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

Michael R. Meador is an ecologist for the U.S. Geological Survey, 3916 Sunset Ridge Road, Raleigh, NC 27607; 919/571-4020; mrmeador@usgs.gov. April O. Layher is a biologist for the Arkansas Game and Fish Commission.

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's responsibility to regulate sand and gravel mining operations under the Section 404 permit but contained only general guidelines for mining activity. 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 waterbodies. 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.

Acknowledgments

We thank the participants for their high-quality, professional presentations at the symposium as well as for their input into this paper: David Dunn, USGS; Stephanie Goudreau, North Carolina Wildlife Resources Commission; Steve Filipek, Arkansas Game and Fish Commission; Paul Hartfield, U.S. Fish and Wildlife Service; Robb Jacobson, USGS; Mark King, COE; David Kurz, Sand Supply Inc.; Bill Layher, University of Arkansas-Pine Bluff; Bill Langer, USGS; Rollin MacRae, Texas Parks and Wildlife Department; and Scott Peyton, Auburn University. The Environmental Concerns Committee thanks the Warmwater Streams Committee for the invitation and opportunity to summarize the symposium.

References

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

EPA (U.S. Environmental Protection Agency). 1976. Erosion and sediment control surface mining in the eastern United States. U.S. Environmental Protection Agency Technical Series Report EPA-625/3-76-006, Washington, DC.

Forshage, A., and **N. E. Carter.** 1973. Effects of gravel dredging on the Brazos River. Proc. Annu. Conf. Southeast. Assoc. Game Fish Comm. 27:695–709.

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

Jacobson, R. B. 1995. Spatial controls on patterns of land-use induced stream disturbance at the drainage basin scale—an example from gravel-bed streams of the Ozark Plateaus, Missouri. Pages 219–239 *in* J. E. Costa, A. J. Miller, K. W. Potter, and P. R. Wilcock, eds. American Geologists Union Geophys. Monogr. 89, The Wolman Volume.

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

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

———. 1997. Hungry water: effects of dams and gravel mining on river channels. Environ. Manage. 21:533–551.

Langer, W. H. 1988. Natural aggregates of the conterminous United States. U.S. Geol. Surv. Bull. 1594. U.S. Geological Survey, Denver, CO.

Langer, W. H., and **V. M. Glanzman.** 1993. Natural aggregate: building America's future. U.S. Geol. Surv. Cir. 1110. U.S. Geological Survey, Denver, CO.

Martin, C. R., and **T. B. Hess.** 1986. The impacts of sand and gravel dredging on trout and trout habitat in the Chattahoochee River, Georgia. Georgia Department of Natural Resources, Atlanta.

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

Newport, B. D., and **J. E. Moyer.** 1974. State-of-the-art: sand and gravel industry. U.S. Environmental Protection Agency Technical Series Report 660/2-74-0066, Washington, DC.

Sandecki, M. 1989. Aggregate mining in river systems. California Geologist 42(4):88–94.

Starnes, L. B. 1983. Effects of surface mining on aquatic resources in North America. Fisheries 8(6):2–4.

USGS (U.S. Geological Survey). 1997. The Front Range Infrastructure Resources Project. U.S. Geological Survey, Denver, CO; http://webserver.cr.usgs.gov/frirp/frirp.html.

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

Webb, W. E., and **O. E. Casey.** 1961. The effects of placer mining (dredging) on a trout stream. Idaho Department of Fish and Game F-034-R-03, Boise.

Woodward-Clyde Consultants. 1980. Gravel removal studies in Arctic and Subarctic floodplains in Alaska. U.S. Fish and Wildlife Service FWS-OBS-80/08, Washington, DC.