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Establishing aquatic restoration priorities using a watershed approach

B. A. Bohn*† and J. L. Kershner‡

† *United States Department of Agriculture (USDA) Forest Service, Bighorn National Forest, Sheridan, Wyoming 82801, USA*
‡ *United States Department of Agriculture (USDA) Forest Service, Fish Ecology Unit, Fish and Wildlife Dept., Utah State University, Logan, UT 84322-5210, USA*

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Since the passage of the Clean Water Act in 1972, the United States has made great strides to reduce the threats to its rivers, lakes, and wetlands from pollution. However, despite our obvious successes, nearly half of the nation's surface water resources remain incapable of supporting basic aquatic values or maintaining water quality adequate for recreational swimming. The Clean Water Act established a significant federal presence in water quality regulation by controlling point and non-point sources of pollution. Point-sources of pollution were the major emphasis of the Act, but Section 208 specifically addressed non-point sources of pollution and designated silviculture and livestock grazing as sources of non-point pollution. Non-point source pollutants include runoff from agriculture, municipalities, timber harvesting, mining, and livestock grazing. Non-point source pollution now accounts for more than half of the United States water quality impairments. To successfully improve water quality, restoration practitioners must start with an understanding of what ecosystem processes are operating in the watershed and how they have been affected by outside variables. A watershed-based analysis template developed in the Pacific Northwest can be a valuable aid in developing that level of understanding. The watershed analysis technique identifies four ecosystem scales useful to identify stream restoration priorities: region, basin, watershed, and site. The watershed analysis technique is based on a set of technically rigorous and defensible procedures designed to provide information on what processes are active at the watershed scale, how those processes are distributed in time and space. They help describe what the current upland and riparian conditions of the watershed are and how these conditions in turn influence aquatic habitat and other beneficial uses. The analysis is organized as a set of six steps that direct an interdisciplinary team of specialists to examine the biotic and abiotic processes influencing aquatic habitat and species abundance. This process helps develop an understanding of the watershed within the context of the larger ecosystem. The understanding gained can then be used to identify and prioritize aquatic restoration activities at the appropriate temporal and spatial scale. The watershed approach prevents relying solely on site-level information, a common problem with historic restoration efforts. When the watershed analysis process was used in the Whitefish Mountains of northwest Montana, natural resource professionals were able to determine the dominant habitat forming processes important for native fishes and use that information to prioritize, plan, and implement the appropriate restoration activities at the watershed scale. Despite considerable investments of time and resources needed to complete an analysis at the watershed scale, the results can prevent the misdiagnosis of aquatic problems and help ensure that the objectives of aquatic restoration will be met.

Keywords: watershed analysis, stream habitat improvement, stream biota, watersheds, geomorphology, stream classification, aquatic restoration.

Introduction

Aquatic ecosystems worldwide are being severely altered or destroyed at an alarming rate (National Research Council, 1992). In western North America, for example, there is growing public and scientific concern over the widespread decline in native fish populations (Minckley and Deacon, 1991; Nehlsen *et al.*, 1991; Frissell, 1993). Recent reports reveal that fishes such as trout and

* Corresponding author.

salmon, once widespread and abundant, are now in jeopardy of becoming extinct across vast portions of their historic ranges (Nehlsen *et al*., 1991; Frissell, 1993). Much of the habitat loss has been attributed to modification of the physical environment. However, most habitat losses originate from disruptive streamside land uses such as riparian vegetation removal, road building, wetland filling, grazing, or mining.

Federal land management agencies are beginning to recognize the importance of a watershed-based approach to develop an understanding of aquatic ecosystems and to then use that information to reverse the decline of native populations. There are now various mandates for conducting a watershed-based analysis and include the Aquatic Conservation Strategy from the Forest Ecosystem Management Assessment Team (FEMAT) report (Thomas *et al*., 1993) and the Unified Watershed Assessments from the Clean Water Action Plan (EPA, 1998). The intent of these directives are to ensure that restoration activities have clear goals and objectives before work begins and that restoration plans address key questions such as: What are the dominate processes operating at the various scales? How have the processes and functions been altered by past activities? What components of the watershed are in need of restoration? What is the end-point of restoration? These questions are to be addressed in an interdisciplinary environment and will require input from physical, biological, and social scientists.

