SWANSON HYDROLOGY + GEOMORPHOLOGY

final technical report

Perazzo Meadows Geomorphic Assessment

for Truckee River Watershed Council

May 2008

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1.0 INTRODUCTION

Over the past several years the Truckee River Watershed Council (TRWC) has been working cooperatively with the U.S. Forest Service (USFS) to evaluate the current condition of the Perazzo Meadows system, identify opportunities and constraints for restoration, and implement restoration projects to improve the geomorphic function of the meadow and enhance its ecologic value. In addition, the TRWC is working with a variety of conservation groups and land trusts to purchase private land to preserve one of the largest intact meadow systems in the northern Sierra Nevada.

To assist in an evaluation and characterization of the Perazzo Meadow complex and the surrounding watershed, the TRWC contracted with Swanson Hydrology and Geomorphology (SH+G) to conduct a geomorphically-based assessment of Perazzo Meadows within the Little Truckee River watershed. The Perazzo Meadow system has been degraded by past land-use practices, although some aspects of ecological function remain intact. A geomorphic characterization of the meadow system is necessary to provide a framework for planning and design of restoration opportunities in the meadow system. It is well documented that "process-based" restoration projects that consider the geomorphic and hydrologic setting of the watershed have a higher likelihood of being successful. Gaining an understanding of these processes will allow for development of feasible restoration approaches that are founded in the physical processes which operate in the meadow system.

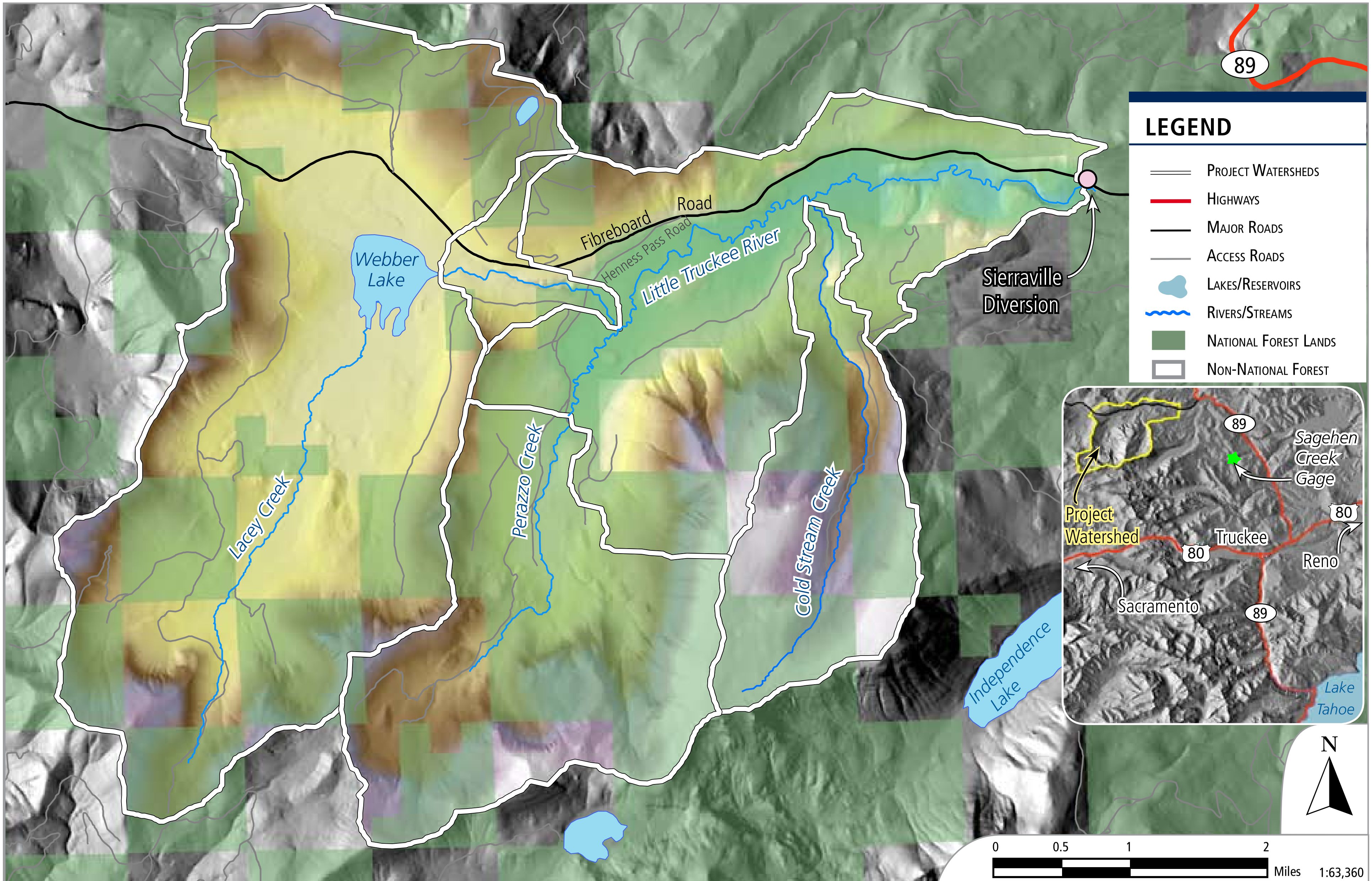
The overall goal of this assessment is to characterize the geomorphic setting of the meadow system. Specific objectives within the geomorphic assessment include:

- Characterization of the hydrologic setting,
- Comparison of past and current geomorphic function as it relates to restoration potential,
- Documentation of geomorphic conditions (e.g., channel form, stability) to inform restoration planning and design, and
- Development of restoration design recommendations.

2.0 SITE SETTING

2.1 Overview

The Perazzo Meadows project area is located in the headwaters of the Little Truckee River in Sierra County, California (Figure 1). Perazzo Meadows consists of a series of wet meadow complexes located along the east slope of the Sierra Nevada mountain range approximately 20



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500 Seabright Ave, Suite 202 Santa Cruz, CA 95062
PH 831.427.0288 FX 831.427.0472

FIGURE 1: General location and watershed area for the Perazzo Meadows Geomorphic Assessment. Perazzo and Lacey Creeks conflue within the upper meadow to form the Little Truckee River.

miles northwest of the Town of Truckee. Primary tributaries draining into Perazzo Meadows include Perazzo Creek, Lacey Creek, and Cold Stream Creek, encompassing a drainage area of approximately 34 square miles. The upper Lacey Creek drainage includes Weber Lake, a privately owned natural lake located in the headwaters that is managed primarily for recreation and delivery of irrigation water.

Although our evaluation extends into the upper watershed to understand hillslope erosion and transport of sediment through Perazzo Canyon, the detailed analysis of the meadow complex extends from the upper meadow at the mouth of Perazzo Canyon to the Sierraville Diversion and encompasses three meadow complexes. The meadow complexes occur at an elevation of approximately 6,500 feet with the elevations of the surrounding peaks reaching over 8,000 feet.

2.2 Climate/Hydrologic Setting

Climatically, Perazzo Meadows is similar to others areas located to the east of the Sierra Nevada Crest. The area is characterized by dry, warm summers and cold winters dominated by snowfall. Over 80 percent of the total annual precipitation in the region falls between November and April, primarily as snowfall. In mid-winter, rain-on-snow events can occur when a deep layer of moist air is entrained from near the Hawaiian Islands, a climatic pattern referred to as the "Pineapple Express." During the summer months (from July through September), localized heavy rainfall from monsoon driven thunderstorms can occur. During most years, however, individual summer months usually have little or no rainfall. Precipitation varies considerably across the watershed depending primarily on elevation and proximity to the Sierra Crest.

Winter storms consist of meso-scale storm systems that originate in the Gulf of Alaska. These storms are driven by jet stream winds and entrain moisture as they pass over the relatively warmer waters of the eastern Pacific Ocean. Precipitation is enhanced on the western slope of the Sierra through orographic dynamics with reduced precipitation on the east side of the Sierra Crest. This "rain shadow" effect is more pronounced the further east you go with areas immediately east of the crest receiving spill-over moisture from orographic precipitation. Precipitation in the Little Truckee watershed averages approximately 31 inches annually, ranging from 15 inches to 55 inches. Snowfall averages approximately 210 inches annually but can exceed 350 inches in wet years (McGraw et. al., 2001).

During most years, precipitation falls as snow from November through April, most of which remains in place until the snowmelt season. The snow pack begins to melt in March, typically reaches a maximum in May, and then recedes through the remainder of the summer. Rainstorms that occur during the spring and summer typically have little to no influence on the mean hydrograph, though intense rainstorms can occur that result in flash floods and debris flows in tributary streams. These events are typically short-lived with summer stream flows during late July through October being mainly derived from subsurface flows and from groundwater from the alluvial filled valley bottom entering the stream channel.

Beginning in the fall, frontal storms begin passing over the watershed. Typically, early storms recharge soil moisture depleted through evapotranspiration over the previous growing season. As the temperature drops, a greater percentage of precipitation falls as snow. Declining temperatures result in reduced evapotranspiration, allowing for efficient soil moisture recharge. Buildup of the snow pack increases soil moisture through the melting of snow in contact with the ground surface. This process, in conjunction with influent groundwater, is the source of base flow over the winter.

Rain-on-snow events appear to occur in clusters and may be tied to El Niño conditions in the Pacific Ocean. Several decades may pass without a single rain-on-snow event, as from 1964 to 1997. The period from 1950 to 1964, on the other hand, saw four rain-on-snow events. Based on longer-term Tahoe City rainfall records, strong El Niño conditions probably occurred in 1850-1860, the mid 1880's, and the first decade of the 1900's. Rain-on-snow events are important to the geomorphology of Sierra Nevada watersheds due to their magnitude. Most of the large floods that have occurred over the last several decades have been associated with rain-on-snow events. Substantial quantities of sediment are moved during rain-on-snow events, and extensive channel change can occur.

2.3 Geology

Perazzo Meadows sits on the eastern edge of the Sierra escarpment and is characterized by a dynamic geologic history of faulting and volcanic activity that is overlain by a more recent period of glaciation and erosion. Much of the landscape was formed by eruptions of andesitic and basaltic flows that occurred during the Neogene and Pleistocene periods (Bailey, 1966). The headwaters of Perazzo Creek are underlain by non-marine meta-sedimentary rocks consisting of hornfels, slate, and calc-silicate rocks (Figure 2). These fractured rocks and presence in the steeper, more confined upper watershed of Perazzo Creek results in the production of significant bed load and formation of a fan surface at the mouth of Perazzo Canyon as it enters the upper meadow.

More specifically, 46% of the subwatershed draining to the upper end of Perazzo Meadows (33% of the study watershed) is underlain by meta-sedimentary rocks and 44% is underlain by andesitic rock and mudflows. In the subwatershed area below Weber Lake that drains to upper Perazzo Meadows (4% of the study watershed excluding the drainage area above Weber Lake), andesitic rock and mudflows underlies 49%, with 33% underlain by the more resistant tuff. The Cold Stream Creek subwatershed (19% of the study watershed) is dominated by andesitic rock and mudflows, which underlies 81% of the total area. The remaining watershed (44% of the study watershed), which includes all of the meadows and smaller tributary drainages, is primarily

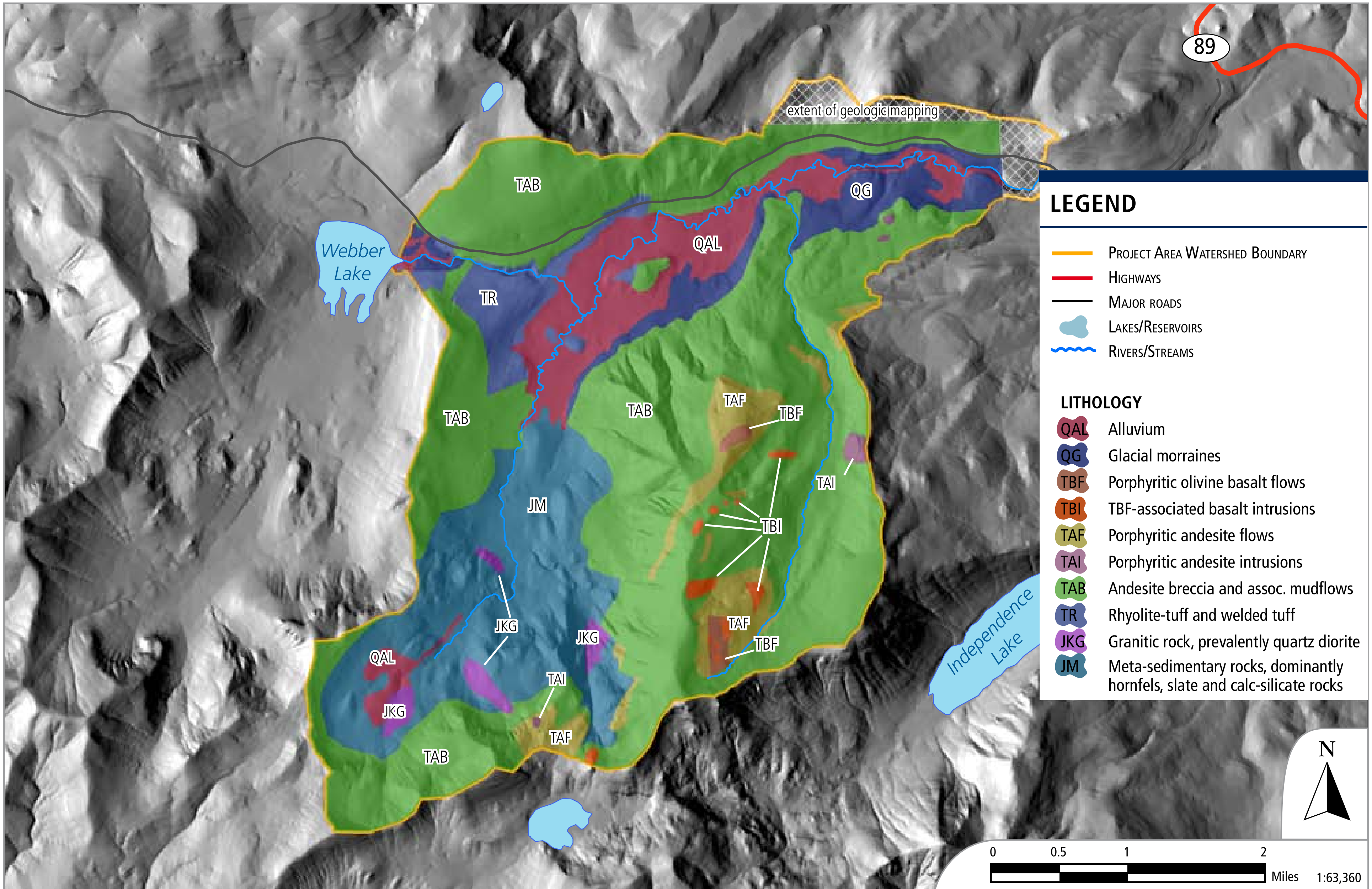

FIGURE 2: Geologic units in the project area and surrounding watershed. The geology is dominated by volcanic and meta-sedimentary rock units overlain by glacial and post-glacial alluvial deposits. (Source: USGS)

underlain with andesitic rock and mudflows (53%), with the valley bottoms composed of recently deposited alluvial material (19%).

The last glacial period, known as the Tioga, peaked about 18,000 years before present. Approximately 10,000 years before present, at the end of the Pleistocene and beginning of the Holocene, glaciers in the Sierra Nevada Range began retreating from the lowland valleys such as the mainstem Little Truckee River, and fluvial forces became more dominant. As the glaciers retreated they left lateral and terminal moraines. The terminal moraines often formed lake basins that filled in slowly to form meadows as glacial deposits were reworked and transported by rivers that swelled with meltwater from the glaciers. Perazzo Meadows and Lacey Valley (Weber Lake) are two examples of these types of landforms in the upper Little Truckee River watershed.

Through oscillations in glacial advance during the Pleistocene, lake formation and filling occurred more than once, resulting in reworking of alluvial surfaces and formation of alluvial terraces. After the disappearance of the glaciers, streamflow in Perazzo Creek and the Little Truckee River declined significantly, resulting in the formation of a meandering channel within a broad glacially-derived alluvial valley. Subsequent erosion of historic glacial deposits and the underlying bedrock material has resulted in the creation of mainstem and tributary alluvial fans overlain onto the meadow complex, as is seen at the mouth of Perazzo Canyon, Lacey Creek, Cold Stream Creek, and other smaller tributaries.

2.4 Soils

Soil conditions in much of the project area consist primarily of various Aquoll soil complexes (Figure 3). Aquolls form where alluvial deposits, high water tables, and overbank deposition of fine material interact to create deep wet meadow soils. Maintenance of a wet meadow is dependent on well-developed soils, periodic overbank deposition of finer grained material, accumulation of organic material, and a high water table. Land use effects that lead to channel incision and widening threaten the continued existence of a wet meadow by lowering the groundwater table, limiting overbank deposition, and reducing production of organic material.

3.0 SITE CONDITIONS

3.1 Overview

Stream channels transport watershed products including water, sediment, woody debris, and nutrients to the lower end of the watershed. Fundamental characteristics of the channel such as plan form, capacity, and width-depth ratio, reflect the quantity and characteristics of watershed products supplied to and eventually transported along the channel. Changes in the quantity or nature of watershed products supplied to the channel are likely to result in changes to channel

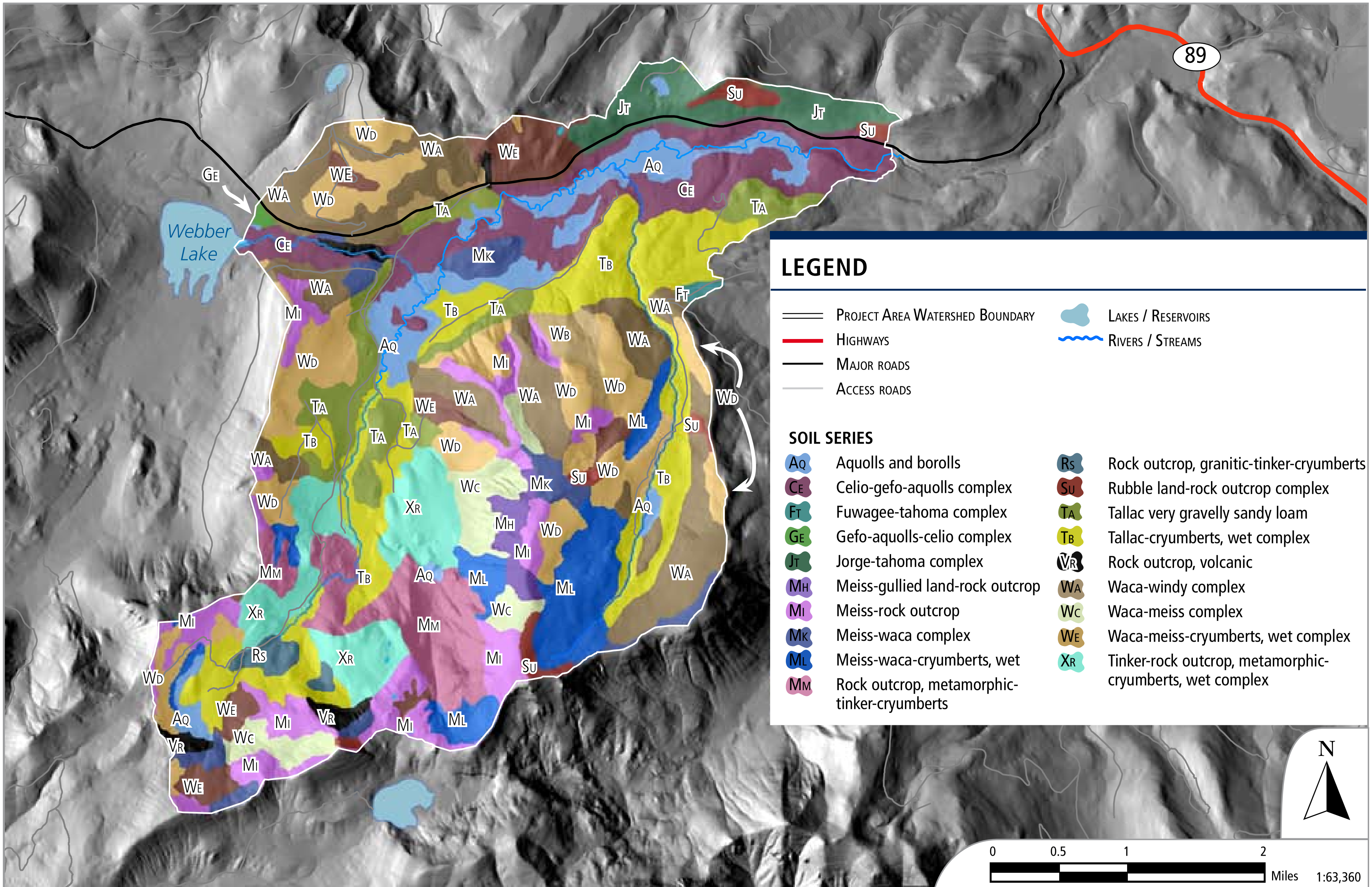

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FIGURE 3: Soil units of the project area and surrounding watershed. The Perazzo Meadows are dominated by soils characterized as aquolls which are weathered alluvial soils with high water tables that typically occur in wet meadow complexes. (Source: NRCS)

characteristics. However, the link between a watershed and its channel is complex and a channel's response to watershed changes can be difficult to predict (Lisle, 1999)

The supply of watershed products to a stream channel is determined, to a great extent, by geology and climate. These factors are termed independent variables in models of channel response. This is because they do not respond to other major factors that govern channel behavior, and they are not influenced by human management. The impact of these independent variables on channel behavior is felt across the watershed. Topography and watershed gradients, which control the rate of erosion, are dictated by tectonic activity and subsequent fluvial erosion, or, in some cases, glacial erosion. The quantity and size of bed load and suspended load sediments available for transport by the channel are a function of how easily rock in the watershed erodes, and their mode of transport from hillside to stream channel. Climate-driven precipitation determines the amount and timing of water and sediment supplied to the channel. Geologic and climatic histories also influence the delivery of watershed products. For example, effects of higher past erosion rates (driven by a wetter climate) still influence how erosion occurs today.

The morphology of stream channels within the Perazzo and Lacey Creek watershed was strongly influenced by a series of glaciations that occurred in the watershed over the past 2 million years. The most apparent remnants of past glacial events include terminal and lateral moraines which dominate the lower portions of Perazzo Meadows and large deposits of unsorted sediment, all left at the terminus and lateral fringe of each glacial advance. These glacial deposits often formed at natural points of constriction that impeded sediment transport and resulted in the establishment of glacial outwash valleys. These valleys were most likely preceded by broad, shallow lakes. The transition from lake to alluvial valley to meadow probably occurred quickly as retreating glaciers delivered large amounts of outwash sediment. Because the meadows are relatively unconfined and have a low gradient, the modern stream channel is relatively sinuous and tends to migrate slowly across the meadow over time.

Where the stream is confined by underlying bedrock or resistant morainal deposits, narrow, confined channel reaches form. High stream flow from glacial melt water provided the energy to cut through these resistance materials. Smaller material was transported out of the confined reaches, leaving behind larger bed materials, which current stream flows cannot move. These reaches often have armored beds that are resistant to erosion but can still be considered source areas for material because of lateral erosion into adjacent bank material. In Perazzo Canyon and along the Lacey Creek gorge, material transported during periods of rapid incision created large alluvial fans as the narrow valley reaches transitioned into wide, unconfined meadows. A significant grade break often exists, resulting in deposition of material that was transported through the steeper, confined reaches (Figure 4a and 4b).

