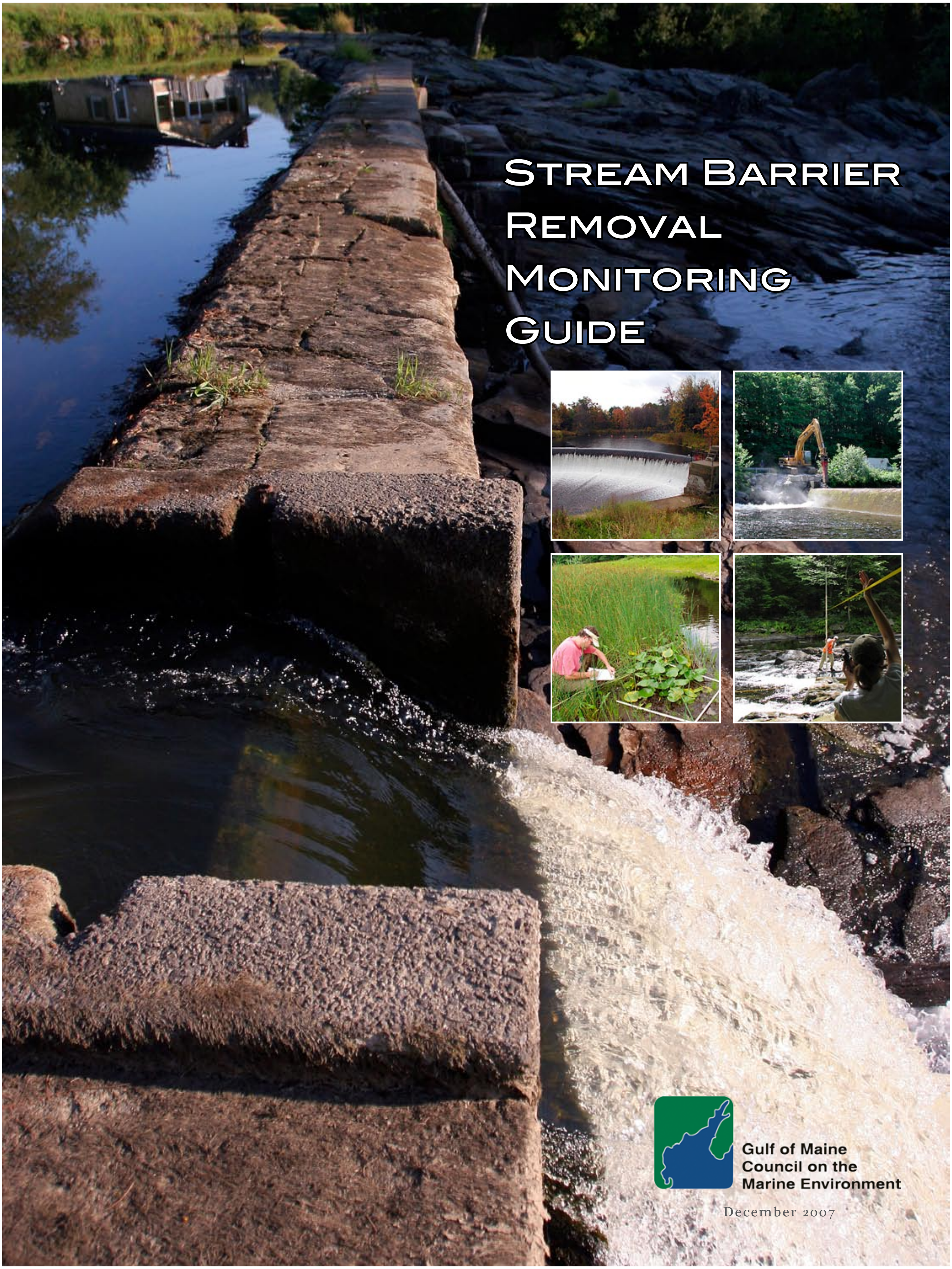
Stream Barrier Removal Monitoring Guide



Gulf of Maine Council on the Marine Environment

December 2007

Stream Barrier Removal Monitoring Guide

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The Gulf of Maine Council's mission:
"To maintain and enhance environmental quality in the Gulf of Maine and to allow for sustainable resource use by existing and future generations."

Gulf of Maine Council on the Marine Environment

December 2007

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Cover photo: Dam on the Royal River in Yarmouth, Maine. *© Peter H. Taylor / Waterview Consulting*
Cover inset photos (clockwise from top left):
Dam removal in progress. *NOAA*
A low-head dam in the Gulf of Maine watershed. *NOAA*
Collecting data along a monumented cross-section. *Karla Garcia / NOAA Restoration Center*
Sampling the riparian plant community. *James Turek / NOAA*

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A stream flows from a culvert under a road.

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Dam and fish ladder.

Karla Garcia / NOAA Restoration Center

Low-head dam spillway on a stream in the Gulf of Maine watershed.

I. ABSTRACT

Across the Gulf of Maine watershed, agencies, non-governmental organizations, and private parties are removing dams and replacing culverts to restore stream processes and fish passage. Significant resources are invested in these stream barrier removal projects, but monitoring the outcomes of the projects usually has not been a priority. The lack of standardized monitoring information for stream barrier removal projects in the Gulf of Maine watershed mirrors a lack of river restoration monitoring nationwide and limits both the ability to document project success and learn from past experiences. The Gulf of Maine Council on the Marine Environment (GOMC) River Restoration Monitoring Steering Committee (Steering Committee) is addressing the need for consistent stream barrier removal monitoring. It has developed a framework of monitoring parameters that can be used for stream barrier removal projects throughout the Gulf of Maine watershed. The watershed covers approximately 70,000 square miles encompassing all of the state of Maine and portions of New Hampshire, Massachusetts, Nova Scotia, New Brunswick, and Quebec.

In June 2006, the Steering Committee convened a Stream Barrier Removal Monitoring Workshop to gather input on stream barrier removal monitoring from more than 70 natural resource scientists, resource managers, and watershed restoration practitioners. Structured breakout and plenary sessions generated priority lists of monitoring parameters specific to stream barrier removal in the Gulf of Maine watershed. From the prioritized lists, the Steering Committee selected eight parameters that, when analyzed collectively, are expected to provide valuable data that will characterize adequately the physical, chemical, and biological response of a given stream to a barrier removal project. These eight parameters, referred to in this document as *critical monitoring parameters*, include monumented cross-sections; longitudinal stream profile; stream bed sediment grain size distribution; photo stations; water quality; riparian plant community structure; macroinvertebrates; and fish passage assessment.

This Stream Barrier Removal Monitoring Guide (Monitoring Guide) presents detailed methods for each of the critical monitoring parameters except for macroinvertebrate and fish passage assessment. Because of the considerable variability associated with assessing these biological parameters, only general guidance is given here. The Monitoring Guide also presents important additional monitoring parameters that practitioners may choose to use on a case-by-case basis.

Mill building and river below a dam.

II. INTRODUCTION

A. CONTEXT

Aging dams and improperly sized culverts are significant natural resource management issues in the Gulf of Maine watershed. Dams and culverts may create impassable barriers for migrating fish, degrade water quality, and negatively alter ecosystem conditions. Many of the thousands of stream barriers in the Gulf of Maine watershed are nearing the end of their design life, and some are being considered for removal or replacement. The socioeconomic costs and ecological impacts posed by aging dams and undersized and impassable culverts have led private entities, natural resource professionals, non-profit organizations, and municipalities to seek dam removal and culvert upgrades as viable options for stream restoration.

Common goals for these stream barrier removal projects include

- reconnecting artificially fragmented stream and riparian systems;
- restoring instream habitat for migratory and resident fishes;
- restoring natural flow regimes and stream processes; and
- improving water quality.

