SEDIMENT REMOVAL FROM FRESHWATER SALMONID HABITAT:

Guidelines to NOAA Fisheries Staff for the Evaluation of Sediment Removal Actions from California Streams.

NOAA Fisheries - Southwest Region

- *DRAFT* -

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EXECUTIVE SUMMARY

PURPOSE and INTRODUCTION (Chapter 1)

Introduction. The National Marine Fisheries Service (NOAA Fisheries) is responsible for protecting, managing, and conserving marine, estuarine, and anadromous fish resources and their habitats under various legal authorities (Appendix 1). A guidance document specific to the NOAA Fisheries Southwest Region (SWR) for instream sediment removal is appropriate, because such actions have the potential to adversely affect all life stages of listed salmonids and because sediment removal actions are widespread in California streams.

The scientific literature documents that instream gravel mining operations and salmonids are often attracted to the same locations. The effects of instream gravel mining and channel maintenance have been widely recognized as potential impacts to aquatic resources. At least 13 States of the U.S., and 8 foreign countries, have implemented restrictions or prohibitions on commercial sediment excavation from fish bearing streams. Oregon and Washington have reallocated their aggregate resource production from streams to predominantly floodplains and geologic deposits. Aggregate production in California is focused primarily on streams. The rate of aggregate excavation in California is estimated to exceed the rate of natural replenishment by an order of magnitude. In California the demand for high quality aggregate materials is high because of a rapidly growing population, expanding industry, and the geologic nature of the most populous areas. NOAA Fisheries anticipates that pressures for stream derived aggregates will continue to increase in the SWR. This unfortunate convergence of geology and accelerating market demand has profound implications for the conservation and recovery of the freshwater habitats entrusted to NOAA Fisheries.

Purpose and Use of these Guidelines. The 1996 National Marine Fisheries Service *National Gravel Extraction Policy* aims to avoid the take of listed salmonids by, for example, disallowing sediment extraction "within, upstream, or downstream of anadromous fish spawning grounds." The purpose of these NOAA Fisheries-SWR Sediment Removal Guidelines is to present thorough scientific information that may be used to conduct effects analyses of proposed actions that would remove sediment from streams, either for commercial sediment production or flood control channel excavation. This information will help staff to identify adverse effects of sediment removal actions and provide reasonable and prudent alternative measures, as necessary. The Recommendations Chapters of these Guidelines establish a strategy to minimize the incidental take of listed salmonids entrusted to NOAA Fisheries protection.

These Guidelines do not present prescriptive measures that must be implemented by parties engaged in sediment removal activities; rather, the Guidelines are intended to be used primarily by SWR staff in conducting effects analyses in response to project proposals in accordance with the Endangered Species Act (ESA). Through various provisions of the ESA, NOAA Fisheries evaluates the consequences of sediment removal activities to determine whether and to what extent such activities might impair the ability of listed species to survive and recover. In meeting its responsibilities under the ESA, NOAA Fisheries strives to ensure that properly functioning habitat is available to support listed species; these Guidelines describe the attributes of properly functioning habitat that can be adversely affected by sediment removal activities. The Guidelines also suggest approaches for

designing sediment removal activities in ways (locations, timing, methods) that minimize adverse effects.

In preparing these Guidelines, the SWR expects that they will be useful not only to SWR staff in conducting effects analyses under the ESA, but that the Guidelines will also be helpful to other federal and state agencies and local jurisdictions, industry, and the interested public. For these entities, the Guidelines should make it easier to understand how the SWR reaches conclusions on effects analyses; prepare sediment removal projects that minimize disturbance to properly functioning habitat; predict the likely outcome of SWR evaluations under the ESA as such evaluations relate to habitat protection; and devise sediment removal projects and programs that are consistent with state and federal recovery planning approaches.

SCOPE (Chapter 2)

The types of activities discussed in the Guidelines include commercial sediment production from terraces, floodplains, and streams, and stream excavation for flood control. Mines from adjacent floodplains and terraces that may have indirect or delayed impacts on nearby streams are included because of their potential for affecting salmonid habitat. The entire channel-floodplain system is important to fluvial ecosystem function and anadromous salmonid health. The range of anadromous fish habitats specifically addressed by these Guidelines includes all freshwater streams, their floodplains and associated wetlands and riparian zones. The objectives of these Guidelines are to provide guidance to our staff on the potential effects of sediment removal activities, to recommend methods that can minimize disturbance from sediment extraction, and where possible, to enhance areas of diminished habitat value.

BASICS OF NATURAL STREAM FORM AND FUNCTION (Chapter 3)

To understand the effects of sediment removal from freshwater habitats, it is necessary to first understand fundamental concepts of fluvial geomorphology, the function of natural stream processes, and the associated salmonid habitat. Channel geometry and geomorphic features within channels are the products of interactions among stream flow, sediment delivered to the channel, the character of the bed and bank material, and vegetation. A stream that is free to develop its own geometry evolves through time to develop a channel shape, dimensions and planform pattern (together termed morphology) that reflect a balance between the sediment and water inputs, the stream's relative energy and the dominant characteristics of the sediments forming the bed and banks. Self-formed channels also adjust their conveyance capacity so that flow inundates the surrounding floodplain on average every 1-2 years. Streams in which the channel geometry and capacity are adjusted in this way are said to be in dynamic equilibrium. The concept of morphological adjustment towards dynamic equilibrium is fundamental to the theory and management of stream corridor processes.

Stream channels are highly organized both in planform and longitudinally. Alternate bars, and the pool-riffle sequences, are the fundamental geomorphic units found in alluvial channels. Mature bars in undisturbed channels are connected to the adjacent floodplain, having elevations corresponding to the water surface elevation associated with the bankfull stage. The long-profile of the bed of a natural stream channel usually displays a systematic pattern of alternate deep and shallow units termed pools and riffles. Pool-riffle formation can be thought of as a vertical expression of the same

processes that drive meandering in the horizontal plane. Gravel beds within riffles provide important spawning habitat for anadromous salmonid species. In addition to spawning habitat, the shallow, swift flows over riffles are also important habitats for numerous species of invertebrates, many of which are important food sources for salmonids. Coarse riffle substrates are among the most productive stream habitats, supporting much higher densities of organisms than sandy or heavily sedimented substrates.

Undisturbed alternate bars deflect low, high frequency flows around them, thus creating a sinuous flow pattern at discharges up to high, over-bank flood events. In nature, sinuosity and slope are adjusted towards achieving dynamic balance between the dominant discharge and the sediment load. Meanders gradually grow in amplitude and migrate down valley through erosion at the outside of bends that is greatest just downstream of the bend apex. Bank retreat is, on average, balanced by deposition at the inside of bends, so that channel-width remains about constant.

Channel migration in floodplain riparian communities recruits large woody debris (LWD) to the channel, adding valuable habitat attributes such as localized bed scour and sediment sorting, cover and shade, and augmenting pool habitats. In general, the health and function of the stream ecosystem are positively related to the degree of dynamism and topographic complexity of the stream channels.

The meandering stream channel pattern represents a continuation of the development of sinuosity as a process of self-regulation of slope and sediment transport to achieve equilibrium. Local sorting of streambed materials is related to the local distribution of stream forces. The convergence and divergence of the stream's flow field maintain complex topographic and sedimentary features. Undisturbed bars and channel bottoms are typically armored with a layer of large cobbles that overlies mixtures of finer-grained deposits. Armoring is especially evident on the heads (upstream end) of bars. The armor layer reduces the mobility of bed sediment, making bar heads and the channel bottom resistant to high flow stresses and providing stability to the channel during flood flows. Areas of heavy armor can provide valuable fish habitat during high flows because of low near-bed velocity, and productive benthic habitat whenever inundated. In both altered and unaltered channels, when the balance between bed material transport and bed mobility is reached a coarse surface layer "armor" develops on the bar surface which hinders or prevents erosion.

Pools are an essential habitat element for salmonids. Pools provide a complex of deep, low velocity areas, backwater eddies, and submerged structural elements that provide cover, winter habitat, and flood refuge for fish. During their upstream migrations, adult salmonids typically move quickly through rapids and pause for varying duration in deep holding pools. Holding pools provide salmon with safe areas in which to rest when low-flows and/or fatigue inhibit their migration.

Pools are also the preferred habitat of juvenile coho salmon and they are an important habitat for juvenile steelhead. Pools with sufficient depth and size can also moderate elevated water temperatures stressful to salmonids. Deep, thermally stratified pools with low current velocities, or connection to cool groundwater, provide important cold water refugia for cold water fish such as salmonids.

Stream corridors are ecosystems containing the stream channel(s) and adjacent floodplain. Water, sediment and nutrients, organisms, and energy transfer dynamically between the stream channels and floodplain. Floods in non-manipulated streams overtop the banks (bankfull flow condition) every 1-2 years. Overbank floods transport water, sediment, and nutrients onto floodplain surfaces,

which support ecologically rich riparian forests and calm water habitats for breeding and feeding of aquatic species. Floodplains retain and absorb flood flows, reducing downstream flood peaks and in turn providing an important source of shallow groundwater (hyporheic zone) that nourishes the stream during dry seasons. The dry season flow of streams is the result of water seepage from floodplain storage and other sources such as springs and tributaries. The quality of the hyporheic water discharging into streams is high, and the temperature is low; conditions highly favorable for anadromous salmonid rearing. Inflowing groundwater can substantially reduce water temperature in pools during high summer ambient temperatures.

Riparian vegetation provides many ecological functions that are important to salmonids. Vegetative structure increases hydraulic boundary roughness resulting in relatively lower velocities near the flow-substrate interface, and it increases channel and habitat stability. These low velocity zones provide refuge habitat to salmonids during high-flow events. Many salmonids seek out low velocity areas close to high velocity areas in order to optimize foraging and maximize net energy gain. Structure in the form of large woody debris (LWD), when recruited into the active channel promotes localized scour, pool formation and is, itself, utilized as cover. The temperature of stream waters at any given time reflects a balance of heat transfer between the water and the surrounding environment. Although heat exchange occurs via several processes, direct insolation (solar radiation) is generally the dominant source of energy input into streams. Riparian vegetation protects stream temperatures from rising by providing canopy that shades the water and reduces direct solar radiation reaching the water surface.

EFFECTS (Chapter 4)

The removal of alluvial material from a streambed has direct effects on the stream's physical boundaries, on the ability of the stream to transport and process sediment, and on numerous associated habitat qualities. These effects are discussed below and summarized in Table 1.

Sediment removal disturbs the dynamic equilibrium of a stream channel because it intercepts material load moving within a dynamic system and triggers an initial morphological response to regain the balance between supply and transport. Sediment removal may also drive more widespread instability because the discontinuity in the sediment transport-supply balance tends to migrate upstream as the bed is eroded to make up the supply deficiency.

Disturbing or harvesting the armor layer of stream channels and bar deposits provides the stream a readily erodible sediment supply because sediment is now available for transport at lower discharge. The new supply of sediment derived from the streambed will be transmitted downstream, where it can adversely affect aquatic habitats. The effects may extend a considerable distance downstream if the disturbance area is large (several consecutive bars). Armor layer disturbance for flood safety enhancement can result in transferring the sediment downstream where flooding will increase in deposition zones.

An undesirable effect of most forms of commercial and flood control sediment removal is reduced channel complexity and surface topography, either directly or through time due to diminishing sediment sorting processes that result in a more uniform stream bed. Reduced complexity, diminished sediment sorting and armor layer development, and reduced topography result in a less stable channel. Therefore, there is high potential for injury to salmonid embryos in areas of channel disturbance by sedimentation of the streambed.

The partial removal (or surface disturbance) of bars can adversely affect salmonid spawning habitats. Historical spawning gravel deposits can be scoured and swept downstream as the result of increased shear stresses at riffles. Elevated bed shear stresses can also preclude the deposition of new spawning gravel supplied from upstream sources. When channel bars are removed, the channel is effectively widened at low and moderate flows. As a result, gravel particles are more likely to continue moving across the riffle and accumulate in pools where the shear stress has been locally reduced thus reducing pool depth and its valuable habitat.

Bed sediment intrusion resulting from the excavation of in-channel bars can occur when an altered bar is initially overtopped and flushed of its fine-grained surface layer. This process, in terms of increased sediment load, is difficult to detect, especially in streams with high background sediment concentration. However, the risk of harm to spawning and incubating salmonids in areas within and downstream of altered bars can be high if reproductive activities coincide with the first winter storms.

A relatively low velocity sub-layer develops when fluids flow across any surface. The thickness of the sub-layer is related to the effective height of roughness elements on the surface. Most natural streams have rough beds created by coarse substrates, frequent larger particles, LWD, and vegetation along the banks, with large effective roughness heights. A basic salmonid strategy is to minimize energy expenditure while maximizing food input. This is accomplished in undisturbed streams by moving about the rough surface particles and searching for invertebrates, which are also utilizing the boundary layer environment. Sediment removal, particularly bar top removal, reduces exposed particle size and LWD in streambeds. Reduced roughness heights, and boundary layer thickness, thereby reduce salmonid habitat by shrinking the area for efficient movement and reducing food sources.

In natural streams, shallow riffles can be migration barriers to upstream migrating adult salmon and steelhead. Channel stability and its effect on the shape of the low flow channel and flow depths govern the extent of the barrier during migration seasons. In addition to reducing stream depths over riffles (as a result of increasing W/D ratio), sediment removal operations can increase current velocities and reduce flow-field complexity, thereby forcing migrating salmonids to expend additional energy from their finite energy reserves. Juvenile salmonids will also face challenges finding and using velocity refuges during high flows in simplified, hydraulically smoother channels.

Removal of alternate bars and other streambed features can adversely affect fundamental physical processes related to pool maintenance. The partial sedimentation of pools during summer low flows and their subsequent scour during winter high flows are widely recognized seasonal processes. Removing or altering in-channel bars reduces effectiveness of the convergence and scour mechanisms that maintain pools. As a result, pool maintenance processes are significantly impaired when alternate bars are removed. The implications of impacts to pool formation and maintenance are considerable. Sediment removal projects degrade these habitat elements and thereby adversely affect the trophic structure and potential production of salmonids in the affected watershed.

Aquatic macroinvertebrates are the principal food source for most juvenile salmonids. The diversity and abundance of macroinvertebrates can be affected by sediment removal operations because they are dependent upon substrate conditions.

The presence of riparian vegetation adjacent to the low flow channel and within the flood prone area contributes to morphological stability, habitat complexity, and cover in several ways. Vegetation,

particularly when it is mature, provides root structure, which consolidates the substrate material and encourages channel stability that resists erosion forces. By enhancing the form of gravel bars, vegetation enhances the frictional resistance of the bar that acts to dissipate hydraulic energy. This decreases the effective channel gradient, moderates flow velocities, and prevents undue erosion downstream.

Sediment removal projects often cause the direct or indirect destruction of riparian vegetation along one or both stream banks in the project area. Annual bar skimming removes riparian vegetation that would otherwise colonize gravel bar surfaces. In the absence of anthropogenic disturbance, this vegetation would have the potential to grow and develop through several stages of ecological succession. Opportunities for colonization and succession of riparian plant communities are limited for the duration of sediment removal activities and until the bars regain a height where flood flows no longer scour emergent vegetation annually.

Riparian vegetation can also be adversely affected by the removal of large woody debris within the riparian zone during sediment removal activities. Large woody debris often protects and enhances the re-establishment of vegetation in streamside areas because it influences hydraulics and disrupts sediment transport. Vegetative structure increases hydraulic boundary roughness resulting in relatively lower velocities near the flow-substrate interface. These low velocity zones provide refuge habitat to salmonids during high-flow events. Vegetated mature bar tops are particularly valuable during floods because the low velocity flow-field found at bar top locations is relatively rare. In addition, many salmonids seek out low velocity areas close to high velocity areas in order to optimize foraging and maximize net energy gain.

Ecological energy is typically derived from detritus in streams and is processed by different organisms in a continuum from larger to smaller particles. Riparian vegetation provides important nutrient inputs to streams such as leaf litter and terrestrial invertebrates that drop into the stream. Such "allochthonous inputs" can be the principal source of energy for higher trophic levels in stream ecosystems. Leaf litter provides the trophic base for aquatic macro-invertebrate communities, that in turn are the fundamental food source for salmonids.

The temperature of stream waters reflects a balance of heat transfer between the water and the surrounding environment. Although heat exchange occurs via several processes, direct insolation (solar radiation) is generally the dominant source of energy input into streams. Riparian vegetation protects stream temperatures from rising unduly by providing canopy that shades the water and reduces direct solar radiation reaching the water surface.

Sediment removal from bars creates a wider, more uniform channel section with less lateral variation in depth, and reduces the prominence of the pool-riffle sequence in the channel. Channel morphology is simplified as a result of degradation following sediment removal. Such losses also diminish overall habitat diversity. Removal or disturbance of instream roughness elements during sediment removal activities also diminishes habitat complexity and the quality and quantity of anadromous fish habitat. Instream roughness elements, particularly large woody debris, play a major role in providing structural integrity to the stream ecosystem and providing critical habitat features for salmonids.

Turbidity is generally highest in streams during the first high flow of the flood season. However, various instream sediment disturbance or removal actions may increase turbidity caused by suspended sediment at different time periods. Careful scheduling to avoid inflicting adverse effects

on anadromous salmonids may alleviate most turbidity concerns. Extraction of sediment from wet stream channels suspends fine sediment during times of the year when concentrations are normally low and the river is less able to assimilate suspended sediment.

Sediment removal operations use heavy equipment and need access to sediment deposits. Interactions with equipment and sediment removal surfaces can be potentially harmful or lethal to salmonids by several mechanisms. Adult and juvenile salmonids can become trapped on surfaces with ill-defined drainage. Heavy equipment crossing wet channels, typically at riffles, can crush juveniles seeking cover in large pores.

The harmful effects of removing geomorphic features from salmon bearing streams are far reaching. This document discusses the most important physical processes affected by sediment removal from stream channels and makes linkages to biological impacts relevant to the trust salmon species (Chapters 3-4). The physical and biological effects discussed are supported by extensive references on site specific studies as well as general principles (Chapter 7). Therefore, the Guidelines have general applicability to freshwater salmon habitats. Individual proposed actions should be assessed using a combination of site-specific information, the experience of local experts, and this Guidance document as background.

Recommendations for maximally reducing the harmful effects of sediment removal from streams (Chapter 8) are presented to help staff evaluate if proposed actions have considered all possible measures for reducing harmful effects. The conservation standard represented by the recommendations is not specific. Each consultation must independently evaluate the intensity of effects and independently reach conclusion consistent with approved ESA *Section* 7 jeopardy analysis methodology.

To a large extent, channel forming processes associated with the effective discharge govern the channel morphology, as described in the effect sections, and the resulting changes to salmonid habitat elements. The effective discharge is the flow most effective in the long-term transport of sediment. The term is often used synonymously with "dominant discharge", which is defined as that discharge of a natural channel which determines the characteristics and principal dimensions of the channel.

All of the geomorphic features found within the channel are highly influenced by the effective discharge. Mature gravel bar features including bar height, armor layer, and replenishment are all determined by flows within a relatively narrow range of flows centered on the effective discharge. Therefore, channel sinuosity, width to depth ratios, and flow convergence and divergence patterns are all functions of the sediment features formed within the range of effective flows.

The physical processes that influence salmonid habitat development and maintenance are also driven primarily within the effective range of discharges. These include formation of suitable spawning gravels, pool formation and maintenance, development of habitat complexity, and the formation of velocity refuge components. In the interest of protecting those habitat elements, it is undesirable for channel disturbance activities to widely alter channel conditions within the range of the channel-forming (effective) flows.

Table 1. Summary of effects of instream sediment removal, and implications for salmonid habitat. [See Table 3 in Chapter 4.]

Element of Instream Sediment Removal	Physical Effect	Possible Consequence for Salmonid Habitat
Removal of sand and gravel from a location or from a limited reach.	Upstream and downstream propagating degradation.	Loss of several habitats.
	Scour of upstream riffles.	Lower success of spawning redds.
	Reduced pool areas.	Possible loss of spawning and rearing habitat.
	Bed surface armoring.	Lower quality of spawning and rearing habitat; changes to invertebrate community.
	Or, scour or burial of armor layer.	
	Surface caking or pore clogging.	
Removal of sand and gravel from a bar.	Loss of sand and gravel from neighboring bars.	Possible loss of several habitats.
	Wider, more uniform channel section, less lateral variation in depth, reduced prominence of the pool-riffle sequence.	More difficult adult and juvenile migration. Reduced trophic food production. Lower quality of rearing habitat.
	Surface caking or pore clogging.	
Removal of sediment in excess of the input.	Channel degradation.	Deeper, narrower channel. Dewatered back channels and wetlands.
	Lower groundwater table.	Possible reduction of summer low flows; possible reduction of water recharge to off-channel habitat.
	Complex channels regress to single thread channels.	Less habitat complexity.
	Armoring of channel bed, may lead to erosion of banks and bars.	Less spawning area. Reduced water quality. Prompt new bank protection works – reducing habitat.
	Or, scour or burial of armor layer.	
Reduced sediment supply to downstream.	Induced meandering of stream to reduce gradient. Erosion on alternate banks downstream.	Reduced riparian vegetation. Increased local sedimentation. Prompt new bank protection works. Propagate river management and habitat losses downstream.
	Armoring of bed, or scour of armor layer.	
Removal of vegetation and woody debris from bar and bank.	Reduce shade.	Increase water temperature in inland, narrow, rivers.
	Decrease channel structure from wood.	Possibly reduce cover; reduce number and depth of pools; reduce area of spawning gravel; limit channel stability.
	Decrease drop-in food, nutrient inputs.	Decrease stream productivity.

RECOMMENDATIONS (Chapter 5)

Land uses, planning, and salmonid conservation and recovery have to be considered at two time-scales; (1) short-term (up to 3 yrs.), and (2) long-term (> 3 yrs). Sediment removal from within stream channels can immediately alter channel geomorphology, hydraulics and sediment transport, and fish habitat. Depending on the scale and method of removal, many of the adverse effects can last from a few years to as little as one year. However, effects can last for centuries if channel incision occurs.

The effects of sediment removal must also be considered at two spatial scales; the area of direct disturbance, and a much larger area that has physical or biological connection to the disturbed area. Also, the scale of disturbance is related to the larger area of extended effects. Large scale sediment removal operations, or the combined effects of multiple operations in a given stream length, can have far reaching effects that extend both upstream and downstream for several kilometers. The deleterious effects on salmonids must be considered at all temporal and spatial scales when habitat modifications such as sediment removal or redistribution are evaluated.

Of the various sediment removal activities discussed in this guidance document, sediment extraction from active stream channels (or redistribution) poses the greatest risk to salmonids and their habitat. The most effective way to protect, or restore, anadromous salmonid habitats is by protecting naturally occurring physical processes that create and maintain fish habitats. Habitats in serviceable condition can be protected by implementing a combination of two methods that can minimize the disturbance of stream channel habitat: minimize local habitat modification and limit sediment extraction to well less than the sediment influx. It is very important that sediment extraction operates at scales that do not intercept high percentages of incoming coarse sediment supplies. Providing for a positive sediment budget downstream from extraction sites is a fundamental requirement for the continued ecological function of downstream habitats.

After completing the required jeopardy analysis for *Section* 7 consultation, staff should follow either the ***National Policy*** for take avoidance or these guidelines for minimizing incidental take, as appropriate. The most effective way to protect, or restore, anadromous salmonid habitats is by protecting naturally occurring physical processes that create and maintain fish habitats. Habitats in serviceable condition can be protected by implementing a combination of two methods that can minimize the disturbance of stream channel habitat: minimize local habitat modification and limit sediment extraction to well less than the sediment influx. It is very important that sediment extraction operates at scales that do not intercept high percentages of incoming coarse sediment supplies. Providing for a positive sediment budget downstream from extraction sites is a fundamental requirement for the continued ecological function of downstream habitats.

Because the sediment load intercepted in sediment removal areas is the "source" for downstream reaches, proposed extraction plans should allow for pass-through of 50% of the unimpaired incoming coarse sediment load to maintain downstream habitats. In addition to maintaining a positive sediment budget that supplies coarse sediment for downstream habitat, site-specific habitat, geomorphic features, and physical maintenance processes should also be protected.

NOAA Fisheries recommends a four-step process for planning and evaluating sediment removal proposals. The steps are: (1) identify appropriate sediment harvest locations, (2) identify the habitat needs of the fish species and life stages that either occur or occurred historically, (3) determine the

physical (hydrologic and geomorphic) processes that create or maintain those habitats, and (4) select an appropriate sediment extraction strategy to protect those habitats and physical processes. Table 2 summarizes the recommended evaluation and planning strategy.

Table 2. Recommended sediment extraction strategies to protect various salmonid habitat, stream hydrology, and retention of geomorphic processes. [See Table 4 in Chapter 5].

LIFESTAGE	Habitat Required	Limiting Physical Process	Constraint on Sediment Extraction
Adult Migration **Juvenile Migration**	Natural channel conditions including roughness elements, cover, shade, resting pools, LWD.	Minimum flow depth of 2-feet, offsetting quality of cover, roughness, resting stations.	Minimum vertical offset from low-flow channel. Free draining extraction surfaces. Avoid riparian vegetation along migration channel. Place LWD.
	Unimpaired water quality.	Localized additional sediment load.	Negligible increase in sediment load within area.
Spawning	Suitable spawning beds, nearby rearing habitat, pool-riffle complexes.	Sediment sorting processes. Premature redd scour.	Vertical offset to ensure negligible increase in bed scour in spawning locations during spawning periods.
	Unimpaired water quality.	Hyporheic flow. Localized additional sediment load. Sedimentation of spawning beds.	Negligible decrease in hyporheic flow. Negligible increase in sediment load from extraction surfaces.
Incubation **Emergence**	Stable substrate. Natural hyporheic flow.	Premature redd scour. Hyporheic flow. Localized additional sediment load.	Vertical offset to ensure negligible increase in bed scour, or increase in sediment load or turbidity from disturbed areas.
	Unimpaired water quality.	Hyporheic flow. Localized additional sediment load. Sedimentation of spawning beds.	Negligible decrease in hyporheic flow. Negligible increase in sediment load from extraction surfaces.
Rearing	Pools. Food source. Cover. Natural water quality including cool, well oxygenated, water.	Pool scour to connect with water table. Coarse and clean substrate. Riparian health.	Retention of bar geometry to bankfull flow or effective flow to ensure negligible decrease in pool maintenance process, disturbance of riparian community, reduction.

Widespread flood control practices remove or redistribute sand and gravel bars from stream channels. It is commonly argued that instream sediment removal is necessary to control flooding or bank erosion. Commercial sediment excavation applications often purport to provide secondary flood control benefits. Yet, there is little credible evidence that the perceived benefits are real or more than ephemeral. In fact, sediment removal from channels can have the opposite of desired flood control effects when it is most needed.

