WHITE PAPER

INSTREAM AGGREGATE MINING ISSUES IN OREGON

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INTRODUCTION AND SCOPE

Sediment is removed from streams throughout the United States and Oregon for many reasons including: flood control, navigation channel maintenance, channel stability, irrigation diversion maintenance, and for the production of aggregate (sand and gravel). This paper focuses on instream removal of sediment for the purpose of acquiring aggregate for commercial use.

This document provides a brief summary of potential instream aggregate mining effects on Oregon streams. For further information, the reader is referred to *Gravel Disturbance Impacts on Salmon Habitat and Stream Health* (OWRRI 1995), *Freshwater Gravel Mining and Dredging Issues* (Kondolf, Smelzer, and Kimball 2002), and *The Effects of Sediment Removal from Freshwater Salmonid Habitat* (Cluer 2003). This paper is not intended as a policy document.

EXTENT OF AGGREGATE MINING IN OREGON STREAMS

Aggregate mining generally occurs within 30 to 50 miles of the intended market because the cost of transport is the primary expense in this industry (Meador and Layher 1998). Hence, many large-scale aggregate operations are found near cities and along major roadways. In Oregon, the focus of much instream aggregate mining activity is along the I-5 corridor in the Willamette Valley and in the Umpqua basin (OWRRI 1995). The market for this aggregate includes Portland, Salem, Albany, Eugene, and Roseburg plus many other smaller municipalities, and counties.

Most aggregate (96%) is used for construction purposes including concrete, road fill, asphalt, and drain rock. The remainder is used for filtration beds, abrasives, glass manufacturing, and foundry operations (Meador and Layher 1998). Instream deposits of gravel are valuable because they are easily accessible, well-sorted, and generally free from fine sediments such as silt and clay.

In Oregon, aggregate extraction that occurs outside of the active channel is regulated by the Oregon Department of Geology and Mineral Industries (DOGAMI) through their Mineral Land Regulation and Reclamation Program housed in the Albany Field Office. Instream aggregate extraction is regulated by the Oregon Division of State Lands (DSL). DOGAMI indicates that annual removal of aggregate from floodplains and upland sites ranges from 44 to 52 million cubic yards per year (based on the past 5-years). DSL reports that annual permitted aggregate extraction rate (based only on the operations that pay royalties to the state) from streams is approximately 5.5 million cubic yards per year. Based on these numbers, approximately 9.5 to 11 percent of commercial aggregate is derived from Oregon streams each year, although the distribution of instream extraction is not equal through-out the state (OWRRI 1995). Sand and gravel usage also varies temporally through-out the state, and is dependent upon major construction activities such as highway and dam building projects. In the near future, aggregate usage will again increase as the state undertakes a vast program to replace Oregon’s highway bridges. While the use of sand and gravel varies both spatially and temporally, overall permitted aggregate extraction has increased from 1967 to the present (OWRRI 1995), however, increases in permitted extraction quantities does not directly correlate to actual increases in extraction.

General Methods for Mining Aggregate

Permit conditions issued by the US Army Corps of Engineers (COE) and DSL limit the extent and quantity of gravel removal in Oregon streams. There are generally requirements for the post-mining site conditions including point bar slopes and buffer zones. Some permits now require pre- and post-extraction surveys with elevational limitations corresponding to a set vertical datum rather than a floating datum. This is often referred to as the “red-line” method.

There are two predominant ways that sand and gravel are mined from the landscape: instream extraction and land mining. Floodplain pits are sometimes considered upland mining and at other times are considered as part of instream extraction. This distinction depends on the adjacency to the stream channel and the likelihood of a channel capture. Only instream extraction, generally excluding floodplain pits, will be addressed in this paper.

Instream extraction can be completed by various methods including scraper, dragline, bulldozer, front-end loader, shovel, and dredge (Meador and Layher 1998). In Oregon, the primary means of obtaining instream aggregate include *instream pit extraction* and *bar scalping*, which are described in more detail below.

Instream Pit Extraction

Major instream pit extraction activities have occurred in the Willamette, Columbia, and the lower Umpqua Rivers (OWRRI 1995), although there are only a few remaining operations in Oregon.

Instream pit extraction generally uses a clamshell dredge or dragline. Sediment is removed from the bed of the channel and transferred to barges. The sediment can be cleaned and sorted on the barge or it can be delivered to a processing site for further sorting. The location of the dredging site can be restricted to individual locations within a stream system, or may be undefined to specific locations but rather constrained by river miles. Depth, extent, and timing of dredging is conditioned in the individual COE and DSL permits.

Bar Scalping

Bar scalping has occurred in many streams throughout Oregon and is currently the most common type of instream mining utilized. Bar scalping occurs extensively throughout western Oregon, but is concentrated in the Willamette and Umpqua basins and in several coastal streams (Figure 1).

Bar scalping typically occurs during low water periods. The aggregate is removed from exposed bar areas (typically alternate bars) with scrapers or other heavy equipment, and then the material is generally carried to a collection point where it is transferred to a processing facility. Excavation depths are limited to an elevation above the low water surface. Depending upon the water year, this datum can fluctuate considerably. During wet years, the depth of excavation may be quite minimal, while dry years may allow significant excavation due to the greater exposure of river gravel. The amount of material removed is also dependent on the level of sediment transport that occurs in any given year and limits imposed by the COE and DSL permits. A significant amount of sediment is not necessarily transported every year, but is rather episodic and is related to high flow and event history in the watershed (*i.e.* bank erosion, landslides, and debris flows).