The watershed analysis procedure has many advantages over past restoration planning and can overcome problems that plagued historic restoration efforts. The analysis template provides a systematic approach to characterize the physical and biological processes active in the watershed and to describe their spatial distribution, history, and linkages. It utilizes past and current conditions to develop relationships between landforms, stream channels, biological systems, and land management activities. In its expanded form, the analysis can help direct future management that will be consistent with the dominant habitat forming processes in the watershed. This article introduces the watershed analysis procedure as an important tool to help restoration practitioners identify, prioritize and implement aquatic restoration activities at the appropriate ecosystem scale.

The mandate for aquatic resource restoration

An unwelcome consequence of an increasing human population has been the elimination or greatly reduced quantity of high quality aquatic habitats. Threats to freshwater fish populations include altered basin hydrology, sedimentation, channel modification, and pollutants of various types. However, degraded freshwater habitats are often implicated as the single most important contributor to the decline in native fish populations (Miller *et al*., 1989; Nehlsen *et al*., 1991; Frissell, 1993). As the health of aquatic habitats decline, so does the natural diversity of aquatic species. For example, in the Pacific Northwest there are currently seven populations of Chinook salmon (*Oncorhynchus tshawytscha*), two populations of Chum salmon (*Oncorhynchus keta*), two populations of Coho Salmon (*Oncorhynchus kisutch*), two populations of Sockeye salmon (*Oncorhynchus nerka*), nine populations of Steelhead (*Oncorhynchus mykiss*), two native trout species (*Oncorhynchus clarki henshawi*; *Oncorhynchus clarki clarki*), and the Bull trout (*Salvelinus confluentus*) that are listed as being either threatened or endangered under the Endangered Species Act (USFWS, 1999). As of September 30, 1999 the US Fish and Wildlife Service has identified 111 species of fishes, 20 crustaceans, 36 reptiles, and 17 amphibian species as being either threatened or endangered (USFWS, 1999).

In response to the rapid decline in high quality aquatic habitats and their dependent species, there is growing public pressure to restore degraded aquatic conditions on Federal lands in the United States. For example, in the Pacific northwest, controversy over the northern spotted owl (*Strix occidentalis caurina*) in old-growth forests led President Clinton to assemble research scientists into a group called the Forest Ecosystem Management Analysis Team (FEMAT). An important product of FEMAT (Thomas *et al*., 1993) was the Aquatic Conservation Strategy. This strategy was designed to reverse the decline of aquatic and riparian conditions in the northwest (Ziemer, 1997). In 1997, Vice President Gore directed the United States Department of Agriculture (USDA) and the Environmental Protection Agency (EPA) to work with other federal agencies and the public to prepare an aggressive Clean Water Action Plan to meet the goal of clean, safe water for all Americans.

These strategies are intended to address the growing public concern over the threats to our aquatic resources. Consequently, federal agencies are being funded to address this issue through interagency watershed planning and are expected to incorporate aquatic restoration as part of their overall land management ethic.

Ecosystem scales and hierarchy in restoration planning

The key to a successful aquatic restoration plan begins with the recognition that ecosystem processes operate at multiple temporal and spatial scales. The Aquatic Conservation Strategy from the FEMAT report (Thomas *et al*., 1993) identified four spatial ecosystem scales. The scales they defined are: regional, basin, watershed, and site (Table 1).

An ecosystem analysis may be conducted at any spatial or temporal ecosystem scale. The appropriate scale must be selected based on the issues and processes being addressed. For example, a broad scale would be chosen to provide the context for policy formulation and laws. At finer scales, analyses provide the context for site-specific projects and their localized consequences or effects (Regional Ecosystem Office, 1995). Mid-scale analyses (i.e. watershed), provide the context for land management by describing ecosystem processes and capabilities. Mid-scale analyses may not be appropriate for all processes. For example, some processes such as wildlife or social components are better analyzed at larger scales such as basin or regional scales.

Table 1. Landscape scales identified in FEMAT (Thomas *et al*., 1993)

Ecosystem scale	Description
Regional	The broadest level of organization; size is normally issue driven. This may include several river basins across several states.
River Basin	A subunit of the regional scale; large, continuous land areas of 500 to over 3000 km^2 that have topographic or geologic integrity.
Watershed	A subunit of the river basin; normally between 50 and 500 km^2.
Site or Project	A subunit of the watershed level; a specific activity area within a watershed, normally between 0·3 and 3·0 km^2.

