Geophysical Assessment of the West Walker River through Antelope Valley

Prepared For

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EXECUTIVE SUMMARY

Otis Bay conducted a geophysical assessment of the West Walker River through Antelope Valley to better understand the geomorphic and hydrologic processes associated with sediment dynamics in the region. After the flood of 1997, the California Department of Transportation (Caltrans) and U.S. Army Corps of Engineers (USACE) made emergency modifications to the West Walker River channel in Walker Canyon and through the town of Walker. Local geology, topography and stream hydrology influence sediment dynamics of the West Walker River through Antelope Valley, but emergency modifications that were made to the river channel through the town of Walker also appear to be influencing sediment transport and deposition patterns. Emergency work in West Walker Canyon may have also exacerbated adverse impacts to downstream properties. Antelope Valley residents have expressed concern over increased sediment loads on their properties, channel avulsion and migration, and costly damage to irrigation canals.

Otis Bay conducted detailed geomorphic, hydrologic, and hydraulic analyses of the West Walker River on a river reach scale within Antelope Valley. Analyses of USGS gage and other hydrologic data were used to better understand the overall hydrologic processes occurring upstream of, within, and downstream of Antelope Valley. Results suggest that the West Walker River exhibits a relatively natural hydrologic regime for streams originating in the eastern Sierra Nevada, with peak flows in the spring and infrequent peak events throughout the winter. Multiple irrigation diversions contribute to water depletion during the summer months; however, these diversions do not significantly impact typical peak runoff.

A one-dimensional hydraulic model was developed using HEC-RAS software, and simulations were used to analyze hydraulic properties of the West Walker River channel and adjacent floodplain through Antelope Valley from the mouth of West Walker Canyon to Topaz Reservoir. The analyses suggest that the river exhibits a wide range of variability in floodplain connectivity throughout the valley segment. Areas where the river is currently confined to an entrenched channel and not connected to the floodplain include some areas where post-flood channel modifications were made in the town of Walker.

Preliminary data on existing irrigation infrastructure and streambed composition were collected using field surveys and Wolman pebble counts. Data were analyzed, and field evaluations of the Big Slough diversion suggest that reconfiguration and relocation of the diversion inlet structure could reduce sediment loads entering the canal. To improve understanding of the likely causes of increased sediment deposition and channel migration in some river reaches, Otis Bay applied the Parker bedload function to calculate approximate sediment transport rates for various points throughout Antelope Valley.

The entrenchment and channelization of the channel through the town of Walker (Reach 1) likely changed Reach 1 from a depositional zone on the Antelope Valley alluvial fan to a sediment transport and supply zone. After post-flood construction, sediment loads were transported farther downstream to less confined river reaches (Reach 2 and 3). In these reaches, in-channel deposition fills the channel and drives erosion and channel migration as reported by downstream residents.

The conclusion of this report makes recommendations for actions that could reduce negative impacts from sediment deposition that drive channel migration and high erosion rates. A next step needed to improve overall watershed health includes a further evaluation of the sediment supply and transport issue in the upper watershed. Information gleaned from hydrological and sediment transport studies could inform restoration planning efforts. Restoration planners should formulate a vision of the desired future condition for various stream geomorphic segments. This vision would direct river restoration or habitat enhancement designs on the West Walker River, which could be prioritized for funding and implementation by a coordinated group of stakeholders. Continued management and monitoring would further guide future restoration efforts to assure that the desired vision for the river is being achieved.

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1 West Walker River Geophysical Assessment and Enhancements

1.1 Purpose and Background

In 1997, a 500-year frequency, rain-on-snow flood event caused the West Walker River to jump its banks, damaging property in the town of Walker and agricultural facilities downstream. After the flood, USACE completed an emergency project where they reconstructed the channel through the town of Walker. The new channel is relatively straight, deep, and armored with rip rap. According to long-term residents, the West Walker River has degraded over time, particularly after the 1997 flood. Problems reported include: 1) transportation and deposition of sand into the Big Slough diversion, which requires frequent, costly dredging; 2) increased deposition of sediment downstream from the town of Walker; 3) channel migration and avulsion driven by the increase in sediment deposition that consumes farmland and disrupts irrigation infrastructure; and 4) a dramatic decline of the fishery.

The purpose of this investigation and report is to 1) determine changes in the physical environment (geomorphic, hydrologic, hydraulic and sediment transport) that have contributed to instability of the riverine system; and 2) make recommendations for correcting some of these physical parameters, or make recommendations for actions that would mitigate the negative effects to the farming community.

The focus of this report is to assess the fluvial processes within Antelope Valley. A complete watershed-scale analysis is beyond the scope of this work, but processes occurring at the watershed level are used to guide this assessment. This document presents the results of Phase I of the Biophysical Assessment of the West Walker River through Antelope Valley. This assessment examines and evaluates five key elements of West Walker River functionality, including:

Upstream Hydrology – Otis Bay analyzed the hydrological characteristics of the catchment basin leading into Antelope Valley.

Local Geomorphology – Otis Bay assessed the geomorphic and geological characteristics of Antelope Valley through literature review.

Hydraulic Conditions – Field data and computer models were used to evaluate hydraulic conditions from the Coleville Gage to the Topaz Diversion in Antelope Valley.

Sediment Transport – Field site visits, data collection, and computations were conducted to understand the sources, type, and quantity of sediment transported at different flow levels in the system.

Floodplain Connection – Otis Bay assessed the response of the West Walker River to high flows and large sediment loads.

Upon completing the assessment of these key elements, Otis Bay used the information gained to formulate recommendations to mitigate the channel instability that has occurred since the 1997 flood. Actions to protect residential and agricultural property while managing an ecologically functioning West Walker riverine environment were identified and are presented in this report.

1.2 Overview of Geographic Location and Recent History

The headwaters of the Walker River drain a portion of the eastern slopes of the Sierra Nevada Mountains and form the East and West Forks. From the base of the Sierra Nevada Mountains, the West Fork flows through Antelope Valley to the northeast. At the most downstream end of Antelope Valley, the West Walker River is mostly diverted through Topaz Reservoir for storage, and returns to the river channel below the lake before exiting the valley via Hoye Canyon, which divides the Pine Nut Range from the Wellington Hills (Figure 1-1). The headwater region of the Walker River Basin exhibits typical climate conditions for the eastern slope of the Sierra Nevada mountain range, with cold winters and precipitation falling mostly in the form of snow. Through Antelope Valley, the West Fork of the Walker River covers a distance of approximately 20 miles, dropping close to 500 feet in elevation over that distance.

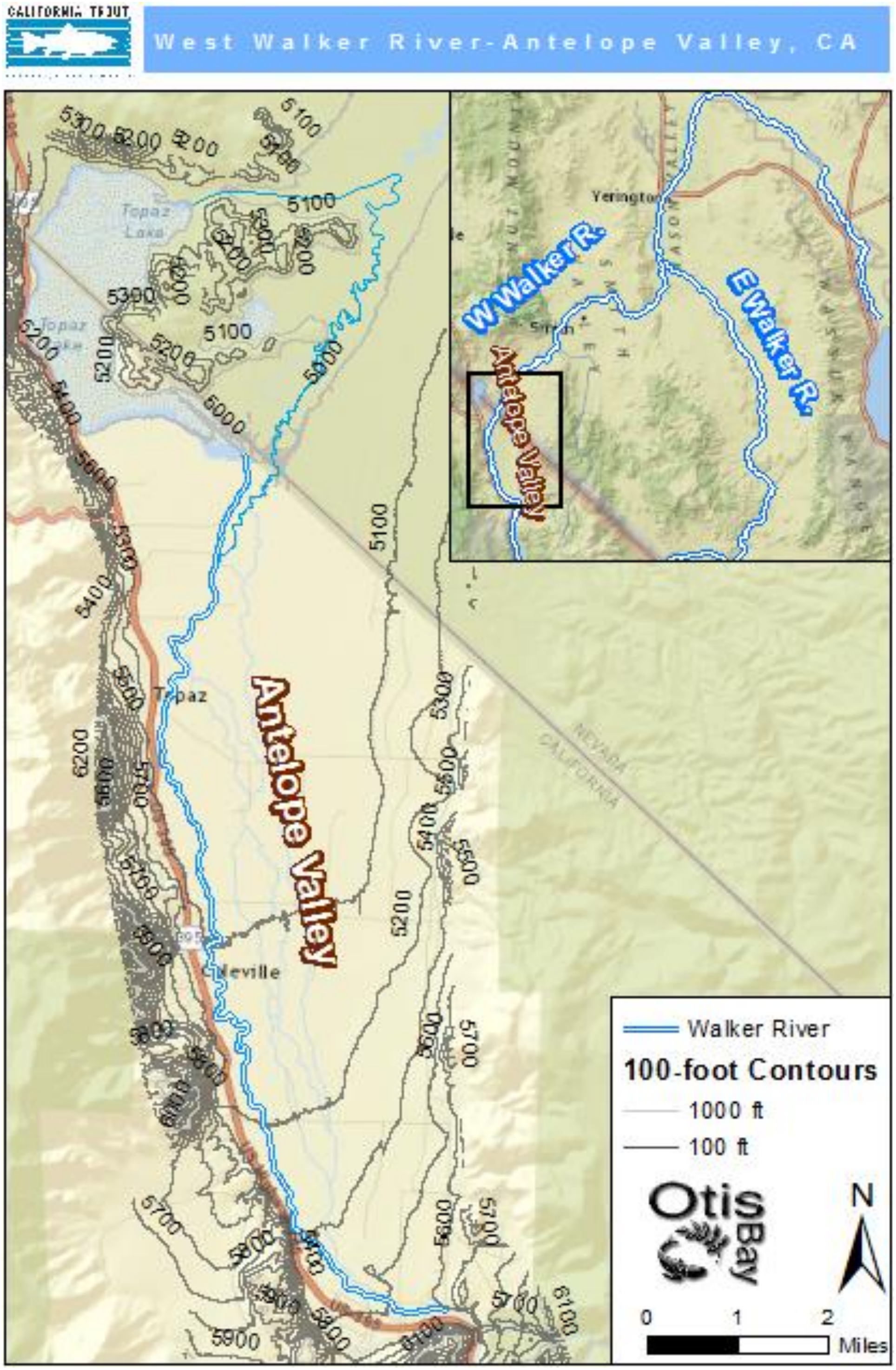

Figure 1-1. Location of Antelope Valley on the West Fork of the Walker River. A majority of the valley is on the California side of the state line.

The California/Nevada border separates the western headwater region from the rest of the Walker River Basin. The majority of the water supply comes from the California headwaters, but the majority of human water consumption takes place farther downstream, in the farming communities of Nevada. In California, the basin lies entirely within Mono County. Within Nevada, downstream portions of the hydrologic basin span parts of Mineral, Douglas, Lyon, and Churchill Counties.

Agriculture has been the main source of human water use in the Walker River Basin for well over 100 years. Settlement and development of the basin began in the mid-1800s, with the first extensive development of irrigation systems occurring around 1860. Irrigation of Antelope Valley began in 1862 (Horton, 1996), and much of the agriculture continues today (Figure 1-2).

Figure 1-2. Low elevation oblique aerial photo of the extensive agricultural fields along the West Walker River in Antelope Valley in 2006. This southwest view from Topaz Lane is looking upstream.

1.3 Post 1997 Flood Changes and Construction

On January 2, 1997, a rain-on-snow event led to the largest flood on record for the West Walker River, causing extensive damage along U.S. Highway 395 through the steep canyon upstream of Antelope Valley (West Walker Canyon) and the town of Walker, CA. The flood of 1997 pulsed vast quantities of sediment out of West Walker Canyon, and caused major and lasting changes to river channel dynamics and irrigation systems of Antelope Valley. Stream gages, both upstream and downstream of Walker, were washed out, with the last recorded discharge being approximately 6,500 cfs. The USGS estimated that the peak discharge likely doubled the previous record discharge (November 1950, 6,200 cfs), and peaked between 13,000 and 14,000 cfs (Mono County Community Development Department, 2006). Based on the frequency analysis (Section 3.3.5), a flood of this magnitude corresponds with a recurrence probability of approximately 0.2% or 500 years. The event was unique in the fact that heavy rainfall (approximately 15 inches over the basin area) occurred on top of a recent snow-storm that deposited up to 8 feet of wet snow at higher elevations in the drainage basin (Horton, 1997; Mono County Community Development Department, 2007).

The economic damages from this event throughout Mono County were estimated to be approximately $78 million (Mono County Community Development Department, 2006). A 9-mile stretch of Hwy 395 was destroyed between Sonora Junction and Topaz Reservoir, and homes and businesses in the town of Walker were completely washed away. The Eastside Lane Bridge was bypassed by the river and new channels began to form throughout Walker. Thirty-four homes were destroyed and sixty-nine others were damaged (Anon., 1997; Mono County Community Development Department, 2007; Mono County Community Development Department, 2006).

The 1997 flood was not the first flood to cause damage and closure of Hwy 395 through West Walker Canyon (California Department of Transportation, 2007). A flood in 1934 also caused extensive road damage, thus the highway through this canyon is vulnerable to washouts from rare, but occasional large storm events. In response to the damage from the 1997 flood, Caltrans rebuilt the highway, stabilized the hill slopes, and reconstructed the West Walker River channel.

Downstream of the canyon, under emergency flood response provisions (PL-84-99) the USACE, along with California Department of Water Resources (CA DWR) and Bureau of Land Management (BLM), constructed an emergency channel from the canyon mouth to the mobile home park in Walker in order to re-stabilize and contain the channel (California DWR Flood Emergency Action Team, 1997). The construction was finished within 3 weeks, and the channel now consists of a straightened, trapezoidal channel lined with large riprap, designed to contain future flood flows while minimizing the risk for erosion or channel migration.

2 Assessment Approach

2.1 Literature Search and Review

To better understand the physical processes influencing West Walker River dynamics, Otis Bay first reviewed existing literature, reports and data. Numerous studies have been conducted on biophysical processes of the entire Walker River Basin. While less work has been done on the West Walker specifically, information is still available from basin-wide studies and studies pertaining to the Antelope Valley region (Alpert, et al., 2014; California Department of Water Resources, 1964; Glancy, 1971; Mono County Community Development Department, 2007; Reid, Bill, Antelope Valley Regional Planning Advisory Committee, and Mono County Community Development District, 2008).

The literature search revealed gaps in data that were needed to complete an assessment of Walker River issues in Antelope Valley, especially with regard to sediment transport. Within budgetary constraints, Otis Bay initiated field studies in the area to address these knowledge gaps. Preliminary hydrologic and sediment data were collected, allowing Otis Bay to develop a thorough qualitative understanding of the geomorphic processes occurring throughout Antelope Valley. The methods used to collect and synthesize these data are described throughout the subsequent sections of this report.

2.2 Field Surveys

Field surveys of floodplain topography and channel cross sections were conducted at each of five sites, and five permanent survey monuments were installed so that the sites could be revisited and referenced for future studies. Due to the abundance of large rocks throughout Antelope Valley, monuments were typically installed directly into very large, non-mobile boulders. Collected field survey data were used to verify remote sensing LiDAR data (discussed in Section 4.1.1), and these LiDAR data were used to generate floodplain topography and channel cross sections. Cross section survey data were further used to calibrate the hydraulic model (discussed in Section 4.1), and can be used for more in depth roughness studies during subsequent phases of this project.

2.2.1 *Study Areas/Site Locations*

Otis Bay used aerial imagery and field visits to develop a more thorough understanding of the geomorphic characteristics of the river throughout Antelope Valley. The field study area extends from the mouth of West Walker Canyon to the Topaz Diversion, and was divided into five geomorphic reaches that vary significantly by channel slope, sinuosity, streambed composition, and channel pattern. Based on site accessibility and feasibility of data collection, five study sites, one in each reach, were selected to represent these distinct geomorphic reaches.

Reach 1 represents a single thread channelized section of the river, where a large portion of the reach was constructed under emergency provisions by USACE immediately after the 1997 flood. The channel bed slope through this reach is steep (approximately 1.6%), and streambed material primarily consists of large boulders and imported riprap, with a fairly uniform trapezoidal channel geometry throughout. The sinuosity is low, and there is minimal floodplain connectivity due to the high banks and channel capacity. In its natural state, Reach 1 would represent an area of initial fan deposition and probably a multiple channel, distributary system.

Through Reach 2, the river exists in a more natural state, with a channel slope that remains steep. This reach occurs downstream of the Big Slough diversion, which serves as the largest agricultural diversion in Antelope Valley. The channel pattern is best characterized as plane-bed throughout this reach, with low sinuosity and bed material that consists mostly of small boulders. The channel is relatively well-connected to the floodplain, and sediment deposition increases throughout the reach.

