ATTACHMENT L

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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

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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 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 annual aggregate extraction in California is estimated to exceed 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 convergence of geology and accelerating market demand has significant 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.

These Guidelines do not present prescriptive measures that must be implemented by parties engaged in sediment removal activities. Alternative means of demonstrating compliance with statutory requirements are acceptable pending review by staff. As such, the language of these guidelines should not be read to establish binding requirements.

These 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, and methods) that may minimize adverse effects.

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 the Guidelines recommendations, particularly where site-specific data do not support less conservative measures.

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 SWR 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 longitudinally and in planform. 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, that increases the quality of 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. The convergence and divergence of the stream's flow field maintain complex topographic and sedimentary features. Local sorting of streambed materials is related to the local distribution of stream forces. 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; which are 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 a 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 smaller sized particles are now available for transport at lower discharge. The new supply of small gravel, sand, and silt 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 to 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, comprised of large particles, LWD, and vegetation along the banks. These features significantly influence flow hydraulics by creating 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. Reductions in roughness height 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 temporary migration barriers to upstream migrating adult salmon and steelhead. Channel stability combined with 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 the width to depth [W/D] ratio), sediment removal operations can reduce flow-field complexity, increasing current velocities and, 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 can be significantly impaired when alternate bars are removed. The implications of impacts to pool formation and maintenance are considerable. Unless carefully managed, sediment removal projects can 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 reduces 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 may 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 annually scour emergent vegetation.

Riparian vegetation can also be adversely affected by the removal of LWD within the riparian zone during sediment removal activities. LWD 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 bar tops are particularly valuable during floods because the low-velocity flow-field found at bar top locations is relatively rare in the stream environment. 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. 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 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 anadromous fish habitat. Instream roughness elements, particularly LWD, 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 effects relevant to the trust salmon species (Chapters 3-4). The physical and biological effects discussed are supported by references on site specific studies as well as general scientific 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 and this Guidance document as background.

To a large extent, channel-forming processes govern the channel morphology and many of the physical elements of salmonid habitat. All of the geomorphic features found within the channel are highly influenced by the effective discharge - the flow most effective in the long-term transport of sediment. Effective discharge is often used synonymously with "dominant discharge", which is defined as that discharge of a natural channel that determines the characteristics and principal dimensions of the channel.

Mature gravel bar features including bar height, armor layer, and replenishment are all determined by a relatively narrow range of flows centered on the effective discharge. As a result, 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 effective discharge's influence in defining channel properties has great effect on the physical processes that influence salmonid habitat development and maintenance. These processes include formation of suitable spawning gravels, formation and maintenance of pools, 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 ES1. 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.	Propogates stream degradation both upstream and downstream from removal site.	Loss or reduction in quality of pool and riffle habitats.
	Scour of upstream riffles.	Lower success of spawning redds.
	Reduced pool areas.	Loss of spawning and rearing habitat.
	Bed surface armoring.	Lower quality of spawning and rearing habitat; changes to invertebrate community.
	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 riffle and pool 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 should 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. Therefore, it is recommended that the deleterious effects on salmonids be considered at all temporal and spatial scales when habitat modifications such as sediment removal or redistribution are evaluated.

After completing the required jeopardy analysis for *Section* 7 consultation, it is recommended that staff follow either the ***National Gravel Extraction Policy*** for take avoidance or these guidelines for minimizing incidental take, as appropriate. 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. Usable habitats can be protected by implementing a combination of two methods that minimize the disturbance of stream channel habitat: minimize local habitat modification and limit the volume of sediment extraction to well less than the sediment influx. It is 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 the "source" for downstream reaches, it is recommended that proposed extraction plans allow for pass-through of 50% of the unimpaired incoming coarse sediment load to maintain downstream habitats. Simply maintaining a positive sediment budget that supplies coarse sediment for downstream habitat may not protect geomorphic resources and habitat at the removal sites. Therefore it is recommended that site-specific habitat, geomorphic features, and physical processes 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 strategies for protecting various stream habitat elements.

Table ES2. Recommended sediment extraction strategies to protect various salmonid habitat elements, stream hydrology, and retention of physical processes. *[See Table 4 in Chapter 5].*

LIFESTAGE	Habitat Element Required	Related Physical Processes	Recommended Strategy for Sediment Extraction
Adult Migration and Juvenile Migration	Natural channel conditions that include roughness elements, cover, shade, resting pools, LWD.	Channel confinement and flow depth over riffles.	#1 Partial retention of bar geometry to provide minimum flow depth >2-feet over hydraulic controls (riffles). Free draining extraction surfaces. Avoid riparian vegetation. Avoid or replace LWD.
	Background levels of suspended sediment load In the water column.	Exposure of fine sediment in the mined area.	Preventing fine sediment mobilization from mined surfaces during fish migration periods.
Spawning	Stable, suitable spawning beds; riffle geometry and composition at expected size and frequency.	Sediment sorting processes that create suitable spawning beds. Premature redd scour.	#2 Partial retention of bar geometry to maintain sediment sorting processes at riffles during flows up to bankfull or effective discharge, and negligible increase in bed scour in spawning-bed locations during spawning periods.
	High water quality in the column, and in intergravel water. Background level of bed material load.	Mobilization of fine sediment from mined area. Sedimentation of spawning beds.	Preventing fine sediment and bed-material mobilization from mined surfaces during spawning periods.
Incubation and Emergence	Stable substrate. Natural rates of bed material transport. Diverse patterns of sediment sorting processes.	Premature redd scour. Deposition of sediment over redds.	#3 Partial retention of bar geometry to ensure negligible increase in bed scour, and negligible increase in sediment load or turbidity from mined areas.
	Background water quality which supplies oxygen to buried eggs and alevins.	Hyporheic flow of oxygen and nutrients to eggs.	Preventing fine sediment and bed-material mobilization from mined surfaces during incubation and emergence periods.
Rearing	Pools, food source, cover, cool, well-oxygenated water.	Optimal pool-scour processes, to connect pools with water table. Coarse and clean substrate. Riparian health.	#4 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. It is recommended that flood control projects also evaluate whether or how sediment removal or its redistribution affects flooding and how these practices affect other processes or stream functions.

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.

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. Monitoring needs are related to the relative risks to salmonids and habitat of the proposed project. Appendix 2 presents an example monitoring plan and performance criteria.

Table ES3. Summary of effects of floodplain and terrace mining, and 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.

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 humans. 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 several 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, some instream gravel mining practices are 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 of mining 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 repeated skimming of bars can result in chronic 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 puts forward 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 or *Law*
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 or *Law*
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	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 riparian zone of 30 meters plus a recommended buffer to protect the riparian zone depending on the types and intensity of mining activities.	*1976, Fisheries Act, section 35* Brief to Aggregate Advisory Panel, 2000

2 SCOPE of the 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 the dredging of stream sediment for maintaining a navigation or flood control channel, or for 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 may be achieved through two objectives;

(1) limiting the physical modification of geomorphic features and safeguarding physical processes that generate or maintain 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 project applicant is encouraged to describe 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. As necessary, NOAA Fisheries will apply the precautionary principle and recommend conservative measures and/or studies in order to ensure adequate protection of trust resources.

The Guidelines also provide a technical 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 RELEVANT STATUTES

NOAA Fisheries has the authority and obligation under several statutes, including the ESA, the Fish and Wildlife Coordination Act, the Magnuson-Stevens Fishery and Conservation 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 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*. Both SMARA and California Fish and Game Code are updated regularly and the most current revisions should be consulted.

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 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 (*Section* 7(a)(1)) and EFH obligations. Further description of the 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 conveyance capacity of a stream is often increased in an attempt to reduce flood risk. If the channel cross-

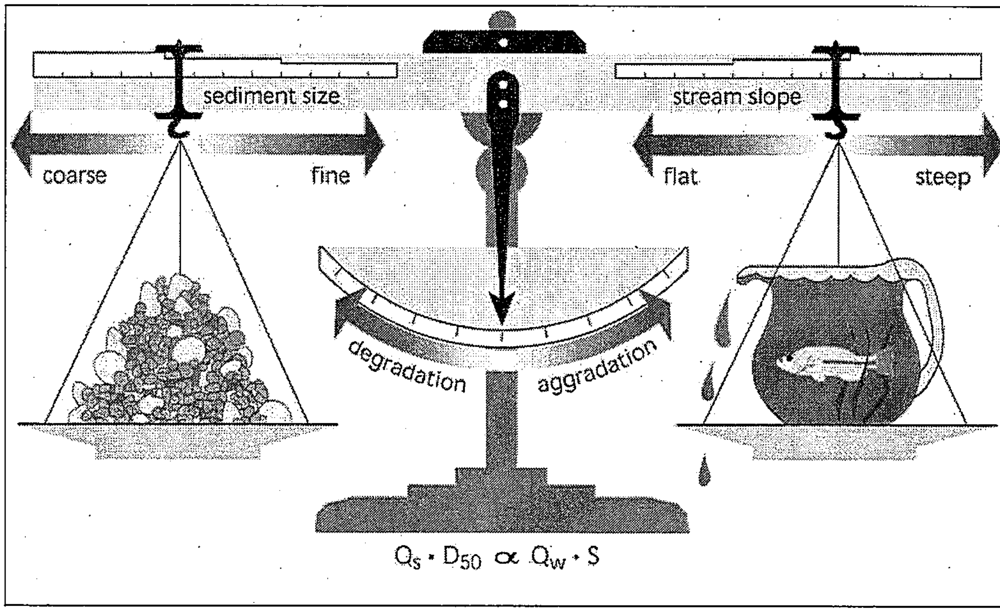


Figure 1. Lane's 'balance' diagram, a useful visual model for predicting stream responses to common disturbances.

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 should be remembered, however, that 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 longitudinally and in planform. 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. Composed 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).

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, 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 and Reiser 1991).

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 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), that 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 that 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 movement 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 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, and 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 effectively 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, 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. 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.

Another criterion of streams in equilibrium is the erosion of stream banks balanced by deposition of bars during frequent winter flows. The "damage" done by large, less frequent floods, which 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 and levee-lined 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, and 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 it 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 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 outmigrating as 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). 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 cannot 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. Channel 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 subsections.

4.1 EFFECTS ON CHANNEL MORPHOLOGY AND HYDRAULICS

As discussed in Section 3, 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 sections describe predictable and widely observed changes initiated by sediment removal.

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 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-RAS), however, hydraulic analyses are not typically used to support environmental assessments for sediment removal operations. Instead, one-dimensional continuity equations are often applied:

$$\mathbf{(WD)_1V_1 = (WD)_2V_2,}$$
$$\mathbf{A_1V_1 = A_2V_2}$$
$$\mathbf{Q_1 = Q_2}$$

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 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 that 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.

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 may not remove the cause of bank retreat – the weakened bank.

4.1.2 Changes in Sediment Transport.

The ability of streams to transport sediment is represented by the bed shear stress. Shear stress calculations are 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 background or undisturbed condition sediment is transported in greater volume and in greater particle size.

A simple form of bed shear stress is:

$$\tau_o = \gamma \cdot R_h \cdot S_f$$

where; τ_o , estimated average boundary shear stress for a cross section, is the product of

γ, the specific weight of water,

$\boldsymbol{R_h}$, the hydraulic radius (equal to the average depth of flow in wide channels),

and $\boldsymbol{S_f}$, the friction slope (or energy slope).

Since the specific weight of water (γ) is approximately constant, the variable terms become depth and slope. In practice, the friction slope $\boldsymbol{S_f}$ is often assumed equivalent to the average bed gradient (taken from map information) or the water surface slope (taken from observations over reach lengths or from flood studies). This practice assumes steady discharge and simple, wide, rectangular channel geometry: conditions not met in natural streams. Estimates of sediment transport rates for stream reaches simplify the cross sectional geometry as well as bed elevation details, thus diminishing their usefulness for assessing changes to habitat. Further difficulties arise when applying cross section averaged velocity and depth to assess habitat changes: (1) $\boldsymbol{S_f}$ is a complex term involving changes in head, velocity, energy losses, and the effects of boundary roughness between two cross-sections, and (2) the average velocity and depth of flow through a cross section can not describe natural streams and habitat features.

A simplified portrayal of a more complicated equation can help clarify the complex and non-intuitive nature of shear stress and friction slope, and therefore aid in understanding the effects of sediment removal actions at local or habitat scales. Consider the relationship of the variable terms for shear stress at a point in a stream (*e.g.*, Julien 2002),

$$\tau_o = \frac{\rho\left[k\left(\frac{v_2}{v_1}\right)\right]^2}{\ln\left(\frac{z_2}{z_1}\right)^2}$$

where the velocity (v) is known at two water depths (z_1 and z_2). The velocity over depth relationship is helpful to rapidly acquire a sense of changes in sediment transport at specific points on the riverbed. For example, upon removing portions of an alternate bar, the cross sectional area is larger and the velocity decreases for the same points measured in the adjacent stream channel. The shear stress decreases adjacent to the excavation and localized deposition in pools is likely. Conversely, the newly exposed excavation surface is now subject to flow, with depth and velocity that can temporarily cause erosion of the new surface.

In general, shear stress increases where velocity increases for a given depth, or where depth decreases but velocity is unchanged. This relationship also reveals that bed shear stress is maximized where velocity is greatest and depth is smallest.

Applying the shear stress and the flow continuity equations, one can estimate the greatest shear stress increase directly upstream from sediment removal areas, where the friction slope increase is most pronounced. This process drives head cut phenomena and the range of associated habitat losses. It can also be shown that when the size of alternate bars is reduced, increased shear stress values may occur both upstream and downstream, usually associated with riffle habitat, while shear stress values decrease adjacent to the excavation (typically at pool habitat). Hydraulic models (NHC 2001) and laboratory experiments (Begin *et al.* 1981) verify this effect.

Excavation areas are often adjacent to pools. By applying the continuity and shear stress equations, it becomes apparent that increased deposition occurs in channel locations where cross sections are widened by excavation. Consequently, the changes in channel geometry and shear stress resulting from skimming alternate bars can cause sediment accumulation in pools and erosion from riffles, the opposite of what occurs normally, greatly simplifying fish habitat. In cases where sediment removal also alters the channel geometry adjacent to riffles, deposition on riffles and damage to sediment sensitive aquatic species and salmonid redds is the anticipated result.

The greatest reduction in shear stress can occur at the unaltered downstream hydraulic control of an extensive sediment removal project. This can cause deposition of fines in areas and at elevations where fines would not otherwise accumulate; potentially creating a point of flow constriction in the channel that requires future intervention.

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 well-constructed 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.

The interpretation of model results, or of rapid assessment using the continuity and shear stress equations, needs to consider the assumptions of the model and the schemes used for simplifying the computations. For example, a one-dimensional, cross section averaged model estimates an increase in shear stress over a riffle. In the real stream the increase is not evenly distributed across the entire riffle. Therefore it should be expected that areas of the riffle will be subject to greater shear stress than predicted.

The relationships given above are useful for estimating several of the effects of proposed channel modifications. Where questions about site specific changes in sediment transport arise due to channel modifications, it is essential that assessments include both the effects on hydraulics, at appropriate scales, and on the ability of the stream to transport sediment in the vicinity of channel modifications. The average bed shear stress equation and cross section averaged hydraulics are less capable in this regard than the location specific relationship.

4.1.3 *Reduced Sinuosity of the Mid-High Flow Channel.*

A naturally functioning channel, with mature alternate bars, has two efficiencies; lower conveyance efficiency when flows are contained within and steered around alternate bars, and 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 during high flows. Local erosion increases the delivery of sediment to downstream areas (Olson 2000), damaging habitats of sediment sensitive species.

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. Natural 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 reduces 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 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 effect 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 or less defined riffles and pools. Reduced bed complexity also results in a less stable channel, which increases the 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 riffle habitats by exacerbating sedimentation of the substrates, changing hyporheic flow patterns, causing barriers to adult migration, and reducing benthic invertebrate production. The following 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), 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 regularly 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, and upstream sources can be depleted by sediment removal. 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 incubating eggs 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. An opposite effect, increased deposition on riffles, can occur where sediment removal extends to bar areas that are adjacent to riffles.

Sediment removal can increase the supply of fine sediments that can clog the interstitial pores of coarse substrates. An armor layer of coarse particles normally covers the surface of mature alternate bars. 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 dominate the coarse sediment load in these streams. As a result of disrupting the natural armoring process and mechanical crushing from heavy equipment passage, disturbed bar surfaces are typically finer-grained than undisturbed bar surfaces.

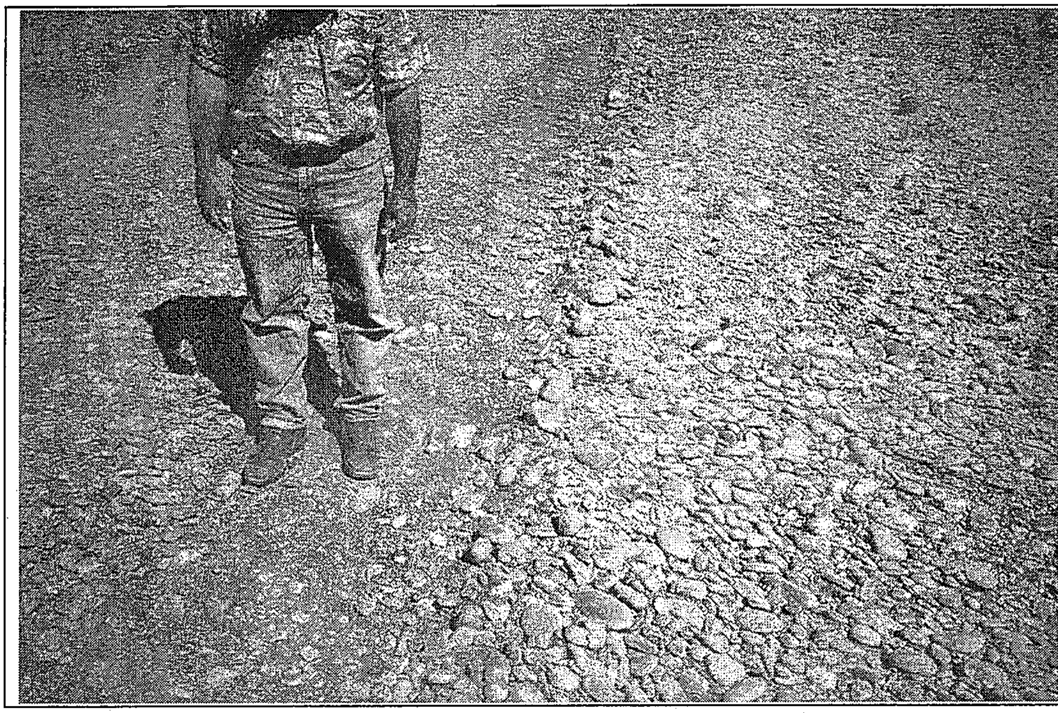


Figure 2. Photo of skimmed (left) and un-skimmed (right) bar surface showing grain-size differences. This is an example of sediment removal creating a fine-grained sediment source at a low elevation within the channel.

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.

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.

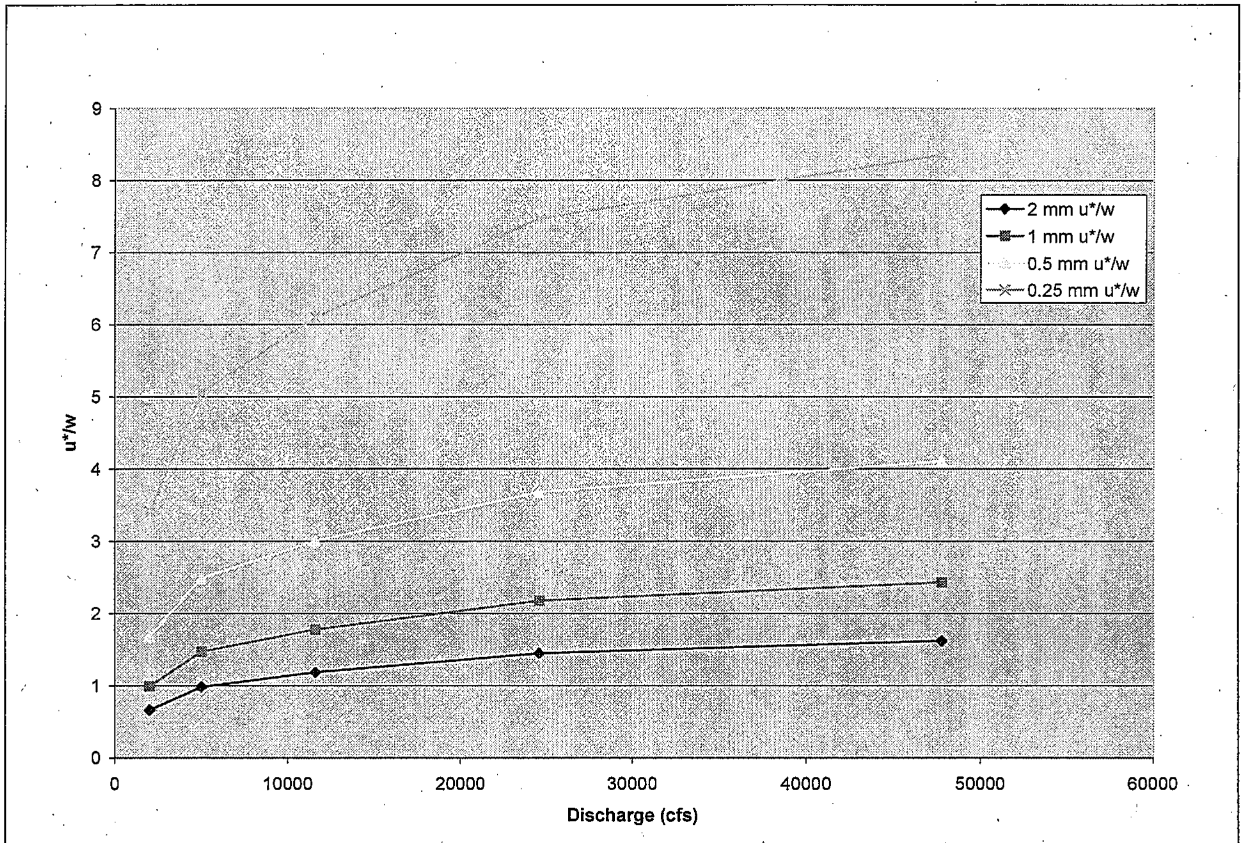
NOAA Fisheries has conducted grain transport mode analysis (e.g., Rouse 1959; Julien 1995) for a gravel removal proposal on the Russian River (figure 3). Transport mode analysis can indicate whether particular sediment sizes will be transported along the stream bed or in suspension, and therefore indicate smothering risks to incubating eggs. The results show 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. This suggested that if sand and gravel particles exposed by a proposed commercial gravel removal project are mobilized during egg incubation periods, the particles would be transported downstream in contact with the bed over a range of frequently observed discharges that occur during the early winter spawning and incubating months.

