TECHNICAL ISSUES IN SMALL DAM REMOVAL ENGINEERING

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ABSTRACT

With thousands of communities facing decisions regarding aging small dams, dam removal is often a viable option to restore aquatic habitat and relieve what can be an economic burden and public safety hazard. Although more than 500 dams have been removed from rivers and streams throughout the United States, there is relatively little published information available to guide resource managers and consultants through a small dam removal project.

While the physical removal of the dam structure itself can be a relatively straightforward process, there are several associated issues to address in order to protect and restore aquatic and riparian habitat and the stream channel. Careful planning can limit the effects of released sediment on aquatic life, prevent extensive erosion in the restored stream channel, and limit the potential intrusion of exotic plant species in the former impoundment. Each restoration project is unique and in some cases these issues may be minor. In other cases they can be complex and need to be appropriately managed.

Two national conservation organizations, Trout Unlimited and American Rivers, gathered a group of professionals and researchers with small dam removal experience to produce a publication entitled, *Removing Small Dams: A Practical Guide to Engineering and Other Technical Considerations*. The publication reviews the current practice and theory in sediment management, channel restoration, impoundment revegetation, timing the removal, permitting, and removing structures. This paper provides an overview of many of the various technical issues discussed in the publication.

INTRODUCTION

The National Inventory of Dams (NID) catalogs more than 75,000 dams that are above specified height and impoundment size parameters. Including all of the nation's smaller

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dams, there are hundreds of thousands to possibly millions of dams in U.S. waterways (Johnston, 1992). As more and more of these structures surpass their designed lives and as societal needs change, decisions are increasingly being made to remove many of them. Hundreds of dam owners, communities and local resource managers are faced with determining how to cost-effectively manage these removal projects while preserving aquatic life, re-establishing natural channel processes, minimizing the effects on surrounding property, and ensuring an aesthetically pleasing result.

Although more than 500 dams have been removed in the United States in the last century, surprisingly little documented research exists on the ecological and geomorphic changes that occur following dam removal or on the techniques for managing these projects to achieve desirable results. The sheer number of aging or obsolete small dams in the United States translates into an increasing need for resource managers to be well informed when decisions are made to remove these aging structures.

Two national conservation organizations, Trout Unlimited and American Rivers, brought together a group of resource managers, engineers, and researchers who have been directly involved in more than 50 small dam removals to produce a publication entitled, *Removing Small Dams: A Practical Guide to Engineering and Other Technical Considerations*. This paper provides an overview of many of the issues discussed in that publication, including protection of aquatic habitat, permitting, removal of structures, sediment management, channel reconstruction, and revegetation of exposed land.

Removing a dam requires a multidisciplinary approach, and there are often unforeseen challenges that must be managed or mitigated. Most dam removal projects have unique issues, different project goals, and regional differences in the governing natural processes. The many issues apply in varying degrees to particular projects. For example, some dams trap very little sediment, so managing sediment may not be a significant issue. Some run-of-river dams that have small impoundments require very little channel reconstruction or revegetation following dam removal. There are no universal solutions or methodologies to address many of the technical issues that arise during dam removal projects. It is advisable to enlist the aid of local experts who are familiar with local resources.

Small Dams

There is no standard specification defining the size of a "small" dam. Some agencies consider dams less than 15 feet high as small, while others use a cutoff of 25 feet. The NID uses a combination of height and impoundment size as a cutoff for inclusion (either at least 25 feet high with at least a 15 acre-foot impoundment or at least 6 feet high with at least a 50 acre-foot impoundment). "Small" is a relative term and is used in this paper as a practical guideline rather than a strict specification. A distinction is made between small and large dams because a small dam removal can usually be planned and implemented within one to several years by a community and resource managers, whereas removing a large dam is often a disproportionately larger project. The vast majority of dams that have been removed in the United States have been less than 15 feet tall (Doyle, et al., 2000). Some agencies classify the smallest structures as weirs rather than dams. Regardless of the classification and size, removing these structures warrants consideration of the various issues discussed in this paper.

GENERAL ISSUES

The ultimate goal of designing a dam removal project is to restore the channel and its biological function to the best long-term sustainable state possible. In reality, projects are often guided by budgets, permitting regulations, and public concerns. These issues are discussed below.

