Missouri Department of Natural Resources

Research Studies and Related Documents Concerning In Stream Sand and Gravel Mining Impacts

For the Development of

Proposed Rules

Prepared for the Missouri Land Reclamation Commission

May, 2003

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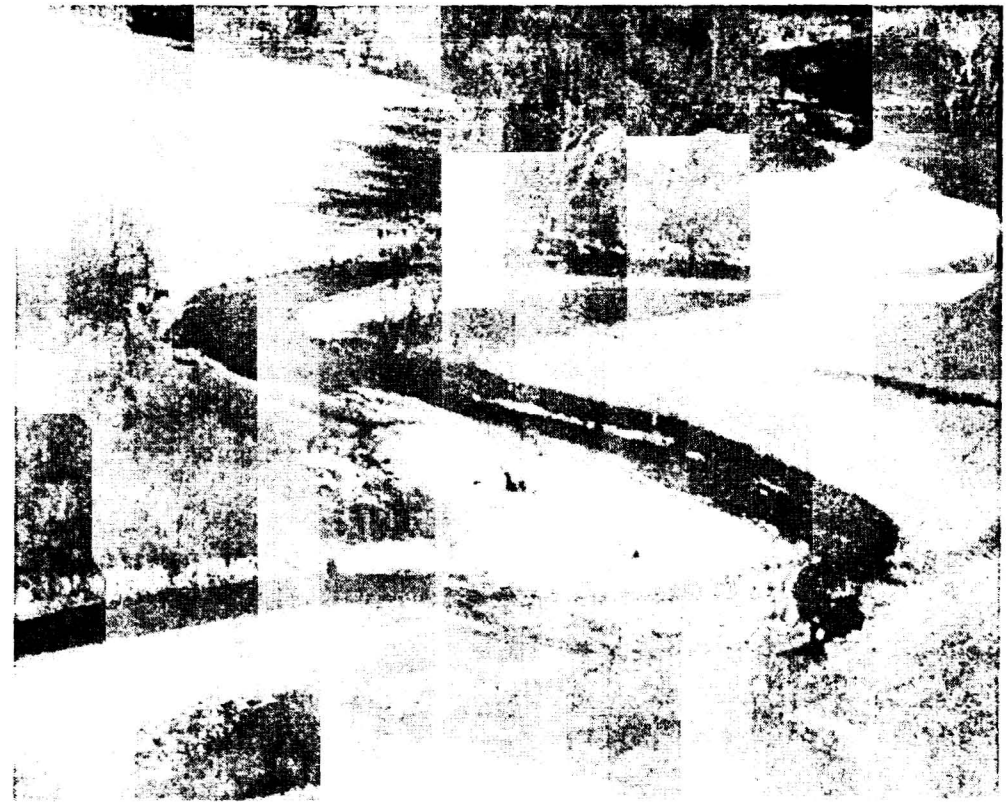
science for a changing world

Instream Gravel Mining and Related Issues in Southern Missouri



Department of Interior

U. S. Geological Survey

Questions

- What is the extent of gravel mining in southern Missouri?
- How are habitats affected?
- What is the influence on erosion and sedimentation?

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Questions:

- What are the short- and long-term effects of gravel mining?
- How are stream biota affected?
- How are public and private property affected?

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- Compare the economic benefits of gravel production against the environmental costs

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Study designed for two phases:

Phase I: began in 2000

- Estimate the number and distribution of active mine sites
- Document character of gravel mines
- Determine relations between basin-level characteristics and gravel mining on channel morphology

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Phase II: Basin scale study

Proposed work

- Fine scale measurements
- One control site
- Two – four sites using varying gravel mining methods

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Benefits and Costs

Benefits

Availability of construction materials can be a limiting factor of growth

- Construction
- Highways and Roads

Costs

Possible negative effects in wetlands, recreational areas, riverine habitat, and loss of land

- Money lost from farms, real estate,fisheries, and recreation
- Channel alteration
- Increased turbidity

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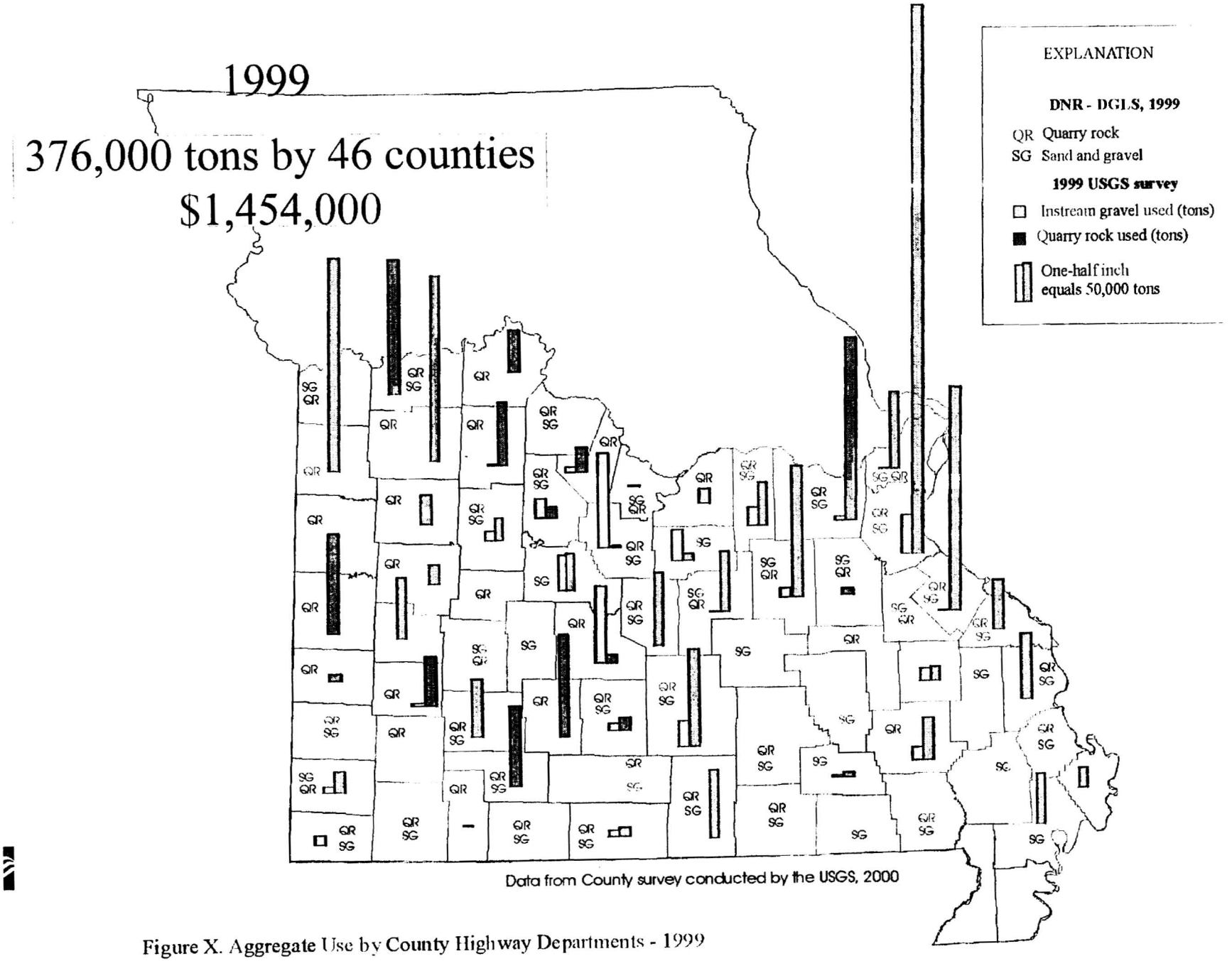

Figure X. Aggregate Use by County Highway Departments - 1999

During 1999, production of construction gravel increased by close to 33% over that in 1998

2000, though Missouri had the highest production level in the United States, Missouri experienced a decrease of 27% from 1999.

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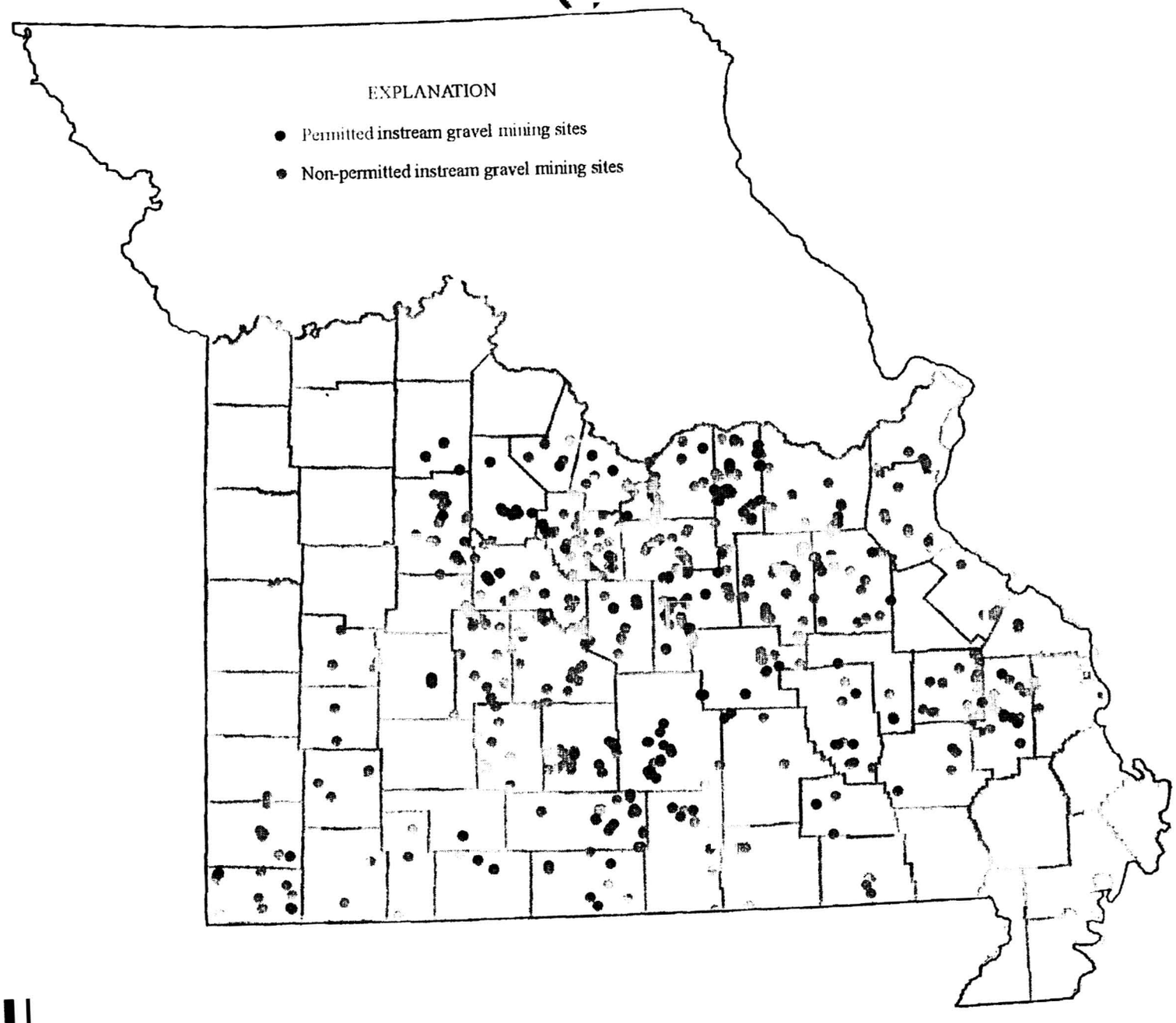
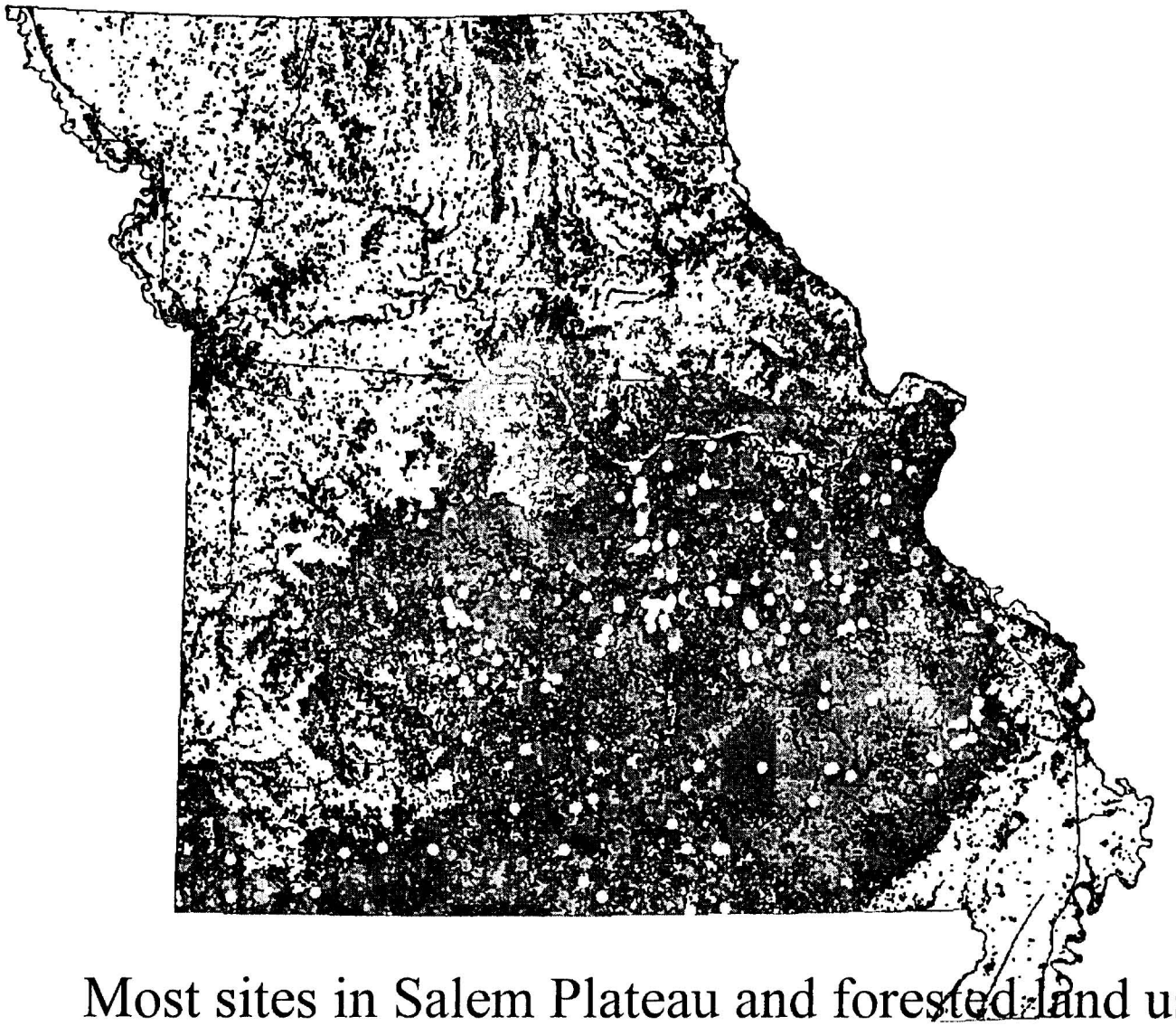


