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

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Executive Summary

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

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

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

Resource Issue

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

Purpose

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

Background

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

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

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

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

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

Stream Sediments and Physical Processes

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

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

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

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

Physical and Biological Effects of Instream Mining

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Economic Considerations

Sand, gravel, and crushed stone, called aggregate in the mining industry, are among the most important and highly demanded mineral resources in the United States, having uses in nearly all commercial, industrial, and residential construction including concrete, general fill, and subgrade material for highways, railroad beds, bridges, airports, road surfacing, and water and sewer systems (Morris 1982; Langer and Glanzman 1993). Aggregate mining is the first or second largest mining industry in the United States depending on the unit of measure (Bull and Scott 1974; Morris 1982; Waters 1995). Growth in demand has been significant in the last two decades. Nationally, nearly 800 million tons of sand and gravel were mined in 1980 (Morris 1982), and 1.1 billion tons were mined in 1998 (Kuhar et al. 1999). Crushed stone from quarries accounted for an additional 1.6 billion tons in 1998. In Missouri, crushed stone leads in value ($337 million) followed by excavated sand and gravel ($41 million) (Fairchild et al. 1997), and 5,200 jobs are supported directly by the industry (MICM 1999). Long-term demand for sand, gravel, and crushed stone will expand (Langer and Glanzman 1993). Short-term demand will be driven in part by 1998 federal legislation called TEA-21 (Transportation Equity Act for the 21st Century - PL105-178), which will provide to the states $215 billion over six years for highway, transit, safety, research, and motor-carrier programs.

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

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

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

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

Policy and Legal Considerations

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

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

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

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

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

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

Regulation of Instream Mining in Other Midwest States

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

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

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

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

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

Alternatives for Managing Instream and Floodplain Mining

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

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

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

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

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

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

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

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

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

Information Needs

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

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

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

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

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

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

Summary and Recommendations

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

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

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Appendix 1

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

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

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

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

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

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

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

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

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

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

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

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

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

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

n. No activity which may affect Historic properties listed, or eligible for listing, in the National Register of Historic Places is authorized, until the District Engineer has complied with the provisions of 33 CFR 325, Appendix C. All prospective permittees must notify the District Engineer if the excavation activity may affect any historic properties listed, determined to be eligible, or which the prospective permittee has reason to believe may be eligible for listing on the National Register of Historic Places, and shall not begin the activity until notified by the District Engineer that the requirements of the National Historic Preservation Act have been satisfied and that the activity is authorized. Information on the location and existence of historic resources can be obtained from the State Historic Preservation Office and the National Register of Historic Places.