Cost Issues

Engineers and contractors have frequently overestimated the cost of removing small dams (Trout Unlimited, 2001). For example, the cost estimate of removing Mounds Dam from the Willow River in Wisconsin was $1.1 million. When the dam was removed in 1998, the actual project cost was approximately $500,000. Faced with inexperience with dam removal projects, it is likely that planners estimate conservatively to make sure their costs are covered. As they become more familiar with the implementation of removal projects, estimates will likely become more accurate more often. In fact, project managers often prefer to use contractors who have experience in removing dams.

While certain techniques may be necessary for a particular project, the greatest expenses incurred by small dam removal projects have included dredging, off-site disposal of materials, developing access to the structure, and water control during construction. Often the time and labor required to physically remove the dam is the least expensive component of the project.

There are generally many options for managing the various technical issues involved in removing small dams. Creative thinking by project managers can often lead to lower cost alternatives without compromising the integrity of the project. Small dam removals can be managed very cost-effectively. For example, since 1995, more than 50 small dams have been removed in Pennsylvania with total project costs ranging from $5,000 to $125,000.

Permits

Depending on the regulatory environment at a particular site, the permitting process can significantly guide project design. Removing a small dam requires federal, state, and local permits. These permits ensure that the project is handled safely and minimizes short- and long-term impacts to the river and floodplain. While federal permits are administered by the U.S. Army Corps of Engineers (ACOE) and, if applicable, the Federal Energy Regulatory Commission (FERC), each state and local government has different permitting requirements.

Because dam removal is relatively new in many areas, the permitting process can be challenging. Many state and federal agencies are not yet practiced at moving restoration projects, such as dam removals, through the permitting process. For the most part, the relevant permitting requirements were designed for projects that are potentially more destructive to navigation or environmental quality, and therefore dam removal does not fit easily into the requirements. Depending on the state's regulatory environment, permitting can be expensive and time-consuming. On the other hand, some states have permitting exemptions for environmental restoration projects.

Public Information

Removing a small dam is often a difficult and controversial decision for a community. Engineers and other project planners can play a crucial role in the public information process, both to inform the public about expectations and to receive input on site restoration possibilities. Perhaps the most important information to relay is that removal of a dam, no matter how well designed, will have some negative impacts on aesthetics and the environment for a short duration. In the long term, environmental benefits outweigh short-term impacts in the vast majority of cases. The public should expect a period of time following dam removal and site restoration that the project area may be aesthetically displeasing.

TIMING THE REMOVAL

There are several issues to consider in timing a small dam removal. When all issues are considered at a particular site, there may not be a time when there will be no short-term impacts or risk of impact on aquatic species. However, such short-term impacts may be acceptable relative to the long-term benefits. Consider the various issues and determine the timing that minimizes the risks. These issues include:

Protecting Aquatic Species: While restoration projects often focus on particular species (i.e., threatened or endangered species, or species of economic or societal value), consider the impact that dam removal will have on all species. Identify the various species that live in the river or on the floodplain and their life histories. Avoid timing the removal during the spawning or migration times of resident or migratory fish.

Avoiding Flood Flows: Reservoir sediment is most vulnerable to erosion immediately following removal when the land is most exposed. Floods can also be particularly detrimental when demolition work is only partially completed. Avoid the risk of flood flows by determining the seasonality of flooding at the site. The potential impacts of a large flood should be estimated for various stages of the project. It is often preferable to proceed with construction during periods of low flow, and in some cases permitting requires it.

Revegetation: If the dam is removed during dormant season for vegetation, then land will remain exposed for longer following removal, increasing erosion risks and the length of time when aesthetics are poor.

REMOVAL OF DAM STRUCTURES

The physical removal of structures is often the simplest aspect of a small dam removal. Several issues that can influence project design and cost include:

Safety: Safety issues should be considered, particularly when heavy equipment is operated in flowing water. An emergency response plan should be developed and ready to be implemented during construction.

Access to the Site: Having to develop special access to the site can significantly increase project costs. If the stream bottom is stable and permitting conditions allow for it, equipment can be driven directly on the streambed. Dams have also been removed by driving equipment directly on top of the crest of the dam, providing it is of sufficient size and stability. Where access is difficult, access roads and ramps can be constructed into the channel or floats can be used for equipment.