Glacial erosion still influences sediment production in the watershed today. Glacial cirques eroded in volcanic and meta-sedimentary rocks in the upper portions of the watershed are over-steepened and produce sediment for stream channels through gully formation, debris flow, and other hill

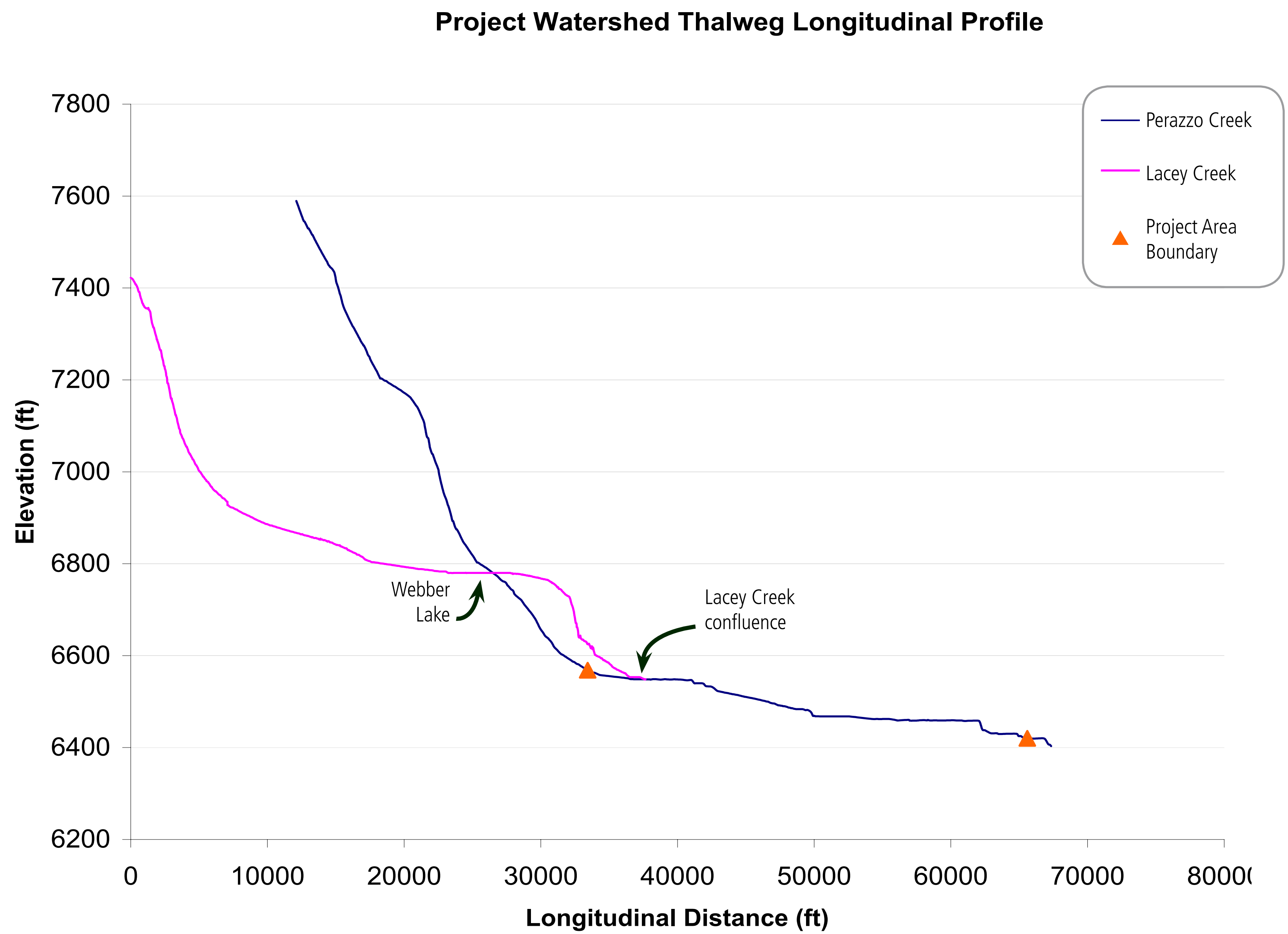

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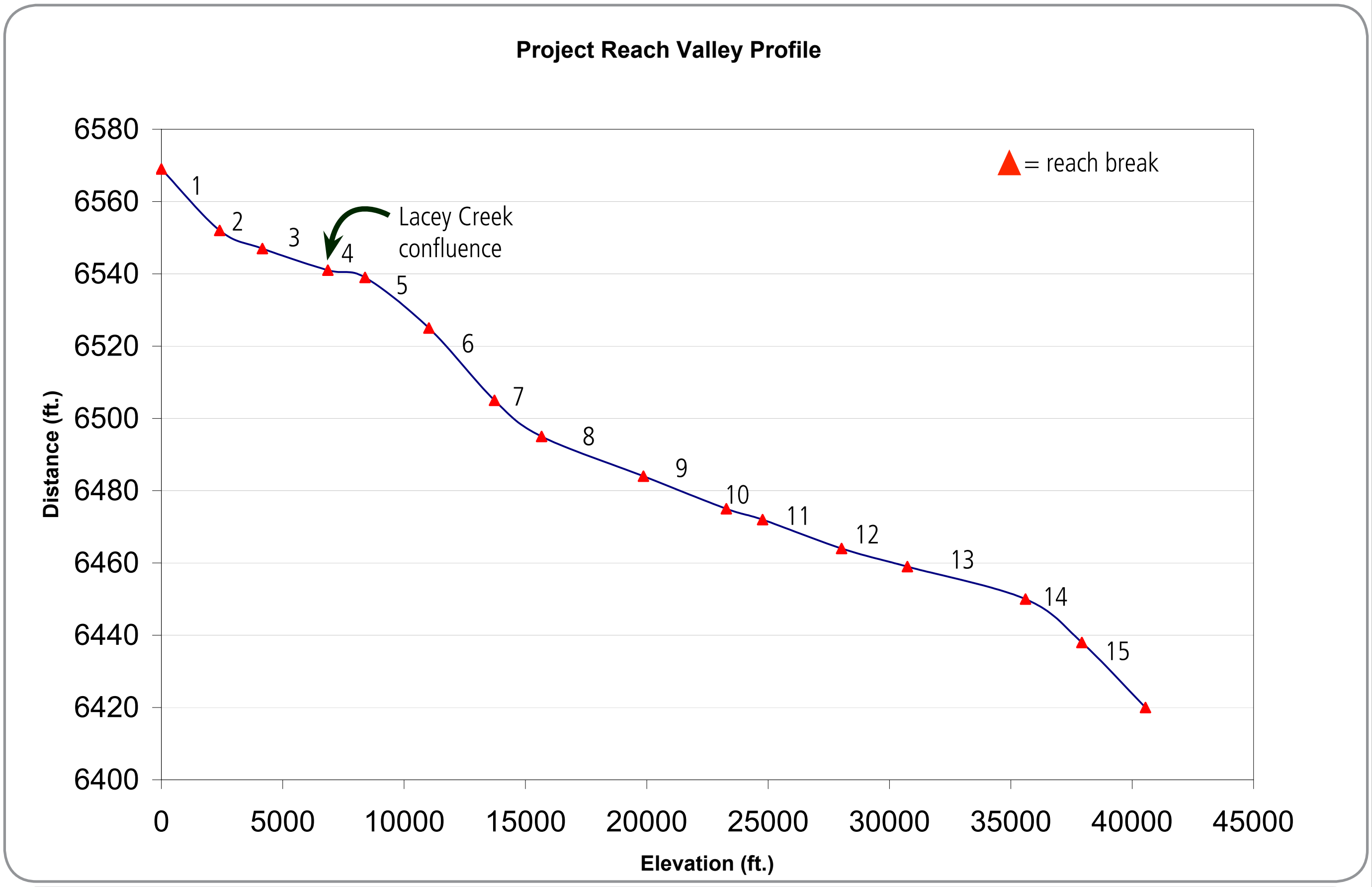
FIGURE 4a: Longitudinal profile of Perazzo and Lacey Creeks. Profiles were developed from 10-meter digital elevation models provided by U.S. Geologic Survey. The project reach is located where the profile flattens out from the higher gradient, narrow valley sections upstream.



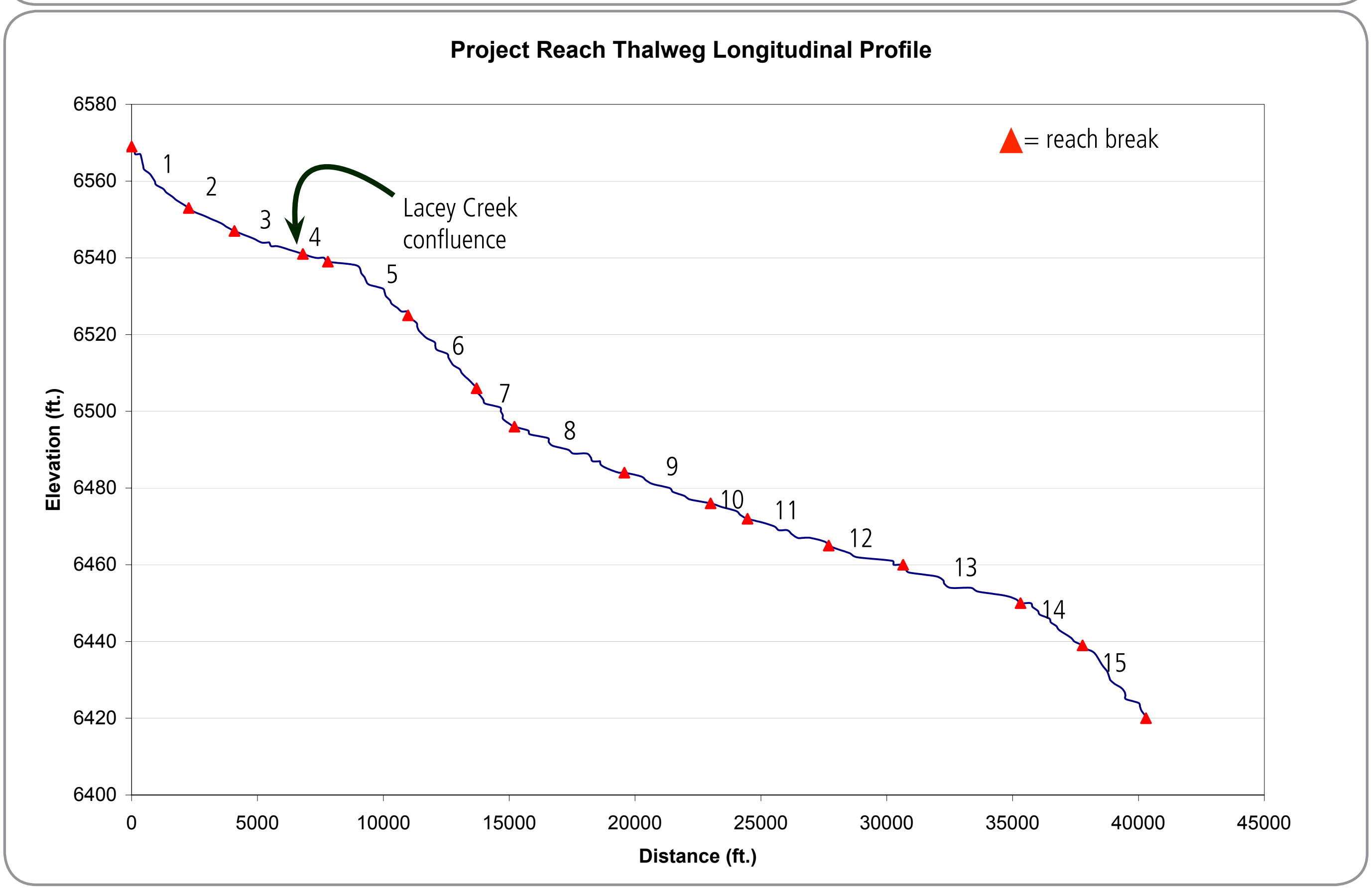


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FIGURE 4b: Longitudinal profile of the valley and thalweg along the project study area. Lower gradient sections of the profile delineate the wide meadow areas with steeper sections in between. The breaks in slope at the downstream end of each of the meadows are associated with deposits of glacially derived material that create the meadows, with the steeper portions of channel cutting through these deposits.

slope processes. These processes are important today in the upper Lacey Creek gorge, upper Perazzo, and Cold Stream Creek.

Dynamism is a fundamental, inherent characteristic of natural streams. Seasonal changes in flow, annual channel, and large floods may rework entire reaches of a channel. To understand ecosystem function it is important to consider how channel dynamics occur over different time scales. Human life spans, decades long, are short when compared to geomorphic processes. Over decadal time scales (10 to 100 years), rivers tend to exhibit steady state equilibrium. Channel pattern and form may change slightly, but they tend to vary around an average condition (hence the term equilibrium). Though changes may occur at specific locations, sediment supply and erosion tend to remain relatively constant. Significant increases and decreases do not occur, especially when considering reaches of a channel rather than specific locations. Pools may form and disappear in specific locations, or individual banks may erode, but the general form of the channel remains constant over reach-wide spatial scales.

The picture becomes more complex over longer time periods. Consider changes along the Perazzo Meadows since the end of the Pleistocene. As the glacial ice melted, the stream probably exhibited characteristics typical of glacial outwash environments; stream channels were most likely braided. Sediment supply and discharge were both much higher than today. As the climate warmed and vegetation began to invade formerly glaciated terrain, sediment supply began to decrease. Precipitation and stream flow also decreased. Invading vegetation promoted relatively stable gravel bars and the once braided channels gradually changed to single-thread channels, and eventually to wet meadow grasslands as meadow sod soils developed. Deposition of fine sediments on adjacent floodplains promoted the development of stable herbaceous plant communities.

Over this transition period, climatic variability resulted in large floods and extended droughts that temporarily increased or decreased sediment supplied to the system, causing short-term changes in channel form or pattern. However, dominant trends from the Pleistocene to the present have been a reduction in the amount of sediment supplied to the channel, and a transition from braided to single thread channels. This model of channel dynamics is termed dynamic equilibrium. The equilibrium is dynamic because average channel behavior changes slowly over time (from braided to single-thread channels, for example).

3.2 Channel Types

Different types of channels have characteristic patterns of sediment transport, erosion, and deposition (Leopold et al. 1964; Rosgen 1994; Mount 1995). The assessment team identified three classes of channel behavior with respect to erosion and deposition in the assessment area: transport, confined response, and unconfined response channels. A total of 15 reaches were delineated in the Perazzo Meadows project area (Table 1). Transport channels are highly efficient at moving sediment, exhibit very low bank erosion, and store little of the sediment in transport

Cross Section Data Summary							
	Site 1	**Site 2**	**Site 3**	**Site 4**	**Site 5**	**Site 6**	**Site 7**
Average Bankfull Width (ft)	35	21	35	51	45	51	51
Average Bankfull Depth (ft)	0.8	1.1	0.6	0.6	0.4	0.6	0.5
Average Pool Maximum Depth (ft)	2.9	1.4	2.7	4.8	4.9	4.3	2.8
Average Area (sq ft)	26	24	21	33	16	31	25
Average Width to Depth Ratio	46	19	59	80	125	83	106
Drainage Area (sq mi)	7.9	8.5	8.5	24.4	27.9	32.9	34.2
Predicted Bankfull Width[1] (ft)	16	17	17	27	28	31	31
Predicted Bankfull Depth[1] (ft)	1.3	1.3	1.3	1.6	1.7	1.8	1.8
Predicted Width to Depth Ratio	13	13	13	16	17	17	18

[1]Based on regional hydraulic geometry data developed for the Tahoe/Truckee region by SH+G.

Longitudinal Profile Data Summary							
Bankfull Slope	0.81%	0.34%	0.20%	0.07%	0.14%	0.35%	0.04%
Riffle Slope	0.80%	0.09%	0.34%	0.02%	0.07%	0.34%	0.22%
Avg. Distance Between Riffles (ft)	134.3	78.4	172.7	285.3	233.8	138.8	106.3
Avg. Distance Between Pools (ft)	89.7	58.2	123.3	127.5	265	139	100.5

Reach Scale Statistical Summary

Reach	Thalweg Length (ft)	Valley Length (ft)	Sinuosity	Thalweg Slope	Valley Slope	Channel Type
1	2404	1592	1.51	0.71%	1.07%	Response unconfined
2	1760	1151	1.53	0.28%	0.43%	Response unconfined
3	2695	1831	1.47	0.22%	0.33%	Response unconfined
4	1534	1045	1.47	0.13%	0.19%	Response unconfined
5	2630	1841	1.43	0.53%	0.76%	Transport
6	2703	1735	1.56	0.74%	1.15%	Response confined
7	1939	1284	1.51	0.52%	0.78%	Response confined
8	4198	2295	1.83	0.26%	0.48%	Response unconfined
9	3414	2051	1.66	0.26%	0.44%	Response unconfined
10	1495	1194	1.25	0.20%	0.25%	Response unconfined
11	3256	2039	1.6	0.25%	0.39%	Response unconfined
12	2711	2252	1.2	0.18%	0.22%	Transport
13	4865	2801	1.74	0.19%	0.32%	Response unconfined
14	2322	2087	1.11	0.52%	0.58%	Response unconfined
15	2623	2099	1.25	0.69%	0.86%	Response unconfined

TABLE 1: Reach and detailed survey site summary statistics. Reach scale statistical summaries were derived from LIDAR data provided by the U.S. Forest Service. Data from the detailed study sites were derived directly from field measurements.

within the channel or on the adjacent floodplain. Response channels are less efficient at moving sediment, show moderate bank erosion, and store some of the transported sediment within the stream banks and on the adjacent floodplain. There are two types of response channels in the watershed: confined response channels with moderate gradients and smaller floodplains, and unconfined response channels with low gradients and large, meadow floodplains.

Transport channels are higher gradient, highly confined (valley walls close to the channel), Rosgen A and B-type channels. They are found predominantly in Perazzo and Lacey Canyons and result in the formation of alluvial fans at their terminus. Plan form is straight. They tend to have very little associated floodplain and are often incised in Quaternary glacial deposits. Channel morphology is generally step-pool or plane bed. Streambed substrate is large. Coarse sediment may be supplied to these channels, but transport capacity is high and even larger particles are transported readily with little deformation of the streambed or banks. Some of the supplied sediment is stored temporarily within the channel, behind large boulders or in other flow shadows. Point bars and other alluvial formations are absent. Stream banks and the streambed are resistant to erosion.

Confined response channels are transitional between higher gradient transport channels and lower gradient response channels. They have moderate gradient (around 1 to 4 percent) and moderate confinement (Rosgen classifications of B, C, and F). These channels constitute most of the channels that occur between meadow reaches within the Perazzo Meadows complex. Plan form is straight to confined meandering. Associated floodplain is variable, but is generally less than two times the width of the bankfull channel. The channel and floodplain are composed primarily of sediment with recent origin.

The processes of channel erosion and deposition in confined response channels can be described as fill-cut. These streams steadily rework bed load on the valley floor during normal flow years. This process is punctuated by massive, episodic inputs of bed load from tributaries and hill slopes to the valley floor during severe floods. Massive erosional events, primarily associated with rain-on-snow events or following fire, result in extensive channel aggradation. The amount of sediment delivered exceeds the capacity of the channel to move the supplied load. Evidence of large-scale aggradation events is often apparent along the main stem as cut-fill terraces and floodplain bar surfaces with a slope that approximates overall valley slope. Subsequent low to moderate magnitude events, such as the annual snow melt flood, result in re-incision of the aggraded rain-on-snow surface. The characteristic "bankfull" channel is formed with a cut face and flat terrace surface abandoned by the recent incision.

Unconfined response channels are found in larger meadows sections of the assessment area. They are low gradient, meandering Rosgen C- and E-type channels. Valley walls do not confine meanders, and bed substrate is relatively small. These channels have extensively reworked valley floor sediments, material that has been deposited during recent times. The channels are associated with wide, flat floodplains on both sides of the river. Erosion and deposition in these channels follows classic alluvial models described by Leopold et al. (1964). Outer bends are slowly eroding, migrating outward and down valley (meander translation). Point bars are deposited on inside bends, and represent floodplain being constructed by the channel.

Much of the sediment in transport within unconfined response channels may be derived from within the channel itself. However, larger floods are obviously capable of supplying large amounts of sediment from upstream sources. Thus, the upstream ends of unconfined meadows tend to be depositional and dynamic. Material supplied during larger floods may then be slowly transported through the system during smaller floods.

3.3 Land Use Impacts on Channel Function

Independent of the slow trend of decreasing sediment supply over geologic time, recent land use impacts can alter the sediment supply regime, and in-channel geomorphic function in significant ways. Land use impacts such as overgrazing on steep hillslopes or in sensitive meadows, a modified fire regime, road building on hillslopes, stream crossings, or direct channel modifications can result in profound and long-lasting changes to the channel morphology, geomorphic function, sediment transport regime, and ecological value of the system. The impact land use changes have on specific reaches varies according to the resiliency and characteristics of each stream type. In addition, past disturbances in the upper watersheds and on adjacent hillslopes may have created a reservoir of highly erodible materials that were deposited in zero order basins (colluvial hollows) and on floodplain margins. These stored materials may be conveyed to tributary and mainstem stream channels in recent times despite the fact that they were eroded from hillslopes decades ago. Such lag effects are an important consideration when attempting to understand impacts associated with historic and current land use.

For example, confined and confined response channels are much more resilient to changes in sediment transport rates and discharge because they are, by nature, responding to changes in sediment regimes as part of their natural function. They often have armored, resistant stream beds that can adjust to aggradation and erosion without significant changing their stream type. Conversely, unconfined response channels, such as the meadow reaches of the project area, are less resilient to abrupt changes in sediment transport rates and discharge. They function within a narrower range of dynamic equilibrium, that when upset, can often push these systems toward a new channel type where recovery back to their original function is either slow or irreversible.

Determining whether or not historic or current land use has pushed a stream channel from one channel type to another is difficult to determine. Several techniques for assessing channel change may include comparisons of channel form and function of an impacted channel to a reference, or undisturbed, channel. In most cases this approach is challenging because finding a reference, or undisturbed, channel that occurs in the same setting (e.g. – geology, drainage area, etc) can be difficult, if not impossible. Another approach is to obtain historic aerial photos of the site and assess past conditions and changes through time. This approach, if enough historic aerial photos are available, is often the most reliable way to detect and/or measure changes in channel form and function can be directly measured. The drawback to this approach is that several key indicators of channel change, such as the degree of channel incision and dominant bed material type, cannot be measured directly from aerial photos at the scales that aerial photos are typically available. In addition, land use impacts and changes in channel form and function that occurred prior to the 1930's cannot be detected because aerial photos typically are not available pre-1930's in most areas. In some cases, ground photos or historic maps can be used to make inferences before the 1930's but they are of limited use and in some cases unreliable when the focus of the mapping was not directly related to the stream channel.

For Perazzo Meadows, historic aerial photos date back to 1939 and are available for every 10-20 years after that. To evaluate past changes in channel form and function from 1939 to present, SH+G obtained historic aerial photos from the U.S. Forest Service archive and scanned and registered the photos so that specific changes could be documented using measurement tools. This section will present a more general overview of changes observed in the upper meadow using aerial photos from 1939, 1952, 1966, and 1983. A more detailed review of changes in channel pattern over time is presented in a later section of this report.

U.S. Forest Service staff have postulated that significant changes in channel form and function may have occurred in Perazzo Meadows, specifically the upper meadow, when cattle and/or sheep ranchers actively modified a portion of the historic channel the runs through the upper meadow in an attempt to dry out the wet meadow and make it more accessible to grazing in the summer months. Under natural conditions, a significant function of wet meadows is that they flood annually during the spring snowmelt season. Flooding of the meadow is variable, depending on the timing and magnitude of the spring snowmelt, but typically, during most years, the meadow will get wet starting in March or April and continue through July, slowly draining through late summer.

The key variable that allows for an annual flooding of wet meadow systems is related to channel geometry, channel capacity, meander pattern, and elevation differences between the bed of the channel and the meadow floodplain, which in turn controls the elevation of the shallow groundwater table. In functional meadow channels the channel geometry approximates a capacity that contains the 1.5 year discharge event, creating a balance between channel slope, which is a function of the valley slope and sinuosity, channel width, and channel depth. At discharges greater than a 1.5 year return period, channel capacity is exceeded and water begins to flood out onto the adjacent meadow. In addition, the water table rises with the height of the flooding, causing water to saturate the meadow from below, fill depressions, and activate secondary flood plain channels. As water spreads out onto the meadow the depth of flow in the primary channel does not increase, limiting additional energy imposed upon the active channel, and thereby maintaining a functional channel geometry.

The location where the U.S. Forest Service postulates that active realignment of the upper meadow channel may have occurred is shown on the 1939 aerial photo (Figure 5). The presence of meander scars on the floodplain to the north and south of the primary channel, as appears in 1939, suggests that modification to the alignment may have occurred. The portion of channel that flows through the two volcanic outcrops would have been the most logical location to cut off the channel to dry out the meadows to the north and south. Unfortunately this change took place prior to 1939, most likely in the Comstock era, pre-1900. Though direct evidence for active channel realignment within the meadow is not available, similar modifications to wet meadow systems were occurring throughout the entire central Sierra Nevada as the Comstock era of logging and mining was bringing more people to the region, requiring the need for food production and resource extraction to support the growing population and the needs of the mines.

If the channel was straightened through this reach, a series of events that would lead to the complete unraveling of the fragile wet meadow system can be envisioned that include the following stages:

- ***Stage 1 - Channel Realignment:*** If the channel was straightened it is likely that factors such as channel geometry, capacity, and meander pattern were not considered. Deepening, widening, and straightening of the channel would have created a nick point in the channel where it was connected back with the existing channel.
- ***Stage 2 - Nick Point Migration/Lateral Migration:*** The nick point would have migrated upstream into the natural channel, resulting in an overall straightening and widening of the natural channel with eroded sediment deposited as bars. In the realigned portion of the channel, the increase in channel capacity and energy would begin to erode banks to reintroduce a meander pattern, resulting in bar formation from locally eroded bank material.
- ***Stage 3 - Erosion into Alluvial Fan:*** As the nick point migrated upstream, it would eventually reach the alluvial fan at the outlet of Perazzo Canyon. Incision into the fan surface would limit the functional value of the fan as a depositional area, resulting in transport of coarse bed load further downstream into the meadow.
- ***Stage 4 - Extension of Fan Function into Meadow:*** Loss of function in the alluvial fan would push bed load into the meadow. The low gradients in the meadow would cause coarse bed load to be deposited, resulting in the formation of large bars, lateral migration of the incised channel, and an increase in local sediment supply.
- ***Stage 5 - Increased Downstream Bed Load Transport:*** An increase in bed load delivery from the fan and upstream bank erosion would extend downstream, causing the meadow channel to unravel in the downstream direction as bars form, banks erode, and the channel widens. The delicate balance between sediment delivery, discharge, and channel geometry would have been disrupted.