Watersheds are a convenient geographic unit for restoration planning because they can be identified on maps and on the ground and because they do not change much over time (Reid *et al*., 1996). Watersheds also internalize many biological, socioeconomic, and physical resources active across the landscape (Dobrowolski and Thurow, 1995). For example, environmental and economic conflicts often arise from changes in stream processes stemming from upslope land use. To address downstream cumulative effects of watershed activities, a holistic perspective is required. The watershed scale is large enough to reveal important processes, distribution patterns, and qualitative categories that may be creating cumulative impacts (Reid *et al*., 1996).

Selecting the appropriate temporal scale upon which restoration is evaluated can be equally as important as selecting the appropriate spatial scale (Ziemer, 1997). Depending upon the resource or audience being addressed, the appropriate temporal scale may extend through several years for political decisions or span several decades for geomorphic or silvicultural issues. Therefore, the appropriate time scale must match the issue or resource being focused on to prevent ineffective or erroneous actions (Ziemer, 1997).

Historic approaches to aquatic restoration planning

Traditional approaches to aquatic habitat restoration concentrated on repairing or enhancing specific habitat conditions rather than restoring the landscape processes that form and sustain high quality aquatic habitats (Beechie *et al*., 1996). The traditional approach to aquatic habitat restoration largely ignored the natural variation in channels and their dynamic ability to distribute high quality habitats throughout a watershed. Early attempts to restore habitat often attempted to impose stability or optimize certain conditions. Many habitats are a function of change; attempts to fix them at a particular point in space or time fail to recognize that stream channels are dynamic and that high quality habitats are a product of this dynamism (Beechie *et al*., 1996).

To be effective, conservation strategies and aquatic habitat restoration must be implemented at the scale of watersheds and then integrated into large geographic regions (USDA Forest Service, 1994b). If a landscape analysis were commonly used to identify and prioritize habitat improvement projects, many costly failures might be avoided. Resources could then be directed to effectively treat the primary causes of habitat problems: sedimentation from eroding roads and slopes, logging, grazing, channelization, and urbanization (Frissell and Nawa, 1992). Unless larger scale watershed issues are addressed in restoration planning, the current practice of direct structural modification of channels at the site level is unlikely to reverse aquatic population declines.

The role of watershed analysis in aquatic restoration planning

The watershed analysis procedure has been shown to be an effective tool to efficiently identify and balance the biological, social, and economic demands on the environment. Developing an understanding of watershed processes is the crux of a watershed analysis (USDA, 1994a). The intent of a watershed analysis is to develop and document a scientifically based understanding of the processes and interactions occurring within a watershed (USDA, 1994a). The understanding is based on specific issues, values, and uses occurring within the watershed. The information collected at the watershed scale is then used to describe the linkages and interactions between land-use activities and the physical and biological environments over a large area. It describes the distribution, pattern, types, and relative importance of resource values, altered environmental conditions, and the mechanisms of environmental change in watersheds. The information collected in the analysis is then used to develop a series of topics to consider during project planning and identifies specific considerations for designing riparian reserves, restoration, transportation routes, cumulative effects, and monitoring (USDA, 1994a).

An interdisciplinary team of resource specialists conducts a watershed analysis using a standard, interagency six-step procedure (Regional Ecosystem Office, 1995; Ziemer, 1997). The steps are question-driven and once answered provide a model of landscape and ecosystem function, disturbance history, and current and potential conditions (Table 2). The procedure generates a logic trail that connects an analysis of landscape conditions with potential management activities. For more information on each step in the watershed analysis, the reader is directed to other sources such as Ziemer (1997).