Dewatering: For most small dam removals, the impoundment is drained prior to removing structures. This is achieved by opening control gates, pulling flashboards, or operating other devices that permit the impoundment to drain. In cases where such devices do not exist or no longer function properly, the impoundment can be drained by creating a breach in the dam and then incrementally increasing the size of the breach to allow the impoundment to slowly drain.

Depending on site conditions, removing the structure during low flow conditions can eliminate the need for extensive dewatering. If necessary, the dam can be breached on one side, commonly at the point of the natural flow channel and then the remainder of the structure removed from the alternate side. During low flow, this may not even be necessary, as much of the structure may no longer be in the water with the impoundment drained.

Cofferdams have been used for dewatering at small dam sites. Common cofferdams used for flow diversion have included earthen structures, jersey barriers, sand bags, and Porta-dams. On many small dams, the cost and complexity of a cofferdam can be avoided by removing the structure "in the wet" if regulatory conditions permit.

Demolition Techniques: Small dams have most commonly been removed by heavy equipment, often a hydraulic hammer or claw attachment mounted on a backhoe. Under some circumstances, such as where structural materials are particularly dense, explosives may be a useful alternative. Many project managers avoid using explosives because of safety and regulatory issues and because the results are less predictable.

Disposal of Materials: If demolition spoils consist of concrete and native materials, on-site disposal may be possible and can significantly decrease costs. In many cases, spoils have been used as part of bank stabilization plans, to fill scour holes caused by the dam, or strategically placed in the channel as habitat structures. Metal reinforcements that may exist in the concrete should be cut flush and hauled away so as to not pose a safety hazard. Some dam materials can be sold and reused, reducing total costs.

Protecting Infrastructure: During the planning phase of the project, floodplain and instream infrastructure should be assessed to determine whether bridges, culverts, utility pipes, or other infrastructure might be affected, particularly by the drop of water level in the impoundment. If necessary, some structures may have to be stabilized or relocated. Structures that have been installed since the dam was built may require the most attention. In some cases, measures taken to protect infrastructure can significantly add to project costs.

SEDIMENT MANAGEMENT

Sediment management can be the most challenging aspect of a small dam removal project, as even small structures can hold back large amounts of sediment. Massive and sudden sediment releases, and potentially long-term erosion of impounded sediment can be harmful to the aquatic environment. On the other hand, a healthy river naturally transports some quantity of sediment, and sediment is often lacking and needed downstream of a dam. Sediment management is not always a major issue because some dams do not trap large quantities of sediment or because the sediment release will be of similar magnitude as natural sediment loads. For example, the greatest sediment release from the Edwards Dam removal on the Kennebec River in Maine was from the earthen cofferdam constructed to facilitate the dam's removal, and not from the impoundment.

Assessing Impoundment Sediment

Assessing the necessary extent of sediment management involves determining the volume of sediment in the impoundment, testing for contamination, and estimating the transport of the sediment. In general, run-of-river dams with impoundments confined to the high water level of the channel have less sediment storage capacity than impoundments that extend beyond the stream channel and inundate the floodplain.

Sediment Quantity and Erodibility: In most small dam impoundments, sediment samples can be gathered and sediment depths assessed with a hand held auger operated from a small boat or by wading. In deeper water or sediment depths, mechanical boring techniques may be necessary. Gathering sediment samples can be significantly simplified by temporarily draining the impoundment, if possible.

Important physical parameters to measure include grain size distribution, density, shear strength, cohesion, stratification, natural armoring potential, organic content, and moisture content. Grain size is an important factor in determining the potential for sediment transport, assessing disposal options, and determining channel stability after dam removal. Measuring organic content can help to determine if the upstream channel will naturally revegetate following dam removal.

<u>Testing</u> <u>and</u> <u>Managing</u> <u>Contamination</u>: Contaminants can collect in impounded sediment and accumulate to toxic levels. Perhaps the most crucial step for project success is evaluating the toxicity of material in the impoundment. Releasing toxins into the environment can be devastating to water quality, aquatic species, and other wildlife that depend on aquatic species for food. The 1974 removal of Fort Edward Dam from the Hudson River in New York released several tons of PCB-laden sediment downstream. The effects have yet to be fully remediated and the experience continues to serve as a lesson for river engineers (American Rivers, et al., 1999).

