Chapter 4.1
HYDROLOGY AND GEOMORPHOLOGY

4.1.1 Introduction

Hydrology is the science (or study) of the different forms of water in the natural environment with a focus on the circulation and distribution of water as expressed in the hydrologic cycle or a water balance (Goudie, 1994). *Geomorphology* is the study of the earth's surface, its landforms and the processes which shape them. Within geomorphology, fluvial geomorphology is the more specific study of rivers and streams, and typically includes aspects of hydrology (the quantity and timing of watershed runoff that enters the river), hydraulics (the behavior of water flows in the river), and sediment dynamics (how sediment is variably eroded, transported, and deposited along the river continuum). This section evaluates the potential for the Proposed Program to affect the geomorphic form and function of rivers, streams, and lakes within the State. While the disciplines of fluvial geomorphology, hydrology, and hydraulics are extensive, the focus of this section is to consider how streamflow, stream and river features, and river (or fluvial) processes affect the functions and values of aquatic and riparian habitats and water quality conditions. As such, this section provides a foundation for and supports the information presented in Chapters 4.2 *Water Quality and Toxicology*) and 4.3 *Biological Resources*. Specifically, this section: (1) provides a broad overview of the existing hydrologic and geomorphic setting throughout the State, (2) discusses potential impacts to these resources associated with the Proposed Program activities, and (3) provides findings and determinations regarding the significance of these impacts.

Sources of Information

Three general types of literature were reviewed to support the findings and determinations within this section. These include:

1. Studies specific to suction dredge mining;
2. More general geomorphic investigations that describe channel processes or features that are relevant to understanding the geomorphic effects of suction dredge mining; and
3. California resource investigations that describe general geologic, mineral, or other resource conditions in the California regions where suction dredge mining primarily occurs.

The most relevant studies that specifically focused on (or included key discussion of) the geomorphic effects of suction dredge mining were generally peer-reviewed or professional publications that employed scientific methods to evaluate the effects of suction dredge mining. Many of these studies included field observation and data collection from California streams and rivers where suction dredge mining has occurred. Other studies used data collected from other Western U.S. states, including Alaska, Idaho, Montana, and Washington. Some studies, including Thomas (1985), used a more experimental approach, whereby a suction dredge rig was operated and monitored in a natural setting to observe and record its effects. Most of the studies referenced for this evaluation were developed to relate how geomorphic effects influence biological and habitat conditions. Many of these same studies are relevant to Chapters 4.2 and 4.3 for their coverage of water quality, biology, and habitat issues.

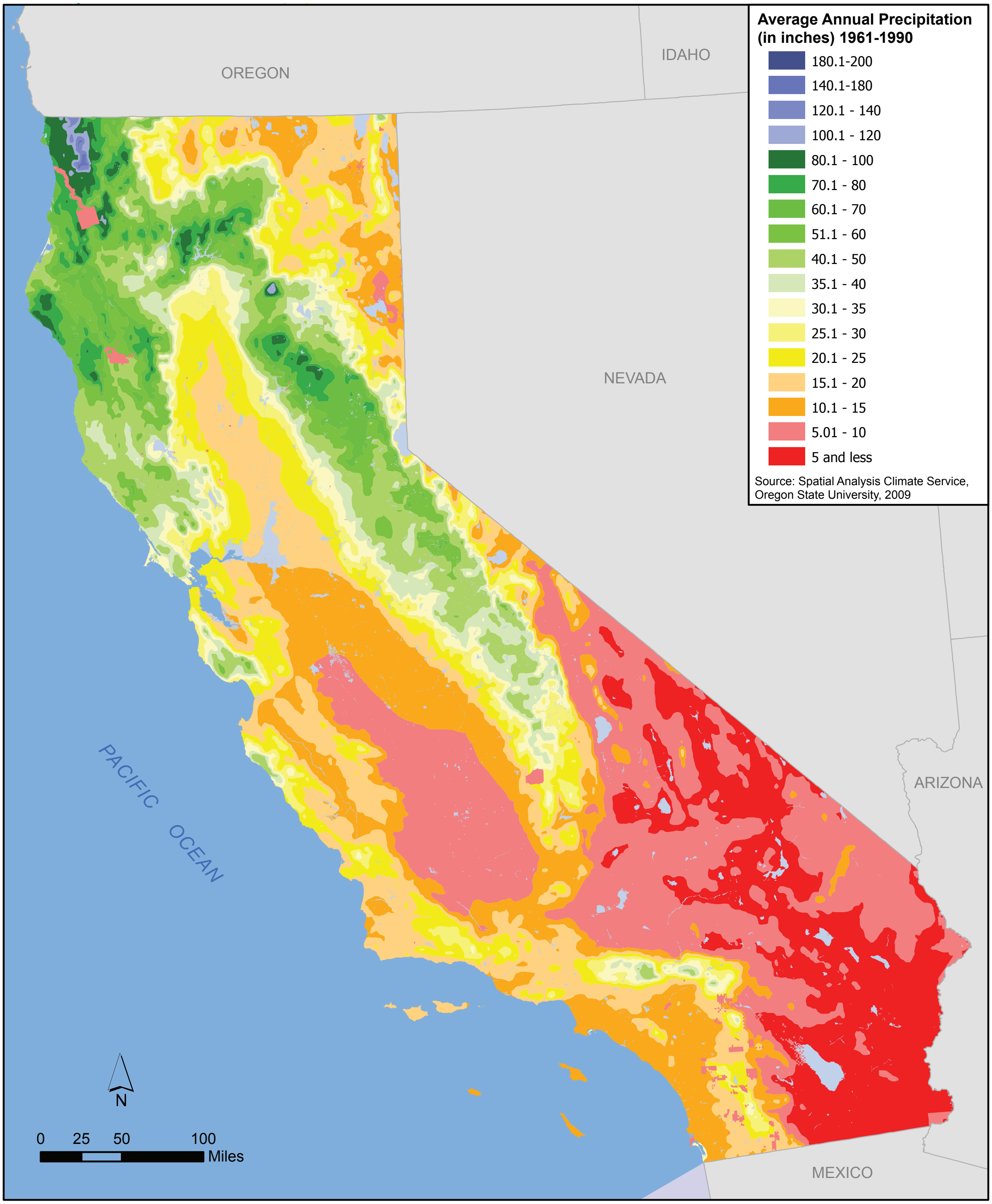
4.1.2 Environmental Setting

The Proposed Program setting includes the entire State of California. In the past, popular locations for suction dredging activities have included the perennial rivers and streams within the Klamath Basin, the Mother Lode Region of the Sierra Nevada, and to a lesser extent, coastal watersheds in southern California (e.g., San Gabriel River watershed). However, the Proposed Program does not limit the activity to these areas, therefore all freshwater streams and lakes and adjacent lands were considered in the environmental setting of this EIR. The existing baseline condition (upon which the Program impact evaluation is applied in sections 4.1.3 and 4.1.4, below) includes past and continuing impacts to aquatic and riparian resources associated with historical (or previous) suction dredge mining activities.

California Hydrology and Climate

Surface water hydrology (primarily runoff and streamflow) is largely a function of climate, land cover, soil, and water resource management (e.g., the capture, storage, release, and transfer of water throughout the state). The majority of California experiences a Mediterranean climate characterized by warm, dry summers and cool, wet winters. However, climate can vary greatly throughout the State depending on latitude, elevation, proximity to the coast, and other site-specific conditions which may create micro-climates. Mean annual precipitation ranges from less than 5 inches throughout most of the Mojave Desert, to over 100 inches in the redwood forests along the North Coast (Figure 4.1-1). Precipitation is mainly concentrated in the winter months and falls primarily as rain along the coast, inland valley and foothills. Significant snowfall occurs in the mid to higher elevations (typically >5,000 ft above mean sea level [msl]) of mountainous regions, particularly the Sierra Nevada, Cascade, Trinity, and Klamath ranges. The generally north-south (or northwest-southeast) trending mountain ranges in the State (e.g., Sierra Nevada and Coast Ranges) exert a strong orographic effect on incoming storms resulting in higher precipitation totals along the western (or windward) side of the ranges, and drier conditions on the eastern (or lee) side where a “rain shadow” effect is often observed. Weather in California is subject to high annual variability as well as longer term climatic cycles, including the Pacific-North American Oscillation, the El Nino Southern Oscillation, and the Pacific Decadal Oscillation (Andrews et al., 2004). These cycles affect temperature, precipitation, and the frequency of extreme weather events.

Rainfall, land cover, soil structure and moisture conditions, slope, watershed size, snowmelt, and releases from reservoirs and other factors all influence the magnitude and duration of streamflow (or discharge) in rivers and streams. In California, unregulated streams along the coast, in the many inland valleys, and throughout the semi-arid and arid regions of the south and east generally demonstrate a rapid runoff response to rainfall



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Horizon WATER and ENVIRONMENT

Figure 4.1-1
Average Annual Precipitation in California

events. Such "flashy" hydrologic systems are noted for the short lag-times between rainfall and peak discharge and show very steep (needle-like) rising limbs of storm hydrographs (for example, see the hydrograph for Sespe Creek shown on Figure 4.1-2). A hydrograph is a graph or measure of streamflow over time, typically with discharge plotted along the vertical axis and time charted along the horizontal axis. Rapid and intense runoff response to rainfall is even more pronounced in the State's urban areas where a higher proportion of impervious surfaces generate more runoff and storm related discharge.

