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Dam Removal: A Tool For Restoring Riverine Ecosystems

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Introduction

According to the 1992 National Inventory of Dams, there are currently over 75,000 dams in the United States blocking over half a million miles of what were once free flowing rivers (Shuman 1995). There are an additional two million smaller dams in existence that do not meet the criteria for inclusion on the dam inventory (Haberman 1995) but that nevertheless obstruct many more miles of streams. Most dams in the United States were built between 1900 and 1949. They were constructed for the purposes of: generating power, providing water supplies and recreation, as flood control structures, for fire protection and irrigation, and to foster community and regional development (Born et al. 1998, Shuman 1995).

The average life expectancy of a dam is 50 years and more than 25% of the dams in the United States have now reached that threshold. In the next 20 years that percentage will rise to more than 80% (American Rivers 1999). As these structures age and deteriorate, or no longer serve their intended purpose, decisions to repair or remove them are, by necessity, becoming increasingly common. The financial investment to rehabilitate a dam often far exceeds that needed to remove the structure without even factoring in future maintenance and liability insurance costs if the dam is left in place (Born et al. 1998, River Alliance of Wisconsin 1999). These high repair costs have led many private entities and municipalities, who own over 90% of dams, to consider dam removal as an alternative to structural rehabilitation.

In addition, there are over 2,400 privately owned hydropower dams in the country that are regulated by the Federal Energy Regulatory Commission (FERC) (American Rivers 1999). The owners of these dams must re-apply for an operating license every 30 to 50 years. During the re-licensing process the owners must be able to demonstrate that the operation of the dam continues to be in the public interest. FERC must consider both power and non-power benefits equally in making its decision. If the owners cannot justify the dam’s continued existence, removal may be the alternative that best serves the public interest. Thus, the FERC re-licensing process is also leading to increased numbers of dam removals (Bowers and Bowman 1995).

There are myriad ecological, legal, historical and socioeconomic considerations that need to be addressed related to the decision to remove or retain a particular dam. This paper will focus primarily on the ecological considerations.

The ecological impacts of dams on river ecosystems have been well reported in both the scientific and popular literature (Winston et al. 1991, National Research Council 1992, Nilsson and Dynesius 1994, Ligon et al. 1995, Federal Interagency Stream Restoration Working Group 1998). The extent and type of effects largely depend on the size and purpose of the dam. In addition to the obvious effects of converting a portion of a riverine ecosystem to a lake environment, altering downstream flow rates and patterns of both water and sediment, and blocking movement of aquatic organisms, dams also affect water quality and cause long-term changes to downstream channels, riparian zones and floodplains.

It must also be noted however, that dams can provide some positive ecological effects. For example, dams can prevent or retard upstream migrations of detrimental non-native species or lacustrine piscivorous predators, provide habitat for different assemblages of flora and fauna, including rare species, and create additional wetland habitat (Ruhr 1956, Minnesota Department of Natural Resources 1994a, author pers. observation).

In contrast to the effects of dam construction, little detailed scientific information has been gathered on the ecological impacts associated with dam removals. While dam removal is generally considered a powerful tool in river restoration, improper handling of dam deconstruction and the associated accumulation of decades worth of sediment as well as other concerns can have catastrophic consequences on stream ecology.

This paper will propose environmental considerations for assessing dam removal alternatives, describe and evaluate techniques for dam removal and handling of the accumulated sediment load and other issues, and provide accounts of strategies currently being used for restoring riverine ecosystems following dam deconstruction.

Restoration and Retention Alternatives

Assessments of proposals for dam retention or removal usually consider a variety of alternatives (Wunderlich et al. 1994, Shuman 1995). Selection of the alternative with the greatest ecological benefits requires a comprehensive assessment of existing conditions and accurate predictions of the post-removal environment. The environmental assessment should consider, and project possible outcomes for, the following alternatives.

> <u>Full restoration</u> – restore river hydrology and floodplain function, flora and fauna and remove all structures and return topography to pre-construction conditions.
>
> <u>Partial restoration</u> – restore river hydrology and floodplain function with limited removal of structures and alteration of topography.
>
> <u>Partial retention</u> – reduce the size of the impoundment while restoring a portion of the impounded river.
>
> <u>Full retention</u> – retain the dam and reservoir with active management for fish and wildlife resources.