Sediment management for flood control objectives should be rigorously evaluated in the context of comprehensive flood hazard management and stream ecology. This includes developing the scientific understanding of the history, causes, and future of channel conditions and related factors that influence flooding. Flood control projects should also evaluate whether or how sediment

removal or its redistribution affects flooding and how these practices affect other processes or attributes, including salmonid habitat.

EFFECTS OF FLOODPLAIN AND TERRACE PIT MINING (Chapter 6)

Alluvial sediment temporarily stored (in geologic time) in deep deposits within floodplains and terraces adjacent to streams is often mined for commercial aggregate. Both terraces and floodplains are used for commercial sediment production activities because of the large volumes of valuable high-quality material stored in this landscape setting. The potential impacts of mining alluvium from terraces and floodplains are directly related to the project's proximity to the adjacent, active stream channel and the connection with the water table. Pits excavated in floodplains or terraces are spatially fixed features that, over time, may interact with stream channel migration processes in dramatic ways. Floodplain and terrace pits are relatively benign as far as salmonids are concerned until the pit and stream becomes connected, which is a possibility during flood events.

The adverse effects of mining sediment deposits from streamside floodplain or terraces should be considered at two time scales; immediate effects and delayed effects. Over decade time scales, the consideration of effects becomes more apparently a question of "when" rather than "if" salmonids and their habitats will interact with pit mines. The spatial attributes of the pit, its size relative to the stream and its coarse sediment load, and the proximity of the pit and stream meander belt govern these temporal considerations in large part.

The adverse effects of removing sediment from floodplains or terraces include chronic temperature increases, reduced ground water tables and stream flows. Relatively catastrophic effects occur when streams capture large deep pits. Pit capture often occurs when insufficient space is reserved for normal stream migration or during floods. Headcutting and widespread channel degradation occur when large pits are captured. The concerns of floodplain and terrace mining are summarized in Table 3.

Table 3. Summary of effects of floodplain and terrace mining - implications for salmonid habitat. [See Table 5 in Chapter 6.]

Element of Floodplain Mining	Physical Effect	Possible Consequence for Salmonid Habitat	Recommended design considerations.
Clearing or filling of floodplain hydrographic features.	Possible loss of channel margin complexity, reduced bank integrity, riparian functions to ecosystem.	Loss of off-channel overwintering and refugia habitat.	Maximize distance from stream to minimize impacts.
Persistence of pits in time, and need to maintain existing or install new bank protection.	Possible narrowing and simplification of channel; loss of gravel recruitment from banks; reduced recruitment of large woody debris from banks.	Reduction in total amount of habitat; possible reduction in spawning habitat; effects of reduced wood recruitment.	Maximize distance from stream, design berms to minimize occurrence. Implement fish rescue. Prevent colonization by exotic species.
Potential for uncontrolled breaching of pit by river.	Potential for rapid upstream and downstream bed scour, channel abandonment, change in stream morphology, water temperature, and ecology.	Short- and long-term changes to types, amount, and quality of habitat. Release of exotic species to stream.	Design to prevent capture during rare floods, and allow for long-term meander of stream. Minimize occurrence, or use wet mining methods.
Presence of lakes near channel. Pumping of water from lakes.	Possible effects on flow, temperature, chemistry, or biota of hyporheic groundwater, or the patterns and locations of groundwater and channel water exchange.	Reduced stream flow, increased water temperature, reduction in trophic food quantity/quality.	Maximize distance from stream to minimize impacts, or use wet mining methods.

MONITORING AND PERFORMANCE CRITERIA (Chapter 7)

The Guidelines recommend establishing monitoring and performance criteria that adequately address the range of concerns evaluated for proposed sediment removal actions. Performance criteria are recommended to establish automatically implemented protective measures in an adaptive management context in lieu of relying only on the reinitiating provisions of ESA § 7. Appendix 2 presents example monitoring plan and performance criteria.

End of Executive Summary

1 INTRODUCTION

The National Marine Fisheries Service (NOAA Fisheries) is responsible for protecting, managing, and conserving marine, estuarine, and anadromous fish resources and their habitats. NOAA Fisheries' Southwest Region administers the Endangered Species Act (ESA) as it relates to three listed species of salmonids (Chinook salmon, coho salmon, and steelhead trout), whose range includes 10 evolutionarily significant units (ESU's), that have been listed as either threatened or endangered with extinction. A Regional guidance document for instream sediment removal is appropriate, because such activities have the potential to adversely affect all life stages of listed salmonids and because sediment removal activities are widespread in streams of California.

Stream channel dimensions and forms are a function of stream discharge and the production, transport, and deposition of sediments within a watershed (Leopold *et al.* 1964; Schumm 1977). Removal of a stream's bedload disrupts the sediment mass balance and can alter a stream channel's geometry and elevation. From geomorphic principles, we can predict that sediment removal should induce relatively predictable channel responses and corresponding changes to riverine habitats. This Guidance document identifies the potential effects of sediment removal on freshwater habitats for Federally listed threatened and endangered salmonid species, and it provides recommendations and guidance for the evaluation, design, and monitoring of sediment removal activities in California streams.

The scientific literature documents that instream gravel mining operations and salmonids are often attracted to the same locations. This is due to geomorphic controls on sediment deposition (Stanford *et al.* 1996) and grain sorting processes (Dauble and Watson 1990) that concentrate clean gravel useful to both fish and mankind. Indeed, commercial gravel extraction targets particle sizes preferred by spawning salmonids (Bates and Jackson 1987). Consequently, commercial gravel extraction can selectively reduce the availability of spawning-sized gravel in river channels (Kondolf 2000).

The effects of instream gravel mining and channel maintenance have been widely recognized as potential impacts to aquatic resources. Many states have implemented strict regulations, including the prohibition of instream sediment removal, for the protection of fishery habitat and geomorphic integrity (*e.g.*, Vermont, Maryland, Arkansas, Texas, and Illinois). Other states (*e.g.*, Maine, Wisconsin, and New York) have implemented rigorous planning and monitoring measures as requirements for obtaining permits, with resulting curtailments in removal of instream sediment (table 1).

Various environmental problems discovered after the much longer histories of anthropogenic channel manipulation and sediment removal have prompted many European countries to ban instream sediment removal altogether (Kondolf 1997, 1998). The long-term environmental costs of sediment removal from streams far outweighed the short-term economic benefits from extraction of public trust resources. It has become apparent that flood-control, sediment removal, and engineering works have to take into account the complex responses of stream channels to actions such as channelization, land use changes and changes to sediment load, flow regulation, and stream bank protection. The US Department of Transportation (US-DOT) issued notice in 1995 to state transportation agencies, including CalTrans, that federal funds will no longer be available for the repair of bridges damaged by nearby sediment removal operations. New Zealand has implemented

strict controls on instream sediment removal to protect its salmonid habitat resources. Regulations governing stream sediment removal in various foreign countries are summarized in table 2. The aggregate industries in these countries are developing new methods of producing aggregate materials from hard rock quarries, and concrete and pavement recycling, to replace stream-derived resources.

Sediment removal remains a major activity that continues at great rates in numerous California coastal streams. Almost all of the approximately 100 million cubic yards of construction aggregate produced annually in California is derived from streams and floodplains (Carillo *et al.* 1990; Tepordei 1992). This rate of extraction from alluvial deposits exceeds estimated sediment yield from watersheds in the entire state of California by an order of magnitude (Kondolf 1995). Additionally, millions of cubic yards of stream sediment are frequently disturbed, redistributed, or removed from California streams for flood control and navigation purposes.

In California, instream gravel mining practices are currently less aggressive than they were in previous years. Only a few decades ago, dredges excavated deep pits that caused widespread channel degradation, tributary incision, and habitat loss (Collins and Dunne 1990). Such channel degradation was responsible for costly damages to highway bridges (*e.g.* 1995 US DOT notice on bridge damages caused by mining), other public infrastructure, and private property (*e.g.* Harvey and Schumm 1987). Regulations to control instream sediment removal were developed to curtail damages to public infrastructure and private property, but little has been accomplished to reverse the damage visited upon instream habitats. In fact, the common remedy to channel incision, rock bank revetment, may further degrade freshwater aquatic habitat (Schmetterling *et al.* 2001).

In recent years, the most widespread method of stream sediment extraction has been bar scalping or skimming, a procedure that removes the surface of channel bars and islands to an elevation slightly above the summer water surface. This method has been widely applied in an effort to alleviate the widespread problem of channel incision; however, skimming to within an offset defined by the low flow channel does not prevent channel degradation from occurring on a reach scale. Furthermore, the degradation of channels may result in simplification of geomorphic features – compromising important fish habitat and properly functioning conditions.

In 1996 the National Marine Fisheries Service established the *National Gravel Extraction Policy* (available online at http://swr.nmfs.noaa.gov/hcd/gravelsw.htm) to avoid the take of listed salmonids by, for example, disallowing sediment extraction "within, upstream, or downstream of anadromous fish spawning grounds." The purpose of the NOAA Fisheries-SWR Sediment Removal Guidelines is to present a thorough discussion of scientific information that may be used to conduct effects analyses of proposed actions that would remove sediment from streams, either for commercial sediment production or flood control channel excavation. This information will help staff to identify circumstances where the adverse effects of sediment removal actions can be reduced by, for example, limiting disturbances to locations, times, and excavation designs and methods that are less environmentally harmful. The Recommendations Chapter of these guidelines establishes a strategy to minimize the incidental take of listed salmonids entrusted to NOAA Fisheries protection.

Table 1. Examples of regulatory limitations on instream sediment removal from various States.

Location	Attributes	Literature, *Law*, or **Policy**
Atlantic States		
Vermont	Prohibits commercial sediment removal from any watercourse. Riparian owners may, by permit, remove 50 cubic yards per year from above the waterline for use on owner's property. However, if the watercourse has been designated as outstanding resource waters, only 10 cubic yards may be removed.	*Vermont Statutes, Title 10, Chap. 41: 10 V.S.A., S 1021.*
Maryland	Prohibits alteration of stream courses on public lands, including sediment removal, except for repair of bridges and flood control where life is threatened.	*Maryland Statutes, 1976.*
New York	Allows bar skimming to within 0.5 feet above summer low flow elevation. Prohibits stream crossings to a single ford for gravel removal. Prohibits removal of all live woody vegetation on bars and banks.	*New York Department of Environmental Quality Guidance Document.*
Maine	Permits instream mining from only one stream. Requires applicants to demonstrate a positive sediment budget, to map affected area with 2-foot contour interval, hydraulic modeling of pre- and post-project area, riparian assessment, and in-depth analysis of impacts resulting from sediment removal project.	*Natural Resources Protection Act*
Texas	Permits aggregate removal from active channels above 0.5 meters above the mean base flow elevation. Requires preserving riparian vegetation, replacing large substrate. Requires cost effective aggregate mines; weighing money earned by the state against costs incurred due to erosion, beach replenishment, property loss, and coastal tourism. Requires estimation of impacts of removal on sediment budgets and the cumulative impacts from several mining operations on one river.	*Texas Natural Resource Conservation Commission; a regulatory guidance document for implementation of Texas water quality certification rules, draft 1999.*
Interior States		
Missouri	Efforts underway to legislate limiting instream mining activities. Department of Conservation report recommends conducting economic analyses that compare costs to society versus economic benefits to industry. Recommends relocating mining operations to floodplain pits and to stream segments with positive sediment budgets.	*Roell 1999*
Arkansas	Prohibits commercial instream mining on about 24 streams and lakes designated that contain unique biological, physical, or recreational attributes. Allowed existing mines 2 years to cease and reclaim in the unique waters. Elsewhere, mining by permit may occur with 1 foot vertical and 25 foot horizontal offsets to low water surface.	*1995, Act #1345* Filipek 1997; Roell 1999
Illinois	Prohibits removal of streambed deposits except as necessary to protect existing low-water crossings.	**Shawnee National Forest, standards and guidelines**
Wisconsin	Denies virtually all applications for mining in or on the banks of a navigable stream, but permits mining in riparian areas away from stream banks.	Roell 1999
Utah	Permits removal of stream sediments above the streambed elevation. Prohibits disturbance of riparian vegetation and discharge of fine material. Prohibits disturbance of gravel spawning areas. Suggests replacing armoring, collecting gravel from off-channel sites, vegetative reclamation.	*State of Utah; nonpoint source management plan for hydrologic modification 1995.*

Table 1. Continued.

Location	Attributes	Literature, *Law*, or **Policy**
Pacific States		
Oregon	Permits bar skimming for removal of aggregate subject to: avoiding upstream end of bars, retaining large woody debris, maintaining vertical offset of not less than 2 feet, protecting habitat features such as oxbows, sloughs, backwaters and wetlands, conducting all work above the water table, excluding all equipment from the active stream. Prohibits removal of gravel in excess of recruitment.	*Appendix 3, Draft Oregon Statewide Programmatic General Permit*
Washington	Delegates authority to counties to oversee environmental impact assessment. Some counties regulate by sediment budget not to exceed long-term average deposition. Prohibits mining below two feet vertically above the low water level and requires the upstream end of bars shall be left undisturbed. Floodplains are the source of about 11-17% of total state sand and gravel production. Only 2-4% of total state production comes from active river channels.	*WA Surface-Mined Reclamation Act 1970. Shoreline Management Act 1971. Dept. Fish and Wildlife; Hydraulic Project Approval 1949 and subsequent. WA Environmental Guidelines Act.* Collins 1995.
California	Delegates authority to local lead agencies, often counties. Regulates instream extraction to control channel degradation. Requires mitigation for rare, threatened, or endangered species in accordance with the ESA. Lead agencies use various protective measures, including: avoid wet stream crossings, conduct work above low flow water table, avoid upstream half of gravel bars, vertical and horizontal offsets from low flow channel, maintain positive sediment budget, avoid riparian vegetation removal. Protective measures and their application vary by lead agency. Virtually 100% of total state sand and gravel production comes from alluvial deposits.	*CA Mining and Reclamation Act 1975, amended 1990.* Carillo et al. 1990; Tepordei 1992.

Table 2. Examples of regulatory limitations on instream sediment removal from other developed nations.

Location	Attributes	Literature or *Law*
Europe		
United Kingdom (England)	Instream mining prohibited.	Kondolf 1997; 1998
Germany	Instream mining prohibited.	Kondolf 1997; 1998
France	Instream mining prohibited.	Kondolf 1997; 1998
Netherlands	Instream mining prohibited.	Kondolf 1997; 1998
Switzerland	Instream mining prohibited.	Kondolf 1997; 1998
Italy	Instream mining strongly regulated	Kondolf 1997; 1998
Portugal	Instream mining strongly regulated	Kondolf 1997; 1998
New Zealand	Instream mining strongly regulated	Kondolf 1997; 1998

Canada, British Columbia	1) Prohibits removal of any substrate from a stream, its banks, or any area that can indirectly impact fish habitat, including the active floodplain. Permits can be granted by Dept. Fisheries and Oceans only for exceptional circumstances (*i.e.,* flood way enhancement) after all other possibilities are exhausted. 2) Permits aggregate mining outside active stream channels. Requires a minimum	*1976, Fisheries Act, section 35* Brief to Aggregate Advisory Panel, 2000

2 SCOPE OF GUIDELINES

The types of activities referred to in this Southwest Regional Sediment Removal Guidelines document (hereafter called the Guidelines) include commercial sediment production from terraces, floodplains, and streams, and stream excavation for flood control. Commercial sediment products include sand, gravel, boulder and aggregate used for construction, road building, cement, and landscaping. The Guidelines also apply to dredging sediment from streams for maintaining a navigation or flood control channel, or reducing bank erosion.

Mines from adjacent floodplains and terraces that may have indirect or delayed impacts on nearby streams are included because of their potential for affecting salmonid habitat. The entire channel-floodplain system is important to fluvial ecosystem function and anadromous salmonid health. These Guidelines address floodplain and terrace pits, because such pits may capture the sediment load of adjacent streams, and because they may affect water quality and quantity in nearby streams.

The range of anadromous fish habitats specifically addressed by these Guidelines includes all freshwater streams, their floodplains and associated wetlands and riparian zones. The objectives of these Guidelines are to provide guidance to our staff on the potential effects of sediment removal activities, to recommend methods to minimize disturbance from sediment extraction, and where possible, to enhance areas of diminished habitat value. This aim may be achieved through two objectives;

(1) limiting the physical modification of geomorphic features and safeguarding physical processes that generate habitat for life stages of anadromous salmonids, and

(2) establishing limits to the cumulative quantity of sediment removal to only a portion of the natural coarse sediment load, rather than harvesting all of the coarse bedload within a stream segment.

These objectives can be accomplished through the coordination of various resource management agencies and industry, combined with increased involvement and guidance from scientists (*e.g.* ecologists and geomorphologists) and engineers.

The Guidelines recommendations are intended to provide constructive guidance and assistance to NOAA Fisheries personnel involved in project review and assessment. These Guidelines embody the best scientific and commercial information available on the subject at the time of distribution. Being general in nature, the Guidelines recognize there may be site constraints or unusual circumstances that necessitate variances from the methods recommended herein. NOAA Fisheries on a project-by-project basis may consider variances. When variances from the technical Guidelines are proposed, the applicant must state the specific nature of the proposed variance, along with sufficient biological, hydrological, and sediment transport rationale to support appropriate alternatives. Subsequent revisions to these Guidelines may be initiated by the NOAA Fisheries Southwest Regional Administrator, Long Beach, California.

Information from these Guidelines may be incorporated into ESA section 7 consultations. For example, terms and conditions contained in an incidental take statement may be based on Guideline recommendations, particularly where site-specific data do not support less conservative measures. If the applicant or action agency fails to adopt these Guidelines or provide data adequate to justify less protective measures, NOAA Fisheries will apply the precautionary principle and recommend conservative measures and/or studies in order to ensure adequate protections are in place.

The Guidelines also provide a basis for other NOAA Fisheries responsibilities under ESA. Under ESA section 4(d), regulations may be issued as necessary to protect species listed as threatened. In California, 4(d) rules have been promulgated that provide for certain activities to be conducted without further regulatory oversight, if conducted in an approved fashion. These Guidelines could furnish the technical foundation for developing a sediment removal program that might be eligible for approval under the ESA 4(d) rule. Also under ESA section 4, NOAA Fisheries is required to develop recovery plans for listed species. The SWR is embarked on a comprehensive recovery planning process in California; within a SWR recovery plan, it is possible that sediment removal programs could be designed on the basis of these Guidelines and incorporated into a long-term recovery program. The ESA contains a provision under section 10 for non-federal applicants to receive permits for take, when activities are conducted in accordance with an approved Habitat Conservation Plan. It is possible that a sediment removal program could be designed on the basis of these Guidelines for the purpose of obtaining a section 10 take permit.

Under the Magnuson-Stevens Fishery and Conservation Management Act, NOAA Fisheries reviews activities that might impair Essential Fish Habitat (EFH). In California, salmon are managed through the Pacific Fishery Management Council, which has identified EFH. In those freshwater areas where managed salmon occupy EFH, these Guidelines provide a basis for evaluating the effects of sediment removal on EFH.

2.1 LEGAL AUTHORITY

NOAA Fisheries has the authority and obligation under several statutes, including the ESA, the Fish and Wildlife Coordination Act, the Magnuson-Stevens Fishery Conservation and Management Act, and the National Environmental Policy Act to review actions that might harm living marine resources or the habitats that support them.

The U.S. Army Corps of Engineers (USACE) has authority to require a permit for dredge and fill operations and other activities associated with streambed disturbance projects under section 404 of the Clean Water Act, as well as section 10 of the Rivers and Harbors Act of 1899. Under the Fish and Wildlife Coordination Act, NOAA Fisheries reviews section 10 and section 404 permit applications for environmental impacts to anadromous, estuarine, and marine fisheries and their habitats. Section 7 of the Endangered Species Act requires Federal action agencies, including USACE, to consult with NOAA Fisheries and the U.S. Fish & Wildlife Service, if it is believed that a listed species may be affected by a project ESA section 7 requires this consultation in order to ensure that such actions are not likely to jeopardize the continued existence of any endangered or threatened species, including harm to habitat of listed species.

The State of California regulates sediment removal from streams under the State Mining and Reclamation Act (SMARA) of 1975. Provisions contained in SMARA require sediment removal operations to post financial reclamation bonds and obtain permits from a local lead agency, usually

the County or City. However, the lead agencies generally do not have the staff expertise or resources to manage stream ecosystems and the complexities of fluvial processes. SMARA recognizes areas of statewide or regional significance, and it can designate and protect sensitive areas from incompatible land uses. SMARA regulations include protection of surface and groundwater from siltation or pollution, prevention of channel degradation, avoidance of wetland habitats, minimizing vegetation removal, replanting requirements, and protecting fish and wildlife habitat using all reasonable measures.

SMARA section 3710(a) protects surface and groundwater from siltation and pollution. Section 3710(c) states "extraction of sand and gravel from river channels shall be regulated to control channel degradation in order to prevent undermining of bridge supports, exposure of pipelines or other structures buried within the channel, loss of spawning habitat, lowering of ground water levels, destruction of riparian vegetation, and increased stream bank erosion." Section 3710(d) states "in-stream mining activities shall not cause fish to become entrapped in pools or in off-channel pits, nor shall they restrict spawning or migratory activities." State performance standards for stream protection also include compliance with California Fish and Game Code section 1600 *et seq*.

The Magnuson-Stevens Fishery Conservation and Management Act also addresses the effects of changes to habitat that supports commercially important fish. Coordination between Federal Agencies is required under the Essential Fish Habitat (EFH) provisions of the Magnuson-Stevens Fishery Conservation and Management Act. Historically, the largest sediment removal projects in California supplied construction materials for large public works projects such as highway and airport construction. This pattern continues today as sediment is used for resurfacing and enlarging public roadways. Federal funding for such projects comes from the U.S. Department of Transportation and is passed through State agencies for material procurement. This is an area where Federal coordination can be applied to better protect public trust resources and to help agencies meet their ESA obligations (Section 7(a)(1)) and EFH obligations. Further description of the state and Federal legal authorities can be found in Appendix 1.

3   STREAM FORM, FUNCTION, AND ANADROMOUS SALMONID HABITAT

Channel geometry and geomorphic features within channels are the products of interactions among stream flow, sediment delivered to the channel, the character of the bed and bank material, and vegetation. A stream that is free to develop its own geometry evolves through time to develop a channel shape, dimensions and planform pattern (together termed morphology) that reflect a balance between the sediment and water inputs, the stream's relative energy and the dominant characteristics of the sediments forming the bed and banks. Self-formed channels also adjust their conveyance capacity so that flow inundates the surrounding floodplain on average every 1-2 years. Streams in which the channel geometry and capacity are adjusted in this way are said to be in dynamic equilibrium. The concept of morphological adjustment towards dynamic equilibrium is fundamental to the theory and management of stream corridor processes.

3.1   STREAM CHANNEL DYNAMICS

A qualitative expression describing the balance between sediment discharge (Q_s), stream discharge (Q), median particle size (d_{50}) and the long-stream slope (S) was presented by Lane (1955). The expression states that:

$$Q_s\, d_{50} \sim\ Q\, S$$

where d_{50} is the median bed material particle size.

This relationship is often characterized as a pair of scales and is commonly referred to as 'Lane's balance' (figure 1).

In addition to illustrating the interactions between sediment, water, and slope, Lane's relation is often used to obtain a general understanding of the way a stream will respond to changes. For example, if Q_s decreases in a stream reach due to sediment extraction in the supply reach upstream, Lane's relation suggests that the disturbance would result in (1) increased d_{50} or (2) decreased slope (assuming the channel forming discharge, Q, is independent of local channel disturbances). In other cases, the

Figure 1. Lane's (1955) 'balance' diagram, a useful visual model for predicting stream responses to various disturbances.
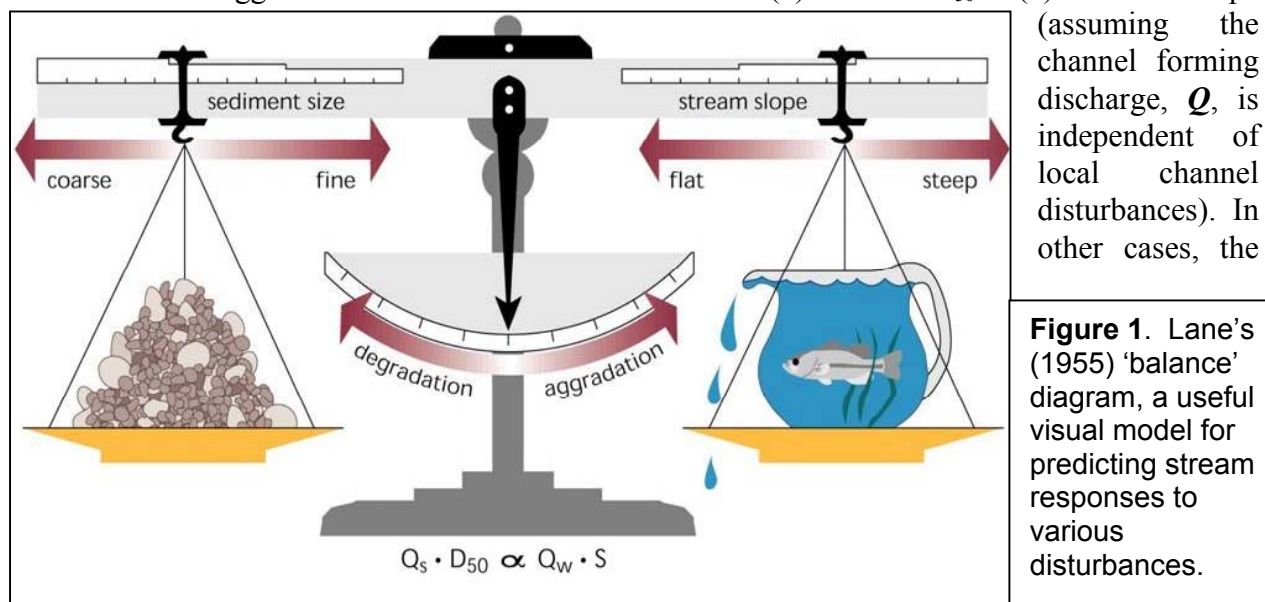
conveyance capacity of a stream is often increased in an attempt to reduce flood risk. If the channel

cross-section is enlarged (Q increases), or the planform straightened (S increases), Q_s and d_{50} can both increase, thus triggering further channel change as the stream responds to artificial enlargement. Significantly, Lane's relation shows us that both Q_s and d_{50} may increase in response to an increase in slope, even if Q remains constant. It must be remembered, however, the Lane's balance provides only a simplified schematization of the complex process-response system that actually operates in disturbed alluvial streams.

A problem that underlies all simplified approaches to the treatment of stream morphology and equilibrium is the need to represent the wide range of flows actually experienced by the channel by a single representative flow. In this context, the concept of a channel forming or "dominant" discharge is often invoked and has in the past proven useful for analytical and discussion purposes. The dominant discharge is the single, steady flow that, if it were to occur all the time, would produce a channel with the equivalent size and shape to that produced by the actual variety of flows happening (Biedenharn *et al.* 2001). It can, therefore, replace the range of discharges that mold the shape and size of the channel for analytical purposes (Copeland *et al.* 2001).