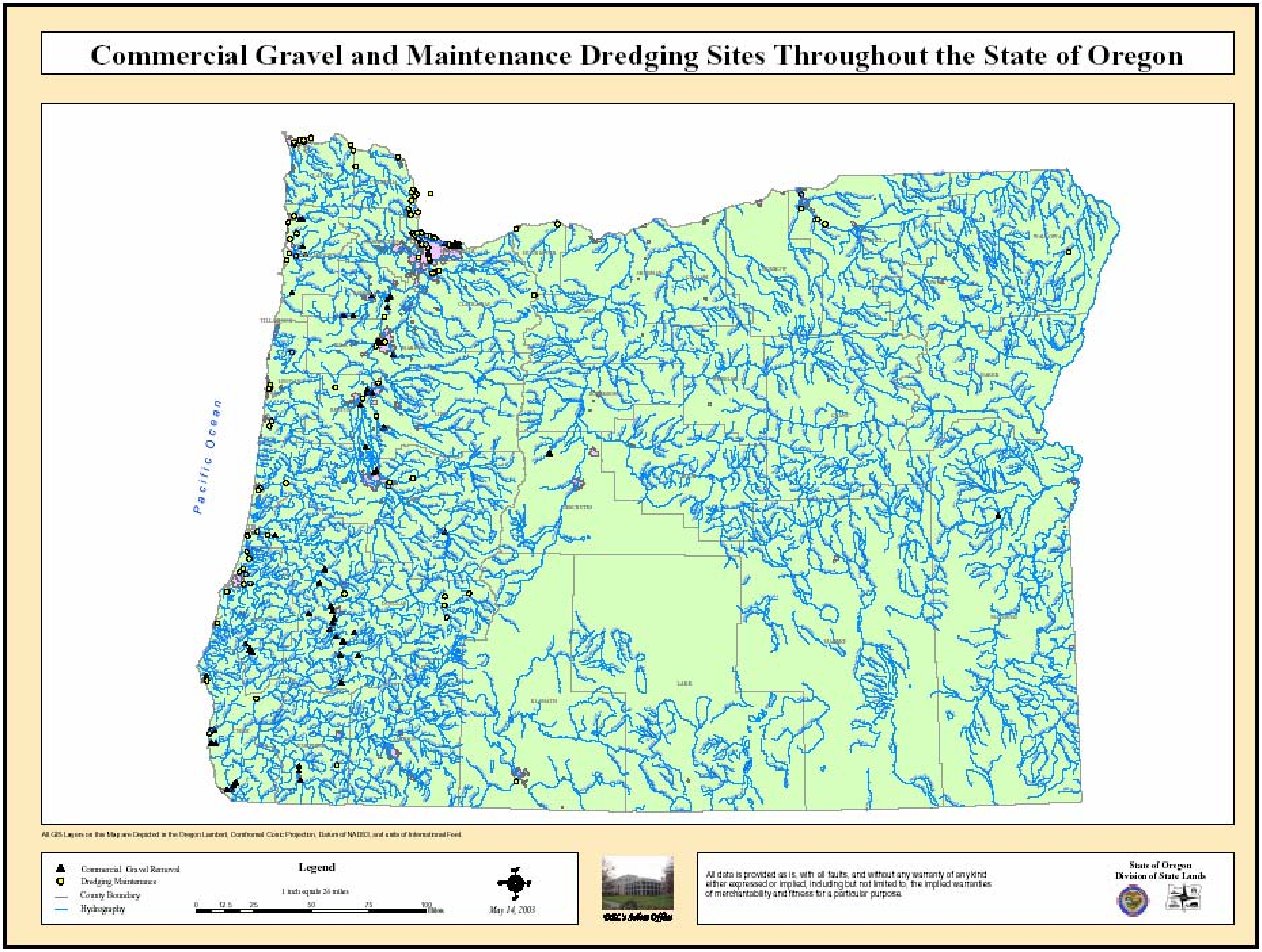

Figure 1. Commercial Gravel and Maintenance Dredging Sites in Oregon.

EFFECTS OF INSTREAM AGGREGATE MINING IN STREAMS

With few exceptions, sediment removal activities for commercial sediment production occur in coarse bed alluvial stream channels that are structured with alternating bars and sequential pool-riffle complexes (Keller and Melhorn 1978; Trush *et al.* 2000). Comprised of deposited coarse sediments, alternate bars occur in straight, sinuous, and meandering channels as well as within straightened and levee-confined engineered channels. Coarse bed materials are typically transported and deposited in appreciable quantities along streams during flood flows on only a few days per year. Transport of coarse bed materials does not necessarily occur every year.

Channel pools form adjacent to the widest portion of alternate bars; riffles occur where the thalweg (deepest part of the channel) crosses from one bank to the other. Pools can also occur where rock outcrops, or where exceptionally large woody debris, collections of small woody debris, or tributary inflow interact with the stream channel. The pools and riffles are the fundamental components of aquatic habitat in riverine ecosystems.

The removal of alluvial material from a streambed has direct impacts on the stream's physical boundaries, on the ability of the stream to transport and process sediment, and numerous associated habitat qualities. Local physical effects that occur immediately following sediment 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 average stream depths, and (7) changes in velocity patterns. In addition, increased turbidity, changes in sediment transport patterns and timing, and changes in air and water temperature, especially if riparian vegetation is removed, may also occur (Rundquist 1980; Pauley *et al.* 1989; Kondolf 1994a, 1994b; OWRRI 1995).

In addition to the local and immediate effects, there are delayed effects that may occur over wide areas. Recovery from some effects can occur quickly once disturbance ceases. However, other effects require longer periods for recovery, and some effects are not recoverable. For example, alternate bars that have been skimmed to low elevations will recover height and dimensions similar to pre-disturbance conditions during subsequent high flow events, but only if adequate sediment load is available from upstream and the stream has not incised. Delayed recovery 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 recovers and substrate stability is regained (not only at the specific site but in the entire stream reach affected). These recovery processes may require many years.

Channel hydraulics, sediment transport, and stream morphology are directly affected by sediment removal activities. When human actions reshape the stream boundary by removing materials, flow hydraulics are altered. These modifications lead to shifts in flow patterns and subsequent changes in sediment transport rates and timing, and local sediment sorting patterns. These physical changes can adversely affect instream biota (Kanehl and Lyons 1992; Hartfield 1993; Benhke 1990; Newport and Moyer 1974; Waters 1995; Brown *et al.* 1998) and the associated riparian habitat (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), and/or cause shifts in species age distributions (Moulton 1980; Benhke 1990).

Activities that disturb stream channels can disrupt the ecological continuum in many ways. Local channel modifications can propagate changes both upstream and downstream, as well as up into tributaries (Pringle 1997). 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 extensively as some activities within the channel (OWRRI 1995). The potential effects of sediment removal activities on stream form and function, riparian habitat, and aquatic habitat are reviewed in the following sections.

Effects on Channel Morphology and Hydraulics

The morphology of a stream is controlled by a dynamic balance between the water quantities 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.

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

The effects of sediment removal on channel hydraulics and thus morphology 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. Effects may be delayed due to the frequency of flood events required to transport the available sediment and thus modify channel and floodplain characteristics. So, effects that are attributed to large flood events may actually be the result of previous years activities that have "set the stage" for major morphologic changes. Therefore, all rivers do not respond exactly alike to the same disturbance and the same river may not respond consistently to the same disturbance over time. The following sections describe predictable and widely observed changes initiated by sediment removal.

Increased Width / Depth Ratio.

The ratio of flow width to average flow depth is a commonly used measure of channel cross-sectional dimensions because the ratio is related to sediment transport processes and has biological relevance. The removal of channel sediments changes the width/depth ratio (W/D) of channel cross-sections by decreasing the height of bar deposits, which results in a wider channel for any given discharge that overtops the altered surface. The greatest effect of increased W/D is observed at alternate bars and islands, with relatively little change observed at the riffles.

These effects are pronounced in hydraulic modeling analyses (*e.g.*, HEC-2; HEC-RAS); however, sophisticated 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 **W** is width; **D** is depth; **V** is velocity; and **A** is area;
where **A = WD**
.

It is possible to predict the effects of sediment removal upon 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.

Bank Erosion.