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

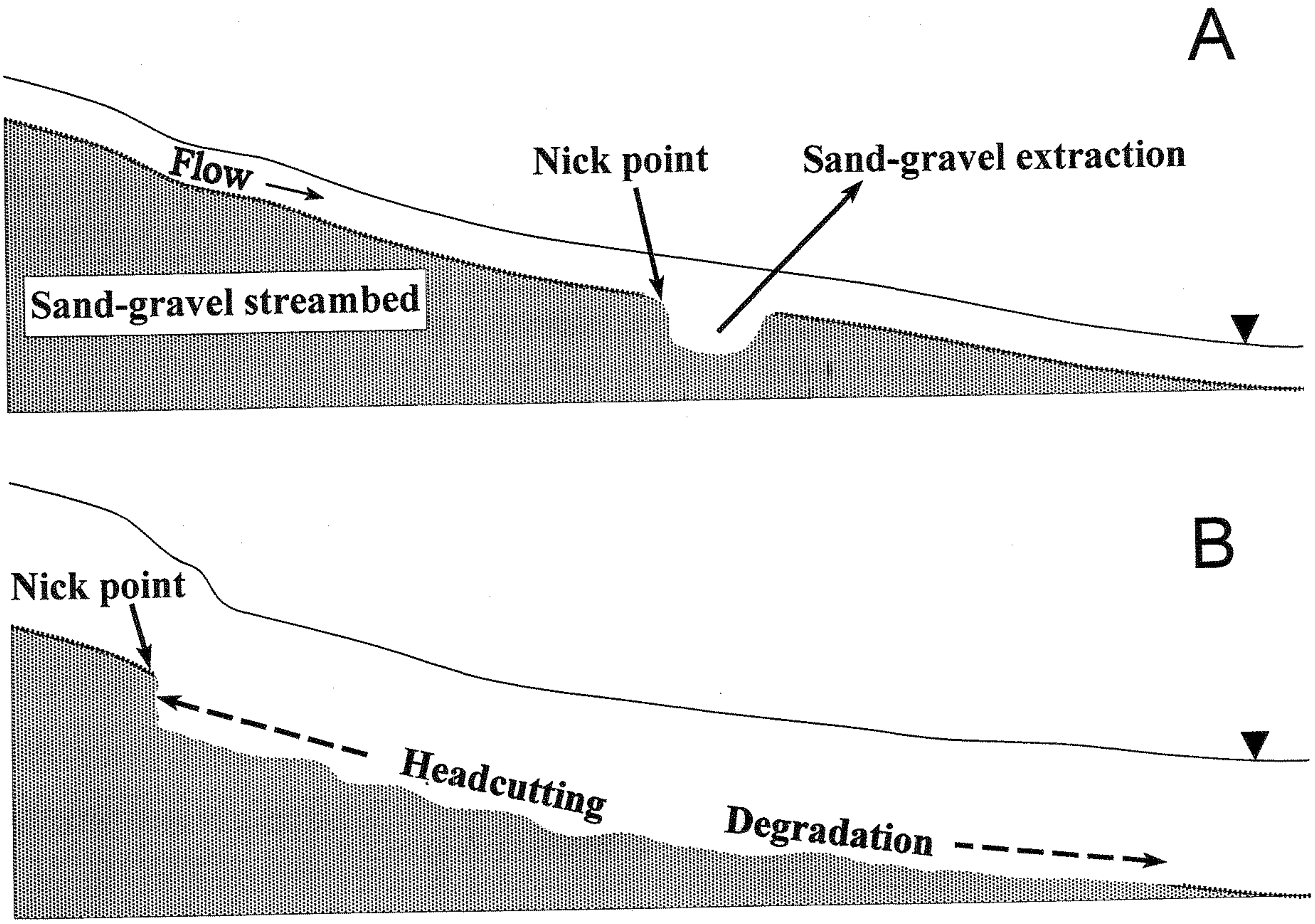

Figure 1. Diagram of a sand-gravel streambed showing (A) the nick point that develops when pit excavation is used to mine sand and gravel from the channel during low flows, and (B) the upstream headcutting and downstream bed degradation that develop during high flows. Inverted triangle denotes the water surface.