Environmental Assessment

An approach to environmental assessment for evaluating dam removal or retention alternatives was proposed by

Shuman (1995). It is based on a prototype developed by the St. John's River Water Management District for the Rodman Dam in northern Florida. This approach contains 18 research components in two broad categories: physical and chemical, and biological and ecological (Table 1). These criteria were selected to provide the information necessary to make a decision whether to remove or retain a particular dam. If the decision is made to remove the structure, additional work would be needed to prepare for dam removal and river restoration. The cost to conduct the studies shown in Table 1 for a large project such as the Rodman Dam which impounds over 3500 hectares can reach over $800,000. Although the criteria suggested by Shuman (1995) are relatively comprehensive, several important groups of wildlife were omitted. Unionacean mussels, amphibians and reptiles, aquatic invertebrates and tiger beetles are all groups that have the potential to be significantly impacted by dam retention or removal and should be considered in such an assessment.

Table 1. Research Components of the Environmental Assessment of Dam Removal and Dam Retention Alternatives.

Physical and Chemical Components	Biological and Ecological Components
• River transect surveying	• Fish population assessment
• Bathymetric & sediment depth mapping	• Migratory fish populations analysis
• Hydraulic and hydrologic modeling	• Aquatic plant populations and management
• Sediment properties & erodibility characteristics	• Bird populations assessment
• Inundated floodplain analysis	• Endangered, threatened, special concern species
• Sediment transport modeling	• Floodplain forest succession modeling
• Sediment resuspension due to wind	• Habitats assessment
• Sediment loading to the river below the dam	
• Surface water quality analysis	

- Groundwater impacts of drawdown

- Sediment characteristics, toxics & seedbank analysis

The most common environmental concerns during and following dam removal are sediment transport and floodplain dynamics (Shuman 1995). Other ecological concerns include: declining water quality during drawdown, invasion of the upstream portion of the river system by exotic species that were formerly blocked by the dam, loss of wetland habitat and the release of toxins or excess nutrients from the sediment (Cooke et al. 1986, Minnesota Department of Natural Resources 1994a).

Sediment Management

The volumes of sediment trapped behind dams can be staggering. For example, the Elwha and Glines Canyon hydropower dams on the Elwha River in Washington state accumulated a combined total of nearly 16 million cubic yards of sediment during the past 70 or so years since they were constructed (Stoker and Harbor 1991). Even relatively small structures can trap substantial amounts of sediment. The Rapidan Dam in southern Minnesota has accumulated 11 million cubic yards of sediment since it was built in 1910. Although sediment is a natural component of riverine ecosystems, in excessive amounts it is a pollutant. Sediment loading and deposition are considered by many to be one of the most serious water quality problems in the world (Osborne and Kovacic 1993). It can cover fish spawning sites, fill in holding pools and interrupt mussel reproduction, as well as kill adult fish, mussels and other aquatic wildlife directly by clogging gills and causing suffocation.

In addition, toxic substances and nutrients contained in the sediment can also be a concern (Cooke 1986, Judy Mader – Minnesota Pollution Control Agency pers. communication). Heavy metals, poly-chlorinated biphenols (PCB's), industrial solvents, agricultural pesticides (including herbicides) and fertilizers are some of the pollutants that are found in sediments. Two of the nutrients commonly found in excess in sediments are phosphorus and ammonium-nitrogen.

Sediment Management Strategies

Sediment transport invariably occurs following dam removal, but the severity of the problem is determined by the volume of sediments impounded and by the dam removal and sediment management strategies used.

Sediment management in dam removal projects can follow one of three strategies: 1) removal of all accumulated material from the inundated regions and relocation to a terrestrial or saltwater site; 2) allow the river to erode a new channel through the sediment; 3) remove material in the anticipated path of the river leaving the remainder in place (Wunderlich et al. 1994). In all cases, staged draw downs of impoundment water level will be important to dewater and stabilize the sediment as well as minimize resuspension of toxins and nutrients. To further minimize downstream impacts, work should be conducted during low-flow, and temporary coffer dams or diversion channels or tunnels should be used when necessary to divert flow during sediment management activities and dam removal operations. As each stage of the draw-down is completed, silt fencing should be installed at the water's edge to prevent newly exposed sediments from re-entering the stream until the material is stabilized by vegetation or removed.