Figure A- Sites where instream gravel mining was recorded, 1999.



Most sites in Salem Plateau and forested land use

USGS

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 includes 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 base flow 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, and 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 redd 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 over wintering 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, a Koski (1992) state 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; and (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 biotic 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. Monitors 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
Rolland A. Schmitten Assistant Administrator for Fisheries U.S. Department of Commerce
National Oceanic and Atmospheric Administration National Marine Fisheries Service

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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; and (7) any other pertinent terms and conditions.

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

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.

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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.

Thinking Like a River

BY WILLIAM H. LANGER

Editor's Note: *This article is the third in a 12-part series focusing on how geology can lessen the "surprises" and help overcome the challenges posed by nature during the process of aggregates extraction.*

Do you think like a river? If you extract aggregates by in-stream mining, it sure can help.

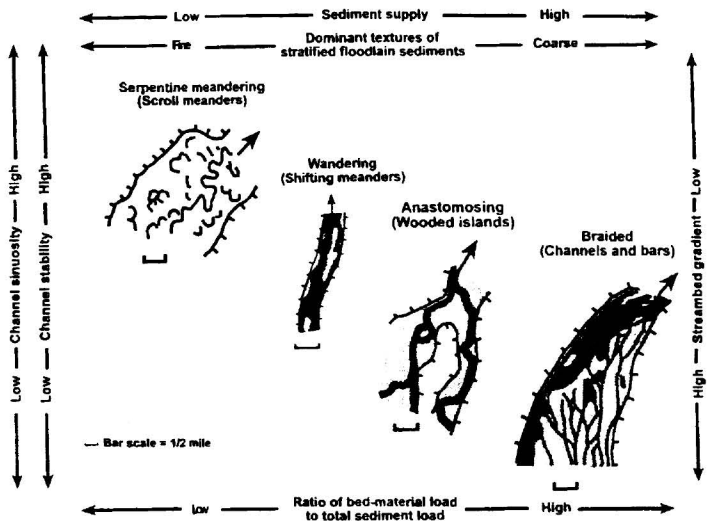
Rivers and streams are widely spread across the landscape. In large parts of the world, the sediments deposited by rivers *(alluvial deposits)* are the only source of sand and gravel. Many aggregate operations extract aggregate from the channels of rivers or streams (commonly referred to as *in-stream mining*) without creating adverse environmental impacts simply by staying within the limits set by the natural system. However, if those limits are violated, serious environmental impacts can result. Thinking like a river can help to characterize alluvial deposits, locate where they are likely to occur and allow extraction of aggregate without causing unwanted environmental impacts.

Rivers are complex, dynamic geomorphic systems whose major function is to transport water and sediment. The climatic and geological character of the drainage basin determines the work demanded of a river, including the amount of water (*discharge*) and amount of sediment (*load*) it must handle under a variety of flow rates. The climatic and geological character of the drainage basin also determines the location, type and amount of sand, gravel and other sediments present along various stretches of the river.

The type of channel pattern (meandering, wandering, braided and so forth) of the river and the slope of the river along its length are other characteristics controlled by the basin environment. Each channel pattern originates in a specific manner, and its form is designed to facilitate the work of a river. Channel patterns also give clues about the type of sediment (coarse versus fine) and amount of sediment present in the river.

Nature has built thousands of years of experience into its rivers, and each river, over time, develops a particular combination of channel width, channel depth, channel slope, channel roughness, bed particle size and water velocity. The combination of these variables is called the *hydraulic geometry*. Its hydraulic geometry allows the river to accomplish its work in the most efficient manner. Once established, the pattern will be maintained as long as the variations in discharge and load are within the limits of the existing hydraulic geometry.

The normal small variations of discharge and load of a river commonly can be accommodated without major changes to the channel. Most river channels form and reform during a distinct range of relatively large flows referred to as the *dominant discharge*. After a dominant discharge event, the river tries to establish a new equilibrium relationship by adjusting its hydraulic geometry. Because the hydraulic variables are mutually interdependent, a change in one variable requires a response in one or more of the others. Because the hydraulic variables are continuously adjusting, equilibrium as a steady-state condition can never be attained. At best, the river might achieve a state of *quasi-equilibrium*.



Modified from Mollard, 1973

The time that it takes for a river to return to its quasi-equilibrium form after a dominant discharge event is called *recovery time*. In humid climates, the recovery time is in the order of one to 20 years, while in semi-arid to arid regions the recovery time tends to be much longer. For a river to return to its state of quasi-equilibrium, the recurrence interval of a dominant discharge event must be greater than the recovery time. If a river is exposed to major long-term changes in climate or basin tectonics, it may not be able to return to its state of quasi-equilibrium between dominant discharge events. The changes from the previous dominant discharge event will not be completely removed by the time the subsequent dominant discharge event takes place, and the river ultimately will create a new quasi-equilibrium form.

If a river is exposed to human-induced changes in the river basin such as agriculture or urbanization, the average discharge or sediment load may be altered to a point where adjustments of the existing hydraulic geometry can no longer maintain the most efficient system. The river will reestablish the greatest fluvial efficiency (and will reach a new quasi-equilibrium form) by making major adjustments such as dramatic changes in the width-depth ratio of the channel, changes in channel patterns and major changes in erosion and deposition patterns. These are considered to be environmental impacts, and sometimes are erroneously blamed on aggregate extraction.

Another way a river can change its form is if human activities such as bridge construction, channelization and in-stream mining alter one or more critical hydraulic variables at a particular site or combination of sites along a river. If one or more variables are altered so much that the river can no longer maintain the most efficient means of accomplishing its work, the system will adjust, thus causing environmental impacts.

Next month's article will describe the environmental impacts that can occur when in-stream aggregate mining alters hydraulic variables beyond their threshold, and will describe methods to avoid or mitigate those environmental impacts. ▲

William H. Langer is a geologist with the Mineral Resources Team of the U.S. Geological Survey.

Thinking Like A River

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Thinking like a river can help to characterise alluvial deposits, locate where they are likely to occur, and allow extraction of aggregate without causing unwanted environmental impacts.

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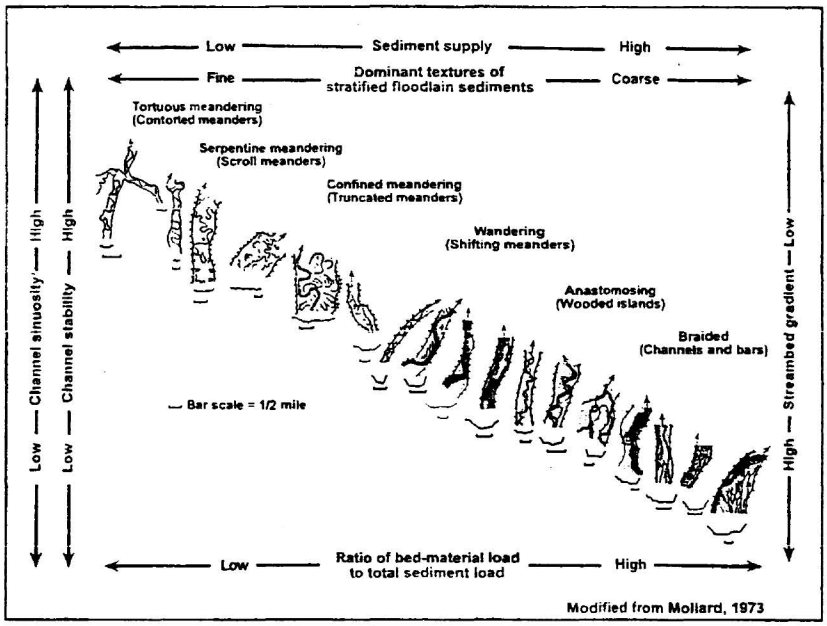

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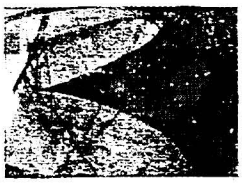
Another way a river can change its form is if human activities such as bridge construction, channelisation, and in-stream mining alter one or more critical hydraulic variables at a particular site or combination of sites along a river. If one or more variables are altered so much that the river can no longer maintain the most efficient means of accomplishing its work, the system will adjust, thus causing environmental impacts.

The article next month will describe the environmental impacts that can occur when in-stream aggregate mining alters hydraulic variables beyond their threshold, and will describe methods to avoid or mitigate those environmental impacts. ■

William H. Langer is a geologist with the mineral resource program of the US Geological Survey. email: blanger@usgs.gov



GEOLOGY, AGGREGATES AND THE ENVIRONMENT
Act Like a River

Photo, taken in 1988, depicts a river in the Southeast United States that drains into the Gulf of Mexico. About five miles downstream, there is a 30-mile stretch that is illegally being mined for sand.

Photo, taken in 1994, shows the same location on the river as the photo to the left. The erosion has caused undercutting of river banks and has severely altered the channel of the river.

