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# 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

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## Abstract

Based on a literature review, the primary physical and biological effects of in-stream sand and gravel mining and stream-connected floodplain excavations are: (1) stream channel modifications, including alterations of habitat, flow patterns, sediment transport, and increased headcutting; (2) water quality modifications, including increased turbidity, reduced light penetration, and increased water temperatures; (3) changes in aquatic plant communities through channel clearing and changes in substrates; (4) changes in aquatic invertebrate populations through direct removal, disruption of habitat, and increased sedimentation; and (5) changes in fish populations through the alteration and elimination of spawning and nursery habitat and through alterations in the food web, which can affect the nutrition, health, and growth of fish. Six case studies from states outside of Wisconsin are presented that document many of these physical and biological effects.

To examine the potential impacts of floodplain and in-stream gravel mining, we surveyed portions of the Big Rib River, Marathon County, Wisconsin, for habitat and fish community characteristics during August 1987. We had 6 stations; 2 had received past in-stream mining, one had been impacted by in-stream mining, one was below extensive, active floodplain mining, and 2 were near limited floodplain or riparian mining (unmined stations). Habitat characteristics—most notably percent sand, percent rubble/cobble, mean channel width, and mean depth of runs—differed among stations. Station 4, which had the most recent in-stream mining (approximately 10 years before sampling), had the worst habitat.

We rated the quality of the fish communities using the Index of Biotic Integrity (IBI). Overall, the 3 stations with in-stream or adjacent floodplain gravel mining had poorer quality fish communities than the 2 unmined stations and the one impacted station. Station 4 had the worst score. Our results suggest that gravel mining has had a negative impact on the fish communities and fish habitat of the Big Rib River.

**Key words:** Streams, sand and gravel mining, habitat alterations, water quality, fish, invertebrates, Big Rib River.

## Contents

# Introduction

Little has been published about the effects of sand and gravel mining on fisheries resources in Wisconsin. To develop insight into possible effects, we conducted a literature review that focused on physical and biological results of sand and gravel mining both in and adjacent to streams. Additionally, we compared fisheries and habitat characteristics in areas with and without mining in the Big Rib River, Marathon County, Wisconsin. The area around the Big Rib River has been mined for the past 40 years (Zmuda 1982). The goals of both the literature review and the field sampling were to develop management recommendations for dealing with possible conflicts between stream fisheries and mining activities. For purposes of this report, sand and gravel mining is defined as excavations of sand, gravel, and larger substrates such as rubble, cobble, and boulders.

As of 1977, there were approximately 34,800 ha in Wisconsin that had been disturbed by surface sand and gravel mining operations (U.S. Dep. Agric. 1977). By 1987, over 4,860 ha in Marathon County alone had been disturbed by sand and gravel operations (Mitch Zmuda, Wis. Dep. Nat. Resour., pers. comm.). In the area near the Big Rib River between Marathon City and Rib Falls, Wisconsin, there are 49 different mining sites that encompass over 170 ha (Mitch Zmuda, pers. comm.). Types of mining in the Big Rib River area include inactive and active riparian (upland) excavations, inactive and active floodplain excavations, which can include unconnected and connected ponds with outlets to a river, and actual in-stream mining (dredging) excavations. For the purpose of this report, we limit our discussion to active floodplain excavations (connected ponds only) and old in-stream dredging.

Wisconsin regulations that require state permits for gravel excavations in or adjacent to navigable water were first enacted in 1961 under Chapter 30, Wisconsin Statutes. Under Chapter 30, permits were required if excavations resulted in removal of material from a streambed, relocation of a stream, creation of an artificial waterway within 150 m of a stream, and/or grading on the bank in excess of 930 m$^2$ (Zmuda 1982). No provisions were included for the reclamation of gravel excavations under Chapter 30. Many of the gravel operations during the late 1960s and early 1970s did not have Chapter 30 permits (Zmuda 1982). With increases in permit applications during the mid-1970s, it became apparent that added regulations were needed.

Therefore, in 1979, new regulations were formulated under Chapter NR 340, Wisconsin Administrative Codes, that gave specific guidelines for gravel excavations in or near navigable waterways. The main purpose of NR 340, rewritten in September 1991, is to minimize adverse effects, provide for reclamation of excavated areas, restrict excavations where adverse effects cannot be minimized or avoided, and define certain terms, including some used in Chapter 30, Wisconsin Statutes (Zmuda 1982, Wis. Dep. Nat. Resour. 1991). After an application is submitted under Sections 30.19, 30.195, or 30.20, the Wisconsin Department of Natural Resources (DNR) reviews the project and compiles an Environmental Assessment (EA) to determine if an Environmental Impact Statement is needed (Zmuda 1982). The EA data are assembled by the fish, wildlife, water resources, and water regulation and zoning programs. The formulation of these laws, regulations, and guidelines have deterred many permit applications to dredge in and around the Big Rib River since 1980.

PHOTO: BOB QUEEN

*Sand and gravel mining operation.*

This report describes the results of surveys conducted on the Big Rib River in 1986 and 1987. In 1986, DNR Fisheries Management and Research personnel conducted a brief fishery survey on 2 sections of the Big Rib River in an area that had experienced in-stream mining almost 10 years before sampling. In 1987, DNR Fish Research personnel conducted a more detailed 2-week survey of the habitat and fish communities at 6 stations on the Big Rib River between Marathon City and Rib Falls. The objective of these surveys was to evaluate and document impacts from active, connected floodplain excavations and from old, abandoned, unreclaimed in-stream-mined areas.

# Methods

To determine what is currently known about in-stream and floodplain sand and gravel mining, we conducted a literature review and contacted DNR water regulations personnel. This evaluation included studies and articles published as of summer 1990. A database search was conducted by the U.S. Fish and Wildlife Reference Service, Bethesda, Maryland, on the key words of gravel mining and streams. Additional reports and articles were provided by Mitch Zmuda (DNR Bur. Water Regul. and Zoning). The articles and reports that we reviewed contained information on additional studies and articles that we attempted to obtain from various agencies.

Our review primarily focused on the physical and biological effects of in-stream sand and gravel mining and secondarily on floodplain (connected ponds only) sand and gravel mining. For the purpose of this report, we excluded such topics as effects on recreation, aesthetics, terrestrial biota, and geotechnical engineering aspects. However, due to the dearth of actual studies conducted on in-stream and floodplain sand and gravel mining, we researched other in-stream modifications and effects, such as channelization, silt deposition, and channel clearing. We also provide short summaries of 6 specific case studies conducted on in-stream and floodplain excavations in other states. These summaries include stream and location, references, types of mining operations, physical and biological effects, and recommendations.

Methods for the Big Rib River surveys conducted in 1986-87 by DNR personnel are discussed in the section of this report titled "Big Rib River: A Wisconsin Case Study of Gravel Mining Impacts."

Taxonomy of fishes cited in the report follows Robins et al. (1991). Scientific names are given in the Appendix.

# Literature Review

## Physical Effects

Gravel mining operations (both in-stream and floodplain excavations) can affect the physical nature of a stream. The stream channel may be modified, flow patterns and bedload transport may be altered, headcutting can increase, and the water quality of a stream may be altered.

### Stream Channel Modifications

The actual dredging or scraping of sand and gravel during mining operations can alter stream channels and banks. Dredging or scraping usually involves enlargement or widening of the stream channel (Etnier 1972, Woodward Clyde Consult. 1976*b*, Yorke 1978), which creates uniform conditions of either deep or shallow reaches throughout the channel (Yorke 1978). These physical effects can change the stream length, gradient, width, and depth of the channel (Woodward Clyde Consult. 1976*b*). Channel deepening can also cause stream banks to become unstable and eroded (Bull and Scott 1974). In the Crooked River, Idaho, where placer mining (a type of gold mining that involves dredging of sand and gravel) occurred, the stream was channelized and straightened; all trees, boulders, and other cover were removed, and pool habitat was eliminated, thus creating a channel devoid of habitat suitable for salmonids (Hair et al. 1986). Widening of the channel also increases the surface area of the stream (Yorke 1978). If dredging occurs, deep pools are often created because the amount of material being removed is greater than the amount of material that the river can redeposit (Bull and Scott 1974, Crunkilton 1982, Rivier and Seguier 1985). However, once the mining operation ceases, these pools often fill with sand or silt in a relatively short period of time, depending upon the rate of sediment renewal (Yorke 1978, Rivier and Seguier 1985). Thus, these pools created by dredging may serve temporarily as sediment traps, which may be beneficial to downstream habitats and organisms (Martin and Hess 1986). This condition is, however, a short-term response, because the sediment basins will eventually fill in.

### Channel Flow Modifications

The physical effects of deepening and widening the stream channel can alter the flow patterns and velocities of the stream (Crunkilton 1982). As in channelization (the creation of a uniform channel), peak flows will be higher, resulting in a shorter duration of flooding (Yorke 1978). Velocities will be changed in 2 ways. Upon entering the dredged area, velocities will increase due to the sharp increase in gradient (Woodward Clyde Consult. 1976*b*). However, once in the dredged area, velocities will decrease due to the increase in stream width or cross-sectional area (Etnier 1972, Yorke 1978). Also, clearing and snagging (removal of trees, woody debris, vegetation, boulders, gravel bars, and other obstructions from the channel and stream banks) during in-stream sand and gravel mining operations will cause velocities to become more uniform throughout the cleared area (Marzolf 1978, Yorke 1978). Other effects from clearing activities include creation of uniform depths (from the removal of obstructions that had created pools), elimination of cover, and the clearing of vegetation from stream banks, which can decrease bank stability (Yorke 1978, Benke et al. 1985).

### Bedload Modifications

The greatest impacts of in-stream sand and gravel mining involve the elimination of habitat diversity, such as riffles and undercut banks, and the removal of in-stream and bank cover (Woodward Clyde Consult. 1976*b*, Marzolf 1978, Yorke 1978). Due to the removal of gravel (or riffle habitats) and changes in river hydraulics, alterations can occur in bottom substrates and bedload transport of the stream (Crunkilton 1982). Substrates will generally change from coarser gravel to sand or silt, depending upon the rate of sediment renewal to the area. The removal of coarser gravel and rubble from the stream eliminates the armor layer of the streambed, which can cause instability in the stream bank and in gravel bars (Woodward Clyde Consult. 1976*b*, Yorke 1978).

Bedload transport and suspended sediments will increase due to bank erosion, which can be quite severe in some dredging operations (Woodward Clyde Consultants 1976*b*). Floodplain mining and associated clearing and removal of vegetation may influence runoff patterns, increase erosion, cause bank destabilization, increase sedimentation, and increase turbidity (Crunkilton 1982). Also, gravel washing operations and the actual in-stream mining operation can increase suspended sediments in the river (Woodward Clyde Consult. 1976*b*). For example, in the River Allier, France, gravel operations discharged approximately 230-3,600 kg per day of suspended sediments into the river (Rivier and Seguier 1985).

An increase in sediment transport can also occur due to increased erosion of the channel bed in the dredged area (Crunkilton 1982, Starnes 1983, Simons and Li 1984). As the channel bed is lowered by the dredging operation, channel gradients (slopes) are increased in the upper portion of the dredged area. This can cause an increase in degradation of the streambed, which progresses upstream. This action is known as headcutting (Simons and Li 1984).

### Headcutting

Dredging can produce changes in the river in both the upstream and downstream direction from the dredged area. Some of the downstream changes have been discussed previously (e.g., channel degradation, increased sediment load, and bank erosion). In the upstream direction, a headcut may form due to the increased velocity as the water enters the dredged hole. The increased velocity is due to an increase in the channel gradient at the upper end of the dredged area. Generally, the headcut will continue to advance upstream until a level of equilibrium is reached, resulting in severe degradation and bank erosion (Bull and Scott 1974, Crunkilton 1982, Simons and Li 1984, Rivier and Seguier 1985).

The area around the headcut can be divided into 3 zones, which include the upstream zone, the headcutting zone, and the downstream zone (West 1978, Simons and Li 1984). The upstream zone is the area that has not been influenced by the mining operation and that also supplies sediment to the downstream zone. Slopes or gradients in this area are fairly uniform. The downstream zone is the area of sediment deposition or aggradation. This area is generally flat and deep, with slow water velocity.

At the farthest upstream portion of the dredged hole where the gradient is very steep, a headcut will form. The headcut is that portion of the steepened slope that is near vertical in form (Leopold et al. 1964, West 1978). The very top portion of the vertical headcut is called a nick point (Leopold et al. 1964, West 1978). This area is very unstable due to the increased slope, which causes an increase in velocities and sediment transport rates (Rivier and Seguier 1985). The increased velocities will erode the nick point or possibly undercut the streambed below the headcut (West 1978). This results in a reduction in the slope of the headcut, and a new nick point is established along with a smaller vertical face (headcut portion). The material that was eroded is deposited downstream, thereby changing the slope of the downstream zone. This cycle of action repeats itself until equilibrium is reached between the upstream and downstream zones.

An exception to this process will occur when the erosion of the headcut retreats back to a point that is unerodable (Leopold et al. 1964, West 1978, MacBroom 1981). For example, if the coarse streambed material (armored layer) is large and erosion resistant, such as bedrock, further degradation will not continue. This condition is known as an arrested nick point (West 1978). It may create a stepped profile consisting of short steep stretches in the armored layer (West 1978) or possibly may cause the river to erode laterally (MacBroom 1981). Therefore, the length of movement upstream of the headcut and nick point are controlled by the discharge of the river, the differences in gradient between the upstream zone and the downstream zone, and the structure and composition of the streambed and bank materials of the river (Leopold et al. 1964). Leopold et al. (1964) designed an experimental model for the maintenance of headcuts, and Li and Simons (1979) developed a mathematical model to estimate erosion and deposition of headcuts caused by in-stream gravel mining operations.