Understanding the effectiveness of barrier removal with respect to these goals requires systematic project monitoring and data reporting. To our knowledge, a systematic approach to stream barrier removal monitoring has not been developed in the United States. Consequently, systematic monitoring data are not available and thus our understanding of barrier removal project effectiveness is limited. The Gulf of Maine Council on the Marine Environment (GOMC) River Restoration Monitoring Steering Committee (Steering Committee) developed this Stream Barrier Removal Monitoring Guide (Monitoring Guide) to improve the ability to

- evaluate the performance of individual restoration projects;
- assess the long-term ecological response of regional restoration efforts;
- advance our understanding of restoration ecology and improve restoration techniques;
- better anticipate the effects of future stream barrier removal projects; and
- communicate project results to stakeholders and the public.

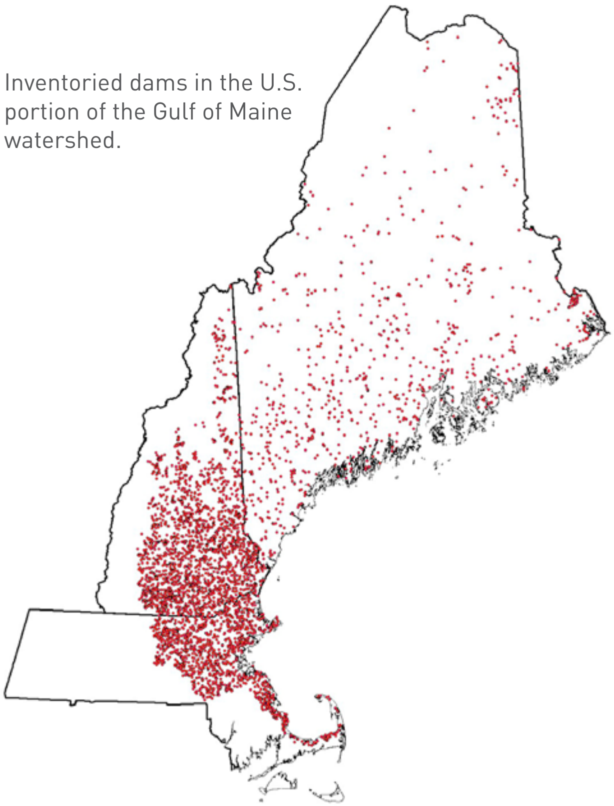
Dams in the Gulf of Maine

The Gulf of Maine watershed is an approximately 69,000-square-mile (179,000-square-kilometer) region encompassing all of the state of Maine and portions of New Hampshire, Massachusetts, Nova Scotia, New Brunswick, and Quebec. On the U.S. side, there are 4,867 inventoried dams: 2,506 in New Hampshire, 782 in Maine, and 1,579 in Massachusetts (Gulf of Maine Council, 2004). Because inventory methods and reporting standards differ from state to state, the completeness of the inventories varies widely. For instance, New Hampshire has a robust inventory method that registers any dam greater than 4 feet (1.2 meters) tall or that impounds more than 2 acre-feet of water. In contrast, Maine relies on a voluntary registry that closed in 1993; undoubtedly, Maine has many more dams that have not been registered (Gulf of Maine Council, 2004). Regardless of the exact figures, habitat fragmentation caused by dams in the Gulf of Maine watershed significantly affects diadromous fish passage.

Most dams in the northeastern United States are run-of-river structures less than 20 feet (6 meters) in height. These low-head dams have relatively small, shallow impoundments. Sediments can accumulate behind the dam, with some impoundments on high-bedload streams filling in rapidly. Small, narrow impoundments located on high-gradient reaches often retain limited sediments because fines, sand, and even gravel can be scoured from the impoundment by storm flows.

NOAA

Removing a dam using an excavator with a hydraulic hammer attachment.



Inventoried dams in the U.S. portion of the Gulf of Maine watershed.

Large, high-head dams associated with storage impoundments are typically constructed for flood control, hydroelectric power, water supply, and/or recreational needs. These larger dams generally are associated with larger rivers, and they may create extensive, deepwater impoundments (Petts, 1984). Large dams are a relatively small proportion of all dams in the Gulf of Maine watershed. For example, only 5% of dams in New Hampshire are used for hydropower (Lindloff, 2002).

Controlled, yet variable, flow releases are characteristic of high-head hydropower or flood-control dams. Stream discharges downstream of certain hydroelectric dams can fluctuate substantially over hours on a daily basis. During certain hours of the day, these facilities minimize releases from the dam to increase head, which is released rapidly to drive turbines to meet peak power demands. At flood-control dams, substantial impoundment drawdowns may be planned to offset snowmelt runoff or large storm events, and larger releases may occur during certain seasonal periods.

Dam Removal

Approximately 600 dams have been removed throughout the United States over the past several decades, the majority of which were less than 20 feet (6.1 meters) tall (ICF, 2005). Ecology, economics, and public safety were the most frequently stated reasons for removal (ICF, 2005). On the U.S. side of the Gulf of Maine, approximately 20 dams have been removed since 1995, and another 20 dams are currently being evaluated for removal.

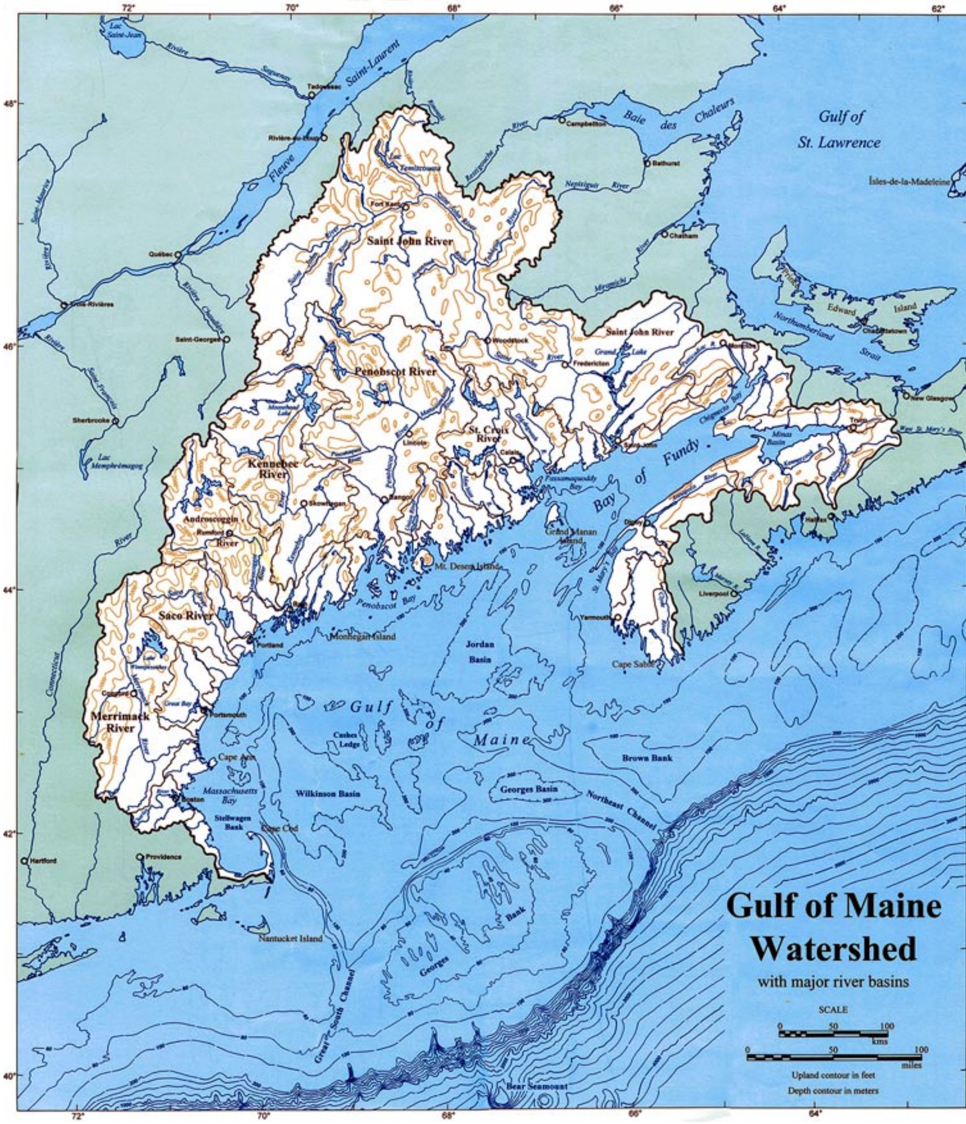
Over the last decade, there has been a resounding call for increased stream monitoring to evaluate the effectiveness of dam removals (Babbitt, 2002; Aspen Institute, 2002; Graf, 2003). Hart et al. (2002) reported that fewer than 5% of dam removals in the United States in the twentieth century were accompanied by published ecological studies. Defining goals at the outset of a barrier removal project is essential to understand the effects of barrier removal projects and to communicate information to stakeholders.