It is recognized that the gross form of the river and its floodplain are, in reality, shaped by larger, less frequent discharges, and modified by local geology and watershed characteristics. However, dominant discharge theory argues that maintenance of channel dimensions and smaller-scale features such as bars, riffles, pools, and islands (habitat features) are most closely related to more frequent, in-bank discharges (Soar and Thorne 2001). It follows that the formation and maintenance of anadromous salmonid habitat is closely controlled by the dominant discharge, although valuable habitat functions do require a wider range of flows.

Maintaining equilibrium channel size requires that the sediment transport capacity of the channel is, on average, matched to the supply from upstream, so that over the long term the channel neither degrades nor aggrades (Emmett 1999). This assumes an available supply of sediment - if there is not an adequate supply, then transport causes incision. Therefore, channel forming processes are most effectively conducted by the flow that transports the most sediment load over time (Wolman and Miller 1960; Leopold *et al.* 1964; Knighton 1984). The stream flow transporting most sediment is referred to as the 'effective discharge' (Biedenharn *et al.* 2001). This is an intermediate discharge event with a return period usually in the range of 1 to 2 years (Soar *et al.* 2001). Although extreme discharge events can transport vast quantities of sediment, they occur infrequently. It is the more frequent storms that cumulatively deliver the most material.

3.1.1   Channel Form and Function

The dimensions of self-formed, alluvial stream channels are influenced by the dominant discharge. Through time, those dimensions adjust so that the bankfull discharge (the maximum flow contained within the channel) converges with the effective discharge (the stream flow doing most sediment transport). Hence, for a stream in equilibrium with its watershed, bankfull and effective discharges are approximately the same and flow spills onto the floodplain every 1 to 2 years.

Stream channels are highly organized both in planform and longitudinally. Stream channel planforms can be characterized as straight, meandering, braided, or anastomosing, although the existence of intermediate patterns means that there is actually a continuum of patterns. Even in undisturbed straight channels, the fundamental geomorphic pattern features a sinuous low-flow channel (thalweg). The thalweg switches from bank to bank as the flow meanders around accumulations of coarse bed material known as alternate bars.

a. Alternate Bars and Point Bars. Alternate bars and point bars, and the associated pool-riffle sequences, are the fundamental geomorphic units found in alluvial channels. It is useful to consider that bars "grow" from an incipient condition to maturity, and can improve from various disturbances to approximately the pre-disturbance conditions. This view of bar dynamics allows the conceptual connection to valuable fish habitat that disturbed bars can provide if allowed to re-establish. Bars develop a maximum height corresponding to the elevation that the river currents (Church *et al.* 2001) can carry gravels, often near normal flood water levels. Sand can be transported to higher elevations and deposited on bar tops. Once vegetation becomes established on the bartop sands and gravels, sand is more rapidly trapped and the bar top approaches the elevation of the adjacent floodplain.

Mature bars in undisturbed channels are connected to the adjacent floodplain, having elevations corresponding to the water surface elevation associated with the bankfull stage. In altered channels, "mature" bars can adjust their heights to correspond to other benchmarks including the dominant discharge, and possibly to heights associated with extreme flood events.

b. Pools and Riffles. The long-profile of the bed of a natural stream channel usually displays a systematic pattern of alternate deep and shallow units termed pools and riffles. A significant feature of riffle-pool geometry is the more or less regular spacing of successive pools or riffles at a distance of 5-7 times channel width (Keller and Melhorn 1978). Pool-riffle formation can be thought of as a vertical expression of the same processes that drive meandering in the horizontal plane. Pools combine with alternate bars to confine the most frequent flows, those less than bankfull, into relatively narrow cross-sections. The greatest channel confinement occurs adjacent to the widest points of bars, where the thalweg lies close to the opposite stream bank. Strong secondary currents and plunging flow occur at these locations, accentuating pool scour to provide important fish habitat. Pools associated with resistant channel boundaries (*i.e.* rock outcrop) may be spaced at different length intervals (greater or less than 5-7 channel widths) but are maintained by the same geomorphic processes described in Chapter 4.3. Meandering (next section) and alternate bar formation are the dominant controls on the pool-riffle sequence and the quality of these habitats.

Pools are an essential habitat element for salmonids (Bjornn and Reiser 1991). Pools provide a complex of deep, low velocity areas, backwater eddies, and submerged structural elements that provide cover, winter habitat, and flood refuge for fish (Brown and Moyle 1991). During their upstream migrations, adult salmonids typically move quickly through rapids and pause for varying duration in deep holding pools (Briggs 1953; Ellis 1962; Hinch *et al.* 1996; Hinch and Bratty 2000). Holding pools provide salmon with safe areas in which to rest when low-flows and/or fatigue inhibit their migration (Moreau and Moring 1993).

Pools are also the preferred habitat of juvenile coho salmon (Hartman 1965; Fausch 1986; McMahon 1983), and they are a preferred habitat of juvenile steelhead, although this latter species is also able to utilize riffle habitat if it is complex with velocity refuges behind cobble and small boulders (Nielsen *et al.* 1994; Hartman 1965; Raleigh *et al.* 1984; Hearn and Kynard 1986). Pools with sufficient depth and size can also moderate elevated water temperatures stressful to salmonids (Matthews *et al.* 1994). Deep, thermally stratified pools with low current velocities, or connection to cool groundwater, provide important cold water refugia for cold water fish such as salmonids (Nielsen *et al.* 1994).

Between alternate bars, riffles and runs form where the stream crosses from one bank to the other and the channel cross-section is substantially wider. Riffles are composed of relatively coarse bed material that is selectively mobilized by flows approaching the dominant or bankfull discharges. Fine sediment is flushed through riffles, while the gravel and cobble material comprising the riffles is mobilized and reworked less frequently, resulting in well-sorted, clean substrate. Gravel beds within riffles provide important spawning habitat for anadromous salmonid species.

All spawning salmonid species excavate depressions within gravel deposits into which they lay their eggs, which are then fertilized and covered by a porous layer of gravel. The embryos incubate within these gravel nests (redds) for several weeks to months before hatching. Alevins, newly hatched fish, reside within the gravel pore spaces for additional weeks, taking nourishment from their abdominal yolk sac. Embryos and alevins depend on the flow of intragravel water (hyporheic flow) to carry off metabolic wastes and supply them with well-oxygenated water. Upon final absorption of the yolk sac, the young fish must then pass up through the gravel pore-spaces to the bed surface (Bjornn 1968).

In addition to spawning habitat, the shallow, swift flows over riffles and runs are also important habitats for numerous species of invertebrates, many of which are important food sources for salmonids. Coarse riffle-run substrates are the among the most productive stream habitats, supporting much higher densities of organisms than sandy or heavily sedimented substrates (Hynes 1970; Fields 1991).

c. Sinuosity and Meandering. Undisturbed alternate bars deflect low, high frequency flows around them, thus creating a sinuous flow pattern at discharges up to high, over-bank flood events. The flow field converges as it flows around the alternate bars, then it diverges as it flows over the riffles (Keller 1971). In a straight channel, the flow path is longer than the distance along the channel. The degree of meandering is indicated by the sinuosity – which is the ratio between the actual length of the flow path and the equivalent straight-line distance. The longer flow path in a natural channel with a sinuous thalweg results in a lower slope and greater energy dissipation than in an equivalent engineered channel with a uniform, trapezoidal cross-section.

In nature, sinuosity and slope are adjusted towards achieving dynamic balance between the dominant discharge and the sediment load. When flood flows overtop the alternate bars, the sinuosity decreases toward unity, and the slope increases to nearly that of the floodplain as the stage increases. Thus, natural (unaltered) alluvial channels have two hydraulic efficiencies; low efficiency for flows significantly less than bankfull, and higher flood flow efficiency.

As water flows around geomorphic features such as alternate bars, sinuosity in the flow field may lead to development of a meandering channel pattern. This occurs because bank retreat is concentrated opposite alternate bars where flow is concentrated and scour depth is greatest. Meanders gradually grow in amplitude and migrate down valley through erosion at the outside of bends that is greatest just downstream of the bend apex. Bank retreat is, on average, balanced by deposition at the inside of bends, so that channel-width remains about constant.

The meandering stream channel pattern represents a continuation of the development of sinuosity as a process of self-regulation of slope and sediment transport to achieve equilibrium. In streams in equilibrium with their watersheds, meanders develop consistent dimensions of wavelength and radius of curvature adjusted to provide a channel slope and degree of energy dissipation that is adjusted to the discharge and sediment load. Meandering streams shift and migrate to rework entire

valley bottom widths over short geologic time spans. Meandering and alternate bar formation is consequently the dominant process of floodplain development, with overbank deposition of fine sediment the secondary process.

d. Sediment Sorting. In addition to the general progressive downstream reduction in size (fining) of particles forming the bed of alluvial channels, local sorting occurs related to the local distribution of stream forces. Channel bed topography causes flow to diverge at riffles and converge in the narrower cross-sections at pools (Keller 1971). Convergent and divergent patterns of flow paths can be inferred from map views of stream channels, and from the shapes and ratios of cross-section width to depth. Undisturbed bars and their associated pools and riffles are arranged in an alternating pattern of convergence and divergence zones. Complex topographic and sedimentary features are maintained by the convergence and divergence of the stream's flow field (e.g., Keller 1971; Keller and Melhorn 1978; Lisle 1979; Andrews 1979).

The non-uniformity of energy dissipation in the zones of convergence and divergence sets up particle sorting mechanisms, and diverse habitat features result (Trush *et al.* 2000). Where the apex or maximum width of an alternate bar is intrinsically linked with the zone of highest flow convergence, the increased depth and turbulence in the flow field form relatively deep scour holes that contain the coarsest bed particles. Such coarse-bedded scour holes form the pool habitats important to fish and the trophic food base of the ecosystem at lower flows. During low summer flows, when pools are most readily observed, a fine-grained veneer may cover the coarse bed.

Where flow diverges over riffles, the flow depth and velocity-field become more uniform, providing conditions conducive to the formation of well sorted patches of gravel. It is these gravel patches, combined with the gradient of the hyporheic flow field (subsurface water), which provide optimal substrates for spawning salmonids (Groot and Margolis 1991).

e. Armor Layer. Undisturbed bars and channel bottoms are typically armored with a layer of large cobbles that overlies mixtures of finer-grained deposits. Armoring is especially evident on the heads (upstream end) of bars. The armor layer reduces the mobility of bed sediment, making bar heads and the channel bottom resistant to high flow stresses and providing stability to the channel during flood flows. Areas of heavy armor can provide valuable fish habitat during high flows (Church *et al.* 2001) because of low near-bed velocity, and productive benthic habitat whenever inundated (Bjornn *et al.* 1977). In both altered and unaltered channels, when the balance between bed material transport and bed mobility is reached a coarse surface layer "armor" develops on the bar surface which hinders or prevents erosion (Leopold and Emmett 1976).

f. Hyporheic Zone. The hyporheic zone is the subsurface stream flow and shallow groundwater environment known to be critical for stream ecosystems. Water in the hyporheic zone moves down valley through interstitial spaces in floodplain and stream bed sediments and is connected to stream waters. For example, the hyporheic zone extends as much as 2 km away from Montana's Flathead River channel and it is a greater source of nutrients to the stream than surface water (Stanford and Ward 1988).

Water diversion or pumping associated with sediment excavation can lower groundwater tables. Where a depressed groundwater table intersects nearby stream channels, especially during low flow seasons, the stream flow will be reduced and possibly subside below the surface of the streambed. This can cause direct mortality to affected fish and the aquatic food base of the stream ecosystem. Locally depressed water tables can reduce stream flows for great distances down stream.

g. Habitat. The incremental growth and translation of stream meanders gradually erodes the outside of bends while depositing sediment on the point bar at the inner bank. Channel migration in floodplain riparian communities recruits large woody debris (LWD) to the channel which can cause localized bed scour and sediment sorting that augment pool habitats and add cover and shade. As described below, the disruption of stream channels affects many attributes of salmonid habitat. In general, the health and function of the stream ecosystem are positively related to the degree of dynamism and topographic complexity of the stream channels.

3.2 WATER QUALITY.

Unaltered stream channels have high levels of variability and complexity at the channel margin, including stream-side wetlands, oxbow lakes, riparian stands at various elevations and stages of maturity. Such areas are protected from direct flood currents and are commonly associated with springs. All elements of channel margin complexity are important habitat for salmonids, during floods, and also during low flow periods. Such areas form low velocity zones during floods where water quality improves (or remains better than the main channel) as suspended sediment settles. Anadromous salmonids are adapted to migration and feeding in relatively clear water, and so floods transporting high suspended sediment concentrations can cause behavioral or physical harm, particularly if the fish cannot find refuge until the flood passes. Consequently, migrating salmonids may be found in large numbers taking advantage of complex channel margin habitats during floods (Church *et al.* 2001).

One of the most valuable floodplain functions is providing a sink for suspended sediment during floods. Unaltered streams inundate floodplains frequently, about every 1-2 years for channels that are in dynamic equilibrium. Channels that have been channelized for flood control, or land development, or have undergone natural incision, do not interact with their surrounding floodplain as frequently. In fact, the goal of many river management schemes is to prevent floodplain interactions for floods of up to the 100-year recurrence interval.

The combination of higher capacity channels and reduced channel complexity increases the magnitude of flood flows that salmonids are subjected to, and reduces habitat used for refuge during floods. These effects are discussed in Chapter 4.

3.3 FLOODPLAIN / CHANNEL CONNECTION

Stream corridors are ecosystems containing the stream channel(s) and adjacent floodplain. Water, sediment and nutrients, organisms, and energy transfer dynamically between the stream channels and floodplain. Floods in non-manipulated streams overtop the banks (bankfull flow condition) every 1-2 years. Overbank floods transport water, sediment, and nutrients onto floodplain surfaces, which support ecologically rich riparian forests and calm water habitats for breeding and feeding of aquatic species.

3.3.1   Floodplains as Sources and Sinks.

Floodplains retain and absorb flood flows, reducing downstream flood peaks and in turn providing an important source of shallow groundwater (hyporheic zone) that nourishes the stream during dry seasons. The dry season flow of streams is the result of water seepage from floodplain storage and other sources such as springs and tributaries. The quality of the hyporheic water discharging into streams is high, and the temperature is low; conditions highly favorable for anadromous salmonid

rearing. Inflowing groundwater can substantially reduce water temperature in pools during high summer ambient temperatures.

Much of the suspended sediment transported to floodplain areas is deposited, adding to the soil and supporting the riparian community health. Frequent communication with the floodplain reduces the concentration of suspended sediment in the channel, thus improving water quality for the more frequent flows contained within the channel.

One important criteria for streams in a state of dynamic equilibrium is interacting with their floodplain every 1-2 years or so. Another criteria is the erosion of stream banks balanced by deposition of bars. "Damage" done by large floods that disturb the channel or floodplain is quickly returned toward dynamic equilibrium because (1) floodplains have great capacity for detaining flood peaks, and (2) the energy within the channel cannot substantially increase beyond the energy applied during the more frequently occurring bankfull condition (Knighton 1984). Incised or leveed streams contain larger, less frequent, floods and are therefore not in dynamic equilibrium.

The ecosystems of streams in dynamic equilibrium have remarkable resiliency to natural disturbances (extreme events) (Pearsons *et al.* 1992), and benefit from large floods (Platts and Nelson 1985). Floods exceeding 10-20 year recurrence scour and rebuild in-channel features, avulse main stem channels, rejuvenate mature riparian stands to early successional stages, form and maintain side channels, reshape or redirect entire meander sequences-forming oxbows and off-channel wetlands (Gordon *et al.* 1992).

3.3.2   Riparian Communities.

Riparian vegetation provides many ecological functions that are important to salmonids. Vegetative structure increases hydraulic boundary roughness resulting in relatively lower velocities near the flow-substrate interface (Beschta and Platts 1986), and increases channel and habitat stability (Lisle 1986). These low velocity zones provide refuge habitat to salmonids during high-flow events. Many salmonids seek out low velocity areas close to high velocity areas in order to optimize foraging and maximize net energy gain (Fausch 1984).

Mature, late succession vegetation provides additional benefits to juvenile salmonids in the form of physical structure. Structure in the form of large woody debris (LWD), when recruited into the active channel promotes localized scour, pool formation and is, itself, utilized as cover. Cover is also provided to juvenile salmonids by overhanging vegetation, submerged vegetation and exposed roots. The cover provided by complexities in structure can increase survival rates for salmonids rearing in summer, overwintering, and as outmigrating smolts (Meehan 1991).

Ecological energy is typically derived from detritus in streams (Cummins *et al.* 1973; Vannote *et al.* 1980) and is processed by different organisms (Anderson and Sedell 1979) in a continuum from larger to smaller particles (Boling *et al.* 1975). Riparian vegetation provides important nutrient inputs to streams such as leaf litter (Cummins *et al.* 1973) and terrestrial invertebrates that drop into the stream. Such "allochthonous inputs" can be the principal source of energy for higher trophic levels in stream ecosystems (Reid 1961; Gregory *et al.* 1991). Leaf litter provides the trophic base for aquatic macro-invertebrate communities that in turn are the fundamental food source for salmonids (Beschta 1991; Bretscko and Moser 1993; Hawkins *et al.* 1982).

The temperature of stream waters at any given time reflects a balance of heat transfer between the water and the surrounding environment. Although heat exchange occurs via several processes,

direct insolation (solar radiation) is generally the dominant source of energy input into streams (Beschta *et al.* 1987; Spence *et al.* 1996). Riparian vegetation protects stream temperatures from rising by providing canopy that shades the water and reduces direct solar radiation reaching the water surface (Beschta 1991; Hetrick *et al.* 1998).

4   EFFECTS OF SEDIMENT REMOVAL FROM STREAMS

With few exceptions, sediment removal activities for either flood control or commercial sediment production occur in coarse bed alluvial stream channels that are structured with alternating bars (Trush *et al.* 2000) and sequential pool-riffle complexes (Keller and Melhorn 1978). Comprised of deposited coarse sediments, alternate bars occur in straight, sinuous and meandering channels as well as within straightened and levee-confined, engineered channels. Coarse bed materials are typically transported and deposited in appreciable quantities along streams during flood flows on only a few days per year (*e.g.* Emmett 1999). Channel pools form adjacent to the widest portion of alternate bars; riffles occur where the thalweg crosses from one bank to the other. Pools and riffles are sequentially spaced along streams at 5-7 channel widths (Keller and Melhorn 1978) and can also occur where rocks outcrop, at exceptionally large woody debris, or where tributary inflow interact with the stream channel. The pools and riffles are the fundamental components of salmonid habitat in riverine ecosystems.

The removal of alluvial material from a streambed has direct impacts on the stream's physical boundaries, on the ability of the stream to transport and process sediment, and on numerous associated habitat qualities. Local effects that immediately occur following removal include, 1) changes in channel geometry, 2) decreased bed elevation, 3) changes in bed or bar substrate composition, 4) reduced form roughness, 5) loss of instream roughness elements, 6) decreased stream depths, and 7) changes in velocity patterns. Physical effects that may also occur include, 1) increased turbidity, 2) changes in sediment transport patterns and timing, and 3) changes in air and water temperature, especially if riparian vegetation is removed (Rundquist 1980; Pauley et al. 1989; Kondolf 1994a, 1994b; OWRRI 1995). Biological effects may include 1) reduced resistance to flooding and 2) reduced resilience of fish assemblages (Pearsons *et al.* 1992).

In addition to the local and immediate effects, there are delayed effects that may occur over wide areas. Improvement from some effects can occur quickly once disturbance ceases. However, other effects require longer periods for restoration, and some effects are not recoverable. For example, alternate bars that have been skimmed to low elevations will regain height and a dimension similar to pre-disturbance conditions during subsequent high flow events, but only if adequate sediment supply is available from upstream. Delayed re-establishment of particle sorting processes that lead to armor layer development, establishment of riparian vegetation, and the formation and maintenance of the riffle-pool complex can not occur until bar geometry is regained and substrate stability is returned. These processes may require many years to promote geomorphic restoration.

Channel hydraulics, sediment transport, and stream morphology are directly affected by sediment removal and redistribution activities. When human actions reshape the stream boundary by removing or moving materials, flow hydraulics are altered. These modifications lead to shifts in flow patterns and subsequent changes in sediment transport rates and timing, and local sediment

sorting patterns. These physical changes can adversely affect instream biota (Kanehl and Lyons 1992; Hartfield 1993; Benke 1990; Newport and Moyer 1974; Waters 1995; Brown *et al.* 1998) and the associated riparian habitats (Rivier and Seguier 1985; Sandecki 1989). For example, sediment removal can reduce fish populations in the disturbed area, replace one species by another, replace one age group by another, allow successful invasion by exotic species (Baltz and Moyle 1993), or cause shifts in species age distributions (Moulton 1980; Benke 1990).

Activities that disturb stream channels can disrupt the ecological continuum in several ways. Local channel modifications can propagate changes both upstream and downstream, as well as up tributaries. It can also trigger lateral migration of the channel or channel widening within the floodplain. Alterations of the riparian zone can change instream habitats as much as some activities within the channel (OWRRI 1995). The potential effects of sediment removal activities on stream form and function, riparian habitat, and anadromous fishes are reviewed in the following chapters.

4.1 EFFECTS ON CHANNEL MORPHOLOGY AND HYDRAULICS

The morphology of a stream is controlled by dynamic adjustment and balance between the quantity of water flowing in the channel, the quantity and size distribution of sediment delivered from upstream sources, the composition of the bed and bank sediments, and type and quantity of vegetation on the banks. When any of these components are altered, channel adjustments occur until a new dynamic equilibrium is achieved. Habitat alteration is inevitable when morphological adjustments take place.

The effects of sediment removal on channel hydraulics show repeated patterns that are generally predictable; however, the extent of these effects depends upon the type and scale of sediment removal operation, the channel's resistance to erosion, and watershed differences in hydrology and sediment transport. Therefore, all rivers do not respond exactly alike to the same disturbance. The following chapters describe predictable and widely observed changes initiated by sediment removal.

Stream corridors are ecosystems containing the stream channel and floodplain. Water, sediment and nutrients, organisms, and energy transfer dynamically between the stream channel and floodplain. Floods in unaltered streams overtop the banks (bankfull flow condition) every 1-2 years. Overbank floods transport water, sediment, and nutrients onto floodplain surfaces, which support ecologically rich riparian forests and calm water habitats for breeding and feeding of aquatic species.

4.1.1   Increased Width / Depth Ratio.

The ratio of flow width to flow depth is a commonly used measure of channel cross-sectional dimensions because the ratio is related to sediment transport processes and it has biological relevance. The removal of channel sediments changes the width/depth ratio (W/D) of channel cross-sections by decreasing the height of bar deposits, which results in a wider channel for any given discharge that overtops the altered surface. The greatest effect of increased W/D is observed at alternate bars and islands, and relatively little change is observed at the riffles and crossovers. The width parameter is more sensitive than depth, and the two variables are inversely related, *i.e.*, an increase in width is accompanied by a proportionately smaller decrease in depth, for a given change in flow.

These effects are pronounced in hydraulic modeling analyses (*e.g.,* HEC-2; HEC-RAS), however, hydraulic analyses are not typically used to support environmental assessments for sediment removal operations. Instead, one-dimensional continuity equations are often applied:

$$(WD)_1V_1 = (WD)_2V_2,$$
$$A_1V_1 = A_2V_2$$
$$Q_1 = Q_2$$

where **A** is area; **W** is width; **D** is depth, **V** is velocity, and **Q** is discharge, and

where $A = W * D$.

It is possible to predict the effects of sediment removal on changes in average width and depth, and the relationship between area and velocity for a steady flow (where the discharge (**Q**) is, by definition, the same at all cross-sections). These simple but very useful relationships show that where stream channels are disturbed by sediment removal, the W/D ratio will increase when the stream floods the disturbed area.

Bank erosion and bank retreat are commonly observed at long-term extraction areas. The stream banks derive their strength and resistance to erosion largely from vegetation (Yang 1996) and to lesser degrees from the height and slope. Simon and Hupp (1992) show there is a positive correlation between bed lowering and channel widening, or bank retreat. The strength of banks and resistance to erosion can be reduced by enlarging channel cross-sections through sediment extraction and by damages to the bank integrity and riparian community at access points and along inadequate buffer strips.

CASE STUDY #1 – Changes to W/D ratio.

Recent data from a gravel mining proposal in the Russian River (NHC 2001) shows that the channel width at the apex of a mature alternate bar will change from 175 feet to 700 feet when flows exceed 5,000 cfs (an average winter base flow). The respective average flow depths change from 5.5 feet to 1.3 feet, as estimated with the continuity equations. The pre-project W/D ratio (at 5,000 cfs) for this cross-section is approximately 32, and following bar skimming it will exceed 500. This magnitude of increase in the W/D ratio substantially alters the hydraulics and sediment transport processes within the river.
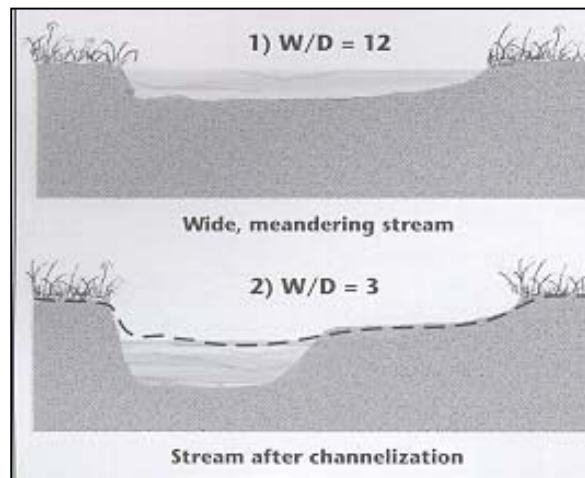
Example W/D ratios.

Once banks become weakened and retreat begins, a common solution has been to repeatedly remove sediment from the adjacent bar deposits. Although there is a flow steering effect associated with bars, removing the bar does not remove the cause of bank retreat – the weakened bank. It is a common fallacy that bars cause bank erosion, while the well accepted geomorphic model recognizes bars as migrating deposits following the natural retreat of meanders. An exception to the above argument is observed in highly disturbed stream channels (incised, straightened, leveed, or widened) where the banks are not protected by riparian vegetation. In this case, riparian vegetation may become temporarily established on bars, making the bars stronger than the banks. However, even in this case, removing bars only temporarily reduces bank retreat and the weakened bank problem persists.

4.1.2   Changes in Sediment Transport.

The ability of stream flow to transport sediment is often represented by the bed shear stress. Shear stress calculations are commonly used to estimate the ability of a flowing fluid to entrain and transport sediment from the riverbed. The sediment particles on the riverbed become mobile when the resistance to shear is exceeded - the critical shear stress or incipient motion condition. Where shear stress increases above the critical or threshold level, sediment is transported in greater volume or in greater particle size. Where shear stress decreases, the mobile particle size and/or total transport volume decreases.

