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Hungry Water: Effects of Dams and Gravel Mining on River Channels

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ABSTRACT / Rivers transport sediment from eroding uplands to depositional areas near sea level. If the continuity of sediment transport is interrupted by dams or removal of sediment from the channel by gravel mining, the flow may become sediment-starved (hungry water) and prone to erode the channel bed and banks, producing channel incision (downcutting), coarsening of bed material, and loss of spawning gravels for salmon and trout (as smaller gravels are transported without replacement from upstream). Gravel is artificially added to the River Rhine to prevent further incision and to many other rivers in attempts to restore spawning habitat. It is possible to pass incoming sediment through some small reservoirs, thereby maintaining the continuity of sediment transport through the system. Damming and mining have reduced sediment delivery from rivers to many coastal areas, leading to accelerated beach erosion. Sand and gravel are mined for construction aggregate from river channel and floodplains. In-channel mining commonly causes incision, which may propagate up- and downstream of the mine, undermining bridges, inducing channel instability, and lowering alluvial water tables. Floodplain gravel pits have the potential to become wildlife habitat upon reclamation, but may be captured by the active channel and thereby become instream pits. Management of sand and gravel in rivers must be done on a regional basis, restoring the continuity of sediment transport where possible and encouraging alternatives to river-derived aggregate sources.

As waters flow from high elevation to sea level, their potential energy is converted to other forms as they sculpt the landscape, developing complex channel networks and a variety of associated habitats. Rivers accomplish their geomorphic work using excess energy above that required to simply move water from one point on the landscape to another. In natural channels, the excess energy of rivers is dissipated in many ways: in turbulence at steps in the river profile, in the frictional resistance of cobbles and boulders, vegetation along the bank, in bends, in irregularities of the channel bed and banks, and in sediment transport (Figure 1). The transport of sand- and gravel-sized sediment is particularly important in determining channel form, and a reduction in the supply of these sediments may induce channel changes. The supply of sand and gravel may be the result of many factors, including changes in land use, vegetation, climate, and tectonic activity. This paper is concerned specifically with the response of river channels to a reduction in the supply of these sediments by dams and gravel mining.

Sediment is transported mostly as suspended load: clay, silt, and sand held aloft in the water column by turbulence, in contrast to bedload: sand, gravel, cobbles, and boulders transported by rolling, sliding, and bouncing along the bed (Leopold and others 1964). Bedload ranges from a few percent of total load in lowland rivers to perhaps 15% in mountain rivers (Collins and Dunne 1990), to over 60% in some arid catchments (Schick and Lekach 1993). Although a relatively small part of the total sediment load, the arrangement of bedload sediments constitutes the architecture of sand- and gravel-bed channels. Moreover, gravel and cobbles have tremendous ecological importance, as habitat for benthic macroinvertebrates and as spawning habitat for salmon and trout (Kondolf and Wolman 1993).

The rate of sediment transport typically increases as a power function of flow; that is, a doubling of flow typically produces more than a doubling in sediment transport (Richards 1982), and most sediment transport occurs during floods.

Continuity of Sediment Transport in River Systems

Viewed over a long term, runoff erodes the land surface, and the river network carries the erosional products from each basin. The rates of denudation, or lowering of the land by erosion, range widely. The Appalachian Mountains of North America are being denuded about 0.01 mm/yr (Leopold and others 1964), the central Sierra Nevada of California about 0.1

KEY WORDS: Dams; Aquatic habitat; Sediment transport; Erosion; Sedimentation; Gravel mining

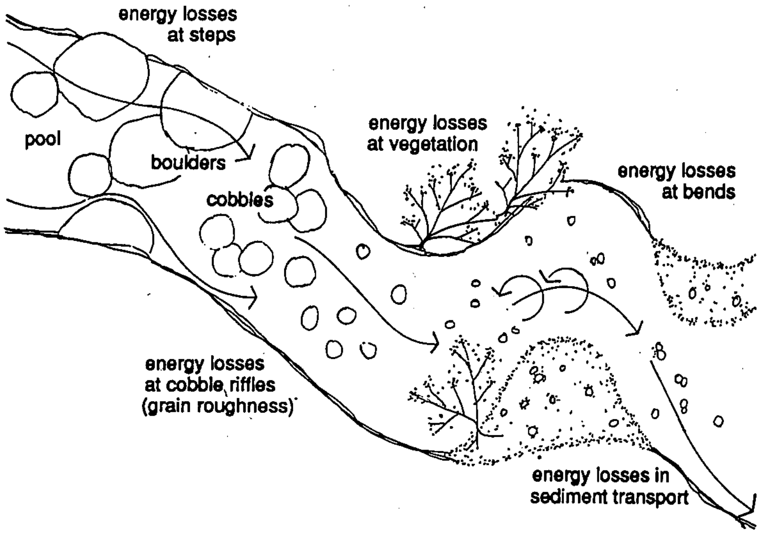

Figure 1. Diagram of energy dissipation in river channels.

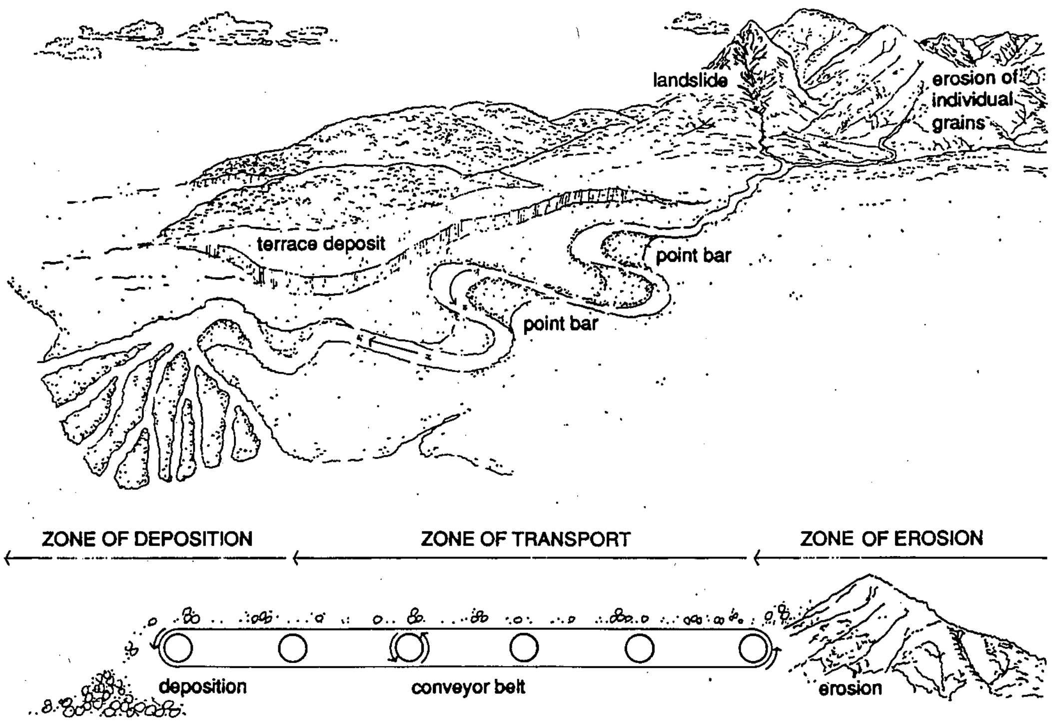

Figure 2. Zones of erosion, transport, and deposition, and the river channel as conveyor belt for sediment. (Reprinted from Kondolf 1994, with kind permission of Elsevier Science-NL.)

mm/yr (Kondolf and Matthews 1993), the Southern Alps of New Zealand about 11 mm/yr (Griffiths and McSaveney 1983), and the southern Central Range of Taiwan over 20 mm/yr (Hwang 1994). The idealized watershed can be divided into three zones: that of erosion or sediment production (steep, rapidly eroding headwaters), transport (through which sediment is moved more or less without net gain or loss), and deposition (Schumm 1977) (Figure 2). The river channel in the transport reach can be viewed as a conveyor belt, which transports the erosional products downstream to the ultimate depositional sites below sea level. The size of sediment typically changes along the length of the river system from gravel, cobbles, and boulders in steep upper reaches to sands and silts in low-gradient downstream reaches, reflecting diminution in size by weathering and abrasion, as well as sorting of sizes by flowing water.

Transport of sediment through the catchment and along the length of the river system is continuous. Increased erosion in the upper reaches of the catchment can affect the river environment many miles downstream (and for years or decades) as the increased sediment loads propagate downstream through the river network. On Redwood Creek in Redwood National Park, California, the world's tallest trees are threatened with bank erosion caused by channel aggradation (building up of sediment in the channel), which in turn was caused by clear-cutting of timber on steep slopes in the upper part of the catchment (Madej and Ozaki 1996, Janda 1978).

Along the river channel conveyor belt, channel forms (such as gravel bars) may appear stable, but the grains of which they are composed may be replaced annually or biannually by new sediment from upstream. Similarly, the sediments that make up the river floodplain (the valley flat adjacent to the channel) are typically mobile on a time scale of decades or centuries. The floodplain acts as a storage reservoir for sediments transported in the channel, alternately storing sediments by deposition and releasing sediment to the channel by bank erosion. For example, the Carmel River, California, is flanked by flat surfaces (terraces) that step up from the river. The lowest terrace is the channel of sand and gravel deposited by the 1911 flood, but the surface now stands about 4 m above the present, incised channel (Kondolf and Curry 1986). By 1960, the terrace had been subdivided for low-density housing, despite the recent origin of the land and the potential for future shifts in channel position.

A river channel and floodplain are dynamic features that constitute a single hydrologic and geomorphic unit characterized by frequent transfers of water and sediment between the two components. The failure to appreciate the integral connection between floodplain and channel underlies many environmental problems in river management today.

Effects of Dams

Dams and diversions are constructed and operated for a wide variety of purposes including residential, commercial, and agricultural water supply; flood and/or debris control; and hydropower production. Regardless of their purpose, all dams trap sediment to some degree and most alter the flood peaks and seasonal distribution of flows, thereby profoundly changing the character and functioning of rivers. By changing flow regime and sediment load, dams can produce adjustments in alluvial channels, the nature of which depends upon the characteristics of the original and altered flow regimes and sediment loads.

Dams disrupt the longitudinal continuity of the river system and interrupt the action of the conveyor belt of sediment transport. Upstream of the dam, all bedload sediment and all or part of the suspended load (depending upon the reservoir capacity relative to inflow) (Brune 1953) is deposited in the quiet water of the reservoir (reducing reservoir capacity) and upstream of the reservoir in reaches influenced by backwater. Downstream, water released from the dam possesses the energy to move sediment, but has little or no sediment load. This clear water released from the dam is often referred to as hungry water, because the excess energy is typically expended on erosion of the channel bed and banks for some years following dam construction, resulting in incision (downcutting of the bed) and coarsening of the bed material until equilibrium is reached and the material cannot be moved by the flows. Reservoirs also may reduce flood peaks downstream, potentially reducing the effects of hungry water, inducing channel shrinking, or allowing fine sediments to accumulate in the bed.

Channel Incision

Incision below dams is most pronounced in rivers with fine-grained bed materials and where impacts on flood peaks are relatively minor (Williams and Wolman 1984). The magnitude of incision depends upon the reservoir operation, channel characteristics, bed material size, and the sequence of flood events following dam closure. For example, the easily eroded sand bed channel of the Colorado River below Davis Dam, Arizona, has incised up to 6 m, despite substantial reductions in peak flows (Williams and Wolman 1984). In contrast, the Mokelumne River below Camanche Dam in California has experienced such a dramatic reduction in flood regime (and consequent reduction in sediment transport capacity) that no incision has been documented and gravels are reported to have become compacted and immobile (FERC 1993).

Reduction in bedload sediment supply can induce a change in channel pattern, as occurred on Stony Creek, a tributary to the Sacramento River 200 km north of San Francisco. Since the closure of Black Butte Dam in 1963, the formerly braided channel has adopted a single-thread meandering pattern, incised, and migrated laterally, eroding enough bedload sediment to compensate for about 20% of the bedload now trapped by Black Butte Dam on an annual average basis (Kondolf and Swanson 1993).

Bed Coarsening and Loss of Spawning Gravels

Channel erosion below dams is frequently accompanied by a change in particle size on the bed, as gravels and finer materials are winnowed from the bed and transported downstream, leaving an armor layer, a coarse lag deposit of large gravel, cobbles, or boulders. Development of an armor layer is an adjustment by the river to changed conditions because the larger particles are less easily mobilized by the hungry water flows below the dam. The armor layer may continue to coarsen until the material is no longer capable of being moved by the reservoir releases or spills, thereby limiting the ultimate depth of incision (Williams and Wolman 1984, Dietrich and others 1989).

The increase in particle size can threaten the success of spawning by salmonids (salmon and trout), which use freshwater gravels to incubate their eggs. The female uses abrupt upward jerks of her tail to excavate a small pit in the gravel bed, in which she deposits her eggs and the male releases his milt. The female then loosens gravels from the bed upstream to cover the eggs and fill the pit. The completed nests (redds) constitute incubation environments with intragravel flow of water past the eggs and relative protection from predation. The size of gravel that can be moved to create a redd depends on the size of the fish, ranging in median diameter from about 15 mm for small trout to about 50 mm for large salmon (Kondolf and Wolman 1993).

Below dams, the bed may coarsen to such an extent that the fish can no longer move the gravel. The Upper Sacramento River, California, was once the site of extensive spawning by chinook salmon (*Oncorhynchus tshawytscha*), but massive extraction of gravel from the riverbed, combined with trapping of bedload sediment behind Shasta Dam upstream and release of hungry water, has resulted in coarsening of the bed such that spawning habitat has been virtually eliminated in the reach (Figure 3) (Parfitt and Buer 1980). The availability of spawning gravels can also be reduced by incision below dams when formerly submerged gravel beds are isolated as terrace or floodplain deposits. Encroaching vegetation can also stabilize banks and further reduce gravel recruitment for redds (Hazel and others 1976).

Figure 3. Keswick Dam and the channel of the Sacramento River downstream. (Photograph by the author, January 1989.)

Gravel Replenishment Below Dams

Gravels were being artificially added to enhance available spawning gravel supply below dams on at least 13 rivers in California as of 1992 (Kondolf and Matthews 1993). The largest of these efforts is on the Upper Sacramento River, where from 1979 to 2000 over US$22 million will have been spent importing gravel (derived mostly from gravel mines on tributaries) into the river channel (Denton 1991) (Figure 4). While these projects can provide short-term habitat, the amount of gravel added is but a small fraction of the bedload deficit below Shasta Dam, and gravels placed in the main river have washed out during high flows, requiring continued addition of more imported gravel (California Department of Water Resources 1995). On the Merced, Tuolumne, and Stanislaus rivers in California, a total of ten sites were excavated and back-filled with smaller gravel to create spawning habitat for chinook salmon from 1990 to 1994. However, the gravel sizes imported were mobile at high flows that could be expected to occur every 1.5–4.0 years, and subsequent channel surveys have demonstrated that imported gravels have washed out (Kondolf and others 1996a,b).

On the border between France and Germany, a series of hydroelectric dams was constructed on the River Rhine (progressing downstream) after 1950, the last of which (the Barrage Iffezheim) was completed in the 1970s. To address the sediment deficit problem downstream of Iffezheim, an annual average of 170,000 tonnes of gravel (the exact amount depending on the

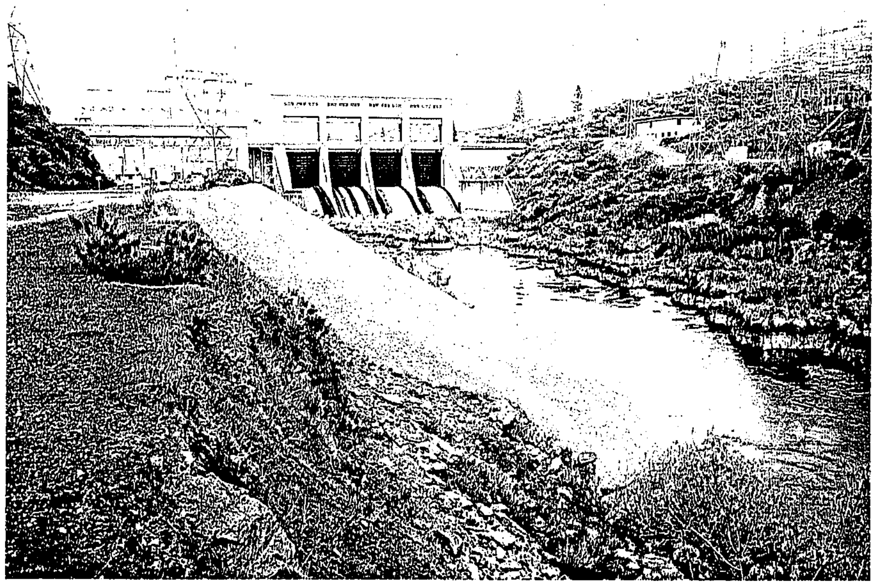

Figure 4. Gravel replenishment to the Sacramento River below Keswick Dam. (Photograph by the author, January 1991.)

magnitude of the year's runoff) are added to the river (Figure 5). This approach has proved successful in preventing further incision of the riverbed downstream (Kuhl 1992). It is worth noting that the quantity of gravel added each year is not equivalent to the unregulated sediment load of the Rhine; the river's capacity to transport sediment has also been reduced because the peak discharges have been reduced by reservoir regulation. The amount of sediment added satisfies the transport capacity of the existing channel, which has been highly altered for navigation and hydroelectric generation.

Sediment Sluicing and Pass-Through from Reservoirs

The downstream consequences of interrupting the flux of sand and gravel transport would argue for designing systems to pass sediment through reservoirs (and thereby reestablish the continuity of sediment transport). To date, most such efforts have been undertaken to solve problems with reservoir sedimentation, particularly deposits of sediment at tunnel intakes and outlet structures, rather than to solve bedload sediment supply problems downstream. These efforts have been most common in regions with high sediment yields such as Asia (e.g., Sen and Srivastava 1995, Chongshan and others 1995, Hassanzadeh 1995). Small diversion dams (such as those used to divert water in run-of-the-river hydroelectric generating projects) in steep V-shaped canyons have the greatest potential to pass sediment. Because of their small size, these reservoirs (or forebays) can easily be drawn down so that the river's gradient and velocity are maintained through the dam

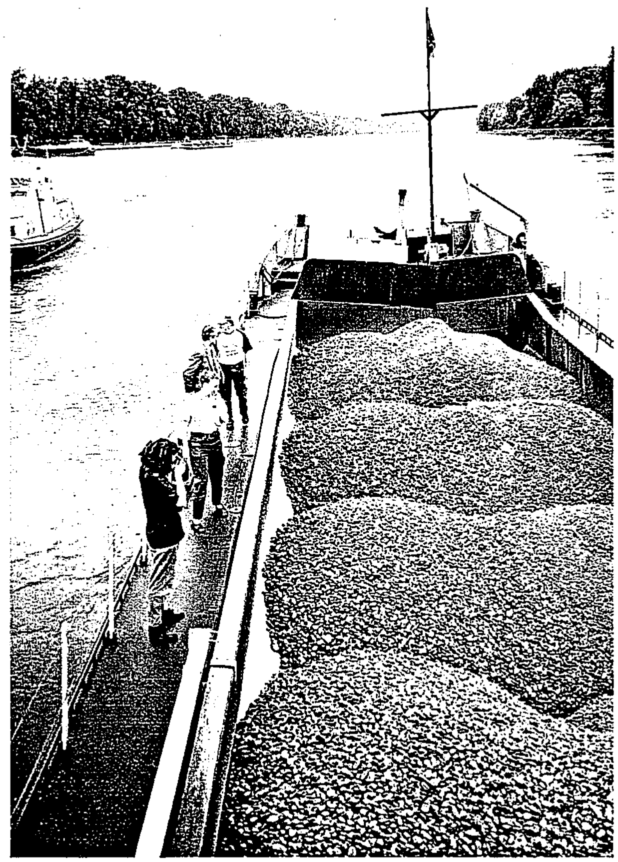

Figure 5. Barge artificially feeding gravel into the River Rhine downstream of the Barrage Iffezheim. (Photograph by author, June 1994.)