To determine which option would be most appropriate for a particular site requires careful evaluation of the sediment and the potential toxins and nutrients it may contain. Important sediment analyses include; 1) calculation of sediment volume; 2) grain size analysis to determine percentage of silts, sands, clays, cobbles, etc. that will indicate erodibility and transport characteristics; 3)sampling for potential nutrients and contaminants, seedbank analysis; and 4) sediment modeling to predict fluvial response to dam removal (Anderson 1991, Stoker and Williams 1991, Shuman 1995).

Evaluation of sediments for nutrient levels and the possibility of toxins requires sediment sampling, review of other data and research into past and present land uses (Judy Mader – Minnesota Pollution Control Agency pers. communication). Fish tissue data can provide indications of what pollutants may be present in the watershed. Knowledge of current and past industrial, agricultural and timber harvest practices upstream from the dam can serve as indicators for the types of nutrients and toxins that are likely to be found in the sediments.

Removal of all accumulated sediments to expose the original riverbank would likely be the best approach from an ecological perspective if the sediments could be removed without significant negative downstream impacts. Since all of the original soils contained within the impoundment were covered with water and accumulated sediments for decades, it is possible that those soils were subjected to some of the same effects that occur when soils are kept in an anaerobic environment for extended periods, such as when they are stockpiled for a long period of time. Harris et al. (1989) found that stored topsoil had an increased level of compaction and bulk density, decreased microbial biomass, a lack of mycorrhizal fungi at depth and significant changes in the size, activity and composition of microflora. If these impacts are also found in terrestrial soils that have been inundated for extended periods, soil remediation may be required to restore natural soil fertility.

The sheer volume of sediments contained behind dams, combined with the enormous expense to remove them, difficulties in locating a disposal area and the potential for higher downstream impacts usually means that total sediment removal is not often selected as a practical alternative except in the very smallest of projects. The preferred option in many cases is excavation of a new channel through the material but retention of all other accumulated sediment (Stoker and Harbor 1991, Minnesota Department of Natural Resources 1994a). This option will not incur the same level of downstream impacts that would occur if a new channel eroded naturally and will keep costs at a more realistic level.

Sediment Removal Techniques

There are two major ways that sediment is removed from reservoirs (Cooke et al. 1986). One method involves the use of a grab bucket, hydraulic dredge or special purpose dredge to remove sediment generally while the water is still in the reservoir. The second method involves drawdown of the water body and then removal of the accumulated sediment with traditional earth-moving equipment after the material has de-watered.

A major concern associated with in-lake dredging is the re-suspension of sediment, and liberation of nutrients and possibly toxins in the process. Special purpose low turbidity dredges made for removing fine grained sediments and some types of toxins have been developed to combat this problem but even these would probably be considered secondary to drawdown and excavation as a sediment extraction technique for dam removal when riverine ecosystem restoration is a primary goal.

Sediment-trapping matting, such as SediMat™, has been used in some smaller projects to minimize the amount of sediment flowing downstream (Phil Gingrich – Geauga Park District pers. communication). It is installed on the bottom of the downstream channel during and after sediment removal and dam deconstruction to capture the inevitable sediment transport that will take place. Rip-rap and vegetative revetments are also used to stabilize sediments after dam removal (Kanehl and Lyons 1997, Phil Gingrich – Geauga Park District pers. communication).

Another strategy recommended for reducing sediment transport down stream is the construction of a sediment trap or sediment basin immediately upstream from the dam during sediment removal activities (Wisbar Legal Resources 1998). Sediment traps are used in small projects when the total contributing drainage area is less than ten acres. Sediment basins are for larger projects where the total contributing drainage area is greater than ten acres and less than 100 acres. The minimum volume of a trap or basin should be 67 cubic yards per acre of drainage area. These traps and basins have been shown to be 50%-80% effective (Mecklenburg 1996).