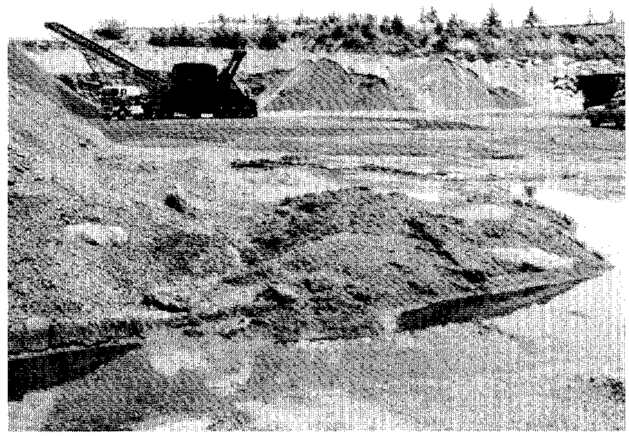


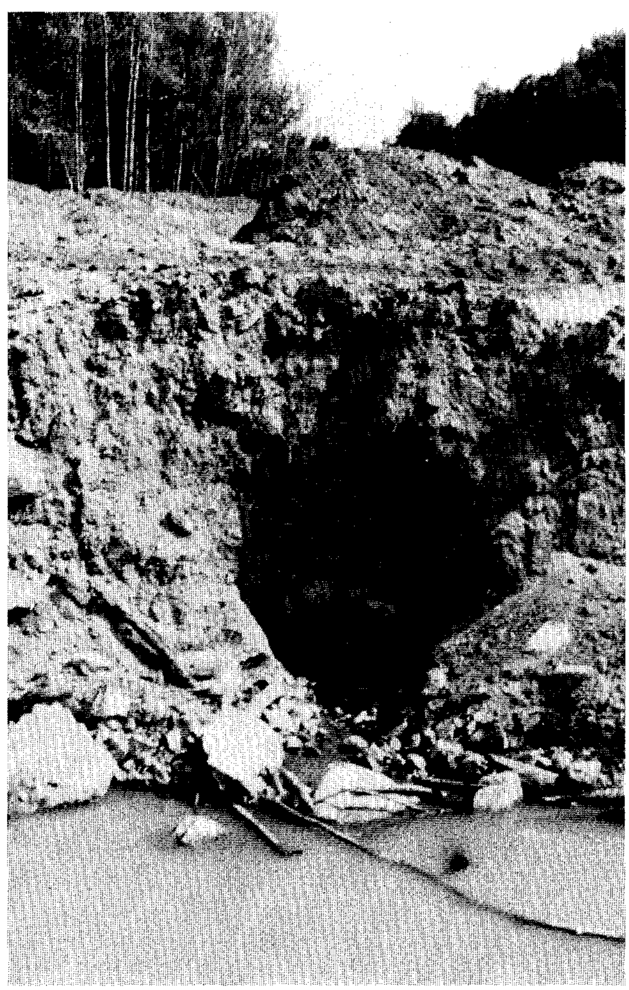
PHOTO: BOB QUEEN

*Gravel mining and washing operations can produce discharges high in sediments and dissolved solids.*

### Water Quality Modifications

Changes in the morphology of the stream channel that result from in-stream mining or from floodplain mining operations that are connected to the stream channel can alter various water quality parameters, such as turbidity, dissolved oxygen, light, and temperature. The actual dredging operation will increase the concentration and discharge of suspended and dissolved solids, thus increasing the turbidity at the site and downstream (Cordone and Kelly 1961, Yorke 1978, Crunkilton 1982). Also, wastewater from gravel washing operations will increase turbidity (Rivier and Seguier 1985). The direct increase in turbidity is a relatively short-term response, in that turbidities will return to near normal levels after dredging has ceased. However, due to increased erosion of stream banks and erosion from headcutting, turbidities may stay above normal for quite some time. Hamilton (1961) noted that turbidities increased from 25 ppm to 3,030 ppm at a gravel washing operation that discharged wastewater into the Fruin Water, Scotland. At approximately 1,000 m downstream, turbidity was 232 ppm and even at 2,000 m downstream, turbidity was still above normal at 68 ppm. Dredging may resuspend organic material, resulting in a decrease in dissolved oxygen concentrations (Cordone and Kelly 1961, Woodward Clyde Consult. 1976*b*, Crunkilton 1982). Dredging may also resuspend toxic material, such as pesticides or metals, associated with sediments (Yorke 1978, Crunkilton 1982).

High turbidities associated with dredging and gravel washing operations may reduce light penetration (Cordone and Kelly 1961, Woodward Clyde Consult. 1976*b*, Yorke 1978, Crunkilton 1982). This may reduce photosynthesis and primary production



DNR PHOTO

*Surface waters receiving these discharges experience high turbidity.*

(Crunkilton 1982). In the River Dore, France, a decrease of 27-75% was noted in primary productivity, and chlorophyll content decreased between 50-70% due to gravel mining operations (Rivier and Seguier 1985). In contrast, clearing activities may increase light penetration due to the removal of stream bank vegetation (Marzolf 1978).

An increase in temperature and temperature ranges might occur due to channel widening because of greater surface area and reduced velocities (Yorke 1978). The removal of bank and riparian vegetation from dredging operations and channel clearing would reduce shading, further increasing stream temperatures (Marzolf 1978, Yorke 1978, Crunkilton 1982), depending upon the amount of area cleared (Woodward Clyde Consult. 1976*b*). An increase in temperatures could also occur due to connected ponds that flow into a stream from floodplain mining operations (Crunkilton 1982). Connected ponds can result in large evaporative losses from a stream or river (Richardson and Pratt 1980).

## Biological Effects

Gravel mining operations (both in-stream and floodplain excavations) and their associated physical effects can affect a wide range of stream biota including plant communities, aquatic invertebrates, and fish populations.

### Effects on Plant Communities

Plant communities can be reduced directly by the actual dredging operations and through channel clearing (Marzolf 1978). The density and metabolism of plants, including algae, can also be reduced by high turbidities, increased sedimentation, decreased light penetration, and changes in the substrate (Cordone and Kelly 1961, Chutter 1969, Marzolf 1978, Rivier and Seguier 1985). Gravel operations on the River Doubs, France, caused a reduction in macrophyte communities through increased deposition of sand and silt and through the disruption of the streambed (Rivier and Seguier 1985). Diatom populations decreased between 54-94% in the River Dore, France, due to gravel operations (Rivier and Seguier 1985).

### Effects on Aquatic Invertebrate Populations

The actual dredging operation can decrease invertebrate populations directly through the actual removal of invertebrates (Starnes 1983, Thomas 1985) and through the disruption of habitat and associated physical effects, particularly sedimentation. Dredging operations may result in reductions of both density and biomass of invertebrates over distances of up to several kilometers (Cordone and Kelly 1961, Rivier and Seguier 1985). Downstream from gravel operations in the River Loire and River Allier, France, total densities of invertebrates were reduced between 13-75%, and biomass was reduced between 10-81% (Rivier and Seguier 1985). Likewise, invertebrate biomass decreased by 62-96% in the River Ouveze, France (Rivier and Seguier 1985). Other studies show similar reductions. Ziebell (1957) found that invertebrates were reduced by 98% at approximately 90 m below the discharge of a gravel washing operation on the South Fork Chehalis River, Washington. Conditions did not return to normal until 10.5 km downstream. Ziebell and Knox (1957) found a 75% reduction in invertebrates at 0.2 km and a 85% reduction at 2.7 km below a gravel washing operation on the Wynooche River, Washington. Cordone and Pennoyer (1960) reported a 90% reduction in invertebrates immediately below a gravel washing operation on the Truckee River, California, and a 75% reduction 16 km downstream.

Reductions in invertebrate densities can also occur indirectly by the removal of suitable substrates such as woody debris. Benke et al. (1985) found that snags, although only 4% of the total surface area, supported 60% of the total invertebrate biomass in the Satilla River, Georgia. Therefore, channel clearing could have a devastating effect on invertebrate populations. Channel clearing has particularly severe effects on certain types of invertebrates (Marzolf 1978). The removal of coarse particulate organic matter will affect shredders and collectors, and likewise, the removal of detritus will affect detritivorus invertebrates. Invertebrates that inhabit woody debris will have to either emigrate or perish. The removal of organic material will reduce food sources and the diversity of substrates available to benthic invertebrates (Woodward Clyde Consult. 1976*b*, Yorke 1978). Altered temperature regimes can lead to altered emergence periods of aquatic invertebrates; this, in turn, may alter reproduction (Woodward Clyde Consult. 1980*b*).

Several studies have been conducted on the effects of small suction dredges on invertebrates. Griffith and Andrews (1981) studied the effects on 4 streams in Idaho. They noted that less than 1% mortality or injury was caused by entrainment of aquatic invertebrates; however, factors such as predation and the suitability of the habitat that the organisms were deposited into could produce additional mortality. Recolonization of the dredged area occurred in 38 days. Griffith and Andrews also noted that larger, commercial dredges could cause substantially greater impacts. Thomas (1985) performed an experiment on two 50-m sections in Gold Creek, Montana. She found that the mean insect abundance decreased greatly after dredging, but downstream insect abundance did not appear to be changed. Recolonization of the dredged area was complete after one month. Harvey (1986) studied the effects on 2 California streams. Effects were highly localized, but dredging did affect some insect taxa, such as *Hydropsyche* spp., when substrates were altered. Recolonization occurred in 45 days. He also noted that the effects of dredging would probably be more severe in streams that contained higher amounts of fine sediments. These studies support a conclusion that small suction dredges can cause limited, short-term, and localized effects on invertebrate populations.

The greatest impacts on aquatic invertebrates are caused by the change in substrates from gravel to sand and/or silt, the removal of riffle habitats, and the associated increase in sedimentation that results from dredging and gravel washing operations. Both quantitative and qualitative changes can occur (Woodward Clyde Consult. 1976*b*, Marzolf 1978). Increases in sedimentation from the dredging activity and from erosion first result in a decrease in density and then, as the interstices of the gravel substrates fill in with sand or silt, a change in species composition. Benthic communities will change from species with very specific habitat requirements to others that are more eurytopic and silt tolerant (Chutter 1969, Crunkilton 1982, Rivier and Seguier 1985). Normally, species richness will decline.

Sedimentation can also adversely affect invertebrates by reducing or covering their food supply and interfering with feeding and respiration (Woodward Clyde Consult. 1976*b*, Rivier and Seguier 1985). Production tends to be lower in sand substrates due to the shifting nature of such bottom types (Cordone and Kelly 1961) and the lack of interstices to entrap coarse particulate organic matter and support biotic activity (Narf 1985). There tends to be a decrease in certain taxa, such as Plecoptera, Trichoptera, Ephemeroptera, and Coleoptera, while certain other taxa, such as chironomids and oligochaetes, are encouraged by the presence of sand and silt (Rivier and Seguier 1985). The coarser substrates of gravel, rubble/cobble, and boulders provide a diverse habitat of multiple textures and different water velocities that can support a greater diversity of invertebrate species (Cordone and Kelly 1961).

Results from field and laboratory studies showed that many common riffle invertebrates were unable to move upstream on long, sandy substrates that were greater than 80 m (Luedtke and Brusven 1976). The uniform currents, the lack of refuge from current flow, and the instability of the sand may be responsible for restricting upstream movement. Luedtke and Brusven (1976) studied the effects of a commercial dredge operation on Emerald Creek, Idaho, where long stretches of sandy reaches were created. Results indicated that there was limited upstream movement by invertebrates; however, there was considerable downstream movement by drifting and crawling of certain Plecoptera species on the sandy substrate, despite low velocities. Moving or shifting sands may create barriers to upstream migration, as well as unsuitable habitat for drifting invertebrates. Narf (1985) studied a channelized section of Bear Creek, Wisconsin, in which sand substrate from the new channel had covered up the coarser substrates, creating a long, sandy reach. He noted that the 4 normal forms of invertebrate migration (i.e., vertical migration from substrate, drift, upstream migration, and aerial dispersion) were reduced to 2: drift and aerial dispersion. The main obstacle to colonization was the absence of a stabilized substrate with its associated coarse particulate organic matter and periphyton and the absence of snags, stream bank vegetation, boulders, and cobble. Therefore, he concluded that colonization was influenced by the elimination of habitat, absence of a food chain base, and a reduced colonizing source of invertebrates. The area took approximately 5.5 years to recover.

Sedimentation, elimination of habitat, and direct physical removal caused by gravel mining operations can be devastating to mussel populations. Grace and Buchanan (1981) studied the effects of in-stream dredging and gravel processing operations on mussel populations in the Osage River, Missouri. Fifteen years after dredging, no living mussels were found in the in-stream dredged area. Recolonization was prevented by the elimination of habitat, destabilization of bottom substrates, and the creation of deep pools. Also, disruption in the life cycle of mussels may have been caused by changes in fish populations that resulted from the dredging. Mussel larvae depend on fish as hosts to complete their life cycle (Crunkilton 1982). Slower growth rates of mussels could occur downstream from gravel dredging and washing sites due to very high turbidities (Yokley and Gooch 1976).

### Effects on Fish Populations

In-stream gravel mining and floodplain excavations that are connected to a stream or river can influence fish and fish populations by eliminating spawning and nursery habitat, by altering habitats, and by influencing the trophic dynamics of fish communities, thereby affecting the nutrition and health of fish. The physical removal of riffle areas and the process of channel clearing may eliminate spawning beds and nursery habitat (Crunkilton 1982, Starnes 1983).

Increased turbidities and siltation of gravel beds can affect reproduction and the development of fish eggs, especially salmonids and other coarse substrate spawners (Cordone and Kelly 1961, Rivier and Seguier 1985). Deposition of suspended sediment can hinder inter-gravel water flow within the substrate, and sediments can settle around eggs, inhibiting the exchange of gases and resulting in egg mortality and interference with fry emergence (Woodward Clyde Consult. 1976*b*, Rivier and Seguier 1985). In the River Allier, France, suspended sediment concentrations between 20-100 mg/L resulted in 75% mortality of brown trout eggs (compared with 20% mortality in the control sections) after 20 days (Rivier and Seguier 1985). In the Fruin Water, Scotland, where gravel washing operations discharged into the river, salmon and seatrout (see Appendix for scientific names of fish species) spawning was eliminated due to siltation of riffle areas (Hamilton 1961). Six months later, after operations had ceased, spawning resumed in some areas. Spawning areas and nursery areas have been reduced in many rivers in Finland due to the removal and siltation of riffle habitats through dredging and channelization for timber floating (Jutila 1985). In the River Simojoki, Finland, densities of Atlantic salmon parr were reduced by up to one third, which resulted in a decrease in smolt production and salmon catches. In the River Piispajoki, Finland, dredging of rapids virtually eliminated the brown trout population in an area of 990 $m^2$. In the River Hassenjoki, Finland, dredging of rapids caused annual catches of whitefish to decline by 4,700 kg and brown trout by 300 kg. It was recommended that riffle habitat be restored in order to enhance reproduction. In 4 streams in Idaho influenced by small suction gold dredges, un-eyed cutthroat trout eggs experienced 100% mortality after entrainment (Griffith and Andrews 1981). Eyed eggs showed 29% and 35% mortalities after 1 hour and 36 hours, respectively. Yolk sacs were found to be detached from 40% of the fry during entrainment.

PHOTO: MITCH ZMUDA

*Channel modifications due to in-stream mining can greatly alter fish habitat, often replacing pool and riffle habitat with runs.*

DNR PHOTO

*Riffle inhabitants such as this darter will be replaced by species tolerant of the new habitat type.*

In-stream gravel mining and channel clearing have been shown to alter the habitat of streams by creating pools, removing riffle areas, changing substrates from gravel to sand or silt, and eliminating important in-stream and stream bank cover types. These alterations can change fish populations both quantitatively (density of fish) and qualitatively (change in fish species diversity or species richness). In the River Loire, France, a decrease of 28% in numbers of fish and a 17% reduction in biomass occurred downstream from gravel removal operations due to the combined effects of trophic and habitat modifications (Rivier and Seguier 1985). Areas on the Yankee Fork of the Salmon River, Idaho, dredged 30 years ago, still produce 97% less biomass of trout and whitefish than the undisturbed areas (Irizarry 1969). In the Middle Fabius River, Missouri, Hickman (1975) reported that the estimated standing crop of the total fish population was 25% lower and the estimated standing crop of catchable-sized fish was 51% lower in areas without snags compared to areas with snags. Martin and Hess (1986) found a reduction in brown trout and rainbow trout abundance downstream of in-stream gravel removal operations in the Chatahoochee River, Georgia. Forshage and Carter (1973) also found reductions in certain minnow and sunfish species, the elimination of other minnow and darter species, and an increase in certain sucker species downstream from an in-stream gravel removal operation on the Brazos River, Texas. For more details on the numbers reduced and specific species affected in the studies by Martin and Hess (1986) and Forshage and Carter (1973), refer to Studies No. 2 and 6, respectively, in the following section under case studies from the literature. Both studies reported that a change in habitat and cover and a reduction in food sources accounted for the alterations of the fish populations.

After gravel mining, the fish community may change from riffle-specific species to ubiquitous and run-specific species (Berkman and Rabeni 1987). Generally, the creation of deeper, quiet pools and the removal of snags creates habitat for some sucker species (Benke et al. 1985). Rivier and Seguier (1985) noted that gravel removal first results in a reduction of species that have specific requirements with regard to food and habitat, with riffle species being reduced first. They outlined 3 stages of change in fish species composition in gravel removal operations:

1) a reduction of running-water species, especially salmonids, accompanied by increases in still-water species;
2) a reduction of still-water species that have exact ecological requirements; and
3) an overall reduction in species composition, with only eurytopic, silt-tolerant, deep-water species surviving in the end.