BY WILLIAM H. LANGER

Editor's Note: *This article is the fourth in a 12-part series focusing on how geology can lessen the "surprises" and help overcome the challenges posed by nature during the process of aggregates extraction.*

Last month, I tried to explain why it is important to *think* like a river. The article pointed out that the major function of a river is to transport water and sediment. In doing this, a river is constantly adjusting its hydraulic variables (the width, depth, slope and roughness of its channel; the particle size of material in the bed of the channel; and water velocity) to work in the most efficient manner.

So now that you know how a river thinks, all you need to do now is to have mining is to *act* like a river. In-stream mining can be conducted without creating adverse environmental impacts provided that you keep the mining activities within the hydraulic limits set by the natural system. However, if in-stream aggregate mining changes the river system to where it can no longer transport water and sediment in an efficient manner, the river will attempt to create a new, more efficient system, and the resulting changes in the hydraulic variables may produce environmental impacts.

A principal cause of impacts from in-stream mining is the removal of more sediment than the system can replenish. Impacts can be initiated by extracting too much coarse material at one site or by the combined result of many small operations. Coarse material transported by a river (*bedload*) commonly is moved by rolling, sliding or bouncing along the channel bed. Some researchers believe that environmental impacts from in-stream mining can be avoided if the annual bedload is calculated and aggregate extraction is restricted to that value, or some percentage of it.

To limit extraction to some percentage of bedload, one must be able to calculate how much sediment is passing by the in-stream mining site during a given period of time. How much coarse material is moved, how long it remains in motion and how far it moves, depends on the size, shape and packing of the material and the flow characteristics of the river. Downstream movement commonly occurs as irregular bursts of short-distance movement separated by longer periods when the particles remain at rest. Because bedload changes from hour to hour, day to day, and year to year, estimating annual bedload rates is a dynamic process involving careful examination.

Constant variations in the flow of the river make the channel floor a dynamic interface where some materials are being eroded while others are being deposited. The net balance of this activity, on a short-term basis, is referred to as *scour* or *fill*. On a long-term basis, continued scour results in erosion (*degradation*), while continued fill results in deposition (*aggradation*).

An alternate method to identify potential impacts that could be initiated by in-stream mining is through careful geologic characterization of the rivers and river basin. Some sections of a river are more conducive to aggregate extraction than others. For example, removal of gravel from some aggrading sections of a river may be preferable to removing it from eroding sections.

Even if a section of river is eroding, aggregate mining may take place without causing environmental damage if the channel floor is, or becomes, armored by particles that are too large to be picked up by the moving water. For example, some sections of rivers underlain with large gravel layers deposited under higher flow rates than those prevailing at the current time may support gravel extraction with no serious environmental impacts. This situation commonly occurs in modern, slow-flowing rivers that were originally created thousands of years ago by torrential glacial meltwater streams.

In some situations, environmental impacts may occur when channels are significantly over-deepened by in-stream aggregate extraction. Defining a minimum elevation for the deepest part of the channel and restricting mining to the volume above this elevation may allow gravel extraction without adverse impacts.

Because rivers are dynamic systems, many of the environmental impacts caused by improper in-stream mining are cascading impacts, where one impact is the initiating event for a second impact, which is the initiating event for a third impact, and so on. For example, improper in-stream mining can cause an increased gradient at the site of excavation. This can lead to upstream incision (head cutting), which can cause bank erosion, which can cause lowering of alluvial water tables, which can cause loss of vegetation along the stream banks, which can cause loss of shade to the river, and on and on. Cascading impacts can result in major changes to aquatic and riparian habitats and to the fish and wildlife occupying those habitats.

Recovery from impacts caused by in-stream sand and gravel mining is highly dependent on the local geologic conditions. Recovery in some rivers can be quite fast. The Meramec River, in Missouri, a river with an abundant bedload, recovered from in-stream mining within two years after channel dredging stopped. Conversely, the Big Rib River, in Wisconsin, was only in the early stages of recovery 20 years after the stream had been mined.

Rivers are constantly working to maintain the most efficient means of transporting water and sediment. Aggregate producers are constantly working to maintain the most effective means of extracting and processing aggregates. Acting like a river can help producers reach their goals while simultaneously maintaining the goals of the river. ▲

William H. Langer is a geologist with the Mineral Resources Team of the U.S. Geological Survey.

In cooperation with the Vermont Agency of Natural Resources,
Department of Enivronmental Conservation

Simulation of the Effects of Streambed-Management Practices on Flood Levels in Vermont

USGS Fact Sheet 064-00

INTRODUCTION

On July 14, 1997, an intense rainstorm resulted in rapid runoff and severe flooding in parts of Vermont. During the storm, streambed and streambank erosion and deposition were significant at several locations in the State. Residents in flooded regions questioned whether deposited sediment constricted water flow and elevated the 1997 flood levels. Since 1986, the State of Vermont's policy on streambed management is to restrict the removal of sand and gravel from channels; however, the extent to which the policy affects stream conditions during severe flooding is unknown. To answer this question, a sediment-transport study by the U.S. Geological Survey (USGS), in cooperation with the Vermont Agency of Natural Resources, Department of Environmental Conservation, began in October 1997 to evaluate the potential effect of various streambed-management practices on future flood levels (Olson, 2000).

Three stream reaches that had been affected by the flood of July 1997, and which covered a wide range of basin characteristics common to Vermont, were selected for the study (fig. 1). The reaches selected were a 4.3-mile reach of the Trout River in Montgomery, Vt., a 6.5-mile reach of the Wild Branch in Wolcott, Vt., and the entire 15.4-mile reach of the Lamoille River within Cambridge, Vt.

The BRIdge Stream Tube Model for Alluvial River Simulation (BRI-STARS) (Molinas and Wu, 1997), calibrated with data for the flood of July 14-16, 1997, was used to simulate channel erosion and deposition of the streambed and the peak water-surface profile during a 10- and 100-year flood for three streambed- management practices. The three practices included (1) no removal of streambed material, (2) "scalping", or removing bars and other alluvial streambed materials to increase channel capacity, and (3) dredging the entire streambed channel by 2 feet.

DESCRIPTION OF INVESTIGATED REACHES

The Wild Branch (fig. 1) flows south through Wolcott, Vt., in the north-central part of the state, and drains into the Lamoille River. Streambed material ranges from sand to boulders with several areas of exposed bedrock.

The Lamoille River (fig. 1) flows west through Cambridge, Vt., in the northwestern part of the state. Streambed material ranges from silt to coarse gravel with several reaches having some cobbles or exposed bedrock.

The Trout River (fig. 1) flows northwest through Montgomery, Vt., and is an upland stream in

the north-central part of the State. Streambed material is primarily gravel and cobbles with some sand and exposed bedrock. Additional characteristics of Trout River and the other studied rivers are listed in table 1.

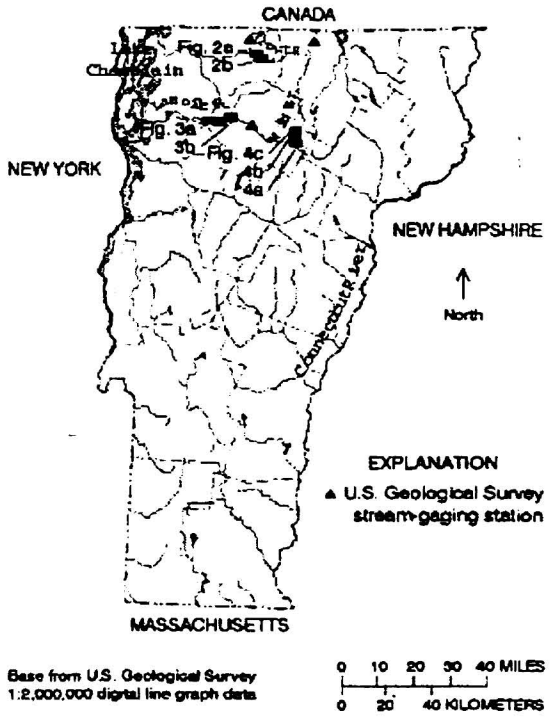


Figure 1. Location of river reaches in the study.

Table 1. Characteristics of studied reaches of three rivers in Vermont

Characteristic	Trout River	Wild Branch	Lamoille River
Mean channel slope of study reach, in feet per mile	19	40	2.3
Approximate valley elevation at downstream end of study reach, in feet	470	670	460
Drainage area near downstream end of study reach, in square miles	71.6	39.5	520

SEDIMENT-TRANSPORT MODEL

BRI-STARS is a computer model that routes water through natural river channels and simulates streambed erosion and deposition. Because computer modeling of sediment transport is still in its developmental stages, the ability of models such as BRI-STARS to exactly simulate sediment-transport processes and effects is limited. For example, computer-based models currently available (1999) do not adequately account for the removal of fine-grained particles by streamflow, which leaves erosion- resistant large-grained particles to protect or armour the stream channel (Richardson and others, 1990). Likewise, stream-bank erosion and the formation of meander bends and bed forms cannot be adequately simulated.

MODEL SIMULATIONS AND (SIMULATION) RESULTS

Table 2. Magnitude of flood discharges used in the BRI-STAR simulations for three rivers in Vermont

Streambed-management practices simulated in this study refer only to the removal of

River	10-year discharge, in cubic feet per second	100-year discharge, in cubic feet per second
Trout River	9,400	18,000
Wild Branch	3,100	6,340
Lamoille River	16,000	29,250

streambed-channel materials; bank protection and other channel improvements were not considered. Three streambed-management practices were selected for evaluation. The first practice evaluated was based on current (1999) State policy, which restricts the removal of streambed materials from channels. The second practice evaluated was based on typical streambed-channel alterations and practices prior to 1986, when the current State policy took effect. Alterations under this practice included removing gravel bars and other features that may constrict flow. The third practice evaluated was based upon the frequent post-flooding argument that entire streambed channels need to be dredged periodically. The BRI-STARS model was used to determine the profile of the peak water surface and the final streambed elevation for a 10-year and a 100-year flood (table 2) in each river that would likely result from implementation of the three practices.

Channel bottoms from flood- insurance studies in effect prior to the 1997 flood are shown in figures 2-4 (Federal Emergency Management Agency, 1980, 1982a,b, and d). Also shown on these figures is the channel bottom after the 1997 flood (post-flood), and the 100-year water-surface profile from a fixed-bed model (Shearman, 1990).

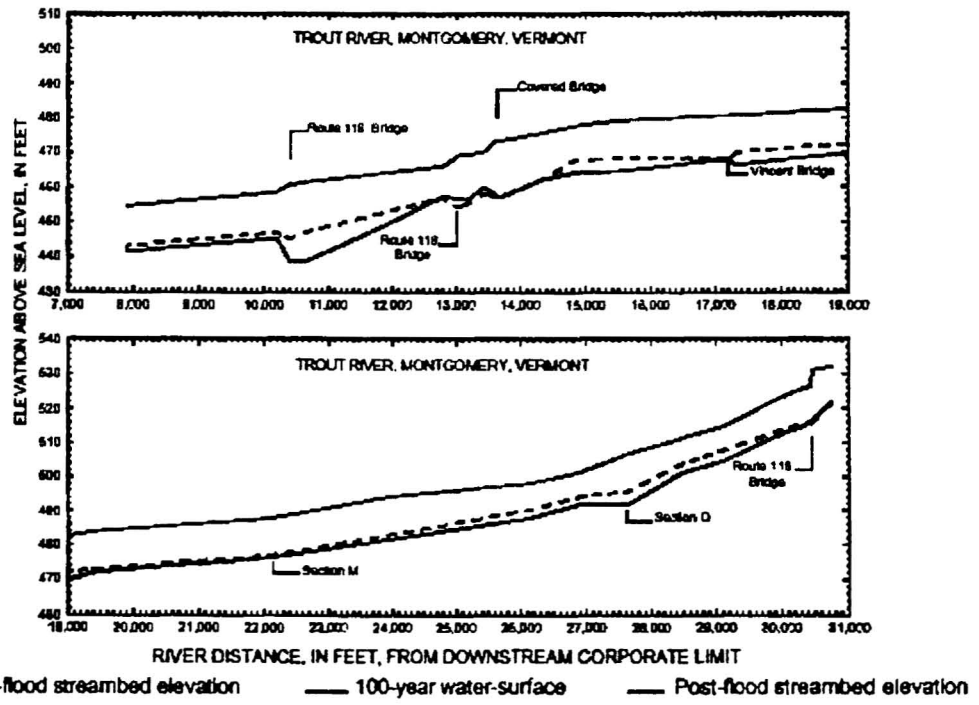


Figure 2. Pre-flood 1997 streambed and 100-year water-surface profiles from flood-insurance study and post-flood 1997 streambed profiles of the Trout River.