Chemical properties should be sampled based on regulatory requirements and the likelihood that a specific contaminant may be present at the site. The most basic analysis for determining the possibility of contaminated sediment is to assess the previous and current industrial, agricultural, and other land uses of the watershed upstream. Because toxins are more likely to bind with fine-grained sediment, a grain size analysis can help with locating potential contaminants.

It can be advantageous to meet with regulatory agencies early on to determine if chemical testing is needed or will be required, and if so what parameters should be tested. Regulatory agencies usually have the best information regarding the potential for contamination within a specific river system.

If contaminated sediment is found, determine if it will be in the flow path when the dam is removed or if it will remain buried. Also determine if the level of contamination is greater than levels upstream and downstream of the dam. Sediment accumulated in an impoundment presents a good opportunity for removing contaminated materials from the system, but if downstream reaches are similarly contaminated, then the additional impacts of removing a dam may be minimal.

Toxicity problems have been successfully managed in many small dam removals. For example, prior to removing Oak Street Dam in 2000 from the Baraboo River in Wisconsin, 3000 cubic yards of material contaminated by coal tar were removed. A cofferdam was utilized to allow contamination removal in dry conditions in order to prevent suspension of material into the water (Vogt, 2000).

<u>Estimating</u> <u>Sediment</u> <u>Transport</u>: There are several simple methods for analyzing the quantity of sediment that may be transported during and following a small dam removal. Selecting the right level of analysis of sediment fate can be challenging. Small dam removals often do not merit expensive detailed analysis, particularly where there are only small quantities of impounded sediment. Projects with a significant amount of impounded sediment or with highly sensitive downstream habitats may require a more detailed modeling approach. Even when not elaborately modeled, the fate of released sediment should be addressed. Regulators will often characterize the specific level of assessment required for a particular dam removal.

There is no standard method for analyzing dam removal sediment transport. One useful approach to predicting sediment release volumes is to compare the existing riverbed profile with an estimate of the post-removal profile. The width and depth of the post-removal upstream channel can be estimated utilizing reference reaches not influenced by the dam impoundment, both upstream and downstream of the dam. Most simply, the overall channel longitudinal slope upstream and downstream can be compared to determine the amount of material that will be transported in order for the channel through the impoundment to reach a comparable slope. In urban areas where the river channel has been highly manipulated, a suitable reference reach may not be available.

This method of estimation assumes a consistent slope connecting the natural riverbed above the impoundment to the downstream riverbed. However, because dams are often constructed at significant changes in grade, such as at small waterfalls, exposed rock outcrops, or riffles, there is often not a consistent slope. Therefore, this method may overestimate the potential quantity of mobilized sediment. Measuring the depth to a consolidated bed material by boring can increase the accuracy of this approach.

In cases where a more precise prediction of sediment transport is needed, sediment transport models are available with varying degrees of complexity. The primary use of these models is to perform a comparative analysis of various alternatives. There are a variety of models that could be used, including models that estimate sediment transport at individual cross-sections, to continuous-simulation models in one- two- and three-dimensions of the entire reach. Most existing sediment transport models have not been critically tested on dam removals and their accuracy remains uncertain.

The Army Corps of Engineers HEC models have commonly been used in conjunction with small dam removals. The modeling of predicted channel stability after the 1999 removal of four dams from the Naugatuck River in Connecticut was completed by applying the critical shear stress and threshold velocity methods to output from the HEC-RAS water surface profile model.

Williams (1977) analyzed the effectiveness of the Army Corp's HEC-6 model in predicting sediment transport following the 1973 removal of Washington Power Dam from the Clearwater River in Idaho. The results were "very satisfactory." The calculated rate of scour was accurate, but lagged by approximately ten months in some upstream sections.

A considerable amount of professional judgment goes into the methods for estimating sediment transport as explained above. These methods can and have been used successfully on numerous small dam removal projects. However, it is important to remember that the accuracy of the final results will rely heavily on the experience and expertise of the practitioner.

Sediment Management Options

The most common techniques for managing sediment include natural erosion, sediment removal, sediment stabilization, or some combination of these techniques. The American

Society of Civil Engineers' guidelines contain a discussion of these management options (ASCE, 1997).