Culverts in the Gulf of Maine

When culverts are perched or undersized, they may impede fish passage. Perched culverts have outlets elevated high above the natural streambed, making it impossible for fish to swim through (Flosi et al., 2003). Undersized culverts restrict the width of the channel, which may cause the water to flow too fast for fish attempting to move upstream through the culvert, particularly during storm flows. These situations are referred to as velocity barriers. Undersized culverts also may cause water to impound on the upstream side during floods.

Effective stream crossings span the width of the stream, have natural streambeds, and do not affect water velocities. Bridges, open-bottomed culverts, and appropriately designed and installed culverts recessed into the streambed are the best available options for stream crossing replacements (Singler and Graber, 2005).

Resource managers in the Gulf of Maine watershed have only recently begun to strategically assess culverts from an ecological improvement perspective. Replacing undersized or perched culverts has proven to be an effective means to increase available habitat to migratory and resident native fishes, and to improve water quality. With proper assessment, engineering design, and installation, replacing stream crossings that have negative ecological impacts can have multiple benefits, including improving public safety by reducing flood risk.



Gulf of Maine Council on the Marine Environment

The white area on this map indicates land that drains into the Gulf of Maine.

B. WORKSHOP PROCESS

On June 20 and 21, 2006, the Steering Committee convened a workshop to discuss stream monitoring with respect to barrier removal projects in the Gulf of Maine watershed. The Steering Committee sought broad representation from state, provincial, and federal resource management agencies, academia, non-governmental organizations, and the private sector. More than 70 attendees with expertise in physical and/or biological stream and floodplain processes were organized into teams on the following topics for structured breakout sessions:

- Hydrology, hydraulics, and sediment
- Wetland and riparian habitat
- Instream habitat
- Fish passage and habitat utilization

The workshop was designed to produce a list of key monitoring parameters and reporting standards from which the Steering Committee subsequently could choose a set to recommend for this Monitoring Guide. The parameters sought for this list ideally would provide fundamental data useful for a broad range of analyses and be relatively inexpensive and straightforward to collect. Cross-cutting parameters, those recommended by more than one topic team, were sought specifically for their value in developing minimum monitoring recommendations.

The following structure and process guided the topic teams to produce the list of parameters:

- Breakout Session I: Topic teams reviewed four barrier removal scenarios designed to capture the range of physical, biological, and management conditions found at Gulf of Maine barrier removal

Table 1.
Critical monitoring parameters identified as priorities by topic teams at the June 2006 workshop. An asterisk indicates that the parameter is to be monitored at monumented cross-sections.

Critical Monitoring Parameters	Topic Teams			
	Hydrology Hydraulics Sediment	Instream Habitat	Wetland Riparian Habitat	Fish Passage
Monumented Cross-sections	✓	✓	✓	
Longitudinal Profiles*	✓	✓		
Grain Size Distribution*	✓	✓		
Photo Stations*	✓	✓	✓	
Water Quality*		✓		✓
Riparian Plant Community Structure*			✓	
Macroinvertebrates		✓		
Fish Passage				✓

sites (Appendix C). After review and discussion in small groups, each topic team developed a prioritized list of monitoring parameters to report back to the entire workshop.

- Plenary Session: Each topic team presented its prioritized parameter lists to the workshop. A facilitated group discussion identified cross-cutting parameters.
- Breakout Session II: Topic teams reconvened to identify important data elements and reporting standards for their prioritized lists of monitoring parameters.

An earlier effort to develop regional monitoring protocols for salt marsh habitat in the Gulf of Maine served as a model for convening this workshop on monitoring protocols for river barrier removals. Information about the Gulf of Maine Salt Marsh Monitoring Protocol is available at www.gulfofmaine.org/habitatmonitoring and in Taylor (2008).

C. SELECTION CRITERIA

By analyzing the lists of prioritized monitoring parameters produced by the workshop's topic teams, the Steering Committee developed the critical monitoring parameters described in this Monitoring Guide.

The *critical monitoring parameters* are common monitoring parameters that, when analyzed collectively, are expected to provide valuable data to characterize adequately the physical, chemical, and biological response of a stream to a barrier removal project.

The Steering Committee selected critical monitoring parameters based on the following selection criteria:

- *Relevance to a range of topic areas*. The Steering Committee focused specifically on monitoring parameters identified as high priorities for more than one of the topic areas. These are referred to as cross-cutting parameters.
- *Usefulness across a range of physical settings and management contexts*. The critical monitoring parameters are intended to be useful for a range of barrier removal projects in the Gulf of Maine watershed.
- *Cost effectiveness*. Recognizing that funding and personnel typically constrain monitoring programs and projects, the Steering Committee targeted monitoring parameters that require relatively modest expenditures.
- *Ability to answer questions relevant to common restoration goals*. Stream restoration and barrier removal projects typically have shared ecological goals. The critical monitoring parameters were selected to provide data useful for answering common questions related to expected restoration goals.

* Indicates critical monitoring parameter

D. THE CRITICAL MONITORING PARAMETERS

Eight critical monitoring parameters emerged from the workshop process and subsequent review by the Steering Committee. These parameters provide fundamental pre- and post-project data for analyses to characterize the physical, chemical, and biological changes at barrier removal sites. Most of the critical parameters are to be monitored at monumented cross-sections (Table 1).

E. INTENDED USE

With this Monitoring Guide, the Steering Committee hopes to encourage systematic monitoring and data reporting for stream barrier removal projects. The Monitoring Guide is specific to stream barrier removal projects in the Gulf of Maine watershed. However, the methods may also be adapted for projects in other regions. We anticipate that this Monitoring Guide will be useful throughout the Gulf of Maine watershed and can be adapted to provincial or state-specific circumstances. In certain instances, we refer users to relevant state or provincial protocols and advocate close coordination with existing government programs.

F. NAVIGATING THIS DOCUMENT

Section III. Scientific Context of Stream Barrier Removal

This section provides scientific discussion of stream barrier removal, focusing on the following topic areas:

A. Hydrology, hydraulics, and sediment
B. Wetland and riparian habitat
C. Instream habitat
D. Fish passage

The subsections summarize the effects of stream barriers with respect to the given topic and the anticipated responses to barrier removal. The subsections also provide the rationale for the critical monitoring parameters, as well as discussions of other parameters identified as priorities at the workshop. While not retained as critical monitoring parameters for the Monitoring Guide, these additional parameters support more detailed investigations and may be necessary on a site-specific basis to answer particular questions.

Section IV. Methods for the Critical Monitoring Parameters

This section provides detailed monitoring methods for the six critical monitoring parameters:

- Monumented cross-sections
- Longitudinal profile
- Grain size distribution
- Photo stations
- Water quality
- Riparian plant community structure

The methods include information about equipment, monitoring design, sampling frequency, and site-specific considerations. Section IV.A, Study Design, provides general guidance on how to implement a monitoring program and describes how the critical monitoring parameters are related to one another.

Fisheries and macroinvertebrate experts in our region agreed that a single method for either fish passage or macroinvertebrates would not be applicable to the variety of expected barrier removal projects. For that reason, we include in this section only a recommendation that users consult with experts in their state or province to identify appropriate methods for macroinvertebrates and quantitative fish passage assessment. We also provide summary tables that describe, in general terms, common monitoring methods for these parameters.

Section V. Data Management

This section describes the importance of common data elements, reporting standards, and metadata. The intention is to ensure that data collection, reporting, and management are systematic and coordinated. This is also the reason we developed detailed data sheets (see Appendix E) for the six critical monitoring parameters for which detailed monitoring methods are provided.

