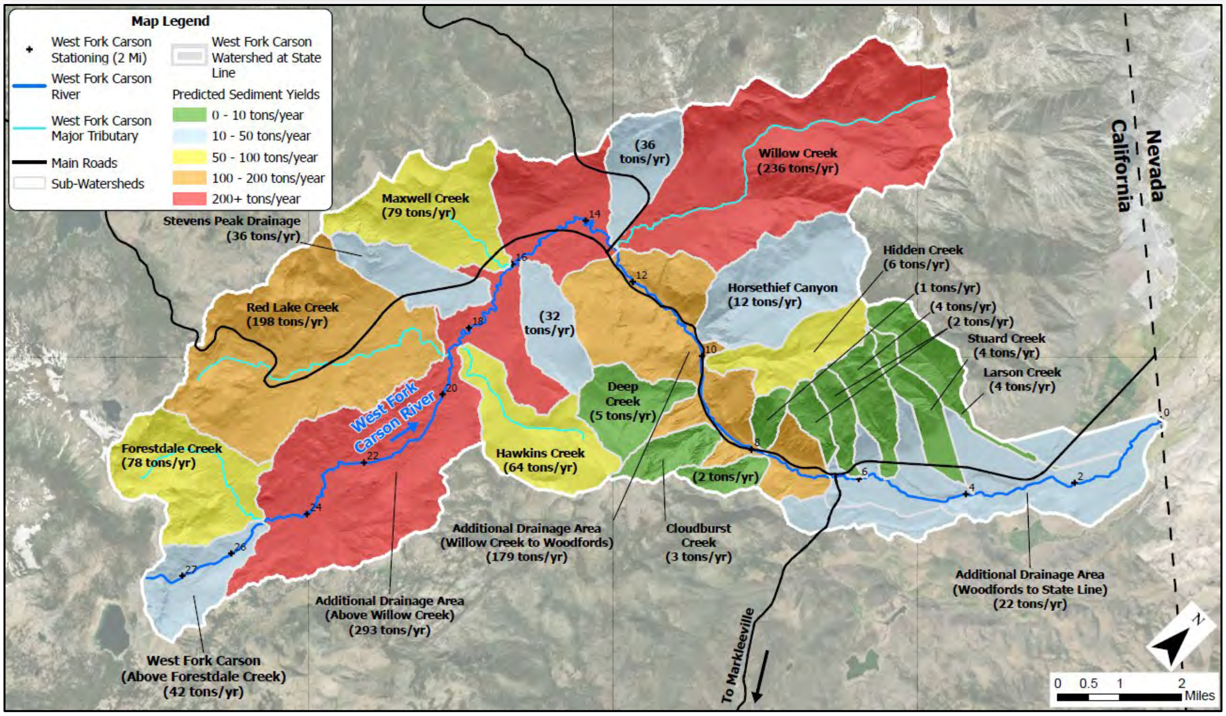


Figure 12*. West Carson Watershed Map Showing Upland Erosion Amounts*

2.3.2 Streambank Erosion

Streambank erosion represents a major source of fine sediment to the WFCR, as can be seen in the field (**Figure 13**). For the purposes of the sediment budget, estimating the amount of fine sediment contributed by bank erosion was done using a combination of field-based indices, empirical relationships, and analysis of historical channel change. Because of the importance of streambank erosion to the sediment budget and to restoration objectives in the WFCR basin, multiple complementary methods were used to constrain reasonable estimates of the approximate magnitude and spatial pattern of bank erosion in the watershed.

***Figure 13**. Bank Erosion Along WFCR in Hope Valley (photo provided by AWG).*

BEHI-Based Estimates of Bank Erosion

One method used to estimate bank erosion rates was a field-based assessment developed by Rosgen (2002), known as the Bank Erosion Hazard Index. The first part of the calculation consists of estimating the Bank Erosion Hazard Index (BEHI), which describes the susceptibility to erosion of bank sections based on combining field data from the WFCR with a set of curves provided by Rosgen (2001). BEHI integrates measurements of bank height, bank angle, root density, surface protection, bank material, and other field evidence into a single index score that is classified into hazard categories ranging from "Very Low" to "Extreme" (**Figure 14**). The field data to compute BEHI were collected along the WFCR mainstem and selected tributaries during summer 2024 by Waterways, Alpine Watershed Group, and Watershed Resiliency Consulting. A full basin map book with BEHI ratings is provided in **Appendix G-2**.

Rosgen (2001) developed empirical relationships linking BEHI ratings to linear bank erosion rates based on datasets from streams in Yellowstone National Park, Montana, and the Front Range in Colorado. Applying these relationships to the WFCR resulted in estimated bank erosion rates for each bank segment. These estimates can be compiled and shown as a plot of cumulative erosion versus river mile to highlight areas along streams where erosion is concentrated (**Figure 15**).

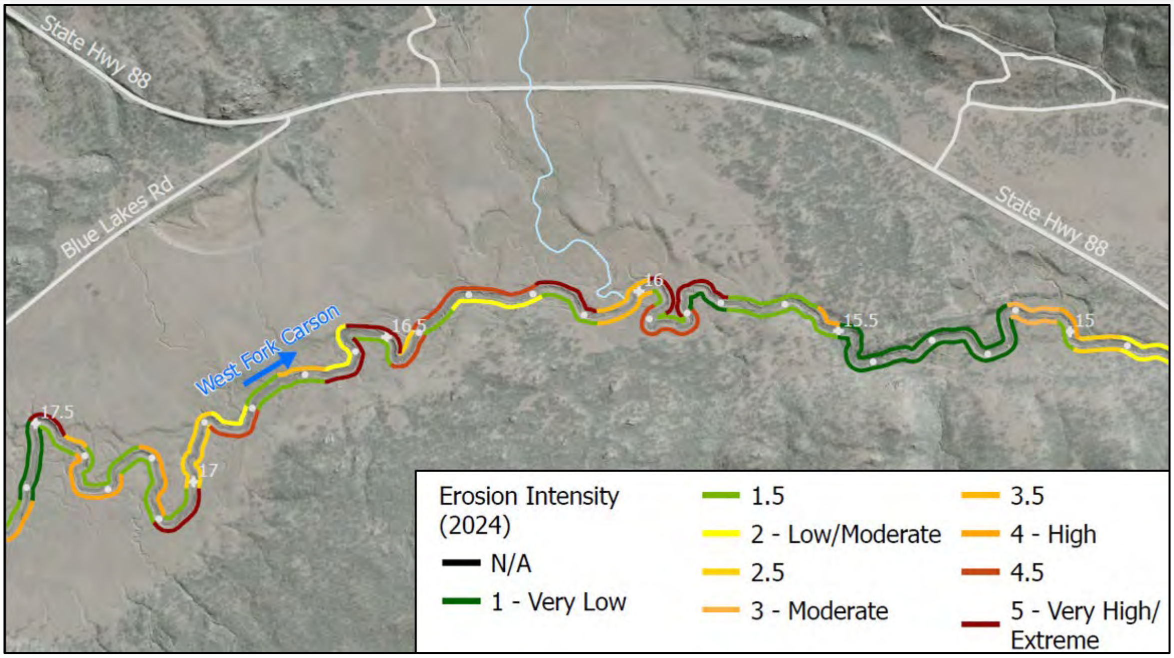


***Figure 14**. Example of Bank Erosion Mapping in Lower Hope Valley*

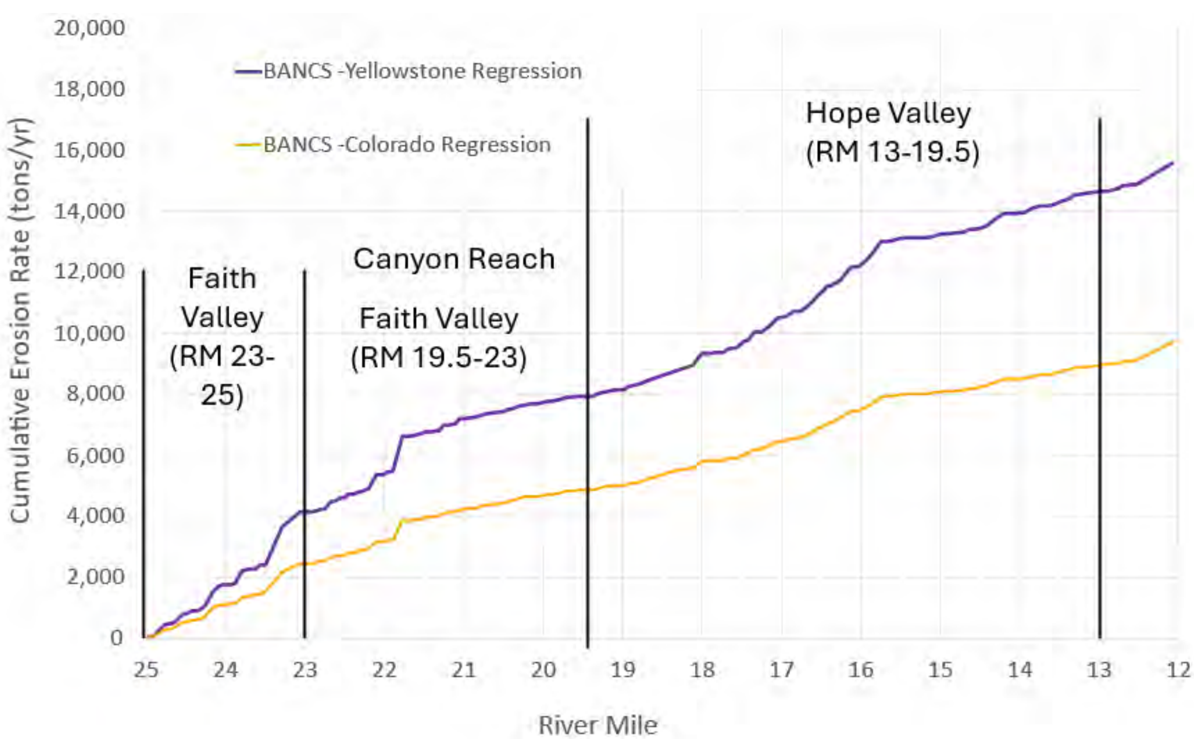


***Figure 15**. Amount of Bank Erosion Estimated Using of Rosgen's (2001) Methods on Mainstem WFCR. Data plotted as a cumulative amount of bank erosion moving from upstream to downstream. No bank erosion occurs downstream of RM 12 due to boulder-lined banks. Tributary bank erosion is not included in this graph.*

Based on the Rosgen (2001) method, bank erosion in the WFCR basin is estimated at 18,000 tons per year using the Yellowstone curve, and 12,000 tons per year using the Colorado curve (**Table 6**).

These estimates appear unrealistically high when compared to independent estimates of suspended sediment flux. The estimated fine sediment load passing the Woodfords gage is on the order of 5,000 tons per year (see **Figure 9**), much lower than the BEHI-predicted bank erosion rates. Although bank erosion is clearly a major sediment source, it is not physically reasonable for bank erosion to be 2- to 4-times greater than the annual sediment load leaving the basin. Because the sediment transport estimates are derived from long-term, site-specific gaging and sampling data, they are considered more reliable than the bank erosion rates derived from empirical relationships developed in other regions. This discrepancy motivated the development of an alternative approach to estimating bank erosion using local data.

Table 6. *Bank Erosion Rates Computed Using the Rosgen (2001) Method*

Stream	Stream Length	BEHI/BANCS Yellowstone Equation	BEHI/BANCS Colorado Equation
	mi	tons/yr	tons/yr
West Fork Carson[1]	13.35	15,600	9,739
Forestdale Creek	2.3	412	346
Red Lake Creek	2.91	1,603	1,203
Willow Creek	2	610	475
West Fork Carson River Basin		**18,225**	**11,763**
Notes:			
1. West Fork Carson River below Woodfords Canyon does not contribute to basinwide bank erosion because the banks are continuously lined with glacial outwash boulders.			

Bank Retreat Rates from Historical Aerial Photography

To develop a more realistic estimate of bank erosion, historical aerial imagery was combined with field-based erosion observations. Historic air photos showing the WFCR channel in Hope Valley are available on Google Earth dating back more than 80 years. Changes in channel position in sequential air photos provide a direct record of bank retreat rates. We selected two representative reaches (lower Hope Valley and lower Red Lake Creek) and digitized the location of stream banks on both sides of the channel from four sets of aerial photographs (approximately 1940, 1992, 2010, and 2024/2025) (**Figure 16**).

To develop a relationship for estimating bank retreat rates applicable across the basin, bank positions from 1992 to 2024/2025 were compared—a 33-year interval that included the largest flood of record in the WFCR. Linear bank retreat rates were calculated at intervals of approximately 0.05 miles (264 feet) by comparing the positions of the left and right bank lines in the sequential photos, providing average bank retreat rates in feet per year for a sample of approximately 20 locations within each of the two, one-mile-long analysis reaches.

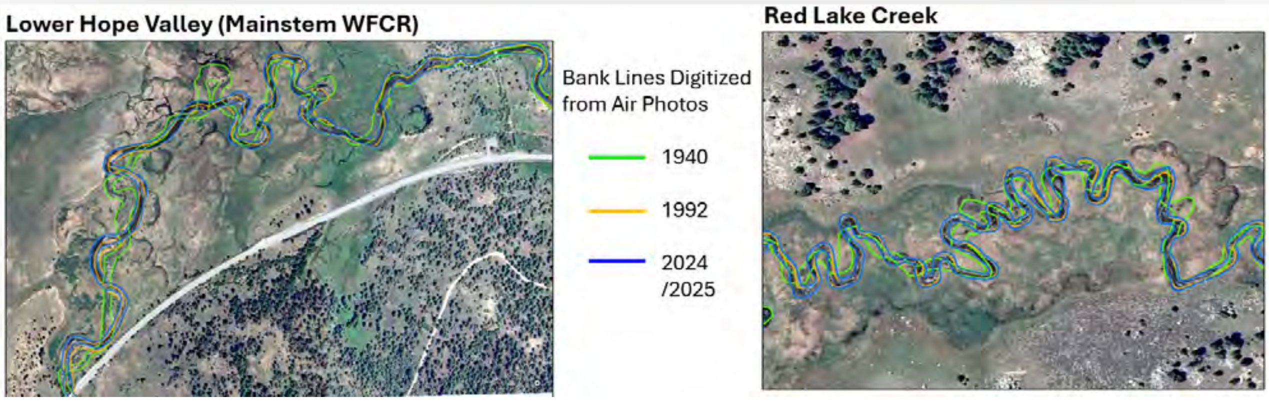


Figure 16*. Channel Migration in Lower Hope Valley and Red Lake Creek Lower Meadow*

To develop an empirical model with the ability to predict sediment contributions from bank erosion around the basin, the long-term bank retreat rates were compared with both BEHI and a subjective field-based Erosion Severity score collected during field work. The Erosion Severity score ranges from 1 to 5, with 5 representing the most heavily eroding banks, such as those shown in **Figure 13**. There is a clear relationship between measured bank retreat rates and both BEHI and Erosion Severity (**Figure 17**); however, the data exhibit substantial scatter. Most regression forms (linear, power law, polynomial) produced relatively weak predictive relationships. The best-performing regression was a linear equation with the intercept forced to zero, yielding an R^2 value of approximately 0.6 (**Figure 17**). The degree of scatter suggests that regression-based predictions could substantially overpredict or underpredict erosion rates at individual locations, and that it is possible that these errors could compound when applied basin-wide.

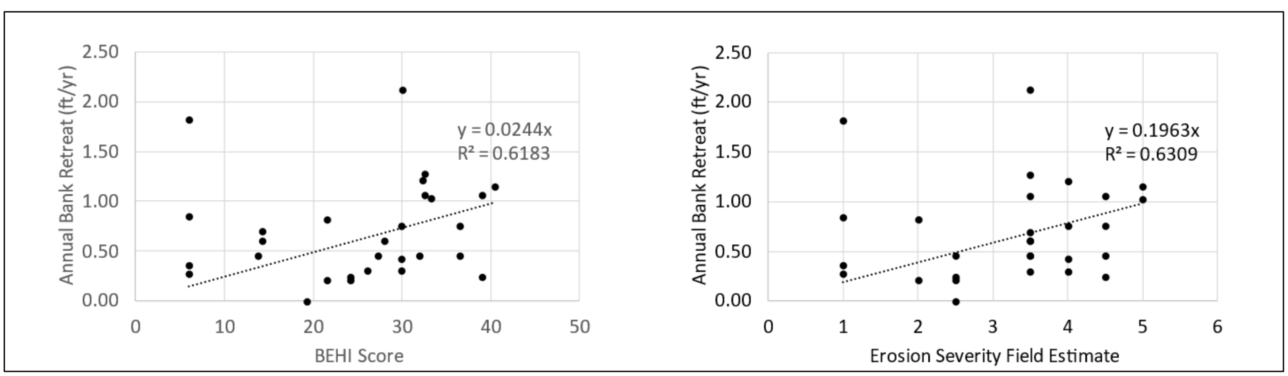


Figure 17*. Data Relating Bank Retreat Rate in Feet Per Year to BEHI and Erosion Severity*

As an alternative to a continuous regression model, an ordinal classification approach was developed in which representative bank retreat rates were assigned to bank sections based on mapped Erosion Severity values. **Figure 18** presents histograms of measured retreat rates grouped by Erosion Severity in lower Hope Valley. These data indicate that severity scores between 1 and 3 generally correspond to little or no measurable long-term erosion, although exceptions exist. Scores between approximately 3 and 4.5 correspond to moderate erosion, with retreat rates typically ranging from 0 to 1 ft/yr (estimated representative value of approximately 0.5 ft/yr). A score of 5 corresponds to severe erosion, with estimated retreat rates typically exceeding 1.0 ft/yr. Based on these relationships, a simple model was developed to estimate bank erosion from Erosion Severity values across the basin (**Table 7**). This approach emphasizes the contribution of a relatively small number of highly eroding banks, accounts for moderately eroding areas, and does not assign erosion to banks with low severity values, such as those commonly observed along the insides of bends.