Bank erosion and bank retreat are commonly observed at long-term sediment extraction areas. The streambanks derive their strength and resistance to erosion largely from vegetation (Yang 1996) and to lesser degrees from their composition, 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 bank integrity and riparian vegetation at access points. Bank strength is further reduced if shallow groundwater drains into the stream through the banks in the case of an incised stream.

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

Changes in Sediment Transport.

The ability of stream flow to transport sediment is often represented by the shear stress. Shear stress calculations are commonly used to estimate the ability of a moving fluid to entrain and transport sediment from the streambed. The sediment particles on the streambed become mobile when the resistance to shear is exceeded, which is referred to as the critical shear stress or incipient motion condition. Where shear stress increases, sediment is transported in greater volume, greater particle size, or both. Where shear stress decreases, the mobile particle size and/or total transport volume decreases.

Shear stress equations are the physical basis of sediment transport models. It is essential that assessments include both the effects on hydraulics and on the ability of the stream to transport sediment in the vicinity of channel modifications. For example, the incipient motion condition and the relative stable grain sizes in particular habitats can be calculated utilizing shear stress formulas and results from simple hydraulic models. Analysis of changes in shear stress on the bed can provide insight as to the fate of macroinvertebrate habitat and spawning areas.

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

Reduced Sinuosity of the Moderate to High Flow Channel.

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

Altered Sediment Sorting Processes.

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

Sediment removal for commercial production typically reduces alternate bar heights. Flow that overtops bars with reduced height have relatively less variation in the flow pattern, and thus reduced convergence and divergence. This results in a more simplified channel (*e.g*. fewer pools and riffles) and less concentrated and less effective particle-sorting processes. Therefore, it can be predicted that reductions in bar height will induce decreases in the area of spawning beds, reductions in pool area and depth, and a general loss of microhabitats within the stream reach.

Alteration of the Sediment Transport Continuum

Over time, stream channels obtain equilibrium between the sediment load and dominant sediment transporting flows. A gradual migration of the stream 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 and others (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."* In Oregon, this phenomenon was observed on the mainstem McKenzie River. Reduction in sediment supply and decreased peak flows due to dam construction, in combination with gravel mining operations, resulted in a 57% reduction in exposed gravel bars from 1949 to 1986 between Trailbridge Dam and Leaburg Dam (OWRRI 1995). A coarsening of the substrate was also noted (OWRRI 1995).

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 for the supply deficiency. If stream bed lowering leads to bank heights that become unstable, rapid bank retreat may arise. This further destabilizes the width while supplying the channel with sediments that make good the transport-supply imbalance. Further degradation is prevented until the available sediments are flushed out (Knighton 1984). Thus sediment removal from a relatively confined area can trigger erosion migrating upstream causing erosion of the bed (incision) and banks which increases sediment delivery to the site of original sediment removal.

The ultimate effect of channel bed lowering is degradation along the entire length of channel by approximately the same amount, leading to a new channel profile. Within the new channel the geometry changes, initially becoming narrower, deeper, and less complex. 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). This process is fully described by channel evolution models (Schumm *et al*. 1984). Few monitoring programs associated with commercial sediment removal projects are capable of detecting the fundamental bed degradation over time scales, or spatial areas, relevant to the potentially effected aquatic ecosystem.

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 occurs. 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 pools aggrade and the already weakened streambanks 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. Fish habitat is reduced in unstable channels (*e.g.* Kanehl and Lyons 1992; Hartfield 1993; Benhke 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 streambeds and bar deposits provides the stream a readily erodible sediment supply because relatively finer grained sediment is now available for transport at a lower discharge. The new supply of sediment derived from the streambed will be moved downstream, where it can adversely affect aquatic habitats. The effects may extend considerable distances downstream if the area of disturbance is large (several consecutive bars).

Downstream from sediment removal sites the dynamic system has less coarse-grained 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.

Two factors ameliorate bed and bank erosion caused by sediment removal: (1) resistance of the bed and banks to increased shear stress, and (2) 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 effects of sediment removal are easily masked by 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 recovery following or between disturbances. Streams that are repeatedly harvested at rates in excess of sediment influx undergo channel degradation, possibly causing incision of an entire stream system including its tributaries. Striking cases of excessive sediment removal are summarized by Harvey and Schumm (1987), Sandecki (1989), Collins and Dunne (1990); Kondolf and Swanson (1993), and Florsheim and others (1998).

Effects on Habitat Components

The removal of sediment in stream channels can adversely affect aquatic habitats used by various species and their respective life stages. The riparian zone is also affected by instream mining operations both directly (removal of vegetation) and indirectly (reduced sediment inputs and reduced stream stability).

Effects on Riffle Habitats.

The movement of water does not cease at the interface between the river and its substrate. Water moves through pore spaces in the streambed, particularly where the bed has topographic relief. Predictable zones of inflow and outflow (downwelling and upwelling) are found on the streambed. The more complex the channel pattern and surface topography, the more strongly developed are downwelling and upwelling hyporheic zones (Brunke and Gonser 1997). 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).

Sediment removal practices can adversely affect proper functioning of riffle habitats by exacerbating fine sedimentation of the substrates, changing hyporheic flow patterns, causing barriers to adult fish migration (due to over-widened channels with shallow flow), reducing benthic invertebrate production, and directly affecting eggs, embryos, and/or young fish inhabiting the interstitial spaces within the substrate.

a. Changes in bar substrate and spawning habitat. Mature gravel bars have a height slightly less than the floodplain (if the channel is in equilibrium, or related to the dominant flow elevation), a coarse armor layer at its head, and vegetation elsewhere that is not frequently disturbed by floods. The condition of maturity is obtained where bars are not frequently disturbed. The partial removal (or surface disturbance) of bars can adversely affect aquatic habitats, including spawning areas.

Riffle habitats can be scoured and swept downstream as the result of increased shear stress. This process can also preclude the deposition of new gravel from upstream sources. When channel bars are removed, the channel is effectively widened at low and moderate flows while channel slope is increased (due to straighter flow path), and migrating gravel particles are then 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. Spawning habitats are especially vulnerable to these changes. The loss of egg inoculated gravel from riffles was documented by Pauley and others (1989), who concluded the eggs were scoured because bar skimming reduced bar heights, increasing shear stress on the streambed.

Sediment removal can increase the load of fine sediments that can clog, or embed, the interstitial pores of coarse substrates. Mature alternate bar surfaces are covered with an armor layer of coarse particles. Because channel bars are coarser at their surface than at depth, bar skimming exposes smaller sediment particles (Figure 2) that are more readily transported downstream, and are transported earlier in the season since higher flows are not required to disrupt the protective armor layer. This newly exposed sediment will not become hydraulically stable for at least one year until the sediments have been exposed to flows of sufficient magnitude to resort the material. If spawning occurs in these unstable sediments, shifting gravels could cause mortality of incubating embryos (OWRRI 1995).