Reach 3 is characterized by a significant decrease in bed slope, along with an increase in sinuosity and a shift to a meandering pattern. Although this reach contains numerous side distributary channels and connected sloughs, the main channel pattern is best classified as single thread, and contains an active floodplain showing widespread sediment deposition. The bed material primarily consists of cobbles and scattered boulders. Channel modifications through portions of this reach include levees that have been built in an attempt to curb channel migration and protect personal property.

The channel through various places in Reach 4 is bordered by large agricultural fields. As a result, the floodplain through this reach is narrow when compared with upstream reaches, and agricultural diversions become more prevalent. The channel slope remains mild, and the streambed material consists of gravel and small cobbles. The pattern is characterized by single thread, meandering riffle-pool sections with a relatively high sinuosity.

Reach 5 begins upstream of Topaz Lane and is characterized by a mild slope containing a gravel bed. The channel reach exhibits a typical, low energy, high sinuosity, single thread meandering riffle-pool pattern. The channel and floodplain become wide and flat, and the amount of riparian vegetation significantly decreases through this reach. Visible sediment deposition in the floodplain is abundant, especially in areas directly adjacent to the river corridor.

Figure 2-1 demonstrates the change in bedslope throughout the study area, Table 2-1 summarizes the geomorphic characteristics of each reach, and Figure 2-2 shows the location of the study sites and channel reaches relative to the entire study area.

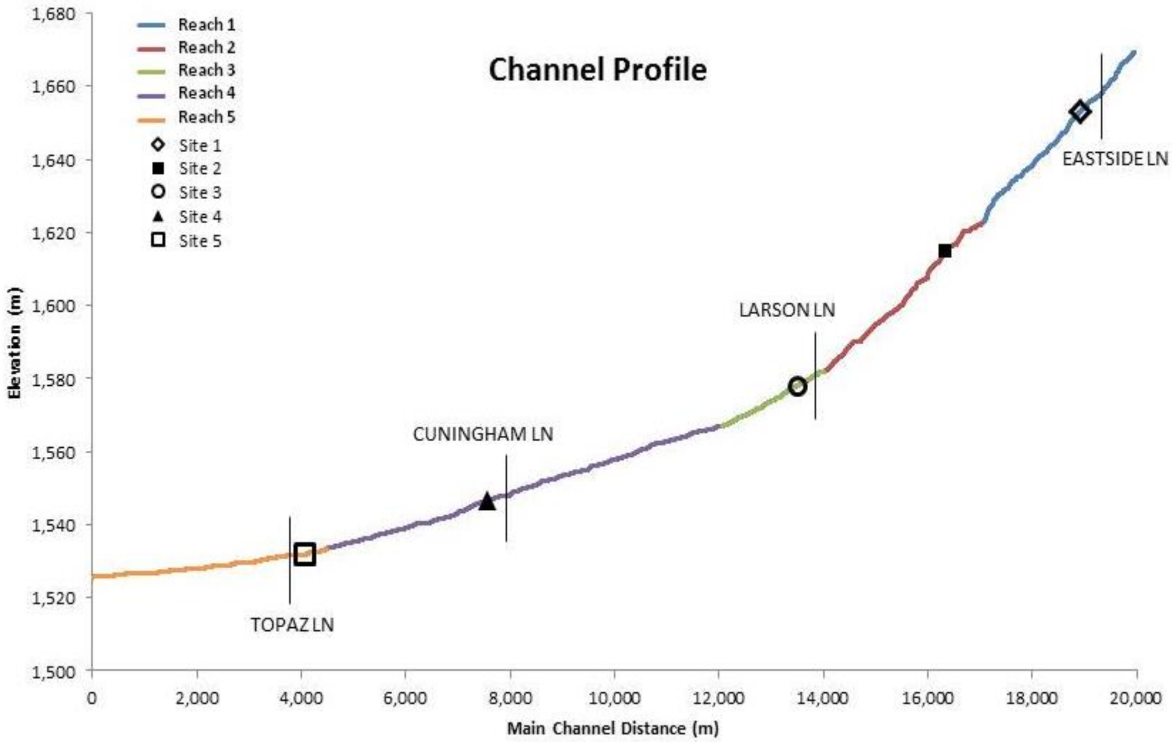

Figure 2-1. Channel profile demonstrating the change in bedslope in relation to channel reaches and study sites.

Table 2-1. Distinguishing characteristics of the 5 geomorphic reaches within the study area.

Segment	Slope	Sinuosity	Median Sediment Size of Streambed (D_{50})	Channel Description
1	0.016	1.08	192 mm	Straight, steep banks, single thread, man-made
2	0.014	1.07	121 mm	Straight, plane bed, single thread
3	0.008	1.2	99 mm	Meandering, riffle-pool, single thread
4	0.005	1.3	62 mm	Meandering, riffle-pool, single thread
5	0.002	1.4	18 mm	Meandering, riffle-pool, single thread

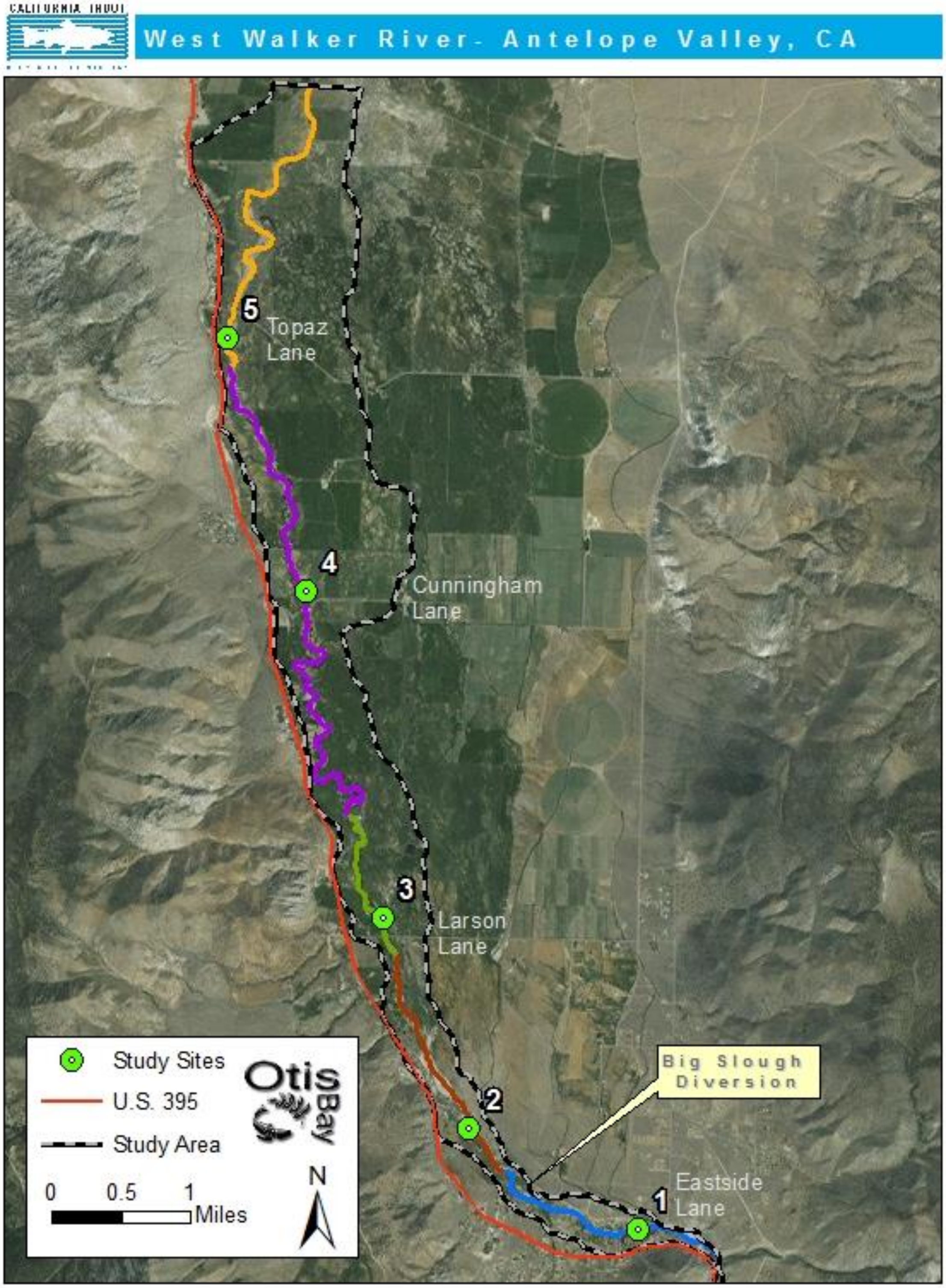

Figure 2-2. Site locations, channel reaches, local roads, and the primary diversion within the overall study area.

2.2.2 *Pebble Counts*

Pebble counts were conducted at the five study sites using the Wolman Method (Wolman, 1954). The Wolman Method is a widely-used, robust method of streambed characterization, consisting of random sampling of at least 100 points within a particular reach, followed by a statistical analysis of the data. The analysis ultimately results in grain size distribution curves that are useful in developing a preliminary understanding of channel roughness, calculating sediment transport rates, and evaluating distribution of sediment sizes throughout a river system. Otis Bay conducted the pebble counts during low flows in August of 2014 so that wading across the channel would be possible in all areas. From these data, distribution curves were developed for each site and preliminary roughness and sediment transport calculations were performed. The results of this analysis will be discussed further in Section 4.2. Figure 2-3 shows an Otis Bay employee conducting a pebble count at Site 1.

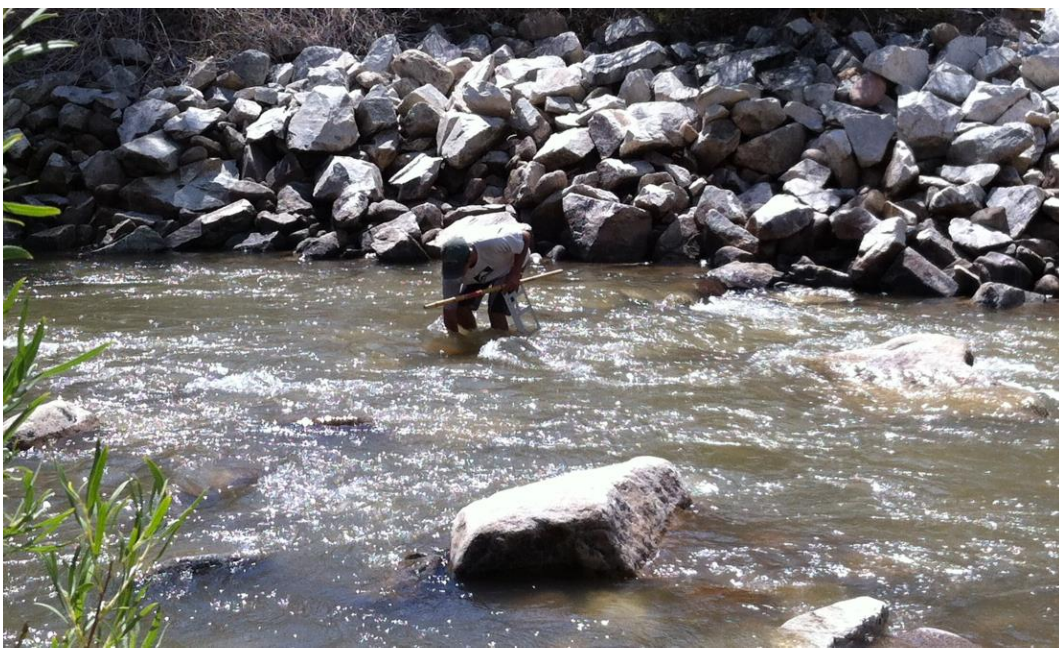

Figure 2-3. Otis Bay employee conducting a pebble count at Site 1.

3 PHYSICAL PROCESSES AND CHANNEL DYNAMICS

3.1 Geologic Characteristics

On the West Walker River, the retreat and disappearance of glaciers leaves behind a significant geomorphic legacy. Glaciers carve large valleys with broad bottoms. Glacial landforms in the West Walker River Basin can be found in the headwater regions of the Sierra Nevada and are the result from relatively recent glaciations (the Tioga, Tenaya, and Tahoe glaciations) which occurred between 79 to 15 thousand years ago (Dohrenwend, 1982). On the West Walker River, a large glacier extending from the Sonora Pass area to Sonora Junction was present during the most recent Tioga glaciation. Leavitt Meadow is an example of an area that has experienced significant glacial activity (Mono County Community Development Department, 2007). As they advance, glaciers push a mass of accumulated sediment along their perimeter. When they retreat, glaciers leave this sediment in a deposit known as a moraine. Vegetation stabilizes these moraines, but the deposited material remains available as sediment input through surface erosion or mass wasting. Terminal moraines from glacial activity occur in West Walker Canyon and provide potential sediment source material to the river. In Antelope Valley, glacial sediment has been transported by West Walker flows, and deposited throughout the valley. Much of this fill occurs in alluvial terraces above the modern floodplain, which resulted as the West Walker River adjusted to less water over the last 10,000 years. Today, the West Walker River flows through a smaller channel and floodplain relative to its prehistoric condition.

The headwaters region of the West Walker River Basin is considered a source of sediment derived from weathering granite and erosion of glacial deposits. Bedrock types throughout the watershed determine river channel pattern and sediment size distribution, which are vital to understand before planning and designing riparian restoration activities. The following descriptions of bed-rock types and their distribution in the West Walker River Basin (Figure 3-1) are derived from four common sources (Halsey, 1953; Ludington, et al., 2005; Raines, et al., 1996; Smith, 1930).

Rock types in the headwaters region are mainly Mesozoic granites common to the Sierra Nevada. Weathered granite can be a significant source of gravel and sand. Moving down the flanks of the Sierra, bedrock types begin to include Tertiary extrusive volcanics mainly composed of basalts. Basalts contain large amounts of minerals that can weather into clay. Surficial deposits include Quaternary glacial deposits consisting of moraines and outwash material (Dohrenwend, 1982). East dipping normal faults of the West Walker River fault zone offset Tioga age (13-20 thousand year old) glacial moraines in the lower slopes of the Sierra Nevada (Sawyer, 1995).

Antelope Valley lies in a transition zone between the Sierra Nevada and the Basin and Range Province. The physical boundary of the Sierra Nevada and the Basin and Range physiographic regions is somewhat indistinct in this area. Antelope Valley is a tilting, down-dropped structural block (half graben) created by east dipping normal faults of the Antelope Valley Fault Zone. This type of faulting is typical of the Basin and Range, but geologic studies place this area in the Sierra Nevada physiographic region (Sawyer, et al., 1998). Rocks to the west of the valley are composed of Mesozoic granites, Cretaceous marine sediments, and Tertiary volcanics. Hills flanking the valley to the east include west-tilted structural blocks on the western edge of the Basin and Range, with outcrops of Tertiary basalts and Cretaceous marine sandstones, marine shale, and terrestrial conglomerates. This Basin and Range style of faulting has created a valley that is a depositional area. Much of the sediment generated upstream on the West Walker has accumulated in Antelope Valley along with sediment eroded from adjacent hillslopes. As a result, almost the entire valley floor is characterized as alluvium rock type (Figure 3-1).

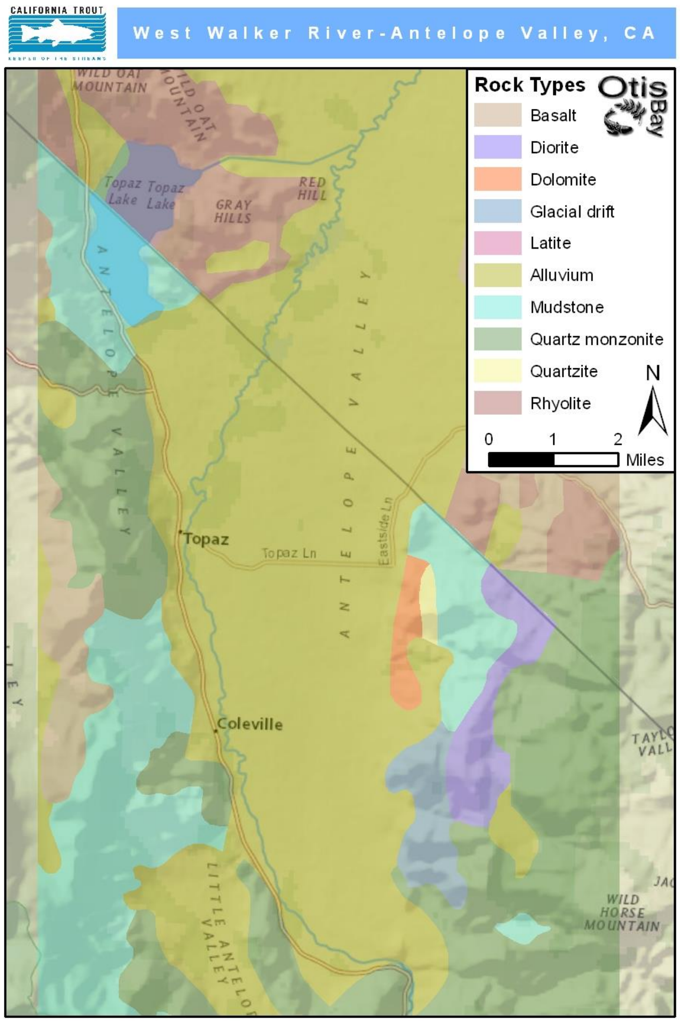

Figure 3-1. Rock types and their distribution in Antelope Valley. This map was produced by merging two maps produced separately for California and for Nevada. In some cases, mapping along the state border has resulted in abrupt changes in the interpretation of rock type. This abrupt change is not a physical reality, but simply a product of different interpretations.