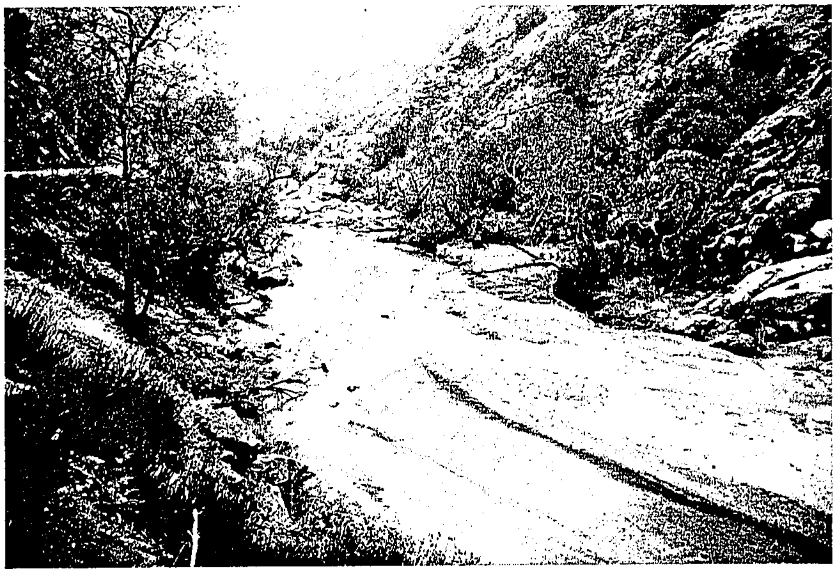

Figure 6. Sand deposited in the bed of the Kern River as a result of sluicing from Democrat Dam in 1986. (Photograph by the author, December 1990.)

at high flow. Large-capacity, low-level outlets are required to pass the incoming flow and sediment load.

If low-level outlets are open at high flow and the reservoir is drawn down, a small reservoir behaves essentially as a reach of river, passing inflowing sediment through the dam outlets. In such a sediment pass-through approach, the sediment is delivered to downstream reaches in essentially the same concentration and seasonal flood flows as prevailed in the predam regime. This approach was employed at the old Aswan Dam on the River Nile and on the Bhatgurk Reservoir on the Yeluard River in India (Stevens 1936). Similarly, on the River Inn in Austria and Germany, floodwaters with high suspended loads are passed through a series of hydropower reservoirs in a channel along the reservoir bottom confined by training walls (Hack 1986, Westrich and others 1992). If topographic conditions are suitable, sediment-laden floodwater may be routed around a reservoir in a diversion tunnel or permitted to pass through the length of the reservoir as a density current vented through a bottom sluice on the dam (Morris 1993). The Nan-Hwa Reservoir in Taiwan was designed with a smaller upstream forebay from which sediment is flushed into a diversion tunnel, allowing only relatively clear water to pass into the main reservoir downstream (Morris 1993).

If sediment is permitted to accumulate in the reservoir and subsequently discharged as a pulse (sediment sluicing), the abrupt increase in sediment load may alter substrate and aquatic habitat conditions downstream of the dam. The most severe effects are likely to occur when sediment accumulated over the flood season is discharged during baseflow (by opening the outlet pipe or sluice gates and permitting the reservoir to draw down sufficiently to resuspend sediment and move bedload), when the river's transporting capacity is inadequate to move the increased load. On the Kern River, the Southern California Edison Company (an electric utility) obtained agency permission to sluice sand from Democrat Dam in 1986, anticipating that the sand would be washed from the channel the subsequent winter. However, several years of drought ensued, and the sand remained within the channel until high flows in 1992 (Figure 6) (Dan Christenson, California Department of Fish and Game, Kernville, personal communication 1992).

On those dams larger than small diversion structures, the sediment accumulated around the outlet is usually silt and clay, which can be deleterious to aquatic habitat and water quality (Bjornn and Reiser 1991). Opening of the low-level outlet on Los Padres Dam on the Carmel River, California, released silt and clay, which resulted in a large fish kill in 1980 (Buel 1980). The dam operator has since been required to use a suction dredge to maintain the outlet (D. Dettman, Monterey Peninsula Water Management District, personal communication 1990). On the Dan River in Danville, Virginia, toxicity testing is required during sluicing of fine sediments from Schoolfield Dam (FERC 1995). Accidental sluices have also occurred during maintenance or repair work, sometimes resulting in substantial cleanup operations for the dam operators (Ramey and Beck 1990, Kondolf 1995).

Less serious effects are likely when the sediment pulse is released during high flows, which will have elevated suspended loads, but which can typically disperse the sediment for some distance downstream. The Jansanpei Reservoir in Taiwan is operated to provide power for the Taiwan Sugar Company, which needs power for processing only from November to April. The reservoir is left empty with open low-level outlets for the first two months of the rainy season (May and June), so sediments accumulated over the months of July–April can be flushed by the first high flows of the season before storing water in the latter part of the rainy season (Hwang 1994).

At present, sediment pass-through is not commonly done in North America, probably because of the limited capacity of many low-level outlets and because of concern that debris may become stuck in the outlets, making them impossible to close later, and making diversions impossible during the rest of the wet season until flows drop sufficiently to fix the outlets. These concerns can probably be addressed with engineering solutions, such as trash racks upstream of the outlet and redundancies in gate structures on the low-level outlet. Large reservoirs cannot be drawn down sufficiently to transport sediment through their length to the outlet works, for such a drawdown would eliminate carryover storage from year to year, an important benefit from large reservoirs.

In most reservoirs in the United States, sediment is simply permitted to accumulate. Active management of sediment in reservoirs has been rare, largely because the long-term costs of reservoir storage lost to sedimentation have not been incorporated into decision-making and planning for reservoirs. Most good reservoir sites are already occupied by reservoirs, and where suitable replacement reservoir sites exist, the current cost of replacement storage (about US$3/m^3 in California) is considerably higher than original storage costs. Mechanical removal is prohibitively expensive in all but small reservoirs, with costs of $15–$50/m^3 cited for the Feather River in California (Kondolf 1995).

Channel Narrowing and Fine Sediment Accumulation Below Dams

While many reservoirs reduce flood peaks, the degree of reduction varies considerably depending upon reservoir size and operation. The larger the reservoir capacity relative to river flow and the greater the flood pool available during a given flood, the greater the reduction in peak floods. Flood control reservoirs typically contain larger floods than reservoirs operated solely for water supply. Downstream of the reservoir, encroachment of riparian vegetation into parts of the active channel may occur in response to a reduction in annual flood scour and sediment deposition (Williams and Wolman 1984). Channel narrowing has been greatest below reservoirs that are large enough to contain the river's largest floods. In some cases, fine sediment delivered to the river channel by tributaries accumulates in spawning gravels because the reservoir-reduced floods are inadequate to flush the riverbed clean.

On the Trinity River, California, construction of Trinity Dam in 1960 reduced the two-year flow from 450 m^3/sec to 9 m^3/sec. As a result of this dramatic change in flood regime, encroachment of vegetation and deposition of sediment has narrowed the channel to 20%–60% of its predam width (Wilcock and others 1996). Accumulation of tributary-derived decomposed granitic sand in the bed of the Trinity River has led to a decline of invertebrate and salmonid spawning habitat (Fredericksen, Kamine and Associates 1980). Experimental, controlled releases were made in 1991, 1992, 1993, 1995, and 1996 to determine the flows required to flush the sand from the gravels (Wilcock and others 1996).

Such flushing flows increasingly have been proposed for reaches downstream of reservoirs to remove fine sediments accumulated on the bed and to scour the bed frequently enough to prevent encroachment of riparian vegetation and narrowing of the active channel (Reiser and others 1989). The objectives of flushing flows have not always been clearly specified, nor have potential conflicts always been recognized. For example, a discharge that mobilizes the channel bed to flush interstitial fine sediment will often produce comparable transport rates of sand and gravel, eliminating the selective transport of sand needed to reduce the fine sediment content in the bed, and resulting in a net loss of gravel from the reach given its lack of supply from upstream (Kondolf and Wilcock 1996).

Coastal Erosion

Beaches serve to dissipate wave action and protect coastal cliffs. Sand may be supplied to beaches from headland erosion, river transport, and offshore sources. If sand supply is reduced through a reduction in sediment delivery from rivers and streams, the beach may become undernourished, shrink, and cliff erosion may be accelerated. This process by which beaches are reduced or maintained can be thought of in terms of a sediment balance between sources of sediment (rivers and headland erosion), the rate of longshore transport along the coast, and sediment sinks (such as loss to deeper water offshore) (Inman 1976). Along the coast of southern California, discrete coastal cells can be identified, each with distinct sediment sources (sediment delivery from river mouths) and sinks (losses to submarine canyons). For example, for the Oceanside littoral cell, the contribution from sediment sources (Santa Margarita, San Luis Rey, and San Dieguito rivers and San Mateo and San Juan creeks) was estimated,

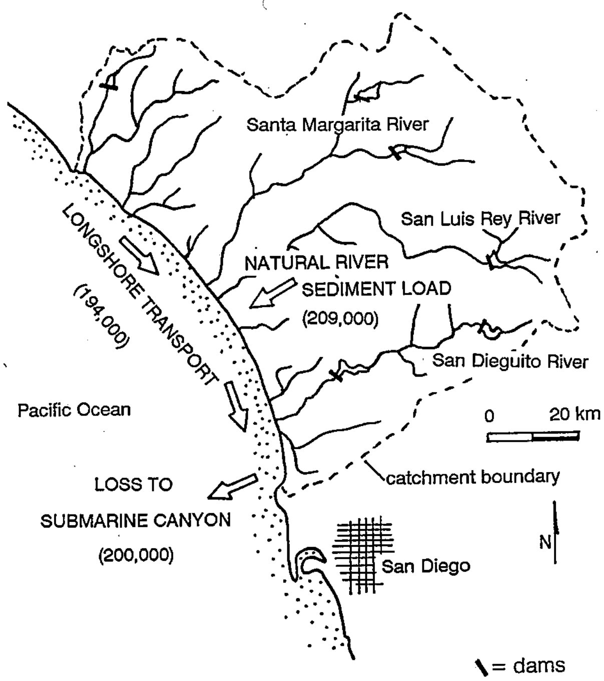

Figure 7. The Oceanside littoral cell, showing estimated sand and gravel supply from rivers, longshore transport, and loss to the La Jolla submarine canyon (in m³/yr). (Adapted from Inman 1985, used by permission.)

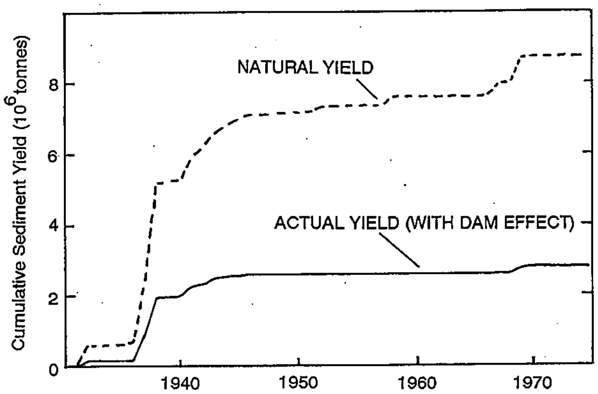

Figure 8. Cumulative reduction in suspended sediment supply from the catchment of the San Luis Rey River due to construction of Henshaw Dam. (Adapted from Brownlie and Taylor 1981.)

under natural conditions, at 209,000 m^3/yr, roughly balancing the longshore transport rate of 194,000 m^3/yr and the loss into the La Jolla submarine canyon of 200,000 m^3/yr (Figure 7) (Inman 1985).

The supply of sediment to beaches from rivers can be reduced by dams because dams trap sediment and because large dams typically reduce the magnitude of floods, which transport the majority of sediment (Jenkins and others 1988). In southern California rivers, most sediment transport occurs during infrequent floods (Brownlie and Taylor 1981), but it is these energetic events that flood control dams are constructed to prevent. On the San Luis Rey River, one of the principal sources of sediment for the Oceanside littoral cell, Henshaw Dam reduced suspended sediment yield by 6 million tonnes (Figure 8), total sand and gravel yield by 2 million tonnes (Brownlie and Taylor 1981).

Ironically, by trapping sediment and reducing peak flows, the flood control dams meant to reduce property damage along rivers contribute to property damage along the coast by eliminating sediment supply to the protective beaches. For the rivers contributing sediment to the Oceanside littoral cell as a whole, sediment from about 40% of the catchment area is now cut off by dams. Because the rate of longshore transport (a function of wave energy striking the coast) is unchanged, the result has been a sediment deficit, loss of beach sand, and accelerated coastal erosion (Inman 1985).

The effects of sediment trapping by dams has been exacerbated in combination with other effects such as channelization and instream sand and gravel mining (discussed below). Although sluicing sediment from reservoirs has been considered in the Los Angeles Basin, passing sediment through urban flood control channels could cause a number of problems, including decreasing channel capacity (Potter 1985). "Beach nourishment" with imported sediment dredged from reservoirs and harbors has been implemented along many beaches in southern California (Inman 1976, Allayaud 1985, Everts 1985). In some cases, sand is transported to critical locations on the coast via truck or slurry pipelines. The high costs of transportation, sorting for the proper size fractions, and cleaning contaminated dredged material, as well as the difficulty in securing a stable supply of material make these options infeasible in some places (Inman 1976).

To integrate considerations of fluvial sediment supply in the maintenance of coastal beaches into the existing legal framework, a system of "sand rights," analogous to water rights, has been proposed (Stone and Kaufman 1985).

Gravel Mining in River Systems

Sand and gravel are used as construction aggregate for roads and highways (base material and asphalt), pipelines (bedding), septic systems (drain rock in leach fields), and concrete (aggregate mix) for highways and buildings. In many areas, aggregate is derived primarily from alluvial deposits, either from pits in river floodplains and terraces, or by in-channel (instream) mining, removing sand and gravel directly from river beds with heavy equipment.

Sand and gravel that have been subject to prolonged transport in water (such as active channel deposits) are particularly desirable sources of aggregate because weak materials are eliminated by abrasion and attrition, leaving durable, rounded, well-sorted gravels (Barksdale 1991). Instream gravels thus require less processing than many other sources, and suitable channel deposits are commonly located near the markets for the product or on transportation routes, reducing transportation costs (which are the largest costs in the industry). Moreover, instream gravels are typically of sufficiently high quality to be classified as "PCC-grade" aggregate, suitable for use in production of Portland Cement concrete (Barksdale 1991).

Effects of Instream Gravel Mining

Instream mining directly alters the channel geometry and bed elevation and may involve extensive clearing, diversion of flow, stockpiling of sediment, and excavation of deep pits (Sandecki 1989). Instream mining may be carried out by excavating trenches or pits in the gravel bed, or by gravel bar skimming (or scalping), removing all the material in a gravel bar above an imaginary line sloping upwards from the summer water's edge. In both cases, the preexisting channel morphology is disrupted and a local sediment deficit is produced, but trenching also leaves a headcut on its upstream end. In addition to the direct alterations of the river environment, instream gravel mining may induce channel incision, bed coarsening, and lateral channel instability (Kondolf 1994).

Channel Incision and Bed Coarsening

By removing sediment from the channel, instream gravel mining disrupts the preexisting balance between sediment supply and transporting capacity, typically inducing incision upstream and downstream of the extraction site. Excavation of pits in the active channel alters the equilibrium profile of the streambed, creating a locally steeper gradient upon entering the pit (Figure 9). This over-steepened nickpoint (with its increased stream power) commonly erodes upstream in a process known as headcutting. Mining-induced incision may propagate upstream for kilometers on the main river (Scott 1973, Stevens and others 1990) and up tributaries (Harvey and Schumm 1987). Gravel pits trap much of the incoming bedload sediment, passing hungry water downstream, which typically erodes the channel bed and banks to regain at least part of its sediment load (Figure 9).

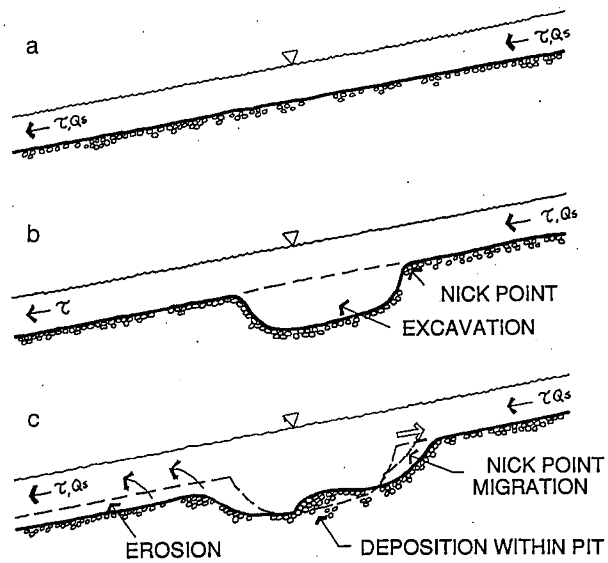

Figure 9. Incision produced by instream gravel mining. **a:** The initial, preextraction condition, in which the river's sediment load (Q_s) and the shear stress (τ) available to transport sediment are continuous through the reach. **b:** The excavation creates a nickpoint on its upstream end and traps sediment, interrupting the transport of sediment through the reach. Downstream, the river still has the capacity to transport sediment (τ) but no sediment load. **c:** The nickpoint migrates upstream, and hungry water erodes the bed downstream, causing incision upstream and downstream. (Reprinted from Kondolf 1994, with kind permission of Elsevier Science-NL.)