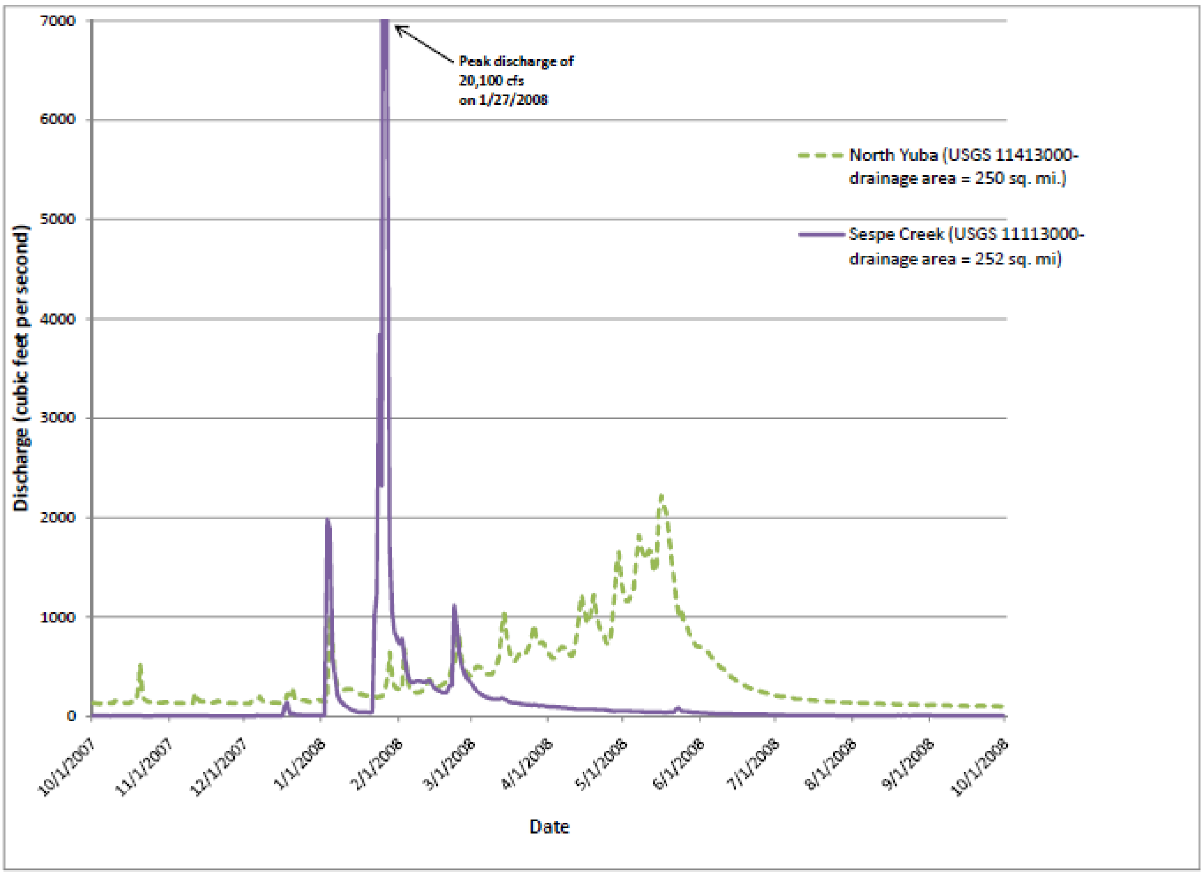


FIGURE 4.1-2: CALIFORNIA ANNUAL HYDROGRAPHS – COMPARISON OF SEMI-ARID AND SNOWMELT WATERSHEDS

(USGS, 2010)

In contrast, in California watersheds with significant snowfall, streamflow hydrographs are generally less episodic in responding to individual winter storm events and have a more seasonal discharge pattern (for example, see the hydrograph for North Yuba River shown on Figure 4.1-2)[1]. In such areas streamflow hydrology is governed by the relative abundance of the year's snowpack and the timing and extent of the snowmelt season.

[1] The North Yuba River hydrograph for the 2007-2008 Water Year is used to illustrate snowmelt-driven hydrology. However, it should be noted that the North Yuba River watershed experiences a mixed rain-snow climate, and discharge may be "flashy", particularly during warm storm events with high snow levels.

Snowmelt watersheds exhibit more uniform annual hydrographs, with peak runoff typically occurring between April and June, depending on elevation. In addition to the spring seasonal snowmelt, "rain-on-snow" events may cause even higher peak discharges. These rapid snowmelt events can occur throughout the winter season, typically associated with a southern swing of the jet stream that brings moisture laden sub-tropical air masses cyclonically against the Sierra Nevada. In these events, temperatures are warm enough and air moisture capacities high enough to maintain rainfall precipitation as high as 8,000 or 9,000 ft above msl. When this occurs a tremendous runoff event is generated that can progress downstream throughout the larger watersheds of the Sierra Nevada, Klamath, or Cascade ranges.

Typically, rain-on-snow events are of a higher magnitude and occur most frequently during the winter months, whereas the peak snowmelt-driven events are of a lower magnitude and occur in spring. This hydrologic setting creates a bimodal distribution of flood events i.e., there is a population of floods associated with snowmelt events, and a distinct population of floods generated from rain-on-snow events that occur, on average, once every 10 years.

Many of the areas used by suction dredge miners are on flow-regulated streams downstream of dams. On these systems, peak downstream discharges are reduced, flow frequency/duration relationships are more equitable (less extreme), and baseflow discharge (seasonal baseline streamflow that is not directly attributable to a precipitation event) is typically extended into the later spring, summer, and fall months. Dam operations may also generate sudden changes in discharge.

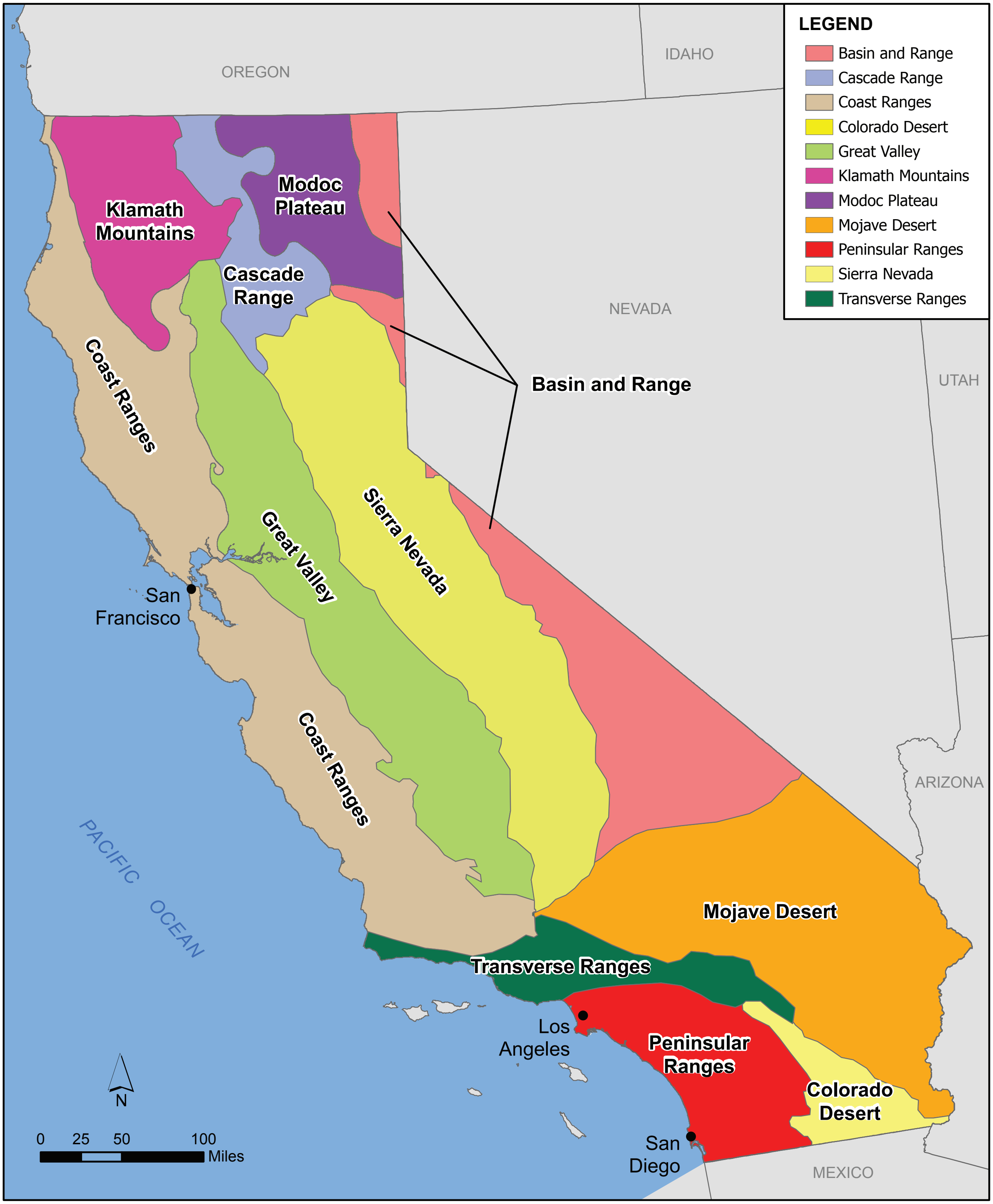
California Geomorphology

This section describes the major geomorphic provinces of California, and provides a broad overview of the geomorphology of the rivers and streams in the State.

Geomorphic Provinces

Geomorphic provinces are naturally defined geologic regions that display a distinct landscape or landform type. Eleven geomorphic provinces are identified in California (CGS, 2002) (Figure 4.1-3). Each province has its own unique, defining features based on geology (rock types, history, and structure), topography, and climate. Summaries of the eleven geomorphic provinces in California are presented below based on a 2002 report by the California Geological Survey.

The **Klamath Mountains** have rugged topography with prominent peaks and ridges reaching 6,000-8,000 feet above msl. Though a different geologic history than the Sierra Nevada, in terms of topography, the Klamath province can be considered as a northern extension of the Sierra Nevada range. The main stem Klamath River follows a circuitous course from the Cascade Range (northeast) through the Klamath Mountains to the southwest. In the western Klamath, an irregular drainage network has incised into an uplifted plateau called the Klamath peneplain. The uplift (and resulting drainage incision) has left successive benches with gold-bearing gravels deposited on the sides of the canyons. Some of this material is transported to the stream system below. Historically, the Klamath Mountains province has seen a high level of use by suction dredgers. Suction dredge activity has been particularly concentrated in the main stem Klamath, Scott and Trinity rivers.