Although sediment removal from reservoirs has been done for decades, the management of sediment resulting from dam deconstruction is a relatively new challenge. Several erosion control experts consulted for an article in a recent issue of the journal, Erosion Control, all stated that they were breaking new ground in this area (Snow 1999). As dam removal projects become more common and new techniques are tried and evaluated, better ways of managing sediment in these situations will undoubtedly emerge.

Sediment Toxins

The decision to leave polluted sediments in place or remove them depends on a number of factors such as: the amounts and types of toxins present, the soil types and surficial geology of the underlying river bed, and the intended uses of the dredged sediment. Few governmental agencies currently have guidelines that address pollutant levels in sediment. However, one of the most comprehensive available today is produced by the Ontario Ministry of Environment and Energy (1993). It lists environmental effect (i.e., no, low, severe) levels for over 50 pollutants including heavy metals, polychlorinated biphenyls, solvents and pesticides. At low effect levels, the deciding factors related to sediment removal often focus on planned uses for the dredged material and the potential for re-suspended toxins entering groundwater through permeable ground layers such as karst topography. In many cases, impounded sediments are free of toxins at levels that would be detrimental to human health or ecosystem function so the material can be removed and used for road base, building pads or for other purposes. As pollutant concentrations near the severe effect level, the potential negative impacts to the riverine ecosystem combined with significant limitations on use of the dredged material usually mean that it is best to leave the sediments and dam in place until a method is found which can remove or de-toxify the pollutants. In place, the toxins are not mobile and are isolated from the aquatic organisms above by layers of cleaner, more recently deposited sediment. Even in sediments that exhibit high levels of pollutants, some dredging may be possible because most toxins are not evenly distributed in sediments. In those cases, sediment removal can occur so long as the areas of high pollutant concentrations are avoided (Judy Mader – Minnesota Pollution Control Agency pers. communication).

Re-vegetation Strategies
Newly exposed sediments should be planted with a cover crop to stabilize them for the short term. Annual rye grass (*Elymus* spp.) has been used in some cases but it is probably not the best choice. Annual rye grass can be allelopathic which could retard or prevent establishment of desirable species. Other species that have been planted on exposed accumulated sediments include: white millet, smartweed (*Polygonum* spp.), and barnyard grass (*Echinochloa* spp.) (Kanehl and Lyons 1997, Phil Gingrich – Geauga Park District pers. communication). Natural recolonization will occur on most sites, but it is important to be alert for and control common streamside exotics such as Japanese knotweed (*Fallopia japonica*) and reed canary grass (*Phalaris arundinacea*) so that they don't overcome the native species and create a depauperate community. At the former Silver Creek impoundment in northeast Ohio, one year after dam removal, remaining sediments were dominated by at least two species of smartweed (*Polygonum* spp.). Other plants found growing in the sediments were: boneset (*Eupatorium perfoliatum*), closed gentian (*Gentiana clausa*), blue vervain (*Verbena hastata*), mad dog skull-cap (*Scutellaria lateriflora*), bur marigold (*Bidens* spp.), ironweed (*Vernonia* spp.), joe-pye weed (*Eupatorium* spp.), great lobelia (*Lobelia siphilitica*), tick-trefoil (*Desmodium* spp.) and yellow iris (*Iris pseudacorus*) (Phil Gingrich - Geauga Park District pers. communication). Additional plantings could augment natural recolonization and help prevent exotics invasion. Unaltered stream banks up and down stream from the impoundment area can be used as reference sites for determining floristic composition.

Other Contaminants

In addition to sediment and the potential toxins and nutrients contained in it, there are two other sources of contaminants that need to be addressed. The powerhouses, turbines, generators and other equipment present in hydroelectric dams could be the source of oil, grease, solvents or other pollutants. In the case of many older hydroelectric dams that are no longer operating, the electric company removed hydropower equipment when dam operations ended and so is not an issue during dam deconstruction. However, in those cases where the equipment is still in place, an evaluation of possible pollutants should be made prior to deconstruction and a plan prepared to prevent releases of those substances during turbine and generator removal. The plan should also include containment and clean-up procedures if accidental spills occur.