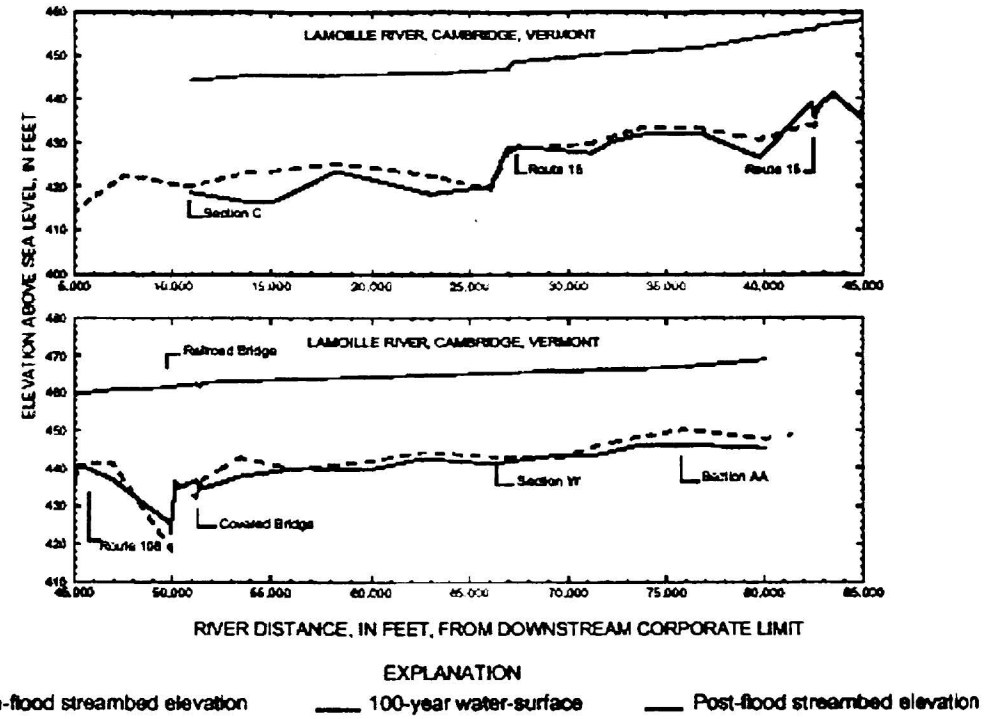
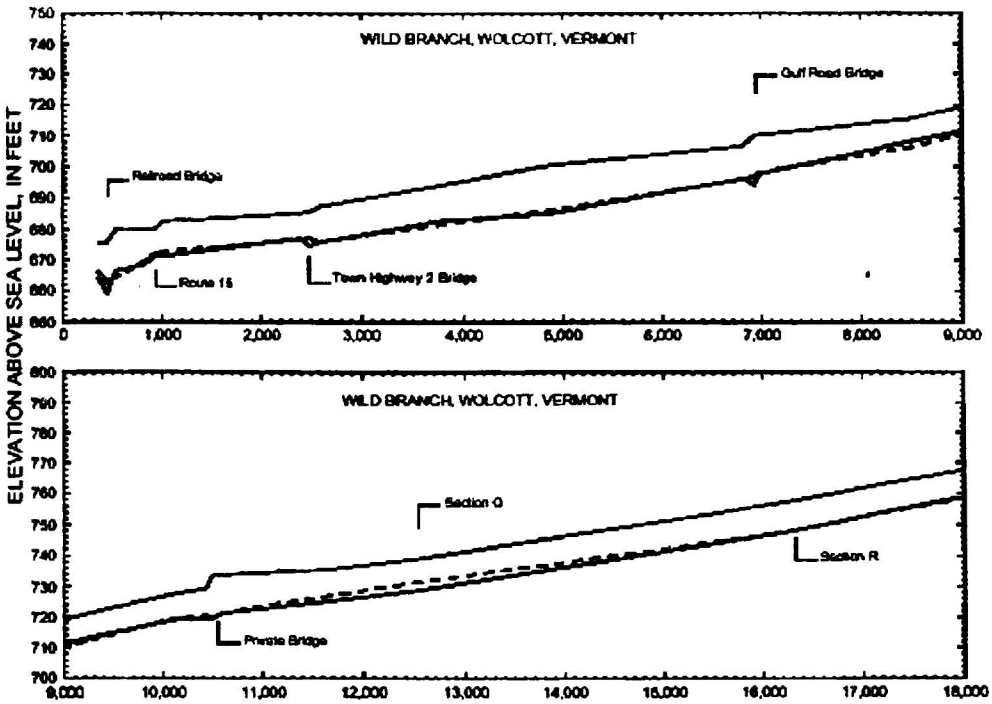


Figure 3. Pre-flood 1997 streambed and 100-year water-surface profiles from flood-insurance study and post-flood 1997 streambed profiles of the Lamoille River.



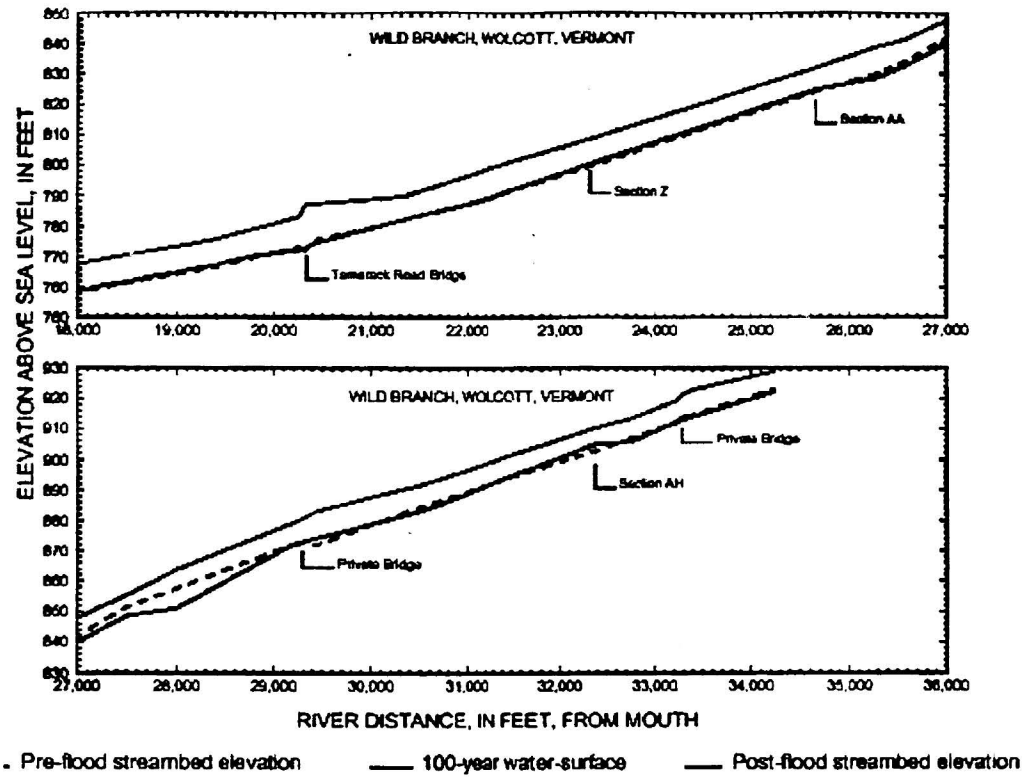


Figure 4. Pre-flood 1997 streambed and 100-year water-surface profile from flood-insurance study and post-flood 1997 streambed profile of the Wild Branch.

Modeled water-surface and streambed-elevation profiles of the three study reaches for the 100-year flood are shown in figures 5-7. These profiles show the streambed profile as surveyed following the flood of 1997, and the corresponding 100-year water-surface elevation. Results from the BRI-STARS model simulations also are shown on these profiles and include the streambed elevation following a 100-year flood and the peak water-surface elevation during a 100-year flood for the three streambed-management practices.

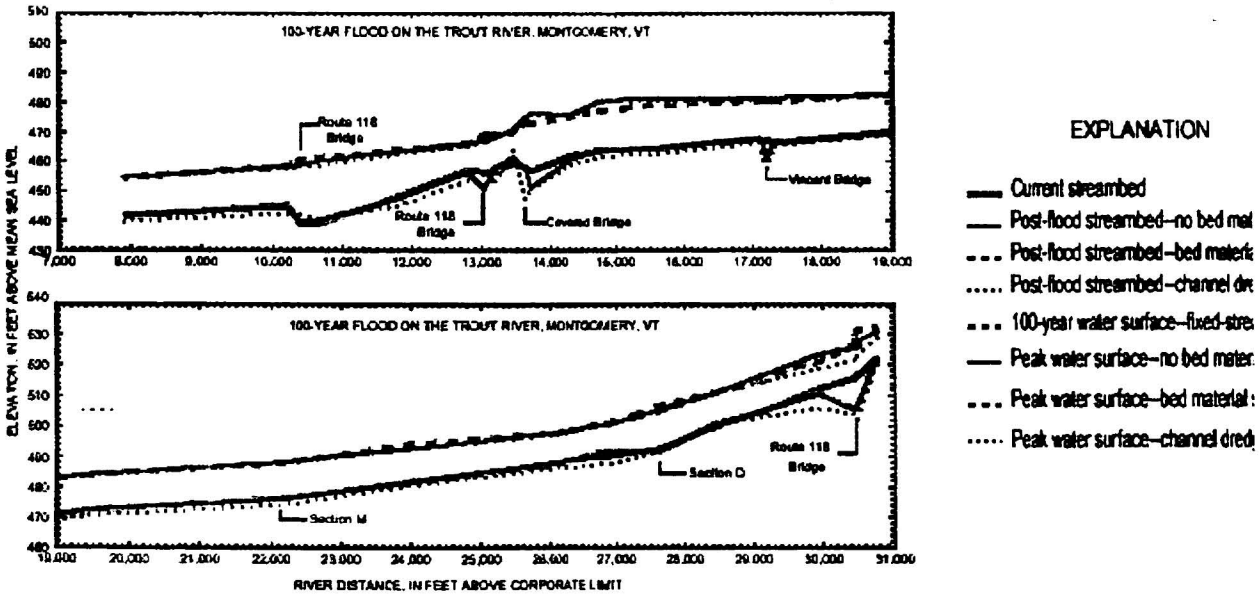
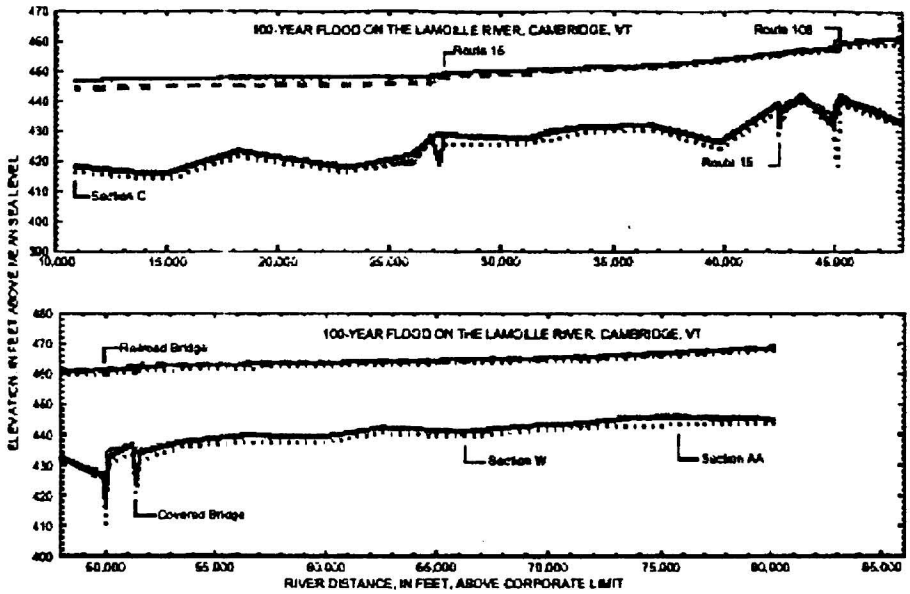


Figure 5. Simulated results of water-surface and streambed-elevation profiles of the modeled reach of the Trou



Figures 6. Simulated results of water-surface and streambed-elevation profiles of the modeled reach of the Lan River.