A vivid example of mining-induced nickpoint migration appears on a detailed topographic map prepared from analysis of 1992 aerial photographs of Cache Creek, California. The bed had been actively mined up to the miner's property boundary about 1400 m downstream of Capay Bridge, with a 4-m high headwall on the upstream edge of the excavation. After the 1992 winter flows, a nickpoint over 3 m deep extended 700 m upstream from the upstream edge of the pit (Figure 10). After the flows of 1993, the nickpoint had migrated another 260 m upstream of the excavation (not shown), and in the 50-yr flood of 1995, the nickpoint migrated under the Capay Bridge, contributing to the near-failure of the structure (Northwest Hydraulics Consultants 1995).

On the Russian River near Healdsburg, California, instream pit mining in the 1950s and 1960s caused channel incision in excess of 3–6 m over an 11-km length of river (Figure 11). The formerly wide channel of the Russian River is now incised, straighter, prevented from migrating across the valley floor by levees, and thus unable to maintain the diversity of successional

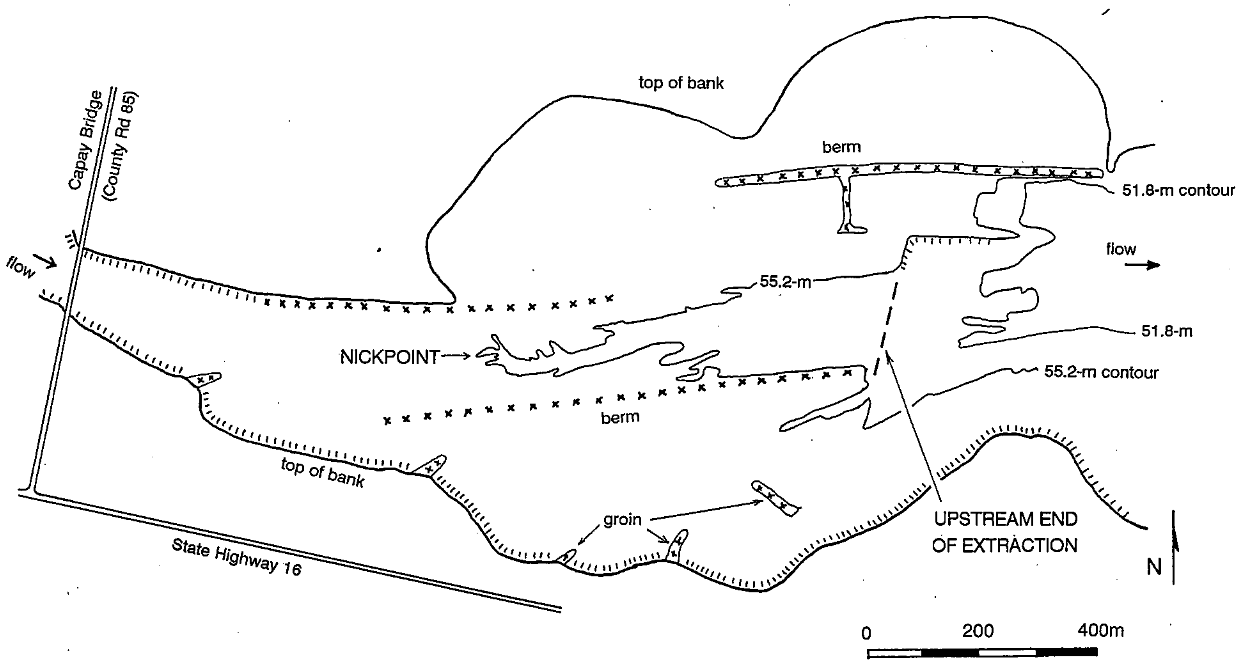

Figure 10. Nickpoint upstream of 4-m-deep gravel pit in the bed of Cache Creek, California, as appearing on a topographic map of Cache Creek prepared from fall 1992 aerial photographs. Original map scale 1:2400, contour interval 0.6 m.

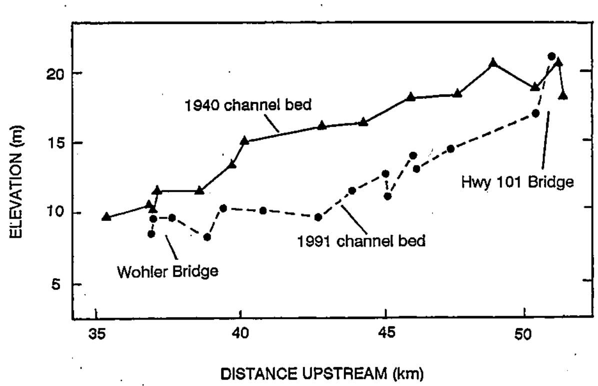

Figure 11. Longitudinal profile of the Russian River, near Healdsburg, California, showing incision from 1940 to 1991. (Redrawn from Florsheim and Goodwin 1993, used by permission.)

stages of vegetation associated with an actively migrating river (Florsheim and Goodwin 1993). With continued extraction, the bed may degrade down to bedrock or older substrates under the recent alluvium (Figure 12). Just as below dams, gravel-bed rivers may become armored, limiting further incision (Dietrich and others 1989), but eliminating salmonid spawning habitat.

In many rivers, gravel mining has been conducted downstream of dams, combining the effects of both impacts to produce an even larger sediment deficit. On the San Luis Rey River downstream of Henshaw Dam, five gravel mining operations within 8 km of the Highway 395 bridge extract a permitted volume of approximately 300,000 m^3/yr, about 50 times greater than the estimated postdam bedload sediment yield (Kondolf and Larson 1995), further exacerbating the coastal sediment deficit.

Incision of the riverbed typically causes the alluvial aquifer to drain to a lower level, resulting in a loss of aquifer storage, as documented along the Russian River (Sonoma County 1992). The Lake County (California) Planning Department (Lake County 1992) estimated that incision from instream mining in small river valleys could reduce alluvial aquifer storage from 1% to 16%, depending on local geology and aquifer geometry.

Undermining of Structures

The direct effects of incision include undermining of bridge piers and other structures, and exposure of buried pipeline crossings and water-supply facilities. Headcutting of over 7 m from an instream gravel mine downstream on the Kaoping River, Taiwan, threatens the Kaoping Bridge, whose downstream margin is now protected with gabions, massive coastal concrete jacks, and lengthened piers (Figure 13).

On the San Luis Rey River, instream gravel mining has not only reduced the supply of sediment to the coast, but mining-induced incision has exposed aqueducts, gas pipelines, and other utilities buried in the

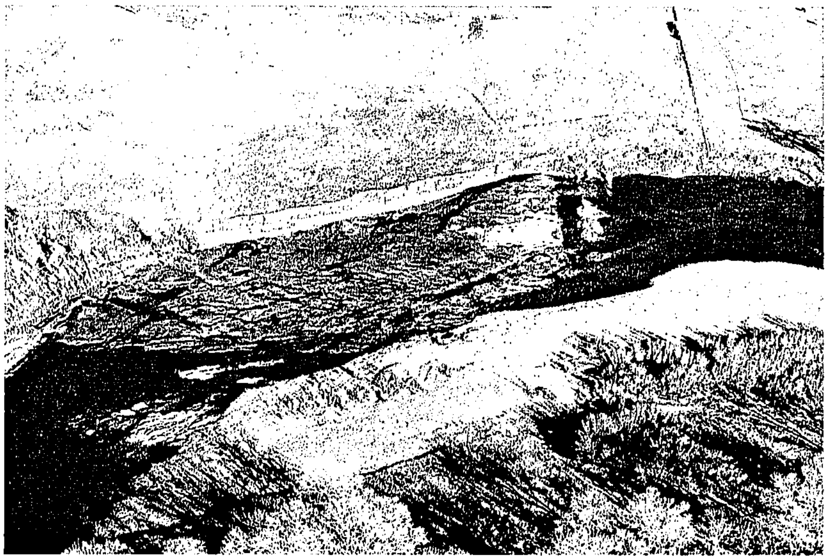

Figure 12. Tributary to the Sacramento River near Redding, California, eroded to bedrock as a result of instream mining. (Photograph by author, January 1989.)

Figure 13. Undercutting and grade control efforts along the downstream side of the Kaoping Bridge over the Kaoping River, Taiwan, to control incision caused by massive gravel mining downstream. (Photograph by the author, October 1995.)

bed and exposed the footings of a major highway bridge (Parsons Brinkeroff Gore & Storrie, Inc. 1994). The Highway 32 bridge over Stony Creek, California, has been undermined as a result of intensive gravel mining directly upstream and downstream of the bridge (Kondolf and Swanson 1993). Municipal water supply intakes have been damaged or made less effective on the Mad (Lehre and others 1993) and Russian (Marcus 1992) rivers in California as the layer of overlying gravel has decreased due to incision.

Channel Instability

Instream mining can cause channel instability through disruption of the existing equilibrium channel form or undercutting of banks caused by incision. Gravel mining in Blackwood Creek, California, caused incision and channel instability upstream and downstream, increasing the stream's sediment yield fourfold (Todd 1989). As a nickpoint migrates upstream, its incision and bank undercutting release additional sediment to downstream reaches, where the channel may aggrade and thereby become unstable (Sear and Archer 1995). Incision in the mainstem Russian River propagated up its tributary Dry Creek, resulting in undercutting of banks, channel widening (from 10 to 400 m in places), and destabilization, increasing delivery of sand and gravel to the mainstem Russian River (Harvey and Schumm 1987).

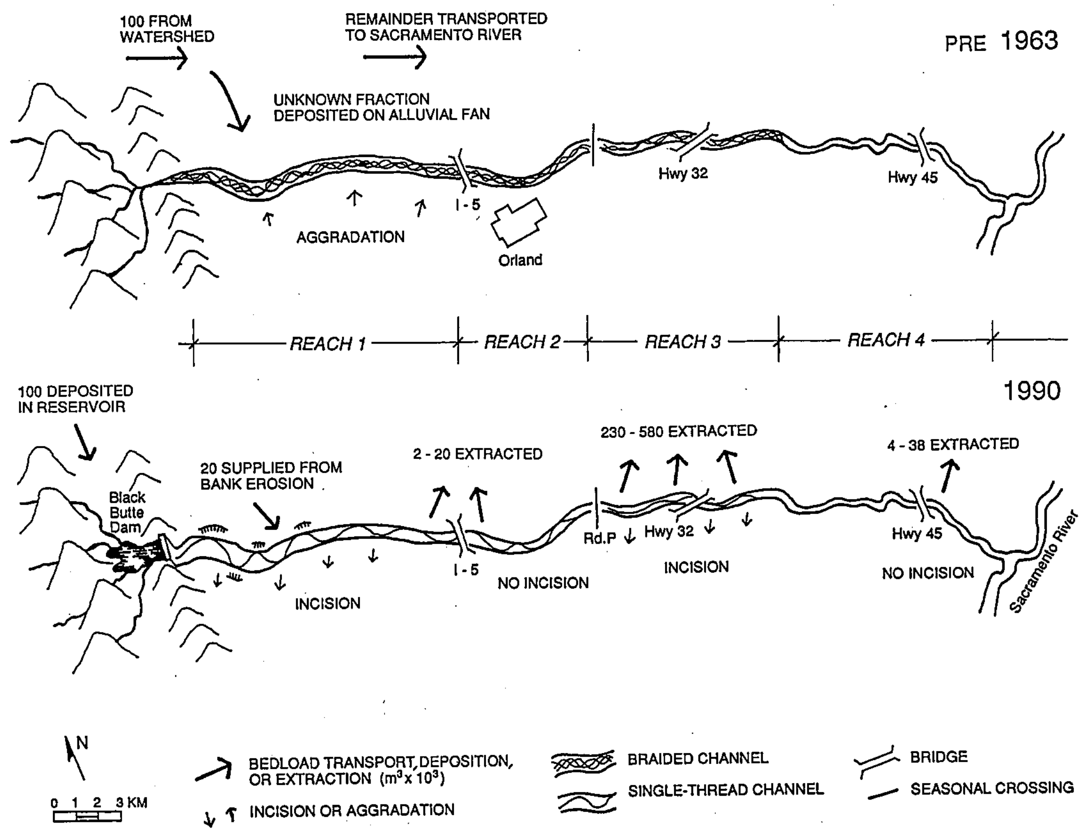

Figure 14. Sediment budget for Stony Creek, California. (Reprinted from Kondolf and Swanson 1993, used by permission of Spring-Verlag, New York.)

A more subtle but potentially significant effect is the increased mobility of the gravel bed if the pavement (the active coarse surface layer) (Parker and Klingeman 1982) is disrupted by mining. Similarly, removal of gravel bars by instream mining can eliminate the hydraulic control for the reach upstream, inducing scour of upstream riffles and thus washout of incubating salmon embryos (Pauley and others 1989).

Secondary Effects of Instream Mining

Among the secondary effects of instream mining are reduced loading of coarse woody debris in the channel, which is important as cover for fish (Bisson and others 1987). Extraction (even bar skimming at low extraction rates) typically results in a wider, shallower streambed, leading to increased water temperatures, modification of pool-riffle distribution, alteration of intergravel flow paths, and thus degradation of salmonid habitat.

Resolving the Effects of Instream Mining from Other Influences

In many rivers, several factors potentially causing incision in the channel may be operating simultaneously, such as sediment trapping by dams, reduced channel migration by bank protection, reduced overbank flooding from levees, and instream mining. However, in many rivers the rate of aggregate extraction is an order of magnitude greater than the rate of sediment supply from the drainage basin, providing strong evidence for the role of extraction in causing channel change. On Stony Creek, the incision produced by Black Butte Reservoir could be clearly distinguished from the effects of instream mining at the Highway 32 bridge by virtue of the distinct temporal and spatial patterns of incision. The dam-induced incision was pronounced downstream of the reservoir soon after its construction in 1963. By contrast, the instream mining (at rates exceeding the predam sediment supply by 200%–600%, and exceeding the postdam sediment supply by 1000%–3000%) produced incision of up to 7 m centered in the mining reach near the Highway 32 bridge, after intensification of gravel mining in the 1970s (Kondolf and Swanson 1993) (Figure 14).

Management of Instream Gravel Mining

Instream mining has long been prohibited in the United Kingdom, Germany, France, the Netherlands, and Switzerland, and it is being reduced or prohibited in many rivers where impacts are apparent in Italy, Portugal, and New Zealand. In the United States and Canada, instream mining continues in many rivers, despite increasing public opposition and recognition of environmental effects by regulatory agencies. Instream mines continue to operate illegally in many places, such as the United States (Los Angeles Times 1992) and Taiwan.

Strategies used to manage instream mining range widely, and in many jurisdictions there is no effective management. One strategy is to define a redline, a minimum elevation for the thalweg (the deepest point in a channel cross section) along the river, and to permit mining so long as the bed does not incise below this line (as determined by annual surveys of river topography). The redline approach addresses a problem common to many permits in California, which have specified that extraction is permitted "*x* feet below the channel bed" or only down to the thalweg, without stating these limits in terms of actual elevations above a permanent datum. Thus the extraction limits have migrated vertically downward as the channel incises.

Another approach is to estimate the annual bedload sediment supply from upstream (the replenishment rate) and to limit annual extraction to that value or some fraction thereof, considered the "safe yield." The replenishment rate approach has the virtue of scaling extraction to the river load in a general way, but bedload transport can be notoriously variable from year to year. Thus, this approach is probably better if permitted extraction rates are based on new deposition that year rather than on long-term average bedload yields. More fundamentally, however, the notion that one can extract at the replenishment rate without affecting the channel ignores the continuity of sediment transport through the river system. The mined reach is the "upstream" sediment source for downstream reaches, so mining at the replenishment rate could be expected to produce hungry water conditions downstream. Habitat managers in Washington state have sought to limit extraction to 50% of the transport rate as a first-cut estimate of safe yield to minimize effects upon salmon spawning habitat (Bates 1987).

Current approaches to managing instream mining are based on empirical studies. While a theoretical approach to predicting the effects of different levels of gravel mining on rivers would be desirable, the inherent complexity of sediment transport and channel change makes firm, specific predictions impossible at present. Sediment transport models can provide an indication of potential channel incision and aggradation, but all such models are simplifications of a complex reality, and the utility of existing models is limited by unreliable formulation of sediment rating curves, variations in hydraulic roughness, and inadequate understanding of the mechanics of bed coarsening and bank erosion (NRC 1983).

In 1995, the US Department of Transportation issued a notice to state transportation agencies indicating that federal funds will no longer be available to repair bridges damaged by gravel mining, a move that may motivate more vigorous enforcement of regulations governing gravel mining in rivers by states.

Floodplain Pit Mining

Floodplain pit mining transforms riparian woodland or agricultural land into open pits, which typically intersect the water table at least seasonally (Figure 15). Floodplain pit mining has effectively transformed large areas of floodplain into open-water ponds, whose water level commonly tracks that of the main river closely, and which are commonly separated from the active channel by only a narrow strip of unmined land. Because the pits are in close hydrologic continuity with the alluvial water table, concerns are often raised that contamination of the pits may lead to contamination of the alluvial aquifer. Many existing pits are steep-sided (to maximize gravel yield per unit area) and offer relatively limited wetlands habitat, but with improved pit design (e.g., gently sloping banks, irregular shorelines), greater wildlife benefits are possible upon reclamation (Andrews and Kinsman 1990, Giles 1992).

In many cases, floodplain pits have captured the channel during floods, in effect converting formerly off-channel mines to in-channel mines. Pit capture occurs when the strip of land separating the pit from the channel is breached by lateral channel erosion or by overflowing floodwaters. In general, pit capture is most likely when flowing through the pit offers the river a shorter course than the currently active channel.

When pit capture occurs, the formerly off-channel pit is converted into an in-channel pit, and the effects of instream mining can be expected, notably propagation of incision up- and downstream of the pit. Channel capture by an off-channel pit on the alluvial fan of Tujunga Wash near Los Angeles created a nickpoint that migrated upstream, undermining highway bridges (Scott 1973). The Yakima River, Washington, was captured by two floodplain pits in 1971, and began undercutting the highway for whose construction the pits had been originally excavated (Dunne and Leopold 1978). High flows on the Clackamas River, Oregon, in 1996 resulted in capture of an off-channel pit and resulted in 2 m of incision documented about 1 km upstream

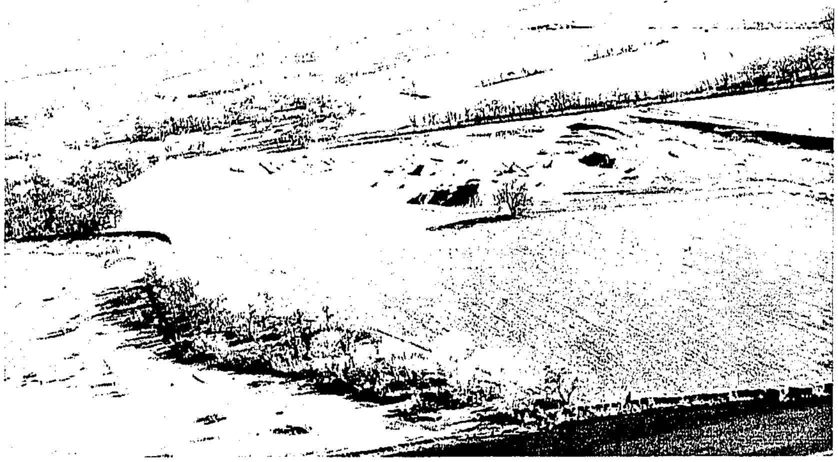

Figure 15. Floodplain pit along Cottonwood Creek near Redding, California. (Photograph by author, January 1989.)