Natural Erosion**:** Natural river erosion simply means allowing sediment to erode on its own until the river channel reaches a state of equilibrium through the former impoundment. The approach takes advantage of the river's natural processes to erode and transport sediment and naturally armor its channel bed. Portions of the sediment may be transported downstream to deposit in areas of low velocity, such as in natural or man-made pools, along the channel banks, and on point bars. A portion of the sediment will often remain within the impoundment and will eventually stabilize itself.

When utilizing the natural river erosion method of sediment management, it is important to assess the downstream river's capacity for handling the quantity of sediment released.

River systems naturally hold and transport sediment. In some cases, the release of sediment during dam removal may be similar to what mobilizes naturally during a flood event. In cases such as this, the impacts of the removal on the river's sediment balance are likely to be minimal. For example, studies of the South Batavia Dam on the Fox River in Illinois found 19,000 cubic yards of fine grain sediment in the impoundment, but this amount was only 38 percent of the total annual sediment yield. Consequently, the release of this sediment or a portion thereof after dam removal was determined to have a minimal impact downstream, similar to natural flow events.

While natural erosion is the least-cost approach, it is obviously not appropriate if the impounded sediment is highly contaminated, if navigation will be impaired, or if critically sensitive downstream habitats (such as endangered species habitat) need to be protected. Excessive quantities of sediment can cover spawning habitat, fill pools used for resting areas, and smother mussel habitat. When suspended for long periods, it can affect fish respiration.

Sediment Removal**:** Sediment can be removed from an impoundment prior to dam removal by mechanical or hydraulic dredging. This approach can be costly and often cost-prohibitive. Dredging costs can range in the hundreds of thousands of dollars, even in small impoundments (Trout Unlimited, 2001). However, if the river is not capable of transporting the sediment through its system and critical downstream habitat could be adversely impacted, then sediment removal can be a preferable option.

Dredging procedures need to be carefully planned. When an upstream channel is dredged, the design engineer must determine the appropriate river alignment, channel configuration, and stabilization techniques. Without careful consideration of the complexity of a healthy, dynamic river system, extensive dredging and stabilization can result in a channel with less habitat value than the impoundment itself.

Downstream sediment traps can be excavated to collect eroding sediment and facilitate its removal. A sediment trap is basically a hole dug in the riverbed downstream. When water and sediment flows over the hole, a portion of the sediment drops out and deposits in the hole. A primary benefit of sediment traps is that they can be located in sites with easy access for removing material. However, sediment traps should be used with discretion because of potential environmental impacts of excavating the riverbed. Sediment traps are best used when access to the impoundment for dredging is difficult or cost-prohibitive.

The disposal of dredged material can be costly and operationally challenging. Dredged material often needs to be dewatered prior to transport. This can be difficult and expensive if space is not readily available at the site. The selection of a disposal site is based primarily on cost and the physical and chemical composition of the sediment. Sediment is often characterized by its potential disposal sites, such as only in areas that have degraded ground water quality, or only in an industrially zoned area. Regulatory authorities must approve of an appropriate disposal location.

Some options for disposing sediment that is clean or of similar quality to that of the general river sediment include reusing the material on-site as fill, topsoil, or for habitat features; burying the material on-site if space is available; reusing the material off-site, such as for concrete mixtures or as fill; transporting the material to a landfill or other suitable site; and disposing material in the ocean (under very specific disposal requirements). Contaminated materials generally need to be transported to a hazardous waste landfill.

Sediment Stabilization: Sediment is often stabilized by slowly or incrementally draining the impoundment, allowing sediment to drain, revegetate, and stabilize. The sediment stabilization method can be used alone if a well-defined upstream channel already existed beneath the impounded water. An example of this would be an impoundment that had been regularly drained or an impoundment with only small amounts of sediment.

Stabilization of impounded sediment and the upstream channel is usually combined with other management techniques, including the placement of stone, vegetation, or grade control structures. Stabilization of sediment on site can also include the relocation of sediment from within the newly formed channel elsewhere on site, such as along the riverbanks, within an old raceway, or on the floodplain.

Combination of Techniques**:** Most commonly, a combination of approaches is used to manage sediment in small dam removals. Combined approaches on past small dam removals have included:

- A controlled drawdown of the impoundment with natural river erosion and sediment stabilization.
- Removal of a portion of the sediment prior to allowing for natural river erosion.
- Natural river erosion with selective stabilization once the river has started to approach equilibrium.