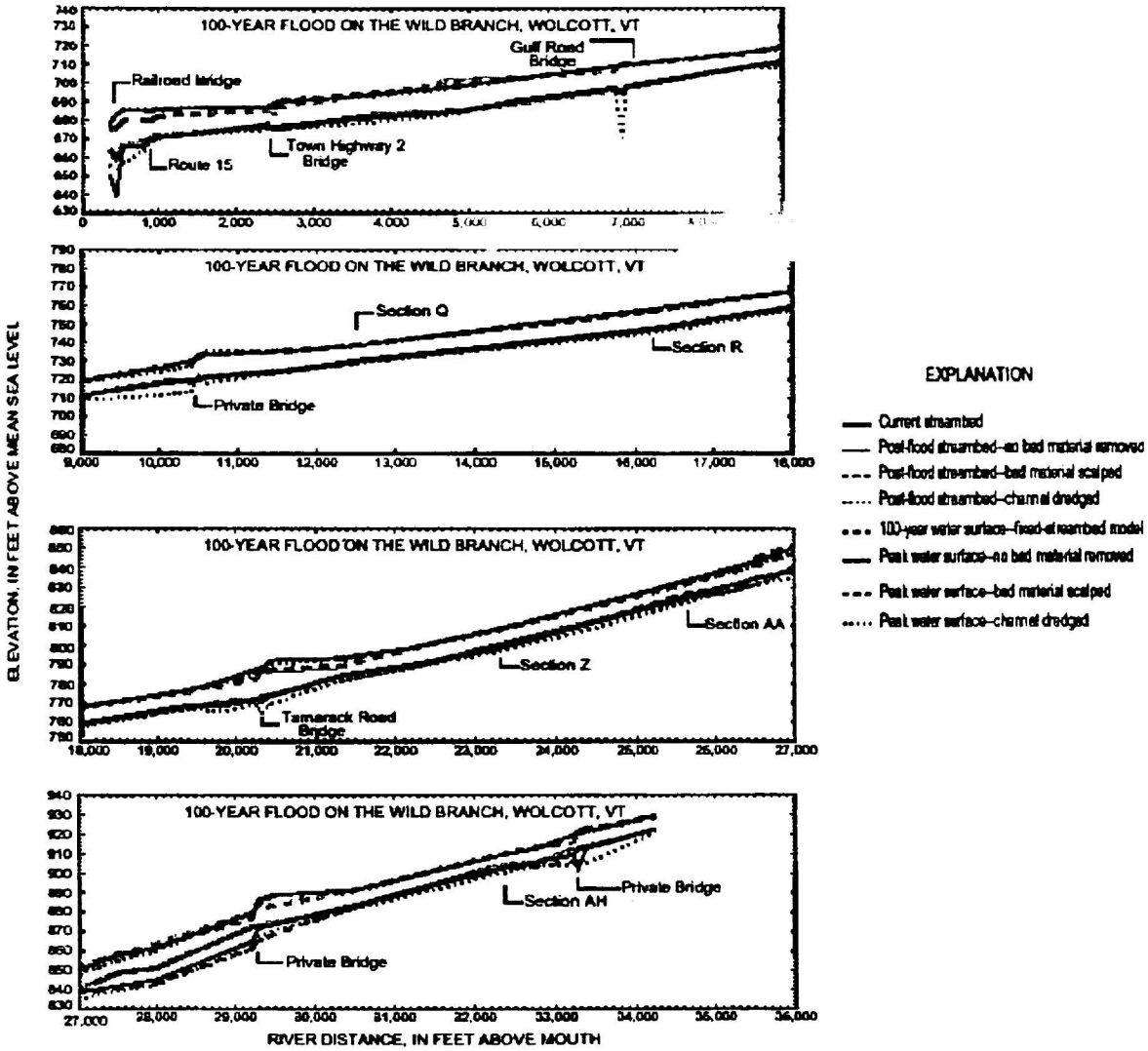


Figure 7. Simulated results of water-surface and streambed-elevation profiles of the modeled reach of the

Wild Branch.

For the Trout and Lamoille Rivers BRI-STARS model simulations, the average water-surface elevation decreased when streambed materials were removed; however, simulations did not show the same average decrease in water-surface elevations for the Wild Branch (table 3). Furthermore, flooding actually increased in some reaches of the maintained or dredged channels. This is because the dredged channel has a greater capacity to convey water and, in turn, transport sediment. The increase in sediment-transport capacity results in greater potential for erosion and deposition. Respective changes to the water-surface profile occur as the channel adjusts to re-establish equilibrium (Richardson and others, 1990). Simulations also showed increased streambed erosion beneath bridges following dredging.

Table 3. Model-simulated changes in peak water-surface elevations resulting from alterations to channels of three rivers in Vermont
[All measurements are in feet; - indicates a decrease; and + indicates an increase in water-surface elevation compared to that in simulation of unaltered channel]

	Trout River			Lamoille River			Wild Branch		
Channel alteration	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum
Bars and obstructions removed, 10-year flood	-1.0	-0.1	+0.2	-0.2	-0.1	0	-2.0	+0.1	+3.8
Bars and obstructions removed, 100-year flood	-2.7	-0.2	+0.4	-0.1	-0.1	0	-3.8	0	+2.1
Channel dredged, 10-year flood	-4.7	-1.5	+1.1	-2.6	-1.4	0	-3.6	0	+4.2
Channel dredged, 100-year flood	-4.8	-1.1	+0.1	-1.7	-1.0	0	-3.1	-0.5	+2.2

Resulting water-surface elevations from BRI-STARS simulations also indicated that channel configuration has a greater effect on the water-surface elevation of a small flood such as a 10-year event than on a large flood such as a 100-year event or the 1997 flood. This result was expected because a large portion of the flood waters flow on the flood plains during a high flood regardless of the condition of the stream channel.

The model used in this study provides information on the short-term effect of streambed-management practices on the water-surface profile during a flood and on the streambed-elevation profile following a flood. The management practices evaluated in this study may have local effects on flooding, erosion, and deposition that are beyond the scope of this study. Investigations of streambed-channel stability by the Center for Watershed Protection (1999) and Rosgen (1996) have documented that containment of high flows within the channel increased erosion rates, generated large volumes of sediment, and ultimately reduced channel capacity. By Scott A. Olson

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Fact Sheet PDF file (210 KB)

Instream Sand and Gravel Mining:

Environmental Issues and Regulatory Process in the United States

By Michael R. Meador and April O. Layher

ABSTRACT

Sand and gravel are widely used throughout the U.S. construction industry, but their extraction can significantly affect the physical, chemical, and biological characteristics of mined streams. Fisheries biologists often find themselves involved in the complex environmental and regulatory issues related to instream sand and gravel mining. This paper provides an overview of information presented in a symposium held at the 1997 midyear meeting of the Southern Division of the American Fisheries Society in San Antonio, Texas, to discuss environmental issues and regulatory procedures related to instream mining. Conclusions from the symposium suggest that complex physicochemical and biotic responses to disturbance such as channel incision and alteration of riparian vegetation ultimately determine the effects of instream mining. An understanding of geomorphic processes can provide insight into the effects of mining operations on stream function, and multidisciplinary empirical studies are needed to determine the relative effects of mining versus other natural and human-induced stream alterations. Mining regulations often result in a confusing regulatory process complicated, for example, by the role of the U.S. Army Corps of Engineers, which has undergone numerous changes and remains unclear. Dialogue among scientists, miners, and regulators can provide an important first step toward developing a plan that integrates biology and politics to protect aquatic resources.

Sand and gravel are essential components of construction materials and are in almost all construction projects, including buildings, roads, bridges, and airports. The importance of these materials has resulted in aggressive mining of sources to meet needs of new construction as well as rehabilitation of aging infrastructures. Abundant deposits of sand and gravel can be found throughout most of the United States, particularly associated with rivers and streams. Approximately 10%–20% of the sand and gravel mined in 1974 was dredged from streams (Newport and Moyer 1974). However, sand and gravel extraction can significantly alter the physical, chemical, and biological characteristics of mined streams (Nelson 1993).

As with many aquatic resource issues, fisheries biologists are called on to provide information about the potential ecological effects of instream sand and gravel mining. Instream mining issues are often characterized by insufficient scientific information and a complex regulatory process that heavily influence the outcome of resource-related decisions and regulations. A better understanding of the status of existing scientific information and an overview of the regulatory process are needed to ensure the biological integrity of streams.

In 1997 the Warmwater Streams and Environmental Concerns committees sponsored a symposium on this topic at the midyear meeting of the Southern Division of the American Fisheries Society in San Antonio, Texas. This paper is an overview of the presentations and comments from the symposium. Our objective is to describe some of the complex issues that fisheries biologists need to consider regarding sand and gravel mining, including supply of and demand for sand and gravel, environmental effects of mining, the regulatory process, and recovery and remediation.

Supply of and demand for sand and gravel

Transport and deposition of eroded bedrock and surficial materials create sand and gravel deposits. In this paper, gravel is considered to be water-transported particles ranging from 0.48 cm–7.62 cm in diameter; thus, crushed stone is excluded. Because water is the principal agent of distribution for sand and gravel, these deposits occur in or near rivers and streams or in historic stream courses. Potential mining sites are typically chosen based on the natural supply of sand and

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gravel material, intended use of the product, quality of the product needed, transportation costs, land ownership, and land use.

Demand for sand and gravel relates to the increasing need for construction materials, which accounts for approximately 96% of the total amount of mined sand and gravel (Langer 1988). The remaining 4% is used for foundry operations, glass manufacturing, abrasives, and filtration beds in water treatment facilities (Langer 1988). Of the sand and gravel used in construction, approximately 43% is used for residential and nonresidential buildings (Langer 1988). The National Sand and Gravel Association reported that almost 91,000 kg of aggregate material (sand, gravel, and crushed stone combined) are needed to construct a 6-room house, and approximately 14 million kg of aggregate are needed to construct a school or hospital (Langer 1988). Although these values are rough approximations, they give some indication of the volume of material used in building construction. Almost 24% of the sand and gravel used in construction is used for building roads. Langer (1988) reported that close to 59 million kg of aggregate are needed to construct 1.6 km of a typical 4-lane interstate highway. In 1990 almost 4,200 companies produced 830 billion kg of sand and gravel from 5,700 operations (Langer and Glanzman 1993). Approximately 63% of the total sand and gravel operations in 1990 were relatively small, e.g., each producing less than 90 million kg.

Not all instream sand and gravel deposits are suitable for commercial use; particle size, shape, hardness, chemical composition, and intended use are considered in determining the suitability of individual deposits. For example, commercial use requires sand and gravel that are chemically inert and able to resist weathering and mechanical breakdown. Instream gravel is particularly desirable because the prolonged transport in water eliminates weak materials by abrasion and attrition, leaving durable, rounded, well-sorted gravel (Kondolf 1997). As a result, instream gravel is typically suitable for producing high-grade concrete (Barksdale 1991).

Kondolf (1997) noted that sand and gravel in reservoir sediments are largely unexploited sources of building materials. Sand and gravel are mined commercially from reservoirs in California, Taiwan, and Israel. Such sediments can be desirable sources of sand and gravel in that they are sorted by size through deposition. An additional benefit to commercial use of reservoir sediments is the partial mitigation of losses in reservoir capacity from sedimentation.

In addition to the distribution, abundance, and quality of sand and gravel, transportation is an important economic factor. Transportation from the area of supply to the area of demand represents the most significant factor in the total cost of sand and gravel mining. Thus, sand and gravel mining typically occurs within 50 km–80 km of the site where demand is the greatest, often near or on transportation routes to reduce costs (Kondolf 1997).

Sand and gravel are mined commercially in every state in the United States (Langer and Glanzman 1993). Mining of sand and gravel occurs in two major forms—(1) instream dredging of a streambed and (2) land mining, which includes floodplain excavations that often involve a connecting outlet to a stream.