Successful aquatic habitat restoration begins with a comprehensive understanding of how the observed site-level resource problems relate to the larger scale processes occurring within the watershed. The watershed analysis procedure is an ideal mechanism to develop that understanding. The process is designed to assist land managers through the myriad of cumulative effects occurring in most watersheds and to then determine those processes that develop and maintain high quality habitats while avoiding activities that degrade them. The watershed analysis provides clear direction for the management of resources within the watershed while identifying actions that

Table 2. Steps used to complete a watershed analysis (Regional Ecosystem Office, 1995)

Step	Purpose
1. *Characterization*	Identify the dominant physical, biological, and social processes or elements of the watershed that affect ecosystem function or condition.
2. *Issues and key questions*	Identify the key elements of the watershed that are most relevant to the management objectives and questions, social values, or environmental concerns.
3. *Current conditions*	Document the current range, distribution, and condition of core topics and important ecosystem elements.
4. *Reference conditions*	Describe the known or inferred history of the landscape that helps develop an understanding of what might have existed in the past and what changes may be affecting current capabilities. Reference conditions also help establish goals and objectives to be used in management plans.
5. *Synthesis and interpretation*	Synthesize and interpret information generated in the previous four steps. Here, the spatial and temporal linkages between the ecosystem processes are defined. The implication of these linkages on the attainment of management objectives outlined in Step 2 is discussed and provides the basis for management recommendations.
6. *Recommendations*	Bring the results of the previous steps to conclusion in the form of management recommendations. A watershed analysis produces information, knowledge, and understanding necessary to support informed land management decisions.

are consistent with the dominant habitat forming processes. The analysis identifies management scenarios that will prevent additional impacts while identifying restoration opportunities and priorities within a watershed context.

Case study: Grave Creek

The following case study illustrates the use of watershed analysis as a guide for restoration planning. The process steps described in Table 2 are highlighted in ***bold italics***.

Concern over the decline in bull trout (*Salvelinus confluentus*) and westslope cutthroat trout (*Oncorhynchus clarki lewisi*) numbers in the Upper Kootenai River drainage in northwest Montana led resource managers on the Kootenai National Forest to ***characterize*** habitat conditions in the Grave Creek watershed (Figure 1). The goals of the analysis were to determine the status of habitat conditions in Grave Creek, an important bull trout and westslope cutthroat tributary in the Upper Kootenai River basin, and to identify and prioritize restorative measures.

The primary ***issue*** in Grave Creek was that cut throat and bull trout populations were declining in the drainage. It was believed by land managers that suitable habitat was the limiting factor to recovery. The bull trout is listed as 'threatened' and the westslope cutthroat trout is listed as 'sensitive', prompting special concern for their recovery and consideration for management.

The ***analysis of current conditions*** showed that runs of mountain whitefish (*Prosopium*

