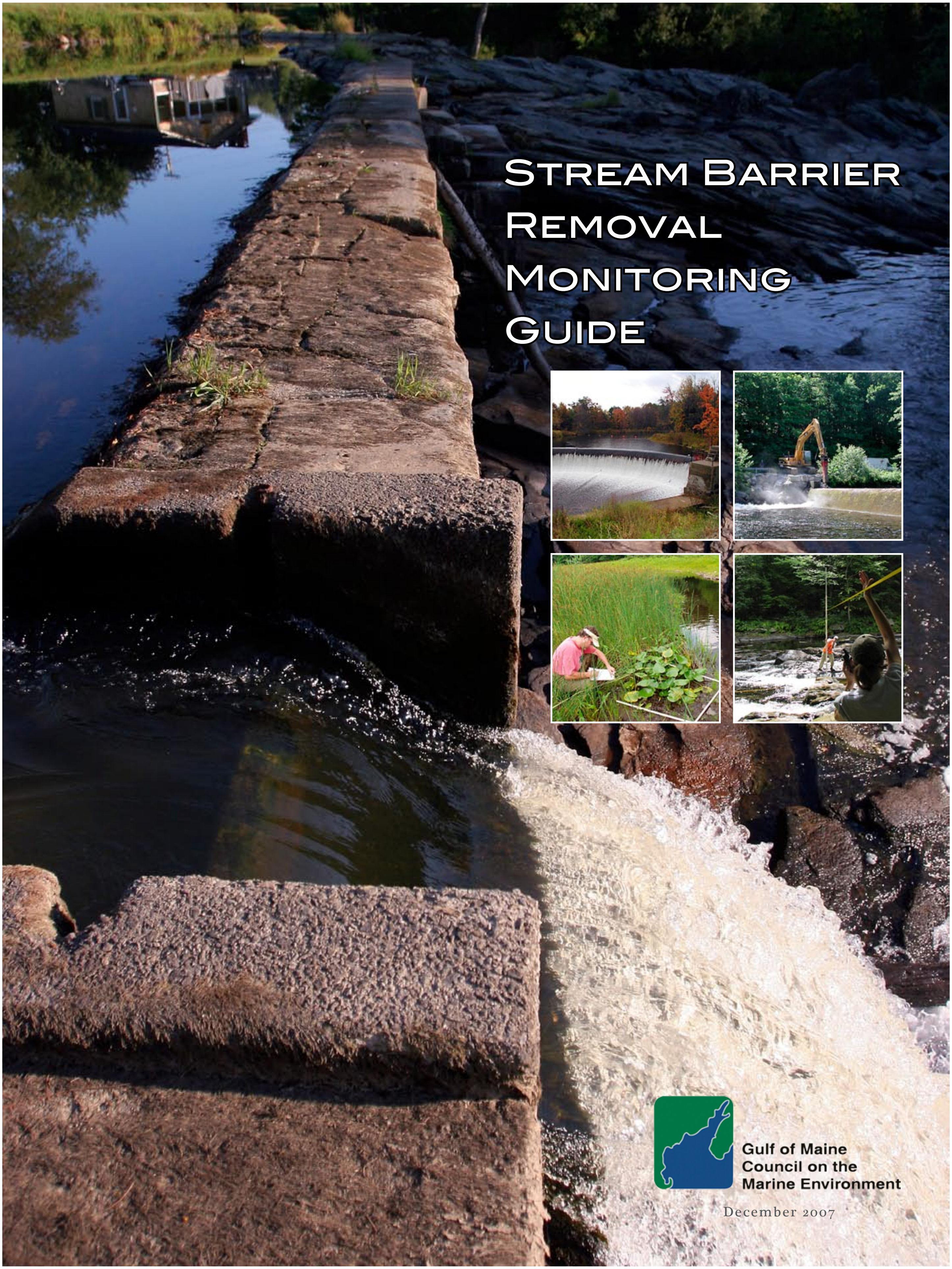


Stream Barrier Removal Monitoring Guide

Gulf of Maine Council on the Marine Environment

December 2007

Stream Barrier Removal Monitoring Guide

Mathias Collins[1], Kevin Lucey[2], Beth Lambert[3], Jon Kachmar[4],
James Turek[1], Eric Hutchins[1], Tim Purinton[3], and David Neils[5]

[1]NOAA Restoration Center, [2]New Hampshire Coastal Program, [3]Massachusetts Riverways Program,
[4]Maine Coastal Program, [5]New Hampshire Department of Environmental Services

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

Stream Barrier Removal Monitoring Workshop Contributors
Gulf of Maine Council on the Marine Environment
National Oceanic and Atmospheric Administration
U.S. Fish and Wildlife Service
New Hampshire Department of Environmental Services
New Hampshire Coastal Program
Maine Coastal Program
Massachusetts Riverways Program
American Rivers
Fisheries and Oceans Canada
New Brunswick Department of Environment and Local Government
New Brunswick Department of Natural Resources

This publication was produced with support from the Gulf of Maine Science Translation Project, which accelerates the transfer of scientific information to management. Support for the Science Translation Project has been provided by the U.S. National Oceanic and Atmospheric Administration, Cooperative Institute for Coastal and Estuarine Environmental Technology, Maine State Planning Office, Massachusetts Office of Coastal Zone Management, New Hampshire Coastal Program, Maine Sea Grant, Woods Hole Oceanographic Institution Sea Grant, and Environment Canada. For more information about the Science Translation Project, go to www.gulfofmaine.org/science_translation.

How to cite this document:
Collins, M., K. Lucey, B. Lambert, J. Kachmar, J. Turek, E. Hutchins, T. Purinton, and D. Neils. 2007. Stream Barrier Removal Monitoring Guide. Gulf of Maine Council on the Marine Environment. www.gulfofmaine.org/streambarrierremoval.

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*

Authors and Editors(*)

Mathias Collins*
Marine Habitat Resource Specialist
Professional Hydrologist
NOAA Restoration Center
1 Blackburn Drive
Gloucester, MA 01930

Beth Lambert*
River Restoration Scientist
Riverways Program
Massachusetts Department of Fish and Game
251 Causeway Street, Suite 400
Boston, MA 02114

Eric W. Hutchins
Gulf of Maine Habitat Restoration Coordinator
NOAA Restoration Center
1 Blackburn Drive
Gloucester, MA 01930

Tim Purinton
River Restoration Planner
Riverways Program
Massachusetts Department of Fish and Game
251 Causeway Street, Suite 400
Boston, MA 02114

Kevin Lucey*
Program Specialist
New Hampshire Coastal Program
New Hampshire Department of Environmental Services
50 International Drive, Suite 200
Portsmouth, NH 03801

Jon Kachmar*
Senior Planner
Maine Coastal Program
State Planning Office
38 State House Station
Augusta, ME 04333-0038

David E. Neils
Aquatic Biologist
New Hampshire Department of Environmental Services
29 Hazen Drive
Concord, NH 03302

James Turek
Assistant Northeast Team Leader
NOAA Restoration Center
28 Tarzwell Drive
Narragansett, Rhode Island 02882

Reviewers
Steve Block *NOAA Restoration Center*
Alison Bowden *The Nature Conservancy*
Karen Bushaw-Newton *American University*
Michael Chelminski *Woodlot Alternatives Inc.*
Dave Courtemanch *Maine DEP Div.of Env. Assessment*
Eric Derleth *U.S. Fish and Wildlife Service*
Wenley Ferguson *Save the Bay*
Alan Haberstock *Kleinschmidt Associates*
Anita Hamilton *Fisheries and Oceans Canada*
Alex Haro *U.S. Geological Survey*
Dan Hayes *Michigan State University*
Ray Konisky *The Nature Conservancy*
Melissa Laser *Maine Atlantic Salmon Commission*
Deb Loiselle *New Hampshire DES Dam Bureau*
Jeff Murphy *NOAA NMFS Protected Resources Division*
Curt Orvis *U.S. Fish and Wildlife Service*
Jeff Peterson *VHB Inc.*
Jim Pizzuto *University of Delaware*
Joe Rathbun *Michigan DEQ Water Bureau NPS Unit*
Trefor Reynoldson *Acadia Center for Estuarine Research*
Roy Schiff *Milone and Macbroom Inc.*
Conor Shea *U.S. Fish and Wildlife Service*
James Turek *NOAA Restoration Center*
Jeff Varricchione *Maine DEP Division of Watershed Mgmt.*
Theo Willis *University of Southern Maine*

Gulf of Maine Council River Restoration Monitoring Steering Committee
John Catena *NOAA Restoration Center*
Kathryn Collet *New Brunswick Dept. of Natural Resources*
Matt Collins *NOAA Restoration Center*
Eric Derleth *U.S. Fish and Wildlife Service*
Ted Diers *New Hampshire DES Coastal Program*
Anita Hamilton *Fisheries and Oceans Canada*
Eric Hutchins *NOAA Restoration Center*
Jon Kachmar *Maine Coastal Program*
Beth Lambert *Massachusetts Riverways Program*
Deb Loiselle *New Hampshire DES Dam Bureau*
Tim Purinton *Massachusetts Riverways Program*
James Turek *NOAA Restoration Center*
Laura Wildman *American Rivers*

Stream Barrier Removal Monitoring Workshop Participants
See Appendix C for a list of workshop participants.

Editing and Design
Peter H. Taylor *Waterview Consulting*

A stream flowing from a culvert under a road.

TABLE OF CONTENTS

List of Figures

List of Tables

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.

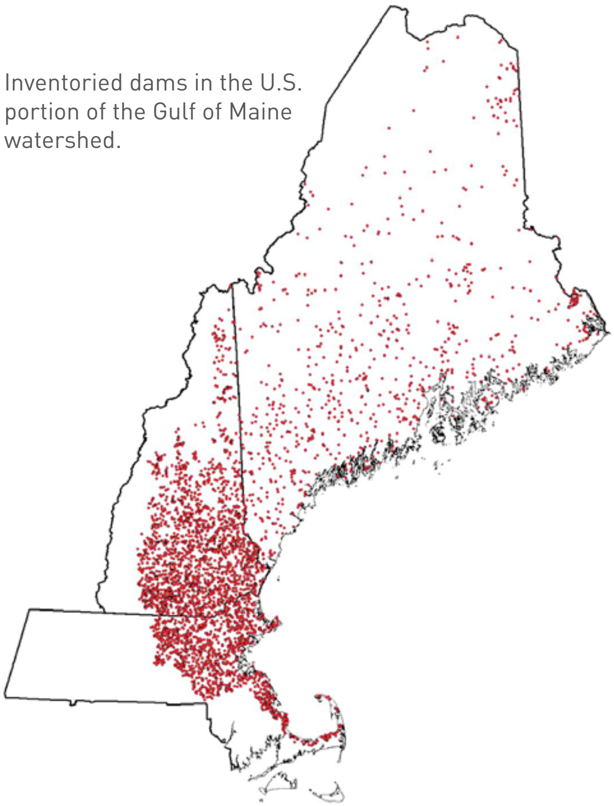
Dams in the Gulf of Maine

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.

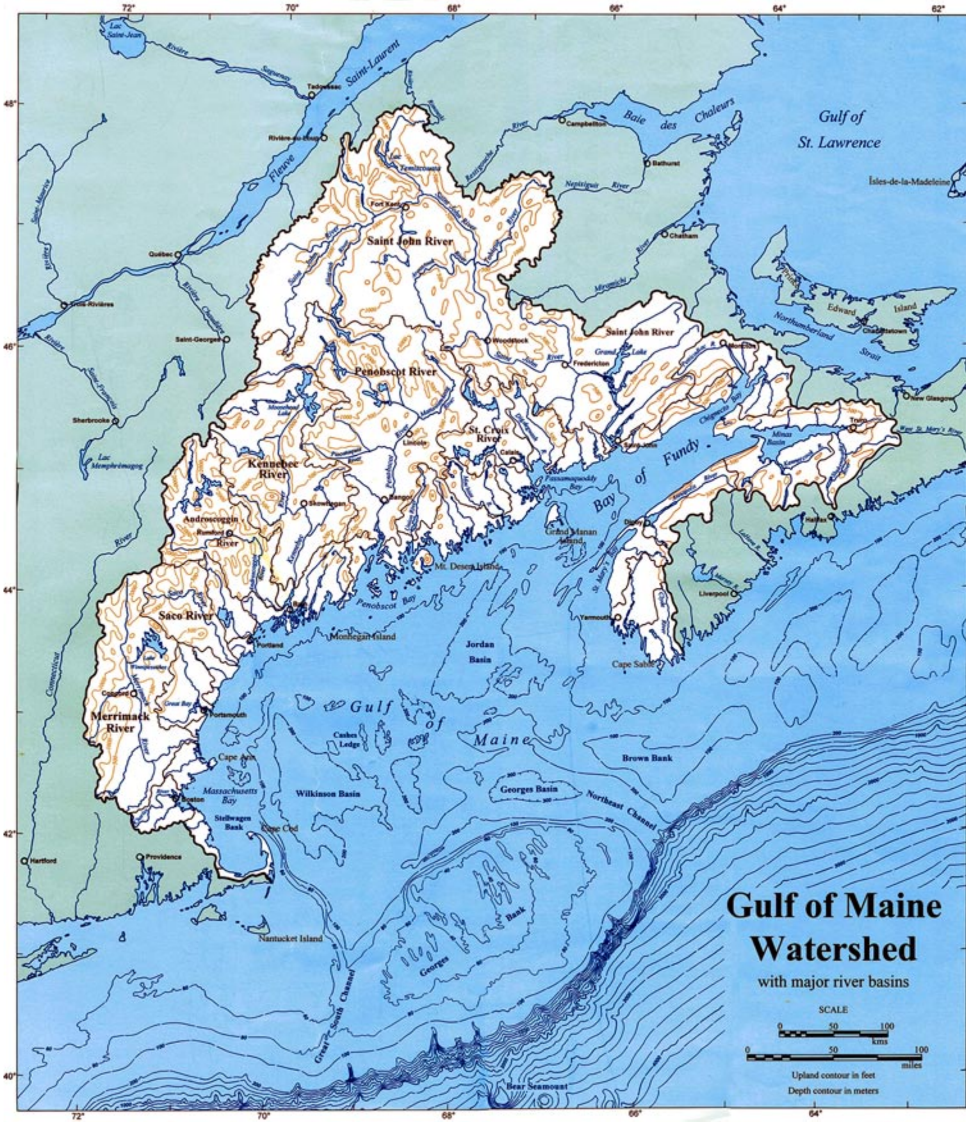
Over the last decade, there has been a resounding call for increased stream monitoring to evaluate the effectiveness of dam removals (Babbitt, 2002; Aspen Institute, 2002; Graf, 2003). Hart et al. (2002) reported that fewer than 5% of dam removals in the United States in the twentieth century were accompanied 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.

New Hampshire Coastal Program

- 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

James Turek / NOAA

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.

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.


New Hampshire Coastal Program

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

NOAA

Mathias Collins / NOAA Restoration Center

Karla Garcia / NOAA Restoration Center

A stream swollen by a recent rainstorm.

Grace Levergood / NHDES

Measuring elevation and distance on a transect.

IV. METHODS FOR THE CRITICAL MONITORING PARAMETERS

A. STUDY DESIGN

The eight critical monitoring parameters are designed to be used together as a monitoring framework. Monumented cross-sections, the skeleton of this framework, are permanently established and georeferenced. Several of the critical monitoring parameters—grain size distribution, photo stations, water quality, and riparian plant community structure—should be evaluated at the monumented cross-sections (Table 1). This study design allows for spatial and temporal consistency for long-term monitoring. Adequate consideration must be given to choosing the cross-section locations because, once set, they should not be changed.

Before cross-sections are established, the monitoring reach must be determined. The monitoring reach is delineated into three segments: reference reach (upstream), impoundment, and downstream reach. Once the monitoring reach is defined, we recommend that the longitudinal profile be conducted to facilitate monumented cross-section placement. General site reconnaissance and review of remote sensing data are also very useful for choosing cross-section locations.

In addition to the cross-section-based spatial and temporal monitoring framework, this Monitoring Guide employs a Before-After (BA) study design that requires an assessment of pre-project and post-project conditions (Kocher and Harris, 2005). A BA design can be improved by including a control site so that environmental conditions (natural and otherwise) affecting both sites can be accounted for when evaluating the restoration. Such a design is called a Before-After-Control-Impact (BACI) design. Where practical, the Steering Committee encourages the use of a control site. However, this Monitoring Guide does not require it for two reasons: (1) project evaluation will be twice as costly, and (2) the uppermost monumented cross-section should be upstream of the project's zone of influence, hence serving as a de facto control site, though not an entire control reach.

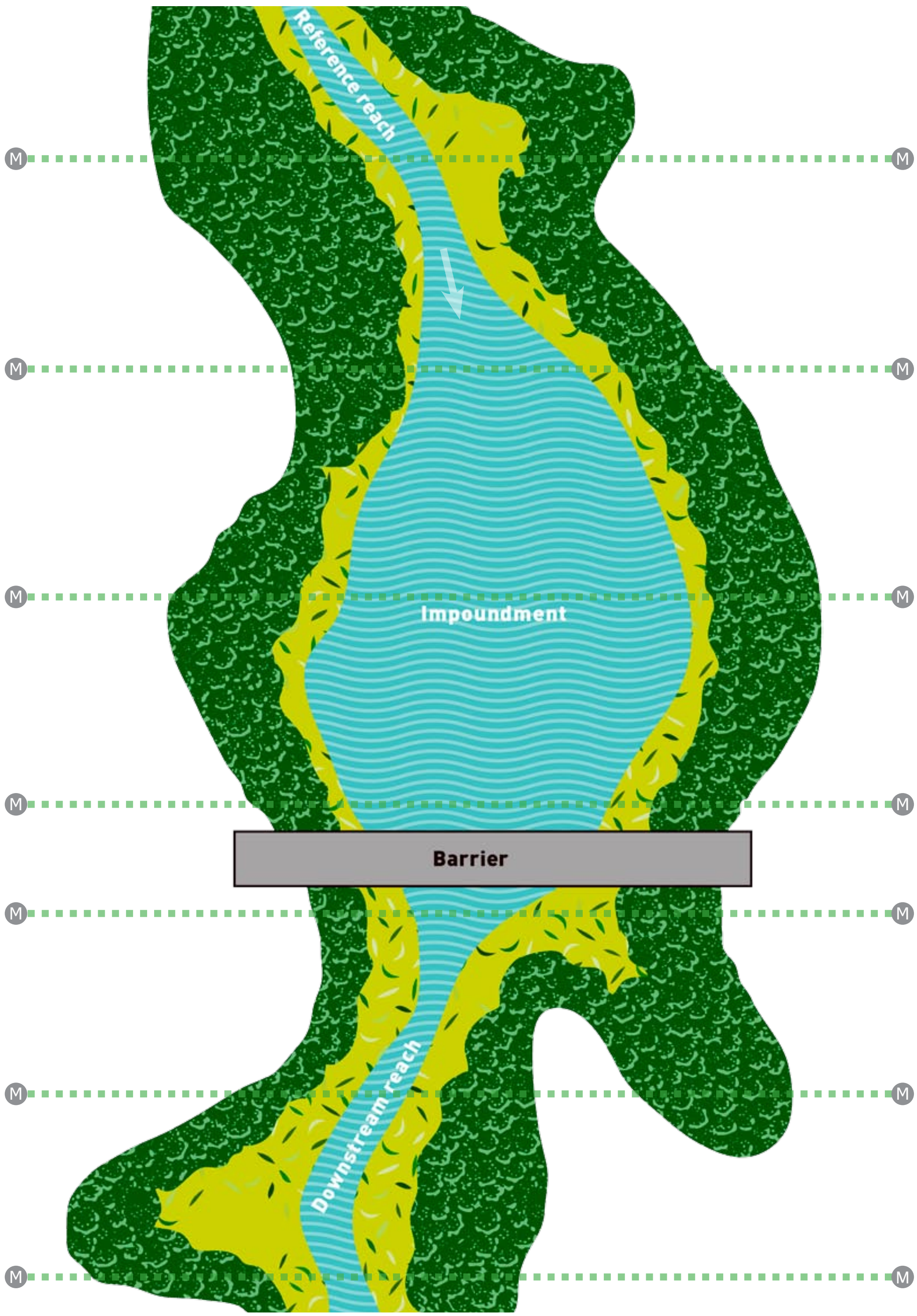
A written monitoring plan, a summary of accomplished work, and a schedule of anticipated work are recommended to provide project partners and data users with a clear account and detailed description of

Karla Garcia / NOAA Restoration Center

Conducting monitoring for a stream barrier removal project.

monitoring that has taken place and the direction of future efforts. We recommend that practitioners leverage field opportunities to optimize the effort and resources employed. For instance, certain parameters can be assessed on the same field day, such as water quality and macroinvertebrates, or photo stations and riparian plant community structure.

Two or more persons should be dedicated to each monitoring team to help complete the data collection expeditiously and facilitate quality assurance. If possible, at least one person should be involved throughout the monitoring period to ensure consistency and uniformity in implementing the monitoring methods. The monitoring team also should designate someone who will be responsible for compiling and retaining the field data.



Monumented cross-sections are a key element of the standardized methods recommended in this Monitoring Guide. This figure shows some possible locations of monumented cross-sections at a hypothetical barrier removal site. Figure not to scale.

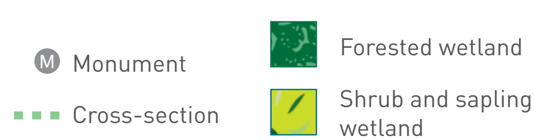


Table 2. Summary of the critical monitoring parameters.