3.2 Geomorphology

Antelope Valley was created along the Sierra Nevada and the Basin and Range transition by half-graben tectonics. The confined river within the West Walker Canyon exits into

Antelope Valley, where the river is less constrained and has migrated across an alluvial fan. On this fan the river has deposited much of its sediment load. The deposition of larger stream-bedload material occurs in the upper reaches of the fan, and the deposition becomes finer in the downstream direction. The slope of the valley decreases in the downstream direction, thereby reducing stream power and promoting sediment deposition of finer material.

As high water flows onto the Antelope Valley alluvial fan, the river begins to dump its sediment load. Particle deposition decreases in size in the down-valley direction. Larger particles are deposited at the head of the fan and become sequentially smaller downstream.

The channel migration across the fan coupled with extreme high flow events that divide into multiple channels has created a network of distributary channels across the fan. This network contains active and inactive channels. Some of the channels only become active during flood events; others are relict channels of the past.

Antelope Valley is bound on the west by the Antelope Valley fault, which is relatively active. This tectonic structure creates the condition which formed the valley. Movement along the fault causes the valley to tilt to the west and thereby promotes river migration toward the west. Many of the small alluvial fans that should be apparent on the west side of the valley are not exposed or minimally exposed as they have been buried in valley fill as the valley slips downward along the Antelope Valley Fault.

The West Walker River flows along the Antelope Valley fault, on the west side of the valley until it runs into the large alluvial fan deposited by Slinkard Creek. The large fan, which lies south of Topaz Reservoir, re-routes the river eastward, where fault systems on the west flank of the Wellington Hills deform the landscape and create a valley that slopes toward the north-east, and the river flows down this valley.

3.3 Hydrology of the West Walker River Basin

A majority of the Walker River Basin has been significantly impacted by anthropogenic alterations such as grazing, storage reservoirs, and irrigation diversions; however, of the entire Walker River Basin, the West Walker River most closely mimics a natural hydrologic regime for any significant portion of its length. This natural hydrology can be found upstream of Antelope Valley and is best represented by the Coleville and Little Walker gages (discussed further in the following section).

Upstream of the confluence with the Little Walker River, the West Walker Sub-Basin is drained by steep, rocky terrain that is typical of the eastern slope of the Sierra Nevada mountain range. The drainage area for this point of the West Walker is approximately 181 sq. mi, and little to no significant lake or reservoir water storage exists upstream of this point. Some meadow systems, such as Pickel, Leavitt, and Sardine, might provide some temporary storage and flood attenuation, but these elements were not studied in this report. Improving the condition of these meadows would enhance these desired attributes. The steep gradient, abundance of impervious surfaces, and lack of storage rapidly concentrates runoff that can lead to large pulses of flow entering the West Walker Canyon and Antelope Valley. Streams of this nature are often high in energy and capable of transporting bed material in large quantities, which ultimately leads to rapid changes in channel morphology. Runoff becomes more sustained during melting of the large winter snowpack, but the steep gradient of the channel maintains flows at high energy levels and the probability for sediment transport remains high.

Through Antelope Valley, the West Walker River becomes altered by diversions and storage at Topaz Reservoir that have cumulative influences on the river's hydrology up to its confluence with the East Walker River in Mason Valley. Aside from the Topaz Diversion, the overall impact of the diversions throughout upper Antelope Valley remains relatively small. Therefore the effects of hydrologic alterations of the upstream portion of Antelope Valley are fairly insignificant. These alterations will be discussed further in Section 3.3.3. When compared with the entire Walker River Basin, the West Walker River segment through Antelope Valley can be considered a relatively natural alluvial fan river system, with minimal human impacts affecting the flow regime throughout the drainage basin.

3.3.1 *Hydrologic Records*

United States Geological Survey (USGS) gage records were analyzed in order to quantify and characterize hydrological patterns that influence geomorphological and ecological processes of the Walker River system. Several characteristics, including mean daily flow values and flood frequencies can be derived from gage records and are important in providing a complete picture of a river system's hydrology.

The USGS currently maintains two streamflow gages along the West Walker River upstream of the Topaz Diversion. One gage is located at the upstream end of West Walker Canyon below the confluence with the Little Walker River (Little Walker - 10296000), and the other is located at the mouth of West Walker Canyon, upstream of the town of Walker (Coleville - 10296500). These gages record stage height and discharge, and they have operated for 76 and 112 years, respectively. Data from these gages are almost identical, where slight differences in peak discharges are likely due to individual storm system characteristics and contributions from small drainages upstream of and through West Walker Canyon. To highlight the similarity, a comparison of the Little Walker and Coleville gage hydrographs over an arbitrary 3-year (calendar year) period is provided in Figure 3-2. The locations of all the USGS gages used in this study, along with their common names and drainage basin areas, are displayed in Figure 3-3.

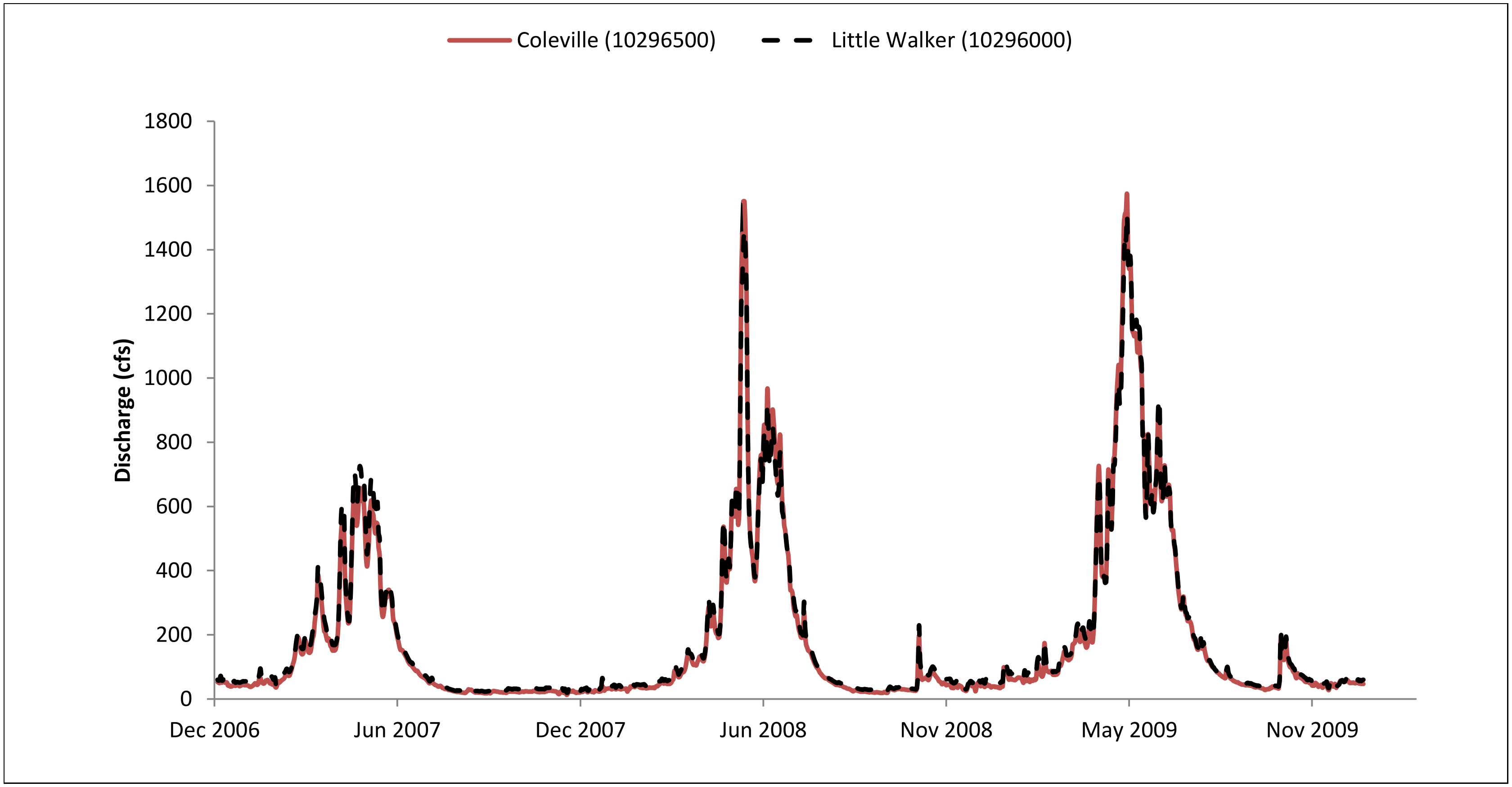

Figure 3-2. Hydrograph comparison of the Little Walker and Coleville gages over a 3-year period (Data obtained from http://waterdata.usgs.gov/nwis, accessed August 2014).

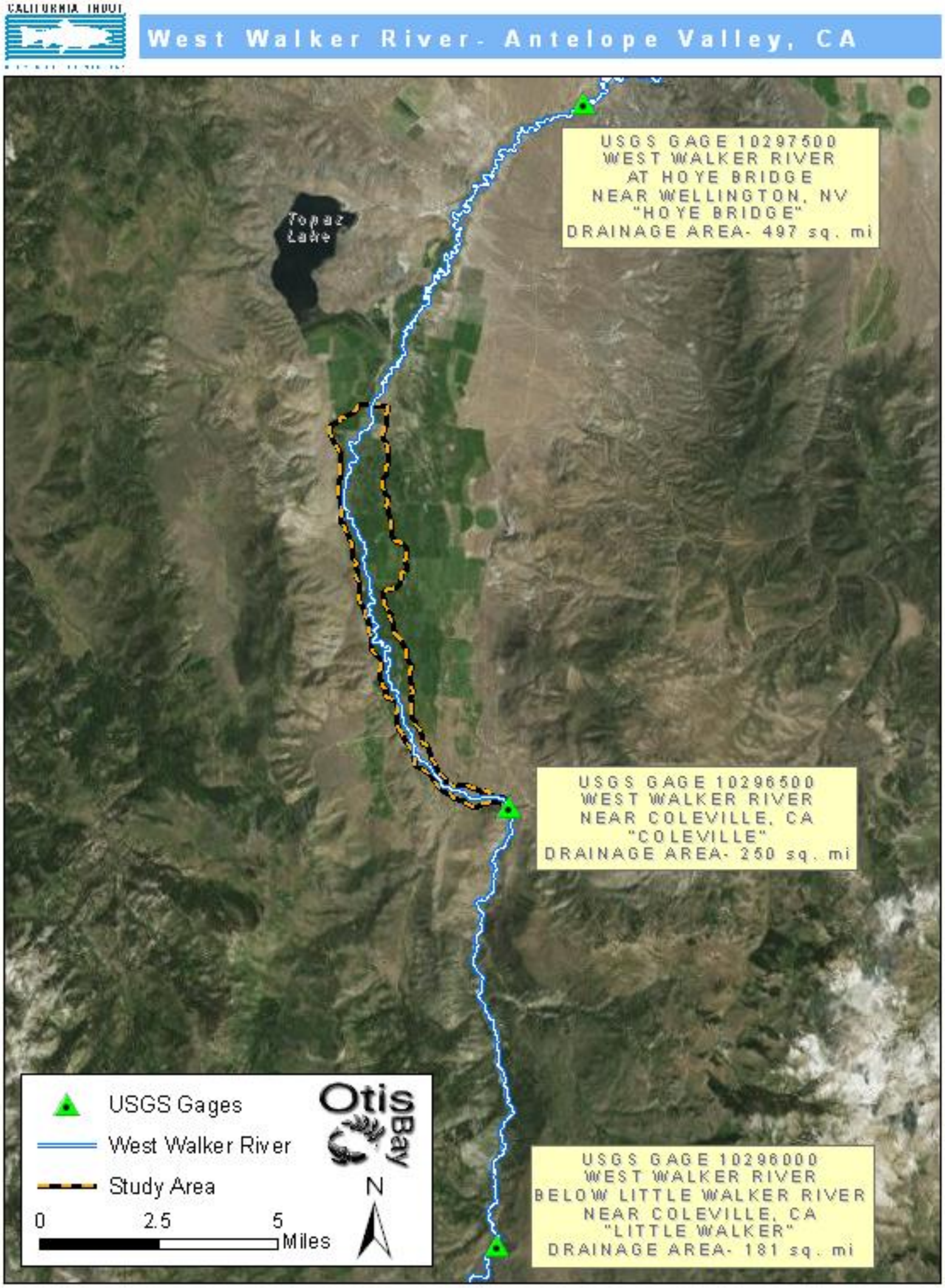

Figure 3-3. Locations and associated information for USGS gages used in this study.

3.3.2 *Natural Hydrologic Regime*

Flow in the West Walker River through Antelope Valley is not influenced by any large dams in the upper reaches; however, it is influenced by Topaz Reservoir, a large impoundment that receives diverted streamflow from the West Walker, at the downstream end of the valley. As a result, the gages higher in the basin exhibit a wider range of variability of flood peaks than the patterns observed at gages in the lower basin. The variability observed in the upper basin is typical of snowmelt-dominated rivers in the western United States.

The natural hydrologic regime of the West Walker River can be best represented by the Little Walker and Coleville gage data, because of similarities in the data and minimal anthropogenic impacts upstream. The majority of the drainage basin is located upstream of the Coleville gage, therefore this gage serves as a useful tool for estimating magnitude and patterns of stream flow entering Antelope Valley. Characteristic stream flow patterns through Antelope Valley emerge from plots of long-term Coleville gage data (see plot examples in Figure 3-4) and include: (1) moderate magnitude, long duration snowmelt peaks that ordinarily occur in May and June, (2) a short period of declining, moderate flow following spring runoff, (3) a period of low flow (baseflow) that ordinarily occurs from August to March, and (4) infrequent, but periodic high intensity, short duration peak flows that can occur during storms in winter months.

In comparing hydrologic records over years of varying snowpack and water supply, deviations in the overall volume of water are apparent; however, the general trend remains the same. To illustrate the similarities in trend despite variations in the overall volume of water, the Coleville gage hydrographs for average, wet, and dry water years (WY) are displayed in Figure 3-4. The 1997 water year is also included in this figure, to show the relative timing of a peak discharge occurring outside of the typical spring snowmelt period. Based on existing gage data, the flood of 1997 is the flood of record (FOR).

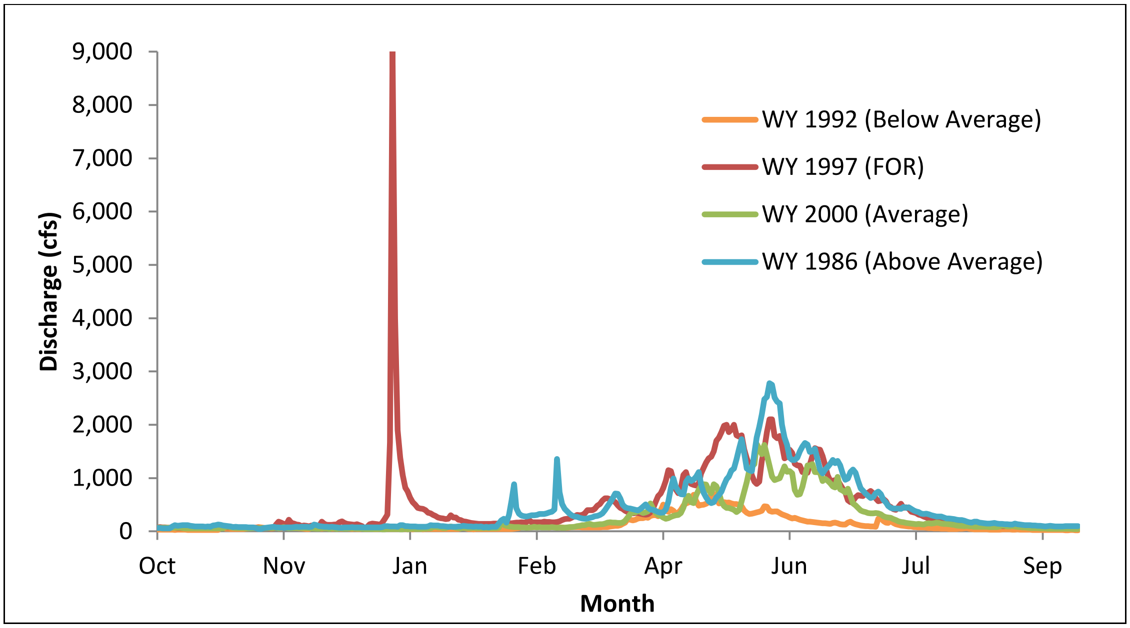

Figure 3-4. Hydrographs at the Coleville gage for average, wet, and dry years, along with the water year (WY) in which the '97 flood occurred (data obtained from USGS).