We believe that once the pools fill in with sand and/or silt, the species composition will again change to species adapted to shallow sandy or silty areas, with possibly some transient fish species moving through the area on their way to other areas in search of food or cover.

There are other studies that document changes in fish communities due to gravel mining. Berkman and Rabeni (1987) studied 3 streams in Missouri where gravel removal operations were taking place. They found that within the riffle communities, as the percent of fine substrates increased, the abundance of benthic insectivores and herbivores (particularly central stonerollers) was reduced and general insectivores increased. Also, they noted that the relative abundance of simple, lithophilous spawners (species that lay eggs on gravel or rubble and do not build a nest or provide parental care) was reduced due to siltation of riffle areas. Campbell (1953) reported a change in fish populations in the Powder River, Oregon, from a gold dredging operation. Populations changed from rainbow trout and whitefish to predominantly squawfish and suckers due to the creation of pools and siltation. In 2 California streams, it was found that dredging with small suction dredges affected riffle sculpins more severely than rainbow trout (Harvey 1986). Riffle sculpin habitat was eliminated, and the gravel areas that remained were covered with sand.

Physical effects, such as increased suspended sediments, increased temperatures, and the resulting alterations in the food webs can affect the nutrition, health, and growth of fish. Excessive amounts of suspended solids from the actual dredging operation and from erosion can abrade the protective slime coatings of fish gills and bodies, which can lead to increased bacterial and fungal infections of fish (Cordone and Kelly 1961, Rivier and Seguier 1985). Also, increased suspended sediments may block vision and impair feeding (Rivier and Seguier 1985). Thus, the growth and survival of fish may be influenced by the elimination of fish food sources, by interference with fish visual feeding, and by removal of important cover types (Cordone and Kelly 1961, Woodward Clyde Consult. 1976*b*).

The removal of cover can disrupt fish territory and orientation, causing fish to move out of an area (Marzolf 1978). In a study of Olson Lake Creek, Alaska, high amounts of suspended sediments from gravel removal operations caused Arctic grayling to move downstream into possibly poorer habitat (Woodward Clyde Consult. 1976*b*). However, increased turbidities caused by dredging operations are relatively short-term, and turbidities return to near-normal levels after operations cease. Cordone and Kelly (1961) point out that the indirect damage to fish populations through destruction of food supplies, eggs, or through changes in habitat probably occur long before adult fish are directly harmed by turbidity and suspended sediments.

The enlargement of stream channels and the creation of connected ponds can increase temperatures, which may influence the density and diversity of fish communities. Tryon (1980) reported that ponds, formed by floodplain excavations, connected to the Little Piney River, Missouri, changed the fish community. The river was predominantly a trout stream, while the pond supported a warm-water fish community dominated by largemouth bass. Temperatures in the pond were reported to be over 29 C, an increase of 17 C from temperatures in the river. Studies in Alaska reported that ponded waters eliminated Arctic char and Arctic grayling habitat, and that entrapment of fish species resulted in fish mortality during low flows (Woodward Clyde Consult. 1980*b*).

We previously discussed alterations in food webs (a decrease in primary and secondary producers, invertebrates, and other food organisms) that may affect the growth of fish, the feeding habits of fish, or actually force fish to move from a dredged area (Crunkilton 1982, Rivier and Seguier 1985). For most fish, certain habitats (based on current velocity, size of substrate, and water depth) are very important and vary according to the age and size of fish (Rivier and Seguier 1985). Disruption of these habitats can therefore influence the growth and survival of the various life stages of fish. In Alaska, younger age classes of trout were actually attracted to disturbed gravel mining areas where currents were lower (Woodward Clyde Consult. 1980*b*).

## Case Studies From The Literature

Summarized below are 6 case studies where physical and biological effects were examined in areas where in-stream and/or floodplain excavations had occurred.

### Study No. 1

**Stream and Location**: Seigal Creek, Idaho

**Reference**: Webb and Casey 1961

**Type of Mining**: Placer mining (in-stream).

**Physical Effects**: A reduction in habitat due to shortening of the stream (natural meanders were removed), elimination of pools, silt accumulation in pools, and a decrease in suitability of riffles for spawning. Turbidities were as high as 3,000 ppm at the dredged site. Dissolved oxygen was not affected. All of Seigal Creek from the mouth upstream to the mined area showed silting effects. Water temperatures rose 3-4 C due to stream bank cover removal.

**Biological Effects**: In the dredged area, aquatic invertebrates and fish were reduced by 99% during dredging, but recovered within one year. Invertebrates 0.5 km below the dredge site were not affected. Species composition of invertebrates was not affected. Mountain whitefish were adversely affected, while mountain suckers increased in both size and number below the dredged area due to warmer temperatures and silting in of pools.

**Recommendations**: None given.

### Study No. 2

**Stream and Location**: Brazos River, Texas

**Reference**: Forshage and Carter 1973

**Type of Mining**: In-stream gravel mining and gravel washing operation with wastewater returned to the river via a settling pit.

**Physical Effects**: Approximately 2.4 km of river was dredged. Construction of an island used for gravel operations changed river flow from one bank to the other. A portion of this island was never removed, thus creating a sandbar 46 m by 30 m. Channel clearing removed logs and brush from the dredged area and stream bank. Dredging changed substrates from a sand-gravel-organic matter complex to a shifting sand and inorganic silt condition. Average depth increased from 0.3-0.9 m with a maximum of 2.1 m. Turbidities increased from 20-75 JTU at the dredging site and did not return to normal for 12 km downstream. Suspended solids increased following dredging from 0.05-2.35 ml/L below the outlet of the settling pond. Suspended solids were deposited within 1.6 km of the dredging site. No change was detected in water temperature or dissolved oxygen.

**Biological Effects**: Invertebrates were reduced by 97% at the dredge site, and 50% at 2.7 km downstream, with conditions returning to normal at 4.3 km downstream. Reduction was due to change in substrates and possibly by high turbidities. Invertebrate populations had not recovered 6 months after dredging ceased. Changes in density and diversity of fish were reported due to the removal of cover, the reduction in food organisms, and the increase in shifting sands and siltation. The following fish species showed no change in density: freshwater drum, gray redhorse, longear sunfish, and logperch. The following species disappeared: redear sunfish, silver chub, redfin shiner, stoneroller, blackstripe topminnow, and orangethroat darter. The following species decreased (an * indicates substantial change): threadfin shad, green sunfish, bluegill, spotted bass*, largemouth bass, red shiner, blacktail shiner, and western mosquitofish. The following species increased: river carpsucker*, longnose gar, smallmouth buffalo*, common carp*, gizzard shad, channel catfish, flathead catfish, warmouth, white crappie*, brook silverside, and inland silverside*.

**Recommendations**: Dredging should be halted in Texas streams to prevent their gradual, but definite, biological deterioration.

### Study No. 3

**Stream and Location**: Cache Creek, California

**Reference**: Woodward Clyde Consult. 1976*a*

**Type of Mining**: In-stream sand and gravel mining, and floodplain excavations.

**Physical Effects**: The area has been mined since 1915 and the average volume of materials removed from 1964-74 was 2,800 kg per year. Effects include streambed lowering between 1.5 m and 4.6 m, with a rate of 0.2 m per year from 1964-74; channel widening creating terraces, thus affecting the riparian zone; in-stream and bank vegetation removal; severe erosion amounting to $6.4 \times 10^8$ kg per year in suspended load since 1950; undermining of piers and/or abutments of bridges; headcuts; and increased groundwater depletion, which caused much of the creek to go dry during summer.

**Biological Effects**: None given; however, due to the depletion of groundwater and subsequent drying of the creek bed, any organisms that might be stranded in small pools would die or have to emigrate downstream to survive.

**Recommendations**: Minimize flooding and loss of land; protect groundwater resources, public works, irrigation facilities, and the environment; maintain gravel industry and agriculture. The authors recommended the following habitat mitigations and limitations on gravel removal: build retards along banks, jetties, check dams, buried sills, and in-channel baffles; limit the rate and depth of extraction; and rebuild and armor bridge piers. Other recommendations included use of permits and restoration plans, land acquisition to provide open-pit riparian mining, and establishment of a long-term monitoring program.

### Study No. 4

**Stream and Location**: 25 Alaskan streams

**Reference**: Woodward Clyde Consult. 1980*b*

**Type of Mining**: In-stream sand and gravel mining (scraping), and floodplain excavations with connected ponds.

**Physical Effects**: The 25 study rivers had been mined 3-20 years ago. Fifteen sites had changed in either hydraulic geometry, slope, or flow obstructions. The hydraulic geometry changes included wider channels, reduced depth, reduced mean velocity, increased water conveyance, and altered pool:riffle ratios. Seven sites had slope or headcut changes. Twelve sites had flow diversions that created braided channel conditions, and at 6 sites the former channel was eliminated and new channels were formed. Bank and in-stream cover were lost at 11 sites. At 8 sites changes in the armor layer of the streambed occurred, with a shift from compacted gravel to a loose, unconsolidated sand-gravel substrate, usually with inter-gravel flow. Channel degradation occurred, which increased suspended sediments leading to silt deposition in the wider, shallower areas and covering of the interstices of the gravel. Also, an increase in suspended solids was reported due to overburden piles and bank erosion, which were more common at meandering and sinuous rivers due to the mining of point bars. Other changes included increased turbidities from the actual mining and bank erosion, and increased temperatures in the shallow, wide areas.

**Biological Effects**: Generally, there were reductions in density and diversity of invertebrates. Due to the formation of braided channels and subsequent reductions in velocity and depth and increases in silt, populations were altered with shifts in species and life stages. The creation of ponds allowed lentic invertebrates to colonize these areas. Generally, there was a decrease in density and diversity of fish communities. Due to increased unstable substrate, braiding, backwaters, ponded waters, and loss of bank and in-stream cover, several sites lost Arctic char and Arctic grayling, with a shift toward slimy sculpin and round whitefish. Other problems for certain fish species included loss of spawning areas, migration blockages due to a decrease in surface flow (which sometimes was reduced to inter-gravel flow), entrapment of species in ponded waters that might dry up during low flows, and loss of over-wintering habitat due to the formation of ice fields on braided streams, which decreased water volume.

**Recommendations**: Mining should avoid active channels, especially split, meandering, sinuous, and straight channels. This leaves only braided rivers for mining. Mining techniques should avoid creating ponded areas and altering stream banks, and altering spawning and over-wintering areas. Also, if floodplain pits are mined, pits should be at least 2.5 m deep. However, pits should be restricted to the inactive floodplain, and buffer zones (between 50 m and 100 m) should be maintained. Mining in the active floodplain should not disturb the edge of the active channel, increase bed slope, form new channels, or have stockpiles removed from near active channels. Guidelines were written that detailed the techniques that should be used when floodplain excavations occur (Woodward Clyde Consult. 1980*a*).

### Study No. 5

**Stream and Location**: Kansas River, Kansas

**References**: U.S. Army Corps Eng. 1982*a*, 1982*b*; Simons and Li 1984

**Type of Mining**: In-stream sand and gravel dredging.

**Physical Effects**: The authors studied different areas of the lower Kansas River. However, all 3 reports are included in this summary because of their similarities. The morphology of the river was altered by local degradation (between 2.4 m and 3.0 m), channel widening (an increase of 46 m), bank erosion, disruption of the sediment load, and upstream degradation and related impacts due to headcutting. Dredged holes acted as sediment traps. Velocities in the dredged areas were lower by up to one half compared to the control sites. Depths increased by 50-200% compared to the control sites. There were very few effects on water quality parameters. Substrates changed from shallow, sand habitats (control sites) to mixed habitats with an increase in the armored layer (gravel and rubble at recently dredged sites) to heavily silted habitats (at older dredged sites).

**Biological Effects**: Control areas had low diversity of invertebrates. Recently dredged areas had higher diversities due to exposure of the armored layer, and increased variety of depths and velocities. Therefore, species characteristic of pools, riffles, and substrates other than sand increased in the recently dredged sites. At the older dredged sites, benthic invertebrates characteristic of pools and silt substrates increased, whereas species characteristic of other habitats decreased in abundance. Species of fish that declined included red shiner, sand shiner, and river carpsucker, which were predominant in the sandy, braided channels of the control sites. Species that increased in the intermediate stages of the progression but then declined included shovelnose sturgeon, sturgeon chub, speckled chub, emerald shiner, blue sucker, shorthead redhorse, smallmouth buffalo, channel catfish, stonecat, flathead catfish, goldeye, and sauger. Fish species that increased in relative abundance throughout the progression included gars, gizzard shad, common carp, silver chub, river shiner, bullhead minnow, bigmouth buffalo, white bass, white crappie, and bluegill. In the later progression, density and diversity of species were less than in the control stations.

**Recommendations**: Various alternatives were discussed, such as no action, cessation of dredging, reduced quantity of material extracted, alternative stream sources for dredged materials, and riparian mining. Proposals were made that would maintain moderate habitat diversity in intensively dredged parts of the channel, and substitution of off-channel sites were suggested for some of the lower channel sites. In another article, Li and Simons (1979) recommended the use of a series of small gabion check dams to control headcutting.

### Study No. 6

**Stream and Location**: Chatahoochee River, Georgia

**Reference**: Martin and Hess 1986

**Type of Mining**: In-stream sand and gravel mining, and gravel washing operations with a small settling basin connected to the river.

**Physical Effects**: One dredged area created a long, deep pool (300 m by 2.5 m) with primarily sand substrate, while the other dredged area created a sediment trap at the upstream end, which protected downstream riffle habitat. Renewal rates varied from 3 days to 2 weeks. Water velocities decreased from 0.71 m/sec in undredged areas to 0.28 m/sec in the long, deep dredged pools. Snags, woody debris, and other cover types were removed to within 3 m of the stream bank. Headcuts were formed at the upper end of dredged areas. Excessive turbidities were evident downstream from the wastewater outlet and existed for 200 m downstream. Dissolved oxygen concentrations decreased from 7.6-6.9 mg/L at the lower end of the dredged site. Bank erosion was evident near the washing operations. No change in temperature was observed.

**Biological Effects**: Densities of invertebrates were lower in the dredged areas due, at least in part, to reduced water velocities; however, power generation probably affected diversity of invertebrates more than the dredging activities. The number of competitive fish and competitive fish species (species with food habits similar to rainbow trout and brown trout) were greater in the dredged area. Species collected only in the dredged area included spotted sucker, common carp, white catfish, redbreast sunfish, warmouth, redear sunfish, and black crappie. At 2 different stations, rainbow trout and brown trout accounted for 96% and 82% of fish captured, respectively, in the undredged stations, 78% and 17% in the recently dredged stations, and 7% and 40% in the stations dredged 7 months previously. The higher percentage of trout caught in the last station was due to better habitat caused by the sediment trap and stockings of trout 2 months prior. Larger trout (> 360 mm) were more abundant in one undredged station, and the condition of trout was poorer in one dredged site due indirectly to poor habitat of loose, fine sand substrate. Generally, it was concluded that the removal of sand can be beneficial to insect and trout abundance, while removal of gravel and woody debris was not. Sand dredging that creates small short pools could be beneficial to trout.

**Recommendations**: Dredged areas should not be longer than 223 m. This figure was derived from a mathematical formula based on size of materials removed, stream discharge, average water temperature, and width of the pool to be dredged. Other recommendations included leaving an area above and below the dredged pool in order to provide for a 40:60 pool:riffle ratio, returning substrates > 2.5 cm, restricting dredging to middle portions of a river (within 6 m of bank) to prevent bank erosion and cover removal, and rehabilitating stream banks that had been affected by gravel washing operations.