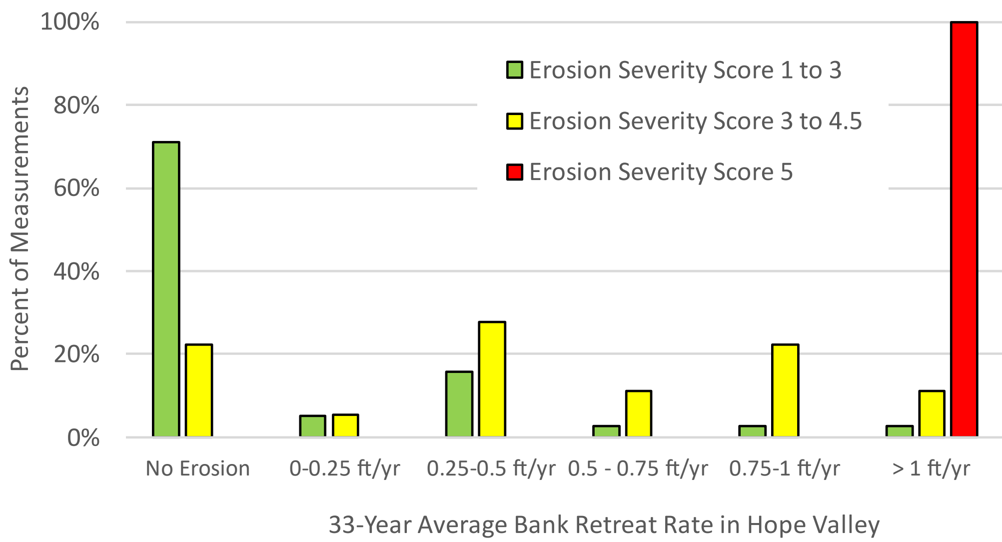


Figure 18. *Histograms Showing Measured Bank Retreat Rates for Different Erosion Severity Values*

Table 7. *Bank Retreat Rates Assigned to Erosion Severity Scores*

Erosion Severity Value	**Assumed Bank Retreat Rate** (ft/yr)
1 to 3	0
3 to 4.5	0.5
5	1

Bank Erosion Estimates using Air Photos and Field Data

Figure 19 (next page) compares cumulative bank erosion estimates derived from multiple methods, including the Rosgen (2001) methods (Yellowstone and Colorado), the two air-photo–based regression models shown in **Figure 17**, and the ordinal method summarized in **Table 6**. The comparison shows that the air-photo–based regressions predict substantially lower bank erosion rates than the Rosgen methods; however, these estimates are still much higher than the independently estimated suspended sediment flux from the basin. **Figure 19** includes only erosion along the mainstem WFCR; if tributary erosion were included, these values would be higher.

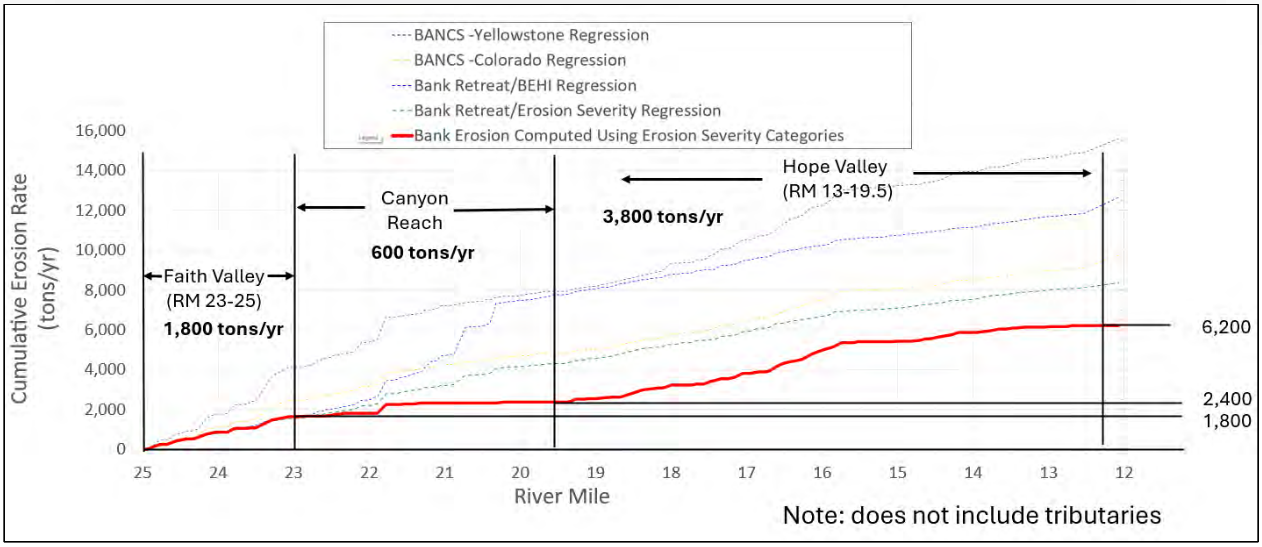


***Figure 19**. Comparison of Cumulative Bank Erosion Estimates Using Multiple Methods. Red line represents the results of the final bank erosion analysis.*

The ordinal method predicts **approximately 6,200 tons per year of sediment derived from bank erosion** along the WFCR mainstem. This value was selected for use in the sediment budget because it is grounded in locally observed erosion severity and long-term channel change and produces estimates that are more consistent with measured sediment transport.

Bank erosion contributions from tributaries were not included in the estimate of 6,200 tons/year used in the sediment budget. BEHI and Erosion Severity were mapped in several tributaries of the WFCR, and showed that bank erosion in tributaries is present, but less prevalent, compared with the WFCR. In Red Lake Creek, channel migration rates are much less than in the main stem (**Figure 16**), and it is unclear whether the retreat rates in **Figure 18** and **Table 7** apply to tributaries. At the basin scale, tributary contributions to bank erosion are expected to be small relative to the mainstem WFCR due to their shorter cumulative bank length, lower bank heights, and generally lower observed erosion severity (using the Rosgen method, tributaries accounted for approximately 15 percent of total estimated basin-wide bank erosion [**Table 6**]). This relatively small contribution of hundreds of tons per year was considered negligible compared the magnitude of the uncertainty in other elements of the sedimentbudget and was not included.

Bank erosion in the basin is spatially concentrated: approximately 60 percent of bank erosion along the 25-mile mainstem WFCR occurs within the roughly 7-mile reach of Hope Valley (**Figure 19**). This spatial concentration directly supports a restoration strategy focused on reconnecting floodplains and reducing bank erosion in Hope Valley as a means of achieving watershed-scale reductions in fine sediment.

2.3.3 Floodplain Deposition

In unconfined, alluvial reaches of the WFCR—most notably in Hope Valley—a portion of fine sediment is stored on floodplains during overbank flooding. Fine sediment (sand-, silt-, and clay-sized material) is transported primarily in suspension and can be deposited on floodplain surfaces when flows exceed channel capacity and spread laterally across the floodplain. Floodplain deposition occurs predominantly during high-flow events, when water carrying sediment overtops the channel banks and inundates adjacent floodplains. The amount of fine sediment deposited on floodplains is controlled by three primary factors:

(1) the magnitude and frequency of flows that access the floodplain,
(2) the fine sediment concentration of those flows, and
(3) the trap efficiency of the floodplain, defined as the fraction of incoming suspended sediment that settles out before water returns to the channel.

In principle, floodplain deposition could be estimated directly using a basin-scale model that explicitly represents overbank hydraulics, sediment concentrations, and spatially variable trap efficiency. While such approaches have been applied in detailed research studies, implementing them for the WFCR at the basin scale would require a substantial amount of additional data and modeling effort, while still yielding results with high uncertainty, due to a lack of calibration data. For the purposes of this project, floodplain deposition was estimated indirectly as the residual term in the sediment budget, and “reality checked” by making an order-of-magnitude calculation of the average deposition rate predicted from this method and comparing that with field observations. Specifically, floodplain deposition in the WFCR was computed by combining the estimated upland erosion (1,400 tons per year) and bank erosion (6,200 tons per year) inputs and subtracting the estimated long-term suspended sediment export from the basin (5,000 tons per year). Using this mass balance approach, floodplain deposition in the WFCR watershed is estimated to **average approximately 2,600 tons per year**. By comparison with the other components of the sediment budget, this value exceeds the estimated contribution from upland erosion and amounts to roughly half of the sediment exported from the basin. This scale of contribution to the sediment budget seems reasonable, given the presence of large, glacially carved valleys in the upper watershed that provide substantial potential storage space for fine sediment.

To evaluate whether this estimate is physically reasonable at a site scale, the implied vertical accretion rate was calculated and compared with field observations. We used the basin-scale hydraulic model to estimate the total area of active floodplain for the seven largest floodplain units in the upper basin (**Table 8**). For this calculation, floodplain area was defined as the area inundated by the modeled 2-year recurrence interval flow, excluding the active channel. This resulted in an estimated floodplain area of approximately 210 acres. Converting 2,600 tons per year of sediment to a volumetric rate (using a typical fine sediment bulk density of 80 lb/ft^3) yields an average vertical accretion rate of approximately **0.007 ft/yr, or about 0.1 inch per year**.

Table 8. *Discrete Floodplain Units in the Upper West Fork Carson River Basin*

Floodplain Unit	2-Year Peak Flow Inundation Area (not including channel)
	Acres
Forestdale Creek	2.3
Willow Creek	6.2
Red Lake Creek	39.6
Upper Faith Valley	7.6
Lower Faith Valley	13.5
Upper Hope Valley	88.6
Lower Hope Valley	53.2

At this rate, it would take on the order of 140 years to accumulate one foot of sediment, averaged across the entire floodplain under current, incised conditions. This magnitude is broadly consistent with field observations, including the thickness of fine-grained deposits exposed in eroding banks (e.g., **Figure 13**), which likely accumulated over timescales of centuries to millennia. Accretion rates were likely higher in the past, prior to channel incision, when floodplain connectivity was greater and overbank deposition occurred more frequently.

These results suggest that increasing floodplain connectivity and overbank sedimentation represents a viable strategy for reducing fine sediment export from the WFCR watershed. Restoration actions that increase the frequency and extent of floodplain inundation have the potential to shift sediment from being exported downstream to being stored within upper-basin floodplains, particularly in large valley settings such as Hope Valley.

2.3.4 Sediment Budget Findings and Interpretations

Sediment Budget Results

Figure 20 presents a schematic summary of the WFCR sediment budget developed in this study. The widths of the arrows are scaled approximately to the magnitude of sediment flux associated with each process. This diagram integrates the four primary components evaluated in Sections 2.4.1 through 2.4.4—upland erosion, streambank erosion, floodplain deposition, and suspended sediment export—and highlights their relative importance at the watershed scale

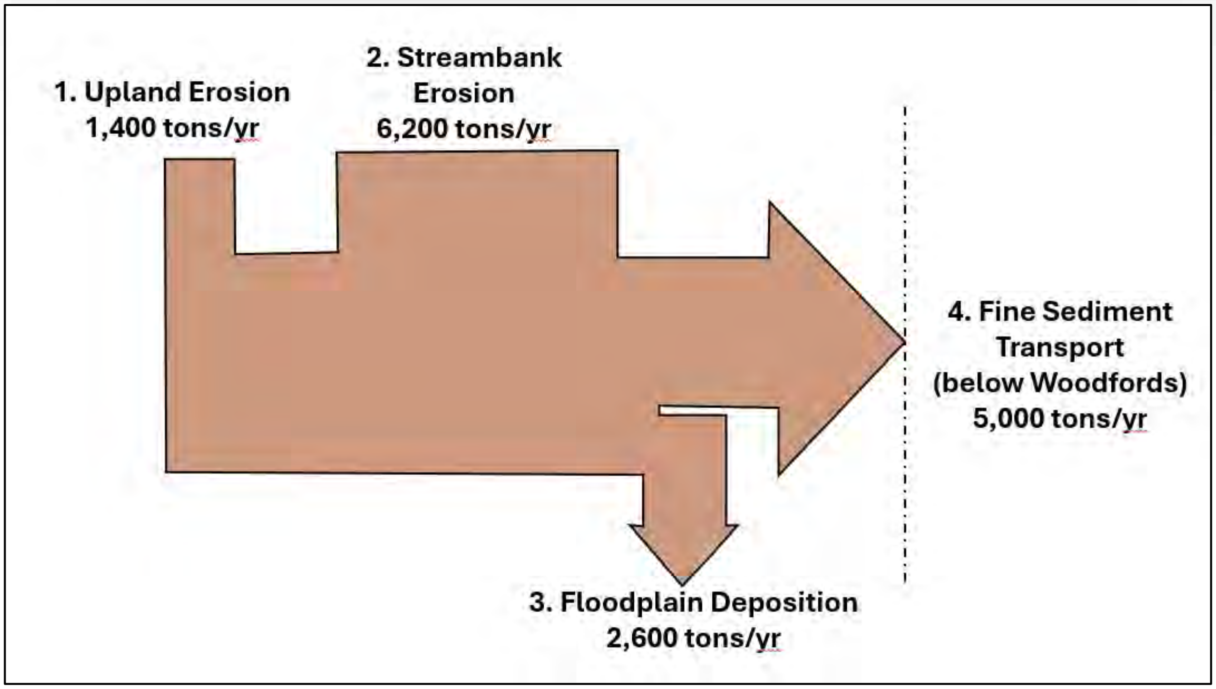


Figure 20*. Schematic Diagram of Sediment Budget for the West Fork Carson River Basin in California. Widths of arrows are approximately proportional to the size of the sediment fluxes associated with the four geomorphic processes*

Interpretations - Current and Historical Sediment Budgets

The sediment budget indicates that, at present, **streambank erosion** (**2,** in **Figure 20**) is the dominant source of fine sediment in the WFCR watershed. Estimated bank erosion rates are comparable to, and likely exceed, the long-term average **suspended sediment flux** exiting the basin (4). In contrast, **upland erosion** (1) contributes a smaller, secondary component of fine sediment input. **Floodplain deposition** (3) represents a substantial sink for sediment within the upper basin, storing roughly half of the sediment that would otherwise be exported downstream. Under current geomorphic conditions, the basin exports on the order of 5,000 tons per year of fine sediment, indicating that the large glacial meadows that had once been sediment storage reservoirs are now the most important sources of sediment in the basin. The direct cause of this change in the sediment budget would have been channel incision and/or widening. The geomorphic processes of channel incision (aka, channel bed lowering relative to the adjacent floodplain elevation) and channel widening can both contribute to an increase in channel capacity and a decrease in the stability of the banks, which in turn result in less overbank sedimentation and more bank erosion.

Figure 21 presents a conceptual reconstruction of how the WFCR sediment budget likely functioned prior to the channel incision and/or widening, when floodplain connectivity was greater. Following the last glacial retreat, **upland erosion** (1, in **Figure 21**) supplied fine sediment, much of which was stored within the large glacial valleys, forming the large floodplain meadow deposits observed today. **Bank erosion** (2) would have been substantially lower, as channels were closer to floodplain grade, with less erosion of tall, vertical exposed banks. At the same time, **floodplain sedimentation** (3) would have been much greater, with frequent overbank flows depositing fine sediment across valley bottoms rather than exporting it downstream. As a result, **sediment export from the basin** (4) would have been correspondingly lower.