During instream mining, sand and gravel deposits are excavated from the streambed by various methods—dragline, bulldozer, front-end loader, shovel, or dredge—and are processed at either an on-site barge or upland location. Processing typically includes screening and grading sand and gravel in wash water (usually stream water), and discharging the wash water into settling pits before releasing it back into the stream or returning the wash water directly to the stream. Processed sand and gravel are sometimes stockpiled along the stream channel for transport to areas of demand. ◆

Arkansas Game and Fish Commission

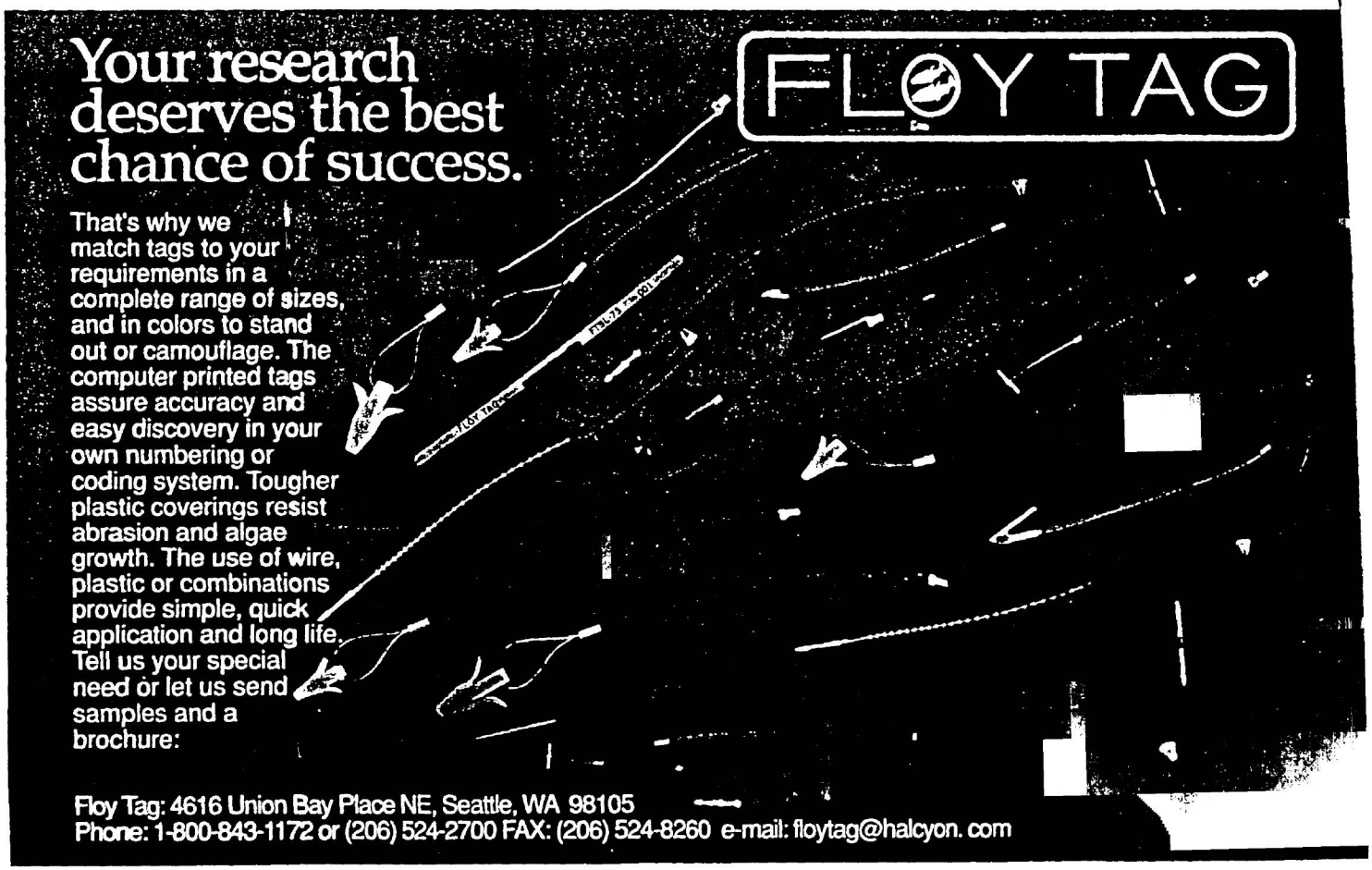
Processed gravel is stockpiled along Crooked Creek, Arkansas, where it is periodically loaded onto vehicles for transport to areas of demand.

An understanding of the distribution, abundance, and quality of instream sand and gravel resources can provide valuable information for evaluating environmental and economic tradeoffs in dealing with instream mining issues. The U.S. Geological Survey's (USGS) Front Range Infrastructure Resources Project is an example of an integrated effort to develop information for improved resource management (USGS 1997). This project addresses problems with sustaining availability of infrastructure resources (natural aggregate, water, and energy) in rapidly growing areas along the Front Range (Colorado) urban corridor. Principal objectives of the project are to develop information, define tools, and demonstrate ways to (1) enable evaluation of the region's infrastructure resources, (2) determine the region's projected needs for infrastructure resources, (3) identify issues that may affect availability of resources, and (4) provide decision makers with tools to evaluate alternatives leading to sustained access to infrastructure resources (W. Langer, USGS, Denver, pers. comm.).

Environmental effects of instream sand and gravel mining

Sand and gravel extraction can result in a number of physical, chemical, and biological effects on mined streams. Sand and gravel mining can change the geomorphic structure of streams (Sandecki 1989; Kondolf 1994), often resulting in channel degradation and erosion from mining operations located either in or adjacent to a stream. Instream mining typically alters channel geometry, including local changes in stream gradient and width-to-depth ratios. Point-bar mining increases gradient by effectively straightening the stream during floods. Thalweg relocation can occur when flooding connects the stream to floodplain mines. Local channel scouring and erosion can occur as a result of increased water velocity and decreased sediment load associated with mined areas. For example, instream mining on the Russian River in California during the 1950s and 1960s caused channel incision in excess of 3 m–6 m throughout a distance of 11 km (Kondolf 1997). As a result, the formerly wide river channel is now incised, straighter, and unable to support the diversity of successional stages of vegetation typically associated with an actively migrating river.

Where mining activities are numerous and concentrated, an upstream progression of channel degradation and erosion can occur—a process referred to as *headcutting*. Headcuts induced by sand and gravel mining can cause dramatic changes in a streambank and channel that may affect instream flow, water chemistry and temperature, bank stability, available cover, and siltation. Channel erosion from headcuts can cause loss of



upstream property values; reduce recreational, fishing, and wildlife values; and contribute to the extirpation and extinction of stream fauna (Hartfield 1993). Sand and gravel mining has been identified as the causative factor in headcutting on the Amite, Bogue Chitto, and Tangipahoa rivers in Mississippi and Louisiana, and on the Buttahatchee and East Fork Tombigbee rivers in Mississippi (Hartfield 1993). Headcutting more than 1 km upstream from an instream mine has been documented in Cache Creek, California (Kondolf 1997).

The combined processes of channel incision and headcutting also can undermine bridge piers and other structures. Channel incision caused by instream gravel mining on the San Luis Rey River in California exposed aqueducts, gas pipelines, and footings of highway bridges (Kondolf 1997).

Sedimentation and increased turbidity also can accrue from mining activities, wash-water discharge, and storm runoff from active or abandoned mining sites. Gravel mining in Blackwood Creek, California, increased the stream's suspended sediment loads four-fold (Kondolf 1997). Turbidity is generally greatest at mining and wash-water discharge points and decreases with distance downstream. Forshage and Carter (1973) found that settleable solids were deposited within 1.6 km of a gravel-dredging operation on the Brazos River, Texas. Nelson (1993) suggested that evaluations of instream mining effects include measurements of sediment loads and turbidity levels taken at the points of mining and wash-water discharges.

Little is known about changes in chemistry as a result of instream sand and gravel mining. Changes may be primarily local and subtle (Nelson 1993). Forshage and Carter (1973) found no significant differences in dissolved oxygen, acidity, specific conductance, chlorides, or hardness between a dredge site and an upstream reference area on the Brazos River in Texas. Martin and Hess (1986) found that dissolved oxygen, temperature, acidity, and total hardness were similar in dredged and reference areas in the Chattahoochee River, Georgia. However, decreases in dissolved oxygen (Martin and Hess 1986) and increases in temperature (Webb and Casey 1961) have been reported downstream from dredging activity.

Charlie Demas, U.S. Geological Survey

Dredged sand is placed along the shoreline of the Amite River, Louisiana, for processing.

Mining-induced changes to the geomorphic structure of the stream can significantly affect fish habitat and abundance. Instream mining can reduce the occurrence of coarse, woody debris in a channel, an important habitat for fish and invertebrates. In the Brazos River, gravel-dredging operations were associated with habitat changes and reduced abundance of sport fishes [spotted bass (*Micropterus punctulatus*); largemouth bass (*M. salmoides*); and bluegill (*Lepomis macrochirus*)] and benthic macroinvertebrates (Forshage and Carter 1973). Gravel mining on floodplains in Alaska produced severe channel alterations, apparently resulting in the elimination of or a reduction in fish populations (Woodward-Clyde Consultants 1980). However, Nelson (1993) reported no major differences in fish species composition, diversity, relative abundance, or biomass in a comparison of dredged and nondredged control areas in the Tennessee and Cumberland rivers in Tennessee.

Effects of mining on fish communities also may vary among and within streams. Fish densities in Uphapee, Line, Cubahatchee, and Mulberry creeks in Alabama were similar among sites affected by mining and sites upstream of mining activity, although Cubahatchee Creek had higher densities at the reference site (S. Peyton, Auburn University, pers. comm.). Comparisons of fish species composition at mined and unmined sites indicated low similarity in Uphapee, Line, and Cubahatchee creeks. At mined sites, relative abundance of cyprinids [(skygazer shiner (*Notropis uranoscopis*); blacktail shiner, (*Cyprinella venusta*); and speckled chub (*Macrhybopsis aestivalis*)] increased, while relative abundance of percids [(speckled darter (*Etheostoma stigmaeum*); greenbreast darter (*E. juliae*); rock darter (*E. rupestre*); and blackbanded darter (*Percina nigrofasciata*)] decreased.

Sedimentation and increased turbidity as a result of mining can have varying effects on fishes. Newport and Moyer (1974) reported that although fish species differ in their ability to tolerate suspended sediments, most could survive short-term exposure to greater than 1,000 ppm. The authors also reported that exposing fishes to concentrations less than 25 ppm caused no harm to a fishery, and chronic exposure to concentrations of 25 ppm–100 ppm would generally be tolerated. High turbidity and sediment loads may favor nonsight feeders such as catfish, whereas sight

feeders such as trout and bass may be harmed (Newport and Moyer 1974). The U.S. Environmental Protection Agency (EPA) (1976) considered turbidity of up to 50 Nephelometric Turbidity Units (NTU) to be satisfactory for aquatic biota in streams, but levels greater than 200 NTU were considered detrimental to biological productivity. Based on information in Newport and Moyer (1974) and the EPA (1976), Nelson (1993) suggested that suspended sediment concentrations greater than 50 ppm and/or turbidities above 50 NTU would likely harm fisheries.

Mining-induced changes to the geomorphic structure of the stream can significantly affect fish habitat and abundance.

It is important to understand the environmental effects of instream mining within the context of natural and other artificial stream disturbances. In the Brazos River the USGS, in cooperation with the Texas Parks and Wildlife Department and the University of Texas Bureau of Economic Geology, is analyzing historical stream flow and sediment transport data (D. Dunn, USGS, Austin, Texas, pers. comm.). This analysis will estimate the effects of main-channel sand and gravel removal on sand delivery to the Gulf of Mexico relative to effects of numerous upstream reservoirs and changes in land-use practices in the Brazos River basin. The local effects of a typical dredging operation also will be analyzed by measuring the flow field and sediment-transport characteristics upstream, through, and downstream of the dredging operation. Managers then can evaluate hydraulic effects of the mining operation with velocity vector maps and comparisons of upstream, mid-reach, and downstream sediment measurements.

Regulatory process for instream mining in the United States

Sand and gravel mining may be one of the least-regulated of all mining activities (Starnes 1983; Waters 1995). However, sand and gravel mining operations must follow federal and state regulatory procedures, although procedures for review and approval of permits differ among states. In addition to any federal permits, a state permit is generally required, and permits usually are reviewed by fisheries biologists to determine if instream sand and gravel operations will potentially harm fisheries.