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 salmon 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.

Figure 3. Mode of sediment transport. For values u*/w less than 0.4, bedload dominates, and a transition between bedload and suspended load exists over the range 0.4<u*/w<2.5.



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.

It has been argued that aggregate mining does not appreciably increase suspended sediment concentrations above background levels already altered by a variety of causes, such as agricultural practices, timber harvest, urban development, and road construction. NHC (2003) estimated that two skimmed bars in the Russian River increased the annual suspended sediment load transported through the study reach by only .04%. However, NHC (2003) also found that aggregate mining in the Russian River increased the amount of fines in the surface layer of skimmed bars by about 33 to 39% compared to unmined surfaces. In addition, NHC reported that the additional amount of sand within one skimmed bar approximates 17% of the sand that was temporarily stored in an adjacent, 700-meter long pool. Moreover, the additional sand produced from two skimmed bars constituted about 10% of the total amount of fine sediment stored in the river reach under undisturbed no-mining conditions. Such increases contribute to the cumulative impact of suspended sediments, a problem facing many northern California coastal streams where designated beneficial uses have been identified as impaired by excessive sedimentation.

Under a program administered by the U.S. EPA and the California Regional Water Quality Control Board, contributors to this sedimentation problem will be given wasteload allocations through a Total Maximum Daily Load (TMDL) process. This program will address excessive sedimentation in rivers such as the Russian River, Mad River, and Eel River, and will require modifications in a wide range of land use activities contributing to this problem. The 2002 Federal Clean Water Act, Section 303(d) list identifies sediment resource extraction as a potential source of excessive sediment in several northern California Rivers. It is important that cumulative adverse effects of sedimentation be limited, especially given the long-range and comprehensive efforts to reduce sedimentation and restore beneficial uses of our rivers through the TMDL process.

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 boundary layer created by LWD, bank complexity, and large cobble-boulder sized particles provides low velocity habitat for fish. 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 boundary layer created by 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, and can reduce future LWD recruitment. 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, it is recommended that this depth 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 has 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.

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 some 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. As discussed in section 3.3.1 pools are essential habitat elements for salmonids 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, flood and thermal refugia 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). 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 that consolidates the substrate material and 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 . As described in section 3.3.2, riparian vegetation provides important nutrient inputs to streams and can serve as the trophic base for aquatic macro-invertebrate communities that in turn are the fundamental food source for salmonids. 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. As discussed in section 3.3.2, riparian vegetation protects stream temperatures from rising unduly by providing canopy that shades the water and reduces direct solar radiation reaching the water surface. In addition, riparian vegetation can lessen 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 it 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 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 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 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 is an important habitat for salmonid juveniles (Bradford and Higgins 2001), 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 and sediment sorting. 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.

Table 3. Summary of effects: 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.	Propogates stream degradation both upstream and downstream from removal site.	Loss or reduction in quality of pool and riffle habitats.
	Scour of upstream riffles.	Lower success of spawning redds.
	Reduced pool areas.	Loss of spawning and rearing habitat.
	Bed surface armoring.	Lower quality of spawning and rearing habitat; changes to invertebrate community.
	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 riffle and pool 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.

5 RECOMMENDATIONS for STREAMS

5.1 INTRODUCTION

Proper assessment of the effects of stream sediment removal should consider two time-scales: (1) short-term (up to 3 years), and (2) long-term (> 3 years). 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.

NMFS recommends that the effects of sediment removal 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 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. Therefore it is recommended that the deleterious effects on salmonids 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 sections, 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.

The recommendations in the following sections are not meant to be binding. Rather they are suggestions. Alternative means of compliance with statutory requirements are acceptable pending review by staff.

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). As a result, these streams 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 industrial sediment harvesting on multiple adjacent bars, and where 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. This change can be justified because frequently manipulated areas offer little of the cover, resting, or hiding attributes of undisturbed channels. In some cases, 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 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 limited information, it is prudent to proceed with caution.

Commercial sediment removal poses low risk 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 existing methods for limiting sediment removal to minimize impacts to anadromous salmonids are discussed in the following sections.

5.3.1 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, regulating extraction to a sediment budget does not provide for maintenance of geomorphic features that serve ecological functions including fish habitat.

Large sediment replenishment events are naturally cyclic and infrequent, and average sediment yield does not exist. Progressive levels of disturbance and loss of habitat result 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.

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), is widely used for 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 limited information that will probably not be improved upon soon (Church *et al.* 2001). The inherent uncertainty in the calculation, as well as poor reporting of volumes extracted, cultivates debates over the formulation and interpretation of sediment budget results. 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) rather than careful interpretation and preserving the coarse sediment supply to downstream habitat or even to downstream sediment extraction sites.

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.

5.3.2 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, with 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. However, the method is probably more effective at simply protecting a portion of bars from disturbance and maintaining some confinement of the low flow channel.

Although this procedure may limit the degradation of riffles, 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 with the head of bar management methods.

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

5.4 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 (*e.g.* Reid and Dunne 2003), 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 portions 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, it is recommended that any sediment removal with the purpose of initiating channel degradation 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 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 unpredictability or inaccuracy in the sediment budget estimate.

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. Simply extracting more sediment from incipient alternate bars may not result in improved habitat. Because the sediment load intercepted in sediment removal areas is the "source" for downstream reaches, it is recommended that proposed extraction plans 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, it is recommended that site-specific habitat, geomorphic features, and the retention of physical processes be protected. To that end, NOAA Fisheries recommends a four-step process for evaluating the effects of sediment removal proposals on anadromous salmonid populations. 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.

5.4.1 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 it is recommended that channels in approximate equilibrium be left alone.

Clearly aggraded stream channels (indicated by W/D ratio high compared to other geometry parameters, coupled with frequent overbank flooding) 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 strategic sediment excavation to increase topographic complexity, thereby creating pool habitat and improving pool maintenance processes.

Degraded and incised stream channels experience increased shear stress during a normal range of flood flows and consequently have poor salmonid habitat due to weak retention of coarse bed sediment. Restoration of incised streams can involve the excavation of large quantities of floodplain sediment to (1) create a new equilibrium channel and fill the incised channel, or (2) create inset floodplain within the existing channel. Through careful design and analysis, stream habitat can be restored or enchanced using sediment excavation strategies. This area of channel restoration and habitat enhancement deserves further research.

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 potentially provide habitat for the entire life history of anadromous salmonids. Operations within seasonally dry channels may be less risky than operations in perennial stream channels. However, it is recommended that the methods of sediment removal 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 because these changes reduce course sediment supplies or storage, reducing habitat and function.

5.4.2 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. It is recommended that sediment extraction plans 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, egg 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, it is recommended that sediment extraction operations preserve important channel features and habitats by anticipating and minimizing adverse geomorphological responses to sediment removal. The following identifies 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, it is recommended that sediment removal activities not reduce pools in size, depth, frequency, or habitat value, or contaminate coarse riffles with smaller sediment, or increase the width of riffles. Riparian vegetation should not be disturbed if it contributes to beneficial riparian functions through providing shade, overhanging cover, large woody debris (LWD), and allochthonous energy inputs. It is recommended that riparian vegetation not be disturbed where it does or may eventually contribute to shade, which moderates summer water temperatures.

b. Spawning and egg incubation habitat. Where spawning habitat is important for salmonids, it is recommended that sediment removal activities not reduce: 1) pools in size, depth, or frequency, 2) topographic complexity of the channel bed riffle-pool complex, 3) areas of spawning gravel, or 4) the hyporheic flow of nutrients to incubating eggs and fry. Furthermore, sediment removal surfaces should not increase the likelihood of sediment intruding into redds during incubation or emergence periods.

c. Adult migration habitat. Where anadromous salmonids migrate upstream, it is recommended that sediment extraction not adversely affect the migration pathway. Migrating adult salmonids should not be subjected to increased energy expenditure resulting from decreased channel bed and margin complexity, over the range of flows that the target fish species migrate. It is recommended that riparian vegetation not be disturbed where vegetation contributes to beneficial migration functions through providing shade, overhanging cover, and LWD inputs.

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) cover, 2) LWD, or 3) roughness and complexity of the channel bed and banks. Food production within the substrate is important to the juvenile life stage. It is recommended that sediment removal not reduce the availability of cobble-sized sediment particles known to support the highest production of macroinvertebrates (*i.e.,* food sources) for juvenile rearing.

5.4.3 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. It is recommended that frequently disturbed areas 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, summer rearing, winter high flow refuge, and predator avoidance functions, pool maintenance processes should be protected. This can be achieved by 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, it is recommended that disturbance of the hydraulic flow field and fluvial processes that result in spawning gravel sorting and accumulation at riffles be avoided. This can be accomplished by avoiding the 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 sedimentation intensified by sediment removal actions. This can be achieved by not contributing to the increase of fine-grained or loose surface materials at elevations that may be inundated by relatively low flows during late fall and early winter when incubating salmon eggs and alevins are within gravel substrates. 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.

5.4.4 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. It is recommended that site specific geomorphic features and habitat values 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.

It is recommended that the methods of sediment removal 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 properly functioning habitats appropriate for the stream. NMFS recommends that sediment extraction not intercept on average more than 50% of the coarse sediment load entering the reach under pre-manipulation conditions. It is recommended that the duration of removal operations be finite, ending as soon as the aggradation problem is solved and when the target habitat conditions are achieved.

Table 4. Recommended sediment extraction strategies to protect various salmonid habitat elements, stream hydrology, and retention of physical processes.

LIFESTAGE	Habitat Element Required	Related Physical Processes	Recommended Strategy for Sediment Extraction
Adult Migration and Juvenile Migration	Natural channel conditions that include roughness elements, cover, shade, resting pools, LWD.	Channel confinement and flow depth over riffles.	#1 Partial retention of bar geometry to provide minimum flow depth >2-feet over hydraulic controls (riffles). Free draining extraction surfaces. Avoid riparian vegetation. Avoid or replace LWD.
	Background levels of suspended sediment load In the water column.	Exposure of fine sediment in the mined area.	Preventing fine sediment mobilization from mined surfaces during fish migration periods.
Spawning	Stable, suitable spawning beds; riffle geometry and composition at expected size and frequency.	Sediment sorting processes that create suitable spawning beds. Premature redd scour.	#2 Partial retention of bar geometry to maintain sediment sorting processes at riffles during flows up to bankfull or effective discharge, and negligible increase in bed scour in spawning-bed locations during spawning periods.
	High water quality in the column, and in intergravel water. Background level of bed material load.	Mobilization of fine sediment from mined area. Sedimentation of spawning beds.	Preventing fine sediment and bed-material mobilization from mined surfaces during spawning periods.
Incubation and Emergence	Stable substrate. Natural rates of bed material transport. Diverse patterns of sediment sorting processes.	Premature redd scour. Deposition of sediment over redds.	#3 Partial retention of bar geometry to ensure negligible increase in bed scour, and negligible increase in sediment load or turbidity from mined areas.
	Background water quality which supplies oxygen to buried eggs and alevins.	Hyporheic flow of oxygen and nutrients to eggs.	Preventing fine sediment and bed-material mobilization from mined surfaces during incubation and emergence periods.
Rearing	Pools, food source, cover, cool, well-oxygenated water.	Optimal pool-scour processes, to connect pools with water table. Coarse and clean substrate. Riparian health.	#4 Retention of bar geometry to bankfull flow or effective flow to ensure negligible decrease in pool maintenance process, disturbance of riparian community, reduction.

5.4.5 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 can 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. Selection of the most appropriate method should be based on site characteristics.

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.

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.

5.5 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, it is recommended that sediment removal plans not substantially reduce the topographic complexity that exists in unaltered reaches of the stream. Altered reaches should not be maintained in altered dysfunctional states by continued use of harmful methods (see criteria below). It is recommended that the complexity of the stream channel be measured by cross-sections, by topographic maps, or by a digital terrain model (DTM). In general, it is recommended that 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. It is recommended that acceptable instream sediment removal methods 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 provides an example of using discharge-based design strategies for sediment removal activities to minimize geomorphic and biologic impacts.

The selection of water surface elevations associated with morphologically important discharges as criteria for designing sediment excavations can control the effects of disturbance on physical processes, and help maintain salmonid habitat for different life stages. 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.

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 requires that premature redd scour does not occur. Where rearing habitat is the desired management goal, it is necessary to protect pool maintenance processes. Pool maintenance is most effective when velocity reversal reaches its maximum at flows close to 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.

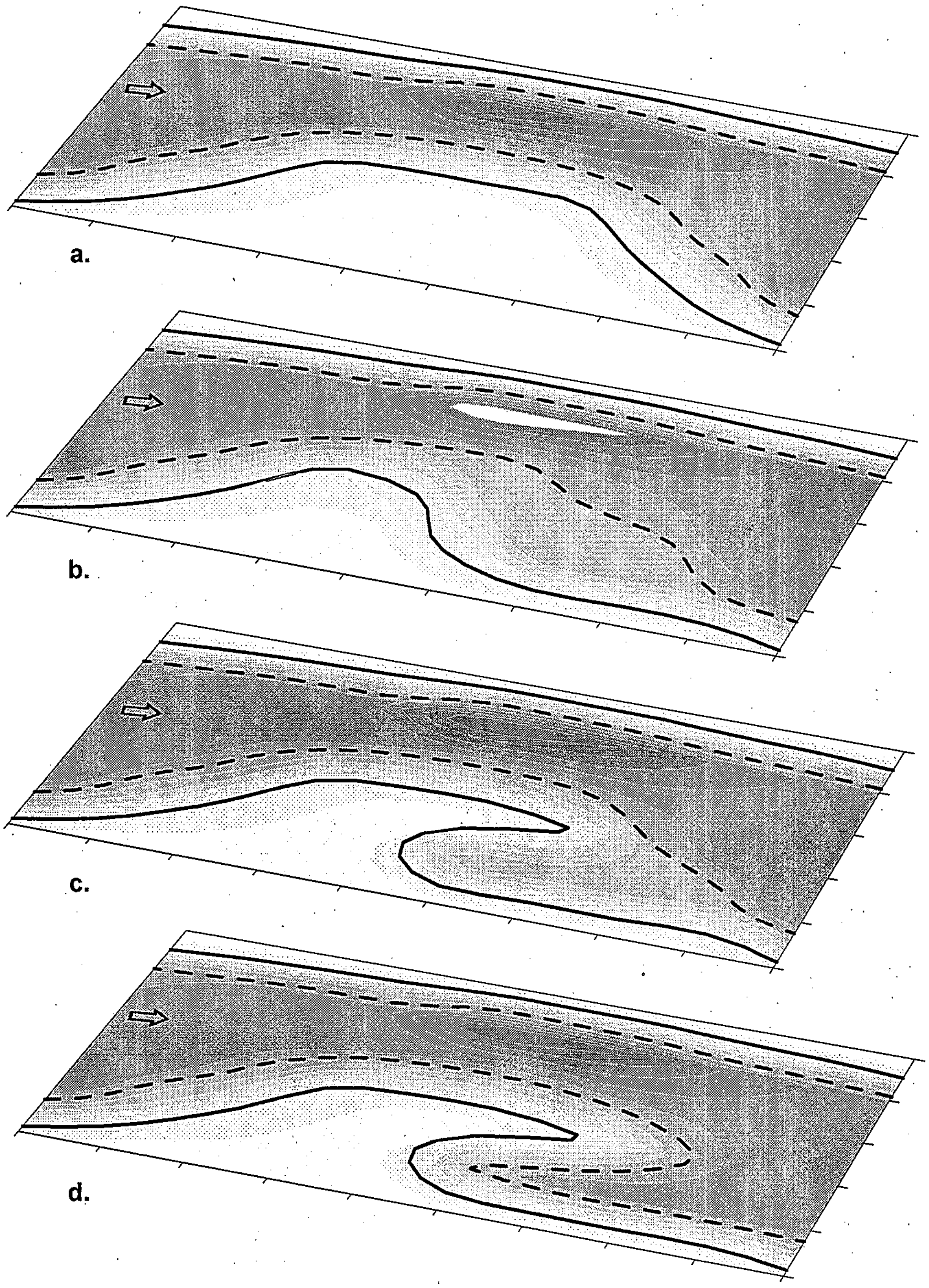


Figure 4. Topographic sketch of a typical alternate bar and pool providing salmonid habitat. The arrow indicates stream flow from left to right. The dashed line indicates the water surface elevation for a representative low flow condition, summer base flow, or migratory flow channel. The solid line represents the water surface elevation for a relatively high flow such as the effective discharge. 4a is the undisturbed condition. 4b depicts an excavation strategy that removes the downstream portion of the alternate bar. While not disturbing the low flow channel, pool filling may result. 4c illustrates an excavation strategy that retains more of the bar area enclosed by the effective discharge, adjacent to the pool, to retain pool maintenance processes. 4d is an alternative to 4c that connects the excavated alcove to the stream during low flow, providing resting habitat.

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

Salmonids often confront flood control projects while migrating to and from upstream habitat. Consequently, it is recommended that sediment management for flood control objectives 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. NMFS recommends that alternative options for flood hazard management 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. It is recommended that evaluation of proposed flood control activities follow the same process as for commercial sediment extraction (as outlined in section 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 is recommended that it 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, NMFS recommends that new flood control projects 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. It is recommended that establishing equilibrium stream channels 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 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 channel migration processes 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.

It is recommended that the size of floodplain pits 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	Recom. 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 hatiat; 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 quantiy/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

It is recommended that terraces and other upland geologic sources be mined preferentially before floodplains. Drainage from terraces and upland pits should follow applicable statues that prevent polluting surface and groundwater. It is recommended that NOAA Fisheries 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, it is recommended that the pit volume relative to the area of adjacent floodplain 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. It is recommended that all material processing 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. It is recommended that a responsible mine plan 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. It is recommended that water pumping from wet-pit mines 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. It is recommended that the maximum depth of excavation not exceed the greatest pool depth of the adjacent stream to reduce risk of stream-pit capture. NMFS recommends that pits 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.

It is recommended that the location and design of separating berms 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 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.

It is recommended that pit size 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, it is recommended that pit size and elevation 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.

It is recommended that sediment removal activities for a single project 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 it is recommended that permanent bridge crossings be established following NOAA Fisheries fish passage guidelines, and other applicable state and local bridge design and construction requirements.

7 Monitoring and Performance Criteria for Streams.

These guidelines are designed to minimize adverse effects to threatened and endangered salmonid species due to instream sediment removal projects. To accomplish this goal, it is recommended that proponents of sediment removal projects and reviewing regulatory authorities consider the potential adverse effects of such projects upon the habitats of several lifestages of fish. Proponents and regulatory authorities should then cooperatively develop sediment removal projects that avoid, or at least minimize, those impacts. As discussed in Chapters 5 and 6, this can be accomplished through alternative strategies and methods of sediment harvest; although as noted in these chapters, some methods afford a greater likelihood of protection for stream-dwelling fish.

For example, excavation down to the stage elevation of the effective discharge within the internal portions of the downstream end of gravel bars (see Figure 3d) may have minimal effects upon a river's morphology and pool maintenance processes. Whereas, a harvest strategy that only maintains the upstream one-third of a bar with excavation to a level appreciably lower than the effective discharge stage, has the potential to diminish pool maintenance processes, with resulting degradation of pool-riffle complexes. To ensure that multi-year sediment removal projects do not adversely affect fishery resources, NOAA Fisheries recommends that sediment removal projects be conditioned with environmental monitoring and performance standards commensurate with the potential impacts of the adopted sediment removal methods.