The simplest form of the shear stress equations is applicable for uniform steady flow and one-dimensional cross-section averaged hydraulics. The equation is:

$$T = Y R_h S_f \,,$$

> where; T, mean boundary shear stress, is the product of

> Y, the specific weight of the fluid,

> R_h, the hydraulic radius (equal to the average depth of flow in wide channels),

> and S_f, the friction slope (or energy slope).

Since the specific weight of water (Y) can be considered a constant, the variable terms become depth and slope. The friction slope S_f is usually assumed equivalent to the average bed gradient S_o under steady, uniform flow conditions and wide rectangular channel geometry. Even with practice it is often difficult to apply the above shear stress equation because S_f, the friction slope, is in fact a complex term involving changes in head, velocity, energy losses, and boundary roughness between cross-sections.

It is more clear and more appropriate for predicting the effects of sediment removal to consider the relationship of the variable terms from the more mathematically complex two-dimensional shear stress formulations (*e.g.* Julien 1995), which reduce to:

$$T \sim v/h,$$

> where; velocity (v) is divided by

> flow depth (h).

This shear stress term, reveals why shear stress increases where velocity increases for a given depth, or where depth decreases but velocity is unchanged. Bed shear stress is maximized where velocity is greatest and depth is smallest.

The bed shear stress is used as the physical basis for many sediment transport models. The simple relationships given above are useful for estimating several of the effects of proposed channel modifications. It is essential that assessments include both the effects on hydraulics and on the ability of the stream to transport sediment in the vicinity of channel modifications. The average bed shear stress equation and one dimensional hydraulics are less capable in this regard than the more location specific relationship of *v/h*.

For example, the incipient motion condition and the sizes of relative stable grains in particular habitats can be calculated given the shear stress formulas and results from simple hydraulic models. Analysis of changes in shear stress on the bed, in the vicinity of salmonid redds, can provide insight

as to the fate of eggs buried in the bed. If shear stress increases as a result of channel modifications redds may be scoured prior to alevin emergence, killing them.

Applying the shear stress and the flow continuity equations, one can expect that shear stress will increase most in the upper reaches of sediment removal areas, where the slope increase is most pronounced. Laboratory experiments (Begin *et al.* 1981) verified this effect. It can also be shown that when sediment removal reduces the size of alternate bars, increased shear stress values occur at riffles and crossovers while shear stress values decrease at pools. Consequently, the changes in channel geometry and flow energy resulting from sediment removal can cause sediment accumulation in pools and erosion from riffles: which is the opposite of what normally occurs. The greatest reduction in shear stress can occur at the downstream hydraulic control of a sediment removal project. This can cause increased deposition and accumulation of fines in areas and at elevations where fines would not otherwise occur.

4.1.3   Reduced Sinuosity of the Mid-High Flow Channel.

A naturally functioning channel, with mature alternate bars, has two efficiencies; a lower conveyance efficiency when flows are contained within and steered around alternate bars, and a higher efficiency when flood flows significantly overtop the bars. Sediment removal projects that decrease bar elevation (*e.g.*, bar skimming) cause bar overtopping to occur at lower discharges. One result is greater flow velocities within the channel during lower discharges that occur in early winter. Invoking the shear stress relations, reducing sinuosity by bar removal can result in increased velocity, in turn causing erosion of the channel. Local erosion increases the delivery of sediment to downstream areas (Olson 2000), damaging habitats of the sediment sensitive species there.

4.1.4   Altered Sediment Sorting Processes.

In addition to the progressive downstream reduction in size (fining) of alluvial streambed particles, local sorting occurs because of the local distribution of stream forces and shear stress variations. Channel topography causes the stream's flow-field to spread out over riffles (divergence) and concentrate over pools (convergence). Complex morphologic and well-sorted sediment features are maintained by the convergence and divergence of the flow-field (*e.g.,* Keller 1971; Keller and Melhorn 1978 Lisle 1979; Andrews 1979).

Sediment removal for flood security or commercial sediment production typically reduce alternate bar heights. Flow that overtops bars with reduced height has relatively less variation in the flow pattern, leading to reduced convergence and divergence. This results in a more simplified channel with less concentrated and less effective particle-sorting processes. Therefore, it can be reliably predicted that reductions in bar height will induce decreases in the quality and area of spawning beds and reductions in pool area and depth. Quantification of altered sediment sorting would require complex hydraulic and sediment transport modeling.

4.2 ALTERATION OF THE SEDIMENT TRANSPORT CONTINUUM

Over time, stream channels adjust towards equilibrium between the sediment load and dominant sediment transporting flows. A gradual migration of the channel by eroding the outside of bends and depositing equal volumes on the inside of bends creates the dynamic equilibrium condition where the bed and banks are not net sources of sediment. Therefore, the equilibrium stream channel is efficient at maintaining its geomorphic form and pattern although the system remains dynamic

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as it responds to cyclic floods and sediment delivery events. Dunne *et al.* (1981) stated "*bars are temporary storage sites through which sand and gravel pass, most bars are in approximate equilibrium so that the influx and downstream transport of material are equal when averaged over a number of years. If all the sand and gravel reaching such a bar is removed, the supply to bars downstream will diminish. Since sand and gravel will continue to be transported from these downstream bars by the river, their size will decrease.*"

Sediment removal disturbs the dynamic equilibrium of a stream channel because it intercepts material load moving within a dynamic system and triggers an initial morphological response to regain the balance between supply and transport. Sediment removal may also drive more widespread instability because the discontinuity in the sediment transport-supply balance tends to migrate upstream as the bed is eroded to make up the supply deficiency. If stream bed lowering increases bank heights to the degree that banks become unstable, rapid bank retreat may arise, further destabilizing the width but supplying the channel with sediments that make good the transport-supply imbalance, to prevent further degradation until they are flushed out (Little *et al.* 1991, Knighton 1984). Thus, sediment removal from a relatively confined area can trigger accelerated erosion migrating upstream (head cut), causing erosion of the bed and banks and damaging aquatic habitat.

The ultimate effects of channel bed lowering is degradation along the entire length of channel by approximately the same amount. The channel becomes narrower and deeper but at the same time does not develop the complex topographic and planform attributes typically associated with equilibrium channels. If further disturbance is arrested, the disturbed channel will ultimately progress to a wider channel where inset floodplains develop, partially restoring ecosystem functions (Thorne 1999). Few monitoring programs associated with commercial or flood control sediment removal projects are capable of detecting the fundamental bed degradation over time scales relevant to the aquatic ecosystem. However, one can readily observe from air photos that channel widths are indeed greater in areas of frequent sediment removal.

Another effect of sediment removal, and the increased sediment load it triggers from upstream, is that within the removal area, the increased incoming sediment load encounters relatively less transport capacity and deposition may occur. Deposition in this zone is less organized than the repeating alternate bars of the equilibrium channel and deposition can occur across the entire channel width. The result is that the already weakened stream banks become further attacked by locally increased current velocities where flow is deflected around growing bars. Stream channels in sediment removal areas typically become progressively wider as the channel is less stable. Salmonid habitat is reduced in unstable channels (*e.g.;* Kanehl and Lyons 1992; Hartfield 1993; Benke 1990; Newport and Moyer 1974; Waters 1995; Brown *et al.* 1998) and the associated riparian habitat deteriorates (Rivier and Seguier 1985; Sandecki 1989).

Disturbing or harvesting the armor layer of stream channels and bar deposits provides the stream a readily erodible sediment supply because sediment is now available for transport at lower discharge. The new supply of sediment derived from the stream bed will be transmitted downstream, where it can adversely affect aquatic habitats. The effects may extend a considerable distance downstream if the disturbance area is large (several consecutive bars). Armor layer disturbance for flood safety enhancement can result in transferring the sediment downstream where flooding will increase in deposition zones.

Downstream from sediment removal sites the dynamic system has less load and the stream compensates by meandering to reduce its gradient, and thus reduce transport capacity. In this situation, the stream can make up the load deficit by eroding the bed and banks (Dunne *et al.* 1981). This process is widely recognized in the body of scientific literature on the effects of dams. Kondolf (1997) describes this condition as "hungry water", occurring downstream from dams as well as sediment removal sites. Although erosion of the banks often creates complex habitat where riparian vegetation is recruited and pools form, this must be considered at the larger reach scale where the increased sediment delivery impacts downstream habitats.

Two factors ameliorate bed and bank erosion caused by sediment removal: resistance of the bed and banks to increased shear stress, and the scale of sediment removal relative to the stream's sediment budget. A sediment budget is analogous to a bank account. If funds withdrawn (sediment removed + natural export) exceed funds deposited (sediment input), a negative budget results in a diminishing balance. Erosion of sediment from the bed and banks (savings) makes up for the import/export deficit. While this is conceptually simple, annual sediment replenishment to a particular sediment removal site is, in fact, highly variable. The variability is not well understood, and the short-term effects of sediment removal are easily masked by natural variability in the sediment budget and general lack of sufficiently detailed monitoring data.

The ratio of sediment extraction to sediment influx not only dictates the scale and severity of adverse effects on the channel geometry and habitat, but also controls the time-scale of rejuvenation following or between disturbances. Streams that are repeatedly harvested at rates in excess of sediment influx undergo channel degradation, resulting in either channel widening or incision, possibly effecting an entire stream system, including its tributaries. Striking cases of excessive sediment removal in California streams, where sediment removal activities continue, are summarized by Harvey and Schumm (1987), Sandecki (1989), Collins and Dunne (1990); Kondolf and Swanson (1993), and Florsheim *et al*. (1998).

4.3 EFFECTS ON SALMONID HABITAT COMPONENTS

The disturbance or removal of sediment in stream channels can adversely effect salmonid habitats used by different species life stages. The most important of those habitats are discussed in the following chapters.

4.3.1 Effects on Riffle Habitats.

An undesirable effect of most forms of commercial and flood control sediment removal is reduced channel complexity and surface topography, either directly or through time due to diminishing sediment sorting processes that result in a more uniform stream bed. The bed material may become finer or coarser, depending on the rate of sediment removal and antecedent conditions of the bed and banks. Reduced complexity, diminished sediment sorting and armor layer development, and reduced topography result in fewer riffles and pools by increasing the spacing between them. Reduced bed complexity also results in a less stable channel and less salmonid habitat. Therefore, there is high potential for injury to salmonid embryos in areas of streambed disturbance.

The movement of water does not cease at the interface between the river and its substrate. Water moves through pore spaces in the riverbed, particularly where the bed has topographic relief. Predictable zones of inflow and outflow (downwelling and upwelling) are found on the riverbed. The more complex the channel pattern and surface topography, the more strongly developed are

downwelling and upwelling hyporheic zones (Brunke and Gonser 1997) characteristic of salmonid spawning habitat (Stanford *et al.* 1996). Zones of downwelling flow are located at the heads of riffles, where the bed topography is sloped slightly upstream and where there is an increasing hydraulic gradient (Thibodeaux and Boyle 1987). Salmonids select this environment for digging redds and laying their eggs (Groot and Margolis 1991).

Sediment removal practices can adversely affect proper functioning of riffle habitats by exacerbating sedimentation of the substrates, changing hyporheic flow patterns, causing barriers to adult migration, and reducing benthic invertebrate production. The following Chapter discusses these impacts.

a. Changes in Bar Substrate and Spawning Habitat. In Chapter 3.1.1 the "mature" bar was described as having an elevation slightly lower than the floodplain (if the channel is in dynamic equilibrium, with dimensions related to the dominant flow elevation), a coarse armor layer at its head and vegetation elsewhere that is not frequently disturbed by floods (Church *et al.* 2001). Bars remain dynamic during frequent floods as a source of sediment from temporary storage that is replaced from upstream supply. The condition of maturity is obtained where bars are not frequently disturbed in their form and dimensions. The partial removal (or surface disturbance) of bars can adversely affect salmonid spawning habitats.

Historical spawning gravel deposits can be scoured and swept downstream as the result of increased shear stresses at riffles. Elevated bed shear stresses can also preclude the deposition of new spawning gravel supplied from upstream sources. When channel bars are removed, the channel is effectively widened at low and moderate flows and migrating gravel particles are, therefore, more likely to continue moving across the riffle and accumulate in pools where the shear stress has been locally reduced, thus reducing pool depth and its valuable habitat. Although redd scour occurs at some critical discharge in unaltered streams, the effect of stream alteration is to lower that critical discharge and increase the probability of premature redd scour in a given year. The loss of egg inoculated gravel from riffles was documented by Pauley *et al.* (1989), who concluded the eggs were scoured because bar skimming reduced bar heights, increasing shear stress on these vital areas of the riverbed.

Sediment removal can increase the supply of fine sediments that can clog the interstitial pores of coarse substrates. An armor layer of coarse particles covers mature alternate bar surfaces. Because channel bars are coarser at their surface than at depth, bar skimming exposes smaller sediment particles (figure 2) that are readily transported downstream to clog coarse sediment interstices.

Reductions in exposed particle size result from the removal of overlying coarse sediments and abrasion and particle breakage caused by the passage of heavy equipment. Many California coastal watersheds are composed of sedimentary and low-grade metamorphic rocks. Particles that easily break into smaller particles when moving downstream, and when heavy equipment crushes them, dominate the coarse sediment load in these streams. As a result of disrupting the natural armoring process and mechanical crushing, disturbed bar surfaces are typically finer-grained than undisturbed bar surfaces.

b. Sediment Intrusion. Sedimentation of streambeds is caused by the settling of suspended particles in low velocity areas and by the process of sediment intrusion. McDowell-Boyer *et al.* (1986) identified two mechanisms by which porous substrates can become clogged with fines: particle straining, and the formation of surface cakes. Jobson and Carey (1989) defined particle

straining as the process where fine particles move through the porous media until they encounter pore spaces too small for passage.

Figure 2. Photo of surface grain-size differences between skimmed (left) and unskimmed (right) bar surface. This is a relatively minor example of sediment removal creating a fine-grained sediment source at a low elevation within the channel.

The potential for particle penetration is a function of the effective pore diameter of the stream bed surface media and the size distribution of the particles moving in occasional contact with the bed (Beschta and Jackson 1979). Beschta and Jackson (1979) also found that most intrusion occurred quickly, during the first 15-20 minutes of experimental fine sediment input events. These experiments were probably detecting the simple geometric relationship between pore-space and particle diameter. Essentially, entrained particles can enter the streambed if the particles are smaller than the pore spaces and there is occasional bed contact.

Surface caking is the filling of pore spaces of gravel/cobble beds from the bottom up. Surface caking experiments were conducted by Einstein and Chien (1953), Simons *et al*. (1963), and Einstein (1968). These authors examined the transport of well-graded material and observed fine sediment (sand to small gravel) accumulations on the bed surface following injection of large concentrations. The accumulated material was then selectively removed as the supply was decreased. When selective removal ceases, the fine sediment trapped in the near bed layer will probably be retained even if upwelling flow is present (Jobson and Carey 1989). Gravel deposits choked with fines have decreased hydraulic conductivity that contributes to diminished oxygen concentrations in subsurface flow and resulting impacts to incubating embryos (Kondolf and Williams 1999).

Generally, when fine sediments are large relative to the spaces between gravel particles, they may only settle into the surface layer of redds, thus blocking other sediments from deeper egg pockets (Hobbs 1937; Chapman 1988). The resulting surface layer can be beneficial if it prevents the deposition of finer sediment or organic material, or it can be detrimental if it impedes the emergence of alevins (Tappel and Bjornn 1983). Chinook salmon, steelhead, and coho salmon alevin all had difficulty emerging from simulated spawning gravels when the percentage of fine sediments exceeded 30-40% by volume (Bjornn and Reiser 1991).

Sediment intrusion resulting from the excavation of in-channel bars is likely a transient process that occurs when an altered bar is initially overtopped and flushed of its fine-grained surface layer. This process, in terms of increased sediment load, is difficult to detect, especially in streams with high background sediment concentration. However, the potential for harm to spawning and incubating salmonids in areas within and downstream of altered bars is great because of the critical timing between reproductive activities and the first winter storms.

Wickett (1954) showed that sediment intrusion is most damaging to young embryos in the first 30 days of incubation because this stage is less efficient at oxygen uptake. Chinook and coho salmon typically spawn in main stem streams from November through January, and steelhead from January through April (CDFG 2001). The early winter storm events described above are likely to occur at the height of the Chinook and coho spawning season. This timing increases the likelihood that increased sedimentation at relatively low flow would impact those species.

Besides inhibiting the emergence of alevins, one of the principal means by which fine sediment reduces survival of salmonid embryos is by reducing intra-gravel water flow, thereby reducing the amount of dissolved oxygen available for respiration (Bjornn and Reiser 1991). Temporary sedimentation episodes, as described above, can exceed the ability of embryos to cope with such conditions (Alderice *et al.* 1958). The transitory natures of these effects make them difficult to detect and monitor. The least desirable situation for sediment removal would combine large disturbed areas with a location in or immediately upstream from spawning habitat.

Removal of an armor layer, which protects the stream bed or bar from sediment transport, creates a less stable bed or bar surface that can be transported earlier in a given flood season. The finer-grained disturbed surfaces, which are at a reduced elevation, create a new source of fine sediment within the active channel that can be mobilized by the first freshets during late fall or early winter. The first freshets may entrain the fine-grained surface material but lack the magnitude or duration to transport the locally derived fine sediment sufficiently downstream.

Fine sediments generated during sediment removal operations can contribute to the anthropogenic-induced concentration of sand and fines that is known to be a factor contributing to the decline or loss of salmon and steelhead populations (Cordone and Kelley 1961). Increased levels of fine sediment have been shown to have direct impacts on salmonid behavior, physiology, growth, reproductive success and the availability of food (Bjornn *et al.* 1974; 1977; Sigler *et al.* 1984; 1988; Waters 1972). Newcombe and Jensen (1996) and Newcombe (2001) discuss response curves for various fish species, life stages, and sediment exposures. The severity of fine sediment increase from excavation surfaces can be largely controlled by careful design and excavation methodology, as explained in the recommendation chapter.

NOAA FISHERIES staff conducted grain transport mode analysis (*e.g.* Rouse 1959; Julien 1995) for a recent gravel removal proposal on the Russian River. The results indicate that particles larger than 1mm diameter would be transported in contact with the bed for all discharges, particles 0.25 mm or smaller would be transported in suspension above the bed, and particles 0.5 mm will be in contact with the bed for flows up to 5,000 cfs (which occurs 11% of years in November, 52% in December, and 67% in January) and in suspension for flows higher than 5,000 cfs. These results suggested that sand and gravel particles exposed by a proposed commercial gravel removal project would be transported downstream in contact with the bed over a range of frequently observed discharges that occur during the early winter months. Furthermore, the literature shows clearly that those size particles can harm incubating salmonids.
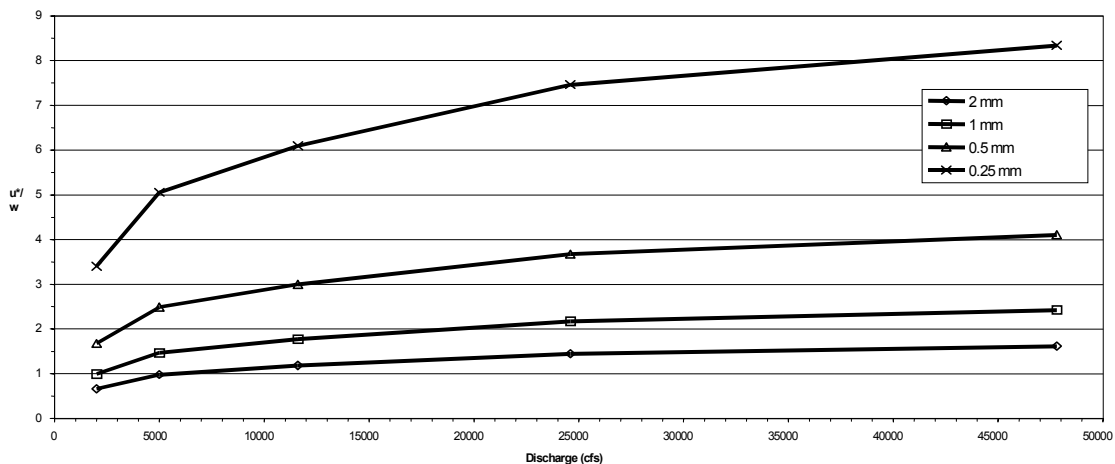
Sediment concentration profile calculated from the Rouse number u*/w for four grain sizes (0.25-2.0 mm) and hydraulic information for a riffle within a sediment removal project. For values u*/w < 2.5, grains move in contact with the bed. The two larger grain sizes move in contact with the bed for all flows examined.

c. Boundary Layer Habitat. A relatively low velocity sub-layer develops when fluids flow across any surface. The thickness of the sub-layer is related to the effective height of roughness elements on the surface. Most natural streams have rough beds created by coarse substrates, frequent larger particles, LWD, and vegetation along the banks, with large effective roughness heights.

Two scales of boundary layer thickness are important to anadromous salmonids. The layer created by LWD, bank complexity, and large cobble-boulder sized particles provides habitat for large fish where they can move about efficiently. Smaller scale boundary layer roughness, created by gravel-sized particles is rich invertebrate habitat, the food source for salmonids.

A basic salmonid strategy is to minimize energy expenditure while maximizing food input (Fausch 1986). This is accomplished in undisturbed streams by moving about the rough surface particles and searching for invertebrates, who are also utilizing the boundary layer environment. Sediment removal, particularly bar top removal, reduces exposed particle size and LWD in streambeds.

Reduced roughness height and boundary layer thickness thereby reduces salmonid habitat by shrinking the area for efficient movement and reducing food sources.

d. Adult Migration and Passage.   In natural streams, shallow riffles can be migration barriers to upstream migrating adult salmon and steelhead. Channel stability and its effect on the shape of the low flow channel and flow depths governs the extent of the barrier during migration seasons. Thompson (1972) provided minimum depths and maximum velocities that enable upstream migration of adult salmon species, criteria that have been widely cited (*e.g.;* Bovee 1982; Bjornn and Reiser 1991) and applied. According to those criteria, Chinook salmon, the largest salmonid species, requires minimum riffle depths of 24 cm and, for successful passage, this depth should be provided "on at least 25% of the total [*cross-sectional*] transect width and a continuous portion equaling at least 10% of its total width." However, it should be recognized that Thompson (1972, pg. 4) cautioned that "the relationship between flow conditions on the transect and the relative ability of fish to pass not been evaluated."

Sediment removal operations that increase W/D ratios (particularly bar scalping) increase the probability that shallow flows at riffles will form migration barriers. Pauley *et al.* (1989) and Woodward-Clyde (1980) verified what the basic river mechanics equations predict that flow depths decreased over riffles, creating barriers to upstream-migrating adult salmonids, adjacent to and upstream from skimmed bars.

CASE STUDY #3 – Sedimentation of streambed.

Gravel excavation in 2001 from a site on the Eel River near the Van Duzen River confluence approximately doubled the channel width for ~1500 feet of length. Prior to excavation the Eel River channel was estimated to be about 10-feet deep during summer low flow conditions. Using the continuity and shear stress equations, and a general understanding of sediment transport processes, one could predict that increasing the channel width as proposed would result in channel aggradation of the low-flow channel. Observations at the 2001 extraction site in summer 2002 showed that the Eel River channel indeed aggraded several feet adjacent to the extraction site. Flow depth is now less than 1-foot across the entire channel width, extending for approximately the length of the excavation. This location on the Eel River was converted from a deep low flow channel habitat to an extremely shallow habitat that now represents migratory passage difficulties, offers no resting function for migrating adults, and has impacted juveniles by converting a preferred pool habitat into a wide, shallow run. Commercial sediment removal has created a large potential fish passage impediment in the main stem Eel River, low in the watershed, where it can impede the migration of the majority of the salmonid populations in this ESU.

In addition to reducing stream depths over riffles (as a result of increasing W/D ratio), sediment removal operations can increase current velocities and reduce flow-field complexity, thereby forcing migrating salmonids to expend additional energy from their finite energy reserves. Reduced flow-field complexity and increased migratory velocities, particularly reduced edge-water eddies and low velocity zones, result from reduced sinuosity, increased W/D ratio at bars, and reduced topographic complexity of geomorphic features.   This can affect adult salmonids during their upstream migrations across riffles, and juvenile salmonids will face challenges finding and using velocity refuges during high flows in simplified, hydraulically smoother channels. Adult salmonid migration can also be adversely affected when sediment removal activities diminish the size and frequency of main stem pools; habitat used for resting.

e. Effects on Aquatic Macroinvertebrates. Aquatic macroinvertebrates are the principal food source for most juvenile salmonids (Spence *et al.* 1996). Immature mayflies (Ephemeroptera),

stoneflies (Plecoptera), and caddisflies (Trichoptera), referred to collectively as EPT, are considered the most productive, preferred, and available foods for stream fishes (Waters 1995).   Indeed, the abundance of these three groups of aquatic macroinvertebrates is commonly used as a food availability index (Lenat 1988). The diversity and abundance of EPT can be affected by sediment removal operations because they are dependent upon substrate conditions (Benke *et al.* 1987).

The EPT group typically inhabit the interstitial spaces of coarse substrates (gravel to cobble sized particles), although some species of mayfly and certain other aquatic insects (*e.g., chironomidae*) prefer highly organic fine sediments. Sands and silt are the least productive substrates for aquatic macroinvertebrates (Hynes 1970) and are more easily mobilized, making them unsuitable because they are less stable (Fields 1982). Therefore, sediment intrusion that reduces the interstitial spaces of cobbles and gravel, directly decreases the habitable area for EPT (Bjornn *et al.* 1974; Bjornn 1977).

Changes in the biomass and structure of macroinvertebrate assemblages can adversely affect the salmonid populations dependent on them. The importance of abundant food sources becomes even greater when stream temperatures are at the upper tolerance limits for steelhead and chinook salmon. Fish may respond to thermal stress by decreased growth rates (Brett *et al.* 1982) and reduced survival (Rich 1987). Since food conversion efficiencies decline at elevated temperatures, and metabolic demands increase, fish must eat more food simply to maintain homeostasis (Smith and Li 1983). Therefore, reductions in food availability due to streambed sedimentation can compound adverse affects of elevated water temperatures.

Impacts to aquatic macroinvertebrates may be protracted. The average life cycle of EPT species is one year, although several species have two-year life cycles. Fine sediments intruded deeply into the bed require mobilization of the bed itself to remove fines (Beschta and Jackson 1979; Diplas and Parker 1985). Bed mobilizing flows generally do not occur annually, so there is potential for the aquatic invertebrate food base to be diminished for some time and for some distance downstream from sediment removal areas. Brown *et al.* (1998), who sampled substrates upstream, downstream, and within an in-stream gravel mining project area, found that upstream from the disturbance: 1) biomass densities of all invertebrates were higher, 2) total fish densities in pools were higher, and 3) silt-sensitive fish species were more abundant, than within the project area or downstream.

