Advancing the Fundamental Sciences

Proceedings of the Forest Service National Earth Sciences Conference, San Diego, CA, 18-22 October 2004

Volume 2

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Top left–The Rio Chama, Santa Fe National Forest, northern New Mexico. Photo from the USDA Forest Service.

Bottom left–Salmon River, Mount Hood National Forest, Oregon. Photo by Bruce McCammon.

Top right–Refuge Lake in the southern High Sierra, California. Photo by Michael J. Furniss.

Middle right–Kayakers on the Cossatot River, Ouachita Mountains, Arkansas, just outside the Ouachita National Forest. Photo by A.C. Haralson, Arkansas Department of Parks & Tourism, Little Rock, Arkansas.

Bottom right–Pawnee Buttes, Pawnee National Grassland, northeastern Colorado. Photo by Terra L. Mascarenas.

Title page: Powder River, Wallowa-Whitman National Forest, northeast Oregon. Photo by Bruce McCammon.

Preface

Bruce McCammon and Bonnie Ilhardt

It is a great pleasure for us to present the proceedings of the Advancing Fundamental Sciences conference held in San Diego, California, in October 2004. This conference was attended by nearly 450 Forest Service earth scientists representing hydrology, soil science, geology, and air. In addition to active members of the earth science professions, many retired scientists also attended and participated in the week's events. Even though it rained much of the week, attendees maintained a high level of enthusiasm and participated actively.

The week was filled with memorable, but transient, events. A variety of keynote speakers reminded us of our history, challenged us with new thoughts, and reaffirmed our responsibility for proper stewardship of the unique physical resources on Forest Service lands. Panel discussions allowed the pioneers of the physical science disciplines to be recognized for their careers and acknowledged for their contributions. Speakers took the opportunity to present new work and interact with their peers. Poster displays gave many people an opportunity to present their work and explain its importance. Everyone who attended will remember the three-part play "The Life and Times of Forrest Stump." The play presented a snapshot of a hypothetical physical scientist's career beginning when physical scientists were new to the agency and ending when he retired after a long and distinguished career. The skit struck close to home for many and left the crowd howling with laughter and asking for more. Conference critiques showed clearly that the variety of events during the week led to the success of the conference.

These proceedings are the durable product of the conference and come to you only as the result of hard work by authors, reviewers, and editors. These proceedings include 60 technical papers that have been through a series of peer and editorial reviews. Fifty-six people participated as reviewers of the technical papers. Each paper was improved through incorporation of two sets of peer-review comments. Our thanks go to each of the people who volunteered to be a reviewer. Special thanks go to Michael Furniss, Caty Clifton and Kathryn Ronnenberg for coordinating the reviews, providing a high level of editorial consistency, and for preparing this proceedings.

We hope that these proceedings will serve as a valuable reference for your work in the future.

Bruce McCammon
Retired, Pacific Northwest Region
Conference Chair

Bonnie Ilhardt
Eastern Region
Conference Co-chair

Editors' Note

Michael J. Furniss, Catherine F. Clifton, and Kathryn L. Ronnenberg

Most earth scientists like rain. We know it is the source of much we hold dear, sustaining the systems we study and love, necessary for flowers to grow and flourish and bloom. But… rain for a week? In San Diego? It was an unusual deluge that greeted us in southern California, but fitting. It accompanied an unprecedented gathering of more than 400 Forest Service earth scientists for a first-ever national conference. It was a landmark event. Good times, along with the precipitation, were in abundance. The weather lifted rather than dampened the mood as we ran through downpours, arriving soaked and excited for the next encounter.

Many attendees expressed surprise that "there are so many of us." We have a lot in common through our work, but until that week, we'd never seen so many soil scientists, geologists, hydrologists, and air specialists together in one place. There was a strong sense of a "community of practice": of shared goals, common experience and participation that reached across the Nation.

We were, perhaps, the largest such collection of public lands earth scientists on Earth. The conference was a celebration and expansion of our collective knowledge, experience, identity, history, and a glimpse of our future potential. We commend the conference organizers for this extraordinary, multidisciplinary conference, for their recognition that knowledge from one branch is unable to advance without knowledge from another, and that together we are a stronger, more sustainable community.

Two thousand four was also the year of the Forest Service Centennial celebration. The sense of history was in the air, as retirees mixed with newer hires. We took stock of the five or six decades that earth scientists have contributed to the Forest Service, the ways times have changed, and the many ways we have advanced the agency and the conservation of earth resources.