3.3.3 *Hydrologic Alteration*

As previously mentioned, the most significant feature of anthropogenic alteration to the hydrology of the West Walker River is Topaz Reservoir. This reservoir provides off-channel storage for water users in Smith and Mason Valleys and is operated by the Walker River Irrigation District (WRID). Topaz Reservoir reduces flood peaks, increases flows on the declining limb, and typically decreases baseflows downstream. These effects are clearly visible in comparing the Hoye Bridge (downstream of Topaz) and Coleville (upstream of Topaz) gages over the same arbitrary time period, as shown in Figure 3-5. The peaks at the Hoye Bridge gage (blue line) are smaller in magnitude, the baseflows are lower, and the declining limb is extended over a longer time period. Alteration of the timing and magnitude of flood peaks allows for a steady supply of water during the summer months; however, these alterations often decrease the ability of a channel to perform geomorphic work by affecting the sediment supply and transport dynamics. While Topaz Reservoir significantly impacts the West Walker River downstream of Antelope Valley, the affected section of river is downstream of the study area for this project, and the channel within the study area remains relatively un-impacted.

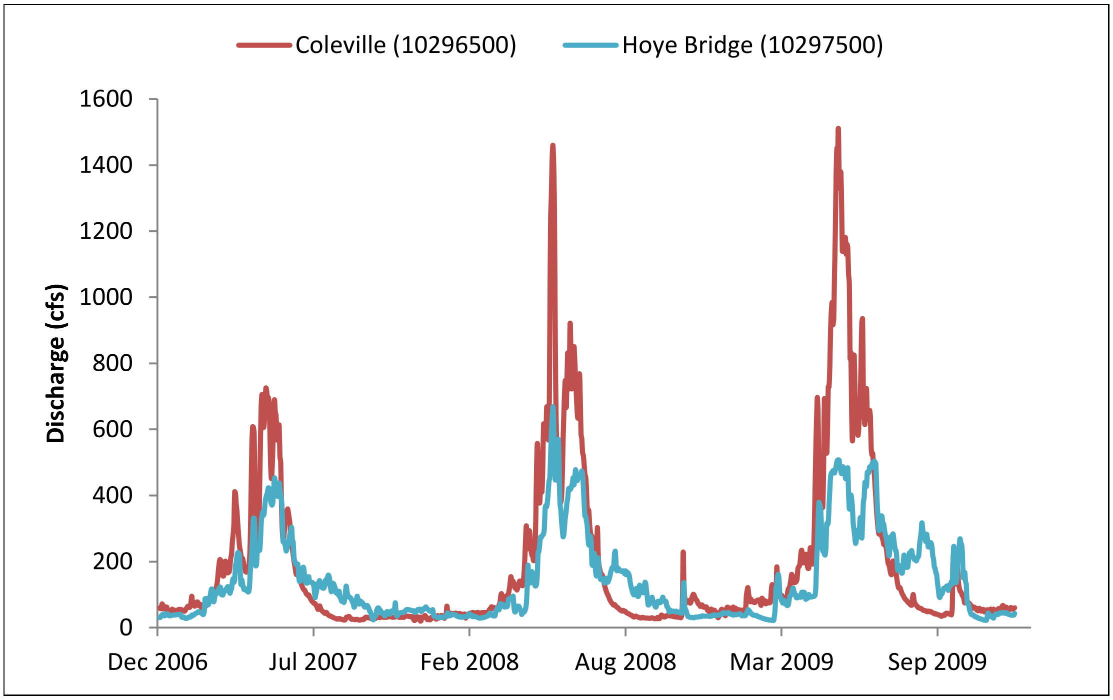

Figure 3-5. Comparison of hydrographs upstream (Coleville) and downstream (Hoye Bridge) of Topaz Reservoir demonstrating the hydrologic effects of the dam (Data obtained from USGS).

3.3.3.1 *River Diversions*

In addition to Topaz Reservoir, various agricultural diversions also exist, and together these make up the bulk of hydrologic alterations within Antelope Valley. The main diversion is the Topaz Diversion, which diverts a majority of the river to Topaz Reservoir. Smaller-scale agricultural diversions such as Main Canal and Big Slough divert water from farther upstream near the town of Walker and supply most of the irrigation water for the southern portion of Antelope Valley.

Overall, diversions (Figure 3-6) affect approximately 11 miles of river through Antelope Valley (Alpert, et al., 2014). The main diversions upstream of the Topaz Diversion that were considered in this study are Main Canal, which is diverted from the river near the Eastside Lane Bridge, and Big Slough, which is diverted from the river near the end of N. River Lane in the town of Walker (Figure 3-7). Together, Main Canal and Big Slough account for nearly 80% of the water diverted upstream of the Topaz Diversion, and are the primary diversions that affect the river through the southern portion of Antelope Valley. Of the two diversions, Big Slough provides the bulk of irrigation water for agricultural operations. Smaller diversions such as the Alkali and Swager ditches were determined to have insignificant water depletion impacts, thus these smaller ditches were not included in the following discussion.

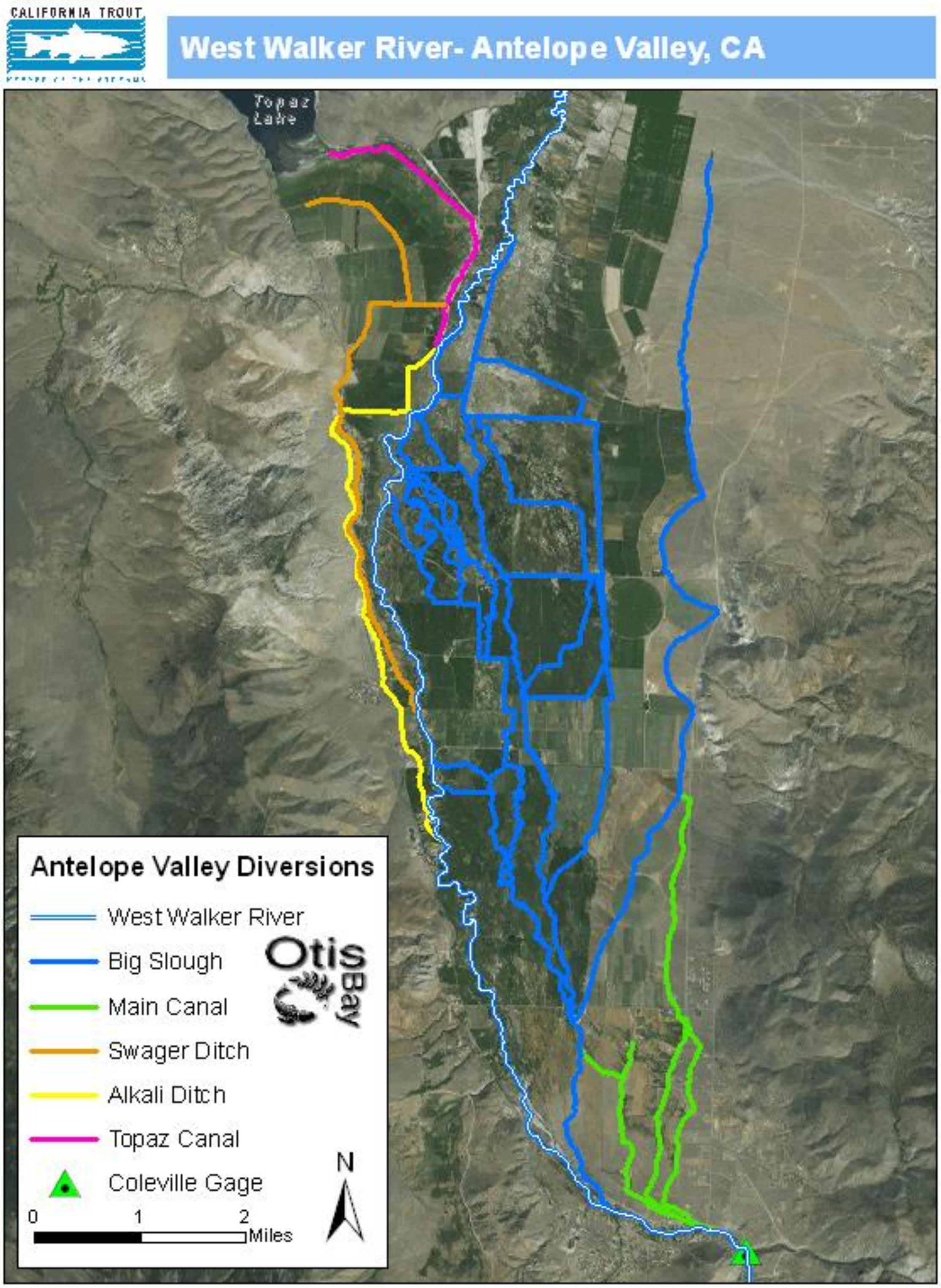

Figure 3-6. The primary diversions through the upstream portion of Antelope Valley. Note: This map does not contain every small supply and return ditch but rather provides a general overview of the main stems of the diversions.

Figure 3-7. Comparison of relative locations of the Main Canal (top) and Big Slough (bottom) diversions on the West Walker River.

Both the Main Canal and Big Slough diversions are unlined canals with various control structures, smaller sub-diversion structures and return ditches throughout the network. As the name suggests, the Big Slough diversion primarily follows a naturally formed slough channel through the valley. The inlet for the Big Slough diversion consists of a stop log diversion dam and two manually operated slide gates at the inlet. Because of the location and configuration of this diversion structure (see comparison in Figure 3-7), a substantial sediment load, primarily consisting of sand particles, regularly enters the diversion canal and users have to dredge the canal on a regular basis.

3.3.3.2 *Water Depletion*

Irrigation diversions typically affect the hydrology of a river system through overall water depletion. Water depletions caused by diversions within Antelope Valley are estimated to total about 65,500 acre-feet/yr (AFY) on average (Pahl, 2000). Based on the volume of West Walker River water entering Antelope Valley during an average water year, approximately 35% of the river's total volume is diverted by the entire valley. According to the Mono County West Walker Assessment (2007), however, an evapotranspiration study conducted by Glancy (1971) suggests that about half of the diverted water returns to the system via return ditches leading directly to the river or groundwater recharge. This recharge, along with diversions accounting for only 35% of the total volume, makes the overall effects of water depletion in the West Walker through Antelope Valley relatively insignificant when compared to the rest of the Walker River Basin (Pahl, 2000).

Based on averages calculated on a month-by month basis, water diverted via the Main Canal and Big Slough diversions does not significantly impact the amount of water in the river during peak runoff. The peak diversion typically occurs in the months of April and May, prior to the peak discharge which typically occurs in June. The fact that diversions do not significantly affect peak flows (approximately 22% reduction in June on average) through the upstream portion of Antelope Valley allows the West Walker to behave as a natural river system, especially during peak discharges. Because the river maintains a relatively natural discharge pattern, geomorphically effective flows are likely to occur regularly throughout the valley.

3.3.4 *Channel Modifications*

In addition to diversion structures, various channel modifications throughout the area have also likely affected streamflow and sediment dynamics through Antelope Valley.

After the devastating flood of 1997, Caltrans rebuilt the highway, stabilized the hill slopes and reconstructed approximately 9 miles of the West Walker River channel in West Walker Canyon. The reconstructed channel through West Walker Canyon has high banks, which disconnect the channel from its floodplain, based on comparisons of riparian establishment in historical and recent aerial photos (see Figure 5-1). Similarly, the USACE took emergency actions against flood damage by modifying the channel geometry through the town of Walker (Figure 3-8). The West Walker River through the town of Walker was constructed with high banks designed to protect local homes and buildings from flooding, and this channel shape resulted in low floodplain connectivity.

Even farther downstream, local residents have stated that portions of the West Walker River, particularly between the town of Walker and Larson Lane, have been leveed or armored in order to contain the river and prevent further channel migration during peak discharges. Residents have further expressed, however, that attempts to confine a dynamic river to a single channel have been largely unsuccessful, as the river typically returns to older, inactive channels during high flow events.

Figure 3-8. Rip-rapped and leveed river banks protect Walker homesteads from overbank flows.

3.3.5 *Flood Frequency Analysis and Flow Duration*

USGS Coleville gage data were used to calculate flood frequency and exceedance probabilities of the West Walker River near the town of Walker. Analysis of these probabilities, based on historical data, provide valuable insight into the magnitude and duration of peak discharges that could occur in any given year. Frequencies are typically expressed in terms of years (e.g., a 100-year flood), while exceedance probabilities are expressed as percentages. Some confusion commonly arises with this notation; a 100-

year flood is not expected to occur only once in 100 years, but rather a 100-year flood corresponds to a 1/100, or 1%, probability that a flood of such magnitude could occur in any given year. Conversely, a 1% exceedance probability implies that the particular discharge is equaled or exceeded 1% of the time in any given year (e.g., 3.65 days).

A flood frequency analysis was conducted on data from the Coleville gage using the USGS PeakFQ program, which utilizes the WRC bulletin 17-B procedure (available online at http://water.usgs.gov/software/PeakFQ). This statistical procedure is widely used in the field of hydrology and provides sound statistical estimates of expected flood frequencies and magnitudes. Plots of the flood frequencies generated by the PeakFQ software for the Coleville gage are provided in Figure 3-9**.** The red line represents the fitted frequency data, blue lines represent the upper and lower 95% confidence limits, and points are measured data for peak discharges for each year. Approximate magnitudes of various floods are presented in Table 3-1.

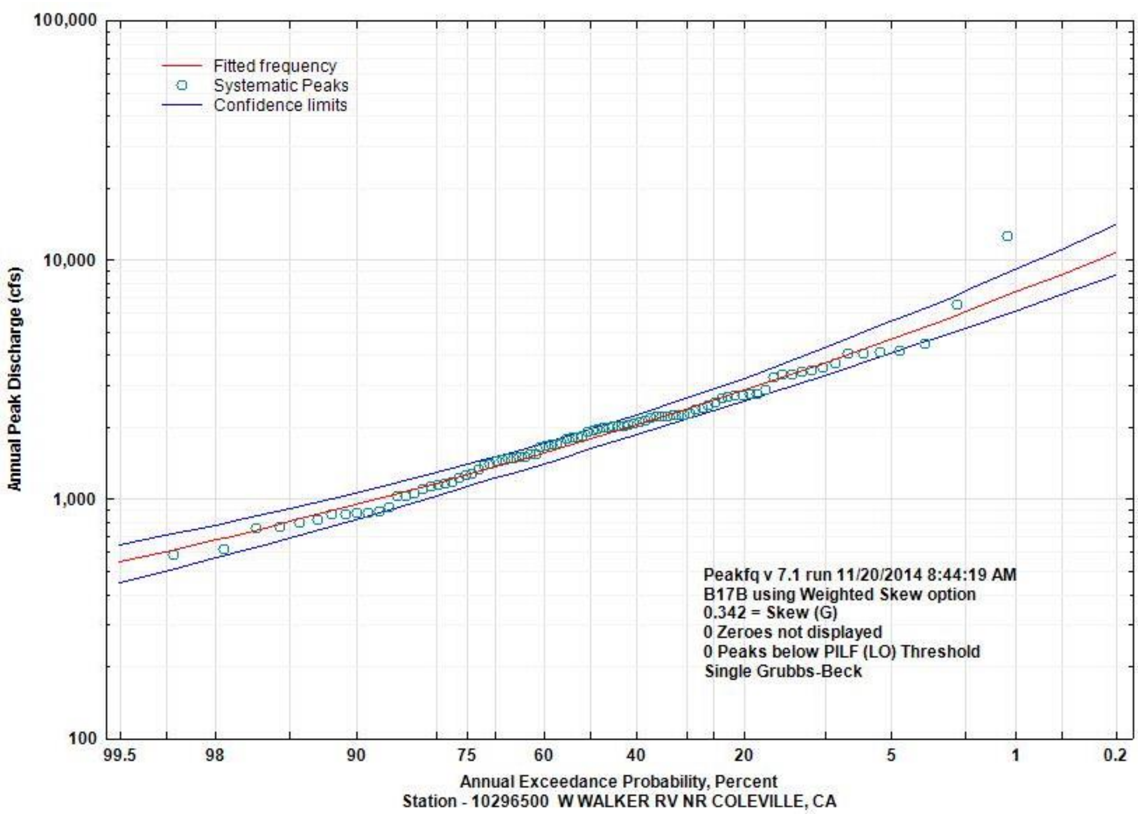

Figure 3-9. Flood frequency plot for the Coleville gage generated using the USGS PeakFQ program.