Section VII. Appendices

The appendices provide information about field safety, workshop products, and macroinvertebrate monitoring, along with a glossary. Data sheets are contained in Appendix E and are available for downloading from www.gulfofmaine.org/streambarrierremoval.

Dam in the Gulf of Maine watershed.

New Hampshire Coastal Program

III. SCIENTIFIC CONTEXT OF STREAM BARRIER REMOVAL

A. HYDROLOGY, HYDRAULICS, AND SEDIMENT

Introduction

Water flow and sediment transport govern the physical characteristics of alluvial rivers and therefore influence the quantity and quality of their aquatic and floodplain/riparian habitats. River barriers such as dams and culverts can change water flow and sediment transport, and thus the river's form and function. A number of studies have described how barriers impact stream processes and/or forms (Andrews, 1986; Graf, 2006; Magilligan and Nislow, 2001; Magilligan et al., 2003; Perry, 1994; Petts, 1979; Williams, 1978; Williams and Wolman, 1984). However, the magnitude, timing, and range of physical changes resulting from barrier removal have not been as well documented (Hart et al., 2002).

This section briefly summarizes 1) how barriers can influence stream form and process; 2) observed and expected stream response to barrier removal; and 3) relevant hydrologic, hydraulic, and sediment transport monitoring parameters for answering questions of interest at proposed barrier removal sites. For the purposes of this document, hydrologic impacts are changes to the quantity and timing of stream flow and hydraulic impacts are changes to the physical properties and behavior of flow as it is influenced by floodplain geometry and instream structures.

Barrier Effects on Stream Process and Form

The primary effects of barriers are changes in stream flow timing (i.e., the hydrograph) and sediment transport processes. These changes cause a variety of secondary effects such as changes in bed slope, channel width, bed forms, and roughness. The magnitude and direction of primary and secondary effects can vary considerably from site to site with barrier type and watershed characteristics (e.g., lithology, tributary sediment loads, vegetation cover).

The upstream effects of barriers tend to be more predictable than the downstream effects. Upstream of the barrier, the reach may become lacustrine in character, or it may remain riverine. In either case, habitats are altered considerably from those farther upstream and downstream. In the case of dams, water often ponds on the upstream side, and the impoundment extends upstream until it intersects the stream water surface elevation approximately equal to the elevation of the dam crest, spillway, or other controlling outlet. The impoundment may cause increased groundwater elevations in the floodplain/riparian zone upstream of the barrier. For run-of-river dams, which operate without flood storage, flood stages for a limited distance upstream of the dam are frequently higher than they would be without the impoundment. Culverts may have much the same effect as dams, particularly during small to moderate flood events when a substantial amount of water may impound behind them. However, during large events their influence may diminish if the roadway is overtopped.

The sediment trapping efficiencies of impoundments vary widely depending on the dam type and operation and on the sediment characteristics. Much of the sediment delivered to the impoundment from upstream reaches is often deposited there as the stream loses energy. For culverts, upstream impacts may be more transient in nature and include impoundment during flood events and debris accumulation on the upstream face.

The downstream effects of barriers vary from site to site. Many primary and secondary effects have been reported in the literature (Collier et al., 1996; Petts, 1979, 1980, 1984; Williams and Wolman, 1984). The type of barrier, its operation, and the watershed's physical characteristics largely govern the variability of downstream changes in river form and process. The following is a brief characterization of some commonly observed stream barrier impacts downstream of barriers.

Hydrology Impacts

- Dams with significant flood storage can decrease the downstream magnitude of flood discharges up to 70% (Andrews, 1986; Graf, 2006; Magilligan and Nislow, 2001; Magilligan et al., 2003; Perry, 1994; Williams and Wolman, 1984).
- Stored flood volumes that are released slowly over time produce a common phenomenon downstream of dams: higher discharges during low flow periods when compared to pre-dam conditions (Andrews, 1986; Hirsch et al., 1990).
- The decreased natural variability of flow in downstream reaches can also be manifest as a decreased range of daily discharges (Graf, 2006; Poff, 1997; Richter and Powell, 1996; Richter et al., 1996).
- Storage dams alter the timing of annual maximum and minimum flows, in some cases by as much as 6 months (Graf, 2006), and alter the duration of flows of a given magnitude (Magilligan and Nislow, 2001).

Hydraulic and Sediment Transport Impacts

- As a consequence of reduced flood discharges below storage dams, flood velocities and shear stresses are also reduced. This is a reduction in flow competence, the ability to entrain and transport sediment of larger size fractions.
- Dams trap upstream sediment loads, thereby reducing sediment loads downstream, sometimes considerably (Williams and Wolman, 1984). Channel degradation, a frequent phenomenon downstream of dams, can result. For rivers in a quasi-equilibrium state, sediment delivery to a reach approximately equals delivery out of the reach such that the river neither aggrades nor degrades (Mackin, 1948). The sharp decrease in sediment supply to a downstream reach subsequent to reservoir construction creates a situation in which sediments eroded in that reach are no longer replaced. Stream incision results and can continue until a reduction in slope, or an increase in roughness (see next bullet), decreases the velocity to accommodate the new, reduced sediment load. Channel degradation is common below culverts as well.
- Increased roughness, or armor development, commonly accompanies channel degradation. Though reduced sediment loads can cause bed erosion in the reaches immediately downstream of a dam, primarily finer sediments are eroded from the channel bed and banks by the reduced flood peaks and under average discharge conditions. These reduced flood peaks lack the competence to transport larger clast sizes, a situation that results in the winnowing of fines and the development of an armor on the bed of coarse materials, which prevents further degradation (Petts, 1979).
- Channel aggradation can result downstream of dams, often from the combination of reduced flow competence and a downstream tributary contribution of sediment (Andrews, 1986). Some proportion of the aggraded sediment may come from upstream scour (Collier et al., 1996).
- Channel narrowing downstream of dams has been reported widely in the literature (Benn and Erskine, 1994; Graf, 2006; Gregory and Park, 1974; Kellerhals, 1982; Williams, 1978; Williams and Wolman, 1984). It is often linked to decreases in flood discharges, especially the channel-forming discharges that have 1- to 2-year recurrence

frequencies (Magilligan et al., 2003).
- Sediment deposition, frequently in the form of gravel bars, often occurs immediately upstream of culverts. The coarse materials are deposited when floodwaters are impounded behind the culvert.

Stream Response to Barrier Removal

Just as construction of river barriers affects stream processes and forms, removal of barriers also affects them. Changes in process and form after barrier removal vary in magnitude, direction, and timing, according to barrier type and operation as well as stream and watershed physical characteristics. The magnitude and frequency of storm events after barrier removal also play an important role. Stream responses to barrier removal may continue for years to decades (Pizzuto, 2002).

- *Stream gradient and longitudinal profile.* One of the most widely seen changes after barrier removal is a shift in patterns of sediment movement and sediment deposition (Hart et al., 2002). As the channel adjusts, the streambed may develop a new slope. This may occur through channel incision in the impounded sediments, manifested initially in a headcut, and progressing upstream through the deposit in a process called headcut or nickpoint migration. This process may happen rapidly, or it may occur gradually with annual (or less frequent) peak flows. As knickpoint migration takes place, the longitudinal profile of the river changes progressively in the incised reach (see Pizzuto, 2002) and likely changes in the downstream reach. Formerly impounded sediments may be deposited in the reaches below and cause bed aggradation. Changes in longitudinal profile will likely result in the redistribution of pools, riffles, and bars.
- *Channel geometry.* Changes in sediment transport will be manifest in stream cross-section geometry changes, and over time the reintroduction of the natural flood regime will influence cross-section shape. The channel upstream of the barrier may narrow and develop a floodplain through incision and/or deposition (Pizzuto, 2002).
- *Stream bed particle size distribution* may change in response to changes in sediment transport regime. Bed sediment size distributions in the upstream reach may show greater proportions of coarse material as fines are transported downstream with increased flow competence; coarsening or fining may take place downstream (Hart et al., 2002).
- *Groundwater levels* proximal to the former impoundment will typically be lowered when the dam is removed.