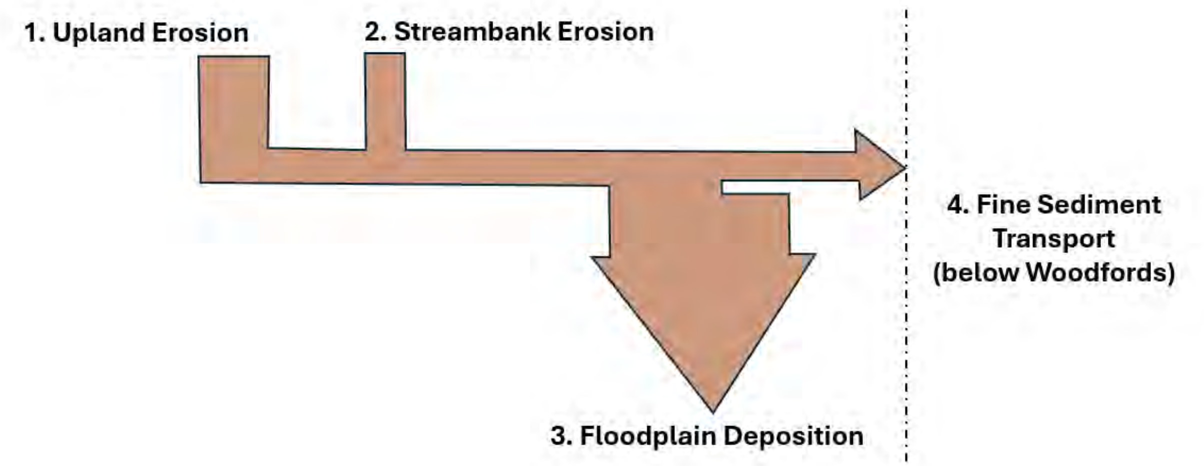


***Figure 21**. Schematic Diagram of Post-Glacial Sediment Budget Prior to Channel Incision.*

Causes of Channel Changes. The contrast between the present-day and conceptual historical sediment budgets raises an important question: what caused channel incision and/or widening in the WFCR, and when did it occur? The precise timing and drivers are not known with certainty; however, several plausible mechanisms exist. One likely factor is the historical reduction of beaver populations and associated riparian vegetation, which may have reduced natural flow dispersion across valley bottoms, increased channel confinement, and promoted incision. Another is channel widening and bank destabilization due to loss of stabilizing vegetation, possibly due to sheep and cattle grazing. A third possible driver could be long-term geologic lowering of downstream base level, particularly through gradual erosion of glacial moraines or boulder-controlled valley constrictions, initiating upstream-propagating channel downcutting. Incision and channel widening may reflect a combination of these mechanisms, or additional processes not evaluated here, such as post-glacial tectonic influences within the Hope Valley Graben (Hagan, et al., 2009). Although unresolved, this question could be addressed through focused geomorphic, stratigraphic, and dating studies.

2.3.5 Bedload and Stream Restoration in the WFCR

Although this sediment budget focuses on fine sediment (washload and suspended load), it is important to acknowledge **bedload**—the coarser material that moves by rolling, sliding, and bouncing near the streambed (bedload) rather than in suspension. Bedload is not a direct driver of water quality impairment (turbidity and fine sediment) and thus was outside the scope of this study, but it plays a crucial role in channel morphology and interacts with the fine sediment budget, particularly in the contexts of floodplain connectivity. A primary goal of restoration is to aggrade the bed and reconnect floodplains, which can be best accomplished through the deposition of bedload. In many natural rivers, bedload comprises only a small fraction of the total sediment flux. For example, empirical data and geologic theory (Turowski et al., 2010) suggest some "rules of thumb" about the bedload commonly represents on the order of about 1-30 % of annual total sediment load in alluvial streams, with smaller percentages (< 2–5 %) in larger systems, larger percentages (30-60%) in sand dominated lowland streams, and a wider range of variability in steep and glaciated landscapes, where geology is the key factor determining the ratio of bedload to suspended load.

Even if one assumes an upper-end bedload proportion of roughly 20 % of the suspended load for the WFCR—at the high end of typical observations—then with an estimated long-term suspended load of ~5,000 tons per year, the corresponding bedload would be on the order of 1,000 tons per year. Using a typical bulk density for gravel and coarse sand (~1.6 tons per cubic yard), this equates to only about ≈625 cubic yards per year of bed material (or 60–70 large 10-yard dump truck loads annually). This amount of gravel is unlikely to provide sufficient material, by itself, to significantly aggrade the channel bed over broad reaches of the WFCR. Observations in Faith Valley indicate that much of the available bedload was trapped upstream of the uppermost beaver dam analog (BDA) and after about 3 to 4 years, only a small amount of gravel has reached the pond behind the second BDA. For larger reach-scale restoration interventions—especially those that aim to raise channel bed elevations and sustain grade control—bedload availability and continuity may be limiting factors. Consideration of sediment supplementation (e.g., importing coarse material from downstream reaches) could be warranted in long-term restoration planning, especially in Hope Valley (discussed further in Section 3.5).

2.3.6 Management Implications of the Fine Sediment Budget

From a management perspective, the cause of the interpreted change in the sediment budget is not critical. Instead, the modern sediment budget, along with our field-based interpretations, suggest that the most effective long-term strategy for reducing fine sediment loads is not to attempt to eliminate sediment sources entirely, but instead, to restore processes that favor floodplain storage and reduce bank erosion. Restoration actions that reconnect floodplains, raise channel beds, and reduce bank heights have the potential to move the system incrementally back toward a sediment balance more characteristic of pre-incision conditions (**Figure 21**). It is unlikely that the sediment budget can be fully restored to immediate post-glacial conditions, particularly in large valley settings such as Hope Valley. However, a realistic restoration objective is to move the balance in meadow reaches toward greater sediment storage and reduced bank erosion.

Another key finding of the sediment budget is the strong spatial concentration of both sediment sources and storage potential. Bank erosion is focused within incised floodplain sections of the WFCR, especially in Hope Valley, and meaningful floodplain storage opportunities are similarly concentrated in these large, unconfined valley bottoms. In contrast, downstream canyon reaches lack significant sediment sources and storage potential and function primarily as efficient sediment transport corridors. This spatial pattern has direct implications for restoration planning: actions aimed at reducing sediment export must focus on the floodplains in the upper basin, especially Hope Valley, where both sediment generation and storage potential are greatest.

The sediment budget clarifies where sediment reduction efforts are most likely to be effective: in upper-basin meadow reaches where bank erosion is concentrated, and where floodplain storage potential exists. Guided by this geomorphic framework, the next phase of work identified and prioritized restoration actions capable of influencing these processes. Section 3 presents the methodology and results of that prioritization effort.

3.0 PRIORITIZATION PLAN

Based on fieldwork and the results of the geomorphological model, Waterways identified a suite of potential stream restoration projects in the West Fork Carson River (WFCR) watershed that could reduce fine sediment loading while also providing additional environmental and societal benefits. Desktop analyses and field visits were used to identify, evaluate, and score potential projects. Project scores were then evaluated using a multi-objective decision-making framework known as Multiple Accounts Analysis (MAA) (Robertson and Shaw, 1998; 2004), which combines technical scoring with stakeholder-informed weighting. This section describes the project identification, evaluation, and prioritization process and concludes with recommendations for a long-term stream restoration strategy.

3.1 PROJECT IDENTIFICATION AND EVALUATION

3.1.1 Project Identification

The initial project identification process focused on physical and geomorphic conditions, using topographic analysis, hydraulic modeling, and field visits along stream reaches within the project area defined by Alpine Watershed Group (AWG, 2024). The primary objective at this stage was to identify locations where restoration actions could increase fine sediment storage and/or reduce streambank erosion. Practical considerations such as land ownership, equipment access, and detailed technical feasibility were not evaluated during this initial screening phase.

One of the primary tools used in project identification were **Relative Elevation Model's (REM**) of the streams in the WFCR watershed. An REM map book for the entire basin is included in **Appendix G-1**. As described in Section 2, an REM is a stream-centered representation of the landscape that shows elevations relative to the adjacent streambed rather than relative to sea level, as in conventional topographic maps. This allows for easy identification of areas where the floodplain is close enough to the channel to be reconnected, as well as locations where steep banks are actively eroding (**Figure 22**). The REM maps provide a rapid visual guide to locations where interventions could store sediment and stabilize banks, and clearly identify former channels in the floodplain that might be reconnected as part of restoration projects. The maps were used as a base for field mapping and project IDs.

A complementary tool was **two-dimensional (2D) hydraulic modeling,** conducted at both watershed and reach scales. The watershed-scale model simulated the inundation extents of the 2-year and 10-year recurrence interval floods. These results highlight areas where floodplain inundation expands substantially between smaller and larger floods, such as in lower Hope Valley (**Figure 23**). Locations exhibiting large differences in inundation extent between the 2-year and 10-year floods were identified as candidates for restoration interventions, since relatively modest changes in channel bed elevation, roughness, or flow dispersion could increase the frequency and extent of overbank inundation and thereby enhance sediment deposition on the floodplain. A basin-wide map book of hydraulic model results is included in **Appendix G-3**. Project areas identified using these desktop analyses were field-verified by Waterways to confirm that the REM and hydraulic model outputs accurately represented site conditions.

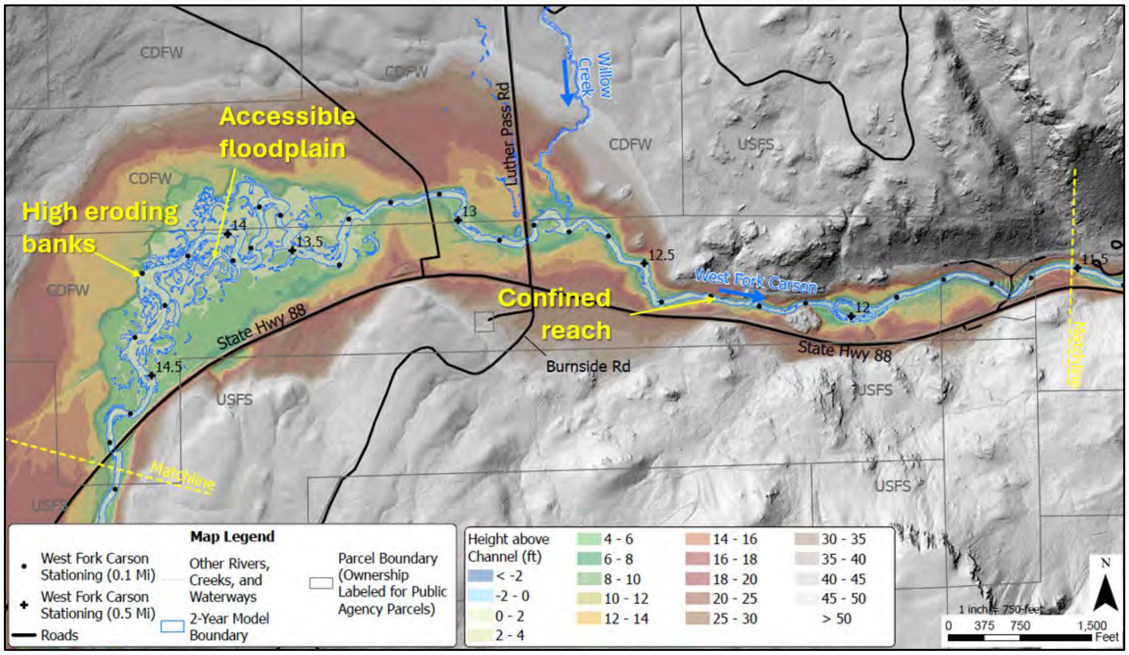


***Figure 22**. Example of Use of the Relative Elevation Model (REM) for Identifying Potential Project Areas*

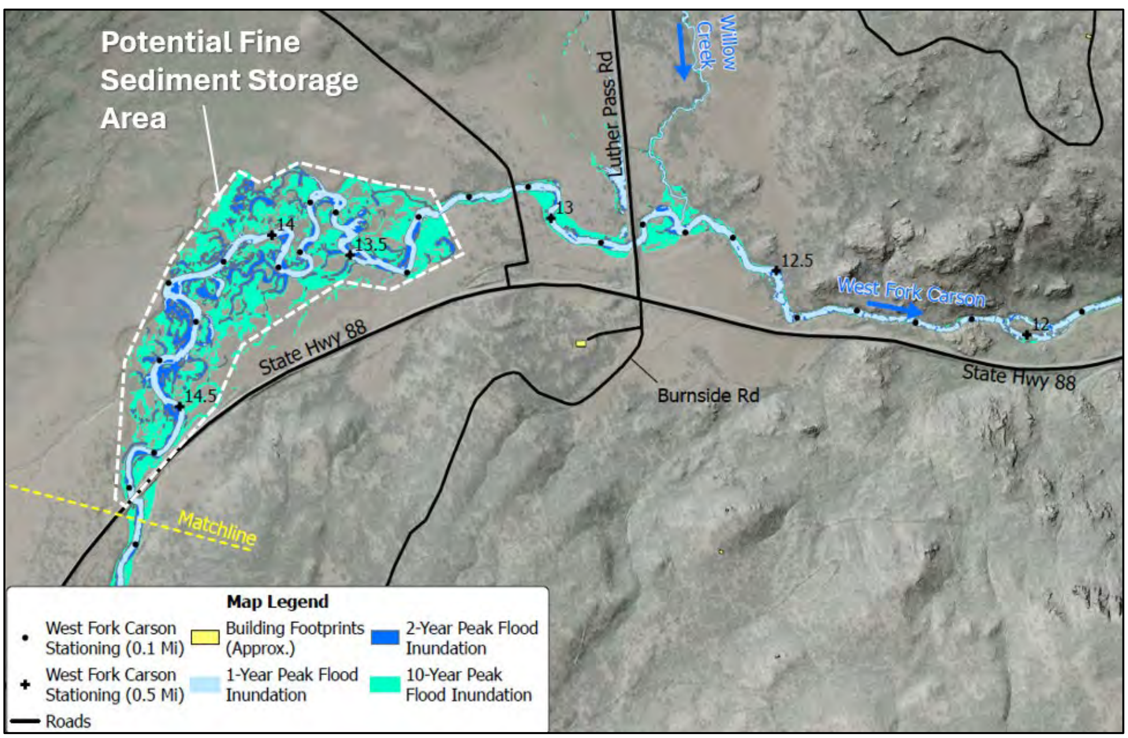


***Figure 23**. Example of Use of the Hydraulic Model Results in Identifying Potential Project Areas*

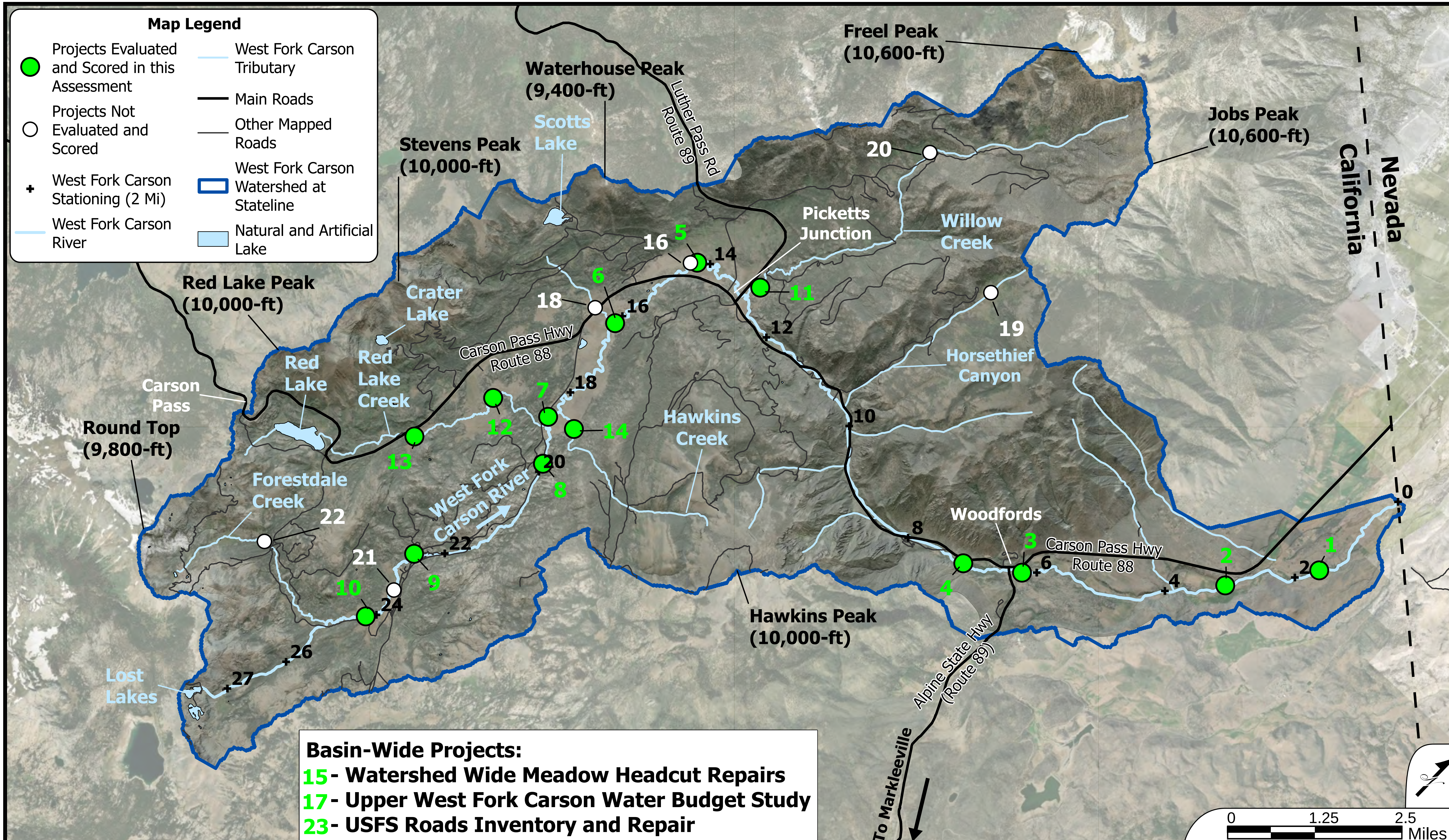
Using a combination of fieldwork, desktop analyses, review of past work, and conversations with local stakeholders and agency staff, a total of 23 potential projects were identified in the basin (**Figure 24)**. These projects included not only in-stream restoration opportunities targeting fine sediment retention, but also activities that could reduce turbidity, improve meadow or riparian health, or provide information to facilitate future restoration efforts. A comprehensive list and brief description of all 23 potential projects is provided in in **Table 9**.