Parameter	Variables	Description	Monitoring Design	Sampling Frequency
Monumented cross-sections	Elevations and distances	Cross-section geometry measured at permanently monumented transects. Horizontal distances recorded to tenths of feet (0.1 ft) and elevations to hundredths of feet (0.01 ft).	The number and location of cross-sections will depend on site-specific conditions. At a minimum, cross-sections should be established immediately upstream and downstream of the barrier, at bridges, in the impoundment, and upstream of the impoundment influence. Permanent geo-referenced monuments must be established at cross-section endpoints.	Monitoring should be conducted in the year preceding barrier removal. In the case of impoundments, pre-removal assessments should be coordinated with drawdown. Resurveys should occur annually or every other year for at least five years.
Longitudinal profile	Elevations and distances	Longitudinal profile measured in conjunction with monumented cross-sections. Horizontal distances recorded to the tenths of feet (0.1 ft) and elevations to hundredths of feet (0.01 ft).	Take elevation readings along the thalweg at important bed features, measuring distances using the baseline. In addition to distances and elevations, note details of features being measured and water-surface elevations at each bed-elevation measurement.	Longitudinal profiles should be resurveyed at the same frequency as the cross-section surveys.
Grain size distribution	Distributions of sediment size classes	Streambed surface grain size distributions characterized by collecting and analyzing sediment samples at monumented cross-sections.	In cross-sections dominated by fine sediments, each sample point should contain 1 liter of surface sediments for laboratory analysis. In cross-sections dominated by gravel, a pebble count should be performed.	Grain size sampling should be conducted at the same frequency as the cross-section surveys, during wading-depth stream conditions.
Photo stations	N/A	Repeat photographs capture a variety of ecosystem conditions and visually document stream response.	Photo stations should be described as distances or bearings from other known points such as cross-section endpoints or other permanent landmarks.	Photo-monitoring should include both leaf out and full vegetation in the year preceding restoration. Post-restoration photo monitoring is recommended for years 1, 2, and 5.
Water quality	Temperature	Precision: +/- 0.2°C. Accuracy: +/- 0.2°C	Select a minimum of three monumented cross-sections to evaluate water quality: upstream of the impoundment influence; deepest part of impoundment; and immediately downstream of the barrier. Properly record site information, including GPS coordinates, for purposes of resurveying. Prepare, test, and calibrate equipment. Collect and record water-quality data and site information.	Monitoring should occur one year prior to removal and annually thereafter for five years. All data should be collected weekly for eight weeks during August and September. If macroinvertebrate data are not being collected, water-quality data should be collected weekly from June through October or through continuous monitoring.
	Dissolved oxygen	Precision: +/- 2% or 0.2 mg/L, whichever is greater. Accuracy: +/- 2% of initial calibration saturation or 0.2 mg/L, whichever is greater		
	Conductivity	Precision: +/- 5%. Accuracy: +/- 5% against a standard solution		
Riparian plant community structure	Herbaceous layer	Using 1-m^2 (10.8 ft^2) quadrat, identify each species, record species percent cover and number of stems for all non-woody and all emergent species less than 3 ft (0.9 m) tall. Identify floating or submerged plants.	Monitor plant community at permanent sampling plots established within the restoration site and within an unaltered upstream reference site. Select three transects at each site, perpendicular to the streambank. Establish three permanent sampling plots along each transect according to vegetation types: herbaceous layer, shrub/sapling layer, and tree layer.	Vegetation monitoring is conducted best during the peak of the vascular plant growing season. In the northeastern U.S., this period is generally between July 15 and August 31. Vegetation monitoring should include a minimum of one year of pre-restoration and three years of post-restoration sampling. Preferably, post-restoration monitoring is conducted over a longer period, such as once every 3 to 5 years.
	Shrub and sapling layer	Within a 5-m (16.4 ft) radius, identify species and record percent cover of all woody stemmed plants with height 3–20 ft (0.9–6.1 m) and DBH 0.4–5.0 inches (1–12.7 cm). Note number of dead standing shrubs.		
	Tree layer	Within a 9-m (29.5 ft) radius, identify species and calculate basal area of each woody plant with height greater than 20 ft (6.1 m) and DBH greater than 5 inches (12.7 cm). Note number of dead standing trees.		
Macro-invertebrates	Recommend that project proponents work with regulatory jurisdictional authorities to develop a monitoring plan for macroinvertebrates. Please see Section IV.B.7 for additional guidance.			
Fish passage	Recommend that project proponents work with regulatory jurisdictional authorities to develop a monitoring plan for fish passage. Please see Section IV.B.8 for guidance.			

B. MONITORING METHODS

1. Monumented Cross-sections

Purpose

This section describes how to establish and survey permanent (i.e., monumented) stream cross-sections for long-term monitoring. It identifies the equipment needed, describes the basic protocol, discusses the frequency with which the cross-sections should be re-surveyed, and presents some site-specific considerations. This section does not provide detailed instruction on basic surveying techniques, such as conducting a level survey. For a more complete treatment of stream surveying techniques, see Harrelson et al. (1994).

Monitoring Design

Sampling Protocol

1. Define the monitoring reach.

Defining the length of the stream monitoring reach is the first step in conducting cross-section surveys. Upstream of the barrier, the monitoring reach should, at a minimum, include the length of the impoundment and a representative portion of undisturbed reach upstream of the barrier (e.g., a reach length of approximately 10 channel widths). The downstream monitoring reach is less easily defined because the length of reach physically impacted by the barrier, and/or its removal, is not generally known precisely beforehand.

Minimum Equipment

- ❑ Automatic level (surveyor's level) or laser level
- ❑ Leveling rod in English (to tenths and hundredths) or metric units, preferably 25-foot length
- ❑ Measuring tape in same units (300 ft or 100 m)
- ❑ Field book with waterproof paper
- ❑ Data sheets (see Appendix E)
- ❑ Pencil
- ❑ Permanent marker
- ❑ Two-way radios
- ❑ Topographic maps and/or aerial photographs
- ❑ Chaining pins
- ❑ Flagging tape
- ❑ Machete
- ❑ Wood survey stakes
- ❑ 4 ft (1.2 m) steel rebar stakes
- ❑ Hacksaw
- ❑ Small sledge or mallet
- ❑ Spring clamps
- ❑ GPS
- ❑ Compass

Karla Garcia / NOAA Restoration Center

Installing a monument.

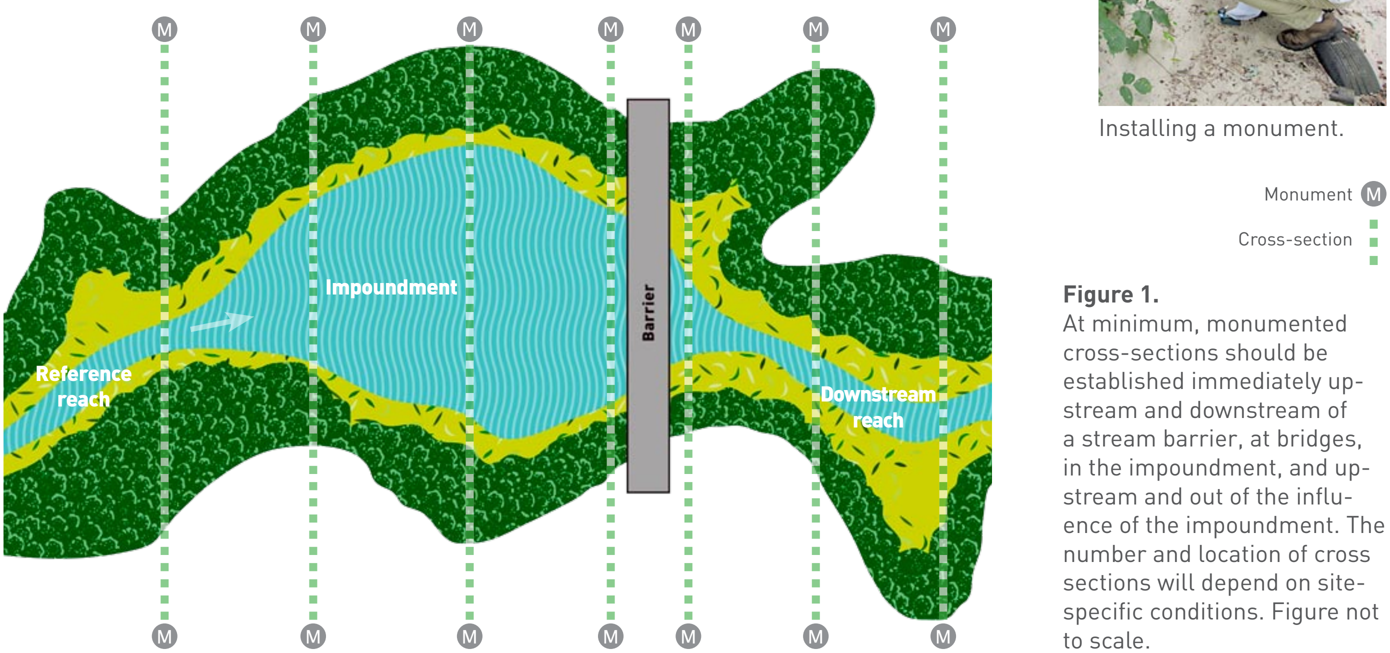


Figure 1.
At minimum, monumented cross-sections should be established immediately upstream and downstream of a stream barrier, at bridges, in the impoundment, and upstream and out of the influence of the impoundment. The number and location of cross sections will depend on site-specific conditions. Figure not to scale.

This length can be estimated, or the downstream limits can be identified based on other project considerations such as downstream habitats of concern, infrastructure, or locations of hydraulic or geomorphic controls such as bridges, outcrops, or knickpoints.

2. Determine number and location of cross-sections.
Once the length of the monitoring reach has been identified, the monitoring team must determine the number of cross-sections needed to adequately represent that reach. The most easily identifiable locations are those areas where infrastructure in the floodplain is likely to be impacted by the project. For example, cross-sections should be established immediately upstream and downstream of the barrier and at bridges within the identified project reach. There also should be cross-sections representing the impoundment (see Site Specific Considerations below), at least one in the undisturbed reach upstream of the impoundment, and at any locations judged to be sensitive to disturbance or of high habitat value. The engineering and geomorphic analyses used to plan the barrier removal should be consulted to identify critical locations. If present in the monitoring reach, cross-sections should be established at existing, monumented cross-sections and/or stream gage locations (Figure 1).

The choice of other cross-section locations should be based on the number of physically homogeneous stream reaches within the monitoring reach—those with similar slopes, bed and bank material, floodplain/terrace sequences, riparian vegetation, and channel-forming processes (Simon and Castro, 2003). For example, the number of cross-sections representing pools, riffles, meander bends, straight reaches, and flow divergence should closely approximate their proportion in the entire monitoring reach. Identification of these sub-reaches or cross-section types should begin with a pre-field inspection of available topographic maps, aerial photographs, surficial/bedrock geology maps, soil surveys, and other relevant information. In addition to subsequent field inspection, you may want to perform and plot a longitudinal profile to use in selecting cross-section locations (see section IV.B.2). Reviewing these data will be valuable for identifying reaches with similar physical characteristics and dominant processes.

3. Locate and establish the cross-section monuments.
At each cross section, establish the permanent markers for both endpoints by driving a ½-inch-diameter, 4-foot rebar stake either flush with the ground or ½ inch above the surface. You may want to cover the tops of the stakes with colored plastic caps available from survey suppliers and use different colors to distinguish different cross-sections (Harrelson et al., 1994). Be sure to note the color associations in the field book. The cross-sections should be straight and perpendicular to the bankfull flow direction, and they should extend across the floodplain/riparian zone to the first terrace or as far as practicable.

To facilitate locating each cross-section for future surveys, establish the horizontal position of the monuments via GPS and one other method. You can fix the position of monuments by taking a bearing and measured distance to the benchmark (see step 4 below), or by triangulating between the monument, benchmark, and another permanent feature on site (e.g., large, healthy tree or bedrock outcrop) (Harrelson et al., 1994; Miller and Leopold, 1961). If the benchmark is not visible from a given cross-section, triangulate with two permanent features. The GPS coordinates of each monument will facilitate mapping the cross-section locations in GIS. Once located, depict the cross-sections on a scaled map or aerial photograph of the project area.

4. Locate or establish the benchmark.
Once the cross-sections have been established, you must either locate, or establish, a local benchmark for the site. This is a permanent marker of known, or assumed, elevation that functions as survey control and the survey starting point. The U.S. Geological Survey (USGS) and other entities historically involved in developing geodetic control networks have benchmarks throughout the country. If one is available at your site, use it. They are typically found on stable site features such as bedrock outcrops; the tops of large, embedded boulders; and bridges.

In the event that a USGS or other geodetic control benchmark is not present in reasonable proximity to the project area, you will need to create a local, or project, benchmark. This offers the opportunity to establish it in a location that is advantageous for the survey; that is, locate it at a point relatively high on the site and visible from most, or at least many, of the permanent cross-sections. You can do so by driving a rebar stake 3 or 4 feet into the ground, chiseling a mark in an outcrop feature or stable boulder, or other means described by Harrelson et al. (1994). Be sure to describe its location in the field book and establish its coordinates with GPS. Always record the horizontal datum employed by the GPS (e.g., NAD 83). If you establish a benchmark, it is conventional to assign it an arbitrary elevation of 100 feet. Alternatively, the benchmark can be tied into an established vertical datum (e.g., NAVD

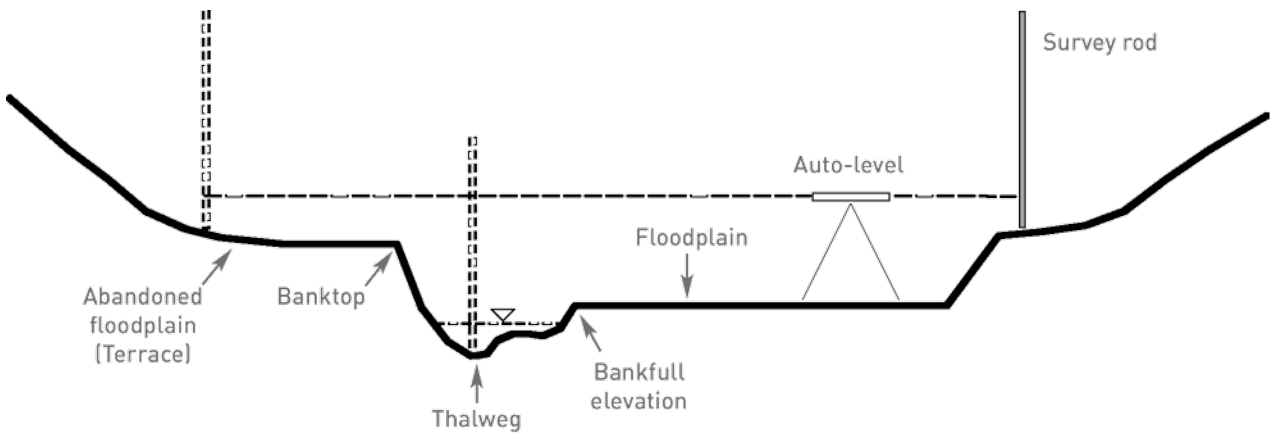


Figure 2. Basic channel and valley features of an unimpacted (reference) stream reach. Note that some features, such as the bankfull elevation, will not be identifiable in the impacted project reach or in all reference reaches.

88) or referenced to mean sea level for projects in areas subject to tidal influence. The horizontal and vertical datums used for the cross-sections should be used also for the longitudinal profile.

5. Set-up the survey instrument and tape.
If possible, set up the survey level in a location from which the local benchmark and all points of one or more cross-sections are visible. Though one or more cross-sections might be shot from one instrument station, to complete all cross-sections for your site you may need to set up two or more instrument stations. From each new instrument station you will need to take backsights on the benchmark (see below), if it is visible, or from turning points if it is not (Harrelson et al., 1994). A machete can be useful to trim low-hanging branches or other vegetation and decrease the number of times you need to move the instrument, but you should avoid cutting large amounts of vegetation for this purpose to minimize property and habitat impacts. At each cross-section, stretch a tape as taut as possible between the monuments. It can be attached to the monument itself with spring clamps, to a shorter rebar stake driven next to the monument with 6 inches exposed for easier attachment, or with chaining pins (Harrelson et al., 1994).

If you are using an optical surveyor's level (auto-level), the person operating the level will make and record the rod readings while the rod person will choose the survey points and call out the lateral distances to the level operator. Lateral distances are referenced to the left bank monument, which is the cross-section zero (left bank is referenced as the left bank looking in the downstream direction). A third person dedicated to recording all readings and descriptions in the field book is recommended and will be necessary for surveying the impoundment with a boat (see Site Specific Considerations below). One advantage of using a laser level is that one person can execute the cross-section survey (or two for impoundment surveys).

6. Survey the cross-section.
Begin with a rod reading on the benchmark. This "backsight" will be added to the elevation of the benchmark to establish the "height of instrument" (HI). All "foresights" on cross-section locations will be subtracted from the HI to obtain the elevation of those points (Harrelson et al., 1994). The first foresight will be taken at the left bank monument. From there, take readings at all breaks in slope and especially at significant geomorphic features as you make your way across the valley (e.g., bankfull, bank top, bank toe, bar tops, edge of water, thalweg), describing each feature in the notes for the respective reading (Figure 2). Capture features such as woody debris and bank-failure deposits, and record in the notes important changes in substrate type.

Also make notes about the nature of the vegetation, especially its structure (e.g., trees, shrub, herbaceous; see Section II.B.7 for the riparian plant community structure method), and be sure to record the locations where discrete changes occur. Adequately characterizing the complexity of the cross-section will typically require a minimum of 30 to 40 rod readings. Larger floodplains and more complex geometry can require many more. Record the horizontal distances to tenths of feet (0.1 ft) and elevations of benchmarks and turning points to hundredths of feet (0.01 ft). Cross-section elevations are also recorded to hundredths of feet.

Bear in mind that identifying a bankfull channel will be most applicable to the cross-section(s) upstream of the hydraulic influence of the impoundment that represent the un-impacted channel reach. The bankfull channel is adjusted to an approximately 1.5- to 2-year recurrence interval discharge and the prevailing sediment transport conditions (Leopold et al., 1964). Because water flow and sediment discharge conditions will, in most cases, be changing at a barrier removal site, a persistent bankfull channel likely will not be identifiable in the monitoring reach. This may also be true of the reference reach, especially in watersheds with changing land use. See Harrelson et al. (1994) for a good discussion about field identification of the bankfull channel. The USDA Forest Service Stream Systems Technology Center (2003) also produces a video specifically geared towards field identification of the bankfull channel in the eastern United States (www.stream.fs.fed.us/publications/videos.html).

Karla Garcia / NOAA Restoration Center

Monument at a cross-section.

Sampling Frequency

Pre-removal surveys are essential for comparison with post-removal data to assess channel and floodplain response. Pre-removal surveys may be most easily accomplished if the impoundment can be drawn down before removal (see Site Specific Considerations below), such as during project feasibility studies. In any case, for efficiency purposes, selection of the long-term monitoring cross-sections and pre-removal data collection should be integrated with any planned feasibility work. As a general guideline, post-removal re-surveys should occur annually, or every other year, for at least 5 years. However, sampling frequency and duration should reflect project objectives and site conditions. For example, sites with great amounts of loose sediment may require more frequent sampling over a longer period than sites with bedrock channels or beds dominated by coarse materials. At a minimum, the frequency should conform to any regulatory requirements. The monuments should be recoverable for much longer so that longer-term studies of channel evolution are possible.

Site-specific Considerations

Some of the pre-removal cross-sections will need to traverse the impoundment. The determination of whether cross-section data in an impoundment can be acquired by wading or using watercraft must consider the depth of the impoundment and suitability of sediment for wading. Impounded sediments may be unconsolidated, fine-grained material with saturated interstitial spaces, making them very soft and incapable of supporting a wader. In such conditions, it will be necessary to obtain the data from a boat. Depending on the nature and depth of the impoundment, surveying cross-sections within it can be accomplished either by employing the methods described in the previous section and taking rod readings at fixed intervals from a small boat, or by using a fathometer from a boat navigated along the transect and integrating the readings with the rod readings on shore via GPS positioning. If you are taking rod readings from a small boat, you will need to take care in positioning the rod and try to make sure the rod rests on top of the sediments and does not sink into soft substrate. At least two people are needed for boat work—one to work the survey rod and the other to station the boat.

Analysis and Calculations

The data from a cross-section survey are elevations and distances. Horizontal distances are recorded to tenths of feet (0.1 ft) and elevations of benchmarks and turning points to hundredths of feet (0.01 ft). Cross-section elevations are recorded to hundredths of feet. These data should be recorded in standard level-survey notation (see Cross-Section Survey Data Sheet in Appendix E). Harrelson et al. (1994) also provide a nice graphic example of proper field book notation for level surveys. The horizontal and vertical datums of the survey must always be recorded (see Site Information Data Sheet in Appendix E). The distances and elevations can be plotted manually on graph paper as 'x' and 'y' coordinates, respectively, or brought into a spreadsheet program for plotting and analyses.

Additional Information

Harrelson et al. (1994) provide an excellent reference for basic survey techniques and for specific information on conducting cross-section and longitudinal profile re-surveys. We strongly recommend that readers with minimal experience consult this reference. It also is a useful review for those with more experience.

2. Longitudinal Profile

Purpose

This section describes how to survey the longitudinal profile of the channel thalweg at your monitoring reach. It identifies the equipment needed, outlines the basic protocol, discusses the frequency with which the profile should be re-surveyed, and presents any site-specific considerations. As with the monumented cross-section method (see Section IV.B.1), this section does not provide detailed instruction on basic surveying techniques. See Harrelson et al. (1994) for a more complete treatment of this subject.

Monitoring Design

Sampling Protocol

1. Define the monitoring reach.

This must be accomplished before surveying the longitudinal profile and the cross-sections. See Section IV.B.1 for general guidelines. Your longitudinal profile should extend the length of the monitoring reach, beginning at a stable channel feature (e.g., riffle) upstream of the impoundment. Your profile should always begin upstream of the uppermost cross-section and should continue to the lowermost cross-section and include survey shots at the thalweg of all monumented cross-sections.