## Big Rib River: A Wisconsin Case Study of Gravel Mining Impacts

### Introduction

During July and August 1987, we conducted a 2-week survey of 6 stations on the Big Rib River in Marathon County between Marathon City and Rib Falls, Wisconsin. The purpose of our survey was to evaluate and document impacts from sand and gravel

PHOTO: JOHN LYONS

*The Big Rib River near Marathon City.*

mining on the habitat and fish community of the Big Rib River. Emphasis was on the area of most recent in-stream sand and gravel mining. We also incorporated a fish survey done in August 1986 by DNR Fisheries Management and Research personnel. That survey was conducted on 2 sections of the Big Rib River at or adjacent to our 1987 habitat and fish community survey. The purpose of the 1986 survey was to document the status of the fishery in the 2 sections.

## Description of Study Area

The Big Rib River, located in north-central Wisconsin, originates at Rib Lake in Taylor County, Wisconsin, and flows southeast for 88.8 km, meeting the Wisconsin River at Wausau. The river has a drainage area of 1267 $km^2$ (Henrich and Daniel 1983). The lower portion of the Big Rib River is Class A muskellunge water and provides recreational fishing for many species including walleye, smallmouth bass, northern pike, white sucker, and redhorse.

At our study area, the Big Rib River is a fifth-order stream (Strahler 1957). Gradients ranged from 1.67 m/km at the upstream station to 0.55 m/km at the downstream station. The area around the Big Rib River contains well-sorted outwash deposits, which include alluvium with stratified sand and gravel deposits with some clay and silt intermixed (Devaul and Green 1971, Zmuda 1982). These deposits average about 30 m in thickness (Devaul and Green 1971). Bedrock is composed of Precambrian crystalline rock that can appear at the surface or be covered with thin drift (Devaul and Green 1971). In the riparian zone, ground moraine deposits contain a greater proportion of silt and clay, with some stony till and fragments of bedrock (Devaul and Green 1971, Zmuda 1982).

## Methods

### Station Selection

Our stations either had in-stream mining, were impacted by in-stream mining, were adjacent to current floodplain gravel mining, or had no past or current in-stream mining or limited nearby floodplain or riparian mining (unmined stations). For the nearby floodplain and riparian mining areas, it was not possible to determine if actual mining was occurring at the time of the study. Stations were numbered sequentially, starting with Station 1 as the downstream station near Marathon City and ending with the upstream Station 6 near Rib Falls (Fig. 1). The description of each station is as follows:

**Station 1** - Located at River Mile[1] 113.1, directly downstream from an intensive floodplain mining operation. This station was also downstream from an area that was channelized in the late 1920s during construction of State Highway 29. There are 12 mining sites in this area. The mining area is characterized by open pits, washing ponds, processing operations, and sand and gravel stockpiles. At high water, some of the ponds are connected to the river. Station 1 was 350 m long.

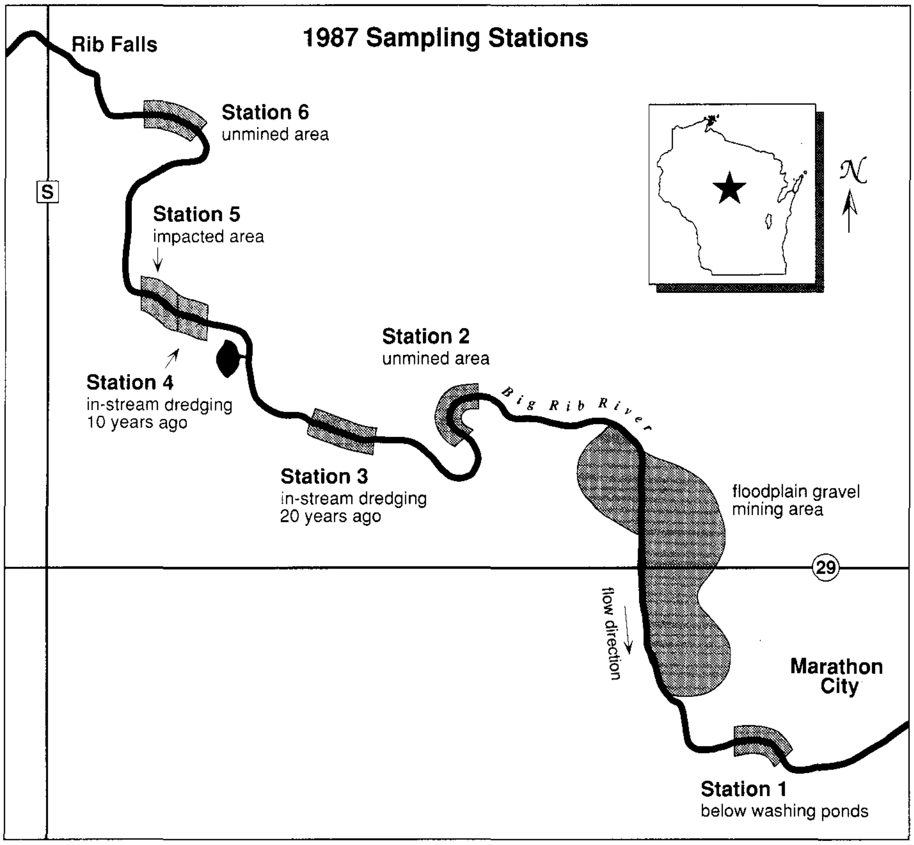
**Station 2** - Located at River Mile 14.7, an unmined station, with no current or historic in-stream mining, and one floodplain mining site and 2 riparian mining sites near the area. Station 2 was 440 m long.

**Station 3** - Located at River Mile 16.5. Station 3 was an in-stream site that was dredged for sand and gravel approximately 20 years ago and is in a state of partial recovery. There are also 2 riparian mining sites and one floodplain mining site located near the area. Station 3 was 460 m long.

**Station 4** - Located at River Mile 17.9, in an area that had in-stream sand and gravel mining approximately 10 years before sampling. Excavation at Station 4 began in 1973 and continued for 6 years. Dredging created a 365 m by 60 m by 2.4 m-deep river channel enlargement (Wis. Dep. Nat. Resour. 1987). The exact measurements of the area before dredging are not known, but it can be assumed that the dimensions were similar to the mean widths and depths of the unmined stations. Figure 2 shows an aerial view of the dredged site in 1979. Note the enlargement of the river channel and uniform conditions in the dredged area. Reclamation of the mined area did not occur due to the lack of requirements in effect at that time under Chapter 30 permits. In 1982, a permit was issued in the same area to grade off the top of a gravel bar on the upstream end of the old excavation. There are 7 floodplain excavations and one riparian excavation site located near this area. There is also a low-water truck crossing at the downstream end of this station. Station 4 was 150 m long.

**Station 5** - Located at River Mile 18.0, immediately upstream from Station 4. This station was impacted by the downstream in-stream mining site. In 1984, after excavation had ceased, the river cut a new channel above the excavation site. The river relocated around an existing waterfall, creating approximately 300 m of new channel. By 1985, nearly 95% of the river flow was passing through the new channel.

[1]Miles upstream from the mouth of a river (Fago 1988).



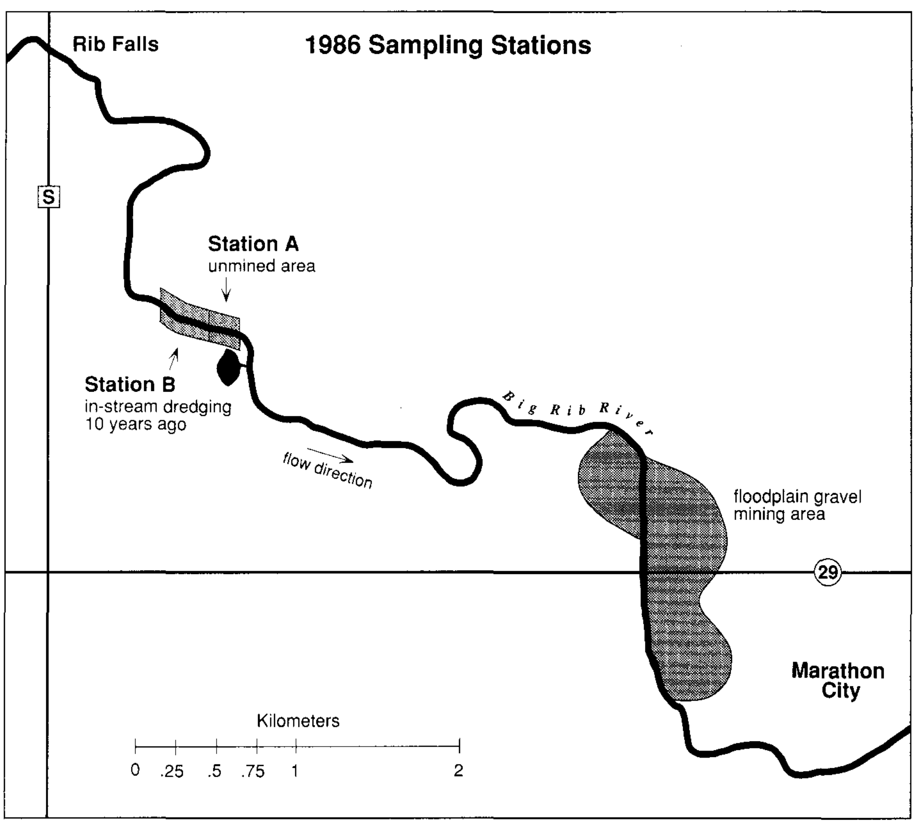




**Figure 1.** *Location of stations sampled on the Big Rib River in 1987 (top) and 1986 (bottom). Known floodplain gravel mining activities along the river are noted.*

During our sampling in 1987, all of the flow was passing through the new channel. Directly upstream from Station 4 is an old scour hole. Station 5 starts at the old scour hole and continues upstream to where the new channel combines with the old channel, upstream from the old waterfall. Figure 3 shows an aerial view of the dredged area in 1987. Note the addition of the new channel, several sand and gravel bars, and the connected pond created since 1979. There is one floodplain excavation and one riparian excavation in the area. Station 5 was 255 m long.

**Station 6** - Located at River Mile 19.0 and used as an unmined station. There is one proposed riparian mining site in the area. Station 6 was 330 m long.

**Stations from 1986 Survey**

Two segments of the Big Rib River had been surveyed in 1986. The description of these stations is as follows:

**Station A** - Located at River Mile 17.8 and used as an unmined station (Fig. 1). Station A was located directly downstream from Station 4 and included 2 riffles and 2 runs. There was a connected pond located downstream from this area (Fig. 3). Station A was 230 m long.

**Station B (1986)** - Located in the same area as Station 4 of the 1987 survey; however, it also included a portion (approximately 130 m) of Station 5. This station was 305 m long.

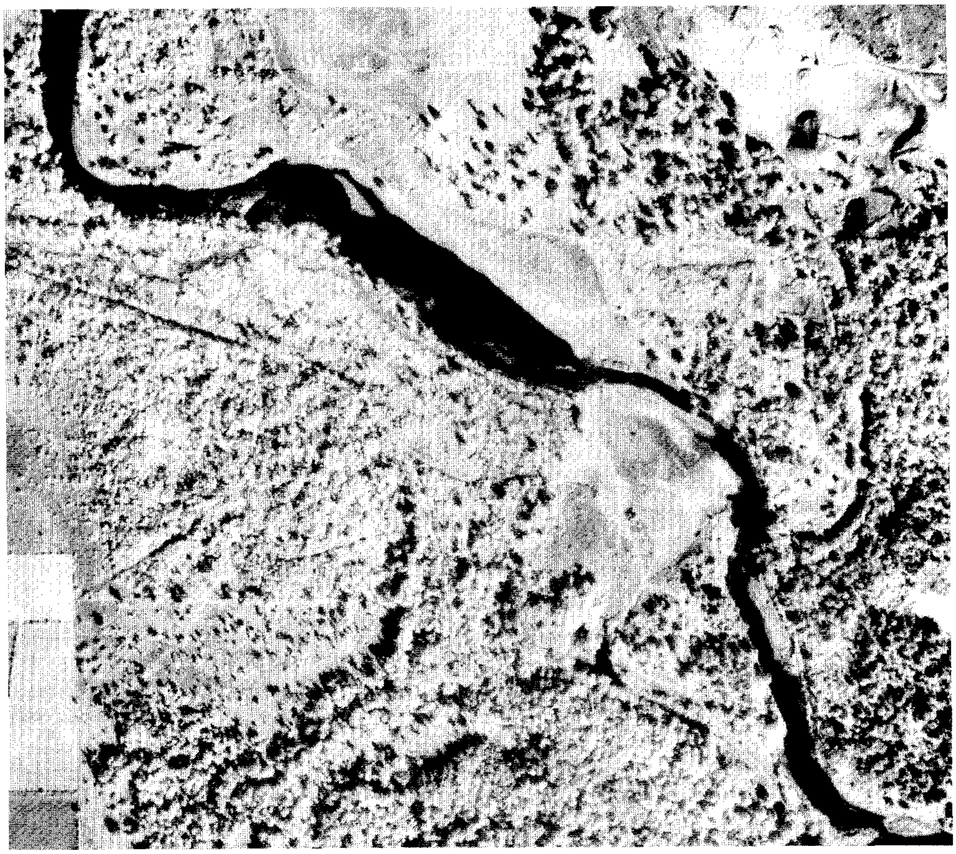


**Figure 2.** Aerial view of the dredged site on the Big Rib River taken in 1979 after dredging had ceased. This area became Station 4 and Station 5 in our 1987 survey. Note the enlargement of the river channel and the uniform conditions in the dredged area.

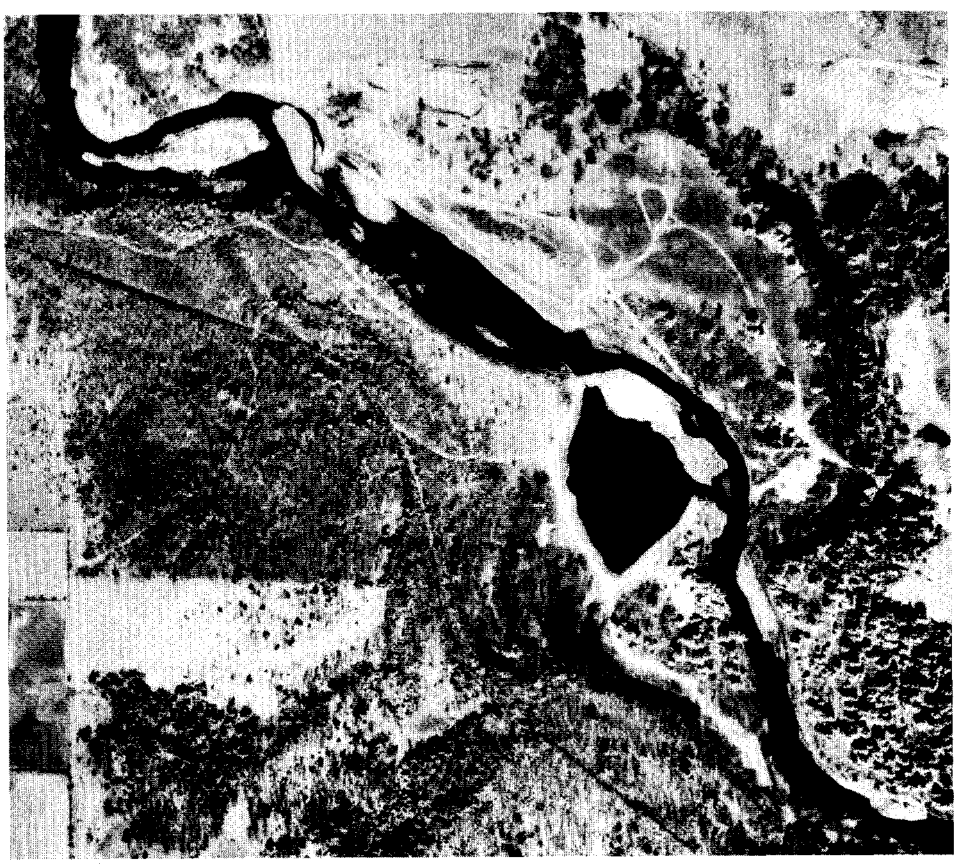


**Figure 3.** Aerial view of the dredged site (Station 4) and impacted site (Station 5) on the Big Rib River taken in 1987. Note the new channel formed upstream from the old dredged site, the formation of gravel bars and braided channel downstream from the new channel, the lack of flow over the old waterfall in the old channel, and the creation of a connected pond downstream from the old dredged site. The connected pond was formerly a flood-plain excavation site.