Monitoring Parameters for Hydrology, Hydraulics, and Sediment

The members of the Hydrology, Hydraulics, and Sediment Topic Team at the June 2006 workshop considered dam and culvert removal. They identified the following monitoring parameters as the most critical for understanding stream response to dam removal:

- Monumented cross-sections*
- Longitudinal profile*
- Grain size distribution*
- Stage/discharge
- Contaminated sediments

Channel cross-sections, longitudinal profile, and grain size distribution were deemed within the technical and budgetary reach of most project proponents and were retained and recommended as critical monitoring parameters. These parameters are used to monitor changes in stream form over time, from which changes in process can be inferred.

Sediment contaminant testing is not recommended in this Guide as a critical monitoring parameter because it is not necessary for every site and it is more relevant to project design, engineering, and implementation monitoring than for long-term ecological monitoring. Stage/discharge gaging, while very valuable, is also not recommended because it is too costly.

Monumented cross-sections:* Repeated cross-section surveys will document vertical and horizontal channel adjustments (i.e., degradation, aggradation, widening, narrowing) in response to the new flow and sediment transport regimes following barrier removal. The cross-section data also are useful for hydraulic models, which can provide a wide variety of quantitative information, including water surface profiles, competence to carry sediment, hydraulic conveyance capacity, flow regime, and water speed. See monumented cross-sections method (Section IV.B.1).

Longitudinal profiles:* Repeated longitudinal surveys will show how the channel slope is adjusting to changes in stream processes. They will document any creation, destruction, and/or movement of pools and riffles. See longitudinal profile method (Section IV.B.2).

* Indicates critical monitoring parameter

Grain size distribution:* Resampling grain size distribution during cross-section re-surveys documents changes in the composition of the bed material over time. The data reveal local changes in the stream's hydraulic characteristics, such as roughness and flow competence. Grain size distribution data can be coupled with hydraulic modeling results to compare the stream's competence to carry sediment with the size of the sediment available on the bed. Both pieces of information are critical to understand the likelihood of actual sediment transport. See grain size distribution method (Section IV.B.3).

B. WETLAND AND RIPARIAN HABITAT

Introduction

Riparian zones are defined as the stream channel between the low- and high-water marks, bordering lands where vegetation may be influenced by elevated groundwater tables or flooding, and soils having the ability to retain water (Naiman et al., 1993). Riparian zones are unique lands with distinct geomorphologic and biological attributes regulating energy and material flows within relatively narrow distances between streams and upland ecosystems (Crow et al., 2000). These systems have physical, chemical, and biological effects on surface water, groundwater, instream conditions, and the biota that use the stream and riparian zone as habitat or as corridors for wildlife movement. See Naiman and Decamps (1997) for a good summary of riparian zone functions.

Vascular plants that border streams and rivers contribute important riparian zone structural components and riverine functions. The setting, structure, and composition of a plant community influence the type and level of functions and services (Haberstock et al., 2000). These functions and services include the following:

- Release of leaf litter, mast, and woody debris that provide cover and a food source for animals, fuel instream detrital food webs, and contribute to instream habitat structure/cover for macroinvertebrates and other biota.
- Alteration of suspended/particulate matter and uptake or transformation of dissolved nutrients and other materials transported in stream flows or groundwater discharge.
- Canopy cover that provides shade and minimizes daily fluctuations of temperature in the stream and riparian zone.

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- Development of ground micro-topography and wildlife habitat.
- Protection of streambanks from erosion.
- Decrease in flood velocities attributable to overhanging and stream-edge vegetation and woody debris.
- Reduction in peak discharge by storing overbank flows in floodplain depressions and former stream-channel features.

Many riparian zones are classified as wetlands. Even where riparian zones do not meet the wetland definition, these zones are saturated by groundwater for at least brief periods during the growing season, within the normal rooting depth of plants, and thus are linked hydrologically to streams (Verry, 2000). Floodplains provide important functions including overbank flow storage and velocity reduction, and they serve as sites for stream-channel meandering or secondary flow channels. Field reconnaissance of a project area will help identify floodplain indicators, such as alluvial soil deposits; debris wrack or wash lines; water marks; debris lodged in trees and shrubs; and floodplain vegetation with flood-adapted features (e.g., buttressed tree trunks; adventitious or suckering roots).

Vegetation response to barrier removal is strongly influenced by changes in the physical environment (Shafroth et al., 2002). Because barrier removals may result in drastic changes in physical conditions, the characterization of riparian plant community structure and composition is an important component of a monitoring regime for barrier removals. This section summarizes 1) how stream barriers influence riparian zone structure and functioning; 2) expected responses of riparian vegetation communities when a stream barrier is removed; and 3) important parameters used to monitor riparian zone communities at barrier removal sites.

Barrier Effects on Riparian Zone Structure and Function

A number of authors (Petts, 1984; Ligon et al., 1995; Collier et al., 1996; Nilsson and Berggren, 2000) discuss the impacts associated with dams and culverts on riparian zones. The following is a brief summary of the physical effects of barriers on riparian zone plant communities.

Low-head dams often convert streams to ponds and forest/shrub-dominated riparian habitat to emergent/floating emergent-dominated habitat. Many impoundments created by low-head dams accumulate organic, fine-grained sediments. These impoundments may become covered by emergent (e.g., reed canary grass, *Phalaris aruninacea*), woody (e.g., water willow, *Decodon verticillatus*), or floating emergent (e.g., pond lilies, *Nuphar* spp.) wetland plants. Organic soils flooded by impoundments may release excess phosphorus and nitrogen that may increase aquatic plant productivity (Nilsson and Berggren, 2000).

Scrub-shrub species (e.g., buttonbush, *Cephalanthus occidentalis*) often colonize shallow waters along the perimeter of an impoundment. In the absence of these impoundments and other disturbances, streams are typically bordered by forested and shrub-dominated riparian habitats.

Dams that regulate flows may disrupt natural disturbance regimes of downstream reaches. Flow disruptions reduce variability and alter the frequency, magnitude, and duration of riparian flooding, and they truncate the pulse of sediments, nutrients, and wood debris to and from the floodplain (Sparks, 1995). With lesser flow and flooding frequency, the riparian zone narrows. Storage impoundment dams may change a downstream reach from a multi-channel river and broad floodplain system with mid-channel bars and islands to a single channel. Loss of these features results from reduced peak flows that historically flooded the riparian zone and cut new channels, receiving sediments from upstream riverbanks and terraces (Ligon et al., 1995).

Reduced peak flows and trapped sediments may cause a loss of fertile floodplain soils and pulse-stimulated riparian vegetation responses. Without flood or soil deposition stimulation, some riparian plants may not successfully reproduce, leading to displacement by more generalist native upland and exotic plant species. Plant seeds with poor floating capacity may have decreased potential for dispersal downstream of dams, affecting the abundance of these species in downstream riparian zones (Jansson et al., 2000).

Riparian Zone Response to Barrier Removal

The degree of riparian zone change after removal of a stream barrier depends on

- size of the stream, barrier, and impoundment;
- stream discharge;
- dewatered sediment grain size and composition; and
- geomorphic characteristics of the stream channel and valley.

Effects on the riparian zone can be distinguished into two primary categories: upstream and downstream effects. Removal of low-head dams and culverts result in plant community structural changes primarily upstream of the barrier, while removal of storage impoundment dams may result in significant plant community changes both upstream and downstream of the project site. A planned staging of a dam breach/removal may also affect how plant species colonize and community succession occurs in the riparian zone.

Upstream Effects

With dam removal, the dewatering of an impoundment may be rapid, resulting in the loss of open water habitat and changes in the hydraulic gradient. Groundwater levels may be lowered by dam removal and dewatering. A new hydraulic gradient will develop with impoundment loss or lowering, and the gradient will be affected by the topography and stage-discharge relationships (ICF, 2005). A broad, flat topography would be expected to result in more homogeneous plant cover types. The tolerance of flooding and soil saturation by each plant species influences the zonation and patterns of plant community development following dam removal and impoundment loss. Besides the loss of deepwater habitats, the vegetation response generally includes plant dieback with decreased cover by non-persistent emergent plants (e.g., *Pontederia cordata*, *Sagittaria* spp.) and loss of submerged aquatic vegetation (e.g., *Vallisneria*, *Potamogeton* spp).