Minimum Equipment

- ❑ Automatic level (surveyor's level), laser level, or total station
- ❑ Leveling rod in English (to tenths and hundredths) or metric units, preferably 25-foot length
- ❑ Measuring tape in same units (300 ft or 100 m)
- ❑ Field book with waterproof paper
- ❑ Data sheets (see Appendix E)
- ❑ Pencil
- ❑ Permanent marker
- ❑ Two-way radios
- ❑ Topographic maps and/or aerial photographs
- ❑ Chaining pins
- ❑ Flagging tape
- ❑ Machete
- ❑ Wood survey stakes
- ❑ Small sledge or mallet
- ❑ Spring clamps
- ❑ Compass

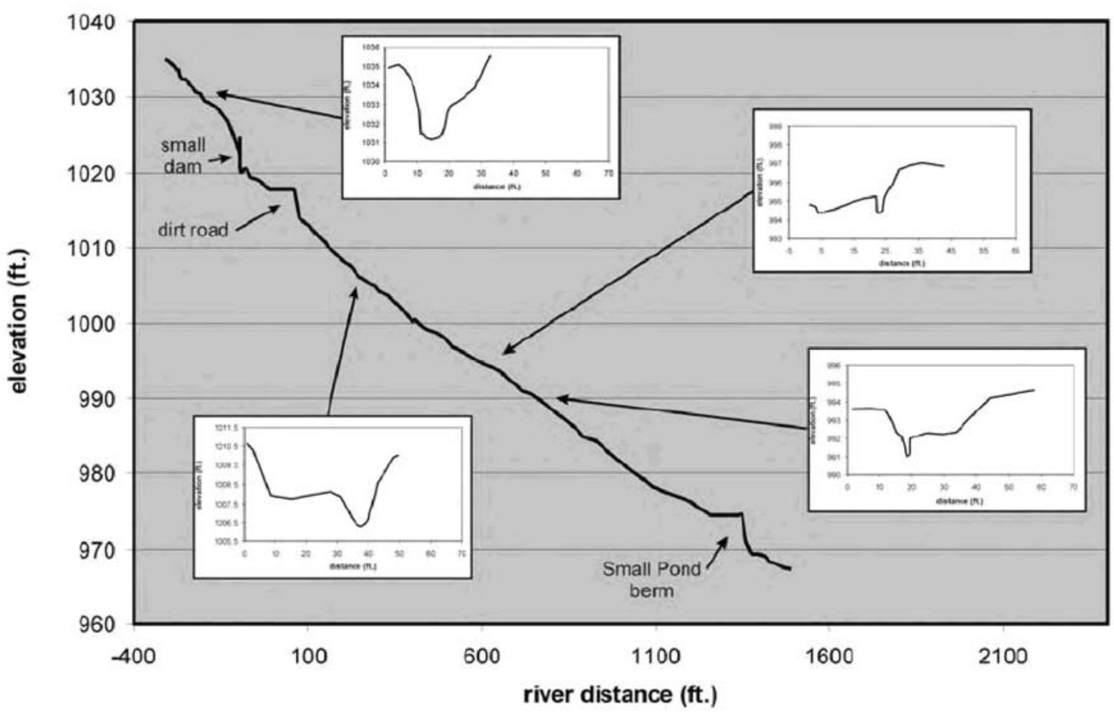


Figure 3. A longitudinal profile surveyed pre-project at Kamrath Creek, Wisconsin. The survey points for a channel bed longitudinal profile are taken at the deepest point in the channel, i.e., the thalweg (see Figure 2). Profile plot courtesy of Brian Graber.

2. Set up the survey instrument.
If possible, set up the level in a location from which the benchmark, and as much of the monitoring reach as possible, is visible (See Section IV.B.1, step 4, for information on benchmarks). You may want to consider setting up the instrument in the channel, if the flow and bed conditions permit (Harrelson et al., 1994). Choose instrument locations carefully to minimize the number of times you need to reposition.

3. Establish the stationing:
Downstream distance should be measured along the channel thalweg. A straightforward method is to station the channel with a baseline along one bank. The downstream distance of each survey shot is measured as the right-angle projection from that location to the baseline on the bank.

The baseline can be established by two people measuring along the stream thalweg with a tape, while someone on shore drives, and clearly marks, wooden survey stakes at regular intervals (commonly a channel width). The purpose of the stationing stakes is to make estimating distances easier. They do not necessarily mark the locations of actual survey shots. See Harrelson et al. (1994) for further information on stationing. Using a total station with a GPS interface, if available, can make stationing unnecessary and considerably simplify profile completion. These units can "fix" the horizontal position of survey shots in known datums such as NAD 83 for subsequent plotting in GIS and calculating distances. Total stations and laser levels are also advantageous for profile surveys because of the long distances over which they can obtain shots (Simon and Castro, 2003).

4. Survey the profile.
Begin with a rod reading on the benchmark to determine the height of the instrument (HI) (see Section IV.B). Then take readings along the thalweg (i.e., deepest part of the channel) at important bed features (e.g., pools, riffles, bedrock sills, woody debris), measuring downstream distance using the baseline. Include enough shots to well define each feature (Simon and Castro, 2003). It is particularly important to determine the highest elevation at pool-riffle (and/or run) transitions.

Along with distances and elevations, record in the field book details about the feature being measured and the locations of important changes in substrate type. Also, take elevations of the water surface at each bed elevation measurement. This can be done easily by taking the elevation of the water's edge closest to the thalweg along the projection to the baseline. Move the instrument as needed to complete the profile.

Sampling Frequency
As with the cross-section surveys, a pre-removal longitudinal profile may be accomplished most easily during an impoundment draw-down and should be integrated with any planned feasibility work (see Site Specific Considerations below). As a general guideline, post-removal re-surveys should occur annually, or every other year, for at least 5 years. However, sampling frequency and duration should reflect project objectives and site conditions. At a minimum, the frequency should conform to regulatory requirements. Note that follow-up surveys should trace the post-barrier removal thalweg, which may not be in the same horizontal position as the pre-removal thalweg.

Site-specific Considerations
A portion of the pre-removal longitudinal profile will run through the impoundment. As with the cross-sections, this may require a boat and should be done with great care. See Site Specific Considerations under Section IV.B.1 for general guidelines and considerations.

Analysis and Calculations
The data from a longitudinal profile survey are elevations and distances. Horizontal distances are recorded to tenths of feet (0.1 ft) and elevations of benchmarks and turning points to hundredths of feet (0.01 ft). Profile elevations are recorded to hundredths of feet as well. These data should be recorded in standard, level survey notation (see Longitudinal Profile Survey Data Sheet in Appendix E). Harrelson et al. (1994) also provide a nice graphic example of proper field book notation for level surveys. The horizontal and vertical datums of the survey must always be recorded (see Site Information Data Sheet in Appendix E). The distances and elevations can be plotted manually on graph paper as 'x' and 'y' coordinates, respectively, or brought into a spreadsheet program for plotting and analyses (Figure 3).

Additional Information
Harrelson et al. (1994) is an excellent reference for basic survey techniques and for specific information on conducting cross-section and longitudinal profile re-surveys. We strongly recommend that readers with minimal experience consult this reference. It also provides a useful review for those with more experience.

3. Grain Size Distribution

Purpose

This section presents methods for characterizing streambed surface grain size distributions by collecting and analyzing sediment samples at a stream channel cross-section. It identifies the equipment needed, outlines the basic protocol, discusses the sampling frequency, and presents site-specific considerations.

Monitoring Design

As with any sampling effort, surface sediment sampling aims to characterize a larger population of bed materials for which a complete census is impractical. To do so, a sample must be random, comprise enough grains for an adequate sample size, and be drawn from a homogenous streambed area. For streams with beds dominated by sand size sediments and finer, it is relatively easy to obtain a large enough sample that can be analyzed in the lab. There, sandy sediments are dried and passed through progressively finer sieves and the weights of materials retained on sieves of particular size classes are recorded. Finer fractions must be separated by sedimentation (e.g., hydrometer or pipette), elutriation, or centrifuge separation (Kondolf et al., 2003). With the weights obtained of the various size fractions, the grain size distribution is then presented as cumulative percent finer by weight.

For gravel-bed streams, however, the requisite sample sizes are too large to be transported off-site and are impractical to sieve in the field. To address this problem, geomorphologists have developed field-sampling techniques that require no lab analyses. The most enduring protocol was developed by Wolman (1954) and is referred to as a Wolman Pebble Count. Put simply, this method prescribes randomly collecting and measuring at least 100 particles from a homogeneous area of the streambed. From these data, a grain size distribution is developed as the cumulative frequency of numbers of stones of different size classes. If the sampled stones are of the same density, which will be true if sampling one lithology, the results obtained will be comparable to a distribution by weight (Kondolf et al., 2003). [If the bed of your cross-section is composed of heterogeneous composition of bed material sizes, or facies (determined by eye), the sample can be improved by collecting 100 particles from each facies and calculating a weighted average grain size distribution with estimated proportions of the bed occupied by each facies. See Kondolf et al. (2003) for a more complete treatment of how to handle a cross-section with mixed populations of bed materials.]

Minimum Equipment

- ❑ Measuring tape in same units as rod (300 ft or 100 m)
- ❑ Ruler marked in millimeters
- ❑ Gravel template (optional)
- ❑ Field book with waterproof paper
- ❑ Pencil
- ❑ Chaining pins
- ❑ Data sheets (see Appendix E)

There are differing standards in the literature regarding the proper sample size for Wolman Pebble Counts, sources of error in conducting them, and ways to improve sampling technique to reduce those errors (see Brush, 1961; Hey and Thorne, 1983; and Fripp and Diplas, 1993 for more discussion). We do not present varying standards here but have adopted some recent modifications to the Wolman Pebble Count that are designed to address observed deficiencies. We also prescribe collecting a minimum of 100 particles, recognizing that collecting larger sample sizes—up to 300 or 400—could improve results (Olsen et al., 2005, Rice and Church, 1996). Within the context of this Monitoring Guide, we do not feel the precision gained merits the extra effort required, although we do encourage collecting a larger sample size if project resources permit.

Sampling Protocol

Because the bed sediment characteristics of a given barrier removal stream reach are not typically known beforehand, nor is the variability between cross-sections, the following protocols address sampling of beds dominated by 1) sand-size and finer sediments or 2) gravel. Note that both methods may be relevant to a given project, particularly for pre-project monitoring of proposed dam removal sites (see Site-specific Considerations below).

At a minimum, collect a bed material sample for at least one of each cross-section type representing physically distinct stream reaches in the monitoring reach and at cross-sections where important infrastructure or habitat zones are located. In all likelihood, this means you will collect bed material samples for only a subset of the cross-sections you re-survey.

At all sampled cross-sections, samples should be collected from within the normal low flow channel unless particular study objectives require characterizing the bed of the larger bankfull channel. In these situations, sample between the toe of bank on each side of the stream (some of which may be dry at sampling time).

Cross-sections Dominated by Fine Sediments (Sand Size and Finer)
At these cross-sections, each sample point should be composed of approximately one liter of surface sediments for laboratory evaluations (i.e., a bulk sample). On exposed beds or bars samples can be obtained with a trowel or shovel. A variety of bed material samplers (e.g., grab samplers) can be used for sample acquisition under water. The number and location of samples required to characterize the cross-section will depend on how heterogeneous the bed material is in that stream reach (Kondolf et al., 2003). If multiple samples are required to characterize a heterogeneous cross-section, compositing those samples for laboratory analyses may be appropriate.

Cross-sections Dominated by Gravel
1. Perform a pebble count at each selected cross-section after a cross-section survey is performed to make use of the tape already stretched across the channel.

2. Assign a sampler to collect and measure the particles and a reader to record the results. The sampler calls out the measurements to the reader. The reader repeats back each measurement as a quality control check.

3. The sampler will walk back and forth along the transect, and perhaps 2 to 4 others closely paralleling the transect, reaching down at regular intervals to pick up a particle near the tip of their boot. The intervals should be scaled to the length of the transect(s) such that 100 particles will be collected. For example, if the transect length is 10 meters and the sampler's stride is a half meter, approximately 20 samples will be collected with each bank-to-bank sampling pass, and at least 5 passes will be required to obtain a minimum of 100 samples.

4. As the sampler's finger falls to the bed to pick up the particle, the sampler should not look at the stream bottom to avoid bias toward selecting larger particles. The sampler should pick up the first particle encountered. Do not count organics such as wood fragments or other detritus. If the sampler touches fine material that is clearly less that 4 mm, the sampler should simply call out "fines" to the reader who will record the occurrence in the < 4 mm size class (see Table 3 in Analysis and Calculations below). For larger particles, the sampler measures the particle's "b-axis" in millimeters (mm) and calls out the measurement to the reader.

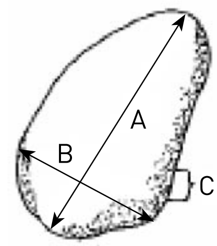


Figure 4. Particle axes (from Potyondy and Bunte, 2002).
A = Longest axis (length)
B = Intermediate axis (width)
C = Shortest axis (thickness)

The b-axis can be identified by first finding the long axis (A), then the short axis (C), and finally the intermediate axis (B) that is perpendicular to both the A and C axes (see Figure 4). The b-axis is the axis that governs whether a particle will fit through a sieve mesh of a given size, so measuring it gives results most comparable to a standard sieve test. The particle can also be measured using a particle size template or "gravelometer" (Potyondy and Bunte, 2002). Doing so can reduce observer error in measuring the b-axis. Whichever measurement method is employed, either ruler or gravel template, be sure to consistently use that method from year to year throughout the monitoring period so that results are directly comparable.

5. Repeat this procedure until at least 100 particles have been collected.

Sampling Frequency
Sampling should be conducted at the same frequency as the cross-section surveys (see Section IV.B.1) and performed during wading-depth stream conditions.

Site-specific Considerations
For dam removal sites, bed material samples should be collected from at least two cross-sections in the impoundment: one representing the upper impoundment and another representing the lower impoundment. Impounded sediments will frequently be sand-size and finer deposits that need to be collected as bulk samples from a boat with a grab sampler or other similar device (see above). As with other cross-section sampling locations, the number and location of samples at a cross-section will depend on the heterogeneity of the bed material there. If the general location of the post-removal channel is also known, this information should influence the choice of sampling locations.

For many dam removal projects, feasibility studies will include contaminant sampling of sediments in the impounded area. For efficiency purposes, the long-term bed sediment monitoring program should be coordinated with any such investigations so that some of the contaminant sampling locations are coincident with at least one long-term monitoring transect and to ensure that the samples are analyzed in the laboratory for grain size.

Analysis and Calculations

The data from a pebble count are simply counts of particles in different size classes. For example, a particle with a b-axis measuring 100 mm will be recorded in the row marked "<128" on Table 3 and a particle measuring 65 mm will be marked in the "<90" row. In the office, hash marks can be tallied and the percent frequency and cumulative percent finer can be calculated with a spreadsheet program. The cumulative percent finer can be plotted as shown in Figure 5. The results of fine sediment bulk samples sent to the lab should be reported in a similar manner.

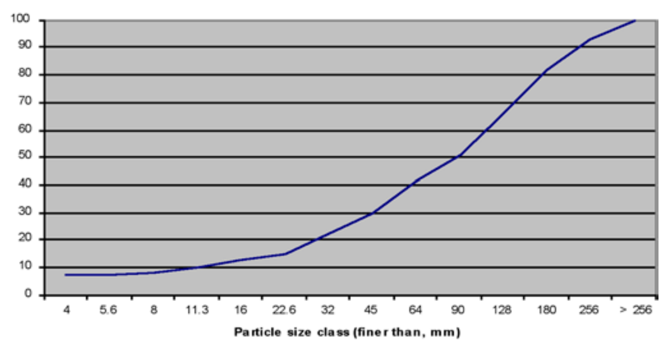
Additional Information

Kondolf and others (2003) provide a good overview of bed sediment sampling in general. Bunte and Abt (2001) and Kondolf (1997) should be reviewed for a more thorough treatment of sampling coarse-grained bed sediments.

Table 3. Example spreadsheet developed from field notes. Note that the first and second columns are the only columns needed in the field book. Note also that recording counts as hashes in the second column builds a histogram in the field.

Size Class (mm)	Count	Count	Frequency (%)	Cumulative % Finer
>=256	卌 ||	7	7	100
<256	卌 卌 |	11	11	93
<180	卌 卌 卌 |	16	16	82
<128	卌 卌 卌	15	15	66
<90	卌 卌	10	10	51
<64	卌 卌 |	11	11	41
<45	卌 |||	8	8	30
<32	卌 ||	7	7	22
<22.6	||	2	2	15
<16	|||	3	3	13
<11.3	||	2	2	10
<8	|	1	1	8
<5.6		0	0	7
<4	卌 ||	7	7	7
	Totals:	100	100	

Figure 5. Cumulative frequency curve generated from pebble counts.



Karla Garcia / NOAA Restoration Center

Bed sediments downstream of a dam in New Hampshire.

4. Photo Stations

Purpose

Maintaining a standardized photo/video monitoring record of stream barrier removal projects can serve multiple purposes, from tracking the visual changes of a site over time to satisfying grant and regulatory requirements. Photographs used for stream restoration monitoring can capture various physical and biological conditions such as changes in riparian vegetation or changes in channel features. Photographic images of pre-and post-restoration conditions can showcase project successes and can be used to promote future restoration projects. This section describes how to conduct standardized photo monitoring specific to stream barrier removal projects in the Gulf of Maine watershed.

Minimum Equipment

- ❑ Digital camera (preferred specifications: optical zoom, video function, >3 megapixel resolution)
- ❑ Extra batteries (digital-camera grade)
- ❑ Compass with degrees
- ❑ Site plans, topo maps, aerial photos
- ❑ Timepiece
- ❑ Field notebook or sketch pad
- ❑ Pencils and pens
- ❑ Data sheets (see Appendix E)
- ❑ Tape measure
- ❑ GPS unit (optional)
- ❑ Monumenting material: stakes, rebar, hammer, flagging (optional)
- ❑ Stadia rod (optional)
- ❑ Chalk board/white board (optional)

Monitoring Design

A critical component of photo monitoring is ensuring that key landscape features are represented at a scale and resolution that is legible and reproducible. Another critical component and perhaps the most complicated aspect of this relatively simple monitoring procedure is being able to locate each photo station over multiple years and reproduce the same vantage point. Detailed documentation is essential to capturing adequate information for resurveying each photo station.

Sampling Protocol

The length of time required to complete photo monitoring will depend upon the size of the site and the scale of monitoring efforts. For quality assurance, photo monitoring is best accomplished with two people. A field partner, equipped with a stadia rod and whiteboard can provide scale to a photograph and convey critical site information. Prior to establishing photo stations in the field, you should chart out potential stations on a site plan, topographic plan, or aerial photo. Ideally this plan should include cross-sections and physical features of your site. Before permanent photo

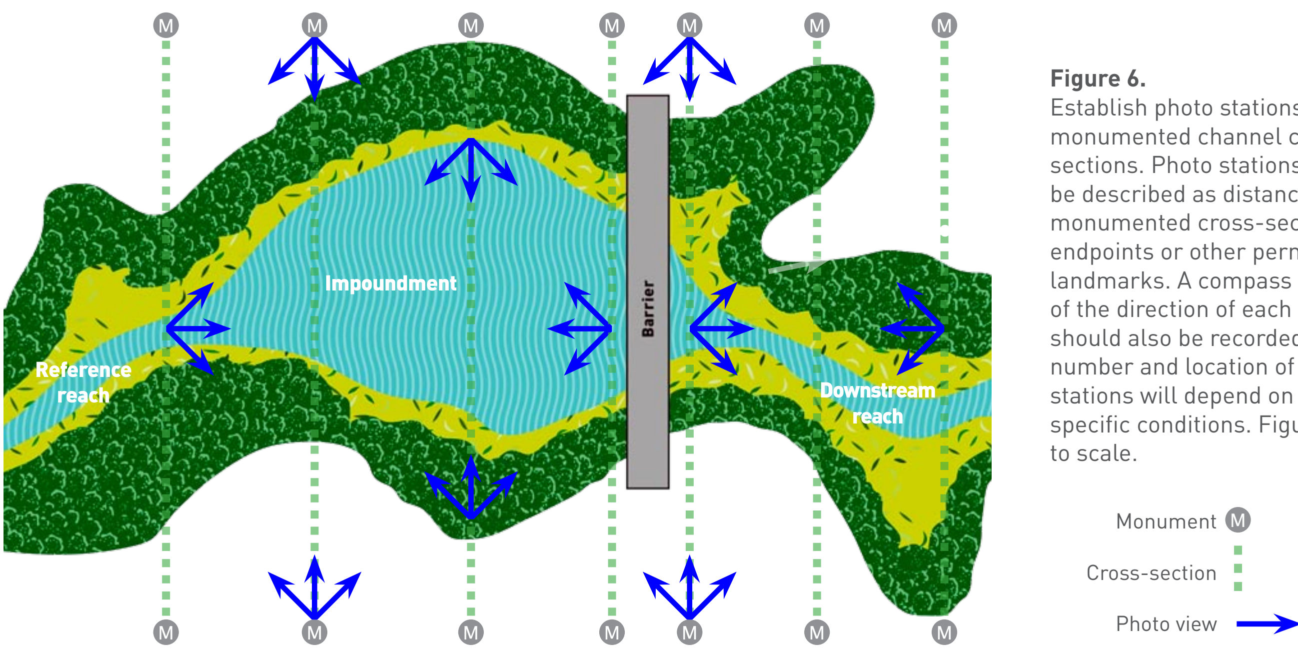


Figure 6.
Establish photo stations along monumented channel cross sections. Photo stations should be described as distances from monumented cross-section endpoints or other permanent landmarks. A compass bearing of the direction of each photo should also be recorded. The number and location of photo stations will depend on site-specific conditions. Figure not to scale.

stations are established, a brief reconnaissance of the site should be conducted to confirm the suitability of predetermined sites.

Locations of photo stations should be described as distances and/or bearings from other known points such as cross-section endpoints or other permanent landmarks. Geographic context of each photo should, at minimum, include: left bank, right bank, upstream, downstream (left and right bank determinations are made facing downstream). Photo station locations should be selected to take advantage of complimentary light, include long-term reference points (buildings or permanent landscape features), and be easily accessible for post-restoration monitoring. Once permanent stations are decided upon, these locations should be monumented with staking, if possible. Flagging can also be used but should be considered a temporary means to mark a photo station. Date-stamping digital photographs can be helpful, but it can be problematic if the date stamp obscures important parts of the image.

The following views are recommended:

- Upstream and downstream view of the barrier.
- Upstream and downstream view from the barrier.
- Across the barrier from left bank to right bank and vice versa.
- Across and along monumented cross-sections from both cross-sectional end points, including floodplain and riparian wetlands.
- Along the longitudinal profile.

Special emphasis should be paid to the following:

- Ecosystem features such as wetland plant communities, floodplains, riparian vegetation, streambanks, meanders, depositional/erosional features, flow-diverting structures, riffles, pools, and large woody debris.
- Events such as barrier removal, high-water conditions, low-flow conditions, and any other noteworthy natural or anthropogenic events.