### Survey Techniques and Assessment

We assessed fish habitat at each station through a habitat survey. Each station was quantitatively and qualitatively sampled for specific habitat parameters, including channel width, depth, velocity, substrate composition, in-stream cover types, bank stability, and bend-to-bend ratio (distance between bends divided by mean channel width). A transect method was used to measure these parameters, with transects spaced apart approximately the same distance as the average stream width. In the case of multiple reach types (riffles, pools, and runs), transects were spaced one quarter of the length of each reach type encountered. At each transect, channel width and 4 depths and velocities (evenly spaced along transects) were measured. Main channel width (wetted portion of channel) was measured with a tape measure to the nearest 0.1 m, along the transect line. Islands, isolated pools, backwaters not in contact with the stream at the transect, and wetlands or swamps along the stream were not included in the measurement. Depths were determined with a calibrated wading staff to the nearest 0.01 m. Depths were averaged in order to calculate a mean depth for each transect. Velocities were measured with a digital current meter (Marsh McBirney Model 201D) to the nearest 0.01 m/sec. Substrate composition, in-stream cover, and bank stability percentages were visually estimated for the area immediately above and below each transect. Estimates were conducted by one observer to prevent observer bias. Substrate types encountered included boulder (> 256 mm along longest axis), rubble/cobble (65-255 mm), gravel (2-64 mm), and sand (inorganic material smaller than fine gravel but coarser than silt, 0.062-1.9 mm) (Platts et al. 1983). Substrate composition was estimated to the nearest 5% of the total surface area for each substrate type encountered. In-stream cover types were also estimated to the nearest 5% and included woody debris, rocks/boulders, overhanging vegetation, undercut banks, submerged macrophytes, emergent macrophytes, rubbish, and channel depth (> 1.0 m deep). Bank stability (surface area protected against erosion) was estimated to the nearest 5% for both the left and right banks. The distance between bends was measured with a tape measure (nearest 1.0 m) from the center of each bend.

The entire station was electroshocked for all fish species with a standard DNR DC (3 probes) stream electroshocker powered by a T & J Power Guard XL 2500 watt AC generator. Generator output was converted to DC current via a rectifier during shocking. All fish captured at each station were preserved for later analysis and identification; however, fish over 200 mm were identified, counted, weighed, and released.

We used the Wisconsin version of the Index of Biotic Integrity (IBI), developed by the DNR Bureau of Research (Lyons 1992), to compare fish communities among stations (Table 1). IBI scores are based on expectations derived from other rivers in a similar geographic region on what a good, fair, or poor fish community should look like. The IBI considers 10 attributes of the fish community that are termed metrics. Scores of 10 indicate that a metric has a value similar to that of a high-quality, undegraded stream. Scores of 5 suggest some level of degradation, and scores of 0 indicate potentially serious problems in the fish community for the section of stream being studied. The maximum possible composite score is 100, indicating a stream representative of the highest environmental quality; the lowest possible score is a 0, indicating a stream suffering from major environmental degradation. We used both adult and young-of-the-year fish species in calculating the IBI scores.

All statistical analyses were performed using the Statistical Analysis System (SAS 1985) software package. One-way analysis of variance (ANOVA) was used to compare habitat variables among stations. Residuals were examined to determine whether assumptions of the analyses were satisfied. Percentages were arcsine-transformed, and mean depths and channel widths were log-transformed to stabilize variance. Pairwise comparisons among stations were carried out using Tukey's Studentized Range Test and were considered significant if $P \leq 0.05$. This test works well when sample sizes (number of transects) are unequal (SAS 1985).

## Results

### Habitat Survey

Four of the stations (Stations 2, 3, 5, and 6) consisted of all 3 reach types (riffles, pools, and runs), while Station 1 consisted of pools and runs, with no riffles present (Table 2). Station 4 consisted entirely of runs, with no large pools or riffles present. Station A, sampled in 1986, consisted of runs and riffles, with no large pools present. Although riffles and pools were present at some stations, runs were the predominant reach type, except for Station 2.

The mean channel widths of the runs for each station were fairly uniform (22-30 m wide), except for Station 4 (Table 3). Station 4 averaged almost 60 m wide, which was significantly wider than the other 5 stations. The in-stream mining operation, completed in 1979, created a 60-m-wide channel

**Table 1.** *Metrics (measurements) used to calculate the Wisconsin version of the Index of Biotic Integrity (IBI) for the Big Rib River fish communities.*

| | | Scoring Criteria | | | | |
|---|---|---|---|---|---|---|
| **Category** | **Metrics*** | **0** | **2** | **5** | **7** | **10** |
| Species richness and composition | Total no. native species | 0-9 | 10 | 11-19 | 20 | ≥ 21 |
| | No. darter species | 0-1 | 2 | 3 | 4 | ≥ 5 |
| | No. sucker species | 0-2 | – | 3-4 | – | ≥ 5 |
| | No. sunfish species | 0-1 | – | 2 | – | ≥ 3 |
| | No. intolerant species | 0-2 | – | 3-5 | – | ≥ 6 |
| Trophic composition and reproductive function | Tolerant species (%) | 51-100 | 50 | 21-49 | 20 | 0-19 |
| | Omnivores (%) | 41-100 | 40 | 21-39 | 20 | 0-19 |
| | Insectivores (%) | 0-29 | 30 | 31-59 | 60 | 61-100 |
| | Top carnivores (%) | 0-6 | 7 | 8-13 | 14 | 15-100 |
| | Simple lithophilous spawners (%) | 0-19 | 20 | 21-49 | 50 | 51-100 |

*Scores for each metric are summed to get an overall score for a fish community sample. The higher the score, the better the fish community (possible range: 0-100). See Lyons (1992) for more detail.

**Table 2.** *Lengths of the various reach types measured in the Big Rib River in 1986 and 1987.*

| | | Reach Type | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Pool | | Riffle | | Run | | |
| **Station** | **Year** | **Length (m)** | **(%)** | **Length (m)** | **(%)** | **Length (m)** | **(%)** | **Total Length (m)** |
| A | 1986 | 0 | 0 | 50 | 22 | 180 | 78 | 230 |
| B | 1986 | 0 | 0 | 0 | 0 | 305 | 100 | 305 |
| 1 | 1987 | 18 | 6 | 0 | 0 | 330 | 94 | 350 |
| 2 | 1987 | 255 | 58 | 55 | 13 | 130 | 29 | 440 |
| 3 | 1987 | 40 | 9 | 40 | 9 | 380 | 82 | 460 |
| 4 | 1987 | 0 | 0 | 0 | 0 | 150 | 100 | 150 |
| 5 | 1987 | 70 | 27 | 55 | 22 | 130 | 51 | 255 |
| 6 | 1987 | 90 | 27 | 75 | 23 | 165 | 50 | 330 |

**Table 3.** *Characteristics of the run reaches in the stations on the Big Rib River in 1987.*

| | | Characteristic | | |
|---|---|---|---|---|
| **Station** | **Description** | **No. Transects** | **Mean Channel Width (m)** | **Mean Depth (m)** |
| 1 | Below floodplain mining | 14 | 27.4 [b]*<br>(14.8) ** | 0.58 [a]<br>(0.41) |
| 2 | Unmined area | 12 | 30.3 [b]<br>(8.6) | 0.60 [a]<br>(0.32) |
| 3 | In-stream mining | 18 | 29.9 [b]<br>(10.9) | 0.69 [a]<br>(0.44) |
| 4 | In-stream mining | 8 | 58.8 [a]<br>(57.2) | 0.26 [b]<br>(0.31) |
| 5 | Impacted area | 12 | 22.4 [b]<br>(17.3) | 0.47 [a]<br>(0.27) |
| 6 | Unmined area | 12 | 29.8 [b]<br>(20.5) | 0.48 [a]<br>(0.25) |

* Values in a column with the same letter are not significantly different from each other; whereas values with different letters are significantly different ($P \leq 0.05$)

** Standard error is in parentheses. Although analyses were done on log-transformed observations, means and standard errors are of the original observations.

enlargement (Wis. Dep. Nat. Resour. 1987). Almost 10 years later, the area was still the same width.

The mean depths of the runs for each station were also fairly uniform (0.47-0.69 m), except for Station 4 (Table 3). Station 4 averaged only 0.26 m deep, which was significantly shallower than the other 5 stations. When mining was discontinued in 1979 at Station 4, a dredge hole was created that was 2.4 m deep (Wis. Dep. Nat. Resour. 1987). Since then, the dredged hole has filled in with sand and some gravel creating a wide, shallow area.

The percentages of substrate types varied among stations. All stations, except Station 4, contained some boulders, although amounts were fairly low compared to other substrates (Table 4). Rubble/cobble percentages ranged from 22-37%, except for Stations 1 and 4 where values were 0%. The amount of gravel substrate varied somewhat among stations, with Station 5 the highest. Gravel substrate values ranged from 23% at Station 2 to 66% at Station 5. Percentages of sand varied greatly among stations with Stations 1 and 4 containing the highest amount (50% and 60%, respectively). Station 5 contained the lowest amount, with only 7% of the surface area covered by sand substrate.

The high percentage of sand at Station 4 is probably due to the combination of the direct removal of gravel and rubble from the in-stream mining operation, leaving only sand substrate, and the filling in of the dredged hole with sand and some gravel from upstream sources. When the channel shifted at Station 5, directly upstream from Station 4, a large amount of eroded material (sand and gravel) was probably transported downstream, filling in the dredged area. Also, at Station 5, bank stability values for the left and right sides of the bank were quite low, with minimum values of 0-10% (Table 5). High flows through this station would wash sand and some gravel downstream into Station 4. The reason for the high percentage of sand substrate at Station 1 is unknown. However, we suspect that sand has been washed into the river from the washing and stockpiling of sand and gravel at the floodplain gravel mining operations located upstream from this station or that this section of river has been affected by the channelization done during the late 1920s when State Highway 29 was constructed.

The lack of rubble/cobble at Station 4 is definitely due to the in-stream mining operation that occurred over 10 years ago (Table 4). All of the rubble/cobble was removed and has not been replaced from upstream sources. Note that Station 3, which was mined approximately 20 years ago, does contain some rubble/cobble. This suggests that Station 3 has partially recovered from the in-stream mining; however, the amount of material removed from the area is not known. The lack of rubble/cobble at Station 1 could be due to sedimentation from upstream sources, such as the floodplain gravel mining operation, thus covering any rubble/cobble in the area. Again, this is only speculation, but there were areas near the stream bank that did contain sand, gravel, and rubble/cobble bars.

Cover is a measure of the area available as shelter for fish. Cover was limited at all stations, except for those stations that contained large, deep pools (Table 5). The predominant cover type at all stations, except Station 4, was channel depth, with some woody debris present at Station 5. Station 4 contained no cover, which is probably directly attributable to in-stream mining. The dredged hole created by the in-stream mining has since filled in with sand and gravel. Any other cover types—such as woody debris, rocks, and boulders—would have been removed by the in-stream mining. No significant differences occurred between stations for percent total cover.

Percent bank stability is a measure of the area that is not susceptible to erosion. Bank stability values were only fair to good at most stations, except for Station 5, where values were very poor (Table 5). Bank stability values averaged only 34% at this station and at certain areas were 0%. The erosion problems at Station 5 were due to the relocation of the channel, which was probably caused by headcutting from the in-stream mining operation just downstream from this station. When the channel relocated around the old waterfall, it cut through an old flood channel and eroded the existing bank, exposing mostly bare soil.

**Fish Community Survey**

The predominant (> 30 individuals) fish species caught during our fishery survey in 1987 included largescale stoneroller (all stations), common shiner (Station 4 only), bigmouth shiner (Station 4 only), longnose dace (Station 5 only), northern hog sucker (Station 4 only), young-of-the-year black bullhead (Station 2 only), smallmouth bass (Stations 2, 3, and 4), rainbow darter (Stations 2, 3, 5, and 6), logperch (Station 4 only), and blackside darter (Station 2 only) (Table 6). All of these species, except bigmouth shiner and young-of-the-year black bullhead, were present (at least one individual) at all the stations sampled in 1987. Species found at Station 4 that were not found at the other stations in 1987 included bigmouth shiner and sand shiner. Both of these species prefer sandy substrates and areas open and free of vegetation (Becker 1983). The habitat characteristics of Station 4 certainly fit this

**Table 4.** *Substrate composition of stations on the Big Rib River in 1987.*

| Station | Description | Area ($m^2$) | Substrate Composition by Type (mean % of area) Boulder | Rubble/Cobble | Gravel | Sand |
|---|---|---|---|---|---|---|
| 1 | Below floodplain mining | 9,590 | 3.0 [ab]* (1.2)** | 0 [b] | 47.0 [ab] (6.8) | 50.0 [ab] (5.7) |
| 2 | Unmined area | 13,330 | 15.6 [a] (3.8) | 36.9 [a] (3.8) | 22.5 [c] (3.7) | 25.0 [bc] (6.6) |
| 3 | In-stream mining | 13,750 | 0.7 [b] (0.7) | 22.1 [a] (5.6) | 40.0 [bc] (4.4) | 37.1 [abc] (7.4) |
| 4 | In-stream mining | 8,820 | 0 [b] | 0[b] | 40.0 [bc] (10.0) | 60.0 [a] (10.0) |
| 5 | Impacted area | 5,710 | 1.4 [b] (0.9) | 25.7 [a] (4.6) | 65.7 [a] (6.0) | 7.1 [c] (1.0) |
| 6 | Unmined area | 9,830 | 9.2 [ab] (3.8) | 21.7 [a] (5.3) | 30.0 [bc] (2.9) | 39.2 [ab] (9.4) |

*Values in a column with the same letter are not significantly different from each other; whereas values with different letters are significantly different ($P \leq 0.05$).

**Standard error is given in parentheses. Although analyses were done on arcsine-transformed data, means and standard errors are of the original data.

**Table 5.** *Available in-stream cover for adult fish and bank stability values for stations sampled in 1987 in the Big Rib River.*

| | | In-stream Cover (% of total surface area) | | | Bank Stability (% stable bank) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Left Bank | | Right Bank | | Grand |
| Station | Description | Channel Depth | Woody Debris | Total Cover | Mean | Minimum | Mean | Minimum | Mean |
| 1 | Below floodplain mining | 17.0 | 0 | 17.0 [a]* | 59 | 30 | 66 | 50 | 62 [ab] |
| 2 | Unmined area | 13.1 | 0 | 13.1 [a] | 59 | 25 | 77 | 60 | 68 [a] |
| 3 | In-stream mining | 4.3 | 0 | 4.3 [a] | 78 | 50 | 90 | 90 | 84 [a] |
| 4 | In-stream mining | 0 | 0 | 0 [a] | 80 | 80 | 50 | 50 | 65 [ab] |
| 5 | Impacted area | 5.7 | 0.7 | 6.4 [a] | 39 | 10 | 29 | 0 | 34 [b] |
| 6 | Unmined area | 7.5 | 0 | 7.5 [a] | 69 | 50 | 73 | 30 | 71 [a] |

*Values in a column with the same letter are not significantly different from each other; whereas values with different letters are significantly different ($P \leq 0.05$).

description and are related to in-stream mining. In contrast, rosyface shiner and banded darter were present at all stations except Station 4. These species prefer areas in or near rocky riffles (Becker 1983), which were lacking at Station 4.