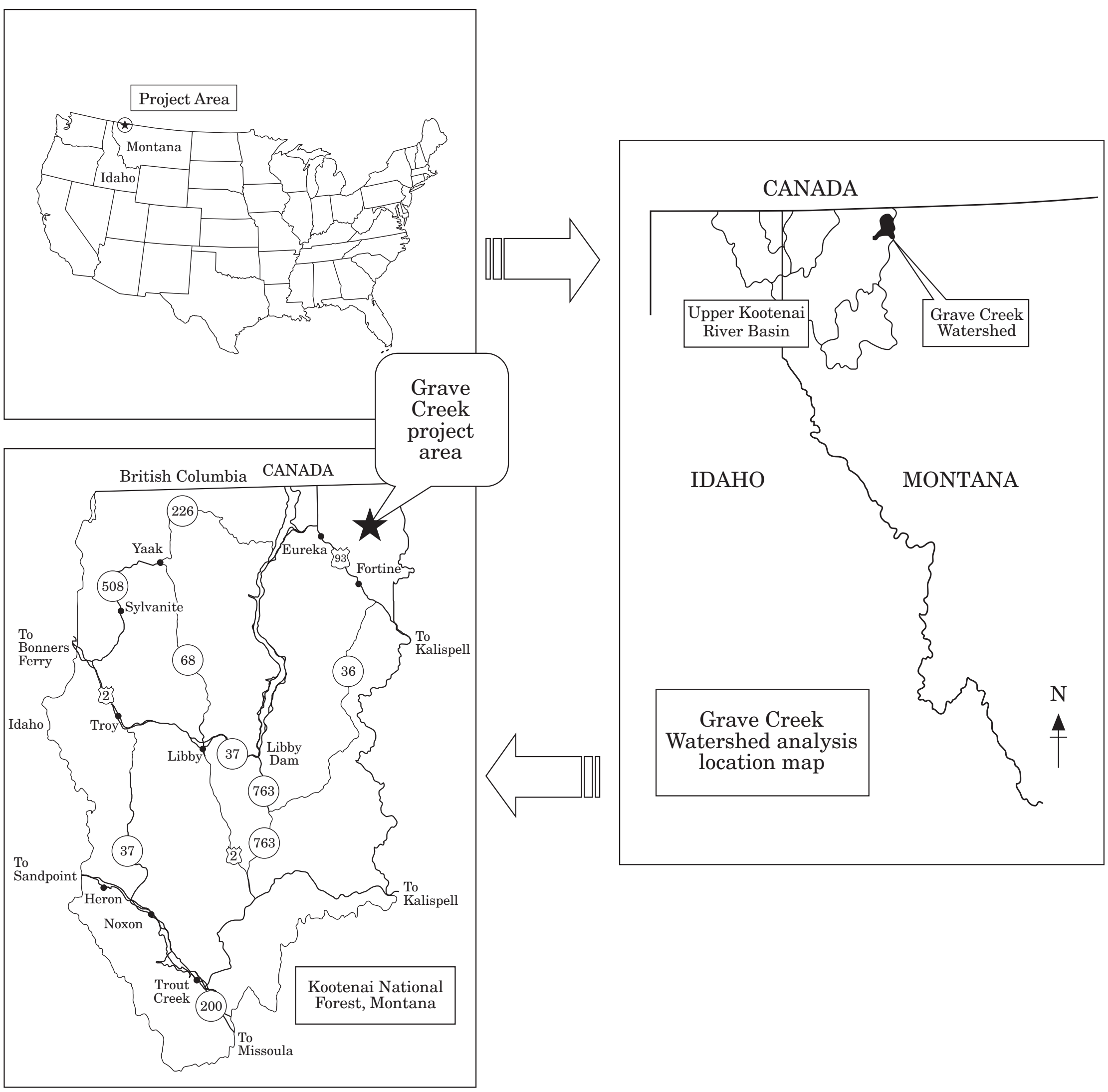

Figure 1. Map of Grave Creek watershed analysis area in Montana, USA.

williamsoni), westslope cutthroat trout, and bull trout from the Kootenai River have declined dramatically since 1948. This decline is attributed to an irrigation diversion dam located in lower Grave Creek and to management activities over the last 100 years in the Tobacco and Grave Creek watersheds. The degraded habitat conditions can at least be partially attributed to the amount, type, and location of land management activities in the Grave Creek watershed and along the Tobacco River.

An interdisciplinary team analysis (Table 3) revealed that over time, the condition of the channels in Grave Creek have degraded as a result of upstream timber harvest, road failures, in-stream wood removal, and increased peak flows. Virtually every reach in the Grave Creek watershed has adjusted to the effects of these actions. For example, the average riffle width in the lower watershed went from 60 ft (18 m) in 1947 to over 130 ft (40 m) in 1992. During the 45 years of aerial photographic record, the sinuosity in the same reach went from 1·23 (1947) to 1·08 (1992). The widening and straightening of the channel resulted in extreme bank erosion rates, pool filling, in-channel bar formation, and a decrease in low water depths (Figure 2). This response is typical throughout the lower basin, however the sensitivity of each reach varies by stream type (Rosgen, 1996).

Reference conditions were determined by comparing historic data with existing conditions, comparing reference to non-reference data, and from reference conditions compiled from other sources (e.g. regional conservation strategies, literature). The analysis suggested that present fish habitat conditions in Grave Creek are generally in fair to poor condition. For example, many of the reaches lack sufficient in-channel large woody debris to form and maintain adequate numbers and quality of pool habitats. Accelerated peak flows from upslope vegetation removal and large amounts of small bed material made scour depths sufficient to effectively wash out spawning redds in some areas during spring runoff. However, the departure from 'reference' in many critical reaches was not extreme, suggesting that alteration in land management techniques and physical restoration of habitats have a high likelihood of success.