The conference program offered a broad diversity of plenary and themed sessions, workshops, and field trips, and received rave reviews throughout the week. The book you hold contains submitted technical papers from the themed sessions. These 60 peer-reviewed papers represent a wide spectrum of earth science investigation, experience, research, and innovation in the Forest Service. Take the time to read and enjoy them, but don't stop there. You are encouraged to give an author a call or email to discuss what you read and how it relates to your work. Load up the CD in the back and review the keynote talks. Check the intranet web site for more memories and resources.

Let this collection be a portal into the rich pool of expertise, engagement, and collaboration that is our community of practice. The bonds formed and strengthened in San Diego can help sustain us in the decades to come. Our community was in full bloom that week, but it exists between conferences. Just as flora (and maybe conferences) need rain, communities of practice need cultivation to flourish. We have many ways to connect across forests, regions, and stations, to inform and support each other. In so doing, each of us can help nurture our community of practice.

We encourage you to call or email someone from another region. Email someone you know but haven't seen since San Diego. Create and participate in informal events that connect people. Convene discussions on common challenges, both remote and in person. Share experiences, successes, and failures. We each have the ability to cultivate and sustain our community of practice. Everything works when we participate and contribute. There is no better time than now.

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About the Advancing the Fundamental Sciences Portable Electronic Presentation CD

The CD in the inside back cover is an interactive learning resource that presents many of the conference plenary talks and two of the workshops in an electronic format. The format provides for interactive access: you may watch them start to finish, or just the parts that most interest you.

A help screen is available from the home page to assist you with navigating the presentations.

The CD runs on both Windows and Macintosh-compatible machines. This CD content can also be found online at *http://www.stream.fs.fed.us/afsc*

See page 577 for a preview of the introductory screen.

I. Concurrent Session Papers

Section 3. Watershed Protection and Restoration

Part 2. Roads

Overleaf:
Decommissioned road on Montague Island, Prince William Sound, Chugach National Forest, Alaska. Photo from the USDA Forest Service.

Lessons Learned From Management Response to Flood-Damaged Roads in the Western Washington Cascades

James Doyle
Gary Ketcheson
Mt. Baker-Snoqualmie National Forest, Mountlake Terrace, Washington

In the Pacific Northwest, within the western Washington Cascade Range, floods are a dominant natural disturbance affecting forest ecosystems. Following flood events, a major management focus for the forests, Mt. Baker-Snoqualmie National Forest (USDA Forest Service Region Six) over the past 20 to 25 years has been to fix or repair flood-damage roads with the traditional "replace-in-kind" approach driven to a large extent by the limitations posed by the primary funding source (Federal Highways-Emergency Relief Federally-Owned [ERFO] Program). Over this time period, a pattern was detected by forest personnel (engineering and aquatic) that at many road failure sites, previous flood damage had occurred and the fix or repair had been unsuccessful in preventing future flood damage. Forest personnel began to identify a number of problems at these sites, including undersized road crossing structures, improper spacing, orientation, location, and number of drainage structures. Beginning in the late 1980s, forest engineers and aquatic specialists, after assessing the mechanism of failure at a number of these sites, began to develop road-stream crossing designs based on this knowledge. The resulting flood repair effort was a major departure from the traditional "replace-in-kind" approach. By the early 1990s some national forests in Region Six were broadening their road-flood repair efforts from a site by site basis to approaching the repair work with a view to the entire road system and within a watershed context. The Mt. Baker-Snoqualmie National Forest has developed and implemented a suite of successful road restoration treatments and techniques to address flood-damaged roads. Since 1990, the Forest has experienced four major flood events (1990, 1995/96, 1997, 2003). A vital component of documenting this management departure from the "replace-in-kind" approach to road flood damage repair has been the development of a database that contains records of flood-damaged road sites from 13 ERFO-qualifying flood events on the Mt Baker-Snoqualmie National Forest (1974-2003). This paper will highlight some interesting and revealing queries from this historical information.