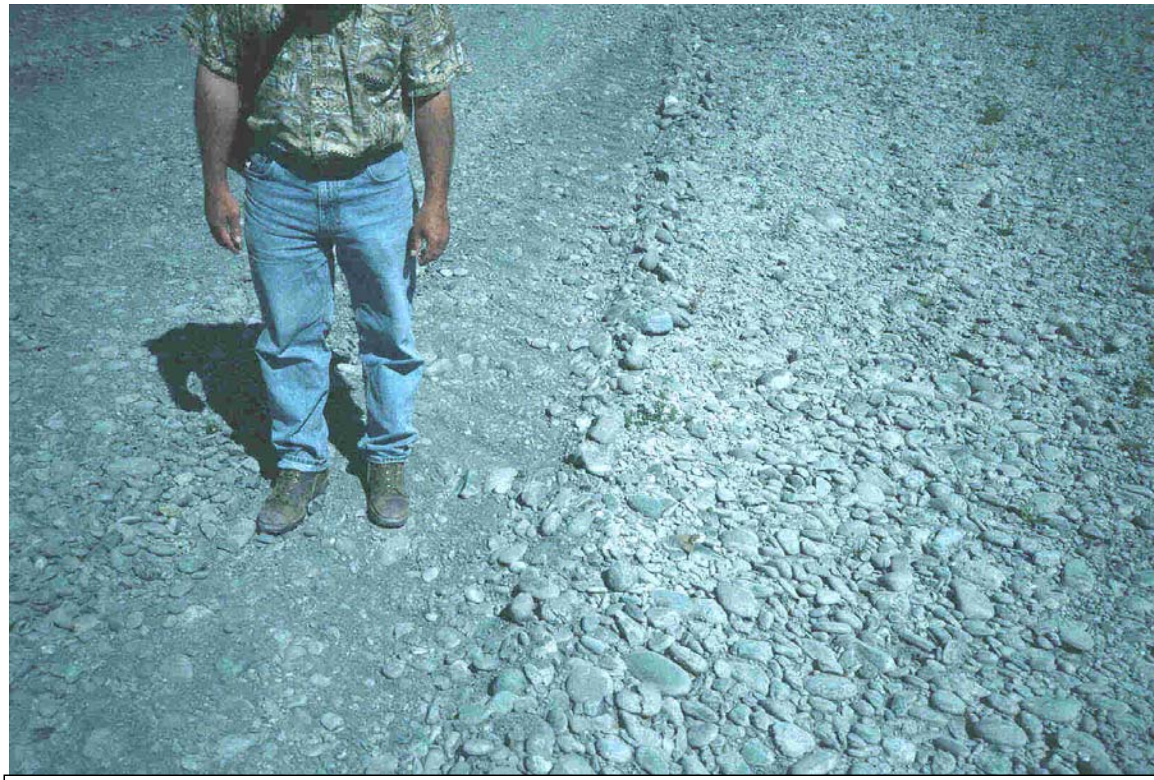

Figure 2. Photo of grain-size differences between skimmed (left) and unskimmed (right) bar surface.

<u>b. Sediment intrusion.</u> Sedimentation of streambeds is caused by the settling of suspended particles in low velocity areas and by the process of sediment intrusion. McDowell-Boyer and others (1986) identified two mechanisms by which porous substrates can become clogged with fines: (1) particle straining, and (2) the formation of surface cakes. Jobson and Carey (1989) defined particle straining as the process where fine particles move into the porous media until they encounter pore spaces too small for passage. Beschta and Jackson (1979) found that the potential for particle penetration is a function of the effective pore diameter of the streambed surface media and the size distribution of the particles moving in occasional contact with the bed. They 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 bed particle pore-space and the diameter of the mobile particles. Essentially, entrained particles can enter streambed material 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), and by Simons and others (1963). The authors examined the transport of well-graded material and observed fine sediment 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 and macroinvertebrates (Kondolf and Williams 1999).

Instream aggregate mining removes the armor layer, thus exposing finer sediment to the flow. This sediment is now available for transport during much lower flows than when it was protected by a coarser armor layer. 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 lack the magnitude or duration to transport the locally derived fine sediment sufficiently downstream. Fine sediments generated during sediment removal operations 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).

c. Boundary layer habitat. A relatively low velocity sublayer develops when fluids flow across any surface. The thickness of the sublayer is related to the height of the roughness on the surface. Most natural streams have rough beds created by coarse substrates, frequent larger particles, woody debris (notably large wood, however aggregates of smaller woody debris also influences the boundary), and vegetation along the banks.

Two scales of boundary layer thickness are important to aquatic species. The layer created by woody debris, bank complexity, and large cobble-boulder sized particles provides habitat for large and small fish where they can move about efficiently, while smaller scale boundary layer roughness created by gravel-sized particles is rich invertebrate habitat. Sediment removal, particularly bar top removal, reduces exposed particle size and LWD in streambeds. Reduced boundary layer height reduces macroinvertebrate production because of the loss of the boundary layer microhabitat.

d. Adult fish migration and passage. In natural streams, shallow riffles can be migration barriers to upstream migrating fish species. 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 (Bovee 1982; Bjornn and Reiser 1991). According to those recommendations, Chinook salmon, the largest salmonid species, requires minimum riffle depths of 24 cm; for successful passage, this depth should be provided "*on at least 25% of the total [cross-sectional] transect width and a continuous portion equaling at least 10% of its total width*." Sediment removal operations that increase W/D ratios (particularly bar scalping) increase the probability that shallow riffles will form migration barriers for some fish species. Pauley and others (1989) and Woodward-Clyde (1980) verified what the basic river mechanics equations predict -- that flow depths decrease over riffles, creating barriers to upstream-migrating adult fish, 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. Reduced flow-field complexity and increased migratory velocities, particularly reduced edge-water eddies and low velocity zones, result from reduced channel sinuosity (however, thalweg sinuosity may persist), increased W/D ratio at bars, and reduced topographic complexity of geomorphic features. This can affect adult fish during their upstream migrations across riffles, and juvenile fish will face challenges finding and using velocity refuges during high flows in relatively simplified, hydraulically smooth channels. Adult fish migration can also be adversely affected when sediment removal activities diminish the size and frequency of mainstem pools; habitat used for resting.

e. Effects on aquatic macroinvertebrates. Aquatic macroinvertebrates provide the principal food source for many aquatic species (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 (Benhke *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.*, midges) 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; 1977).

Impacts to aquatic macroinvertebrates may be protracted. The average life cycle of EPT species is one year, although several species have two-year life cycles. Fine sediments intruded deeply into the bed require mobilization of the bed itself to remove fines (Beschta and Jackson 1979; Diplas and Parker 1985). Bed mobilizing flows generally do not occur annually, so there is potential for the aquatic invertebrate food base to be diminished for some time and for some distance downstream from sediment removal areas. Brown and others (1998), who sampled substrates upstream, downstream, and within an instream 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 in downstream reaches.