3.1.2 Development and Evaluation of 15 Projects

Of the 23 potential projects, **15 were selected for further development** to better define project extent, project elements, implementation challenges, and anticipated benefits. Projects advanced at this stage focused primarily on in-stream interventions with the potential to reduce fine sediment loading. The remaining eight projects, while not evaluated in detail, remain relevant and worthwhile. These include several headwater meadow restoration projects identified by American Rivers (2018) that may improve meadow health but are unlikely to significantly reduce fine sediment; road assessment and repair projects managed by the U.S. Forest Service, which are outside the scope of the WFCPP but could contribute to sediment reduction; and a proposed water balance study to help quantify the downstream effects of restoration actions.

Most of the **15** advanced projects were visited in the field, some multiple times. Two projects were not visited due to property access constraints but were evaluated using aerial imagery, LiDAR, and hydraulic modeling. Each project was developed to a level sufficient to allow an initial feasibility assessment, including evaluation of geomorphic setting, hydraulic conditions, potential benefits, anticipated costs, and logistical considerations.

For brevity, detailed descriptions of the 15 projects are not included in the main body of this report. Instead, **Appendix P-1** provides detailed, three-page descriptions and evaluations for each project. These project descriptions include maps, photos, summaries of relevant modeling results, and discussion of key design considerations and constraints. **Figure 25** presents an example project description for a relatively small project in the lower portion of Willow Creek, illustrating the format and level of detail provided for all projects evaluated in the prioritization process.



Watershed Map with Locations of Potential Projects

West Fork Carson River Prioritization Project

WATERWAYS CONSULTING, INC.

Santa Cruz, CA watways.com Portland, OR

FIGURE 24

Table 9. *West Fork Carson Watershed - Explanation of Project Opportunities*

Project #	Project Name	Stream Name	RM (Down-stream End)	RM (Up-stream End)	Project Objectives	Potential Project Elements	Key Considerations and Constraints
Projects on West Fork Carson River							
1	River Ranch Road Floodplain Reconnection	West Fork Carson	0	2	Spill more floodwater into old fan channels to deposit sediment, recharge groundwater, and expand riparian/wetland habitat.	Fish-passable boulder grade control riffle; large wood installations; willow planting	Project could potentially offer significant flood benefit downstream and deposit of fine sediment on a broad fan close to the CA/NV state line. Multiple private properties would be affected. Unknown landowner interest. Not clear if project would be compatible with current land uses. The project would likely require modifying irrigation infrastructure. Only flood flows should be affected, base flows must be unaffected by project. Project must avoid interfering with flows or causing erosion in irrigation ditch. Higher risk project.
2	Ace Hereford Ranch Floodplain Reconnection	West Fork Carson	2.6	3.3	Increase overbank flow during floods, deposit sediment, recharge groundwater	Fish-passable boulder grade control riffle; wetland enhancements, willow planting, possible livestock exclusion fencing,	Only one landowner property. Landowner would be open to potential project. Big lift (~6-10') reconnect the floodplain. Multiple opportunities to enhance springs and wetlands in conjunction with an in channel project. Compatibility wth current land uses is not known. Project may have relatively small impact on flood flows and sediment storage relative to the scale of effort.
3	Woodfords Fan Reconnection	West Fork Carson	4.5	6.5	Increase flow into alluvial fan, deposit sand and fines, recharge groundwater, expand wetland, improve wetland vegetation.	Boulder Grade Control, ELJs, Willow Planting, Fencing, Off-Channel Wetland Enhancements	Project could potentially offer significant water quality and flood benefit, recharge groundwater, and deposit of fine sediment on a broad fan. Not clear if project would be compatible with current land uses. Multiple private properties would be affected. Unknown landowner interest. Project must avoid interfering with flows or causing erosion in irrigation ditch. Higher risk project.
4	Crystal Springs Floodplain Reconnection	West Fork Carson	6.8	7.5	Increase overbank flow, deposit sediment, reduce bank erosion, recharge groundwater	Boulder Grade Control, Willow Planting, Possible Off-Channel PBRs	Among the only locations in canyon reach where floodplain could be reconnected. Smaller benefit project; high lift to reconnect side channels; boulder structure and/or excavation at side channel inlets would be needed.
5	Lower Hope Valley Restoration	West Fork Carson	12.9	14.7	Raise base level, increase overbank flow, deposit fine sediment, reduce bank erosion, add channel habitat complexity, recharge groundwater; improve scenery, education and collaboration opportunities	Rock Grade Control, BDAs, ELJs, Floodplain Channel Excavation, Willow Planting, Log Weirs	Large scale project in high visibility location. Would reduce bank erosion in heavily eroding area, and shift the balance to retaining sediment in a large basin in a strategic location. High Must carefully consider visual effects, recreation impacts, and public perception.Likely to require multi-year outreach and design effort and a phased implementation. Could apply lessons learned from the 2022-2024 Faith Valley Restoration project, as it has similar geomorphology. Bedload management will be important.
6	Middle Hope Valley Restoration	West Fork Carson	15.5	16.6	Raise base level to increase overbank flow, deposit sediment, and reduce erosion, and recharge groundwater; expand wet meadow, attract beaver. Similar to the Faith Valley project	Managed Avulsions, Boulder Grade Control, BDAs, PALS, ELJs, Bank Layback, Tree Felling, Willow Planting	Similar project type, geomorphic setting, and potential benefit as project #5 above, but may be slightly smaller in scale and less visible to the public. Very heavily eroding reach, big contributor of fine sediment. There could be opportunities to manage meander cutoffs to circumvent some of the most heavily eroding bank line.
7	Upper Hope Valley Reconnection	West Fork Carson	17.8	19.5	Increase overbank flow during floods; deposit fine sediment in floodplain; reduce bank erosion; recharge groundwater	Boulder Grade Control, Floodplain Channel Excavation, Managed Avusion; Engineered Log Jams, Wood, Willow Planting	Largest and potentially the highest disturbance project on the list. In a frequently visited area at the head of Hope Valley. Not clear how well it would work because of the amount of lift needed to spill water into the floodplain.
8	Blue Lakes Road Restoration	West Fork Carson	19.7	20.6	Protect and expand beaver influence in a confined reach	BDAs and Large Wood; Reinforce Existing Beaver Dams	Habitat improvement with minor benefits related to sediment storage/reduction; relatively minor and localized habitat uplift compared with meadow projects, but would be a much smaller project to design and build.
9	Faith Valley Campground Restoration and Repair	West Fork Carson	22	22.9	Stabilize eroding reach near a USFS campground	Bank Erosion Protection, Grade Control, BDAs, Large Wood, Reinforce Beaver Dam	Combined habitat/minor infrastructure improvement project at eroding campsites adjacent to WFCR. Minor sediment benefit. Project would stabilize and recover recently breached beaver complexes. Project would need interest and funding from USFS
10	Upper Faith Valley Restoration	West Fork Carson	24.1	25	Reconnect floodplain, reduce bank erosion, improve vegetation, attract beaver	Felled trees, BDAs, Large Wood	Project would reconnect large disconnected floodplain area and improve instream complexity in upper portion of Faith Valley. Remote site and unclear if equipment access will be allowed. Relatively large benefit for being so high up in the watershed.
Projects on Willow Creek							
11	Willow Creek Meadow Restoration	Willow Creek	0	1.7	Reconnect floodplain, reduce bank erosion, improve vegetation, attract beaver	BDAs, PALs, Tree Felling, Willow Planting, Reinforce Existing Beaver Dams,	Relatively small scale and low risk project with potential for sediment reduction and floodplain reconnection in a sediment-producing tributary. Project area contains both remote and high visibility areas, with opportunities for education and public outreach.
Projects on Red Lake Creek							
12	Red Lake Creek Lower Meadow Restoration	Red Lake Creek	0.9	2	Reconnect floodplain, reduce bank erosion, improve vegetation, attract beaver	BDAs, Tree Felling, Willow Planting	Very large meadow that is incised and eroding and could easily be reconnected to its floodplain. Bed load limited, relatively difficult access; few other concerns. American Rivers (2018) assessed meadow and determined future assessments to determine project potential would be worthwhile.
13	Restoration	Red Lake Creek	0.9	2	Reconnect floodplain, reduce bank erosion, improve vegetation, attract beaver	BDAs and Willow Planting	Smaller project in two meadows, one public land and the other in private property. Abandoned beaver dam locations could be reoccupied and stabilized. Extensive willow planting could attract and sustain beaver. American Rivers visited this meadow and did not include in first set of sites but planned to revisit.
Projects on Hawkins Creek							
14	Hawkins Creek Fan Reconnection	Hawkins Creek	0	0.5	Reconnect fan channel, increase habitat complexity	BDAs, ELJs, Grade Control Structure to Reactivate Fan Channel	Project would spill flood water into a former fan channel in an incised fan, increasing sediment storage and groundwater recharge. Difficult equipment access. There may not be enough of a benefit to justify project cost and effort.

Project #	Project Name	Stream Name	RM (Down-stream End)	RM (Up-stream End)	Project Objectives	Potential Project Elements	Key Considerations and Constraints
Basin Wide Treatments							
15	Watershed Wide Meadow Headcut Repairs	NA	NA	NA	Prevent future damage and loss of wet meadows by finding and treating headcuts basin-wide	Site by site basis	Protection of existing resources, not uplft; high benefit with little effort; may be unusual to permit given the multiple small sites rather than a single work location.
Additional Potential Projects in the Basin (these projects were not scored with Multiple Accounts Analysis)							
16	Lower Hope Valley Adaptive Management	West Fork Carson	14.2	14.5	Complete ongoing adaptive management program using willow trenches and micro benching.	Micro-benching, willow planting, willow trenches on outsides of bends; possibly other small scale treatments.	There is a small currently funded project in progress by AWG to adaptively manage previous efforts in lower Hope Valley, in the area of proposed project #5. This smaller ongoing effort would be a part of the larger scale, high-scoring reach scale restoration project. Current effort will begin to establish willow now to benefit a potential future larger scale project in the same area.
17	Upper West Fork Carson Water Budget	Basin wide			Better quantify the overall water balance of the WFCR; answer questions about the impact that expanding wet meadow and willow would have on water deliveries and water rights; predict effect of climatic change and restoration projects on water deliveries at different times of the year	Measurements, modeling, analysis, and public outreach	One of the concerns raised by stakeholders during the WFCPP outreach process is the impact that restoration projects like the ones proposed here will have on water deliveries and water rights. American Rivers collected some data on water flows into and out of the Faith Valley Restoration project and found no measurable impact. More analyses, data, and likely modeling would be useful for answering these questions and addressing concerns in different ways.
18	Highway 88 West Meadow Restoration	Unnamed tributary	NA	NA	Improve meadow conditions, repair headcuts (per American Rivers)	Did not develop concepts for project	This unnamed tributary was not part of the project area of the current project. However, this meadow was prioritized by American Rivers Carson meadows assessment (2018) as a degraded meadow below Highway 88. Not a major contributor of fine sediment to WFCR; however, project here
19	Horsethief Canyon Meadow Restoration	Horsetheif Canyon	NA	NA	Reduce gully erosion, headcuts, treat bare ground	Did not develop concepts for project	This meadow was not part of the current project area, but was prioritized in the middle of the list of Carson meadows by American Rivers (2018) meadow assessment. The meadow is high up in a tributary of WFCR, and is not a major contributor to fine sediment in WFCR. However, there appear to be opportunities for a small scale meadow restoration, especially repairing headcuts and reducing gully erosion of the meadow.
20	Middle Willow Creek Meadow Restoration	Unnamed tributary	NA	NA	Repair headcuts	Did not develop concepts for project	This meadow was not part of the current project area, but was prioritized by American Rivers (2018) meadow assessment. Small tributary is not a major contributor to fine sediment in WFCR. Project was listed as the lowest priority meadow among those in the assessment.
21	Faith Valley Adaptive Management	West Fork Carson	23.8	23.5	Improve function of past restoration project, understand benefits, identify lessons learned where project did not meet objectives.	Maintain some BDAs, possibly reducing the number or height of some of the BDAs to improve bedload sediment continuity; continue to monitor groundwater, survey post-project conditions after several years, develop document on lessons learned	The Faith Valley Restoration Project was a recent, largely successful project on the upper WFCR that included a valley-spanning rock grade control structure, roadway improvements, and numerous BDAs built and repaired over several years. The project has raised water table, improved meadow, and reduced bank erosion, and appears to be depositing fine sediment in the floodplain. These objectives and methods are similar to many of the potential projects described above, and therefore provides a opportunity to learn from past similar work and help stakeholders visualize potential project outcomes. One area where the project did not meet objectives was in aggrading the bed, because most bedload is being trapped above the upstream-most BDA. While it appears that bed aggradation above the uppermost BDA is achieving project goals of reducing bank height and aggrading the bed, most bedload does not get past it. The BDAs may have been built higher and more numerous than was optimal. Continuing to monitor and adaptively manage that project could enhance long term outcome and provide lessons learned that can be applied to other projects in the basin and elsewhere.
22	Forestdale Meadow Headcut Repairs	Forestdale Creek	2.3	2.8	Reinforce beaver dams, stabilize headcuts, avoid possible future degradation	Stabilize headcuts with posts; no other treatments are necessary	Forestdale Meadow was listed as a priority restoration area in American Rivers meadow assessment (2018). In 2018, technical advisory team for the Faith Valley and Forestdale Meadow restoration project opted to not include Forestdale meadow as part of that project because it is remote from main project area and the technical advisory group determined that its condition was mostly good compared to Faith Valley. The project would have negligible impact to sediment or water quality due to its location at the top of the WFCR watershed. We recommend including Forestdale Meadow as part of Project #15 above, basin wide heacut treatments, as the main impairment is headcuts.
23	Willow Creek/Forestdale Creek/ Upper West Fork Carson Watershed Roads Inventory and Repair	NA	NA	NA	Reduce fine sediment, improve recreation, reduce upland impacts	Roads and trails inventory and assessment; map and rank repairs.	Official and unofficial ATV roads are a source of human-caused fine sediment in the watershed. The current effort focuses on opportunities to address stream geomorpholog, and it was not part of the scope of the current project to map and assess road conditions throughout the watershed. A watershed scale assessment effort, especially in Willow, Forestdale, and Upper West Carson watersheds, to inventory eroding roads and unofficial trails, would help identify opportunities and prioritize treatments.

Project 11: Willow Creek Meadow Restoration

Willow Creek, River Mile 0.0 to 1.7

Existing Conditions:

The potential project area is along Willow Creek from its confluence with the West Fork Carson River to approximately 2 miles upstream. The upper section is in a geologically confined basin with a floodplain 100 to 250 feet wide, and the lower section encompasses the Willow Creek fan as it enters the West Fork Carson River. In the upper area, the channel is about 2 to 4 feet below the meadow surface (see Figure 11-A). In the lower part of Willow Creek the channel is mostly disconnected from its floodplain (see Figure 11-B). Beaver are extensive in Willow Creek, but their influence is confined to areas where there are healthy willow stands. The channel has incised about two to three feet, leading to a drop in the water table in the meadow, a loss of connectivity, and loss of willow in some meadow areas.

The upper and middle portions of the project area are rarely visited but the lower portion near the West Carson River is close to Pickett's Junction and gets significant foot traffic.

Project Concept:

The project would employ "low-tech process based restoration" (LTPBR) techniques to reconnect the floodplain, expand and enhance wetland, store sediment, and support beaver in lower Willow Creek. The scale of the channel and the relatively moderate amount of incision makes this area a good candidate for a low cost, low risk, beaver-focused restoration effort. Hand crews would build beaver dam analogs and post-assisted log structures, fell trees, and install willow in strategic locations to accomplish the project objectives of raising the water table, storing fine sediment, improving in-channel habitat, and expanding beaver influence. There is a small fen in the confined section that could be protected with additional BDAs and fencing. There are opportunities for public education and outreach in the frequently visited lower portion of Willow Creek.

Potential Project Elements:

Beaver dam analogs (BDAs), tree felling, post-reinforced beaver dams, post assisted log structures (PALS), willow plantings, fencing to protect fen.