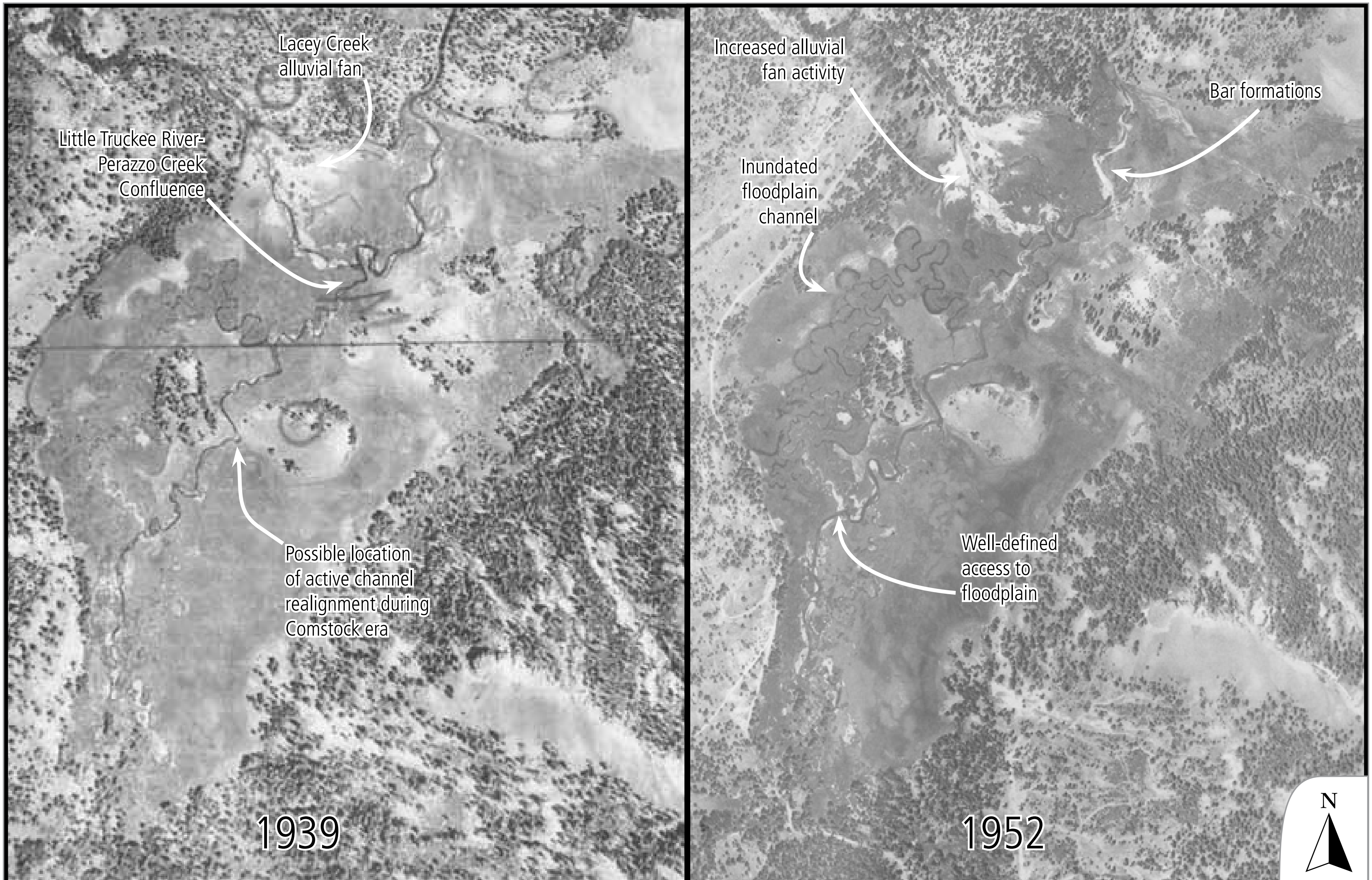

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FIGURE 5: 1939 and 1952 historic aerial photos of upper Perazzo Meadows and Lacey Creek confluence. By 1939, Perazzo Creek had already been redirected to the east through the rhyolite tuffs, although access to historic floodplain channels was still apparent. In 1952 the Lacey Creek fan is more active, suggesting active erosion in the Lacey Creek watershed. (Source: Tahoe National Forest)

Although the system will never function the way it historically had, eventual reformation of the functional value of the alluvial fan will allow for stabilization of banks and bar deposits, resulting in the development of an inset channel and floodplain. Unfortunately, this process greatly reduces the area of functional wet meadow, shrinking it to the area within and adjacent to the inset floodplain.

Evidence of this unraveling process, or series of events, can be observed in the aerial photo series. In 1939 (Figure 5), despite the fact that the main channel appears to already be going through Stage 2, access to historic floodplain channels is still evident downstream of the alluvial fan. The floodplain channels appear relatively wet (Note: 1939 photo was taken on July 27th) and the primary channel lacks significant bar formation. In 1939, headward erosion of the nick point into the alluvial fan may have begun and interactions between the active channel and meadow surface may have been reduced, but it doesn't appear that bed load transport from the fan (Stage 3) was significant at this point.

Between 1939 and 1952 (Figure 5), some changes occur in the alluvial fan that are evident in the photos. The channel emanating from the fan appears to more well-defined, indicating that headward erosion of the nick point may be limiting fan function through incision, thereby reducing coarse sediment deposition onto the fan surface. The effects of this process appear limited in 1952, but some exposed bar surfaces are starting to appear in the primary channel downstream of the fan.

In addition to the changes observed in the upstream end of the meadow, sediment transport from Lacey Canyon appears to have increased significantly between 1939 and 1952 as evidenced by fresh alluvial fan deposits on the alluvial fan surface entering Perazzo Meadows from the north. Fresh bar deposits can be seen in the channel downstream of the confluence suggesting that this portion of the meadow may already be in Stage 4 and 5 of the process described earlier. Significant increases in bed load transport from Lacey Canyon may be due to road building across the top of the alluvial fan surface or increased erosion within Lacey Canyon itself due to logging, road building, or grazing of hillslopes. Road building across fan surfaces can enforce flow and bed load discharge into a single channel, resulting in channel incision into the fan, thereby impacting fan function by conveying sediment further downstream.

Between 1952 and 1966 significant changes occur in the upper portion of Perazzo Meadows with a rapid progression through Stages 3, 4, and 5 (Figure 6). The fan emanating from Perazzo Canyon is well defined in the 1966 photo as compared to previous photos, large bars have formed in the main channel downstream of the fan, and access to historic floodplain channels appear less distinct. The Lacey Canyon alluvial fan also has enlarged with bars persisting downstream on the mainstem of the channel. Two large rain on snow events occurred in February, 1963 and December, 1964 with estimate return periods of 35 years and 15 years, respectively. Two large events occurring back to back most likely pushed the system past a breaking point. By 1983, access to the historic floodplain channels appears limited and the large, unvegetated bars that appear in the 1966 photos persist, even to this day.

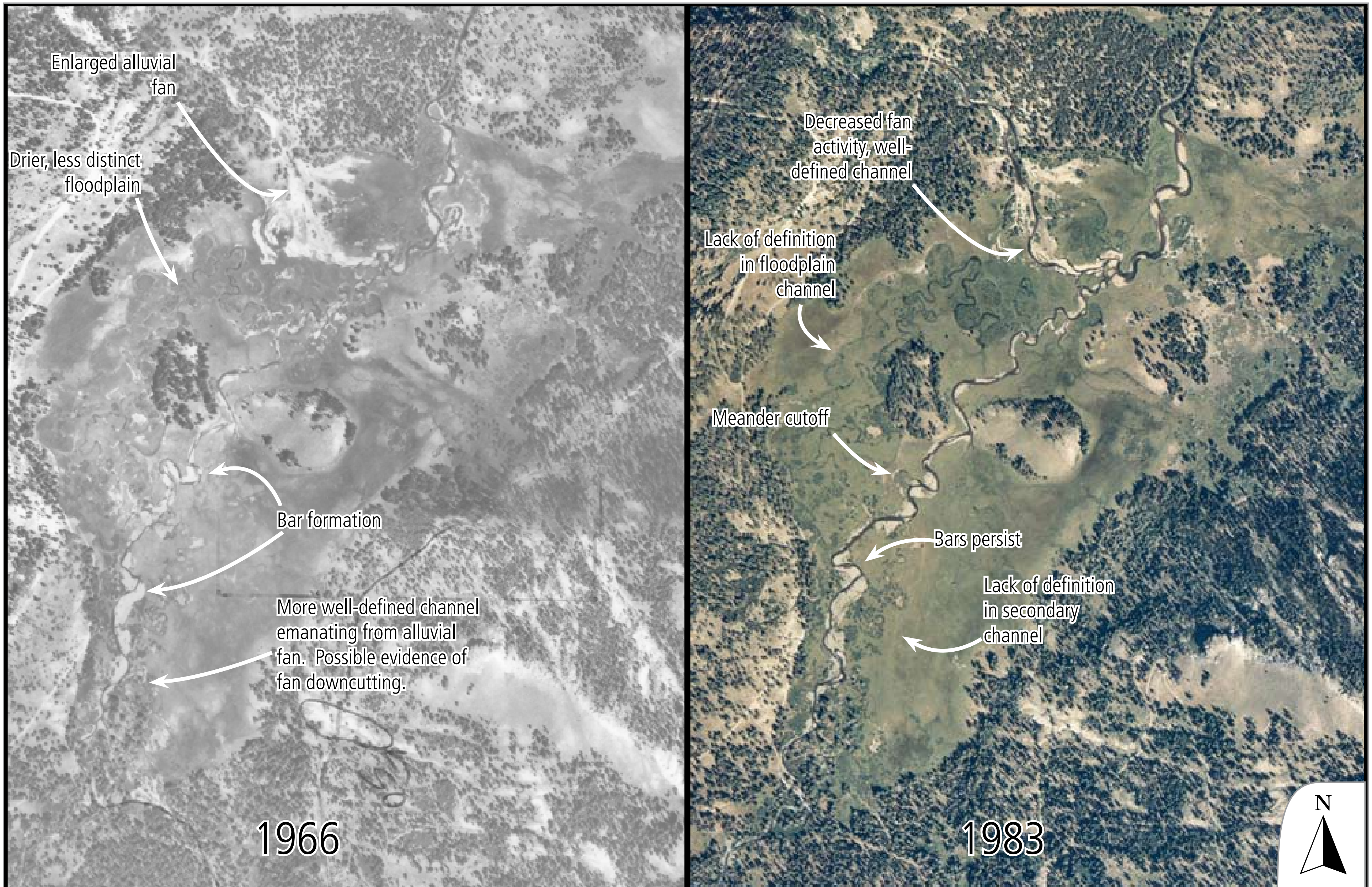

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FIGURE 6: 1966 and 1983 historic aerial photos of upper Perazzo Meadows and the Lacey Creek confluence. Significant bar formation occurred throughout the meadow between 1952 and 1966 and persists through 1983. Part of this could be attributed to active fans on Perazzo and Lacey Creek, but is also a result of poor access to floodplain channels, most likely due to channel incision. (Source: Tahoe National Forest)

4.0 SITE HYDROLOGY

A primary objective of the geomorphic study in Perazzo Meadows is to understand the degree to which the meadow is incised and the frequency with which floodwaters access the surrounding floodplain. To meet these objectives requires that we first understand the magnitude and frequency of flood events within the system. Unfortunately, historic streamflow information has not been collected in Perazzo Creek. The closest gage on the Little Truckee River with recorded annual peak events is downstream of several large diversions, which makes it difficult to correlate with conditions in Perazzo Meadows. The gage with the longest period of measurement and similar watershed conditions is on Sagehen Creek.

The Sagehen Creek gage (USGS ID #10343500) has a continuous record dating back to 1954, is located at 6,320 feet above sea level and has a drainage area of 10.5 square miles. Several assumptions were made in order to use the Sagehen gage to create a long-term synthetic peak discharge record for Perazzo Meadows. One assumption is that the watersheds exhibit similar characteristics in terms of geology, climate, and runoff characteristics. The other assumption is that Weber Lake would be full during peak discharge events. Because Weber Lake is not strictly a water supply reservoir but is instead used primarily for recreation, this is a reasonable assumption. If we were attempting to develop a long-term synthetic record of mean daily flows, especially summer flows, we would need to revisit the second assumption.

Table 2: Discharge for a range of return periods for each study reach of Perazzo Meadows

Reach	Area (mi^2)	1-Yr (cfs)	1.5-Yr (cfs)	2-Yr (cfs)	5-Yr (cfs)	10-Yr (cfs)	25-Yr (cfs)	50-Yr (cfs)
1	7.9	5	49	79	200	329	561	795
2 & 2a	8.5	6	53	86	216	355	605	858
4	24.3	17	151	244	617	1012	1726	2448
8	27.9	20	173	279	705	1156	1973	2798
11	32.9	23	204	329	832	1364	2327	3300
13	34.2	24	212	342	864	1418	2418	3429

The annual peak discharge record for the Sagehen gage was used to develop a flood frequency curve (USGS Bulletin 17B, 1976). Peak values for the 1-year, 1.5-year, 2-year, 5-year, and 10-year, 25-year, and 50-year events were determined. These values were then used to estimate peak event return periods for each reach of the study area by applying a ratio of the Sagehen gage site drainage area to the drainage area of Perazzo at the downstream end of each reach. The results are presented in Table 2. The drainage area ratio between Sagehen and two reaches of Perazzo (Reach 2, located upstream of the Lacey Creek confluence; Reach 8, located downstream of the

Lacey Creek confluence) were applied to the Sagehen annual peak flow record to produce a synthetic record of annual peak flows for Perazzo dating back to 1954 (Figure 7). The New Years rain on snow flood of 1997 was by far the largest flood peak that the region has seen in the last 50+ years. Based on the flood frequency curve for Sagehen, the 1997 flood had an estimated return period of around 100 years.

5.0 REACH HYDRAULICS, BED MOBILITY, AND CHANNEL MORPHOLOGY

5.1 Purpose and Approach

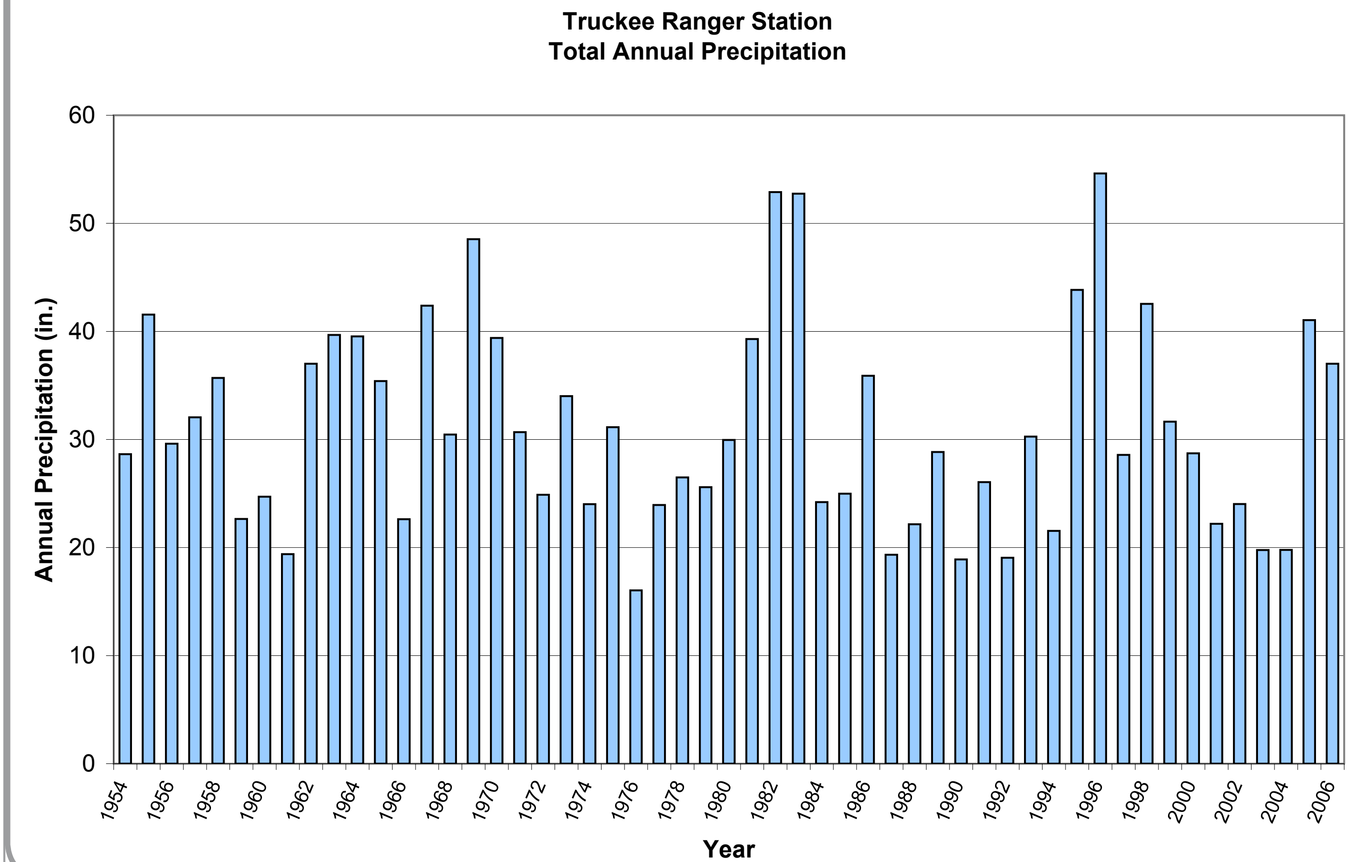
Qualitative and inferred evidence from the aerial photo analysis suggests that Perazzo Creek and the Little Truckee River, through Perazzo Meadows, has incised and widened due to historic land uses. To test this hypothesis a field data collection effort was conducted and combined with computer modeling to evaluate the degree to which the channel has incised and widened and the frequency with which water accesses the floodplain. Field and modeling efforts were limited to meadow reaches that were classified as unconfined response channels. That approach was taken because meadow channels are considered to be less resilient to perturbation, have a much longer recover time, and are likely to be the areas where restoration efforts are targeted. It is the meadows of the Sierra Nevada that have been most impacted by historic land use effects. Consequently, they are the ecological systems that have received the most attention, in terms of recovery efforts.

5.2 Field Analysis

A total of seven field sites were selected in six reaches (Figures 8, 8a, 8b, and 8c). Six of the selected areas consisted of sites along the mainstem of the primary channel, whereas one of the sites is located in one of the historic floodplain channels. Detailed field assessments were conducted in selected reaches. Collected geomorphic data included longitudinal profiles, cross sections, bankfull indicators, and bed material samples (Dunne and Leopold 1978; Wolman 1954; Church et al. 1987). Dunne and Leopold (1978) define the bankfull stage as follows:

> "The bankfull stage corresponds to the discharge at which channel maintenance is most effective, that is, the discharge at which moving sediment, forming or reforming bars, forming or changing bends and meanders, and generally doing work that results in the average morphologic characteristics of channels."

They note that, based on research elsewhere, the bankfull stage is associated with a momentary maximum flow, which, on average, has a recurrence interval of 1.5 years. Although these definitions are relatively precise, the bankfull stage is often difficult to identify in the field, and the recurrence interval of bankfull discharge may vary widely from the 1.5-year recurrence flood



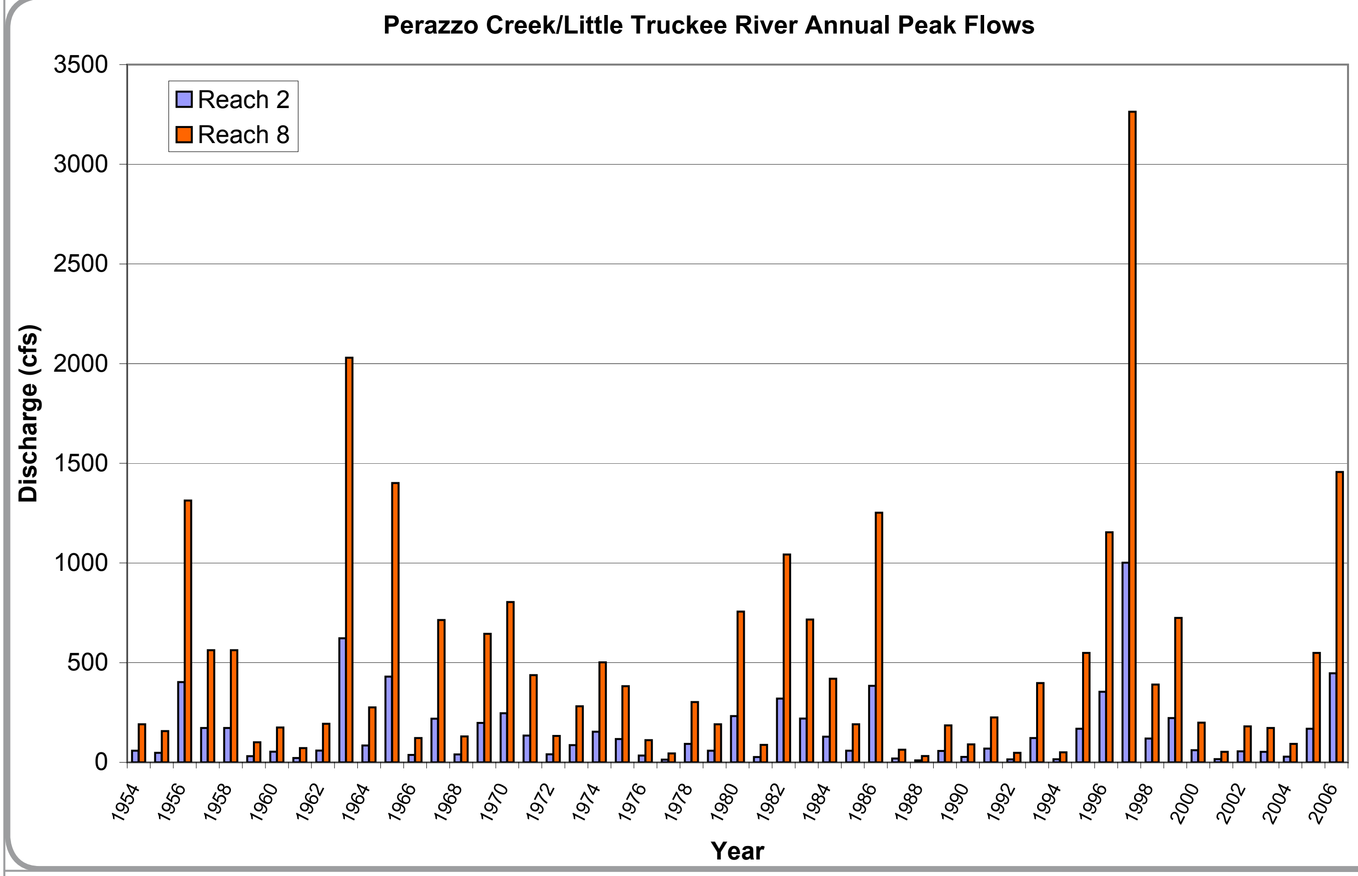


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FIGURE 7: Annual precipitation (Source: USFS, Truckee Ranger Station) and estimated peak discharges for the project area from 1954 to present. Annual peak discharges were developed using the USGS gage at Sagehen (Gage ID #10343500)

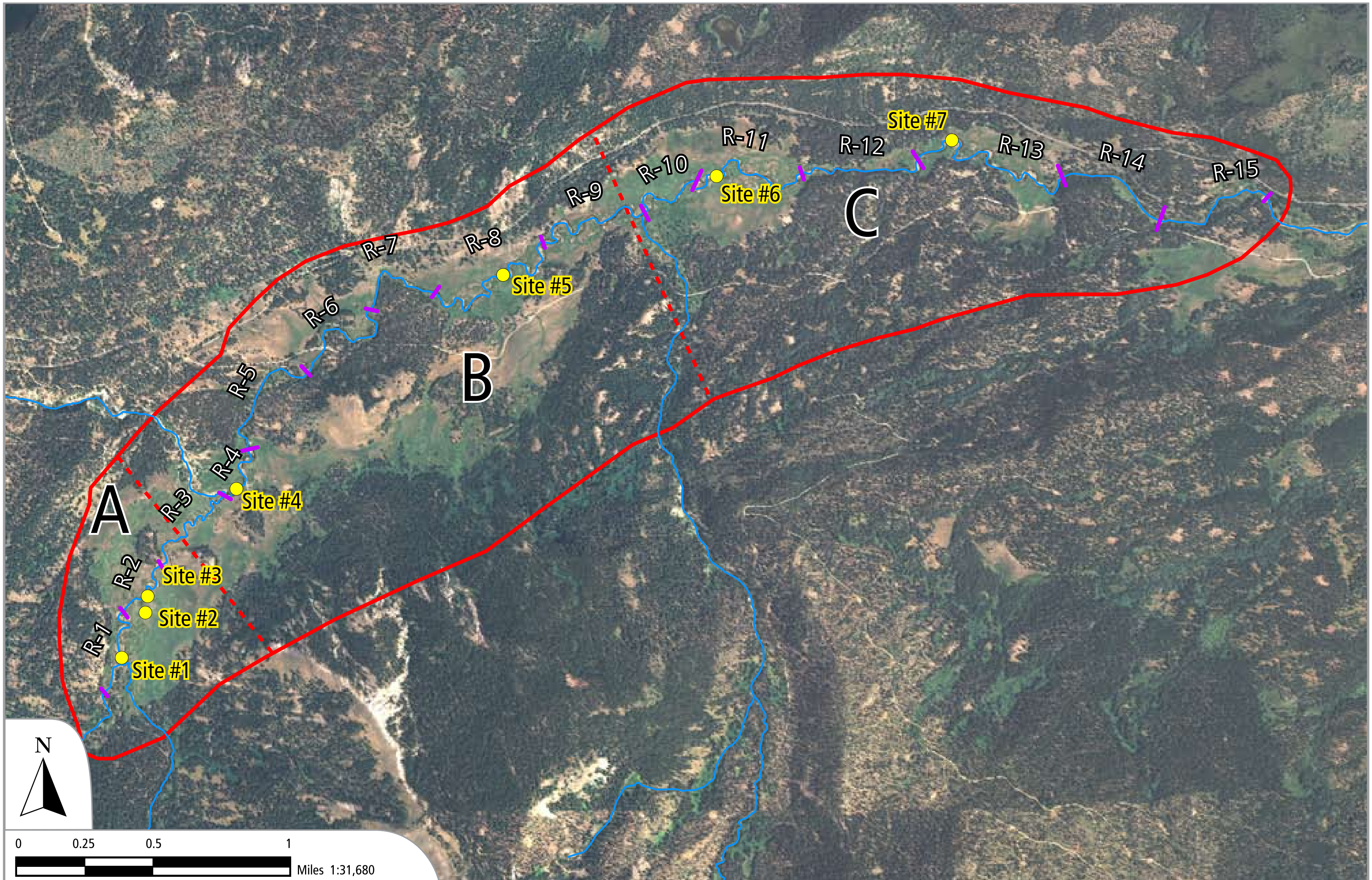

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FIGURE 8: Overview of Perazzo Meadows project area boundary, reach delineations, and SH+G survey site locations. Please refer to Figures 8a, 8b, and 8c for site specific information.