Exposed sediments resulting from impoundment loss may be colonized rapidly if a seedbank of wetland plants exists within the wetland soils and/or adjacent communities provide wind-blown seed sources. Plant colonization period depends on the timing of the dam removal, as well as the grain size composition and water content of the soils. Nutrient levels in the former impoundment sediments may also affect plant species colonization and plant community composition in riparian zone succession. Persistent and non-persistent hydrophytes may colonize areas that continue to have prolonged inundation. Persistent emergent (e.g., *Scir-*

pus spp.) and non-persistent emergent plants will dominate the semi-permanently saturated soil zone, while scrub-shrub (e.g., *Alnus*, *Cornus* spp.) and tree (e.g., *Acer* spp., *Nyssa sylvatica*) species will dominate the riparian zone underlain by permeable soils with temporarily to seasonally flooded or saturated soil conditions.

A primary concern of stream restoration practitioners is the fate of the impoundment area after dam removal and potential invasion of non-native plants. See Orr and Koenig (2006) for a case study of non-native and native plant establishment after removal of two low-head dams. In places with nutrient-rich soils, weedy plants are typically the early colonizers, produce seeds at high rates, have effective dispersal mechanisms, and are invasive, non-native species.

Soils with high levels of micronutrients or metals may support only nuisance plant species tolerant of these contaminants. Non-native species may out-compete native riparian vegetation by rapidly colonizing exposed sediments, if the exotic species already existed in the impoundment. Other modes of dispersal include seeds transported by stream flows from upstream parent stock, carried in by animals (e.g, *Lythrum salicaria*, *Elaeagnus angustifolia*), or dispersed by wind (e.g., *Phragmites australis*).

Riparian plant diversity is expected to be lower with a well-established and dominant invasive plant cover. Hydrologic conditions at the site and the species' flood tolerance will dictate the limits and vigor of the invasive species cover in the riparian zone. Once established, a healthy invasive plant cover may modify microhabitat conditions in ways that are likely to inhibit or prevent natural plant community succession in riparian zones. To combat potential invasions with planned dam removals, restoration practitioners often prepare plans including seeding and/or planting of native species and other practices such as use of geo-fabrics to help expedite growth of a desired riparian zone vegetation cover.

Downstream Effects

Removal of storage reservoir dams results in an increase in downstream flooding and sediment transport. Sediment transport is also often increased after removing low-head, run-of-river dams. Downstream floodplain communities may be altered as floods remove or bury vegetation in downstream habitats lacking regular flooding. Subsequently, riparian habitats dominated by flood-tolerant species will re-establish on the newly deposited barren soils. Restoring sediment transport processes to downstream reaches may result in sediment deposits and increases in transient bed elevation and lateral stream channel migration within the floodplain (Healy et al., 2003). A greater frequency of depositional bars and other landforms that could support pioneer plant species (e.g., *Salix*, *Populus* spp.) would also be expected to form (Shafroth et al., 2002).

Following dam removal, seed dispersal via stream flow may help to restore native plants in the downstream riparian zone (Jansson et al., 2000). For dams that increase groundwater elevations, wetlands that form locally both downstream and along impoundment margins by lateral seepage around a dam may be affected by lowering of the groundwater table. A lowering of the water table may result in the loss or conversion of wetlands that had been sustained by seasonally to permanently saturated soils (ICF, 2005), but any conversions would be expected to be localized, and are frequently offset by new wetland formation elsewhere (i.e., along the new stream margin upstream of the removed barrier).

Monitoring Parameters for Wetland Riparian Habitat

The Wetland and Riparian Habitat Topic Team at the June 2006 workshop identified the following monitoring parameters as most important to assess the response of vegetation to stream barrier removal:

- Riparian plant community structure*
- Invasive plant species monitoring
- Restoration planting survival
- Plant condition assessment
- Groundwater elevations

Riparian plant community structure:* Of the parameters discussed by the Wetland and Riparian Habitat Topic Team, plant community structure was the only one recommended as a critical monitoring parameter. Repeated plant community assessments at permanent stream/riparian cross-sections at both the barrier removal site and upstream or nearby reference reaches will reveal changes in species percent cover, plant composition, and community succession attributed to the barrier removal. Riparian plant community monitoring will help explain changes in ecological functions associated with restoring the riparian zone, such as wildlife habitat quality and plant material export to the stream. See riparian plant community structure method (Section IV.B.6).

* Indicates critical monitoring parameter

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Invasive plant species monitoring: Although invasive species monitoring was not recommended as a critical monitoring parameter, the Wetland and Riparian Habitat Topic Team identified invasive plants as a significant management concern at barrier removal sites. Depending on the objectives, budget, number of monitoring staff, and study period associated with the project, monitoring methods may be considered to document the extent of any non-native, invasive species. While monitoring of sampling plots may provide adequate information about the relative percent cover and frequency of invasive plants, it may be desirable also to record stem density per unit area at a site. This is particularly true in dense patches or near monotypic stands of plants. Delineation and mapping of the spatial limits of exotic plants (e.g., common reed, *Phragmites australis*; purple loosestrife, *Lythrum salicaria*; reed canary grass, *Phalaris arundinacea*; Japanese knotweed, *Fallopia japonica*) can show the extent of the invasion of the project area over time.

Physical disturbance in riparian areas can result in increased proportions of invasive species. For this reason, special attention should be paid to all disturbed areas including the dewatered impoundment area, bordering vegetation, and construction areas. The limits of the invasive plant cover should be recorded via GPS and depicted on a site map or aerial photo. For broad project sites or long stream reaches, an alternative method—using a scaled series of annual color or infrared aerial photographs complemented by limited field groundtruthing—should be considered for mapping invasive plants.

Restoration planting survival: Some barrier removal projects may include installing plantings, cuttings, and seeds of native plants to expedite the restoration of bare riparian soils. For barrier removal restoration sites that have been planted (e.g., plugs, containerized stock, or bare root), annual monitoring should include the percentage of dead, stressed, or surviving plants out of the total number of plantings of each species. Woody plantings should be mapped/tagged or depicted on the restoration-planting plan because often many plantings do not survive and might be difficult to locate. Dormant material such as livestakes or wattles (typically willows, *Salix* spp.) should be monitored for at least the first full growing season (e.g., percent survival for stakes or posts; percent cover for wattles). Natural regeneration of trees and shrubs also will occur, potentially leading to artificially high estimates of survival if plantings are not mapped/tagged (Pollack et al., 2005). If an entire planted area is not assessed, care should be taken to document the location and area of the monitored sub-area. This information may be used in recommending plant species to be replaced or other native species as substitutes in the replanting, especially if a warranty has been secured with a landscaper/plant nursery supplier contract for the restoration project.

Plant condition assessment: Plant condition, particularly of exotic plants, can be described by measuring plant height of a representative number of plants (e.g., 10) within each sample plot, as well as recording whether each randomly selected plant is flowering or has fruit as an indicator of successful seed production. Documenting the amount of grazing by herbivores (e.g., beaver, deer) and impacts of insect pests is another suggested practice.

Groundwater elevation monitoring: Barrier removal often results in dewatering or lowering of surface water impoundments and will influence riparian groundwater elevations. If time and budget allow, groundwater monitoring may be conducted to help define changes in sub-surface hydrology influencing riparian community development at barrier removal sites. This monitoring requires installation of multiple monitoring wells at both barrier removal and reference sites, and effort to monitor groundwater elevations over multiple seasons.

C. INSTREAM HABITAT

Introduction

Removing river barriers results in changes to chemical, physical, and biological processes that, in turn, influence instream habitat conditions (Hart et al., 2002). These changes can cascade throughout all components of instream habitat, influencing habitat structure, water quality, and biotic assemblages. This section briefly summarizes 1) how stream barriers influence instream habitat; 2) how instream habitat responds when a stream barrier is removed; and 3) important parameters to monitor to document changes in instream habitat as a result of barrier removal.


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Dam removal site in New Hampshire showing remaining left-bank abutment.