Sediment removal projects that conform to the four steps outlined in section 5.4 should not appreciably affect anadromous salmonids. Collectively, these steps protect the physical processes that create or maintain habitats for all lifestages of resident salmonid species, and they involve the choice of sediment extraction strategies that minimize disturbance of those habitats. After meeting all state and county monitoring requirements, projects that fully and clearly conform to these recommendations should need only minor follow-up monitoring to confirm habitat protection.

For projects that adopt harvest strategies that have the potential to disturb habitats or diminish physical stream maintenance processes, additional physical and biological monitoring is warranted. It is recommended that such projects include monitoring surveys to be done during each year of extraction. Project owners should anticipate that operations may need to be modified in succeeding project years, if adverse environmental effects exceed those anticipated during environmental review for the project. Performance criteria can be established that identify deviations necessitating project modifications. This could effectively build an adaptive monitoring and management strategy for the project. It is recommended that applicants be encouraged to use modern data collection methods to support evaluation of existing conditions and the monitoring of changes to landforms and habitats.

7.1 Stream Channel Monitoring Methods

Where robust cross-section monitoring programs currently exist, it is recommended that any new method fully integrate with the older system to maintain temporal 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. However, 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. In addition, most monitoring data from commercial sediment excavation has not included data from the wet portion of the channel. Given these limitations, it is important that projects, which may adversely affect stream maintenance processes, include physical monitoring of wetted areas of the channel including habitat features such as pools, runs, and riffles.

Where cross-sections continue to be used for monitoring sediment extraction, it is recommended that monitoring elements include a component 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 happens on the downstream side. Using geo-referenced cross-sections and the assumption that bars will be replenished in the same location year after year, together with rigid redline surface definitions to regulate aggregate extraction from downstream migrating bars, results in progressively enlarged 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 habitat including 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. It is recommended that geomorphic features be monitored using methods that quantify their physical dimensions and changes at appropriate time scales. Monitoring programs should use sufficient numbers of cross-sections to adequately cover the geomorphic features. It is also recommended that they use topographic mapping techniques that do not rely solely on cross-sections but rather follow terrain and habitat features. All physical monitoring of the stream channel should allow discernment of features as small as 1-foot. As with cross-sections, it is recommended that any mapping be repeatable: that is, geographically referenced to permanent datum points that respect fluvial processes.

Because sediment removal can have effects upstream and downstream from the excavation site, monitoring should extend appropriate distances depending on the scale of excavations. Where one or two bars are disturbed by small-scale excavation, it is recommended that monitoring extend upstream and downstream one pool-riffle complex. Where three or four bars are disturbed, it is recommended that monitoring extend two pool-riffle complexes upstream and downstream. In areas where pool-riffle complexes are difficult to discern, the widely recognized ratio of five to seven 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, it is recommended that cross-sections be spaced approximately ½ the distance as the channel is wide. For example, where a channel is 500 feet wide, cross-sections should be spaced at approximately 250 feet. In addition, it is recommended that sediment excavation surfaces be quantified using at least three cross-sections. Where more closely spaced cross-sections or more detailed mapping is already used for monitoring sediment removal programs, the data density should remain at the higher level.

7.2 Biological Monitoring Methods

The types of biological monitoring that may be requested should be dependent upon the affected life stages. For example, if pool maintenance processes or juvenile rearing habitat is potentially affected, then pool habitats should be monitored to ensure that existing pool cover (e.g., LWD and boulders), maximum pool depths, pool volume, and adjacent riparian vegetation are not diminished. It is recommended that potentially affected pools also be monitored if they may be used as resting areas by upstream or downstream migrating salmonids. If upstream passage of migrating adults is potentially affected by anticipated increases in W/D ratio, then cross-sectional depth profiles could be collected during early seasonal runoff events (*e.g.*, October or early November in the rivers of Sonoma and Mendocino counties). Such an exercise need not be a safety risk, but rather a demonstration that depths of 1 to 2 feet are maintained across substantial portions of the channel when salmon are expected to migrate past areas affected by the project.

For projects that may pose a potential adverse cumulative effect on spawning, egg incubation, or invertebrate production due to possible measurable increases in suspended sediment, it is recommended that suspended sediment concentrations and the percentage of fines in substrates be quantified upstream, downstream, and within the project site during early seasonal runoff events. It is recommended that monitoring of fine sediment deposition in substrates be done in a systematic, quantitative fashion to document possible lost spawning habitat. Projects that may pose a risk to invertebrate production could include a benthic invertebrate monitoring component. Other biological parameters of importance to juvenile rearing include the age, size, and density of riparian vegetation, changes in stream shading, LWD, and channel margin complexity. Each of these should be monitored as appropriate.

7.3 ADDITIONAL RECOMMENDATIONS FOR ALL SEDIMENT REMOVAL PROJECTS

Prior to any sediment removal, it is recommended that a thorough review 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).

It is recommended that sediment contaminants be analyzed and considered. 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. Therefore it is recommended that contaminated sediment disturbance be evaluated on a case-by-case basis.

Noxious and invasive plants should be removed using methods that prevent spreading. It is recommended that an invasive plant management plan 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. It is recommended that turbidity levels 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. It is recommended that those that are disturbed 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. It is recommended that sediment removal in vegetated riparian areas 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. It is recommended that sediment stockpiles, overburden and/or vegetative debris not be stored within the riparian zone. Operation and storage of heavy equipment within riparian habitat should be restricted.

8 REFERENCES CITED

Alderice, D.F., W.P. Wickett, and J.R. Brett, 1958. Some effects of temporary exposure to low dissolved oxygen levels on Pacific salmon eggs. J. Fish. Res. Bo. Canada 15(2):229-249.

Anderson, N.H. and J.R. Sedell. 1979. Detritus processing by macroinvertebrates in stream ecosystems. Annual Review of Entomology 1979, 24: 351-377.

Andrews, E.D., 1979. Scour and fill in a stream channel, East Fork River, western Wyoming. U.S. Geological Survey Professional Paper 1117, 49pp.

Andrews, E.D., and Nankervis, J.M., 1995. Effective discharge and the design of channel maintenance flows for gravel-bed rivers. *In* Natural and Anthropogenic Influence in Fluvial Geomorphology, Geophysical Monograph 89, pp. 151-164. American Geophysical Union, Washington, DC.

Baltz, D.M. and P.B. Moyle. 1993. Invasion resistance to introduced species by a native assemblage of California stream fishes. Ecological Applications 3(2):246-255.

Barnhart, R.A. 1986. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest) -- steelhead. United States Fish and Wildlife Service Biological Report 82 (11.60), 21 pages.

Bates, R.L., and Jackson, J.A., 1987. *Glossary of Geology*. American Geological Institute. Alexandria, Virginia.

Begin, Z.B., D.F. Meyer, and S.A. Schumm, 1981. Development of longitudinal profiles of alluvial channels in response to base-level lowering. Earth Surface Processes and Landforms, v.6, pp.49-68.

Behnke, A.C., 1990. A perspective on America's vanishing streams. Jour. North Am. Bentho. Soc. 9:77-88.

Benhke, A.C., and six coauthors, 1987. Bioenergetic consideration in the analysis of stream ecosytems. Proceedings of a symposium on "Community structure and function in temperate and tropical streams," April 24-28, 1987, Flathead Lake Biological Station, Univ. Montana, Polson.

Belt, C.B., 1975. The 1973 flood and man's constriction of the Mississippi River. Science 189: 681-684.

Beschta, R.L., and W.L. Jackson, 1979. The intrusion of fine sediments into a stable gravel bed. Journal of Fisheries Research Board of Canada. 36:204-210.

Beschta, R.L., and W.S. Platts, 1986. Morphological features of small streams: significance and function. Water Resources Bulletin 22, 369-379.

Beschta, R. L., R. E. Bilby, G. W. Brown, L. B. Holtby, T. D. Hofstra. 1987. Stream temperature and aquatic habitat: fisheries and forestry interactions. In E. O. Salo and T. W. Cundy, eds., Streamside Management: Forestry and Fishery Interactions, p. 191-232. University of Washington Institute of Forest Resources, Contribution No. 57.

Beschta, R.L., 1991. Stream habitat management for fish in the Northwestern United States: the role of riparian vegetation. Am. Fish. Soc. Symposium 10:53-58.

Biedenharn, D S and Thorne, C R (1994) "Magnitude-Frequency Analysis of Sediment Transport in the Lower Mississippi River" Regulated Rivers Research and Management, vol. 9, 237-251.

Biedenharn, D S, Thorne, C R, Soar, P J, Hey, R D and Watson, C C (2001) "Effective discharge calculation guide", International Journal of Sediment Research, 16(4), 445-459.

Bilby, R.E., and P.A. Bisson, 1992. Allochthonous versus autochthonous organic matter contributions to the trophic support of fish populations in clear-cut and old-growth forested streams. Can. J. Fish. Aq. Sci. 49:540-551.

Bjornn, T.C., and seven coauthors, 1974. Sediment in streams and its effects on aquatic life. Univ. Idaho, Water Resources Research Institute, Research Technical Completion Report Project B-025-IDA, Moscow.

Bjornn, R.E., and six coauthors, 1977. Transport of granitic sediment in streams and its effects on insects and fish. U.S. DOI, Office of Water Research Technology. Research Technical Completion Report Project B-036-IDA.

Bjornn, T.C. and D.W. Reiser, 1991. Habitat requirements of salmonids in streams. In: Meehan, W.R., ed. Influences of forest and rangeland management on salmonid fishes and their habitats; pp. 83-138. Amer. Fish. Soc. Spec. Pub. 19. 751 pp.

Boling, R., Jr., E. Goodman, J. Van Sickle, J.Zimmer, K.Cummins, R.Peterson. 1975. Toward a model of detritus processing in a woodland stream. Ecology 56: 141-151.

Bovee, K.D. 1982. A guide to stream habitat analysis using the instream flow incremental methodology. Instream Flow Information Paper No. 12. Cooperative Instream Flow Service Group, FWS/OBS-82/26: 248 pp.

Bradford, M.J., P.S. Higgins. 2001. Habitat-, season-, and size-specific variation in diel activity patterns of juvenile chinook salmon (*Oncorhynchus tshawytscha*) and steelhead trout (*Oncorhynchus mykiss*). Can. J. Fish. Aquat. Sci. 58:365-374.

Bretscko, G., and H. Moser, 1993. Transport and retention of matter in riparian ecotones. Hydrobiologia 251:95-101.

Brett, J.R., W.C. Clarke, and J.E. Shelbourn, 1982. Experiments on thermal requirements for growth and food conservation efficiency of juvenile chinook salmon (*Oncorhynchus tshawytscha*). Can. Tech. Report of Fishereis and Aquatic Sciences No. 1127. Dept. Fish. Oceans, Fisheries Research, Pacific Biological Station, Nanaimo, B.C.

Briggs, J.C. 1953. The behavior and reproduction of salmonid fishes in a small coastal stream. Fish Bulletin, No. 94, California Department of Fish and Game, Marine Fisheries Branch: 62 pp.

Brown, A.V., M.M. Lyttle, and K.B. Brown, 1998. Impacts of gravel mining on gravel bed streams. Trans. Am. Fish. Soc. 127:979-994.

Brown, L.R., and P.B. Moyle, 1991. Status of coho salmon in California. Report the National Marine Fisheries Service, July 1991, 114 p. Portland, Oregon.

Brunke, M., and T. Gonser, 1997. The ecological significance of exchange processes between rivers and ground water. Freshwater Biology 37:1-33.

Bugert, R.M., T.C. Bjornn. 1991. Habitat use by steelhead and coho salmon and their responses to predators and cover in laboratory streams. Transactions of the American Fisheries Society 120:486-493.

Bull, W.B., and K.M. Scott, 1974. Impact of mining gravel from urban stream beds in the southwestern United States: Geology, v.2, pp.171-174.

Bundt, K., and S. Abt, 2001. Sampling Surface and Subsurface Particle-Size Distributions in Wadable Gravel- and Cobble-bed Streams for Analysis in Sediment Transport, Hydraulics, and Streambed Monitoring. US Forest Service, General Technical Report RMRS-GTR 74.

Busby, P.J., and six coauthors, 1996. Status review of west coast steelhead from Washington, Idaho, Oregon and California. U.S. DOC, NOAA Technical Memo NMFS-NWFSC-27, Seattle, Washington.

Bustard, D.R., and D.W. Narver, 1975. Preferences of juvenile coho salmon (*Oncorhynchus kisutch*) and cutthroat trout (*Salmo clarki*) relative to simulated alteration of winter habitat. Jour. of the Fisheries Research Borad of Canada 32:681-687.

California Department of Fish and Game (CDFG), 2001. Draft Russian River Basin Fisheries Restoration Plan. Cal. Dept. Fish Game, Central Coast Region. Hopland, California.

California Regional Water Quality Control Board, 2002. A primer on stream and river protection for the regulator and program manager. Tech. Reference Circular W.D. 02 - #1.

Carillo, F.V., J.F. Davis, J.L. Burnett, 1990. California: Annual Report. US Department of Interior, Bureau of Mines. Washington, DC.

Chang, H.H., 1987. Modeling fluvial processes in streams with gravel mining. *In: Sediment Transport in Gravel-bed Rivers,* C.R. Thorne, J.C. Bathurst and R.D. Hey, *eds*. John Wiley & Sons: 977-988.

Chapman, D.W., 1988. Critical review of variables used to define effects of fine sediment in redds of large salmonids. Trans. Amer. Fish. Soc. 117, pp. 1-21.

Chapman, D.W., and T.C. Bjornn. 1969. Distribution of salmonids in streams, with special reference to food and feeding, p. 153-176. *In*: T.G. Northcote *editor*. Symposium on Salmon and Trout in Streams. H.R. Macmillan Lectures in Fisheries. Institute of Fisheries, University of British Columbia, Vancouver, BC.

Church, M.A., D.G. McLean, and F.J. Wolcott, 1987. River bed gravels: sampling and analysis. *In* C.W. Thorn, *et.al.,* editors. Sediment Transport in Gravel Bed Rivers. John Wiley and Sons, England.

Church, M., D. Ham, and H. Weatherly, 2001. Gravel management in lower Fraser River. Report to The City of Chilliwack, British Columbia; 110p.

Collins, B. and T. Dunne, 1990. Fluvial geomorphology and river-sediment mining: a guide for planners, case studies included. Calif. Depart. Conserv., Div. Mines Geol., Spec. Pub. 98. 29 pp.

Copeland, R. R., McComas, D. N., Thorne, C. R., Soar, P. J., Jonas, M. M. and Fripp, J. B. (2001) "Hydraulic Design of Stream Restoration Projects" Technical Report ERDC/CHL TR-01-28, Vicksburg, US Army Research and Development Center. 175p. Available in pdf from http://libweb.wes.army.mil/uhtbin/hyperion/CHL-TR-01-28.pdf

Cordone, A.J. and D.W. Kelley, 1961. The influences of inorganic sediment on the aquatic life of streams. Calif. Fish Game 47: 189-228.

Criss, R.E., and E.L. Shock, 2001. Flood enhancement through flood control. Geology v.29, n.10: 875-878.

Cummins K.W., R. Petersen, F. Howard, J. Wuycheck, V. Holt, 1973. The utilization of leaf litter by stream detritivores. *Ecology* 54(2): 336-345.

Cummins, K.W., 1974. Structure and function of stream ecosystems. *Bioscience* 24(11):

Dauble, D.D., and D.G. Watson, 1990. Spawning and abundance of fall chinook salon in the Hanford Reach of the Columbia River, 1948-1988. PNL-7289. Pacific Northwest Laboratory, Richland, WA.

Diplas, P., and Parker, G., 1985. Pollution of gravel spawning grounds due to fine sediment. St. Anthony Falls Hydraulic Lab. Project Report 240, University of Minnesota, Minneapolis.

Dunne, T., W.E. Dietrich, N.F. Humphrey, and D.W. Tubbs, 1981. Geologic and geomorphic implications for gravel supply. *In* Proceedings of the Conference on Salmon-Spawning Gravel: A Renewable Resource in the Pacific Northwest? Washington Water Resource Center, Pullman: 75-100.

Einstein, H.A., 1968. Deposition of suspended particles in a gravel bed. Journal of the Hydraulics Division, American Society of Civil Engineers, v. 94, pp. 1197-1205.

Einstein, H.A., and Chien, N., 1953. Can the rate of wash load be predicted from the bed-load function? Eos, Transactions of the American Geophysical Union, v. 34, n. 6, pp. 876-882.

Ellis, D.V. 1962. Preliminary studies on the visible migrations of adult salmon. J. Fish. Res. Bd. Canada 19:137-148.

Emmett, W.W., 1999. Quantification of channel-maintenance flows for gravel-bed rivers; pp. 77-84 *in* Wildland Hydrology, American Water Resources Association, TPS-99-3, 536 p.

Everest, F.H., and D.W. Chapman. 1972. Habitat selection and spatial interaction by juvenile chinook salmon and steelhead trout. J. Fish. Res. Board Can. 29:91-100.

Fausch, K.D., and T.G.Northcote, 1992. Large woody debris and salmonid habitat in a small coastal British Columbia strea. Canadian Journal of Fisheries and Aquatic Sciences 49:682-693.

Fausch, K.D. 1986. Competition among juveniles of coho salmon, brook trout, and brown trout in a laboratory stream, and implications for Great Lakes Tributaries. Trans. Am. Fish. Soc. 115:363-381.

Fausch, K.D., 1984. Profitable stream positions for salmonids: relating specific growth rate to net energy gain. Canadian Journal of Zoology, 62: 441-451.

Fields, Wayne C. 1982. Diel drift sampling in the lower Carmel River. Report to D.W. Kelley and Associates, Newcastle CA.

Fields, Wayne C., Jr. 1991. Riparian vegetation as a fish food source. Report to Aquatic Systems Research, Loomis, CA

Florsheim, J., P. Goodwin, and L. Marcus, 1998. Geomorphic effects of gravel extraction in the Russian River, California. *In* Bobrowsky, P.T., ed., *Aggregate Resources; A Global Perspective.* Balkema Publishers, Rotterdam, Netherlands: 87-99.

Follman, E.H., 1980. Interdisciplinary overview of sediment removal. In: Woodward-Clyde Consultants, ed. Sediment removal studies in arctic and subarctic floodplain in Alaska - technical report; pp. 331-384. U.S. Fish Wildl. Serv., Biological Services Program, FWS/OBS-80/08. 403 pp.

Franklin, J.F., P.M. Frenzen, and F.J. Swanson, 1995. Re-creation of ecosystems at Mount St. Helens: contrasts in artificial and natural approaches. In: Cairns, J., Jr., ed. Rehabilitating damaged ecosystems, 2nd edition; pp. 287-334. Lewis Publishers, Boca Raton, FL. 425 pp.

Gordon, N.D., T.A. McMahon, and B.L. Finlayson, 1992. Stream Hydrology: An Introduction for Ecologists. John Wiley and Sons.

Gregory, S.V., F.J. Swanson, W.A. McKee, and K.W. Cummins. 1991. An ecosystem perspective of riparian zones. BioScience, 41 (8): 540-551.

Groot, C.L., and L. Margolis, 1991. Pacific salmon life histories. Univ. British Columbia Press, Vancouver, B.C.

Hartfield, P., 1993. Headcuts and effect on freshwater mussels. *In* Conservation and management of freshwater mussels, K.S. Cummings, A.C. Buchanan, and L.M. Loch, eds.: Proceedings of the Upper Mississippi River Conservation Committee, Rock Island, Illinois: 131-141.

Hartman, G.F. 1965. The role of behavior in the ecology and interaction of underyearling coho salmon and steelhead trout. J. Fish. Res. Bd. Can. 22: 1035-1081.

Harvey, M.D., and S.A. Schumm, 1987. Response of Dry Creek, California, to land use change, gravel mining and dome closure. International Association of Hydrological Science, Publication 165 (*Erosion and Sedimentation in the Pacific Rim*): 451-460.

Hawkins, C.P., M.L. Murphy, and N.H. Anderson, 1982. Effects of canopy, substrate composition, and gradient on the structure of macroinvertebrate communities in Cascade Range streams of Oregon. Ecology 63(6):1840-1855.

Hearn, W.E., and B.E. Kynard. 1986. Behavioral interactions and habitat utilization of juvenile rainbow trout and Atlantic salmon in tributaries of the White River of Vermont. Can. J. Fish. Aquat. Sci. 43: 1988-1998.

Heggberget, T.G., 1988. Timing of spawning in Nrowegian Atlantic salmon (*Salmo salar*). Canadian Journal of Fisheries and Aquatic Sciences 45:845-849.

Hetrick, N.J., M.A. Brusven, W.R. Meehan, and T.C. Bjornn, 1998. Changes in solar input, water temperture, periphyton accumulation, and allochthonous input and storage after canopy removal along two small salmon streams in Southeast Alaska. Trans. Am. Fish. Soc. 127: 859-875/

Hinch, S.G., and five coauthors, 1996. Use of electromyogram telemetry to assess difficult passage areas for river-migrating adult sockeye salmon. Trans. Am. Fish. Soc. 125: 253-260.

Hinch, S.G., and J. Bratty, 2000. Effects of swim speed and activity pattern on success of adult sockeye salmon migration through an area of difficult passage. Trans. Am. Fish. Soc. 129: 598-606.