- Natural river erosion with downstream sediment collection and removal (i.e. sediment trap).
- Partial removal of sediment with stabilization of the remaining portion.
- Relocation of sediment on-site with selective stabilization.

CHANNEL AND BANK RECONSTRUCTION

Many small dam removal projects have simply allowed channels to form naturally through the former impoundment in conjunction with some stabilization of exposed banks. In some cases, more active reconstruction is needed to restore habitat, natural river function, and channel stability. The need for channel reconstruction should be assessed during project planning. Although large-scale channel reconstruction can significantly add to project costs, repairing damage done to habitat or floodplain infrastructure can be more expensive in the long run.

Natural Channel Formation

Allowing the channel to form naturally through the former impoundment is a common low-cost approach. If natural formation is used along with bank stabilization, care should be taken that the channel has settled into a relatively stable pattern before banks are stabilized. As the channel adjusts to the material in the former impoundment, it can shift position, and jump out of even stabilized banks.

Some channels have a natural armor that develops on the bed, consisting of larger particle sizes. This armor layer prevents the scour of underlying materials. However, future hydraulic events, such as an increase in flow velocity, may increase the carrying capacity of the flow, causing the armor layer to break and additional scour to occur (Yang and Simoes, 1998).

Often the longitudinal channel slope through sediment accumulated in the impoundment is flat compared to downstream of the dam and upstream of the impoundment. In channels that lack a self-armoring substrate, the channel bed will erode until the resulting slope linking the upstream with the downstream stabilizes.

To achieve this more stable slope, what is known as a headcut can occur. Headcuts result at large changes in slope, often beginning at the site of the dam. As the channel slope adjusts, channel banks can erode rapidly. As it erodes and adjusts the channel slope, the headcut will migrate upstream until the channel slope stabilizes or it reaches an impermeable barrier. A headcut can be a minor issue in an impoundment with relatively small amounts of sediment, simply resulting in a channel with a more stable slope. However, in an impoundment where the channel must cut through a significant sediment depth, a headcut can leave behind steep, entrenched banks and can release a large amount of sediment into the river. Entrenched banks offer little habitat and can continue to erode and overload downstream areas with sediment.

Active Channel Reconstruction

Active channel reconstruction is only necessary when stabilization of sediment or habitat enhancements are major concerns. The approach utilizes a combination of stable channel design, bank protection, and vegetation for bank and floodplain erosion control. Channel design efforts benefit from consultation with an experienced fluvial geomorphologist.

Designing a channel involves meeting several objectives. The first is flood conveyance. Particularly in urban areas, waterways should convey at least a 100-year flood without causing flood damages. A second criterion is channel stability. Ecological river restorations commonly include channels that can laterally migrate as they do naturally (Miller and Skidmore, 1999). However, harder stability may be necessary where the channel is constrained by structures such as roads or bridge footings. Final criteria include habitat enhancement for aquatic species and aesthetics. In all, it is important to come to agreement with the various stakeholders on the objectives and criteria during the design phase.

One simple approach to channel design is to estimate channel dimensions and planform based on historical dimensions of the channel prior to construction of the dam. This information can be gathered from historical photos. If historical photos are not available, a series of soil cores through the reservoir sediment can provide similar information. Lenhart (2000) was able to estimate channel planform and slope of the pre-dam channel by coring reservoir sediment. However, it is important to assess the changes in the watershed since the time of the historical channel. For instance, if the watershed was primarily forested prior to the construction of the dam, but more recently has been converted to agriculture, then the dimensions of the pre-dam channel will most likely be inapplicable to the new watershed characteristics.

Empirical channel design involves computing estimates of channel longitudinal slope, depth, width, and sinuosity. Channel design is inevitably an iterative process in that a stable design is estimated and then assessed with respect to requisite conveyance of water and sediment. Channel reaches upstream and downstream of the impoundment can be used as reference reaches. Care should be taken to ensure that flow depths, velocities and substrate are appropriate for aquatic species. Local fisheries biologists can help with determining these factors.

Channel stability should also be assessed downstream of the dam. While impoundments fill with sediment, the channel downstream of a dam can become sediment-starved. Renewed sediment flows can alter the downstream channel.