Design Considerations and Potential Constraints:

The primary constraint is proximity to busy intersection and popular recreational area. The main constraint in the upper section is the relatively difficult access. No roads or infrastructure that would be impacted, and there would be little impacts to recreational uses during construction. Opportunities for signage, education, and tours. The upper project area could be built using hand crews and materials could be harvested on site or brought in by pack animals or ATVs.

Multiple Accounts Analysis Scores:

Technical: 4.31

Economic: 3.50

Environmental: 3.48

Social and Cultural: 4.28

Overall MAA Score: 3.84

MAA Rank: #2 of 15

Summary:

Relatively small, low risk project would reconnect small meadow and store sediment, plus provide opportunities for education and signage in a high visibility area.

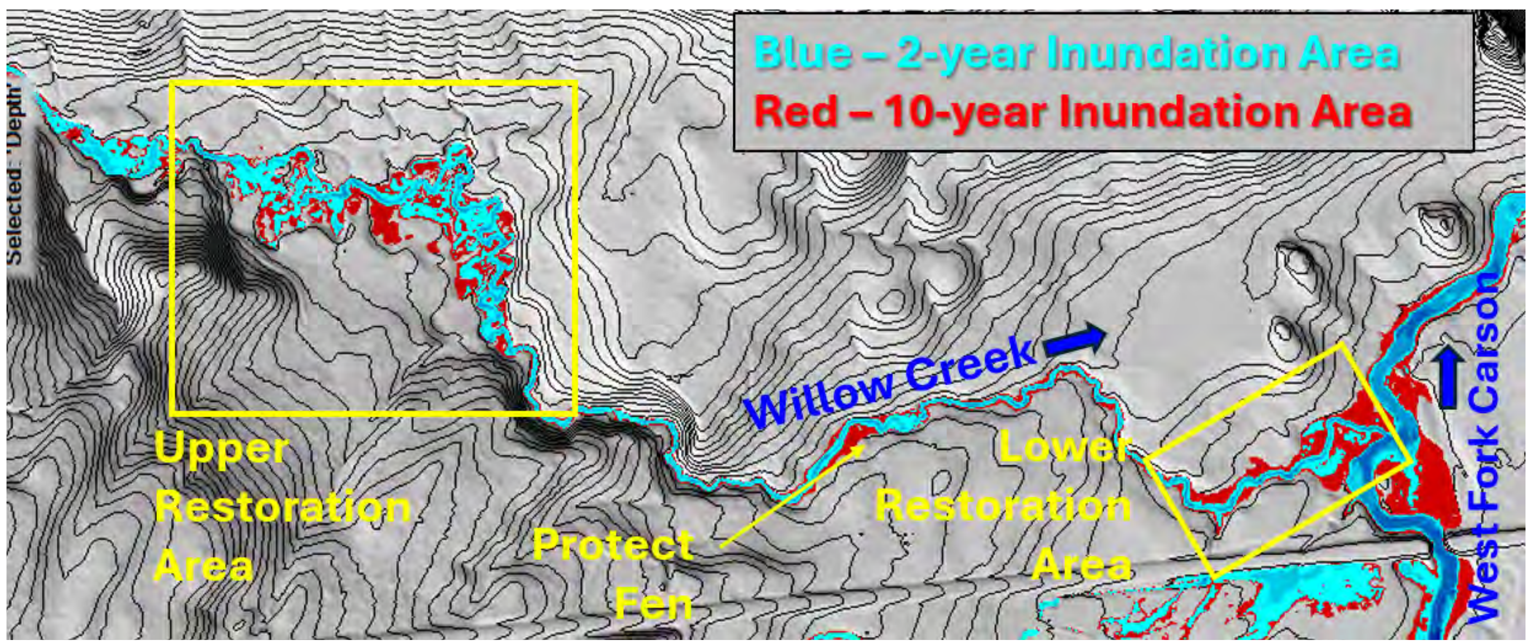


Figure 11-A. Topography and hydraulic model results showing flood extent during 2-year and 10-year events in the lower portion of Willow Creek (existing conditions).

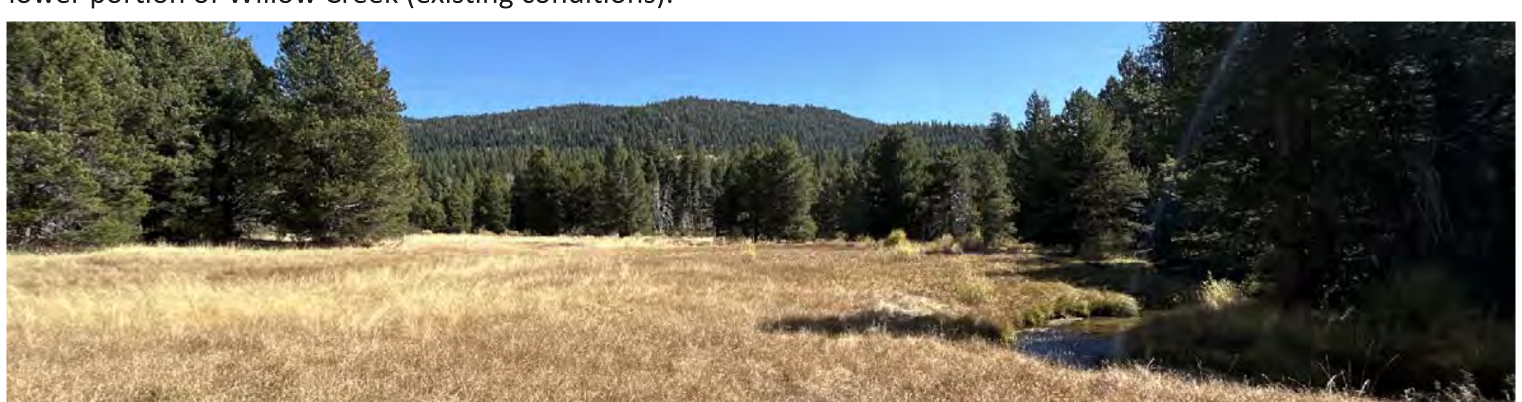


Figure 11-B. Photo of Willow Creek channel and floodplain in the upper area, which could be easily reconnected with LTPBR.

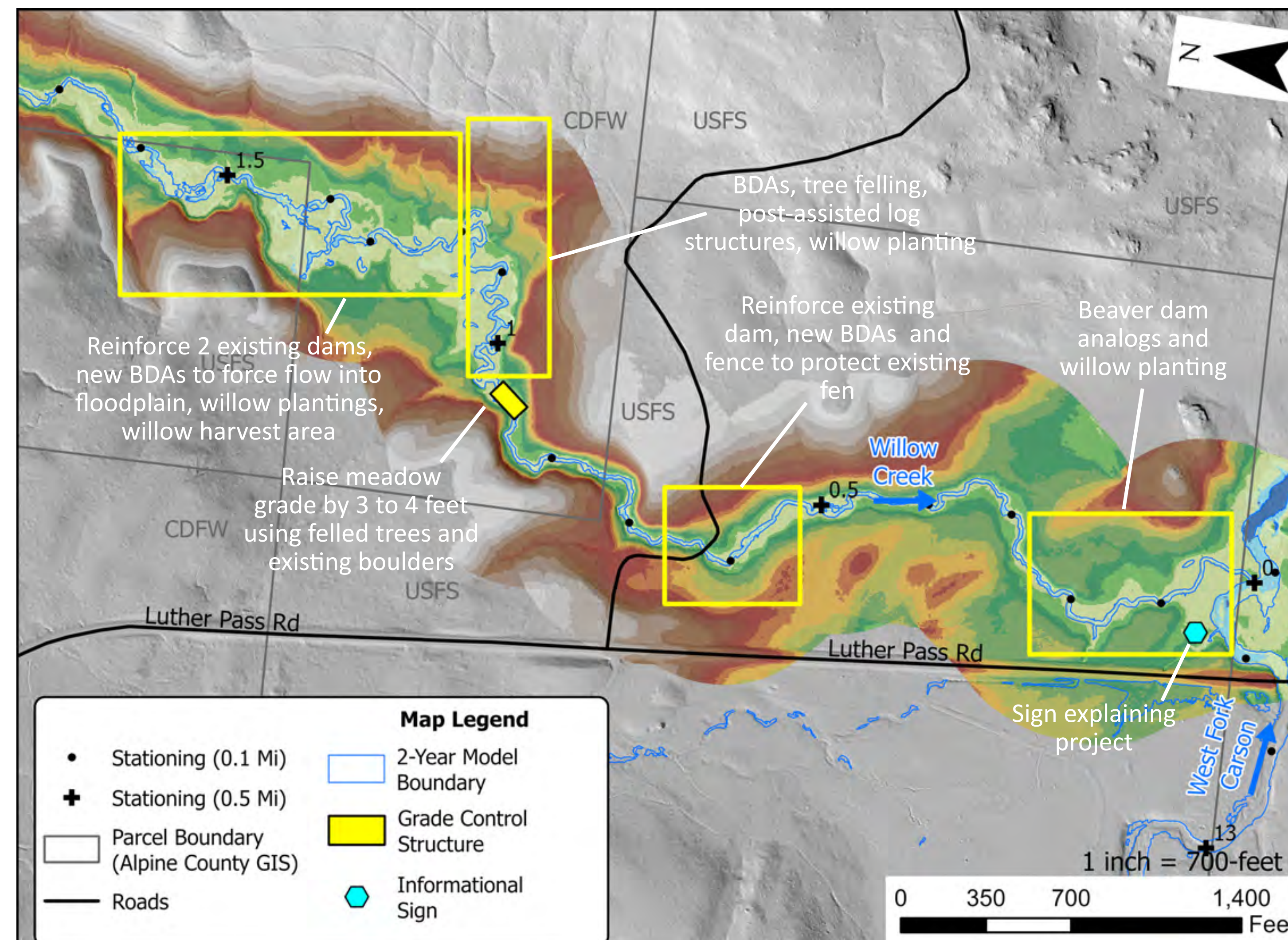


Figure 11

3.2 PROJECT SCORING

To enable a transparent and consistent comparison among projects with very different settings, objectives, and levels of complexity, each of the 15 projects advanced for evaluation were scored using a standardized set of 20 evaluation factors, referred to as **Indicators** (**Table 10**). The Indicators include technical, environmental, economic, and social/cultural considerations and are organized into sub-accounts and primary accounts (**Table 10**), consistent with the Multiple Accounts Analysis (MAA) framework described below (Section 3.3).

Table 10. *Project Indicators and Scoring Criteria*

Account	Sub-Account	Indicator
Technical	Engineering Feasibility	Geomorphic Difficulty
		Access
		Constructability
	Risks	Risk of Failure to Perform/Likelihood of Success
		Potential Risks to Infrastructure or Existing Natural Resource Values
Economic	Cost	Design and Construction Costs
		Ongoing Maintenance Cost
Environ-mental	Water Quality	Fine Sediment Reduction
		Water Temperature or Pollutant Reduction
	Habitat	In-Channel Habitat Improvement
		Riparian Habitat Improvement
	Geomorphic Process	Prevents or Reverses Degradation
		Improves Channel-Floodplain Connectivity[2]
		Increases Channel Complexity
	Groundwater	Increases Groundwater Recharge and Meadow Recovery
Social and Cultural	Social	Property Ownership
		Flood Benefit
		Ease of Permitting, Water Rights, and Right of Way
	Cultural[4]	Recreational Impact
		Will be viewed as a successful project by stakeholders and the public

Initial scores were independently assigned to each of the Indicators by two experienced restoration practitioners (Daniel Malmon and Loren Roach), both of whom visited the project sites in the field. Each Indicator was scored on a 1 to 5 ordinal scale, where a score of 1 represents relatively low potential or high concern, and a score of 5 represents high potential or favorable conditions. Independent scoring was used to reduce individual bias and to ensure that differing professional judgments were identified and resolved prior to scoring the projects.

Following initial field-based scoring, the two sets of scores were reviewed and reconciled using desktop analyses, hydraulic modeling, LiDAR and aerial photo interpretation, and review of constraints. This produced a single set of 20 Indicator scores for each project. The scores are intended to support relative comparison among projects, rather than to predict absolute outcomes.

A detailed example of the scoring process is provided in **Table 11** (following 2 pages) which presents the full set of Indicator scores for **Project 11** (Willow Creek), along with a brief justification for each score. Similar evaluations were completed for all 15 projects and form the basis for the weighting and prioritization process described in Section 3.3.

***Table 11** . Example Project Scoring Table for Willow Creek Meadow Restoration (Project 11)*

Project 11 - Willow Creek Beaver Restoration

Account	Sub-Account	Indicator	Project Features Creating Higher Indicator Scores	Scoring Criteria	Final Indicator Score[2] (1-5)	Notes
Technical	Engineering Feasibility	Geomorphic Difficulty	Low height to raise bed; able to use LTPBR instead of rock; narrow channel; confined channel without a risk of flanking.	(1-difficult, 3-moderate, 5-easy)	4	Not severely incised, small lift to reconnect floodplain
		Access	Easy equipment access; adequate staging areas; minimal disturbance expected. Note: this indicator reflects physical constraints, not related to considerations around access permission from private landowners. That aspect is covered under the indicator "Property Ownership".	(1-difficult, 3-moderate, 5-easy)	4	Hand crews only; could bring materials to upper work area with livestock
		Constructability	Ease of construction - uses lower tech, lower impact, and lower cost methods. If using heavy equipment, requires less exavation or import of materials.	(1-difficult, 3-moderate, 5-easy)	5	Low tech methods with hand crews.
	Risks	Risk of Failure to Perform/Likelihood of Success	High probability of project providing intended benefits.	(1-high risk, 3-typical risk, 5-high chance of success)	4	High chance of achieving positive response for relatively small effort
		Potential Risks to Infrastructure or Existing Natural Resource Values	No roads, houses, or irrigation infrastructure present; unlikely to negatively impact scenery, fishing, recreation, or other qualities valued by landowners (on private land) or by the public (public land).	(1-high risk, 3-typical risk, 5-high chance of success)	5	CDFW property, rarely used. Cattle grazing could be affected.
Economic	Cost	Design and Construction Costs	Low design and construction costs.	(1-more than $2M, 2-$1M to $2M, 3-$500K to $1M 4-$250K to $500K 5-less than $250K)	4	Envision a small low tech, low risk project with some engagement and permitting required. Design cost will be high compared with construction.
		Ongoing Maintenance Cost	Project will not require require only monitoring, with minimal ongoing maintenance, adaptive management or repair.	(1-require long term commitment, 3 - monitoring and adaptive management, 5-minimal maintenance anticipated	3	Monitoring and adaptive maintenance typical for LTPBR projects
Environ-mental	Water Quality	Fine Sediment Reduction	Reduces bank erosion and/or increases the amount of sediment that will be stored in the floodplain	(1-little benefit compared with other projects, 3-moderate benefit, 5-highest benefit)	4	Willow Creek watershed produces lot of sediment. Could deposit a relatively large portion of this in the lower meadow. Would also reduce bank erosion.
		Water Temperature or Pollutant Reduction	Contributes to reducing warm season water temperatures; directly prevents pollutants from entering WFCR; impact would be observable downstream, where WFCR is considered impaired with respect to these Parameters.	(1-negligible impact on water quality, 3-moderate impact compared with other projects, 5-one of the projects with the most WQ benefits)	2	Slight water temp reduction through more groundwater recharge.
		In-Channel Habitat Improvement	Addresses limiting factors for aquatic species in West Fork Carson River or tributary streams	(1 - negative impact, 3 - some improvement of in-stream habitat, 5 - significant reach-scale improvement of in-channel habitat)	4	Opportunities to expand the amount of beaver-influenced channel, which will improve in-channel habitat for aquatic organisms.