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Horizon WATER and ENVIRONMENT

Figure 4.1-3
California Geomorphic Provinces

The **Cascade Range** is a chain of volcanic cones that extends from northern California north through central Oregon and Washington. In California, the province is dominated by Mount Shasta, a glacier-mantled volcanic cone, rising 14,162 feet above msl. South of Mount Shasta and the southern termination of the Cascade Range is Mount Lassen (10,462 feet msl), which last erupted in the early 1900s. The Cascade Range is transected by deep canyons of the Pit River. In its headwaters, the Pit River exits Goose Lake and traverses the Modoc Plateau (a volcanic table land) before flowing through the lava rich and volcanic landscape between the Mount Shasta and Mount Lassen peaks. The Pit River then descends toward Lake Shasta and the confluence with the Sacramento River.

The **Modoc Plateau** is a volcanic table land (elevation 4,000- 6,000 feet above sea level) consisting of a thick accumulation of lava flows and tuff beds along with many small volcanic cones. Occasional lakes, marshes, and sluggishly flowing streams meander across the plateau. The plateau is cut by many north-south faults. The province is bordered by the Cascade Range to the west and the Basin and Range province to the east and south. Streams emanating from the Modoc Plateau may extend to these neighboring provinces, noting that discharge to the east that flows into the Basin and Range province remains as interior drainage, while flows draining to the west enter the Sacramento River system.

The **Sierra Nevada** Range is the most significant topographic and geomorphic feature in California. The range is a tilted fault block nearly 400 miles long. It is geologically complex, with a history that dates to island-arc collision in the Triassic, with subsequent subduction tectonics and the forming of the signature granitic batholith through the Jurassic and Cretaceous periods. More recently in the Tertiary period, and especially during the last 4 million years, the extensional faulting of the Basin and Range province to the east, along with a tilting of the Sierra block to the west produced a “trap door” mountain building event. As a result, the eastern face of the Sierra Nevada Range formed a rugged escarpment with a steep topographic descent to the Mono and Owens valleys to the east. In contrast, along the western Sierra Nevada a more gently sloping range (about 2%) ascends from the Central Valley and lower foothills of the range. Along its spine (axis), the range is lowest at its northern end, transitioning to the volcanic Cascade Province further north, and rises to its peak elevation at Mount Whitney (14,495 feet above msl) in its southern-central zone. Lode and some placer gold in the Sierra Nevada has its source in the metamorphic rocks formed during the Mesozoic era subduction process, whereby veins of gold solidified in the cooling magmatic intrusion. Subsequent exposure, uplift, and erosion of the range transported and deposited gold as placer deposits in the sedimentary terraces and benches along the Sierra river courses and canyons. In addition, gold-rich, Eocene-age river channels course across the western Sierra Nevada slope and have been “robbed” of their gold when eroded by today’s Sierra Nevada Rivers. These Eocene-age river channels located on ridges often 1,000 feet or more above today’s rivers were the primary targets of hydraulic gold mining. More recently Quaternary period glacial advance and retreat cycles resulted in high sediment loads to the main downstream large rivers. The principal rivers of the Sierra Nevada Mother Lode include the Yuba, American, Cosumnes, Mokelumne, Stanislaus, and Tuolumne rivers. These principal rivers of the Mother Lode and their tributaries have been the focus of intensive suction dredging activities in recent decades.

The **Great Valley** is a north-south oriented alluvial plain about 50 miles wide and 400 miles long in central California. Its northern section is the Sacramento Valley, drained by the Sacramento River and its southern part is the San Joaquin Valley drained by the San Joaquin

River. The Great Valley is a trough in which sediments have been deposited almost continuously since the Jurassic period (about 160 million years ago). Great oil fields have been found in southernmost San Joaquin Valley and along anticlinal uplifts on its southwestern margin. In the Sacramento Valley, the Sutter Buttes, the remnants of an isolated Pliocene epoch volcano, rise above the valley floor. Historically, there has been limited, if any, suction dredging in this province. The deep alluvium on the valley floor is not likely to contain concentrated gold deposits that could be effectively mined with standard suction dredging equipment.

The **Coast Ranges** are northwest-southeast trending mountain ranges with peak elevations ranging from 2,000 to 4,000 feet msl, with occasional peaks exceeding 6,000 feet above msl. The range follows the California coastline north of Point Conception running generally parallel to the San Andreas Fault system. The bulk of the Coast Ranges are comprised of thick marine and non-marine Mesozoic and Cenozoic sedimentary strata. The northern and southern ranges are separated by a structural depression containing the San Francisco Bay. The northern Coast Ranges are dominated by irregular, knobby slopes, many with active landslides developed in the surface rocks of the Franciscan Complex. The eastern transition from the Coast Ranges to the Great Valley is characterized by sequential strike-ridges and valleys that terminate along the western boundary of the Great Valley. Between the many parallel ridgelines of the Coast Ranges are alluvial valleys, again oriented with the general alignment of the San Andreas Fault system. The immediate coastline along the Coast Ranges includes embayments such as San Francisco and Monterey bays with their surrounding baylands and lowlands, as well as uplifted, terraced and wave-cut platforms and older hard rock complexes. Prominent rivers and streams of the Coast Ranges include the Eel, Russian, Napa, Putah, Alameda, Coyote, Guadalupe, San Lorenzo, Pajaro, Salinas, Santa Maria, and Santa Ynez systems. Most of these rivers travel parallel to the orientation of the surrounding ridgelines and valleys. Some rivers drain to the San Francisco and Monterey bays, while others drain directly to the coast through crossing the ranges.

The **Transverse Ranges** are an east-west trending series of extremely steep mountain ranges with interspersing valleys. The east-west structure of the Transverse Ranges is oblique to the general alignment of coastal California, hence the name "Transverse." Intense north-south compression is squeezing and uplifting the Transverse Ranges. This compression along with the rotation of the ranges has created a unique “transpressional” situation with some of the highest rates of tectonic uplift measured on Earth. The province includes the San Gabriel, Santa Susana, Santa Monica, Santa Ynez, and San Bernardino mountains, as well as the Santa Barbara Channel Islands. The highest elevation in the province is 11,503 feet, at San Gorgonio Mountain in the San Bernardino Range. While the lower elevations in the province are known for their mild Mediterranean climate, the steep ridgelines and higher elevations of the ranges generate a strong orographic effect. This effect is exacerbated when cyclonic storm tracks northerly rotation strike the face of the ranges acutely. This orographic effect greatly increases precipitation intensities and amounts. El Niño conditions (approximate decadal oscillation) further intensify rainfall amounts. High intensity episodic storm events together with a relatively high frequency fire ecology of the coastal sage and chaparral communities creates extremely high sediment yields, particularly in the post-fire scenario. Alluvial fans and large valleys and basins at the base of the mountain ranges store abundant sediment deposits. Great thicknesses (in excess of 35,000 feet) of Cenozoic petroleum-rich sedimentary rocks have been folded and faulted, making this one of the important oil producing areas in the United States. The primary rivers of the region include the Ventura, Santa Clara, Los Angeles, San Gabriel, and Santa Ana systems.

The **Peninsular Ranges** province follows the coastline of southern California in Orange, Riverside, and San Diego counties and extends inland to the watershed divide to areas that drain east to the Colorado Desert province. The Peninsular Ranges are bound to the north by the Los Angeles Basin of the Transverse Ranges and extend into Baja California (Mexico) to the south. The province includes the Santa Catalina, Santa Barbara, and the distinctly terraced San Clemente and San Nicolas islands. The Peninsular Ranges are oriented generally north-south, parallel to the coast. While their alignment is similar to the more northerly Coast Ranges, the structure and geology of the Peninsular Ranges is quite different from the sedimentary rocks of the Coast Ranges. The geology of the Peninsular Ranges is more similar to the Sierra Nevada, with granitic rock intruding older metamorphic rocks. The coastal margin includes geologically young and well developed marine and fluvial terraces (sedimentary deposits) that have been uplifted and dissected by local streams. Primary rivers and streams in the province include the San Juan, Santa Margarita, San Luis Rey, San Dieguito, San Diego, Sweetwater, Otay, and Tijuana systems.

The **Mojave Desert** province is a broad interior region of isolated mountain ranges separated by expanses of desert plains. It has an interior enclosed drainage and many evaporative lake beds (playas). The Mojave province occupies the wedge east of the intersection of the Garlock and San Andreas fault zones, south of the Sierra Nevada and east of the Transverse Ranges. The primary river systems of the Mojave Desert include the Mojave and Colorado Rivers, though the Colorado River drains the large Colorado Basin of the interior continent and is the eastern boundary of the province. While there have been several historic (and current) gold mines in the Mojave Desert province, most of these mines have been pit type mines. There was some placer deposit mining in the 1930s along the alluvial fan outwash plains to the Yellow Aster Mine, but this practice is not documented in the current period (Norris and Webb, 1990).

The **Basin and Range** province in California is located east of the Modoc Plateau and Sierra Nevada provinces, representing a very small portion of the western edge of the Great Basin which extends into portions of Oregon, Nevada, Idaho, and Utah. This province is characterized by interior draining streams that flow to lakes and playas with no ocean outlet. The extensional normal-faulting of the Basin and Range results in parallel fault-bounded ranges separated by down-dropped basins. Death Valley, the lowest area in the United States (280 feet below msl at Badwater), is one of these down-dropped basins (or grabens). Another basin, the Owens Valley, lies between the bold eastern escarpment of the Sierra Nevada and the Inyo Mountains. The northern Basin and Range Province includes the Honey Lake Basin. Lying east (in the rain shadow) of the Sierra Nevada and Cascade ranges the Basin and Range is an arid zone with limited runoff.

The **Colorado Desert** province of southeastern California is commonly known as the "low desert" because of its relatively low elevation compared to the higher regions of the Peninsular Ranges to the west and the Mojave Desert ("high desert") to the north. Most of the Colorado Desert province lies below 1,000 feet msl, with extensive areas around the Salton Sea below msl. The province is extremely arid with high summer temperatures. The landscape includes extensive dunes, alluvial plains, and ancient beach forms and silt deposits associated with Pleistocene epoch Lake Cahuilla.