4.3.2   *Effects on Pool Habitats.*

Removal of alternate bars and other streambed features can adversely affect fundamental physical processes related to pool maintenance. The partial sedimentation of pools during summer low flows and their subsequent scour during winter high flows are widely recognized seasonal processes. During high flows, coarse particles eroded from upstream riffles are transported through pools to downstream riffles. This process occurs because velocity and shear stress increase at pools at a faster rate than at riffles as flow increases toward bankfull (Keller 1971; Andrews 1979; Lisle 1979). Through this mechanism, as discharge increases, the energy to transport coarse sediment increases in pools at a faster rate than at riffles. A threshold is reached when flows exceed about 60% of bankfull flow, the pool scour process begins and coarse sediment eroded from upstream reaches can continue through pools to downstream riffles where it may be deposited. The pool scour process becomes most effective at bankfull flow in undisturbed stream channels, as flow depth increases only slightly once the banks are overtopped and the floodplain is inundated.

Another consequence of the pool scour and maintenance mechanism is that the beds of pools typically have the largest substrate particles, although this may not be immediately apparent during low flow periods when pool substrates are temporarily covered with sand or gravel. The predominantly large substrate beneath this veneer is due to the concentrated energy that sweeps smaller particles downstream through pools during episodes of high flow.

Removing or altering in-channel bars reduces or eliminates the convergence of flows through pools, thereby reducing the effectiveness of the convergence and scour mechanisms that maintain pools. The reduced confinement of flows can be expressed as an increased width to depth (W/D) ratio. Bar skimming for channel maintenance or commercial sediment production typically increases W/D by an order of magnitude or more. As a result, pool maintenance processes are significantly impaired when alternate bars are removed.

Pools can become partially filled with sand-sized particles when the load of fines is substantially greater than the transport capacity of the flow (Lisle and Hilton 1991). For example, pools have been observed to completely fill with fines where forest fires or large-scale logging have occurred within the watershed (Lisle 1982; 1989). Pools have also filled where adjacent lands are converted to high sediment yielding agriculture (*i.e.*, grasslands to vineyards) or where riparian vegetation dies and the unvegetated banks erode or collapse (Kondolf and Curry 1986).

The implications of these impacts to pool formation and maintenance are considerable. Pools are essential habitat elements for salmonids (Bjornn and Reiser 1991) and are found in unmanipulated channels at regular spacings of 5-7 channel widths (Keller and Melhorn 1978). Spacing between pools can increase due to bar removal and simplification of the channel, as well as reduced effectiveness of the pool maintenance process. Pools provide a complex of deep, low velocity areas, backwater eddies, and submerged structural elements that provide cover (Brown and Moyle 1991), winter habitat and flood refuge for fish. During their upstream migrations, adult salmonids typically move quickly through rapids and pause for varying duration in deep holding pools (Briggs 1953; Ellis 1962; Heggberget 1988). Holding pools provide salmon with safe areas in which to rest when low-flows and/or fatigue inhibit their migration (Moreau and Moring 1993).

Pools are also the preferred habitat of juvenile coho salmon (Hartman 1965; Fausch 1986; McMahon 1983), and they are a preferred habitat of juvenile steelhead, although this latter species is also able to utilize riffle habitat if it is complex with velocity refuges behind cobble and small boulders (Nielsen *et al.* 1994; Hartman 1965; Raleigh *et al.* 1984; Hearn and Kynard 1986). Pools with sufficient depth and size can also moderate elevated water temperatures stressful to salmonids (Matthews *et al.* 1994). Deep thermally stratified pools with low current velocities, or connection to cool groundwater, provide important cold water refugia for coldwater fish such as salmonids (Nielsen *et al.* 1994). Sediment removal projects can reduce the number of, and degrade, these habitat elements and thereby adversely affect the trophic structure and potential production of salmonids in the affected watershed.

4.3.3   Effects on Riparian Vegetation

The presence of riparian vegetation adjacent to the low flow channel and within the flood prone area contributes to morphological stability, habitat complexity, and cover in several ways. Vegetation, particularly when it is mature, provides root structure, which consolidates the substrate material and encourages channel stability that resists erosion forces (Beschta 1991). By enhancing the form of

gravel bars, vegetation enhances the frictional resistance of the bar that acts to dissipate hydraulic energy (Kondolf 1997). This decreases the effective channel gradient, moderates flow velocities, and prevents undue erosion downstream.

Sediment removal projects often cause the direct or indirect destruction of riparian vegetation along one or both stream banks in the project area. Annual bar skimming removes riparian vegetation that would otherwise colonize gravel bar surfaces. In the stream reaches that are not confined by levees or naturally resistant boundaries, long-term or repeated modification of gravel bars at low elevations promotes frequent channel shifting that precludes the establishment of riparian vegetation. In the absence of anthropogenic disturbance, this vegetation would have the potential to grow and develop through several stages of ecological succession (Hupp and Ostercamp 1996; Sonoma County 1994). Opportunities for colonization and succession of riparian plant communities are limited for the duration of sediment removal activities and until the bars regain a height where flood flows no longer scour emergent vegetation annually.

Heavy equipment, processing plants and sediment stockpiles at or near the extraction site can destroy riparian vegetation (Joyce 1980; Kondolf 1994a, OWRRI 1995). Heavy equipment also causes soil compaction, thereby increasing erosion by reducing rainfall infiltration and causing overland flow. Road construction, road use, and temporary bridges associated with sediment removal projects can also degrade the riparian zone.

Riparian vegetation can also be adversely affected by the removal of large woody debris within the riparian zone during sediment removal activities (Weigand 1991; OWRRI 1995). Large woody debris often protects and enhances the re-establishment of vegetation in streamside areas (Franklin *et al.* 1995) because it influences hydraulics and disrupts sediment transport (Hupp and Osterkamp 1996).

Sediment extraction may also remove portions of undercut banks, thereby decreasing vegetative bank cover, reducing shading and increasing water temperatures (Moulton, 1980). Banks may be scraped to remove "overburden" to reach the sediment below. This may result in destabilized banks and increased sediment inputs (Moulton, 1980). The reduction in size or height of bars can cause adjacent banks to erode more rapidly or to stabilize, depending on how much sediment is removed, the distribution of removal, and on the geometry of the particular bed (Collins and Dunne 1990).

Sediment removal conducted at rates exceeding sediment influx, resulting in channel degradation, will cause the water table to decline by the amount of channel elevation degradation. The riparian vegetation may not be able to reach the lowered water table, or stress may occur in lifting the water from greater depth. Kondolf and Curry (1986) discussed this process on a coastal California stream. Destruction of riparian vegetation adversely affects and salmon and steelhead in the following ways:

a. Loss of Velocity Refugia and Cover. Vegetative structure increases hydraulic boundary roughness resulting in relatively lower velocities near the flow-substrate interface. These low velocity zones provide refuge habitat to salmonids during high-flow events. Vegetated mature bar tops are particularly valuable during floods because the low velocity flow-field found at bar top locations is relatively rare (Church *et al.* 2001). In addition, many salmonids seek out low velocity areas close to high velocity areas in order to optimize foraging and maximize net energy gain (Fausch 1984).

Coho and steelhead often occupy areas of low water velocities near stream banks, especially at low water temperatures during winter months. Survival rates can be low during this period, and reductions in the availability of pools and backwaters stabilized by riparian vegetation can further reduce overwinter survival. Bustard and Narver (1975) reported that juvenile coho and steelhead showed strong dependence on certain types of habitat during winter. Sidepools and back channels with logs, debris, and overhanging riparian vegetation provide important cover and refugia for overwintering salmonids. Most of this cover is associated with stable streambanks. Therefore, streamside logging or road building, overzealous stream clearing, or channelization can adversely affect salmonid winter habitat and reduce overwinter survival of these species.

Mature vegetation provides additional benefits to juvenile salmonids in the form of physical structure. Structure in the form of large woody debris (LWD), when recruited into the active channel, promotes localized scour, pool formation, and is itself utilized as cover. Cover is also provided to juvenile salmonids by overhanging vegetation, submerged vegetation and exposed roots. The cover provided by complexities in structure can increase survival rates for salmonids rearing in summer, overwintering (in higher flows - see velocity refuge above), and as outmigrating smolts.

b. Trophic Impacts . Ecological energy is typically derived from detritus in streams (Cummins *et al.* 1973; Vannote *et al.* 1980) and is processed by different organisms (Anderson and Sedell 1979) in a continuum from larger to smaller particles (Boling *et al.* 1975). Riparian vegetation provides important nutrient inputs to streams such as leaf litter (Cummins *et al.* 1973) and terrestrial invertebrates that drop into the stream. Such "allochthonous inputs" can be the principal source of energy for higher trophic levels in stream ecosystems (Reid 1961; Gregory *et al.* 1991). Leaf litter provides the trophic base for aquatic macro-invertebrate communities that in turn are the fundamental food source for salmonids (Beschta 1991; Bretscko and Moser 1993; Hawkins *et al.* 1982).

Sediment removal actions often limit the extent, average age, size, and species of riparian trees, thereby impacting salmonid food resources by reducing the amount of allochthonous inputs (Bilby and Bisson 1992). Hetrick *et al.* (1998) has documented decreases in allochthonous inputs associated with open canopy stream sections. However, others suggest that riparian canopy does not have a strong influence on invertebrate food resources in streams (Meehan 1996), and that geomorphic features (substrate, riffle habitats, etc.) are the principal forces governing food production in streams (Benke *et al.* 1987). Although many factors contribute to the production of food resources for fishes, it is evident that allochthonous inputs from riparian vegetation do play a role.

c. Increased Water Temperatures. The temperature of stream waters reflects a balance of heat transfer between the water and the surrounding environment. Although heat exchange occurs via several processes, direct insolation (solar radiation) is generally the dominant source of energy input into streams (Beschta *et al.* 1987; Spence *et al.* 1996). Riparian vegetation protects stream temperatures from rising unduly by providing canopy that shades the water and reduces direct solar radiation reaching the water surface (Beschta 1991; Hetrick *et al.* 1998). Stream temperatures are affected to a lesser degree by ambient air temperatures (Spence *et al.* 1996). In addition, riparian vegetation lessens the temperature differential between the air and the water by creating a cool and moist microclimate near the water surface.

As streams get larger, they typically get wider. The resulting increase in surface area exposes the water to more insolation and more heat gain (Beschta *et al.* 1987). The influence of riparian vegetation decreases in proportion to the fraction of the water's surface shaded by trees adjacent to the watercourse. The influence of heat energy transfer is also diminished as stream flows increase (Beschta *et al.* 1987). This decreases the cooling influence of shade on main stem waters, particularly those that have higher than normal summer flows, because of releases from upstream storage reservoirs. However, recent temperature modeling efforts (Ligon *et al.* 2001) indicate that the Russian River, a relatively large stream in Sonoma County, is well below the channel width threshold that would nullify the temperature mitigating influence of riparian vegetation. Stream temperature is also influenced by season, latitude, elevation, topography, orientation, and local climate (Spence *et al.* 1996). Despite this, the relative contribution of riparian vegetation and its inverse relationship to channel width, as represented in this model, indicates that a channel width roughly seven times greater than tree height is needed before changes to insolation are reduced to insignificance.

Increased water temperatures due to losses of riparian vegetation are of particular concern, given that salmon and steelhead prefer relatively coldwater habitats with water temperatures less than about 15°C. Water temperature influences juvenile steelhead growth rates, population densities, swimming ability, ability to capture and metabolize food, and disease resistance (Barnhart 1986; Bjornn and Reiser 1991). Upper lethal temperature limits generally range in the vicinity of about 23°-25°C, although many salmonid species can survive short-term exposures to temperatures as high as 27°-28°C (Lee and Rinne 1980). Fluctuating diurnal water temperatures also help salmonids survive short episodes of high temperature (Busby *et al.* 1996). Large, thermally stratified pools, springs, and cool tributary inflow can also provide cold water refuges that help juveniles survive hot summer temperatures (Nielsen *et al.* 1994).

4.3.4   Effects on Stream Complexity and Diversity

Sediment removal from bars creates a wider, more uniform channel section with less lateral variation in depth, and reduces the prominence of the pool-riffle sequence in the channel (Collins and Dunne 1990). Channel morphology is simplified as a result of degradation following sediment removal (Church *et al.* 2001). Reporting on an experiment, Lisle *et al.* (1993), elegantly illustrate the channel degradation process. In a laboratory flume, a series of alternate bars were developed by flow and sediment feed, until equilibrium developed. Sediment supply was then reduced to one-third of its former rate to simulate sediment removal at a point upstream. The artificial channel incised by twice its former mean depth and bed particle size increased (increased armoring). The downstream bars emerged and became inactive surfaces. Degradation initially creates a deeper, narrower channel. Back channels are cut off and river-edge wetlands are de-watered. Initially complex channels tend to degenerate toward less sinuous single-thread channels; these effects amount to reduction in habitat diversity.

Sediment removal can diminish pools and adversely affect riparian vegetation that affords important cover and shelter from high velocity currents. Such losses also diminish overall habitat diversity (Pearsons *et al.* 1992). Juvenile salmonids prefer heterogeneous stream environments comprised of riffle-pool complexes containing a mix of pools with ample cover and shallow riffles supporting high production of macroinvertebrates (Bjornn and Reiser 1991; Groot and Margolis 1991). The production of juvenile salmonids can be directly related to stream channel complexity (Fausch and

Northcote 1992; Horan *et al.* 2000). More structurally complex streams containing boulders, logs, and bushes support larger numbers of coho salmon fry than simpler stream sections (Scrivener and Andersen 1982). Sediment removal operations generally diminish habitat complexity by reducing stream sections to long sections of wide, contoured riffles with a shallow, low flow channel.

Removal or disturbance of instream roughness elements during sediment removal activities also diminishes habitat complexity and the quality and quantity of anadromous fish habitat. Instream roughness elements, particularly large woody debris, play a major role in providing structural integrity to the stream ecosystem and providing critical habitat features for salmonids (Koski 1992; Naiman *et al.* 1992; Franklin *et al.* 1995; Murphy 1995; OWRRI 1995). These elements are important in controlling channel morphology and stream hydraulics, in regulating the storage of sediments, and in creating and maintaining habitat diversity and complexity (Koski 1992; Murphy 1995; OWRRI 1995).

Large woody debris in streams creates pools and backwaters that salmonids use as foraging sites, overwintering areas, refuges from predation, and rearing habitat (Koski 1992; OWRRI 1995). Large wood jams at the head of sediment bars can anchor the bars and increase sediment recruitment behind the jam (OWRRI 1995). Loss of large woody debris from sediment bars can also negatively impact aquatic habitat (Weigand 1991; OWRRI 1995). The importance of large woody debris has been well documented, and its removal can often result in an immediate decline in salmonid abundance (*e.g.*, see citations in Koski 1992; Franklin *et al.* 1995; Murphy 1995; OWRRI 1995).

4.3.5   Effects on Water Quality

a. Episodic turbidity. Turbidity is generally highest in streams during the first high flow of the flood season. However, various instream sediment disturbance or removal actions may increase turbidity caused by suspended sediment at different time periods. Careful scheduling to avoid inflicting adverse effects on anadromous salmonids may alleviate most turbidity concerns. Extraction of sediment from wet stream channels suspends fine sediment during times of the year when concentrations are normally low and the river is less able to assimilate suspended sediment (Weigand 1991).

Sediment removal or disturbance above the wetted stream may still create a persistent source of turbidity from the crossing of streams by heavy equipment and from activities associated with bridge construction occurring during the summer low-flow period. Stream crossing and bridge building activities are likely to cause short-term increases in turbidity during periods of low stream flow when salmonids present may be stressed by other environmental factors such as high water temperatures.

The severity of impacts to fish from suspended sediment pollution is generally acknowledged to be a function of sediment concentration and duration of exposure. Newcombe and Jensen (1996) performed a meta-analysis of 80 published studies on fish responses to suspended sediment in streams and developed empirical equations that relate biological response to duration of exposure and suspended sediment concentrations. From these equations were developed a set of matrices for various life stages of salmonids which predict the severity of ill effects as functions of suspended sediment concentration and duration of exposure.

The continuum of effects of increased turbidity on anadromous salmonids range from behavioral (avoidance), to rapid mortality (Newcombe and Jensen 1996). For example; juvenile salmonids

subject to a concentration of 8100 *mg/L* of suspended sediment for up to 1-day suffered sub-lethal effects, but after 2-days up to 20% mortality can be expected rising to 80% mortality after four months exposure. For eggs and larvae of salmonids, a concentration of 148 *mg/L* of suspended sediment for up to 1-day is sub-lethal, with 2-days showing up to 20% mortality, 50% mortality at two weeks of exposure and 80% mortality after 7 weeks exposure (Newcombe and Jensen 1996).

b. Chronic turbidity. Additional water quality risks are posed by most commercial sediment extraction operations that use fines settling pits for sediment washing operations. Settling pits can have various levels of effectiveness. If wash water is reintroduced to the stream, settling pits may contribute to chronic levels of suspended sediment during sensitive low flow seasons. Episodic discharge of suspended sediments can occur when pits overflow or when pit retaining walls fail. Furthermore, once settling pits fill, they become a future source of fine sediment from the floodplain. In addition, subsequent channel migration can access the filled pit and release concentrated fine sediments into the channel. During high flows, stockpiles and overburden left in the floodplain can release fine material and organic debris to the stream and they may alter channel hydraulics and cause fish blockage or entrapment (Follman, 1980).

c. Toxic chemicals. Sediment removal operations may have harmful chemicals at the processing site that could be introduced to the stream's surface or subsurface flow. Wetting agents, flocculents, and even mercury can be used at sediment processing plants. All sediment removal and processing operations use equipment powered by diesel fuel and lubricated by other petroleum products that are potentially hazardous. With the use of this equipment, there is potential for spill of hazardous compounds in the stream, on bars in contact with the hyporheic zone, or at nearby processing sites. The risk of potential chemical pollution should be considered significantly higher near or in streams because of the proximity of sensitive aquatic species and because of the role of water in transporting contaminants to sensitive receptors.

4.3.6   Direct Harm and Mortality

Sediment removal operations use heavy equipment and need access to sediment deposits. Interactions with equipment and sediment removal surfaces can be potentially harmful or lethal to salmonids by several mechanisms.

a. Stranding. Stranding of salmonids primarily occurs after river stages rise, enabling fish to move into newly inundated areas, and then recedes so that fish are trapped in depressions. Migrating adults and juvenile fish can become trapped in the substrate or in isolated pools and depressions. Sediment removal operations can leave depressions on the mined bars that increase the potential for stranding. Salmonid fry that have just absorbed their yolk sac and have recently emerged from the gravel are the most vulnerable to stranding (Hunter 1992). In addition, large numbers of migrating adults have been stranded and died on surfaces directly altered by sediment removal, and in nearby braided channels that were associated with sediment removal projects. Groomed and graded surfaces with gradients to facilitate even drainage as flows recede, help to avoid stranding.

b. Crushing. Salmonids select gravel substrate in shallow water with intra-gravel flow, typically the crests of riffles, to bury their fertilized eggs. The number of days required for eggs to hatch varies from about 19 days to about 90 days depending on species and water temperature. Alevin then emerge from the gravel two to three weeks after hatching (Barnhart 1986). Once they emerge, alevin (now fry) disperse to occupy available low-velocity portions of the stream and areas with

cover (Raleigh *et al.* 1984). During this early life stage, juveniles usually occupy shallow water along the stream banks (Barnhart 1986). Steelhead also use riffles and other areas not strongly associated with cover which provide increased foraging opportunities (Bradford and Higgins 2001) and large pore spaces in the stream bed. In one experiment using artificial stream channels, over 50% of juvenile steelhead 31-44mm in length were located in riffle habitat (Bugert and Bjornn 1991). They remain in these rearing areas throughout the summer, with some shift in habitat use as they age and as conditions change (Chapman and Bjornn 1969).

Cover is an important habitat component for juvenile salmonids, both as a velocity refuge and as a means of avoiding predation (Shirvell 1990; Meehan and Bjornn 1991). Salmonid juveniles will balance their use of cover and foraging habitats based on their competing needs for energy acquisition and safety (Bradford and Higgins 2001). Critical forms of cover include bubble curtains, submerged vegetation, woody debris, and the interstitial spaces of streambed gravel substrate (Raleigh *et al.* 1984). Steelhead juveniles will respond to threats of predation, including overhead motions, by huddling together and/or fleeing to nearby cover (Bugert and Bjornn 1991). Few young of the year (YOY) are found more than one meter from cover (Raleigh *et al.* 1984). Juvenile steelhead, particularly the younger, smaller individuals, have a notably docile response to disturbance; they rely on nearby substrate particles (*i.e.,* gravel) for cover more than other salmonids (Chapman and Bjornn 1969; Wesche 1974; Everest and Chapman 1972).

Frequently disturbed stream channels have relatively less abundance and diversity of cover habitat for juvenile salmonids. Therefore, in sediment removal areas, hiding in substrate pores may be the main response to threats (Chapman and Bjornn 1969; Wesche 1974; Everest and Chapman 1972). Even where other forms of cover are present, YOY will respond to noise, movement, and other disturbances by entering pore spaces in the streambed at riffles (Shirvell 1990; Meehan and Bjornn 1991).

Heavy equipment used for sediment removal usually cross wet stream channels where water depth is shallowest, at riffles. Because this an important habitat for salmonid juveniles (Bradford and Higgins 2001), where these fish occur in areas of channel crossing, it is likely that a portion of the juveniles in the path of equipment would take cover within the gravel and be crushed as the equipment passed over. Multiple observations by NOAA Fisheries biologists indicate that even wading fishermen can crush juvenile salmonids hiding within gravel substrate. Therefore, it is difficult to scare, herd, or chase juveniles from stream crossings ahead of equipment, with any confidence that the tactics adopted are being effective.

Larger juveniles are less prone to crushing from equipment crossings. They will likely flee the area because the substrate size is not large enough to provide cover for them. However, these juveniles could flee into areas of higher predator concentration or lower quality instream habitat.

Bridges are placed at riffles for sediment hauling equipment. The placement and removal of temporary bridges can adversely affect salmonids and habitat by crushing during construction and removal, and by turbidity and sedimentation from pushing up bridge approaches and abutments.

4.4 SUMMARY OF EFFECTS

Sediment removal from streams can result in destruction of spawning, feeding, and resting habitats. Other undesirable physical effects include bed degradation, bank erosion, channel and habitat simplification, and reduced effectiveness of geomorphic processes such as pool maintenance,

sediment sorting, and sediment intrusion. Adverse biological effects include reduced egg and alevin growth and increased mortality, reduced riparian vegetation and all associated aquatic benefits, reduced water quality, and direct mortality of juveniles.

In many locations, the ongoing industrial removal of sediment from stream channels is in conflict with widespread resource management measures to reduce sediment supply and delivery to streams, the damming and regulation of streams, and widespread bank protection and channelization of stream channels. The current published and gray scientific literature, reviewed in this document, explains a wide range of harmful physical and biotic effects resulting from sediment removal. Table 3 briefly lists the effects of sediment removal from streams, and correlates the physical effects to possible biological consequences for salmonids.

4.4.1   The Importance of Channel Maintenance Processes

To a large extent, channel maintenance processes govern the channel morphology and the resulting salmonid habitat. Changes to channel maintenance processes resulting from sediment removal actions reduce the properly functioning condition of salmonid habitat. Physical processes that maintain and contribute to salmon habitat occur at a variety of discharges. The most important processes and habitats are maintained by the discharges that transport bed sediment in specific habitats, or most efficiently for a given reach of stream. Bankfull flow and the effective discharge are two widely used prescriptions for channel maintenance. The effective discharge is typically less than the bankfull flow. Because identification of bankfull flow is often subjective, in the next Chapter the Guidelines recommend the use of the effective discharge determination for general channel maintenance of coarse bedded streams. However, bankfull flow may be the more appropriate benchmark discharge for streams that are in dynamic equilibrium.

While effective discharge is in theory a single flow (Biedenharn *et al.* 2001), in practice it is possible to identify a relatively narrow range of discharges centered on the effective discharge that constitute the 'effective range of flows' responsible for forming and maintaining the channel and its significant morphological features (Biedenharn and Thorne 1994). In the interest of protecting those habitat elements, it is undesirable for channel disturbance activities to widely alter channel conditions within the range of the channel-forming (effective) flows.

The effective discharge is the flow most effective in the long-term transport of sediment (Wolman and Miller 1960). The term is often used synonymously with "dominant discharge", which is defined as that discharge of a natural channel which determines the characteristics and principal dimensions of the channel (Bates and Jackson 1987). The channel forming flows identified by the two terms are often similar, and sometimes identical. Effective and dominant discharges have been used to determine the equilibrium status of channels (*e.g.* Florsheim *et al.* 1998), to quantify channel maintenance flows (Nash 1994), and to specify instream flow requirements (e.g.; Schmidt and Potyondy 2001; Andrews and Nankervis 1995).

All of the geomorphic features found within the channel are highly influenced by the effective discharge. Mature gravel bar features including bar height, armor layer, and replenishment are all determined by flows within a relatively narrow range of flows centered on the effective discharge (Thorne *et al.* 1993; Biedenharn and Thorne 1994). Therefore, channel sinuosity, width to depth ratios, and flow convergence and divergence patterns are all functions of the sediment features formed within the range of effective flows.

Table 3. Summary of effects of instream sediment removal, and implications for salmonid habitat.

Element of Instream Sediment Removal	Physical Effect	Possible Consequence for Salmonid Habitat
Removal of sand and gravel from a location or from a limited reach.	Upstream and downstream propagating degradation.	Loss of several habitats.
	Scour of upstream riffles.	Lower success of spawning redds.
	Reduced pool areas.	Possible loss of spawning and rearing habitat.
	Bed surface armoring.	Lower quality of spawning and rearing habitat; changes to invertebrate community.
	Or, scour or burial of armor layer.	
	Surface caking or pore clogging.	
Removal of sand and gravel from a bar.	Loss of sand and gravel from neighboring bars.	Possible loss of several habitats.
	Wider, more uniform channel section, less lateral variation in depth, reduced prominence of the pool-riffle sequence.	More difficult adult and juvenile migration. Reduced trophic food production. Lower quality of rearing habitat.
	Surface caking or pore clogging.	
Removal of sediment in excess of the input.	Channel degradation and/or widening.	Deeper and narrower or wider channel. Dewatered back channels and wetlands.
	Lower groundwater table.	Possible reduction of summer low flows; possible reduction of water recharge to off-channel habitat.
	Complex channels regress to single thread channels.	Less habitat complexity.
	Armoring of channel bed, may lead to erosion of banks and bars.	Less spawning area. Reduced water quality. Prompt new bank protection works – reducing habitat.
	Or, scour or burial of armor layer.	
Reduced sediment supply to downstream.	Induced meandering of stream to reduce gradient. Erosion on alternate banks downstream.	Reduced riparian vegetation. Increased local sedimentation. Prompt new bank protection works. Propagate river management and habitat losses downstream.
	Armoring of bed, or scour of armor layer.	
Removal of vegetation and woody debris from bar and bank.	Reduce shade.	Increase water temperature in inland, narrow, rivers.
	Decrease channel structure from wood.	Possibly reduce cover; reduce number and depth of pools; reduce area of spawning gravel; limit channel stability.
	Decrease drop-in food, nutrient inputs.	Decrease stream productivity.