Effects of Barriers on Instream Habitat

Habitat Structure

Barriers impound water and may result in a shift from a riverine habitat to a lacustrine, or lake-like, habitat. The alteration of hydrologic regime and the changes in sediment transport caused by river barriers may change the quality and distribution of instream habitat types such as riffles, runs, and pools. Riffles are composed of cobbles and gravel, and typically they are free from finer-grained material. These shallow, high-velocity environments are well aerated, provide important habitat for spawning, and serve as critical nurseries for fish eggs. Pools are found between riffles, and they are characterized by smoother bottoms, deeper water, and lower flow velocities than riffles.

Pools provide important refugia and rearing habitat for multiple age classes of fish species during high-water events and low-flow conditions. Riffle and pool complexes also incorporate runs of swift-moving water between each complex, which provide habitat for fish and other biota. These habitats, and the organisms that depend on them, may be eliminated by a stream barrier's impoundment.

Stream barriers also reduce large woody debris recruitment from upstream sources. Large woody debris is an important contributor to instream habitat complexity and diversity, including the formation of mid-channel bars and islands (Abbe and Montgomery, 1996). Large woody debris enhances microhabitat diversity and surface roughness in floodplains and riparian zones, thereby encouraging flow dissipation versus concentrated flow patterns. This debris also enhances plant and wildlife habitat diversity.

Some stream barriers create tidal restrictions, which may exclude the daily tidal exchange or allow a muted tide to progress past the barrier. In both instances, the impacts of tidal barriers are complex and often result in a shift from estuarine habitats to freshwater habitats with a corresponding shift in species composition.

Water Chemistry

Barriers influence water chemistry by trapping nutrients and sediment and by changing water temperature and dissolved oxygen concentrations. Impoundments in urban, suburban, or agricultural areas may develop high nutrient concentrations as a consequence of receiving nutrient-rich runoff. These nutrients may result in increased macrophyte and algae growth, potentially at nuisance levels.

Because the microorganisms that decompose dying macrophytes and algae consume dissolved oxygen, elevated nutrient concentrations can lead to low dissolved oxygen concentrations in impoundments, particularly at depth. Also, impoundments may have higher temperatures than free-flowing river reaches upstream and downstream. Elevated temperature may further reduce dissolved oxygen concentrations. Increased water temperatures and decreased oxygen concentrations can prevent sensitive species such as trout and many invertebrates from using the pond habitat.

Sediment and sediment-bound toxic contaminants carried by rivers may settle in impoundments as water velocities slow. Modern and legacy industrial pollution have contributed persistent contaminants (i.e., contaminants that do not break down easily) to surface and ground waters, and the contaminants may bioaccumulate in intermediate to higher trophic organisms (Hart et al., 2002). These bioaccumulative contaminants include but are not limited to DDT, PCBs, mercury, and dioxins. Contaminated sediments may adversely impact aquatic ecological resources or humans who consume these resources.

Benthic Communities

Changes in habitat structure and water chemistry may result in a shift in macroinvertebrate communities (e.g., aquatic insects, clams, mussels, worms, snails). Communities of macroinvertebrates upstream of a barrier may resemble those of lake-like environments. Macroinvertebrates are important components of most freshwater riverine ecosystems, functioning as a link between primary producers (algae), nutrient inputs such as leaves and woody debris, and tertiary consumers (fish) (Resh, 1995). Mussels are among the least mobile macroinvertebrates in stream systems and therefore may be affected most strongly by habitat changes.

The physical changes caused by a stream barrier, particularly when an impoundment is created, provides a change in habitat conditions that sometimes favors freshwater mussels. Upon dam removal, however, freshwater mussels are vulnerable, particularly during the dewatering period. Furthermore, if any impounded sediments are released downstream when a dam is removed, the sediments may affect downstream habitats of mussels and other macroinvertebrates.

Response of Instream Habitat to Barrier Removal

Small barriers are the chief focus of removal efforts in the Gulf of Maine watershed. Little information exists on the ecological impacts of these smaller and/or partial removals. The primary goal of most barrier removal projects is to increase fish passage. The rapid achievement of this goal has been documented in high-profile scientific studies and confirmed by many anecdotal reports (O'Donnell et al., 2001). However, less is known about the responses of other instream habitat components to barrier removal projects and the implications for other aquatic organisms.

Barrier removal is expected to result in reestablishment of riverine habitats upstream of the barrier. Upstream and downstream impacts of barrier removal on the physical stream structure are further described in Section III.A.

Stream barrier removal effects on water chemistry vary from site to site depending on geomorphic and hydrologic factors (e.g. Doyle et al., 2003; Gergel et al., 2005). Barrier removal may increase dissolved oxygen in the formerly impounded reach, reduce water temperature, release stored nutrients from the impoundment, and/or release fine sediments to downstream reaches. Prior to barrier removal, the nutrients in an impounded reach are stored in the sediments (Ahearn et al., 2005).

After the barrier is removed, and the upstream sediments are available for transport, the nutrients may be mobilized. The extent to which nutrients are mobilized and transported may depend on geomorphic changes at the site. For example, Ahearn et al. (2005) found that removing a small dam on Murphy Creek in California resulted in increases in sediment and nitrogen export from the recovering reach. In contrast, Velinsky et al. (2006) found that removing a small dam in southeastern Pennsylvania had no significant effects on upstream or downstream water chemistry, including nutrients and dissolved oxygen concentrations.

Stream barrier removal projects can affect water chemistry through the mobilization of accumulated sediments and sediment-bound contaminants to downstream aquatic environments. Post-dam removal sediment mobilization can increase the downstream occurrence of fine-grained sediments, which can smother important spawning grounds, fill pools, and decrease water clarity. Before dam removal occurs, it is common to conduct a grain size analysis to determine sediment size and sediment mobility. Testing for the presence of pollutants is also common. This Monitoring Guide does not specifically recommend monitoring the toxicity of impounded sediments. However, sediment toxicity testing may fall under regulatory requirements for projects that occur in some jurisdictions. The project manager should contact federal, provincial/state, and municipal regulatory authorities for advice on how to proceed.

Barrier removal may affect benthic organisms that in turn provide food for other organisms. Macroinvertebrates are used frequently by researchers and managers to document changes in community composition and habitat type (Casper et al., 2001; Collier and Quinn, 2003; Doyle et al., 2005; Kanehl et al., 1997). The ability of many aquatic macroinvertebrate taxa to opportunistically recolonize areas of previously unavailable habitat is made possible by short life cycles (~1 year) coupled with mobile terrestrial adult phases. Macroinvertebrate populations are expected to shift from lake or pond species to riverine species over time frames of days to years upstream of the barrier removal (Bushaw-Newton et al, 2002). Benthic communities downstream of the barrier removal site may be affected as well. Thomson et al. (2005) found that macroinvertebrate density and algal biomass declined downstream of a dam during 12 months of sampling after removal. This was attributed to increased fine sediment transport from the restored reach. The authors hypothesized that over time the downstream benthic communities would recover to resemble upstream communities. In general, recovery processes should be expected to vary in length of time and magnitude of community change.

Freshwater bivalves may be particularly affected by barrier removal. A study of a dam removal project on the Koshkonong Creek in Wisconsin documented upstream and downstream impacts to freshwater bivalves (Sethi et al., 2004). The study documented 95% mortality of mussels in the former impoundment due to desiccation and exposure (Sethi et al., 2004, cited in Nedeau, 2006). The study also reported that a downstream increase of silt and sand from the former impoundment resulted in decline of mussel densities and extirpation of rare mussel species. Efforts to relocate mussels during the Edwards Dam removal in 1999 successfully rescued 607 tidewater muckets and 16 yellow lampmussels, both of which are listed by every New England state as threatened or endangered (Nedeau, 2006).

Monitoring Parameters for Instream Habitat

Techniques to assess instream habitat either 1) quantify specific physical instream habitat components (e.g., stream bed cross-sections or grain size distribution) or 2) use indicators to assess overall instream habitat quality (e.g., macroinvertebrates). This Monitoring Guide recommends using both quantitative measurements and ecosystem indicators to assess instream habitat.