4.1.3 Impact Analysis

The methodology described below accounts for activities conducted in accordance with the proposed regulations contained in Chapter 2. Additional or more extensive impacts related to hydrology and geomorphology may result for suction dredge activities requiring notification under Fish and Game Code section 1602. Notification is required for the following activities:

- Use of gas or electric powered winches for the movement of instream boulders or wood to facilitate suction dredge activities;
- Temporary or permanent flow diversions, impoundments, or dams constructed for the purposes of facilitating suction dredge activities;
- Suction dredging within lakes; and
- Use of a dredge with an intake nozzle greater than 4 inches in diameter.

A general description of how such activities requiring Fish and Game Code section 1602 notification would deviate from the impact findings are described at the end of the impact section below.

Findings of 1994 Environmental Impact Report

In the 1994 EIR, The effects of suction dredge activities were found to have potentially negative effects on stream substrate by channelizing streams, increasing embeddedness of substrates downstream, and developing dredge holes and tailings piles. However, the 1994 EIR concluded that the regulations adequately addressed these potential effects such that there would be a less-than-significant impact.

Methodology

Geomorphic Approach for SEIR

Fluvial geomorphology involves studying a stream's historic evolution, its morphology (form), and the processes that shaped the stream's form. In terms of form, a river or stream can be described according to its width dimension (cross-sectional geometry), pattern (planform alignment or sinuosity), and profile (slope or gradient). In terms of the shaping processes, a geomorphic evaluation considers many natural and anthropogenically-driven variables and the complex interactions between these variables. At the landscape-scale, the most critical independent forces that influence the morphology of California's rivers and streams are topography, geology and climate. Topography, which is largely shaped by the interaction between plate tectonics and regional geology, is responsible for the major geomorphic provinces throughout the State (described in the previous section). At the province and watershed-scale, climate and hydrology interact with topography and geology to form drainage networks. At the individual river or reach-scale, channel form and function are largely dependent on the balance (or imbalance) between the streamflow (discharge), sediment load (type and amount) and the channel's width, depth, and slope. Land use practices and riparian vegetation are also important variables affecting channel morphology at the reach scale.

This EIR considers all rivers, streams, and lakes of the State as part of the Proposed Program Area. This represents an enormously diverse set of geomorphic conditions from steep, bedrock-dominated streams in the headwaters of the San Gabriel Mountains of southern California, to low gradient meandering rivers in the Central Valley. Rivers and streams that have historically been, and are likely to be, the focus of suction dredging activities are generally located in foothill and mountainous regions, most notably in the Klamath Mountains, Sierra Nevada, and Transverse Ranges. These streams have variable morphology, but some common characteristics that make them attractive to suction dredging. They are generally moderate to high gradient streams with prominent bedrock exposures with a shallow layer of alluvium over bedrock. Regardless of the precise location or setting, general principles of fluvial geomorphology such as deposition, erosion and transport, are applicable. These general principles form the basis of the impact analysis and discussion presented in the following section.

Role of Dams and Reservoirs

A special hydrologic and geomorphic consideration for suction dredge mining in California is the role and effects of dams and reservoirs. Dams and reservoirs alter the natural hydrograph of streams by retaining and detaining flows. This typically results in reduced peak discharges downstream of dams with a seasonal (or longer) extension of higher maintained base flows. In California this may result in reduced peak and average daily discharges following winter storms and during spring snowmelt. Summer flows downstream of dams/reservoirs may be higher and involve higher stream velocities than typically expected in the summer dry season. The specific hydrologic effect of a dam/reservoir will be dependent on the conditions of the river system, as well as the designed objective and operational management of the dam and reservoir system.

Dams and reservoirs also affect sediment processes. Depending upon a dam's design and trap efficiency and the characteristics of the sediment load of the contributing streams, sediment will be variably deposited (and stored) behind the dam or transported downstream. Over time large reservoirs can trap a significant portion of a stream's overall sediment load, and particularly trap larger, non-suspended sediments (i.e., bed load). Depending upon the dam's release structure and design, discharge downstream of the dam may possess sufficient stream energy to transport sediment. However, the actual sediment load of the discharge is typically absent. This release of "clean water" has been observed to lead to a "hungry water" condition, whereby excess energy is expended on erosion of the channel bed and banks for some years following dam construction. These processes may result in channel incision (the downcutting of the bed) and a general coarsening of the bed material (Kondolf, 1997). Other downstream geomorphic and ecological adjustments related to dams include channel narrowing, fine sediment accumulation and vegetation encroachment. Dams may also result in shifts in riparian community composition due to modified hydrology, seed dispersal mechanisms and flood disturbance regimes.

Geomorphic Effects of Suction Dredging

The effects of suction dredging on rivers and streams can be likened to, or described in terms of, geomorphic processes. A suction dredge event of any scale or magnitude will instigate some degree of erosion, transport, and deposition of sediment, along with some potential modification of the channel form and streamflow hydraulic conditions. Thus, from a geomorphic perspective, the effects that a suction dredging operation has on a river or stream can be described in the following context:

1. ***Erosive processes****:* include the physical mobilization of alluvial sediment by the suction nozzle, which results in the scouring of the channel bed. Stream bed erosion can include the creation of scour potholes, the deepening of existing pools, and the removal of sediment from in-channel depositional features such as longitudinal bars and riffles.
2. ***Transport processes***: occur as sediment is passed through the suction dredge rig and discharged back to the river. Upon discharge, sediment is suspended in the water column and is available for downstream transport.
3. ***Depositional processes***: occur following transport, whereby sediment variably settles and deposits according to its particle size, density, and shape. Streamflow conditions (including flow velocity, river stage, channel roughness, channel alignment, presence of structures, etc.), also influence the rate of settling and deposition. Coarse and heavy sediment will deposit near the discharge location, while finer and lighter materials are carried further downstream in the water column before settling. Another depositional process related to suction dredge mining (though not caused by the dredge rig itself) is the hand piling and rolling of cobbles and small boulders (i.e., sediment too large to be entrained by the suction nozzle) in other locations within the channel bed by miners to access the finer sediments at depth.
4. ***Other hydraulic processes***: include the redirecting of in-channel flows as the result of miners' placement of river cobbles and boulders. Existing instream flow paths can be disrupted by such structural changes along the stream bed, with flows being channelized, or re-oriented, toward new alignments.

The impacts of these activities at a dredge site are governed by several factors that operate at a range of spatial and temporal scales. These include:

- Regional factors, including climate, geologic structure, and parent geologic materials
- Watershed factors, including basin size, the drainage network, and sediment supply
- Location of the mining site within the watershed (e.g., small tributary or mainstem channel)
- Hydrologic factors influencing flow and river stage
- Dredging location relative to dams or diversions
- Hydraulic factors influencing flow characteristics including the longitudinal profile (channel slope), channel dimensions, and roughness
- Channel substrate and sediment composition at the mining site (e.g., bedrock, alluvium, grain size)
- Existing instream features such as a pools, riffles, bars, large woody debris, etc.
- Other structural features, including road crossings, engineered banks, etc.

The interaction of these factors, along with the Proposed Program regulations, is considered in the analysis of the impacts detailed in this section. Table 4.1-1 below is used to initially identify (and qualify) potential geomorphic impacts of suction dredging according to various temporal and spatial scales. Table 4.1-1 is not summarizing the degree or significance of potential impacts, but rather is used to contextualize the range of possible impacts.

In the matrix of Table 4.1-1, the "dredging site" refers to the immediate area physically disturbed by the suction dredge equipment and operator. The "reach" includes the geomorphic functional unit that the dredger is operating in. The length of a given reach may vary significantly within and among streams, but can generally be thought of to range between 50 and 500 m. The planning watershed scale encompasses effects that would be carried downstream along the river or stream to the next planning watershed. The official California watershed system, known as CalWater has been developed by the California Interagency Watershed Mapping Committee and may be inspected at http://www.ca.nrcs.usda.gov/features/calwater/. Mapped planning watersheds range from 3,000 to 10,000 acres in size (5 to 16 square miles). The "province and state" scale considers the effects of suction dredge activities at the geomorphic province and State scales (approximately 40,000 to 400,000 km^2).

TABLE 4.1-1. SCREENING MATRIX TO EVALUATE GEOMOPHIC IMPACTS OF THE PROPOSED PROGRAM

		Spatial Scales			
		At dredging site	*Along reach (50-500 m downstream of site)*	*Downstream to next planning watershed*	*At geomorphic province and State scale*
Temporal Scales	*Impacts occuring immediately during or after dredging event*	Yes	Yes	Maybe	No
	Impacts remaining during the season following dredging	Maybe	Maybe	Maybe	No
	Impacts remaining after next bankfull dishcarge event (1.5-2.5 years) following dredging	Maybe	Maybe	No	No
	Impacts remaining 2.5-10 years after dredging event	Unlikely	Unlikely	No	No

The discussion of environmental impacts below is organized sequentially according to these spatial scales, first considering potential impacts at the immediate dredging site (or cross-section scale) and then proceeding to reach, sub-watershed/watershed, and finally state scale.

Criteria for Determining Significance

For the purposes of this environmental analysis, it was determined that the Proposed Program would result in a significant impact if it would result in:

A. Substantial modifications to the geomorphic form or function of rivers or streams which would persist following a bankfull or dominant discharge event (with an expected frequency of 1.5-2.5 years following the suction dredging activities);

B. Modifications to the geomorphic form or function of rivers or streams that are collectively considered substantial at the watershed or statewide scale; or

C. Substantial alteration to the geomorphic form of a lake bed or shoreline which would persist for more than 1 year.

Bankfull discharge is a general hydrologic concept, describing a certain discharge (and river stage) for any given channel which fills the channel capacity, whereby additional discharge would exceed the channel capacity and cause overflows to the adjacent floodplain (Dunne and Leopold, 1978). In alluvial channels that form in their own sediments, bankfull discharge may approximate the flow magnitude and recurrence (frequency) that is generally responsible for shaping the channel. This concept relates that the bankfull discharge is the flow that effectively forms the alluvial channel and has a magnitude and frequency that conducts the most geomorphic work (Wolman and Miller, 1960). Because of this, bankfull discharge is sometimes also known as the "channel forming flow" or the "effective" or "dominant" discharge (Leopold, 1994).