Keywords: *floods, roads, restoration, ERFO, road-stream crossings*

Introduction

The Mt. Baker-Snoqualmie National Forest (Washington) covers 1.7 million acres (687,900 ha), stretching along the western Cascade Range from the Canadian border on the north to Mt. Rainier National Park on the south. The Cascade Range can be separated into two distinct geological regions, with the approximate division occurring at Interstate 90 (I-90) from Seattle east to Snoqualmie Pass. Much of the present configuration of the Cascades is the result of glacial activity that began about one million years ago. Continental glaciers are believed to have advanced into and withdrawn from the Puget Sound region at least four times during the Quaternary Period; the last glacier retreated about 10,000 years ago. The differences, north and south of I-90, in geology, topography, bedrock, and soils are important because the aquatic environment resources are influenced by the character of the geologic material. Glacial ice, a powerful agent of erosion, abraided and scoured the North Cascades topography at an accelerated pace. Valley floors were broadened and deepened and valley walls were over-steepened. Many predominant features of the landscape were caused by glacial activity: jagged peaks, cirque basins, lakes, and hanging valleys. The rugged topography resulting from glacial modification is most pronounced north of I-90. The soils of the forest are complex and varied. There are over 200 unique soil mapping units, based on soil type, geologic type, and topographic shape. There are differences in soils in the north half and south half of the forest (split by I-90), due to the differences in bedrock and the extent of glaciation and volcanism (USDA FS 1990).

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Forty-one percent of the forest is designated as wilderness (eight Wilderness Areas). The diverse vegetation communities of the forest are a result of extremes in elevation, aspect, soil depth and climate. The forest contains three primary forest zones (western hemlock [*Tsuga heterophylla*], Pacific silver fir [*Abies amabilis*], and mountain hemlock [*Tsuga mertensiana*]). Thirty-six percent of the forest is designated as riparian area containing over 2,000 miles (3,200 km) of fish-bearing channels, (5,000 miles [8,000 km] of perennial, non-fish channels) and 13,000 acres (5,261 ha) of lakes. A diversity of aquatic species reside in these waterbodies; anadromous and resident salmonid fish species include: Chinook (*Oncorhynchus tshawytscha*), coho (*O. kisutch*), sockeye (*O. nerka*), pink (*O. gorbuscha*) and chum (*O. keta*) salmon, steelhead and rainbow trout (anadromous and resident *O. mykiss*, respectively), cutthroat (*O. clarkii clarkii*), brook (*Salvelinus fontinalis*) and bull trout (*S. confluentus*). Other fish species present include grayling (*Thymallus arcticus*), whitefish (*Prosopium williamsoni*), and sculpin (*Cottus* spp.) (USDA FS 1990).

The Mt. Baker-Snoqualmie is a designated urban national forest in the U.S., with about 7 million people residing in the forest's zone of influence. About 20 million people cross through the forest over a one year period with about half stopping to recreate a day or more on the forest (USDA FS 2000). Recreational sites include four ski area complexes, 1700 miles (2720 km) of trails, and 50 developed campgrounds. Summer recreation activities include camping, picnicking, hunting, fishing, hiking, mountain climbing, mountain biking, boating, swimming, canoeing, kayaking, white-water rafting, off-highway vehicle (OHV) use, auto touring, and berry picking. Winter recreation includes downhill and cross-country skiing, snow-shoeing, snowmobiling, and winter mountaineering.

Flood Disturbance

Winter storms in the Pacific Northwest (October-February) are of three general types. The first and most common is a low pressure system in the northern Pacific that draws moisture easterly across the Pacific and produces light to moderate rain with snow in the mountains above 4,000 feet (1,220 m). The second type is a low pressure system in Alaska that moves southeast over a high pressure ridge located along the California coast. This system draws cold air and moisture from the Gulf of Alaska across the Pacific Northwest and can deposit large amounts of snow as low as sea level, but mostly above 1,000 feet (305 m). The third type, varying in intensity, is known as a Pineapple Express. This is a low pressure system that draws warm moisture from the Pacific around the Hawaiian Islands, having torrential rain and wind, with freezing levels as high as 10,000 to 12,000 feet (3050 to 3660 m). When a cold Alaska system is followed by a Pineapple Express, major floods occur. Hillslope saturation occurs rapidly, with snowmelt caused by the warm wind and rain at mid-elevations. The high elevation snowpack densifies, but often does not contribute significant amounts of runoff (USDA FS 1992). Flooding occurs on both small and large channels and landslides are common. The effects of these rain-on-snow storms in the Western Cascades has been well documented (Copstead and Johansen 1998; Furniss et al. 1998).

Management Response: Traditional vs. Current

The traditional Mt. Baker-Snoqualmie National Forest response to flood damage was a rapid mobilization to assess damage and assist anyone stranded or imperiled by the flood. Complete damage assessment was made as soon as possible using a procedure involving the use of a Damage Situation Report (DSR). The DSR form was developed in partnership with the Federal Highway Administration [FHWA] 30 to 40 years ago to document and record site damage. These forms were and still are the basis for securing Emergency Relief Federally Owned (ERFO) funds to repair flood damaged sites. ERFO funding was basically limited to a "replace-in-kind" philosophy. All flood repair work and coordination was done exclusively by forest engineering personnel.