Hobbs, D.F., 1937. Natural reproduction of quinnat salmon, brown and rainbow trout in certain New Zealand waters. New Zealand Marine Department Fisheries Bulletin 6, Wellington.

Horan, D.L., J.L.Kershner, C.P. Hawkins, and T.A. Crowl. 2000. Effects of habitat area and complexity on Colorado River cutthroat trout density in Uinta mountain streams. Trans. Am. Fish. Soc. 129:1250-1263.

Hunter, M.A., 1992. Hydropower flow fluctuations and salmonids: a review of the biological effects, mechanical causes, and options for mitigation. State Wash. Dept. Fisheries. Technical report Number 9.

Hupp, C.R, and W.R. Ostercamp, 1996. Riparian vegetation and fluvial geomorphic processes. Geomorphology 14:277-295.

Hynes, H.B.N., 1970. The ecology of running waters. Univ. Toronto Press, Toronto.

Jobson, H.E., and W.P Carey, 1989. Interaction of fine sediment with alluvial streambeds. Water Resources Research, v. 25, n. 1, pp. 135-140.

Joyce, M.R, 1980. Effects of sediment removal on terrestrial biota. In: Woodward-Clyde Consultants, ed. Sediment removal studies in arctic and subarctic floodplain in Alaska - technical report; pp. 215-272. U.S. Fish Wildl. Serv., Biological Services Program, FWS/OBS-80/08. 403 pp.

Julien, P.Y., 1995. *Erosion and Sedimentation.* Cambridge University Press.

Julien, P.Y., 2002. *River Mechanics.* Cambridge University Press.

Kanehl, P., and J. Lyons, 1992. Impacts of in-stream sand and gravel mining on stream habitat and fish communities, including a survey of the Big Rib River, Marathon Conty, Wisconsin. Wisconsin Dept. Nat. Res., Research Report 155, Madison.

Keller, E.A., 1971. Areal sorting of bed load material: the hypothesis of velocity reversal. Bulleting of the Geological Society of America, v. 82, pp. 753-756.

Keller, E.A., and W.N. Melhorn, 1978. Rhythmic spacing and origin of pools and riffles. Bulletin of the Geological Society of America 89, 723-30.

Kern, K., 1992. Restoration of lowland rivers: the German experience. *In: Lowland Floodplain Rivers: Geomorphological Perspectives.* ed.: P.A. Carling and G.E. Petts. John Wiley & Sons: 279-297.

Knighton, D., 1984. *Fluvial Forms and Processes.* Edward Arnold/Hodder & Stoughton, London.

Kondolf, G.M., 1993. The reclamation concept in regulation of sediment mining in California. Jour. Environ. Plan. Manage. 36: 395-406.

Kondolf, G.M., 1994a. Geomorphic and environmental effects of instream sediment mining. Landscape Urban Plann. 28: 225-243.

Kondolf, G.M., 1994b. Environmental planning in regulation and management of instream sediment mining in California. Landscape Urban Plann. 29: 185-199.

Kondolf, G.M., 1995. Managing bedload sediment in regulated rivers: examples from California, USA. Geophysical Monograph 89:165-176.

Kondolf, G.M., 1997. Hungry water: effects of dams and gravel mining on river channels. Environmental Management 21, n. 4, pp. 533-551.

Kondolf, G.M., 1998. Environmental effects of aggregate extraction from river channels and floodplains. *In* Bobrowsky, P.T., ed., *Aggregate Resources: A Global Perspective,* Balkema, Rotterdam, Netherlands: 113-129.

Kondolf, G.M., 2000. Assessing salmonid spawning gravel quality. Trans. Am. Fish. Soc., 129:262-281.

Kondolf, G.M., and Curry, R.R., 1986. Channel erosion along the Carmel River, Monterey County, California. Earth Surface Processes and Landforms 11:307-319.

Kondolf, G.M., and E. Lutrick, 2001. Changes in bed elevation and sediment storage in the Mad River, 1970-1999. Prepared for Eureka Ready Mix.

Kondolf, G.M., and J.G. Williams, 1999. Flushing flows: a review of concepts relevant to Clear Creek, California. Report to U.S. Fish and Wildlife Service, Red Bluff, CA.,

Kondolf, G.M., and M.L. Swanson, 1993. Channel adjustments to reservoir construction and gravel extraction along Stony Creek, California. Environmental Geology 21: 256-269.

Koski, K.V., 1992. Restoring stream habitats affected by logging activities. In: Thayer, G.W., ed. Restoring the nation's marine environment; pp. 343-404. Maryland Sea Grant College, College Park, MD. 716 pp.

Knutti, K., 2003. Assessment of changes in channel morphology and bed elevation in the Mad River, California, 1972-2000. U.S. Army Corps of Engineers, San Francisco, CA.

Lane, E.W., 1955. The importance of fluvial morphology in hydraulic engineering. Proc. Am. Soc. Civil Engineers 81(745): 1-17.

Lee, R.M., and J.N. Rinne, 1980. Critical thermal maxima of five trout species in the Southwestern Unites States. Trans. Am. Fish. Soc. 109:632-635.

Lehre, A., R. Klein, and W. Trush, 1993. Appendix F, River Institute Consultants Report. A technical suppliment to the Draft Environmental Impact Report for the surface mining of sand and gravel on the Mad River, Humbolt County, California. Prepared for the Humbolt County Board of Supervisors, Eureka, CA.

Lenat, D.R., 1988. Water quality assessment using a qualitative collection method for benthic macroinvertebrates. Jor. Am. Benth. Soc. 7:222-233.

Leopold, L.B., 1994. A View of the River. Harvard University Press, Cambridge, MS, London.

Leopold, L.B., and W.W. Emmett, 1976. Bedload measurements, East Fork River, Wyoming. Am. Phil. Soc. 123; 168-202.

Leopold, L.B., M.G. Wolman, and J.P. Miller, 1964. Fluvial Processes in Geomorphology. San Francisco: W.H. Freeman.

Ligon, F., et al., 2001 Stillwater Sciences. Berkeley, CA.

Lisle, T.E., 1979. A sorting mechanism for a riffle-pool sequence. Bulletin of the Geological Society of America, v.90, part 2, pp.1142-57.

Lisle, T.E., 1982. Effects of aggradation and degradation on riffle-pool morphology in natural gravel channels, Northwestern California. Water Resources Research, V. 18, n. 6, pp. 1643-1651.

Lisle, T.E., 1986. Stabilization of a gravel channel by large streamside obstructions and bedrock bends, Jacoby Creek, northwestern California. Geological Society of America Bulletin 97, 999-1011.

Lisle, T.E., 1989. Sediment transport and resulting deposition in spawning gravels, north coastal California. Water Resources Research, v. 25, n. 6, pp. 1303-1319.

Lisle, T.E., and S. Hilton 1991. Fine sediment in pools; and index of how sediment is affecting a stream channel. FHR Currents 6;1-7.

Lisle, T.E., Iseya, F., and Ikeda, H., 1993. Response of a channel with alternate bars to a decrease in supply of mixed-sized bed load: a flume experiment. Water Resources Research 29: 3623-3629.

Little, W C, Thorne, C R & Murphey, J B (1981) "Mass Bank Failure Analysis of Selected Yazoo Basin Streams", Transactions of the American Society of Agricultural Engineers, Vol 25, No 5, 1321-1328.

Mathews, K.R., N.H. Berg, D.L. Azuma, and T.R. Lambert, 1994. Cool water formation and trout habitat use in a deep pool in the Sierra Nevada, California. Trans. Am. Fish. Soc. 123:549-564.

McDowell-Boyer, L.M., J.M. Hunt, and N. Sitar, 1986. Particle transport through porous media. Water Resources Research, v. 22, n. 13, pp. 1901-1922.

McMahon, T.E. 1983. Habitat suitability index models: coho salmon. U.S. Dept. Int., Fish Wildl. Serv. FWS/OBS-82/10.49. 29 pp.

Meehan, W.R., 1996. Influence of riparian canopy on macroinvertebrate composition and food habits of juvenile salmonids in several Oregon streams. U.S. Dept. Ag., Forest Service, Pacific Northwest Research Station, Research Paper NNW-RP-496. Portland, Oregon.

Meehan, W.R., and T.C. Bjornn, 1991. Habitat requirments of salmonids in streams. Am. Fish. Soc. Special Publication 19:83-139.

Meehan, W.R., 1991. Influences of forest and rangland management on salmonid fishes and their habitats. American Fisheries Society special publication 19. Bethesda, MD.

Moreau, D.A., and J.R. Moring, 1993. Refinement and testing of the habitat suitability index model for Atlantic Salmon. U.S. Fish and Wildlife Service, Maine Cooperative Research Unit, Orono, ME. 50 pp.

Moulton, L.L., 1980. Effects of sediment removal on aquatic biota. In: Woodward-Clyde Consultants, ed. Sediment removal studies in arctic and subarctic floodplain in Alaska - technical report; pp. 141-214. U.S. Fish Wild. Serv., Biological Services Program, FWS/OBS-80/08. 403 pp.

Murphy, M.L., 1995. Forestry impacts on freshwater habitat of anadromous salmonids in the Pacific Northwest and Alaska -- requirements for protection and restoration. NOAA Coastal Ocean Program, Decision Analysis Series No. 7. 156 pp.

Naiman, R.J., T.J. Beechie, L.E. Benda, D.R. Berg, P.A. Bisson, L.H. MacDonald, M.D. O'Connor, P.L. Olson, and E.A. Steel, 1992. Fundamental elements of ecologically healthy watersheds in the Pacific Northwest coastal ecoregion. In. Naiman, R.J., ed. Watershed management; pp. 127-188. Springer-Verlag, New York. 542 pp.

Nash, D.B., 1994. Effective sediment-transporting dishcarge from magnitude-frequency analysis. Journal of Geology, v. 102, pp. 79-95.

Newcombe, C. P., 2001. Impact assessment model for clear water fishes exposed to conditions of reduced visual clarity. Proc. Seventh Fed. Interagency Sed. Conf., March 25-29,2001; II-116-123. Reno, Neveda.

Newcombe, C. P., and J. O. T. Jensen. 1996. Channel suspended sediment and fisheries: a synthesis for quantitative assessment of risk and impact. North American Journal of Fisheries Management 16(4):693-726.

Newport, B.D., and J.E. Moyer, 1974. State-of-the-art: sand and gravel industry. U.S. Environmental Protection Agency, EPA-660/2-74-066, Washington, D.C.

Nielsen, J. T.E. Lisle, and V. Ozaki. 1994. Thermally stratified pools and their use by steelhead in northern California streams. Trans. Am. Fish. Soc. 123:613-626

NHC (Northwest Hydraulic Consultants Inc), 2001. Alexander valley reach of the Russian River: overview of regional geology, sediment production, and historical geomorphology. Report to Shamrock Materials, Inc. NHC, West Sacramento, California.

Olson, S.A., 2000. Simulation of the Effects of Streambed-Management Practices on Flood Levels in Vermont. USGS Fact Sheet 064-00, 8 p.

OWRRI-Oregon Water Resources Research Institute, 1995. Sediment disturbance impacts on salmon habitat and stream health. A report for the Oregon Division of State Lands. Vol 1: Summary Report. 52 pp. Vol 2: Technical background report. 225 pp.

Pauley, G.B., G.L. Thomas, D.A. Marino, and D.C. Weigand, 1989. Evaluation of the effects of sediment bar scalping on juvenile salmonids in the Puyallup River drainage. Final Report to the Washington Department of Fisheries, Service Contract No. 1620. Coop. Fish. Res. Unit, Univ. Wash., Seattle, WA. 150 pp.

Pearsons, T.N., H.W. Li, and G.A. Lamberti, 1992. Influence of habitat complexity on resistance to flooding and resilience of stream fish assemblages. Transactions of the American Fisheries Society 121: 427-436.

Petersen, R.C., L.B.M. Petersen, and J. Lacoursiere, 1992. A building flock model for stream restoration. *In: River Conservation and Management, ed.:* P.J. Boon, P. Calow, and G.E. Petts. John Wiley & Sons: 293-309.

Petts, G.E., A.R.G. Large, M.T. Greenwood, and M.A. Bickerton, 1992. Floodplain assessment for restoration and conservation: Linking hydrogeomorphology and ecology. *In: Lowland Floodplain Rivers: Geomorphological Perspectives, ed.:* P.A. Carling and G.E. Petts. John Wiley & Sons: 217-234.

Phillip Williams and Associates (PWA), 1993. Geomorphic and Hydrologic Conditions in the Russian River, CA; Historic Trends and Existing Conditons. (authors; Florsheim and Goodwin 1993)

Platts, W.S., and R.L. Nelson, 1985. Stream habitat and fisheries response to livestock grazing and instream improvement structures, Big Creek, Utah. Journal of Soil and Water Conservation, 40, 374-379.

Raleigh, R.F., T. Hickman, R.C. Solomon, and P.C. Nelson. 1984. Habitat suitability information: rainbow trout. U.S. Fish Wildl. Serv. FWS/OBS-82/10.60

Reid, G.K. 1961. Ecology of inland waters and estuaries. Van Nostrand Reinhold Co. New York, NY. 375 pp.

Reid, L.M., and T. Dunne, 2003. Sediment budgets as an organizing framework in fluvial geomorphology. *In: Tools in Fluvial Geomorphology, eds.,* Kondolf, G.M, and H. Piegay, John Wiley and Sons: 463-500.

Rich, A.A., 1987. Water temperatures which optimize growth and survival of the andromous fishery resources of the lower American River. Unpublished report prepared for McDonough, Holland and Allen. Sacramento, California.

Rivier, B. and J. Seguier, 1985. Physical and biological effects of sediment removal in river beds. In: Alabaster, J.S., ed. Habitat modification and freshwater fisheries; pp. 131-146. Butterworths, London.

Roell, M.J., 1999. Sand and gravel mining in Missouri stream systems: aquatic resource effects and management alternatives. Missouri Department of Conservation. Columbia, Missiouri.

Rouse, H., 1959. *Advanced Mechanics of Fluids.* New York: Wiley.

Rundquist, L.A., 1980. Effects of sediment removal on river hydrology and hydraulics. In: Woodward-Clyde Consultants, ed. Sediment removal studies in arctic and subarctic floodplain in Alaska - technical report; pp. 67-140. U.S. Fish Wildl. Serv., Biological Services Program, FWS/OBS-80/08. 403 pp.

Sandecki, M., 1989. Aggregate mining in river systems. Calif. Geol. 42: 88-94.

Schmetterling, D.A., C.G. Clancy, and T.M. Brandt, 2001. Effects of riprap bank reinforcement on stream salmonids in the Western United States. Fisheries, 26, 7: 6-13.

Schmidt, L. J., and J.P. Potyondy. 2001. Flow regimes needed to maintain channels in gravel-bed rivers. Proceedings of the Seventh Federal Interagency Sedimentation Conference, March 25-29, 2001, Reno, Nevada. 1:(66-69).

Schumm, S.A., 1977. *The Fluvial System.* New York: Wiley-Interscience.

Scott, K.M., 1973. Scour and fill in Tujunga Wash – a fanhead valley in urban southern California-1969: U.S. Geological Survey Professional Paper 732-B, 29p.

Scrivener, J.C., and B.C. Andersen, 1982. Logging impacts and some mechanisms which determine the size of spring and summer populations of coho salmon fry in Carnation Creek, pp257-272. *In* G.F. Hartman (*ed.*) Proc. Carnation Creek Workshop, Pacific Biological Station, Nanaimo, B.C.

Shirvell, C.S., 1990. Role of instream rootwads as juvenile coho salmon (*Onchorhynchus kisutch*) and steelhead trout (*O. Mykiss*) cover habitat under varying streamflows. Can. Jour. Fish. Aqua. Sci. 47:852-860.

Sigler, J.W., 1988, and 1990. Effects of chronic turbidity on anadromous salmonids: Recent studies and assessment techniques perspective. *In* Effects of dredging on anadromous pacific coast fishes. Workshop proceedings, Seattle, September 8-9, 1988, published 1990, Washington Sea Grant Program. Washington Univ., Seattle:26-37.

Sigler, J.W., T.C. Bjornn, and F.H. Everest, 1984. Effects of chronic turbidity on density and growth of steelheads and coho salmon. Trans. Am. Fish. Soc. 113:142-150.

Simon, A., and C.R. Hupp, 1992. Geomorphic and vegetative recovery processes along modified stream channels of West Tennessee. U.S. Geological Survey Open-File Report 91-502.

Simons, D.B., E.V. Richardson, and Haushild, W.L., 1963. Some effects of fine sediment on flow phenomena. U.S. Geological Survey Water Supply Paper, 1498-G.

Simons, Li & Associates, Inc., 1983. Hydraulic, erosion, and sedimentation study of the Santa Clara River, Ventura County, California: report to Ventura County Flood Control District, Ventura, CA.

Simpson, C.J. and D.G. Smith. 2001. The braided Milk River, northern Montana, fails the Leopold-Wolman discharge - gradient test . Geomorphology, 41(2001):337-353.

Smith, J.J. and H.W. Li. 1983. Energetic factors influencing foraging tactics of juvenile steelhead trout. *In* Noakes et al. (eds.) *Predators and Prey in Fishes.* ISBN 90 6193 Smith 922 8, 1983, Dr. W. Junk Publishers. The Hague, Netherlands.

Snyder, G.R., 1959. Evaluation of cutthroat trout reproduction in Trappers Lake inlet. Quart. Rept. Colo. Fish. Res. Un. 5: 12-52.

Soar, P. J. and Thorne, C. R. (2001) *Channel Restoration Design for Meandering Rivers*, Final Report ERDC/CHL CR-01-1, Vicksburg, US Army Research and Development Center, 416p plus appendices. Available electronically in pdf format from http://libweb.wes.army.mil/uhtbin/hyperion/CHL-CR-01-1.pdf

Sonoma County, 1994. Aggregate resources management plan and environmental impact report. Sonoma County, Santa Rosa, CA.

Sonoma County, 2001. Sonoma County aggregate resources management plan 1997 and 1998 (revised) annual monitoring program results, Russian River, Sonoma County, CA.

Spence, B.C., G.A. Lomnicky, R.M. Hughes, R.P. Novitzki, 1996. An ecosystem approach to salmonid conservation. TR-4501-96-6057. ManTech Environmental Research Services Corp., Corvallis, OR.

Stanford, J.A., and J.V.Ward, 1988. The hyporheic habitat of river of river ecosystems. Nature 335:64-66.

Stanford, J.A., and six others, 1996. A general protocol for restoration of regulated rivers. Regulated Rivers: Research and Management 12:391-413.

Tappel, P.D., and Bjornn, T.C., 1983. A new method of relating size of spawning gravel to salmonid embryo survival. N. Am. J. Fish. Man. 3:123-135.

Tepordei, V.V., 1992. Construction sand and gravel: annual report. US Department of Interior, Bureau of Mines. Washington, DC.

Thibodeaux, L.J., and Boyle, J.D., 1987. Bedform-generated convective transport in bottom sediment. Nature, v. 325, n. 6102, pp. 341-343.

Thompson, K. 1972. Determining stream flows for fish life. Proc., Instream Flow Requirement Workshop; *Pac. NW River Basin Commission.* Vancouver, Washington.

Thorne, C R (1999) "Bank Processes and Channel Evolution in the Incised Rivers of North-Central Mississippi", in, Darby, S E and Simon, A (eds.), Incised River Channels, J Wiley, Chichester, UK, ISBN 0-471-98446-9, 97-122.

Thorne, C.R., Russell, A.P.G. and Alam, M.K. (1993) "Planform Pattern and Channel Evolution of the Brahmaputra River, Bangladesh" in, Braided Rivers, J L Best and C S Bristow (eds), Geological Society of London Special Publication No. 75, ISBN 0-903317-93-1, 257-276.

Trush, W.J., McBain, S.M., and Leopold, L.B., 2000. Attributes of an alluvial river and their relation to water policy and management. Proceedings of the National Academy of Sciences, v. 97, n. 22, pp. 11858-11863.

Vannote *et al.* 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Science 37: 130-137.

Waters, T.F., 1972. The drift of stream insects. Annual Review of Entomology 17:253-272.

Waters, T.F., 1995. Sediment in streams: sources, biological effects, and control. Am. Fish. Soc. Monograph 7.

Weigand, D.C., 1991. Effects of sediment scalping on juvenile salmonid habitat. M.S. Thesis, Univ. Washington, Seattle WA.

Wesche, T.A. 1974. Evaluation of trout cover in smaller streams. Paper presented to American Fisheries Society Western Division meetings, Albuquerque, New Mexico.

Wickett, W.P., 1954. The oxygen supply to salmon eggs in spawning beds. Journal of the Fisheries Research Board of Canada, v. 11, pp. 933-953.

Wolman, M.G., and Miller, J.P., 1960. Magnitude and frequency of forces in geomorphic processes. Journal of Geology, v. 68, pp. 54-74.

Woodward-Clyde Consultants, Inc., 1980. Gravel removal guidelines manual for Arctic and Subarctic floodplains: report to U.S. Fish and Wildlife Service, contract FWS-14-16-0008-970, WWS/OBS-80/09, 169 p.

Yang, C.T., 1996. Sediment transport theory and practice. McGraw-Hill, New York.