The concept of bankfull discharge is relevant to the environmental analysis of suction dredging because this magnitude flow fills the channel, and is believed to have sufficient hydraulic properties (velocity, shear stress, etc.), and occurs at a frequency regular enough, to ameliorate or mitigate many small scale channel bed modifications caused by suction dredging activities. However, there are caveats in using bankfull discharge as the de facto channel forming flow. First, the concept assumes an alluvial channel shaped in its own sediment. For bedrock channels, the channel forming flow may be related to higher magnitude and less frequent (i.e., more extreme) flood flows. Most suction dredge activities do occur in alluvial channels, or at least in bedrock channels with some amount of alluvium covering the bed. In these instances, suction dredging would not alter the bedrock channel per se, but may displace the overlying alluvial material that is subject to transport during flow events that approximate the bankfull discharge.

Another key consideration of bankfull discharge is the recurrence frequency of such a flow event. A common frequency given for bankfull discharge is the discharge that occurs with a 1.5-year recurrence (Dunne and Leopold, 1978). However, in semi-arid and arid climates the effective discharge frequency is likely less frequent (Wolman and Gerson, 1978). The setting of recurrence intervals to a bankfull discharge requires careful data collection (Goudie, 1994). There are many methods to relate frequency to bankfull discharge (Williams, 1978).

As shown in Table 4.1-1 above and described in the significance criteria above, this analysis assumes that a discharge with a 1.5 to 2.5-year recurrence interval approximates the bankfull discharge event, which is relatively equivalent to the effective or dominant discharge for streams that would typically be subject to suction dredging activities. These hydrologic scenarios were established as thresholds for significance because they are important indices with regard to maintenance of geomorphic form and function. In general, these scenarios also correspond to hydrologic events that will mobilize the median grain size (D_{50}) of the stream bed substrate (Saldi-Caromile et al., 2004). The mobilization of the median grain size is an important threshold for resetting streambed morphology following a suction dredging event. Dredging impacts that are not reset or mitigated by a bankfull discharge event are anticipated to have increased potential for impacts to geomorphic form and function, as well as to water quality, biological resources, aesthetics, recreation and potentially other resources.

The threshold of significance for impacts to lakes differs from that established for rivers and streams because the geomorphic processes that reset morphology in rivers and streams are either absent or occur at longer time scales in lakes. Thus, the impact threshold for lakes is lower than that for rivers and streams. A modification to the lake bed or shoreline that would persist for longer than one year would be considered a potentially significant change in morphology, due to the increased potential for impacts to water quality, biological resources, aesthetics, recreation, and potentially other resources.

4.1.4 Environmental Impacts

Impact GEO-1: Erosion, Transport, and Deposition of Alluvial Material in Rivers and Streams Resulting in Dredge Potholes, Tailings Piles, and Other Suspension/Depositional Features (Less than Significant)

<u>Discussion</u>

All suction dredge operations result in the redistribution of alluvial material. The redistribution of alluvial material has the potential to impact geomorphic form and function, water quality and aquatic habitat. The severity of such impacts is related to the location of the dredging operation(s), volume and particle size of the material displaced, as well as the total area dredged. Impacts associated with the volume of material displaced and the area of disturbance is addressed under *Impact Geo-1*. Other potential impacts that are related to (or derive from) the sediment issues of *Impact Geo-1,* such as turbidity and aquatic habitat degradation, are addressed in the Water Quality and Toxicology, and Biological Resources chapters (See Chapters 4.2 and 4.3, respectively).

Impacts at Dredging Sites (Scour Holes, Tailing Piles, Downstream Sediment Deposits)

Erosional-type processes at the suction dredge site (intake) include the erosion and scouring of the channel bed through the direct entrainment of bed sediments. The suction dredge process can result in the general lowering of the alluvial bed, and/or where dredging is focused, result in scour holes (conical depressions or pits). The dimensions of scour holes will vary depending on the dredging equipment (e.g., nozzle size), sediment size, channel bed structure, and the individual dredging style/approach of the operator. Table 3-2 provides volume estimates for the material displaced by a suction dredge operation for varying nozzle sizes and substrate types. The proposed regulations limit the nozzle size to 4 inches or smaller. Based on the data presented in Table 3-2, it is estimated that the volume of material moved by a suction dredge operation using a 4 inch nozzle would range from 2.1 to 3.2 cubic meters (m^3) over the course of a six hour workday. The total area impacted would depend on the depth of dredging and substrate type, but is estimated to range between 1.6 to 2.3 square meters (m^2) per six hour workday (based on a uniform, approximate average dredging depth of 1.35 meters as reported in the Suction Dredger Survey [Appendix F]). Griffith and Andrews (1981) reported that a 2.5-inch dredge consistently moved 0.043 to 0.055 m^3 of substrate per hour in two Idaho streams; this is equivalent to 0.294 m^3 per 6 hr day. The U.S. Forest Service (2009a) notes that the volume of material moved by small-scale suction dredgers using five inch nozzles on creeks in Idaho varied widely, ranging from less than a cubic meter per day up to 3.8 or 7.5 m^3 per day.

Streambed sediment that is too large to pass through the intake nozzle is typically placed in piles adjacent to scour pits or along the stream margin at the banks. Piling of stream substrate alters the grain size distribution of the bed at the dredging site to some degree, generally leaving the bed coarser. In addition to this hand-placed piling of cobbles and small boulders near the intake location, depositional processes generally occur some distance downstream of the suction dredge site (see discussion of reach-scale depositional processes below). Hassler, et al. (1986) noted that deposited dredge tailings are highly unstable and can mobilize under slight increases in stream discharge and velocity because they are unconsolidated and rest on top of the streambed. This change in bed sediment stability and mobility is a concern for spawning habitat suitability, which is discussed in Chapter 4.3 *Biological Resources*.

Geomorphic Recovery at Dredging Sites

Geomorphic recovery is the concept that, following disturbance, a landform will return to its general form or trend through moderating physical and biological processes. The notion of geomorphic recovery is predicated on an assumption that the fluvial system (in this case, streams) functions at a dynamic equilibrium with alterations or disturbances occurring around a central tendency of form (Schumm and Lichty, 1965).

The concept of geomorphic recovery has been applied to the study of suction dredge mining sites by several researchers. These researchers observed that erosive scour holes, hand piled tailings, or downstream sediment deposits caused by suction dredge mining (during the relatively low-water summer conditions of California rivers) were removed following bed-mobilizing (or recovery) flows that occurred during the following fall, winter, or spring. Harvey, et al. (1982), Thomas (1985), Hassler, et al. (1986)[2], Harvey (1986), Stern (1988), Somer and Hassler (1992), and Prussian et al. (1999) all reported that some level of geomorphic recovery occurred during the seasons that followed suction dredge mining based on visual inspections a year after dredging. Additionally, Harvey, et al. (1982) suggested that geomorphic recovery may likely be slower or less effective on streams with controlled flows compared to streams that experience uncontrolled bed-mobilizing or "flushing" flows. Findings from the literature regarding geomorphic recovery at the dredging site are summarized below:

- Stern (1988) conducted visual inspection of dredging sites one year following mining activities to observe conditions and found no evidence of scour holes or tailing piles along the mid-channel thalweg[3] that had been observed in the

[2] There is considerable overlap in sampling locations for data reported by Hassler, et al. (1986) and Stern (1988).
[3] The thalweg is the line of maximum depth in a stream.

previous year. However, visible scour holes and piles that were located outside of the stream thalweg toward the streambanks remained. This difference reflects the stronger velocity flows that occurred through the central channel and thalweg were effective at removing dredging features, while flows along the stream margin were not strong enough (in that year) to remove the dredging features. In this case, after one year, dredging features remained along the stream margin. However, monitoring two seasons after the dredging activity by Stern (1988) indicated that scour holes and tailings piles from dredging two years previously were either filled (for the holes) or removed (for the piles) during the second year's flows that followed dredging. It is noteworthy that the second year's flows included a bankfull discharge event (24 cubic meters per second with a 1.9 year recurrence interval). It appears that this magnitude flow was effective in reshaping the overall channel bed and providing some degree of geomorphic recovery to the streambed.

- Similar to Stern (1988), Hassler, et al. (1986) returned to inspect 30 dredge scour holes and tailing piles measured during the previous summer and found that only 9% of the surface area of the previously measured disturbance areas was visible during the following year. For the holes and tailing piles that remained more than one year following dredging activities, it was observed that the holes were particularly deep and the tailings piles were generally located toward the stream margins.
- Thomas (1985) found that deposited sediment piles downstream of a 2.5-inch suction dredge nozzle were barely distinguishable one year after suction dredging activities.
- Prussian, et al. (1999) observed that tailing piles generated by 8 and 10-inch suction dredge nozzles were barely visible a year following the dredging activities. The tailings which remained visible had moved from the sides of the channel towards the thalweg of the river during the winter flow events.
- Harvey (1986) observed that dredging activities on large streams, such as the main stem Feather and Yuba Rivers in California, resulted in localized disturbances, whereas dredging activities on smaller tributaries had a proportionally larger and more significant area of disturbance. For example, dredging activities conducted by a single dredge on a smaller tributary of Butte Creek resulted in flow diversions that transformed riffles into exposed gravel bars within 10 days of operation. These substrate changes were not observed in Butte Creek the following year.
- Harvey, et al. (1982) monitored conditions a year following suction dredge activities on the American River and Butte Creek in California and observed that scour holes and downstream sand deposits observed the previous years were not present the following year.

In contrast to these observations, State Water Resources Control Board staff more recently has documented dredging pits persistent for one or more years in several streams of the Mother Lode region including the South Fork of the Yuba River, North Fork of the American River, and Bear River (pers. comm., Humphreys 2010).