Reconstruction of a channel requires dewatering, grading the channel to specified dimensions, stabilizing bed and bank materials, then reconnecting the segments. Channel banks have historically been stabilized with rock riprap. However, bioengineering stabilization techniques (i.e., using plants, rounded stone, and other natural materials for stabilization) can provide more natural habitat and more dynamic geomorphic stability. Various methods of bioengineered bank protection are reviewed in detail by USDA

(1996) and Shields and others (1995). Bioengineering techniques were used to stabilize banks following the 2001 removal of Kamrath Dam from the Onion River in Wisconsin.

REVEGETATION OF EXPOSED LANDS

The removal of a dam presents the opportunity to restore the newly exposed riparian area of the drained impoundment. Restoring vegetation can provide bank stabilization and erosion control, improve water quality and wildlife habitat, and promote biodiversity.

Natural Revegetation

The revegetation of drained impoundments often occurs quickly without management, because nutrient-rich, highly organic sediment commonly found in impounded areas offers good growth conditions for plants. Significant growth, while dependent on local climate and soil type, may be observed within weeks. For example, plant growth was visible just one week following the May drawdown of Stebbinsville Dam in southern Wisconsin. Three months later, the site was completely revegetated. Notable plant growth had occurred within three to six weeks following the drawdown of Ward Dam in northern Wisconsin in October. In Maine, natural revegetation following the summer removal of Edwards Dam was rapid and exceeded expectations.

In order for natural revegetation to occur, plants must emerge and establish from seed banks, spread to the site from adjacent areas, or disperse (via seeds) from nearby, similar habitats (Middleton, 1999). Some plant species, such as oak and hickory trees, do not colonize well without human intervention.

Natural revegetation is inexpensive, can result in more natural spatial patterns of vegetation, and can preserve naturally occurring species (Middleton, 1999). However, a potential drawback of allowing natural revegetation is that aggressive and exotic species (non-native to the United States) can dominate the site.

Exotic species more readily invade in systems that are highly impacted by human activities (Cox, 1999). Exposed former impoundments may be especially susceptible to such invasions because they contain large areas of bare ground and may contain plentiful banks of non-native seeds. Exotic species can lower overall diversity, furnish poor habitat for wildlife, and can be extremely difficult to eradicate.

Lenhart (2000) surveyed vegetation in five former impoundments in southern Wisconsin that had naturally revegetated over periods of three to 49 years. Plant communities at all five sites were dominated by herbaceous vegetation, and two of the sites contained areas of shrub coverage. However, none of the communities strongly resembled any native Wisconsin plant communities. The younger sites tended to be dominated by individual species, such as stinging nettle. Older sites had higher species diversity, but also possessed larger percentages of exotic species, such as reed canary grass.

Connor (2000) reported on revegetation in three drained impoundments in the Rocky Mountain National Park. Seven years after impoundment levels were dropped, plant diversity was high, with 43 to 48 species present. One exotic species was established at two of the sites, but monitoring in later years indicated the plant was decreasing in density and percent coverage. Park managers expect that the shorelines will eventually return to spruce-fir forest, but the process in such high altitude habitat could take up to 400 years.

Active Revegetation

A more managed approach to revegetation may be desirable to help prevent exotic species invasion, improve bank stability, limit erosion, increase aesthetic and recreational values, and help meet conservation goals. Reference sites near the area can provide a good template. The most successful revegetation efforts following small dam removals have included public input in the restoration plan.

Well-managed revegetation can provide immediate bank stability and protection (Gore, et al., 1995). A fast-growing annual cover crop can quickly stabilize sediment and discourage dominance by aggressive, exotic species. Cover crop species can then be replaced by slower-growing desired species. Annual cover crops, composed mainly of non-native species, were planted in the first year following the 1988 removal of Woolen Mills Dam from the Milwaukee River in eastern Wisconsin. Although certain cover crops species, such as barnyard grass, did not compete strongly with native species once they began to establish, others, such as timothy grass, did inhibit native plants (Kline, 1991). Thus, care should be taken in selecting cover crop species, and the use of native cover crops is highly preferable to non-native ones.

Woody plants can provide more extensive bank stability. Revegetation projects using woody plants begin with species that grow quickly and have extensive rooting for erosion control. Willows are commonly used for this purpose. Willow species occur naturally over much of the country and it is advisable to use local varieties. Other slower growing species can be planted along with the willows to create a succession of species.