The smallmouth bass populations at the stations were dominated by young-of-the-year, with very few adults captured (Table 6). Of the captured adults, only 3 were greater than the quality size (280 mm) (Anderson and Gutreuter 1983), and none were greater than the current minimum size limit, enacted in 1989 (356 mm). Populations of walleye, which were present but not common, were also dominated by smaller individuals, with only one greater than the quality size (380 mm) (Anderson and Gutreuter 1983). The rock bass, green sunfish, pumpkinseed, and black crappie populations were also dominated by smaller individuals, with none greater than their respective quality size (Anderson and Gutreuter 1983).

The predominant (> 30 individuals) fish species caught during the 1986 survey include largescale stoneroller, northern hog sucker, and rainbow darter (all at Station A only) (Table 6). Very few species and individuals were captured at Station B during the 1986 survey. Again, the smallmouth bass populations were dominated by young-of-the-year, and

**Table 6.** *List of species, their classification, and number captured at stations surveyed in the Big Rib River during 1986-87.*

| | Classification* | | | Station | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1987 | | | | | | 1986 | |
| **Common Name** | **1** | **2** | **3** | **1** | **2** | **3** | **4** | **5** | **6** | **A** | **B** |
| Lamprey ammocoetes** | Fi | I | – | 2 | 2 | 4 | 4 | 3 | 3 | 3 | 4 |
| American brook lamprey ammocoetes | Fi | I | – | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| Central mudminnow (A)[a] | In | T | – | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Largescale stoneroller (A) | He | – | – | 76 | 64 | 72 | 160 | 140 | 127 | 93 | 1 |
| Hornyhead chub (A) | In | – | – | 0 | 1 | 5 | 6 | 1 | 0 | 1 | 0 |
| Hornyhead chub (YOY) | In | – | – | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Common shiner (A) | In | – | SL | 3 | 7 | 21 | 87 | 7 | 7 | 0 | 0 |
| Bigmouth shiner (A) | In | – | – | 0 | 0 | 0 | 31 | 0 | 3 | 0 | 0 |
| Rosyface shiner (A) | In | I | SL | 1 | 6 | 1 | 12 | 5 | 0 | 0 | 0 |
| Sand shiner (A) | In | – | – | 0 | 0 | 0 | 17 | 0 | 0 | 0 | 0 |
| Mimic shiner (A) | In | – | – | 0 | 2 | 4 | 15 | 1 | 6 | 0 | 0 |
| Bluntnose minnow (A) | Om | T | – | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| Longnose dace (A) | In | – | SL | 2 | 27 | 12 | 3 | 46 | 10 | 11 | 0 |
| Creek chub (A) | Ge | T | – | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 0 |
| White sucker (A) | Om | T | SL | 1 | 0 | 0 | 5 | 2 | 0 | 1 | 0 |
| White sucker (YOY) | Om | T | SL | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 |
| Northern hog sucker (A) | In | I | SL | 3 | 23 | 8 | 5 | 15 | 15 | 36 | 2 |
| Northern hog sucker (YOY) | In | I | SL | 0 | 0 | 1 | 68 | 0 | 0 | 0 | 0 |
| Silver redhorse (A) | In | – | SL | 0 | 1 | 0 | 0 | 0 | 1 | 26 | 0 |
| Golden redhorse (A) | In | – | SL | 6 | 4 | 12 | 0 | 1 | 0 | 0 | 0 |
| Golden redhorse (YOY) | In | – | SL | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 |
| Shorthead redhorse (A) | In | – | SL | 2 | 0 | 1 | 0 | 2 | 0 | 14 | 0 |
| Black bullhead (YOY) | In | – | – | 0 | 890 | 0 | 0 | 0 | 0 | 0 | 0 |
| Yellow bullhead (A) | In | T | – | 0 | 0 | 1 | 0 | 0 | 3 | 0 | 0 |
| Yellow bullhead (YOY) | In | T | – | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| Stonecat (A) | In | – | – | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 |
| Stonecat (YOY) | In | – | – | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 |
| Burbot (A) | Tc | – | SL | 0 | 9 | 0 | 0 | 5 | 6 | 0 | 0 |
| Rock bass (A) | Tc | I | – | 0 | 13 | 0 | 0 | 0 | 0 | 0 | 0 |
| Rock bass (YOY) | Tc | I | – | 0 | 7 | 0 | 0 | 0 | 1 | 0 | 0 |
| Green sunfish (A) | In | T | – | 0 | 2 | 0 | 0 | 3 | 0 | 0 | 0 |
| Pumpkinseed (A) | In | – | – | 3 | 6 | 0 | 0 | 0 | 2 | 0 | 0 |
| Smallmouth bass (A) | Tc | I | – | 2 | 19 | 2 | 3 | 0 | 1 | 2 | 0 |
| Smallmouth bass (YOY) | Tc | I | – | 24 | 44 | 74 | 44 | 10 | 14 | 20 | 3 |
| Black crappie (A) | Tc | – | – | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Rainbow darter (A) | In | I | SL | 27 | 168 | 172 | 15 | 387 | 178 | 51 | 0 |
| Rainbow darter (YOY) | In | I | SL | 1 | 3 | 8 | 7 | 0 | 5 | 0 | 0 |
| Fantail darter (A) | In | – | – | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| Johnny darter (A) | In | – | – | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Banded darter (A) | In | I | SL | 2 | 13 | 5 | 20 | 9 | 22 | 0 | 0 |
| Yellow perch (A) | In | – | – | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Logperch (A) | In | – | SL | 9 | 17 | 19 | 33 | 14 | 18 | 16 | 6 |
| Blackside darter (A) | In | – | SL | 27 | 31 | 8 | 4 | 18 | 13 | 9 | 4 |
| Walleye (A) | Tc | – | SL | 1 | 1 | 0 | 0 | 1 | 7 | 8 | 0 |
| Walleye (YOY) | Tc | – | SL | 0 | 8 | 0 | 7 | 1 | 5 | 0 | 0 |
| Total number captured | | | | 195 | 1,375 | 435 | 521 | 697 | 441 | 314 | 23 |
| Distance sampled (m) | | | | 350 | 440 | 460 | 150 | 260 | 330 | 230 | 305 |

* Classification-1-Trophic Guild: Fi = Filter Feeder, Ge = Generalist Feeder, He = Herbivore, In = Insectivore, Om = Omnivore, Tc = Top Carnivore; 2-Tolerance: I = Intolerant, T = Tolerant; 3-Spawning: SL = Simple Lithophilous.

** Scientific names are listed in the Appendix.

[a] Letters in parentheses refer to maturity: A = Adult, YOY = Young of the year.

**Table 7.** *Values used in calculating the Index of Biotic Integrity (IBI) scores for the stations surveyed in the Big Rib River during 1986-87.*

| | Values and IBI Scores by Station | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1987 | | | | | | 1986* |
| **Metric** | **1** | **2** | **3** | **4** | **5** | **6** | **B** |
| Total no. native species | 19 (5)** | 23 (10) | 17 (5) | 17 (5) | 22 (10) | 22 (10) | 15 (5) |
| No. darter species | 4 (7) | 5 (10) | 4 (7) | 3 (5) | 4 (7) | 4 (7) | 5 (10) |
| No. sucker species | 4 (5) | 3 (5) | 3 (5) | 2 (0) | 4 (5) | 2 (0) | 4 (5) |
| No. sunfish species | 1 (0) | 3 (10) | 0 (0) | 0 (0) | 2 (5) | 3 (10) | 0 (0) |
| No. intolerant species | 7 (10) | 7 (10) | 6 (10) | 5 (5) | 7 (10) | 7 (10) | 5 (5) |
| Tolerant species (%) | 2 (10) | 0 (10) | 0 (10) | 2 (10) | 1 (10) | 1 (10) | 0 (10) |
| Omnivores (%) | 1 (10) | 0 (10) | 0 (10) | 2 (10) | 1 (10) | 0 (10) | 0 (10) |
| Insectivore (%) | 45 (5) | 88 (10) | 65 (10) | 56 (5) | 77 (10) | 62 (10) | 60 (7) |
| Top carnivores (%) | 14 (7) | 7 (2) | 17 (10) | 10 (5) | 3 (0) | 8 (2) | 10 (5) |
| Lithophilous spawners (%) | 44 (5) | 23 (5) | 63 (10) | 46 (5) | 76 (10) | 63 (10) | 62 (10) |
| IBI Total | (64) | (82) | (77) | (50) | (77) | (79) | (67) |
| Rating | Good to Excellent | Excellent | Excellent | Fair to Good | Excellent | Excellent | Good to Excellent |

* No IBI score was computed for Station A (1986) due to the very low number of individuals caught.

** Numbers in parentheses are the score assigned to calculate the IBI: 10 = Best, 0 = Worst. The higher the total IBI score, the better the fish community (possible range: 0-100).

none were greater than the quality size at either station. Also, the walleye population at Station A was dominated by smaller individuals, with none greater than the quality size.

The fish communities at the stations were rated using the Wisconsin version of the IBI (Lyons 1992) (Table 7). The IBI score is an index of the overall environmental quality of a stream or river. By itself, the score does not indicate types of environmental problems. However, scores of the individual metrics often provide insight into the specific causes of environmental degradation. Station 2 scored the highest (82), which corresponds to a rating of excellent. Similarly, Stations 3, 5, and 6 also scored high (77, 77, and 79, respectively) and had excellent ratings. Stations 1 and A had similar scores (64 and 67, respectively) and were rated between good and excellent. Station 4 scored the lowest (50), which still corresponds to a rating between fair and good. No IBI score was computed for Station B due to the very low number of individuals caught. However, based on this low number, the biotic integrity of this section was rated as very poor (Lyons 1992).

Metrics that consistently scored high for all stations included percentages of tolerant and omnivore species. Very few individuals categorized as tolerant or omnivore were captured during both years of sampling. The metric that consistently scored low for all stations was number of sucker species. Although 5 species of suckers were caught in the entire survey, usually only 3 or less were captured at any one station. This could be due to the lack of efficiency of capturing fish—especially suckers—in the deeper pools at the stations. Several pools were fairly deep (1.5-2.0 m) and were difficult to shock, which could have lowered our catch of sucker species as well as larger game fish. Other metrics that generally scored low for most stations were number of sunfish species, percentage of top carnivores, and number of native species. Sunfish and top carnivores do best in deeper pool habitats and areas of extensive cover. Except for the deeper pools, cover (such as woody debris and rocks/boulders) was lacking at all stations. Thus, the low scores for these metrics could be due to the lack of habitat for sunfish species and top carnivores, and/or the inefficiency of capturing fish in the large deep pools at some of the stations. The reason for the lower scores at some of the stations for the number of native species is related to the other metrics. The lack of sucker species, sunfish species, and top carnivores at most of the stations tended to lower the number of total species caught. Generally, most stations, except Station 4, contained good species richness and had low numbers of fish in certain undesirable metrics (percentages of tolerant and omnivore species), which tended to raise the overall IBI score. This suggests that little environmental degradation has occurred at most of the stations, especially the unmined stations (Stations 2 and 6).

However, at Station 1, the site downstream from a major floodplain gravel mining and washing operation, species richness was lower than the unmined stations, and certain metrics—percentages of insectivores, top carnivores, and lithophilous spawners—also scored low. As in some of the other stations, the number of sucker species, sunfish species, and top carnivores was low, which could be due to the lack of cover (other than channel depth) and/or the low efficiency of sampling deeper pools. The lower scores in percentages of insectivores and lithophilous spawners are cause for concern. The lack of riffle habitat, possibly caused by sedimentation from the gravel washing operations, may have an effect on these types of species. The IBI scores indicate that some degradation has probably occurred.

At Station 4, the in-stream mining site, species richness was fairly low and certain metrics (e.g., percentages of insectivores and lithophilous spawners) also scored low. In addition, in 1986, the catch was so low that an IBI score could not be computed. This variability in catch between years shows that the fish community at this station is unstable and degraded, even though scores in 1987 were between fair and good. One measure of poor biotic integrity is a fish community that fluctuates greatly in fish abundance and species composition from year to year. Also, the fish found in 1987 may have been transient, staying in this area for a while, but then moving either upstream or downstream in search of cover and/or food. The fish communities above and below this site scored either good or excellent and almost certainly influenced the fish community at Station 4. The habitat at Station 4 is definitely not conducive to permanent habitation, except for some cyprinid species. Sand was the dominant substrate, and the station lacked cover, vegetation, and deeper areas. In contrast, the habitat above and below this station is considerably better, containing a variety of substrates and some cover, especially channel depth. Although there were differences in the results between the 2 surveys at Station 4, the fish community was consistently in only fair condition, which suggests that environmental degradation has occurred due to in-stream mining.

## Discussion

The unmined stations (Stations 2 and 6) and the impacted station (Station 5) were found to have fairly good habitat with a variety of reach types (riffles, runs, and pools) and a variety of substrates. The main problem at these stations was bank stability. Bank stability values were only fair to good at Stations 2 and 6; values were poor at Station 5, with 0-10% bank stability in certain areas.

Station 5 was formed when the channel was relocated around an existing waterfall. Before this, part of Station 5 was an overflow channel used by the river during high flow (Wis. Dep. Nat. Resour. 1987). This relocation was caused by a change in river hydraulics and channel slope, which resulted from the downstream dredged area (Station 4) (Wis. Dep. Nat. Resour. 1987).

The relocation of the channel was probably caused by a headcut. According to Leopold et al. (1964), West (1978), and MacBroom (1981), a headcut will progress upstream until an unerodable formation is encountered. MacBroom (1981) also noted that a headcut may move laterally at this point. This could have happened at Station 5 when the waterfall was encountered; thus, the headcut may have moved laterally into the high flow channel, which then became permanent. Associated with headcuts are severe bank erosion and degradation (Bull and Scott 1974, Crunkilton 1982, Simons and Li 1984, Rivier and Seguier 1985). The poor bank stability at Station 5 is probably a result of this headcut and associated degradation, and also, in part, to being the former overflow channel.

The higher amounts of gravel and low percentages of sand at Station 5 were probably also the result of channel degradation. As the channel degraded, sand was washed downstream, which may have exposed the underlying gravel. The soils in this area are the Sturgeon type, which occur on floodplains and islands in large rivers, often dissected by overflow channels (Fiala et al. 1989). The substratum of some Sturgeon soils can be composed of gravel or very gravelly sand (Fiala et al. 1989). This could explain the high gravel content at Station 5. The presence of the cover types channel depth and woody debris was probably the result of channel degradation and fallen trees from the eroded banks or debris brought in by floodwaters.

IBI scores for the unmined stations (Stations 2 and 6) and the impacted station (Station 5) were all excellent. These stations contained the highest numbers of native species, with at least 22 captured. Generally, these stations contained good species richness, with the exception of sucker species and top carnivores. The lack of these species was evident throughout all of the stations sampled in the Big Rib River. The lack of cover, and possibly poor sampling efficiency in the deeper pools (especially at Station 2) could account for the lack of suckers and top carnivores. Stations 2 and 5 contained the highest number of individual fish captured. Rainbow darters comprised 56% of the total number of fish caught at Station 5, probably due to the predominance of gravel substrates (riffle habitat).