Sampling Frequency

At a minimum, pre-and post-project photo monitoring is needed to create a valuable image record. The best time to take pre-restoration photos or videos is during leaf-out so landscape features and physical structures are clearly visible, unless the goal of the photo and video record is to document vegetation changes. In that case, specific emphasis should be on the flowering periods of signature riparian plants. We recommend that pre-restoration photo monitoring include both leaf out and full vegetation in the year preceding restoration. Post-restoration photo monitoring is recommended for 1, 2, and 5 years after the restoration project (Table 4). Photo monitoring during construction is equally important as pre-and post-restoration monitoring and can be used to capture short-term changes in ecosystem conditions; inform the efficacy of implementation techniques; confirm implementation success; and support as-built design plans.

Site-specific Considerations

The scale of the project will dictate how photo monitoring is done. For example, it may be difficult to portray adequately a large impoundment with normal photography, in which case aerial photography should be considered. Aerial photography can be used to determine landscape feature changes such as large-scale changes in impoundment area, stream-course narrowing, thalweg configuration, and large-scale vegetation changes. Historical aerial photographs can illuminate important landscape changes, which is particularly useful for informing pre-restoration decisions.

Analysis and Calculations

Appropriate documentation and organization is necessary to store and properly manage digital photos. The photo log form should be filled out if any photos are taken (see Appendix E). Each photo station should be marked on a plan or sketch with arrows indicating direction or compass bearing of the photo (Figure 6). Once uploaded, picture files should be properly labeled and stored in appropriate folders labeled by site name and date. Metadata should be stored with pictures.

Additional Information

These methods for photo monitoring of stream barrier removal monitoring projects were informed by Collins (2003), Landry (2002), and Hall (2002).

Table 4. Recommended photo-monitoring timeline for stream barrier removal projects.

Project phase	Pre-restoration		Restoration	Post-restoration					
Year	–1		0	1		2		5	
Timing of photo monitoring	Full vegetation	Leaf out	Multiple times throughout	Full vegetation	Leaf out	Full vegetation	Leaf out	Full vegetation	Leaf out

5. Water Quality

Purpose

Aquatic organisms such as fish and macroinvertebrates have varying tolerances to dissolved oxygen, temperature, conductivity, salinity, and pollution. Measuring water quality parameters at a barrier removal site offers insight regarding the quality of habitat available and the species that can be supported at that site. Conductivity data can show evidence of pollution and groundwater sources of surface water. Salinity, when measured at an intertidal barrier, may be used predict the aquatic species as well as vegetation that may colonize an area after the barrier is removed.

This section describes how to measure temperature, dissolved oxygen (DO), conductivity, and salinity at a barrier removal site. We recommend that the user monitor these parameters at least once per week for eight weeks during August and September (see Sampling Frequency below for further discussion). Monitoring should be done as close to dawn as possible. This monitoring design will allow the user to describe how a barrier is impacting water quality at a site and how conditions change with barrier removal. This design is intended as a minimum, and the user may choose to conduct more monitoring to answer questions specific to a particular barrier removal project.

Minimum Equipment

- ❑ Pencils
- ❑ Clipboard
- ❑ Multi-parameter probe
- ❑ Equipment calibration solutions
- ❑ Data sheets (see Appendix E)
- ❑ Bucket (if necessary)
- ❑ Watch
- ❑ Air thermometer
- ❑ Chest waders
- ❑ Boat

Equipment Considerations

Water temperature, conductivity, and salinity are most commonly measured using electrometric equipment. Temperature, conductivity, and salinity probes and meters are available from a number of vendors. Conductivity is often reported in terms of specific conductance (i.e., conductivity results that have been adjusted to what it would be at 25°C). Most conductivity probes have a feature that can automatically convert conductivity readings at any temperature to specific conductance values. Probes and meters are available that measure all three of those parameters—temperature,

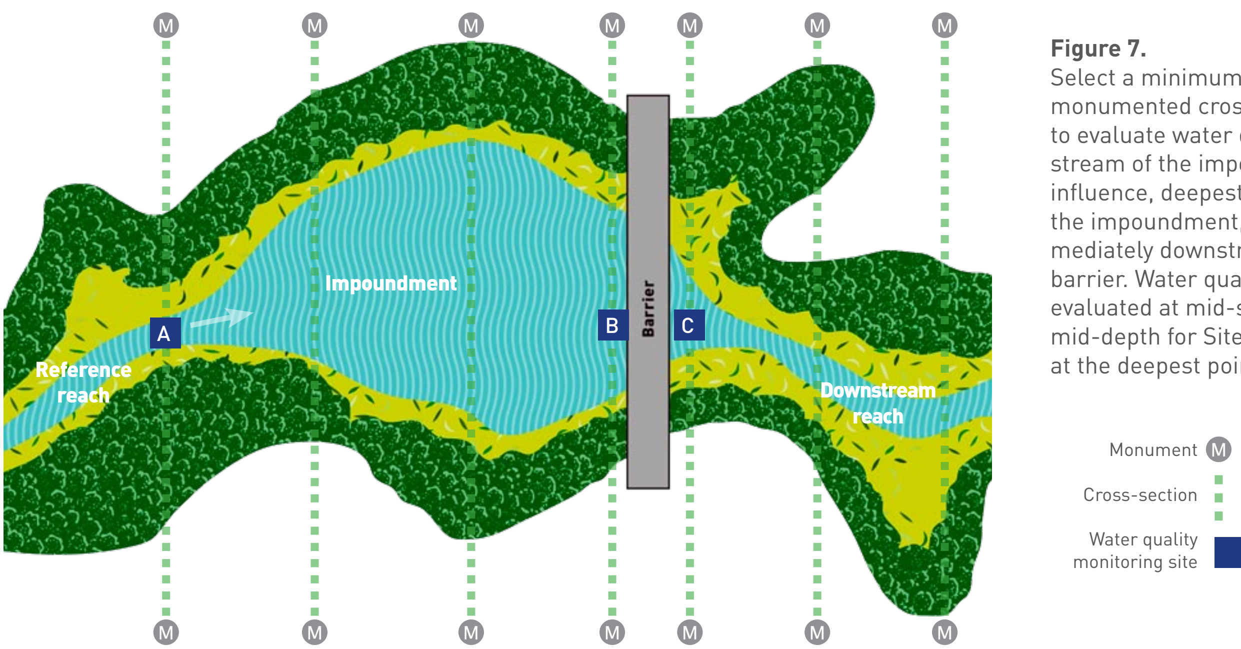


Figure 7.
Select a minimum of three monumented cross-sections to evaluate water quality: upstream of the impoundment influence, deepest point within the impoundment, and immediately downstream of the barrier. Water quality should be evaluated at mid-stream and mid-depth for Sites A and C and at the deepest point for Site B.

conductivity, and salinity—plus dissolved oxygen (DO) (see below). Calibration, use, and maintenance will vary among equipment and between manufacturers. Careful treatment and regular equipment maintenance are essential for accurate data collection. Salinity need only be measured if barrier removal is occurring in an intertidal area and the removal is expected to restore tidal flow. If it is necessary to collect data along a vertical profile, be sure to purchase or secure the use of a probe with a long cord so that the data can be collected at the appropriate depth.

Two methods are commonly used for measuring dissolved oxygen: the Winkler method and the electrometric method. Each requires different equipment. The choice of method depends on the desired accuracy, convenience, staff training level, and available equipment. In general, the Winkler method is held to be more precise and accurate than a meter and probe. However, the results can be influenced in the field by such factors as nitrite, organic matter, iron, and the capabilities of the person collecting the data. A comparison of the two methods is beyond the scope of this document; refer to sources such as Standard Methods for the Treatment of Water and Wastewater (APHA, 2006) and the National Environmental Methods Index (www.nemi.gov) for detailed information about both methods.

The Winkler method is a titration procedure based on the oxidizing property of dissolved oxygen (USEPA, 1983). Samples analyzed with the Winkler method can be analyzed on site or fixed (stabilized), refrigerated, and analyzed in the lab up to six hours after collection. Several vendors sell kits that include the necessary equipment, chemicals, and detailed instructions for analyzing water samples. The user must read Material Safety Data Sheets (MSDS) for all chemicals and take safety precautions.

The electrometric method relies on the diffusion of oxygen across a membrane located in a probe-based sensor. Measurements must be taken either in the stream or impoundment itself or immediately after collection in a bucket. DO instruments are available from a number of commercial vendors. The instructions for calibration, use, and maintenance may differ from instrument to instrument and among manufacturers. Therefore, the user is encouraged to read the instructions carefully and follow them closely. DO probes in particular are extremely sensitive. Careful treatment and equipment maintenance are essential for accurate data collection. The U.S. Geological Survey offers a thorough discussion of dissolved oxygen equipment calibration in its National Field Manual for the Collection of Water-Quality Data (Wilde, 2005). Note that if DO is being measured in a saline environment, a correction factor must be applied after the data are collected.

Monitoring Design

This monitoring design is based on the cross-section design described in section IV.B.1. The sampling design will describe water quality conditions upstream of the zone of influence of the barrier, just upstream of the barrier, and downstream of the barrier. These data will reveal how the barrier is affecting water quality before barrier removal. After the barrier is removed, returning to the previously monitored sites will show how barrier removal has affected water quality at the site.

Sampling Protocol

1. Identify three water quality data collection sites.
Site A should be upstream of the area influenced by the barrier, preferably along the furthest upstream cross-section (Figure 7). Water-quality data should be collected mid-stream and at mid-depth.

Site B should be along a cross-section that traverses the deepest part of the impoundment, and water-quality data should be collected at the deepest point. If there is no impoundment, Site B should be located along the cross-section immediately upstream of the barrier.

Site C should be located along the cross-section just downstream of the barrier. Water-quality data should be collected mid-stream and at mid-depth (Figure 7).

2. Document location of each water-quality monitoring site so user may return to sites in the future.
Describe the location of each monitoring site in relation to the cross-sections and in relation to any permanent markers or landmarks at the site, making sure to note cross-section number. Document with GPS the location of each monitoring site. Compile this information so that it can be accessed as necessary.

3. Prepare for field data collection.
Review the instruction manuals for each meter and probe being used. Make sure that probes are undamaged and are functioning properly. Inspect electrical connections and batteries. Install new batteries if necessary. Test calibration. Collect and inventory field equipment. If the Winkler titration method is being used, review the method, and make sure that the reagents have not expired. Before handling chemicals, check Material

Safety Data Sheets (MSDS) for safety precautions.

4. On the day of field data collection, calibrate the meters, being sure to follow the manufacturer's instructions. Record all calibration data. Bring calibration solutions into the field in case recalibration is necessary.

5. Collect water quality data.
Data must be collected early in the morning, preferably close to daybreak, in order to capture the lowest dissolved oxygen readings of the diurnal cycle. The USGS National Field Manual for the Collection of Water-Quality Data (Wilde, 2005) has an excellent discussion of surface-water sampling. All data should be collected in situ. Record the time of each water-quality measurement.

Sites A and C: Collect dissolved oxygen, temperature, and specific conductance data mid-stream at mid-depth. Follow manufacturer's instructions for meters and probes. For the Winkler titration method, it will be necessary to collect a water sample in a labeled "Biological Oxygen Demand" bottle.

Site B: If this site is located in an impoundment, collect a water-quality vertical profile. Collect dissolved oxygen, temperature, and conductivity information just below the surface of the impoundment and then at foot-intervals below the surface until the probe is located just above the bottom of the impoundment.

Step 6. Maintain equipment.
After the field visit, clean equipment and conduct any necessary maintenance.

Sampling Frequency

All data should be collected weekly for eight weeks during August and September. Data should be collected early in the morning, as close to dawn as possible. This is necessary in order to collect information on dissolved oxygen when it is at its lowest point in the diurnal cycle.

Macroinvertebrate data will complement the water-quality data. If macroinvertebrate data are not being collected, however, then water-quality data should be collected weekly from June through October or through continuous monitoring. Data should be collected at least one year prior to barrier removal at a minimum, immediately after barrier removal, and annually thereafter for five years. Additional water-quality monitoring prior to barrier removal projects is preferred.

Table 5. Recommended precision and accuracy levels for water quality data.

Parameter	Precision	Accuracy
Dissolved oxygen	+/- 2% or 0.2 mg/L, whichever is greater	+/- 2% of initial calibration saturation or 0.2 mg/L, whichever is greater
Conductivity	+/- 5%	+/- 5% against a standard solution
Temperature	+/- 0.2° C	+/- 0.2° C (checked against a NIST-certified thermometer)

Site-specific Considerations

If the barrier is located in an intertidal area, salinity should be added to the monitoring protocols at all sites before and after barrier removal. Refer to Lane and Fay (1997) for guidance on safety procedures (e.g., sample collection safety, wading in streams, boating safety, chemical handling).

Analysis and Calculations

We recommend precision and accuracy levels for the data collected rather than specific pieces of equipment. Water-quality equipment varies widely in its precision and accuracy. State and provincial governments may prefer different types of equipment, and project budgets may vary. The user is encouraged to use equipment available through project partners or that fits their budget, as long as the data meet the recommended precision and accuracy guidelines (Table 5). QA/QC samples should be collected at a frequency of 1 in 10, or 10%.

6. Riparian Plant Community Structure

Purpose

This section describes the equipment, sampling protocols, sampling frequency, and site selection considerations for monitoring of the riparian zone plant community. Parameters include species abundance, composition, percent cover, stem density, and basal area. These parameters describe the riparian plant community and identify changes in the riparian zone that may occur over time.

Monitoring Design

A plant community is an association of plant species in a given place. Community structure is inclusive of all plants that occur in the tree, sapling and shrub, and ground cover (vine/liana and herbs) vegetative layers. The composition and percent areal cover of plants, as well as their general condition with respect to both native and non-native species, describes riparian plant communities. Collecting and analyzing plant community data following well-recognized methods, such as the step-by-step protocol listed below, provides the basis for documenting these communities for purposes of their protection, conservation, and/or restoration. A data sheet that is specific to the protocol outlined below is provided in Appendix E. We recommend using it for your site assessments.

Minimum Equipment

Riparian vegetation monitoring requires relatively limited equipment but should be conducted by persons trained in botany, field plant identification, and the use of systematic keys for plant identification. Field equipment should include, at a minimum:

- ❑ Laminated, scaled maps (e.g., NWI, soil survey maps) or aerial photographs, protected in clear, resealable plastic bag or folder, depicting the stream/river reach, riparian study area, and bordering uplands
- ❑ Field notebook, pencils, waterproof permanent markers, and clipboard
- ❑ Data sheets (see Appendix E)
- ❑ Tape measure (100 ft or 300 ft open-reel fiberglass tape)
- ❑ Meter stick for measuring plant heights
- ❑ Rebar or wooden survey stakes to serve as permanent monuments/markers to identify transect endpoints and plot locations
- ❑ Diameter at breast height (DBH) tape to measure trees
- ❑ Camera and photo monitoring data sheets
- ❑ Resealable plastic bags for plant specimens
- ❑ Hand lens for keying-out plants
- ❑ Plant identification keys

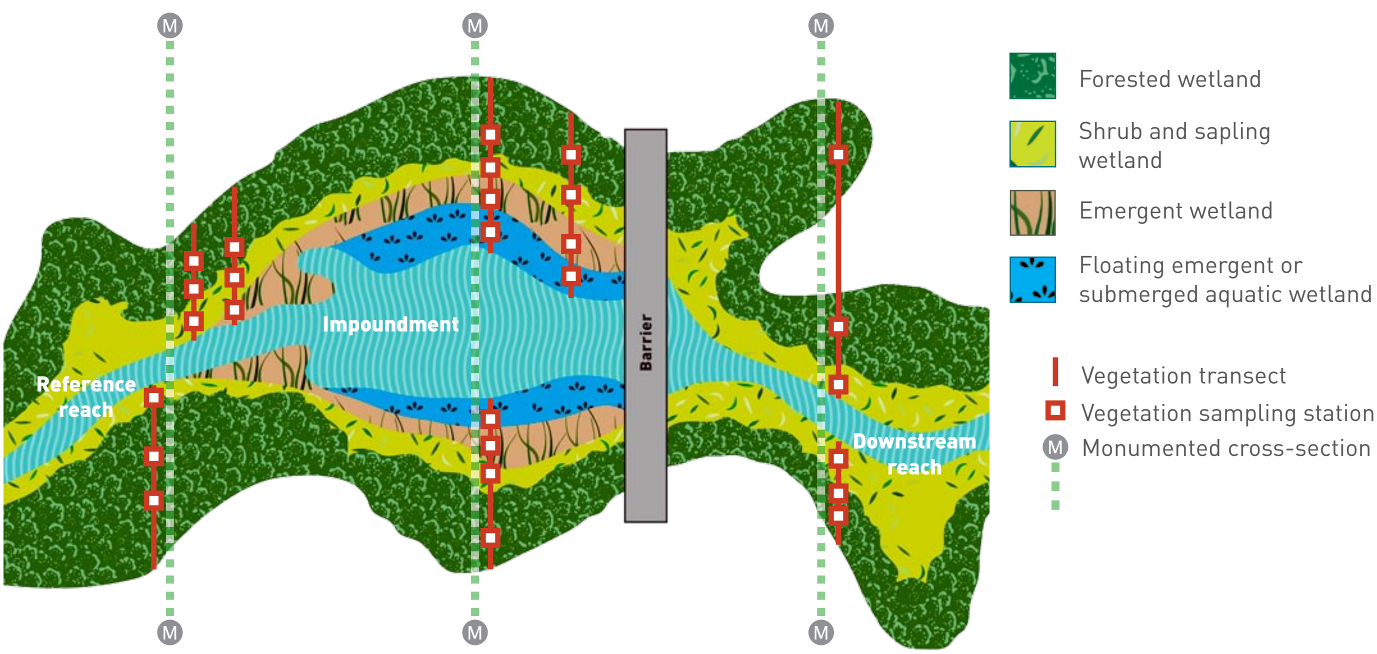


Figure 8. Establish 3 vegetation monitoring transects within the reference reach, 3 transects within the impoundment reach, and 2 transects in the downstream reach. A transect that spans the channel and both banks should be counted as 2 separate transects. At least 1 transect should coincide with, but be offset from, a monumented cross-section for each reach. The number and location of transects and vegetation sampling stations will depend on site-specific conditions. Figure not to scale.

Sampling Protocol

The goal of this protocol is to characterize riparian vegetation by sampling permanent vegetation monitoring stations along permanent transects. Transects should be established within each of the three reaches: 1) the reference reach upstream of the barrier's influence; 2) the impoundment or reach affected by the barrier; and 3) the reach downstream of the barrier. Along each transect, sampling stations are selected to characterize the vegetation within general cover types such as floating emergent and submerged aquatic vegetation; emergent wetlands; scrub/ shrub wetlands; and forested wetlands. The instructions below describe where to locate the transects and sampling stations and how to sample the vegetation at each station.

1. Identify vegetation cover types present at the barrier removal monitoring site.
Using aerial photos and field visits, identify cover types (tree, shrub, vine, liana, and herbaceous layers), wetland versus adjacent upland community types, and their condition. See Cowardin et al. (1979) for classifying wetland cover types.

2. Establish the transects.
Establish a minimum of three transects in the reference reach, three transects in the impoundment reach, and two transects in the downstream reach (Figure 8). Transects should adequately represent the plant cover types identified in step 1. Additional transects should be established if time and resources allow, particularly for extended riparian zone/stream reaches that may be affected by the barrier removal.

3. Install rebar/wooden survey stakes at each transect's start and end point.
End points should be located upgradient of the wetland-upland boundary or outside the area that is expected to change with barrier removal. Label/number each transect stake. Transects may also be referenced to monumented cross-sections or offset a known distance from the cross sections. Transects should not be co-located with the monumented cross sections because surveying will trample vegetation.

4. Mark and label the transect start and end points.
Mark them on a scaled site map or aerial photo. Record the GPS coordinates of these locations.

5. Establish at least one sampling station within each distinct vegetation cover type along each transect.
Sampling stations should be chosen to characterize each of the cover types identified in step 1. Ideally, sampling stations will be established via a systematic random approach, where the vegetation units are first identified in step 1, and station locations are then randomly selected along the transect within the identified cover types (e.g., herbaceous plants sampled every 5 meters, shrubs every 15 meters, and trees every 30 meters). Supplemental, post-restoration sampling stations may need to be established to accommodate changing cover types, particularly where deepwater impoundment drawdown results in a vegetation community (Figure 9).

Additional Recommended Equipment

- ❑ Handheld GPS for recording the location of transects, plots, or other specific points
- ❑ Compass for laying out transects and describing photo station direction
- ❑ Plastic flagging tape for field marking monitoring plots and transects
- ❑ Hammer/mallet to install rebar or wooden stakes into the ground
- ❑ Daypack and/or field vest
- ❑ Waders, hip boots, brimmed hat, insect repellent, and sun block
- ❑ Storage cooler with ice to help preserve plant specimens and other field samples

6. Mark each station with a stake or other permanent monument.
Use GPS to determine station location, and record the distance along the transect from the starting point to the station. Document whether a station stake is the center point or a corner point for each plot, particularly if a station differs from the layout used for the remainder of the monitoring area stations.

7. At each station, estimate species cover.
Estimate cover within all of the layers that are present: herbaceous; sapling and shrub; and tree. Herbaceous vegetation is sampled using a 1 m^2 (10.8 ft^2) quadrat. The sapling/shrub layer is sampled within a 5 m (approx. 16 ft) radius of the sampling station. Trees are sampled within a 9 m (approx. 30 ft) radius of the station.