CONCLUSION

When managed thoughtfully, removing a small dam can significantly and cost-effectively improve aquatic habitat and water quality. No matter how well a small dam removal project is designed and implemented, there may be some negative short-term impacts to the environment. Restoration of aquatic communities is not an immediate process; stabilization of the stream channel and habitat improvements may take several years as the complex interactions of sediment and flowing water approach an equilibrium. More research and monitoring are needed to quantify the specific effects, positive and negative, of removing small dams.

Nonetheless, there are documented cases of rapid recoveries of aquatic populations. Just one year after the removal of Waterworks Dam from the Baraboo River in Wisconsin, water quality improvements were indicated by increases in both total numbers of aquatic species and species diversity, including increases in less tolerant species. One year following the removal of the Edwards Dam from the Kennebec River in Maine, migratory fish runs returned in numbers that had not been seen for more than 150 years. These cases are representative of an increasing number of situations where resource managers, project engineers, and communities have successfully managed the various issues, resulting in cost-effective improvements to water quality and habitat.

REFERENCES

Allen, J. D. 1995. *Stream Ecology: Structure and Function of Running Waters*. Chapman and Hall.

American Rivers, Friends of the Earth, and Trout Unlimited. 1999. *Dam Removal Success Stories: Restoring Rivers through Selective Removal of Dams that Don't Make Sense*.

American Society of Civil Engineers (ASCE). 1997. *Guidelines for Retirement of Dams and Hydroelectric Facilities*. Task Committee on Guidelines for Retirement of Dams and Hydroelectric Facilities.

Connor, J. 2000. Natural Resources Specialist, National Park Service. Personal communication.

Cox, G. W. 1999. *Alien Species in North America and Hawaii*. Island Press.

Doyle, Martin W., Emily H. Stanley, Michelle A. Luebke, and Jon M. Harbor. 2000. Dam removal: physical, biological, and societal considerations. *American Society of Civil Engineers Joint Conference on Water Resources Engineering and Water Resources Planning and Management*, Minneapolis, MN, July 30 -–August 2, 2000.

Gore, J. A., F. L. Bryant, and D. J. Crawford. 1995. River and stream restoration. In: J. Cairns (ed.). *Rehabilitating Damaged Ecosystems*. CRC Press, p. 245-275.

Johnston, L. R., Associates. 1992. *A Status Report on the Nation's Floodplain Management Activity*. Prepared for the Interagency Task Force on Floodplain Management. Contract No. TV-72105A, Knoxville, TN.

Kline, J. 1991. Riverside Park vegetation inventory and restoration analysis. Part II – 1991 vegetation survey and soil seed bank results. Prepared for the city of West Bend, Wisconsin.

Lenhart, C. F. 2000. *The Vegetation and Hydrology of Impoundments After Dam Removal in Southern Wisconsin*. M. S. Thesis, University of Wisconsin-Madison.

Middleton, B. 1999. *Wetland Restoration: Flood Pulsing and Disturbance Dynamics*. John Wiley and Sons.

Miller, D. E. and P. B. Skidmore. 1998. Application of deformable stream bank concepts to natural channel design. *Proceedings of ASCE International Water Resources Engineering Conference*, Memphis, TN.

Shields, F. D., C. M. Cooper, and S. Testa. 1995. Towards greener riprap: Environmental considerations from micro- to macroscale. In: C. R. Thorne, S. R. Abt, F. B. J. Barends, S. T. Maynord, and K. W. Pilarczyk (eds.) *River, Coastal and Shoreline Protection: Erosion Control Using Riprap and Armourstone*. John Wiley and Sons.

Trout Unlimited. 2001. *Small Dam Removal: A Review of Potential Economic Benefits*.

United States Department of Agriculture (USDA). 1996. Streambank and shoreline protection. Engineering Field Handbook. USDA Natural Resources Conservation Service, Washington, D.C.

Vogt, Rich. 2000. Wisconsin Department of Natural Resources Baraboo River Dam files.

Williams, D. T. 1977. Effects of dam removal: An approach to sedimentation. Technical Paper No. 50. U. S. Army Corps of Engineers, Hydrological Engineering Center.

Yang, C. T. and F. J. M. Simoes. 1998. Simulation and prediction of river morphologic changes using GSTARS 2.0. *3rd International Conference on Hydro-Science and Engineering*, Cottbus/Berlin, Germany, August 31 – September 3, 1998.