Figure 16. Incision of Clackamas River approximately one mile upstream of captured gravel pit near Barton, Oregon. The three men on the right are standing on the bed of a side channel that formerly joined the mainstem at grade, but is now elevated about 2 m above the current river bed, after upstream migration of a nickpoint from the gravel pit. View upstream. (Photograph by author, April 1996.)

(Figure 16) and caused undermining of a building at the gravel mine site (Figure 17).

Off-channel gravel pits have been used successfully as spawning and rearing habitat for salmon and trout in Idaho (Richards and others 1992) and on the Olympic Peninsula of Washington (Partee and Samuelson 1993). In warmer climates, however, these off-channel pits are likely to heat up in the summer and provide habitat for warm-water fish that prey on juvenile salmonids. During floods, these pits may serve as a source of warm-water fish to the main channel, and juvenile salmon can become stranded in the pits. The Merced River, California, flows through at least 15 gravel pits, of which seven were excavated in the active channel, and eight were excavated on the floodplain and subsequently captured the channel (Vick 1995). Juvenile salmon migrating towards the ocean become disoriented in the quiet water of these pits and suffer high losses to predation by largemouth and smallmouth bass (*Micropterus salmoides* and *M. dolomieui*). On the nearby Tuolumne River, a 1987 study by the California Department of Fish and Game estimated that juvenile chinook salmon migrating oceanward suffered 70% losses to predation (mostly in gravel pits) in the three days required to traverse an 80-km reach from LaGrange Dam to the San Joaquin River (EA 1992). To reduce this predation problem, funding has been allocated to repair breached levees at one gravel pit on the Merced River at a cost of

Figure 17. Building undercut by bank erosion as the Clackamas River flows through a captured gravel pit near Barton, Oregon. (Photograph by the author, April 1996.)

US$361,000 (Kondolf and others 1996a), and refilling of two pits on the Tuolumne River has been proposed at a cost of $5.3 million (McBain and Trush 1996).

Aggregate Supply, Quality, and Uses

Aggregates can be obtained from a wide variety of sources (besides fluvial deposits), such as dry terrace mines, quarries (from which rock must be crushed, washed, and sorted), dredger tailings, reservoir deltas, and recycling concrete rubble. These alternative sources usually require more processing and often require longer transportation. Although their production costs are commonly higher, these alternative sources avoid many impacts of riverine extraction and may provide other benefits, such as partially restoring reservoir capacity lost to sedimentation and providing opportunities for ecological restoration of sterile dredger tailings.

In California, most aggregate that has been produced to date has been PCC-grade aggregate from instream deposits or recent channel deposits in floodplains. These deposits were viewed as virtually infinite in supply, and these high-grade aggregates have been used in applications (such as road subbase) for which other, more abundant aggregates (e.g., crushed rock from upland quarries) would be acceptable. Given that demand for aggregate commonly exceeds the supply of sand and gravel from the catchment by an order of magnitude or more, public policy ought to encourage reservation of the most valuable aggregate resources for the highest end uses. PCC-grade instream gravels should be used, to the extent possible, only in applications requiring such high-quality aggregate. Upland quarry and terrace pit sources of lower-grade aggregate should be identified, and alternative sources such as mining gold dredger tailings or reservoir accumulations, should be evaluated. Wherever possible, concrete rubble should be recycled to produce aggregate for many applications.

Reservoir sediments are a largely unexploited source of building materials in the United States. In general, reservoir deposits will be attractive sources of aggregates to the extent that they are sorted by size. The depositional pattern within a reservoir depends on reservoir size and configuration and the reservoir stage during floods. Small diversion dams may have a low trap efficiency for suspended sediments and trap primarily sand and gravel, while larger reservoirs will have mostly finer-grained sand, silt, and clay (deposited from suspension) throughout most of the reservoir, with coarse sediment typically concentrated in deltas at the upstream end of the reservoir. These coarse deposits will extend farther if the reservoir is drawn down to a low level when the sediment-laden water enters. In many reservoirs, sand and gravel occur at the upstream end, silts and clays at the downstream end, and a mixed zone of interbedded coarse and fine sediments in the middle.

Sand and gravel are mined commercially from some debris basins in the Los Angeles Basin and from Rollins Reservoir on the Bear River in California. In Taiwan, most reservoir sediments are fine-grained (owing to the caliber of the source rocks), but where coarser sediments are deposited, they are virtually all mined for construction aggregate (J. S. Hwang, Taiwan Provincial Water Conservancy Bureau, Taichung City, personal communication 1996). In Israel, the 2.2-km-long Shikma Reservoir is mined in its upper 600 m to produce sand and gravel for construction aggregate, and in its lower 1 km to produce clay for use in cement, bricks, clay seals for sewage treatment ponds, and pottery (Laronne 1995, Taig 1996). The zone of mixed sediments in the mid-section of the reservoir is left unexcavated and vegetated so it permits only fine-grained washload to pass downstream into the lower reservoir, thereby ensuring continued deposition of sand and gravel in the upstream portion of the reservoir and silt and clay in the downstream portion. The extraction itself restores some of the reservoir capacity lost to sedimentation. Similarly, on Nahal Besor, Israel, the off-channel Lower Rehovot Reservoir was deliberately created (to provide needed reservoir storage) by gravel mining. Water is diverted into the reservoir through a spillway at high flows, as controlled by a weir across the channel (Cohen 1996).

Extraction of reservoir sediments partially mitigates losses in reservoir capacity from sedimentation. Because of the high costs and practical problems with construction of replacement reservoir storage and/or mechanical removal of sediment, restoration of reservoir capacity may be seen as one of the chief benefits from mining aggregate and industrial clays from reservoirs. If these benefits are recognized, mining reservoir deposits may become more economically attractive in the future, especially if the environmental costs of instream and floodplain mining become better recognized and reflected in the prices of those aggregates. In the United States, construction of reservoirs was often justified partially by anticipated recreational benefits, and thus reservoir margins are commonly designated as recreation areas, posing a potential conflict with an industrial use such as gravel mining. Furthermore, wetlands may form in reservoir delta deposits, posing potential conflicts with regulations protecting wetlands.

Conclusions

Comprehensive management of gravel and sand in river systems should be based on a recognition of the natural flow of sediment through the drainage network and the nature of impacts (to ecological resources and to infrastructure) likely to occur when the continuity of sediment is disrupted. A sediment budget should be developed for present and historical conditions as a fundamental basis for evaluation of these impacts, many of which are cumulative in nature.

The cost of sediment-related impacts of existing and proposed water development projects and aggregate mines must be realistically assessed and included in economic evaluations of these projects. The (very real) costs of impacts such as bridge undermining, loss of spawning gravels, and loss of beach sand are now externalized, borne by other sectors of society rather than the generators of the impacts. The notion of sediment rights (analogous to water rights) should be explored as a framework within which to assess reservoir operations and aggregate mining for these impacts.

Sediment pass-through should be undertaken in reservoirs (where feasible) to mimic the natural flux of sediment through the river system. Pass-through should be done only during high flows when the sediment is likely to continue dispersing downstream from the reservoir. The cost of installing larger low-level outlets (where necessary) on existing dams will generally be less than costs of mechanical removal of sediments over subsequent decades. In larger reservoirs where sediment cannot be passed through a drawn-down reservoir, alternative means of transporting the gravel and sand fractions around (or through) reservoirs using tunnels, pipes, or barges should be explored.

Flushing flows should be evaluated not only in light of potential benefits of flushing fine sediments from mobilized gravels, but also the potential loss of gravel from the reach due to downstream transport.

The regional context of aggregate resources, market demand, and the environmental impacts of various alternatives must be understood before any site-specific proposal for aggregate extraction can be sensibly reviewed. In general, effects of aggregate mining should be evaluated on a river basin scale, so that the cumulative effects of extraction on the aquatic and riparian resources can be recognized. Evaluation of aggregate supply and demand should be undertaken on the basis of production–consumption regions, encompassing the market for aggregate and all potential sources of aggregate within an economical transport distance.

The finite nature of high-quality alluvial gravel resources must recognized, and high-quality PCC-grade aggregates should be reserved only for the uses demanding this quality material (such as concrete). Alternative sources should be used in less demanding applications (such as road subbase). The environmental costs of instream mining should be incorporated into the price of the product so that alternative sources that require more processing but have less environmental impact become more attractive.

Instream mining should not be permitted in rivers downstream of dams by virtue of the lack of supply from upstream or in rivers with important salmon spawning (unless it can be shown that the extraction will not degrade habitat).

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ATTACHMENT I

Attach 4I

National Marine Fisheries Service National Gravel Extraction Guidance

A review of the effects of in- and near-stream gravel extraction on anadromous fishes and their habitats, with recommendations for avoidance, minimization, and mitigation

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U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

NOAA Technical Memorandum NMFS-F/SPO-70
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U.S. Department of Commerce
Carlos M. Gutiérrez, Secretary

National Oceanic and Atmospheric Administration
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Under Secretary for Oceans and Atmosphere

National Marine Fisheries Service
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NATIONAL MARINE FISHERIES SERVICE
NATIONAL GRAVEL EXTRACTION GUIDANCE

I. INTRODUCTION

The National Marine Fisheries Service (NMFS) is responsible for protecting, managing and conserving marine, estuarine, and anadromous fishes and their habitats. The watersheds of the United States provide essential spawning and rearing habitat for anadromous fishes including salmon, shad, sturgeon, and striped bass.

A national guidance document on gravel extraction is necessary because extraction in and near streams can cause many adverse impacts to anadromous fishes and their habitats. Potential impacts include: direct harm to trust species; loss or degradation of spawning, rearing, resting, and staging habitat; migration delays and/or blockages; channel widening, shallowing, or ponding; loss of channel stability; loss of pool/riffle structure; increased turbidity and sediment transport; increased bank erosion and/or stream bed downcutting; and loss or degradation of riparian habitat. The impacts can extend far beyond the mining site, and stream recovery can take decades.

In the context of Federal trust responsibilities, as defined in the collective body of Federal law and regulations, NMFS must ensure that Federal actions, including authorizations to conduct gravel extraction operations, avoid, minimize, or mitigate to the greatest extent possible, any adverse impacts to anadromous fishes and their habitats. NMFS has been delegated the responsibility and authority under several Federal laws to address the effects of gravel extraction activities when the activities affect marine or anadromous fish under NMFS jurisdiction or their habitats. These authorities are summarized in the Appendix I, and include the Endangered Species Act (ESA), Clean Water Act (CWA), National Environmental Policy Act (NEPA), Magnuson-Stevens Fishery Conservation and Management Act (Magnuson-Stevens Act), and the accompanying implementing regulations of each law.

This document revises and replaces NMFS' 1996 National Gravel Extraction Policy. The objectives of the NMFS Gravel Guidance are to (1) assist NMFS staff in determining whether proposed gravel extraction operations will be conducted in a manner consistent with Federal law, while (2) avoiding, minimizing, and mitigating any adverse impacts to anadromous fishes and their habitats. NMFS recommends that gravel extraction operations not interfere with anadromous fish migration, spawning, or rearing, or negatively impact viable existing or historic anadromous fish habitat. Further, it is recommended that individual gravel extraction operations be judged in the context of their spatial, temporal, and cumulative impacts, and that potential impacts to habitat be viewed from a watershed management perspective. Although this Guidance applies nationwide, it is not to be regarded as static or inflexible, as project recommendations must be made specific to individual sites, streams, and watersheds.

This Guidance does not specify the measures, if any, that would need to be implemented by parties engaged in gravel extraction activities in any given case to comply with applicable statutory requirements. In formulating its recommendations or prescriptions, NMFS will determine the acceptable means of demonstrating compliance with statutory requirements based on information available to the agency, as appropriate under the circumstances presented. As such, the language of this Guidance for NMFS staff should not be read to establish any binding requirements on agency staff or the regulated community.

II. SCOPE OF GRAVEL GUIDANCE

This Guidance document addresses freshwater and tidal reaches of rivers and streams, tidal sloughs, and their associated wetlands and riparian zones where anadromous fish are currently or were historically present. Gravel extraction, as well as sand mining and dredging, also occurs in marine habitats such as the lower reaches of large tidal streams, estuaries and offshore. Marine extraction operations generally raise different concerns than those in streams. Although many elements of this Guidance are germane to all areas where gravel extraction occurs, the primary focus of this Guidance is extraction of gravel in streams rather than in marine environments.

The types of gravel extraction activities referred to in this Gravel Guidance generally entail commercial gravel mining (i.e., removing or obtaining a supply of gravel for industrial uses, such as road construction material, concrete aggregate, fill, and landscaping). Gravel can also be removed from stream channels for navigation and flood control purposes. Gravel extraction often occurs at multiple times and at multiple sites along a given stream, resulting in impacts that are likely to be both chronic and cumulative. When the rate of gravel extraction exceeds the rate of natural deposition over an extended time period, a net cumulative loss of gravel occurs (Oregon Water Resources Research Institute [OWRRI] 1995).

This Gravel Guidance document addresses three types of instream gravel mining, described as dry-pit and wet-pit mining in the active channel, and bar skimming (or "scalping") (Kondolf 1993, 1994a, 1997, 1998a). Dry-pit refers to excavation on dry ephemeral stream beds and exposed bars with conventional bulldozers, scrapers, and loaders. Wet-pit mining involves the use of a dragline or hydraulic excavator to remove gravel from below the water table or in a perennial stream channel. Bar skimming or scalping removes the surface from gravel bars without excavating below the low water flow level.

In addition to the instream mining described above, this Guidance document also addresses another method, which involves the excavation of pits on the adjacent floodplain or river terraces (Kondolf 1993, 1994a, 1997, 1998a). Pits located above the water table are also known as dry-pits, whereas wet-pits are below, depending on the elevation of the floodplain or terrace relative to the baseflow water elevation of the channel. The isolation of these pits from an adjacent active channel may be only short-term. During a sudden change in channel course during a flood, or as part of gradual migration, the channel may shift into the gravel pits (Kondolf 1998a). Because floodplain pits can become integrated into the active channel, Kondolf (1993, 1994a) suggests that they should be regarded as part of the active channel if considered on a time scale of decades, and managed accordingly.

III. ENVIRONMENTAL EFFECTS OF GRAVEL EXTRACTION

Extraction of alluvial material from within or near a stream bed has a direct impact on the stream's physical habitat parameters such as channel geometry, bed elevation, substrate composition and stability, instream roughness elements (large woody debris, boulders, etc.), depth, velocity, turbidity, sediment transport, stream discharge, and temperature (Rundquist 1980; Pauley et al. 1989; Kanehl and Lyons 1992; Kondolf 1994a, 1994b, 1997, 1998a; OWRRI 1995; Brown et al. 1998; Florsheim et al. 1998; Meador and Layher 1998; Langer 2001, 2003). OWRRI (1995) states that:

> Channel hydraulics, sediment transport, and morphology are directly affected by human activities such as gravel mining and bank erosion control. The immediate and direct effects are to reshape the boundary, either by removing or adding materials. The subsequent effects are to alter the flow hydraulics when water levels rise and inundate the altered features. This can lead to shifts in flow patterns and patterns of sediment transport. Local effects also lead to upstream and downstream effects.

Altering these habitat parameters can have deleterious impacts on instream biota, food webs, and the associated riparian habitat (Sandecki 1989; Kanehl and Lyons 1992; Koski 1993; Spence et al. 1996; Brown et al. 1998). For example, impacts to anadromous fish populations due to gravel extraction can include reduced fish populations in the disturbed area, replacement of one species by another, replacement of one age group by another, or a shift in the species and age distributions (Moulton 1980). Changes in physical habitat characteristics of aquatic systems can alter competitive interactions within and among species; similarly, changes in temperature or flow regimes may favor species that prey on anadromous fish populations (Spence et al. 1996). In general terms, Rivier and Seguier (1985) suggest that the detrimental effects to biota resulting from bed material mining are caused by two main processes: (1) alteration of the flow patterns resulting from modification of the river bed, and (2) an excess of suspended sediment. OWRRI (1995) adds:

> Disturbance activities can disrupt the ecological continuum in many ways. Local channel changes can propagate upstream or downstream and can trigger lateral changes as well. Alterations of the riparian zone can allow changes in-channel *[sic]* conditions that can impact aquatic ecosystems as much as some in-channel activities.
>
> One consequence of the interconnectedness of channels and riparian systems is that potential disruptions of the riparian zone must be evaluated when channel activities are being evaluated. For example, aggregate mining involves the channel and boundary but requires land access and material storage that could adversely affect riparian zones; bank protection works are likely to influence riparian systems beyond the immediate work area.

It should be emphasized that cobble and gravel substrates are in and of themselves extremely important habitat for anadromous fish, including salmon, shad, striped bass, and sturgeon. Gravel habitat provides protective crevices and well-oxygenated interstitial spaces that are important for anadromous fish egg hatching. Gravel habitat also contains rich assemblages of benthic nutrients used as food for developing fish larvae, and provides macroinvertebrate food sources for post-larval juveniles.

The potential effects of gravel extraction activities on stream morphology, riparian habitat, and anadromous fishes and their habitats are summarized as follows:

1. **Instream gravel mining can disrupt the preexisting balance between sediment supply and transporting capacity, and can result in channel incision and bed degradation** (Kondolf 1997, 1998a; Florsheim et al. 1998; Meador and Layher 1998; Langer 2001, 2003). This is partly because gravel "armors" the bed, stabilizing banks and bars, whereas removing this gravel causes erosion (Lagasse et al. 1980; OWRRI 1995; Kondolf 1997, 1998a). Degradation and erosion can extend upstream and downstream of an individual extraction operation, and can result from bed mining either in or above the low-water channel (Collins and Dunne 1990; Kanehl and Lyons 1992; Kondolf 1994a, 1994b, 1997, 1998a; OWRRI 1995; Pringle 1997; Brown et al. 1998). For example, headcutting (upstream erosion), increased velocities, concentrated flows, and bank undercutting with subsequent loss of riparian habitat can occur upstream of the extraction site due to a steepened river gradient (Kanehl and Lyons 1992; OWRRI 1995; Kondolf 1997; Pringle 1997), resulting in the release of additional sediment to downstream reaches, where the channel may aggrade and become unstable (Kondolf 1997). Accelerated delivery of sediment from upstream can falsely indicate recruitment in balance with removal. Degradation can deplete the entire depth of gravel on a channel bed, exposing other substrates that may underlie the gravel, reducing the amount and quality of usable anadromous spawning and rearing habitat (Collins and Dunne 1990; Kondolf 1994a, 1997, 1998a; OWRRI 1995). For example, gravel removal from bars may cause erosion if they subsequently receive less bed material from upstream than is being carried away by fluvial transport (Collins and Dunne 1990). Thus, gravel removal not only impacts the extraction site, but also may reduce gravel delivery to downstream spawning and rearing areas (Pauley et al. 1989; Brown et al. 1998). Gravel mining itself often selectively removes gravels of approximately the same sizes as needed by salmonids for spawning (median diameters between 15 and 45 mm [Kondolf and Wolman 1993; see also Kondolf 2000]), again reducing the amount of usable spawning and rearing habitat.