The current flood management approach still involves the rapid mobilization by forest personnel to assess damage and assist anyone stranded or imperiled by the flood. However, DSRs now include a supplemental sheet detailing the cause and initial result of failure. Discussions with FHWA personnel on the adequacy of fixing or repairing sites with ERFO's "replace-in-kind" occur, comparing documented new flood damage to forest roads history. The FHWA determines funding taking into account the needs of Endangered Species Act, Clean Water Act, and Forest Plan standards, and the potential for the site to fail again. The forest requests supplemental flood funding when ERFO funds aren't adequate. All this work is done in an interdisciplinary fashion with the aquatic program sharing lead responsibility with engineering.

Flood Damage to Roads

One of the highlights of this paper is documenting some of the initial information we are gleaning from our roads-flood damage database (Table 1). This database contains 935 records from 13 flood years (from 1974 to 2004)

Table 1. General history of flood damaged roads on the Mt. Baker-Snoqualmie National Forest from 1974 to 2003. The impact location "both" indicates that areas both north of and south of I-90 were affected by the event.

Flood Year	# of Floods	Flood Date	# of Sites	Impact Location
1974	1	13 January	72	Both
1977	3	25, 29 Nov.; 12 Dec.	61	South of I-90
1979	2	13-15 and 17-20 Dec.	57	North of I-90
1980	1	24-27 Dec.	74	Both
1982	3	5 Jan., 12 Dec., 10 Jan. 1983	90	Both
1984	2	4 Jan., 16 Nov.	41	Both
1989	1	11 Nov.	25	North of I-90
1990	2	9-10 and 22-24 Nov.	124	Both
1991	1	8 Jan.	97	South of I-90
1994-95	2	26 Dec. 1994, 14 Jan. 1995	7	North of I-90
1995-96	3	8 Nov., 28-30 Nov. 1995, 1-3 Jan. 1996	223	Both
1999	1	6 Jan.	14	North of I-90
2003	1	18-23 Oct.	50	North of I-90

on road sites that were flood damaged and subsequently fixed or repaired. More than one flood event occurred in some years (1977, 1979, 1982, 1984, 1990, 1994-95, and 1995-96). Six flood years resulted in damage throughout the entire forest (1974, 1980, 1982, 1984, 1990, and 1995-96). Most of the flood impacts have occurred north of I-90, in a geological zone containing the forest's most dissected landscape and most unstable soil types.

Flood return intervals are not available for all these flood events, but information exists to compare their relative severity. The post-1990 floods, especially the floods in 1990, 1994-95, 1995-96, and 2003, are the floods of record in many of the forest's river basins, most located in the geologic zone north of I-90. These four flood years caused road damage at 404 sites. The database includes ERFO DSR records and other non-ERFO funded flood repair records.

Flood damage to roads, as discussed in this paper, is separated into two general categories; damage to road fills, and damage to the road drainage system. Sidecast fills may sag or settle from consolidation, saturation, or both. Subsidence may open surface cracks that accept water rapidly, often resulting in failure of the fill material. On steep slopes, the failure may travel long distances. Poor ditch drainage and plugged culverts can also cause road prism or fill failures by saturating the sub-grade (Forman and Sperling 2003).

Road ditches need to be constructed and maintained to carry the expected flows. Cutslope ravel or slumping, hillslope creep, and vegetation reduces ditch capacity and efficiency. Where ditches do not function properly, roads will fail during a flood event. Proper ditchline function depends on proper sizing and spacing of ditch-relief culverts and cross-drain or channel crossing culverts. If the ditch relief culvert is inadequate or cross-drain culverts and stream crossings plug, roads will fail, releasing sediment into the channel in amounts that may exceed the transport capacity of most channels. Undersized culverts also do not allow passage of bedload sediment, resulting in upstream deposition. Many of these undersized culverts also are barriers for fish passage.

Many arterial roads in the Western Cascades (state highways and high-volume forest roads) are located along river corridors, encroaching upon or crossing floodplains and river terraces. Bridges are expensive, and are typically built to minimal lengths, often constricting the channel floodplain width. Where topography doesn't dictate otherwise, bridges are usually built with minimal freeboard above design flows. This doesn't allow for passage of large organic material, such as whole trees with the root ball attached (Forman and Sperling 2003).