The following parameters were identified by the Instream Habitat Topic Team at the June 2006 workshop as most important for assessing the response of instream habitat to stream barrier removal:

- Macroinvertebrates*
- Water quality*
- Photo stations*
- Longitudinal profiles*
- Monumented cross-sections*
- Grain size distribution*

Macroinvertebrates:* Surveys of macroinvertebrates are used by many organizations to indicate the health of freshwater riverine ecosystems. In 1995, the U.S. EPA reported that 41 out of 50 states had biological assessment programs in place and that macroinvertebrates were the most commonly utilized assemblage (U.S. EPA, 2002). Each state and province bordering the Gulf of Maine has its own specific macroinvertebrate assessment protocol. Therefore, this Monitoring Guide does not recommend a particular methodology but rather advocates using the protocol that is recommended by the project's regulatory authority.

Water quality:* Water quality is an important component of instream habitat that should be considered when removing stream barriers. Depending on project specifics, the following water quality parameters may be important for barrier removal projects: temperature, dissolved oxygen, total suspended solids, pH, salinity, conductivity, nutrients, chlorophyll a, carbon, pathogens, and contaminants. Of these parameters, temperature, dissolved oxygen, and conductivity are the recommended critical monitoring parameters. See water quality method (Section IV.B.5).

Photo stations:* A properly executed and documented photo record can be an invaluable resource for project proponents, regulatory authorities, and outreach and education. The monumented cross-section-based monitoring framework of this Monitoring Guide will provide the spatial and temporal basis for a detailed and robust photo record. An accurate photo record should, at a minimum, start the year preceding implementation and continue through years 1, 2, and 5 after the project has been completed. See photo stations method (Section IV.B.4).

The cross-sections, longitudinal profile, and grain size distribution can provide quantitative information on habitat types, including pool depth, habitat unit length, and critical grade control points (see Section III.A for further discussion of these three critical monitoring parameters). Qualitative habitat information can also be gleaned from certain quantitative monitoring parameters. For example, cross-section survey notes should include qualitative descriptions of bank conditions, bed substrate, large woody debris occurrences, and vegetation type.

* Indicates critical monitoring parameter

D. FISH PASSAGE

Introduction

Since European settlement, dams have contributed to the decline of diadromous fish species in the Gulf of Maine region. To protect annual harvests, colonial laws were enacted to counter the detrimental effects of blocking fish from spawning habitat (Trefts, 2006). Many of the earliest dams still remain, some having been rebuilt multiple times for different purposes. The long history of industrial, commercial, and residential development in the region has meant that road and rail stream crossings are also ubiquitous. Massachusetts alone has an estimated 3,000 dams, along with an estimated 30,000 culverts and bridges associated with road and rail crossings, according to the state's Geographic Information System database.


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It is not known what percentage of existing road and rail crossings create barriers to fish movement. It is known that many of these bridges and culverts do not fully span the stream's full width, have perched outlets, are constructed with high longitudinal slopes, and otherwise present velocity or elevation barriers to fish migrating upstream. As barrier removal becomes a prevalent practice for fishery enhancement, there is a greater need to quantify the impacts of these efforts. Measuring the success of these restoration projects has been challenging in part because of a lack of established, systematic monitoring protocols.

This section briefly summarizes: 1) how stream barriers affect fish passage; 2) fish passage response when a stream barrier is removed; and 3) important monitoring parameters to assess fish passage.

Effects of Barriers on Fish Passage

Dams, dikes, perched culverts, and other stream barriers have the potential to limit or completely restrict access to spawning habitat and other habitats for various life stages of native resident species and anadromous species. Many watersheds in the Gulf of Maine no longer sustain runs of anadromous fish. Atlantic salmon (*Salmon salar*) were extirpated from most of the U.S. east coast by the early 1800s. Other anadromous fish including alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*), American and hickory shad (*Alosa sapidissima* and *A. mediocris*), Atlantic sturgeon (*Acipenser oxyrhynchus*), sea lamprey (*Petromyzon marinus*), and rainbow smelt (*Osmerus mordax*) have suffered dramatic population declines. Also in decline is the once-abundant American eel (*Anguilla rostrata*), a catadromous species. Inability of fish to reach historic spawning habitat may contribute to these declines.

Complete barriers to passage have obvious implications for fish migration, but partial passage barriers and poorly constructed or failing fish ladders also can have deleterious effects. Fish ladders that are poorly designed, in disrepair, or not managed properly can be significant barriers to passage. In some cases, fish ladders may be temporal barriers for weak-swimming fish or for different age classes of fish at certain flows or tides. Dams with fish ladders that do not have adequate provision for juvenile out-migration can reduce population viability. Dams that are partially breached can allow strong-swimming fish to pass but not allow weaker fish, or fish of different age classes, to pass. Perched culverts and undersized culverts, although considered hydraulically adequate under certain flows, can be as problematic to upstream fish migration as dams.

Fish Passage Response After Barrier Removal

Fish monitoring has been an integral part of some Gulf of Maine barrier removal projects. The removal of the Edwards Dam in Maine and the Billington Street Dam in Massachusetts both included fish monitoring. Fish movement response to barrier removal has been researched, and findings show that improvement is immediate and significant. If a dam or barrier is properly and fully removed, and natural stream hydraulic and geomorphic conditions are restored, natural fish migration patterns are likely to return during the subsequent migratory period. Removal of a small dam at Town Brook in Plymouth, Massachusetts, resulted in more than 95% passage efficiency of alewife through the restored river reach with concomitant median transit times of less than 20 minutes (Haro, personal communication 2007).

Improved fish movement has been observed in the Gulf of Maine region for non-anadromous fish species following barrier removal. Migrations of native species, such as brook trout and white sucker, typically are restored following barrier removal.

Monitoring Parameters for Fish Passage

Many different fish sampling or monitoring techniques have been developed for streams, and state and provincial agencies have adopted a variety of them. Monitoring methods to assess fish passage through a reach where a barrier has been removed are of two general types: measurement of physical stream characteristics or measurement of fish movement.

Measurement of physical stream characteristics: This approach uses physical stream characteristics such as water depth, water velocity, and the presence or absence of any abrupt changes in bed elevation as a surrogate for fish passage and assumes that if physical stream characteristics fall within a predetermined range, then fish will be able to pass. If a culvert has been replaced, then additional assessment components may include culvert length, height of any inlet or outlet drops, and pitch of the culvert.

An example of this approach is FishXing, a U.S. Forest Service software product used by engineers, hydrologists, and fish biologists to evaluate and design culverts for fish passage. FishXing compares known fish swimming abilities with culvert measurements and physical stream characteristics to model hydraulic properties of a crossing to evaluate fish passage (USFWS, 2005). The community of expert fisheries scientists in our region indicated that the swimming abilities of Gulf of Maine diadromous fish are not well understood and that because of our lack of understanding of fish capabilities, this approach would not confirm whether fish passage had been restored at a barrier removal site. Consequently, it was not selected as a critical monitoring parameter.

Direct fish measurement:* Our recommended approach is the direct measurement of fish movement to determine whether the barrier removal project has been successful at restoring fish passage. This approach assumes that a project has been effective if fish, previously known to be restricted below the barrier, are documented above the barrier removal site.

There are, however, several difficulties in recommending the direct measurement of fish movement at a barrier removal site:

- *High diversity of diadromous fish in the Gulf of Maine:* The 10 species of diadromous fish within the Gulf of Maine each have specific life history strategies, migration periods, and habitat utilization preferences.
- *Diadromous fish populations may be small or not yet restored* making presence or absence determinations difficult.
- *Stream barrier removal projects present unique site-specific conditions:* The scope of this Monitoring Guide includes all types of stream barriers in the Gulf of Maine watershed, which occur in many habitat types.
- *Required expertise:* Measurement of fish movement requires advanced expertise, specific equipment, and substantial personnel and financial resources.

Given the variability of fish species affected by stream barriers, the variability of site-specific conditions, reduced population size of some target species, and the expertise required to conduct fish assessments, recommending one fish passage method for all sites is not possible. We recommend that project proponents work with jurisdictional authorities to develop direct fish assessment methods that are appropriate for their barrier removal project.

* Indicates critical monitoring parameter


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