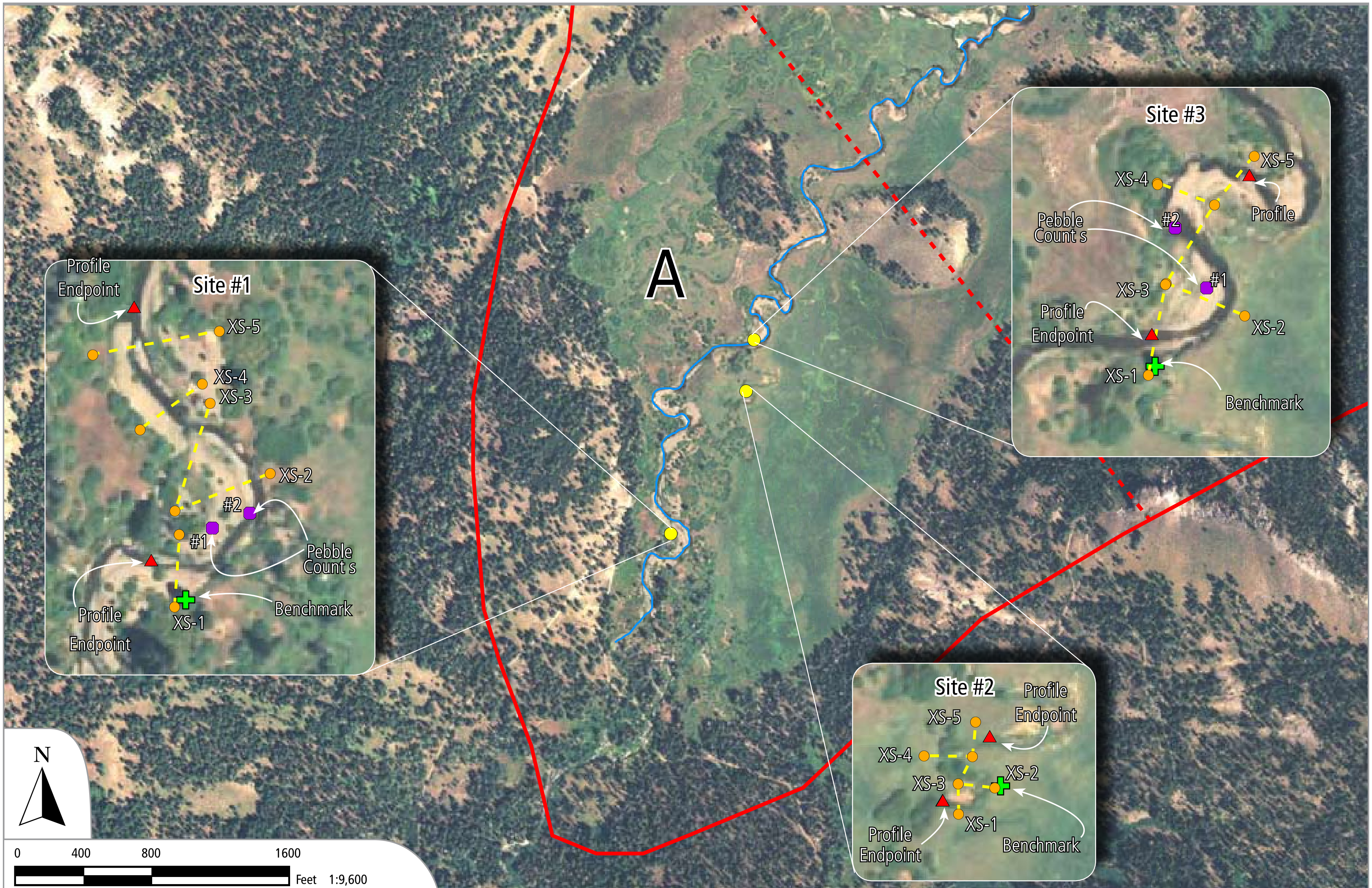

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FIGURE 8a: Survey locations assessed by SH+G in the Perrazzo Meadows watershed. Map insets show cross section locations, longitudinal profile endpoints, pebble count sites, and survey benchmarks.

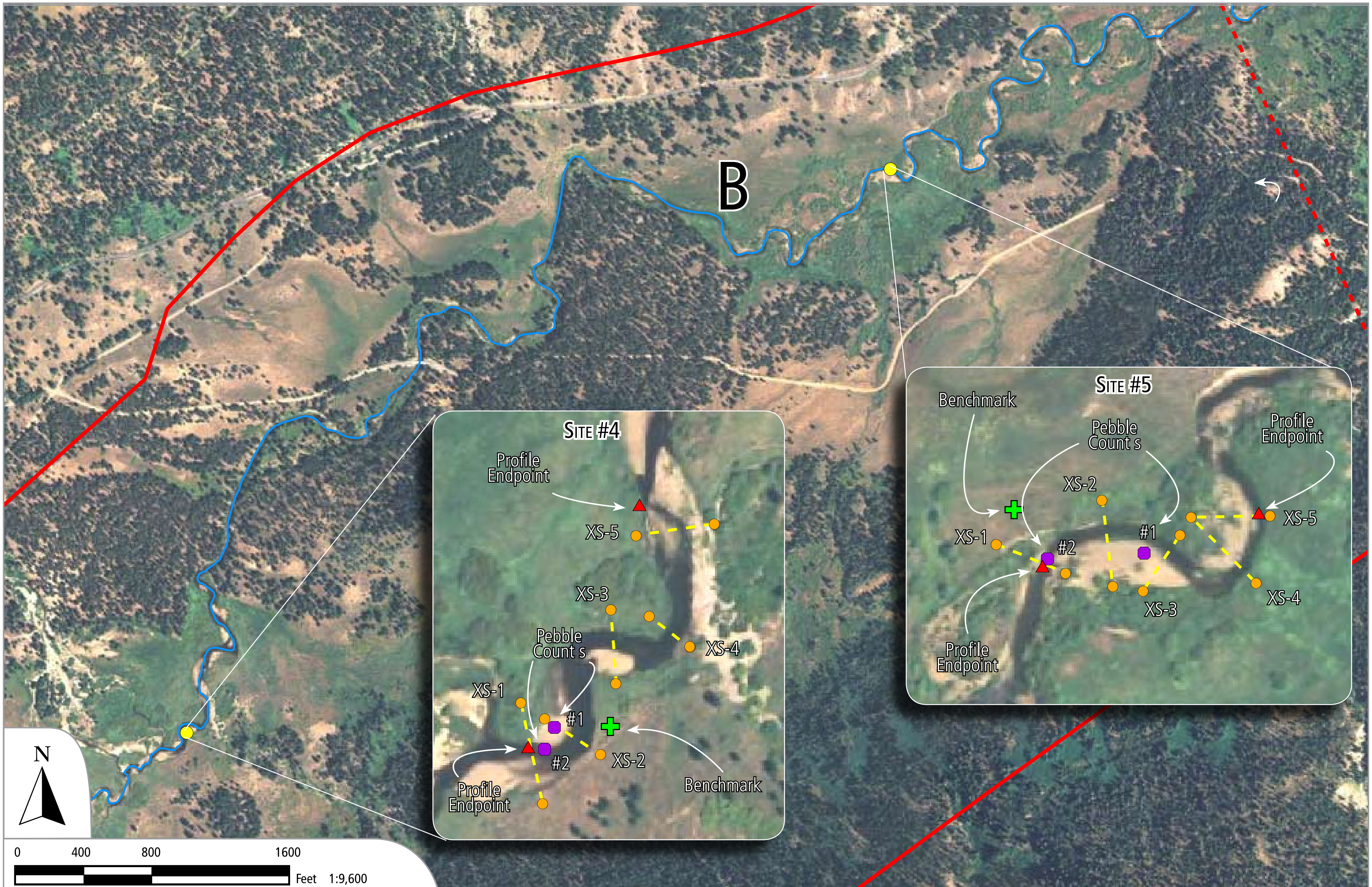

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FIGURE 8b: Survey locations assessed by SH+G in the Perrazzo Meadows watershed. Map insets show cross section locations, longitudinal profile endpoints, pebble count sites, and survey benchmarks.

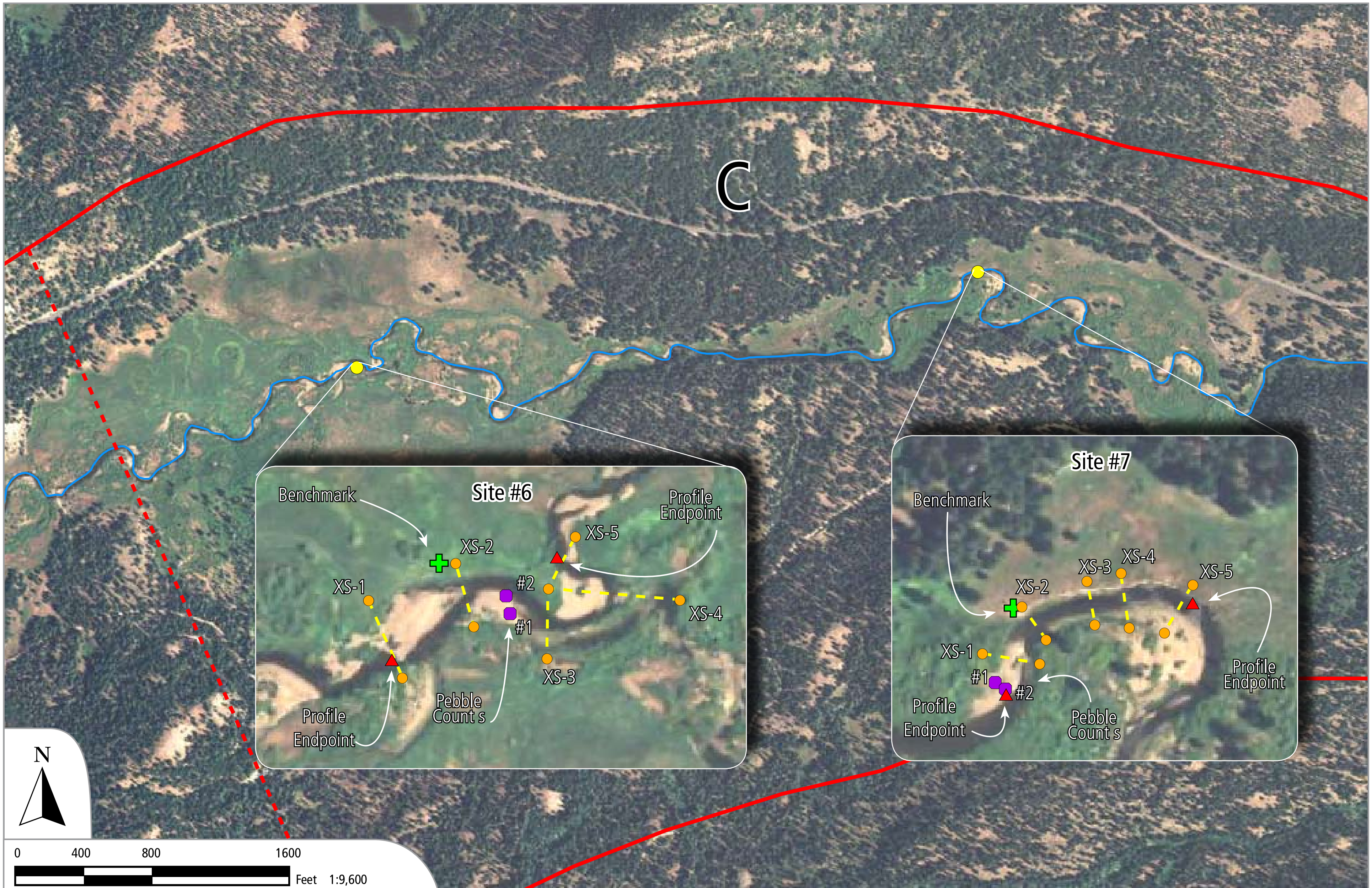

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FIGURE 8c: Survey locations assessed by SH+G in the Perrazzo Meadows watershed. Map insets show cross section locations, longitudinal profile endpoints, pebble count sites, and survey benchmarks.

(Williams, 1978). Nonetheless, several indicators are used to identify the bankfull stage, including new floodplain development, other channel forming features such as scour lines or point bars, or the growth of certain species of riparian vegetation (BLM, 1998). Note that the bankfull stage is not always at the top of bank.

The survey included a level, tape and rod survey of a longitudinal profile and four to six cross sections. The length of the longitudinal profile, the number of cross sections, and the distance between cross sections was dependent upon the overall scale and complexity of the channel features. An attempt was made to sample one continuous sinusoidal pattern in the channel. Typically, an appropriate channel length to survey should be 10 to 15 times the measured bankfull width (Dunne and Leopold, 1978; Leopold et al, 1964; Flosi et al, 1998). The longitudinal profile survey also included shots on identifiable bankfull features and top of bank features in order to generate a profile for each. Cross-sections were sampled on bends and at riffles to capture variability within the channel and riffle controls.

The following information was derived from longitudinal profile measurements and cross section data:

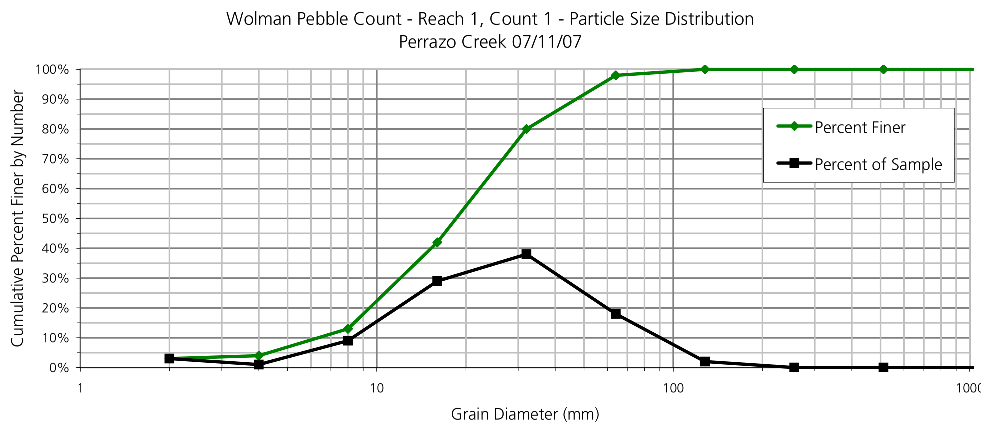
- bankfull width,
- bankfull depth,
- bankfull width to depth ratio,
- pool-riffle spacing,
- average channel and bankfull slope, and
- average pool depth.

Bed material was also sampled at each of the detailed study reaches using the pebble count method (Wolman 1954). At each site, a representative riffle and bar was sampled. A riffle and bar was chosen because they represent threshold conditions for bed mobility and bed load transport, respectively. Estimates of D_{16}, D_{50}, and D_{84} were calculated for each sample, along with the percentage of material within each size class. D_{16}, D_{50}, and D_{84} describe a grain size distribution through a percent finer notation. For example, D_{16} describes the grain size at which 16 percent of the sample is finer than the noted value. Results of the survey are presented in Figures 9a, 9b, 9c, 9d, 9e, and 9f, with summary results presented in Table 3. Photo points were also established at each of the survey sites and throughout the meadow to document changes in meadow conditions over time (Figure 10; Digital Photo Appendix). Each photo point was documented with a metal stake, flagging, GPS point, and photo direction (azimuth) to allow for reoccupation in the future (NOTE: We recommend using a GPS unit and metal detector to reoccupy the photo point sites).

Reach 1 - Count 1 - Bar Sample
Sample taken from high bar above bankfull near upstream end of the reach.

D_{16}	D_{50}	D_{84}
11	20	34

mm	Percent Finer	Percent of Sample
0	0%	0%
2	3%	3%
4	4%	1%
8	13%	9%
16	42%	29%
32	80%	38%
64	98%	18%
128	100%	2%
256	100%	0%
512	100%	0%
1024	100%	0%
	Total	100%



Reach 1 - Count 2 - Riffle Sample
Sample taken from riffle near upstream end of the reach.

D_{16}	D_{50}	D_{84}
12	22	35

mm	Percent Finer	Percent of Sample
0	0%	0%
2	5%	5%
4	6%	1%
8	10%	4%
16	30%	20%
32	79%	49%
64	100%	21%
128	100%	0%
256	100%	0%
512	100%	0%
1024	100%	0%
	Total	100%

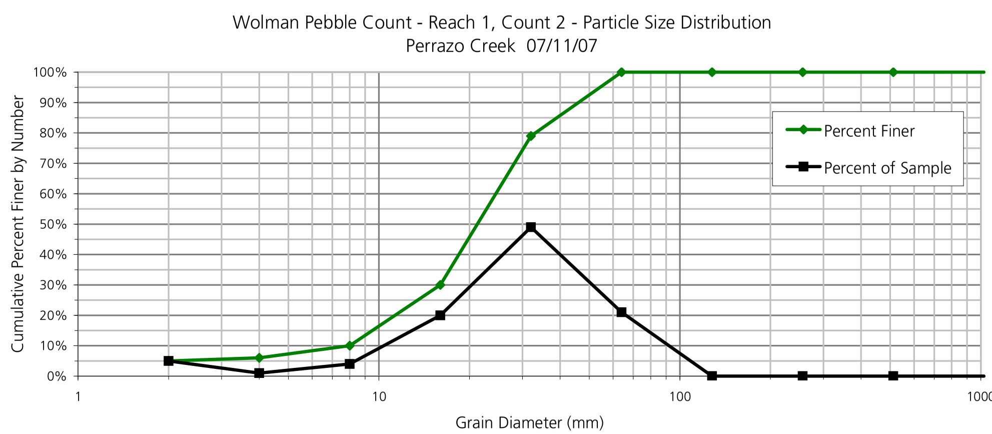


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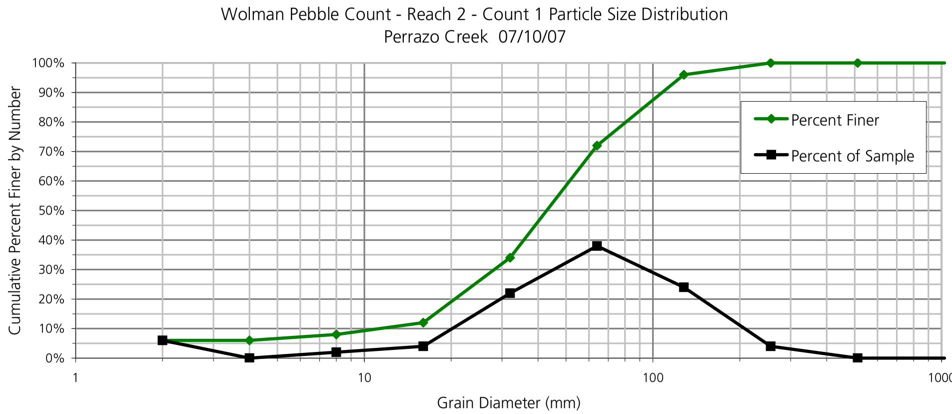
FIGURE 9a: Bed material sampling for Site 1, Reach 1 within the Perazzo Meadows project area. Samples were taken on active bars and at riffles within the low flow channel.

Reach 2 - Count 1 - Bar Sample

Sample taken from bar crest above bankfull channel.

D_{16}	D_{50}	D_{84}
19	42	85

mm	Percent Finer	Percent of Sample
0	0%	0%
2	6%	6%
4	6%	0%
8	8%	2%
16	12%	4%
32	34%	22%
64	72%	38%
128	96%	24%
256	100%	4%
512	100%	0%
1024	100%	0%
	Total	100%



Reach 2 - Count 2 - Riffle Sample

Sample taken from adjacent riffle within bankfull channel.

D_{16}	D_{50}	D_{84}
29	51	74

mm	Percent Finer	Percent of Sample
0	0%	0%
2	1%	1%
4	2%	1%
8	2%	0%
16	4%	2%
32	21%	17%
64	72%	51%
128	96%	24%
256	100%	4%
512	100%	0%
1024	100%	0%
	Total	100%

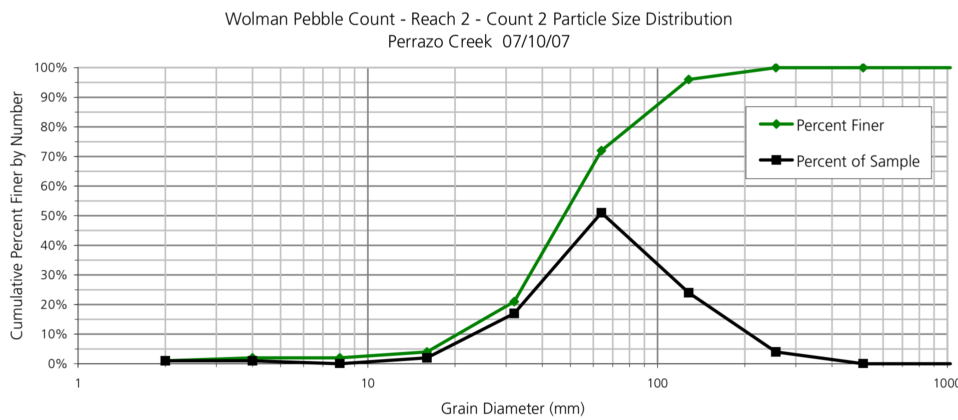


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FIGURE 9b: Bed material sampling for Site 3, Reach 2 within the Perazzo Meadows project area. Samples were taken on active bars and at riffles within the low flow channel. (NOTE: Pebble count data was not collected for Reach 2, Site 2 since the site is located in an historic channel that has been filled with fine sediment over time via overbank deposition from the primary channel)

Reach 4 - Count 1 - Bar Sample

Sample taken from upstream bar above the bankfull channel.

D_{16}	D_{50}	D_{84}
7	12	17

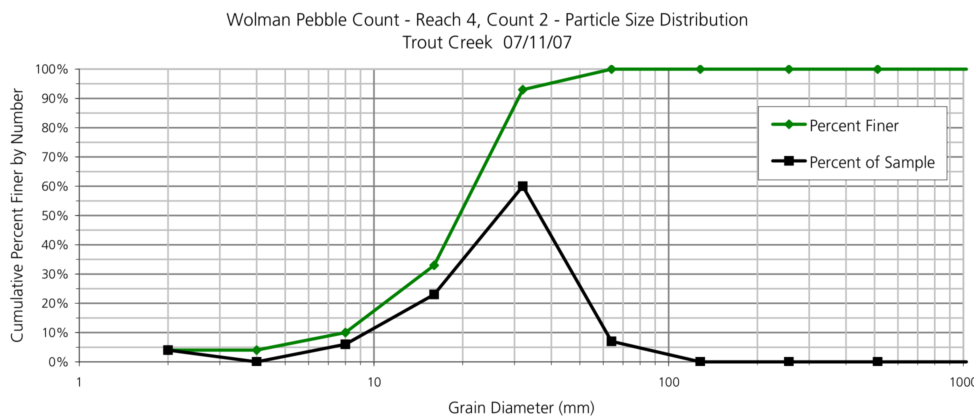
mm	Percent Finer	Percent of Sample
0	0%	0%
2	2%	2%
4	4%	2%
8	27%	23%
16	79%	52%
32	99%	20%
64	100%	1%
128	100%	0%
256	100%	0%
512	100%	0%
1024	100%	0%
	Total	100%

Reach 4 - Count 2 - Riffle Sample

Sample taken from adjacent upstream riffle within the bankfull channel.