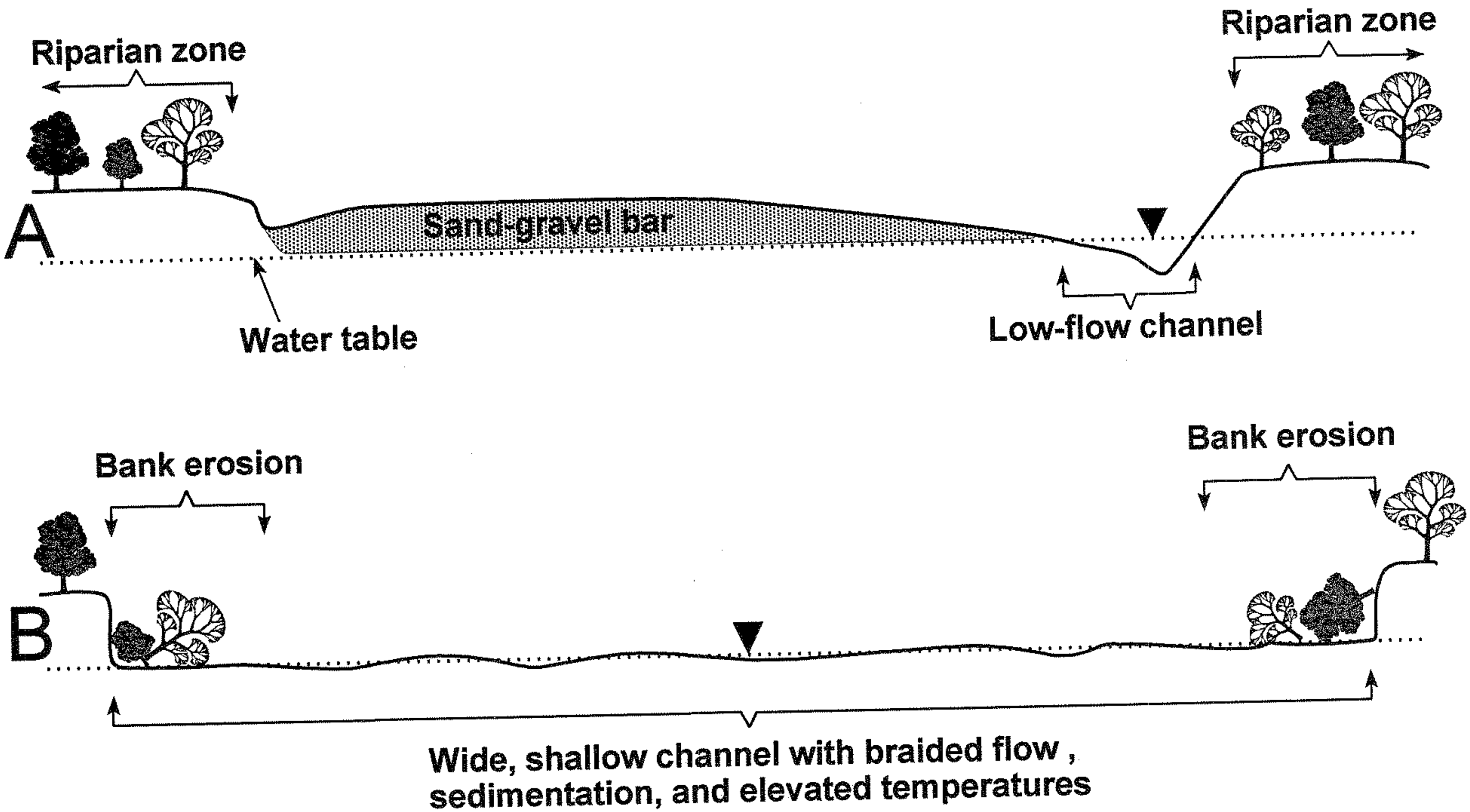

Figure 2. Diagram of channel cross sections showing (A) a typical sand-gravel bar in relation to the low-flow channel, riparian zone, and water table, and (B) the wide, shallow channel that results from unrestricted mining and that is characterized by bank erosion, braided flow, sedimentation, and elevated water temperatures. Inverted triangle denotes the water surface.