Roads adjacent to rivers create persistent management challenges. Normal river channel and floodplain processes, such as channel migration, transport of sediment and large organic material, and the dissipation and storage of flood flows, are altered. The proximity of smaller channels and roads can also lead to the creation of new channels due to flood damage. When road crossings divert flood flows, new undesirable diversion channels often develop through the road prism (Havlick 2002).

Causes and Patterns of Failure - Structures

In characterizing road failures in the Cascades, we have documented the following observations. The most common failure is one involving a culvert. Most often the culvert inlet is partially or completely plugged with bedload and organic debris, forcing most of the flood water over the road. This may result in saturation and failure of a fill slope, or erosion and piping along a culvert, slicing through the entire road prism.

Culvert blockages can be the result of improper sizing, too small a culvert, spacing too far apart, improper alignment, culvert rusting resulting in physical collapse, or inadequate maintenance.

Bridge damage during floods is most often caused by the erosion or scour of the riprap protecting the abutments. Bank scour increases under a bridge that constricts the floodplain. If the span width is too narrow, or if the rip rap is not keyed into the streambed to the normal depth of scour, floods may remove the riprap. Over time, channel migration across the floodplain will result in bridge damage, including bridge approach loss, bridge abutment damage, and even loss of bridge decking.

The database reveals that 56 percent of the 935 sites involved culvert failures, 16 percent involved fill or cutslope failures, 11 percent were due to road and channel encroachments, 7 percent involved damaged to bridges, 5 percent were due to ditchline failure, and 5 percent to landslides on the road.

Causes and Patterns of Failure - Land Related

Road failures during floods can often be related to landform and land use patterns. Knowing what landforms have unstable slopes that are prone to debris avalanches can benefit road location and drainage design, maintenance, and repair approaches. Land uses that alter runoff and erosional processes should be accounted for in the road drainage design. Mt. Baker-Snoqualmie National Forest examples of these landforms are sensitive watersheds with a legacy of intensive timber harvesting and road building, such as Canyon, Deer, and Finney Creeks. Flood damage to road systems, especially repeated failures at the same sites, should be documented in forest-wide assessments such as road analysis (USDA FS 1999).

Flood Damaged Road Repair

Traditionally, repair of Forest Service roads that have been damaged by floods in the Pacific Northwest has been strongly influenced by the available funding sources. The kind and amount of funding has, until recently, dictated the kind and type of repair.

The best example of this has been funds allocated by the Federal Highway Administration under the Emergency Relief Federally Owned (ERFO) program. These federal emergency repair funds were typically allocated based on the principle, "replace-in-kind". The cost of the repair had to be equal to or less than the original cost. This approach has resulted in a history of repeated failures on many road systems and at individual road sites after one or more documented flood events.

For example, plugged or damaged culverts were either cleaned and repaired, or were replaced with the same size culvert at the same location following a flood event. These sites were often documented as failing again from subsequent flood events. Another example of a "replace-in-kind" project was loss or damage to road bridge approaches or abutments. In most cases, the fix was to replace the approach with the same type and amount of material as in the original construction, or to replace the bridge abutment or armoring with the same amount and type of material.

Road prism damage such as ditchline scour, cut-slope, fill slope or retaining wall failures were usually fixed or repaired using the original specifications. Damage from channel erosion or channel diversion into the road prism was usually addressed with the same design standards as in the original construction.

By the mid-1980s, after learning from six major flood events (1977-1984), the forest began to recognize that this "replace-in-kind" approach to repairing flood damaged roads was not effective forest management. A new approach was initiated.

After observing and documenting numerous road and channel site failures, we began developing new techniques and technologies for dealing with road and stream crossing structures, road prism construction, and road / channel encroachments. For example, we designed and installed low-water fords and sloped-concrete box culverts that could not only pass high water but also the bedload and organic debris typically mobilized and transported during flood events.

Beginning in the mid 1990s, bridge span widths were increased at existing bridge sites, spanning, at a minimum, the bankfull channel, and where warranted, the entire flood-prone channel width. Bridge replacement design called for abutments to be installed outside the active channel width. In addition, culverts were replaced by bridges at sites with a history of failure, or where they posed a barrier to fish passage.

Cross-drain structures were increased in number and relocated to better mimic the natural channel drainage network along flood-prone road segments. In addition, more detail was given to the inlet and outlet controls at many of these culverts (constructing inlet catch basins and trash racks; outlet grade control structures and energy dissipaters). In a few cases, road segments from 100 feet (30 m) to over 2 miles (3.2 km) were either realigned or relocated away from recurring channel encroachment locations.