Table 3-1. Recurrence intervals and probabilities of peak flows at the Coleville gage.

Recurrence Interval (years)	Recurrence Probability	Magnitude (cfs)
<1	99.5%	550
2	50.0%	1,770
5	20.0%	2,840
10	10.0%	3,700
25	4.0%	5,000
50	2.0%	6,100
100	1.0%	7,400
Flood of Record (estimated by USGS)		12,500

The results of this analysis were used in conjunction with the hydraulic model (Section 4.1) to better understand the potential effects of peak flows on the geomorphology and ecosystems of Antelope Valley. Flood flows can transport significant amounts of sediment, thereby impacting instream and adjacent floodplain areas.

Flow duration, which is derived from exceedance probability, is another useful hydrologic analysis that provides information about the overall distribution of discharge in a river system. Flow duration curves are developed from historical stream flow data, and represent the percentage of time that a particular discharge is equaled or exceeded within the period of record. Ultimately, flow duration curves can be used to determine the overall expected duration of a given discharge in any year, with reasonable accuracy. Understanding flow duration is crucial for estimating sediment transport quantities, a process which will be discussed further in Section 4.2. A flow duration curve was developed for the Coleville gage, based on complete water years during the period of record, and is displayed in Figure 3-10.

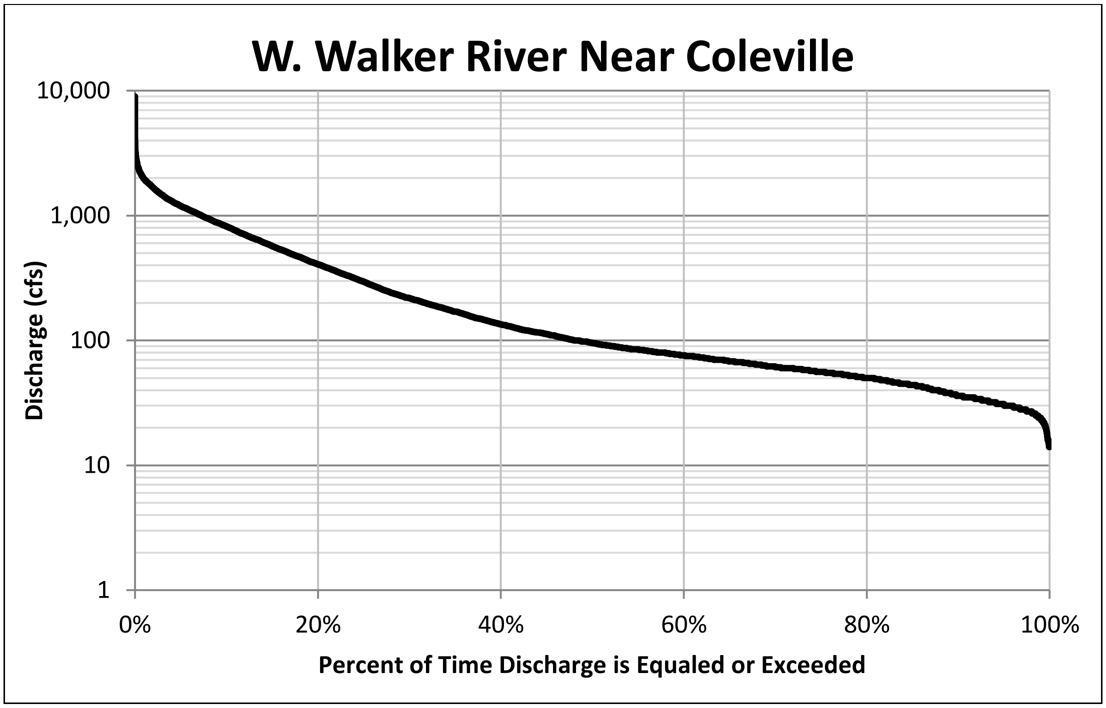

Figure 3-10. Flow duration curve for the Coleville gage (data obtained from USGS).

4 ANALYSES

4.1 Hydraulic Modeling

4.1.1 *Modeling the Existing Hydraulic Condition of the West Walker River*

Otis Bay developed a hydraulic model of the West Walker River through Antelope Valley using Light Detection and Ranging (LiDAR) data (obtained through USFWS), HEC-GeoRAS, and HEC-RAS. HEC-RAS is a 1-dimensional step-backwater hydraulic model used to compute water surface profile elevations for different stream flow scenarios under various channel conditions. HEC-RAS is a useful and robust model for evaluating hydraulic parameters such as water surface profile elevations, channel velocities, sediment transport, and areas of floodplain inundation for natural stream channels.

Otis Bay used a Digital Elevation Model (DEM) derived from LiDAR data collected in the fall of 2011 and processed to generate the topographic data used in the hydraulic model. LiDAR does not penetrate water or capture accurate water surface elevations; however, during low flow conditions in fall, maximum river channel bed is exposed for topographic measurement. In order to verify that LiDAR data provided an accurate representation of the stream channel cross sections, Otis Bay conducted field surveys at the five study sites and compared the existing topography to LiDAR data. The results of these comparisons suggested that the LiDAR data were sufficiently accurate for use in the model.

After verifying the accuracy of LiDAR data, cross-sections were automatically cut in HEC-GeoRAS at intervals of approximately 100 m, manually edited, adjusted, and converted to geometric data that could be used for hydraulic analysis in HEC-RAS. The length of each cross section varied with topography, and large obstructions such as ridges, roads, and canals were used as cross section endpoints. Interpolated cross sections at intervals of approximately 10 m were added to assist in model convergence and smoothing of the water surface profile results.

Once cross sections were refined and adjusted to suitable lengths, steady-state computations for flows ranging between 340 cfs (flow during field survey) and 7,400 cfs (approximate 100-year flood) were performed. Ineffective flow areas, channel obstructions, bridges, and levees were added to the model and adjusted as needed. Manning's n friction coefficients were adjusted throughout the entire reach to represent floodplain and channel characteristics. Field surveys and USGS rating curves were used for model calibrations. Once the model was determined to be sufficiently accurate, it was used to evaluate existing hydraulic conditions through Antelope Valley.

4.1.2 *Model Outputs and Results*

The model outputs were converted back to GIS files and used to assess floodplain inundation at various flow rates for existing conditions. Results suggest that hydraulic conditions through Antelope Valley vary considerably with changes in channel characteristics. The HEC-RAS cross section for Study Site 5 (Figure 4-1) shows the similarity between the observed water surface elevation (WSE; obtained during a field survey) and the modeled WSE. Further, maps displaying floodplain inundation during various flood events are presented in Figure 4-2 through Figure 4-4. These maps demonstrate the variation in floodplain depths and areas of inundation throughout the study area.

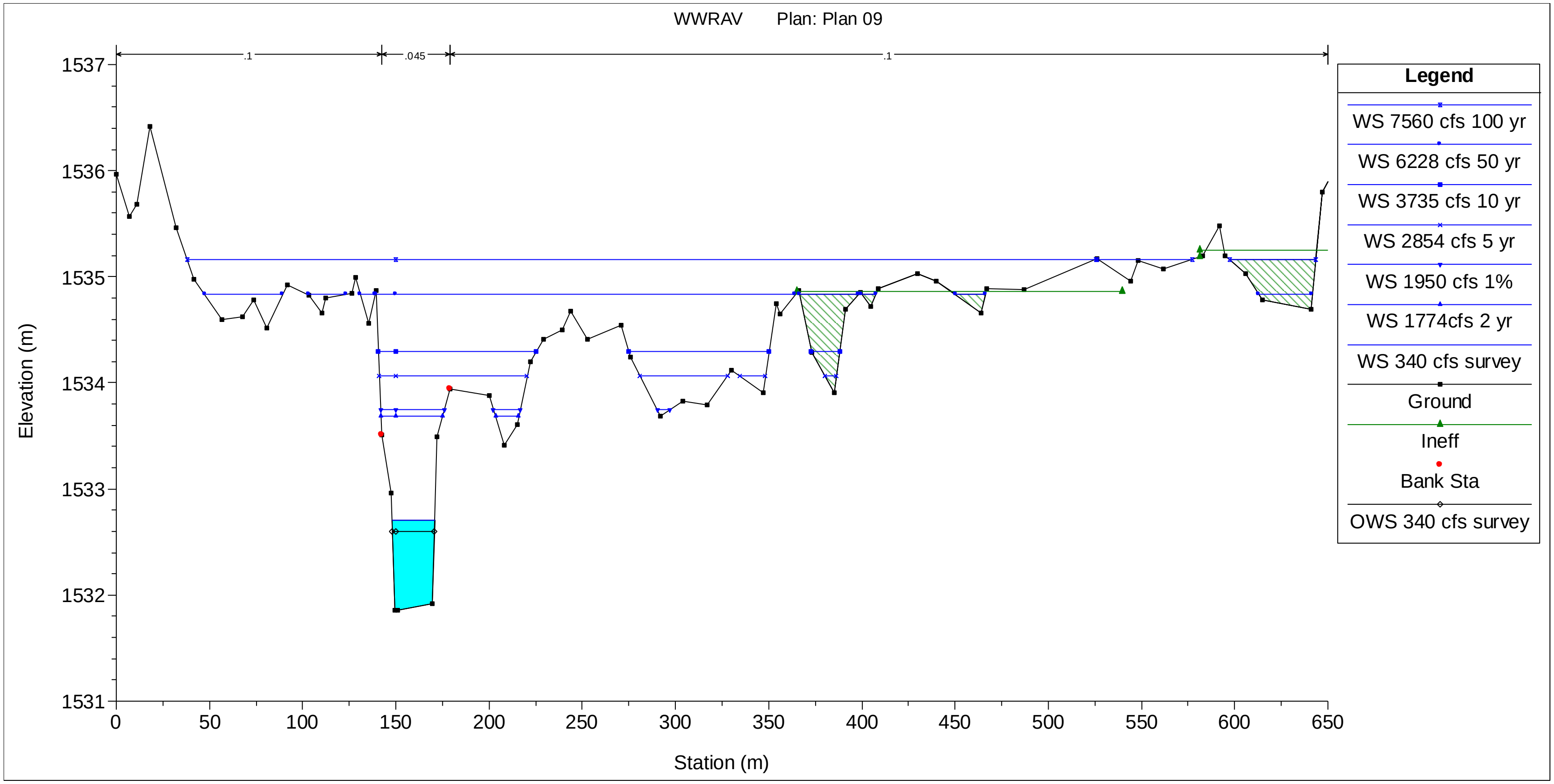

Figure 4-1. HEC-RAS cross section for Site 5. Blue lines represent water surface profiles for various flow rates. Green hatched areas represent ineffective flow areas.

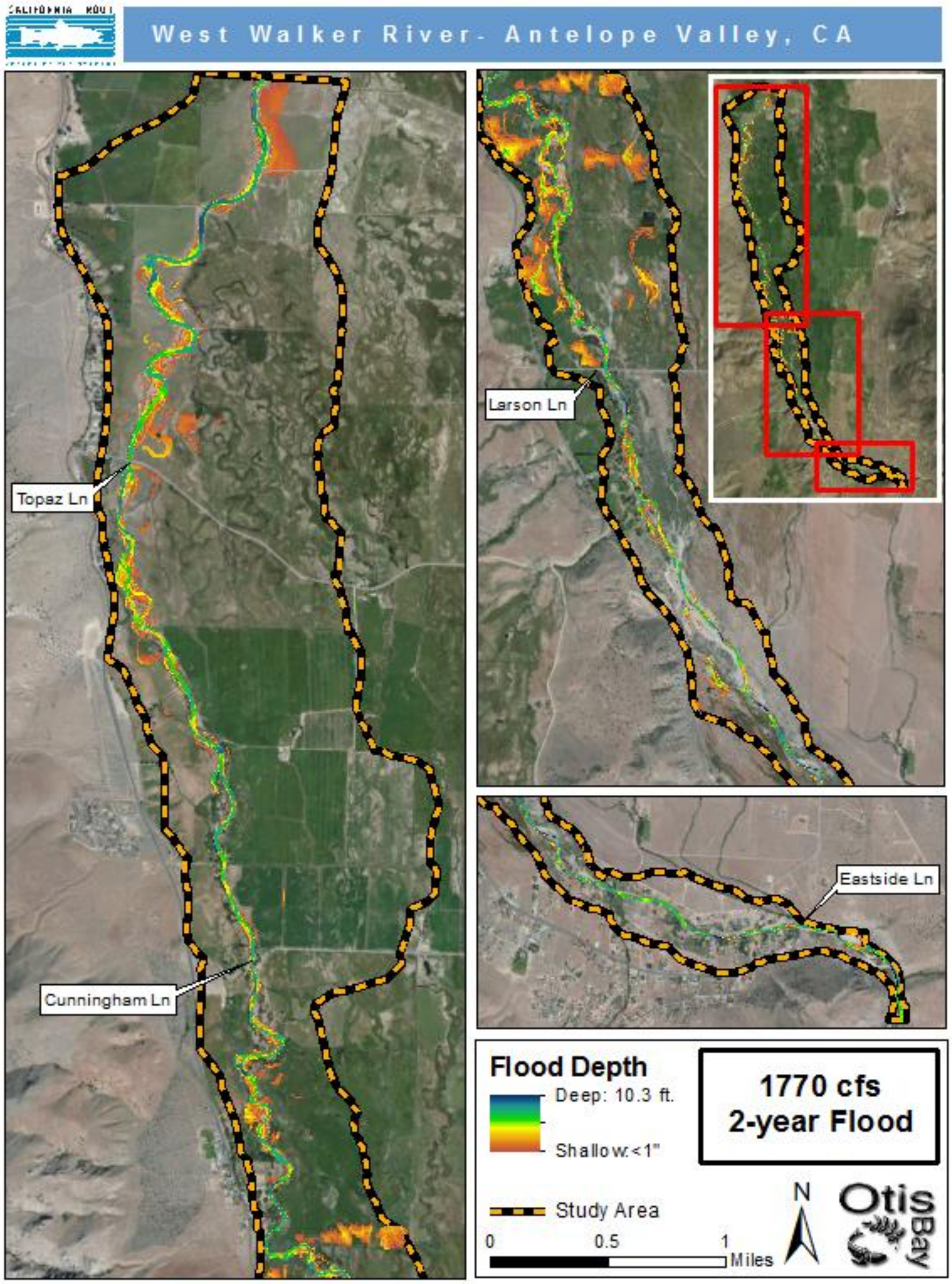

Figure 4-2. Modeled flood depths for a 2-year flood event (1,770 cfs) showing mostly bankfull flow with some areas of overbank flow.

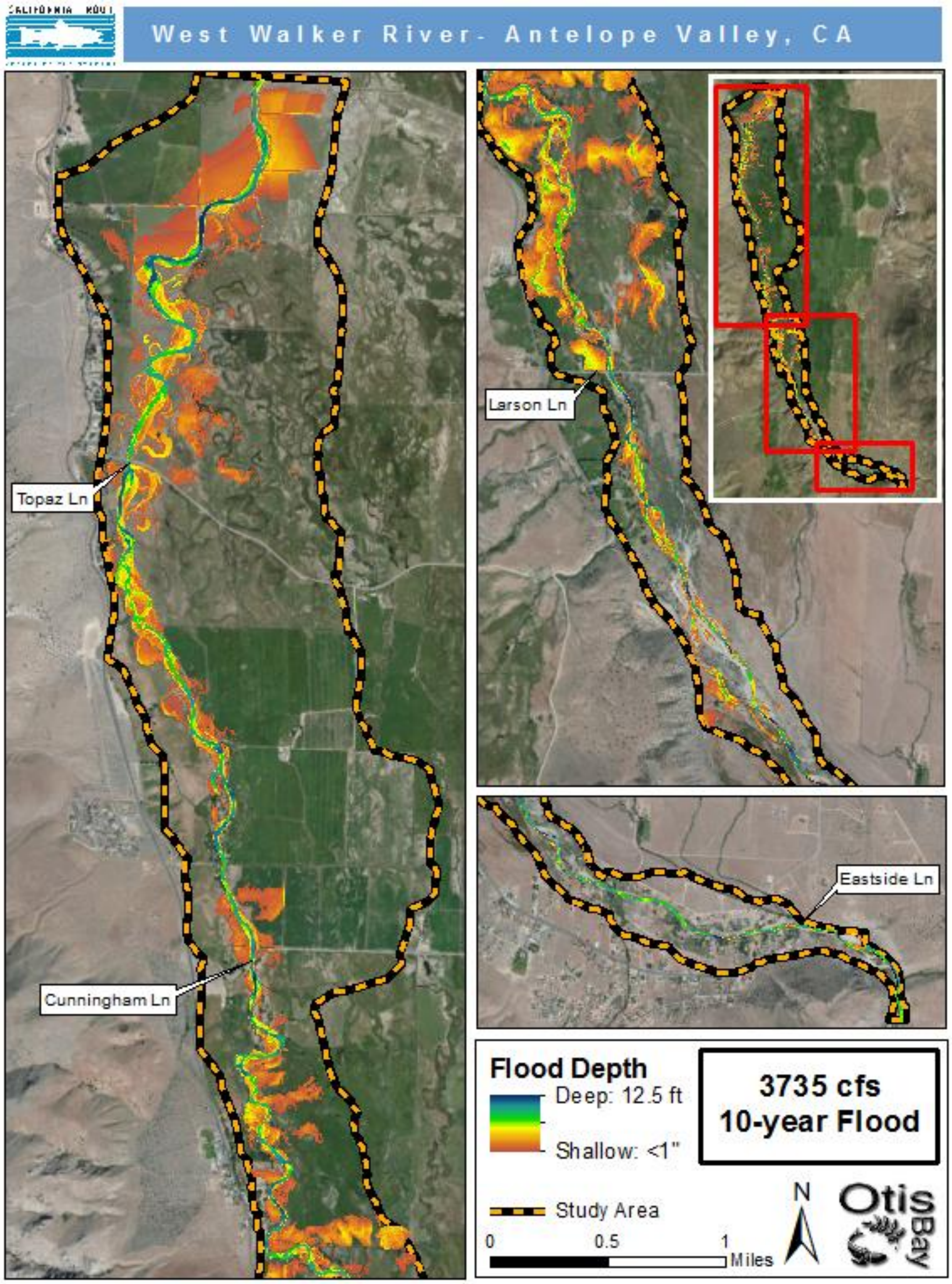

Figure 4-3. Modeled flood depths for a 10-year flood event (3,735 cfs) showing widespread floodplain inundation.