A second source of contaminants is the road-building materials, fuel and lubricants necessary to provide access for, and maintenance of, the heavy equipment involved in sediment removal and dam deconstruction. The use of clean boulder rubble for construction of temporary roadways, current deflectors and coffer dams will minimize additional sediments loads and help prevent accidental introductions of invasive exotic plant species to the project site (Minnesota Department of Natural Resources 1994b). Careful handling of fuels and lubricants combined with a contingency plan for accidental spills should prevent any of these potential pollutants from negatively impacting the area.

Exotic Species

One of the benefits of dam removal is the re-opening of the river corridor for passage by fish and other aquatic organisms. Unfortunately, it also provides the opportunity for non-native aquatic species to invade sections of rivers and lakes upstream of the dam site from which they have been previously excluded. One of the principal concerns related to the Kettle River dam removal in Minnesota was the potential introduction of the common carp (*Cyprinus carpio*) to the lakes and streams of the upper Kettle River watershed (Minnesota Department of Natural Resources 1994a). Carp can negatively impact aquatic habitats of lakes and wetlands because of their feeding behavior. Carp feed primarily on invertebrates and other benthic materials. This increases the turbidity of a water body in two ways. First, flocculent materials become suspended in the water column as carp search for food in the substrate. Secondly, digestion of benthic organisms results in the excretion of nutrients, many of which are soluble and thus available to phytoplankton for growth. Increased turbidity can result in declining macrophyte abundance due to less sunlight penetrating the water column. Lakes with historically marginal oxygen supplies may experience winter kill after carp invasion because of increased oxygen demand by algae.

The carp is just one of a whole host of non-native aquatic organisms that have been, and continue to be introduced to North American waters. Two of the most recent fish introductions to the United States are the ruffe (*Gymnocephalus cernuus*) and the round goby (*Neogobius melanostomus*). The rusty crayfish (*Orconectes rusticus*), a species native to the southeastern United States has been introduced to streams in other parts of the country. Where it has invaded, the rusty crayfish has been found to out-compete native crayfish, disrupt fish spawning, severely impact aquatic vegetation and potentially impact benthic invertebrates (Karns and Maercklein, 1999). Although zebra mussels (*Dreissena polymorpha*) can have major impacts on aquatic systems, they are usually not able to naturally extend their range upstream because their veliger life stage does not attach to fish.. Another exotic mussel species, the Asiatic clam (*Corbicula fluminea*) however, has spread throughout the entire United States except for portions of the northern tier of states. It can occur in spectacularly high densities (> 10,000 individuals per meter^2) and has been reported to displace native mussels (Peckarsky et al. 1990).

Although barriers can be constructed to prevent natural invasions of some non-native species, none of the barricades currently known are selective for certain species. A "swinging fingers" gate made of iron was installed at the outlet of a lake upstream from the Kettle River dam to prevent carp from entering the lake after dam removal. During high flows, when upstream fish movement would be retarded, the "fingers" are pushed upward by the force of the water draining out of the lake. At lower flows, the "fingers" rest back on the sill and prevent larger fish from entering the lake from downstream. Fish less than one and one-half inches wide could swim between the bars, but it was felt that the habitat in the Kettle River was so poor for carp and the lake far enough upstream that only larger fish would make it to the lake outlet (Dirk Peterson – Minnesota Department of Natural Resources pers. communication). Other methods for preventing upstream fish movement include: a drop-off of two and one-half feet without a plunge pool or three and one-half feet with a plunge pool, acoustic barriers and electric barriers.

Special Concerns

Freshwater mussels, which inhabit lakes and rivers are considered the most endangered faunal group in continental North America. Current extinction rates for mussels exceed those of amphibians, birds, mammals and all other groups. Future extinction rates for mussels are predicted to be nearly twice that of any other organismal group (Ricciardi and Rasmussen 1999). Mussel declines have been linked to dams, siltation, agricultural run-off, acid mine drainage, industrial pollution and heated effluent. Although dams have clearly played a role in mussel declines, they have also created refugia for remnant populations. Often the richest mussel beds are now found immediately downstream from dam structures (Dan Hornbach – Macalester College pers. communication). The relatively silt-free coarse sediments and greater concentration of algal food sources provide excellent habitat for these organisms. Mussels filter feed and therefore are highly impacted by fine sediments although within the group there is a wide range of sensitivity. Thin-shelled, fast growing species are likely to be more sensitive whereas thick-shelled, slow growing species will be less sensitive.