The ***synthesis*** of the data suggested that the cause of degraded conditions stem from US Forest Service management activities in the upper watershed beginning in the early 1950s and extending through the 1980s. Early spruce harvesting occurred along riparian areas, removing large diameter trees for saw logs, thereby reducing the number of large trees available for recruitment into the stream. Early harvesting also increased the routing efficiency of the watershed by constructing an extensive skid trail network in and around first order tributaries. Factors contributing to degraded conditions in the lower watershed include conversion of riparian communities to pasture, urban development along the riparian corridor, and channel realignment.

The existing road network in Grave Creek has been identified as being a chronic source of sediment to the stream network. Many of the roads in the watershed are located in landtypes rated 'High' for erodibility. Roads located on highly erodible landtypes are subject to slumping and erosion. Sediment eroded from roads is being routed to the channel network because many of the roads are located in the bottom of the basin and along perennial streams. In some cases, the fill-slope of the road is located sufficiently close to the channel to make the fill-slope an actively eroding channel bank.

Table 3. Watershed analysis team members and area of expertise

Team member	Discipline	Representing
Bryce Bohn[a]	Hydrology/Aquatic Ecology	United States Department of Agriculture, Forest Service
Kirk Sullivan[b]	Hydrology/Riparian	United States Department of Agriculture, Forest Service
Roxanne Rogers[c]	Fisheries/Partnerships	United States Department of Interior, Fish and Wildlife Service
Guenter Heinz[d]	Fisheries/Wildlife	United States Department of Agriculture, Forest Service
Scott Snelson[e]	Fisheries/Partnerships	Montana Department of Fish, Wildlife, and Parks
Annje Bohn[f]	Geographic Information Systems	Boise-Cascade, Corp.
Gary Decker[g]	Fluvial Geomorphology	Water Consulting, Inc.
John Muhlfeld[g]	Fluvial Geomorphology	Water Consulting, Inc.

[a] 2013 Eastside Second Street, Sheridan, WY 82801.
[b] 655 Hwy 93 North, Eureka, MT 59917.
[c] 780 Creston Hatchery Road, Kallispell, MT 59901-8283.
[d] P.O. Box 116, Fortine, MT 59918.
[e] 475 Fish Hatchery Road, Libby, MT 59923.
[f] 1274 Boise Road, Kettle Falls, WA 99141.
[g] 120 South Fifth Street, Suite 201, P.O. Box 981, Hamilton, MT 59840.

Figure 2. An example of high bedload accumulations in Grave Creek. Excessive erosion and increased peakflows from upstream sources have resulted in a dramatic increase in the width-depth ratio. This reach will require reconstruction to a narrower width-depth ratio in order to pass the sediment delivered to it from upstream sources.

Riparian harvest has affected the type, density, and size of woody material in the channel. Today, much of the wood in reaches adjacent to riparian clearcutting consists of small diameter logging slash that has accumulated into dense, unstable debris jams. These jams trap bedload and create lateral scour channels that undermine the unstable side slopes. Following the completion of timber harvest, the roads, stream crossings, and skid trails were left without erosion control structures. Many of the existing skid trails and closed roads continue to actively erode and are increasing the routing efficiency of peak flows from tributary watersheds.

The cumulative effect of the spruce harvest of the 1950s, followed by clearcutting in the 1980s, reduced the quality of aquatic conditions in the Grave Creek watershed. The large openings and poorly located roads along the main channel and in the tributary watersheds have resulted in increased peak flows and increased sediment delivery. The tributary channels contain steep reaches that efficiently transport the combined effects of increased peak flows and sediment to the main Grave Creek channel. This analysis suggests that the combined effects of 40 years of increased sediment yield, woody debris removal, and increased peak flows have left the aquatic habitats in the watershed in a generally degraded condition.

The information and understanding gained by the watershed analysis has been translated into specific management ***recommendations***. Recommendations are possible solutions to the issues or problems identified during the watershed analysis. They include actions that protect, enhance, or restore the valuable aquatic resources within the watershed.

A general list of management recommendations and priorities for Grave Creek are outlined in Table 5. The aquatic restoration priorities are geared towards restoring upslope processes first. Instream projects will be initiated after substantial progress is made on removing the causative factors.