Effects on Pool Habitats.

Extensive removal of alternate bars and other streambed sediments can adversely affect fundamental physical processes related to pool maintenance. The scour of pools during the high flows of winter and their subsequent reversal to sedimentation during summer are widely accepted physical processes. During high flows, coarse particles eroded from upstream riffles are transported through pools to downstream riffles. The process responsible for pool and riffle maintenance has been termed “velocity reversal” (Keller 1971) or “shear stress reversal” (Andrews 1979; Lisle 1979). Under this mechanism, as discharge increases, the energy to transport coarse sediment increases in pools at a faster rate than in riffles. As a result, when flows exceed about 60% of bankfull flow, the “reversal” process begins and coarse sediment eroded from upstream reaches can continue through pools to downstream riffles where they may become deposited. The “reversal” process becomes most effective at bankfull flow in undisturbed stream channels, as flow depth and velocity can increase only incrementally once the banks are overtopped.

Another consequence of the “reversal” process 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 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 physical process that maintains pools. The reduced confinement of flows can be expressed as an increased width to depth (W/D) ratio. Bar skimming for commercial sediment production typically increases W/D by varying degrees. As a result, pool maintenance processes are significantly impaired when alternate bars are removed.

Pools in altered channels 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.*, forest to vineyards) or where riparian vegetation dies and the vegetated banks fail (Kondolf and Curry 1986).

The implications of these impacts to pool formation and maintenance are considerable. 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). Pools are highly productive aquatic habitat that can be easily impacted by changes in the watershed causing increased sediment load as well as local changes in bars and pool scour processes.

Effects on the Riparian Zone.

The riparian zone represents the transitional area between uplands and stream channels, and is itself a transitional feature with varying zones of disturbance, moisture, and vegetation. Riparian areas are used by both aquatic and terrestrial species, thus concentrating many species into a relatively small land area. According to the Natural Resources Conservation Service (1999) "*riparian corridors are used by over 70% of all terrestrial species during some part of their life cycle, including many threatened and endangered species*." Examples of some of the more aquatic dependent species are Pacific giant salamander, red-legged frog, tailed frog, great blue heron, harlequin duck, belted kingfisher, American dipper, water vole, beaver, and river otter (Knutson and Naef 1997). Other benefits of riparian zones include: reduced flooding, reduced soil erosion, improved water quality, increased water quantity, groundwater recharge, bank stabilization, and improved air quality (NRCS 1999).

The presence of riparian vegetation adjacent to the low flow channel and within the flood prone area controls or affects morphological stability, microclimate, habitat complexity and diversity, migration corridors, abundance and retention of large woody debris, filtering of sediment and nutrient inputs from upland sources, nutrient cycling, particulate terrestrial inputs, and seed dispersal (Gregory *et al.* 1991). Riparian vegetation influences the evolution of geomorphic surfaces and is therefore critical in defining and maintaining the character of a river system (Gregory *et al.* 1991).

Vegetation, particularly when it is mature, provides root structure, which consolidates the substrate material and encourages channel stability that resists erosion forces (Beschta 1991) and helps to maintain or reduce channel width to depth ratios. By strengthening 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. 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).

Forested riparian zones create their own microclimates by moderating solar input during the summer and reducing heat loss during the winter. Reduced solar input along with increased humidity combine to form a moderated microclimate that is heavily utilized by various terrestrial species. The degree of shading is related to the canopy height and density in relation to the channel width and to the geographic location and directional orientation of the channel (Gregory *et al.* 1991). Sediment extraction may remove portions of undercut banks, thereby decreasing vegetative bank cover, reducing shading and increasing water temperatures (Moulton 1980).

Functioning riparian zones provide the necessary stability to support a diversity of backwater and microhabitat features in the floodplain. These features are created during scouring flood events, channel avulsions, wind throw, and other natural disturbances. Chute cut-off channels that are "sealed" with large wood on the upstream end provide excellent backwater habitat and also provide refugia during flood events. The diversity and complexity of the riparian zone and floodplain add diversity and complexity to the stream system as flows expand into the floodplain during high flow events.

Since riparian zones tend to be linear, they provide a natural migration corridor for terrestrial species. This is especially important in disturbed areas where habitat is fragmented. Marbled murrelet, elk, marten, some types of bats, beaver, and bald eagle use riparian zones as travel corridors for seasonal migration (Knutson and Neaf 1997). Riparian corridors can be narrow to wide, can have a simple to complex plant community structure, and can have low to high connectivity (NRCS 1999). Bar scalping typically widens the stream channel and hence decreases the width of the riparian zone. Connectivity is also decreased as access roads increase edge habitat and cause habitat fragmentation.

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 recovery of vegetation in streamside areas (Franklin *et al.* 1995) because it influences hydraulics and disrupts sediment transport (Hupp and Ostercamp 1996). The riparian zone acts as both a source for large woody debris and a factor in retention time. Natural bank erosion and tree mortality provide a source for large and small woody debris in stream channels. Floodplain roughness due to riparian vegetation disrupts flow paths and intercepts floating woody debris which may (1) create initially small jams that form new floodplains, (2) collect at the head of existing islands, or (3) reinforce an existing floodplain (Gregory *et al.* 1991).

Nutrient, sediment, and environmental pollutant filtration, retention, and processing is another important component of the riparian zone. Riparian buffer widths are often determined based on their ability to filter out sediments and/or specific nutrients. According to Knutson and Neaf (1997), 40 – 99% of organic debris and environmental pollutants can be filtered and biodegraded by riparian vegetation and soils. Decreasing the width of the riparian zone, either directly or indirectly, results in a decrease in the buffering or filtering capacity and may negatively affect water quality.

According to Gregory and others (1991) much of the food base for stream ecosystems is derived from adjacent terrestrial ecosystems. Riparian vegetation is an important component of the food web because it supplies nutrients via leaf fall and insect drop into the active stream channel. Both aquatic invertebrates and vertebrates consume this "outside" source of energy which provides one of the building blocks for the aquatic ecosystem (Gregory *et al.* 1991).

Sediment removal conducted at rates exceeding sediment influx, resulting in channel degradation, will cause the water table to decline by the amount of 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. Streambed degradation along the mainstem Willamette River was found to be occurring at a rate of one-foot per decade. The degradation was attributed to sand and gravel extraction, along with natural geologic events, bank stabilization, supply interception (from dams), and changes in the watershed. Local effects (*i.e.* sediment extraction and bank stabilization) were believed to be the primary causes of channel incision because the tributaries were less severely impacted (OWRRI 1995).

Sediment removal projects often cause the direct or indirect destruction of riparian vegetation along one or both streambanks 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). Gravel bars are incipient floodplain features. Left undisturbed, these bars may aggrade over time, allowing for the establishment of vegetation and further development of floodplain. Opportunities for colonization and succession of riparian plant communities are limited for the duration of sediment removal activities and remain limited until the bars recover to 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.