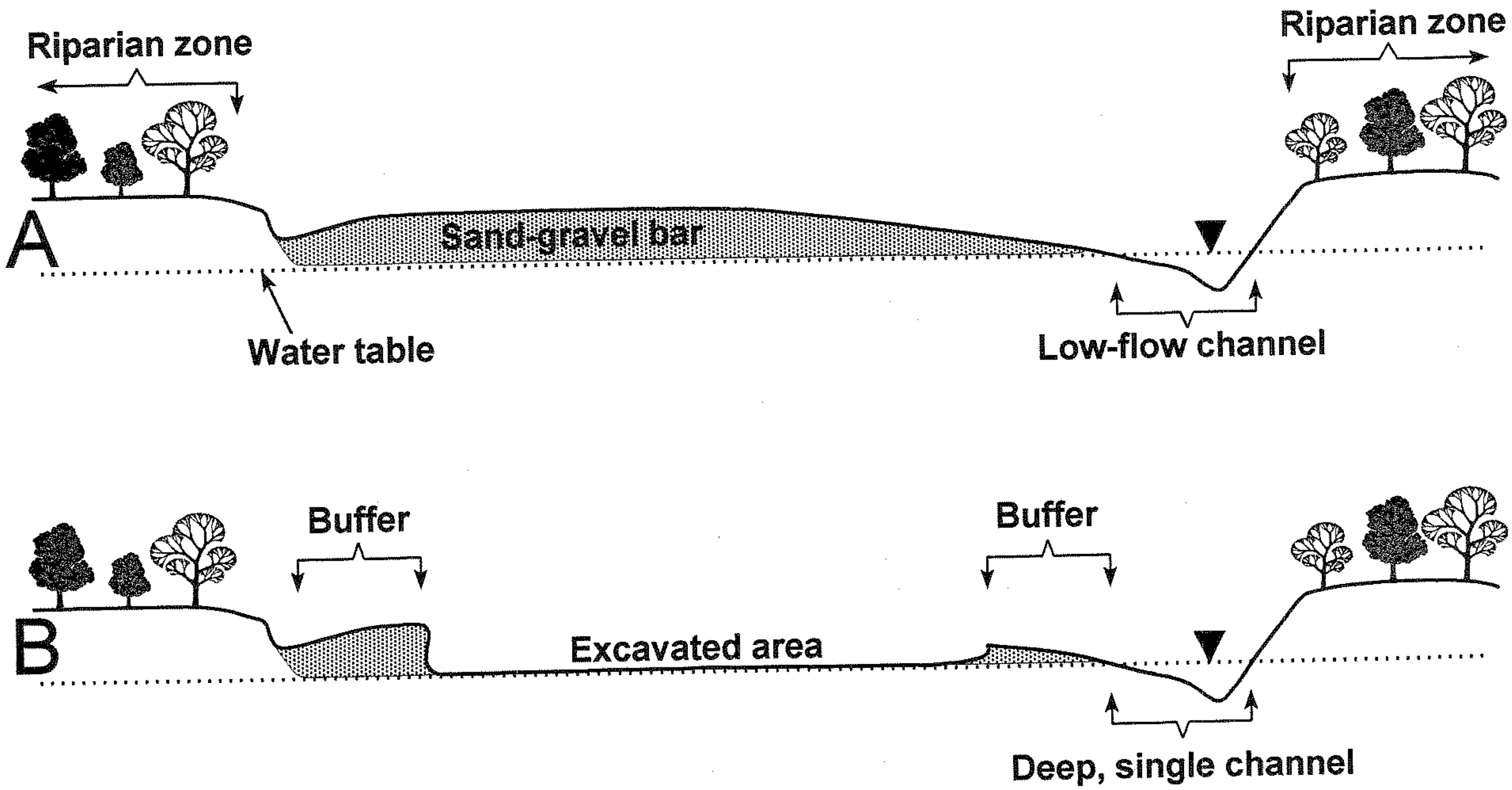

Figure 3. Diagram of channel cross sections showing (A) a typical sand-gravel bar in relation to the low-flow channel, riparian zone, and water table, and (B) the protected deep, single channel and channel banks when mining is restricted within a buffer of designated width and above the water table. Inverted triangle denotes the water surface.