The habitat at Station 3, which had in-stream mining approximately 20 years ago, appeared to be in a state of recovery. Station 3 contained all 3 reach types; however, runs were predominant. Only one small riffle and one small pool were found. This was probably related to the in-stream mining that occurred, which could have created a uniform channel (Yorke 1978). This station also had a fairly high bend-to-bend ratio (BB = 20) and a sinuosity of 1.00. This suggests that channel straightening occurred, probably from the in-stream mining activities (Woodward Clyde Consult. 1976*b*, Yorke 1978). Mean channel widths were similar to the unmined stations, indicating that channel widening had not occurred due to the dredging operations. Station 3 contained the deepest mean depths of all the stations. The lack of pool habitat, however, indicates again the uniformity of the channel created by the dredging operation 20 years ago.

Station 3 contained a variety of substrates, including a fairly high percentage of rubble/cobble and gravel (62% of the total substrate). This again indicates that this station is recovering and corresponds well to the recovery rate of 10-25 years reported by Simpson et al. (1982) for Midwestern woodland streams and floodplains of medium-sized, channelized rivers. Recovery rates depended upon the recovery of substrates and other physical conditions and the degree of mitigation.

Station 3 contained the second lowest amount of in-stream cover. Again, the creation of uniform conditions throughout the channel, the elimination of pool habitat, and channel clearing is characteristic of some in-stream mining operations (Hair et al. 1986). Bank stability was not a problem at this station. In fact, Station 3 had the highest overall bank stability. Higher bank stabilities can be expected in some channelized streams due to the lack of meanders and increased conveyance of flood flows (Yorke 1978). Woodward Clyde Consultants (1980*b*) noted that increased conveyance occurred in some Alaskan streams due to in-stream gravel mining.

The IBI score for Station 3 was rated as excellent, although species richness was lower than at the unmined stations. This station lacked sunfish species, and the total number of species and number of sucker species was low. However, this station scored the highest in percentage of top carnivores due to a fairly high number of young-of-the-year smallmouth bass. The lower species richness indicates that some degradation has occurred due to the in-stream dredging; however, the overall score indicates that the area is recovering. The lack of sunfish species and sucker species is probably due to the lack of in-stream cover and pool habitat, respectively. Due to the in-stream mining, most of the habitat consisted of runs. In order to have a high quality stream or river, habitat must contain a variety of reach types (pools, riffles, and runs) and cover types.

The high number of young-of-the-year smallmouth bass at Station 3 could have been due to uniform velocities, which have been shown to attract younger age classes of fish (Woodward Clyde Consult. 1980*b*). In a study done on preferred velocities for feeding young-of-the-year smallmouth bass, Simonson and Swenson (1990) found that the optimum range was from 0.08-0.13 m/sec, with an average of 0.11 m/sec. Mean velocities for the run reach types at Station 3 were 0.19 m/sec; however, nearshore velocities averaged 0.13 m/sec. Nearshore velocities at Station 2, which had the second highest number of young-of-the-year smallmouth bass present also averaged 0.13 m/sec. All other stations had higher velocities and lower numbers of young-of-the-year smallmouth bass.

The habitat at Station 1, downstream from a major floodplain gravel mining and washing operation, also contained predominantly run reach types, with one small pool. No riffle habitats were found in this stretch. Ninety-seven percent of the substrate was sand and gravel, with no rubble/cobble observed. However, rubble/cobble was noted in the gravel bars located on the stream banks. Riffle habitats and rubble/cobble substrate exist in the unmined and impacted sites, reference sites, and even in the older dredged site (Station 3). Gravel washing operations can discharge large amounts of suspended sediments into rivers (Woodward Clyde Consult. 1976*a*, 1976*b*; Rivier and Seguier 1985), and overburden piles can also contribute to suspended sediments (Woodward Clyde Consult. 1980*b*). It is possible that any riffle habitats or rubble/cobble substrate that existed in this stretch of the main channel may have been covered up by the sediments from the gravel operations upstream from Station 1. This area may also have been affected by sedimentation from the channelization that occurred during the late 1920s.

Mean channel widths and depths at Station 1 were similar to the unmined stations. As in most of the other sites, channel depth was the only cover type found. Bank stability values were only fair at this station. Bank erosion has been documented at gravel washing operations (Martin and Hess 1986). Increased erosion could also add to the suspended sediments being deposited in the river channel. The soils in this area of the Big Rib River are mostly Fordum and Sturgeon types (Fiala et al. 1989). Sturgeon soils were discussed earlier, and Fordum soils are very similar. Fordum soils are found in overflow channels, low floodplain areas, and on islands in large rivers. The substratum is composed entirely of sand. Therefore, increased erosion would also contribute sand and gravel to the river.

The IBI score for Station 1 was rated between good and excellent. Species richness was lower than at the unmined sites, but similar to the older dredged site (Station 3). However, lower scores in percentages of insectivores, top carnivores, and lithophilous spawners resulted in a decrease in the overall IBI score. Deposition of fine substrates has been shown to affect insectivores and simple, lithophilous spawners (Berkman and Rabeni 1987) by filling the interstices of gravel, thus decreasing invertebrate densities and species richness (Chutter 1969, Woodward Clyde Consult. 1976*b*, Crunkilton 1982, Rivier and Seguier 1985). Increased sedimentation of gravel beds also affects spawning habitat and the development of fish eggs (Cordone and Kelly 1961, Woodward Clyde Consult. 1976*b*, Rivier and Seguier 1985). This station also had the lowest number of fish caught of any of the stations sampled in 1987. In addition to deposition, the floodplain gravel mining operation and associated connected ponds might cause other problems related to water quality, such as high turbidities and temperatures, which could influence the fish community. The IBI scores indicate that some degradation has probably occurred.

The habitat at Station 4, which had in-stream dredging approximately 10 years ago, had the worst habitat of all the stations. No pools or riffles existed in this stretch, mean channel widths were nearly twice the width of the unmined stations, mean depths were at least one half of the depth of the unmined stations, substrates consisted predominantly of sand with some small gravel intermixed, no cover existed, and bank stability values were only fair. Basically, the area is flat, wide, shallow, and sandy, with no in-stream cover. The obvious cause of this was the in-stream dredging that occurred 10 years before sampling. The mining excavation enlarged the channel, cleared the area of all snags and vegetation, and removed the majority of the rubble/cobble and gravel that existed. The dredged hole has since filled in with sand and some gravel from upstream sources. Not only did the mining operation affect the actual dredged area, but it also affected the upstream area by creating a headcut, which diverted the channel into a former high flow channel, completely eliminating an existing waterfall. All of these impacts were discussed in the literature review and typically occur with in-stream sand and gravel mining operations.

The fish community at Station 4 was rated as only fair to good in 1987, and was so poor in 1986 that an IBI score could not be computed. While scores improved in 1987, the high variability in the fish community indicated a degraded condition. The higher scores and more diverse communities both upstream and downstream from this area may have accounted for some of this variability, and certain fish species may be moving through this dredged area en route to better habitat. Although our sampling was limited to 2 brief surveys, we believe that the in-stream dredging 10 years ago degraded the fish community in this stretch, and that it will take years to recover.

# Summary and Conclusions

## Literature Review

The literature review focused on the physical and biological effects of in-stream and stream-connected floodplain sand and gravel mining. The primary physical effects included modifications of the stream channel, flow patterns, bedload transport, and water quality; an additional effect was increased headcutting. Stream channel modifications included enlargement of the stream channel causing uniform conditions similar to the effects of channelization and channel clearing. Deep pools are often created, but often fill with sand or silt in a short time. Flow patterns and velocities may be altered, with velocities increasing upon entering the dredged area and then decreasing due to channel widening. Bottom substrates and bedload transport are often altered with a change in substrates from coarser gravel to sand or silt, thus eliminating habitat diversity. Bedload transport and suspended sediments will increase due to bank erosion, gravel washing operations, and the actual dredging operation. Increased headcutting will occur at the upstream end of the dredged hole and can cause severe degradation and bank erosion. Headcutting will occur until gradients become uniform or until an unerodable source is met, but then may move laterally across the stream. Changes in the stream channel and the actual mining operation can alter water quality parameters, including increased turbidity, reduced light penetration, and increased water temperatures.

Gravel mining operations and the associated physical effects can affect stream biota including plant communities and invertebrate and fish populations. Plant communities and plant metabolism may be reduced by high turbidities, increased sedimentation, decreased light, changes in substrate, and channel clearing. Invertebrate populations, including mussels, can be reduced by the actual removal of the organisms. Reduction can also occur through the disruption of habitat by sedimentation, removal of woody debris, or by changes in substrates from gravel to sand and/or silt. Fish populations may be influenced or altered by eliminating spawning and nursery habitat and by removing riffle habitat and cover. Changes in habitat may change fish communities from riffle-specific species to run-specific species. Fish populations can also be influenced by changes in the trophic dynamics of fish communities, which affect the nutrition and health of fish.

In conclusion, fish, aquatic invertebrate, and plant communities can be altered by gravel mining operations both in density and diversity by alterations in channels, stream banks, and water quality, and by the outright elimination of habitat. Most of these alterations can be adverse to various fish species, and can result in degradation of habitat and the biological communities in the affected streams. Six case studies from states outside of Wisconsin that documented many of these physical and biological effects of in-stream and floodplain sand and gravel mining were outlined.

## Big Rib River Survey

A survey was conducted on portions of the Big Rib River for habitat and fish community characteristics during 1986-87 in order to examine the potential impacts of floodplain and in-stream gravel mining. Two stations were surveyed in 1986: one had received in-stream mining approximately 10 years prior (Station A) and one was downstream from this station (Station B). Six stations were surveyed in 1987: 2 had received in-stream mining in the past (Stations 3 and 4), one had been impacted by an in-stream mined station (Station 5), one was below an active floodplain mining operation (Station 1), and 2 had only limited nearby floodplain or riparian mining (unmined Stations 2 and 6).

Habitat characteristics, including percentages of sand and rubble/cobble, mean channel width, and mean depth of runs differed among stations. Station 4 had the worst habitat. The in-stream mining operation created an area that is flat, wide, shallow, and sandy, with no in-stream cover. The mining operation also affected the upstream area by creating a headcut, which diverted the channel into a former high flow channel (Station 5) and completely eliminated an existing waterfall. Station 1 contained no riffle habitats, and substrates were predominantly sand and gravel, with no rubble/cobble present. Any riffle habitats or rubble/cobble substrate that existed in this stretch may have been covered up by sediments from the upstream gravel mining operations. Station 3, which had in-stream mining approximately 20 years ago, appeared to be in a state of recovery. This station contained all 3 reach types and contained a variety of substrates, including rubble/cobble.

The quality of the fish communities was rated using the Index of Biotic Integrity (IBI). Again, Station 4 had the worst score. IBI scores in 1987 were fair to good, while in 1986 the fish community was so poor that no score could be computed. This high variability in the fish community at Station 4 indicates a degraded condition. IBI scores for Station 1 indicated that some degradation has probably occurred because of low numbers of fish and lower scores in the trophic and reproductive metrics, possibly due to sedimentation. The unmined stations (Stations 2 and 6), the older in-stream mined station (Station 3), and the impacted station (Station 5) all scored excellent ratings.

In conclusion, physical habitat assessment and the IBI are 2 different ways of examining the effects of sand and gravel mining. The IBI can be used as an index of the quality of the entire ecosystem, whereas the habitat assessment can be more sensitive to impacts such as changes in substrate composition, channel width, depth, and bank stability. In the stations affected by sand and gravel mining, the physical habitat was affected more than the fish communities. However, in the area that was dredged 10 years before sampling (Station 4), the fish community was quite variable between the 2 sampling years. This is a definite indication of a degraded fish community, which was probably influenced by the fish communities upstream and downstream. Overall, our results suggest that gravel mining has had a negative impact on the fish communities and the fish habitat of the Big Rib River.

## Management and Research Recommendations

The literature review shows that serious environmental damage, both physical and biological, can result from in-stream and floodplain sand and gravel mining. Also, our habitat survey of the Big Rib River showed that in-stream mining can not only affect the physical habitat of the dredged area, but also upstream areas. Although recent regulations allow in-stream mining only in unusual circumstances, we still recommend that consideration be given to banning all in-stream mining activities.

If such a ban is not implemented, we would recommend a monitoring and research program that involves inter-disciplinary studies of stream conditions before, during, and after gravel mining. There is a nationwide void in the literature related to these types of studies. Techniques for mitigation, which is now required under NR 340, should also be evaluated. Mitigation techniques could include bank stabilization, erosion control, rehabilitation of stream channels, and revegetation. In addition, the sizes and types of buffer strips that best protect streams from floodplain mining, types of pit designs, and influences of connected pits need to be studied. Devices or techniques need to be developed that could recycle wastewater from gravel washing operations.

Specific recommendations for the Big Rib River and the surrounding area influenced by gravel excavations include continued monitoring of mined areas (both in-stream and floodplain) and unmined areas through continued habitat and fishery surveys. Due to variability in the results of these relatively short-term surveys, we recommend that surveys be done every 3-5 years, in order to document further impacts and possible recovery of these sites. Future surveys should be conducted by an interdisciplinary team from DNR Fisheries Management and other DNR programs, such as Wildlife Management and Water Resources. Future surveys should also look at the effects of mining on: water quality, suspended sediments from erosion and gravel washing operations, invertebrate populations of the river, and connected ponds. Rehabilitation of the in-stream mined area (Station 4) should be considered, in order to determine what habitat improvement techniques will work on dredged areas. For example, rock gabions could be used to control headcutting or rechannel the flow back into the old channel above Station 4, re-establishing the old waterfall.

Our research indicates that a statewide survey of the extent of mining in Wisconsin is needed. We believe that mining and its attendant effects on stream resources are more widespread than most people realize. This survey should document the location of impacts, the extent of the problem, and types of mining operations. This information could then be used to formulate a statewide data base.

Finally, research should also be conducted on the effects of floodplain and riparian (upland) mining, such as open-pit mining, which were not considered in this report. A literature review should be conducted to examine the effects on terrestrial habitat and biota, including wetlands; the effects on groundwater, flood flows, surface runoff, water retention, and flood elevations; the extent of this type of mining; and the guidelines that are needed to regulate riparian mining.