2. **Instream gravel extraction can increase suspended sediment, sediment transport, water turbidity, and gravel siltation** (Kanehl and Lyons 1992; OWRRI 1995; Kondolf 1997). The most significant change in the sediment size distribution resulting from gravel removal is a decrease in sediment size caused by fine material deposition into the mining site (Rundquist 1980). Brown et al. (1998) also note that the fine material can travel long distances downstream as a plume of turbidity while the gravel is being removed and, during floods, turbidity is likely to be higher than normal for even longer distances downstream due to the higher flow rate and increased entrainment of sediments as a result of channel deformation or armor layer removal. As reviewed by Everest et al. (1987), fine sediments in particular are detrimental to salmonid redds (nests) because (1) interstitial spaces blocked by deposited silt prevents oxygenated water from reaching the incubating eggs within the redd, and inhibits the removal of waste metabolites; (2) embryos or sac fry can be smothered by high concentrations of suspended sediments that enter the redd; and (3) emerging fry can become trapped if enough sediment is deposited on the redd (Koski 1966, 1981; Chapman 1988; Reiser and White 1988; Waters 1995). High silt loads may also inhibit larval, juvenile, and

adult behavior, migration, or spawning (Snyder 1959; Cordone and Kelly 1961; Koski 1975; Bisson and Bilby 1982; Berg and Northcote 1985; Bjornn and Reiser 1991; Kanehl and Lyons 1992; Servizi and Martens 1992; OWRRI 1995). Excessive amounts of suspended material can abrade the protective slime coatings on the surface of the fish and their gills, which can lead to increased bacterial and fungal infections (Cordone and Kelly 1961; Rivier and Seguier 1985). Increased suspended sediments may block vision and impede feeding (Sigler et al. 1984; Rivier and Seguier 1985). Siltation, substrate disturbances and increased turbidity also negatively affect the invertebrate food sources of fishes and severely alter the aquatic food web, thus affecting the growth and survival of the fish (Kanehl and Lyons 1992; OWRRI 1995; Spence et al. 1996; Brown et al. 1998).

3. **Bed degradation can change the morphology of the channel and decreases channel stability** (Moulton 1980; Rundquist 1980; Sullivan et al. 1987; Collins and Dunne 1990; Kanehl and Lyons 1992; Kondolf 1994a, 1994b, 1997; OWRRI 1995; Brown et al. 1998; Florsheim et al. 1998). Gravel extraction can cause a diversion or a high potential for diversion of flow through the gravel removal site (Rundquist 1980). Mined reaches of a river or stream that show decreased depth and/or surface flow, which can occur where the flow is spread over a wide area and there is considerable intergravel flow, could block fish migration during periods of low flows (Moulton 1980). This could be caused by gravel bar skimming in particular (see Environmental Effect Number 4, below), and may compound problems in many areas where flows may already have been altered by hydropower operations, irrigation, or other human uses. Even if the gravel extraction activity is conducted away from the active river channel during low water periods (see Environmental Effect Number 8, below), substrate stability and channel morphology outside the excavated area's perimeter could be affected during subsequent high water events (Kondolf 1997, 1998a).

4. **Gravel bar skimming can significantly impact aquatic habitat.** Bar skimming creates a wide, flat cross section, eliminating confinement of the low flow channel, which can then result in a thin sheet of water at baseflow (Kondolf 1994a, 1997). Sediment transport efficiency may be reduced through the unconfined reach due to the increased width-to-depth ratio, causing deposition and subsequent instability (Kondolf 1998a). Removal of the bar may alter channel hydraulics upstream as well as at the gravel extraction site (Kondolf 1998a). Bar skimming can also remove the gravel "pavement," leaving the finer subsurface particles vulnerable to entrainment (erosion) at lower flows (Kondolf 1994a, 1998a; OWRRI 1995). A related effect is that bar skimming lowers the overall elevation of the bar surface and may reduce the threshold water discharge at which sediment transport occurs (OWRRI 1995). Salmon redds downstream are thus susceptible to deposition of displaced alluvial material, resulting in egg suffocation or suppressed salmon fry emergence, while redds upstream of scalped bars are vulnerable to regressive erosion (Pauley et al. 1989). Gravel bar skimming also appears to reduce the amount of side channel areas, which can reduce and/or displace juvenile salmonid fishes that use this habitat (Pauley et al. 1989). All these effects can be particularly problematic if upstream flows are already reduced by diversions, dams, or other human activities.

5. **Operation of heavy equipment in the channel bed can directly destroy spawning habitat, rearing habitat, the juveniles themselves, and macroinvertebrates; can produce**

increased turbidity and suspended sediment downstream; and has the potential to cause toxic chemical spills (Forshage and Carter 1973; Kondolf 1994a). Heavy equipment usually crosses stream channels where the stream is shallowest, at riffles. Riffle habitat is important for juvenile salmonids (Bradford and Higgins 2001) because, for example, the juveniles often respond to disturbances by entering the interstitial spaces between the gravel substrate at riffles (Shrivell 1990; Meehan and Bjornn 1991). These pore spaces in the gravel substrate are important sources of cover or refuge (Raleigh et al. 1984). Therefore, juveniles in this riffle habitat could be susceptible to crushing from heavy equipment. Additional disturbances to redds may occur from increased foot and vehicle access to spawning sites, due to access created initially for gravel extraction purposes (OWRRI 1995). Also, heavy equipment is powered by diesel fuel and lubricated by other hazardous petroleum products, leading to the potential for toxic chemical spills.

6. **Stockpiles of overburden and gravel left or abandoned in the channel or floodplain can alter channel hydraulics during high flows.** During high water, the presence of stockpiles can cause fish blockage or entrapment, and fine material and organic debris may be introduced into the water, resulting in downstream sedimentation (Follman 1980). The stockpiles may also concentrate flows on the stream bed or floodplain resulting in increased, localized erosion.

7. **Removal or disturbance of instream roughness elements during gravel extraction activities can negatively affect both quality and quantity of anadromous fish habitat.** Instream roughness elements, including the gravel itself and large woody debris, play a major role in providing structural integrity and complexity to the stream or river ecosystem and provide habitat critical for anadromous fish (Koski 1992; Naiman et al. 1992; Franklin et al. 1995; Murphy 1995; OWRRI 1995; Abbe and Montgomery 1996; Collins and Montgomery 2002; Collins et al. 2002). These elements are important in controlling channel morphology and stream hydraulics; in regulating the storage of sediments, gravel and particulate organic matter; and in creating and maintaining habitat diversity and complexity (Franklin 1992; Koski 1992; Murphy 1995; OWRRI 1995). Large woody debris in streams creates pools and backwaters that fish use as foraging sites, critical overwintering areas, refuges from predation, and spawning and rearing habitat (Koski 1992; Maser and Sedell 1994; OWRRI 1995). Large wood jams at the head of gravel bars can anchor the bar and increase gravel recruitment behind the jam (OWRRI 1995). Loss of large woody debris from gravel bars can also negatively impact aquatic habitat (Weigand 1991; OWRRI 1995). The importance of large woody debris has been well documented, and its removal results in an immediate decline in salmonid abundance (e.g., see citations in Koski 1992; Franklin et al. 1995; Murphy 1995; OWRRI 1995). It is also important to remember that gravel deposits are themselves instream roughness elements, which is key to recognizing that the same type of effects apply (i.e., linking hydraulics and habitat is also applicable for gravel deposits underwater or on bars).

8. **Dry pit and wet pit mining in floodplains may reduce groundwater elevations, reduce stream flows, increase water temperature, and create potential for fish entrapment** (Langer 2003; NMFS 2004). A reduction in groundwater elevation may occur when floodplain pits are pumped by operators to increase production, and by evaporation of

surface water in large pits. Reductions in groundwater elevations can consequently result in a decrease in stream flow, which is particularly hazardous to fish during low flow periods. Subsurface connectivity between pits and streams also presents a possibility of increased stream temperatures when pit surface water is heated by the sun and eventually drains to the stream. The risk of fish entrapment associated with floodplain pit mining is due to two processes: (1) floods overtopping the pit perimeter, and (2) natural migration of the channel into the excavated area (Kondolf 1998a). Ponded water isolated from the main channel may strand or entrap fish carried there during high water events (Moulton 1980; Palmisano et al. 1993; Kondolf 1997). Fish in these ponded areas could experience higher temperatures, lower dissolved oxygen, increased predation compared to fish in the main channel, an altered food web, desiccation if the area dries out, and freezing (Moulton 1980; Spence et al. 1996; Kondolf 1997, 1998a).

The likelihood and extent of groundwater, stream flow, water temperature, and entrapment effects associated with floodplain mining are directly related to the pit's proximity to the active stream channel, pit size relative to the stream, and the frequency of flood inundation (Langer 2003; NMFS 2004).

9. **Destruction of the riparian zone during gravel extraction operations can have multiple deleterious effects on anadromous fish habitat.** The importance of riparian habitat to anadromous fishes (Koski 1993) should not be underestimated. For example, Koski (1992) states that a stream's capacity to produce salmonids is controlled by the structure and function of the riparian zone. The riparian zone includes stream banks, riparian vegetation, and vegetative cover. Damaging any one of these elements can cause stream bank destabilization resulting in increased erosion, sediment and nutrient inputs, and reduced shading and bank cover leading to increased stream temperatures. Destruction of riparian trees also means a decrease in the supply of large woody debris. This results in a loss of instream habitat diversity caused by removing the source of materials partially responsible for creating pools and riffles that are critical for anadromous fish growth and survival, as outlined in Environmental Effect Number 7, above (Koski 1992; Murphy 1995; OWRRI 1995).

   Gravel extraction activities can damage the riparian zone in several ways:

   - If the floodplain aquifer discharges into the stream, groundwater levels can be lowered because of channel degradation. Lowering the water table can kill riparian vegetation (Collins and Dunne 1990).
   - Long-term loss of riparian vegetation can occur when gravel is removed to depths that result in permanent flooding or ponded water. Also, loss of vegetation occurs when gravel removal results in a significant shift of the river channel that subsequently causes annual or frequent flooding into the disturbed site (Joyce 1980).
   - Heavy equipment, processing plants, and gravel 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 soil infiltration and causing overland flow. As mentioned in Environmental Effect Number 5 above, the use of heavy equipment also leads to the increased risk of chemical pollution;

hazardous chemicals may also be used in nearby sediment processing plants. In addition, roads, road building, road dirt and dust, and temporary bridges can also impact the riparian zone.

- Removal of large woody debris from the riparian zone during gravel extraction activities negatively affects the plant community (Weigand 1991; OWRRI 1995). Large woody debris is important in protecting and enhancing recovering vegetation in streamside areas (Franklin et al. 1995; OWRRI 1995).
- Rapid bed degradation may induce bank collapse and erosion by undercutting and by increasing the heights of banks (Collins and Dunne 1990; Kondolf 1994a, 1997).
- Portions of incised or undercut banks may be removed during gravel extraction, resulting in reduced vegetative bank cover, causing reduced shading and increased water temperatures (Moulton 1980).
- Banks may be scraped to remove overburden to reach the gravel 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 gravel is removed, the distribution of removal, and the geometry of the particular bed (Collins and Dunne 1990).

10. **Gravel mining can cause a change in disturbance regimes and patterns with a concomitant change in habitat and species** (Castro and Cluer, unpublished report). Stream and river systems are disturbance driven, which can temporarily or permanently alter the character of the system. These disturbances include natural variations in flow regimes and flood events, sediment delivery to the system, large inputs of organic materials, changes in base level, etc. Disturbances can be described by their frequency (e.g., the 100-year flood), duration (length of time), magnitude (areal extent), intensity (force exerted), and severity (biological response) (OWRRI 1995). The bed within the active stream channel experiences the greatest disturbance frequency, which could be as often as every year (i.e., sediment transport events). The 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). Floodplains are disturbed even less frequently than the main and side channels; it may take a major flood event on the order of a decade or longer before the floodplain shows significant alteration. Finally, terraces and hillslopes have the lowest disturbance frequency (e.g., slope failures and mass movements).

    Common to all these disturbances is that the episode of disturbance is followed by a period of recovery (OWRRI 1995). If the disturbance events become so frequent that the system cannot fully recover before the next event, then the system is held in a constant state of disequilibrium or instability (Castro and Cluer, unpublished report). Organisms in these habitats show different responses to these disturbances, depending on such factors as their differences in developmental times, behavior, and their responses to environmental factors (OWRRI 1995). Pringle (1997) contends that anthropogenic activities downstream, including urbanization, dams, gravel mining, etc., can cause effects on organisms upstream, 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 shift of the plant and animal communities to ones that are more adapted to constant disturbance (OWRRI 1995). Incised streams and rivers may be subject to chronic disturbance because of the disconnection of the floodplain. Instream gravel mining may cause chronic disturbance with a concomitant change in the habitat and associated species. Although sediment transport events may occur annually, and may be compared to gravel mining activities, the latter are temporally distinct from natural events. As OWRRI (1995) affirms about salmonids:

> 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.

IV. RECOMMENDATIONS

The following recommendations do not specify the measures, if any, that would need to be implemented by parties engaged in gravel extraction activities in order to comply with applicable statutory requirements. In formulating its recommendations or prescriptions, NMFS will determine the acceptable means of demonstrating compliance with statutory requirements based on information available to the agency, as appropriate under the circumstances presented. As such, the language of this Guidance should not be read to establish any binding requirements on agency staff or the regulated community. The recommendations should not be regarded as static or inflexible, and are meant to be revised as the science upon which they are based improves and areas of uncertainty are resolved. Furthermore, the recommendations are meant to be modified for regional or local use, so a degree of flexibility in their interpretation and application is essential.

In general terms, gravel extraction operations located in or immediately adjacent to streams have greater impacts to anadromous fish resources and habitats than operations located farther from the stream. **Therefore, NMFS recommends that all reasonable efforts be made to identify gravel sources in upland areas and terraces before deciding to site project operations in or near streams.** This is commensurate with the CWA section 404 rationale of *avoiding* impacts, *minimizing* (when not reasonably possible to avoid), and then *mitigating* (when not reasonably possible to minimize).

If, after a thorough alternatives analysis, instream, floodplain, or terrace mining is going to proceed, NMFS recommends that project operations be carefully designed to minimize impacts to trust resources, including habitat. If the recommendations outlined in this Guidance are followed, such that (1) anadromous fishes and their habitats are protected and (2) appropriate and timely restoration is implemented to mitigate unavoidable impacts, gravel mining can, as suggested by Langer (2003), take place within acceptable limits. Many factors must be considered when designing a gravel mining project that conforms to environmental constraints. The recommendations below present only a general list of these considerations. Each project should be considered in its own context, based on project design, stream type and condition, natural resources, and cumulative impacts. NMFS Regional Offices are encouraged to adopt more detailed guidelines tailored to specific physical settings and biological needs.

1. **NMFS recommends that upland aggregate sources, terraces and inactive floodplains be used preferentially to active channels, their deltas and floodplains.** It is recommended that gravel extraction sites be situated outside the active floodplain and that the gravel not be excavated from below the water table. In other words, dry-pit mining on upland outcrops, terraces, or the floodplain is preferable to any of the instream alternatives. Bar skimming is generally preferable to wet-pit mining (deep water dredging) within the active channels if no upland or floodplain sources are reasonably available (see Recommendation Number 6, below). In addition, it is recommended that operators not divert streams to create an inactive channel for gravel extraction purposes, and avoid the formation of isolated ponded areas that cause fish entrapment. In all cases, it is recommended that efforts be made to minimize the need for crossing active channels with heavy equipment.

2. **NMFS recommends that pit excavations located on the adjacent floodplain or terraces should be preferentially sited outside the channel migration zone, and as far from the stream as possible. NMFS recommends that pits be separated from the active channel by a buffer designed to maintain this separation for several decades.** As previously discussed in Section II, the effects of floodplain mining are related to the subsurface hydrological connections between pits and streams, as well as the potential for active channel migration into the floodplain pits ("pit capture"). Therefore, as noted by Kondolf (1993, 1994a), NMFS recommends that pits be considered as potentially instream when viewed on a time scale of decades. Consequently, it is recommended that floodplain pits be located outside the channel migration zone and as far from the stream as possible. This is particularly important given that the likelihood and extent of adverse effects associated with floodplain mining is directly related to the pit's proximity to the active channel (Langer 2003; NMFS 2004). It is recommended that buffers or levees that separate the pits from the active channel be sufficient to accommodate long-term channel migration, infrequent flooding, or inundation; and to avoid fish entrapment. Kondolf (1997) reminds us that:

    > A river channel and floodplain are dynamic features that constitute a single hydrologic and geomorphic unit characterized by frequent transfers of water and sediment between the two components. The failure to appreciate the integral connection between floodplain and channel underlies many environmental problems in river management today.

    Generally, the physical setback of the pit from the channel should be based on several channel widths, or on the meander belt. Pit size should also be considered in determining appropriate buffers. Larger pits have the capacity to absorb a much greater volume of sediment than smaller pits, upon pit capture.

3. **NMFS recommends that larger rivers and streams be used preferentially to small rivers and streams.** Larger systems generally have more gravel and a wider floodplain, and a proportionally smaller disturbance in large systems will reduce the overall impact of gravel extraction (Follman 1980). On a smaller river or stream, the location of the extraction site is more critical because of the limited availability of exposed gravel deposits and the relatively narrower floodplain (Follman 1980). In either case, NMFS recommends that the extraction volume relative to coarse sediment load be low.

4. **NMFS recommends that braided river systems be used preferentially to other river systems.** The river systems, listed in the order of increasing sensitivity to physical changes caused by gravel extraction activities, are: braided, split, meandering, sinuous, and straight (Rundquist 1980). Because braided river systems are dynamic and channel shifting may be a frequent occurrence, channel shifting resulting from gravel extraction might have less overall impact because it is analogous to a naturally occurring process (Follman 1980). However, gravel extraction from braided streams is still considered instream extraction, and NMFS recommends that it be avoided.