The location of refugia directly below dams places these, already rare, species at great risk during dam removal operations. A thorough mussel inventory downstream from a proposed dam removal is essential to obtain the information needed to begin to assess environmental concerns. Comprehensive sediment control strategies must be implemented if rare species or large populations are located downstream from the dam site to prevent significant negative impacts.

Another technique that has been used successfully for preserving the richness and abundance of mussel species in certain areas is relocation (Cope and Waller 1995, Cunningham et al. 1999). Mussels have been relocated within the same river and have also been removed from a stream during a time when disturbance was occurring, stored in a holding area and returned when the effects of disturbance were no longer present. This procedure could prove invaluable for preserving mussel populations at sites where dam deconstruction is planned.

Evaluation

In spite of increasing efforts directed at restoration of riverine ecosystems, postproject evaluations have generally not been conducted. Recent papers on river restoration have recommended an emphasis on geomorphic characteristics of the restored reach as the basis for evaluating project success (Gore and Shields 1995, Kondolf and Micheli 1995). This is based on the recognition that interactions between the river channel, floodplain and stream flows provide the supporting framework for aquatic and riparian structures and functions. Post-project evaluation must be incorporated in project planning to insure that baseline studies and clearly defined criteria for success, based on project goals, are included as well as adequate funding for completion. It is recommended that the evaluation program be conducted for at least ten years (Kondolf and Micheli 1995).

Conclusion

Currently, there are increasing numbers of aging dams in need of repair and an unusually large number of hydropower dams that must be relicensed to continue operating. This provides an unprecedented opportunity for restoration of riverine ecosystems that have been blocked by dams for a half-century to a century or more. Although dam removal was once considered a radical approach to river restoration it is now considered a cost-effective and ecologically sound practice for restoring riverine ecosystems (American Rivers 1999). However, inadequate evaluation of the ecological consequences of dam removal or insufficient implementation of measures to protect the down stream environment can be disastrous. With North America's freshwater fauna experiencing extinction rates five times greater than terrestrial wildlife, it is imperative that dam deconstructions be undertaken utilizing the best information and technology available to minimize environmental impacts.

Literature Cited

American Rivers. Background on dam removal. <http://www.amrivers.org/damback.html>1997 (Accessed September 21, 1999).

Anderson, J. D. 1991. Predicted fluvial response to dam removal in the Kalamazoo river valley, Michigan. in Hydraulic Engineering. proceedings of the 1991 National Conference of the American Society of Civil Engineers. ASCE. New York, New York. 686-691.

Born, S. M., Genskow, K. D., Filbert, T. L., Hernandez-Mora, N., Keefer, M. L., and K. A. White. 1998. Socioeconomic and institutional dimensions of dam removals: the Wisconsin experience. Environmental Management 22 (3): 359-370.

Bowers, R. and M. Bowman. 1995. Hydroelectric relicensing. River voices 5 (4): 7-10.

Federal Interagency Stream Restoration Working Group. 1998. Stream corridor restoration: principles, processes and practices. 650 pp.

Cooke, G. D., E. B. Welch, S. A. Peterson and P. R. Newroth. 1986. Lake and River Restoration. Butterworth Publishers. Stoneham, Massachusetts. 392 pp.

Cope, W. G., and D. L. Waller. 1995. Evaluation of freshwater mussel relocation as a conservation and management strategy. Regulated Rivers: Research and Management 11: 147-155.

Cunningham, L. A., D. J. Hornbach and M. C. Hove. 1999. The efficacy of mussel relocation as a resource management tool: an experiment in the St. Croix river. In Eleventh Annual St. Croix River Research Rendezvous Program Schedule and Abstracts.

Gore, J. A. and F. D. Shields, Jr. 1995. Can large rivers be restored? Bioscience 45 (3): 142-152.