The physical processes that influence salmonid habitat development and maintenance are also driven primarily within the effective range of discharges. These include formation of suitable spawning gravels, pool formation and maintenance, development of habitat complexity, and the formation of velocity refuge components.

One of the impacts discussed in the previous sections is the potential for increases in the fine sediment load; particularly as it relates to increases in sediment intrusion and surface caking of spawning gravels. The unit transport rate (not the concentration) of the sediment load peaks, by definition, at the effective discharge. As will be explained in Chapter 5, these Guidelines recommend management prescriptions that use the stage height attained at the local effective discharge to define the perimeter of disturbance in stream channels.

5   RECOMMENDATIONS for STREAMS

5.1   INTRODUCTION

The following recommendations can be used by the NOAA Fisheries Southwest Region Field Offices in conducting ESA § *7* consultations, developing § *4(d)* take limitations and § *10* habitat conservation plans, and devising sediment removal programs for inclusion in state and/or federal recovery plans. The recommendations may also be useful for participating in other regulatory and programmatic arenas where resource planning and management issues may be influenced by NOAA Fisheries. Examples here include review of county aggregate resource management (ARM) plans, county ordinances or general plan provisions relating to sediment removal. In addition to providing recommendations for agency personnel engaged in reviewing sediment removal proposals, the recommendations lay out a strategy for evaluating the effects of different sediment removal designs and methods, and discussion on the strengths and weaknesses of various regulatory methods. It should be noted that these recommendations are general in nature and that there are likely to be situations where deviation or variance from the Guidelines may be called for. In these circumstances, the Guidelines can help the reviewer to identify and specify the nature and scope of information needed to adequately evaluate these variances. Depending on the outcome of the jeopardy analysis for § 7 consultation, staff should follow either the *National Gravel Extraction Policy* for take avoidance or these Guidelines for minimizing incidental take, whichever is applicable.

Land uses, planning, and salmonid conservation and recovery have to be considered at two time-scales; (1) short-term (up to 3 yrs.), and (2) long-term (> 3 yrs). Sediment removal from within stream channels can immediately alter channel geomorphology, hydraulics and sediment transport, and fish habitat. Depending on the scale and method of removal, many of the adverse effects can last from a few years to as little as one year. However, effects can last for centuries if channel incision occurs. The adverse effects of excavating alluvial sediment from stream terraces or floodplains may not occur for several decades, but the potential effects of pit capture by streams are long lasting and severe.

The effects of sediment removal must also be considered at two spatial scales; the area of direct disturbance, and a much larger area that has physical or biological connection to the disturbed area.

Also, the scale of disturbance is related to the larger area of extended effects. If done at small scales (relative to channel size), the effects of sediment removal from channels may be generally confined to the location of disturbance. Furthermore, those effects may last only a few years or until the next large storm flow occurs. However, large scale sediment removal operations, or the combined effects of multiple operations in a given stream length, can have far reaching effects that extend both upstream and downstream for several kilometers. The deleterious effects on salmonids must be considered at all temporal and spatial scales when habitat modifications such as sediment removal or redistribution are evaluated.

Of the various sediment removal activities discussed in this guidance document, sediment extraction from active stream channels (or redistribution) poses the greatest risk to salmonids and their habitat. Each fish within, upstream, and downstream from a project area, each life stage, and multiple year classes may potentially suffer from channel disturbances. This is especially true of projects located low in watershed areas because all anadromous fish must migrate through the manipulated area. Many areas of long-term sediment extraction have degraded salmonid habitat. Because of long term sediment over-harvest and inadequate sediment replenishment, the river no longer naturally builds and maintains suitable spawning or rearing habitat.

In the following chapters, flood control and commercial sediment removal are treated separately. However, the same physical processes and habitat functions apply to both activities. The intent of the recommendations is to describe how different excavation methods result in altered physical processes that create or maintain suitable habitats for anadromous salmonids, and to provide an understanding of the limitations of existing regulatory methodologies.

5.2   CURRENT CONDITIONS AND RESTORATION OF FORM AND FUNCTION.

Some California streams have been subjected to repeated sediment removal actions, significant channel alteration for flood security reasons, and floodplain/channel encroachment (*e.g.,* Collins and Dunne 1990; Florsheim *et al*. 1998) and no longer provide the historic quantity and quality of suitable habitats for the indigenous anadromous salmonids. This is generally the case where the natural geomorphic features have been heavily altered and the channel W/D ratio is enlarged such that even the low flow channel is ill confined or defined..

Distinct geomorphic features (*i.e.,* pools and riffles) within stream channels can recover from natural and anthropogenic disturbances given adequate time, sufficient flow magnitude and sediment supply. Alternate bars may be partially restored from scalping during an average flood flow, leading to the general perception that bar scalping is a sustainable harvest of a renewable resource. Repeated sediment extraction not only depletes sediment sources and habitats downstream, frequently scalped bars are incapable of driving the pool maintenance and sediment sorting processes that create valuable salmonid habitat such as pools, riffles, and spawning beds. Thus, there tends to be diminishment of habitat even when relatively conservative sediment removal restrictions are followed. This is particularly true in cases of large-scale industrial sediment harvesting on multiple adjacent bars, and where large-scale flood security maintenance operations disturb multiple bars.

Hydrologic events are typically cyclic, especially along the Pacific coast where the El Niño Southern Oscillation influences the distribution of wet and dry years over approximately seven-year cycles. Wetter than average years, occurring on decade time scales, can largely restore most in-channel geomorphic features. Thus, natural weather cycles offer an opportunity for improved management

and protection of habitats from currently degraded conditions that may only provide adult migration habitat to more productive conditions that may provide spawning and rearing habitat. However, this assumes there is an adequate sediment supply and the banks have not been armored.

Although adult fish are known to migrate through shallow channels for short distances on the order of 1-foot or less (Thompson 1972), additional depths are necessary for fish to migrate extended distances. Bovee (1982) states that when considering minimum depth passage criteria, investigators should factor in the number and length of shallow crossings the fish must make. Fish that encounter very few passage barriers can probably negotiate some fairly shallow water, whereas the same species moving up a stream with many passage bars may arrive at the spawning area in poor condition if the passage depths are minimal (Bovee 1982). Fish passage can be improved simply by increasing the vertical offset of skim floors as natural deposition events allow. As an example, if a summer stream flow over riffles was ½ foot deep and bar skimming was permitted to within 1-foot of the summer water surface elevation, migration flows during fall would be temporarily limited to 1.5-feet depth. Simply increasing the elevation of skim surfaces from one to two feet would substantially increase the depth of early winter migration flows. Frequently manipulated areas offer little of the cover, resting, or hiding attributes of undisturbed channels. Fish can utilize increased flow depth as surrogates for those missing attributes in disturbed areas (Bjornn and Reiser 1991).

Rehabilitating geomorphic features and their habitat functions can be accomplished quickly if decade scale hydrologic events occur, or more slowly by incrementally adjusting sediment removal strategies while allowing average hydrologic events to slowly improve conditions. However, rehabilitating habitat in highly degraded areas that have suffered repeated disturbance will probably require lengthy proscription of sediment removal activities until complementary geomorphic processes return.

5.3   RECOMMENDED PROCESS TO EVALUATE COMMERCIAL SEDIMENT REMOVAL PROPOSALS

The most effective way to protect, or restore, anadromous salmonid habitats is by protecting naturally occurring physical processes that create and maintain fish habitats. Habitats in properly functioning condition can be protected by implementing a combination of two methods that can minimize the disturbance of stream channel habitat: minimize local habitat modification and limit sediment extraction to well less than the sediment influx. It is very important that sediment extraction operates at scales that do not intercept high percentages of incoming coarse sediment supplies. Providing for a positive sediment budget downstream from extraction sites is a fundamental requirement for the continued ecological function of downstream habitats.

Methods for estimating sediment budgets are defined in the scientific literature, but the appropriate percentage that should be allowed to pass downstream requires site specific studies and understanding of the watershed. It is reasonable that commercial sediment removal operations be limited to extracting only a portion of the total coarse sediment load from any stream unless a documented anomalously high sediment load exists because of watershed disturbance and precipitating channel degradation is an identified habitat management or improvement goal. However, any sediment removal with the purpose of initiating channel degradation should carefully consider the possibilities and consequences of associated channel widening or other adjustments.

California has delegated regulatory authority over commercial sediment extraction to local agencies. Some counties have developed sediment budgets of varying qualities. Other counties rely on "redline" methods, and some use both methods. The most reliable regulation of sediment extraction

using sediment budget methods is on a reach-length scale, or by small watershed. Therefore, it is appropriate that the local permit authority develop sediment budgets to regulate the scale of resource extraction within their jurisdiction. As a planning tool, NOAA Fisheries recommends that sediment quantities extracted annually should allow a minimum 50% of the natural total coarse sediment load to pass through extraction areas. This seemingly conservative (restrictive) recommendation may in practice be necessary to simply account for errors in the sediment budget estimate (see Case Study #4).

The effects of frequently removing a high percentage of a stream's sediment influx may be delayed by bed armoring, protective vegetation on the banks, and natural variability in the hydrology and sediment transport of streams. Undesirable effects are likely when the protective layers are disturbed during subsequent large flood events, as riparian vegetation diminishes, and when other factors diminish sediment supply and transport. Sediment removal activities are likely to increase the level of harm to the species in an already impaired habitat if sediment budget studies for the subject stream indicate: (1) there is an inadequate supply (a tendency for erosion), (2) if historic geomorphic assessment indicates the stream has a history of incision or degradation, (3) if the channel shows evidence of eroding banks and bars, or (4) if the riparian fringe is weak or diminishing.

Sediment removal from previously undisturbed areas may also increase risk to the species and their critical habitat unless a credible sediment budget analysis indicates that the area is actively aggrading, and the sediment budget study is further supported by appropriate habitat studies and a plan to enhance habitat by the physical removal of sediment. Because the sediment load intercepted in sediment removal areas is the "source" for downstream reaches, proposed extraction plans should allow for pass-through of 50% of the unimpaired incoming coarse sediment load to maintain downstream habitats.

In addition to maintaining a positive sediment budget that supplies coarse sediment for downstream habitat, site-specific habitat, geomorphic features, and the retention of physical processes should also be protected. NOAA Fisheries recommends a four-step process for evaluating sediment removal proposals. The steps are: (1) identify appropriate sediment harvest locations, (2) identify the habitat needs of the fish species and life stages that either occur or occurred historically, (3) determine the physical (hydrologic and geomorphic) processes that create or maintain those habitats, and (4) determine if the sediment extraction strategy is adequate to protect those habitats and physical processes. These steps are discussed in detail below.

5.3.1   *Identify appropriate sediment harvest locations.*

a.   Determine if proposed site is in equilibrium.   Determine if the stream channel at the proposed extraction site is in (or approaching) a condition of dynamic equilibrium between the current channel geometry and its discharge, sediment input, hydrology, and bed and bank materials (*e.g.,* Florsheim *et al*. 1998). Degrading channels are not desirable extraction locations, and channels in approximate equilibrium should be left alone. Clearly aggraded stream channels (W/D ratio high compared to other geometry parameters) are candidates for sediment removal when their sediment loads significantly exceed local transport capacity. Indeed, the morphology and habitats provided by stream channels that have experienced excessive sediment delivery events in recent history, and have clearly aggraded as a result, may be improved by sediment removal activities.

However, the methods of sediment removal should be designed to enhance topographic complexity

within the channel, and to encourage natural restoration of self-sustaining geomorphic features and associated aquatic and riparian habitats. The rate and volume of sediment removal should not exceed that needed to promote the desired conditions and habitats appropriate for the stream. Sediment extraction should not intercept on average more than 50% of the coarse sediment load entering the reach under pre-manipulation conditions. The duration of removal operations should be finite, ending as soon as the aggradation problem is solved and when the target habitat conditions are achieved.

b. Stream channel type should be considered. Removal of sediment from stream channels with naturally high W/D ratio is less risky than from low W/D streams. For example, braided river channels are better candidates for sediment removal than other river channel types (Dunne *et al.* 1981). Because braided river systems are highly dynamic and channel shifting is relatively frequent and rapid, channel shifting due to sediment extraction may have less of an impact (Follman 1980). However, not all braided streams are necessarily aggrading (Simpson and Smith 2001).

c. Larger streams are better candidates for sediment removal than smaller streams. Larger systems are preferable because they have more sediment, larger channels and wider floodplains, and the proportionally smaller disturbance in large systems will reduce the overall impact of sediment removal (Follman, 1980). Additionally, smaller streams are more valuable as rearing habitat and therefore have greater exposure to sediment excavation related disturbances. On a smaller stream, the location of the extraction site is more critical because of the limited availability of exposed sediment deposits and the relatively narrower floodplain.

d. Seasonally dry stream channels are better candidates for sediment removal than channels with perennial flow. Perennial streams provide habitat for the entire life history of anadromous salmonids. Operations within seasonally dry channels are less risky than operations in perennial stream channels. However, the methods of sediment removal should be tailored to the site in order to enhance channel topographic complexity so that fish migration is not made more difficult. Also, ephemeral stream channels often have highly mobile beds and unstable banks because of limited riparian stands, making them naturally tend toward lateral and vertical instability. Extraction designs should not compromise the integrity of the stream banks, and should maintain the form and function of these channels because destabilizing the channel can have direct impact on migration conditions and on fish bearing streams downstream.

e. The cumulative effects of changes in sediment supply should be considered at the watershed scale. Reservoir construction, stream channel straightening, levee construction, bank protection works, and flow regulation can all substantively change the sediment load, morphology and habitat qualities of streams. The effects may occur shortly after project completion or be delayed for decades. In general, sediment removal from streams is imprudent downstream from reservoirs or where channels are confined between levees or bank protection works.

5.3.2 Identify species, life stages present, and habitat elements needed.

Site specific geomorphic features and their related habitat values should be used to define post-extraction habitat conditions for salmonids in order to minimize potential deleterious effects of sediment removal. Sediment extraction plans should promote sediment harvest methods that avoid impacts to lifestages of anadromous salmonids known to exist upstream, downstream, as well as within the project area. Life stages to be considered include migratory stages (both upstream and downstream), spawning, embryo incubation, fry emergence, and juvenile rearing. Habitats for these life stages are maintained, in part, by the duration and frequency of certain magnitude flows and the effects of those flows on channel morphology. Therefore, to minimize impacts to salmonid habitats, sediment extraction operations should preserve important channel features and habitats by anticipating and minimizing adverse geomorphological responses to sediment removal. The following sub-chapters identify specific geomorphic features and habitat elements that should be preserved for various life stages of anadromous salmonids.

a. Rearing habitat. Where juvenile rearing habitat is (or was) important for salmonids, sediment removal activities should not reduce <u>pools</u> in size, depth, frequency, or habitat value, or contaminate coarse <u>riffles</u> with smaller sediment, or increase the width of riffles. Riparian vegetation should not be disturbed if it contributes to beneficial riparian functions through providing <u>shade</u>, overhanging <u>cover</u>, large woody debris (LWD), and allochthonous <u>energy inputs</u>.

b. Spawning and egg incubation habitat. Where spawning habitat is important for salmonids, sediment removal activities should not reduce 1) <u>pools</u> in size, depth, or frequency, 2) topographic complexity of the channel bed <u>riffle-pool complex</u>, 3) areas of <u>spawning gravel</u>, or 4) the <u>hyporheic flow</u> of nutrients to incubating eggs and fry. Furthermore, sediment removal surfaces should not increase the likelihood of <u>sediment intruding into redds</u> during incubation or emergence periods. Riparian vegetation should not be disturbed where it contributes to <u>shade</u>, which moderates summer temperatures.

c. Adult migration habitat. Where anadromous salmonids migrate upstream, sediment extraction should not adversely affect the migration pathway or its hydrodynamic flow field. Migrating adult salmonids should not be subjected to increased <u>energy expenditure</u> resulting from decreased channel bed and margin <u>complexity</u>, over the range of flows under which the target fish species migrate. Riparian vegetation should not be disturbed where vegetation contributes to beneficial migration functions through providing <u>shade</u>, overhanging <u>cover</u>, and <u>LWD inputs</u>.

d. Juvenile migration habitat. Where downstream migration of smolts and the unimpeded movement of juveniles between habitats is important, sediment removal activities should not reduce riparian vegetation that could potentially provide 1) <u>cover</u>, 2) LWD, or 3) <u>roughness and complexity</u> of the channel bed and banks. Food production within the substrate is important to the juvenile life stage. Sediment removal should not reduce availability of cobble-sized sediment particles known to support highest production of macroinvertebrates (*i.e.,* food sources) for juvenile rearing. Also, the hydrodynamic flow field should not be altered such that fish <u>energy expenditure</u> would increase over the range of flows and time-periods when the target fish species may be migrating.

5.3.3   *Identify physical processes that create or maintain habitat elements.*

The most important habitat elements identified for each fish life stage (above, underlined) are formed and maintained by morphological processes. This step of the recommendations identifies the physical processes that coincide with specific hydrologic and geomorphic events.

a. Cover is provided by mature riparian vegetation. Stable substrate, infrequent disturbance, and adequate moisture are needed to support the ecological succession of riparian plant communities. Dense vegetation on stream banks and mature bars helps initiate plant succession. LWD inputs arise from mature riparian forests and normal channel migration processes. Riparian forests provide refuge during high flow events, temperature amelioration, bank stability, cover, and allochthonous inputs.

b. Pools and riffles are maintained by the dominant flow. Sediment extraction areas can become so highly disturbed by repetitive extraction at rates in excess of the sediment supply that pool-riffle formation processes can no longer function during channel forming flows. Areas in this condition provide degraded rearing, spawning, or even effective migration habitat. Continued removal of sediment exacerbates and prolongs the time needed for natural restoration of the appropriate geomorphic forms and functions that contribute to provision of fish habitat. These areas should be identified in conjunction with identifying the crucial fish habitat needs. The appropriate action to remedy the effects of excessive disturbance should include restoration of the appropriate geomorphic attributes and physical processes.

c. Pool maintenance processes occur most effectively during high flow events, when bed shear stress in pools exceeds that on riffles. Where pool habitats fulfill necessary resting, high profit feeding, winter high flow refuge, and predator avoidance functions, pool maintenance processes must be protected. This requires avoiding disturbance of bars with elevation lower than the dominant flow elevation. In altered channels, pool maintenance processes may occur during mobilization of a significant bed particle size (*i.e.,* D_{50}), under flows approximating the dominant range of discharges.

d. Spawning gravel patches collect in riffle locations because the pool maintenance process effectively sorts incoming sediment into discrete patches located near riffle crests. Where spawning may occur, disturbance of the hydraulic flow field and fluvial processes that result in spawning gravel sorting and accumulation at riffles should be avoided. This requires avoiding disturbance of bars with elevations below the bankfull stage in natural channels, or below the effective discharge stage in manipulated channels.

e. Redds can be disturbed by premature scour events, by sediment intrusion that reduces hyporheic flow to incubating eggs, and by sediment caking that impacts fry emergence. Where spawning occurs, redds should be protected from disturbance induced by sediment removal actions. This requires avoiding the creation of fine-grained or loose material surfaces at elevations that may be inundated during times when emergence of spawning through alevin may occur. Protecting redds from premature scour events requires avoiding bar disturbance that results in increased bed shear stress in spawning areas during the period that encompasses spawning through alevin emergence.

5.3.4 Choose sediment extraction strategies that minimize disturbing habitat or diminishing physical maintenance processes.

Localized methods for sediment removal that conserve the physical processes that create or maintain identified habitat elements should be implemented. Site specific geomorphic features and habitat values should be used to identify preferred post-extraction conditions for salmonids, with the findings applied to minimize the deleterious effects of sediment removal. The habitat attributes of common geomorphic features, the physical processes that maintain these features, and suitable sediment removal strategies to minimize impacts to the physical processes are listed in Table 4.

5.4 CURRENT MANAGEMENT OF COMMERCIAL SEDIMENT REMOVAL FROM STREAMS

Although the commercial extraction of stream sediment is a historical industry within which there is accumulated copious practical experience, little has been learned about how to reduce adverse ecological impacts while maintaining present extraction rates. In the face of imperfect information, it is prudent to proceed with caution.

Commercial sediment removal is most appropriate in channel locations where; (1) degraded habitat can be improved by sediment removal, (2) the interactions between salmonids and consequences of sediment removal are known reliably to be rare or non-existent, and where (3) risks of habitat loss caused by long term geomorphic adjustments are low. Various methods have been developed to limit different harmful effects of sediment removal for commercial purposes. These methods and recommendations for limiting sediment removal to minimize impacts to anadromous salmonids and their habitats are discussed in the follow chapters.

5.4.1 Sediment Budget Methods

Sediment budget methods are used in some areas to limit the volume of material involved in commercial sediment removal operations. Regulating extraction by sediment budget methods typically allows for fairly consistent annual extraction rates even though sediment delivery depends on decade to century cycles. Commercial operators and local regulatory agencies may prefer this method because it implies that a long-term average production will protect stream habitats from degradation. However, large sediment replenishment events are naturally cyclic and infrequent, and average sediment yield does not exist. Progressive levels of disturbance and loss of habitat results from protracted annual extraction rates during prolonged periods between large replenishment events. Maintenance of a steady rate of extraction through prolonged dry periods is undesirable. Neither should extraction rates be increased automatically in response to a major flood.

Sediment transport for streams is exceedingly variable because sediment transport is a power function of stream flow, which varies significantly from year to year, and depends on sediment availability – which is difficult to characterize. Thus, an annual average sediment load may be meaningless (Kondolf 1993; 1994b). A calculated annual average deposition rate could bear little relation to the actual sediment load in a river in any given year. Moreover, sediment transport processes are very difficult to model, so calculations or other estimates of bedload transport may prove unreliable.

Table 4. Sediment extraction strategies suitable for various salmonid habitat requirements, stream hydrology, and the retention of geomorphic processes.

LIFESTAGE	Habitat Required	Limiting Physical Process	Constraint on Sediment Extraction
Adult Migration **Juvenile Migration**	Natural channel conditions including roughness elements, cover, shade, resting pools, LWD.	Minimum flow depth of 2-feet, offsetting quality of cover, roughness, resting stations.	Minimum vertical offset from low-flow channel. Free draining extraction surfaces. Avoid riparian vegetation along migration channel. Place LWD.
	Unimpaired water quality.	Localized additional sediment load.	Negligible increase in sediment load within area.
Spawning	Suitable spawning beds, nearby rearing habitat, pool-riffle complexes.	Sediment sorting processes. Premature redd scour.	Vertical offset to ensure negligible increase in bed scour in spawning locations during spawning periods.
	Unimpaired water quality.	Hyporheic flow. Localized additional sediment load. Sedimentation of spawning beds.	Negligible decrease in hyporheic flow. Negligible increase in sediment load from extraction surfaces.
Incubation **Emergence**	Stable substrate. Natural hyporheic flow.	Premature redd scour. Hyporheic flow. Localized additional sediment load.	Vertical offset to ensure negligible increase in bed scour, or increase in sediment load or turbidity from disturbed areas.
	Unimpaired water quality.	Hyporheic flow. Localized additional sediment load. Sedimentation of spawning beds.	Negligible decrease in hyporheic flow. Negligible increase in sediment load from extraction surfaces.
Rearing	Pools. Food source. Cover. Natural water quality including cool, well oxygenated, water.	Pool scour to connect with water table. Coarse and clean substrate. Riparian health.	Retention of bar geometry to bankfull flow or effective flow to ensure negligible decrease in pool maintenance process, disturbance of riparian community, reduction.

Managing extraction volumes within a sediment budget, and retaining minimal geomorphic form (to define a low flow migration channel, or head of bar to reduce headcutting), can be considered state-of-the-art commercial sediment regulation. The limitations of this approach are that rigorous and reliable sediment budgets are difficult to develop, subject to change from many variables, never provide a definitive metric of what a safe yield should be to allow for downstream sediment needs, and are not often carefully interpreted. Even the best sediment budgets provide imperfect information that will probably not be improved upon soon (Church *et al.* 2001). Where sediment budget estimates are used to regulate commercial sediment extraction in California, the inherent uncertainty in the calculation, as well as poor reporting of volumes extracted, cultivates debates over the formulation of sediment budgets in lieu of careful interpretation of results, while disregarding the need to provide coarse sediment supply to downstream habitat or even to downstream sediment extraction sites. A general lack of understanding or appreciation for the ecological value of sediment continuity can result in excessive allocation of the long-term average sediment load (Kondolf 1995).

> **CASE STUDY #4 – Sediment Budget Studies and Management of the Mad River.**
>
> Prior to 1992, industry removed approximately 380,000 yds³ of gravel from the Mad River annually. Widespread channel degradation and concerns from several agencies and the public resulted in regulations to limit sediment removal, based on sediment budget analysis (Lehre 1993). Lehre (1993), using multiple reasonable lines of evidence, estimated the safe yield of the Mad River commercial extraction area at approximately 200,000 yds³/yr. and suggested a potential target extraction volume of 100,000 yds³/yr. A 1992 multiagency memorandum of agreement with industry seeks to stop channel degradation, limit extraction volumes to the estimated sustained yield, and provide for a slow rate of channel recovery. Since 1992, average annual gravel extraction has been limited to approximately 100% of the estimated safe yield, just under 200,000 yds³/yr, by a scientific review panel.
>
> Citing new cross section evidence and a desire to reevaluate the Lehre (1993) report, the gravel mining industry contends that the Mad River is capable of producing twice that volume with no adverse morphologic consequences (Knutti 2003). In 2000, one of the largest gravel extraction companies (Eureka Ready Mix) engaged a qualified geomorphologist to assess the channel changes and refine the sediment budget estimate for safe yield. Kondolf and Lutrick (2001) compared old and new cross section data supplied by industry, aerial photographs and previous reports. They concluded that the mean annual sediment replenishment to the extraction reach is about 270,000 yds³/yr.
>
> At roughly the same time that Kondolf and Lutrick (2001) were employed by Eureka Ready Mix to reevaluate past channel change, the USACE was conducting a thorough sediment budget reexamination on the Mad River. Knutti (2003) painstakingly resurveyed all available cross sections, quantified bed sediment gradations, compared historical series of aerial photographs, examined tributary mouths for telltale signs of channel change, and estimated sediment transport rates numerically using all available data. Knutti (2003) found very good agreement between the methods that he used.
>
> Knutti (2003) draws several conclusions from his comprehensive study. (1) Bed sediment grain-size is significantly smaller in the frequently mined reach than outside. (2) Armor layer development is precluded in the mined reach. (3) Conclusions 1 and 2 indicate that the mined reach channel is less stable than if it were not manipulated. (4) Sinuosity has increased in the extraction area. (5) Tributary mouths affected by sediment extraction are undergoing incision. (6) The Mad River is incising upstream from the extraction area. (7) The average annual sustainable gravel yield

Sediment budgets are most appropriately used for planning and long-range management of sediment extraction industries. A combination of conservatively applied sediment budget and retention of important geomorphic forms and functions can meet the goals of these Guidelines.