9 APPENDIX 1 – SUMMARIES OF RELEVANT STATUTES

The following summaries of the major Federal statutes mentioned in these 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

[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. NOAA Fisheries (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 where salmonid spawning habitat exists. 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.

Applicant 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 development 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.

Applicant 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.

Applicant shall measure the grain size distribution of sediment exposed on all disturbed surfaces using sieving and volumetric methods. Applicant shall measure the area and depth, and estimate the volume of exposed fine material. In addition, applicant 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 section 10.1.6 below).

10.1.4 Pools.

Applicant 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.

Applicant 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.

Applicant 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 $\mathbf{d_{84}}$ or $\mathbf{d_{16}}$ 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 applicant 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. Applicant 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 NOAA Fisheries no later than 30 days prior to the start of mining activity each year. Mining plans will be subject to the NOAA Fisheries approval prior to the beginning of operations.

c. Applicant 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 (____), applicant shall submit monitoring plans to NOAA Fisheries for approval prior to initiation of monitoring. Monitoring plans are to be received by no later than January 1 of that year (*i.e.*, the first monitoring plan will be due 1 January, ____).

e. Those applicant 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..

ATTACHMENT M

Attach 11m 11

NORTH CAROLINA CHAPTER OF THE AMERICAN FISHERIES SOCIETY

POSITION PAPER ON
INSTREAM SAND AND GRAVEL MINING ACTIVITIES IN NORTH CAROLINA

6 FEBRUARY 2002

A. Issue Definition

The two major forms of sand and gravel mining are instream dredging of a streambed and land surface mining, which includes floodplain excavations. Instream mining operations remove accumulated sand and gravel directly from stream channels in increasingly larger quantities in the U.S. (EPA 1995), primarily for construction and industrial uses. Instream mining is prohibited in the United Kingdom, Germany, France, the Netherlands, and Switzerland and is restricted in select rivers in Italy, Portugal, and New Zealand (Kondolf 1997). In addition, instream mining is not allowed in Saskatchewan or most of Canada (Starnes and Gasper 1996). Sand and gravel are mined commercially in every state in the U.S.; however, due to numerous research studies that have demonstrated long lasting environmental effects from instream mining, many states have imposed strict regulations on instream mining, and some no longer allow it (Roell 1999). Some of the more detrimental effects of instream mining include channel degradation and erosion, headcutting, increased turbidity, stream bank erosion, and sedimentation of riffle areas. All of these changes can adversely affect fish and other aquatic organisms, either directly by damage to the organisms or through habitat degradation, or indirectly through disruption of the food web. Further, effects on stream geomorphology (e.g., channel incision) can result in infrastructure damage such as undermining bridge piers and exposure of buried pipeline crossings and water supply intakes (Kondolf 1997). Each mining operation not only exerts an individual effect on the stream, but effects of multiple mining operations within a river system may be cumulative. Therefore, individual extraction operations should be evaluated in the context of their spatial and temporal cumulative impacts.

B. Background

Sand and gravel are used to produce concrete, asphalt, and bricks, which are essential building materials for residential, commercial, and industrial buildings, and in most public work projects such as roads and bridges. Even though sand and gravel mining is a common practice, the industry may be the least regulated of any form of mining (Starnes and Gasper 1996). Demand for sand and gravel for construction continues to increase in the U.S. Construction sand and gravel output increased 5.4% in 2000 and was projected to increase by an additional 2.6% in 2001, and domestic sales of industrial sand and gravel increased 2% in 2000 (USGS 2001). Approximately 10-20% of the sand and gravel mined in the U.S. in 1974 was dredged from streams (Newport and Moyer 1974). North Carolina was ranked seventh in total production (method of removal not specified) of industrial sand and gravel in 1998, producing 10,900,000 metric tons valued at $58,000,000 (USGS 1999). In 1999, the total number of permitted mines in North Carolina was 854. Six-hundred-and-two (70%) of the permits were for mining sand and gravel, and 53 (8.8% of the 70%) were instream mines. There were another nine new permits issued for instream mines in 2000 (totaling 62 permitted instream mines), and six additional permits have been applied for as of July 2001. Nine permitted instream mining operations are in the Mountain region and 53 are located in the Piedmont. Mining permits are typically effective for 10 years, at which time the applicant has the option to apply for a renewal permit. Mining operations that affect less than 1 acre of upland area (instream area is not taken into account) are not regulated; therefore, the number of actual instream mining operations is underestimated.

Draglines and hydraulic dredges are the two main types of equipment permitted to mine sand and gravel from North Carolina streams. Mining operations typically remove sand and gravel from a section of river extending to 2,500 linear feet. Processing usually includes grading and screening the sand and gravel in wash water and stockpiling the aggregate along the riverbank for subsequent transport. Wash water is discharged into settling pits before being released back into the river. After removal of alluvial materials, the river bottom may be as much as 8 feet deeper than adjacent upstream and downstream areas. Many of the streams with permitted mines contain federal or state endangered, threatened, special concern, significantly rare, or other sensitive aquatic species.

C. Impacts on Aquatic and Riparian Environments

Stream Geomorphology
Removal of alluvial materials by instream sand and gravel mining disrupts the balance between sediment supply and transport capacity, typically inducing incision upstream and downstream of the extraction site (Kondolf 1997). The alteration of geomorphic structure may occur due to increased velocity and decreased sediment load associated with mined areas. Excavation in the active channel lowers the streambed, creating a nick point that steepens channel slope and increases velocity (Kondolf 1997). The nick point migrates upstream due to increased water speed, i.e., headcutting. The deposition of sediments at the mine site creates a sediment-deficient flow leaving the site, this in turn results in the water picking up more sediment from the stream reach below the mine site; ultimately resulting in bed degradation downstream. Both processes can move long distances (as much as 7 river miles) and headcutting can additionally move into tributaries (Kondolf 1997). Channel incision can also cause lateral instability by increasing stream bank heights, resulting in bank failure and additional transport of sediments downstream.

Aquatic and Riparian Habitat
Effects directly related to extraction and to changes in geomorphology include increased sedimentation, turbidity, and bankfull widths (Rosgen 1996), higher stream temperatures, reduced dissolved oxygen, lowered water table, decreased wetted periods in riparian wetlands, and degraded riparian habitat (see reviews by Nelson 1993; NMFS 1996; Meador and Layher 1998; Bork 1999; Roell 1999; and original research by Kanehl and Lyons 1992; Brown et al. 1998; and references therein). Channel geomorphology changes, such as a wider and shallower streambed (Kanehl and Lyons 1992; Brown et al. 1998) may consequently result in increased stream temperature (Kondolf 1997). Although studies have shown differing results, chemical changes such as reduced dissolved oxygen and changes in pH levels have been reported downstream of instream mining areas (Nelson 1993; Meador and Layher 1998). Loss of riparian habitat may result from direct removal of vegetation along the stream bank to facilitate the use of a dragline or through the process of lowering the water table, bank undercutting, and channel incision (Kondolf 1997; Brown et al. 1998). The physical composition and stability of substrates are altered as a result of instream mining, and most of these physical effects may exacerbate sediment entrainment in the channel. Furthermore, the process of instream mining and gravel washing produces fine sediments under all flow conditions, resulting in a deposition of fine sediment in riffles as well as other habitats at low discharge (Nelson 1993). Excess sediment is considered the greatest pollutant in U.S. waters and constitutes one of the major environmental factors in the degradation of stream fisheries (Waters 1995). Much of the excess sediment is a result of poor watershed and riparian land use. However, instream mining may contribute additional sediment to downstream reaches due to the disruption of substrate stability. Once sediment enters the stream, it is best to let natural geomorphological and hydrological processes reach a dynamic equilibrium, rather than further exacerbating the situation by additional disturbance.

Aquatic Organisms
The distribution of stream biota is strongly related to physical habitat (Brown et al. 1998); therefore, fundamental changes in the total biotic community are to be expected when the physical structure of the stream is altered. Suspended sediments can limit primary production by reducing light penetration (Nelson 1993; Waters 1995), which, in turn, will affect the aquatic food chain and limit production at higher trophic levels. Both fish and aquatic invertebrate abundance may be significantly diminished by direct damage, removal of the substrate, degradation of habitat, riparian habitat removal, reduction in spawning success, reduction in food availability, and clogging and damage of gills (see reviews by Nelson 1993; NMFS 1996;

Meador and Layher 1998; Bork 1999; Roell 1999; and original research by Kanehl and Lyons 1992; Brown et al. 1998; Lake and Hinch 1999; and references therein). Brown et al. (1998) found significant reductions in invertebrate densities and biomass and significantly lower biomass of most fishes as a result of instream gravel mining in Ozark streams. In addition, Hartfield (1993) found severe effects on the mussel fauna in Mississippi streams due to headcutting that resulted from instream mining. Increases in suspended sediment can disrupt respiration and modify behavior in aquatic invertebrates and fishes, reduce fish tolerance to disease and toxicants, increase physiological stress in fish, and smother fish eggs (Waters 1995).

In addition to the effects of mining activities at the site of extraction, physical and biotic effects can extend far upstream and downstream (Brown et al. 1998). All of these adverse impacts can result in shifts in species composition, decrease in species diversity and abundance, and a loss of sensitive species and ecosystem integrity. The effects of sand and gravel extraction on stream ecosystem recovery time can be extensive. Kanehl and Lyons (1992) found conditions in some stream reaches in Wisconsin to remain in early stages of recovery 20 years after mining had stopped, and other reaches were in worse condition after 10 years. Further, total restoration of severely affected streams has been considered to be improbable (Brown et al. 1998).

D. Needed Actions

Minimization or mitigation of the effects of instream mining is problematic, if not unlikely, because physical structure is the very foundation upon which stream communities are assembled (Brown et al. 1998). Gravel replenishment has been used as a technique to mitigate the reduction of sediment load below dams (Kondolf 1997), but has not been considered to be a viable option for instream mining sites because of the difficulty in distributing the aggregate naturally and completely throughout the basin prior to the next high water event (Brown et al. 1998). Even when results have been successful below dams, effects are short termed and require continual replenishment efforts (Kondolf 1997). In addition, strategies to minimize impacts are often not effective. The State of California permits extraction of a specified depth below the channel bed or only down to the thalweg. However, a limit in actual elevation was not stated, and therefore, the extraction limits have migrated vertically downward as the channel incises (Kondolf 1997). Another approach that has been examined is to estimate the annual bedload to determine the "safe sustainable yield". However, there are complications with this approach as well, due to the variability in bedload transport from year to year. Alternatively, if extraction rates were instead based on the amount of new deposition per year, the channel may remain negatively affected because mining at the replenishment rate is expected to produce sediment-deficient flow conditions downstream, since the upstream area is the sediment source for downstream reaches (Kondolf 1997).

Implementation of rock gabions may halt headcutting (Kanehl and Lyons 1992), however this and other types of "hard" engineering can impede fish movement (Waters 1995) and ultimately do more harm than good. Measures such as installing rock vanes and rootwads and revegetating stream banks may be used to enhance habitat and stabilize stream banks once mining has completely ceased, and may provide a level of restoration. However, even with mitigative practices, instream excavation causes extreme damage (Waters 1995).

Recommended Guidelines
In circumstances that may warrant instream mining for construction or industrial purposes on a case-by-case basis, we offer the following recommendations.

?? Waters containing state or federally endangered, threatened, special concern, or significantly rare aquatic species, or waters designated by the North Carolina Division of Water Quality (NCDWQ) as

Outstanding Resource Waters, Trout Waters, High Quality Waters, Swamp Waters, or Nutrient Sensitive Waters, or North Carolina Wildlife Resources Commission designated spawning and primary nursery areas or anadromous fish waters should be avoided.

?? Examine alternatives to instream mining and demonstrate that it is the only practicable means of obtaining the materials.

?? An integrated environmental assessment, management, and monitoring program should be part of any instream gravel or sand extraction operation. Individual extraction operations should be evaluated from a perspective that includes their potential secondary and cumulative impacts.

?? Prior to sand and gravel removal, a thorough review should be undertaken of potentially toxic sediment contaminants where extraction operations are proposed or where bed sediments may be disturbed (upstream and downstream) by the operation.

?? Evaluate physical, chemical, and biological effects of instream mining on a river basin scale, so that the cumulative effects of extraction on the aquatic and riparian resources can be recognized.

?? Develop a sediment budget based on present and historical conditions. Evaluate limiting instream mining to 50% of the replenishment rate as a safe yield to minimize effects (Kondolf 1997).

?? Establish long-term monitoring programs funded by permitting fees. Monitoring should include extraction rates, volume of aggregate removal, and measures of stream morphology, riparian vegetation, bottom composition, bank erosion, and downstream turbidity rates.

?? Reduce the period of time that a permit is valid to 3 years.

?? Implement a time of year restriction on in-water activities and processing activities (that involve a discharge of wash water) during the generalized fish spawning season (for warmwater streams—15 March through 30 July, for streams supporting anadromous fishes—15 February through 30 June, and for trout streams 15 October through 15 April).

?? Evaluate minimization and control measures such as bank stabilization, revegetation of buffer strips, influences of connected floodplain pits, devices to control headcutting, and wash water recycling. Restoration efforts should concentrate on techniques that will optimize fish production, promote aquatic diversity, and restore biotic integrity.

?? We encourage the development of legislation that minimizes the environmental impacts from instream mining. It is incongruous that any private citizen, commercial entity, or government agency is required to implement well-established and necessary measures (best management practices) to reduce turbidity, erosion, and siltation in land disturbing activities; but, commercial instream mining has minimal restrictions on instream turbidity, downstream siltation, or habitat degradation impacts. [Mining operations are required to obtain a National Pollutant Discharge Elimination System (NPDES) wastewater discharge permit for discharges from settling ponds.]

E. Position

Due to the numerous credible studies demonstrating environmental degradation that results from instream mining, it is quite probable that the existing operations in North Carolina streams and rivers have adversely affected fisheries and aquatic communities in those systems, and particularly those species that are already rare or endangered, due to the elimination of suitable habitats and reduction in quantity and quality of food resources.

It is therefore the position of the North Carolina Chapter of the American Fisheries Society:

1. that the continued degradation of North Carolina streams due to instream mining and the cumulative impacts of the many mining operations and other stressors on these systems is likely impacting the state's aquatic resources.

2. to support state and federal regulations to prohibit commercial instream sand and gravel mining in North Carolina streams containing state or federally endangered, threatened, special concern, or significantly rare species or waters designated by the North Carolina Division of Water Quality as Outstanding Resource Waters, Trout Waters, High Quality Waters, Swamp Waters, or Nutrient Sensitive Waters, or North Carolina Wildlife Resources Commission designated spawning and primary nursery areas or anadromous fish waters. If these conditions do not exist, we recommend that the guidelines listed above for instream mining operations are followed.

3. to encourage energy conservation and resource recycling (i.e. recycling concrete rubble to produce aggregate) to minimize the need for sand and gravel mining, with the ultimate goal of conserving our natural resources.

4. to encourage assessment of non-point sources of sedimentation and advocate erosion control at the local level.

Literature cited:

Bork, K. 1999. Floodplain and instream mining: a TU primer. Trout Unlimited, Arlington, Virginia.

Brown, A.V., M.M. Lyttle, and K.B. Brown. 1998. Impacts of gravel mining on gravel bed streams. Transactions of the American Fisheries Society 127:979–994.

EPA (U.S. Environmental Protection Agency). 1995. Sector notebook project: profile of the non-fuel, non-metal mining industry. EPA, Office of Compliance, Washington, D.C.

Hartfield, P. 1993. Headcuts and their effect on freshwater mussels. Pages 131–141 *in* K.S. Cummings, A.C. Buchanan, and L.M. Kock, eds. Conservation and management of freshwater mussels. Proceedings of an Upper Mississippi River Conservation Committee (UMRCC) symposium, 12–14 October 1992, St. Louis, Missouri, UMRCC, Rock Island, Illinois.

Kanehl, P., and J. Lyons. 1992. Impacts of in-stream sand and gravel mining on stream habitat and fish communities, including a survey on the Big Rib River, Marathon County, Wisconsin. Wisconsin Department of Natural Resources Research Report 155, Madison.

Kondolf, G.M. 1997. Hungry water: effects of dams and gravel mining on river channels. Environmental Management 21:533–551.

Lake, R.G., and S.G. Hinch. 1999. Acute effects of suspended sediment angularity on juvenile coho salmon. Canadian Journal of Fisheries and Aquatic Sciences 56:862–867.

Meador, M.R., and A.O. Layher. 1998. Instream sand and gravel mining: environmental issues and regulatory process in the United States. Fisheries 23(11):6–13.

NCDWQ (North Carolina Division of Water Quality). A guide to surface freshwater classifications in North Carolina. http://h2o.enr.state.nc.us/csu/swcfaq.html

Nelson, K.L. 1993. Instream sand and gravel mining. Pages 189–196 *in* C.F. Bryan and D.A. Rutherford, eds. Impacts on warmwater streams: guidelines for evaluation. Southern Division, American Fisheries Society, Little Rock, Arkansas.

Newport, B.D., and J.E. Moyer. 1974. State-of-the-art: sand and gravel industry. U.S. Environmental Protection Agency, EPA-660/2-74-066, Washington, D.C.

NMFS (National Marine Fisheries Service) 1996. NMFS National Gravel Extraction Policy. NMFS Southwest Region, Habitat Conservation Division, Long Beach, California.

Roell, M.J. 1999. Sand and gravel mining in Missouri stream systems: aquatic resource effects and management alternatives. Executive Summary. Missouri Department of Conservation, Columbia.

Rosgen, D. 1996. Applied river morphology. Wildland Hydrology, Pagosa Springs, Colorado.

Starnes, L.B., and D.C. Gasper. 1996. Effects of surface mining on aquatic resources in North America. Fisheries 21(5):24–26.

USGS (U.S. Geological Survey). 2001. Mineral Commodity Summaries. USGS, Geologic Division, Reston, Virginia.

USGS (U.S. Geological Survey). 1999. Minerals yearbook. USGS, Geologic Division, Reston, Virginia.

Waters, T. F. 1995. Sediment in streams: sources, biological effects, and control. American Fisheries Society Monograph 7, Bethesda, Maryland.

Glossary

Alluvial – Related to material deposited by running water.

Channel – A natural or artificial waterway that periodically or continuously contains moving water, has a definite bed, and has banks that serve to confine water at low to moderate stream flows.

Channel Incision – A result of down-cutting into the substrate.

Dragline – Equipment used to excavate and remove bottom materials from a water body. The materials are removed with a bucket that is pulled toward the piece of equipment with cables.

Geomorphology – Study of the origin of landforms, the processes that form them, and their material composition.

Headcutting – Erosion of the channel upstream of dredging.

Hydraulic Dredge – Equipment used to excavate and remove bottom materials from a water body using suction.

Nick Point – Where the channel dips into the head of the mine pit.

Thalweg – Deepest point in a channel cross section.

Watershed – Region or area drained by surface and groundwater flow in rivers, streams, or other surface channels.

ATTACHMENT N

Sand and Gravel Mining in Missouri Stream Systems: Aquatic Resource Effects and Management Alternatives

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Executive Summary

Many Missouri streams and their floodplains have abundant quantities of sand and gravel that are mined conveniently and economically for a variety of uses. Unfortunately, instream extraction of these minerals can reduce water quality and can destabilize the stream bed and banks, causing aquatic habitats to be simplified and reducing or eliminating populations of aquatic species. The stability of sand-bed and gravel-bed streams depends on a delicate balance among stream flow, sediment supply from the watershed, and stream channel form. Mining disrupts sediment supply and channel form, which can result in a deepening of the channel (incision) over great distances upstream and downstream of the mine site as well as sedimentation of habitats downstream. Channel incision often leads to accelerated bank erosion, a wider and shallower channel, and lowering of the floodplain water table. Channel instability and sedimentation from instream mining also can damage public infrastructure (bridges, pipelines, and utility lines) and result in losses of fishery productivity, biodiversity, recreational potential, streamside land, and real estate value. An instream mine therefore can function as a point source for more widespread problems.

Instream mineral mining and some forms of floodplain mining can be harmful to Missouri's stream resources, public infrastructure, and personal property. Current legal requirements do not adequately protect these public and private resources, and enforcing agencies are hampered by inadequate funding and low staffing levels. New guidelines or regulations that increase protection of these resources are needed and should have flexibility to fit local needs and conditions.

Instream mineral mining can be managed with four alternatives: (1) no change to existing regulations, (2) bar skimming only, (3) floodplain mining only, and (4) no mining in channels or floodplains. These alternatives range from best case (1) to worst case (4) in terms of economic effects on the industry and from worst case to best case for stream resource conservation and costs to society. Bar skimming (alternative 2) is recommended as a means for advancing stream resource conservation while maintaining a viable extraction industry. Bar skimming would be conducted above the water table and within a minimum-width buffer that separates the excavation site from the low-flow channel and the adjacent active channel bank. This alternative would lower the risks of headcutting upstream and sedimentation downstream. Several operational conditions would address stockpiling, renovation, material processing, access by removal equipment, storage and release of petroleum products, and species of concern.