Haberman, R. 1995. Dam fights of the 1990's: removals. River voices 5 (4): 1-6.

Harris, J. A., P. Birch and K. C. Short. 1989. Changes in the microbial community and physio-chemical characteristics of soils stockpiled during opencast mining. Soil Use and Management 5: 161-168.

Kanehl, P. D. and J. Lyons. 1997. Changes in the habitat and fish community of the Milwaukee river, Wisconsin, following removal of the Woolen Mills dam. North American Journal of Fisheries Management 17: 387-400.

Karns, B. N. and R. Maercklein. 1999. 1999 crayfish distribution survey of the St. Croix National Scenic Riverway, St. Croix and Namekagon Rivers, Minnesota and Wisconsin. In Eleventh Annual St. Croix River Research Rendezvous Program Schedule and Abstracts.

Kondolf, G. M. and E. R. Micheli. 1995. Evaluating stream restoration projects. Environmental Management 19 (1): 1-15.

Ligon, F. K., W. E. Dietrich and W. J. Trush. 1995. Downstream ecological effects of dams. Bioscience 45 (3): 183-192.

Mecklenburg, D. 1996. Rainwater and land development. Ohio Department of Natural Resources. Columbus, Ohio. 189 pp.

Minnesota Department of Natural Resources. 1994a. Kettle River dam removal environmental assessment worksheet. Minnesota Department of Natural Resources St. Paul, Minnesota

Minnesota Department of Natural Resources. 1994b. Kettle River dam removal project, need for an environmental impact statement (EIS) record of decision. Minnesota Department of Natural Resources St. Paul, Minnesota

National Research Council. 1992. Restoration of aquatic ecosystems. National Academy Press. Washington, D.C. 552pp.

Nilsson, C. and M. Dynesius. 1994. Ecological effects of river regulation on mammals and birds: a review. Regulated Rivers: Research and Management 9: 45-53.

Ontario Ministry of Environment and Energy. 1993. Guidelines for the protection and management of aquatic sediment quality in Ontario. Ontario Ministry of Environment and Energy. Ontario, Canada.

Osborne, L. L. and D. A. Kovacic. 1993. Riparian vegetated buffer strips in water-quality restoration and stream management. Freshwater Biology 29 243-258.

Peckarsky, B. L., P. R. Fraissinet, M. A. Penton and D. J. Conklin Jr. 1990. Freshwater macroinvertebrates of North America. Cornell University Press. Ithaca, New York. 442 pp.

Ricciardi, A., and J. B. Rasmussen. 1999. Extinction rates of North American freshwater fauna. Conservation Biology 13 (5) 1220-1222.

River Alliance of Wisconsin. Restoring rivers through small dam removal. <wysiwyg://14/http://www.wisconsinrivers.org/smldam> (Accessed September 22, 1999).

Ruhr, C. E. 1956. Effect of stream impoundment in Tennessee on the fish populations of tributary streams. Transactions of the American Fisheries Society 86: 144-157.

Shuman, J. R. 1995. Environmental considerations for assessing dam removal alternatives for river restoration. Regulated Rivers: Research and Management 11: 249-261.

Snow, D. 1999. Dam removal and sedimentation issues. Erosion Control 6 (2) 32-44.

Stoker, B. and J. Harbor. 1991. Dam removal methods, Elwha river, Washington. in Hydraulic Engineering. proceedings of the 1991 National Conference of the American Society of Civil Engineers. ASCE. New York, New York. 668-673.

Stoker, B., and D. T. Williams. 1991. Sediment modeling of dam removal alternatives, Elwha river, Washington. in Hydraulic Engineering. proceedings of the 1991 National Conference of the American Society of Civil Engineers. ASCE. New York, New York. 674-679.

Wisbar Legal Resources. Kurt F. Froebel versus Wisconsin Department of Natural Resources. <http://www.wisbar.org/WisCtApp2/1q98/97-0844.html> 1998 (Accessed September 22, 1999).

Wunderlich, R. C., B. D. Winter and J. H. Meyer. 1994. Restoration of the Elwha river ecosystem. Fisheries 19 (8) 11-19.