5.4.2   Redline (elevation) Methods.

"Redline" methods are used in many California counties to regulate maximum channel disturbance, and indirectly limit extraction quantities. Redlines define an initial extraction surface (*i.e.,* elevation, slope, area) with vertical and horizontal offsets from the banks and the low flow channel. In subsequent years only the aggregate that is replenished above the redline surface is allowed to be extracted. During wet years, deposition above the redline can be voluminous, while during dry years there may not be any deposition. One advantage of the redline management method is that it can allow for varying climatic and sediment transport events. It can tie sediment extraction more closely to the natural hydrologic and sediment cycles than can allocating by a sediment budget. However,

local sediment depletion can occur when only the redline method is used for regulating extraction in large-scale sediment production areas. In effect, a consistently applied redline regulation imposes a localized sediment budget approach to managing extraction, but it can allow for extracting 100% of the incoming load, which can significantly reduce sediment supply to downstream habitat.

The purpose of defining a redline is simply to limit sediment removal to control gross degradation of the streambed. Unless applied judiciously, specifying relatively large vertical and horizontal offsets from the low flow channel, redline methods do not maintain a positive sediment budget so that downstream habitats receive coarse sediment input and in-channel geomorphic features continue contributing to ecosystem health.

Redline methods can provide adequate short-term protection of low flow channel habitat for fish migration. However, the long-term protection of the geomorphic processes that maintain riffle-pool complexes and deep pool habitats can not be provided by the use of redline methods alone, unless accompanied by relatively high vertical offsets.

The importance of geomorphic processes in stream habitats is recognized by methods sometimes used to limit the effects of commercial sediment removal operations. The most common process-based method is avoiding extraction from the 'head of bar'. The head of bar is arbitrarily defined as the upstream 1/3 of a bar, or 300 feet downstream from a riffle crest. The aim of managing sediment extraction by this method is to retain the hydraulic control exerted by bars during high flows. Not allowing direct disturbance of the high flow hydraulic controls supposedly protects upstream riffles from degradation, that can in turn cause more extensive disturbance through headcutting and channel incision processes. This approach may have merit, however, it has not been rigorously evaluated for effectiveness. Restricting sediment removal from the head of bars may protect upstream riffles from degradation. The method is probably more effective at simply protecting a portion of bars from disturbance and maintaining some confinement of the low flow channel.

Retaining the heads of bars does not sufficiently preserve pool maintenance processes. The pool maintenance process functions where the channel is most confined by bars, and that typically occurs at a bar midpoint or somewhat downstream. For these reasons, stream channel areas undergoing frequent sediment removal restricted to retain heads of bars will likely evolve with less distinct pools and riffles. Thus, fundamental pool-riffle complexes and their ecological benefits may be diminished or eliminated by regulations that implement redline or the head of bar management methods.

Carefully applied, conservative, redline methods can be appropriate for regulating small or spatially isolated sediment extraction and flood control projects. The following Chapter(5.5) describes a sophisticated method of defining a redline method to retain important geomorphic features and their functions.

5.5 LEAST HARMFUL METHODS OF SEDIMENT REMOVAL

In order to minimize the harmful effects discussed in these Guidelines, and meet the habitat needs of anadromous salmonids, sediment removal plans should not substantially reduce the topographic complexity that exists in unaltered reaches of the stream. Neither should altered reaches be maintained in altered dysfunctional states by continued use of harmful methods (see criteria below). The complexity of the stream channel should be measured by cross-sections, by topographic maps,

or by a digital terrain model (DTM). The elevation variation, or other suitable shape parameters, of the entire channel utilized by salmonids should not be significantly reduced.

Geomorphic functions and habitats may be least adversely affected by retaining the wet edges of bars, and mining from the downstream interior. The acceptable instream sediment removal methods should not disturb bar form, in its natural configuration and size for elevations related to a design discharge. The selection of the design discharge should be based on retaining the physical processes that either create or naturally modify specific fish habitat elements, such as (1) bed mobilization and redd scouring, (2) pool scouring and maintenance, (3) flushing flows for spawning beds, or (4) preventing fine sediment introduction from removal surfaces, or from modified hydraulics, during egg incubation. Figure 4 and Case Study #5 provide examples of using discharge criteria to design sediment removal activities for minimizing geomorphic and biologic impacts.

Reference to morphologically important discharges and their associated water surface elevations for designing sediment excavations can control the effects of disturbance on physical processes, and help maintain salmonid habitat. Several conditions related to discharge can be defined, and the selection of the appropriate condition applied to fish life stage and habitat needs. For example, migrating adults need at least a minimum depth of flow over riffles, adequate cover, roughness, and non-degraded water quality. These conditions can be met by selecting the discharge that gives reasonable certainty that fines will not degrade water quality as they are transported from disturbed surfaces until most adult migration is completed.

CASE STUDY #5 – Flow and sediment transport based extraction design.
A design discharge method was used by NOAA Fisheries staff and an applicant to reduce the adverse effects of proposed commercial sediment removal from a large mature bar on the Russian River in a recent ESA § 7 consultation. The design specifies that the bar will not be inundated until discharge exceeds the "effective discharge" of about 11,000 cfs (PWA 1993). The effective discharge transports the greatest quantity of sediment over time (Wolman and Miller 1960) and is comparable to the bankfull flow in undisturbed stream channels. This method for designing sediment removal projects provides an elegant solution to potential sediment intrusion problems by delaying inundation and transport of fines from a skim surface until the river is already at a high sediment load condition. The design also delays morphologic effects of bar alteration on the pool-riffle hydraulics until the river has obtained its most effective discharge, when bedload transport is expected to occur at a substantial rate. Therefore, the altered bar surface interacts with flow during only a few days per year when bedload actually occurs in the Russian River (PWA 1993; Florsheim *et al.* 1998). Although the dominant discharge design method suggests a habitat maintenance solution, by delaying the adverse effects until the river is capable of quickly repairing the channel modification, the method is "new" to industry and may require some experience before wide application. However, other commercial extractions in California have voluntarily adopted this basic methodology because it can minimize adverse effects to salmonid habitat. Monitoring the method's performance over the next few years will determine the effectiveness for protecting habitat and dictate how widely it may be used.
 Figure 3 illustrates and describes this method and where sediment removal is preferred.

If protecting spawning habitat is the desired management goal, then channel disturbances should minimize the possibility of sediment intrusion in redds, siltation of riffles, or filling of pools, until flows are sufficient to reliably move sediment through the system. Also, successful spawning

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requires that premature redd scour does not occur. Where rearing habitat is the desired management goal, protecting pool maintenance processes is necessary. Pool maintenance is most effective when velocity reversal reaches its maximum at flows close to but just less than the bankfull condition.

All of the above morphological processes and habitat conditions can be determined with reasonable accuracy using (1) repeated observations and channel mapping, (2) common hydraulic models (*i.e,* HEC-RAS), (3) flow records, (4) site specific channel geometry and, (5) grain size measurements.
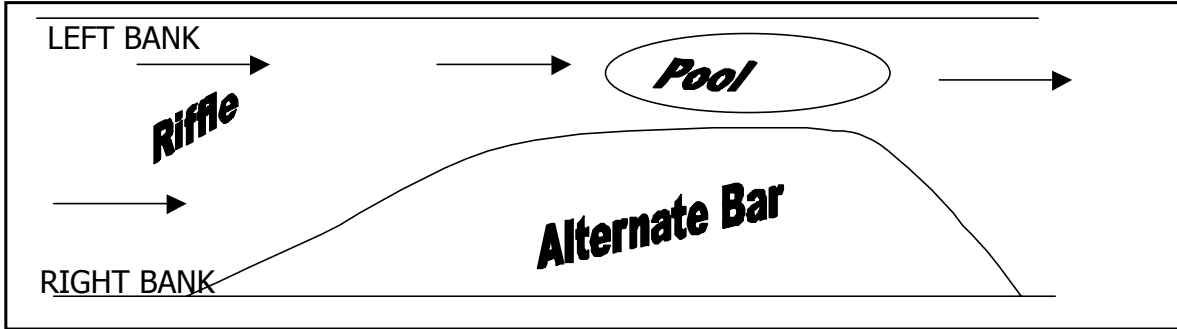
Figure 3a. Sketch of fundamental geomorphic features, essential to salmonids, found in alluvial stream channels.

Figure 3b. Outline of summer low-flow channel and exposed bar area (solid line), exposed bar area during early winter flow (dashed line).

Figure 3c. Outline of exposed bar area during higher winter storm flow when the coarse sediment load is greatest (dashed line).

Figure 3d. Conceptually idealized sediment removal design that retains the geomorphic form and function of bar for flows less than some identified threshold flow.

5.6 SEDIMENT REMOVAL FROM STREAM CHANNELS FOR FLOOD CONTROL

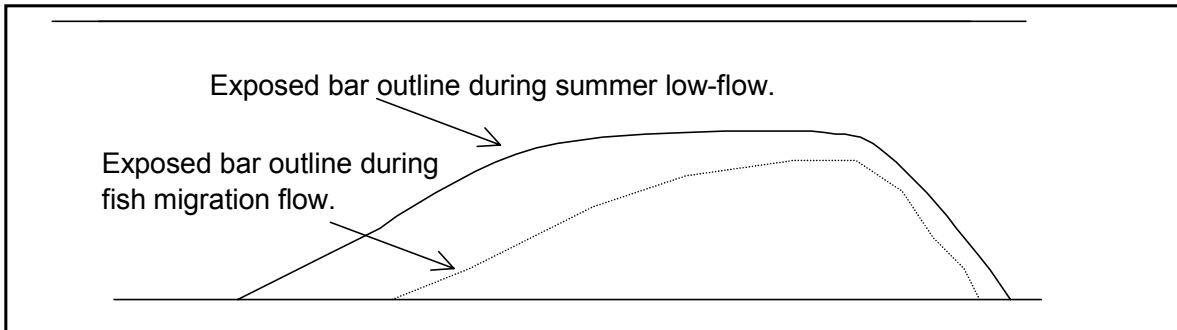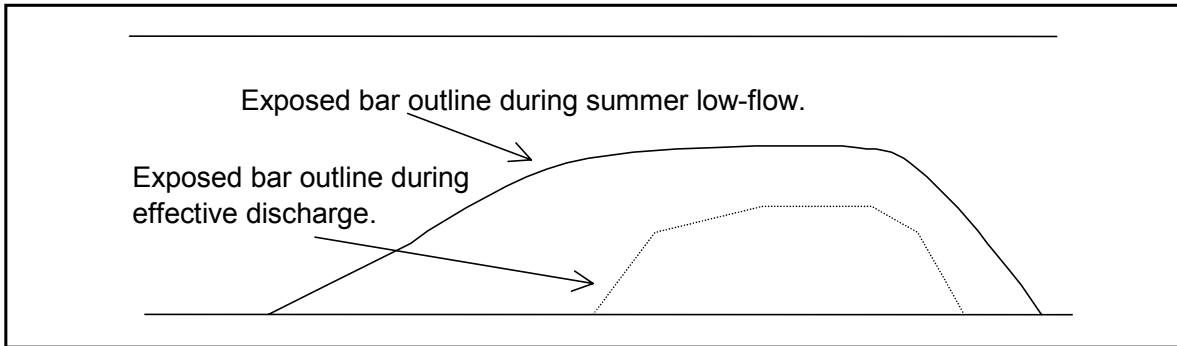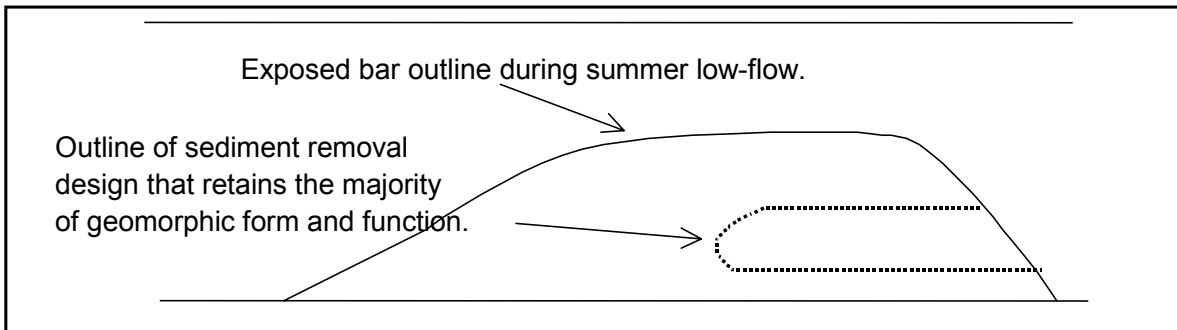Widespread flood control practices remove or redistribute sand and gravel bars from stream channels. It is commonly argued that instream sediment removal is necessary to control flooding or bank erosion. Commercial sediment excavation applications often purport to provide secondary flood control benefits. Yet, there is little credible evidence that the perceived benefits are real or more than ephemeral. In fact, sediment removal from channels can have the opposite of desired flood control effects when it is most needed (*e.g.,* Olson 2000).

It is rare that objective and scientifically rigorous analyses (*e.g.,* hydraulic modeling, accompanied by sediment transport modeling) support such arguments for flood control or bank stabilization activities. The effectiveness of most sediment removal activities for flood control is highly questionable for the following reasons.

a. The flow continuity equations state that flow capacity will not increase unless the cross-sectional area and/or the velocity increase. Yet, in some cases, flood "management" simply consists of redistributing sediment within the stream channel - a futile exercise. Flow velocity may be affected somewhat by straightening the alignment of a channel or by reducing the friction caused by bars or vegetation. However, any velocity or area benefits derived from sediment removal would be temporary and could be diminished or lost during crucial flood events because the greatest bedload volumes are transported during floods and roughness due to bedforms significantly changes the flood stage. Olson (2000) found that greater flood risks and potential damage can result from channel maintenance activities because disturbed channels may scour, producing increased sediment loads downstream during floods.

b. Flood elevations in a reach are limited primarily by riffles, hardpoints, bridges and other channel constrictions that act as hydraulic controls. In reaches with highly effective hydraulic controls (*e.g.* upstream from bridges) the channel cross-section and roughness may be irrelevant because of the backwater effect of the downstream control. Sediment removal would be entirely ineffective in such cases, and may prove counterproductive by inducing bed scour and thereby increasing sediment load. Without altering or removing the hydraulic control points, the removal of sediment deposits simply increases the channel's capacity to store water, not to convey it. Increased water storage capacity can be rapidly filled by flood flows. In hydraulic modeling terms, the ineffective flow areas of the channel remain ineffective when bars are removed, and the effective flow areas are unchanged.

c. In cases where a sufficient reach-length is altered by removing sediment and/or vegetation for flood control, the goal of increasing channel capacity by increasing flow velocity can be expected to cause results similar to stream channelization projects. Those results include reduced flood attenuation in the modified reach and increased flood magnitudes and flood damage in downstream reaches.

5.6.1 Recommended Evaluation of Flood Control Practices

Sediment management for flood control objectives should be rigorously evaluated in the context of comprehensive flood hazard management and stream ecology. This includes developing the scientific understanding of the history, causes, and future of channel conditions and related factors that influence flooding. Flood control projects should also evaluate whether or how sediment

removal or its redistribution affects flooding and how these practices affect other processes or attributes, including salmonid habitat. Criss and Shock (2001) conclude that flood stages are increasing over time owing to river engineering and that major floods are occurring more frequently. Belt (1975) found the most severe effects of flood damages are found along stretches with wing dams and levees. Alternative options for flood hazard management should be evaluated in a comprehensive reach or watershed-scale planning context. Other flood security options should be carefully considered, such as flood proofing, returning lands to public ownership, obtaining flood easements on private lands, constructing setback levees, and flood insurance.

Sediment removal for flood control often destroys other important forms and functions of natural channels. Salmonid habitat elements are often disturbed or completely destroyed. Evaluation of proposed flood control activities should follow the same process as for commercial sediment extraction (as outlined in Chapter 5.3 of this document). Impacts to vital habitats should be minimized both spatially and temporally.

The ecological functions of floodplains connected to their streams through hyporheic exchanges and overbank flooding are important aspects of the ecosystems that sustain salmonids. It should be a higher priority to provide for the most basic natural floodplain function - flood water storage - as it can be highly effective in reducing flood peaks, flood velocities, and flood damage. Therefore, new flood control projects should no longer seek to disconnect stream channels from their floodplain. Existing flood control projects should examine methods of reestablishing floodplain connections rather than eliminating those connections. Establishing equilibrium stream channels should be a high priority when flood control projects are reevaluated, rather than continuing the periodic disturbance of disequilibrium stream channels and ecological functions as is now common practice. Flood control projects should be designed to provide the desired flood benefits while requiring the least frequent and least extensive channel disturbance. These suggestions are all consistent with recent scientific literature on the effectiveness of, and actual increased property damages caused by, flood control projects as echoed by changes in objectives of state and Federal flood insurance agencies (*e.g.,* Federal Emergency Management Agency) and water quality agencies (*e.g.,* California Regional Water Quality Control Board 2002).

6   FLOODPLAIN AND TERRACE PIT MINING

6.1   EFFECTS OF FLOODPLAIN AND TERRACE PIT MINING

All alluvial sediment has a downstream velocity, although movement is episodic and punctuated by relatively long periods of rest. Alluvial sediment temporarily stored (in geologic time) in deep deposits within floodplains and terraces adjacent to streams is often mined for commercial aggregate. Both terraces and floodplains are used for commercial sediment production activities because of the large volumes of valuable high-quality material stored in this landscape setting. The potential impacts of mining alluvium from terraces and floodplains are directly related to the project's proximity to the adjacent, active stream channel and the connection with the water table. Pits excavated in floodplains or terraces are spatially fixed features that, over time, may interact with stream channel migration processes in dramatic ways. Floodplain and terrace pits are relatively

benign as far as salmonids are concerned until the pit and stream becomes connected, which is a possibility during flood events.

6.1.1   Short-term hazards.

Pit mines removing alluvial material from terraces or floodplains can result in reduced groundwater elevations, reduced stream flows, and increased stream temperatures. Each of these factors can adversely affect fish. Pit mines are a conversion of land use from riparian or agriculture to commercial/industrial where the vegetation is completely removed. Evaporation of free surface water from large pits can be substantial, especially in hot and arid locations where water temperatures can approach the ambient air temperature. If pit mines penetrate the water table, the operators often reduce the local water table to increase pit production. This is usually done with pumps in the pit or wells installed near the pit that withdraw shallow ground water. Pumping and evaporation can both depress the local ground water table.

The hyporheic zone is the subsurface stream and shallow groundwater flow environment, which is known to be critical to stream ecosystems. Water in the hyporheic zone moves down valley through interstitial spaces in floodplain and stream bed sediments and is connected to stream waters. For example, the hyporheic zone extends as much as 2 km away from Montana's Flathead River channel and it is a greater source of nutrients to the stream than surface water (Stanford and Ward 1988).

Where a depressed ground water table intersects nearby stream channels, especially during low flow seasons, the stream flow will be reduced and possibly subside below the surface of the streambed. This can cause direct mortality to affected fish and the aquatic food base of the stream ecosystem. Locally depressed water tables can reduce stream flows for great distances down gradient, typically down valley.

Solar insolation heats water in wet pits. Nearby stream temperature can increase if the warm water in the pit drains to the stream, especially if a shallow connection preferentially drains the surface water. Increased summer water temperature in streams can adversely affect fish and aquatic organisms, especially coldwater salmonid species. Pits located too close to streams can increase the water temperature and decrease the flow: both are undesirable changes in salmon bearing streams.

The strength of barrier levees or banks between pits and streams is compromised by high water pressure gradients occurring during sudden freshets. Because the stream water level rises much faster than the pit water level the pit barriers may fail if they are too narrow to retain material strength under high pore-water pressure gradients. This type of failure will cause the stream to spill into the pit with a velocity that may cause additional barrier weaknesses and failures. Anadromous salmonids may become trapped in such pits, where they will not contribute to the reproductive success of the population. Also, any exotic fishes or other organisms in the pit will have access to the salmonid stream habitat.

6.1.2   Long-term hazards.

Floodplain pits also cause long-term hazards. Pits excavated to depths greater than the nearby streambed pose substantial long-term risk to the integrity of the stream. Pit capture happens when either flood flows or normal channel migration erode the bank separating the stream from the pit. Pit capture can also occur by flood flows overtopping the separating bank. Without adequate

strengthening, the land separating pits from streams is often inadequate to resist erosion during floods or from normal channel migration processes.

Fish may become trapped in pits when the stream overtops the barrier, or when the barrier erodes or fails for other reasons. These fish are likely to encounter unsuitable feeding conditions, predation, or disease, and will not complete spawning, particularly if return access to the stream is blocked. If exotic fish stocks exist in pits when they are flooded or breached, the exotics enter the salmonid habitat.

The size of floodplain pits should be considered relative to the long-term delivery of sediment from the adjacent stream. Many pit mines along streams have the capacity of hundreds years of sediment input. Clearly, the risk of pit capture increases relative to the size of pit and the sediment load of the stream that it may capture.

When streams capture large pits, dramatic channel changes can occur that adversely affects salmonid habitat. Effects can include rapid bed scour upstream or downstream and abandonment of the existing channel and its habitat (avulsion), followed by replacement with a wide, deep channel (Dunne *et al.* 1981). Catastrophic channel realignment and bank erosion (Scott 1973) upstream and downstream have been experienced where channel pits were excavated in ephemeral channels of the American southwest (Bull and Scott 1974; Chang 1987; Simons-Li 1983). Because floodplain pits can become integrated into the active channel, Kondolf (1993; 1994a) suggests that they should be regarded as if they existed instream when considered on a time scale of a few decades.

Stream bank protection typically accompanies floodplain pit development. What is viewed in the short-term as necessary structural integrity performs over the long-term to reduce streambank riparian habitat and reduce natural channel migration processes that create the most productive salmonid habitat - undercut vegetated banks.

Restoring floodplain morphologic complexity and connections with rivers is possible (Kern 1992; Petersen *et al.* 1992; Petts *et al.* 1992) and desirable in many locations to improve ecosystem function and downstream flood protection. However, the presence of large, deep floodplain pits may limit the range of options or success of restoration activities.

Streams with connected floodplains and minor human encroachments may offer relatively low-risk sediment removal options using pit excavation, if conducted at appropriate scales. Relatively small pits excavated on floodplain surfaces that are overtopped by 2-10 year floods pose less long-term risk to salmonids, and may provide habitat for other wildlife during the intervening years. Such pits can be restored by sediment transport during relatively frequent flood events and pose little threat to channel stability. The use of small floodplain pits, excavated from 2-5 year floodplains, for commercial sediment production in Humbolt County over the past decade appear to have been generally successful, although the effects have not been rigorously monitored.

6.1.3   Summary of Effects

The adverse effects of mining sediment deposits from streamside floodplain or terraces should be considered at two time scales; immediate effects and delayed effects. Over decade time scales, the consideration of effects becomes more apparently a question of "when" rather than "if" salmonids and their habitats will interact with pit mines. The spatial attributes of the pit, its size relative to the stream and its coarse sediment load, and the proximity of the pit and stream meander belt govern these temporal considerations in large part.

The adverse effects of removing sediment from floodplains or terraces include chronic temperature increases, reduced ground water tables and stream flows. Relatively catastrophic effects occur when streams capture large-deep pits. Pit capture often occurs when insufficient space is reserved for normal stream migration or during floods. Headcutting and widespread channel degradation occur when large pits are captured. The concerns of floodplain and terrace mining are summarized in Table 5.

Table 5. Summary of effects of floodplain and terrace mining - implications for salmonid habitat.

Element of Floodplain Mining	Physical Effect	Possible Consequence for Salmonid Habitat	Recommended design considerations.
Clearing or filling of floodplain hydrographic features.	Possible loss of channel margin complexity, reduced bank integrity, riparian functions to ecosystem.	Loss of off-channel overwintering and refugia habitat.	Maximize distance from stream to minimize impacts.
Persistence of pits in time, and need to maintain existing or install new bank protection.	Possible narrowing and simplification of channel; loss of gravel recruitment from banks; reduced recruitment of large woody debris from banks.	Reduction in total amount of habitat; possible reduction in spawning habitat; effects of reduced wood recruitment.	Maximize distance from stream, design berms to minimize occurrence. Implement fish rescue. Prevent colonization by exotic species.
Potential for uncontrolled breaching of pit by river.	Potential for rapid upstream and downstream bed scour, channel abandonment, change in stream morphology, water temperature, and ecology.	Short- and long-term changes to types, amount, and quality of habitat. Release of exotic species to stream.	Design to prevent capture during rare floods, and allow for long-term meander of stream. minimize occurrence, or use wet mining methods.
Presence of lakes near channel. Pumping of water from lakes.	Possible effects on flow, temperature, chemistry, or biota of hyporheic groundwater, or the patterns and locations of groundwater and channel water exchange.	Reduced stream flow, increased water temperature, reduction in trophic food quantity/quality.	Maximize distance from stream to minimize impacts, or use wet mining methods.

6.2 RECOMMENDATIONS FOR MINING TERRACES AND FLOODPLAINS.

6.2.1 Terrace Mines

Terraces and other upland geologic sources should be mined preferentially before floodplains. Drainage from terraces and upland pits should follow applicable statues that prevent polluting surface and groundwater. NOAA Fisheries should determine if existing ordinances provide adequate protection from mine drainage and potential groundwater pollution. However, the scale of terrace mines and the depth of excavation should be considered because mining can convert terraces to floodplains, a process that may impact salmonids. Applicants should consult with NOAA Fisheries prior to excavating floodplain pits.

6.2.2   Dry Pit Floodplain Mines

Dry-pits located outside the riparian zone and on the boundaries of the stream's meander belt can have relatively low risk of impacts on salmonid habitat. The risk of stream capture is low because the pit floor is higher than the stream channel. However, the pit volume relative to the area of adjacent floodplain should be considered because the pit will not provide many of the ecological services for salmonids provided by undisturbed floodplains.

Dry-pit floodplain mines do not intersect the summer water table, by definition. However, during wet seasons pits may accumulate precipitation and runoff and have direct connection to the water table. Furthermore, floods can inundate dry pits. Dry-pits can affect water quality because there is risk of contaminating the groundwater table, which in turn can contaminate the nearby stream. Contaminant spills that drain into the pit may migrate to the water table and eventually enter surface waters. Therefore, dry-pit mines should have an adequate plan and resources to contain and remediate contaminant spills promptly and thoroughly. All material processing should be conducted where spills and drainage can be intercepted and controlled.