A monitoring plan has been developed to track the recovery of stream channels, habitats, and aquatic populations in Grave Creek. Disturbances in the Grave Creek watershed have manifested themselves at the watershed level. However, habitat improvement projects and changes in land use activities will occur on the local or site scales. Therefore, the evaluation of watershed recovery must cover several spatial and temporal scales. The criteria developed to measure restoration success are based on the objectives of the restoration efforts and are appropriate to the scale of expected watershed response.

The recovery and maintenance of high quality habitats in Grave Creek depend upon actions on both public and private lands. Therefore, private landowners are key to both the restoration and monitoring of aquatic conditions. To determine the success or failure of restorative measures in Grave Creek, a long-term commitment to monitoring will be required (Table 4).

Table 4. Expected ecosystem responses to changes in management or restoration

If restoration or change in management leads to this...	And this occurs...	Then the expected ecosystem response would be...
Increased size and amount of wood available from the riparian zones	The material is incorporated into the active channel	Increased fish cover Increased pool frequency and quality Increased gravel storage Increased bed and bank stability
Decrease the amount of chronic sediment being delivered from landslides and hillslope erosion	The amount of large woody debris is increased in the channel	Increased pool frequency Retain and sort spawning gravels Reduce the amount of local channel filling with fine sediment
Remove man-caused fish passage barriers in the main channel and tributaries	Reduce the width-depth ratios via active restoration and enhanced riparian conditions	Fish access to all critical habitats within the watershed.
Decommission roads located on unstable geology and within the rain-on-snow zone	Disconnect hydraulic connections between the road and stream networks	Reduce the concentration of peakflows during storm events Reduce the amount of bank erosion and sedimentation to downstream reaches
Identify stream reaches on private property that are not functioning at their geomorphic potential	Landowners are organized into a watershed group that can effectively work together to accomplish restoration goals	Reduce the overall sediment delivery Improve aquatic habitats in critical lower reaches Improve riparian habitats on private property

Table 5. Prioritized aquatic restoration actions in the Grave Creek watershed

Priority	Vicinity or location	Aquatic rationale	Restoration objectives
1	Tributary watersheds	Important westslope cutthroat trout and bull trout spawning and rearing areas. These watersheds are contributing large amounts of fine and coarse sediment.	Restore sediment regime through road improvements and obliteration. Minimize watershed efficiency by adding road ditch drainage, outsloping, and obliteration. Reduce contribution of coarse sediment by treating areas with active mass wasting. Restore degraded riparian areas. Reduce road crossings.
2	Tributary watersheds	Contributor to increased peakflows and increased watershed efficiency.	Treat old skid trails and roads in upper basin to reduce the effects of flood routing.
3	Colluvial draws	Large contributor of coarse sediment to main stem of Grave Creek.	Manage for a healthy riparian area. Reduce road densities.
4	Diversion dam and irrigation ditch intake.	Inhibits upstream migration of adult bull trout. Juvenile bull trout to pass into ditch and become lost to system.	Remove diversion dam and reconstruct a stable channel. Construct self-cleaning fish screen at ditch intake.
5	Mainstem of Grave Creek	Important migration, spawning, rearing, and over-wintering areas.	Restore sediment transport capacity. Restore degraded riparian areas. Manage for instream pools. Reduce angler access from the few remaining large pools.
6	Lower Grave Creek	Currently contributing large amounts of fine and coarse sediment. The wide, shallow channel inhibits upstream movement of trout.	Work with landowners to improve riparian management along Grave Creek. Reconstruct a stream channel capable of accommodating sediment and water without yearly geomorphic adjustments.

Conclusion

The watershed analysis procedure is a valuable tool for managers responsible for the protection and enhancement of aquatic resources. As the concern for the condition of our aquatic resources grow, the demand for responsible planning and cost efficient habitat improvement projects will grow also. Therefore, rather than identifying restoration opportunities using the traditional 'quick-fix' approach, such as treating the worst-degraded or ugliest-looking sites, aquatic resource managers can now use an ecosystem approach to determine appropriate land uses and effective habitat improvement measures.

The strength of a watershed analysis is that restoration opportunities are identified in a multidisciplinary and interagency environment. The focus of restoration is to improve ecosystem function rather than single resource management. Once the causal mechanisms of disturbance are identified, the appropriate restoration practices can be planned that address the limiting factors for an aquatic species or community.

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