In summary, the displacement of alluvial material at a dredge site results in impacts to streambed morphology in the form of dredge pits and tailings piles. The literature suggests that these features generally do not persist following a moderate (annual frequency) type winter flow events, and bed morphology recovers as a result of natural geomorphic processes. Some studies (Harvey et al., 1982, Harvey and Lisle, 1998) have noted that streams with modified hydrology (through reservoirs or other structures) are less likely to provide flushing flows to facilitate channel recovery. The potential for this type of impact to occur is reduced by the proposed regulations, which require dredgers to level tailings piles to the pre-mining grade to the extent possible (see *Findings* in this impact discussion). In addition, the "Best Management Practices" guidance will contain recommendations for dredgers to backfill dredging pits and other measures to reduce effects on streambed.

Reach, Sub-basin and Watershed Scales

Erosion, Transport, and/or Deposition of Channel Alluvium**.** Erosional processes related to suction dredging that occur at the reach, sub-basin and watershed scales are primarily a factor of one or more dredging operations occurring within the same stream or drainage basin. Several studies and reports provide estimates of the area of streambed disturbed by suction dredging, and the volume of material displaced (Hassler et al., 1986; Stern, 1984; USFS, 2006). Hassler et al. (1986) and Stern (1988) monitored the geomorphic impacts of suction dredge mining in the Canyon Creek tributary of the Trinity River in 1984 and 1985. In 1984, Stern (1988) found the total instream surface area disturbed by 20 dredges was 1,137 square meters (m^2). In 1985 the area disturbed by 15 dredges operating in the same vicinity was 1,075 m^2. Stern (1988) reported the average area mined by an individual was 39 m^2 in 1984 and 49 m^2 in 1985. Hassler et al. (1986) monitored 24 dredges in 1984 and 18 dredges in 1985. Total streambed disturbance in the Hassler et al. study area in 1984 was 1,164 m^2, and 1,075 m^2 in 1985. This resulted in average affected areas of 48.5 m^2 (1984) and 59.7 m^2 (1985) for individual dredging rigs. These authors found average scour hole depths of 1.2m (based on 30 holes in 1984) and 1.5 m (based on 22 holes in 1985). The U.S Forest Service (USFS) (2006) reported that the anticipated average surface area of an excavation site for 18 permits in Lolo Creek, Idaho, averaged slightly more than 93 m^2.

The annual average area mined reported in the studies listed above ranges from 39 to 93 m^2 per suction dredge operation (Hassler et al., 1986; USFS 2006), with average depth ranges from 1.2 to 1.5 m (Hassler et al., 1986; Stern, 1988). This is generally consistent with the results of the Suction Dredge Survey, which found the average annual area dredged to be approximately 14 and 63 m^2 (for California resident and non-resident dredgers, respectively), with average depths on the order of 1.35 m. Assuming the average dredger mines 63 m^2 annually to an average depth of 1.35 m, then the average dredge operation would displace approximately 85 m^3 or 163 metric tons[4] of sediment annually. Between 1989 and 2009 the average number of suction dredge permits issued was 3,650. If each permit holder displaced 85 m^3 of sediment, then the total volume of sediment displaced annually would have been approximately 335,410 m^3 or approximately 644,658 metric tons when considered statewide. Note, this estimated volume/mass of material displaced due to suction dredging is not the same measure as sediment yield. Sediment yield is typically defined as the total mass of particulate material (sediment) exiting the outlet of a

[4] Assumes 1922 kilograms per cubic meter of gravel sediment including sand in a natural state (www.simetric.co.uk/si_materials).

watershed, or passing by a defined location (Goudie et. al 1994). Of the net estimate of material displaced by suction dredging described above, much of this material will be held in storage within the river or creek downstream of the suction dredge operation and would not be measured as "yield" exiting the basin.

For context, Table 4.1-2 presents a range of observed and estimated values for sediment yields reported in the literature for select watershed and regions in California. As demonstrated in Table 4.1-2, sediment yields for California watersheds and regions vary widely. Suction dredge mining in watersheds like the Middle and South Yuba has a relatively higher potential to displace an abundance of sediment compared to these system's relatively low annual sediment yields. This suggests that sediment displaced from suction dredge mining in such watersheds would likely be stored as instream sediment at some locations within the watershed. In contrast, in the Klamath Basin with higher annual sediment yields, the mass of sediment displaced due to suction dredging is relatively low compared to the overall watershed sediment yield.

TABLE 4.1-2. SEDIMENT YIELDS REPORTED FOR SELECT WATERSHEDS/REGIONS OF CALIFORNIA

Watershed/Region	Drainage area		Annual sediment yield		Reference
	(mi^2)	(km^2)	(tons/mi^2)	(metric tons/km^2)	
Middle Yuba River	198	513	5	1.8	Curtis et al., 2006[1]
South Yuba River	308	798	14	4.9	Curtis et al., 2006
Klamath Basin (Iron Gate to d/s end of Seiad Valley)	6,940[2]	17,975	192 - 450	67.2 - 157.5	USBR, 2005
Sierra Nevada	varies	varies	571	200	Kondolf, 1995
Western Transverse Range	varies	varies	2,114 - 15,142	740 – 5,300	Warrick and Mertes, 2009

[1] =Data from sampling conducted between 2001 to 2003, which were low water years in the Yuba drainage.
[2] =Drainage area from USGS stream gage site #11520500 (Klamath River near Seiad Valley, CA)

In the Transverse Ranges of southern California, the relative proportion of material displaced by suction dredging compared to annual sediment yield is even smaller. Note that the relative intensity of suction dredging in these areas is described in Chapter 3 based on the Suction Dredge Survey results.

Disturbance of an Armored Boundary Layer. Another erosion-based, reach-scale effect of suction dredging is the potential to degrade an armored channel bar or other bed surface. Armoring is the process by which the surface of depositional features such as mid-channel bars is stabilized through the interlocking of coarser grained materials. Beneath this surface armoring of well sorted deposits is typically a substrate of finer and less consolidated materials. The armored surface protects the underlying finer sediments from erosion until the next streamflow event of sufficient magnitude to erode the armored bar surface (Goudie, 1994). An armored surface is indicative of a channel in equilibrium. Suction dredge mining, when targeted at mid channel bars and other surfaces that have a protective "armored" surface, can lead to the physical removal of the armored layer. This type of disturbance may result in secondary erosion of the finer sediments beneath the previously armored surface. While disruption of an armored boundary layer may not significantly alter the total sediment load within a given reach, it may result in additional fine sediment contribution to the water column with associated water quality/toxicology and biological impacts (See Chapters 4.2 and 4.3, respectively). Additionally, the removal of the armored surface can destabilize the entire bar feature and lead to downstream bar migration. In scoping comments, supporters of suction dredging have opined that removal of the armored surface may to some degree benefit aquatic organisms, such as gravel-spawning fishes, by loosening the substrate and making it more suitable for spawning. However, some studies suggest that substrate loosened by dredging may be too unstable for spawning (See Chapter 4.3, Impact BIO-FISH-1).

Depositional Processes The effects of redistribution of alluvial sediment by suction dredging largely occurs at the reach where the operator is dredging, but these effects may also extend downstream of the reach. In general, coarser sediments (small cobbles, gravel, and coarse sand) settle out of transport in proximity to the sluice box discharge. Finer sediments (transitioning from coarse to medium and finer sands) are transported further downstream. Finer silt and clay particles (generally less than 0.063 millimeters [mm]) may become part of the suspended load or wash load in the water column and be transported much farther downstream (Thomas, 1985; Harvey and Lisle, 1998).

Sedimentation rates and patterns occurring downstream of suction dredge mining operations are described from several studies are summarized below. The summary below reviews literature findings for sedimentation rates and patterns in an approximately 100 m zone immediately downstream of suction mining activities. General methods used to measure sedimentation include collecting suspended sediment samples, placing sediment markers or collection devices (discs) on the channel bed, conducting repeat surveys of the channel cross-section to compare elevations and bed form, and visual observations.

- Harvey et al. (1982); Somer and Hassler (1992); and Stern (1988) calculated sedimentation rates based on repeat measurements and observations of dredging operations in northern California streams. These studies found statistically significant increases in sediment rates within the first 4-10 m downstream of the sluice box discharge. Sedimentation rates within 12 m below the sluice box were measured as high as 2,060 grams/m^2/day above background levels (Harvey et al., 1982). Harvey et al. (1982) also found that sediment deposition rates returned to background levels within 60-120 m, while turbidity levels and settleable solids concentrations returned to background rates approximately 30 m downstream.
- Stern (1988) monitored sediment deposition downstream from suction dredge operations and observed how deposition rates decreased with distance. At 9 to 10 m below the dredge rig, the average daily deposited sediment load varied between 674 to 42,366 grams/m^2/day. Where sluice box discharge occurred in the thalweg or mid-channel locations (where velocities were greater), sediment was carried further downstream in the mid-channel location. In contrast, where sluice box discharges occurred toward the outer stream margin, where velocities are less, it resulted in deposition along the shore for a shorter distance.
- Thomas (1985) measured a 10-20 fold increase above background levels in sediment deposited immediately downstream from suction dredging. He found that the majority of sediments discharged from the sluice box settled on the

stream bottom within the first 15 m. The amount of deposited sediment decreased exponentially with distance downstream from the dredge. The study also indicated that sediment deposition varies greatly depending on the particle size distribution of the substrate being dredged and stream discharge conditions.