Project 11 - Willow Creek Beaver Restoration

Account	Sub-Account	Indicator	Project Features Creating Higher Indicator Scores	Scoring Criteria	Final Indicator Score[2] (1-5)	Notes
	Habitat	Riparian Habitat Improvement	Improves extent and/or health of native riparian plants within project area	(1 - negative impact on riparian habitat quality, 3 - some improvement of riparian habitat, 5 - significant reach-scale improvement of riparian habitat)	4	Relatively large area of floodplain can be reconnected with somewhat little effort
Environ-mental (cont)	Geomorphic Process	Prevents or Reverses Degradation	Reverses a presently degraded condition by aggrading the bed and/or hydraulically reconnecting floodplain.	(1-no impact; or the reach is already in non-degraded condition, 3- moderate improvement compared with other projects, 5-significant reversal of degraded condition)	4	This is a primary project objective, with high probability of success. Moderate to small area of impact (on the order of 5-10 acres).
		Improves Channel-Floodplain Connectivity[3]	Increases the frequency and volume of water and sediment entering the floodplain and off channel areas during floods.	(1-does not improve connectivity, 3-reconnects some meadow floodplain, 5-large benefit in terms of frequency and meadow area)	5	Improves floodplain connectivity in two separate incised meadows.
		Increases Channel Complexity	Increases the diversity of geomorphic and habitat types within the channel.	(1- minor improvements 3- moderate or temporary impact, 5-larger or self-sustaining benefits)	4	Adds felled trees, PALS and BDAs to the channel.
	Groundwater	Increases Groundwater Recharge and Meadow Recovery	Improves and expands wet meadow and associated vegetation	1-no wetland benefit, 3-moderate benefit compared with other projects, 5-significant expansion or improvement of wetlands and meadows	3	Several acres of enhanced wetlands. BDAs will protect existing spring and fen from headcut and dewatering.
Social and Cultural	Social	Property Ownership	Property owner(s) in favor of the project, maximizes landowner benefits, limits short term and long term negative impacts	(1-difficult, 3-moderate, 5-easy)	5	CDFW property.
		Flood Benefit[3]	Attenuates the peak flood flow at the California-Nevada state line during moderate and large floods.	(1-no impact on floods downstream, 3-could contribute some flood benefit if combined with other projects, 5-one of the proposed projects with the largest flood benefits)	2	Hardly any impact on flood attenuation at the CA/NV state line
		Ease of Permitting, Water Rights, and Right of Way[4]	Clear permitting pathway, no major issues with acquiring permission for the project, water rights issues	(1-difficult, 3-moderate, 5-easy)	4	Probably will be easy to permit if kept to a LTPBR project. Reasonably high likelihood of cultural resources in the area but these would not be disturbed
	Cultural[4]	Recreational Impact	Improve user experience; little construction impact	(1-negative impact, 3-neutral, 5-significant benefit)	4	Opportunities for education in high visibility area. Upper part of project is rarely visited, which may be a benefit. Could improve fishing
		Will be viewed as a successful project by stakeholders and the public	Immediate and obvious benefits, especially in higher visibility areas; project benefits will be seen at the site, rather than only downstream.	(1-high risk of negative perceptions, 3-moderate risk 5-project benefits will be obvious to stakeholders, landowners, or the public)	5	Lower part is next to Pickett's Junction, easy access, lots of visitors. Could incorporate signage to explain the project and do field tours.

Notes:

1. An initial set of indicator scores was assigned independently by Waterways and Watershed Resiliency Consulting (WRC) during field visits to potential project sites. The final indicator scores reported in this column were assigned after further analysis, considering the initial (field-based) indicator scores along with hydraulic model results, aerial photographs, and other considerations.

2. These indicators were added based on input from stakeholders. This occurred after the field assessments and scoring were completed, so these were not initially scored during field assessments by Waterways and WRC.

3. Impact to archaeological resources is not explicitly included as an indicator because the presence or absence of artifacts is not known for each of the proposed project sites. The indicator "Ease of permitting" includes a field estimation of the likelihood of cultural resources that would make it difficult to permit the project.

3.3 STAKEHOLDER WEIGHTING AND MULTIPLE ACCOUNTS ANALYSIS

While the Indicator scores described in Section 3.2 provide a consistent technical evaluation of project attributes, not all Indicators are equally important in determining which projects should be prioritized. To incorporate stakeholder values into the prioritization process, the project used a Multiple Accounts Analysis (MAA) framework (Robertson and Shaw, 1998; 2004). MAA is a multi-objective decision-making approach designed to compare alternatives that differ across multiple, often competing, objectives by making tradeoffs explicit and transparent. A key advantage of MAA is that it separates technical scoring from value-based weighting, allowing scientific evaluations and stakeholder preferences to be examined independently and then combined in a clear and reproducible manner (Shaw, 2004).

Stakeholder input on Indicator importance was coordinated by Alpine Watershed Group and obtained from 18 participants representing federal and state agencies, non-governmental organizations, and other entities with an interest in restoration and water quality outcomes in the West Fork Carson River watershed. Participants were asked to assign relative weightings to the primary accounts, associated sub-accounts, and Indicators defined in **Table 10**, reflecting the importance of different categories of outcomes (e.g., environmental benefits, technical feasibility, economic considerations, and social or implementation factors). Individual responses were aggregated to produce a single set of representative weightings used in the analysis.

The resulting stakeholder weightings showed a high degree of consistency across respondents (**Figure 26**). Environmental outcomes received the greatest overall weight, followed by technical feasibility, with economic and social considerations receiving comparatively lower but still meaningful weightings. This pattern indicates broad alignment among stakeholders regarding the primary objectives in the watershed, and supports the use of a single, aggregated weighting scheme for project prioritization. The final weightings used in the MAA were the modified stakeholder averages in the first column in **Table 12**.

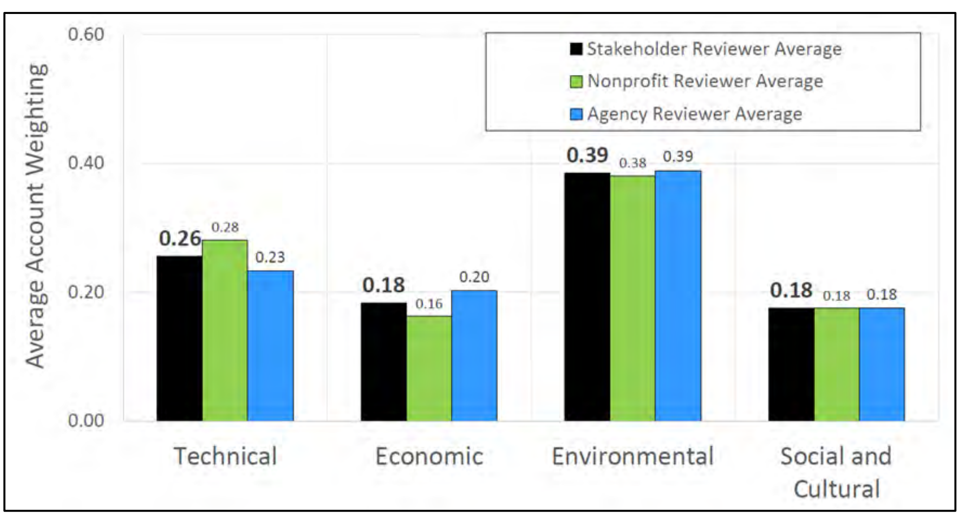


***Figure 26**. Summary of Results of Stakeholder Weightings for Primary Accounts*

PLACEHOLDER PAGE – STAKEHOLDER RESULTS TABLE

Table 12. *Results of Stakeholder Prioritization Weightings*

Table X. *Stakeholder Prioritization Results for Account, Subaccount, and Indicator Weightings*

	Modified Stakeholder Average[1]	Stakeholder Average (n=13)	Nonprofit Reviewer Average[2]	Agency Reviewer Average[3]	Alpine Watershed Group: AWG Average	AWG-KM	AWG-DK	AWG-NM	AWGB-JT	AWGB-CR	AWGB-MY	AWGB-ZW	Carson Water Sub-Conservancy District: CWSD-BH	CWSD-KH	Lahontan Regional Water Quality Control Board (Water Board) Reviewers: LRWQCB Average	Re-viewer-1	Re-viewer-2	Re-viewer-3	Re-viewer-4	Re-viewer-5	US Forest Service: USFS-DK	American Rivers: AR-SH	Ca. Dept. Fish and Wildlife: CDFW-AC	Deso-lation Hotel: DH-ZS
Accounts																								
Technical	0.26	0.26	0.28	0.23	0.29	0.20	0.30	0.10	0.40	0.40	0.10	0.50	0.30	0.20	0.26	0.25	0.25	0.30	0.30	0.20	0.30	0.25	0.20	0.00
Economic	0.18	0.18	0.16	0.20	0.16	0.35	0.20	0.10	0.20	0.10	0.10	0.10	0.30	0.30	0.20	0.02	0.25	0.25	0.30	0.20	0.30	0.15	0.10	0.00
Environmental	0.39	0.39	0.38	0.39	0.38	0.35	0.30	0.50	0.30	0.40	0.50	0.30	0.30	0.30	0.35	0.50	0.25	0.30	0.30	0.40	0.70	0.40	0.45	1.00
Social and Cultural	0.18	0.18	0.18	0.18	0.17	0.10	0.20	0.30	0.10	0.10	0.30	0.10	0.10	0.20	0.19	0.23	0.25	0.15	0.10	0.20	0.10	0.20	0.25	0.00
Sub Accounts																								
Technical																								
Engineering Feasibility	0.55	0.55	0.59	0.52	0.59	0.50	0.40	0.60	0.60	0.70	0.50	0.80	0.60	0.40	0.57	0.65	0.50	0.60	0.50	0.60	0.50	0.60	0.30	1.00
Risk	0.45	0.45	0.41	0.48	0.41	0.50	0.60	0.40	0.40	0.30	0.50	0.20	0.40	0.60	0.43	0.35	0.50	0.40	0.50	0.40	0.50	0.40	0.70	0.00
Economic																								
Cost	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Environmental																								
Water Quality	0.30	0.27	0.28	0.26	0.30	0.25	0.30	0.20	0.40	0.30	0.50	0.30	0.40	0.50	0.32	0.50	0.25	0.25	0.20	0.40	0.30	0.25	0.10	0.00
Habitat	0.20	0.21	0.22	0.21	0.21	0.25	0.30	NA[4]	NA[4]	0.20	NA[4]	0.10	NA[4]	NA[4]	0.14	0.13	0.25	0.10	0.10	0.10	0.20	0.25	0.60	1.00
Geomorphic Process	0.30	0.26	0.24	0.27	0.25	0.25	0.20	0.20	0.30	0.20	0.30	0.30	0.30	0.20	0.26	0.13	0.25	0.40	0.30	0.20	0.40	0.25	0.20	0.00
Groundwater	0.20	0.19	0.22	0.18	0.20	0.25	0.20	0.50	0.30	0.20	0.20	0.20	0.30	0.30	0.21	0.13	0.25	0.15	0.30	0.20	0.30	0.25	0.10	0.00
Social and Cultural																								
Social	0.60	0.59	0.56	0.61	0.56	0.75	0.50	0.40	0.60	0.60	0.60	0.50	0.50	0.60	0.63	0.50	0.80	0.55	0.80	0.50	0.75	0.50	0.50	1.00
Cultural	0.40	0.41	0.44	0.39	0.44	0.25	0.50	0.60	0.40	0.40	0.40	0.50	0.50	0.40	0.37	0.50	0.20	0.45	0.20	0.50	0.25	0.50	0.50	1.00
Indicators																								
Technical																								
Geomorphic Difficulty	0.40	0.40	0.36	0.43	0.35	0.33	0.20		0.40	0.50		0.30			0.47	0.50	0.34	0.50	0.40	0.60	0.60	0.60	0.30	1.00
Access	0.30	0.30	0.33	0.28	0.36	0.33	0.40		0.50	0.25		0.30			0.24	0.30	0.33	0.25	0.20	0.10	0.25	0.20	0.50	0.00
Constructability	0.30	0.30	0.31	0.29	0.30	0.33	0.40		0.10	0.25		0.40			0.30	0.20	0.33	0.25	0.40	0.30	0.15	0.40	0.20	0.00
Risk of Failure to Perform/Likelihood of Success	0.67	0.63	0.62	0.64	0.60	0.50	0.70	NA[4]	0.30	0.80	NA[4]	0.70	NA[4]	NA[4]	0.64	0.75	0.50	0.67	0.70	0.60	0.65	0.70	0.60	1.00
Potential Risks to Infrastructure or Existing Natural Resource Values	0.33	0.37	0.39	0.36	0.40	0.50	0.30		0.70	0.20		0.30			0.36	0.25	0.50	0.35	0.30	0.40	0.35	0.30	0.40	0.00
Economic																								
Design and Construction Costs	0.50	0.48	0.46	0.49	0.50	0.40	0.60		0.40	0.80		0.50			0.50	0.60	0.50	0.40	0.70	0.30	0.45	0.25	0.50	1.00
Ongoing Maintenance Efforts	0.50	0.52	0.54	0.51	0.50	0.60	0.40		0.60	0.40		0.50			0.50	0.40	0.50	0.60	0.30	0.70	0.55	0.75	0.50	0.00
Environmental																								
Fine Sediment Reduction[5]	0.80	0.49	0.45	0.53	0.44	0.50	0.50		0.60	0.40		0.20			0.54	0.40	0.50	0.50	0.50	0.80	0.50	0.50	0.50	0.00
Water Temperature Reduction[5]	0.20	0.51	0.55	0.47	0.56	0.50	0.50	NA[4]	0.40	0.60	NA[4]	0.80	NA[4]	NA[4]	0.46	0.60	0.50	0.50	0.50	0.20	0.50	0.50	0.50	1.00
In-stream Habitat Improvement	0.50	0.52	0.55	0.49	0.56	0.50	0.50		0.50	0.60		0.70			0.50	0.40	0.50	0.50	0.40	0.70	0.50	0.50	0.40	1.00
Riparian Habitat Improvement	0.50	0.48	0.45	0.51	0.44	0.50	0.50		0.50	0.40		0.30			0.50	0.60	0.50	0.50	0.60	0.30	0.50	0.50	0.60	0.00
Reverses Degradation	0.40	0.58	0.48	0.68	0.46	0.60	0.50		0.60	0.50		0.30			0.60	0.60	0.50	0.40	0.70	0.80	0.60	0.60	0.80	1.00
Increases Channel-Floodplain Connectivity[6]	0.30	INDICATOR ADDED AFTER STAKEHOLDER REVIEW																						
Increases Channel Complexity	0.30	0.44	0.52	0.37	0.54	0.40	0.50	NA[4]	0.60	0.50	NA[4]	0.70	NA[4]	NA[4]	0.40	0.40	0.50	0.60	0.30	0.20	0.40	0.40	0.20	0.00
Groundwater Recharge	1.00	1.00	1.00	1.00	1.00	1.00	1.00		1.00	1.00		1.00			1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00
Social and Cultural																								
Property Ownership	0.50	0.50	0.46	0.53	0.40	0.50	0.60	NA[4]	0.20	0.60		0.30	NA[4]	NA[4]	0.44	0.60	0.20	0.40	0.50	0.50	0.60	0.75	0.80	0.00
Flood Benefit[6]	0.25	INDICATOR ADDED AFTER STAKEHOLDER REVIEW																						
Permitting, Water Rights, and Right of Way	0.25	0.50	0.54	0.47	0.60	0.50	0.40	NA[4]	0.80	0.60	NA[4]	0.70	NA[4]	NA[4]	0.56	0.40	0.80	0.60	0.50	0.50	0.40	0.25	0.10	1.00
Recreation Impacts	0.30	1.00	1.00	1.00	1.00	1.00	1.00		1.00	1.00		1.00			1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Public Perception[6]	0.70	INDICATOR ADDED AFTER STAKEHOLDER REVIEW																						

Notes:

1. Modified Stakeholder Average are values used in the main analysis. Small modifications in the average value were made to approximate and account for differences between the final scoring criteria and the set of criteria that was sent to stakeholders for input.
2. Nonprofit Reviewer Average reflects the average of responses from reviewers from Alpine Watershed Group and American Rivers.
3. Agency Reviewer Average reflects the average of responses from reviewers from CWSD, LRWQCB, USFS, and CDFW
4. Cells with "NA" are those in which stakeholders either did not respond, or responded to an early version of the questionnaire that did not include these specific criteria. Averages do not include responses where missing values would affect the scores.
5. Weighting for the water quality indicators does not use the stakeholders preferences. Instead, relative importance of fine sediment versus water temperature and other benefits is relative to the scope of the West Fork Carson River Prioritization Plan project.

3.4 PROJECT RANKING RESULTS AND INTERPRETATION

The MAA analysis combines the stakeholder-informed weightings in **Table 12** with the Indicator scoring for each of the projects (e.g., **Table 11**) to produce prioritization scores for the 15 projects (**Table 13**). **Table 13** is a summary of the project rankings in prioritized order. **Table 14** shows the details of the MAA scoring, and includes the overall scores for each project, along with detailed scores for each of the accounts, subaccounts, and indicators.

3.4.1 Overall Project Rankings and Account-Level Performance

The overall project rankings in **Table 13** reflect the weighted combination of scores across the primary accounts, including Technical Feasibility, Costs, Environmental Benefits, and Social and Cultural accounts. High-ranking projects consistently score strongly (above 3.5) in the Environmental account, reflecting their potential to reduce fine sediment, reconnect floodplains, and improve instream and riparian habitat. Differences in overall ranking are sometimes driven by technical and logistical considerations rather than environmental benefits alone. For example, projects with the highest Environmental scores (e.g., Projects 5 and 6) are ranked slightly lower overall (ranked #4 and #5) due to anticipated challenges such as scale, cost, permitting, or constructability. Conversely, smaller projects with moderate environmental potential (e.g., Projects 11 and 12) rank highly overall because they combine some benefits with low technical and logistical risk.

For planning purposes, we recommend that the top seven highest ranked projects, with overall scores much higher than 3, be strongly considered for implementation as part of a long-term program, while projects ranked 8 to 10 (scores close to 3) should be revisited to see if they are worthwhile in the context of other efforts. Projects ranked 11 through 15 are lower priority, because they provide comparatively limited value under the stakeholder-weighted objectives, and/or face substantial feasibility or implementation constraints.