5. **NMFS recommends that instream gravel removal quantities be strictly limited so that gravel recruitment and accumulation rates are sufficient to avoid prolonged impacts on channel morphology and anadromous fish habitat.** While this is conceptually simple, annual gravel recruitment to a particular site is, in fact, highly variable and not well understood. Recruitment is the rate at which bedload is supplied from upstream to replace the extracted material. Kondolf (1993, 1994b) dismisses the common belief that instream gravel extraction can be conducted safely as long as the rate of extraction does not exceed the rate of replenishment. Kondolf (1993, 1994b) states that this approach to managing instream gravel extraction is flawed because it fails to account for the upstream/downstream erosional effects that change the channel morphology as soon as gravel extraction begins. In addition, Kondolf (1993, 1994b, 1997) reiterates that flow and sediment transport for most rivers and streams is highly variable from year to year, thus an annual average rate may be meaningless. An "annual average deposition rate" could bear little relation to the sediment transport regimes in a river in any given year. Moreover, sediment transport processes are very difficult to measure and to model, so estimates of bedload transport may prove unreliable (Kondolf 1997). These problems and uncertainties indicate a need for cautious interpretation of sediment yield results, and the conservative application of volume limitations on extraction projects. Any gravel removal in streams or rivers that have a recent history of eroding bars or banks and/or stream bed lowering is not recommended.

   Collins and Dunne (1990) recommend that appropriate rates and locations for instream gravel extraction should be determined on the basis of:

   - the rate of upstream recruitment;
   - whether the river bed elevation under undisturbed conditions remains the same over the course of decades, or the rate at which it is aggrading or degrading;
   - historic patterns of sediment transport, bar growth, and bank erosion;
   - prediction of the specific, local effects of gravel extraction on bed elevations, and the stability of banks and bars, taking into account an analysis of present or past effects of gravel extraction at various rates; and
   - a determination of the desirability or acceptability of the anticipated effects.

   In addition, it is recommended that the habitat values of remaining (or newly recruited) sediments be functionally adequate or equivalent for the purposes of migration, spawning, rearing, benthic invertebrate production, and any other identified habitat needs. Upstream recruitment is ineffective if the necessary ecological functions are not replaced or restored.

6. **NMFS recommends that gravel bar skimming be allowed only under restricted conditions.** (See Section III, Environmental Effect Number 4, for the environmental impacts of gravel bar skimming.) Therefore, NMFS recommends that:

   - gravel be removed only during low flows and from strictly defined areas above the low-flow water level;
   - berms and buffer strips be used to direct stream flow away from the site and to provide for continued migratory habitat;
   - the final grading of the gravel bar not significantly alter the flow characteristics of the river during periods of high flows (OWRRI 1995);
   - bar skimming operations be monitored to ensure they are not adversely affecting gravel recruitment or channel morphology either upstream or downstream from the site;
   - geomorphic features be monitored using methods that quantify their physical dimensions and changes at appropriate time scales. This will likely include densely spaced cross sections to cover the geomorphic features, topographic mapping techniques that do not rely solely on cross sections but follow terrain features, and modern mapping techniques that grid entire areas with closely spaced data; and
   - any gravel removal in streams or rivers that have a recent history of eroding bars or banks, or stream bed lowering, be discouraged.

7. **NMFS recommends that, prior to gravel removal, a thorough review of sediments and point and non-point sources of contaminants be conducted.** Toxic compounds from a variety of sources (municipalities, manufacturing plants, hardrock mines, etc.) may be present in sediments, and can be released into the stream when disturbed during gravel extraction operations. It is recommended that sediment testing be conducted to detect metals and organic compounds (DDT, PCBs, etc.), and residual acid or heavy metal drainage from hardrock mining operations; and that during project operations, extracted gravel, sand, and sediments not be washed directly in the stream or river or within the riparian zone.

   In addition, it is recommended that an assessment of contaminant sources be completed to assist in determining potential problems with contaminated sediments. Sources can include farming, mining, National Pollutant Discharge Elimination System (NPDES)-permitted activities, forestry, sewage treatment plants, and other municipal infrastructure.

   To minimize the suspension of sediments, it is recommended that measures be taken to contain turbidity plumes, and to avoid excessive disturbance of sediments. It is also recommended that turbidity levels do not exceed maximum allowable turbidity limits for anadromous fish and their prey.

8. **NMFS recommends that removal or disturbance of instream roughness elements during gravel extraction activities be avoided, and that those that are disturbed be replaced or restored.** As previously stated in Section III, Environmental Effect Number 7, instream roughness elements, particularly large woody debris, are critical to stream and river ecosystem functioning. This may be particularly true in small streams where large woody

debris plays a relatively greater role in channel morphology and sediment dynamics than it does in larger streams or rivers. In addition, it is recommended that gravel itself be considered an instream roughness element, and that consideration be given to leaving similar-sized gravel in the stream bed, in addition to replacing large woody debris.

9. **NMFS recommends that gravel extraction operations be managed to avoid or minimize damage to stream/river banks and riparian habitats.** Therefore, NMFS recommends that:

- gravel extraction in vegetated (or those that would be vegetated without repeated anthropogenic disturbances) and riparian areas be avoided;
- gravel pits located on the adjacent floodplain not be excavated below the water table;
- berms and buffer strips in the floodplain that keep active channels in their original locations or configurations be maintained for several decades (as in Recommendation Number 2, above);
- undercut and incised vegetated banks not be altered;
- large woody debris in the riparian zone be left undisturbed or replaced when moved;
- all support and processing operations (e.g., gravel washing) be done outside the riparian zone;
- gravel stockpiles, overburden and/or vegetative debris not be stored within the riparian zone, and they be disposed of properly after extraction;
- operation and storage of heavy equipment within riparian habitat be restricted;
- access roads not encroach into the riparian zones; and
- riparian zone protection extend well upstream and downstream from the project site when possible because the erosional effects of instream gravel mining can be manifested miles upstream and downstream from the site of operations.

10. **NMFS recommends that the cumulative impacts of gravel extraction operations to anadromous fishes and their habitats be addressed by the Federal, state, and local resource management and permitting agencies and be considered in the permitting process.** The cumulative impacts on anadromous fish habitat caused by multiple extractions and sites in a given stream, river, or watershed are compounded by other riverine impacts and land use disturbances in the watershed. These additional impacts may be caused by river diversions/impoundments, flood control projects, logging, grazing, and channel/riparian encroachment. The technical methods for assessing, managing, and monitoring cumulative effects are a future need outside the scope of this Gravel Guidance document. Nevertheless, it is recommended that individual gravel extraction operations be judged from a perspective that includes their potential adverse cumulative impacts (Kondolf 1997, 1998a; see also Council on Environmental Quality 1997 and U.S. EPA, Office of Federal Activities 1999 for general cumulative impact guidance). It is recommended that this be reflected in any gravel extraction management plan. NMFS will promote the same watershed approach to cumulative impact analysis when reviewing non-mining activities in or near the aquatic environment.

11. **NMFS recommends that an integrated environmental assessment, management, and monitoring program be a part of any gravel extraction operation, and encouraged at Federal, state, and local levels.** Assessment is used to predict possible environmental impacts. Management is used to implement plans to prevent, minimize, and mitigate negative impacts. Monitoring is used to determine if the assessments were correct, to detect environmental changes, and to support management decisions.

    Before gravel mining operations commence, it is recommended that operators submit plans to the appropriate Federal, state and local agencies outlining their proposed project, including but not limited to location, methods, timing, duration, proposed extraction volumes, and post-mining landscape morphology. Prior to extraction, it is important to establish existing biological and physical conditions, evaluate possible environmental impacts, and describe ways in which adverse environmental impacts are to be prevented or minimized, with the goal of achieving and maintaining the natural ecological functions of the habitat. Using a combination of best available technologies and methods, it is recommended that the following be assessed:

    - Characterize and identify fish species distributions, abundances, and life stages.
    - Identify habitat requirements and determine limiting environmental factors of the anadromous fish populations. In addition to the limiting factors identified by Koski (1992), it is recommended that this analysis evaluate the proposed timing of extraction operations relative to adult and juvenile migration patterns and choose in-water work windows accordingly.
    - Develop a flow frequency curve.
    - Calculate sediment budgets, taking into consideration such periodic natural events as floods (Meador and Layher 1998).
    - Predict possible changes in water quality, channel morphology, and potential adverse cumulative impacts.
    - Propose a mitigation and restoration strategy based on preventing impacts, minimizing unavoidable impacts, and mitigating for all immediate and cumulative impacts (see Recommendation Number 12, below).

    NMFS recommends that the operators also check with their NMFS Regional Offices for any regionally specific procedures and guidelines.

    While gravel mining operations are ongoing, it is important to monitor permitted operations and verify environmental safeguards. At a minimum, it is recommended that the following attributes be monitored on a regular basis:

    - extraction rates and volumes;
    - impacts to the river bed, banks, and bars adjacent to, upstream, and downstream of the project using benchmarked channel cross sections, Digital Elevation Models, and aerial photographs;
    - species distributions and abundances;
    - water quality, including turbidity, dissolved oxygen and contaminants; and
    - effectiveness of mitigation activities.

NMFS recommends that permits have a maximum 5-year limit and be subject to annual review and revision to protect anadromous fish and their habitats (e.g., it is recommended that one element of the annual review determine whether resource management and monitoring objectives are being met). NMFS recommends that a third party be responsible for carrying out monitoring activities and reporting these results to the permitting agency, the operator, the appropriate natural resource agencies, and other stakeholders.

12. **NMFS recommends that mitigation be an integral part of the management of gravel extraction projects.** It is important that mitigation be based on replacing equivalent habitat values and functions, as per the U.S. Army Corps of Engineers (USACE) Regulatory Guidance Letter No. 02-2 (2002) on compensatory mitigation. It is recommended that a mitigation strategy be included in the management program of each project, and, where possible, mitigation activities be initiated concurrently with the gravel mining operations. NMFS recommends that a mechanism for correcting problems identified via monitoring be written into the permit, as monitoring is not worthwhile unless there is a mechanism to address problems that are identified as a result of the monitoring program. In terms of National Environmental Policy Act (NEPA) regulations, mitigation includes, in sequential order:

- avoidance of direct or indirect impacts or losses;
- minimization of the extent or magnitude of the action;
- repair, rehabilitation or restoration of integrity and function;
- reduction or elimination of impacts by preservation and maintenance; and
- compensation by replacement or substitution of the resource or environment.

Thus, restoration follows avoidance and minimization. The preceding definitions recommend that restoration aim to restore the biotic integrity of a riverine ecosystem, not just repair the damaged abiotic components. An overview of river and stream restoration can be found in Gore et al. (1995). A universal, prototype long-term monitoring strategy for watershed and stream restoration can be found in Bryant (1995); see also the various papers by Kondolf and others (e.g., Kondolf and Larson 1995; Kondolf and Micheli 1995; Kondolf 1998b). In addition, see Beechie and Bolton (1999), who discuss approaches to restoring salmonid habitat-forming processes in Pacific Northwest watersheds, and Roni et al. (2002), who review stream restoration techniques and present a hierarchical strategy for prioritizing restoration in these watersheds.

Koski (1992) states that the concept of stream habitat restoration as applied to anadromous fishes is based on the premise that fish production increases when those environmental factors that limit production are alleviated. Thus, an analysis of those "limiting factors" is critical to the restoration process. Koski (1992) further states that effective stream habitat restoration must be holistic in scope, and approached through a three-step process:

1. First, a program of watershed management and restoration must be applied to the watershed to ensure that all major environmental impacts affecting the entire stream ecosystem are addressed (i.e., cumulative impacts). Obviously, an individual gravel extraction project is not expected to restore an entire watershed

suffering from cumulative effects for which it was not responsible. Rather, needed mitigation and restoration activities in a riverine system should focus on direct and indirect project effects and must be designed within the context of overall watershed management.

2. Next, restore the physical structure of the channel, instream habitats, and riparian zones (e.g., stabilize stream banks through replanting of riparian vegetation, conserve spawning gravel, and replace large woody debris). This would reestablish the ecological carrying capacity of the habitat.

3. Finally, the fish themselves should be managed to ensure that there are sufficient spawning populations for maximizing the restored carrying capacity of the habitat.

Without restoration, stream recovery from gravel mining can take decades (Kanehl and Lyons 1992). However, NMFS recommends that reliance on restoration be put into proper perspective. It is important to acknowledge that there are significant gaps in our understanding of the methodology and effectiveness of restoration of streams and anadromous fish habitat affected by gravel extraction activities. Overall, restoration as a science is relatively young and experimental, and the processes and mechanisms are poorly understood. Little is known about the functional value, stability and resiliency of many so-called "restored" habitats. To date, existing regulations or plans pertaining to the mitigation and restoration of gravel extraction sites have been simplistic or vague, and, because restoration science and planning is still rudimentary, NMFS recommends that each project first begin its mitigation analysis with avoidance and minimization.

As an example, gravel extraction in California is regulated under the concept of "reclamation," which is derived from open-pit surface mining, such as large coal mines. Although the definition and implementation of reclamation may vary among states, Kondolf (1993, 1994b) states the concept of reclamation, as applied to open-pit mines, often assumes that the environmental impacts are confined to the site; therefore, site treatment is considered in isolation from changes in the surrounding terrain. Kondolf (1993, 1994b) suggests that this definition treats the site as an essentially static feature of the landscape. He argues that, while these assumptions may work for extraction operations located in inactive stream or river terraces, active channels and floodplains are dynamic environments, where disturbances can spread rapidly upstream and downstream from the site during and after the time of operation. The stream or river will irrevocably readjust its profile during subsequent high flows, eradicating the gravel pits and giving the illusion that extraction has had no impact on the channel. Kondolf (1993, 1994b) claims that a survey of bed elevations will show a net lowering of the bed, which reflects the more even distribution of downcutting (erosion) along the length of the channel. Even if the channel profile were to recover after project completion due to an influx of fresh sediment from upstream, habitat will have been lost in the meantime. Thus, it is not possible to disturb one site in isolation from the rest of the ecosystem, or confine the disturbance to a single, detached location, and then subsequently reclaim or reverse the impacts (Brown et al. 1998). Kondolf (1993, 1994b) concludes that reclamation can be applied to gravel pits in terrace deposits above the water table, but the reclamation concept is not workable for regulating instream gravel extraction. Similarly, regarding instream gravel mining, Brown et al. (1998) conclude that "total restoration of severely affected streams would probably be impossible."

Moreover, Kondolf (1998a) reminds us that:

> The effects of instream gravel mining may not be obvious immediately because active sediment transport is required for the effects (e.g. incision, instability) to propagate upstream and downstream. Given that geomorphically-effective sediment transport events are infrequent on many rivers, there may be a lag of several or many years before the effects of instream gravel mining are evident and propagate along the channel. Thus, gravel mines may operate for years without apparent effects upstream or downstream, only to have the geomorphic effects manifest years later during high flows. Similarly, rivers are often said to have "long memories," meaning that the channel adjustments to instream extraction or comparable perturbations may persist long after the activity itself has ceased.

This delayed manifestation of geomorphic effects leads to the false assumption that floods cause damage to stream systems, when in actuality anthropogenic changes often "set the stage" for geomorphic change. Large flood events simply provide the necessary stream power for the changes to occur.

For further guidance on mitigation, refer to the USACE Regulatory Guidance Letter (USACE 2002) noted above and the joint guidance on the Use of In-Lieu-Fee Arrangements for Compensatory Mitigation Under Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act (65FR 66913, November 7, 2000).

13. **NMFS recommends that gravel extraction projects proposed as stream restoration activities be regarded with caution.** Resource management agencies acknowledge that, under the right circumstances, some gravel extraction projects, whether commercial or performed by the agencies themselves, may offer important opportunities for anadromous fish habitat enhancement. That is, gravel removal itself can be used beneficially as a tool for habitat creation, restoration, or rehabilitation (OWRRI 1995). While it is tempting to promote gravel extraction as a means to enhance or restore stream habitat, the underlying objective of this Guidance document is to prevent adverse impacts caused by commercial gravel extraction operations. Therefore, NMFS recommends that gravel extraction for habitat enhancement purposes, done in conjunction with commercial gravel operations, not take precedence over, and not be a substitute for, habitat protection. It is recommended that any proposals to perform gravel extraction for habitat enhancement purposes be done in consultation with NMFS regional field offices and technical experts.

    NMFS recommends that either a mitigation fund, with contributions paid by the operators, or royalties from gravel extraction be used to fund mitigation programs and to perform effectiveness monitoring. A possible use of mitigation funds and royalties could include conducting studies to further the knowledge of extraction impacts in a given watershed. Such studies might include: a review of historical impacts; identification of alternative aggregate sources; a watershed-based evaluation of mitigation alternatives; identification of sites where it is recommended that extraction activities be avoided; and recommended removal thresholds.

In light of the dynamic, unpredictable, and episodic nature of stream hydrology and sediment transport, NMFS cautions against relying too heavily on restoration, and agrees with both Murphy (1995) and Langer (2001) that the best form of habitat mitigation is to avoid or minimize adverse impacts to the environment.

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APPENDIX 1
SUMMARIES OF MAJOR STATUTES

The following summaries of the major statutes mentioned in this Gravel Guidance document, with the exception of the Rivers and Harbors Act of 1899, are based on Buck (1995)[1].

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 filling of wetlands. The intent of the CWA Section 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. The National Marine Fisheries Service (NMFS) can provide comments to the U.S. Army Corps of Engineers (USACE) as to the impacts to living marine resources of proposed activities and can recommend methods for avoiding such impacts.

If NMFS determines that a proposed action will result in "substantial and unacceptable adverse impacts on aquatic resources of national importance," the Assistant Secretary for Oceans and Atmosphere may request that the decision be reviewed at a higher level in the USACE. A 404(q) elevation pauses the permit process for about 2 months while the two departments exchange information to address concerns about the proposed project. Although outright permit denials are rare, there are often modifications to the project proposal resulting in a less harmful action.

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. If a Federal action may affect ESA-listed species or their critical habitat, the action agency must initiate consultation with NMFS under section 7 of the ESA. Other pertinent sections of the ESA include section 9 (direct take) and section 10 (exemptions from take prohibitions).

[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.

Fish and Wildlife Coordination Act

The Fish and Wildlife Coordination Act (FWCA) (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 U.S. Fish and Wildlife Service, NMFS and appropriate state agencies whenever any body of water is proposed to be modified in any way and a Federal permit or license is required. These agencies determine: (1) the possible harm to fish and wildlife resources; (2) the measures needed to both prevent the damage to and loss of these resources; and (3) 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 provides recommendations to prevent harm.

Magnuson-Stevens Fishery Conservation and Management Act

The Magnuson-Stevens Fishery Conservation and Management Act, first passed in 1976 and amended in 1996, is the primary legislation governing marine fisheries in the United States. This legislation established eight Regional Fishery Management Councils to manage fishery resources in the Exclusive Economic Zone under Fishery Management Plans (FMPs) for Federally managed fisheries. Plans may include one or several species and are designed to achieve specified management goals for a fishery.