- Somer and Hassler (1992) recorded seasonal sedimentation rates downstream from a 4-inch suction dredge as 1,711 grams/m^2 and 698 grams/m^2 at 40 m and 113 m downstream of the dredge, respectively. These values represent an increase over baseline rates of 23 grams/m^2 recorded 50 m above the dredge. These researchers monitored how downstream deposition fined with distance. The percentage of sediment by weight, trapped at 40 m and 113 m below the dredge, was 21% and 38% of particles less than 0.1 mm in diameter, respectively.
- Hassler et al. (1986) recorded a baseline sedimentation rate upstream from a dredge as 105 grams/m^2/day. Four meters downstream from the active dredge, the sedimentation rate increased to 12,080 grams/m^2/day and 285 grams/m^2/day at 25 m downstream from the dredge.
- Prussian et al. (1999) noted substantial changes to bed morphology at a dredging site on the Fortymile River in eastern Alaskan river, but no discernable effects either laterally or downstream of the channel. However, they did observe increased fine sediment deposited on downstream gravels within the dredge-generated turbidity plume.
- Stern (1988) monitored sediment deposition, substrate particle size, substrate embeddedness (the filling of interstitial pores), and channel scour and fill along transects upstream and downstream from dredging sites. Monitoring conducted by Stern (1988) concluded that substrate embeddedness increased significantly after dredging activities at all transects monitored (up to 50 m downstream). Stern also noted that particle size decreased significantly downstream of dredging activities.
- Harvey et al. (1982) observed that areas downstream of suction dredging activities that had no deposited sand prior to dredging would become embedded with sand following dredging. Sand comprised 25-40% of the substrate composition 30 m downstream from the dredging area and was observable up to 60 m downstream in areas that did not have any sand prior to dredging. The following year, all the embedded sand had been flushed away from the cobble substrate (see recovery discussion below).
- Hassler et al. (1986) noted that deposited dredge tailings are highly unstable and can mobilize under slight increases in stream volume and velocity because they are unconsolidated and rest on top of the streambed. Downstream deposited sediments are vulnerable to resuspension and transport during subsequent stormflow events or dam releases that raise discharge and velocity.
- Thomas (1985) noted that sediment deposited downstream from suction dredge discharge is very unstable and mobilizes quickly to fill downstream pools. Harvey and Lisle (1998) also described the relatively unstable nature of downstream deposited tailings and related these mobile sediments to the timing of spawning activities and when high flows might remove the sediment.

The sedimentation effects described above have several important consequences for aquatic organisms and their habitat. Deposition of coarse material immediately downstream of dredging operations, the downstream transport and deposition of finer sediment that potentially cover and embed downstream riffles, and the filling of downstream pools through the mobilization and re-transport of dredged sediment can all potentially negatively affect aquatic species and their habitats. Streambed particle size distribution is an important variable in the determining the impacts of suction dredging. Generally, dredging in coarse bed material with few fines would have a lower potential to result in water quality impacts (e.g. turbidity plumes) that may adversely affect aquatic organisms and their habitat. These considerations are described more thoroughly in Chapter 4.3, *Biological Resources*. From a geomorphic perspective, alluvial material redistributed by dredging operations is likely to be more readily transported than materials that have not been dredged and therefore may alter local hydraulic conditions. The proposed regulations that require that suction dredge operators to restore channel grades following excavation will reduce these impacts (see Findings in this impact discussion).

Province and State Scales

The redistribution of alluvial material associated with the Proposed Program is not likely to result in substantial modification to landforms and processes that occur at the province and State scales. At the province and State scales, geomorphic form and function are largely governed by processes (e.g., plate tectonics) that operate at time scales that are not detectable or relevant to the assessment of the Proposed Program impacts.

Findings

The discussion and literature review presented above identifies impacts on geomorphic form and function associated with the redistribution (erosion, transport, and deposition) of alluvial material at multiple spatial scales. At the dredging site, reach and sub-basin scales there is likely to be a measurable departure from the baseline condition in the volume of alluvial material eroded and transported in the channel. The effects of dredging are likely to be most evident in small channels and watersheds, along the margins of channels, downstream of dams, and in areas with a high concentration of dredging activity. Small watersheds and dredging sites downstream of dams are less likely to experience substrate mobilizing flows that facilitate recovery of the natural stream bed form as described above.

The proposed regulations require that suction dredge operators level the tailings piles generated from suction dredging, and guidance to restore dredge holes will be included in the "Best Management Practices" document. Removing these irregular bed surfaces following dredging will reduce impacts to geomorphic form and function. Furthermore, in most streams and rivers throughout the state, natural sediment transport process will restore irregular bed surfaces caused by suction dredging. As such, potential sediment redistribution impacts caused by dredging (including potholes, tailings piles and other suspension/deposition events) conducted in compliance with the proposed regulations are considered to be less than significant.

Impact GEO-2: Destabilization of the Streambanks (Less than Significant)

Discussion

Dredging Site and Reach Scales

A suction dredge operation can destabilize streambanks at a dredging site through several mechanisms including: (1) direct dredging of streambanks; (2) removal of riparian vegetation; (3) dredging a pit near the channel margin which effectively increases bank height; (4) dredging across the entire channel width; and (5) dredging which results in changes in hydraulic roughness (R2 Consultants, 2006; Harvey and Lisle, 1998). Although not a permitted activity in the past, direct mining into streambanks has been documented by several studies (McCleneghan and Johnson, 1983; Hassler et al., 1986; Stern, 1988), as well as by the USFS (2009 b).

Of the 200 suction dredging operations surveyed throughout the Mother Lode region of the Sierra Nevada by McCleneghan and Johnson (1983), 14 (7%) were documented to be undercutting banks. The survey did not obtain measurements of the extent of the undercutting; it only documented visual observations. According to Hassler et al. (1986), 4% of the 68 surveyed dredging operations resulted in damaged streambanks (from research along Canyon Creek, 1982-85). The Hassler et al. (1986) study followed the same survey methods as the McCleneghan and Johnson (1983) study, and no physical measurements of the bank effects were recorded. Stern (1988) reported 34 percent of miners undercut streambanks and noted that undercutting of streambanks was the most common adverse impact of suction dredge mining from his studies on Canyon Creek in the mid-1980s.

The undercutting and eroding of streambanks can destabilize streamside vegetation, such as trees. When this happens, downed trees may divert stream flow toward the opposite bank (which can cause further erosion). The loss of streamside vegetation can also result in reduced shading and increased water temperatures. Downed trees can also generate a sediment pulse from the tree root wad that is delivered to the stream. Downed trees can also provide a source of coarse woody debris (CWD) for the channel. Coarse woody debris is recruited naturally into a stream through episodic events such as a wind storm or fire, or gradual events such as tree mortality or bank failure through channel migration (Bilby and Bisson, 1998). Downed trees may provide backwater habitats where quiet reverse flows (eddies) are found (Keller and Swanson, 1978; Lisle, 1986a; Montgomery et al., 1995). Large roughness elements such as CWD can govern the location of scour and deposition at the scale of pools and riffles (Lisle, 1986b; Montgomery et. al., 1995). While the presence of CWD in a stream is often a habitat benefit, the mechanical undercutting and erosion of streambanks (as a product of suction dredging) is not considered a preferred mechanism for generating CWD supply. Inputs of CWD under natural conditions allow for the transport of fine sediments from the bank to be dispersed together with storm flows. In contrast, streambank erosion and CWD inputs initiated by mechanical conditions such as suction dredging, could result in localized inputs of sediment affecting summer low-flow habitats, such as pools.

It has been documented that some suction dredge operators, in moving larger cobbles and small boulders around the bed to improve access to gravel below, will place large rocks along the bank or even within the concave cavity created by a naturally undercut bank.

Illustrations of this activity are included in Gunn-Morrison's (1994) *A Gold Dredger's Primer to Survival in a Shrinking World*, which encourages miners to place tailing rocks beneath undercut banks as a form of bank protection. The occurrence of an undercut bank alone is not a meaningful indicator of instability, and a priori treatment as such is an inappropriate response that can result in the loss of an important habitat type for many riparian species and enhance bank erosion up- and downstream of the hardened bank area. The proposed regulations prohibit movement of boulders outside the existing water line to prevent other impacts to channel form.

Watershed, Province and State Scales

Streambank erosion or instability caused by suction dredging operations typically occurs at the on-site or reach scales as described above. While the potential presence of multiple dredging operators throughout an entire sub-watershed or watershed could cause this effect to be observed more extensively throughout the river system, in general, this has not been observed. Hence, suction dredge activities associated with the Proposed Program are not likely to result in streambank destabilization that would manifest at the watershed, province and state scales.

Findings

Streambank erosion and destabilization has been observed as a result of suction dredging. The proposed regulations clearly state that it would be illegal under the Proposed Program to dredge in proximity to or beneath a streambank, or to divert flow into a streambank. Regulations that prohibit the removal or disturbance of riparian vegetation would also protect streambanks. Additionally, the regulations that require the permittee to notify CDFG of locations of planned mining activities would provide additional oversight and enforcement capabilities, as well as a deterrent effect on illegal activities. Even with clear regulations that prohibit suction dredge activities along streambanks, it is likely that some illegal activity will continue to occur that will cause bank erosion and instability. However, due to the limited extent of potential bank erosion and instability caused by suction dredging, this impact is considered to be less-than-significant when considered statewide.

Impact GEO-3: Destabilization of Channel Bed Forms such as Riffle and Bars (Less than Significant)

Discussion

In addition to the direct physical effects of creating scour holes and tailings piles, suction dredging may also disturb channel bed forms such as riffles and gravel bars. Riffles and gravel bars play important roles in the development and maintenance of geomorphic form and function, as well as stream ecology. In alluvial channels, riffles control channel profile and establish bed characteristics that provide important habitat functions (e.g., sediment sorting, pool formation). Gravel bars are important for geomorphic function and stream ecology as they are responsible for scour pool formation, creation and destruction of floodplain surfaces, and variation in flow fields that create velocity refugia.

Dredging Site and Reach Scales

In evaluating potential effects of suction dredging on benthic invertebrates, Somer and Hassler (1992) found that the scour holes were excavated below the armored gravel layer, exposing a finer sand and silt layer below. Bedrock and large cobbles were encountered at the bottom of the holes. Harvey and Lisle (1998) report on the erosive effects of dredging near or at riffle crests, and how suction dredging at those locations can destabilize the entire riffle complex. Similarly, Harvey et al. (1982) observed that dredging in riffles has a higher potential to influence substrate changes than dredging in pools. Harvey (1986) concluded that, in general, dredging in streams with larger proportions of fine sediments resulted in more severe erosional and depositional impacts. It is evident that multiple dredging operations within a single reach of a river or stream will compound the impacts on channel bed forms, though it is not feasible to estimate the carrying capacity of a given stream for each has its own unique set of variable that determine geomorphic form and function.