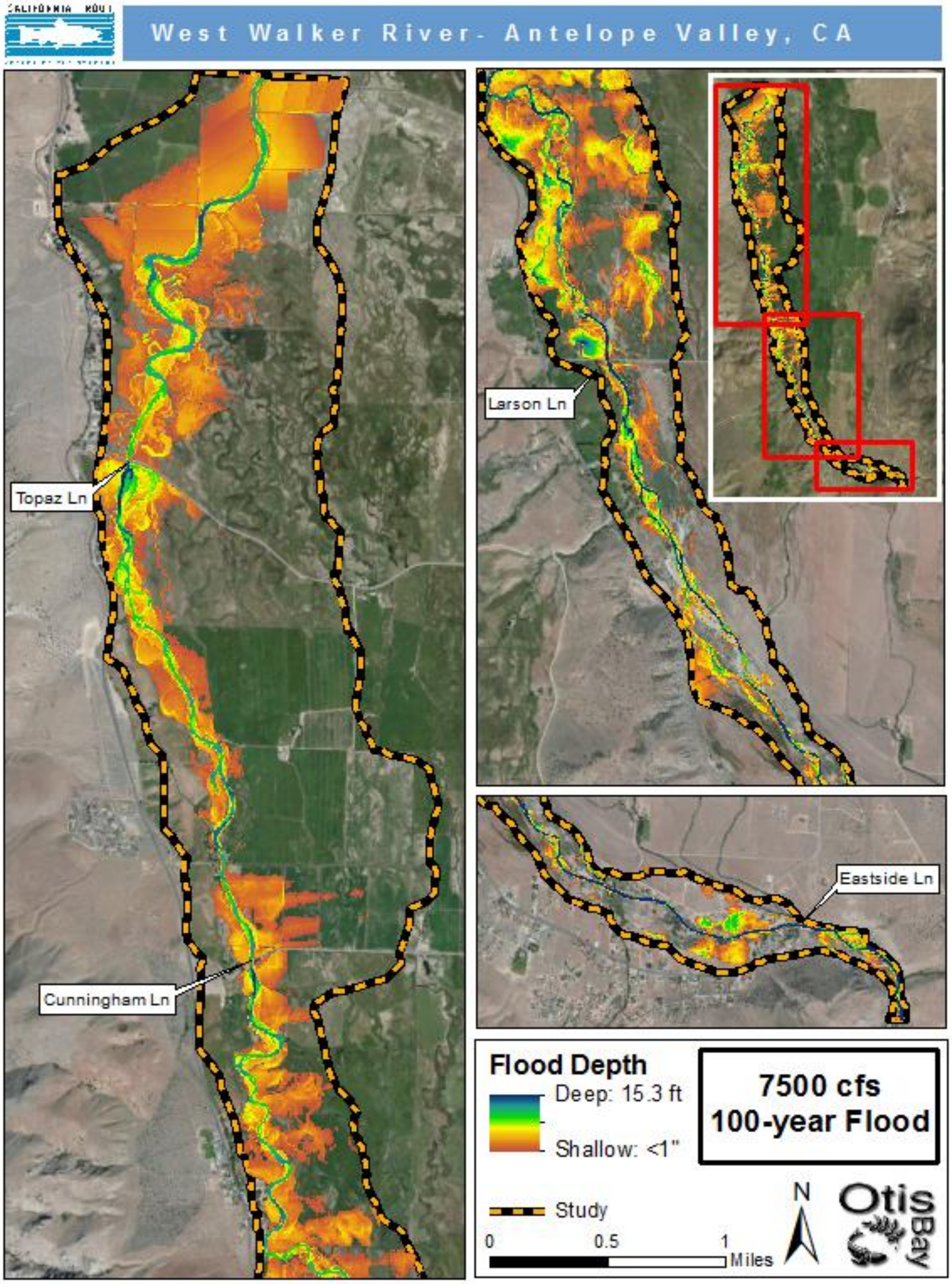

Figure 4-4. Modeled flood depths for a 100-year flood event (7,500 cfs) showing extensive floodplain inundation throughout the entire valley.

The analysis suggests that minimal overbank flow occurs through the town of Walker, except for small areas during extreme events, which is consistent with expectations, as the channel was constructed during emergency repairs in 1997 with the capacity to contain large floods. Downstream of the town of Walker and the Big Slough diversion, widespread floodplain inundation is observed during higher flow events (i.e., >10-year floods). Although the floodplain remains relatively narrow upstream of Larson Lane, downstream of Larson Lane the channel is well connected to the floodplain, where fewer channel modifications have been made aside from the built-up levees near the Larson Lane Bridge. Inactive channels become activated, and the inundation is widespread. The reach between Cunningham and Topaz Lanes consists of agricultural fields on the east side of the river, resulting in a substantially altered floodplain, with most of the overbank flow being confined to a narrow area directly adjacent to the river channel during moderate flows up to a 10-year flood event. Overbank flow becomes widespread again downstream of Topaz Lane, even in areas with agricultural fields. During a 100-year event, overbank flow is widespread throughout the valley, regardless of channel configurations in various reaches, as is expected for extreme events.

4.2 Sediment Transport

4.2.1 *Stream-bed Composition*

As outlined in Section 2.2.2, Wolman pebble counts were conducted at the five study sites, in order to determine the streambed composition. Particle-size distribution curves were developed for each location, and the data were used to calculate particle diameter percentiles, D_p, so that further calculations could be performed based on streambed composition. The curves are displayed in Figure 4-5, and the percentiles are provided in Table 4-1. As expected, the median diameter of streambed particles is largest upstream, and decreases with downstream distance. This is typical in streams of this nature, with deposition of larger particles occurring upstream, and deposition of finer particles farther downstream. The particle-size distribution curves were used in the sediment transport calculations discussed in Section 4.2.2.

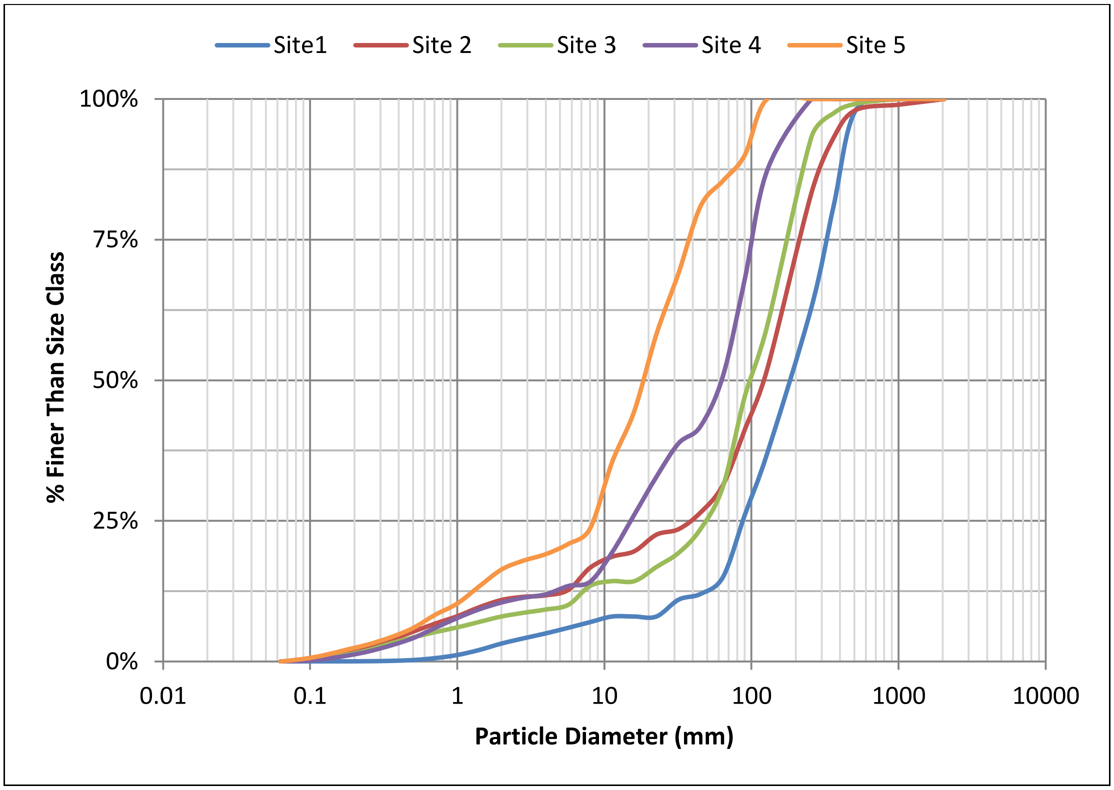

Figure 4-5. Particle size distribution curves for the five study sites.

Table 4-1. Particle diameters and corresponding percentile categories.

Particle Size Distributions (mm)

D_p	Site 1	Site 2	Site 3	Site 4	Site 5
D_{10}	28.9	1.6	5.5	1.8	1.0
D_{16}	66.4	7.6	20.5	9.2	1.9
D_{35}	121.1	73.6	70.4	26.0	11.2
D_{50}	192.0	121.1	98.9	62.4	18.6
D_{65}	267.8	181.2	148.3	85.6	28.5
D_{84}	388.5	263.2	220.7	121.5	57.9
D_{90}	441.4	328.1	243.5	155.1	90.0
D_{95}	485.5	419.0	299.5	205.6	109.0

4.2.2 *Bedload Sediment Transport Rates and Effective Discharge*

The transport rate of bedload particles was calculated over the range of discharges that have been recorded at the Coleville gage by applying the Parker (1990) bedload function to the particle-size distributions obtained through the pebble counts. The Parker bedload function is widely used to calculate sediment transport, and is based on the notion that the fluid forces acting parallel to the wetted perimeter of a channel are balanced by several sources of flow resistance, including form drag (roughness due to bedforms) exerted by bars, bed form, bank irregularity, and grain resistance. Because of these sources of flow resistance, only a portion of the total shear stress is exerted on the bed-material. The portion that is associated with particle motion is represented by the dimensionless critical shear stress, ($\tau_c^{*\prime}$), and is calculated using a refined approach developed by Meyer-Peter and Muller (1948), Einstein (1950), and Englund and Hansen (1967). The dimensionless critical shear stress is given as:

$$\tau_c^{*\prime} = \frac{R'S}{1.65 d_{50}} \qquad (1)$$

where *S* is the bed slope, d_{50} is the median particle diameter of the stream bed, and *R'* is the hydraulic radius sufficient to support the mean velocity at the given energy slope, if grain resistance is the only source of flow resistance. *R'* is solved for iteratively using the following relationship:

$$\frac{u_{av}}{\sqrt{gR'S}} = 2.5 \ln\left(\frac{4R'}{d_{84}}\right) \qquad (2)$$

where u_{av} is the mean velocity through the channel cross section, *g* is the acceleration of gravity (9.81 m/s^2), and d_{84} represents the particle diameter of the *84th* percentile in the streambed composition. The resultant value of R' is substituted into Equation (1) to determine the critical shear stress. The threshold for incipient motion is assumed to correspond with a dimensionless critical shear stress of approximately 0.03, which suggests that initial motion of the median particle size will occur when the dimensionless critical shear stress reaches this value.

Based on these relationships, Parker (1990) formulated an empirical bedload transport function for poorly-sorted mixtures of gravel and cobbles referenced to the particle-size distribution of the surficial bed material. This function can be used to estimate the quantity and size classes of bedload sediment moving through a particular reach. The Parker bedload function is given by the following equations:

$$W_i^* = 0.00218G(\phi_i) \quad (3)$$

$$G(\phi_i) = \begin{cases} 5474\left(1 - \frac{0.853}{\phi_i}\right)^{4.5} & \phi_i > 1.59 \\ \exp[14.2(\phi_i - 1) - 9.28(\phi_i - 1)^2 & 1 \le \phi_i \le 1.59 \\ \phi^{14.2} & \phi_i < 1 \end{cases} \quad (4)$$

$$W_i^* = \frac{q_{bi}(\frac{\rho_s}{\rho} - 1)}{f_i\sqrt{g}(R'S)^{3/2}} \quad (5)$$

where q_{bi} represents the volumetric bedload transport rate of the *i*th particle fraction, per unit width of channel. The variable ρ_s is the density of the sediment (assumed to be 2.65), ρ is the fluid density (assumed to be 1), and f_i represents the percentage of the *i*th size fraction in the bed surface.

In order to use this approach to solve for the volumetric bedload transport rate a reference dimensionless shear stress, τ_{ri}^* value is developed. This term is given by the relationship:

$$\tau_{ri}^* = \tau_{rsk}^*(50)(\frac{d_i}{d_{50}})^{-b} \quad (6)$$

where $\tau_{rsk}^*(50)$ and the exponent b vary from river to river, depending on the streambed composition, particle shape, and bed material packing. Equation (6) is termed a "hiding function" because it describes the exposure of a given particle size, d_i, to the fluid forces given the range and packing of all particle sizes present in the bed-material. Once the reference dimensionless shear stress is determined, ϕ_i can be calculated using the relationship:

$$\phi_i = \frac{\tau_i^*}{\tau_{ri}^*} \quad (7)$$

which is simply the ratio of the *i*th particle dimensionless shear stress to the dimensionless reference shear stress for that particle size. The resultant value is then substituted into the Parker bedload function and the volumetric bedload transport rate for any size class can be calculated to a reasonable approximation.

In order to assess conditions on a fine scale, bedload transport rates were calculated for five study sites within Antelope Valley. Without a sufficiently significant amount of data covering a wide range of conditions, uncertainty typically increases as the scale of the assessment decreases. Understanding limitations of the data that were collected within the scope of this project is important when interpreting results. Despite inherent uncertainties, the results provide a sound basis for understanding and assessing the conditions within Antelope Valley. Focusing on relationships rather than absolute values provides a clear qualitative understanding of the geomorphic and hydrologic processes that are occurring. Increasing the amount of data would allow for a more quantitative and precise understanding of these processes, which would be necessary for actual implementation of recommendations outlined in subsequent sections of this report.

The Parker bedload transport function was applied to data from each of the five study sites, and average annual sediment loads were determined based on hydrologic data from complete water years at the Coleville gage. Daily sediment bedloads were calculated and summed over complete water years, then averaged, in order to obtain the average annual bedload. The results of this analysis are summarized in Figure 4-6, where the particle size classes are broadly categorized as sand, gravel, cobbles, and boulders for simplicity.