D_{16}	D_{50}	D_{84}
12	20	29

mm	Percent Finer	Percent of Sample
0	0%	0%
2	4%	4%
4	4%	0%
8	10%	6%
16	33%	23%
32	93%	60%
64	100%	7%
128	100%	0%
256	100%	0%
512	100%	0%
1024	100%	0%
	Total	100%



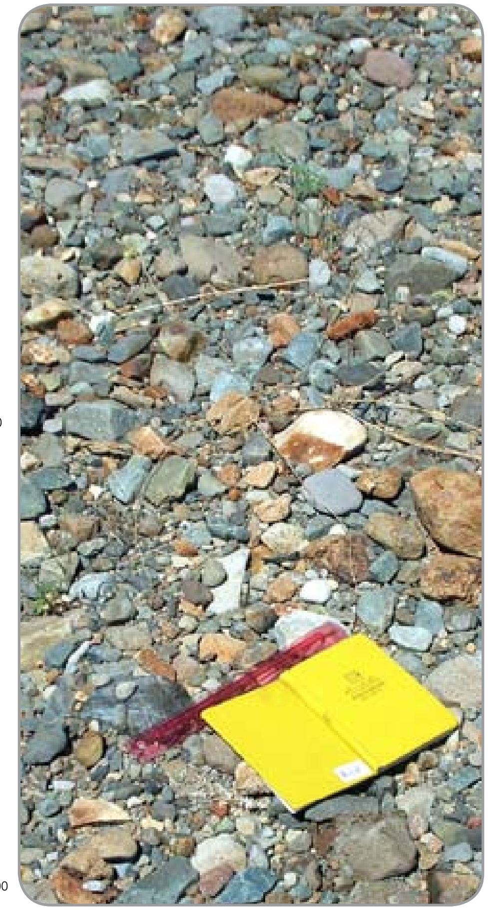


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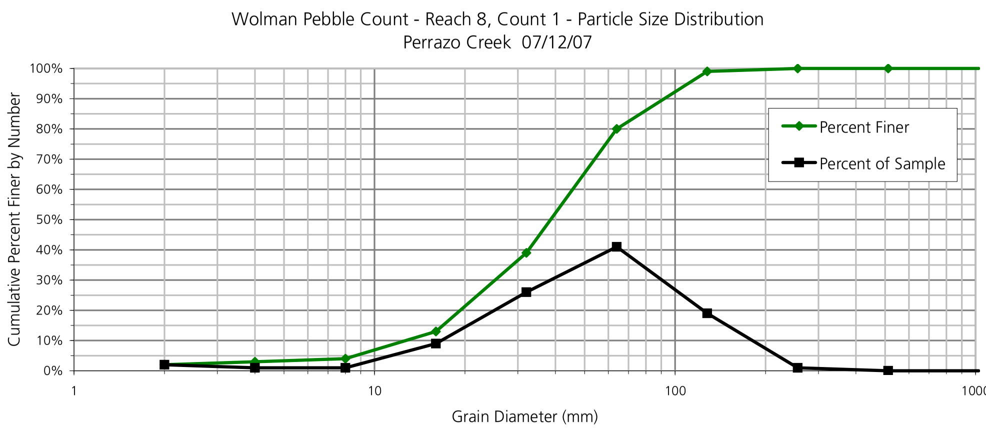
FIGURE 9c: Bed material sampling for Site 4, Reach 4 within the Perazzo Meadows project area. Samples were taken on active bars and at riffles within the low flow channel..

Reach 8 - Count 1 - Bar Sample
Sample taken from high bar above the bankfull channel at the upstream end of the reach.

D_{16}	D_{50}	D_{84}
18	37	36

mm	Percent Finer	Percent of Sample
0	0%	0%
2	2%	2%
4	3%	1%
8	4%	1%
16	13%	9%
32	39%	26%
64	80%	41%
128	99%	19%
256	100%	1%
512	100%	0%
1024	100%	0%
	Total	100%



Reach 8 - Count 2 - Riffle Sample
Sample taken from riffle within the bankfull channel at the upstream end of the reach.

D_{16}	D_{50}	D_{84}
9	18	36

mm	Percent Finer	Percent of Sample
0	0%	0%
2	10%	10%
4	10%	0%
8	16%	6%
16	42%	26%
32	79%	37%
64	95%	16%
128	98%	3%
256	100%	2%
512	100%	0%
1024	100%	0%
	Total	100%

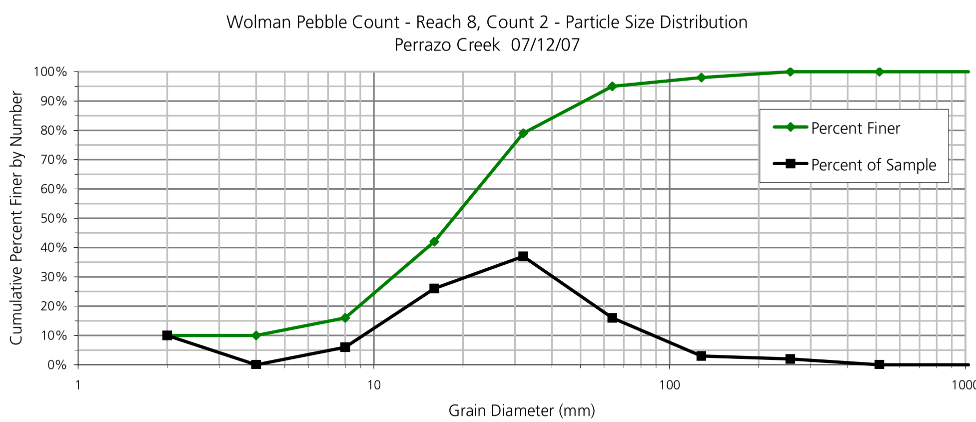


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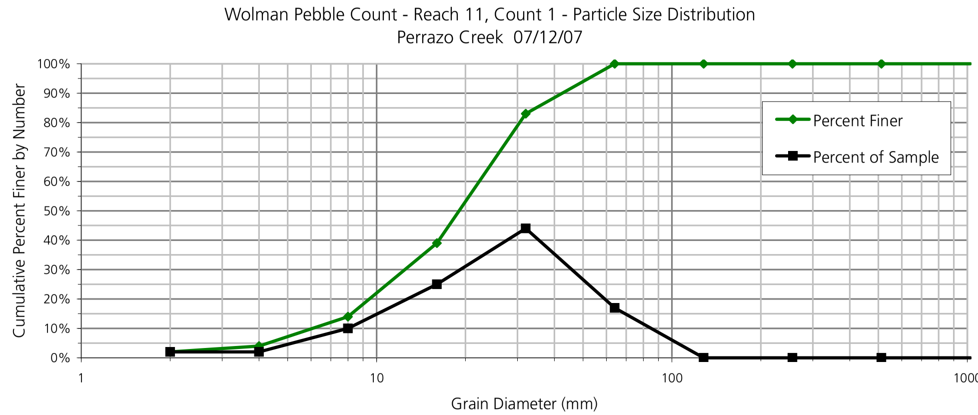
FIGURE 9d: Bed material sampling for Site 5, Reach 8 within the Perazzo Meadows project area. Samples were taken on active bars and at riffles within the low flow channel.

Reach 11 - Count 1 - Bar Sample		
Sample taken from bar above bankfull at upstream end of reach.		

D_{16}	D_{50}	D_{84}
10	20	33

mm	Percent Finer	Percent of Sample
0	0%	0%
2	2%	2%
4	4%	2%
8	14%	10%
16	39%	25%
32	83%	44%
64	100%	17%
128	100%	0%
256	100%	0%
512	100%	0%
1024	100%	0%
	Total	100%



Reach 11 - Count 2 - Riffle Sample		
Sample taken from adjacent riffle within bankfull channel.		

D_{16}	D_{50}	D_{84}
21	37	63

mm	Percent Finer	Percent of Sample
0	0%	0%
2	4%	4%
4	4%	0%
8	6%	2%
16	10%	4%
32	42%	32%
64	84%	42%
128	100%	16%
256	100%	0%
512	100%	0%
1024	100%	0%
	Total	100%

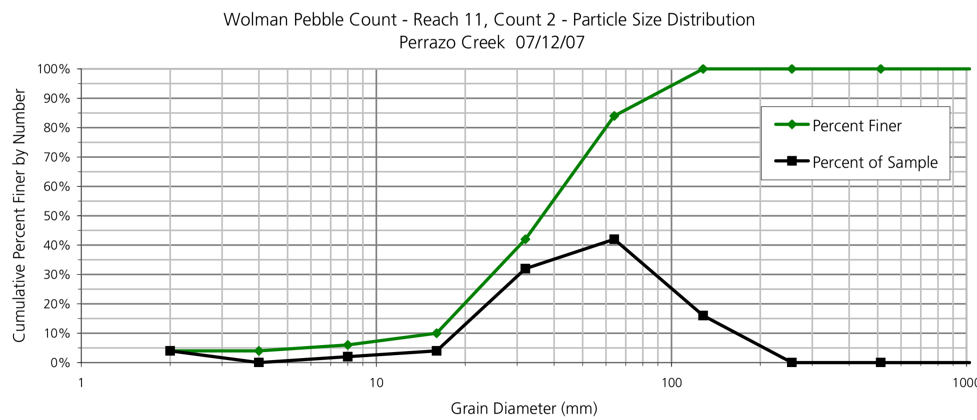


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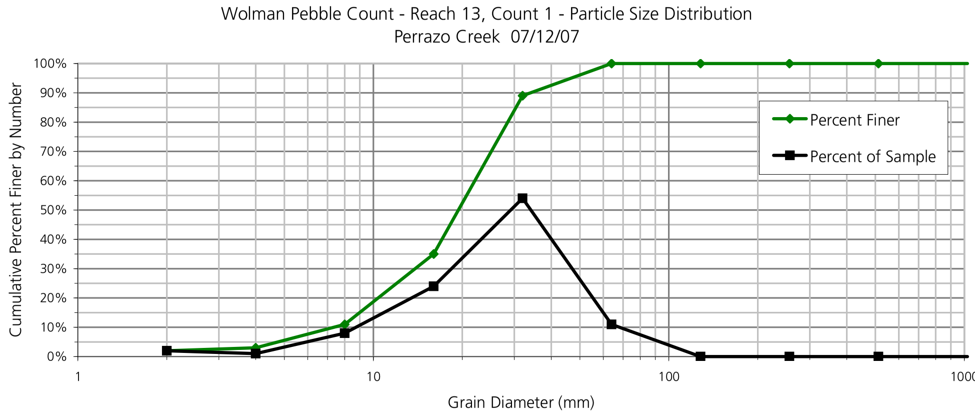
FIGURE 9e: Bed material sampling for Site 6, Reach 11 within the Perazzo Meadows project area. Samples were taken on active bars and at riffles within the low flow channel.

Reach 13 - Count 1 - Bar Sample
Sample taken from bar surface above the bankfull channel at the upper end of the reach.

D_{16}	D_{50}	D_{84}
13	22	29

mm	Percent Finer	Percent of Sample
0	0%	0%
2	2%	2%
4	3%	1%
8	11%	8%
16	35%	24%
32	89%	54%
64	100%	11%
128	100%	0%
256	100%	0%
512	100%	0%
1024	100%	0%
	Total	100%



Reach 13 - Count 2 - Riffle Sample
Sample taken from adjacent riffle within the bankfull channel.

D_{16}	D_{50}	D_{84}
13	30	47

mm	Percent Finer	Percent of Sample
0	0%	0%
2	3%	3%
4	3%	0%
8	7%	4%
16	25%	18%
32	58%	33%
64	95%	37%
128	99%	4%
256	100%	1%
512	100%	0%
1024	100%	0%
	Total	100%

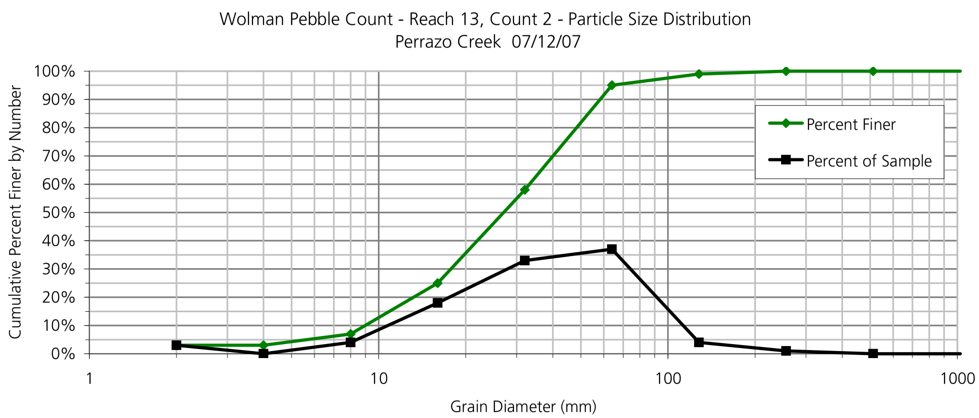


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FIGURE 9f: Bed material sampling for Site 7, Reach 13 within the Perazzo Meadows project area. Samples were taken on active bars and at riffles within the low flow channel.

PEBBLE COUNT SUMMARY DATA

Sample Location	**Reach 1- Site 1**	**Reach 1 - Site 2**	**Reach 2 - Site 1**	**Reach 2 - Site 2**	**Reach 4 - Site 1**	**Reach 4 - Site 2**	**Reach 8 - Site 1**	**Reach 8 - Site 2**	**Reach 11 - Site 1**	**Reach 11 - Site 2**	**Reach 13 - Site 1**	**Reach 13 - Site 2**
Type	**Bar**	**Riffle**	**Bar**	**Riffle**	**Bar**	**Riffle**	**Bar**	**Riffle**	**Bar**	**Riffle**	**Bar**	**Riffle**
D_{16} (mm)	11	12	19	29	7	12	18	9	10	21	13	13
D_{50} (mm)	20	22	42	51	12	20	37	18	20	37	22	30
D_{84} (mm)	34	35	85	74	17	29	66	36	33	63	29	47

mm	**Percent Finer**											
0	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2	3%	5%	6%	1%	2%	4%	2%	10%	2%	4%	2%	3%
4	4%	6%	6%	2%	4%	4%	3%	10%	4%	4%	3%	3%
8	13%	10%	8%	2%	27%	10%	4%	16%	14%	6%	11%	7%
16	42%	30%	12%	4%	79%	33%	13%	42%	39%	10%	35%	25%
32	80%	79%	34%	21%	99%	93%	39%	79%	83%	42%	89%	58%
64	98%	100%	72%	72%	100%	100%	80%	95%	100%	84%	100%	95%
128	100%	100%	96%	96%	100%	100%	99%	98%	100%	100%	100%	99%
256	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
512	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
1024	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

mm	**Total Count**											
0	0	0	0	0	0	0	0	0	0	0	0	0
2	3	5	6	1	2	4	2	10	2	4	2	3
4	1	1	0	1	2	0	1	0	2	0	1	0
8	9	4	2	0	23	6	1	6	10	2	8	4
16	29	20	4	2	52	23	9	26	25	4	24	18
32	38	49	22	17	20	60	26	37	44	32	54	33
64	18	21	38	51	1	7	41	16	17	42	11	37
128	2	0	24	24	0	0	19	3	0	16	0	4
256	0	0	4	4	0	0	1	2	0	0	0	1
512	0	0	0	0	0	0	0	0	0	0	0	0
1024	0	0	0	0	0	0	0	0	0	0	0	0
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

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TABLE 3: Summary of pebble count data.

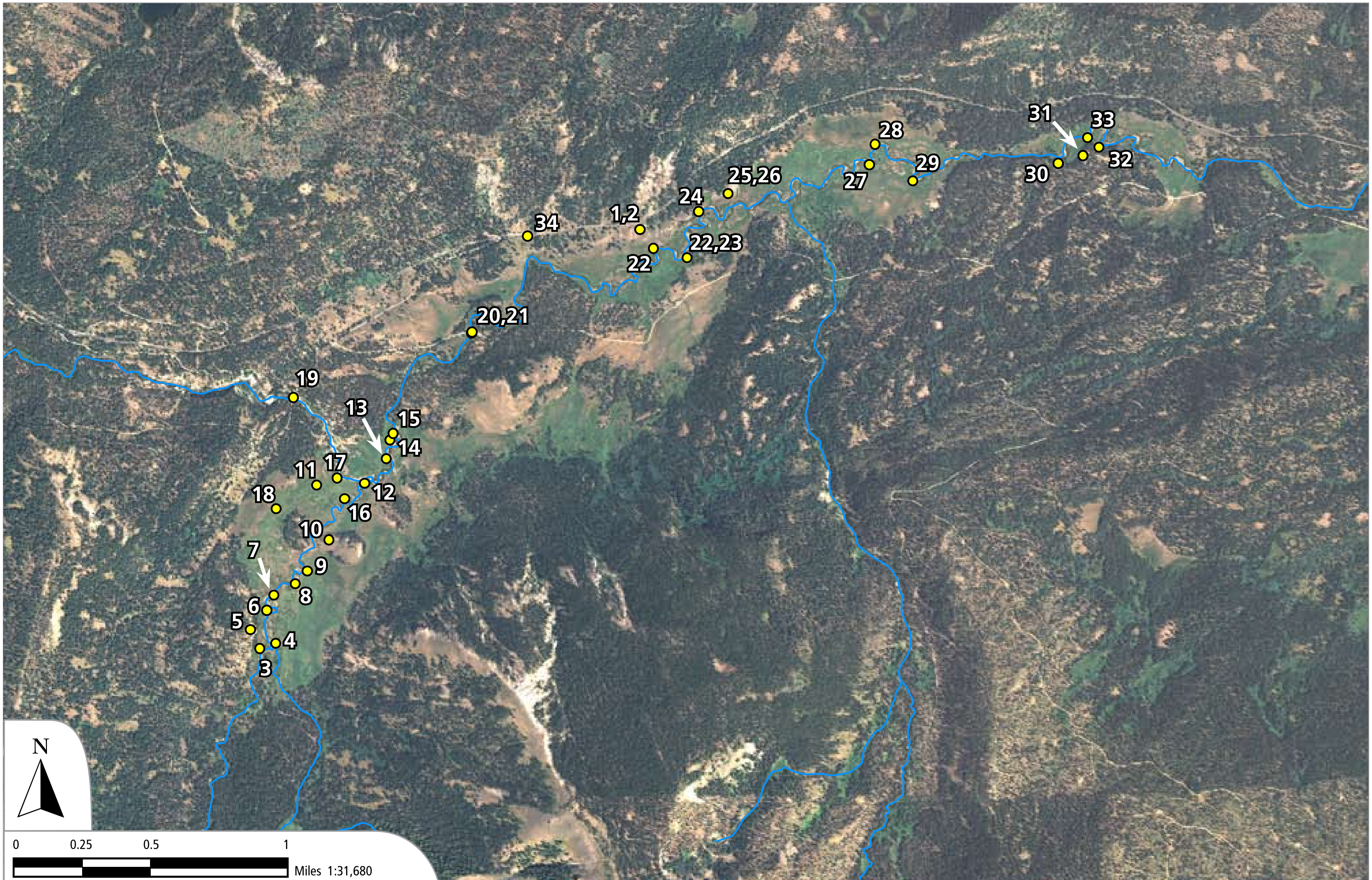

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FIGURE 10: Photo point locations within the Perazzo Meadows project area. For detailed information about each photo point we have provided a database appendix on disk. Information in the database includes a table with the photo point, latitude, longitude, azimuth, date taken, and photo reference along with all the photos.

Although the historical analysis suggests that the active channel has incised into the meadow, there is evidence that the bankfull channel has widened and become more shallow, most likely in response to the increase in bed load delivery to the meadow and lateral bank erosion. Average bankfull width to depth ratios, measured from field indicators, range from a low of 43 in Reach 1, to a high of 113 in Reach 8. Site 2, located in Reach 2 within a historic floodplain channel, has a width to depth ratio of 19 and can be considered a reference channel condition. Low width to depth ratios imply a condition where the channel is narrow and deep and is often associated with high quality aquatic habitat within meadow systems. High quality habitat often correlates with low width to depth ratios because stable undercut banks can develop, providing escape cover for fish.

To evaluate the extent to which the bankfull widths, bankfull depths, and width to depth ratios in the project area diverge from reference conditions, we applied the drainage areas for each of the study sites to regional hydraulic geometry curves developed for the Tahoe-Truckee region to determine a predicted geometry for the Perazzo Meadows channel. The regional hydraulic geometry curves were generated using stream gaging sites in the Tahoe and Truckee region (Dunne and Leopold, 1976). A total of 27 gage sites were used in the analysis, all of which are within watersheds where snowmelt hydrology dominates. At each of the gaging sites, USGS measurement data was used to evaluate wetted width and depth at discharges that approximate the 1.5 year event. These data were then plotted against drainage area and regressed to develop equations. For channel width, an R^2 of 0.87 resulted from a linear regression on a log-log plot. A linear regression on a log-log plot of channel depth produced an R^2 of 0.75.

The results, presented in Table 1, suggest that the bankfull channel through Perazzo Meadows is much wider and shallower than what would be expected regionally. This is even more the case when you consider that the regional hydraulic geometry database includes many non-meadow stream systems with armored beds, where wider and shallower channels typically occur. In all the study sites, actual bankfull widths are almost twice what is predicted. The only exception is at Site 2, the reference site, where actual widths are approximately 20% greater than predicted, which is well within the error of the analysis.

5.3 Hydraulic Analysis

To further refine the analysis of appropriate channel geometry for the site and frequency of floodplain inundation, the measured field cross-sections were used to develop a hydraulic model for each of the sites. Hydraulic conditions were estimated through the use of HEC-RAS, the U.S. Army Corps of Engineers one-dimensional hydraulic model. Cross sections were entered into HEC-RAS and separate models were built for each site using field data and other information derived from the aerial photos (e.g. – bank length) and ground photos (e.g. – channel roughness). Model complexity was kept at a minimum as the focus was to generally assess hydraulic condition in relation to channel geometry (e.g. – recurrence interval of floodplain activation, shear stress, and bed mobility).

The hydrology data developed from the Sagehen gage was used to evaluate water surface elevations at each cross-section for the 1-year, 1.5-year, 2-year, 5-year, and 10-year events. The results are presented in Figures 11a, 11b, 11c, 11d, 11e, 11f, and 11g. The model was checked by comparing modeled water surfaces for the 1.5-year to 2-year events to the elevation of the bankfull indicators measured in the field. At most cross-sections, the modeled water surfaces for the 1.5 to 2-year events correlated well with the bankfull indicators measured in the field.

The results indicate a trend of increasing flood flow access to the floodplain with distance downstream. In Reach 1 (Site 1) where the channel is incised into the alluvial fan surface, the 10-year discharge is still contained within the primary channel. In Reach 2 (Site 3), located at the upstream end of the meadow, flow starts accessing the floodplain somewhere between the 5-year and 10-year event. In Reach 4 (Site 4), the results were variable, but flow consistently accesses the floodplain at around a 5-year event. In Reach 8 (Site 5), consistent access to the floodplain occurs at around the 5-year event. In Reach 11 (Site 6) and Reach 13 (Site 7), flow starts to access the floodplain between the 2-year and 5-year event. Conversely, in the floodplain channel reference site located along Reach 2 (Site 2), flow consistently accesses the floodplain meadow at the 2-year event.

The hydraulic data supports other lines of evidence that the active channel, especially in the upper meadow, is incised and widened and that the meadow only floods during high magnitude, low frequency discharge events. Based on the geometry of the reference floodplain channel, it also appears that the meadow historically flooded during the 2-year return period event. The fact that floodplain inundation is more frequent in the downstream direction can be attributed to the presence of the diversion dam at the downstream end of the project area. The diversion dam holds grade, preventing further incision of the channel upstream. The lack of additional incision, due to stabilization of the grade at the diversion dam, may mean that the channel is purely in a widening phase, attempting to create an inset floodplain surface with a consequent reduction in flow depths and shear.