Table 13. *Summary of MAA Prioritization Results.*

Project #	MAA Rank	Projects	Creek	Project Size	Overall Score	Technical	Economic	Environ-mental	Social and Cultural
Project 12	1	Red Lake Creek Lower Meadow Restoration	Red Lake Creek	Small-Medium	**4.07**	4.37	3.50	4.08	4.18
Project 11	2	Willow Creek Beaver Restoration	Willow Creek	Small	**3.84**	4.31	3.50	3.48	4.28
Project 15	3	Basinwide Headcut Repairs	Basinwide	Small-Medium	**3.72**	4.37	3.50	3.54	3.40
Project 5	4	Lower Hope Valley Restoration	West Fork Carson	Large	**3.60**	3.36	2.00	4.24	4.15
Project 6	5	Middle Hope Valley Restoration	West Fork Carson	Large	**3.57**	3.34	2.00	4.24	4.00
Project 13	6	Red Lake Creek Upper Meadows Restoration	Red Lake Creek	Small	**3.49**	3.84	4.00	3.04	3.43
Project 10	7	Upper Faith Valley Floodplain Reconnection	West Fork Carson	Medium	**3.26**	3.65	2.50	3.34	3.30
Project 8	8	Blue Lakes Road Restoration	West Fork Carson	Small	**3.01**	4.15	4.00	1.60	3.45
Project 9	9	Faith Valley Campground Restoration	West Fork Carson	Medium	**2.97**	3.55	2.50	2.54	3.55
Project 7	10	Upper Hope Valley Restoration	West Fork Carson	Large	**2.77**	2.47	2.00	3.24	2.97
Project 14	11	Hawkins Fan Reconnection	Hawkins Creek	Small	**2.74**	2.45	3.00	2.68	3.02
Project 4	12	Crystal Springs Road Floodplain Reconnection	West Fork Carson	Medium-Large	**2.41**	2.31	2.50	2.30	2.70
Project 2	13	Ace Hereford Ranch Floodplain Reconnection	West Fork Carson	Large	**2.28**	2.11	2.50	2.14	2.60
Project 1	14	River Ranch Road Fan Reconnection	West Fork Carson	Large	**2.27**	2.15	1.50	2.84	1.97
Project 3	15	Woodfords Fan Reconnection	West Fork Carson	Large	**2.13**	2.13	1.50	2.56	1.82

The MAA results synthesize the geomorphologic analysis, project-level evaluation, and stakeholder input to provide a comprehensive understanding of where restoration actions are likely to be most effective in reducing fine sediment loads and achieving additional environmental and societal benefits. The results provide both spatial guidance—identifying the reaches where interventions are most promising—and strategic guidance—informing the type, scale, and phasing of restoration actions across the watershed.

Table X. *Results of Multiple Accounts Analysis for All Projects*

Account	Account Weight	Sub-Account	Sub-Account Weight	Indicator	Indicator Weight	Project 1 River Ranch Road Fan Reconnection	Project 2 Ace Hereford Ranch Floodplain Reconnection	Project 3 Woodfords Fan Reconnection	Project 4 Crystal Springs Road Floodplain Reconnection	Project 5 Lower Hope Valley Restoration	Project 6 Middle Hope Valley Restoration	Project 7 Upper Hope Valley Restoration	Project 8 Blue Lakes Road Restoration	Project 9 Faith Valley Campground Restoration	Project 10 Upper Faith Valley Floodplain Reconnection	Project 11 Willow Creek Beaver Restoration	Project 12 Red Lake Creek Lower Meadow Restoration	Project 13 Red Lake Creek Upper Meadows Restoration	Project 14 Hawkins Fan Reconnection	Project 15 Basinwide Headcut Repairs
Tech-nical	0.26	Engineer-ing Feasibility	0.55	Geomorphic Difficulty	0.4	2	1	4	2	4	4	2	4	4	4	4	5	4	2	5
				Access	0.3	3	4	2	3	3	2	3	3	5	2	4	3	3	2	4
				Constructability	0.3	1	2	1	2	2	2	2	5	3	3	5	5	4	2	4
				Subaccount Rating		2.00	2.20	2.50	2.30	3.10	2.80	2.30	4.00	4.00	3.10	4.30	4.40	3.70	2.00	4.40
				Weighted Subaccount Value		1.10	1.21	1.38	1.27	1.71	1.54	1.27	2.20	2.20	1.71	2.37	2.42	2.04	1.10	2.42
		Risks	0.45	Risk of Failure to Perform/Likelihood of Success	0.67	3	2	2	2	4	4	3	4	3	4	4	4	4	2	4
				Potential Risk to Infrastructure or Natural Resources	0.33	1	2	1	3	3	4	2	5	3	5	5	5	4	5	5
				Subaccount Rating		2.34	2.00	1.67	2.33	3.67	4.00	2.67	4.33	3.00	4.33	4.33	4.33	4.00	2.99	4.33
				Weighted Subaccount Value		1.05	0.90	0.75	1.05	1.65	1.80	1.20	1.95	1.35	1.95	1.95	1.95	1.80	1.35	1.95
				Account Rating		2.15	2.11	2.13	2.31	3.36	3.34	2.47	4.15	3.55	3.65	4.31	4.37	3.84	2.45	4.37
				Account Value Weight		0.55	0.54	0.55	0.60	0.86	0.86	0.63	1.07	0.91	0.94	1.11	1.12	0.99	0.63	1.12
Eco-nomic	0.18	Cost	1	Design and Construction Cost	0.5	1	2	1	2	1	1	1	5	2	2	4	4	5	3	4
				Ongoing Maintenance Effort	0.5	2	3	2	3	3	3	3	3	3	3	3	3	3	3	3
				Subaccount Rating		1.50	2.50	1.50	2.50	2.00	2.00	2.00	4.00	2.50	2.50	3.50	3.50	4.00	3.00	3.50
				Weighted Subaccount Value		1.50	2.50	1.50	2.50	2.00	2.00	2.00	4.00	2.50	2.50	3.50	3.50	4.00	3.00	3.50
				Account Rating		1.50	2.50	1.50	2.50	2.00	2.00	2.00	4.00	2.50	2.50	3.50	3.50	4.00	3.00	3.50
				Account Value Weight		0.27	0.45	0.27	0.45	0.36	0.36	0.36	0.71	0.45	0.45	0.62	0.62	0.71	0.53	0.62
Environ-mental	0.39	Water Quality	0.3	Fine Sediment Reduction	0.8	4	3	3	1	5	5	4	1	2	4	4	5	3	4	5
				Water Temperature or Pollutant Reduction	0.2	3	2	4	1	4	4	3	1	1	3	2	3	2	2	4
				Subaccount Rating		3.80	2.80	3.20	1.00	4.80	4.80	3.80	1.00	1.80	3.80	3.60	4.60	2.80	3.60	4.80
				Weighted Subaccount Value		1.14	0.84	0.96	0.30	1.44	1.44	1.14	0.30	0.54	1.14	1.08	1.38	0.84	1.08	1.44
		Habitat	0.2	In-Channel Habitat Improvement	0.5	2	1	3	4	4	4	3	4	3	3	4	4	3	2	2
				Riparian Habitat Improvement	0.5	3	4	4	3	5	5	4	2	4	4	4	5	4	3	4
				Subaccount Rating		2.50	2.50	3.50	3.50	4.50	4.50	3.50	3.00	3.50	3.50	4.00	4.50	3.50	2.50	3.00
				Weighted Subaccount Value		0.50	0.50	0.70	0.70	0.90	0.90	0.70	0.60	0.70	0.70	0.80	0.90	0.70	0.50	0.60
		Geo-morphic	0.3	Prevents or Reverses Degradation	0.33	2	2	2	3	5	5	4	1	4	4	4	4	4	3	5
				Improves Channel-Floodplain Connectivity	0.34	4	2	3	4	5	5	4	3	4	4	5	5	4	4	4
				Increases Channel Complexity	0.33	3	1	2	4	4	4	3	2	3	4	4	4	3	3	2
				Subaccount Rating		3.01	1.67	2.34	3.67	4.67	4.67	3.67	2.01	3.67	4.00	4.34	4.34	3.67	3.34	3.67
				Weighted Subaccount Value		0.90	0.50	0.70	1.10	1.40	1.40	1.10	0.60	1.10	1.20	1.30	1.30	1.10	1.00	1.10
		Ground-water	0.2	Increases Groundwater Recharge	1	3	3	2	2	5	5	3	1	2	3	3	5	4	1	4
				Subaccount Rating		1.50	1.50	1.00	1.00	2.50	2.50	1.50	0.50	1.00	1.50	1.50	2.50	2.00	0.50	2.00
				Weighted Subaccount Value		0.30	0.30	0.20	0.20	0.50	0.50	0.30	0.10	0.20	0.30	0.30	0.50	0.40	0.10	0.40
				Account Rating		2.84	2.14	2.56	2.30	4.24	4.24	3.24	1.60	2.54	3.34	3.48	4.08	3.04	2.68	3.54
				Account Value Weight		1.10	0.83	0.99	0.89	1.64	1.64	1.25	0.62	0.98	1.29	1.34	1.58	1.17	1.04	1.37
Social and Cultural	0.18	Social	0.6	Property Ownership	0.5	1	4	1	2	5	5	3	5	5	5	5	5	3	5	4
				Flood Benefit	0.25	4	2	3	3	5	4	3	1	1	2	2	4	3	1	1
				Permitting, Water Rights, and Right of Way	0.25	1	2	1	3	2	2	2	4	2	2	4	4	4	3	3
				Subaccount Rating		1.75	3.00	1.50	2.50	4.25	4.00	2.75	3.75	3.25	3.50	4.00	4.50	3.25	3.50	3.00
				Weighted Subaccount Value		1.05	1.80	0.90	1.50	2.55	2.40	1.65	2.25	1.95	2.10	2.40	2.70	1.95	2.10	1.80
		Cultural	0.4	Recreation Impacts	0.3	3	2	3	3	4	4	4	3	4	3	4	3	3	3	4
				Public Perception of Project	0.7	2	2	2	3	4	4	3	3	4	3	5	4	4	2	4
				Subaccount Rating		2.30	2.00	2.30	3.00	4.00	4.00	3.30	3.00	4.00	3.00	4.70	3.70	3.70	2.30	4.00
				Weighted Subaccount Value		0.92	0.80	0.92	1.20	1.60	1.60	1.32	1.20	1.60	1.20	1.88	1.48	1.48	0.92	1.60
				Account Rating		1.97	2.60	1.82	2.70	4.15	4.00	2.97	3.45	3.55	3.30	4.28	4.18	3.43	3.02	3.40
				Account Value Weight		0.35	0.46	0.32	0.48	0.74	0.71	0.53	0.61	0.63	0.59	0.76	0.74	0.61	0.54	0.61
TOTAL MATRIX SCORE						**2.27**	**2.28**	**2.13**	**2.41**	**3.60**	**3.57**	**2.77**	**3.01**	**2.97**	**3.26**	**3.84**	**4.07**	**3.49**	**2.74**	**3.72**

Total Score	**2.27**	**2.28**	**2.13**	**2.41**	**3.60**	**3.57**	**2.77**	**3.01**	**2.97**	**3.26**	**3.84**	**4.07**	**3.49**	**2.74**	**3.72**
Technical Score	2.15	2.11	2.13	2.31	3.36	3.34	2.47	4.15	3.55	3.65	4.31	4.37	3.84	2.45	4.37
Economic Score	1.50	2.50	1.50	2.50	2.00	2.00	2.00	4.00	2.50	2.50	3.50	3.50	4.00	3.00	3.50
Environmental Score	2.84	2.14	2.56	2.30	4.24	4.24	3.24	1.60	2.54	3.34	3.48	4.08	3.04	2.68	3.54
Social and Cultural Score	1.97	2.60	1.82	2.70	4.15	4.00	2.97	3.45	3.55	3.30	4.28	4.18	3.43	3.02	3.40

3.4.2 Spatial Patterns of Prioritized Projects

The map of project rankings in **Figure 27** reveals a clear spatial trend: the highest-ranking projects are all located in the upper, glaciated portion of the watershed, including both the mainstem West Fork Carson River and its tributaries. This pattern aligns with the findings from the geomorphologic model and sediment budget, which indicate that nearly all fine sediment originates from streambank erosion in the upper basin, particularly in Hope Valley.

The upper basin contains broad, glacially-formed valleys where sediment can be stored, providing geomorphic capacity for interventions to increase floodplain connectivity and sediment retention. In contrast, the lower basin is characterized by deeply incised channels, limited opportunities for improved floodplain connectivity, and minimal active bank erosion due to the boulder-lined channels. These physical constraints, coupled with predominantly private ownership and land uses that may be incompatible with floodplain restoration, reduce both the environmental potential and feasibility of restoration projects in the lower basin. The low geomorphic potential and practical barriers contribute to the lower rankings of projects in the lower basin.

The high-ranking projects in the upper basin are on public lands owned by U.S. Forest Service (USFS) and California Department of Fish and Wildlife (CDFW). Public ownership reduces access constraints and land use conflicts, facilitates permitting, and allows project proponents to work more easily with regulatory agencies and other stakeholders. These factors point clearly to the upper basin as the logical focus for restoration efforts targeting fine sediment reduction in the basin.

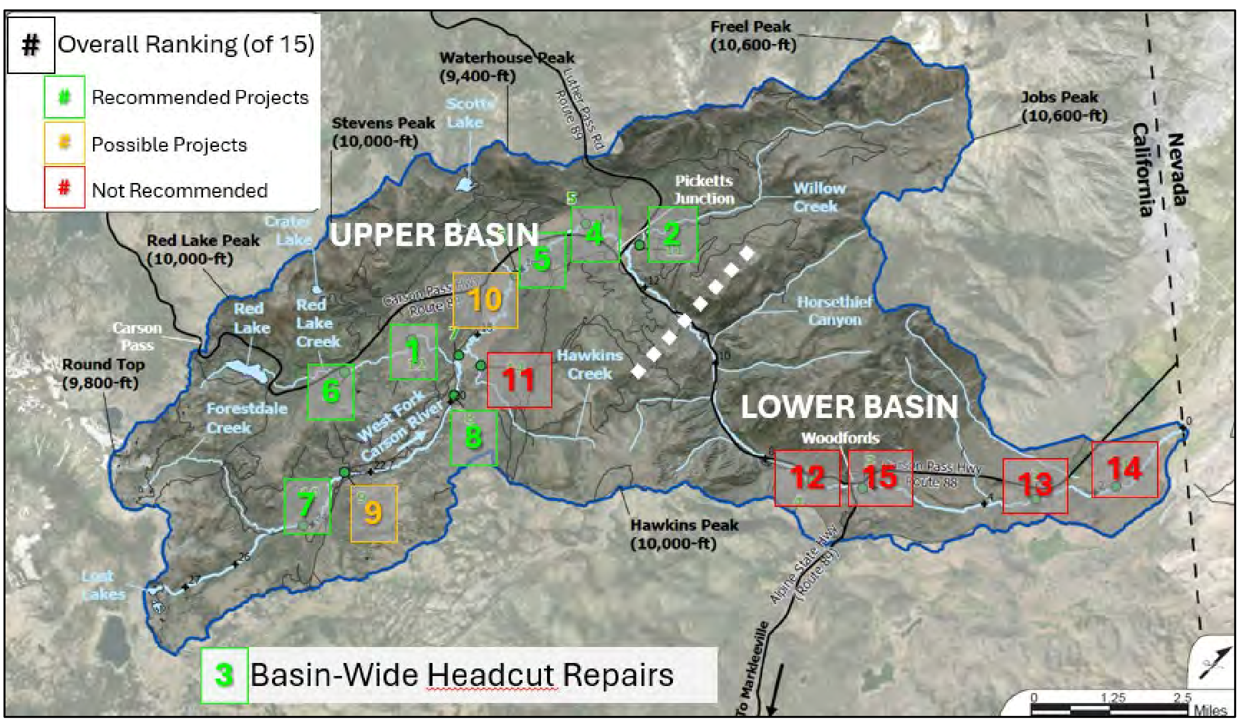


__Figure 27__. Spatial Pattern of 15 Potential Projects Identified by MAA Ranking

3.4.3 "Low-Hanging Fruit" Restoration Opportunities

Among the 15 projects advanced for detailed evaluation, a subset can be categorized as "low-hanging fruit." (**Table 15**). These projects are generally small in scale, low-risk, and involve actions that enhance sediment retention and floodplain connectivity through simple in-stream or floodplain features. Many mimic or support natural processes, such as beaver dam activity, which slows water, raises local channel bed elevations, reduces bank erosion, and traps sediment, among other beneficial outcomes. These projects can often be constructed with hand labor and minimal equipment, making them suitable for implementation using volunteers, stewardship crews, or small local contractors. Their low cost, low risk, and modular nature allow for phased implementation, monitoring, and adaptive management. These types of projects are valuable for generating near-term environmental benefits, building local experience and support, providing education and outreach opportunities, and informing subsequent, larger-scale restoration interventions. The methods used in these projects have been referred to collectively as Low-Tech Process Based Restoration (LTPBR) (Wheaton, et al., 2019) techniques.