Plant communities in the floodplain include submerged species in the channel, emergent species along the margins of the river, and species along the banks and adjacent of the river. Any change in substrate and/or depth is likely to affect species composition (Bolton and Shellberg 2001). A few rare plants in Oregon that may occupy gravel areas, stream terraces, floodplain pools, ponds, and backwater channels include: *Astragalus diaphanus var. diurnus, Howellia aquatilis, Lomatium cookie, Rorippa columbiae*, and *Sphaerocarpos hians* (J. Christy *personal communication* 2003).

Effects on Stream Complexity and Diversity.

Sediment removal from bars creates a wider, more uniform channel section with less lateral variation in depth, and reduces the prominence of the pool-riffle sequence in the channel (Collins and Dunne 1990). Channel morphology is simplified as a result of degradation following sediment removal (Church *et al.* 2001). Reporting on an experiment, Lisle and others (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 feed 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 adjacent wetlands are dewatered. Initially complex channels tend to degenerate toward less sinuous single-thread channels; these effects amount to reduction in habitat diversity.

Removal or disturbance of instream roughness elements during sediment removal activities diminishes habitat complexity and the quality and quantity of 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 (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 (Franklin *et al.* 1995; Koski 1992; Murphy 1995; OWRRI 1995).

Large woody debris in streams creates pools and backwaters that fish 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, creating more stable features, 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 fish abundance (*e.g.*, see citations in Koski 1992; Franklin *et al.* 1995; Murphy 1995; OWRRI 1995).

Effects on Water Quality.

a. Episodic turbidity. Various instream sediment disturbance or removal actions may increase turbidity at different time periods. 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). Newly exposed areas of fine sediment will cause elevated levels of turbidity during the first freshet. Sediment removal or disturbance above the wetted stream may still create a persistent source of turbidity from the crossing of streams by heavy equipment and from activities associated with bridge construction occurring during the summer low-flow period. Stream crossing and bridge building activities are likely to cause short-term increases in turbidity during periods of low stream flow when aquatic species present may be stressed by other environmental factors such as high water temperatures.

The severity of impacts to fish from suspended sediment pollution is generally acknowledged to be a function of sediment concentration and duration of exposure. Newcombe and Jensen (1996) performed a meta-analysis of 80 published studies on fish responses to suspended sediment in streams and developed empirical equations that relate biological response to duration of exposure and suspended sediment concentrations.

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 flood or when pit retaining walls fail. Furthermore, once settling pits fill, they become a future source of fine sediment in 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. Temperature. Increases in the channel width to depth ratio, loss of hyporheic storage, loss of floodplain connectivity and thus shallow groundwater storage, removal or exclusion of riparian vegetation, and loss of channel complexity all lead to increases in water temperature during summer months. Water temperatures may be significantly reduced during winter months due to decreased flow depth and greater exposure which may also lead to an increase of anchor ice formation.

d. Dissolved oxygen and pH. According to the Oregon Water Resources Research Institute's 1995 report concerning gravel mining impacts in Oregon, *"[e]xposure of unoxidized (anaerobic) layers of sediments by gravel removal and other operations can lead to appreciable oxygen demand, both as biochemical oxygen demand (BOD) and as chemical oxygen demand (COD) from oxidation of reduced inorganic compounds (e.g., ferrous iron, sulfides, ammonia). Oxygen depletion of the water column occurs in the vicinity of and downriver from the gravel removal operation."* (OWRRI 1995). Reactive sediments may undergo a chemical change when resuspended, potentially reacting with hydrogen ions which can result in a change in pH. Except under unique circumstances, changes in pH due to aggregate extraction are expected to be minimal (OWRRI 1995).

e. Toxic compounds and heavy metals. Some sediment removal operations may have harmful compounds in the processing site that could be introduced to the stream's surface or subsurface flow. Wetting agents, flocculent, 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 hazardous petroleum products. 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.

Excavation of stream sediments also poses the risk of disturbing and mobilizing contaminated sediments and heavy metals that may be temporarily stored in the bed or banks of a stream. This is of particular concern near urban centers or downstream of known contaminated sites (such as Superfund sites). Contaminate surveys prior to excavation will significantly reduce this risk.

Fish and Wildlife: Harm, Harassment, and Mortality.

<u>a. Salmonids</u>. Cover is an important habitat component for juvenile salmonids, both as 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 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) salmonids 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 so 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. 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.

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

<u>b. Bull trout</u>. Bull trout have more specific habitat requirements than most other salmonids (Rieman and McIntyre 1993). Habitat components that particularly influence their distribution and abundance include water temperature, cover, channel form and stability, spawning and rearing substrate conditions, and migratory corridors (Fraley and Shepard 1989; Watson and Hillman 1997).

Bull trout are closely associated with stream substrates and are particularly vulnerable to substrate alterations, fine sedimentation, and channel instability. Spawning areas often are associated with cold-water springs, groundwater infiltration, and the coldest streams in a given watershed (Pratt 1992; Rieman and McIntyre 1993; Rieman and Clayton 1997). The preferred spawning habitat of bull trout consists of low-gradient stream reaches with loose, clean gravel (Fraley and Shepard 1989). Depending on water temperature, egg incubation is normally 100 to 145 days (Pratt 1992). Juveniles remain in the substrate after hatching, such that the time from egg deposition to emergence of fry can exceed 200 days. During the relatively long incubation period in the gravel, bull trout eggs are especially vulnerable to fine sediments and water quality degradation (Fraley and Shepard 1989). Increases in fine sediment appear to reduce egg survival and emergence (Pratt 1992). Juveniles are likely similarly affected. High juvenile densities have been reported in areas characterized by a diverse cobble substrate and a low percent of fine sediments (Shepard *et al*. 1984). Baxter and McPhail (1996) reported that newly emerged fry are secretive and hide in gravel along stream edges and in side channels. The stability of stream channels and stream flows are important habitat characteristics for bull trout populations (Rieman and McIntyre 1993). The side channels, stream margins, and pools with suitable cover for bull trout are sensitive to activities that directly or indirectly affect stream channel stability and alter natural flow patterns. For example, altered stream flow in the fall may disrupt bull trout during the spawning period, and channel instability may decrease survival of eggs and young juveniles in the gravel during winter through spring (Fraley and Shepard 1989; Pratt 1992).

Bull trout typically spawn from August to November during periods of decreasing water temperatures. Such areas often are associated with cold-water springs or groundwater upwelling (Rieman and Clayton 1997). Bull trout rely on migratory corridors to move from spawning and rearing habitats to foraging and overwintering habitats and back. Bull trout are opportunistic feeders; resident and juvenile migratory bull trout prey on terrestrial and aquatic insects, macro-zooplankton, and small fish (Donald and Alger 1993; Baxter and McPhail 1996). Adult migratory bull trout feed almost exclusively on other fish (Rieman and McIntyre 1993). Throughout their lives, bull trout require complex forms of cover, including large woody debris, undercut banks, boulders, and pools (Fraley and Shepard 1989).