The herbaceous layer includes all non-woody, emergent species of all heights (including bryophytes) and woody-stemmed plants < 3 ft (approx. 1 m) in height. The monitoring quadrat should be 1 m^2 (10.8 ft^2) and can be defined using an increment-calibrated, 1-meter-by-1-meter frame made of PVC-pipe, or a similar meth-

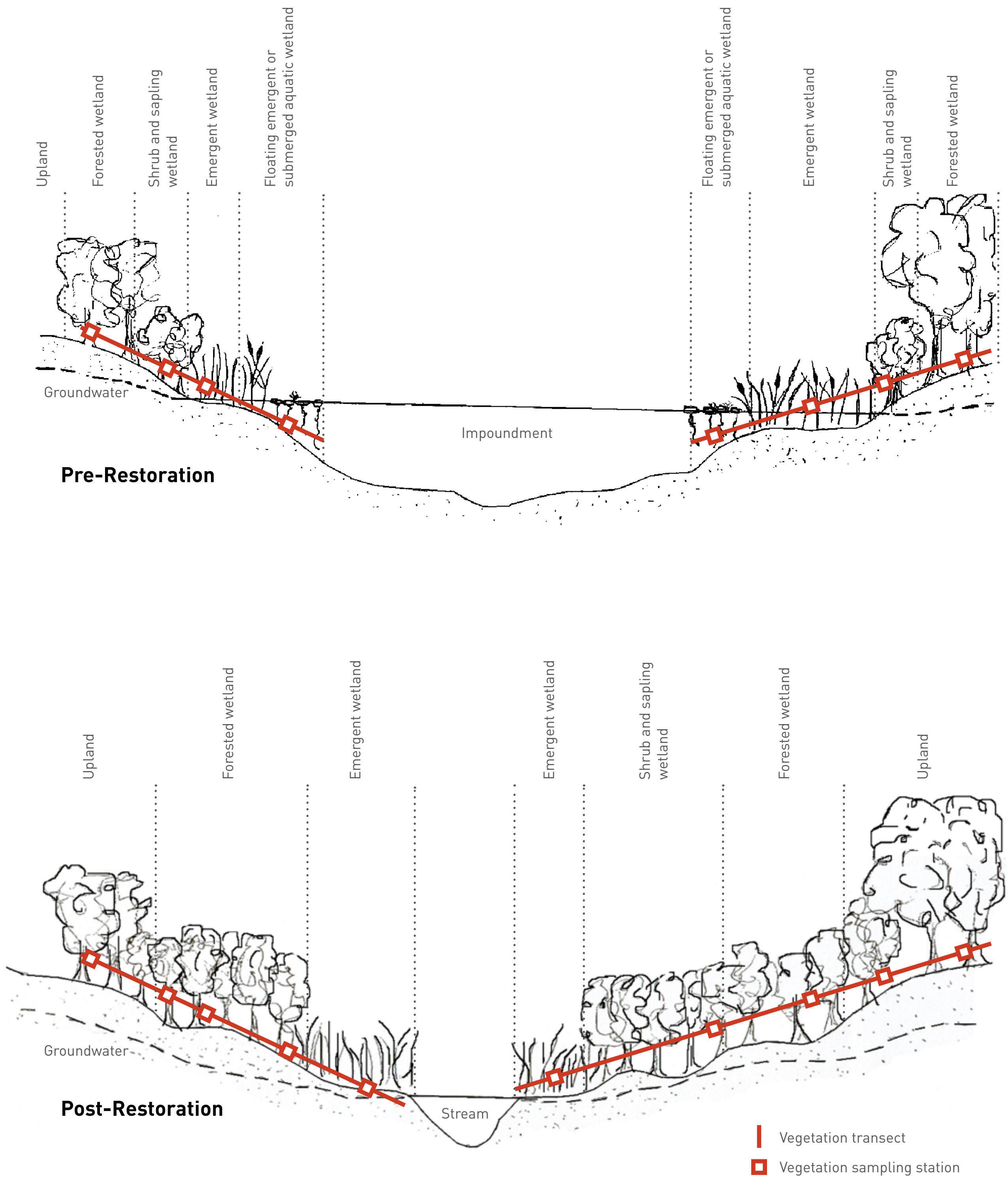


Figure 9. During pre-restoration monitoring (top), establish at least one vegetation monitoring station within each distinct vegetation cover type along each monumented vegetation transect. For post-restoration monitoring (above), vegetation monitoring stations may be added where vegetation has become established on the former bed of the impoundment. Within each monitoring reach, it is optimum to have three vegetation monitoring stations per cover type. Vegetation cover types should be sampled using the following plot size at each permanent monitoring station: 1 m^2 (10.8 ft^2) quadrat for the herbaceous layer, 5 m (approx. 16 ft) radius for the scrub and sapling layer, and 9 m (approx. 30 ft) radius for the tree layer. Figure not to scale.

Drawings by Kevin Lucey / NHDES

od. Estimate cover of the vertical plant shoots' aerial projections lying only inside the plot as a percentage of the plot area. Total cover in a plot may exceed 100 percent, as plant projections often overlap one another. When the project area has high stem density of herbaceous plants but relatively low species (< 5) diversity, a 0.5 m^2 (5.4 ft^2) quadrat may be used. When monitoring prior to barrier removal with plots located inside or near the edge of the impoundment, identify floating or submerged plants that are present. Identify each species, and record each species percent cover within the plot. Also estimate and record percent of both barren ground and dead plant cover. If time allows, also count the number of stems in a 0.25 m^2 (2.7 ft^2) or 0.5 m^2 (5.4 ft^2) quadrat.

The shrub and sapling layer includes all woody stemmed plants that are more than 3 ft (approx. 1 m) but no taller than 20 ft (approx. 6 m) tall and that have a diameter at breast height (DBH) between 0.4 inch (1 cm) and 5.0 inches (approx. 13 cm). DBH is measured at 4.5 ft (approx. 1.5 m) above ground level. For the shrub and sapling layer, monitor within a 5 m (approx. 16 ft) radius of the sampling station point. Identify the species of each plant, and record species percent cover within plot. Note the number of dead standing shrubs. If time allows, randomly sub-sample the plot by counting woody stems in a 1 m^2 (10.8 ft^2) quadrat.

The tree layer includes all woody plants that are taller than 20 ft (approx. 6 m) and have a DBH greater than 5 inches (approx. 13 cm). Monitor within a 9 m (approx. 30 ft) radius of the sampling station point. Identify the species of each plant, and use a DBH measuring tape to obtain individual DBHs, which will be used later to calculate basal area [$A = \pi (d)^2/4$, where $\pi = 3.14$ and d = DBH] of each species within each plot. Also note the number of dead standing trees within the sample area.

When estimating percent cover, values should be recorded as whole integers that can be categorized according to a standardized, commonly used Braun-Blanquet cover class scale (Table 6) (Braun-Blanquet, 1932; Mueller-Dombois and Ellenberg, 1974). These cover class categories can be used to expedite field sampling; the mid-point values are used in place of the actual corresponding field estimate values to minimize the variability of results that can arise when multiple people estimate cover. Once field assessments are completed, cover-abundance scores can be used to calculate plant species cover for assessment sites. Refer to the Analysis and Calculations section below for database management and calculations used for generating results.

Table 6. Braun–Blanquet cover class scale and mean values to estimate cover class.

Category	Percent Cover	Mid-Point
T	<1	None
1	1-5	3
2	6-15	10.5
3	16-25	20.5
4	26-50	38
5	51-75	63
6	76-95	85.5
7	96-100	98

Sampling Frequency

It is optimal to monitor vegetation during the peak of the vascular plant growing season. For the northeastern United States, this period is generally between July 15 and August 31. Some riparian plant species flower in spring or early summer, so the monitoring team may want to consider a site assessment during spring, if time allows. Monitoring is conducted at least once annually for each monitoring year (see below), and all stations should be monitored during each monitoring period. The project and reference sites should be monitored within the same time period and as close in time to one another as possible. Vegetation monitoring should include a minimum of one year of pre-restoration and three years of post-restoration assessment, and preferably over a longer period (such as once every 3 to 5 years) for post-restoration assessment. This is particularly important for reforesting sites and if a goal of the restoration is to document ecological succession of the riparian zone.

Baseline Versus Post-Removal Monitoring: Ideally, monitoring plots are monitored at least once prior to removal of the stream barrier to define a baseline condition. When funding and time allow, it may be beneficial to monitor two or more years prior to a barrier removal because this better accounts for environmental variability. Some removals result in very little change in riparian shoreline locations, whereas others can result in substantial change. If changes in shoreline vegetation are expected with impoundment drawdown, then baseline vegetation transects should include areas of impoundment habitat where vegetation and substrate conditions are documented.

Deborah Loiselle / NHDES

Using GPS to record location of a vegetation quadrat.

Analysis and Calculations

After field assessments are completed using standardized field data sheets and handwritten data are checked for clarity and legibility, vegetation data should be entered into an Excel spreadsheet where it can be manipulated for statistical analysis. In the spreadsheet, columns should represent species, and rows should represent the sampling plots. First create columns for all species found at the project site(s). Then enter percent cover data. Alternatively, the data can be entered using the Braun-Blanquet cover scale, which uses a ranking system that facilitates similarity testing and ordination procedures (Roman et al., 2001). Note that basal area for tree plot data can be calculated as described above. Tree plot basal areas are then totaled to derive percent cover of tree species within the plot.

Non-parametric tests can be used to evaluate differences in vegetation communities between sites (e.g., project restoration reach versus reference reach) or site conditions between sampling years. Refer to Kent and Coker (1992), Elzinga et al. (1998), and Roman et al. (2001) for detailed discussions on methods for statistical analysis of vegetation data.

Additional Information

As part of the vegetation sampling process, photographs should be taken routinely during each monitoring period to document vegetation and other riparian features. Refer to the photo station methods in this document for more detailed information (Section IV.B.4).

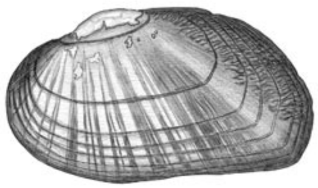
These plant monitoring protocols and the additional monitoring methods presented in Section III.B have been adapted from the Corps of Engineers Wetlands Delineation Manual (Environmental Laboratory, 1987), GPAC protocols for tidal wetland restoration (Neckles and Dionne, 2000), U.S. Geological Survey salt marsh protocols (Roman et al., 2001), and vegetation assessment methods of the Bureau of Land Management (Elzinga et al., 1998), U.S. Forest Service (USFS, 1987), and NOAA (Merkey and Keeland, 2005).

Elzinga et al. (1998) provides an in-depth discussion of monitoring plant populations (with a single species focus), including a step-by-step overview of developing and implementing a vegetation monitoring program, basic principles of sampling, sampling design, field techniques, data management, and statistical analysis of field data.

Many guides to plant identification are available. Some are comprehensive with user-friendly descriptive keys and accompanying drawings or photographs. Most provide specific geographic coverage, and many are targeted to a specific plant type such as woody plants, ferns and allies, bryophytes, or sedges. Guides specific to the northeastern United States include Gleason and Cronquist (1991), Magee and Ahles (1999), Conard, (1979), and Tryon and Moran (1997). Voss (1972, 1985, 1996) offers excellent keys for Michigan flora that are representative of northeastern U.S. plants; these volumes are noted for their clear, easy-to-follow keys, especially for difficult groups such as the sedges (genus *Carex*). Newcomb (1977) is another user-friendly plant guide.

7. Macroinvertebrates

We do not recommend a specific macroinvertebrate method in this Monitoring Guide because of the inherent complexity of conducting statistically valid macroinvertebrate assessments. We recommend that the user consult with professionals in their region who have the expertise necessary to design a macroinvertebrate monitoring plan appropriate for the stream barrier removal project. Appendix D provides an in-depth discussion of planning macroinvertebrate monitoring for stream barrier removal projects. Table 8 provides a summary of macroinvertebrate monitoring protocols used by different Gulf of Maine jurisdictions.



Brook floater

8. Fish Passage Assessment

We do not recommend a specific fish-monitoring method in this Monitoring Guide because fish monitoring should be managed by trained fisheries experts and must be tailored to the project site and target species. We recommend consulting with experts in the region with the necessary jurisdiction to design and implement fish monitoring for barrier removal projects.

Fish ladders sometimes are not effective at enabling fish to move past dams. After a dam is removed, monitoring can reveal if more fish are traveling up and down the river.

Table 7. Fish–monitoring methods that may be recommended by local fisheries experts.

Method	Technique	References
Visual	Human visual identification and counts of fish at specific locations.	Nelson, 2006; Stevenson et al., 1999
Simple presence/absence	Electrofishing is a commonly used and inexpensive technique to assess the presence or absence of fish species above and below a barrier.	Reynolds, 1997
Video	Pre-positioned video camera recording fish at specific locations.	Bowen, 2006
Passive Integrated Transponder (PIT tags)	Fish are captured and are inserted with a Passive Integrated Transponder (PIT tag). Fish injected with this tag can be automatically recognized by strategically located detecting/recording devices.	Bruyndoncx, 2002
Mark and recapture	Fish are captured and are fin clipped and/or have an external fish tag attached; employs nets, traps, or electrofishing.	Nielson, 1992; Parker, 1990
Telemetry	Fish are captured and tagged with electronic transmitters. Transmitters can be applied to fish internally or externally. Fish movements are subsequently determined by locating fish/transmitters using mobile and/or fixed telemetry receivers.	Amlaner and MacDonald, 1980; Baras, and Phillipart, 1996; Burnham et al., 1987; Cheeseman and Mitson, 1982; Finkenzeller, 2000; Lucas and Baras, 2001; Moore and Russell, 2000; Pincock, and Voegeli, 1990; Priede and Swift, 1992; Sibert and Neilson, 2001; Spedicato et al., 2005; Winter, 1983; Winter, 1996; Zydlewski et al., 2006

Table 8. Relevant state and provincial protocols for monitoring macroinvertebrates.

	Recommended Collection Method	Index Period	Recommended Sampling Processing Protocol	Identification Level	Recommended Assessment Approach	Protocol Reference
New Hampshire	Artificial substrates (wire mesh, rock-filled baskets); 6-8 week deployment in riffles or at base of riffles	Fall	Standardized gridded tray with sample evenly distributed across tray; 1/4 of grids randomly selected for complete sorting with 100 individual minimum subsample; additional 1/4 of grids incrementally selected for complete sorting until 100 individual subsample satisfied	Genus (if possible), except for chironomids (sub-family), ribbon worms (phylum Nemertea), nematodes (phylum Nemata), and oligochaetes (subclass)	Multimetric index: average score of 7 metrics; index range 0 (poorest condition) to 100 (best condition); biological condition threshold established via minimally impacted reference sites	Neils, D. 2007. New Hampshire Department of Environmental Services (NHDES) Protocols for Collection, Identification and Enumeration of Aquatic Macroinvertebates for Computation of a Benthic Index of Biotic Integrity (B-IBI). Concord, NH: NHDES.
Maine	Artificial substrates (wire mesh, nylon bags, or cone-shaped containers filled with standard-sized stones); 24- to 32-day incubation; rock containing device	Fall	Full sample sort using shallow sorting pan(s) unless >500 individuals; if >500 individuals, then 100 individual subsample permissible using air-generated suspension of individuals in Imhoff-type settling cone	Genus or species for all individuals (if possible)	Multivariate linear discriminate model to predict probabilities of membership to predetermined water quality classes	Davies, S.P. and L. Tsomides. 2002. Methods for Biological Sampling and Analysis of Maine's Rivers and Streams. DEP LW0387-B2002. Augusta, ME: Department of Environmental Protection.
Massachusetts	Kick nets (500μm); 10 area delineated sampling efforts composited for a single sample within 100m reach; 2 m^2 total area; samples collected from areas with coarse substrates OR artificial substrates (rock baskets, Hester-Dendy multiplate samples in deep water or soft bottom habitats or as directed)	Fall	Standardized gridded tray with sample evenly distributed across tray; individual grids randomly selected and sorted until 100 individual subsample requirement satisfied; large and rare organisms sorted for entire sample OR full sort of entire sample for artificial substrates where quantitative sample is desired	Genus or species for all individuals (if possible)	Multimetric index following RBP II or III (Plafkin et al., 1989); index range 0 (poorest) to 54 (best) and compared to applicable reference sites	Nuzzo, R.M. 2003. Standard Operating Procedures: Water Quality Monitoring in Streams Using Aquatic Macroinvertebrates. Massachusetts Department of Environmental Protection, Division of Watershed Management.
Canada Ecological Monitoring & Assessment Network	Several noted depending on water body and habitat types; kick net (400μm) suggested as technique for wading-depth streams; multihabitat collection effort; one to many 3-minute collection efforts	Late fall or early spring	Several noted; subsampling at the 100, 200, or 300 individual target level suggested; gridded trays, flotation, or elutiation can be used to obtain representative subsample	Genus or species for all individuals (if possible)	None recommended; several options referenced	Rosenberg, D.M., I.J. Davies, D.G. Cobb, and A.P. Wiens. 1997. Protocols for Measuring Biodiversity: Benthic Macroinvertebrates in Fresh Waters. Winnipeg, Canada: Canada Department of Fisheries and Oceans, Freshwater Institute.
Canada Canadian Aquatic Biomonitoring Network	Kick net (400μm); multihabitat	None indicated	Even distribution of entire sample across gridded tray; 300 individual subsample target	Family	Multivariate discriminate model using Observed: Expected species occurrence ratios to determine similarity to a "reference" condition (1=identical; 0=no similarity)	Reynoldson, T.B., C. Logan, T. Pascoe, and S.P. Thompson. CABIN (Canadian Aquatic Biomonitoring Network): Invertebrate Biomonitoring Field and Laboratory Manual. Environment Canada, National Water Research Institute.

Cross-section established for stream barrier removal monitoring.
Mathias Collins / NOAA Restoration Center

V. DATA MANAGEMENT

A. DATA CAPTURE AND REPORTING

As noted in the Introduction, there are five primary reasons for establishing regional guidelines for barrier removal monitoring:

- evaluating the performance of individual restoration projects;
- assessing the long-term ecological benefits of regional restoration efforts;
- advancing our understanding of restoration ecology to assist in the development of more effective restoration techniques;
- better anticipating the effects of future stream barrier removal projects; and
- communicating results to stakeholders and the public.

Previous sections of this Monitoring Guide have focused on critical monitoring parameters that should be monitored at barrier removal sites and how those parameters should be measured in a consistent manner so that results are comparable across the region. Equally important to accomplishing the goals noted above are consistent data capture and reporting. This requires common data elements, reporting standards, and site metadata.

Karla Garcia / NOAA Restoration Center

Data elements are the specific pieces of information recorded when monitoring a given parameter. For example, the data elements for cross-sections are station (STA), backsight (BS), height of instrument (HI), foresight (FS), and elevation (ELEV). To properly perform and document a cross-section survey, these data must be collected and recorded. Each critical monitoring parameter has a set of necessary data elements.

Reporting standards specify how the data elements are recorded. Examples include what units are used and the precision to which measurements are reported. For example, for the cross-section data elements we specify that horizontal distances and elevations be reported in units of feet with precisions of tenths (0.1) and hundredths (0.01), respectively.

Metadata are "data about the data". Besides collecting and recording the data elements that are the key measurements for a parameter, it is very useful to record other quantitative and descriptive information during data collection. The metadata may be parameter-specific or general to the site. Examples of parameter-specific metadata include documenting the investigators, time/date of data collection, and notes. The latter generic category is often used to record any problems encountered in the field with equipment, weather, or extraordinary conditions. Information of this sort is particularly useful for data analyses. Metadata general to the site can include benchmark location, project datum, and watershed name.

Data elements, reporting standards, and metadata needs have been identified for each *critical monitoring parameter* for which this Monitoring Guide provides detailed methods and are defined on the data sheets provided in Appendix E. A site information datasheet to capture site metadata is also provided. Completing these data sheets will ensure that the necessary data elements and metadata are captured for each parameter, as well as for the site in general, and are reported in a consistent manner. Additionally, having field investigators transfer their data from the hard copy data sheets to the electronic versions serves as an important quality assurance mechanism.

B. DATA COLLECTION

Use of the critical monitoring parameters is encouraged to the extent practical for all barrier removal projects in the Gulf of Maine watershed. Potential recipients of funds from competitive grant programs administered by entities sponsoring this document may be requested or required to monitor some, or all, of the critical monitoring parameters as an award condition. Any prescribed monitoring would be mutually agreeable to all parties and explicitly funded through the grant. In these cases, completed field data sheets (hard copy and electronic) would be a reporting requirement for the grant. In all other cases, submitting data sheets in hard copy and electronically to the Gulf of Maine Council on the Marine Environment is strongly encouraged. For submission information, visit www.gulfofmaine.org/streambarrierremoval.

VI. BIBLIOGRAPHY

Abbe, T.B. and D.R. Montgomery. 1996. Large Woody Debris Jams, Channel Hydraulics, and Habitat Formation in Large Rivers. Regulated Rivers: Research and Management 12:201–221.

Ahearn, D.S. and R.A. Dahlgren. 2005. Sediment and Nutrient Dynamics Following a Low-head Dam Removal at Murphy Creek, California. Limnology and Oceanography 50:1752–1762.

American Public Health Association. 1999. Standard Methods for the Examination of Water and Wastewater. American Water Works Association, Water Environment Federation. www.standardmethods.org. Accessed June 2007.

Amlaner, C.J. and D.W. MacDonald, editors. 1980. A Handbook on Biotelemetry and Radio Tracking. New York: Pergamon Press. 804 pp.

Andrews, E.D. 1986. Downstream Effects of Flaming Gorge Reservoir on the Green River, Colorado and Utah. Geological Society of America Bulletin 97:1012–1023.

Aspen Institute. 2002. Dam Removal: A New Option for a New Century. 81 pp.

Babbit, B. 2002. What Goes Up, May Come Down. BioScience 52:656–658.

Bailey, R.C., R.H. Norris, and T. F. Reynoldson. 2001. Taxonomic Resolution of Benthic Macroinvertebrate Communities in Bioassessments. Journal of the North American Benthological Society 20:280–286.

Baras, E. and J.C. Phillipart, editors. 1996. Underwater Telemetry. University of Leige, Belgium. 257 pp.

Barbour, M.T. and J. Gerritsen. 1996. Subsampling of Benthic Samples: A Defense of the Fixed-Count Method. Journal of the North American Benthological Society 15:386–391.

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. Rapid Bioassessment Protocols for Use in Streams and Wading-depth Rivers: Periphyton, Benthic Macroinvertebrates, and Fish. Second edition. EPA 841-B-99-002. Washington, D.C.: U.S. Environmental Protection Agency.

Barbour, M.T., J.B. Stribling, and J.R. Karr. 1995. Multimetric Approach for Establishing Biocriteria and Measuring Biological Condition. In: W. S. Davis and T. P. Simon, editors. Biological Assessment and Criteria. Boca Raton: Lewis Publishers. pp. 63–77.

Benn, P.C. and W.D. Erskine. 1994. Complex Channel Response to Flow Regulation: Cudgegong River below Windamere Dam, Australia. Applied Geography 14:153–168.

Blocksom, K.A. and J.E. Flotemersch. 2005. Comparison of Macroinvertebrate Sampling Methods for Non-Wading-depth Streams. Environmental Monitoring and Assessment 102:243–262.

Bowen, M.D., S. Marques, L.G.M. Silva, V. Vono, and H.P. Godinho. 2006. Comparing on Site Human and Video Counts at Igarapava Fish Ladder, South-Eastern Brazil. Neotropical Ichthyology 4:291–294.