## **Appendix.** *Scientific names of fishes cited.**

| Common Name | Scientific Name | Common Name | Scientific Name |
|---|---|---|---|
| Lamprey | *Ichthyomyzon* spp. | Blue sucker | *Cycleptus elongatus* |
| American brook lamprey | *Lampetra appendix* | Northern hog sucker | *Hypentelium nigricans* |
| Shovelnose sturgeon | *Scaphirhynchus platorynchus* | Smallmouth buffalo | *Ictiobus bubalus* |
| Gars | *Lepisosteus* spp. | Bigmouth buffalo | *Ictiobus cyprinellus* |
| Longnose gar | *Lepisosteus osseus* | Spotted sucker | *Minytrema melanops* |
| Gizzard shad | *Dorosoma cepedianum* | Redhorse | *Moxostoma* spp. |
| Threadfin shad | *Dorosoma petenense* | Silver redhorse | *Moxostoma anisurum* |
| Goldeye | *Hiodon alosoides* | Gray redhorse | *Moxostoma congestum* |
| Whitefish | *Coregonus* spp. | Golden redhorse | *Moxostoma erythrurum* |
| Salmon | *Oncorhynchus* spp. | Shorthead redhorse | *Moxostoma macrolepidotum* |
| Sockeye salmon | *Oncorhynchus nerka* | White catfish | *Ameiurus catus* |
| Rainbow trout | *Oncorhynchus mykiss* | Black bullhead | *Ameiurus melas* |
| Cutthroat trout | *Oncorhynchus clarki* | Yellow bullhead | *Ameiurus natalis* |
| Round whitefish | *Prosopium cylindraceum* | Channel catfish | *Ictalurus punctatus* |
| Mountain whitefish | *Prosopium williamsoni* | Stonecat | *Noturus flavus* |
| Atlantic salmon | *Salmo salar* | Flathead catfish | *Pylodictis olivaris* |
| Brown trout | *Salmo trutta* | Burbot | *Lota lota* |
| Arctic char | *Salvelinus alpinus* | Blackstripe topminnow | *Fundulus notatus* |
| Arctic grayling | *Thymallus arcticus* | Western mosquitofish | *Gambusia affinis* |
| Central mudminnow | *Umbra limi* | Brook silverside | *Labidesthes sicculus* |
| Northern pike | *Esox lucius* | Inland silverside | *Menidia beryllina* |
| Muskellunge | *Esox masquinongy* | White bass | *Morone chrysops* |
| Stoneroller | *Compostoma* spp. | Rock bass | *Ambloplites rupestris* |
| Stoneroller | *Campostoma* spp. | Redbreast sunfish | *Lepomis auritus* |
| Central stoneroller | *Campostoma anomalum* | Green sunfish | *Lepomis cyanellus* |
| Largescale stoneroller | *Campostoma oligolepis* | Pumpkinseed | *Lepomis gibbosus* |
| Common carp | *Cyprinus carpio* | Warmouth | *Lepomis gulosus* |
| Speckled chub | *Macrhybopsis aestivalis* | Bluegill | *Lepomis macrochirus* |
| Sturgeon chub | *Macrhybopsis gelida* | Longear sunfish | *Lepomis megalotis* |
| Silver chub | *Macrhybopsis storeriana* | Redear sunfish | *Lepomis microlophus* |
| Hornyhead chub | *Nocomis biguttatus* | Smallmouth bass | *Micropterus dolomieu* |
| Emerald shiner | *Notropis atherinoides* | Spotted bass | *Micropterus punctulatus* |
| River shiner | *Notropis blennius* | Largemouth bass | *Micropterus salmoides* |
| Common shiner | *Luxilus cornutus* | White crappie | *Pomoxis annularis* |
| Bigmouth shiner | *Notropis dorsalis* | Black crappie | *Pomoxis nigromaculatus* |
| Red shiner | *Cyrinella lutrensis* | Rainbow darter | *Etheostoma caeruleum* |
| Rosyface shiner | *Notropis rubellus* | Fantail darter | *Etheostoma flabellare* |
| Sand shiner | *Notropis stramineus* | Johnny darter | *Etheostoma nigrum* |
| Redfin shiner | *Lythrurus umbratilis* | Orangethroat darter | *Etheostoma spectabile* |
| Blacktail shiner | *Cyprinella venusta* | Banded darter | *Etheostoma zonale* |
| Mimic shiner | *Notropis volucellus* | Yellow perch | *Perca flavescens* |
| Bluntnose minnow | *Pimephales notatus* | Logperch | *Percina caprodes* |
| Bullhead minnow | *Pimephales vigilax* | Blackside darter | *Percina maculata* |
| Squawfish | *Ptychocheilus* spp. | Sauger | *Stizostedion canadense* |
| Longnose dace | *Rhinichthys cataractae* | Walleye | *Stizostedion vitreum* |
| Creek chub | *Semotilus atromaculatus* | Freshwater drum | *Aplodinotus grunniens* |
| River carpsucker | *Carpiodes carpio* | Seatrout | *Cynoscion* spp. |
| White sucker | *Catostomus commersoni* | Slimy sculpin | *Cottus cognatus* |
| Mountain sucker | *Catostomus platyrhynchus* | Riffle sculpin | *Cottus gulosus* |

*Taxonomy of fishes cited in the report follows Robins et al. (1991).

## Literature Cited


Anderson, R. O. and S. J. Gutreuter
1983. Length, weight, and associated structural indices. L. A. Nielson and D. L. Johnson, eds. pp. 283-300 *in* Fisheries techniques. Am. Fish. Soc., Bethesda, Md. 468 pp.

Becker, G. C.
1983. Fishes of Wisconsin. Univ. Wis. Press, Madison. 1053 pp.

Benke, A. C., R. L. Henry, III, D. M. Gillespie, and R. J. Hunter
1985. Importance of snag habitat for animal production in southeastern streams. Fisheries 10(5):8-13.

Berkman, H. E. and C. F. Rabeni
1987. Effect of siltation on stream fish communities. Environ. Biol. Fish. 18(4):285-94.

Bull, W. B. and K. M. Scott
1974. Impact of mining gravel from urban streambeds in the southwestern United States. Geology 2(4):171-74.

Campbell, H. J.
1953. Report on biological reconnaissance on the effect of gold dredging and mining operations on Powder River, Oregon, September 29-October 1, 1953. Oreg. State Game Comm., Portland. 8 pp.

Chutter, F. M.
1969. The effects of silt and sand on the invertebrate fauna of streams and rivers. Hydrobiologia 34:57-96.

Cordone, A. J. and D. W. Kelly
1961. The influences of inorganic sediment on the aquatic life of streams. Calif. Fish and Game 47(2):191-228.

Cordone, A. J. and S. Pennoyer
1960. Notes on silt pollution in the Truckee River drainage, Nevada and Placer Counties. Calif. Dep. of Fish and Game. Inland Fish. Adm. Rep. No. 60-14. 25 pp.

Crunkilton, R. L.
1982. An overview of gravel mining in Missouri and fish and wildlife implications. pp. 80-88 *in* W. D. Svedarsky and R. D. Crawford, eds. Wildlife values of gravel pits. Northwest Agric. Exp. St., Univ. Minn. Tech. Coll., Crookston. Misc. Publ. No. 17. 249 pp.

Devaul, R. W. and J. H. Green
1971. Water resources of Wisconsin—central Wisconsin River basin. U. S. Geol. Surv., Madison, Wis. and Wis. Geol. and Nat. Hist. Surv. Hydrol. Invest. Atlas HA-367. 4 pp.

Etnier, D. A.
1972. The effects of annual rechanneling on a stream fish population. Trans. Am. Fish. Soc. 101(2):372-75.

Fago, D.
1988. Retrieval and analysis system used in Wisconsin's statewide fish distribution survey, second edition. Wis. Dep. Nat. Resour. Res. Rep. No. 148. 53 pp.

Fiala, W. D., D. A. Buss, S. D. Hagedorn, K. A. Kidney, and J. O. Werlein
1989. Soil survey of Marathon County, Wisconsin. U. S. Dep. Agric., Soil Conserv. Serv. Washington, D.C. 339 pp.

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

Grace, T. B. and A. C. Buchanan
1981. Naiades (mussels) of the Lower Osage River, Tavern Creek, and Maries River, Missouri. Mo. Dep. Conserv., Jefferson City. 147 pp.

Griffith, J. S. and D. A. Andrews
1981. Effects of a small suction dredge on fishes and aquatic invertebrates in Idaho streams. North Am. J. Fish. Manage. 1:21-28.

Hair, D. E., R. Stowell, and W. Paradis
1986. To hell and back: rehabilitation of a placer mine stream. pp. 145-52 *in* J. G. Miller, J. A. Arway, and R. F. Carline, eds. The 5th trout stream habitat improvement workshop. Pa. Fish Comm., Harrisburg, Pa. 265 pp.

Hamilton, J. D.
1961. The effect of sand-pit washings on a stream fauna. Verh. Int. Ver. Limnol. 14:435-39.

Harvey, B. C.
1986. Effects of suction gold dredging on fish and invertebrates in two California streams. North Am. J. Fish. Manage. 6:401-09.

Henrich, E. W. and D. N. Daniel
[1983]. Drainage area data for Wisconsin streams. U. S. Geol. Surv., Madison, Wis. Open-File Rep. No. 83-933. 322 pp.

Hickman, G. D.
1975. Value of instream cover to the fish populations of Middle Fabius River, Missouri. Mo. Dep. Conserv. Aquat. Ser. No. 14. 7 pp.

Irizarry, R. A.
1969. The effects of stream alteration in Idaho. Idaho Fish and Game Dep. Proj. F-55-R-2. 29 pp.

Jutila, E.
1985. Dredging of rapids for timber-floating in Finland and its effects on river-spawning fish stocks. pp. 104-08 *in* J. S. Alabaster, ed. Habitat modification and freshwater fisheries. Food and Agric. Organ. U.N., Rome. 278 pp.

Kendall, R. L.
1988. Taxonomic changes in North American trout names. Trans. Am. Fish. Soc. 117(4):321.

Leopold, L. B., M. G. Wolman, and J. P. Miller
1964. Fluvial processes in geomorphology. W. H. Freeman and Co., San Francisco. 522 pp.

Li, R. and D. B. Simons
1979. Mathematical modeling of erosion and sedimentation associated with instream gravel mining. pp. 420-29 *in* Proceedings of the specialty conference on conservation and utilization of water and energy resources. Am. Soc. Civil Eng. San Francisco, Ca. 529 pp.

Luedtke, R. J. and M. A. Brusven
1976. Effects of sand sedimentation on colonization of steam insects. J. Fish. Res. Board Can. 33(9):1881-86.

Lyons, J. and C. C. Courtney
1990. A review of fisheries habitat improvement projects in warmwater streams, with recommendations for Wisconsin. Wis. Dep. Nat. Resour. Tech. Bull. No. 169. 34 pp.

Lyons, J.
1992. Using the index of biotic integrity (IBI) to measure environmental quality in warmwater streams of Wisconsin. General Technical Report. North Central Forest Experiment Station, St. Paul, Minnesota. 51 pp.

MacBroom, J. G.
1981. Applied fluvial geomorphology. Univ. Conn., Inst. Water Resour. Rep. No. 31. 167 pp.

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. Ga. Dep. of Nat. Resour. Proj. No. F-26-13. 37 pp.

Marzolf, G. R.
1978. The potential effects of clearing and snagging on stream ecosystems. U. S. Fish and Wildl. Serv., Washington, D.C. FWS/OBS-78/14. 32 pp.

Narf, R. P.
1985. Aquatic insect colonization and substrate changes in a relocated stream segment. Great Lakes Entomol. 18(2):83-92.

Platts, W. S., W. F. Megahan, and G. W. Minchall
1983. Methods for evaluating stream, riparian, and biotic communities. General Technical Report INT-138. U.S. Forest Service, Intermountain Forest and Range Experiment Station, Ogden, Utah. 70 pp.

Richardson, B. and M. Pratt
1980. Environmental affects of surface mining of mineral other than coal: annotated bibliography and summary report. U. S. For. Serv. Publ. No. INT-95. Ogden, Utah. 145 pp.

Rivier, B. and J. Seguier
1985. Physical and biological effects of gravel extraction in river beds. pp. 131-46 *in* J. S. Alabaster, ed. Habitat modification and freshwater fisheries. Food and Agric. Organ. U.N., Rome. 278 pp.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott
1991. A list of common and scientific names of fishes from the United States and Canada. 5th ed. Am. Fish. Soc. Spec. Publ. No. 20. 183 pp.

SAS Institute, Inc.
1985. SAS user's guide: statistics, version 5 edition. SAS Inst., Inc., Cary, N.C. 956 pp.

Simons, D. B. and R. Li
1984. Final report for analysis of channel degradation and bank erosion in the lower Kansas River. U. S. Army Corps of Eng., Kansas City, Mo. MRD Sediment Ser. No. 35, Contract No. DACW 41-83-C-01.

Simonson, T. D. and W. A. Swenson
1990. Critical stream velocities for young-of-year smallmouth bass in relation to habitat use. Trans. Am. Fish. Soc. 119:902-09.

Simpson, P. W., J. R. Newman, M. A. Keirn, R. M. Matter, and P. A. Guthrie
1982. Manual of stream channelization impacts on fish and wildlife. U.S. Fish and Wildl. Serv., Washington, D.C. FWS/OBS-82/24. 155 pp.

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

Strahler, A. N.
1957. Quantitative analysis of watershed geomorphology. Trans. Am. Geophys. Union 38: 913-920

Thomas, V. G.
1985. Experimentally determined impacts of a small, suction gold dredge on a Montana stream. North Am. J. Fish. Manage. 5(3B):480-88.

Tryon, C. P.
1980. A study of extreme water temperatures at the Lane Spring Trout Management Area. [Mark Twain Nat. For., Rolla, Mo. unpubl. in-service rep. 9 pp.]

U. S. Army Corps of Engineers
1982*a*. Report on the impacts of commercial dredging on the fishery of the lower Kansas River. U.S. Army Corps Eng., Kansas City, Mo. Rep. No. DACW 41-79-C-0075.

1982*b*. Report on the cumulative impacts of commercial dredging on the Kansas River: a social, economic, and environmental assessment. U.S. Army Corps Eng., Kansas City, Mo. Rep. No. DACW 41-79-C-0017.

U.S. Department of Agriculture
1977. The status of land disturbed by surface mining in the United States: basic statistics by state and county as of July 1, 1977. U.S. Dep. Agric. SCS-TP-158. Washington, D.C. 124 pp.

Webb, W. E. and O. E. Casey
1961. The effect of placer mining (dredging) on a trout stream. Idaho Dep. Fish and Game. Job Complet. Rep., Proj. No. DJ-F-34-R. 22 pp.

West, E. A.
1978. The equilibrium of natural streams. Geo Abstracts Ltd., Univ. East Anglia, Norwich, G.B. 205 pp.

Wisconsin Department of Natural Resources
1987. Environmental impact assessment—application to dredge sand and gravel from the Big Rib River. Wis. Dep. Nat. Resour., North Cent. Dist. Docket No. 3-NC-85-045. 18 pp.

1991. Nonmetallic mining and reclamation associated with navigable waterways and associated areas. Chap. NR 340. Wis. Admin. Code: 37-45.

Woodward Clyde Consultants
1976*a*. Aggregate extraction in Yolo County: a study of impacts and management alternatives. Woodward Clyde Consult., San Francisco. 128 pp.

1976*b*. Gravel removal studies in selected arctic and subarctic streams in Alaska. U. S. Fish and Wildl. Serv., Washington, D.C. FWS/OBS-76/21. 126 pp.

1980*a*. Gravel removal guidelines manual for arctic and subarctic floodplains. U. S. Fish and Wildl. Serv., Washington, D.C. FWS/OBS-80/09. 169 pp.

1980*b*. Gravel removal studies in arctic and subarctic floodplains in Alaska. U. S. Fish and Wildl. Serv., Washington, D. C. FWS/OBS-80/08. 403 pp.

Yokley, P., Jr. and C. H. Gooch
1976. The effect of gravel dredging on reservoir primary production, invertebrate production, and mussel production. Tenn. Wildl. Resour. Agency. Proj. No. 2-245-R. 32 pp.

Yorke, T. H.
1978. Impact assessment of water resource development activities: a dual matrix approach. U. S. Fish and Wildl. Serv., Washington, D.C. FWS/OBS-78/82. 27 pp.

Ziebell, C. D.
1957. Silt and pollution. Wash. Pollut. Control Comm. Inf. Ser. No. 57-1. 4 pp.

Ziebell, C. D. and S. K. Knox
1957. Turbidity and siltation studies, Wynooche River. Wash. Pollut. Control Comm. Olympia, Wash. 7 pp.

Zmuda, M. J.
1982. The formulation of lowland sand and gravel excavation regulations: Wisconsin Administrative Code NR-340. pp. 67-72 *in* W. D. Svedarsky and R. D. Crawford, eds. Wildlife values of gravel pits. Northwest Agric. Exp. Stn., Univ. Minn. Tech. Coll., Crookston. Misc. Publ. No. 17. 249 pp.

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