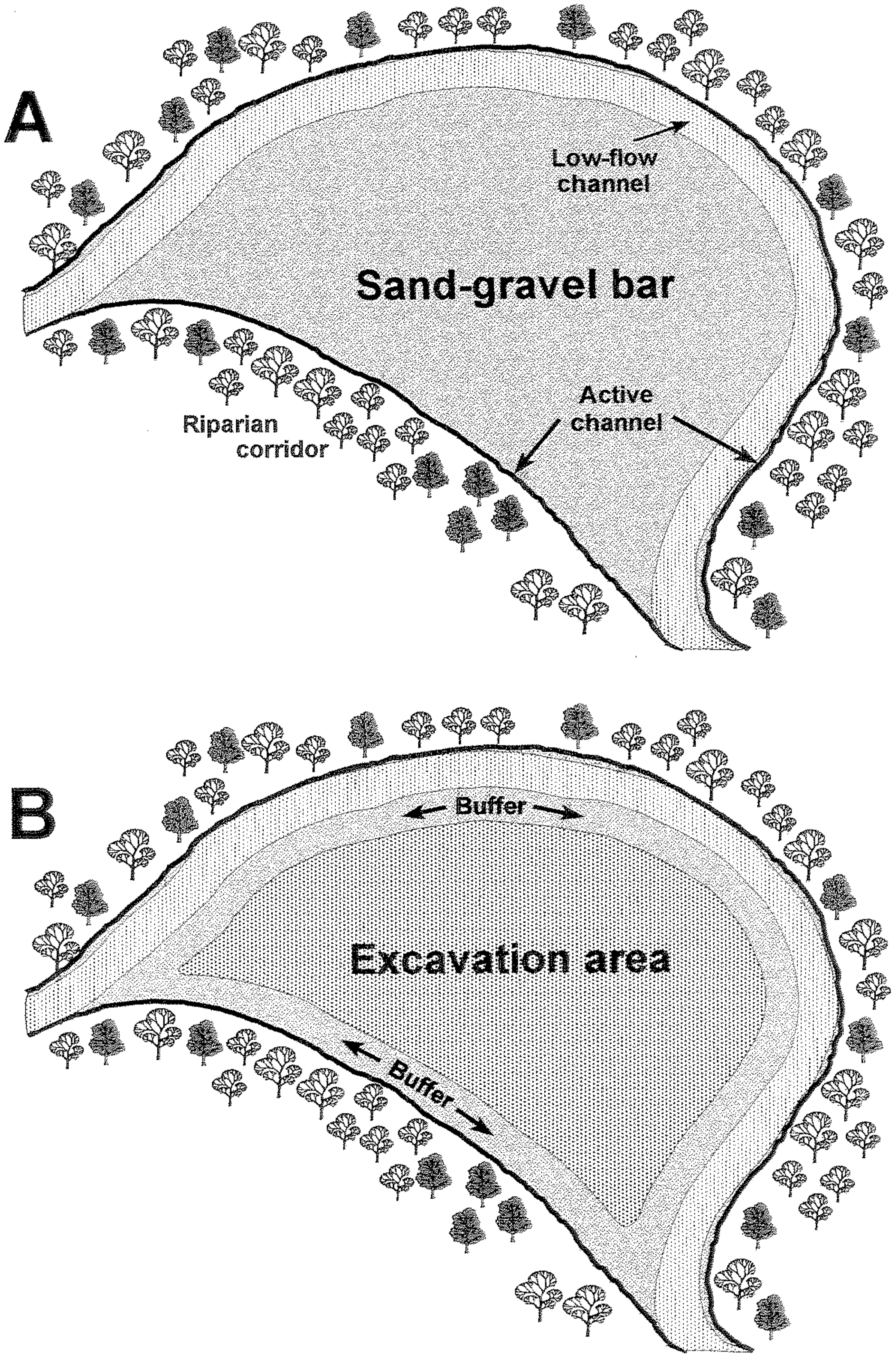

Figure 4. Diagram of a typical sand-gravel bar showing (A) the relative positions of the bar, the riparian corridor, the active (or bankfull) channel, and the low-flow channel, and (B) the area of excavation defined by a no-disturbance buffer of designated width.