Braun-Blanquet, J. 1932. Plant Sociology. New York: McGraw-Hill. Fuller, G.D. and H.S. Conrad, translators. 539 pp.

Brush, L.M. 1961. Drainage Basins, Channels, and Flow Characteristics of Selected Streams in Central Pennsylvania. USGS Professional Paper 282-F: 145–181.

Bruyndoncx, L., G. Knaepkens, W. Meeus, L. Bervoets, and M. Eens. 2002. The Evaluation of Passive Integrated Transponder (PIT) Tags and Visible Implant Elastomer (VIE) Marks as New Marking Techniques for the Bullhead. Journal of Fish Biology 60:260–262.

Bunte, K. and S.R. Abt. 2001. Sampling Surface and Subsurface Particle-Size Distributions in Wading-depth Gravel- and Cobble-Bed Streams for Analyses in Sediment Transport, Hydraulics, and Streambed Monitoring. General Technical Report RMRS-GTR-74. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 428 pp.

Burnham, K.P., D.R. Anderson, G.C. White, C. Brownie, and K.H. Pollock. 1987. Design and Analysis Methods for Fish Survival Experiments Based on Release-Recapture. American Fisheries Society Monograph 5, Bethesda, Maryland. 437 pp.

Bushaw-Newton, K.L., D.D. Hart, J.E. Pizzuto, J.R. Thomson, J.Egan, J.T. Ashley, T.E. Johnson, R.J. Horwitz, M. Keeley, J. Lawrence, D. Charles, C. Catenby, D.A. Kreeger, T. Nightengale, R.L. Thomas, and D.J. Velinsky. 2002. An Integrative Approach Towards Understanding Ecological Responses to Dam Removal: The Manatawny Creek Study. Journal of the American Water Resources Association 38:1581–1599.

Casper, A.F., J.H. Throp, S.P. Davies, and D.L. Courtemanch. 2001. Initial Response of Benthic Primary Consumers to Dam Removal on the Kennebec River, Maine. Bulletin of the North American Benthological Society 18:172.

Cheeseman, C.L. and R.D. Mitson, editors. 1982. Telemetric Studies of Vertebrates. Symposia of the Zoological Society of London. New York: Academic Press. 368 pp.

Collier, K.J. and K.W. Quinn. 2003. Land-use Influences Macroinvertebrate Community Response Following a Pulse Disturbance. Freshwater Biology 48: 1462–1481.

Collier, M., R.H. Webb, and J.C Schmidt. 1996. Dams and Rivers: Primer on the Downstream Effects of Dams. U.S. Geological Survey Circular 1126. Washington, D.C.: U.S. Government Printing Office.

Collins, B. 2003. California Coastal Salmonid Restoration Monitoring and Evaluation Program: Interim Restoration Effectiveness and Validation Monitoring Protocols. California Department of Fish and Game.

Conard, H.S. and P.L. Redfearn, Jr. 1979. How to Know the Mosses and Liverworts. Second edition. Boston: McGraw-Hill.

Courtemanch, D. 1996. Commentary on the Subsampling Procedures Used for Rapid Bioassessments. Journal of the North American Benthological Society 15:381–385.

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of Wetlands and Deepwater Habitats of the United States. Washington, D.C.: Office of Biological Services, Fish and Wildlife Service, U.S. Department of Interior. FWS/OBS-79/31. 103 pp.

Crow, T.R., M.E. Baker, and B.V. Barnes. 2000. Diversity in Riparian Landscapes. In: Riparian Management in Forests. E.S. Verry, J.W. Hornbeck, and C.A. Dolloff, editors. New York: Lewis Publishers. pp. 43–66.

Doberstein, C.P., J.R. Karr, and L.L. Conquest. 2000. The Effect of Fixed-Count Subsampling on Macroinvertebrate Biomonitoring in Small Streams. Freshwater Biology 44:355–371.

Doyle, M.W., E.H. Stanley, M.A. Luebke, and J.M. Harbor. 2000. Dam Removal: Physical, Biological, and Societal Considerations. In: Hotchkiss, R.H. and N. Glade, editors. Proceedings of the 2000 Joint Conference on Water Resource Engineering and Water Resource Planning and Management. New York: American Society of Civil Engineers.

Doyle, M.W., E.H. Stanley, C.H. Orr, A.R. Selle, S.A. Sethi, and J.M. Harbor. 2005. Stream Ecosystem Response to Small Dam Removal: Lessons from the Heartland. Geomorphology 71:227–244.

Elzinga, C.L, D.W. Salzer, and J.W. Willoughby. 1998. Measuring and Monitoring Plant Populations. BLM Technical Reference 1730-1. Denver, CO: Bureau of Land Management. BLM/RS/ST-98/005+1730. 477 pp.

Environmental Laboratory. 1987. Corps of Engineers Wetlands Delineation Manual. Technical Report Y-87-1. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station. 100 pp. + appendices.

Finkenzeller, K. 2000. RFID Handbook: Radio Frequency Identification Fundamentals and Applications. New York: John Wiley and Sons. 322 pp.

Flosi, G, S. Downie, J. Hopeland, M. Bird, R. Coey, B. Collins. 2003. California Stream Habitat Restoration Manual, Part IX: Fish Passage Evaluations at Stream Crossings. California Department of Fish and Game.

Fripp, J.B. and P. Diplas. 1993. Surface Sampling in Gravel Streams. American Society of Civil Engineers. Journal of Hydraulic Engineering 119:473–490.

Gergel, S.E., S.R. Carpenter, and E.H. Stanley. 2005. Do Dams and Levees Impact Nitrogen Cycling? Simulating the Effects of Flood Alterations on Floodplain Denitrification. Global Change Biology 111:1352–1367.

Gerritsen, J. 1995. Additive Biological Indices for Resource Management. Journal of the North American Benthogical Society 14:451–457.

Gleason, H.A. and A. Cronquist. 1991. Manual of the Vascular Plants of the Northeastern United States and Adjacent Canada. Second edition. New York: New York Botanical Garden.

Graf, W.L. 2003. Dam Removal Research: Status and Prospects. H. John Heinz III Center for Science, Economics and the Environment.

Graf, W.L. 2006. Downstream Hydrologic and Geomorphic Effects of Large Dams on American Rivers. Geomorphology 79:336–360.

Gregory, K.J. and C. Park. 1974. Adjustment of River Channel Capacity Downstream from a Reservoir. Water Resources Research 10:870–873.

Gulf of Maine Council on the Marine Environment. 2004. The Gulf of Maine Habitat Restoration Strategy. Gulf of Maine Council on the Marine Environment. www.gulfofmaine.org.

Haberstock, A.E., H.G. Nichols, M.P. DesMeules, J.Wright, J.M. Christensen, and D. Hudnut. 2000. Method to Identify Effective Riparian Buffers Widths for Atlantic Salmon Habitat Protection. Journal of the American Water Resources Association 36:1271–1286.

Hall, F.C. 2002. Photo Point Monitoring Handbook, Part A: Field Procedures. Pacific Northwest Research Station, USDA Forest Service. General Technical Report PNW-GTR-526.

Harrelson, C., C. Rawlins, and J. Potyondy. 1994. Stream Channel Reference Sites: An Illustrated Guide to Field Technique. Gen. Tech. Rep. RM-245. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 61 p. ww.stream.fs.fed.us/publications/PDFs/RM245E.PDF

Hart, D.D., T.E. Johnson, K.L. Bushaw-Newton, R.J. Horwitz, A.T. Bednarek, D.F. Charles, D.A. Kreeger, and D.J. Velinsky. 2002. Dam Removal: Challenges and Opportunities for Ecological Research and River

Restoration. Bioscience 528:669–681.
Hawkins, C.P., R.H. Norris, J. Gerritsen, R.M. Hughes, S.K. Jackson, R.K. Johnson, and R.J. Stevenson. 2000. Evaluation of the Use of Landscape Classifications for the Prediction of Freshwater Biota: Synthesis and Recommendations. Journal of the North American Benthological Society 19:541–556.
Healy, D.F., S.J. Rheaume, and J.A. Simpson. 2003. Environmental Effects of the Big Rapids Dam Remnant Removal, Big Rapids, Michigan, 2000–02. U.S. Department of Interior and U.S. Geological Survey. Water-Resources Investigations Report 03-4136. 54 pp.
Herbst, D.B. and E.L. Silldorff. 2006. Comparison of the Performance of Different Bioassessment Methods: Similar Evaluations of Biotic Integrity from Separate Programs and Procedures. Journal of the North American Benthological Society 25:513–530.
Hey, R.D. and C.R. Thorne. 1983. Accuracy of Surface Samples from Gravel Bed Material. Journal of Hydrological Engineering 109:842–851.
Hirsch, R.M., J.F. Walker, J.C. Day, and R. Kallio. 1990. The Influence of Man on Hydrologic Systems. In: Wolman, M.G. and H. C. Riggs, editors. Surface Water Hydrology: The Geology of North America. Boulder, CO: Geological Society of America. pp. 329–359.
ICF Consulting. 2005. A Summary of Existing Research on Low Head Dam Removal Projects. American Association of State Highway and Transportation Officials. 3 pp.
Jansson, R., C. Nilsson, and B. Renofalt. 2000. Fragmentation of Riparian Floras with Multiple Dams. Ecology 8:899–903.
Kanehl, P.K., J. Lyons, and J.E. Nelson. 1997. Changes in the Habitat and Fish Community of the Milwaukee River, Wisconsin, Following Removal of the Woolen Mills Dam. North American Journal of Fisheries Management 17:387–400.
Karr, J.R. and E.W. Chu. 1999. Restoring Life in Running Waters. Washington, D. C.: Island Press.
Kellerhals, R. 1982. Effect of River Regulation on Channel Stability. In: Hey, R.D., J.C. Bathhurst, and C.R. Thorne, editors. Gravel Bed Rivers. Chichester, England: John Wiley and Sons. pp. 685–705.
Kent, M. and P. Coker. 1992. Vegetation Description and Analysis: A Practical Approach. Chichester, England: John Wiley and Sons. 363 pp.
Kocher, S.D. and R.R. Harris. 2005. Qualitative Monitoring of Fisheries Habitat Restoration. Berkeley, CA: University of California, Center for Forestry. 166 pp.
Kondolf, G.M. 1997. Application of the Pebble Count: Reflections on Purpose, Method, and Variants. Journal of the American Water Resources Association 33:79–87.
Kondolf, G.M., T.E. Lisle, and M.G. Wolman. 2003. Bed Sediment Measurement. In: G. M. Kondolf and H. Piégay, editors. Tools in Fluvial Geomorphology. Chichester, England: John Wiley and Sons. pp. 347–395.
Landry, S. 2002. Photo Documentation Procedure for Measuring the Success of Restoration Projects and Best Management Practices. New Hampshire Department of Environmental Services.
Lane, S.L. and R.G. Fay. 1997. Safety in Field Activities: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 9, Chapter A9. http://pubs.water.usgs.gov/twri9A9/.
Lazorchak, J.M., D.J. Klemm, and D.V Peck, editors. 1998. Environmental Monitoring and Assessment Program–Surface Waters: Field Operations and Methods for Measuring the Ecological Condition of Wading-depth Streams. EPA/620/R-94/004F. Washington, D.C.: U.S. Environmental Protection Agency.
Lenat, D.R. and V.H. Resh. 2001. Taxonomy and Stream Ecology: The Benefits of Genus- and Species-Level Identifications. Journal of the North American Benthological Society 20:287–298.
Leopold, L.B., M.G. Wolman, and J.P. Miller. 1964. Fluvial Processes in Geomorphology. New York: Dover Publications. 522 pp.
Ligon, F.K., W.E. Dietrich, and W.J. Trush. 1995. Downstream Ecological Effects of Dams: A Geomorphic Perspective. BioScience 45:183–192.
Lindloff, S.D. 2003. Institutionalizing the Option of Dam Removal: The New Hampshire Initiative. Water Science and Technology 48:9–16.
Lucas, M.C. and E. Baras. 2001. Migration of Freshwater Fishes. Cornwall, England: Blackwell Science. 420 pp.
Mackin, J.H. 1948. Concept of the Graded River. Geological Society of America Bulletin 59:463–512.
Magee, D.W. and H. E. Ahles. 1999. Flora of the Northeast. Amherst, MA: University of Massachusetts Press.
Magilligan, F.J. and K.H. Nislow. 2001. Hydrologic Alteration in a Changing Landscape: Effects of Impoundment in the Upper Connecticut River Basin, USA. Journal of the American Water Resource Association 37:1551–1569.
Magilligan, F.J., K.H. Nislow, and B.E. Graber. 2003. A Scale-Independent Assessment of Discharge Reduction and Riparian Disconnectivity Following Flow Regulation by Dams. Geology 31:569–572.
Merkey, D. and B. Keeland. 2005. Restoration Monitor-

ing of Riverine Forests. In: Science-Based Restoration Monitoring of Coastal Habitats. Volume Two: Tools for Monitoring Coastal Habitats. Thayer, G.W., T.A. McTigue, R.J. Salz, D.H. Merkey, F.M. Burrows, and P.F. Gayaldo, editors. NOAA Coastal Ocean Program. Decision Analysis Series No. 23, Volume 2. Silver Spring, MD: U.S. Department of Commerce, National Oceanic and Atmospheric Administration.

Miller, J.P. and L.B. Leopold. 1961. Simple Measurements of Morphological Changes in River Channels and Hillslopes. In: UNESCO Symposium on Changes of Climate Proceedings. pp. 421–427.

Moore, A. and I.C. Russell, editors. 2000. Advances in Fish Telemetry. Proceedings of the Third Conference on Fish Telemetry in Europe. Lowestoft, England: CEFAS. 264 pp.

Mueller-Dombois, D. 1974. Aims and Methods of Vegetation Ecology. New York: John Wiley and Sons. 547 pp.

Murphy, B.R. and D.W. Willis. 1996. Fisheries Techniques. Second edition. Bethesda, MD: American Fisheries Society. 732 pp.

Naiman, R.J. and H. Decamps. 1997. The Ecology of Interfaces: Riparian Zones. Annual Review of Ecology and Systematics 28:621–658.

Naiman, R.J, H. Decamps, and M. Pollack. 1993. The Role of Riparian Corridors in Maintaining Regional Biodiversity. Ecological Applications 3:209–212.

Neckles, H.A. and M. Dionne, editors. 1999. Regional Standards to Identify and Evaluate Wetlands Restoration in the Gulf of Maine. Wells, ME: Wells National Estuarine Research Reserve. 21 pp.

Nedeau, E. 2006. Freshwater Mussels and Dam Removal. Gulf of Maine Times 10(3).

Nelson, G.A. 2006. A Guide to Statistical Sampling for the Estimation of River Herring Run Size Using Visual Counts. Massachusetts Division of Marine Fisheries Technical Report TR-25.

Newcomb, L. 1977. Newcomb's Wildflower Guide. New York: Little, Brown and Company. 490 pp.

Nielson, L.A. 1992. Methods of Marking Fish and Shellfish. American Fisheries Society Special Publication 23.

Nilsson, C. and K. Berggren. 2000. Alterations of Riparian Ecosystems Caused by River Regulation. BioScience 50:783–792.

North American Lakes Management Society. 2007. Water Words Glossary. http://www.nalms.org/Resources/Glossary.aspx. Accessed March 2007.

O'Donnell M., N. Gray, G. Wippelhauser, and P. Christman. 2001. Kennebec River Diadromous Fish Restoration Annual Progress Report 2000. Augusta, ME: Maine Department of Marine Resources.

Olsen, D.S., B.B. Roper, J.L. Kershner, R. Henderson, and E. Archer. 2005. Sources of Variability in Conducting Pebble Counts: Their Potential Influence on the Results of Stream Monitoring Programs. Journal of the American Water Resources Association 41:1225–1236.

Orr, C.H. and S. Koenig. 2006. Planting and Vegetation Recovery on Exposed Mud Flats Following Two Dam Removals in Wisconsin. Ecological Restoration 24:79–86.

Orr, C.H., K.L. Rogers, and E.H. Stanley. 2006. Channel Geomorphology and P Uptake Following Removal of a Small Dam. Journal of the North American Benthological Society 25:556–568.

Parker, N.C., A.E. Giorgi, R.C. Heidinger, D.B Jester, Jr., E.D. Prince, and G.A. Wimans, editors. 1990. Fish-Marking Techniques (American Fisheries Society Symposium 7). Bethesda, MD: American Fisheries Society.

Perry, C.A. 1994. Effects of Reservoirs on Flood Discharges in the Kansas and Missouri River Basins, 1993. U.S. Geological Survey Circular 1120-E. Washington, D.C.: U.S. Government Printing Office.

Petts, G.E. 1979. Complex Response of River Channel Morphology Subsequent to Reservoir Construction. Progress in Physical Geography 3:329–362.

Petts, G.E. 1980. Long-Term Consequences of Upstream Impoundment. Environmental Conservation 7:325–332.

Petts, G.E. 1984. Impounded Rivers: Perspectives for Ecological Management. Chichester, England: John Wiley and Sons. 326 pp

Pincock, D.G. and F.A. Voegeli. 1990. Quick Course in Underwater Telemetry Systems. 32 pp. Available from www.vemco.com.

Pizzuto, J. 2002. Effects of Dam Removal on River Form and Process. Bioscience 52:683–691.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The Natural Flow Regime: A Paradigm for River Conservation and Restoration. Bioscience 47:769–784.

Pollack, M.M., T.J. Beechie, S.S. Chan, and R. Bigley. 2005. Monitoring Restoration of Riparian Forests. In: Monitoring Stream and Watershed Restoration. P. Roni, editor. Bethesda, MD: American Fisheries Society. pp. 67–94.

Potyondy, J. and K. Bunte. 2002. Sampling with the US SAH-97 Hand-Held Particle Size Analyzer. Vicksburg, MS: United States Army Corps of Engineers Waterways Experiment Station Federal Interagency Sedimentation Project. Available from http://fisp.wes.army.mil/Instructions%20US_SAH-97_040412.pdf.

Priede, I.G. and S.M. Swift, editors. 1992. Wildlife Telemetry: Remote Monitoring and Tracking of Animals. West Sussex, England: Ellis Horwood.

Resh, V. H. 1995. Freshwater Benthic Macroinvertebrates and Rapid Assessment Procedures for Water Quality Monitoring in Developing and Newly Industrialized Countries. In: W. S. Davis and T. P. Simon, editors. Biological Assessment and Criteria. Boca Raton: Lewis Publishers. pp. 167–177.

Reynolds, J.B. 1997. Aquatic Habitat Evaluation. In: B.R. Murphy and D.W. Willis, editors. Fisheries Techniques. Second edition. Bethesda, MD: American Fisheries Society. pp. 221–251.

Reynoldson, T.B., C. Logan, T. Pascoe, and S.P. Thompson. 2007. CABIN (Canadian Aquatic Biomonitoring Network): Invertebrate Biomonitoring Field and Laboratory Manual. Environment Canada, National Water Research Institute.

Reynoldson, T.B., R.H. Norris, V.H. Resh, K.E. Day, and D.M. Rosenberg. 1997. The Reference Condition: A Comparison of Multimetric and Multivariate Approaches to Assess Water-Quality Impairment Using Benthic Macroinvertebrates. Journal of the North American Benthological Society 16:833–852.

Rice, S.P. and M. Church. 1996. Sampling Fluvial Gravels: Bootstrapping and the Precision of Size Distribution Percentile Estimates. Journal of Sedimentary Research 66:654–665.

Richter, B.D. and J. Powell. 1996. Simple Hydrologic Models for Use in Floodplain Research. Natural Areas Journal 16:362–366.

Richter, B.D., J.V. Baumgartner, J. Powell, and D.P. Braun. 1996. A Method for Assessing Hydrologic Alteration Within Ecosystems. Conservation Biology 10:1163–1174.

Roman, C.T., M.J. James-Pirri, and J.F. Heltshe. 2001. Monitoring Salt Marsh Vegetation: A Protocol for the Long-Term Coastal Ecosystem Monitoring Program at Cape Cod National Seashore. U.S. National Park Service. 47 pp.

Rosenberg, D.M., I.J. Davies, D.G. Cobb, and A.P. Wiens. 1997. Protocols for Measuring Biodiversity: Benthic Macroinvertebrates in Fresh Waters. Winnipeg, Canada: Department of Fisheries and Oceans, Freshwater Institute.

Sethi, S.A, A.R. Selle, M.W. Doyle, E.H. Stanley, and H.E. Kitchel. 2004. Response of Unionid Mussels to Dam Removal in Koshkonong Creek, Wisconsin (USA). Hydrobiologia 525:157–165.

Shafroth, P.B, J.M. Friedman, G.T. Auble, M.L. Scott, and J.H. Braatne. 2002. Potential Responses of Riparian Vegetation to Dam Removal. BioScience 52:703–712.

Sibert, J.R. and J.L. Neilsen, editors. 2001. Electronic Tagging and Tracking in Marine Fisheries. Netherlands: Kluwer Academic Publishers.

Simon, A. and J. Castro. 2003. Measurement and Analysis of Alluvial Channel Form. In: Kondolf, G.M. and H. Piégay, editors. Tools in Fluvial Geomorphology. Chichester, England: John Wiley and Sons. pp. 289–322.

Singler, A. and B. Graber. 2005. Massachusetts Stream Crossing Handbook. Massachusetts Department of Fish and Game, Massachusetts Riverways Program.

Sparks, R.E. 1995. Need for Ecosystem Management of Large Rivers and their Floodplains. BioScience 45: 168–182.

Spedicato, M.T., G. Lembo, and G. Marmulla, editors. 2005. Aquatic telemetry: advances and applications. Proceedings of the Fifth Conference on Fish Telemetry held in Europe. FAO/COISPA, Rome. 295 p.

Stevenson R.D., D.C. Mountain, and B.C. Roolf. 1999. One Fish, Two Fish, Community Volunteers Count Alewives in New England's Parker River. Shad Journal 4(1).

Taylor, P.H. 2007. Salt Marshes in the Gulf of Maine: Human Impacts, Habitat Restoration, and Long-term Change Analysis. Gulf of Maine Council on the Marine Environment. www.gulfofmaine.org. iv+42 pages.