Resource Issue

Many Missouri stream channels and their floodplains are economical sources of sand and gravel for construction, road maintenance, and other purposes. Research in sand- and gravel-bed streams of the United States and elsewhere has shown that instream extraction of these minerals can reduce water quality and destabilize channel bed and banks, causing aquatic habitats to be simplified and reducing or eliminating populations of aquatic species. Floodplain extraction of these minerals can result in capture of the active stream channel by the excavation pit during floods, causing abrupt relocation of the channel and extensive instability. Information about mining effects is needed to develop stream resource protection strategies that also allow a viable sand and gravel extraction industry.

Purpose

I reviewed scientific literature and other technical sources to summarize information about the physical and biological effects of sand and gravel extraction in stream systems. I also discuss economic and legal aspects, identify priority information needs, and outline management alternatives for mining in Missouri stream systems.

Background

Missouri stream systems have been dramatically altered since the middle nineteenth century, when significant settlement by European homesteaders began. As human population expanded to the present, vegetation and land use have changed in association with agriculture, timber harvest, urbanization, and mining activities, destabilizing whole stream systems as channels adjusted to altered flow regimes and heavy burdens of eroded sediment (Meade 1982). Stream channelization facilitated agricultural expansion in floodplains and created further instability. As transportation and construction infrastructure expanded during the twentieth century, demands for construction-grade sand and gravel increased. Today, in some Missouri stream systems, these minerals in channels and floodplains are heavily exploited. Sand is mined primarily in large rivers like the Grand, Osage, Missouri, and Mississippi rivers, while gravel is mined from small and intermediate-sized streams, primarily in the Ozarks (Fairchild et al. 1997). Instream mining in Missouri occurs at approximately 400 - 500 permitted sites and many unpermitted sites (Mike Larsen, Missouri Department of Natural Resources, personal communication), many of which are alternately active and inactive as mining depletes available minerals and as infrequent high stream flows replenish them. Unfortunately, methods and rates of mineral extraction at many of these sites have introduced further instability to stream channels, and harmful effects on aquatic life is likely significant (Kanehl and Lyons 1992; Meador and Layher 1998; Brown et al. 1998).

Streams are important resources to the citizens of Missouri, and protection of streams is a common theme. For example, in a 1994 attitude survey of 2,011 Missouri households conducted by Gallup Organization, the most important aquatic resource issues identified by respondents were protection of water quality (4.69 on a five point scale), conservation education (4.62), protection of native aquatic animals and plants (4.33), legislation to protect streams (4.27), and assistance to landowners for solving stream problems (4.22) (Weithman 1994). Given that only 3% of Missourians rated the condition of the state's streams as excellent and 41% rated stream condition as good, nearly half (49%) of Missourians want more emphasis on river and stream conservation (Larsen and Holland 1991). From 1982 to 1986, only 9% of anglers owned land along Missouri streams, but 89% had visited a stream during the period (Weithman 1991), which may partly explain why 40% of Missourians in general recognizes that gravel mining occurs in streams (Weithman 1984).

This review summarizes previous information about effects of instream and floodplain mineral extraction on aquatic resources and was undertaken to aid decision making about appropriate protection actions for Missouri streams. Most previous research has focused on mineral extraction from gravel-bed stream systems, but the geomorphology principles involved are also largely applicable to sand-bed streams. I focus on technical sources that describe relevant stream processes and on studies of extraction effects in stream channels and floodplains throughout North America and elsewhere. Although virtually all studies have been done outside Missouri, basic physical and biological principles common to all stream systems allow application of some study results to the stream system mining issue in Missouri. By discussing principles and concepts in general terms, I attempted to balance the need for technical detail with the opposing need to make this document understandable by readers with varied backgrounds, recognizing that an angler could be overwhelmed and a highly-trained geomorphologist disappointed.

I attempted to be comprehensive in my review of the literature relevant to Midwest stream resources, although the collective experience of assessing mining effects in the Midwest is limited. I also relied on the experience of Missouri stream resource managers when reviewing case histories of instream mining effects in Missouri. Review of how other Midwest states manage instream mining was greatly aided by information provided by biologists in those states.

In this review, I first discuss the roles of sediments and physical processes in the maintenance and development of stream channels and aquatic habitats. I then address how mineral extraction interacts with stream processes to alter channels and habitats of aquatic plants and animals. I continue with discussions about economic, policy, and legal considerations, and then conclude by reviewing mining regulations in other Midwest states, discussing management alternatives, identifying information needs, and proposing a course of action.

Stream Sediments and Physical Processes

An understanding of the general distribution, sources, and fates of sediment in stream systems is necessary before the effects of mineral extraction can be understood. Stream channels transport sediments and water from headwaters to mouth, systematically depositing and eroding, abrading and breaking sediment particles during the transport process (Knighton 1982). Sediments range from large boulders and cobbles to less coarse gravels and pebbles to finer sands, silts, and clays. The largest sediment particles (as well as all other sizes) typically occur in the low-order, high-gradient stream channels within a watershed, decreasing in abundance in downstream reaches where lower channel gradients favor retention of smaller sediments and the development of floodplains. The largest particles (primarily boulders) typically remain at or near their point of entry to the stream from the valley walls, while high-flow-induced sorting and abrasion of cobbles and smaller sediments produces a progressive downstream decrease in average sediment size (Knighton 1982; Kondolf 1997). So, in general, gravel-sized particles are more abundant in the middle reaches of stream systems, while sand-sized and smaller grains predominate in lower reaches. However, along lower reaches, smaller tributaries can introduce particles that are larger than those typically found in the receiving main stream, creating channel sediment conditions like those further upstream and changing the relative amounts of gravel, sand, and other particle sizes in the immediate area (Knighton 1982). In Missouri, the geologic history of the Ozarks region is such that substantial quantities of gravel enter streams in their headwaters, a condition that is accelerated by modern land use (Jacobson and Primm 1997).

Three sediment delivery processes are generally recognized (Collins and Dunne 1990; Leopold 1994): mass wasting on hillslopes, hillslope erosion by precipitation (or irrigation), and erosion of stream channel bed and banks. Mass wasting processes include landslides and soil creep, and occur when gravity alone moves soil and rock down hillslopes to stream channels. Landslide-produced sediment typically reflects the particle size distribution of the hillslope materials, ranging in size from boulders to clay. Processes like frost heaving, tree fall, and animal activity produce the slower downslope movement of sediments called soil creep, which typically moves sediments to floodplains and stream banks where bank erosion ultimately causes sediment entry to the channel.

Water erosion of upland hillslopes occurs when precipitation intensity exceeds the absorption capacity of the soil and generates overland flow (runoff). In humid and subhumid areas like Missouri, overland flow and related erosion are typically greatest in unvegetated disturbance areas like tilled agricultural land, construction sites, and unpaved roads (Collins and Dunne 1990; Jacobson and Primm 1997). Surface erosion typically involves sands and smaller sediments (Reid and Dunne 1984), although smaller gravels are likely involved during high-intensity precipitation.

Stream channels and floodplains are built and maintained by erosion and deposition of sediments during high stream flows (Leopold 1994; Whiting 1998). In relatively undisturbed stream systems, gradual erosion of outside bends of stream meanders and deposition of eroded material on inside bends causes an often imperceptible shifting of the channel within its floodplain. This is a form of stability called dynamic equilibrium (Heede 1986), where channel bed and banks are not a net source of sediment to the stream system. Channel stability in a given stream reach occurs from a delicate balance among stream flow, channel form, influx of sediment from the watershed, and loss of sediment to downstream reaches. This "conveyor belt" effect, where streams transport eroded materials from headwaters toward the oceans, provides the necessary quantities and sizes of sediment during channel-forming flows such that channels remain in a dynamically stable condition (Leopold 1994; Kondolf 1997). Although stream flows and sediment loads are variable within and among years, sediment balance and channel stability occur over the long term. Instabilities introduced by humans (from channelization, streamside deforestation, sand and gravel mining, and other activities) but also by natural means (from extreme precipitation, wildfire, and other events) can cause channel bed and banks to become net sources of sediment. Also, land use changes that hasten precipitation runoff and that result in clearing of woody riparian vegetation along the uppermost headwater channels can cause headward extension of such channels resulting in release of additional sediments (Jacobson and Primm 1997). Regardless of the sources of sediment, streams have a limited capacity to assimilate excessive sediment loads before in-channel instabilities and biological damage develop (Cairns et al. 1977; Waters 1995).

Physical and Biological Effects of Instream Mining

All species require specific habitat conditions to ensure long-term survival. Native species in streams are uniquely adapted to the habitat conditions that existed before humans began large-scale alterations to the pre-settlement conditions of watersheds. These alterations caused major habitat disruptions that favored some species over others, but caused overall declines in biological diversity and productivity (Benke 1990). In most rivers and streams, habitat quality is strongly linked to the stability of channel bed and banks — unstable stream channels are inhospitable to most aquatic species. Factors that increase or decrease sediment supply often destabilize bed and banks and result in dramatic channel readjustments. For example, human activities that accelerate stream bank erosion, such as riparian forest clearing or instream mining, cause stream banks to become net sources of sediment that often have severe consequences for aquatic species. Activities that artificially lower stream bed elevation cause bed instabilities that result in a net release of sediment in the local vicinity. Unstable sediments simplify and therefore degrade stream habitats for many aquatic species, and few species benefit from these effects (Newport and Moyer 1974; Waters 1995).

The most widespread effects of instream mineral extraction on aquatic habitats are bed degradation and sedimentation, which can have substantial negative effects on aquatic life (Kanehl and Lyons 1992; Hartfield 1993; Waters 1995; Brown et al. 1998). Because the stability of sand-bed and gravel-bed streams depends on a delicate balance among stream flow, sediment supplied from the watershed, and present channel form, mining-induced changes in sediment supply and channel form disrupt channel and habitat development processes (Lagasse et al. 1980). Furthermore, movement of unstable substrates above, at, and below mine sites results in downstream sedimentation of habitats where the affected distance depends on the intensity of mining, sizes of freed particles (Carling 1984), stream flows, and channel form.

Bed degradation: All stream flows have a given amount of flow energy, where the greatest flows moving on the steepest channel slopes have the highest energies (Collins and Dunne 1990). Flow energy is dissipated as friction in internal flow turbulence, on channel obstructions, and on channel bed and banks. Depending on the material composition of the channel, additional flow energy may be used in the process of sediment tranport. Erosion and transport of large sediment particles require higher energies than do smaller sediments, so cobbles, pebbles, and gravels require greater flows and/or steeper channel slopes in this regard than do sands, silts, or clays. Excess flow energy causes additional channel scour and transported sediment, but sediment transport in excess of flow energy results in sediment being deposited. Stream flow energy has an important role in the way instream sand and gravel mining affects stream channels.

Several studies have documented the bed degradation caused by pit excavation and bar skimming, the two general forms of instream mining (Kondolf 1997). Bed degradation, also known as channel incision, occurs through two primary processes: headcutting and "hungry" water. In the first, excavation of a mining pit in the active channel lowers the stream bed, creating a nick point that locally steepens channel slope and increases flow energy (WCC 1980a; Kondolf 1998). During high flows, a nick point becomes a location of bed erosion that gradually moves upstream in a process called headcutting (Figure 1) (Bull and Scott 1974; Hartfield 1993; Kondolf 1997). Headcutting mobilizes substantial quantities of stream bed sediments that are then transported downstream to deposit in the excavated area and locations further downstream. In gravel-rich streams, effects downstream of mining sites may be short-lived when mining ends, because the balance between sediment input and transport at a site can reestablish relatively quickly. Effects in gravel-poor streams may develop rapidly and persist for many years after mining has concluded. Regardless of downstream effects, headcutting in both gravel-rich and gravel-poor streams remains a major concern. Headcuts often move long distances upstream and into tributaries (Scott 1973; Harvey and Schumm 1987; Hartfield 1993; Kondolf 1997), in some watersheds moving as far as the headwaters or until halted by resistant surfaces in the stream bed such as bedrock or man-made structures. Of the two forms of bed degradation, headcutting is more recognizable in the field and represents the greater risk to aquatic resources (Pringle 1997). For example, headcuts from instream gravel mining and channelization were responsible for depletion or elimination of more than 30 mussel species in 10 streams draining portions of Mississippi and Louisiana (Hartfield 1993); for some species, degradation of microhabitats can be dramatic with little apparent change in channel form. In the Osage River, Missouri, a mussel decline in and adjacent to three sand and gravel mines was linked to mining-caused bed instability (Grace and Buchanan 1981).

A second form of bed degradation occurs when mineral extraction increases the flow capacity of the channel (Cross et al. 1982; Kondolf 1997). A pit operation locally increases flow depth (Figure 1) and a bar skimming operation increases flow width (Figure 2). Both conditions produce slower stream flow velocities and lower flow energies, causing sediments arriving from upstream to deposit at the mine site. As stream flow moves beyond the site and flow energies increase in response to the "normal" channel form downstream, the amount of transported sediment leaving the site is now less than the sediment carrying capacity of the flow. This sediment-deficient flow or "hungry" water picks up more sediment from the stream reach below the mine site, furthering the bed degradation process (Figure 1); this condition continues until the balance between input and output of sediments at the site is reestablished. In the Russian River, California, hungry water leaving an instream pit mine caused 10-20 feet of channel incision over 7 miles of river (Kondolf 1997). A similar effect occurs below dams, which trap sediment and release hungry water downstream where channel incision usually ensues; instream mineral excavation below dams compounds this problem (Kondolf and Swanson 1993; Kondolf and Larson 1995). Although other factors such as levees, bank protection, and altered flow regimes also promote channel incision, mineral extraction rates in many streams are often orders of magnitude in excess of sediment supply from the watershed (Cross et al. 1982), suggesting that extraction is largely responsible for observed channel changes (Collins and Dunne 1989; Kondolf and Swanson 1993; Kondolf 1997). Susceptibility to hungry water effects would depend on the rate of extraction relative to the rate of replenishment from upstream. Gravel-poor streams would be most susceptible to disturbance.

Channel incision not only causes vertical instability in the channel bed, but also causes lateral instability in the form of accelerated stream bank erosion and channel widening (WCC 1980a; Chang 1987; Heede and Rinne 1990). Incision increases stream bank heights, resulting in bank failure when the mechanical properties of the bank material cannot sustain the material weight. Channel widening causes shallowing of the streambed (Figure 2), producing braided flow or subsurface intergravel flow in riffle areas, hindering movement of fishes between pools (WCC 1980a; Kondolf 1997). Channel reaches become more uniformly shallow as deep pools fill with gravel and other sediments, reducing habitat complexity, riffle-pool structure, and numbers of large predatory fishes (Brown et al. 1998). Shallowing and widening of the channel also increases stream temperature extremes (Crunkilton 1982), and channel instability increases transport of sediments downstream (Parker and Klingeman 1982). For example, a headcut moving up a large California river also moved up a tributary, producing substantial bank undercutting, increased channel widths ranging from 30 to 1300 feet, and increased delivery of sediments to the main river (Harvey and Schumm 1987). Mining-induced bed degradation and other channel changes may not develop for several years until major channel-adjustment flows occur, and adjustments may continue long after extraction has ended (Kondolf 1998).

Sedimentation: Excess sediment is the single greatest pollutant in United States waters (Waters 1995). In streams, primary sources of this sediment are erosion of uplands, accelerated lateral erosion of streambanks, and downcutting of streambeds. The latter two sources are common effects of instream sand and gravel mining (Kondolf 1997) as is the mobilization of fine sediments during the process of material extraction, when stream flows are typically low and incapable of flushing suspended and depositing sediments (Forshage and Carter 1974; Kondolf 1998).

Waters (1995) has compiled the most comprehensive summary of sedimentation effects on aquatic life in streams, reviewing over 700 published works in his analysis. The following narrative is an overview of his conclusions on this issue. He says "After a half-century of the most rigorous research, it is now apparent that fine sediment, originating in a broad array of human activities (including mining), overwhelmingly constitutes one of the major environmental factors - perhaps the principal factor - in the degradation of stream fisheries." Sedimentation can be viewed in terms of effects from suspended sediment (that is, sediment held in suspension by stream flow) and effects from deposited sediment. Suspended sediment can decrease primary productivity (photosynthesis) by shading sunlight from aquatic plants, affecting the overall productivity of a stream system. Suspended sediment has several sublethal effects on fishes including avoidance and redistribution by some species (the most important sublethal effect), reduced feeding efficiency and therefore reduced growth by sight-feeding fishes, respiratory impairment (manifested in a thickening of the gill epithelium that causes loss of respiratory function), reduced tolerance to diseases and toxicants, and increased physiological stress. Most research on sublethal effects has been done on trout and salmon species with few studies directed at warmwater species. Lethal effects on fish from suspended sediment have apparently been difficult to document in the wild due to the challenge of distinguishing these effects from other mortality factors. Limited information exists about the effects of suspended sediment on benthic macroinvertebrates, although several studies have documented an increase in the drift response, a redistribution phenomenon where individuals temporarily enter the water column from the stream bed and move downstream, generally in response to lowering light levels (Waters 1965) or moving sediment (Culp et al. 1986). Newcombe and MacDonald (1991) have developed a stress index that predicts suspended sediment effects from measures of sediment concentration and duration of exposure.

Most sediment-caused biological disruption is from deposited sediment (Waters 1995). Most research on this aspect has focused on fish reproductive success with emphasis on the viability of eggs and fry of salmon and trout species. Salmonid species are particularly susceptible to sedimentation due to their reproductive strategy, the building of redds (nests) where deposited sediment reduces or halts the flow of oxygen-bearing water to embryos or sac fry. The effect of deposited sediment on reproductive success of warmwater fishes is not well known, although Berkman and Rabeni (1987) found in a Missouri study that sedimentation significantly reduced abundance of species requiring clean stony spawning sites. Another area of research has been the effect of deposited sediment on fish habitat, particularly that of the salmonids (Waters 1995). Much of the emphasis of this work has been on winter survival of fry in the interstitial spaces of riffle cobbles, pebbles, and gravels and on depths of pools providing critical summer cover. Rearing habitat for salmonids is highly vulnerable to deposited sediment. For example, in a 15-year study, Alexander and Hansen (1986) experimentally increased the sand bed load of a northern Michigan stream by 4 - 5 times, which eliminated most pools and reduced the brook trout (*Salvelinus fontinalis*) population to less than half its pre-experiment abundance; reduced survival rates in the egg-to-fry and fry-to-fingerling life stages caused the population adjustment. On a Texas stream, Forshage and Carter (1974) found that downstream sedimentation caused by a gravel mining operation reduced the overall abundance of fishes but increased abundance of those species adapted to sand-silt substrates.

Deposited sediment can have substantial negative effects on benthic macroinvertebrates and affect whole species groups such as mussels. Furthermore, because some fishes prey heavily on benthic macroinvertebrates, Waters (1995) said the "influence of sediment deposition on the productivity of benthic organisms as food for fish is one of the most critical problems affecting stream fisheries." Benthic macroinvertebrates are affected by deposited sediment in three primary ways: substrate size composition in the stream bed is altered, stream bed substrates are embedded (encased) in finer sediments, and species composition is altered. In general, every benthic invertebrate species is adapted to specific substrate particles sizes. In a stream community, a wide variety of species uses a wide variety of substrates such that nearly all substrate sizes are inhabited. Mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Trichoptera) are the benthic invertebrates most available to foraging fishes, and these species groups typically have their greatest abundances where stream bed substrates are a mixture of cobbles, pebbles, and gravels. Although densities of species adapted to finer substrates (sand, silt, and clay) can be very high, these species (for example, chironomids and oligochaetes) are generally available to only a few fish species with feeding strategies adapted to these finer substrates. Cobble-pebble-gravel substrate mixtures are highly susceptible to alteration and encasement by deposited sediment, which reduces benthic invertebrate species diversity, abundance, and productivity. Freshwater mussels are particularly sensitive to sedimentation-caused substrate alteration, which can result in complete loss of species (Ellis 1931, 1936; Bates 1962; Stein 1972; Harman 1974; Marking and Bills 1980; Parmalee 1993). Sedimentation from a gravel mining operation on a Texas stream reduced benthic macroinvertebrate abundances 97% at the site and 50% 2 miles downstream, but abundances were "normal" again 3 miles downstream (Forshage and Carter 1974).

Secondary Effects of Instream Mining: Instream mining also has secondary consequences. Expansion of a mine site or mining at a new site often is preceded by riparian forest clearing, which can affect instream habitat and contribute to bank instability (Bull and Scott 1974; Nelson 1993; Kondolf 1997). Bed degradation from instream mining lowers the elevation of stream flow and the floodplain water table (alluvial aquifer; Kondolf 1997), which in turn can eliminate water table-dependent woody vegetation in riparian areas (Kondolf 1998) and decrease wetted periods in riparian wetlands. Entry to mine sites by mining equipment may result in disturbance from repeated crossing of the stream channel and from road building through riparian areas.

Floodplain mining: Floodplains and terraces (former floodplains) are the sites of sediment storage in stream systems, and can contain large quantities of sand and gravel that can be mined economically. Floodplain mining pits often extend below the water table, which can provide a convenient water source for separating desired particle sizes from excavated materials. A floodplain mine also can become the nucleus of major instability in the adjacent stream channel when lateral channel movement or overbank flows redirect the active channel through the excavation pit. When floodplain pits "capture" the active channel, off-channel mines become instream mines that then produce the negative symptoms associated with instream excavation (Kondolf 1997). Channel capture often happens abruptly and usually occurs where the excavation pit offers flood flows a path of less resistance, often where the path is a shorter distance for flow to move down valley. Captured pits that are large relative to the stream channel create lake-like environments that can locally change environmental conditions and therefore the biological community, in some cases enhancing populations of problematic non-native species (WCC 1980a; Kondolf 1998). Similar effects can occur when mining directly connects floodplain pits to the active channel (WCC 1980a).