The highest ranked projects in the study are LTPBR meadow restoration projects in Lower Red Lake Creek (**Project 12**) and Willow Creek (**Project 11**), two tributaries to the WFCR in Hope Valley. Another highly ranked project would be a basin-wide effort to identify, stabilize, and monitor meadow headcuts to protect intact meadows across the upper basin (**Project 15**). These projects are recommended as clear low-hanging fruit in the basin. The concepts for each of these projects are described in more detail in **Appendix P-1**.

Table 15. *Summary Table of "Low-Hanging Fruit" Projects*

Projects scored with Multiple Accounts Analysis

Project #	Projects	Creek	Project Size	Overall Score	Technical	Economic	Environ-mental	Social and Cultural
Project 12	Red Lake Creek Lower Meadow Restoration	Red Lake Creek	Small-Medium	4.07	4.37	3.50	4.08	4.18
Project 11	Willow Creek Beaver Restoration	Willow Creek	Small	3.84	4.31	3.50	3.48	4.28
Project 15	Basinwide Headcut Repairs	Basinwide	Small-Medium	3.72	4.37	3.50	3.54	3.40
Project 13	Red Lake Creek Upper Meadows Restoration	Red Lake Creek	Small	3.49	3.84	4.00	3.04	3.43
Project 10	Upper Faith Valley Floodplain Reconnection	West Fork Carson	Small-Medium	3.26	3.65	2.50	3.34	3.30
Project 8	Blue Lakes Road Restoration	West Fork Carson	Small	3.01	4.15	4.00	1.60	3.45

Additional Projects not scored with MAA

Project 19	Highway 88 West Meadow Restoration	Unnamed tributary	Unknown	Meadow restoration projects prioritized by American Rivers (2018); projects that offer benefits but that may not offer significant sediment storage or water quality benefit at the watershed scale.
Project 20	Horsethief Canyon Meadow Restoration	Horsethief Canyon	Unknown	
Project 21	Middle Willow Creek Meadow Restoration	Unnamed tributary	Small	
Project 16	Lower Hope Valley Adaptive Management	West Fork Carson	Small	Currently funded and should be moved forward as an early phase of Project #5.

Projects 8 and **10**, two LTPBR projects along the mainstem WFCR, have moderately high MAA scores (**Table 15**), indicating they could be worth including as part of a long-term, basin-scale restoration program. These two reaches are identified as places where relatively low risk and low cost projects could have a positive impact on habitat within the mainstem WFCR. **Project 8**, in the upper part of Faith Valley, just below the confluence with Forestdale Creek, is an opportunity to increase

connectivity with a large area of floodplain on river right. **Project 10**, along Blue Lakes Road, would help enhance conditions for an existing beaver population in a confined reach by increasing the stability of dams and adding large wood to the floodplain.

In addition to the projects evaluated through the MAA, other low-hanging fruit opportunities include restoration of headwater meadows identified as impaired by American Rivers (2018) (**Projects 19** through **21** in **Table 15**), which could improve meadow health and habitat but are unlikely to substantially affect the basin-scale sediment budget.

3.4.4 Higher Impact, Complex Restoration Projects

The projects that offer the highest environmental benefits are the large, reach-scale interventions on the mainstem West Fork Carson River, especially in Hope Valley **(Table 16**). These projects address the dominant sources of fine sediment and target the largest areas of geomorphic potential for sediment storage. In addition to water quality benefits, the projects in **Table 16** also offer the greatest potential for improvements to habitat, groundwater recharge, and geomorphic function, while potentially offering some flood attenuation benefits. For these reasons, they consistently receive the highest Environmental account scores in **Table 13**. These high-impact projects are more complex, have higher costs, and present more risks than the "low-hanging fruit" projects, leading to lower Economic and Technical account scores. The larger projects are more complex for many reasons: they require heavy equipment and possible import of unknown quantities of rock; they are in iconic, highly visible areas, where visual impacts to the landscape are important; the projects will be interrelated, in that upstream projects will affect downstream projects; and will have higher costs, technical demands, and permitting requirements.

Several of these higher-impact projects seem to offer enough benefits to justify the high costs and risks, particularly in Hope Valley (**Table 16**). Because of the higher costs and risks, these should be approached differently from the low-hanging fruit projects. Implementation of these more complex projects will require careful phasing, detailed design, and extensive stakeholder engagement. For many of these projects, monitoring and adaptive management will be essential to ensure that the projects achieve the intended outcomes and to allow for course corrections as the system responds to the interventions.

Table 16. *Larger Scale Restoration Opportunities*

Project #	Projects	Creek	Project Size	Overall Score	Technical	Economic	Environ-mental	Social and Cultural
Project 5	Lower Hope Valley Restoration	West Fork Carson	Large	3.60	3.36	2.00	4.24	4.15
Project 6	Middle Hope Valley Restoration	West Fork Carson	Large	3.57	3.34	2.00	4.24	4.00
Project 9	Faith Valley Campground Restoration	West Fork Carson	Medium	2.97	3.55	2.50	2.54	3.55
Project 7	Upper Hope Valley Restoration	West Fork Carson	Large	2.77	2.47	2.00	3.24	2.97

3.4.5 Water Budget for the WFCR and Impacts of Restoration on Water Delivery

In addition to the physical interventions listed here, restoration efforts in the basin could benefit from a water budget focused on quantifying the impacts of restoration actions on downstream water deliveries (Section 2.3.2). Downstream water users have expressed concern that upstream restoration actions—such as willow planting, floodplain reconnection, and the use of beaver dam analogs (BDAs)—could affect water deliveries by increasing evapotranspiration or otherwise altering the timing and magnitude of downstream flows. These concerns are reasonable given the importance of irrigation water in the lower basin and the visibility of restoration techniques that intentionally retain water on the landscape. At the same time, restoration approaches that increase floodplain inundation may alternatively have the potential to improve late-season water availability by enhancing groundwater recharge during high-flow periods, when excess water is available and irrigation deliveries are typically unaffected. This stored floodwater may subsequently return to the channel as baseflow during drier periods, when water demand is higher. Thus, the effect of restoration actions on downstream water deliveries to irrigators could be either beneficial, detrimental, or neutral. Evaluating these potentially offsetting effects requires a quantitative water budget capable of resolving seasonal storage, evapotranspiration, and groundwater–surface water interactions.

Developing such a water budget is outside the scope of this project, and no attempt is made here to predict changes in downstream water delivery due to the restoration actions being proposed. However, a basin-scale water budget focused on restoration-related flow timing is recommended as part of a long-term restoration management program and is identified as a potential action in Section 3. American Rivers has collected some data at the Faith Valley project that could be leveraged for this effort. While this is outside the scope of work of the current project, which focuses on sediment transport and geomorphology, answering those questions could answer stakeholder questions, and help secure funding and ongoing community support for a long-term restoration program in the upper WFCR basin.

3.5 HOPE VALLEY: RESTORATION POTENTIAL AND LONG-TERM APPROACH

3.5.1 Restoration Potential and Challenges in Hope Valley

Hope Valley, a glacially carved, fault bounded basin along seven miles of the mainstem WFCR and its tributaries, emerged from the prioritization analysis as the most important landscape for achieving meaningful, long-term geomorphic and water quality improvements in the WFCR watershed. Hope Valley is a broad, glacially carved meadow complex that includes multiple distinct sub-basins and tributaries. Hope Valley is highly visible, frequently visited, and deeply valued for its scenic, recreational, and ecological importance (**Figure 28**). It is also the location where the watershed's largest sources of bank erosion coincide with the greatest opportunities for floodplain reconnection and fine sediment storage. As shown in **Figure 15**, multiple high-ranking projects are clustered within Hope Valley along both the mainstem West Fork Carson River and key tributaries, forming a contiguous zone of restoration opportunity on public land where there is extensive public interest.

Figure 28. Photo of Lower Hope Valley and WFCR Watershed Looking Upstream (West).

Beneficial Geologic/Geomorphic Settings for Restoration. The best opportunities for reversing degradation and reconnecting the floodplain are in Lower Hope Valley (**Project 5**) and Middle Hope Valley (**Project 6**). As shown in **Figure 29**, these projects benefit from a geomorphic configuration similar to Faith Valley, where a project has recently been completed. These reaches share a configuration in which a wide alluvial meadow reach with active bank erosion is situated immediately upstream of a narrow, confined reach with boulder or bedrock constraints. These transitions occur throughout the upper basin where streams cross boulder-rich glacial end moraines, or where streams enter narrow bedrock canyons. This type of geomorphic transition in the WFCR and tributaries provides an advantageous geomorphic setting for restoration because it allows the base level to be raised or stabilized without a high risk of the river laterally bypassing, or "flanking", the constructed base level control. Similar geomorphic transitions can be found in tributaries as well, including in Willow Creek (**Project 11**), and in Upper and Lower Red Lake Creek (**Projects 12** and **13**).

Overall Geomorphic Approach. If channel incision and floodplain disconnection are considered drivers of degradation in Hope Valley, then the most effective long-term solution is to raise the channel bed closer to the floodplain elevation in order to increase the magnitude, frequency, and spatial extent of overbank flooding. The most reliable way to accomplish this is through the installation of stable grade control structures at the downstream end of the eroding meadow reaches. Where the channel transitions into confined bedrock or boulder-controlled segments. These structures can remain stable through high flows and establish a higher base level that promotes floodplain inundation and sediment deposition for hundreds to thousands of feet upstream. Upstream of these grade control locations, a wide range of complementary restoration treatments could be applied to further enhance sediment retention, reduce bank erosion, and improve riparian and meadow function. These may include non-channel-spanning large wood structures, engineered rock riffles, beaver dam analogs (BDAs), willow trenching, floodplain roughening, and other established or experimental techniques. The specific mix of treatments would depend on site conditions, project objectives, and stakeholder priorities, but the overarching intent would be to work with natural processes rather than impose a rigid channel form.

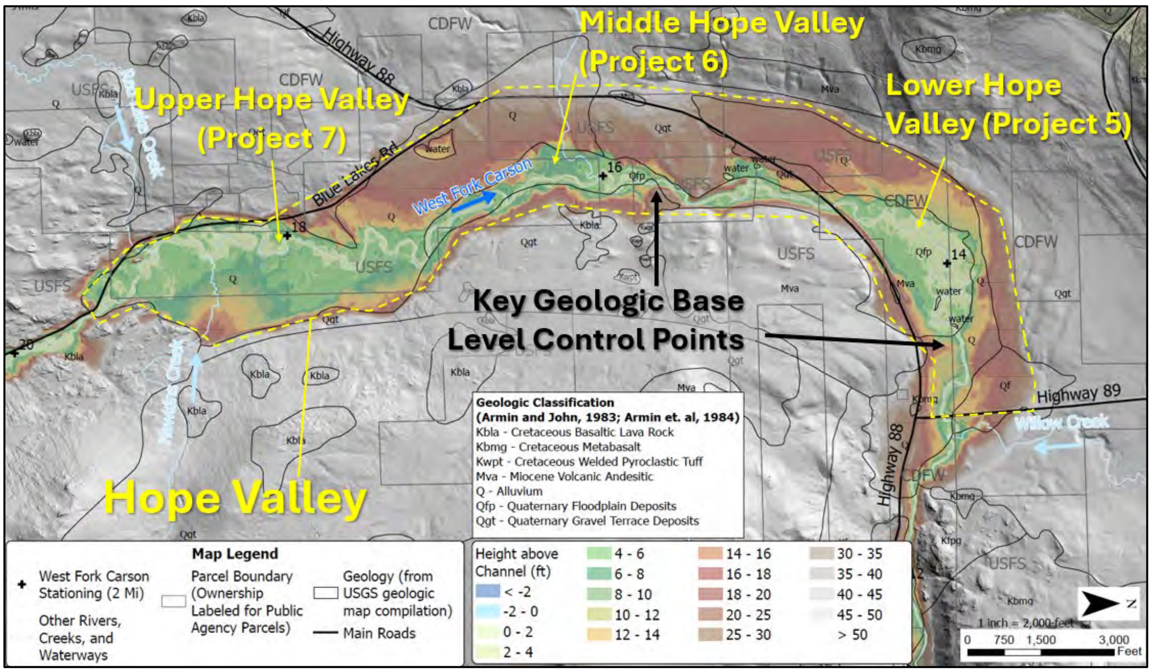


Figure 29. Annotated REM Map of Hope Valley

Bedload Limitations. Based on recent experience in Faith Valley, one key technical consideration for restoration planning in Hope Valley is the availability, continuity, and management of coarse sediment (bed material), which is required for channel aggradation and long-term floodplain reconnection. Although fine sediment traveling in suspension (washload) is a primary constituent driving water quality impairment, coarser sediment, includingsand and gravel, transported as bedload,provides the structural framework necessary to raise the channel bed and maintain restored elevations. Restoration elements such as grade control structures, BDAs, and engineered riffles that retain sediment will, by design, trap bedload, thereby reducing downstream supply of this material, potentially limiting aggradation in downstream reaches. Consequently, the spatial distribution, density, and phasing of grade control features throughout Hope Valley must be evaluated in the context of basin-scale sediment continuity to avoid adverse cumulative effects. Given the limited natural bedload supply in parts of the WFCR, it may also be appropriate to evaluate the feasibility of importing coarse sediment as part of restoration implementation, potentially from reaches of the Carson River downstream in Nevada. These issues underscore the need for a valley-scale sediment management strategy that explicitly considers interdependencies among projects and long-term sediment budgets rather than treating individual restoration sites in isolation.

3.5.2 Comprehensive, Long-Term Restoration Program

Given the scale, visibility, and complexity of Hope Valley, restoration should not be approached as a series of isolated, site-specific projects. Instead, the prioritization results point clearly toward the need for an integrated, multi-decade restoration program. While this time horizon may not always align with funding opportunities, permitting constraints, and other realities of stream restoration, that level of planning for this landscape is justified. Not only is it the nexus of the sediment budget and geomorphology in the WFCR watershed, and provides critical habitat to many animal and plant species, but Hope Valley is also a highly visible and beloved landscape to many people. Any restoration actions will be subject to public scrutiny. As a result, aesthetic outcomes, recreational compatibility, and perceived improvements to the landscape could be as important to long-term success as geomorphic or water quality performance of the specific projects.

A comprehensive program would include the following elements:

- Stakeholder Coordination: Bringing together agencies, non-profits, local land managers, and other interested parties to define shared objectives, priorities, and success metrics.
- Goal Definition and Phasing: Establishing clear, long-term goals for sediment reduction, floodplain reconnection, habitat improvement, aesthetic values, recreation benefits, and hydrologic function, and sequencing projects to maximize cumulative benefit while minimizing risks.
    - For example, although Lower Hope Valley (**Project 5**) may offer slightly greater geomorphic potential than Middle Hope Valley (**Project 6**), it may be beneficial to implement elements of Project 6 first as a demonstration and learning site before advancing to larger, more visible actions in Lower Hope Valley.
- As discussed in Section 2.3.5, bedload availability and continuity may be a limiting factor for reach-scale restoration in Hope Valley, particularly for projects that rely on sustained channel aggradation to reconnect floodplains. Although bedload transport in the WFCR is likely small relative to suspended sediment loads, this constraint suggests that some large-scale projects may require careful phasing, sediment management planning, or consideration of supplemental coarse material to achieve long-term stability.
- Monitoring and Adaptive Management: Implementing a robust monitoring framework to evaluate project outcomes, inform adaptive management, and refine restoration approaches over time.

While full restoration of Hope Valley is likely to require decades, strategically sequenced actions implemented within a coherent framework can gradually shift the system toward improved geomorphic resilience, floodplain connectivity, and water quality, while preserving recreation and aesthetic values.

3.6 LONG-TERM RESTORATION STRATEGY

The prioritization results support a two-track approach to long-term restoration in the West Fork Carson River watershed:

(1) The first track focuses on implementing "low-hanging fruit" projects—small, low-risk actions that can be constructed incrementally as staff time, funding, and volunteer capacity allow. These projects, often on tributaries or small reaches, are well suited to hand labor and adaptive maintenance, and can generate near-term sediment retention and habitat benefits while building local experience, monitoring data, and public support for restoration.

(2) The second track would be a comprehensive, long-term restoration program for Hope Valley. Given its geomorphic significance, sediment contribution, visibility, and public ownership, Hope Valley warrants a coordinated, valley-scale effort rather than a series of isolated projects. This program should be collaborative and multi-decadal in scope, involving federal and state agencies, non-profits, land managers, and other stakeholders, and guided by shared goals for sediment reduction, floodplain reconnection, ecological function, and aesthetic quality. Leadership of a Hope Valley Restoration Program by long term committed partners in the basin, such as Alpine Watershed Group and/or American Rivers, would provide the continuity, technical capacity, and stakeholder coordination necessary to plan, phase, implement, and adapt restoration actions over a 20-year time horizon.

This two-track approach allows work to begin immediately while building toward a coordinated, long-term effort in Hope Valley.

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