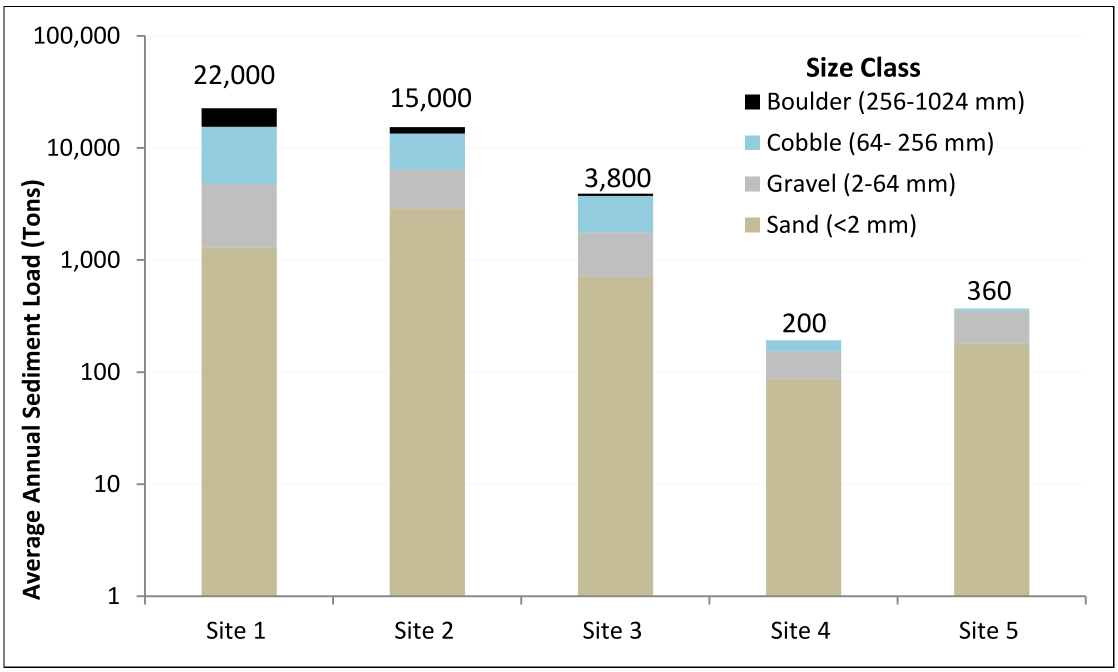

Figure 4-6. Average annual sediment loads for each of the five study sites which represent the various reaches through Antelope Valley.

Effective discharges were determined for each of the study sites by combining the data obtained through developing the flow duration curve (Section 3.3.5), and the results from the bedload transport calculations. The effective discharge of a particular reach typically corresponds to geomorphically significant flows (Andrews, 1980; Andrews & Nankervis, 1995), and determining the effective discharge yields an understanding of the range of discharges that will likely transport a majority of the bedload. The effective discharges throughout the study area ranged from 1,750 to 2,750 cfs, and the results varied between the five study sites, as displayed in Figure 4-7. Once again, particle size classes are grouped into broad categories, for simplicity.

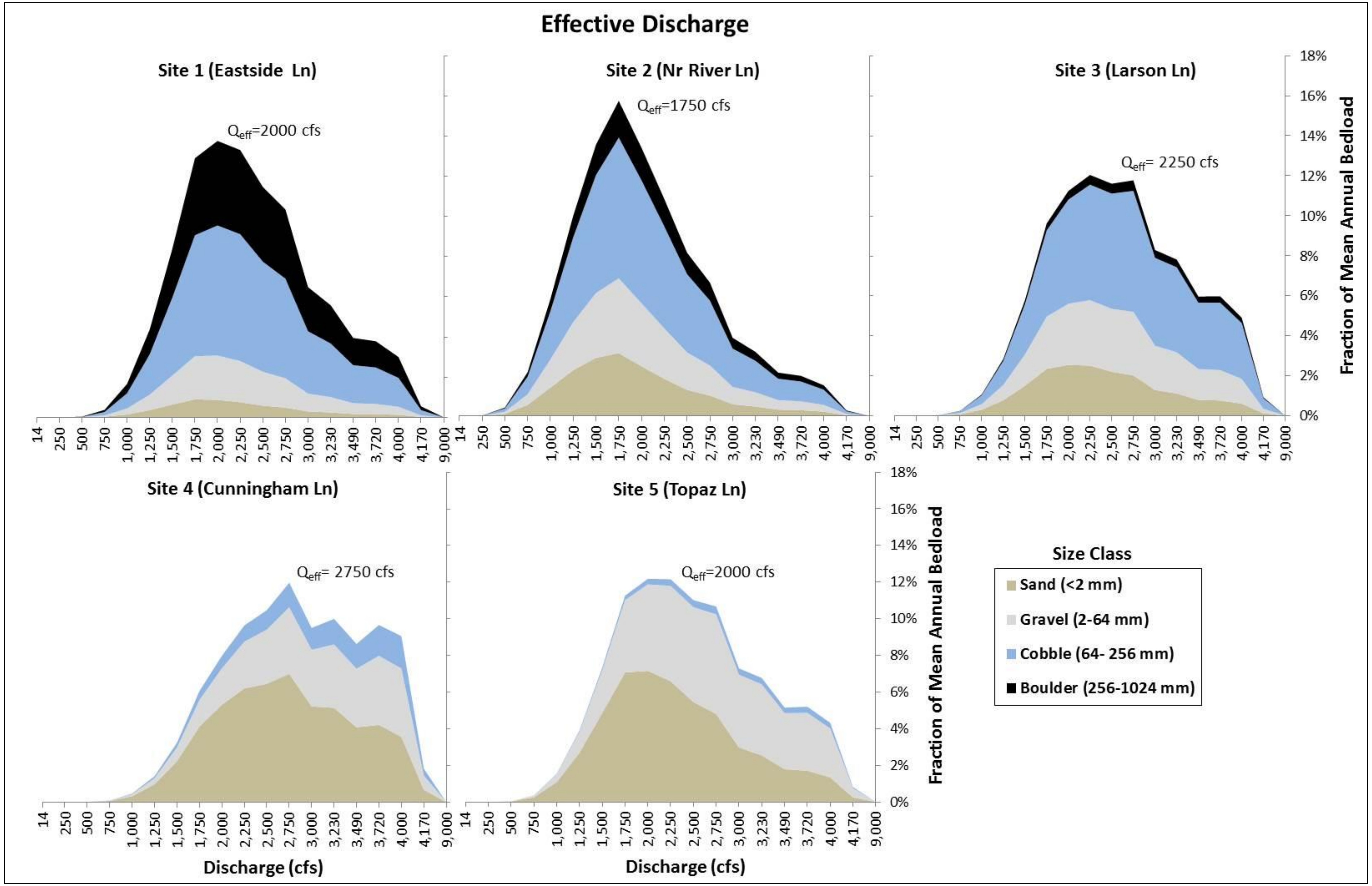

Figure 4-7. Effective discharges for the five study sites.

5 Synthesis of Study Results

To gain an understanding of the driving forces that influence West Walker River hydrology, geomorphology, and sediment dynamics within Antelope Valley, Otis Bay examined the area at different temporal and spatial scales. Looking back in time to prehistoric climate patterns, including occurrences of local glacial deposits and past faulting activity, gives insight into the formation of the Sierra Nevada mountains and Antelope Valley. A large landscape-scale overview of the geology and origins of parent earthen material available for erosion, transport, and deposition by the West Walker River were also examined. On a more local scale, Otis Bay looked at the West Walker River in two broad geomorphic channel segments that included the West Walker Canyon segment and the flatter Antelope Valley segment. Slope, general local climate patterns, hydrologic gage data, and soil material were examined to determine differences in sediment transport and stream behavior between the steeper canyon and flatter valley river segments. Lastly, Otis Bay divided the West Walker River into five geomorphic reaches within Antelope Valley, that varied by channel slope, sinuosity, streambed composition, and channel pattern. These smaller channel reaches were examined; landscape altering effects from the relatively recent 1997 winter flood and channel-modifying construction that occurred after the flood were investigated to determine causes of current sediment deposition patterns and channel migration in Antelope Valley. Understanding these processes is the first step toward determining viable solutions to mitigate for active sediment deposition and channel migration that impairs irrigation structures and farm productivity in a historical ranching community.

5.1 Landscape Context

In Antelope Valley, West Walker River stream pattern is heavily influenced by erosion of weathered granite and glacial deposits in the West Walker River headwaters region. Steep canyon slopes and high forces associated with rare rain on snow flood events can cause major erosion events and sediment inputs to the river system. This parent rock material has been deposited throughout Antelope Valley over time as alluvial fill. An examination shows that when combined with general slope characteristics and stream flow patterns, sediment deposition influences channel migration patterns within the valley.

5.2 Upstream of Antelope Valley

Upstream of Antelope Valley the West Walker River flows through a steep, rocky canyon. The canyon confines the riverine system and floodplain. The 500-year-occurrence flood that occurred with the rain on snow event in the winter of 1997 extensively eroded the canyon. During the flood, copious amounts of sediment were entrained and mobilized downstream, and significant amounts of sediment were deposited at the upper end of Antelope Valley. In response to road destruction and erosion produced by flood waters, Caltrans rebuilt the damaged highway and reshaped the river channel and floodplain.

Whether or not post-flood channel work in West Walker Canyon actually increased erosion, entrainment and transport of sediment into Antelope Valley is unknown because in-depth sediment data have not been measured, but post-flood channel modifications likely increased the potential for these processes to occur. Low floodplain areas created during the flood, or left over from the pre-flood system appear to have been substantially cut off from ordinary high flow levels with post-flood channel modifications, and areas of deposition in West Walker Canyon were probably reduced. Floodplain areas would normally provide temporary storage of water and sediment, and would provide ideal conditions for growth of riparian vegetation. Instead, these areas appear to have been graded to elevations that were too high to create conditions for natural riparian vegetation establishment. Although the flood occurred more than a decade and a half ago, little riparian vegetation establishment has occurred (Figure 5-1). Although more study is needed, post-flood channel modifications on the West Walker River segment through West Walker Canyon may likely have increased fluvial sediment transport, allowing a majority of sediment from upstream sources to be carried by the river to locations farther downstream.

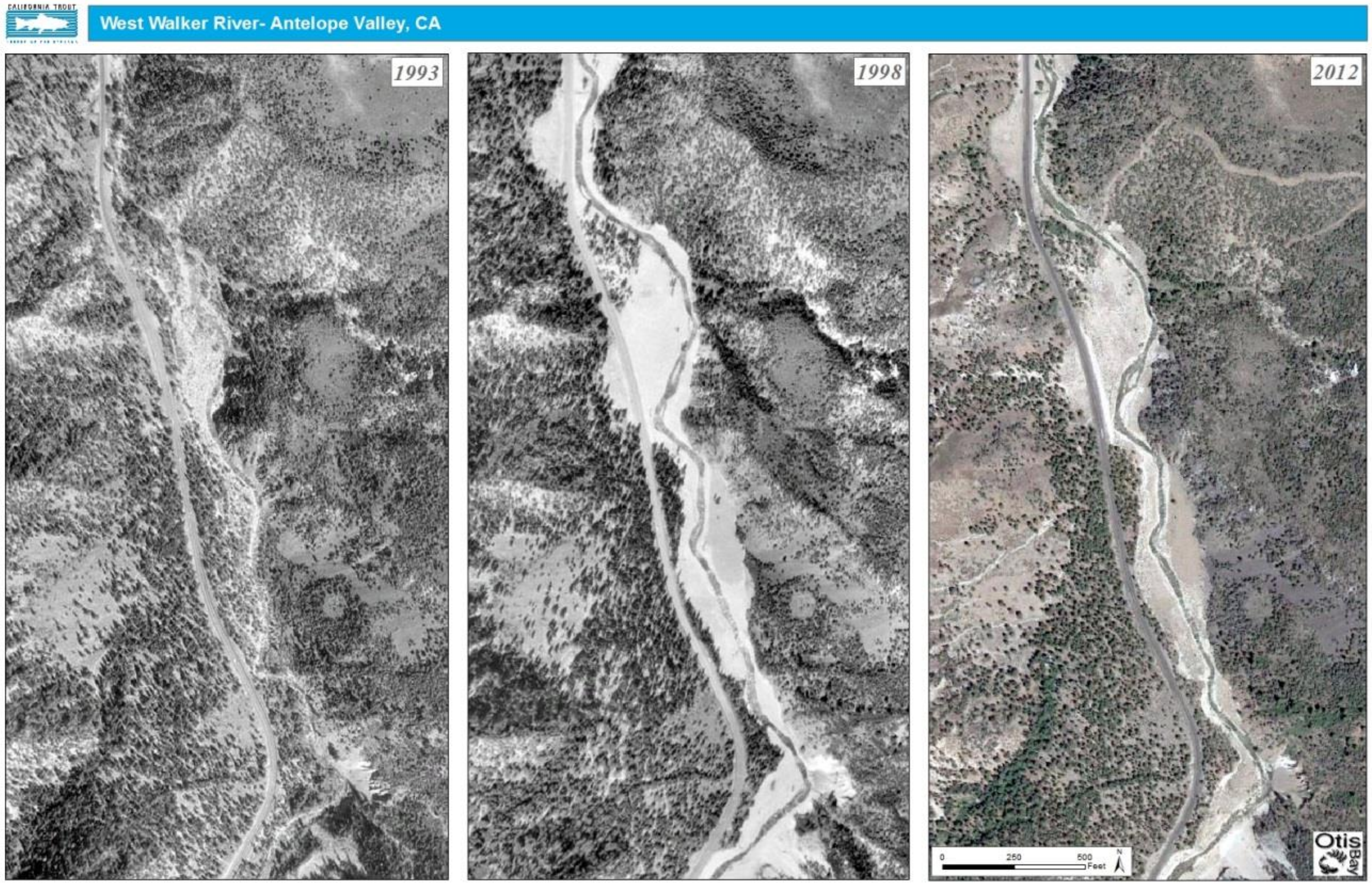

Figure 5-1. Aerial photos of a section of West Walker Canyon from 1993, 1998, and 2012 demonstrate the change in floodplain condition pre and post-flood (left and middle photos), and show no significant changes in riparian growth in 2012, 15 years after the flood. Photos obtained from Google Earth.

5.3 Antelope Valley

Examining Antelope Valley at a fine scale reveals that the river changes character from the top of the valley in the town of Walker to the lower reaches near the Topaz Diversion. Our research identified five geomorphically distinct reaches (Figure 2-1, Figure 2-2 and Table 2-1).

Channel type is a product of the hydrologic characteristics, physical characteristics, and sediment supply (Figure 5-2). At the mouth of West Walker Canyon, where the West Walker River enters Antelope Valley, a constrained alluvial fan has been deposited. Relict distributary channels are visible in older aerial imagery. These channels and fan are a result of flowing water pushing sediment over the fan and building the fan into the valley, similar to the process of a delta forming where a stream channel flows into a lake. The toe of the fan is located near Larson Lane. Downstream of Larson Lane the valley slope flattens, the channel type changes, bed sediment becomes finer and the topography reflects a valley setting rather than an alluvial fan.

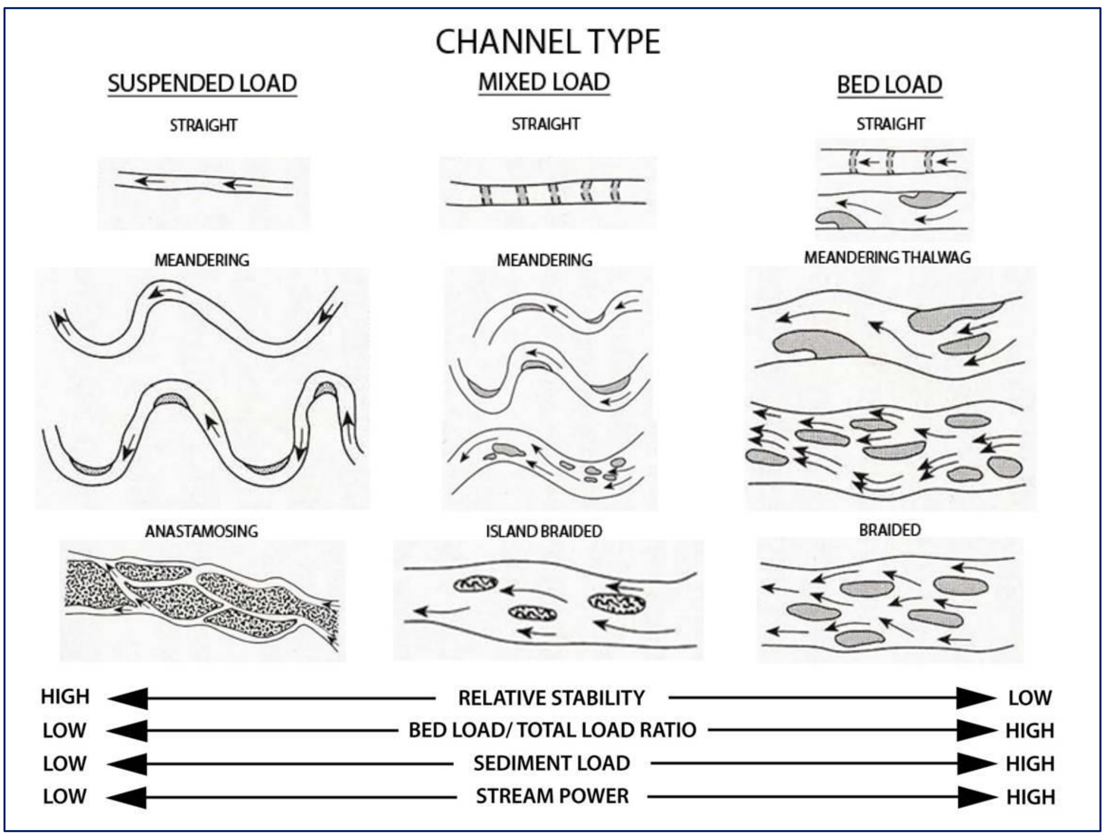

Figure 5-2. Illustration of the range of channel types that may occur (Knighton, 1998). In Antelope Valley the channel types range from high stream power, high bed load, and low stability channel types near the town of Walker to a lower stream power, mixed load, meandering channel near Topaz Lane.