The 1996 reauthorization of the Magnuson-Stevens Act included a provision for Essential Fish Habitat (EFH). The act states: "One of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats. Habitat considerations should receive increased attention for the conservation and management of fishery resources of the United States" (16 U.S.C. 1801 (A)(9)). The definition of EFH in the legislation covers "those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity." The legislation mandates that NMFS and the Councils implement a process for conserving and protecting EFH. Key features of this process are:

1. *Designate EFH.* Councils are required to describe and identify EFH for each life stage of the species included in their FMPs.
2. *Minimize to the extent practicable the adverse effects of fishing on EFH.* Councils must assess fishing impacts to EFH, taking Habitat Areas of Particular Concern (HAPCs) into special consideration (i.e., habitat types that are especially sensitive, ecologically important, or rare), and minimize the impacts of fishing on EFH to the extent practicable.
3. *Consult on potential fishing and non-fishing impacts to EFH.* NMFS and the Councils are required to comment on activities proposed by Federal action agencies (e.g., U.S. Army Corps of Engineers, Federal Energy Regulatory Commission, and Department of the Navy) that may adversely impact areas designated as EFH.
4. *Further review of decisions inconsistent with NMFS or Council recommendations.* If a Federal agency decision is inconsistent with a NMFS conservation recommendation, the

Assistant Administrator for Fisheries may request a meeting with the head of the Federal action agency to review and discuss the issue.

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 that would significantly affect the human environment. It specifically requires agencies to use a systematic, interdisciplinary approach in planning and decision making to ensure 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.

Rivers and Harbors Act of 1899

The Rivers and Harbors Act of 1899, Section 10 (33 *U.S.C.* 403), authorizes the USACE to regulate activities that affect waters of the United States. These activities include construction of wharves, piers and jetties and excavating or altering stream channels of navigable waters. NMFS may comment on proposed activities (usually via the FWCA), and the CWA 404(q) elevation process (see Clean Water Act, above) is available to NMFS under the Rivers and Harbors Act.

ATTACHMENT J

Attachment

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

MEMORANDUM FOR: Regional, Science, and Office Directors, NMFS

FROM: Rolland A. Schmitten

SUBJECT: NMFS National Gravel Extraction Policy

The NMFS National Gravel Extraction Policy, henceforth "Gravel Policy," describes general policy, procedures, and recommendations of NMFS's National Habitat Program pertaining to any gravel extraction projects within or near current or historic anadromous fish habitat. The Gravel Policy incorporates elements from the gravel mining policy of the NMFS Southwest Region plus information provided by the other Regions. It consolidates published and unpublished material developed at other Federal, state, and private institutions. The intent of the Gravel Policy is to strengthen NMFS efforts in conserving anadromous fish habitat and to foster consistency at the national level, while maintaining regional flexibility. The Gravel Policy will provide guidance and recommendations to regional field staff who must manage gravel mining activities. It will also streamline Government and foster predictability for the intra- and interstate operations of gravel miners. The Gravel Policy is designed to be robust in its protection of anadromous fishes and their habitats.

I wish to commend Dave Packer of the James J. Howard Marine Sciences Lab of the Northeast Fisheries Science Center for his work as the principal author. This policy bridges the interface of scientific and management considerations surrounding gravel extraction, and was developed while Dave was on a rotational assignment to the Headquarters Office of Habitat Protection.

The following Regional staff also deserve recognition for their cooperation and comments: from the Southwest, Dick Butler and Marty Golden; from the Northwest, Ben Meyer, Michelle Day, and Joanne Wu; from Alaska, Andrew Grossman; and, from the Northeast, Mike Ludwig. The continued assistance of the Regions will be necessary as part of the future review process.

Comments or questions on this National Policy should be directed to: Dave Packer (F/NEC23) at James J. Howard Marine Sciences Laboratory Sandy Hook, Highlands, New Jersey 07732 (908/872-3044), Dave.Packer@noaa.gov; or, to Stephen Waste (F/HP4), 1315 East-West Highway, Room 12625, Silver Spring, Maryland 20910 (301-713-2325x157), Stephen.Waste@noaa.gov.

Attachment

National Marine Fisheries Service

NMFS National Gravel Extraction Policy

August 1996

NMFS NATIONAL GRAVEL EXTRACTION POLICY
NATIONAL MARINE FISHERIES SERVICE

I. INTRODUCTION

The National Marine Fisheries Service (NMFS) is responsible for protecting, managing and conserving marine, estuarine, and anadromous fish resources and their habitats. A national policy on gravel extraction is necessary because extraction in and near anadromous fish streams causes many adverse impacts to fishes and their habitats. These impacts include: loss or degradation of spawning beds and juvenile rearing habitat; migration blockages; channel widening, shallowing, and ponding; loss of hydrologic and channel stability; loss of pool/riffle structure; increased turbidity and sediment transport; increased bank erosion and/or stream bed downcutting; and loss or degradation of riparian habitat.

The objective of the NMFS Gravel Policy is to ensure that gravel extraction operations are conducted in a manner that eliminates or minimizes to the greatest extent possible any adverse impacts to anadromous fishes and their habitats. Gravel extraction operations should not interfere with anadromous fish migration, spawning, or rearing, nor should they be allowed within, upstream, or downstream of anadromous fish spawning grounds. The intent is to conserve and protect existing viable anadromous fish habitat and historic habitat that is restorable. Individual gravel extraction operations must be judged in the context of their spatial and temporal cumulative impacts; i.e., potential impacts to habitat should be viewed from a watershed management perspective.

The U.S. Army Corps of Engineers may require a permit for dredge and fill operations and other activities associated with gravel extraction projects under Sections 401 and 404 of the Clean Water Act, and/or Section 10 of the Rivers and Harbors Act of 1899. Under the Fish and Wildlife Coordination Act, NMFS reviews Section 10 or Section 404 permit applications for environmental impacts to anadromous, estuarine, and marine fisheries and their habitats. Gravel extraction projects not subject to Section 404 or Section 10 permits may still be reviewed by NMFS pursuant to the applicable County/State public hearing processes. The Magnuson Fishery Conservation and Management Act also addresses the effects which changes to habitat may have upon a fishery. None of the recommendations presented in this document are intended to supersede these regulations or any other laws, such as the Endangered Species Act. Rather, the policy's recommendations are intended as guidance for NMFS personnel who are involved in the review of gravel extraction projects. (See Appendix 1 for summaries of the relevant statutes.)

This Gravel Policy is subject to comprehensive biennial review and revision that will be initiated and coordinated by the Office of Habitat Conservation. Requests for specific changes or revisions requiring immediate attention should be brought to the attention of Stephen M. Waste, NMFS's Office of Habitat Conservation in Silver Spring, Maryland.

II. SCOPE OF GRAVEL POLICY

The types of gravel extraction activities referred to in this Gravel Policy generally entail commercial gravel mining; i.e., removing or obtaining a supply of gravel for industrial uses, such as road construction material, concrete aggregate, fill, and landscaping. Gravel can also be removed for maintenance dredging and flood control. Gravel extraction often occurs at multiple times and at multiple sites along a given stream, resulting in impacts that are likely to be both chronic and cumulative. When the rate of gravel extraction exceeds the rate of natural deposition over an extended time period, a net "mining" occurs due to the cumulative loss of gravel (Oregon Water Resources Research Institute [OWRRI] 1995).

The range of anadromous fish habitats specifically addressed by this Gravel Policy include tidal rivers, freshwater rivers and streams, and their associated wetlands and riparian zones. Gravel extraction is a major and longstanding activity in rivers and streams, particularly in salmonid habitats on the west coast of the United States, including Alaska. Gravel extraction, as well as sand mining and dredging, also occurs on the northeast coast of the United States, but primarily in marine habitats such as the lower reaches of large tidal rivers, estuaries and offshore. Gravel and sand mining or dredging in the northeast generally raises different concerns than for the west coast. For example, few of the anadromous species found in the northeastern United States are bottom spawners or rely on specific habitat for their reproductive activities. Although many elements of the Gravel Policy are germane to all areas where gravel extraction occurs, the primary focus of this Policy is on west coast gravel extraction issues. Northeast coast bottom disturbance activities will be addressed in greater detail in a future policy.

This Gravel Policy addresses three types of instream gravel mining, which Kondolf (1993; 1994a) describes as follows: dry-pit and wet-pit mining in the active channel, and bar skimming or "scalping." Dry-pit refers to pits excavated on dry ephemeral stream beds and exposed bars with conventional bulldozers, scrapers, and loaders. Wet-pit mining involves the use of a dragline or hydraulic excavator to remove gravel from below the water table or in a perennial stream channel. Bar skimming or scalping requires scraping off the top layer from a gravel bar without excavating below the summer water level.

In addition to instream gravel mining, this Policy also addresses another method, which Kondolf (1993; 1994a) describes as the excavation of pits on the adjacent floodplain or river terraces. Dry pits are located above the water table. Wet pits are below, depending on the elevation of the floodplain or terrace relative to the baseflow water elevation of the channel. Their isolation from an adjacent active channel may be only short term. During a sudden change in channel course during a flood, or as part of gradual migration, small levees may be breached and the channel will shift into the gravel pits. Because floodplain pits can become integrated into the active channel, Kondolf (1993; 1994a) suggests that they should be regarded as existing instream if considered on a time scale of decades.

III. ENVIRONMENTAL EFFECTS OF GRAVEL EXTRACTION

Extraction of alluvial material from within or near a stream bed has a direct impact on the stream's physical habitat parameters such as channel geometry, bed elevation, substrate composition and stability, instream roughness elements (large woody debris, boulders, etc.) depth, velocity, turbidity, sediment transport, stream discharge and temperature (Rundquist 1980; Pauley et al. 1989; Kondolf 1994a, b; OWRRI 1995). OWRRI, (1995) states that:

> Channel hydraulics, sediment transport, and morphology are directly affected by human activities such as gravel mining and bank erosion control. The immediate and direct effects are to reshape the boundary, either by removing or adding materials. The subsequent effects are to alter the flow hydraulics when water levels rise and inundate the altered features. This can lead to shifts in flow patterns and patterns of sediment transport. Local effects also lead to upstream and downstream effects.

Altering these habitat parameters has deleterious impacts on instream biota and the associated riparian habitat (Sandecki, 1989). For example, impacts to anadromous fish populations due to gravel extraction include: reduced fish populations in the disturbed area, replacement of one species by another, replacement of one age group by another, or a shift in the species and age distributions (Moulton, 1980). In general terms, Rivier and Seguier (1985) suggest that the detrimental effects to biota resulting from bed material mining are caused by two main processes: (1) alteration of the flow patterns resulting from modification of the river bed, and (2) an excess of suspended sediment. OWRRI (1995) adds:

> Disturbance activities can disrupt the ecological continuum in many ways. Local channel changes can propagate upstream or downstream and can trigger lateral changes as well. Alterations of the riparian zone can allow changes in-channel [*sic*] conditions that can impact aquatic ecosystems as much as some in-channel [*sic*] activities.
>
> One consequence of the interconnectedness of channels and riparian systems is that potential disruptions of the riparian zone must be evaluated when channel activities are being evaluated. For example, aggregate mining involves the channel and boundary but requires land access and material storage that could adversely affect riparian zones; bank protection works are likely to influence riparian systems beyond the immediate work area.

The potential effects of gravel extraction activities on stream morphology, riparian habitat, and anadromous fishes and their habitats are summarized as follows:

1. **Extraction of bed material in excess of natural replenishment by upstream transport causes bed degradation.** This is partly because gravel "armors" the bed, stabilizing banks and bars, whereas removing this gravel causes excessive scour and sediment movement (Lagasse et al. 1980; OWRRI, 1995). Degradation can extend upstream and downstream of an individual extraction operation, often at great distances, and can result from bed mining either in or above the low-water channel (Collins and Dunne 1990; Kondolf 1994a, b; OWRRI, 1995). Headcutting, erosion, increased velocities and concentrated flows can occur upstream of the extraction site due to a steepened river

gradient (OWRRI, 1995). Degradation can deplete the entire depth of gravel on a channel bed, exposing other substrates that may underlie the gravel, which would reduce the amount of usable anadromous spawning habitat (Collins and Dunne, 1990; Kondolf, 1994a; OWRRI, 1995). For example, gravel removal from bars may cause downstream bar erosion if they subsequently receive less bed material from upstream than is being carried away by fluvial transport (Collins and Dunne, 1990). Thus, gravel removal not only impacts the extraction site, but may reduce gravel delivery to downstream spawning areas (Pauley et al., 1989).

2. **Gravel extraction increases suspended sediment, sediment transport, water turbidity and gravel siltation** (OWRRI, 1995). The most significant change in the sediment size distribution resulting from gravel removal is a decrease in sediment size caused by fine material deposition into the site (Rundquist, 1980). Fine sediments in particular are detrimental to incubating fish eggs as blockage of interstitial spaces by silt prevents oxygenated water from reaching the eggs and removal of waste metabolites (Chapman, 1988; Reiser and White, 1988). High silt loads may also inhibit larval, juvenile and adult behavior, migration, or spawning (Snyder, 1959; Cordone and Kelly, 1961; Bisson and Bilby 1982; Bjornn and Reiser, 1991; OWRRI, 1995). Siltation, substrate disturbances and increased turbidity also affect the invertebrate food sources of anadromous fishes (OWRRI, 1995).

3. **Bed degradation changes the morphology of the channel** (Moulton, 1980; Rundquist, 1980; Collins and Dunne, 1990; Kondolf, 1994a,b; OWRRI, 1995). Gravel extraction causes a diversion or a high potential for diversion of flow through the gravel removal site (Rundquist, 1980). Mined areas that show decreased depth or surface flow could result in migration blockages during low flows (Moulton, 1980). This may compound problems in many areas where flows may already have been altered by hydropower operations and irrigation. Even if the gravel extraction activity is conducted away from the active river channel during low water periods, substrate stability and channel morphology outside the excavated area's perimeter could be affected during subsequent high water events. As active channels naturally meander, the channel may migrate into the excavated area. Also, ponded water isolated from the main channel may strand or entrap fish carried there during high water events (Moulton, 1980; Palmisano, 1993). Fish in these ponded areas could experience higher temperatures, lower dissolved oxygen, increased predation compared to fish in the main channel, desiccation if the area dries out, and freezing (Moulton, 1980).

4. **Gravel bar skimming significantly impacts aquatic habitat**. First, bar skimming creates a wide flat cross section, then eliminates confinement of the low flow channel, and results in a thin sheet of water at baseflow (Kondolf, 1994a.) Bar skimming can also remove the gravel "pavement," leaving the finer subsurface particles vulnerable to entrainment (erosion) at lower flows (Kondolf, 1994a; OWRRI, 1995). A related effect is that bar skimming lowers the overall elevation of the bar surface and may reduce the threshold water discharge at which sediment transport occurs (OWRRI, 1995). Salmon redds (nests) downstream are thus susceptible to deposition of displaced, surplus alluvial material, resulting in egg suffocation or suppressed salmon fry emergence, while redds

upstream of scalped bars are vulnerable to regressive erosion (Pauley et al., 1989). Gravel bar skimming also appears to reduce the amount of side channel areas, which can result in the reduction and/or displacement of juvenile salmonid fishes that use this habitat (Pauley et al., 1989).

5. **Operation of heavy equipment in the channel bed can directly destroy spawning habitat, and produce increased turbidity and suspended sediment downstream** (Forshage and Carter, 1973; Kondolf, 1994a). Additional disturbances to redds may occur from increased foot and vehicle access to spawning sites, due to access created initially for gravel extraction purposes (OWRRI, 1995).

6. **Stockpiles and overburden left in the floodplain can alter channel hydraulics during high flows.** During high water, the presence of stock piles and overburden can cause fish blockage or entrapment, and fine material and organic debris may be introduced into the water, resulting in downstream sedimentation (Follman, 1980).

7. **Removal or disturbance of instream roughness elements during gravel extraction activities negatively affects both 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 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, gravel and particulate organic matter, and in creating and maintaining habitat diversity and complexity (Franklin, 1992; Koski, 1992; Murphy, 1995; OWRRI, 1995). Large woody debris in streams creates pools and backwaters that salmonids use as foraging sites, critical overwintering areas, refuges from predation, and spawning and rearing habitat (Koski, 1992; OWRRI, 1995). Large wood jams at the head of gravel bars can anchor the bar and increase gravel recruitment behind the jam (OWRRI, 1995). Loss of large woody debris from gravel bars can also negatively impact aquatic habitat (Weigand, 1991; OWRRI, 1995). The importance of large woody debris has been well documented, and its removal results in an immediate decline in salmonid abundance (e.g., see citations in Koski, 1992; Franklin et al., 1995; Murphy, 1995; OWRRI, 1995).

8. **Destruction of the riparian zone during gravel extraction operations can have multiple deleterious effects on anadromous fish habitat.** The importance of riparian habitat to anadromous fishes should not be underestimated. For example, Koski (1992) states that a stream's carrying capacity to produce salmonids is controlled by the structure and function of the riparian zone. The riparian zone includes stream banks, riparian vegetation and vegetative cover. Damaging any one of these elements can cause stream bank destabilization, resulting in increased erosion, sediment and nutrient inputs, and reduced shading and bank cover leading to increased stream temperatures. Destruction of riparian trees also means a decrease in the supply of large woody debris.

This results in a loss of instream habitat diversity caused by removing the source of materials responsible for creating pools and riffles, which are critical for anadromous fish growth and survival, as outlined in Number 7, above (Koski, 1992; Murphy, 1995; OWRRI, 1995).

Gravel extraction activities can damage the riparian zone in several ways:

a. If the floodplain aquifer discharges into the stream, groundwater levels can be lowered because of channel degradation. Lowering the water table can destroy riparian vegetation (Collins and Dunne, 1990).

b. Long-term loss of riparian vegetation can occur when gravel is removed to depths that result in permanent flooding or ponded water. Also, loss of vegetation occurs when gravel removal results in a significant shift of the river channel that subsequently causes annual or frequent flooding into the disturbed site (Joyce, 1980).

c. Heavy equipment, processing plants and gravel 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 soil infiltration and causing overland flow. In addition, roads, road building, road dirt and dust, and temporary bridges can also impact the riparian zone.

d. Removal of large woody debris from the riparian zone during gravel extraction activities negatively affects the plant community (Weigand, 1991; OWRRI, 1995). Large woody debris is important in protecting and enhancing recovering vegetation in streamside areas (Franklin et al., 1995; OWRRI, 1995).

e. Rapid bed degradation may induce bank collapse and erosion by increasing the heights of banks (Collins and Dunne, 1990; Kondolf, 1994a).

f. Portions of incised or undercut banks may be removed during gravel extraction, resulting in reduced vegetative bank cover, causing reduced shading and increased water temperatures (Moulton, 1980).

g. Banks may be scraped to remove "overburden" to reach the gravel below. This may result in destabilized banks and increased sediment inputs (Moulton, 1980).

h. The reduction in size or height of bars can cause adjacent banks to erode more rapidly or to stabilize, depending on how much gravel is removed, the distribution of removal, and on the geometry of the particular bed (Collins and Dunne, 1990).

IV. RECOMMENDATIONS

The following recommendations should not be regarded as static or inflexible. The recommendations are meant to be revised as the science upon which they are based improves and areas of uncertainty are resolved. Furthermore, the recommendations are meant to be adapted for regional or local use (e.g., Alaska often has opportunities to comment through their State coastal management programs), so a degree of flexibility in their interpretation and application is necessary.