5.4 Bed Mobility Analysis

One of the primary impacts associated with incision within the meadow is postulated to be the extension of the incision into alluvial fans located at the upstream end of the meadow and at Lacey Creek. Incision of the fan limits a primary function of the fan, which is to deposit coarse bed load before the stream channel enters the meadow. Bed load that would have been

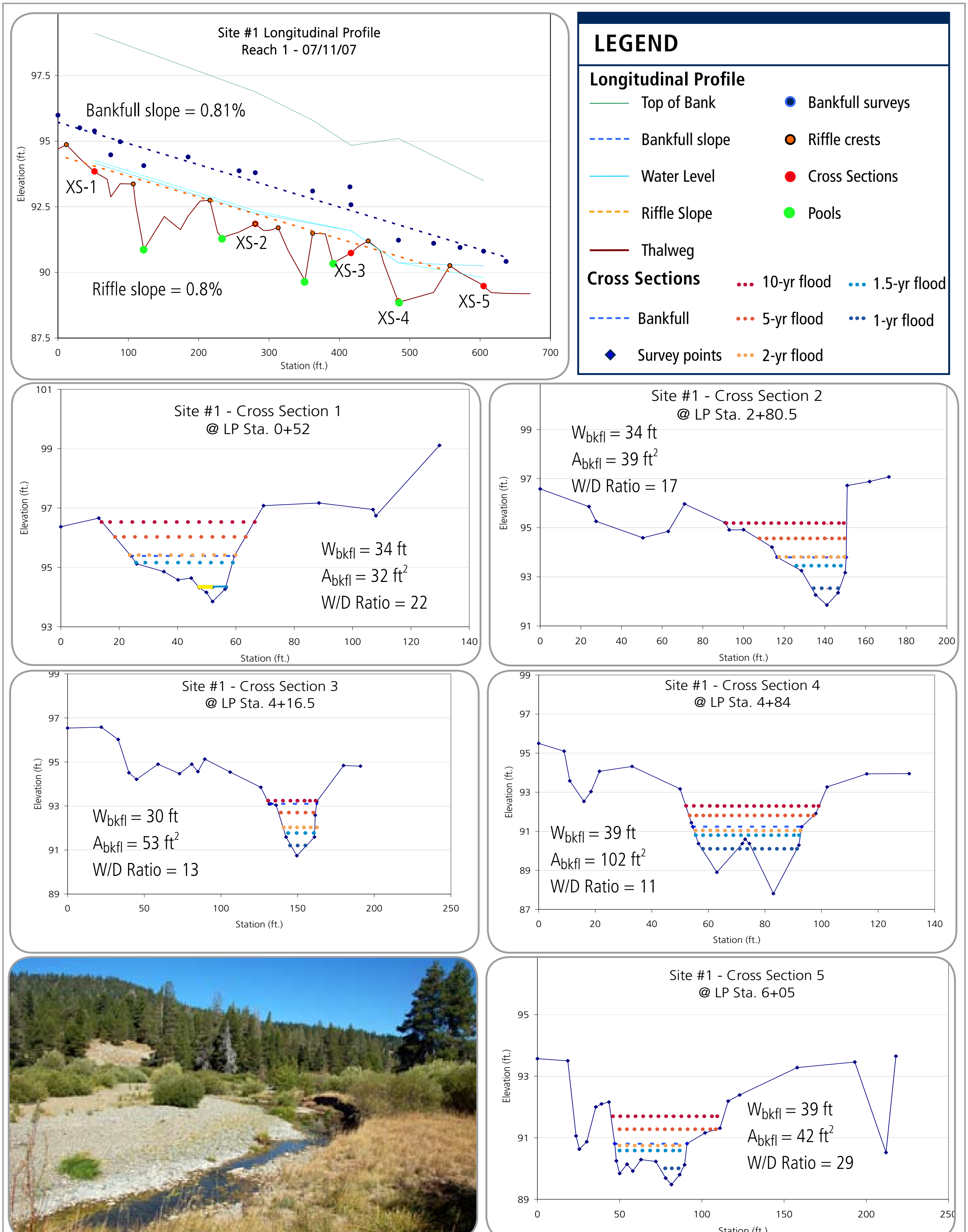

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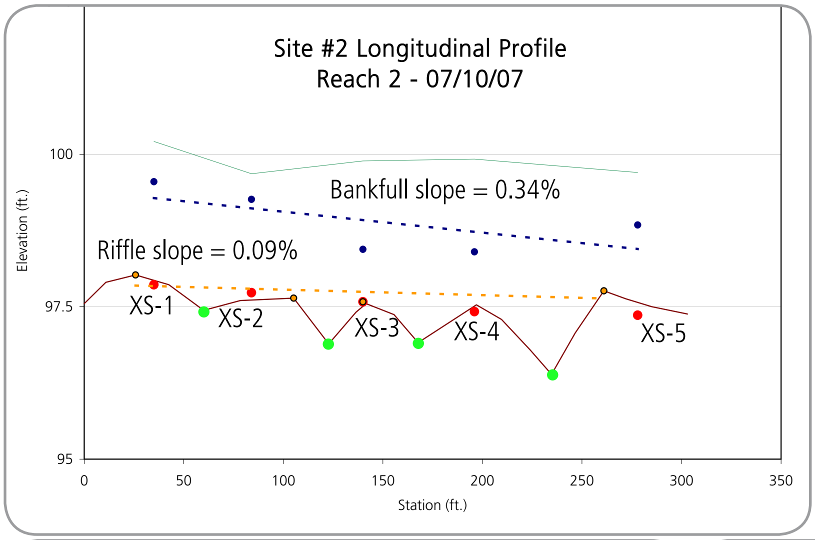
FIGURE 11a: Survey data results for Site 1, Reach 1. All survey data was collected in the field using an auto-level, tape, and rod. Peak water surface elevations were developed using a 1-dimensional hydraulic model (HEC-RAS). Wbkfl = Bankfull width; Abkfl = Channel cross-sectional area at bankfull; W/D = Width to Depth; LP = Long profile.



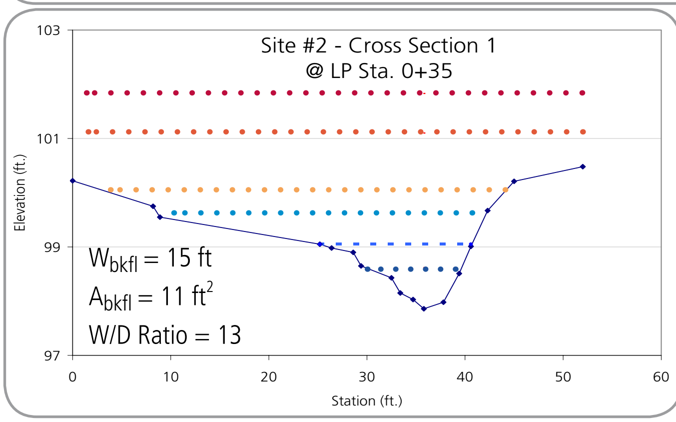
LEGEND

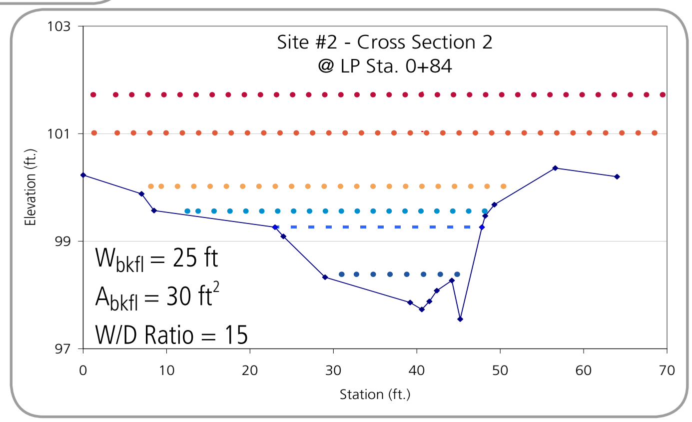
Longitudinal Profile

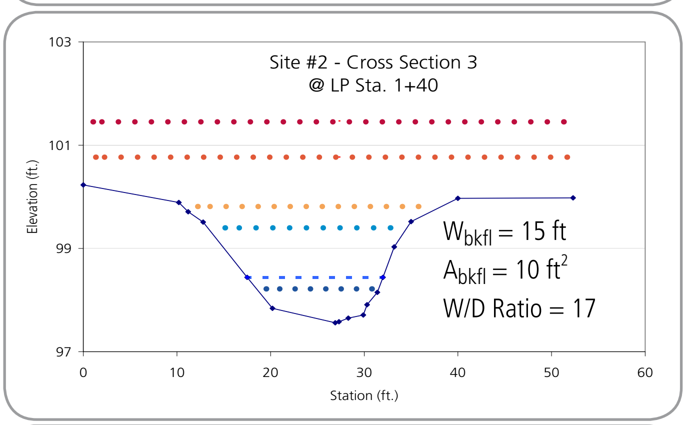
- Top of Bank
- Bankfull surveys
- Bankfull slope
- Riffle crests
- Water Level
- Cross Sections
- Riffle Slope
- Pools
- Thalweg

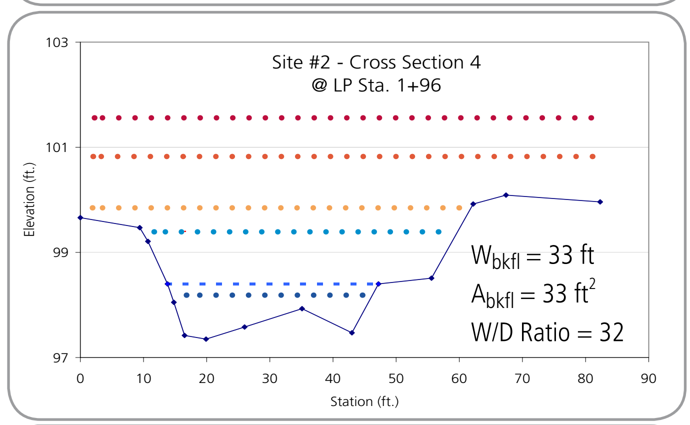
Cross Sections

- 10-yr flood
- 1.5-yr flood
- Bankfull
- 5-yr flood
- 1-yr flood
- Survey points
- 2-yr flood









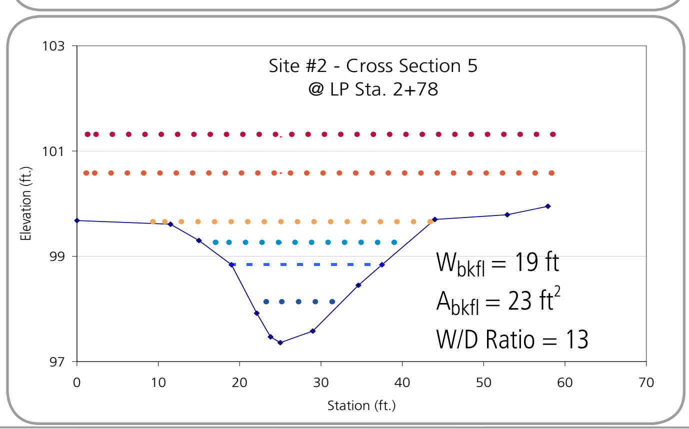


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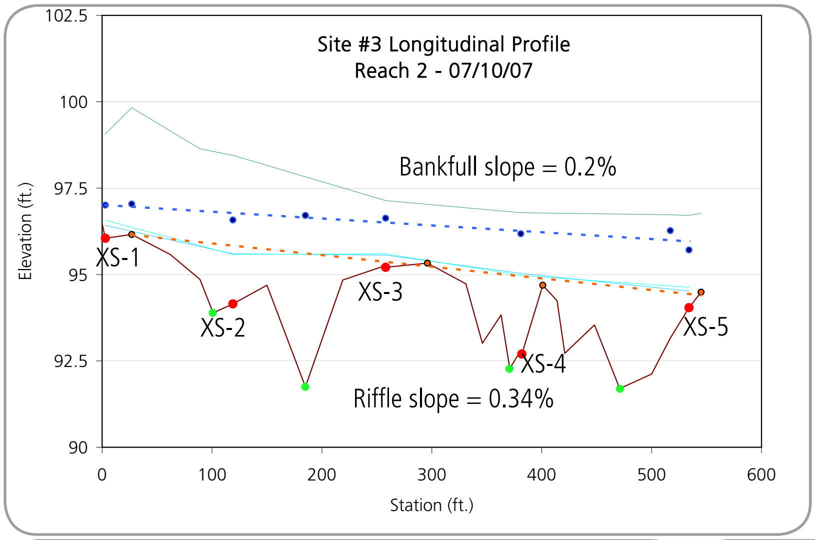
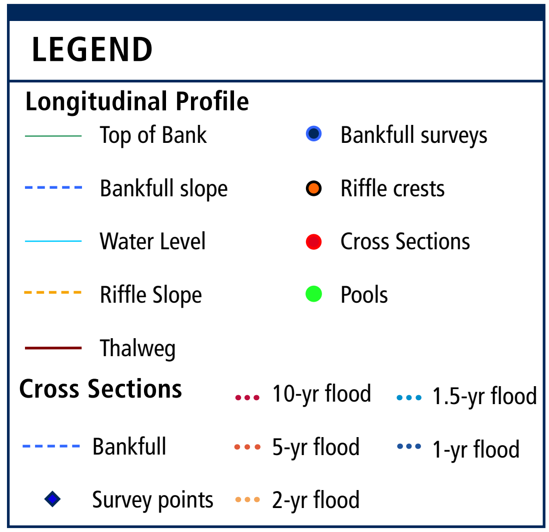
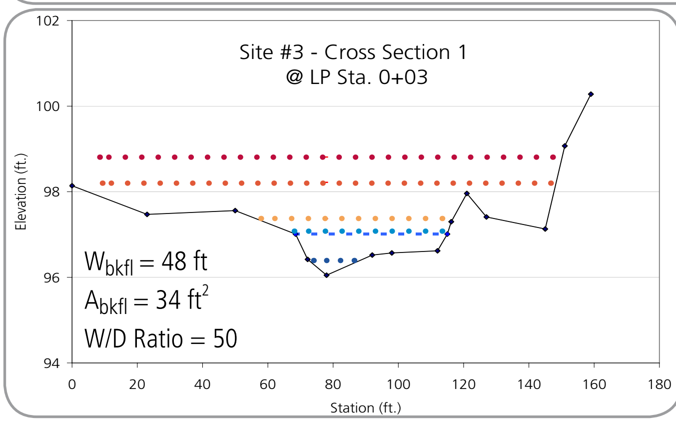
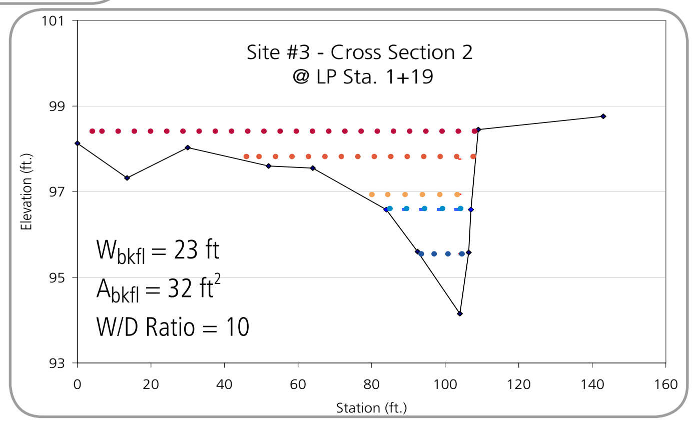
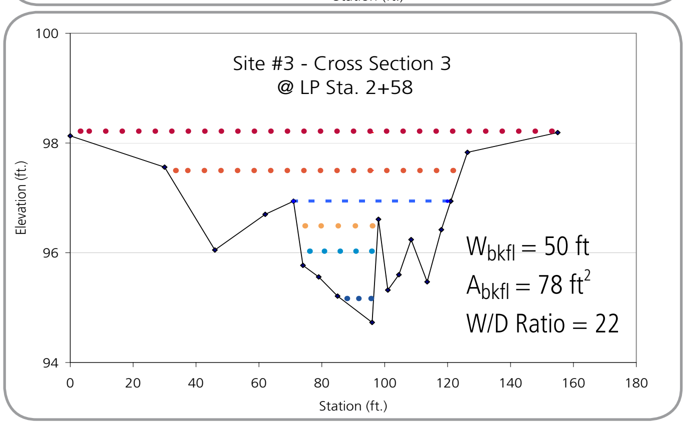
FIGURE 11b: Survey data results for Site 2, Reach 2. All survey data was collected in the field using an auto-level, tape, and rod. Peak water surface elevations were developed using a 1-dimensional hydraulic model (HEC-RAS). Wbkfl = Bankfull width; Abkfl = Channel cross-sectional area at bankfull; W/D = Width to Depth; LP = Long profile.

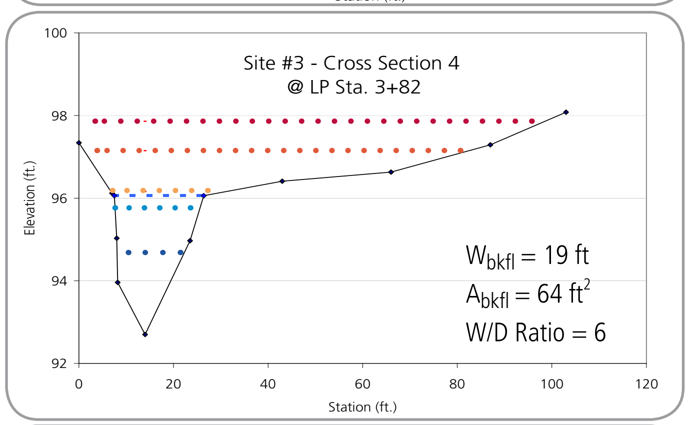












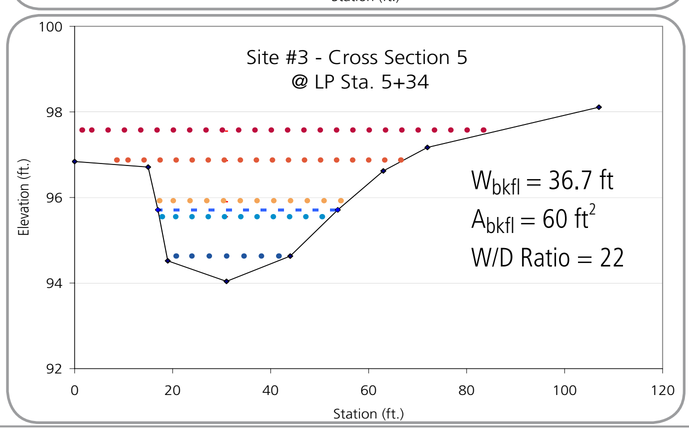


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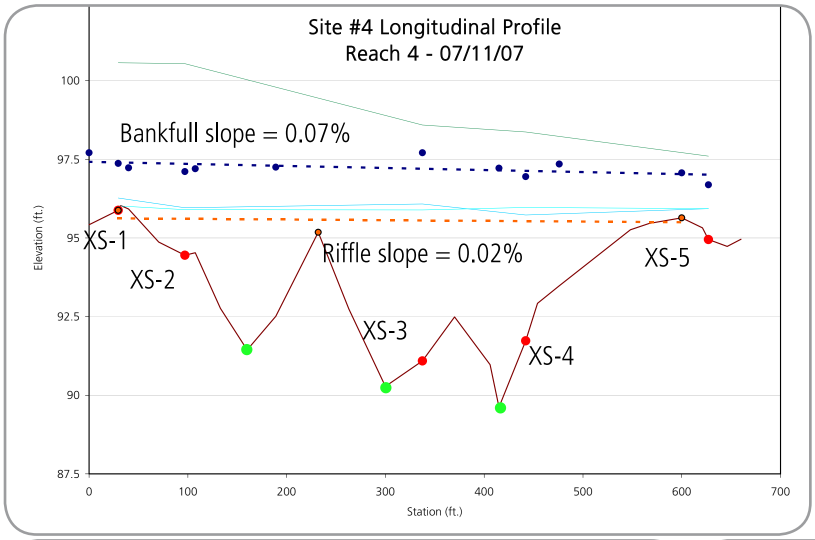
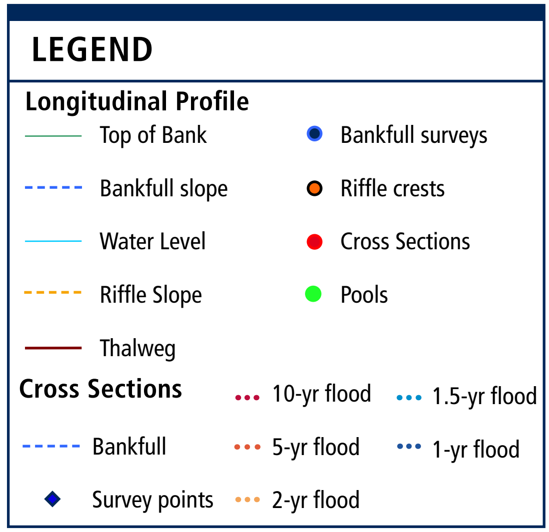
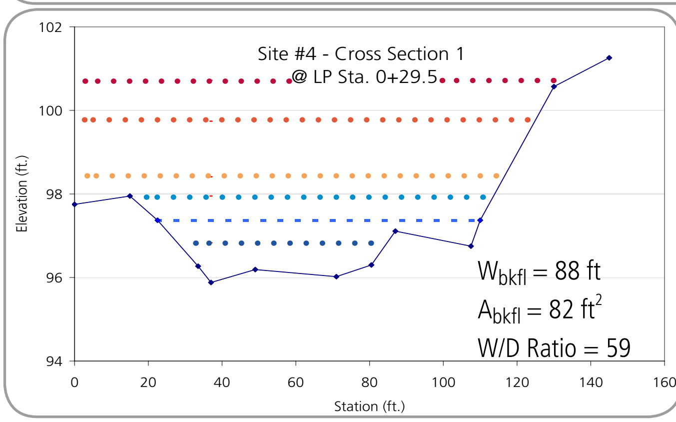
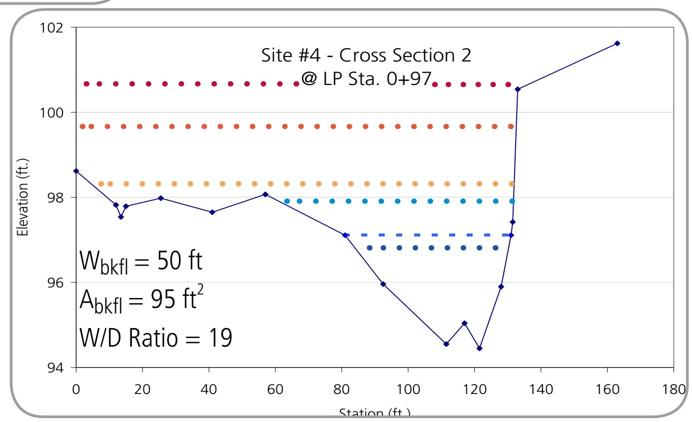
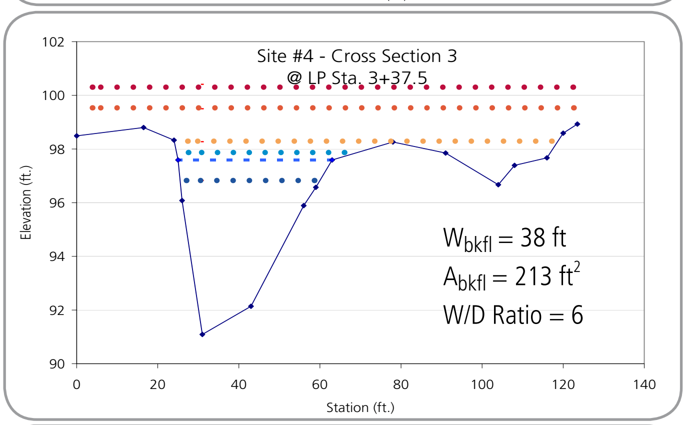
FIGURE 11c: Survey data results for Site 3, Reach 2. All survey data was collected in the field using an auto-level, tape, and rod. Peak water surface elevations were developed using a 1-dimensional hydraulic model (HEC-RAS). Wbkfl = Bankfull width; Abkfl = Channel cross-sectional area at bankfull; W/D = Width to Depth; LP = Long profile.

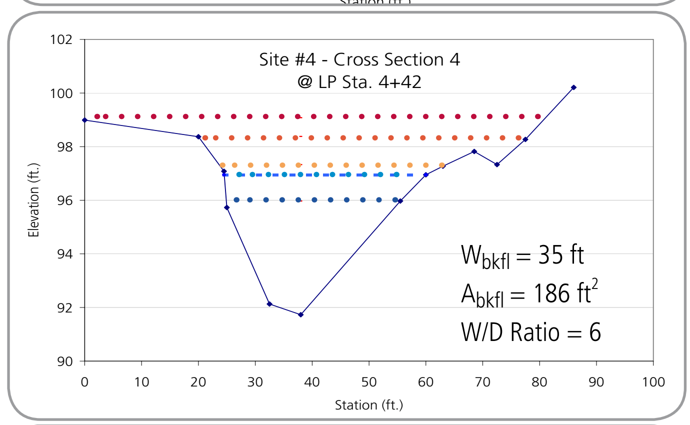












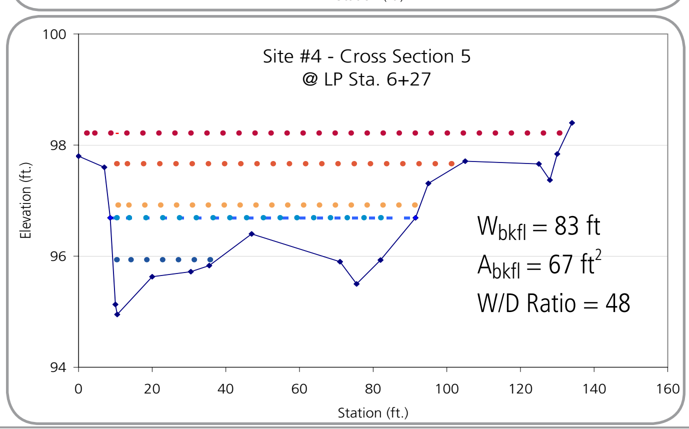


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FIGURE 11d: Survey data results for Site 4, Reach 4. All survey data was collected in the field using an auto-level, tape, and rod. Peak water surface elevations were developed using a 1-dimensional hydraulic model (HEC-RAS). Wbkfl = Bankfull width; Abkfl = Channel cross-sectional area at bankfull; W/D = Width to Depth; LP = Long profile.