Disturbed channels can directly affect the ability of bull trout to migrate, spawn, and rear. While bull trout may not spawn in most areas utilized for gravel mining in Oregon they may be affected while over-wintering, foraging, and migrating. They may also be affected indirectly from a reduction in forage base, loss or reduction of available cover habitat, migration barriers, or thermal barriers.

c. Oregon chub. The Oregon chub (*Oregonichthys crameri*) is a small minnow endemic to the Willamette River drainage of Oregon. This species was formerly distributed throughout the Willamette River Valley in off-channel habitats such as beaver ponds, oxbows, stable backwater sloughs, and flooded marshes. These habitats usually have little or no water flow, have silty and organic substrate, and have an abundance of aquatic vegetation and cover for hiding and spawning (Scheerer *et al.* 2003). Historically, rivers overflowed their banks, scouring new side channels and backwaters while filling in other areas. Habitat loss has occurred from the loss of these floodplain habitats. This loss of habitat combined with the introduction of nonnative species to the Willamette Valley resulted in a sharp decline in Oregon chub abundance.

Oregon chub can be affected by aggregate extraction activities by the direct loss of backwater habitats and riparian vegetation and indirectly through the change in flooding regimes or channel degradation.

d. Other fish. Many other fish species including lamprey (*Lampetra sp.*), sculpin (*Cottus sp.*), dace (*Rhinichthys sp.*), chub (*Gila sp.*), and other species may also be affected by gravel mining through the loss of habitat and changes in water quality. Many of these fish are primary prey for salmonids and other wildlife. As an example, lamprey larvae (*ammocoetes*) are food for many other fish and birds. Spawning is similar to salmonids in that they deposit their eggs in nests in gravel substrate. After they hatch the larval form drift along the edges of streams to fine substrate areas such as backwater habitat and pools where they bury themselves and are filter feeders for several years, after which metamorphosis occurs and they become juvenile then adult lamprey. Their close association with channel bottoms makes them very susceptible to substrate disturbances such as gravel extraction, streambed degradation, sedimentation, and loss of floodplain wetlands, side channels, and other slow backwater habitats.

e. Wildlife. Many semi-aquatic and terrestrial wildlife species are very dependent upon the various floodplain habitats. A variety of species use early successional and emergent vegetation along gravel bars for cover and foraging. The near-stream, riffle, and flatwater habitats are also used by many amphibians, reptiles, birds, and mammals for foraging. Gravel bars with large wood and a variety of substrate can serve as cover for a variety of small mammals and other wildlife and basking habitat for pond turtles. Floodplain habitats are very high in species richness and gravel bar habitat has been shown to contain a great abundance, high species richness, and unique species composition for riparian beetles (LaBonte 1998). Arthropods play a critical link in the food web as well and are essential to ecosystem function.

Some amphibians utilize streams for breeding -- generally the slower backwater habitat and ponds associated with gravel bars. Stream breeders include tailed frogs and Cope's and Pacific giant salamander. Many amphibians also utilize flatwater and riffle habitats. Gravel bars, stream edges, and backwater areas provide foraging, cover, and basking areas for many reptiles and amphibians (Table 1). Disturbance and alteration of the natural gravel bars shape, undulations, backwater ponds, and microhabitats reduces habitat for feeding and breeding areas for a variety of amphibians and reptiles.

A high percentage of birds are dependent on riparian areas for at least a portion of their lifestage. In Washington, 101 bird species depend on riparian habitats exclusively (Knutsen and Naef 1997). Eagles, osprey, and great blue herons are a few of the birds that depend on other prey species in the riparian area such as fish, frogs, and small mammals. Many birds use gravel bars for foraging and roosting, and some, such as killdeer, may use them for nesting areas. A variety of species such as the American dipper, harlequin duck, least tern, piping plover, and spotted sandpiper are closely associated with stream systems and their habitats (Table 1).

The value and use of floodplain habitats for wildlife movement, foraging, cover, and reproduction is critical and well-documented for many species. Loss and/or disturbance to these areas will have deleterious effects on wildlife populations and ecosystem function.

Table 1. Table of wildlife species use of stream and associated floodplain habitats that may be affected by gravel mining operations (not all inclusive).

Species	**Stream Use**	**Gravel Bar Use**	**Backwater(s) Use**	**Other notes**
Pacific giant salamander *Dicamptodon tenebrosus*	Breeding	Cover, forage		Impacted by sedimentation
Northwestern salamander *Ambystoma gracile*	Breeds in slow streams		Breeding	Lives underground
Southern torrent salamander *Rhyacotriton variegatus*	Breeding	Cover & forage	Cover	
Northern red-legged frog *Rana aurora aurora*	Slow streams for breeding	Cover	Ponds for breeding	Terrestrial outside of breeding period
Oregon spotted frog *Rana pretiosa*	Forage & cover	Cover, forage, and	Ponds for breeding & cover	Most aquatic native frog using floodplain habitats
Foothill yellow-legged frog *Rana boylii*	Breed low gradient rivers gravel substrate	Cover, forage	Pools for foraging & cover	
Western toad *Bufo boreas*	During dry periods	Basking	Ponds for breeding	Adults live underground & debris
Pond turtle *Clemmys marmorata*	Foraging	Basking and cover, LWD	Foraging & cover	Nest and torpor in upland areas
Garter snake *Thamnophis elegans*	Stream margin for cover & feeding	Basking, cover, feeding	Cover, foraging	Upland areas for breeding
Spotted sandpiper *Actitis macularia*	Foraging	Nesting		
Harlequin duck *Histrionicus histrionicus*	Foraging	Nests under banks or vegetation		

Killldeer *Charadrius vociferus*	Foraging	Nesting		
American Dipper *Cinclus mexicanus*	Foraging	Nesting		
Wood duck *Aix sponsa*	Foraging	Foraging, loafing	Foraging	Nests in trees, needs vegetation
American belted kingfisher *Megaceryle alcyon*	Foraging			Nest in streambanks
Great Blue Heron *Ardea herodias*	Foraging	Foraging	Foraging	Nests in tree tops in colonies
Water shrew *Sorex palustris*	Foraging		Nesting	Nests in vegetation, tunnels or under logs
River Otter *Lutra canadensis*	Foraging	Basking	Foraging, cover	Breeds in river banks
Beaver *Castor canadensis*	Forage, breed		Breed, forage	
Black bear *Ursus americanus*	Forage	Forage	Cover	
Bats *Myotis sp.*	Foraging and drinking		Roosts in trees	
Mink *Mustela vison*	Foraging, travel	Forage	Cover	Breed in streambanks

Disturbance Regimes

Stream systems are disturbance driven. Disturbances include natural variations in flow regimes and flood events, sediment delivery to the system, large inputs of organic materials, changes in base level, and other mechanisms which serve to temporarily or permanently alter the character of a stream or river. Disturbances are often described by their frequency (such as the 100-year flood), duration (length of time), magnitude (areal extent), intensity (force exerted), and severity (biological response) (OWRRI 1995). In Oregon, the two most recent major disturbances that are considered "benchmarks" for stream processes are the 1964 and 1996 floods.