1. **Abandoned stream channels on terraces and inactive floodplain should be used preferentially to active channels, their deltas and floodplain.** Gravel extraction sites should be situated outside the active floodplain and the gravel should not be excavated from below the water table. In other words, dry-pit mining on terraces or floodplain is preferable to any of the alternatives, in particular, wet-pit mining instream, but also bar skimming and wet-pit mining in the floodplain. In addition, operators should not divert streams to create an inactive channel for gravel extraction purposes, and formation of isolated ponded areas that cause fish entrapment should be avoided. Also, all gravel extraction activities for a single project should be located on the same side of the floodplain. This will eliminate the need for crossing active channels with heavy equipment.

2. **Larger rivers and streams should be used preferentially to small rivers and streams.** Larger systems are preferable because they have more gravel and a wider floodplain, and the proportionally smaller disturbance in large systems will reduce the overall impact of gravel extraction (Follman, 1980). On a smaller river or stream, the location of the extraction site is more critical because of the limited availability of exposed gravel deposits and the relatively narrower floodplain (Follman, 1980).

3. **Braided river systems should be used preferentially to other river systems.** The other systems, listed in the order of increasing sensitivity to physical changes caused by gravel extraction activities, are: split, meandering, sinuous, and straight (Rundquist, 1980). Because braided river systems are dynamic and channel shifting is a frequent occurrence, theoretically, channel shifting resulting from gravel extraction might have less of an overall impact because it is analogous to a naturally occurring process (Follman 1980). In addition, floodplain width progressively decreases in the aforementioned series of river systems. If gravel extraction is to occur in the adjacent floodplain, it is likely that the other four river system types will experience greater environmental impacts than the braided river system (Follman, 1980).

4. **Gravel removal quantities should be strictly limited so that gravel recruitment and accumulation rates are sufficient to avoid extended impacts on channel morphology and anadromous fish habitat.** While this is conceptually simple, annual gravel recruitment to a particular site is, in fact, highly variable and not well understood. (Recruitment is the rate at which bedload is supplied from upstream to replace the extracted material.) Kondolf (1993; 1994b) dismisses the common belief that instream gravel extraction can be conducted safely so long as the rate of extraction does not exceed the rate of replenishment. Kondolf (1993; 1994b) states that this approach to managing

instream gravel extraction is flawed because it fails to account for the upstream/downstream erosional effects that change the channel morphology as soon as gravel extraction begins. In addition, Kondolf (1993; 1994b) reiterates that flow and sediment transport for most rivers and streams is highly variable from year-to-year, thus an annual average rate may be meaningless. An "annual average deposition rate" could bear little relation to the sediment transport regimes in a river in any given year. Moreover, sediment transport processes are very difficult to model, so estimates of bedload transport may prove unreliable. These problems and uncertainties indicate a need for further research.

5. **Gravel bar skimming should only be allowed under restricted conditions.** (See Section III, Number 4, for the environmental impacts of gravel bar skimming.) Gravel should be removed only during low flows and from above the low-flow water level. Berms and buffer strips must be used to control stream flow away from the site. The final grading of the gravel bar should not significantly alter the flow characteristics of the river during periods of high flows (OWRRI, 1995). Finally, bar skimming operations need to be monitored to ensure that they are not adversely affecting gravel recruitment downstream or the stream morphology either upstream or downstream of the site. If the stream or river has a recent history of rapidly eroding bars or stream bed lowering, bar skimming should not be allowed.

6. **Pit excavations located on adjacent floodplain or terraces should be separated from the active channel by a buffer designed to maintain this separation for two or more decades.** As previously discussed in Section II, the active channel can shift into the floodplain pits, therefore Kondolf (1993; 1994a) recommends that the pits be considered as potentially instream when viewed on a time scale of decades. Consequently, buffers or levees that separate the pits from the active channel must be designed to withstand long-term flooding or inundation by the channel.

7. **Prior to gravel removal, a thorough review should be undertaken of potentially toxic sediment contaminants in or near the stream bed where gravel removal operations are proposed or where bed sediments may be disturbed (upstream and downstream) by the operations. Also, extracted aggregates and sediments should not be washed directly in the stream or river or within the riparian zone.** Turbidity levels should be monitored and maximum allowable turbidity levels for anadromous fish and their prey should be enforced.

8. **Removal or disturbance of instream roughness elements during gravel extraction activities should be avoided. Those that are disturbed should be replaced or restored.** As previously stated in Section III, Number 7, instream roughness elements, particularly large woody debris, are critical to stream ecosystem functioning.

9. **Gravel extraction operations should be managed to avoid or minimize damage to stream/river banks and riparian habitats.** Gravel extraction in vegetated riparian areas should be avoided. Gravel pits located on adjacent floodplain should not be excavated below the water table. Berms and buffer strips in the floodplain that keep active channels

in their original locations or configurations should be maintained for two or more decades (as in Number 6, above). Undercut and incised vegetated banks should not be altered. Large woody debris in the riparian zone should be left undisturbed or replaced when moved. All support operations (e.g., gravel washing) should be done outside the riparian zone. Gravel stockpiles, overburden and/or vegetative debris should not be stored within the riparian zone. Operation and storage of heavy equipment within riparian habitat should be restricted. Access roads should not encroach into the riparian zones.

10. **The cumulative impacts of gravel extraction operations to anadromous fishes and their habitats should be addressed by the Federal, state, and local resource management and permitting agencies and considered in the permitting process.** The cumulative impacts on anadromous fish habitat caused by multiple extractions and sites along a given stream or river are compounded by other riverine impacts and land use disturbances in the watershed. These additional impacts may be caused by river diversions/impoundments, flood control projects, logging, and grazing. The technical methods for assessing, managing, and monitoring cumulative effects are a future need outside the scope of this Gravel Policy. Nevertheless, individual gravel extraction operations must be judged from a perspective that includes their potential adverse cumulative impacts. This should be a part of any gravel extraction management plan.

11. **An integrated environmental assessment, management, and monitoring program should be a part of any gravel extraction operation, and encouraged at Federal, state, and local levels.** Assessment is used to predict possible environmental impacts. Management is used to implement plans to prevent or minimize negative impacts. A mitigation and restoration strategy should be included in any management program. Monitoring is used to determine if the assessments were correct, to detect environmental changes, and to support management decisions.

12. **Mitigation and restoration should be an integral part of the management of gravel extraction projects.** Mitigation should occur concurrently with gravel extraction activities. In terms of National Environmental Policy Act (NEPA) regulations, mitigation includes:
(1) avoidance of direct or indirect impacts or losses;
(2) minimization of the extent or magnitude of the action;
(3) repair, rehabilitation or restoration of integrity and function;
(4) reduction or elimination of impacts by preservation and maintenance;
(5) compensation by replacement or substitution of the resource or environment.
Thus, restoration is a part of mitigation, and according to the preceding definitions, the aim of restoration should be to restore the biotic integrity of a riverine ecosystem, not just to repair the damaged abiotic components. (However, see also Phase III of Section V, below.) An overview of river and stream restoration can be found in Gore et al. (1995). Koski (1992) states that the concept of stream habitat restoration as applied to anadromous fishes is based on the premise that fish production increases when those environmental factors that limit production are alleviated.

Thus, an analysis of those "limiting factors" is critical to the restoration process. Koski (1992) further states that effective stream habitat restoration must be holistic in scope, and approached through a three-step process:

- First, a program of watershed management and restoration must be applied to the watershed to ensure that all major environmental impacts affecting the entire stream ecosystem are addressed (i.e., cumulative impacts). Obviously, an individual gravel extraction project is not expected to restore an entire watershed suffering from cumulative effects for which it was not responsible. Rather, needed mitigation and restoration activities in a riverine system should focus on direct and indirect project effects and must be designed within the context of overall watershed management.

- Next, restore the physical structure of the channel, instream habitats and riparian zones (e.g., stabilize stream banks through replanting of riparian vegetation, conserve spawning gravel, and replace large woody debris). This would reestablish the ecological carrying capacity of the habitat, allowing fish production to increase.

- Finally, the fish themselves should be managed to ensure that there are sufficient spawning populations for maximizing the restored carrying capacity of the habitat.

NMFS recommends that either a mitigation fund, with contributions paid by the operators, or royalties from gravel extraction be used to fund the mitigation and restoration programs as well as for effectiveness monitoring.

13. **Habitat protection should be the primary goal in the management of gravel extraction operations.** Resource management agencies acknowledge that, under the right circumstances, some gravel extraction projects, whether commercial or performed by the agencies themselves, may offer important opportunities for anadromous fish habitat "enhancement". That is, gravel removal itself can be used beneficially as a tool for habitat creation, restoration, or rehabilitation (e.g., OWRRI, 1995). However, stream restoration and enhancement projects should be regarded with caution (see caveats on restoration and reclamation in Section V, Phase III, and OWRRI, 1995). While it is tempting to promote gravel extraction as a means to enhance or restore stream habitat, the underlying objective of this Gravel Policy is to prevent adverse impacts caused by commercial gravel extraction operations. Therefore, gravel extraction for habitat enhancement purposes done in conjunction with commercial gravel operations will not take precedence over and is not a substitute for habitat protection.

V. OPTIMUM MANAGEMENT OF GRAVEL EXTRACTION OPERATIONS

This section outlines a simple management scenario for gravel extraction operations, with the goal of minimizing impacts to anadromous fishes and their habitats. It is organized around the three program elements outlined in recommendation 11. This general framework is intended only as an introductory guide for creating a more comprehensive assessment, management and monitoring program. Other examples can be found in the literature (e.g., Collins and Dunne, 1990; OWRRI, 1995).

Before implementing Phase I, the operators should submit plans to the appropriate Federal, State and local agencies outlining their proposed project, including locations, methods, timing, duration, proposed extraction volumes, etc. The operators should also check with their NMFS Regional offices for any region specific procedures and guidelines.

Phase I. Prior to extraction, conduct comprehensive surveys and research to establish and document baseline environmental data, evaluate possible environmental impacts, and prescribe ways in which adverse environmental impacts are to be prevented or minimized. Use a combination of best available technologies and methods, including field sampling and surveys, modeling, GIS technology and analyses of archival materials and historical databases; e.g., aerial photographs, maps, previous surveys, etc. Characterize and identify species distributions and abundances; identify habitats critical to fisheries management objectives and NMFS responsibilities under a variety of legislative mandates; determine the limiting environmental factors of the anadromous fish populations (see Koski 1992); calculate sediment budgets and hydraulic flow rates; predict possible changes in water quality, channel morphology, etc. Also address potential adverse cumulative impacts (see Recommendation No. 10, above) and propose a possible mitigation and restoration strategy (see Recommendation No. 12, above, and also discussion in Phase III, below). For example, from a perspective limited to abiotic factors, Collins and Dunne (1990) recommend that appropriate rates and locations for instream gravel extraction should be determined on the basis of:

a. The rate of upstream recruitment (note Recommendation No. 4, above).

b. Whether the river bed elevation under undisturbed conditions remains the same over the course of decades, or if not, the rate at which it is aggrading or degrading.

c. Historic patterns of sediment transport, bar growth, and bank erosion in particular bends.

d. Prediction of the specific, local effects of gravel extraction on bed elevations, and the stability of banks and bars. The prediction should take into account an analysis of present or past effects of gravel extraction at various rates.

e. A determination of the desirability or acceptability of the anticipated effects.

Phase II. Monitor permitted operations and verify environmental safeguards. Extraction rates and volumes should be closely regulated. Impacts to the river bed, banks and bars upstream and downstream of the project should be documented using bench-marked channel cross-sections and aerial photographs taken at regular intervals. Species distributions and abundances should be surveyed regularly. Water quality should be monitored. Mitigation and restoration should be an ongoing process (see Recommendation No. 12, above), with continual monitoring for effectiveness. Also, NMFS recommends that permits should have a 5 year limit and be subject to annual review and revision to protect anadromous fish and their habitats (e.g., one element of the annual review should determine whether fishery management objectives are being met).

Phase III. Establish and implement a long-term monitoring and restoration program. This should continue Phase II objectives after completion of the project. A universal, prototype long-term monitoring strategy for watershed and stream restoration can be found in Bryant (1995). However, reliance on restoration should be put into proper perspective. It is important to acknowledge that there are significant gaps in our understanding of the methodology and effectiveness of restoration of streams and anadromous fish habitat affected by gravel extraction activities. Overall, restoration as a science is relatively young and experimental, and the processes and mechanisms are poorly understood. Little is known about the functional value, stability and resiliency of many so-called "restored" habitats. To date, existing regulations or plans pertaining to the mitigation and restoration of gravel extraction sites have been simplistic or vague. As an example: gravel extraction in California is regulated under the concept of "reclamation," which is derived from open-pit surface mining, such as large coal mines. Kondolf (1993; 1994b) states the concept of reclamation, as applied to open-pit mines, assumes that the environmental impacts are confined to the site; therefore, site treatment is considered in isolation from changes in the surrounding terrain.

Because reclamation does not occur until after the cessation of extraction, Kondolf (1993; 1994b) suggests that this definition treats the site as an essentially static feature of the landscape. Kondolf (1993; 1994b) argues that, while these assumptions may work for extraction operations located in inactive stream or river terraces, active channels and floodplain are dynamic environments, where disturbances can spread rapidly upstream and downstream from the site during and after the time of operation. The stream or river will irrevocably readjust its profile during subsequent high flows, eradicating the gravel pits and giving the illusion that extraction has had no impact on the channel. Kondolf (1993; 1994b) claims that a survey of bed elevations will show a net lowering of the bed, which reflects the more even distribution of downcutting (erosion) along the length of the channel. Even if the channel profile were to recover after completion of the project due to an influx of fresh sediment from upstream, habitat may have been lost in the meantime.

Thus, it may not be possible to disturb one site in isolation from the rest of the ecosystem, or confine the disturbance to a single, detached location, and then subsequently reclaim or reverse the impacts. Kondolf (1993; 1994b) concludes that reclamation can be applied to gravel pits in terrace deposits above the water table, but the reclamation concept is not workable for regulating instream gravel extraction. For all of these reasons, it is important to heed Murphy's (1995) assertion that:

> The best form of restoration is habitat protection. There is no guarantee that restoration efforts will succeed, and the cost of restoration is much greater than the cost of habitat protection. The most prudent approach is to minimize the risk to habitat by ensuring adequate habitat protection.

Adopted August 29, 1996

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APPENDIX 1

SUMMARIES OF MAJOR STATUTES

The following summaries of the major statutes mentioned in this Gravel Policy, with the exception of the River and Harbor Act of 1899, were obtained from Buck (1995)[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;
(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;
(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.

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

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

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 shall seek to conserve endangered and threatened species and shall utilize their authorities in furtherance of the purposes of the ESA.

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 any body of water is proposed to be modified 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.

Magnuson Fishery Conservation and Management Act

The Magnuson Act requires that fishery management plans shall "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).

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.

Rivers and Harbors Act of 1899

The Rivers and Harbors Act of 1899, Section 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.

ATTACHMENT K

Attach "E"

WHITE PAPER

INSTREAM AGGREGATE MINING ISSUES IN OREGON

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EXTERNAL REVIEW DRAFT
October 2003

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).

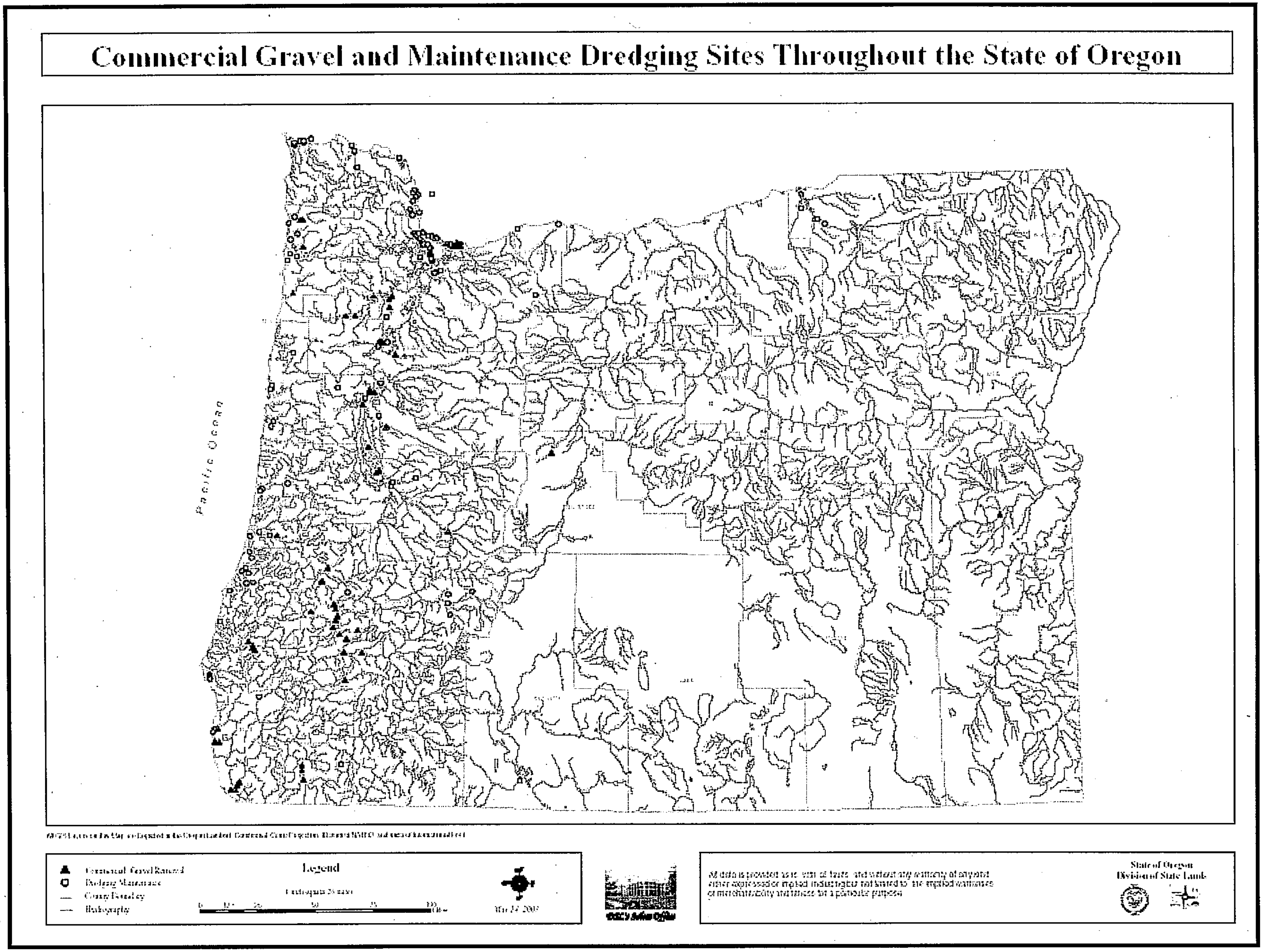

Figure 1. Commercial Gravel and Maintenance Dredging Sites in Oregon.

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.

<u>a. Changes in bar substrate and spawning habitat.</u> 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.

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 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.

a. Salmonids. 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.

b. Bull trout. 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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