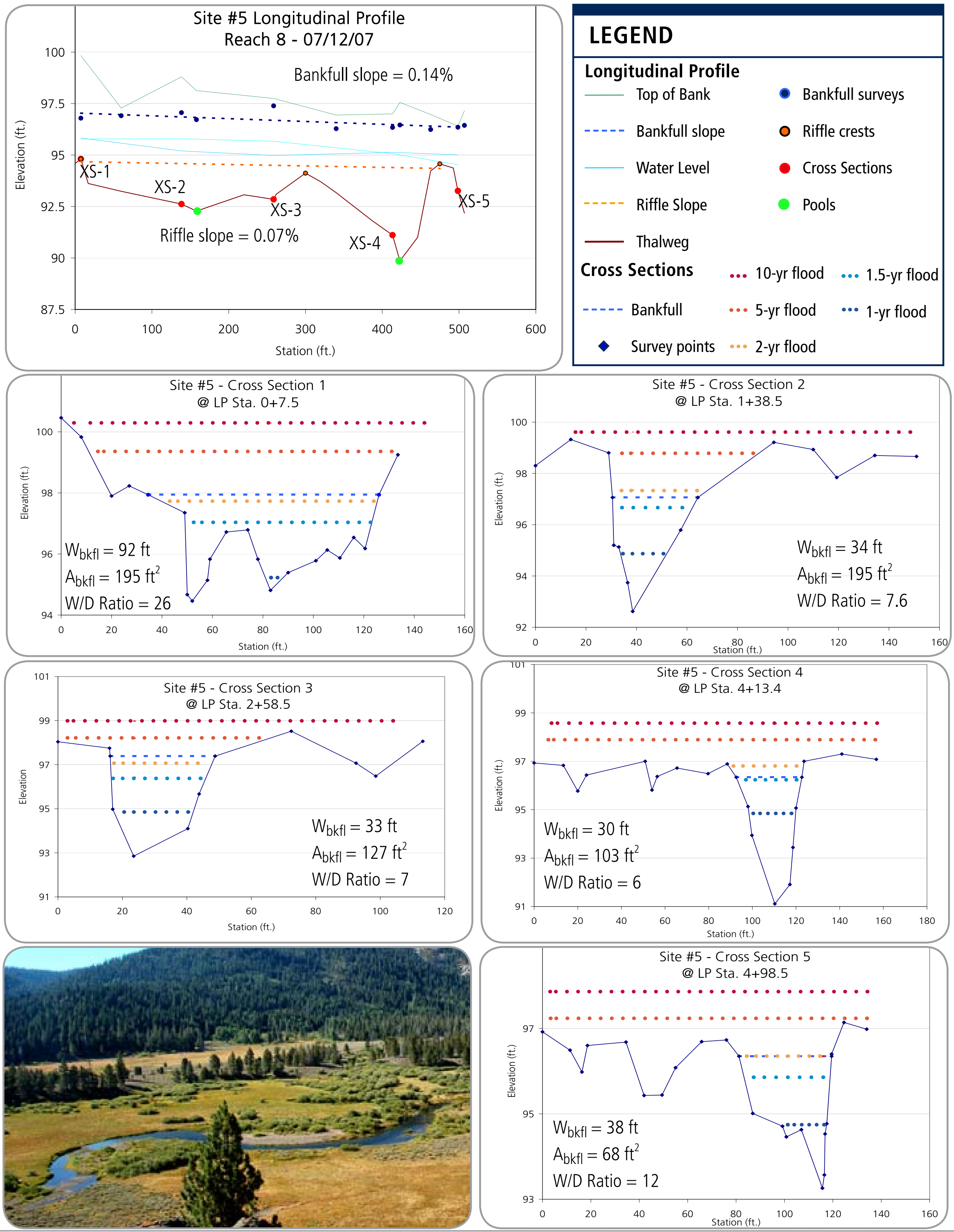

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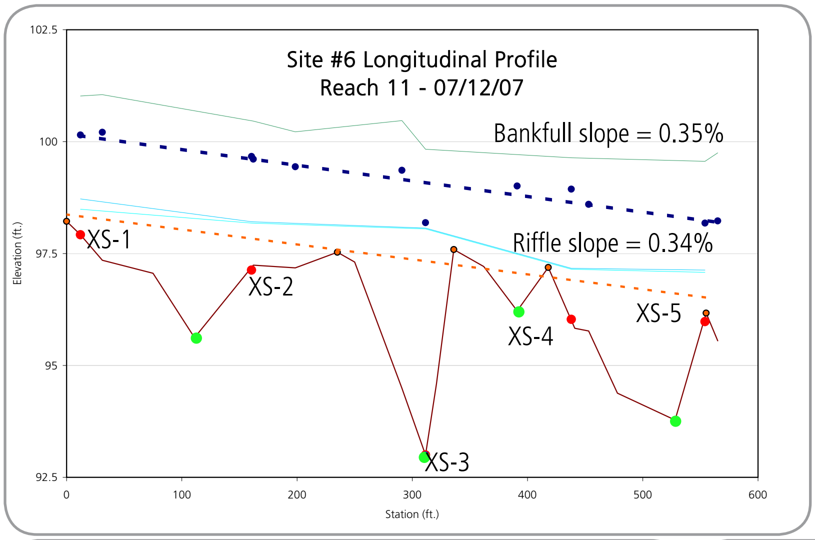
FIGURE 11e: Survey data results for Site 5, Reach 8. All survey data was collected in the field using an auto-level, tape, and rod. Peak water surface elevations were developed using a 1-dimensional hydraulic model (HEC-RAS). Wbkfl = Bankfull width; Abkfl = Channel cross-sectional area at bankfull; W/D = Width to Depth; LP = Long profile.



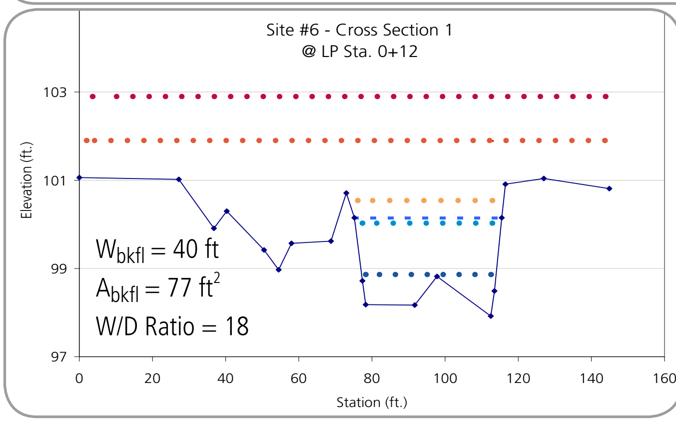
LEGEND

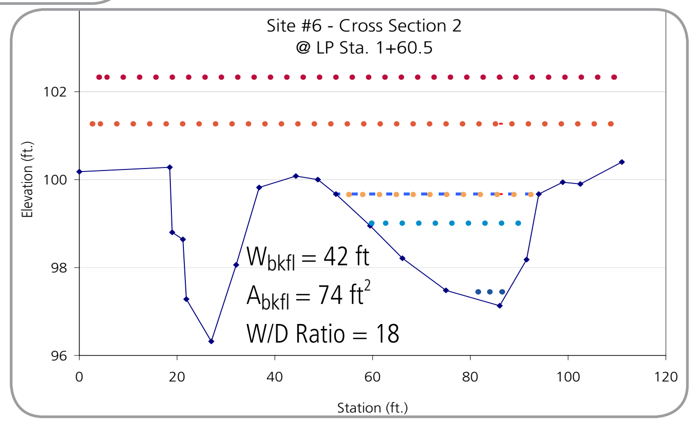
Longitudinal Profile

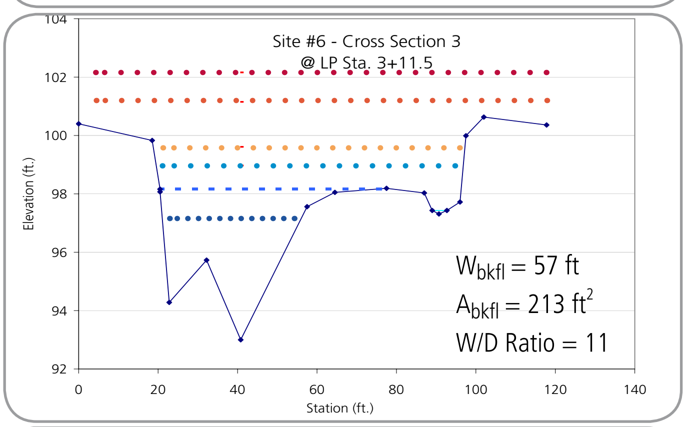
- Top of Bank
- Bankfull slope
- Water Level
- Riffle Slope
- Thalweg
- Bankfull surveys
- Riffle crests
- Cross Sections
- Pools

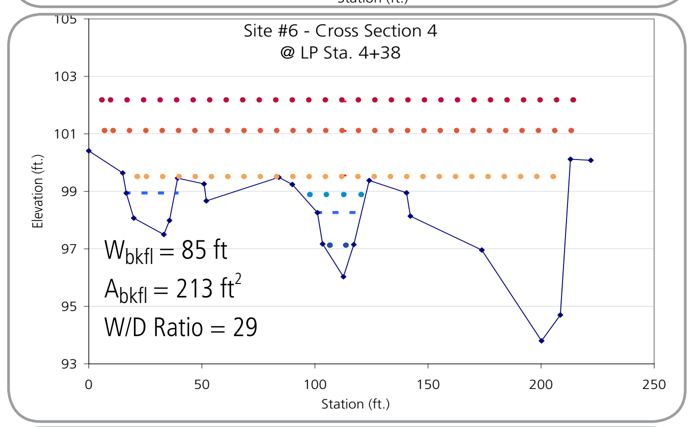
Cross Sections

- 10-yr flood
- 1.5-yr flood
- Bankfull
- 5-yr flood
- 1-yr flood
- Survey points
- 2-yr flood









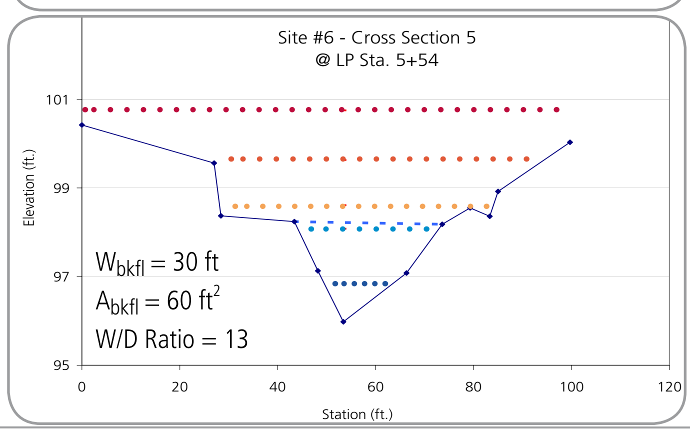


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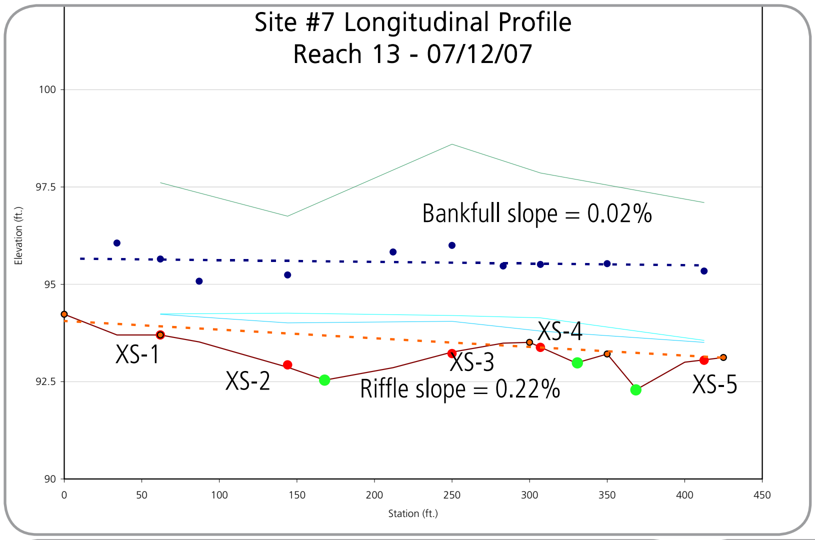
FIGURE 11f: Survey data results for Site 6, Reach 11. All survey data was collected in the field using an auto-level, tape, and rod. Peak water surface elevations were developed using a 1-dimensional hydraulic model (HEC-RAS). Wbkfl = Bankfull width; Abkfl = Channel cross-sectional area at bankfull; W/D = Width to Depth; LP = Long profile.



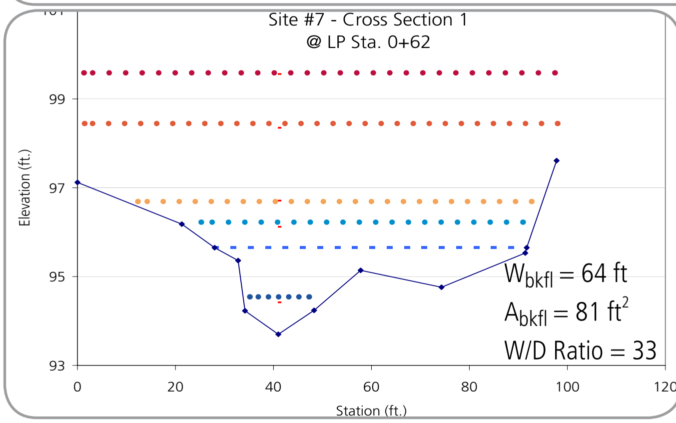
LEGEND

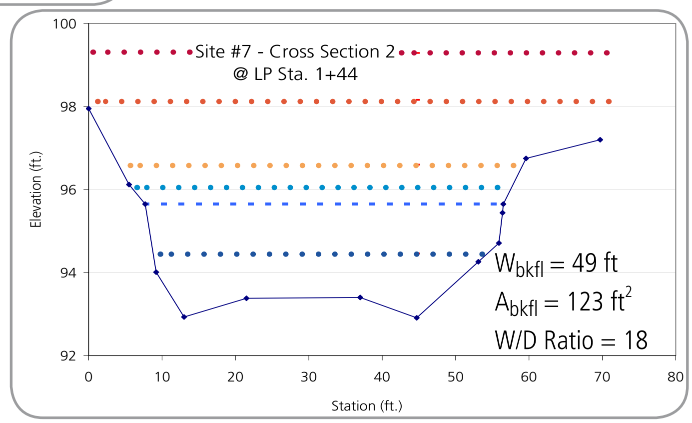
Longitudinal Profile

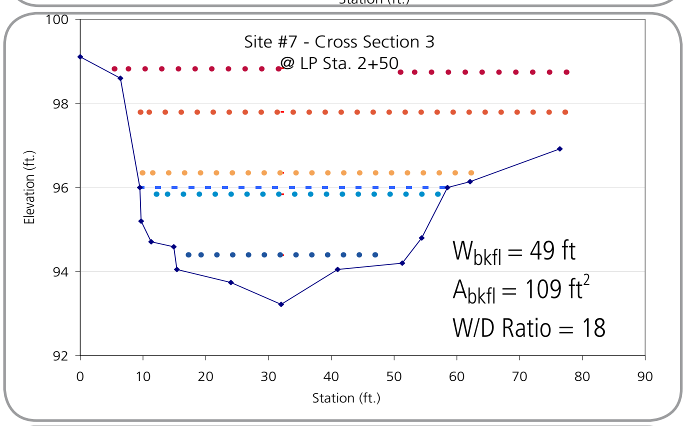
- Top of Bank
- Bankfull slope
- Water Level
- Riffle Slope
- Thalweg
- Bankfull surveys
- Riffle crests
- Cross Sections
- Pools

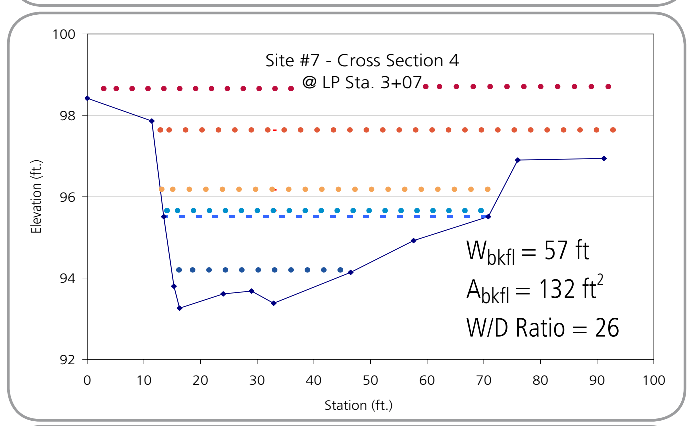
Cross Sections

- 10-yr flood
- 1.5-yr flood
- Bankfull
- 5-yr flood
- 1-yr flood
- Survey points
- 2-yr flood









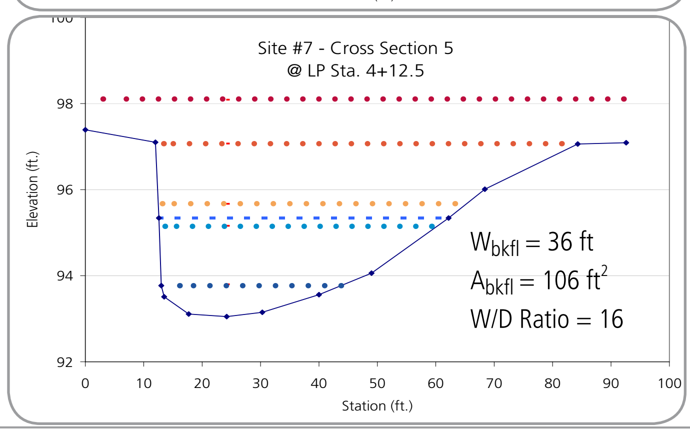


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FIGURE 11g: Survey data results for Site 7, Reach 13. All survey data was collected in the field using an auto-level, tape, and rod. Peak water surface elevations were developed using a 1-dimensional hydraulic model (HEC-RAS). Wbkfl = Bankfull width; Abkfl = Channel cross-sectional area at bankfull; W/D = Width to Depth; LP = Long profile.

deposited on the fan is transported to the downstream meadow. To evaluate the degree to which material currently in the channel and bar deposits within the meadow is mobile, an analysis was conducted to assess bed mobility under a range of flow conditions.

Shear values from the hydraulic model were used in conjunction with grain size (Figures 9a, b, c, d, e, f) information to assess bed mobility at each cross-section. The analysis was not conducted at Site 2 since the current bed material is a result of overbank deposition. Cross section specific bed mobility estimates were calculated using the Shields equation of particle motion (Shields, 1936; Simons and Senturk, 1992) to produce an estimate of the percentage of the bed that would be expected to move under a range of flow conditions. The discharges analyzed included the 1.5-year, 2-year, 5-year, and 10-year events. Results of this analysis are presented in Figure 12 and Table 4.

As expected, bed mobility is high in Reach 1 due to the channel incision within the fan surface, then declines considerably in Reach 2 as the large bed material is deposited in the lower gradient, lower energy environment of the meadow. The remaining downstream reaches show considerable variability in bed mobility with a lack of a discernible pattern. Specific cross-sections, such as 3 and 4 in Reach 11, have low bed mobility, but the overall pattern suggests that extension of the fan into the meadow is limited to Reach 2. Other noticeable patterns are most likely associated with bed mobility variability associated with riffles and pools or waves of sediment moving through the system creating localized areas where large material is immobile.

5.5 Channel Morphology

Channel form along a valley bottom, including sinuosity and radius of curvature, and internal features such as pool and riffle spacing can also be used to evaluate the degree to which channel adjustments associated with land use changes have had an effect on a meadow system. These metrics, though not definitive in representing what historic conditions may have been like; because they require measurement of remnant features on modern meadow systems; nonetheless provide another valuable tool in assessing how conditions have changed and what variables may be important when considering restoration.

Radius of curvature can be defined as the radius of a circle a curve ought to have. A stream channel consists of a series of curves and straight lines. The differences in energy fields around a stream bend (or curve) is much different then along a straight section, thereby enforcing pools in the bends and riffles in the straight sections. To evaluate changes in both radius of curvature and pool-riffle spacing in the current and historic Perazzo Meadows channel, aerial photos were analyzed. The analysis was conducted separately for each meadow reach. Radius of curvature was measured at representative bends in the current and historic channels and an average, by

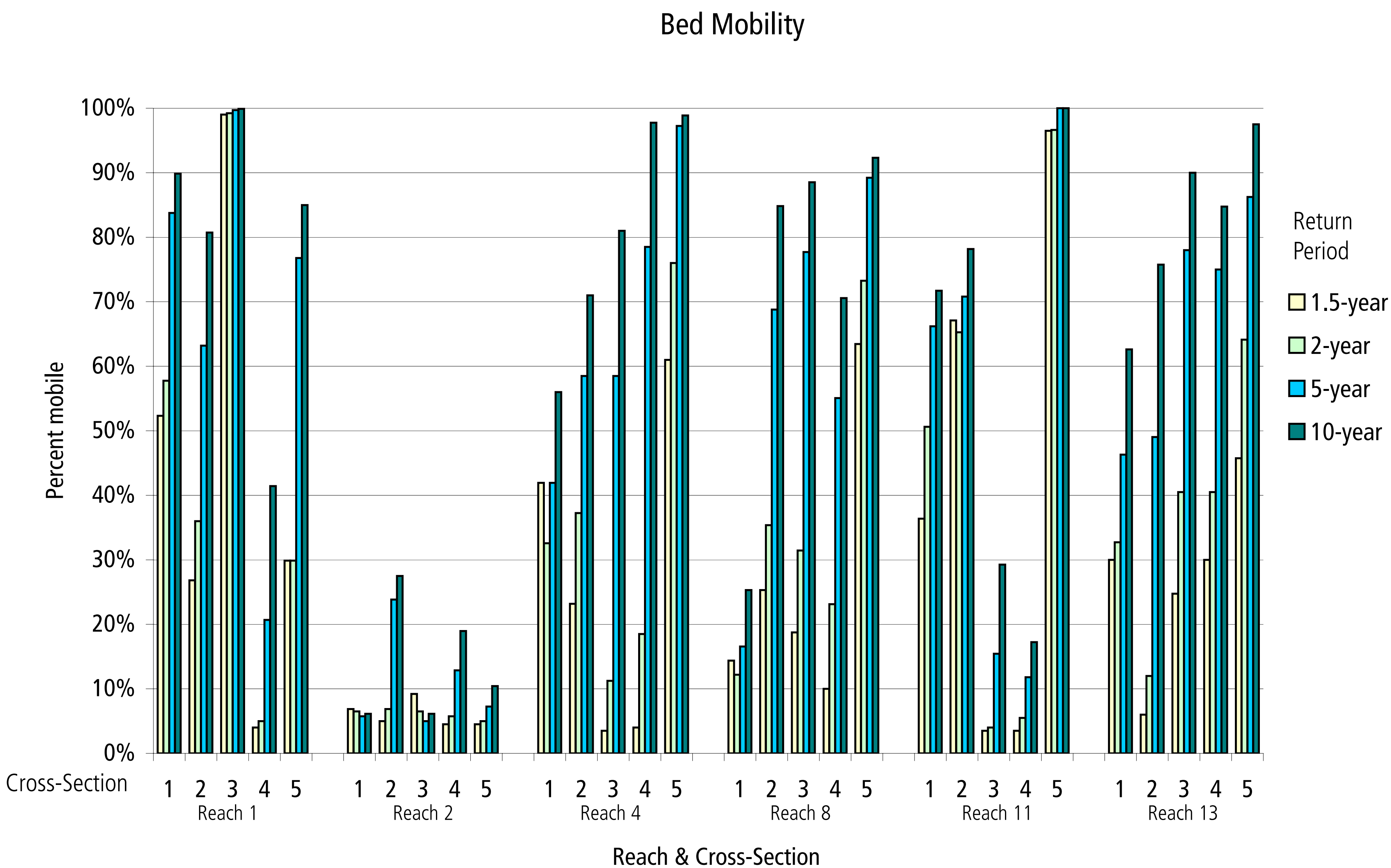

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FIGURE 12: Estimated bed mobility for each reach and cross-section surveyed along Perazzo Meadows. Bed mobility was estimated from the bed material sampling data, the shear generated from the hydraulic model, and Shields' estimates of grain size mobility.