Federal regulatory authority has been assigned to the U.S. Army Corps of Engineers (COE). The COE began regulating activities within the nation's navigable waterways after passage of the Rivers and Harbors Act in 1899. In 1972 EPA charged COE with lead responsibility for administering Section 404 of the Clean Water Act. Under Section 404, permits are required that regulate the discharge of dredged material into U.S. waters. Until 1993 COE did not use Section 404 to regulate excavation activities that involved removing material from waters such as landclearing, ditching, channelizing, and mining sand and gravel, even if those activities might harm wetlands or waters.

In 1993 COE authority to regulate excavation activities was changed because of the Tulloch rule, an outgrowth of a settlement agreement in the court case *North Carolina Wildlife Federation versus Tulloch* (civil number C90-713-CIV-5-BO). In that case a North Carolina developer without a 404 permit used several techniques to move soil from a 283-ha wetland, which avoided the discharging of dredged material near the excavation. Environmental groups sued COE, EPA, and the landowners, alleging that the landclearing and excavation activities destroyed and degraded wetlands and, therefore, should have been subject to regulation under Section 404. The agencies settled the case by adopting a rule to redefine the term *discharge of dredged material* to include incidental soil movement resulting from excavation. As a result, a Section 404 permit was required for mechanized landclearing, ditching, channelizing, or other excavation such as sand and gravel mining.

The Tulloch rule increased COE responsibility to regulate sand and gravel mining operations under the Section 404 permit but contained only general guidelines for mining activities. In January 1997 the American Mining Congress successfully challenged the Tulloch rule by arguing that *discharge of dredged material* referred to disposal not excavation (*American Mining Congress versus the U.S. Army Corps of Engineers and National Wildlife Federation*, Civil Action Number 93-1754). The Federal District Court in Washington, DC, ruled (1997, WL 31153 DDC) that the agencies overstepped their authority in trying to regulate excavation practices in or near water bodies. After the court's decision a referendum for stay and appeal was filed. A stay was granted 25 June 1997 to continue requiring permits for excavation activities until the appeal has been decided in court (expected sometime this year).

The COE typically requires individual permits under Section 404 for potentially significant effects of dredged material discharged into waters. However, COE often grants more-lenient permits on a nationwide basis called Nationwide Permits for categories of activities it believes will only minimally affect water quality. Under Nationwide Permit 26, which was issued for projects relating to headwaters and isolated waters, a project review by COE was not necessary for projects that affected less than 0.4 ha. Areas from 0.4 ha–4 ha required an abbreviated COE review. In 1996, after considering the potential harm created by Nationwide

Sand and gravel mining may be one of the least-regulated of all mining activities

Permit 26, COE revised the permit's requirements for abbreviated review to include areas 0.13 ha–1.2 ha. In addition, COE decided that Nationwide Permit 26 should eventually be phased out. However, a bill introduced in the U.S. House of Representatives in July 1997 (H.R. 2155) would reinstate Nationwide Permit 26 in its original form. Thus, the role of COE in the regulatory process of sand and gravel mining remains unclear.

Although not directly linked to a federal role in the regulatory process, the U.S. Department of Transportation (USDOT) has initiated action that may affect state regulatory activities pertaining to instream mining. In 1995 USDOT issued a notice to state transportation agencies that federal funds no longer would be available to repair bridges damaged by instream mining (Kondolf 1997).

Without remediation, stream recovery from sand and gravel mining can take decades.

States vary in their focus on mining operations and related impacts. Thus, state regulations and the number of agencies and organizations within a state that are involved in the regulation process also differ.

Arkansas is an example of a state with detailed permitting procedures for sand and gravel mining. The Arkansas Department of Pollution Control and Ecology (ADPCE), Surface Mining and Reclamation Division, regulates sand and gravel mining under the Arkansas Open-Cut Land Reclamation Act. Permitted mining can be conducted in upland areas and in bank sand and gravel deposits below high-water marks. Mining permit applications require (1) the appropriate application form; (2) proof of right to mine the land; (3) maps of the vicinity and site and reclamation plans; (4) a mining plan, including plans for pollution control and stream protection; (5) a reclamation plan; and (6) a reclamation bond. An application fee of at least $50 is charged, depending on the area of the site. Permit terms do not exceed 5 years, and they carry a renewal fee of $5 to $10 per 0.4 ha (1 acre). Miners cannot operate equipment in the water and may not excavate deeper than 0.3 m (1 ft) above the water surface elevation at the time of removal. A minimum 7.6-m (25-ft) buffer strip is required adjacent to the stream channel.

Arkansas requires mining operators to take reasonable steps and precautions to ensure that their activities do not violate state water-quality standards or impair streambank stability or channel integrity. Turbidity monitoring is not required. Operators are required to store fluids such as fuel, oil, and hydraulic fluid to prevent them and their residues from entering the stream channel, but a written plan for accomplishing this is not specified.

Texas could be viewed as a microcosm of the evolving state process of regulating sand and gravel mining. The Texas Parks and Wildlife Department has regulated the "disturbance of taking" streambed materials since 1911. Although regulations have not changed greatly, interpretations have evolved, and the focus and intensity of enforcement have waxed and waned (R. MacRae, Texas Parks and Wildlife Department, pers. comm.). The greatest changes have occurred in the last 10–20 years as the public has become more sensitive to the environmental effects of human activities.

Even if scientific information were adequate and the regulatory process streamlined, fisheries biologists face additional challenges when dealing with instream mining issues. In the course of developing regulations, educating legislators and the public is crucial. Several studies conducted during 1990–1992 by the Arkansas Game and Fish Commission were the basis of a bill enacted by the Arkansas Legislature in 1993. This bill prohibits commercial instream gravel mining on extraordinary resource waters (ERW) and requires state permits to be issued for all other waters. In Arkansas ERW consist of 24 streams and lakes designated as unique biological, physical, or recreational water. Although the bill was signed into law (Act 378 of 1993), the ADPCE, under pressure from gravel miners and politicians, banned the enforcement of the law for two years to give miners time to find new sources of gravel. When gravel miners and politicians tried in 1995 to have the legislation repealed, the Arkansas Game and Fish Commission, along with several other agencies, produced and distributed an educational video demonstrating the effects of gravel mining on streams. A second bill passed in 1995 (Act 1345 of 1995) prohibiting gravel mining in ERW and requiring permits elsewhere.

Recovery and remediation of instream mining

Without remediation, stream recovery from sand and gravel mining can take decades. For example, Kanehl and Lyons (1992) found that conditions in the Big Rib River, Wisconsin, remained in the early stages of recovery 20 years after the stream had been mined. Some stream reaches 10 years after mining were reported to be in worse condition, with significant signs of channel alteration and no available fish cover. Conversely, recovery in some streams can be rapid. Using streambed elevation data, Jacobson (1995) reported that the Meramec River, Missouri, recovered within two years after channel dredging stopped. The author suggested that the relatively quick recovery of streambed elevation in the Meramec River was indicative of a river with an abundant bedload that may have mediated the effects of mining.

Instream mining has been prohibited in the United Kingdom, Germany, France, the Netherlands, and Switzerland and is being reduced or prohibited in rivers in Italy, Portugal, and New Zealand.

Waters (1995) reported that erosion-control measures related to sand

and gravel mining operations generally have not been well developed but that several general guidelines might be appropriate. These guidelines include (1) complete avoidance of sand and gravel mining in streambeds, (2) avoidance of direct connection of floodplain excavations with streams, and (3) adherence to filtering of wash water before returning it to streams.

Kanehl and Lyons (1992) also suggested banning instream mining operations. Instream mining has been prohibited in the United Kingdom, Germany, France, The Netherlands, and Switzerland and is being reduced or prohibited in rivers in Italy, Portugal, and New Zealand (Kondolf 1997). In the absence of a ban, Kanehl and Lyons (1992) recommended that studies be conducted to evaluate control measures such as bank stabilization, re-vegetation, buffer strips, influences of connected floodplain pits, devices to control headcutting, and wash-water recycling.

Waters (1995) suggested that sand and gravel pits excavated below the water table could be drained, backfilled, and re-vegetated, or impounded to create recreational waterbodies. Although rock gabions can be used to halt headcutting, they are an extreme measure that may alter fish movements and behaviors (Waters 1995).

Another approach to mediate disturbance effects is to estimate the annual bedload sand and gravel supply from upstream, considered the replenishment rate, and limit annual mining to some fraction of the replenishment rate considered to be a "safe yield" (Kondolf 1997). For example, Washington biologists have sought to limit instream mining to 50% of the replenishment rate as an estimate of safe yield to minimize mining effects on salmonid spawning habitat (Kondolf 1997). Although this approach has the appeal of scaling mining to the river bedload in a general sense, bedloads are extremely variable from year to year. Also, the premise that mining can be tied to the replenishment rate without affecting the channel may ignore downstream bedload requirements for channel maintenance and the complex physicochemical and biotic responses to changes in bedload (Kondolf 1997).

Conclusions

Participants in the symposium concluded that a multidisciplinary geomorphic approach is needed to gain a better understanding of the complex integrated response of streams and biota to sand and gravel. Though some information is available regarding effects of sand and gravel extraction, much of this information is discipline- and site-specific. Comprehensive, integrated, multidisciplinary studies are needed to evaluate links between physical and biological responses to improve an understanding of how streams and biota respond to instream mining. In particular, studies should address natural (such as physiographic) and anthropogenic (for example, bank stabilization) controls that mediate stream responses to mining.

Symposium presentations revealed that evaluation of instream mining effects must include determinations of reference physical, chemical, and biological conditions of a channel. However, reference conditions are difficult to define due to natural and other anthropogenic stream impacts. Natural periodic events such as floods can greatly alter sediment budgets and channel hydraulics. To accurately measure the effects of sand and gravel mining, managers must consider such natural events. However, the effects of all factors influencing stream systems are extremely complex; evaluating potential mining impacts may require historical and spatial approaches to river analyses.

Symposium presentations suggested that the variation and complexity of instream mining regulations represent a confusing maze of federal and state requirements. Participants in the symposium recognized that despite this confusing regulatory process, innovative actions taken to decrease environmental impacts have been conceived and voluntarily implemented by some mining operators. However, not all mining operators comply with the regulatory process. Because of the nature of such operations, little or no information is available on the distribution and magnitude of illegal instream mining operations. In addition, little information is available regarding the level of compliance monitoring by regulatory agencies. Ultimately, responsibility for minimizing the number of mining operations established outside of the regulatory process may have to be jointly shared among federal and state agencies and responsible sand and gravel mining operators. Information presented at the symposium suggested that responsiveness, education, accurate scientific information, and compliance monitoring are important components of an effective regulatory process.

As with many competing resource issues, continued dialogue and education among all parties are crucial. This symposium provided an important step in sharing information and presenting the diverse perspectives of biologists, hydrologists, regulators, and mining operators. A better understanding of complexities involved in scientific and regulatory aspects of instream mining issues is urgently needed to develop a plan that integrates biology and politics.

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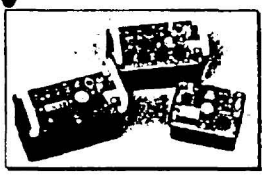
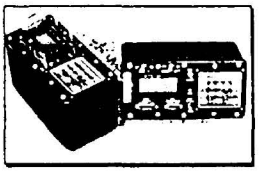
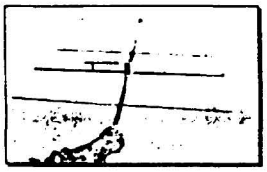

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Instream Gravel Mining and Related Issues in Southern Missouri

—Suzanne R. Femmer

The issue of instream gravel mining has many dimensions. In a growing economy, the availability of construction materials can be a limiting factor of growth and the economic benefits of gravel production must be weighed against the environmental costs. At the present time, quarry rock is used in much greater quantities than instream gravel in most counties in southern Missouri and for most uses, though the physical properties of instream gravel make it desirable for use as an aggregate for concrete. The extent of gravel mining in southern Missouri streams is not well known because only commercial entities need permits to operate. State conservation and regulatory agencies need information on the extent, character, and effects of instream gravel mining to manage and protect streams, streamside wetlands, and the beneficial uses these resources provide while also accommodating a viable mining industry. The economic benefits of gravel production must be weighed against the environmental costs. The Missouri Department of Conservation, U.S. Environmental Protection Agency, and the U.S. Geological Survey are working together to study these issues.