Thomson, J.R., D.D. Hart, D.F. Charles, T.L. Nightengale, and D.M. Winter. 2005. Effects of Removal of a Small Dam on Downstream Algal and Macroinvertebrate Assemblages in a Pennsylvania Stream. Journal of the North American Benthological Society 24:192–207.

Trefts, D. 2006 (draft). Key Findings from Dams, Overfishing and Environmental Crises: The Historic Link Between New England's Declining Anadromous and Ground Fisheries, 1600–1900. Paper for the Penobscot River Restoration Trust.

Tryon, A.F. and R.C. Moran. 1997. The Ferns and Allied Plants of New England. Lincoln, MA: Massachusetts Audubon Society, Center for Biological Conservation.

U.S. Environmental Protection Agency. 1983. Oxygen, Dissolved (Modified Winkler, Full-Bottle Technique). Methods for the Chemical Analysis of Water and Wastes. EPA/600/4-79/020.

U.S. Environmental Protection Agency. 2002. Summary of Biological Assessment Programs and Biocriteria Development for States, Tribes, Territories, and Interstate Commissions: Streams and Wading-depth Rivers. EPA-822-R-02-048. Washington, D.C.: U.S. Environmental Protection Agency.

U.S. Fish and Wildlife Service. 2005. National Inventory and Assessment Procedure for Identifying Barriers to Aquatic Organism Passage at Road-Stream Crossings. National Technology and Development Program.

U.S. Forest Service. 1987. Forester's Field Handbook. Portland, OR: U.S. Forest Service, Pacific Northwest Region.

U.S. Forest Service. 2003. Identifying Bankfull Stage in Forested Streams in the Eastern United States. Stream Systems Technology Center. DVD: 46 minutes.

Vermont Department of Environmental Conservation. 2006. Water Quality Field Methods Manual. Waterbury, VT: Vermont Department of Environmental Conservation, Water Quality Division.

Vermont Department of Environmental Conservation. 2004. Biocriteria for Fish and Macroinvertebrate Assemblages in Vermont Wading-depth Streams and Rivers. Waterbury, VT: Vermont Department of Environmental Conservation, Water Quality Division.

Velinsky, D.J., K.L. Bushaw-Newton, D.A. Kreeger, and T.E. Johnson. 2006. Effects of Small Dam Removal on Stream Chemistry in Northeastern Pennsylvania. Journal of the North American Benthological Society 25:569–582.

Verry, E.S. 2000. Water Flow in Soils and Streams: Sustaining Hydrologic Function. In: Verry, E.S., J.W. Hornbeck, and C.A. Dolloff, editors. Riparian Management in Forests. New York: Lewis Publishers. pp. 99–124.

Vinson, M.R. and C.P. Hawkins. 1996. Effects of Sampling Area and Subsampling Procedure on Comparisons of Taxa Richness Among Streams. Journal of the North American Benthological Society 15:392–399.

Voss, E.G. 1972. Michigan Flora, Part I: Gymnosperms and Monocots. Bloomfield Hills, MI: Cranbrook Institute of Science Bulletin 55 and University of Michigan Herbarium.

Voss, E.G. 1985. Michigan Flora, Part II: Dicots (Sauruaceae-Cornaceae). Ann Arbor, MI: Cranbrook Institute of Science Bulletin 59 and University of Michigan Herbarium.

Voss, E.G. 1996. Michigan Flora, Part III: Dicots (Pyrolaceae-Compositae). Ann Arbor, MI: Cranbrook Institute of Science Bulletin 61 and University of Michigan Herbarium.

Wilde, F.D., editor. 2005. Field Measurements: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 9, Chapter A6. http://pubs.water.usgs.gov/twri9A6/.

Williams, G.P. 1978. The Case of the Shrinking Channels: The North Platte and Platte Rivers in Nebraska. U.S. Geological Survey Circular 781. Washington, D.C.: U.S. Government Printing Office.

Williams, G.P. and Wolman, M.G. 1984. Downstream Effects of Dams on Alluvial Rivers. U.S. Geological Survey Professional Paper 1286. Washington, D.C.: U.S. Government Printing Office.

Winter, J.D. 1983. Underwater Biotelemetry. In: Nielsen, L.A. and J.D. Johnsen, editors. Fisheries Techniques. Bethesda, MD: American Fisheries Society. pp. 371–395.

Winter, J.D. 1996. Advances in Underwater Biotelemetry. In: Murphy, B.R. and D.W. Willis, editors. Fisheries Techniques. Second edition. Bethesda, MD: American Fisheries Society. pp. 555–590.

Wolman, M.G. 1954. A Method of Sampling Coarse River-Bed Material. Transactions of the American Geophysical Union 35:951–956.

Zydlewski, G.B., G. Horton, T. Dubreuil, B. Letcher, S. Casey, and J. Zydlewski. 2006. Remote Monitoring of Fish in Small Streams: A Unified Approach Using PIT Tags. Fisheries 31:492–502.

VII. APPENDICES

APPENDIX A: FIELD SAFETY

Field crews implementing the recommended practices in this Monitoring Guide can encounter hazardous conditions. It is crucial, particularly when involving volunteers, to ensure that adequate safety precautions are taken. This section identifies the most common hazards associated with conducting ecological monitoring of riverine and riparian habitats and recommends general field safety precautions. This is not a comprehensive safety protocol, but rather a guideline to ensure safe field conditions.

General

- Develop a safety plan. Safety plans can be as simple as letting someone else know where you are, when you intend to return, and what to do if you don't come back at the appointed time.
- Always monitor with at least one partner.
- Listen to weather reports. Caution should be exercised if severe weather is forecasted.
- Have a first-aid kit accessible. Team leaders should be trained in first aid/CPR.
- If at any time you feel uncomfortable about the condition of the stream or your surroundings, monitoring efforts should be terminated.

Impoundments

- Be careful wading into the impoundment, even if it is shallow. Impounded sediments are often unconsolidated fine-grained material having interstitial spaces. This makes them very soft and dangerous because they may not support a person's weight.
- In some instances, it may be necessary to use a boat to monitor conditions in impoundments. In such cases, a personal flotation device (PFD) is needed for each person on a boat.

Stream Safety

- Do not enter the water if the stream is at flood stage.
- If you must cross the stream, use a walking stick to steady yourself and to probe for deep water and unstable terrain.
- Streambeds composed of coarse substrates and/or bedrock can be slippery and have deep pools.
- Streambeds composed of finer substrates can prove treacherous in areas where mud, silt, or sand creates unstable terrain.

Poison Ivy

- Watch for poison ivy, poison oak, sumac, and other types of vegetation in your area that can cause rashes and irritation.

Mosquitoes

Mosquito-borne illnesses in the such as West Nile virus and eastern equine encephalitis have become more prevalent. The following steps can reduce the incidence of mosquito bites.

- Apply an effective repellent to exposed skin and clothing.
- Wear long-sleeves, long pants, and socks when outdoors.
- Limit field activities during peak mosquito hours. The hours from dusk to dawn are peak biting times for many species of mosquitoes.

Ticks

Ticks, which can carry the Lyme disease bacterium (*Borrelia burgdorferi*), prefer wooded and bushy areas with high grass and abundant leaf litter. Extra precaution should be taken in May, June, and July, when ticks that transmit Lyme disease are most active.

- Use insect repellent with 20-30% DEET on adult skin and clothing to prevent tick bite. Permethrin is another type of repellent. It can be purchased at outdoor equipment stores that carry camping or hunting gear. Permethrin kills ticks on contact.
- Wear long pants, long sleeves, and long socks to keep ticks off your skin. Light-colored clothing will help you spot ticks more easily. Tucking pant legs into socks or boots and tucking shirts into pants help keep ticks on the outside of clothing.
- Perform daily tick checks after being outdoors. Inspect all parts of your body carefully, including your armpits, scalp, and groin. Remove ticks immediately using fine-tipped tweezers.

Sun/Heat

- Dress for the heat. Wear a hat and lightweight, light-colored clothing. Light colors will reflect away some of the sun's energy.
- Drink water.
- Take regular breaks when engaged in physical activity on warm days. Take time out to find a cool place. If you recognize that you or someone else is showing the signals of a heat-related illness, stop activity and find a cool place.

APPENDIX B: GLOSSARY

Aggradation
The building up of a river channel by deposition of sediment on the channel bed.

Alluvial
Pertaining to or composed of alluvium, or deposited by a stream or running water.

Anadromous
Used to describe fish that spend a part of their life cycle in the sea and return to freshwater streams to spawn, such as salmon, river herring, and shad. Contrast with catadromous.

Avulsion
The sudden creation of a new river channel where flow leaves the existing channel during large floods and carves a new channel with a new slope and length.

Catadromous
Used to describe fish that live in fresh water but migrate into the sea to breed. Contrast with anadromous.

Critical monitoring parameters
Framework of common monitoring techniques necessary to adequately assess the physical, chemical, and biological response of stream barrier removal projects.

Degradation
The general lowering of the surface of the land by erosive processes, especially by the removal of material through erosion and transportation by flowing water.

Deposition
A natural river process in which sediment is distributed along the bed after floods recede or a change in cross-section leads to slower velocities, such as moving from a riffle to a pool. Sediment deposition is often altered in developed watersheds.

Diadromous
Used to describe fish that migrate between salt and fresh waters. See also anadromous and catadromous.

Effectiveness monitoring
Evaluation of whether or not an implemented action is having the desired effects. If the action is having undesirable effects, this should be revealed through effectiveness monitoring.

Floodplain
That portion of a river valley, adjacent to the channel, which is built of sediments deposited during the present regimen of the stream and is covered with water when the river overflows its banks at flood stages.

Grace Levergood / NHDES

Hydraulics
Related to the physical properties and behavior of stream flow as it is influenced by floodplain geometry and structures within it.

Hydrograph
A graphic representation or plot of changes in the flow of water or in the elevation of water level plotted against time.

Hydrology
The science of waters of the earth, including their occurrence, distribution, and circulation; their physical and chemical properties; and their reaction with the living and non-living environment. Also, pertaining to the quantity and timing of stream flow.

Implementation monitoring
Evaluation of whether a specific action occurred as planned. A variant called compliance monitoring evaluates whether an action meets regulatory standards. Implementation monitoring provides baseline information before and immediately after a project occurs.

Lacustrine
Pertaining to, produced by, or inhabiting a lake.

Lithology
(1) The scientific study of rocks, usually with the unaided eye or with little magnification. (2) Loosely, the structure and composition of a rock formation.

Low-head dam
A constructed barrier in a river with a hydraulic height (head water to tail water) not exceeding 25 feet. This definition encompasses run-of-river dams and other small dams. It does not include industrial dams that were designed not to create an impoundment in a river.

Riparian
Pertaining to the banks of a river, stream, waterway, or other body of water, as well as to plant and animal communities along such bodies of water.

Run-of-river dam
A constructed barrier in a river that forms an impoundment with minimal storage capacity and the inflow to the impoundment approximately equals outflow from the dam.

Stream crossing
Any human-made crossing over or through a stream channel, including bridges, culverts, paved roads, unpaved roads, railroads, trails, and paths.

Thalweg
The line connecting the lowest points along a stream bed or valley.

Wetland
Wetlands are defined and classified by the U.S. Department of Interior as "lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or land is covered by shallow water, and have one or more of the following attributes: (1) at least periodically the land supports hydrophytes; (2) the substrate is predominantly undrained hydric soil; and (3) the substrate is non-soil and is saturated with water or covered with shallow water at some time during the growing season of each year" (Cowardin et al., 1979).

Sources used to develop this glossary:

Bates, R.L. and J.A. Jackson. 1984. Dictionary of Geologic terms. Third edition. Prepared under the direction of the American Geological Institute. New York: Anchor Books, Doubleday. 571 pp.

New Hampshire Department of Environmental Services. 2007. Guidelines for Naturalized River Channel Design and Bank Stabilization.

North American Lakes Management Society. 2007. Water Words Glossary. http://www.nalms.org/Resources/Glossary.aspx. Accessed March 2007.

Flosi, G., S. Downie, J. Hopeland, M. Bird, R. Coey, and B. Collins. 2003. California Stream Habitat Restoration Manual, Part IX: Fish Passage Evaluations at Stream Crossings. California Department of Fish and Game.

APPENDIX C: WORKSHOP PRODUCTS

Participants in the Stream Barrier Removal Monitoring Workshop, June 2006

Sarah Allen
Normandeau Associates

Bill Arcieri
Vanasse Hangen Brustlin, Inc.

Matt Bernier
Kleinschmidt Associates

Steve Block
NOAA Restoration Center

Henry Caracristi
Bedford Institute of Oceanography

Tim Carney
New Hampshire Department of Environmental Services

John Catena
NOAA Restoration Center

Lisa Cavallaro
NOAA Restoration Center

Brad Chase
Massachusetts Division of Marine Fisheries

Michael Chelminski
Woodlot Alternatives

Kathryn Collet
New Brunswick Department of Natural Resources

Matt Collins
NOAA Restoration Center

Cathy Conrad
Saint Mary's University

Aaron Corr
Corr Consulting

Dave Courtemanch
Maine Department of Environmental Protection

Melinda Daniels
University of Connecticut/The Nature Conservancy

Eric Derleth
U.S. Fish and Wildlife Service

Robert Dudley
U.S. Geological Survey

Kristen Ferry
Massachusetts Division of Marine Fisheries

John Field
Field Geology Services

Brian Fitzgerald
Vermont Department of Environmental Conservation

Merry Gallagher
Maine Department of Inland Fisheries and Wildlife

Andy Goode
Atlantic Salmon Federation

Brian Graber
Massachusetts Department of Fish and Game

Alan Haberstock
Kleinschmidt Associates

Denis Haché
Canada Department of Fisheries and Oceans

Anita Hamilton
Canada Department of Fisheries and Oceans

David Hart
University of Maine

Daniel Hayes
Michigan State University

Charles Hebson
Maine Department of Transportation

Darren Hiltz
Canada Department of Fisheries and Oceans

Eric Hutchins
NOAA Restoration Center

Jon Kachmar
Maine Coastal Program

Michael Kline
Vermont Department of Environmental Conservation

John Kocik
NOAA Maine Field Station

Raymond Konisky
Wells National Estuarine Research Reserve

Brandon Kulik
Kleinschmidt Associates

Beth Lambert
New Hampshire Department of Environmental Services

Steve Landry
New Hampshire Department of Environmental Services

Sandra Lary
U.S. Fish and Wildlife Service

Robert Lent
U.S. Geological Survey

Grace Levergood
New Hampshire Department of Environmental Services

Christine Lipsky
NOAA Maine Field Station

Deb Loiselle
New Hampshire Department of Environmental Services

Kevin Lucey
New Hampshire Department of Environmental Services

Jim MacBroom
Milone and MacBroom

Jim MacCartney
Trout Unlimited

Elizabeth Maclin
American Rivers

John Magee
New Hampshire Fish and Game Department

Frank Magilligan
Dartmouth College

Timothy Milligan
Bedford Institute of Oceanography

Jeff Murphy
NOAA Maine Field Station

Ethan Nedeau
Biodrawversity

Keith Nislow
U.S. Forest Service/University of Massachusetts

Piotr Parasiewicz
University of Massachusetts

Cheri Patterson
New Hampshire Fish and Game Department

J. Michael Penko
U.S. Army Corps of Engineers

Tim Purinton
Massachusetts Department of Fish and Game

Trefor Reynoldson
Acadia Center for Estuarine Research

John Richardson
Blue Hill Hydraulics

Josh Royte
The Nature Conservancy

Gordon Russell
U.S. Fish and Wildlife Service

David Santillo
Northern Ecological Associates

Roy Schiff
Milone and MacBroom

Conor Shea
USFWS/Chesapeake Bay Field Office

Lee Swanson
New Brunswick Department of Environment

Steve Timpano
Maine Department of Inland Fisheries and Wildlife

Joan Trial
Atlantic Salmon Commission

James Turek
NOAA Restoration Center

Mark Wamser
Gomez and Sullivan

Laura Wildman
American Rivers/Northeast Field Office

Theo Willis
Maine Rivers

Gail Wippelhauser
Maine Department of Marine Resources

Craig Wood
Louis Berger

Jed Wright
U.S. Fish and Wildlife Service

Joseph Zydlewski
Maine Cooperative Fish and Wildlife Research Unit

Gulf of Maine Council on the Marine Environment

Stream Barrier Removal Monitoring Workshop Scenarios

	Head-of -Tide Restriction	High Head Dam with Wide Impoundment	Low Head Dam with Narrow Impoundment	Undersized Perched Culvert
Watershed Position	Near head-of-tide in large (>1000 mi^2) watershed; avg. channel width u/s 10m	Low-order stream in a large watershed (>1000 mi^2)	High order stream in a mid-sized watershed (100 mi^2<>1000 mi^2)	Second order stream
Watershed Land Use	Agriculture; light industry; forestry	Forest and rural residential.	Urban; post-industrial revolution	Suburban
Valley Geomorphic Setting	Meandering, low gradient stream; wide floodplain	Moderate gradient, low-sinuosity, riffle-run; subwatershed has areas of outwash deposits	Low gradient, slight sinuosity; channelized through town; poorly developed floodplain. Watershed dominated by till and bedrock	Steep step-pool channel
Riparian Condition	Unfenced livestock pasture adjacent to / above impoundment; wide 2nd growth forest buffer u/s.	Wide (>8xW_{bkf}) mature forested buffer; some residences	Narrow (<1xW_{bkf}) mature forested buffer; Japanese knotweed prevalent; riprap on bank	Narrow (<1xW_{bkf}) mixture of saplings, shrubs adjacent to lawns
Barrier Type	12 ft high by 300 m long earthen dyke extending across floodplain; concrete water control structure; failing fish passage structure (partial barrier)	20-foot tall concrete dam in good condition with low-level outlet for flow modification	10-foot high timber crib/rock fill spillway with concrete patching; earthen with sheetpile core, stone armoring	70-foot length; 48'' diam. double-barreled culverts; perched 3 feet; 10-foot head to unpaved road
Aquatic Species Present	Shellfish; Atlantic salmon, smelt, gaspereau, American eel, and brook trout.	Rare mussels d/s; alewife and salmon targeted for restoration	Shad, eel, herring lamprey downstream; smallmouth bass u/s	Brook trout. Salmon target for restoration
Sediment Characteristics	Fine grained potentially contaminated (domestic sewage; mild industrial)	Large quantity of coarse sand and gravel	Fine-grained; some build-up behind dam	Gravel/cobble mixed with woody debris immediately u/s of culverts; braiding of channel
Upstream Waterbody Characteristics	Shallow, wide impoundment with summer algae growth	Wide, deep, storage impoundment	Run-of-the-river; impoundment is narrow, shallow, and riverine in character	Riverine; debris, sediment, high flows blocked
Wetlands	Small wetland areas along impoundment margin; salt marsh areas between dam and causeway (d/s)	None	Oxbow wetland adjacent to channelized reach; small emergent wetland at u/s end of impoundment	None
Infrastructure and Community Concerns	Loss of u/s waterfowl habitat, hunting, trapping; loss of First Nations' traditional uses; d/s causeway / bridge; release of contaminated sediments	Concern for adjacent landowner wells; loss of water frontage u/s; potential for flooding d/s	Old / deteriorating structure. Community desire to keep dam and preserve adjacent historic structures; potential for flooding, braiding u/s;	Minimize erosion of road fill.
Restoration Issues	Full removal of barrier including all floodplain fill. Mobile sediments removed prior to breaching dam. Restore diadromous fish. Improve fish passage for traditional uses	Decommissioning of power dam; dam/ foundation removed to banks. Sediment behind dam removed. Work u/s to align channel / stabilize banks, limit fine sediment transport.	River seeded w/ shad 1 year prior to dam removal. Contaminated sediment capped; invasives control during / post dam removal. Spillway removed; earthen/ sheetpile embankment remains.	Highway improvement project. Replace with bottomless arch culvert

Gulf of Maine Council on the Marine Environment

Stream Barrier Removal Monitoring Workshop Agenda

Gulf of Maine Council River Restoration Monitoring Steering Committee
June 20-21, 2006 University of Maine, Orono

Workshop Outcomes:

1. A list of prioritized monitoring metrics / parameters by topic area, some of which are crosscutting, for barrier removal projects.
2. A refined list of monitoring questions or issues that those metrics / parameters address.

Tuesday, June 20th 2006

9:00 Welcome

1. Introduction
2. Purpose
3. History of Salt Marsh Monitoring Protocol Development

9:30 Plenary Sessions

1. Plenary A: James MacBroom, Milone and MacBroom, Inc.
2. Plenary B: Michael Kline, VT DEC River Management Program

12:00 Lunch

1:00 Instructions to Topic Teams

1:30 Breakout Groups: Topic Teams and Facilitators

A. Topic Teams review sets of typical dam removal scenarios in the context of key management issues/ monitoring questions.

B. Brainstorm appropriate monitoring parameters for each scenario.

C. Identify parameters repeatedly suggested for multiple scenarios.

D. Topic Team produces a summary parameter list highlighting those that are useful in multiple scenarios.

3:30 Break

Post Topic Team flip chart summaries; mill around; eat snacks; look at summaries.

4:00 Plenary: Integrative Metrics

A. Background

B. Topic Teams share results

C. Synthesis of results: identify crosscutting metrics, if any; identify priority metrics for each topic team; identify how this will feed into the next day's work.

8:00 Evening Presentations (optional)

Wednesday June 21st, 2006

8:00 Plenary: Ray Konisky, Ph.D., Wells National Estuarine Research Reserve

9:00 Breakout Session: Topic Teams

A. Focus on integrative metrics. Depending on the outcome of Day 1, this discussion might include arm twisting to get Topic Teams to identify possible crosscutting metrics and at the very least identify their most important 1 or 2 metrics. The goal is to refine the topic teams larger parameter list to include only their highest priorities.

B. Appropriate methods (sampling techniques, frequencies, etc.)

C. Reporting standards (common data elements, etc.)

11:00 Reporting Back and Concluding Remarks

APPENDIX D: MACROINVERTEBRATE MONITORING GUIDANCE

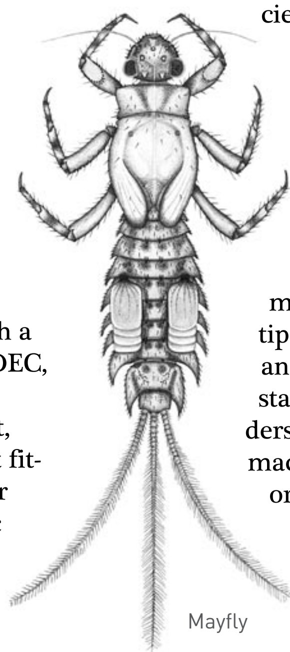
Planning Macroinvertebrate Monitoring at Stream Barrier Removal Projects

Given their utility as indicator organisms, macroinvertebrates are frequently used to document the responses of the aquatic community following barrier removal. The sections below describe the important components necessary in planning macroinvertebrate monitoring to assess aquatic community health and document shifts in community composition.