Watershed, Province and State Scales

The destabilizing of channel bed forms due to suction dredging operations typically occurs at the on-site or reach scales as described above. While the potential presence of multiple dredging operators throughout an entire sub-watershed or watershed could cause this effect to be observed more extensively throughout the river system, in general, this has not been observed. Hence, suction dredge activities associated with the Proposed Program are not likely to result in destabilizing channel bed forms that would manifest at the watershed, province and state scales.

Findings

The discussion and literature review presented above identifies mechanisms by which suction dredging may destabilize channel forms such as riffles and bars. At the dredging site and reach this may result in a measurable departure from the baseline condition. In most cases the geomorphic process for recovery would reset and reestablish these channel forms within 1 to 3 years following dredging. The effects of dredging are likely to be most evident in small channels and watersheds, downstream of dams, and in areas with a high concentration of dredging activity. The proposed regulations include several provisions intended to protect aquatic habitat that would reduce the disturbance to riffles and bar features including: (1) restrictions on nozzle size, (2) dredging being restricted to the wetted portion of the channel, (3) requirements to restore irregular bed surfaces and channel grades following excavation, (4) guidance to avoid areas of fine sediment, and (5) prohibitions on dredging in gravel bars at the tails of pools. It is likely that suction dredge mining will cause some degree of destabilizing channel riffles and bars. However, given the proposed regulations which would reduce these potential effects, and due to the limited extent of this potential impact when considered for the form and function of rivers and streams at the statewide scale, the potential effect of suction dredging on destabilizing instream channel bed forms is considered less than significant.

Impact GEO-4: Destabilization of Channel Profile (Less than Significant)

Discussion

Geology, topography and landforms interact to shape the longitudinal profile of a channel. In alluvial channels, profile is maintained through a delicate balance between water and sediment supply. Maintenance of profile stability is a key component of geomorphic function. Excessive stream bed aggradation or degradation (i.e., incision) is indicative of profile instability and disequilibrium in a channel. Streambed incision typically degrades important geomorphic and ecological conditions such as floodplain function, bank stability and off-channel wetland habitat. Channel bed aggradation can bury valuable aquatic habitat.

Suction dredging-related activities that have the potential to destabilize channel profile include: (1) movement of channel structural elements such as boulders and CWD, (2) destabilization of riffles and gravel bars, and (3) dredging of excessively deep pits. Any of these activities can lead to development of breaks in channel slopes, or knickpoints[5] in the channel profile. Such knickpoints can migrate upstream and cause further channel incision, thereby creating a self-propelling feedback that drives channel incision up the river system.

The U.S. Forest Service provided a comment letter (2009b) that described observations from Dutch Creek, a small creek in Trinity County, where multiple dredge operations resulted in several negative effects to the stream channel. Abundant mining on this small creek (average width of 8 feet, and a 2 cubic feet/second summer baseflow discharge rate) destabilized the channel resulting in the downstream transport of gravels. The creek became entrenched within and below the areas of mining activities. While situations similar to what was observed at Dutch Creek may occur in the future, this type of channel destabilization on small creeks is now less likely because of regulations prohibit dredging within 3 feet of the existing water line, which would result in dredging being prohibited in streams that are 6 feet or less across.

Scale of Effects

For any given suction dredging location there is a unique threshold for which the activities listed above may cause destabilization of the channel profile. In general, steep channels are more susceptible to being destabilized than channels with shallow or moderate gradients. Channels with non-cohesive fine sediment will be more prone to destabilization, than channels dominated by coarse material. In all instances, depth to bed rock and the distance to upstream natural or artificial grade control (e.g., bridges or culverts) would determine the extent to which the impact can manifest in the channel. In many cases dredgers are working in sections of stream with shallow bed rock, which would limit the potential for large-scale modification of the channel profile. However, knickpoints formed by destabilization actions may migrate upstream until they encounter erosional resistant material, or until the channel profile adjusts to a new equilibrium gradient. If the mainstem of the river becomes incised, tributary streams would then also likely incise as they adjustment to meet the lowered receiving stream. Hence, destabilization of the channel profile that occurs at the on-site or localized scale can manifest beyond the immediate reach and extend to the broader sub-watershed and watershed scales. However, these effects, as related to suction dredging activity, are not anticipated to be measureable at the province or State-wide scales.

Findings

The discussion presented above identifies mechanisms by which suction dredging activities could destabilize channel profile. The proposed regulations would prohibit the movement of CWD and the use of power winches to move bed material. This would limit the potential

[5] A knickpoint is a location in a river or channel where there is a sharp change in channel slope, resulting from differential rates of erosion above and below the knickpoint.

for the channel profile to be destabilized by suction dredging operations. In addition, regulations that (1) establish restriction on nozzle size, and (2) require suction dredge operators to restore channel grades and bed irregularities following excavation would further reduce the potential for development of knickpoints in the channel profile. Therefore, the extent of channel profile destabilization due to suction dredge mining is considered a less than significant impact when considered on the geomorphic form and function of rivers and streams statewide.

Impact GEO-5: Streamflow Channelization, Diversion, or Obstruction (Less than Significant)

Discussion

During low flow conditions suction dredge operators are known to move streambed material to divert and concentrate flows into one portion of the stream to assist in dredging activities (McCleneghan and Johnson, 1983; Hassler et al,. 1986). This influence of suction dredging activities on the stream channel has been documented through visual observations and channel measurements by McCleneghan and Johnson (1983), Hassler et al. (1986), and Stern (1988). Of the 200 suction dredging operations surveyed by McCleneghan and Johnson (1983), 12 operations were observed to have channelized flows in the stream. From his study of 68 dredging sites in Canyon Creek (1982-1985), Hassler et al. (1986) noted that 10% of the dredging operators he observed channelized portions of the stream, 15% caused riparian damage, 4% damaged the bank, and 36% impacted spawning gravels.

Stern (1988) observed that the risk for bank failure increased when stream bed material was relocated to divert and concentrate flows toward the banks, bank vegetation was removed, and suction dredging activities also occurred near the banks. The study also observed that re-directed flows that were channelized toward the streambanks could result in the erosion and loss of riparian vegetation, including the destabilization and recruitment of overhanging vegetation and root wads.

Findings

The discussion and literature review presented above identifies mechanisms by which flow obstructions and diversions associated with suction dredging may impact stream morphology and disrupt channel hydraulics. The effects of flow modifications are likely to be most evident in small channels. At the dredging site and reach scales this may result in a measurable departure from the baseline condition. The proposed regulations include the following prohibitions: (1) no construction of permanent or temporary dams, (2) no concentrating flow in a way that reduces the total wetted area of the stream, and (3) no diversion of a stream or lake into the bank. Additionally, the regulations would require the permittee to notify CDFG of locations of planned mining activities. This would provide additional oversight and enforcement capabilities, as well as a deterrent effect on illegal activity. Even if illegal dredging activities were to occur that led to instream channelization, diversions, or obstructions, in most cases geomorphic recovery processes would likely reset and reestablish the channel form within 1 to 3 years following dredging activities. It is therefore concluded that flow obstructions and diversions associated with suction dredging would have a less than significant impact on the geomorphic form and function of rivers and streams.

Impact GEO-6: Alteration or Destabilization of Lake Bed or Shoreline (Less than Significant)

Although suction dredging is not known to commonly occur in lakes, Fish and Game Code section 5653 does not expressly preclude the activity from lakes, and therefore potential impacts must be considered in this analysis.

Discussion

Suction dredging in lakes (i.e., lentic systems) has the potential to alter lake bed morphology and potentially destabilize the lake shoreline. A suction dredge operation would excavate and disperse sediment, leaving a dredging pit. Since lake bed sediments are typically composed of sorted fine grained material, a suction dredge operator would have difficulty backfilling the excavated pit because the fine sediment would be widely dispersed. The dredge pit would likely be persistent for a significant period of time because the geomorphic processes of recovery (i.e., erosion, transport and deposition) that occur with typical annual recurrence in river and streams are either absent or occur at spatial and temporal-scales that are not functionally relevant to the Proposed Program.

One or several dredge pits in a lake bed could impact a lake shoreline by causing slumping of the lake bed or destabilization of the shoreline slope. The magnitude and severity of the impact would be dependent on the slope of the lake bed/shoreline, the dimensions of the dredging pit, geotechnical properties of the substrate, the proximity of the pit to the shoreline, and lake level fluctuations.

Findings

The discussion above identifies mechanisms by which suction dredging could modify the lake bed or destabilize the lake shoreline. At a dredging site this may result in a measurable departure from the baseline condition. The proposed regulations require that a permittee submit notification to CDFG (pursuant to Fish & G. Code, §1602) of any suction dredging activity proposed in a lake. If CDFG determines that the proposed dredging activity would not substantially alter the lake bed or shoreline, and does not require a Lake or Streambed Alteration Agreement, then the activity would have a less than significant impact to the geomorphic form of the lake. Alternatively, if CDFG determines that the proposed dredging activity would substantially alter the lake bed or shoreline, and requires a Lake or Streambed Alteration Agreement, then the activity would be subject to CEQA review outside the scope of this SEIR. For this reason, the impacts of the Proposed Program are considered less than significant.

Activities Requiring Fish and Game Code Section 1602 Notification

Activities which require notification under Fish and Game Code section 1602 may increase the potential for adverse effects related to hydrology and geomorphology. The increased substrate movement capacity associated with the use of larger nozzle sizes could increase alterations to the forms and functions of stream beds and/or banks, and increase effects associated with sedimentation transport. Similarly, the use of power-winching techniques may cause greater destabilization of channel profiles and disturbances of in-stream and streambank features. The damming or diverting of flows is not permitted under the proposed regulations, and therefore use of such methods would increase effects on stream morphology and channel hydraulics beyond that which has been described in this SEIR. As discussed in Impact GEO-6, suction dredging in lakes is an activity which requires notification to the CDFG (pursuant to Fish & G. Code, §1602) in order to determine whether the activity would substantially alter the lake bed or shoreline. These issues, to the extent to which they could be significant, would need to be evaluated in a CEQA document.