Several examples of channel capture by excavation pits have been documented. A gravel pit located in an inactive floodplain channel of Tujunga Creek, California, captured the active channel during a flood and initiated two headcuts that moved 2,600 and 3,000 feet upstream with vertical incision up to 14 feet (Bull and Scott 1974; Collins and Dunne 1990); the pit trapped sediment arriving from upstream, and the hungry water exiting the pit continued the bed degradation downstream. Two gravel mine pits in the floodplain of the Yakima River, Washington, captured the active channel during a flood, relocating the channel laterally nearly 2000 feet within a day (Dunne and Leopold 1978). An off-channel pit captured the active channel of the Clackamas River, Oregon, causing 6 feet of channel incision over 3000 feet upstream (Kondolf 1997). Eight gravel mining pits, originally in floodplain locations, are now in-channel pits following capture by the Merced River, California (Vick 1995). In several Alaska streams, floodplain mine sites with forested buffer strips between the site and the channel did not capture the channel, but many non-buffered sites did (WCC 1980a). In Missouri, a floodplain gravel mine captured the active channel of the Little Piney River, increasing stream temperature 30 F between an upstream spring discharge and the first downstream spring (Tryon 1980).

Substantial wildlife benefits from floodplain mining pits have been realized (Svedarsky and Crawford 1982). Floodplain pits often provide unique habitats to which a variety of vertebrates and invertebrates are adapted, and these pits can be managed to provide significant opportunities for non-consumptive and consumptive forms of recreation. However, before mining begins, careful site planning should incorporate a protective forested buffer between the pit and the active channel (WCC 1980a), should locate mines to minimize the risk of pit capture during floods (WCC 1980a), and should anticipate post-mining needs for aquatic resources management (Bauer 1982; Matter and Mannan 1988). In addition to buffers, WCC (1980b) recommended that miners avoid extraction in active channels, sites that favor channel capture, clearing of riparian vegetation, and disturbance to natural stream banks.

Economic Considerations

Sand, gravel, and crushed stone, called aggregate in the mining industry, are among the most important and highly demanded mineral resources in the United States, having uses in nearly all commercial, industrial, and residential construction including concrete, general fill, and subgrade material for highways, railroad beds, bridges, airports, road surfacing, and water and sewer systems (Morris 1982; Langer and Glanzman 1993). Aggregate mining is the first or second largest mining industry in the United States depending on the unit of measure (Bull and Scott 1974; Morris 1982; Waters 1995). Growth in demand has been significant in the last two decades. Nationally, nearly 800 million tons of sand and gravel were mined in 1980 (Morris 1982), and 1.1 billion tons were mined in 1998 (Kuhar et al. 1999). Crushed stone from quarries accounted for an additional 1.6 billion tons in 1998. In Missouri, crushed stone leads in value ($337 million) followed by excavated sand and gravel ($41 million) (Fairchild et al. 1997), and 5,200 jobs are supported directly by the industry (MICM 1999). Long-term demand for sand, gravel, and crushed stone will expand (Langer and Glanzman 1993). Short-term demand will be driven in part by 1998 federal legislation called TEA-21 (Transportation Equity Act for the 21st

Century - PL105-178), which will provide to the states $215 billion over six years for highway, transit, safety, research, and motor-carrier programs.

Construction application determines the specific grade and quality of sand, gravel, or crushed stone needed for a project (Morris 1982). For example, stream gravel can be in high demand for some applications, because abrasion during the water transport process typically removes weak materials leaving gravel that is durable, rounded, well sorted, and suitable for high quality concrete (Barksdale 1991). High tranportation costs often require that construction minerals be mined close to the site of use (Bull and Scott 1974; Morris 1982; Kondolf 1997). As a result, minerals with grade and quality specifications exceeding project needs may be used due to convenient availability. Given the abundance and availability of sand and gravel in Missouri stream systems, these minerals are likely used in some applications that could otherwise use crushed stone. Kondolf (1997) suggests that high-grade minerals from stream systems be reserved for applications that require such minerals, thereby reducing their demand.

Sand and gravel mining in stream systems can damage public and private property. Channel incision caused by gravel mining can undermine bridge piers and expose buried pipelines, utility lines, and other infrastructure (Hartfield 1993; Kondolf 1997). For example, Bull and Scott (1974) described 13 feet of gravel mining-induced incision that threatened the stability of piers supporting a new bridge across an Arizona stream. A gravel pit mine in the floodplain of Tujunga Creek, California, captured the active channel during a flood, producing two headcuts (2,600 and 3,000 feet; up to 14 feet deep) that caused failure of three major highway bridges (Bull and Scott 1974); bed degradation downstream from the mine contributed to damage of a four-lane highway. Two gravel mine pits in the floodplain of the Yakima River, Washington, captured the active channel, moving it laterally almost 2000 feet to a highway embankment where erosion ensued (Dunne and Leopold 1978). In Cache Creek, California, a gravel mine produced a 10-foot deep headcut that moved upstream nearly a mile in four years to cause near-failure of a highway bridge (Kondolf 1997). A headcut with a depth of 23 feet moved upstream from a gravel mine in the Kaoping River, Taiwan, to threaten a large highway bridge that ultimately required the expensive protection provided by gabions, concrete jacks, and lengthened piers (Kondolf 1997). Instream gravel mining above and below a highway bridge over Stony Creek, California, caused that structure to be undermined (Kondolf and Swanson 1993).

In Missouri, a gravel mine in Linn Creek (Camden County) caused a 5-10 foot deep headcut that moved upstream into two tributaries threatening the structural integrity of abutments supporting four highway bridges (Greg Stoner, Missouri Department of Conservation, personal communication); a grade control structure built to protect one bridge later failed due to further incision. Other infrastructure damage along Linn Creek required $20,000 worth of repairs for telephone poles, cables, and phone lines, and $19,000 worth of repairs for a sewer line. Up to 100 feet of lateral bank erosion occurring over nine years undermined nine family residences and two businesses, resulting in an $875,000 buyout of those properties in 1994 by the Federal Emergency Management Agency. Headcutting from a gravel mine in Mill Creek (Phelps County) contributed to failure of three bridges one mile upstream at a replacement cost in excess of $200,000 (Mike Smith, Missouri Department of Conservation, personal communication). Ironically, agencies charged with construction, maintenance, and safety of transportation infrastructure are often primary recipients of sand and gravel from instream mines (Kondolf 1998), some of which are immediately adjacent to the use site.

Instream mining can have other costly effects well beyond immediate mine sites (Hartfield 1993). Many acres of fertile streamside land are lost annually as are the valuable timber resources and wildlife habitats in forests growing there. Degraded stream habitats result in lost fishery productivity, biodiversity, and recreational potential, and severely degraded channels may lower land and aesthetic values (Kaminarides et al. 1996). For example, costs to society ($7.58 million in the form of lost farm revenue, real estate value, fishery productivity, and recreational spending) exceeded economic benefits ($6.56 million as direct and indirect total expenditures from mined gravel) in an economic analysis of instream gravel mining in five Arkansas streams (Kaminarides et al. 1996). Once damages have occurred, costs for restoring fishery productivity and other values are generally very high (Kondolf 1997). Though mine operators and individual landowners benefit from instream mining, significant economic and natural resource costs are borne by offsite landowners and the public (Hartfield 1993). Given the property damage that can occur from mining-induced channel incision, streamside landowners and public agencies should be informed about mines where damage can potentially occur (Hartfield 1993). Kondolf (1997, 1998) suggested that the costs of public and private property damage be incorporated into the price of the mined products to better reflect the true costs of extraction. This approach would make other mineral sources (for example, crushing stone in upland quarries) more economically competitive with instream sources (Kondolf 1998). Furthermore, while the effects of upland quarries are generally contained and more easily mitigated during reclamation, mineral mining in stream systems creates physical disturbances that often move well beyond the mine site in the form of channel adjustments that require decades before equilibrium is reestablished (Kondolf 1998).

Policy and Legal Considerations

The 1972 Clean Water Act has been the primary agent for regulating instream mining. The U.S. Environmental Protection Agency (USEPA) oversees the Act, but Section 404 of the Act (regulation of discharge of dredged and fill materials in surface waters) is implemented by the U.S. Army Corps of Engineers (USACE) and Section 401 (regulation of water quality standards) is carried out in Missouri by Missouri Department of Natural Resources (MDNR). Section 404 establishes a permit program to ensure that dredged and fill discharges comply with other state and federal environmental regulations.

Before January 1997, instream mining was more strictly regulated in that "incidental fallback" of material during a dredging action was considered fill in surface waters, thus triggering Sections 404 and 401 authorizations. Incidental fallback is defined as "the incidental soil movement from excavation, such as the soil that is disturbed when dirt is shoveled, or back-spill that comes off a bucket and falls into the same place from which it was removed" (U.S. District Court for the District of Columbia). Historically, incidental fallback was not considered a regulated discharge, but, as a result of litigation brought by the National Wildlife Federation, incidental fallback was added to the definition of "discharge of dredged and fill material" by USACE and USEPA on August 25, 1993. This change, referred to as the Excavation Rule (or Tulloch Rule), was challenged by the American Mining Congress in the U.S. District Court for the District of Columbia. On January 23, 1997, the Court handed down a decision in American Mining Congress versus USACE, where the Court considered the Rule to be outside the agencies' statutory authority and contrary to the intent of Congress to the extent that the Rule asserted Clean Water Act jurisdiction over activities where the only discharge associated with the activity is incidental fallback. On September 28, 1998, the Court rejected the USACE request for a review of the decision, and, at this time, the USACE is not seeking an appeal of the decision. As a result, only activities resulting in discharge of fill material greater than incidental fallback (such as instream stockpiling, stream crossings, bank stabilization activities, and select removal methods) are regulated under Section 404.

Under authority of the Clean Water Commission, MDNR enforces Sections 401 and 402 of the Clean Water Act. Regarding instream excavation activities, Section 401 is required in all instances falling under the jurisdiction of Section 404. Section 402 authorization (National Pollution Discharge Elimination System) may be required if mineral washing occurs at the mining site.

The Land Reclamation Program of MDNR, under authority of the 1972 Land Reclamation Act, regulates commercial instream mining operations. However, instream mining may be conducted without a Program permit by (1) individuals for personal use, and (2) political subdivisions including county, city, state, or branch of the military that uses its own personnel and equipment to obtain minerals. Program rules state that an operator is exempt from Program permitting requirements if covered by a Section 404 permit that is more strict than the Program. The Program is significantly underfunded and understaffed for its mission.

Mining below the ordinary high water mark of a navigable stream is considered a legally distinct issue as defined in Section 10 of the 1899 Rivers and Harbors Act. This Act applies to rivers classified as navigable by USACE and the U.S. Coast Guard, and in Missouri includes large rivers such as the Missouri and lower Osage rivers. USACE jurisdiction under Section 10 was not affected by the court decision involving incidental fallback.

Missouri Department of Conservation (MDC) has no legal jurisdiction over instream mining activities, with the exception of using the Public Trust Doctrine. The Doctrine states that human activities that negatively affect resources held in trust by government agencies for the public can be challenged legally (Sax 1970). MDC and other Missouri agencies have not used the Doctrine to compel public or private entities to use conservation-minded resource practices. Regulators with the State of Wisconsin have used this concept to deny permits to proposed sand and gravel operations that would infringe on scenic resources along navigable waters (that is, waters capable of floating the shallowest-draft recreational boat at high water during spring; Chenoweth et al. 1982). The State of Arizona also has used the Doctrine to regulate mineral mining.

Regulation of Instream Mining in Other Midwest States

Review of how other states address the issue of sand and gravel mining in stream systems could be instructive (Meador and Layher 1998). I limited my search to Midwest states and included here only those measures that go beyond authorities arising from the 1899 Rivers and Harbors Act and the 1972 Clean Water Act.

Arkansas: Instream mining in Arkansas is controlled by The Arkansas Open-Cut Mining and Land Reclamation Code (Regulation Number 15) under authority of the Arkansas Department of Environmental Quality. No mining is allowed in streams designated as "extraordinary resource waters" with the exception of operators mining on streams that receive the "extraordinary" designation after January 1, 1995; operators on these waters may continue mining under permit for two years after the designation date and then must reclaim the mining area in accordance with the operator's approved reclamation plan. On other waters, mining may occur under permit in the active channel, but equipment (trucks, loaders, dozers, and so on) must not enter the water and excavation may not occur deeper than one foot above the water surface elevation at the time of operation. In dry streams, material may be removed to a depth of one foot above the lowest point of the channel cross section at the mining location. A minimum 25-foot-wide buffer strip is required from the low-flow channel edge landward for the length of the mining site; buffer strip disturbance would be limited to well maintained access roads for ingress and egress only. Operators must take reasonable steps and precautions to assure that mining activities do not violate state water quality standards or impair stream bank stability and channel integrity. Material processing or storage may not occur within the stream channel. Storage of fluids such as fuel, oil, or hydraulic fluid must occur such that none can enter the stream channel. A landowner may remove mineral material on his/her own land for personal use on said land without obtaining a mining permit. Other conditions for planning, reporting, and special situations also apply. (Steve Filipek and Brian Wagner, Arkansas Game and Fish Commission, personal communications)

Illinois: The Illinois Department of Natural Resources oversees instream sand and gravel mining. Instream mining is highly localized and small scale, occurring primarily in western and southern Illinois in the river hills regions bordering the Mississippi and Ohio rivers. The "standards and guidelines" for the Shawnee National Forest in extreme southern Illinois prohibit removal of stream bed deposits except as necessary to protect existing low-water crossings. (Randy Sauer, Illinois Department of Natural Resources, personal communication)

Iowa: Instream sand and gravel mining is authorized by permit from the Iowa Department of Natural Resources (IDNR) for meandered streams, which are clearly defined stream reaches in 14 rivers. A meandered stream is one that "was surveyed as a navigable and important water body to be granted to the states . . . upon their admission to the union. The state of Iowa holds sovereign title to the bed of meandered streams up to the Ordinary High Water Line. Title is held in trust for the benefit of the public. Also included are islands, abandoned river channels and accretions. The Ordinary High Water Line is determined on a case-by-case basis under criteria prescribed by court cases." The maximum continuous length of stream covered by each permit may not exceed 4500 linear feet. Removal operations may not occur within 30 feet of the existing bank or may not breach the bank at any location without written permission from the IDNR director or designee. Operations may not obstruct the flow of water and may not prevent passage of watercraft. Permits may be terminated by the director or designee if a permit holder fails to fulfill permit obligations in a timely and proper manner. Several provisions are made for reporting. (Eileen Bartlett, Iowa Department of Natural Resources, personal communication)

Wisconsin: Excavators mining sand and gravel near or in a stream or lake must have a Wisconsin Department of Natural Resources (WDNR) permit. Virtually all permit applications for mining in or on the banks of a navigable stream (see above definition) are denied, but permits for mining in riparian areas away from stream banks are usually approved. Public opposition to instream mining, a WDNR commitment to limit mining effects, and credible research results from other states were the foundation of regulation changes. (John Lyons, WDNR, personal communication).

Alternatives for Managing Instream and Floodplain Mining

Instream mineral mining is prohibited in many countries including England, Germany, France, the Netherlands, and Switzerland, and is strongly regulated in selected rivers in Italy, Portugal, and New Zealand (Kondolf 1997, 1998). In the United States, instream mining may be the least regulated of all mining activities (Waters 1995; Starnes and Gasper 1996) and regulations vary by state. In Missouri, few restrictions govern mineral mining in stream channels and floodplains; counties and municipalities operate largely unregulated. Some instream mining operations do not have the necessary permits, and permitting agencies are underfunded for their function of tracking compliance (Fairchild et al. 1997).

In general, stream system mining in Missouri can be managed with four excavation alternatives:

(1) Minimal guidelines or regulations: This alternative represents the current state of instream mineral mining in Missouri. Operators extract minerals in any amounts and from any locations in the stream channel or floodplain under the minimal restrictions specified in the 1899 Rivers and Harbors Act, 1972 Clean Water Act, and MDNR's Land Reclamation Program. Aquatic resources are prone to high risk from headcutting, hungry water, and sedimentation. Costs to society (damage to public and private property) are the greatest in this alternative as well. Many instream mining operations are not regulated under existing state and federal programs.

(2) Bar skimming only: Operators would extract minerals from in-channel bars and only above the water table (Figure 3). Mining would be conducted under guidelines similar to many of the special conditions (Appendix 1) that accompanied the "Section 404 General Permit, Sand and Gravel Excavation Activities" (GP-34M) formerly issued by the USACE for instream mining in Missouri; those special conditions were developed in collaboration with members of the mining industry. Among these guidelines would be a minimum-width buffer that would separate the extraction site from the low-flow channel and the adjacent active channel bank (Figure 4).

This alternative would lessen the risk of mining-induced headcuts, but could nevertheless cause hungry water and associated channel incision downstream of mine sites. Bar skimming also could cause other problems such as elimination of side channels, abrupt relocation of the low-flow channel, and higher mobility of loosened sediments (Kondolf 1998). Gravel-rich streams would be less susceptible to disturbance from this form of mining than would gravel-poor streams, because replenishment by excess gravel from upstream sources would partially mitigate channel disruption; mining of bars in gravel-rich streams should be emphasized over mining in gravel-poor streams. Furthermore, specific reaches in individual streams may be better locations for mining, because these reaches may receive high deposits of sediment while other reaches do not (Jacobson and Pugh 1997). Special guidelines would be needed for mining in so-called "losing" streams, which do not have perennial flow.

(3) Floodplain pit mining only: Operators would not extract minerals from any location in the active channel, but would extract from floodplain and terrace locations that have a forested buffer between the site and the channel to reduce risk of channel capture by the pit during flood flows. Pre-project site planning would minimize the risk of channel capture and maximize post-mining use of the site.

(4) No mining from stream channels or floodplains: Construction minerals would be obtained from upland quarries or other upland sources.

These alternatives range from worst case (1) to best case (4) for stream resource conservation and costs to society (damage to private and public property) and from best case (1) to worst case (4) for economic effects on the industry. Alternatives 2 and 3 represent the most realistic courses of action for conservation of stream resources statewide while allowing for a viable extraction industry. Designation of "extraordinary waters", where only alternatives 3 or 4 would be allowed, also should be considered as an additional feature to a statewide approach.

Guidelines or regulations that result in instream mining that is less harmful to channels and habitats may provide opportunities for channel and habitat protection and restoration. The ability of some stream channels to self-recover from disturbance given enough time and no additional disturbance provides opportunity to use passive restoration, perhaps coupled with limited active restoration of streamside vegetation. The scope and complexity of stream channel processes essentially precludes protection and restoration with extensive engineering solutions, which are often expensive and may ultimately do more harm than good.

Information Needs

The effects of instream sand and gravel mining on stream channels and habitats was identified as a priority information need in a 1998 survey conducted by MDC Fisheries Research Section; 39 resource professionals from several state and federal agencies were surveyed. The following discussion is a more detailed description of information that would further our understanding of the effects of instream mining on people, stream channels, habitats, and biota.

An economic analysis that compared costs to society versus economic benefits from mining would be valuable information. For example, Kaminarides et al. (1996) compared costs associated with stream bank erosion (lost farm revenue, real estate value, fishery productivity, and recreational spending) to economic benefits (direct and indirect total expenditures) arising from gravel mining in five Arkansas streams (Kaminarides et al. 1996). This information was useful in later discussions about instream mining laws in Arkansas.

The regional extent of mineral mining in Missouri stream systems also would be valuable information (Kanehl and Lyons 1992). Unknown is whether instream mining is conducted throughout Missouri or is concentrated in specific stream basins. More than 500 mining sites occur in Missouri (Mike Larsen, Missouri Department of Natural Resources, personal communication), which is clearly a level that warrants further attention. Two efforts in this regard are underway. The first effort involves evaluating the use of helicopter-based videography to assess extent and character of instream mine sites. The second effort is a proposed research collaboration between MDC and United States Geological Survey (with additional guidance provided by personnel from MDNR and USACE). Extent and character of instream mine sites throughout the Ozarks region, where the bulk of instream mining occurs, would be evaluated using methods developed in the first effort as well as other means. Funding for this work is currently being sought.

Information is needed on how basin-level factors affect the way instream mining alters channel form and associated stream and wetland habitats. This work is represented in the proposed collaboration discussed above and would use a geographical information system and aerial photography to relate basin-level factors to the identified changes. This work would use a correlational approach and would be done in three basins that represent different levels of material extraction (low, medium, and high). Unfortunately, high study costs preclude a more rigorous study design involving more study basins and "treatment" replication.

Finally, information is needed on the effectiveness of mining guidelines designed to limit channel and habitat damage from headcutting, sedimentation, and channel widening. For example, evaluation could focus on guidelines that limit extraction to material above the waterline and that require a no-disturbance buffer zone separating the extraction site from the low-flow channel and from the stream banks (Alternative 2 above). Researchers would likely collaborate with miners in this effort.