Salmonids can be trapped in dry-pits during flood events. Without provisions for fish rescue, all trapped fish will expire when the pit dries out. The magnitude of the effect on salmonid populations is related to the size of pit, the duration of surface flow to the pit, and the frequency of such events. Geomorphic and hydrologic studies (site specific stage, discharge, and gaging records) should be prepared that identify the contemporary and anticipated frequency of inundation events, inundation depth, the past history of channel migration in the vicinity of the pits, and delineation of the migration belt. A responsible mine plan should seek to minimize the probability of future stream connection.

Potential end uses of dry-pits should also be considered when evaluating cumulative effects of proposed projects. Exhausted and derelict dry-pit mines have in the past been used inappropriately as refuse disposal sites. State and local statues may prohibit dumping in pits, however those statutes may not be effectively enforced in remote locations.

There is potential for dry-pits to provide flood control benefits by providing controlled stream channel connections. Pits can store flood peaks and attenuate downstream flooding. From a reach- or watershed-scale perspective, permitting dry-pit floodplain mines that will later provide flood attenuation services can be a valuable alternative to channel maintenance programs in downstream reaches. Designing off-channel flood detention pits to back-flood and drain following storms may minimize fish entrapment.

6.2.3   Wet-Pit Floodplain Mines.

Wet-pit floodplain mines can adversely affect the local groundwater level and quality either as a result of dewatering operations or from evaporation or contamination. Hydrologic assessments of wet mine pits on nearby stream flow should examine not only normal hydrologic conditions, but also extreme conditions including drier than normal and drought conditions. Water pumping from wet-pit mines should not decrease the water table elevation, or reduce ground water flow to nearby salmonid stream habitat.

The risk of stream interaction based on geomorphic processes should be considered while evaluating pit locations. The maximum depth of excavation should not exceed the greatest pool depth of the adjacent stream to reduce risk of stream-pit capture. Pits should not be excavated inside of meander

bends where there is high risk for meander cut off and channel avulsion. Floodplain pits should be separated from streams by wide riparian buffer strips or well-designed and robustly constructed berms that will withstand at least a 100-year flood.

The location and design of separating berms should also allow for stream channel migration without relying on hard engineering structures or bank protection to resist bank erosion, because such treatments diminish fish habitat quality. Site specific design details should consider the width of the geologically recent meander belt of the stream, and they should provide at least two channel widths as a riparian buffer between the stream and pit. The meander belt of alluvial streams is generally contained within two channel widths on each side of a stream (Leopold 1994), if the stream is centered in the meander belt width.

California statues require mines to establish reclamation funds. It is reasonable to establish fish rescue protocols, provisions for maintaining the separating berm, and channel restoration elements either separately or concurrently with the state reclamation fund requirements.

6.2.4   Wetland Pit – Frequent Floodplain Mines.

Excavating a wetland pit in a frequently inundated floodplain (2-5 year floodplain) may be a relatively low risk method for producing high quality aggregate outside the bankfull stream channel. The frequency of fish interaction is lower than within the bankfull channel, but fish can become trapped in pits. An advantage of excavating wetland pits compared to instream excavation is that the impacts on fish may be determined with greater certainty – a pit becomes a closed system when it is not flooded. A fish rescue protocol can be developed to mitigate impacts to fishes stranded in the pits.

Pit size should consider conservative bedload estimates so that the stream can refill pits during floods without starving downstream habitats of coarse sediment. The maximum pit size should not exceed what could reasonably be replenished by approximately 50% of the coarse sediment load for the discharge event that inundates and delivers coarse sediment to a specific pit. Therefore, pit size and elevation should be designed relative to the flow frequency and magnitude that can be expected to refill the sediment trap. A reliable sediment budget is therefore required to design a responsible wetland pit excavation.

Sediment removal activities for a single project should be located on the same side of the floodplain. This will eliminate the need for, and harmful effects of, crossing active channels with heavy equipment, and building temporary bridges for haulage roads. If wet stream crossings cannot be avoided entirely, then permanent bridge crossings should be established following NOAA Fisheries fish passage guidelines, and other state and local bridge design and construction requirements.

7   Monitoring and Performance Criteria.

Monitoring and project performance criteria should be included in sediment removal applications. It is recommended that procedures should be designed to continually check important habitat features for potential negative impacts, and test the validity of the *a priori* assumptions, as defined in the project evaluation process. Re-evaluation should be anticipated if negative impacts exceed those foreseen during evaluation. Performance criteria can be established that recognize reasonable

deviations from current or anticipated conditions, and different monitoring and/or management activities can be linked to the performance criteria. This can effectively build adaptive monitoring and management into a project evaluation and permit process.

7.1 MONITORING METHODS.

Applicants should be encouraged to use modern data collection methods to support evaluation of existing conditions and monitoring changes in landforms, habitats, and quantifying disturbances. However, where robust cross-section monitoring programs currently exist, any new method should fully integrate with the older system to maintain spatial continuity. Cross-sections, topographic mapping, and aerial mapping by various methods can provide the information necessary to manage and monitor fluvial systems. Stream channel monitoring has traditionally been accomplished using cross-sections. Newer techniques provide broader coverage, greater point density, and more flexibility for analysis. Costs between new and old methods are now comparable or favor new methods.

The disadvantages of some new mapping methods are that they are unable to provide information from below the water surface and produce poor data in the densest riparian areas. However, most monitoring data from commercial sediment excavation has not included data from the wet portion of the channel. It is imperative that habitat (pools, runs and riffles) be monitored regardless of the methods used. A combination of methods can be the most efficient and is recommended.

Where cross-sections continue to be used for monitoring sediment extraction, they should include an element of flexibility that allows for tracking important geomorphic features such as riffle crests and pools. Stream channels and their geomorphic features are dynamic, generally migrating incrementally downstream as erosion occurs on the upstream side of bars and deposition occurs on the downstream side. Employing georeferenced cross-sections and the expectation that bars will be replenished in the same location year after year, and using rigid redline surface definitions to regulate aggregate extraction from downstream migrating bars, results in progressively enlarged mining areas and/or reduced bar sizes.

A dynamic monitoring method should be used to accommodate the dynamic bar relocation process. This would include additional cross-sections for pools and riffles that are all geographically referenced. Similarly, a longitudinal profile running the length of the stream channel could be used to compliment a network of fixed cross-sections. If instream geomorphic features are not migrating downstream, this is an indication that the incoming sediment load is inadequate to justify sediment removal activities, or that the channel has obtained an efficient geometry for processing and releasing the incoming load without undergoing substantial changes in shape. Such "equilibrium" channels should not be disturbed for flood control purposes or for commercial sediment removal.

Geomorphic features should be monitored using methods that quantify their physical dimensions and changes at appropriate time scales. Monitoring programs should use densely spaced cross-sections to cover the geomorphic features, topographic mapping techniques that do not rely solely on cross-sections but rather follow terrain features, and modern mapping methods that grid entire areas with equally spaced data. All monitoring methods should be required to discern features as small as 1-foot. As with cross-sections, any mapping method is required to be repeatable: that is, geographically referenced to permanent datum points.

Pre- and post-extraction surveys are required for each extraction period. Continuous annual time step monitoring is required for ongoing extraction operations, even when time breaks may occur between extractions. Documenting the natural variability of geomorphic features is desirable for all parties concerned in sediment extraction and habitat provision.

Because sediment removal can have effects upstream and downstream from the excavation site, monitoring must extend appropriate distances depending on the scale of excavations. Where 1-2 bars are disturbed by small-scale excavation, monitoring should extend upstream and downstream one pool-riffle complex. Where 3-4 bars are disturbed, monitoring should extend 2 pool-riffle complexes upstream and downstream. In areas where pool-riffle complexes are difficult to discern, the widely recognized ratio of 5-7 channel widths per pool-riffle complex can be used instead to scale monitoring activities.

Stream channel size will determine the spacing between cross-sections. Unless previously established at a closer spacing, cross-sections should be spaced approximately ½ the distance as the channel is wide. Where a channel is 500 feet wide, cross-sections should be spaced at approximately 250 feet. In addition, sediment excavation surfaces should be quantified using at least three cross-sections. Where more closely spaced cross-sections or more detailed mapping is already utilized for monitoring sediment removal programs, the data density should remain at the higher quantity.

7.2   MONITORING ELEMENTS

Monitoring of commercial or flood control sediment removal areas should include geomorphic and biologic elements.

Where salmonids spawn in areas of sediment disturbance, spawning conditions should be monitored. Reproductive success may be compared to control areas upstream and downstream using artificial incubators. Changes in hyporheic exchange may be compared to control areas upstream and downstream also.

Rearing and spawning habitat may be monitored with emerging habitat mapping protocols (*e.g.* B. Trush and D. Halligan, personal communication 2002) although the effects of stream flow interacting with disturbed areas can be brief and ephemeral. Monitoring should include appropriate times of sampling and repeat measurements for cyclic processes such as pool scour and fill.

In cases where turbidity or increased fine sediment transport is anticipated downstream from sediment disturbance sites, benthic invertebrate monitoring should be conducted. The physical effects of increased fine sediment may also be monitored as it relates to reduced porosity or increased percentages of fine sediment in riffles and spawning areas.

Appropriate physical monitoring parameters to consider include changes in: riffle crest elevation, pool depth and volume, spawning gravel size and area, hyporheic flow volumes and water quality, substrate size and range, and suspended sediment loads and grain sizes. Biological parameters to consider include; riparian community density, age, and size, riparian attributes such as cover, shade, channel margin complexity, allocthonous inputs, and LWD recruitment. Monitoring the health and changes in the invertebrate food base should also be considered where impacts on rearing functions are anticipated.

Annual sediment removal records, and extraction rates, should be reported as a condition of authorization. Despite public ownership of and interest in floodplains and channels, sediment

production data are treated as proprietary information. This is public information that should be reported accurately and reliably in order to responsibly manage the fluvial resource and salmonid habitat. A monitoring plan example is presented in Appendix 2.

7.3 PERFORMANCE CRITERIA.

Analysis of the impacts of a proposed sediment removal project is conducted with imperfect information. Therefore, project authorization should be predicated on well-defined monitoring programs. Incidental take statements should incorporate specific terms and conditions that clearly identify the functions of necessary geomorphic features and habitat elements. Where pool habitat is important, monitoring should track changes in pool depth and volume. Where spawning substrate is important, monitoring should track changes in sediment size or permeability at appropriate spawning time intervals. Where water temperature and shade from riparian vegetation is important, the density and height of riparian plants should be monitored along with water temperature. Where historic habitat use is known, but recent use is unknown, fish monitoring should be included.

Deviation of monitoring parameters outside the range of values used for estimating incidental take should trigger reinitiating § 7 consultation, or implementation of additional monitoring requirements to determine the causes. Recently, scientific review panels have been convened to direct the additional monitoring and investigation activities and interpret the results. This team should have authority to order the cessation of excavation if habitat losses are observed and the causes are found to be directly resulting from excavation, or if indeterminate, spatially isolated about the excavation area.

7.4 ADDITIONAL RECOMMENDATIONS FOR ALL SEDIMENT REMOVAL PROJECTS

Prior to any sediment removal, a thorough review should be undertaken of potentially toxic sediment contaminants, and noxious or invasive plant species, in or near the streambed where sediment removal operations are proposed or where bed sediments may be disturbed by the operations (including upstream and downstream adjacent banks and floodplain).

Sediment contaminants should require analysis and consideration. Generally, there should be no reasonable justification for disturbing contaminated sediment that could conceivably enter the stream ecosystem if disturbed. However, the removal of contaminated sediment from future interaction with the stream ecosystem may be of benefit if it can be accomplished with sufficient isolation and little risk. Contaminated sediment disturbance should be evaluated on a case-by-case basis.

Noxious and invasive plants should be removed using methods that prevent spreading. An invasive plant management plan should be developed as part of all sediment removal or redistribution actions that addresses noxious or invasive plants in a long-term management context.

Extracted aggregates and sediments should not be washed directly in the stream or within the riparian zone. Turbidity levels should be monitored and significant increases above background turbidity levels should not be exceeded.

Instream roughness elements (LWD, rocks, etc.) should not be removed during sediment removal activities. Those that are disturbed should be replaced or restored. Additional roughness elements may be placed in mining areas to improve habitat and contribute to partial mitigation for habitat disturbance.

Sediment removal operations should be managed to avoid or minimize damage to stream/river banks

and riparian habitats. Sediment removal in vegetated riparian areas should be avoided. Access roads should not encroach into the riparian zones. Undercut vegetated banks are highly productive habitat for salmonids and should not be altered.

All support operations (e.g., sediment washing) should be done outside the riparian zone and at floodplain elevations that can be protected from infrequent flood events. Sediment stockpiles, overburden and/or vegetative debris should not be stored within the riparian zone. Operation and storage of heavy equipment within riparian habitat should be restricted.

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9 APPENDIX 1 – SUMMARIES OF MAJOR STATUTES

The following summaries of the major statutes mentioned in these Sediment Guidelines, with the exception of the River and Harbor Act of 1899, were obtained from Buck[1].

9.1 ANADROMOUS FISH CONSERVATION ACT

The Anadromous Fish Conservation Act (16 *U.S.C.* 757a-757g) authorizes the Secretary of Commerce, along with the Secretary of Interior, or both, to enter into cooperative agreements to protect anadromous and Great Lakes fishery resources. To conserve, develop, and enhance anadromous fisheries, the fisheries which the United States has agreed to conserve through international agreements, and the fisheries of the Great Lakes and Lake Champlain, the Secretary may enter into agreements with states and other non-Federal interests. An agreement must specify:

(1) the actions to be taken;
(2) the benefits expected;
(3) the estimated costs;
(4) the cost distribution between the involved parties;
(5) the term of the agreement;
(6) the terms and conditions for disposal of property acquired by the Secretary; and
(7) any other pertinent terms and conditions.

Pursuant to the agreements authorized under the Act, the Secretary may: (1) conduct investigations, engineering and biological surveys, and research; (2) carry out stream clearance activities; (3) undertake actions to facilitate the fishery resources and their free migration; (4) use fish hatcheries to accomplish the purposes of this Act; (5) study and make recommendations regarding the development and management of streams and other bodies of water consistent with the intent of the Act; (6) acquire lands or interests therein; (7) accept donations to be used for acquiring or managing lands or interests therein; and (8) administer such lands or interest therein in a manner consistent with the intent of this Act. Following the collection of these data, the Secretary makes recommendations pertaining to the elimination or reduction of polluting substances detrimental to fish and wildlife in interstate or navigable waterways. Joint NMFS-FWS regulations applicable to this program are published in 50 *C.F.R.* Part 401.

9.2 CLEAN WATER ACT

The Clean Water Act (CWA) (33 *U.S.C.* 1251-1387) is a very broad statute with the goal of maintaining and restoring waters of the United States. The CWA authorizes water quality and pollution research, provides grants for sewage treatment facilities, sets pollution discharge and water quality standards, addresses oil and hazardous substances liability, and establishes permit programs for water quality, point source pollutant discharges, ocean pollution discharges, and dredging or

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[1] Buck, E.H. 1995. Summaries of major laws implemented by the National Marine Fisheries Service. CRS Report for Congress. Congressional Research Service, Library of Congress, March 24, 1995.

filling of wetlands. The intent of the CWA § 404 program and its 404(b)(1) "Guidelines" is to prevent destruction of aquatic ecosystems including wetlands, unless the action will not individually or cumulatively adversely affect the ecosystem. National Marine Fisheries Service (NMFS) provides comments to the U.S. Army Corps of Engineers as to the impacts to living marine resources of proposed activities and recommends methods for avoiding such impacts.

9.3   ENDANGERED SPECIES ACT

The purpose of the 1973 Endangered Species Act (ESA) (16 *U.S.C.* 1531-1543) is to provide a means whereby the ecosystems upon which endangered or threatened species depend may be conserved and to provide a program for the conservation of such endangered and threatened species. All Federal departments and agencies should seek to conserve endangered and threatened species and should utilize their authorities in furtherance of the purposes of the ESA.

9.4   FISH AND WILDLIFE COORDINATION ACT

The Fish and Wildlife Coordination Act (16 *U.S.C.* 661-666c) requires that wildlife, including fish, receive equal consideration and be coordinated with other aspects of water resource development. This is accomplished by requiring consultation with the FWS, NMFS and appropriate state agencies, whenever modification of any body of water is proposed in any way and a Federal permit or license is required. These agencies determine the possible harm to fish and wildlife resources, the measures needed to both prevent the damage to and loss of these resources, and the measures needed to develop and improve the resources, in connection with water resource development. NMFS submits comments to Federal licensing and permitting agencies on the potential harm to living marine resources caused by the proposed water development project, and recommendations to prevent harm.

9.5   MAGNUSON FISHERY CONSERVATION AND MANAGEMENT ACT

The Magnuson Act requires that fishery management plans should "include readily available information regarding the significance of habitat to the fishery and assessment as to the effects which changes to that habitat may have upon the fishery" 16 U.S.C. 1853 (a)(7).

9.6   NATIONAL ENVIRONMENTAL POLICY ACT

The National Environmental Policy Act (NEPA) (42 *U.S.C.* 4321-4347) requires Federal agencies to analyze the potential effects of a proposed Federal action which would significantly affect the human environment. It specifically requires agencies to use a systematic, interdisciplinary approach in planning and decision-making, to insure that presently unquantified environmental values may be given appropriate consideration, and to provide detailed statements on the environmental impacts of proposed actions including: (1) any adverse impacts; (2) alternatives to the proposed action; and (3) the relationship between short-term uses and long-term productivity. The agencies use the results of this analysis in decision making. Alternatives analysis allows other options to be

considered. NMFS plays a significant role in the implementation of NEPA through its consultative functions relating to conservation of marine resource habitats.

9.7   RIVERS AND HARBORS ACT OF 1899

The Rivers and Harbors Act of 1899, § 10 (33 *U.S.C.* 403) requires that all obstructions to the navigable capacity of waters of the United States must be authorized by Congress. The Secretary of the Army must authorize any construction outside established harbor lines or where no harbor lines exist. The Secretary of the Army must also authorize any alterations within the limits of any breakwater or channel of any navigable water of the United States.

10   APPENDIX 2 – EXAMPLE MONITORING PLAN

The following example demonstrates a practicable monitoring plan for an instream commercial sediment excavation. The example assumes that the project application was supported by a hydraulic model that quantified the project's effects on various hydraulic and sediment transport processes, which allows for analysis and interpretation of effects on habitat.

10.1 PHYSICAL MONITORING.

All survey measurements shall be made in compliance with accepted published protocols for procedures and accuracy, and with reference to a permanent geodetic datum. The density of survey data shall be sufficient to capture geomorphic features with 1 foot elevation change, or sufficient to construct a 1 foot contour map. All data shall be prepared and processed to visually discern changes from year to year.

10.1.1   Pre and post-extraction topography.

Applicants shall continue to survey river channel cross-sections spaced at the lesser of 400 feet or every one half channel width (average channel width), and including every pool and riffle, in order to characterize the channel topography. This shall be done twice annually, at the end of the mining season and prior to the beginning of the next mining season. Topography shall be measured over the entire project reach and extend both upstream and downstream at least two riffles, or a length equivalent to the project length, whichever is greater. The develop and use new surveying techniques should be encouraged, such as aerial mapping and hydrographic mapping, to replace and/or augment cross-section measurements.

10.1.2   Longitudinal profile.

Applicants shall annually survey the river thalweg, connecting the pools and riffle crests. The longitudinal profile shall be measured over the entire project reach and extend both upstream and downstream at least three riffles, or a length equivalent to the project length, whichever is greater.

10.1.3   Excavation surfaces.

Applicants shall measure the grain size distribution of sediment exposed on all disturbed surfaces using sieving and volumetric methods. Applicants shall measure the area and depth, and estimate the volume of exposed fine material. In addition, applicants shall update the initial hydraulic model to estimate the discharge range corresponding to the initiation of motion of exposed particles to facilitate the prediction and monitoring of sediment intrusion processes (see Chapter *10.1.6* below).

10.1.4   Pools.

Applicants shall measure the grain size distribution of all pools in the project area, and extending two pools upstream and downstream, or a length equivalent to the project length, whichever is greater. Grain size shall be measured by wet sieving volumetric methods or Wolman pebble count methods, depending on the material size. If a fine sediment layer overlies a coarse bed, the depth of the fine layer shall be measured at its maximum thickness and the size distribution of both the fine and coarse materials shall be measured. Residual pool volume (*e.g.* Lisle and Hilton 1991) shall be determined, either with surveying methods or with a combination of surveying and hydraulic modeling, to monitor changes in pool habitat quantity, relative to a permanent vertical datum and to the water surface corresponding to summer low flow.

10.1.5   Riffles.

Applicants shall measure the grain size distribution of riffles using bulk samples and wet sieving methods as described in Church *et al.* (1987), Bundt and Abt (2001), or Schuett-Hames *et al.* (1994), or equivalent procedure. The sample size should be based on the largest particle representing no more than 5% by weight of the total sample size. The grain size of all riffles in the project area shall be measured at annual intervals, in consistent locations, and extending three riffles upstream and downstream, or one project length upstream and downstream, whichever is greater. Sampling locations should be geomorphically similar; riffle crests, pool tail outs, mid-points of runs, *et cetera*.

10.1.6   Sediment Intrusion.

Applicants shall measure the effects of fine sediment intrusion of potential spawning gravels at riffles, consistent with item 'e' above. Intrusion effects shall be measured by losses of permeability, increases in bulk density, or a suitable alternative method approved by NOAA Fisheries. This monitoring shall be done at no less than three locations, at the downstream end of the mining area, at a similar riffle location at least two riffles immediately upstream from the upstream extent of the mined area, and at one location downstream from the mining area that is located within one additional project length distance downstream from the downstream extent of the mining area. NOAA Fisheries shall approve monitoring locations.

Artificial spawning beds shall be constructed by digging the bed with shovels to expose and clean the fine particles from the bed, to the maximum extent possible. Measurements shall be made in the prepared artificial bed. If continuous measurements are made, they shall be at 1-hour (maximum) intervals with in situ instruments and data recorders. If manual measurements are made they shall be made in late Fall prior to the spawning season, and again within 24-hours following the earliest storm flow that results in inundation of at least half the skimmed mining surfaces (by area). If a measurable affect of sediment intrusion is found with the second measurement, twice-weekly measurements shall be conducted to document the duration of the effect.

10.2 PERFORMANCE CRITERIA:

10.2.1   Physical Monitoring:

a. Pools.   If residual pool volume decreases within the mining area by 20% or more, mining will cease until pool volume is restored to pre-project dimensions.

b. Riffles.   If the d_{84} or d_{16} grain sizes change, on average in the mining reach, one phi size class or more, compared to the upstream riffles, mining will cease until riffle particle size is restored to pre-project dimensions.

c. Sediment intrusion.   Mining shall cease if permeability of the artificial spawning locations, within or downstream from the mining area, decreases by 20% or more during any time interval, and does not relax within 48-hours to 90% of original permeability, relative to measured changes that occur at the upstream control site during the same time interval. Mining shall not resume until a suitable alternative management method is presented and agreed upon that will prevent additional intrusion.

10.2.2   Hydraulic Monitoring:

All applicants shall utilize the required annual cross-sections and annually collect additional data for, and run, a hydraulic model specific to the mined river reaches. Data yielded from this effort shall include, the stage discharge relationships for each mined bar, the effective discharge stage height, and the incipient motion threshold flows for the mined surfaces. The results of this effort shall be used as a check on the other monitoring requirements, and to estimate changes in sediment load resulting from the mining operation, including estimates of changes in bed material load, suspended sediment load, and turbidity.

10.2.3   Biotic Monitoring:

a. Rearing. Annual surveys of juvenile salmonid distribution and abundance in the Alexander Valley reach using visual estimation techniques shall be conducted to determine the extent of use and species composition. Ancillary data on micro-habitat use, predator/prey interactions, or other pertinent observations leading to a better understanding of factors limiting salmonid survival are encouraged.

b. Spawning. Annual surveys for spawning adults, their redds, and carcasses shall be conducted at the appropriate time and with a frequency adequate to provide data on species composition, run timing, spawning abundance and distribution.

c. Temperature. Stream temperature monitoring shall be conducted annually between June 1 and September 31 to 1) characterize the biologically relevant temperature conditions both seasonally and spatially (*i.e.,* temperature changes as the river flows through the valley), and 2) identify and characterize temperature refuge from sub-surface seepage or any other source that may allow juvenile salmonids to utilize the habitat during the hottest time of year. Automated temperature data loggers shall be placed upstream, within, and below mined reaches with numbers and spacing adequate to characterize the rate of temperature change, spatially, so any change in temperature correlated with mining reaches may be distinguished from background changes.

d. Riparian vegetation. The applicants shall, by their own efforts or in cooperation with local agencies and other interested parties, provide monitoring data that describes the condition of riparian vegetation along the _____River in the _____ reach. This shall include the extent, species composition, and age structure of the riparian plant community. Emphasis shall be placed on those attributes that provide ecological functions pertinent to salmonids such as, shade, cover, velocity refuge, LWD, LWD recruitment, and allochthonous inputs. It shall also specifically address changes in these values over time relative to both natural and anthropogenic processes.

10.2.4   Reporting Requirements:

a. Applicants shall submit a compliance monitoring report detailing the nature of the observations, the effort of the observer(s), and any significant deviations from planned operations. Suggestions on ways to improve implementation of gravel extraction methods, and terms and conditions shall also be included. This report will be due within 60 days after operations have been completed.

b. Each applicant shall submit annual mining plans detailing the specific gravel bars to be mined in that season. These will be based on cross-sectional survey data from the spring of the same year. Plans shall also include maps detailing the areas to be mined, surfaces or cross-sections indicating pre and post mining contours, and estimated volumes to be extracted. These reports are to be

received by the NMFS no later than 30 days prior to the start of mining activity each year. Mining plans will be subject to the NMFS approval prior to the beginning of operations.

c. Applicants shall notify NOAA Fisheries in writing of their intent to begin operations no later than one week prior to initiation of extraction activity each year.

d. Subsequent to this year (_____), applicants shall submit monitoring plans to the NMFS for approval prior to initiation of monitoring. Monitoring plans are to be received by the NMFS no later than January 1 of that year (*i.e.,* the first monitoring plan will be due 1 January, _____).

e. Those applicants operating for more than one year shall submit an annual monitoring report concurrent with subsequent mining plans. These reports shall include clear descriptions of how the monitoring results were taken into consideration in the development of the mining plan.

10.2.5   *Interpretation of Monitoring Results and Adaptive Management:*

A scientific review panel will be established before the end of the first annual monitoring and reporting period. The panel will review the monitoring information, make site visits, and following the performance criteria determine the appropriate actions for the next year before subsequent extraction begins. The panel will include qualified experts in geomorphology, biology, ecology and engineering from the regulatory agencies as well as consultants for the applicant.