Currently, the active depositional lobe of the alluvial fan is migrating downstream because the channel was artificially incised through the town of Walker by emergency channel modifications made by USACE after the 1997 flood. For a variety of reasons, depositional lobe migration can occur in natural systems. For example, channel incision can begin to occur on an alluvial fan after some significant event such as an abnormally large flood or fault slip, and the newly entrenched channel changes from a distributary, depositional environment to an erosional, transport environment. Typically, the resultant processes happen slowly, and the effects are propagated downstream over a number of years. An example of a naturally incised alluvial fan in northeastern Nevada is provided in Figure 5-3. This image shows the active depositional area of the fan has migrated downstream due to an incised channel that has formed on the original fan lobe.

Figure 5-3. Naturally occurring incised alluvial fan in northeastern Nevada. The active depositional lobe has migrated beyond the toe of the fan.

In the case of the West Walker River through Antelope Valley, channel manipulation for flood control has changed the natural character of the channel on the Antelope Valley alluvial fan. Post-flood construction removed flood deposits and entrenched the channel through Reach 1, which is the residential area (Figure 3-8). The construction that entrenched the West Walker through Reach 1 has resulted in the zone of active deposition to migrate downstream, similar to the process observed on a naturally incised alluvial fan (Figure 5-3): 1) the river reach now confines flow and has increased stream power to transport bed sediment; 2) the entrenchment now supplies sediment to the river as it has become an erosional environment instead of depositional area; and 3) the depositional area has moved to the lower fan and beyond where the channel is not entrenched.

Reach 3 has a flatter slope and is not capable of transporting bed sediment at the same rate as upstream reaches. If more sediment is being delivered to this reach then it would be deposited in the channel, thereby driving channel migration.

5.3.1 *Bedload Sediment Transport and Effective Discharges through Antelope Valley*

Results of the sediment transport analysis suggest that Reach 1 has the capacity to transport a significant amount of sediment, regardless of the size class. This result is consistent with expectations, as the channel at Site 1 is steep, straight, and narrow with tall banks, ultimately resulting in a channel capable of transporting large quantities of sediment. Further, any deposition that would have occurred in this reach prior to the modifications following the 1997 flood is transferred farther downstream, due to disconnection with the floodplain and a lack of overbank storage areas. Therefore, the river in this reach acts as an incised transport system, and allows a majority of the bedload that is transported through West Walker Canyon to be transported through Reach 1 to areas downstream. Similar to the channel within West Walker Canyon, these effects are compounded even further, because by confining peak flows within the channel, high stream velocities and erosive forces cause increased bank degradation, adding increased sediment input to the stream.

Moving downstream, the results suggest that approximately 30% of the calculated bedload is deposited between Sites 1 and 2, and a majority of the deposition consists of particles in the boulder size class (>256 mm). Although the bed slope at Site 2 remains steep (approximately 1.4%), the channel begins to widen and is fairly well connected with the floodplain. This allows for overbank flow at a wide range of discharges and results in deposition of larger particles, especially in overbank areas. Overbank deposition was clearly visible during field visits, and a majority of the large flood debris (house wreckage, refrigerators, etc.) from the 1997 flood was deposited near Site 2. Although some deposition is still occurring through this reach, the effective discharge corresponds with a relatively frequent discharge (2-year flood, 1.75% exceedance), suggesting that particles in the cobble, gravel, and sand size classes are likely to be mobilized and transported farther downstream during most regular high flow events.

As expected, a majority of the sediment deposition occurs between Sites 2 and 3, with over 80% of the calculated bedload that is transported through Reach 1 being deposited before reaching Site 3. The slope flattens significantly and abruptly between reaches two and three, and the river transforms into a semi braided form as it escapes its entrenchment and passes over the lower fan. This analysis solidifies observations made through examination of aerial photographs and field visits, suggesting that Reach 3 serves as the main sediment sink in Antelope Valley, especially for particles in the cobble size class (64-256 mm). The calculated effective discharge is also greater than that of upstream locations, suggesting that particles which are deposited in this reach of river are likely to remain there for a longer duration.

Bed sediment is deposited in Reach 3 as the river is incapable of transporting the quantities of sediment transported from upstream (Figure 4-7). In addition, larger river bed material is selectively deposited as stream power and competence diminishes in the downstream direction. The stream channel type evolves from a braided channel with islands to a single-thread, meandering channel in Reach 3. In this reach the flatter slope diminishes bed sediment transport rates and, therefore, deposits substantial amounts of sediment on exceptionally active, growing point bars.

The effects of such sudden deposition of a large quantity of sediment are frequent channel avulsion and migration, as relatively stable bars and islands are rapidly formed and can significantly alter the course of the river. Although the effective discharge corresponds to a fairly low exceedance probability of approximately 0.5% (Figure 3-10), that discharge has been exceeded seven times since the 1997 flood, suggesting that portions of the large sediment load that are deposited can be mobilized relatively frequently.

This cycle of rapid deposition and re-mobilization of the bedload has likely been exacerbated in the years following the 1997 flood, as any sediment that would have been deposited in upstream reaches is now transported farther downstream. The increase in sediment loading to this segment of river causes channel migration and avulsion to occur more frequently, as compared to pre-1997 flood conditions, when it would have taken multiple high flow events to deposit similar amounts of sediment. Alluvial fan distributary systems are dynamic in nature, and these effects have become much more intensified through human alteration of the system upstream.

Because of reduced slope and spreading of floodwater in the lower reaches, substantial quantities of bed sediment are deposited upstream of Reaches 4 and 5. Sediment transport load calculations indicate that in Reaches 4 and 5, transport rates are much lower than upstream. In fact, in these reaches, average fluvial forces are not adequate to transport bed sediments larger than small cobbles. This deposition drives channel migration and instability.

In summary: 1) Post-flood construction and channel modifications through West Walker Canyon have resulted in an increased sediment transport capacity through the canyon segment, possibly delivering a larger sediment load downstream; 2) The constructed channel through the town of Walker is essentially a man-made incised channel on an alluvial fan, thus promoting deposition farther downstream; and 3) The increased sediment load that arrives downstream as a result of the construction caused the most active area of fan deposition to migrate downstream.

6 Preliminary Recommendations

Remedial actions can help alleviate negative impacts of current river channel conditions:

1. As reported at our field inspection, the Big Slough Diversion carries much sand into irrigation ditches resulting in the need for regular cleaning. On the other hand, the Main Canal Diversion, located upstream, does not exhibit the same problem. In the Main Canal ditches, some fine-grain sediment is periodically cleaned, but the volume is significantly less than the amount of sand removed from the Big Slough system.

   Recommendation:
   - *Redesign the Big Slough Diversion to function similar to the Main Canal Diversion and to reduce the amount of maintenance. The design would realign the river and call for a new diversion structure.*

2. Excess sediment deposition in the dynamic, migrating channel in Reaches 3 through 5 could be mitigated by constructing a system to collect and remove sediment from the system.

   Recommendation:
   - *Design and construct a sediment collection basin. Partners could be instrumental in sharing the cost. For example, this basin could reduce sediment filling Topaz Reservoir and could generate opportunities for cost-share partnerships, or a sand and gravel operator might find sufficient economic value in the sediment as a marketable product.*

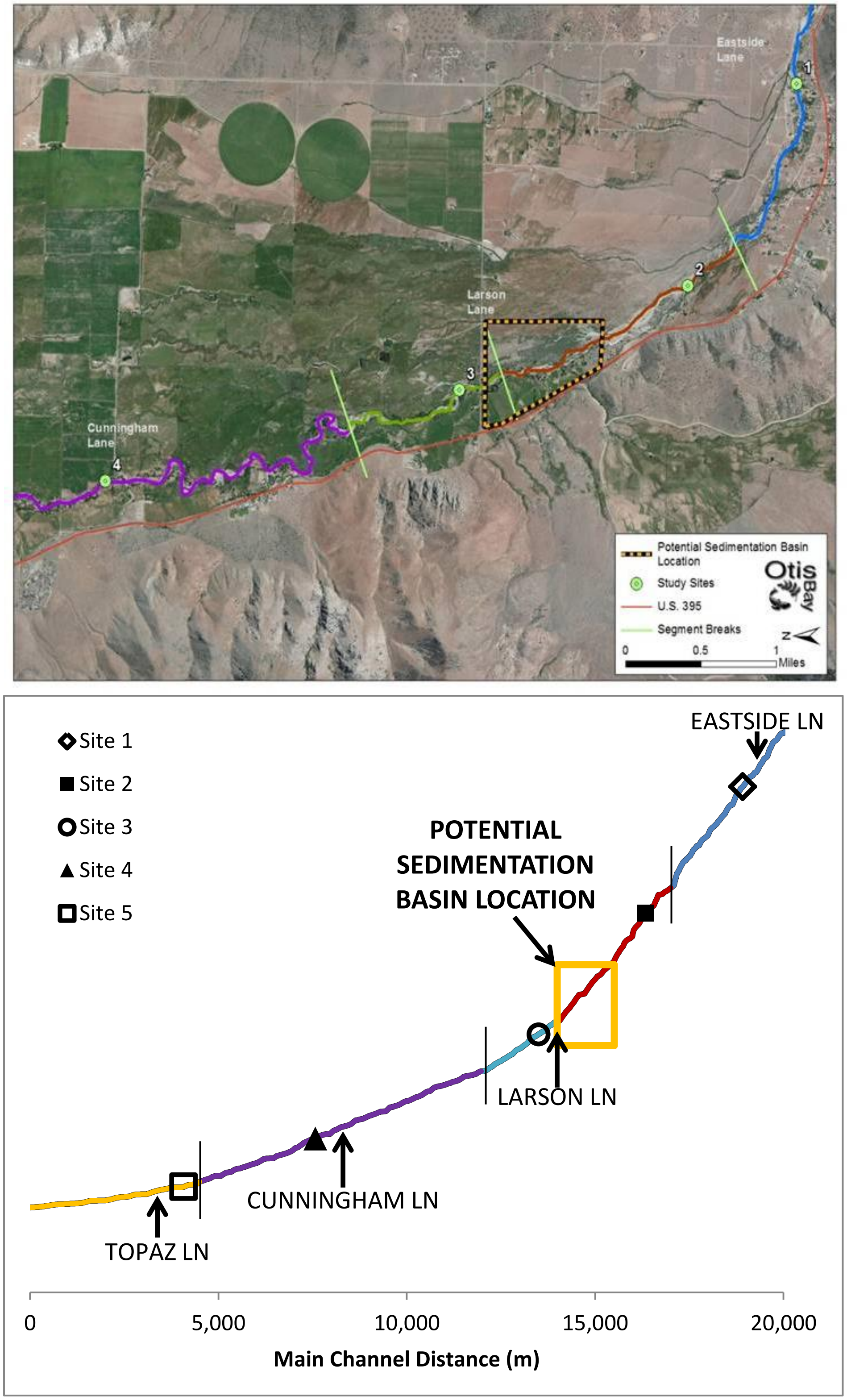

Figure 6-1. Potential location of a sediment catchment basin on the West Walker River near Larson Lane.

3. Sediment load calculations in this report could inherently have large error bars; therefore, measurement of sediment supply could improve the accuracy of the calculated sediment transport rates.

   Recommendation:
   - *Measure bed sediment transport rates during high flow levels in the West Walker River so the sediment transport equations can be fitted to the data. These data should be collected near the Coleville Gage by trained crews.*

4. Perform a detailed assessment of the river and watershed above Antelope Valley to expand upon information presented in the existing West Walker River Basin Watershed Assessment report (Mono County Community Development Department, 2007) and to develop potential restoration solutions.

   Recommendation:
   - *Assess the condition of the stream channel and upper watershed. This assessment will build upon known information and identify specific problem areas that exacerbate conflicts associated with the river in Antelope Valley.*

5. Design and plan enhancement projects and activities for the river channel, floodplain and watershed upstream of Antelope Valley.

   Recommendation:
   - *Employ experts to develop enhancement plans for the upstream river channel and watershed.*

6. To enhance West Walker's ecology and fishery, and to allow the forest to help stabilize the channel, river managers should consider implementing a managed corridor strategy.

   Recommendation:
   - *Develop a managed river corridor to allow dynamic riverine processes that would naturally regenerate a healthy riparian forest.*

7 NEXT STEPS

Our understanding of Antelope Valley river hydraulics and sediment transport has greatly increased with this study. We have formulated general recommendations for improving conditions and correcting problems. Future work in Antelope Valley should focus on designing enhancements for geomorphic Reaches 1 through 5.

In addition to the work completed so far in Antelope Valley, experts and stakeholders should engage a detailed assessment of the upstream river channel and watershed to focus efforts on feasible solutions to issues previously presented in the earlier assessment (Mono County Community Development Department, 2007). Currently, the hydrology and sediment dynamics of the West Walker River, extending from Sonora Pass downstream through Walker Canyon, have not been extensively studied. A hydro-geomorphic study of the upper reaches of the West Walker River leading into Antelope Valley would give a larger landscape-scale understanding of sediment sources and how they are transported throughout the upper watershed and valley river segments. Enhancement of the upper meadow systems and the West Walker River channel, including the canyon reach, could return stream-to-floodplain connectivity and riparian ecological function. These enhancements could help alleviate some of the water quality and channel instability issues occurring downstream in Antelope Valley. More study is needed to determine potential beneficial actions that could be considered upstream of the valley.

Steps that could be considered to determine potential restoration actions above Antelope Valley include:

1. Divide upper basin and tributaries into geomorphic reaches

Geomorphologists should assess aerial imagery, topography, geology, soils and vegetation types, and then divide the upper West Walker Basin into geomorphic reaches that possess similar stream and floodplain characteristics. The purpose of these divisions is to allow planners to develop enhancement strategies for each reach.

2. Complete a detailed watershed assessment with a focus on restoration planning

Scientists should be employed to complete in-depth hydrological and sediment transport studies of the upper West Walker drainage areas and tributaries. The assessment would build upon existing knowledge (Mono County Community Development Department, 2007) and consider stream channel state, vegetation condition, sediment supply, sediment transport, wildlife ecology and processes that drive the ecosystem. This detailed assessment would provide additional knowledge to inform ongoing, coordinated planning efforts (Alpert, et al., 2014) for West Walker stream and basin enhancement.

3. Collect high-flow sediment samples at several locations upstream of Antelope Valley

Geomorphologists should be employed to collect bed sediment and suspended sediment at key sites upstream of Antelope Valley, including the USGS Coleville Gage site. This information can be used to accurately determine the rate of sediment movement in the watershed and provide a baseline for monitoring the efficacy of enhancements.

4. Formulate a vision

Planners should formulate a vision for desired future condition for each geomorphic reach or sub-reach upstream and within. Restoration planners, working with stakeholders, should discuss the natural range of variability inherent in the riverine system and choose a common goal that falls within that range. This vision will inform and direct an upper watershed and river channel restoration and enhancement plans.

5. Develop management and monitoring plans

Stakeholders, working with experts, should develop a drainage basin management plan that will guide the improvement of watershed conditions to a desired future condition. Planners would have to work with stakeholders in the basin to develop a consensus strategy for land management. A corresponding monitoring plan will provide methods to quantitatively track changes in watershed conditions.

6. Develop and design enhancement plans for geomorphic reaches and sub-reaches

Enhancement action requires development of a plan to guide improvement activities; therefore, qualified restoration designers should use information gained during the assessment to formulate these action plans. Scientists, with the input from stakeholders, should create these plans for each reach or sub-reach. These plans could range from recommending new land-management strategies to designing river and floodplain restorative construction.

7. Prioritize and implement restoration and enhancement projects

After conditions within the watershed and Antelope Valley have been assessed and potential management or restoration actions have been determined, experts and stakeholders should rate, rank and prioritize the enhancement projects. The prioritization should consider: 1) the effectiveness of the proposed action in resolving recognized issues; 2) the feasibility of completing the project; 3) the cost-benefit relationship associated with the proposed action; and 4) the consideration of using active verses passive action.

8. Organize stakeholders and obtain restoration funding

An existing or newly created organization/agency should be used to organize stakeholders, facilitate the planning effort, seek funding, hire experts, coordinate the designs and implement high priority projects.

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