Streams and their watersheds are complex systems, so researchers must be careful to properly link causes and effects during research efforts. For example, sediment-deficient flows from dams, high erosive power created by levees, and headcutting from instream mining all contribute to channel incision. Deforestation of streamside land can cause accelerated bank erosion and channel widening, which are effects that also arise from instream mining. In gravel-bed streams, sediment movement can be in the form of highly variable pulses or waves (Sidle 1988; Jacobson 1995). Furthermore, the combined effects of multiple mines in a stream system are potentially troublesome and worthy of study (WCC 1980a). Studies of instream mining effects must assure that confounding factors such as these do not lead researchers to erroneously attribute observed effects to instream mining. In some systems, rates of extraction by instream miners substantially exceed rates of sediment replenishment from upstream sources, which allows researchers to more confidentally link mining to channel and habitat changes (Kondolf 1997). The goal of this work is to develop strategies for aquatic resource protection while also allowing a viable mineral extraction industry.

Summary and Recommendations

Instream mineral mining and some forms of floodplain mining can be harmful to Missouri's stream resources, public infrastructure, and personal property. Current legal requirements do not adequately protect these public and private resources, and enforcing agencies are hampered by inadequate funding and low staffing levels. New guidelines or regulations that increase protection of these resources also should have flexibility to fit local needs and conditions.

Instream mineral mining can be managed with four alternatives: (1) no change to existing regulations, (2) bar skimming only, (3) floodplain mining only, and (4) no mining in channels or floodplains. These alternatives range from best case (1) to worst case (4) in terms of economic effects on the industry and from worst case to best case for stream resource conservation and costs to society. Bar skimming (alternative 2) is recommended as a means for advancing stream resource conservation while maintaining a viable extraction industry. Bar skimming would be conducted above the water table and within a minimum-width buffer that separates the excavation site from the low-flow channel and the adjacent active channel bank. This alternative would lower the risks of headcutting upstream and sedimentation downstream. Several operational conditions would address stockpiling, site renovation, material processing, access by removal equipment, storage and release of petroleum products, and species of concern.

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References

Alexander, G. R., and E. A. Hansen. 1986. Sand bed load in a brook trout stream. North American Journal of Fisheries Management 6:9-23.

Barksdale, R. D. 1991. The aggregate handbook. National Stone Association, Washington, D.C.

Bates, J. M. 1962. The impact of impoundment on the mussel fauna of Kentucky Reservoir, Tennessee River. American Midland Naturalist 68:232-236.

Bauer, A. M. 1982. Manipulating mining operations to create wildlife habitats: a pre-mining planning process. Pages 41-43 *in* W. D. Svedarsky and R. D. Crawford, editors. Wildlife values of gravel pits. University of Minnesota Agricultural Experiment Station, Miscellaneous Publication 17-1982, St. Paul.

Benke, A. C. 1990. A perspective on America's vanishing streams. Journal of the North American Benthological Society 9:77-88.

Berkman, H. E., and C. F. Rabeni. 1987. Effect of siltation on stream fish communities. Environmental Biology of Fishes 18:285-294.

Brown, A. V., M. M. Lyttle, and K. B. Brown. 1998. Impacts of gravel mining on gravel bed streams. Transactions of the American Fisheries Society 127:979-994.

Bull, W. B., and K. M. Scott. 1974. Impact of mining gravel from urban stream beds in the southwestern United States. Geology 2:171-174.

Cairns, J., Jr., K. L. Dickson, and E. E. Herricks. 1977. Recovery and restoration of damaged ecosystems. University Press of Virginia, Charlottesville.

Carling, P. A. 1984. Deposition of fine and coarse sand in an open-work gravel bed. Canadian Journal of Fisheries and Aquatic Sciences 41:263-270.

Chang, H. H. 1987. Modeling fluvial processes in streams with gravel mining. Pages 977-988 *in* C. R. Thorne, J. C. Bathurst, and R. D. Hey, editors. Sediment transport in gravel-bed rivers. John Wiley, New York.

Chenoweth, R. E., W. G. Tlusty, and B. J. Niemann, Jr. 1982. Public rights to scenic resources: infringement is sufficient cause for denial of lowland sand and gravel operations in

Wisconsin. Pages 73-79 *in* W. D. Svedarsky and R. D. Crawford, editors. Wildlife values of gravel pits. University of Minnesota Agricultural Experiment Station, Miscellaneous Publication 17-1982, St. Paul.

Collins, B., and T. Dunne. 1989. Gravel transport, gravel harvesting, and channel-bed degradation in rivers draining the Southern Olympic Mountains, Washington, USA. Environmental Geology and Water Science 13:213-224.

Collins, B., and T. Dunne. 1990. Fluvial geomorphology and river-gravel mining: a guide for planners, case studies included. California Department of Conservation, Division of Mines and Geology, Special Publication 98, Sacramento.

Cross, F. B., F. J. DeNoyelles, S. C. Leon, S. W. Campbell, S. L. Dewey, B. D. Heacock, and D. Weirick. 1982. Impacts of commercial dredging on the fishery of the lower Kansas River. Report to the U.S. Army Corps of Engineers, Kansas City.

Crunkilton, R. L. 1982. An overview of gravel mining in Missouri and fish and wildlife implications. Pages 80-88 *in* W. D. Svedarsky and R. D. Crawford, editors. Wildlife values of gravel pits. University of Minnesota Agricultural Experiment Station, Miscellaneous Publication 17-1982, St. Paul.

Culp, J. M., F. J. Wrona, and R. W. Davies. 1986. Response of stream benthos and drift to fine sediment deposition versus transport. Canadian Journal of Zoology 64:1345-1351.

Dunne, T., and L. B. Leopold. 1978. Water in environmental planning. W. H. Freeman and Company, San Francisco.

Ellis, M. M. 1931. A survey of conditions affecting fisheries in the Upper Mississippi River. U.S. Bureau of Fisheries, Fisheries Circular 5, Washington, D.C.

Ellis, M. M. 1936. Erosion silt as a factor in aquatic environments. Ecology 17:29-42.

Fairchild, J., D. Menown, J. Besser, and J. Czarnezki. 1997. Position statement on mining in Missouri. Missouri Chapter, American Fisheries Society, Columbia.

Forshage, A., and N. E. Carter. 1974. Effects of gravel dredging on the Brazos River. Southeastern Association of Game and Fish Commissioners Proceedings 27:695-709.

Grace, T. B., and A. C. Buchanan. 1981. Naiades (mussels) of the lower Osage River, Tavern Creek; and Maries River, Missouri. Missouri Department of Conservation, Jefferson City.

Harman, W. N. 1974. The effects of reservoir construction and canalization on the mollusks of the upper Delaware watershed. Bulletin of the American Malacological Union Incorporated May:12-14.

Hartfield, P. 1993. Headcuts and their effect on freshwater mussels. Pages 131-141 in K. S. Cummings, A. C. Buchanan, and L. M. Loch, editors. Conservation and management of freshwater mussels. Proceedings of a UMRCC symposium. Upper Mississippi River Conservation Committee, Rock Island, Illinois.

Harvey, M. D., and S. A. Schumm. 1987. Response of Dry Creek, California, to land use change, gravel mining and dam closure. Pages 451-460 *in* Erosion and sedimentation in the Pacific Rim. Proceedings of the Corvallis symposium, August 1987. International Association of Hydrological Sciences Publication 165.

Heede, B. H. 1986. Designing for dynamic equilibrium in streams. Water Resources Bulletin 22:351-357.

Heede, B. H., and J. N. Rinne. 1990. Hydrodynamic and fluvial morphologic processes: implications for fisheries management and research. North American Journal of Fisheries Management 10:249-268.

Jacobson, R. B. 1995. Spatial controls on patterns of land-use induced stream disturbance at the drainage-basin scale: an example from gravel-bed streams of the Ozark Plateaus, Missouri. Pages 219-239 *in* J. E. Costa, A. J. Miller, K. W. Potter, and P. R. Wilcock, editors. American Geophysical Union, Geophysical Monograph 89.

Jacobson, R. B., and A. T. Primm. 1997. Historical land-use changes and potential effects on stream disturbance in the Ozark Plateaus, Missouri. U. S. Geological Survey, Water-Supply Paper 2484, Washinton, D.C.

Jacobson, R. B., and A. L. Pugh. 1997. Riparian-vegetation controls on the spatial pattern of stream-channel instability, Little Piney Creek, Missouri. U.S. Geological Survey, Water-Supply Paper 2494, Washington, D.C.

Kaminarides, J. S., R. Kesselring, D. Marburger, R. Grippo, and G. Harp. 1996. An economic impact analysis of stream bed gravel mining. Report submitted to Arkansas Gravel Mining Task Force, State of Arkansas.

Kanehl, P., and J. Lyons. 1992. Impacts of in-stream sand and gravel mining on stream habitat and fish communities, including a survey on the Big Rib River, Marathon County, Wisconsin. Wisconsin Department of Natural Resources, Research Report 155, Madison.

Knighton, A. D. 1982. Longitudinal changes in the size and shape of stream bed material: evidence of variable transport conditions. Catena 9:25-34.

Kondolf, G. M. 1997. Hungry water: effects of dams and gravel mining on river channels. Environmental Management 21:533-551.

Kondolf, G. M. 1998. Environmental effects of aggregate extraction from river channels and floodplains. Pages 113-129 *in* P. T. Bobrowsky, editor. Aggregate resources: a global perspective. A. A. Balkema, Brookfield, Vermont.

Kondolf, G. M., and M. Larson. 1995. Historical channel analysis and its application to riparian and aquatic habitat restoration. Aquatic Conservation 5:109-126.

Kondolf, G. M., and M. L. Swanson. 1993. Channel adjustments to reservoir construction and instream gravel mining, Stony Creek, California. Environmental Geology and Water Science 21:256-269.

Kuhar, M. S., D. Constantino, and C. A. Dorn. 1999. State of the industry report. Pit and Quarry magazine site on the World Wide Web (www.pitandquarry.com).

Lagasse, P. F., B. R. Winkley, and D. B. Simons. 1980. Impact of gravel mining on river system stability. Journal of the Waterway, Port, Coastal and Ocean Division 106:389-404.

Langer, W. H., and V. M. Glanzman. 1993. Natural aggregate: building America's future. U.S. Geological Survey, Circular 1110, Washington, D.C.

Larsen, M. D., and R. D. Holland. 1991. Missouri stream and river study. Report of The Gallup Organization, Incorporated, Princeton, New Jersey.

Leopold, L. B. 1994. A view of the river. Harvard University Press, Cambridge, Massachusetts

Marking, L. L., and T. D. Bills. 1980. Acute effects of silt and sand sedimentation on freshwater mussels. Pages 204-211 *in* J. L. Rasmussen, editor. Proceedings of the symposium on Upper Mississippi River bivalve mollusks. Upper Mississippi River Conservation Committee, Rock Island, Illinois.

Matter, W. J., and R. W. Mannan. 1988. Sand and gravel pits as fish and wildlife habitat in the Southwest. U.S. Fish and Wildlife Service, Resource Publication 171, Washington, D.C.

Meade, R. H. 1982. Sources, sinks, and storage of river sediments in the Atlantic drainage of the United States. Journal of Geology 90:235-252.

Meador, M. R., and A. O. Layher. 1998. Instream sand and gravel mining: environmental issues and regulatory process in the United States. Fisheries 23(11):6-13.

MICM (Mining Industry Council of Missouri). 1999. The impacts on the economy of Missouri of mining industrial minerals for use in construction, 1995. MICM site on the World Wide Web (www.momic.com).

Morris, R. A. 1982. Regulatory and land use aspects of sand and gravel mining as they affect reclamation for wildlife habitat and open space: a national perspective. Pages 16-23 *in* W. D. Svedarsky and R. D. Crawford, editors. Wildlife values of gravel pits. University of Minnesota Agricultural Experiment Station, Miscellaneous Publication 17-1982, St. Paul.

Nelson, K. L. 1993. Instream sand and gravel mining. Pages 189-196 *in* C. F. Bryan and D. A. Rutherford, editors. Impacts on warmwater streams: guidelines for evaluation. Southern Division, American Fisheries Society, Little Rock, Arkansas.

Newcombe, C. P., and D. D. MacDonald. 1991. Effects of suspended sediments on aquatic ecosystems. North American Journal of Fisheries Management 11:72-82.

Newport, B. D., and J. E. Moyer. 1974. State-of-the-art: sand and gravel industry. U.S. Environmental Protection Agency, EPA-660/2-74-066, Washington, D.C.

Parker, G., and P. C. Klingeman. 1982. On why gravel bed streams are paved. Water Resources Research 18:1409-1423.

Parmalee, P. W. 1993. Freshwater mussels (Mollusca: Pelecypoda: Unionidae) of Tellico Lake: twelve years after impoundment of the Little Tennessee River. Annals of Carnegie Museum 62:81-93.

Pringle, C. M. 1997. Exploring how disturbance is transmitted upstream: going against the flow. Journal of the North American Benthological Society 16:425-438.

Reid, L. M., and T. Dunne. 1984. Sediment production from forest road surfaces. Water Resources Research 20:1753-1761.

Sax, J. 1970. The public trust doctrine in natural resource law: effective judicial intervention. Michigan Law Review 6:471.

Scott, K. M. 1973. Scour and fill in Tujunga Wash - a fanhead valley in urban southern California - 1969. U. S. Geological Survey Professional Paper 732-B.

Sidle, R. C. 1988. Bed load transport regime of a small forest stream. Water Resources Research 24:207-218.

Starnes, L. B., and D. C. Gasper. 1996. Effects of surface mining on aquatic resources in North America. Fisheries 21(5):24-26.

Stein, C. B. 1972. Population changes in the naiad mollusk fauna of the lower Olentangy River following channelization and highway construction. Bulletin of the American Malacological Union Incorporated February:47-49.

Svedarsky, W. D., and R. D. Crawford. 1982. Wildlife values of gravel pits. University of Minnesota Agricultural Experiment Station, Miscellaneous Publication 17-1982, St. Paul.

Tryon, C. P. 1980. A study of extreme water temperatures at the Lane Spring Trout Management Area. U.S. Forest Service, Mark Twain National Forest, Rolla.

Vick, J. 1995. Habitat rehabilitation in the Lower Merced River: a geomorphological perspective. Masters thesis. University of California, Berkeley.

Waters, T. F. 1965. Interpretation of invertebrate drift in streams. Ecology 46:327-334.

Waters, T. F. 1995. Sediment in streams: sources, biological effects, and control. American Fisheries Society Monograph 7.

Weithman, A. S. 1984. Opinions and outdoor activities of Missouri residents. Missouri Department of Conservation, Jefferson City.

Weithman, A. S. 1991. Stream use and awareness in Missouri. Missouri Department of Conservation, Jefferson City.

Weithman, A. S. 1994. Fisheries Division's opinion and attitude survey about Missouri's aquatic resources. Missouri Department of Conservation, Jefferson City.

WCC (Woodward-Clyde Consultants). 1980a. Gravel removal studies in arctic and subarctic floodplains in Alaska. U.S. Fish and Wildlife Service, Report FWS/OBS-80/08, Washington, D.C.

WCC (Woodward-Clyde Consultants). 1980b. Gravel removal guidelines manual for arctic and subarctic floodplains. U.S. Fish and Wildlife Service, Report FWS/OBS-80/09, Washington, D.C.

Whiting, P. J. 1998. Floodplain maintenance flows. Rivers 6:160-170.

Appendix 1

Special Conditions - U.S. Army Corps of Engineers, Kansas City District, Issuance of General Permit (GP-34M), Sand and Gravel Excavation Activities - December 1995:

a. If any part of the authorized work is performed by a contractor or other party, before starting work [the permittee] must discuss the terms and conditions of this permit with the contractor or party; and, [the permittee] must give a copy of this entire permit to the contractor or other party involved in the excavation activities. The permittee remains responsible for ensuring compliance with all aspects of this permit.

b. [The permittee] must limit excavation of sand or gravel deposits to unconsolidated areas containing primarily smaller material (at least 85% of material is less than 3" in diameter) that is loosely packed and contains no woody perennial vegetation greater than 1 inch in diameter, measured at breast height (4.5 feet).

c. [The permittee] must maintain an undisturbed buffer of twenty (20) feet (or as specified on the attached project authorization page(s) of this permit) between the removal area and the water line at the time of excavation, and between the removal area and bank vegetation. Personal use activities involving excavation under 100 cubic yards of material, as specified in Appendix 1, paragraph 3, must maintain an undisturbed buffer of ten (10) feet in the areas specified previously.

d. [The permittee] must maintain a twenty five (25) foot wide streamside (riparian) corridor in an undisturbed condition landward of the high bank for the length of the gravel removal site. Disturbed areas in this riparian zone shall be limited to maintained access road(s) for ingress and egress only. No clearing within this riparian area is authorized in association with work authorized by this permit.

e. [The permittee] must not excavate sand or gravel below the elevation of the water at the time of removal. If the stream is dry at that time, [the permittee] must not excavate deeper than the lowest undisturbed elevation of the stream bottom adjacent to the site, unless specified otherwise on the attached project authorization page(s) of this permit.

f. [The permittee] must not relocate, straighten, or otherwise modify water conveyance areas within the channel. A "water conveyance area within the channel" is defined as that area between the high banks of the creek where water is flowing or, in the case of a dry stream, where water would flow after a rain event.

g. Within 30 days of the removal of excavation equipment from the site, [the permittee] must revegetate or otherwise protect from erosion, those streambank areas disturbed by the removal operation. For long-term operations (longer than 30 days) or for sites that will be periodically revisited as gravel is deposited, access points must be appropriately constructed and maintained such that streambanks and access roads are protected from erosion.

h. Prior to the removal of excavation equipment from the site, oversized material or other disturbed bed material must be removed or replaced in the removal areas and smoothed to approximately the original contours of the sand or gravel deposit, as much as possible.

Oversized material is preferred when available as it better stabilizes the disturbed bar. All required buffer areas must remain intact and should not be smoothed as part of this condtion. Any aggregate, fines, and/or oversized material removed from the site must be placed in an upland, nonwetland site that has been approved by the landowner. No material, including oversized, that results from the excavation activity may be stockpiled or otherwise placed into flowing water or placed against streambanks as bank stabilization, unless specifically authorized in writing by the Corps of Engineers.

i. [The permittee] must conduct all sand or gravel washing, gravel crushing, and gravel sorting above the high bank, in a nonwetland area away from areas that flood, such that gravel, silt, and wash water that is warm, stagnant, or contains silty material can not enter the stream or any wetland. A separate permit and/or settling basin for the discharge of return water may be required under Section 402 of the Clean Water Act from the Missouri Department of Natural Resources, Water Pollution Control Program, Permit Section ([573]-751-6825). Gravel crushing and/or sorting activities which do not require wash water are allowed to occur on the gravel bar, provided all fines are immediately removed from the gravel bar and not stockpiled or otherwise disposed of on the gravel bar, into the stream or any other water of the U.S. (including wetlands). All fines resulting from the sorting operation must be captured in a transport truck or other suitable container and removed from the sorting location to a suitable disposal site the same day the sorting occurs. All sorted aggregate must be removed from the gravel bar at the end of each working day, with the exception of oversized material that will be spread out in the excavation areas following project completion.

j. [The permittee] must not excavate in those areas authorized by this general permit during the dates specified on the attached project authorization page(s) in the block identified as "Seasonal Restrictions". This time period restriction is for the purpose of protecting spawning habitat and juveniles indigenous to the cited stream.

k. [The permittee] must limit vehicles and other equipment to removal sites and existing crossings. Streams must be crossed perpendicular to the stream. [The permittee] must obtain written approval from the Corps of Engineers, Regulatory Branch, before constructing any temporary or permanent stream crossing(s). Use of off road vehicles in streams is also regulated under Missouri State Law (RSMo 1991 Section 304.013).

l. Fuel, oil, and other wastes and equipment containing such wastes shall not be stored nor released at any location between the high banks or in a manner such that they could enter the stream channel. [The permittee] must dispose of such materials at authorized locations.

m. No activity is authorized under this general permit which is likely to jeopardize the continued existence of a threatened or endangered species or a species proposed for such designation, as identified under the Federal Endangered Species Act, or which is likely to destroy or adversely modify the habitat of such species. See Appendix II, paragraph No. 1 for permitting requirements if these species are likely to be present or their habitat would be adversely modified.

n. No activity which may affect Historic properties listed, or eligible for listing, in the National Register of Historic Places is authorized, until the District Engineer has complied with the provisions of 33 CFR 325, Appendix C. All prospective permittees must notify the District

Engineer if the excavation activity may affect any historic properties listed, determined to be eligible, or which the prospective permittee has reason to believe may be eligible for listing on the National Register of Historic Places, and shall not begin the activity until notified by the District Engineer that the requirements of the National Historic Preservation Act have been satisfied and that the activity is authorized. Information on the location and existence of historic resources can be obtained from the State Historic Preservation Office and the National Register of Historic Places.

o. [The permittee] must provide notification to the appropriate Corps of Engineers district, as specified in Appendix I, before [the permittee] initiate[s] any gravel removal activity and receive[s] written confirmation of authorization under this general permit from the Corps of Engineers before [the permittee] start[s] any excavation or related operations.