Site - Reach	Cross Section	Drainage Area (sq mi)	1.5 yr Discharge (cfs)	1.5 yr Shear (lbs/ft^2)	1.5 yr Max Particle Size Moved (mm)	1.5 yr % mobility	2 yr Discharge (cfs)	2 yr Shear (lbs/ft^2)	2 yr Max Particle Size Moved (mm)	2 yr % mobility	5 yr Discharge (cfs)	5 yr Shear (lbs/ft^2)	5 yr Max Particle Size Moved (mm)	5 yr % mobility	10yr Discharge (cfs)	10yr Shear (lbs/ft^2)	10yr Max Particle Size Moved (mm)	10yr % mobility
Site 1 - Reach 2	1	7.9	49	0.46	22	73%	79	0.5	24	75%	200	0.82	39	99%	329	1.02	49	99%
	2			0.27	13	28%		0.32	16	70%		0.54	26	76%		0.7	34	99%
	3			1.33	65	100%		1.6	78	100%		2.24	109	100%		2.51	122	100%
	4			0.05	2	2%		0.09	4	5%		0.23	11	22%		0.38	18	71%
	5			0.28	14	31%		0.37	18	31%		0.64	31	79%		0.85	41	99%
Site 2 - Reach 2	1	8.5	53	0.27	13	4%	86	0.25	12	3%	216	0.21	10	1%	355	0.22	11	2%
	2			0.17	8	-2%		0.27	13	4%		0.6	29	23%		0.65	32	28%
	3			0.34	17	7%		0.24	12	3%		0.2	8	-2%		0.23	11	2%
	4			0.12	6	4%		0.2	10	1%		0.42	20	11%		0.51	25	18%
	5			0.13	6	4%		0.16	8	-2%		0.28	14	6%		0.37	18	8%
Site 4 - Reach 4	1	24.4	151	0.26	13	49%	244	0.23	11	44%	617	0.26	13	49%	1012	0.32	16	56%
	2			0.18	9	39%		0.24	12	46%		0.36	17	94%		0.45	22	95%
	3			0.06	3	0%		0.12	6	9%		0.35	17	94%		0.53	26	95%
	4			0.08	4	4%		0.16	8	36%		0.52	25	95%		0.95	46	100%
	5			0.37	18	94%		0.5	24	95%		0.86	42	100%		1.14	55	100%
Site 5 - Reach 8	1	27.9	173	0.2	10	16%	279	0.19	9	14%	705	0.22	11	18%	1156	0.31	15	26%
	2			0.31	15	26%		0.41	20	48%		0.89	43	84%		1.25	61	87%
	3			0.25	12	20%		0.38	18	47%		1.09	53	86%		1.45	70	98%
	4			0.16	8	12%		0.28	14	24%		0.62	30	57%		0.92	45	84%
	5			0.77	37	83%		0.98	48	85%		1.52	74	98%		1.89	92	98%
Site 6 - Reach 11	1	32.9	203	0.43	21	52%	329	0.55	27	58%	832	0.76	36	89%	1364	0.86	42	89%
	2			0.77	37	89%		0.73	35	88%		0.85	41	89%		1.01	49	90%
	3			0.06	3	3%		0.09	4	4%		0.23	11	13%		0.37	18	50%
	4			0.06	3	3%		0.11	5	5%		0.18	9	8%		0.25	12	15%
	5			2.07	100	100%		2.08	101	100%		3.49	169	100%		3.23	156	100%
Site 7 - Reach 13	1	34.2	212	0.32	16	62%	342	0.35	17	62%	864	0.45	22	66%	1418	0.58	28	71%
	2			0.12	6	4%		0.2	10	14%		0.47	23	67%		0.72	35	97%
	3			0.29	14	25%		0.42	20	41%		0.78	38	97%		1.12	54	97%
	4			0.33	16	30%		0.42	20	41%		0.71	34	97%		0.96	47	97%
	5			0.45	22	46%		0.59	29	65%		1.01	49	97%		1.32	64	98%

TABLE 4: Estimates of percent bed mobility using field-based bed material samples, hydraulic variables derived from a one-dimensional hydraulic model, and Shields equation of particle motion. The results suggest a significant discontinuity in bed mobility between Reaches 1 and 3.

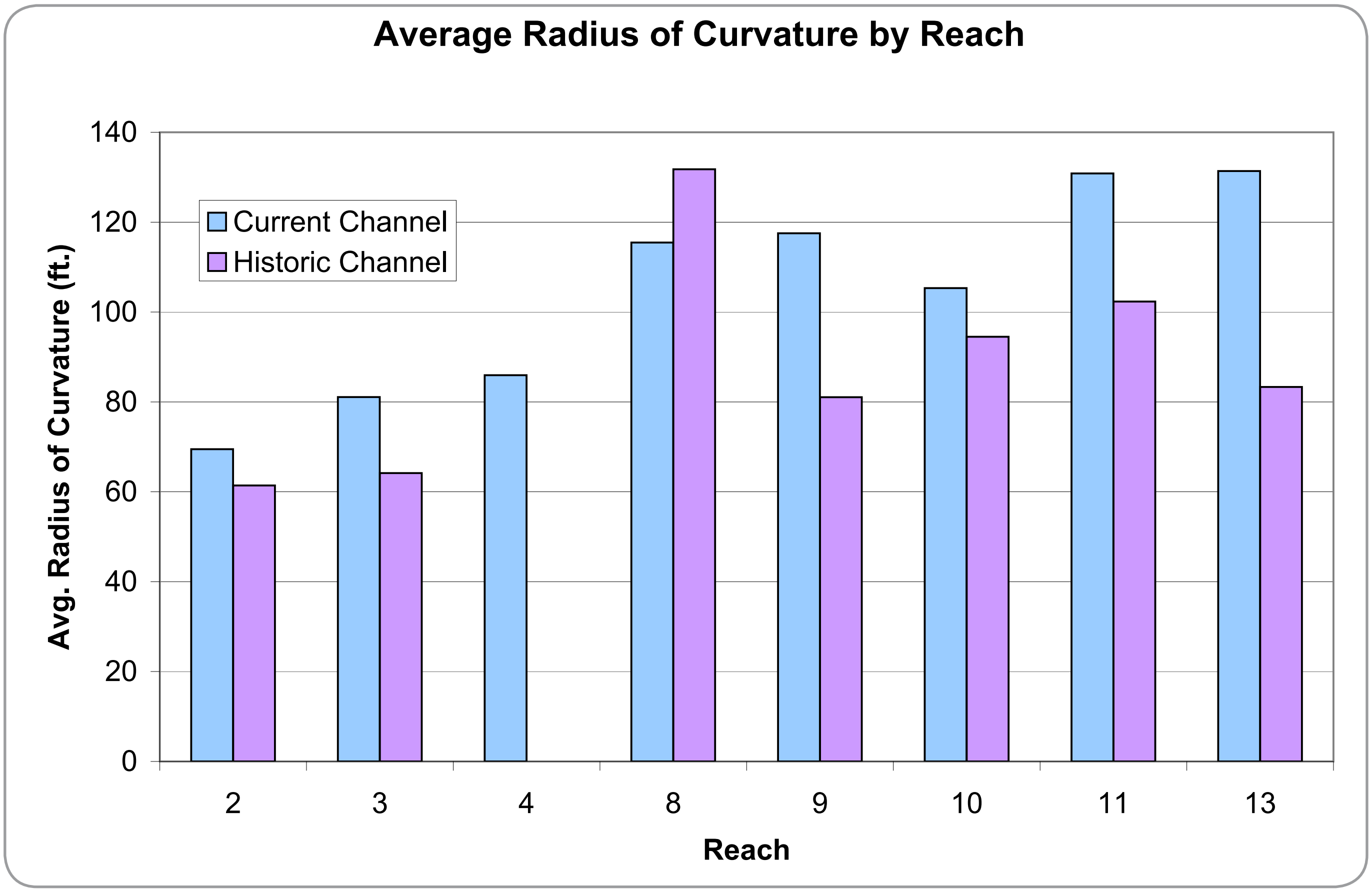
reach, was generated. Historic channels were not measured in Reach 4 because the number of historic channels present through this reach was limited. The results are presented in Figure 13.

The results of the radius of curvature analysis show a moderate increase in radius of curvature between existing and historic channels within each reach, except in Reach 8 where radius of curvature decreases. It is not clear why this is the case. The most likely cause for the increase in the radius of curvature through most of the reaches is due to the presence of increased bed load and bar formation, and the likelihood that a significant component of channel change was associated with meander cut-offs that straightened the channel. In the 1983 photo (Figure 6) a meander cut-off is shown that clearly increases the radius of curvature of that portion of the channel. A larger radius of curvature is then enforced by the presence of coarse material on the bar that is immobile during most flow conditions.

A larger radius of curvature is also reflected in the spacing of pools and riffles. Pool and riffle spacing was extracted from the longitudinal profile measured at each study site, including Site 2 which is located on an historic floodplain channel. These data are summarized in Table 1. Direct comparison is most appropriate between Site 2 and Site 3 since they are in the same reach and have the same drainage area. The results show a two fold increase in the average distance between pools and riffles from the historic channel and the current channel.

6.0 CONCLUSIONS

Multiple lines of evidence suggest that significant morphological change has occurred in the Perazzo Meadows system with a consequent impact on the systems ecological value, both as a wet meadow system and a valuable fishery. These changes, though likely due to a variety of factors, can be attributed most significantly to direct modification to the channel, in one or more locations, that reduced the seasonal inundation of the meadow, thereby allowing for more consistent grazing. The impacts created by direct modification of the channel have been exacerbated by the presence of alluvial fans at the mouth of Perazzo and Lacey Canyons. Modification to the meadow channel resulted in incision of these fan surfaces, limiting their functional value, with delivery of coarse bed load to the upper meadow a result. As stated previously, extension of the alluvial fan and the associated increase in the delivery of coarse bed load to the meadow appears limited to reaches adjacent to the historic fans (i.e. – Upper Meadow, Cold Stream Creek). Global instability appears to be a function of historic channelization activities, resulting in incision of the channel and reduced interaction between the channel and floodplain. The observed channel incision and loss of floodplain interaction has been exacerbated by localized deposition of coarse material due to bank erosion as the channel attempts to meander and create nascent floodplain areas.



	Reach	2	3	4	8	9	10	11	13
Current Channel	Average Radius (ft.)	69	81	86	115	118	105	131	131
	Standard Deviation	22	30	18	48	24	7	48	13
	N	3	4	4	7	7	2	3	4
Historic Channel	Average Radius (ft.)	61	64	-	132	81	94	102	83
	Standard Deviation	28	23	-	28	35	20	28	46
	N	12	11	-	7	6	5	4	2
	Current vs. Historic % Difference	12%	23%	-	13%	37%	11%	24%	45%

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FIGURE 13: Radius of curvature estimates for the project area. Estimates are based on aerial photo analysis of the existing channel and remnant channels that currently exist on the floodplain.

The primary impacts associated with these morphological changes has been cessation of the annual flooding of the meadow system during the spring snowmelt season, abandonment of historic floodplain channels that distributed water throughout the meadow system, bar formation and widening of the active channel, and lengthening of the pool and riffle spacing within the channel as the meander pattern lengthens. Based on the modeling, flooding of the meadow occurs less frequently, on the order of once every five to ten years instead of annually or once every other year. These morphological changes have resulted in impacts to aquatic habitat because of increased water temperatures associated with a wider, shallower channel with less vegetative cover, less undercutting of banks due to the fact that the banks are higher and the meadow sod is less vigorous, resulting in more bank sloughing, and a muted pool sequence, which often provide summer refuge habitat for trout.

Channel incision appears to have stopped but the system still appears to be in a widening phase in an attempt to build additional floodplain and restore a more natural meander pattern. This process, although beneficial in that it will allow for overbank flows and eventually create an inset channel and floodplain system, leaves a lower water table and less frequent inundation of the meadow. In addition, the bank erosion inherent in a prolonged widening phase not only contributes fine sediment that has an impact on aquatic function, but results in local deposition of coarse sediment that enhances the widening phase.

7.0 RESTORATION RECOMMENDATIONS

Improvement of the Perazzo Meadows system through active restoration of morphological functions should definitely be considered. Meadow restoration efforts are common in the Sierra Nevada with a variety of approaches applied throughout the Tahoe-Truckee region. Some examples of restoration efforts completed in the Tahoe-Truckee region by SH+G include Trout Creek in South Lake Tahoe and Cookhouse Meadow in the Upper Truckee River watershed near Meyers. These restoration efforts consisted of complete channel reconstructions in a system where the current channel was severely incised.

Owing to the presence of somewhat continuous floodplain channels, the U.S. Forest Service is proposing a meadow restoration approach for the upper meadow using a technique referred to in short hand as “plug and pond”. This method consists of identifying crossover points between the existing channel and the historic channel, excavating the existing channel in the vicinity of the crossover point, and plugging the channel downstream with the excavated material. The ponds provide the material to create the plug, avoiding import of material to the site, and the plugs backwater the pond, thereby forcing flow into the historic channel. Some excavation of the historic channel may be required due to the formation of natural levees at the inlets. The approach is a cost effective way of rapidly aggrading the existing channel and can be used effectively in areas where continuous floodplain channels are still present.

As part of this study, SH+G staff reviewed the proposed restoration approach for the upper meadow at Perazzo and accompanied U.S. Forest Service staff on a site visit to evaluate field conditions in more detail. Based on our review, field visits, and additional discussions with U.S. Forest Service staff, the following recommendations were developed:

- ***Downstream Control:*** The "plug and pond" approach backwaters the entire existing channel throughout the upper meadow but does not currently address the significant grade break that will result at the downstream end of the meadow as it enters more confined reaches. If this area is not addressed, there is a potential for a headcut to migrate up the reactivated channel, negating the benefits provided via the restoration effort. Due to the confined nature of the stream channel downstream of the meadow, there is an opportunity to provide effective grade control at the downstream end of the meadow. How a grade control structure might look will be dependent upon regulatory requirements and cost. Typically, the drop at each structure cannot exceed one foot, in order to keep the structures fish friendly. In some cases, where juvenile fish passage is a concern, the drop cannot exceed 6 inches. If fish are a concern, grade control can be achieved via a series of 3 to 6 rock weir structures that would raise existing grade up to two feet. Access and cost would be a concern for these types of structures given the fact that the site is remote, the structures would require import of material, and dewatering and temporary fish relocation would be required.

- ***Plug Stability on Perazzo Fan:*** The "plug and pond" approach proposed by the U.S. Forest Service extends up into the alluvial fan that emanates from Perazzo Canyon. This approach is necessary in order to repair fan incision and restore fan function. Given the fact that the reach is steep and large quantities of bed load are being delivered to the fan, additional consideration should be given to the long term stability of the plug at this location. Excavation of material at the site to form the plug may not be sufficient because the plug may be overtopped during a high magnitude, low frequency event, resulting in failure of the plug. Failure of the fan plug could be catastrophic to the project given the fact that the plug is not backwatered and failure would deliver both plug material and bed load into the downstream reaches. Additional fortification of the plug should be considered including import of larger material or engineered log jam structures.

- ***Road Crossings on Fan Surfaces:*** When roads cross fan surfaces they often disrupt fan function. Remediating the road crossings on both the Perazzo and Lacey fans should be considered essential components to restoration of the upper meadow. Road crossings often focus flow into a single channel and in most cases, secondary channels are filled. These activities accelerate fan incision and encourage bed load transport through the fan surface instead of deposition on the fan surface. The risk associated with not fixing the road crossings and not focusing on restoring fan function is that coarse sediment, normally deposited on the fan surface, will be delivered to activated historic floodplain channels, causing them to erode and widen. The best approach to address the lack of fan function is to reverse the conditions whereby a single, primary channel has incised into the fan. Aggradation of the primary channel, via grade control, engineering log jams, or other means, and removing blockages to historic primary and secondary fan channels, will improve fan function and limit coarse sediment delivery to the downstream meadows.

- ***Continuity of Reactivated Channels:*** When the "plug and pond" approach is implemented, streamflow will enter historic floodplain channels. If these channels are discontinuous or have sediment blocks associated with overbank deposition or beaver activity, streamflow will be forced out of bank more frequently than is desired, with unknown consequences. Additional planning should be undertaken to evaluate continuity of discharge within the reactivated channel system. Since high resolution data are available for the meadow, one approach would be to develop a hydraulic model of the historic channel system. The model would be used to run a 2-year event through these channels to evaluate capacity and continuity. This approach would allow the restoration team to identify areas where additional spot treatments might be necessary to ensure success of the project.

- ***Flushing of Reactivated Channels:*** The historic floodplain channels that currently exist on the floodplain may represent the appropriate target channel geometry, but the appropriate bed substrate is most likely buried under fine sediment and shallow organic soil layers that have developed over the last 50-100 years. Reintroducing active channel flow into these channels will result in a large pulse of fine sediment (i.e. – turbidity) with an unknown duration. To avoid the potential impacts that such a pulse of sediment could cause downstream, a plan should be prepared to flush and filter these channels prior to opening them up to significant discharge.

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Photo Point	Date	X-coordinate (dec. deg)	Y-coordinate (dec. deg)	Bearing (deg)	Notes	Filename
1	8/14/2007	39.49139709	-120.3591601	104	Atop rocky volcanic outcrop alongside road	DSC_0087
2	8/14/2007	39.49140573	-120.359161	166	Atop rocky volcanic outcrop alongside road	DSC_0088
3	8/14/2007	39.4697385	-120.3860206	77	Reach 1 to bar from meadow	DSC_0094
4	8/14/2007	39.46998575	-120.3849339	305	Reach 1 to bar from meadow	DSC_0099
5	8/14/2007	39.47074536	-120.3866363	100	From rocky slope N of reach 1	DSC_0102
6	8/14/2007	39.47177326	-120.385485	163	Upstream shot from bottom of reach 1 meadow	DSC_0106
7	8/14/2007	39.47255773	-120.3849586	252	Upstream shot of reach 2 from meadow	DSC_0109
8	8/14/2007	39.47312836	-120.3834548	21	Downstream reach 2	DSC_0112
9	8/14/2007	39.47378089	-120.3826267	325	Downstream reach 2	DSC_0114
10	8/14/2007	39.47540972	-120.3810575	356	Reach 3 from morraine hill	DSC_0115
11	8/14/2007	39.47755709	-120.3799441	70	Reach 3 downstream	DSC_0125
12	8/14/2007	39.47834521	-120.3785322	63	Reach 3/4, stream confluence	DSC_0127
13	8/14/2007	39.47961976	-120.3769746	5	Reach 4	DSC_0133
14	8/14/2007	39.48059397	-120.3767107	85	Reach 4	DSC_0134
15	8/14/2007	39.48095759	-120.376453	345	Reach 4	DSC_0135
16	8/14/2007	39.47868461	-120.3803878	335	Little Truckee River	DSC_0145
17	8/14/2007	39.4783232	-120.3817945	250	Meander scar	DSC_0149
18	8/14/2007	39.47713886	-120.3846213	230	Meander scar	DSC_0150
19	8/14/2007	39.48303146	-120.3832155	104	From bridge @ center I-beam downstream side	DSC_0152
20	8/14/2007	39.48616762	-120.3708968	200	From reach 6 bridge, downstream side @ 9th I-beam from right bank	DSC_0157
21	8/14/2007	39.48622404	-120.3708807	334	From reach 6 bridge, downstream side @ 9th I-beam from right bank	DSC_0158
22	8/14/2007	39.49038328	-120.3582825	58	Reach 8	DSC_0166
23	8/14/2007	39.48982401	-120.3559777	300	Reach 8 downstream	DSC_0174
24	8/14/2007	39.49226553	-120.3551169	42		DSC_0181
25	8/14/2007	39.49316365	-120.3530607	119	Reach 9 downstream	DSC_0182
26	8/14/2007	39.4931628	-120.3530569	162	Reach 9, same as pp25 but upstream	DSC_0183
27	8/14/2007	39.49449666	-120.3433285	326	Reach 11	DSC_0186
28	8/14/2007	39.49556818	-120.3428964	51	Reach 11	DSC_0189
29	8/14/2007	39.49354695	-120.340383	62	Reach 11	DSC_0197
30	8/14/2007	39.49425814	-120.3304185	15	Atop high RB terrace	DSC_0227
31	8/14/2007	39.49464004	-120.3286851	256	Atop high RB terrace, near campsite	DSC_0230
32	8/14/2007	39.49504228	-120.3275739	8	Atop high RB terrace, above logjam	DSC_0237
33	8/14/2007	39.49557455	-120.3283197	18	On RB meadow surface	DSC_0241
34	8/14/2007	39.49123783	-120.3668927	177	Side of Fibreboard lookout near turnoff to perazzo dirt road	DSC_0252

APPENDIX A: Table of photo point location information including coordinates, bearings[1] (azimuths), descriptions and filenames.

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PH 831.427.0288
FX 831.427.0472
A California Corporation
500 Seabright Avenue Suite 202 Santa Cruz, California USA 95062
www.swansonh2o.com

May 8, 2008

TO: Ms. Beth Christman
Watershed Coordinator
Truckee River Watershed Council
P.O. Box 8568
Truckee, CA 96161

FROM: Mr. John Dvorsky
Swanson Hydrology + Geomorphology
1340 SW Bertha Blvd, Suite 20
Portland, Oregon 97219

RE: Response to Comments on Geomorphic Study – Perazzo Meadows

Dear Ms. Thomas,

Attached is our revised Final Report – Perazzo Meadows Geomorphic Assessment. I have also prepared a response to the comments you have provided.

Comment #1. We would like to have copies of all the raw data files and GIS layers that were used in the assessment.

THIS HAS BEEN PROVIDED ON THE CD THAT INCLUDES THE DIGITAL PHOTO POINT DATABASE.

Comment #2. Can you address upland sediment sources? Our understanding is that upland areas are not serving as a significant influence to the stream however this is not addressed in the report. We do not expect a detailed analysis of the uplands, but it would be good to briefly document the lack of or presence of upland sources in the report.

EVALUATION OF UPLAND EROSION SOURCES WAS NOT A COMPONENT OF OUR AGREED UPON SCOPE OF WORK. SINCE YOU ARE CORRECT, UPLAND CONDITIONS AND LAND USE DO HAVE AN EFFECT ON SEDIMENT SUPPLY AND TRANSPORT WITHIN THE CHANNEL, I HAVE ADDED A BRIEF DISCUSSION OF GEOLOGY BY SUBWATERSHED AND THE INFLUENCE PAST DISTURBANCE HAS ON CURRENT SEDIMENT SUPPLY TO THE CHANNEL. TO DISCUSS UPLAND SOURCES IN ANY MORE DETAIL WOULD REQUIRE A MORE COMPLETE EVALUATION OF CURRENT AND HISTORIC AERIAL PHOTOS.

Comment #3. Please strengthen the relationship of the bed load study to lateral movement and in-stream sediment sources. Is there a way to quantify or estimate the percentage of sediment movement presently occurring from the current channel instability?

QUANTIFYING SEDIMENT MOVEMENT WOULD REQUIRE A SEDIMENT TRANSPORT MODEL AND DEVELOPMENT OF A SEDIMENT BUDGET WHICH IS OUT OF THE SCOPE OF THIS PROJECT. I ALSO DON'T THINK AN ACTUAL QUANTIFICATION IS NECESSARY. I HAVE STRENGTHENED THE DISCUSSION OF WHERE IN THE CHANNEL DIFFERENT SOURCES DOMINATE, BUT THE OVERALL DISCUSSION LAYS OUT AN ARGUMENT, WITH THE DATA SUPPORTING IT, THAT REACHES ADJACENT TO FAN SURFACES RECEIVE BED LOAD FROM THE FANS WHICH HAS EXCERBATED INSTABILITY THROUGH DEPOSITION OF COARSE MATERIAL. ELSEWHERE, WE SEE A SIMILAR PATTERN OF DEPOSITION AND BANK EROSION BUT FROM A

DIFFERENT MECHANISM. IN NON-FAN REACHES, INCISION OF THE CHANNEL HAS LED TO MORE ENERGY AND LATERAL EROSION. THE ERODED MATERIAL IN MANY CASES IS NOT TRANSPORTED. INSTEAD IT IS DEPOSITED LOCALLY, CREATING BARS THAT ENCOURAGE LATERAL MOVEMENT AND BANK EROSION.

Comment #4. Please strengthen the discussion regarding the use of the regional analysis in relation to the estimated return period discharges to validate those estimates.

NOT SURE WHAT YOU ARE GETTING AT IN THIS COMMENTS. BY THE REGIONAL ANALYSIS DO YOU MEAN THE CHANNEL GEOMETRY? IF SO, THAT ANALYSIS FOCUSES ON THE GEOMETRY AT EACH OF THE USGS GAGES BASED ON AN ESTIMATED 1.5 YEAR RETURN PERIOD. THE RETURN PERIOD DISCHARGES WERE ONLY ESTIMATED FROM A SINGLE GAGES. PLEASE CLARIFY. THANKS.

Comment #5. Please strengthen the fan terminus discussion. What is the relationship of the fan incision and delivery of coarse bed load to the channel and its functional value? How much of the current channel instability is related to delivery of coarse bedload from the fan? What is that relationship?

REFER TO THE RESPONSE TO COMMENT #3.

Comment #6. Does the currently proposed design of adding riffles to aggrade the fan coming out of Lacey Creek address function as related to the discussion of Road Crossings on Fan Surfaces.

OUR UNDERSTANDING WAS THAT THE DESIGN FOR THE LACEY CREEK FAN WAS TO ADDRESS INCISION AT THE CROSSING AND WATER WOULD BE ENCOURAGED TO ENTER HISTORIC OVERFLOW CHANNELS. I DON'T RECALL SEEING A SPECIFIC DESIGN BUT AN APPROACH WAS DISCUSSED. I'VE ADDED SOME ADDITIONAL LANGUAGE TO THE FAN RECOMMENDATION DISCUSSION TO ENCOURAGE AN APPROACH WHEREBY THE FAN HEAD OF THE FAN IS REMEDIATED TO ENCOURAGE DEPOSITION WITHIN THE PRIMARY FAN CHANNEL AND ENCOURAGE REACTIVATION OF DISTRIBUTARY CHANNELS.