We advise that macroinvertebrate sampling be conducted in close coordination with the project's regulatory authority. Because of the inherent complexity of conducting statistically valid macroinvertebrate assessments, we encourage practitioners to use protocols recognized by state, provincial, or federal authorities.

Equipment

Several types of sampling equipment can be used to collect macroinvertebrates from wading-depth streams. Devices range from a Surber sampler to artificial substrates. While each sampling device has its benefits, the most commonly used and cost-effective sampling device currently employed is the dip net. Standard collection techniques call for the frame to be fitted with a 500µm mesh net (Lazorchak et al., 1998; VTDEC, 2006; Barbour et al., 1999) attached to a long wooden pole. Along with the rectangular net, often referred to as a kick-net, a sieve bucket fitted with 500µm mesh, and several 1- to 4-liter plastic sample containers complete the basic elements necessary to collect a representative macroinvertebrate sample.



Mayfly

Design

As for all scientific studies, considerable time and effort should be spent prior to any fieldwork to determine what questions are to be answered through the collection of data. Once determined, careful study design must be employed so that sufficient data are collected in an accurate manner. For studies associated with barrier removal projects, documentation of the changes in macroinvertebrate community composition, abundance, or overall biomass may be of interest. In all cases, an understanding and accounting of the natural sources of variation (error) must be completed in order to draw correct conclusions. The basic sources of error that are manifested in all sampling efforts include collection techniques, laboratory processing, and spatial and temporal heterogeneity in macroinvertebrate populations. A good study design will minimize, or at least account for, each of the potential sources of error. In reality, minimizing error sources means the selection of appropriate field techniques, collection of an adequate number of samples, careful adherence to standardize operating procedures in the field and laboratory, and the use of well-developed biological indices.

With respect to biological indices, a section below focuses on regionally developed macroinverterbate indices that are widely applicable to the detection of pollution sources, including nutrient enrichment, toxic inputs, and flow modifications. In general, these indices have been developed by resource agencies and use a network of reference or minimally disturbed sites to establish acceptable conditions in overall macroinvertebrate community composition. Benefits of using regionally developed indices include the direct comparison of sample results to index thresholds, known estimates of natural variation in undisturbed macroinvertebrate community composition, use of metrics known to be most responsive to multiple pollution sources, and predetermined field and laboratory techniques. In most cases, the statistical properties of these indices are well understood and will allow for the determination of macroinvertebrate community health as above or below an established threshold and/or placement into one of many narrative categories (i.e., poor, fair, good) with a known level of certainty.

However, regional biological indices are, in most cases, not specific to barrier removal projects and have drawbacks that should be considered based on the study's questions of interest. For example, if macroinvertebrate community biomass or area of colonizable habitat is of interest, alternative measures will be required. In cases where previously developed indices are not applicable, one must decide what community measures are most representative of the questions being asked, how to obtain the necessary data, and what comparisons will best assist in determining if significant changes have occurred. In cases where established indices are not applicable, the greatest limiting factor frequently will be the establishment of thresholds for detecting change. In other words, if data collected at a site is presumed to be impacted by an existing barrier, how can that be determined if the macroinvertebrate community differs from a site where no barrier exists? While it is beyond the scope of this document to develop a detailed discussion of study designs and the limitations of data usage, the before-after-control-impact (BACI) study design provides a basic framework to begin answering such questions. Under a BACI study design, samples are collected at sites where target conditions are presumed to exist before and after a barrier removal. These are considered control sites. Concurrently, samples are collected at sites presumed to be impacted by the barrier. These are considered impact sites. Ultimately, differences between control and impacted sites are compared before and after the barrier improvement or removal event to determine if significant changes have occurred. The ability to detect significant differences is a function of the number of samples collected and the quality of data.

Other study designs are possible. All parties involved in the project should be consulted to determine how best to design the macroinvertebrate monitoring efforts. The use of regional biological indices offers the most cost effective and least labor intensive approach in determining overall changes in community condition, but may be limited in terms of the specific questions that can be answered.

Areas of Sample Collection

Macroinvertebrate samples can be collected from several macrohabitat types, such as riffles, pools, stream banks, or a combination of habitat types. Sample collection from each specific habitat type requires careful consideration of available collection techniques. Current collection techniques include two main approaches: single- or multi-habitat sampling. Single-habitat sampling is used by several states and usually includes the collection of samples at the "single, most productive" area within a selected stream reach (Barbour et al., 1999). Macroinvertebrate production generally is maximized in riffle habitats leading to the common terminology of "riffle-kick" for single-habitat samples (VTDEC, 2004). Single-habitat sampling techniques employ multiple, individual, timed sampling efforts in one or many riffles within the study reach. Individual timed sampling efforts generally range from 3 to 5 in number and are grouped together for a representative sample of the macroinvertebrate community.

More recently, some U.S. and Canadian macroinvertebrate sampling protocols have promoted the use of multi-habitat collection techniques (Lazorchak et al., 1998; Rosenberg et al., 1997) as a more complete representation of the resident community. Multi-habitat sampling techniques include the collection of macroinvertebrates from a variety of habitats in approximate proportion to the habitat types observed within the study reach. Points of collection may be randomly selected or placed along predetermined transects. Multiple, individual, timed sampling efforts are used to standardize collection techniques and are variable in number depending on the sampling protocol. As with single-habitat collection techniques, individual timed sampling efforts are grouped together to approximate the macroinvertebrate community within the study reach.

Sampling Timing and Frequency

Most macroinvertebrate collection protocols have an established index period that standardizes a window of time (weeks) during which samples should be collected. Since many aquatic macroinvertebrates have regular development and emergence patterns, the establishment of a standardized collection window minimizes the amount of observed natural variation in community composition. Based on known life cycle patterns, macroinvertebrate sampling for riverine systems in northeastern North America occurs primarily from September through November (USEPA 2002). Alternative sampling times are possible but should be considered with respect to organism developmental patterns, climatic conditions, and the protocols advocated by the applicable regulatory authority.

Site-specific Considerations

The sampling methods described herein are applicable to wading-depth sections of riverine systems. Wading-depth streams can be defined as first through fourth order streams ranging in watershed size from approximately 2 to >200 km^2 (0.77 to >77 mi^2). However, from a practical standpoint, wading-depth can be defined as any section of river where water depth is less than thigh high. Conditions prior to barrier removal often preclude wading-depth sampling techniques. In these cases, alternative macroinvertebrate sampling procedures must be employed. See Blocksom and Flotemersch (2005) for comparison of several non-wading-depth methods.

Sample Processing

Macroinvertebrate sample processing consists of two main phases: sorting and identification. In the sorting phase, organisms are separated from the sample debris. Identification generally takes place following the sorting phase and requires varying levels of expertise depending on the desired level of taxonomic specificity.

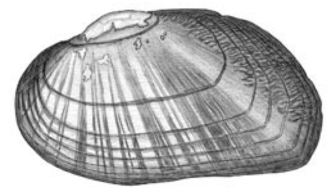
Sample Sorting

Because most whole samples contain more organisms and/or debris than can be processed, the sorting phase usually includes a sub-sampling method. Sub-sampling usually involves the homogenization of all sample contents in a single shallow pan followed by an objective process for selecting a pre-determined fraction of the sample. Currently, the most common method of sub-sampling uses the separation of a fixed-count target number of organisms from a predetermined fraction of the whole sample (Barbour et al., 1999; Lazorchak et al., 1998; Rosenberg et al., 1997). The sample fraction generally is defined by randomly selecting a minimum number of standardized areas (grids) identified by a template overlain upon the entire sample.

Debate still exists over the proportion of the whole sample that must be processed and number of organisms retained for identification and enumeration (Courtemanch, 1996; Barbour and Gerritsen, 1996; Vinson and Hawkins, 1996). A common target is the removal of organisms from enough full grids to meet a 300-individual fixed count target (VTDEC, 2006; Barbour et al., 1999). Doberstein et al. (2000) demonstrated that the results of samples processed using fixed counts of less than 300 individuals differed significantly from whole sample counts of the same sample and that sub-sample counts of up to 1,000 individuals incrementally increased the similarity to whole sample results. Thus, fixed sub-sample count targets are often based on resource availability and may vary among protocols. For this reason, one should consult the protocols advocated by the relevant resource agency before selecting a fixed count target and general sorting procedures. In all cases and regardless of the target, the fraction of the sample processed may differ among samples based on stream productivity. Therefore, a record must be kept for each sample so estimated whole sample results can be standardized.

Identification

The recommended level of taxonomic identification (i.e., family, genus, species) can be highly variable. Several protocols call for the lowest practical level (Barbour et al., 1999; VTDEC, 2006), but researchers have differing opinions as to what taxonomic level is most appropriate (Bailey et al., 2001; Lenat and Resh, 2001; Hawkins et al., 2000; Reynoldson et al., 1997). The academic reasons (i.e., geographic location, ecological diversity, evaluation tool) to select one level of taxonomic specificity over another must be considered in concert with the required level of expertise necessary to achieve the desired results. Highly trained taxonomic experts and expensive equipment generally are required to identify aquatic macroinvertebrates to genus and species levels. In contrast, an experienced field biologist may be able to identify insects to the family level with the naked eye. Thus, one must consider resource availability when deciding on a prescribed taxonomic identification level.



Brook floater

Regardless of taxonomic level of resolution chosen, the protocol must provide detailed identification directions to the people responsible for sample processing. Some groups of macroinvertebrates (i.e., chironomids, nematodes) require additional taxonomic expertise and steps for identification. A less specific identification endpoint is common for these groups. Correct identification serves as the foundation for building the final dataset. Therefore, it is critical that this phase of sample processing be performed in a consistent manner to produce accurate results.

Because of the debate regarding recommended sorting processes and identification levels, specific sample processing protocols are not included herein. If well-tested and widely accepted field and laboratory protocols are selected, evidence suggests that differences between methods can be small. However, it is important they meet minimal performance measures (Herbst and Silldorff, 2006). In Canada and the United States, national protocols exist and should be consulted for further guidance (Barbour et al., 1999; Lazorchak et al., 1998; Rosenberg et al., 1997). Ideally, state, provincial, or federal protocols will be available to guide sample processing.

QA/QC

After sample processing is complete, it is important to verify the results. A common practice for determining the quality of the results is to re-process a minimum of 10% of the samples. A rigorous quality assurance program should test the effectiveness of the sorting and identification phases. As recommended above, it is best to follow the QA/QC procedures advocated by the appropriate regulatory authority. The goals are to document that the reported results are repeatable and that minimal variation can be attributed to the processing methods. As an example, the following is a generic QA/QC procedure:

1. For previously sorted grids, have a second qualified individual re-examine each grid. If less than 95% of the individuals or 95% of the taxa were not removed in the original sort then the sample fails to meet the QA/QC requirements.

2. From a previously identified and enumerated sort, have a second qualified taxonomist re-identify and enumerate all individuals. If 5% or greater of the individuals are misidentified or incorrectly counted, then the sample fails to meet the QA/QC requirements.

3. Individual samples that fail by either (1) or (2) must be reprocessed and adequately justified. An overall sample failure of greater than 2% requires reprocessing for the entire lot of samples.

Use of Resulting Data

In contrast to chemical samples where individual parameter results are compared to their respective thresholds, results from macroinvertebrate samples initially are more complex. With multiple species and individual abundances for each species, long lists of scientific names must be translated into an understandable format. Contemporary efforts to understandably convey taxonomic composition and abundance information include two approaches. First, the multimetric approach relies on the differential tolerances, ecological roles and strategies, and overall composition of the macroinvertebrate taxa found in the sample. Multiple individual measures that are most important in describing community condition are aggregated together to produce a single index of biologic health. This multimetric approach is well documented and has been widely advocated for bioassessments (Karr and Chu, 1999; Barbour et al., 1995; Gerritsen, 1995). Alternatively, the multivariate approach uses detailed statistical estimates of community similarity to establish expected community compositions at minimally disturbed sites. Once these expectations are established, test sites are compared to the minimally disturbed sites to determine the difference in community composition. An observed (test site) to expected (reference expectation) (O/E) ratio is used as the measure of community health (or taxonomic loss). Ratios near 1 indicate minimal taxonomic loss while lower ratios indicate divergence of test sites from expectations. Originally developed in Great Britain and Australia, the multivariate approach has gained acceptance in North America (Reynoldson et al., 1997; Hawkins et al., 2000).

Regardless of the approach used, both techniques provide defensible alternatives to collapse taxonomic lists and respective abundances into understandable and similar assessment outcomes (Herbst and Silldorff, 2006). Prior to any sampling, protocols for collection and processing must be selected that are consistent with the approach and evaluation tool that will be used to assess the status of the macroinvertebrate community. In most cases, the appropriate regulatory authority should be contacted to suggest a recommended index that is locally applicable. In addition, the suggested index may have one or more threshold levels to assist in estimating biological condition and completing formal assessments for water quality reporting requirements.

Documentation

Integral to the success of all components of macroinvertebrate sampling is the maintenance and documentation of the associated data. Given the wide variety of potential sampling methods, laboratory protocols, and data summary approaches, a detailed record must be kept of all data elements. The primary data elements for sampling techniques are sampling device (including net mesh size, if applicable); type(s) of habitat sampled; approximate area sampled; number and approximate length of individual sampling efforts (i.e., five one-minute kicknet efforts); length of incubation (if artificial substrates are used); extent to which individual sampling efforts are grouped together; and the number of replicates. Laboratory processing data elements should include subsample fraction (percent of whole sample sorted); target number of individuals (i.e., 300 individual minimum); number of individuals per taxon; current scientific nomenclature for each taxon (with reference to naming organization); stage of development (larvae, pupa, adult); and QA/QC results for overall sample lot processing. In addition, laboratory metadata should include subsampling procedure (e.g., grid, number of cells, aeration); keys used to identify major taxonomic groups; and target level of identification for major taxonomic groups (i.e., family, genus, species). Data summary approach elements should include final metric and index results for each replicate/sample and reference to applicable index. The referenced index should detail the computation of individual metrics and the final index score, as well as the distribution of index scores for the reference condition and the method for threshold establishment. The ideal data storage vehicle is a relational database that allows for the efficient and long-term storage of large quantities of data in a consistent manner.

APPENDIX E: DATA SHEETS

This appendix contains data sheets for

- site information,
- monumented cross-sections,
- longitudinal profile,
- grain size distribution,
- water quality,
- riparian plant community structure, and
- photo stations.

Data sheets are available for downloading from www.gulfofmaine.org/streambarrierremoval.

Stream Barrier Removal Monitoring
Site Information

Stream Name:	**Site Name:**	**SITE ID#:**
Date of Removal:	**Watershed Area (mi^2):**	**Stream Order:**
Town:	**State:**	**Province:**

Latitude (__°__'__")	**Longitude (__°__'__")**
Benchmark Location:	**Project Datum:**

Circle One

Barrier Type	Dam	Culvert	Other	
Reason For Removal	Fish Passage	Habitat Improvement	Public Safety	Economics
Fish Passage Barrier?	Yes	No		
Impoundment?	Yes	No		
Adjacent Landuse	Urban (%)	Agricultural (%)	Residential (%)	Natural (%)

Assessors Name:	**Affiliation:**
Phone Number:	**Email:**

Cross-Section Survey Data Sheet

Form #___ of ____

Site Name:	**SITE ID #:**
Town, State/Province:	**Stream Name:**
Pre-restoration **Post-restoration** (circle	**Date:**
Form completed by:	**Time (24hr):**
Investigators:	

CROSS SECTION ID #	**Left Monument (UTM)**	**N**	**E**
	Right Monument (UTM)	**N**	**E**

Location Description	**Benchmark Description**
Left Monument Description	**Right Monument Description**

Station (STA)	**Backsight** (BS)	**Height of Instrument** (HI)	**Foresight** (FS)	**Elevation** (ELEV)	**Notes**
ft.	ft.	ft.	ft.	ft.	

Legend	**HI = ELEV + BS;**	**TP ELEV = HI - FS;**	**New HI = TP ELEV + BS**	
	LB: Left Bank RB: Right Bank	LEW: Left Edge of Water REW: Right Edge of Water	BKF: Bankfull CL: Center Line	BM: Benchmark TP: Turning Point

This data sheet can be downloaded at www.gulfofmaine.org/streambarrierremoval

Cross-Section Survey Data Sheet (2)

Form #___ of ____

Site Name:		**SITE ID #:**	**XS ID #**
Date:		**Investigators:**	

Station (STA)	Backsight (BS)	Height of Instrument (HI)	Foresight (FS)	Elevation (ELEV)	Notes
ft	ft	ft	ft	ft	

Legend	**HI = ELEV + BS;**	**TP ELEV = HI - FS;**	**New HI = TP ELEV + BS**	
	LB: Left Bank	LEW: Left Edge of Water	BKF: Bankfull	BM: Benchmark
	RB: Right Bank	REW: Right Edge of Water	CL: Center Line	TP: Turning Point

Longitudinal Profile Survey Data Sheet

Form #___ of ____

Site Name:	**SITE ID #**
Town, State/Province:	**Stream Name:**
Pre-restoration Post-restoration (circle one)	**Date:**
Form completed by:	**Time (24hr):**
Investigators:	

LONG PROFILE ID #	**US end (UTM) N**	**E**
	DS end (UTM) N	**E**

Starting Location Description	**Benchmark Description**

Station (STA)	**Backsight** (BS)	**Height of Instrument** (HI)	**Foresight** (FS)	**Elevation** (ELEV)	**Notes**
ft.	ft.	ft.	ft.	ft.	

Legend	**HI = ELEV + BS;**	**TP ELEV = HI - FS;**	**New HI = TP ELEV + BS**	
	LB: Left Bank RB: Right Bank	LEW: Left Edge of Water REW: Right Edge of Water	BKF: Bankfull CL: Center Line	BM: Benchmark TP: Turning Point

Longitudinal Profile Survey Data Sheet (2)

Form #___ of ____

Site Name:	**SITE ID #:**	**LP ID #:**
Date:	**Investigators:**	

Station (STA)	**Backsight** (BS)	**Height of Instrument** (HI)	**Foresight** (FS)	**Elevation** (ELEV)	**Notes**
ft.	ft.	ft.	ft.	ft.	

Legend	**HI = ELEV + BS;**	**TP ELEV = HI - FS;**	**New HI = TP ELEV + BS**	
	LB: Left Bank RB: Right Bank	LEW: Left Edge of Water REW: Right Edge of Water	BKF: Bankfull CL: Center Line	BM: Benchmark TP: Turning Point

Pebble Count Data Sheet

Form #___ of ____

Site Name:	**SITE ID #**
Town, State/Province:	**Stream Name:**
Pre-restoration Post-restoration (circle one)	**Date:**
Form completed by:	**Time (24hr):**
Investigators:	
Description/notes:	**CROSS SECTION ID #**

Size Class (mm)	Count	Total (#)	Frequency (%)	Cumulative (% Finer)
>=256				
<256				
<180				
<128				
<90				
<64				
<45				
<32				
<22.6				
<16				
<11.3				
<8				
<5.6				
<4				
	TOTAL:			

Water Quality Data Sheet	Form #____ of _____
Site Name:	**SITE ID #:**
Town, State/Province:	**Stream Name:**
Pre-restoration Post-restoration (circle one)	**Date:**
Form completed by:	
Investigators:	

Station	X Section ID #	Depth (ft)	Temp (° C)	Dissolved Oxygen (mg/l)	Oxygen Saturation (%)	Specific Conductance (uS/cm)	Time
A							
B							
C							
Replicate Station ___							
Vertical Profile- Station B		(ft)	(° C)	(mg/l)	(%)	(uS/cm)	
Weather Notes:		Surface					
		1					
		2					
		3					
		4					
		5					
		6					
		7					
		8					
		9					
		10					

Wetland-Riparian Plant Community Monitoring Data Form

Form #___ of ____

Site Name:	**SITE ID #:**
Town, State/Province:	**Stream Name:**
Pre-restoration Post-restoration (circle one)	**Date:**
Form Completed By:	
Investigators:	

VEG PLOT ID # **CROSS SECTION ID #**

Plant Species and Layer Type*	Stratum	% Cover	Plant Cover and Other Observations**

Large Woody Debris (number and description):

Leaf, Needle, and other Plant Cover (eg,, Mast, Invasive plants):

Notes

Cover Class	Range (%)	Mean (%)
T	<1	None
1	1-5	3
2	6-15	10.5
3	16-25	20.5
4	26-50	38
5	51-75	63
6	76-95	85.5
7	96-100	98

*Herbaceous (H), tree (T), and shrub and sapling (S) layers. Note, also record the percent barren ground.
**Description of plant condition may include plant height measurement, indication of flowering/inflorescence, presence of chlorosis, signs of disease, insect infestation or presence of animal browsing/grazing. Other observations may include indication of whether plant was planted or seeded and whether site has undergone natural or human disturbance.

Wetland-Riparian Plant Community Monitoring Data Form (2)

Form #___ of ____

Site Name:	**SITE ID #:**
Town, State/Province:	**Stream Name:**
Investigators:	**Date:**

VEG PLOT ID # **CROSS SECTION ID #**

Plant Species and Layer Type*	Stratum	% Cover	Plant Condition and Other Observations**

Notes

Cover Class	Range (%)	Mean (%)
T	<1	None
1	1-5	3
2	6-15	10.5
3	16-25	20.5
4	26-50	38
5	51-75	63
6	76-95	85.5
7	96-100	98

This data sheet can be downloaded at www.gulfofmaine.org/streambarrierremoval

Photo Monitoring Data Form

Form #___ of ____

Site Name:	**Stream Name:**	**SITE ID #**
Form Completed By:	**Photographer**	**Date:**
Pre-restoration **Post-restoration** (circle one)		

Photo Station ID #	Photo Station Description	Photo #	Compass Bearing	Time	Cross Section ID #	Distance Along X-Section	Subject Description Upstream or Downstream

General Notes or Comments: (weather, rainfall data, cloud cover, time of sunrise and sunset, other pertinent information