Streambeds within the active stream channel experience the greatest frequency of geomorphic disturbance that may be on the order of every year or two (sediment transporting events). Side channel and backwater areas are not as frequently disturbed, but are affected by higher flow events and channel avulsions (perhaps 5 to 10-year flows). Generally, floodplains have even less frequent disturbances than the main and side channels; it may require a 10-year or larger flood event before a floodplain can be significantly altered. Terraces and hillslopes typically have the lowest frequency disturbance regime when placed in context of stream processes (slope failures and mass movement). Common to all of these disturbances is the episode of disturbance followed by a period of recovery (OWRRI 1995). If the disturbances become so frequent that the system cannot recover before the next disturbance event, then the stream is held in a constant state of disequilibrium or instability.

According to Poff (1992) *"[t]hat a physical event may constitute a disturbance at one level but not another indicates the hierarchical nature of disturbances."* Related to this hierarchy of physical disturbances, is relative stability of various habitat types. Habitat stability in the main channel is generally on the order of years (even though habitat units may form and reform in the same place for tens of years), whereas habitat stability on the floodplain may be on the order of decades.

Organisms respond to disturbances very differently depending upon their differences in developmental times, behavioral movements, and responses to environmental factors (OWRRI 1995). For instance, anadromous salmonids recover from massive disturbances, such as extreme floods, by having multi-year life spans that ensure a stable population even if an entire year class of fish are lost in a single flood event. Pringle (1997) argues that downstream human activities such as urbanization, dams, gravel mining, and channelization can cause upstream biological legacies such as genetic isolation, population-level changes, and ecosystem-level changes.

Alteration of a punctuated disturbance regime (as described above) to one of chronic disturbance overlain with larger infrequent disturbances, often results in a change of plant, fish, and wildlife communities that are more adapted to constant disturbance (OWRRI 1995). Incised streams and engineered channels may be subject to chronic disturbance because of floodplain disconnection. Instream activities, such as aggregate extraction, can cause chronic disturbance with a concomitant change in habitat and species. Although sediment transporting events may occur on an annual basis, and may be compared to aggregate extraction activities, they are temporally distinct from natural events. Natural sediment transporting events in Oregon generally occur during the late fall, winter, and spring, whereas sand and gravel excavation typically occurs in the summer months during low flow periods. "*Over the last six million years salmonids have evolved within the natural disturbance regime. Novel disturbances can shift the ecological rules governing community structure making the recovery of the original biota impossible*" (OWRRI 1995).

SUMMARY

Sediment removal from streams can result in bed degradation, bank erosion, channel and habitat simplification, reduced geomorphic processes such as pool maintenance, sediment sorting, and sediment intrusion, reduction in large woody debris, direct or indirect loss of riparian zones, and lowering of the shallow aquifer/hyporheic zone. Adverse biologic effects may include reduced primary productivity and macroinvertebrate populations, reduced ability for fish to avoid predators, reduced fish growth and success, reduced riparian vegetation and all associated aquatic and terrestrial benefits, reduced water quality, and direct mortality of fish.

Most rivers experiencing sediment removal activities are also subject to additional anthropogenic influences that could induce physical and biological changes similar to, or compounded by, those caused by instream sediment removal. Other influences include increased peak runoff from land use changes in the catchment, bank protection and flood control works, or upstream dam construction and water withdrawal. However, attributing impacts to commercial sediment production is justified because of (1) the scale of extraction relative to bedload sediment supply (extraction commonly equals or exceeds supply), and (2) the proximity of sediment removal actions and altered channel geometry, hydraulics, sediment transport, and riparian impacts.

Stream alterations typically increase sediment transport rates and lead to deeper incised channel geometry. Channel degradation is caused by individual or compounded stream management actions including: channelization, flood control, riparian vegetation removal, encroachment, dam construction, water table declines, and sediment extraction. Most Oregon streams have had more than one such alteration visited on them in the past century. The only system-wide alteration that can counteract the degradation tendency is increased sediment production within the watershed. Although land use practices have increased sediment production in many of Oregon's watersheds, the era of greatest impact is waning. Past sediment removal may have benefited the recovery of channels disturbed by increased sediment loads, but as the production of sediment returns to semi-natural levels, the continued removal will have to be curtailed to prevent unwanted channel degradation. This has already happened in some California streams (*e.g.* Kondolf and Swanson 1993; Collins and Dunne 1990; Florsheim *et al.* 1998).

The current scientific and gray literature, reviewed in this document, explains a wide range of harmful physical and biotic effects resulting from sediment removal. Table 2 briefly lists the effects of sediment removal from streams.

Table 2. Summary of effects of instream sediment removal.

Element of Instream Sediment Removal	**Physical Effect**
Removal of sand and gravel from a location or from a limited reach.	Upstream and downstream propagating degradation.
	Scour of upstream riffle.
	Reduced pool area.
	Bed surface armoring.
Removal of sand and gravel from a bar.	Loss of sand and gravel from neighboring bars.
	Wider, more uniform channel section, less lateral variation in depth, reduced prominence of the pool-riffle sequence.
Removal of sediment in excess of the input.	Channel degradation (incision).
	Lower groundwater table.
	Complex channels regress to single thread channels.
	Armoring of channel bed, may lead to erosion of banks and bars.
Reduced sediment supply to downstream.	Induced meandering of stream to reduce gradient. Erosion on alternate banks downstream.
Removal of vegetation and woody debris from bar and bank.	Reduce shade.
	Decrease channel structure from wood.
	Decrease drop-in food, nutrient inputs.

Geomorphic features within stream channels can recover from disturbances given adequate time, sufficient flow magnitude, and sediment supply. With alteration in runoff hydrology and sediment supply due to dams and land management, geomorphic recovery may be protracted. The basic building blocks for recovery, floods and sediment, are generally lacking. Once there is geomorphic recovery, we can expect ecologic recovery to follow.

Many of Oregon's major rivers have been subjected to repeated sediment removal activities, periodic dredging to maintain navigation, significant channel alteration for flood security reasons, floodplain/channel encroachment, and bank stabilization projects. This has resulted in substantial changes in the quality, quantity, and diversity of aquatic habitats. Channels have been simplified through straightening, large wood removal, and levee confinement. Many channels have either purposefully or inadvertently been disconnected from their floodplains resulting in the loss of side channel and back water areas. Where riparian areas remain, their extent and integrity have been diminished. All of these activities have culminated in simplified stream channels that may not provide sufficient habitat type, quantity, and quality for maintenance and recovery of native aquatic communities.

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