This fact sheet presents an overview of instream gravel mining, including economic and environmental issues, in southern Missouri. As the streams respond to mining disturbances, real estate can be lost, aquatic habitats altered, and fisheries and recreation damaged. An understanding of the effects of gravel mining will contribute to the establishment of an environment of minimal impact.

INTRODUCTION

In southern Missouri, gravel is mined extensively from the channels and flood plains of streams. Research in other regions has shown that instream gravel mining destabilizes stream channels and substantially degrades instream habitats and habitats of associated wetlands (Bull and Scott, 1974; Woodward-Clyde Consultants, 1980; Lyttle, 1993; Kondolf, 1997). There is very little information on gravel mining and its related issues in Missouri.

Considerations

There are many questions about the effects of instream gravel mining on the aquatic resources of Missouri. What is the extent of gravel mining? How are habitats affected by changing the shape of the channel? How does instream mining affect erosion and sedimentation? What are the short- and long-term effects on stream habitat? What are the effects on stream biota? How is public and private property affected by mining? Should guidelines be developed to govern how instream mining is conducted?

Known Effects

Extraction of gravel from a stream alters the sediment budget creating the potential for channel instability, increased turbidity, and degradation of habitats (fig. 1). Wetlands may be altered or lost by erosion, the lowering of the water table, relocation of the stream channel, or by moving gravel into wetland areas. Instream gravel mining may be linked to loss of fishery resources and wetlands, increased bank erosion, and damage to infrastructure caused by channel degradation. The extent to which this potential is realized depends on the hydrologic character, sediment load, and riparian condition of a stream. In Missouri, there is little information about the extent and distribution of instream mining. This information is needed for a science-based understanding for future instream mining policy in Missouri.

Figure 1. An example of habitat degradation at a gravel mining site at Sellars Creek in Camden County, 2000.

ECONOMIC CONSIDERATIONS

Known Gravel and Quarry Rock Production

Many Missouri stream channels and their flood plains are sources of gravel for construction, road maintenance, and other uses. In addition, the limestone and dolostone hills of southern Missouri are a plentiful source of quarry rock, which is used in some areas in place of gravel. According to the U.S. Geological Survey (USGS) and the Missouri Department of Natural Resources, Division of Geology and Land Survey, quarry rock, by value, has been Missouri's primary nonfuel mineral commodity since 1997, exceeding lead, which was leading in 1996 (U.S. Geological Survey and Missouri Department of Natural Resources, Division of Geology and Land Survey, 2000). The regions around metropolitan areas such as St. Louis and Kansas City consume a large part of the quarry rock produced (fig. 2). Missouri also is a significant producer of construction gravel. During 1999, Missouri's production of construction gravel increased by nearly one-third over that in 1998 (U.S. Geological Survey and Missouri Department of Natural Resources, Division of Geology and Land Survey, 2000). Although the 2000 total annual national production of construction gravel was the highest production level recorded for the United States as a whole, Missouri experienced a decrease of 27 percent from 1999 (U.S. Geological Survey, 2001).

Production Survey

The USGS conducted a survey, in 2000, of 70 county highway departments in southern Missouri to determine gravel and quarry rock use, estimated rock value, and locations of gravel mining operations during 1999. This information was not available from other sources because in Missouri, county highway departments do not need mining permits to remove gravel. Of the 70 counties surveyed, 46 counties responded concerning their instream gravel and quarry rock use in 1999 (fig. 2). Instream gravel used by these 46 counties in 1999 was estimated to be 376,000 tons at an approximate value of $1,454,000. Quarry rock was used in greater quantities in most of the counties that responded. Approximately 2,480,000 tons of quarry rock at a value of approximately $10,321,000 was used in 1999.

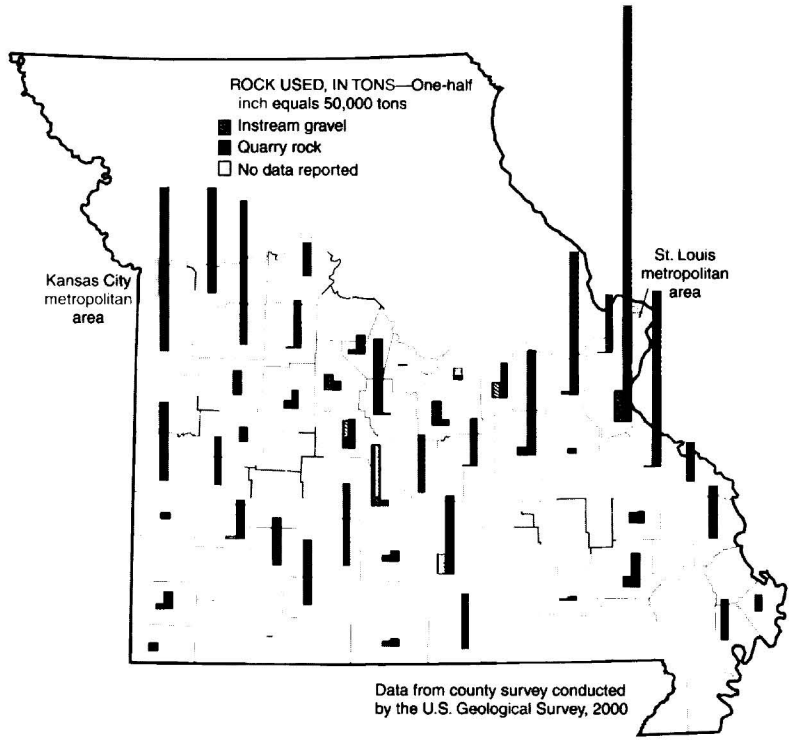

Figure 2. Rock use by county highway departments, 1999.

Uses for Gravel

Commercial construction, such as home building and commercial development, is another consumer of gravel. The size, shape, hardness, and chemical composition of the gravel in many streams make the gravel ideal for use in concrete. Instream gravel can be in great demand for construction material because the water has already eroded the weak material out of the rock, leaving durable, rounded, and well-sorted gravel (Kondolf, 1997). Because of the low oil content of certain rocks, the problem of concrete crumbling is lessened. Construction near areas of population growth and high population density consume a large volume of instream gravel. Road building and maintenance is another industry that uses gravel and quarry rock. As shown by the survey described in the previous section, some county highway departments use quarry rock exclusively, while a few use only gravel.

On the other side of economic benefits of gravel mining is the possibility of negative effects in wetlands, recreational areas, riverine habitat, and a potential loss of land. A study conducted by Arkansas State University (Kaminarides and others, 1996), in an area similar to southern Missouri, determined that the economic benefits of instream gravel mining did not outweigh the environmental costs in Crooked Creek and Kings, Spring, Illinois, and Caddo Rivers in Arkansas. The environmental costs were listed as money lost from farms, real estate, fisheries, and recreation. These conclusions indicated that

although instream gravel mining was an important industry, mining would not be acceptable or safe in some streams as it was being practiced.

ENVIRONMENTAL CONSIDERATIONS

In addition to changing the aesthetic character of a stream, instream gravel mining potentially alters channel depth and width, riparian vegetation, streambed substrate texture, bank vegetation and substrate, and aquatic habitat, as shown in the two photographs of Barren Fork, Miller County, Missouri, within and downstream from gravel mining (figs. 3A and 3B). Studies have indicated that gravel mining on gravel bars and the riparian corridor of streams can result in head cutting, channel incision and lateral instability, increasing stream gradient, channel relocation, and scouring and erosion (Sandecki, 1989; Kondolf, 1994). These physical changes can result in increased stream turbidity and temperature. The removal of the larger gravel particles releases fine sediment into the stream system. These habitat disruptions and channel instability can cause overall reduction in biological diversity and production (Benke, 1990; Brown and others, 1998; Waters, 1995). The released sediments increase the turbidity of the stream, which obstructs sunlight from reaching aquatic plants and algae, reducing the primary productivity of the stream and associated wetlands.

Effects on Fish Communities

Fish communities are potentially impacted by changes in turbidity and sediment erosion, transport, and deposition. Increased turbidity can affect fish by reducing their feeding efficiency, reducing their tolerance to diseases, and increasing their overall physiological stress. Increased sediment loads also can disrupt fish reproductive success by interfering with the viability of their eggs and fry (Waters, 1995). Arkansas Game and Fish Commission conducted a short-term study on the Kings River that demonstrated a 50 percent decrease in smallmouth bass downstream from gravel mines because of a 15-fold increase in silt or turbidity. The fine sediments cause smallmouth bass and other sensitive game fish to have poor survival rates because of the smothering of their eggs and fry (Arkansas Game and Fish Commission, written commun., 1997).

Effects on Invertebrate Communities

Benthic invertebrates can suffer significant negative effects from deposited sediments because they are adapted to specific substrate particle sizes. A stream with a diverse substrate size composition will support a diverse benthic invertebrate community. As sediment settles into the interstitial spaces in the streambed, the availability of diverse substrate decreases, resulting in decreased species diversity, abundance, and productivity. A mussel community is especially sensitive to fine sediments and substrate alteration, which can result in a total loss of a species (Parmalee, 1993). Fish communities depend on the benthic invertebrate community as a food source. Healthy fish populations rely on diverse invertebrate communities.

Figure 3. Barren Fork in Miller County, Missouri, 2000. ***A***, Active instream gravel mining ***B***, the natural channel approximately 100 meters downstream from photograph A.

EXTENT OF GRAVEL MINING

Instream gravel mining in Missouri is regulated by the Missouri Department of Natural Resources, Land Reclamation Program (MDNR, LRP) and to a lesser extent, the U.S. Army Corps of Engineers. All commercial gravel operations must obtain a permit from MDNR, LRP, though non-commercial operations and county and local governments do not need a permit. Because many operations do not need to obtain a permit, it is difficult to know the

extent of instream gravel operations in southern Missouri.

The survey of county highway departments, described in a previous section, contributed to the understanding of the extent and density of gravel mining operations. Drive-by field reconnaissance throughout most counties contributed information on gravel mining locations. As illustrated by figure 4, most gravel mining sites located are not permitted by the State. Of the approximately 750 gravel mining sites identified, about 23 percent were permitted by the State. Also noticeable in figure 4 are gaps of information in the dataset. As populations grow and shift locations, changes in gravel mining sites would likely occur.

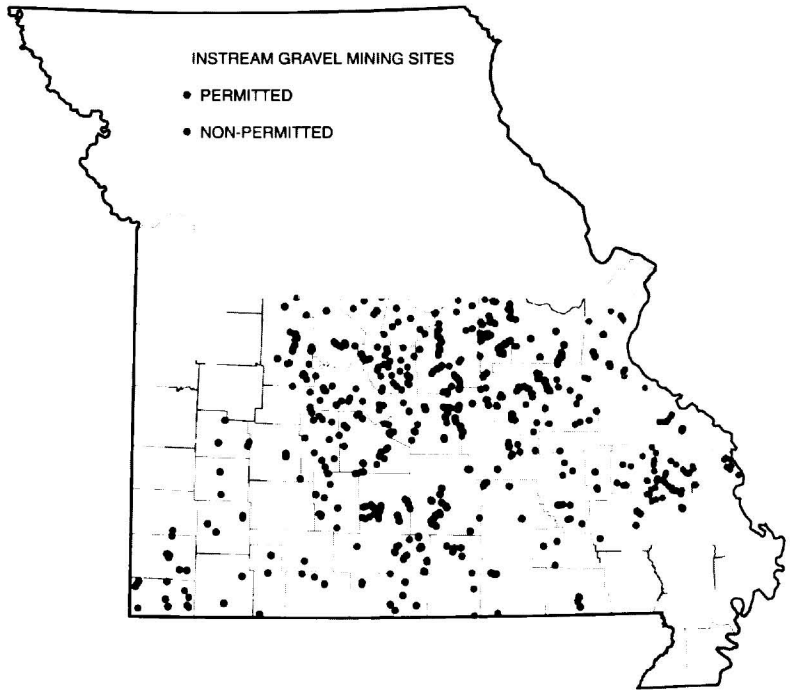

Figure 4. Sites where instream gravel mining was recorded in 1999.

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