By the mid 1990s, rock and log deflectors replaced the traditional riprap-constructed groins used to deflect channel encroachments on road embankments. Also during this time, our focus regarding road flood damage prevention and action moved beyond the site concern to the road system and watershed scale. Guidance from planning processes such as watershed analysis and road analysis promoted an interdisciplinary approach to looking for solutions at the watershed scale. The focus is not just on treating the symptoms but attempting to address the causes of road flood damage, especially at chronic failure sites.

The most common type of repair done over this 30-year flood period was fixing or replacing culverts (Table 2). At many sites, both a primary repair and a secondary treatment were needed; for example, replacing a damaged culvert with a bigger culvert, and replacing the lost road fill. Repairing, or replacing culverts was by far the most frequently used treatment (554 sites). Fifty-three sites involved repairing or replacing bridges, and 256 sites involved primarily road prism treatment (fill, cutslope, fillslope, ditchline, etc.). Sixty sites primarily involved road re-alignment, re-location or decommissioning, and twelve sites involved installing channel rock or log deflectors to reduce the risk of further channel and road encroachment.

The amount of federal funds spent on repair of flood damaged roads on this national forest from 1974 to 2003 is pretty staggering. FHWA funds covered 96 percent of the cost. Over half of the total costs are due to the floods of record in 1990 and 1995-96. This table also shows that the cost to repair roads damaged by floods is increasing over time. In the 1970-1989 period, 420 sites were repaired with a total cost of $11.9 million, while during the 1990-1999 period, 465 sites were repaired costing $38.3 million (both values in 2003 dollars).

The database supports the forest's contention that road damage would have involved more sites and cost more in the 1990-1999 time period without the road restoration that began in the early 1990s. During the 1990-1999 flood period, chronic flood damage failure sites on roads in sensitive watersheds such as Canyon, Deer, and Finney Creek did not recur following major road restoration (decommissioning, stormproofing, upgrading) in these watersheds.

The total costs of forest flood repairs over the 1974-2004 timeframe were $53,336,750; pro-rating this total over the 30-year period gives an annual value of $1,777,892-more than the forest's annual road maintenance budget (about $1,000,000 per year) for the same period. If the forest had a higher annual road maintenance budget, some of this flood damage might have been avoided by conducting more road restoration.

Since 2000, the region has been receiving decreasing annual road restoration and maintenance budgets, hampering the forest's capacity to stormproof additional road segments and systems. Future floods will provide additional information as to the effectiveness of road restoration in treated watersheds as well as the results of little or no treatment in other watersheds.

The amount of road prism (fill, fillslope, cutslope) lost or eroded away by these floods is also staggering. Most of this material ended up in stream and river channels, and had impacts on fish habitats. The forest has not attempted to estimate the volume of this transport and deposition to the stream channel network.

Lessons Learned

The most basic lessons learned from an aquatics management viewpoint of management's response to flood damaged roads can be summed up in four statements:

1. ***Be involved early and stay engaged.*** Don't wait to be asked by engineering, offer assistance immediately and be active in all phases of project development and implementation.
2. ***Bring the big picture to the table.*** Look beyond the site for remedies and consider the whole road system and a watershed context. The traditional approach has been focused entirely at the site scale.

Table 2. Costs of repairing flood damaged roads on the Mt. Baker-Snoqualmie National Forest from 1974 to 2003 (cost figures adjusted to 2003 dollars).

Time Period	Fund Source	# of Projects	Repair Category	Amount ($)
1970-1979	FHWA-ERFO	190	Road prism, culverts	$10,561,546
1980-1989	FHWA-EFRO	221	Road prism, culverts	$946,451
1980-1989	CFS	9	Culverts, bridges	$380,845
Total		*420*		*$11,888,842*
1990-1999	FHWA-ERFO	411	Road prism, culverts	$33,252,382
1990-1999	WR-JITW	42	Road removal, culverts	$3,500,000
1990-1999	CFS	12	Culverts, bridges	$1,550,000
Total		*465*		*$38,302,382*
2000-2003	FHWA-ERFO	50	Prism,culverts, bridges	$6,695,526
Grand Total		***935***		***$53,336,750***

3. ***Become a forest resource historian.*** Document the history of previous failure and subsequent repair.

4. ***Advocate for fixes or repairs that look into the future.*** Promote higher structure design standards and longer design lifespans.

5. ***Be committed to data management.*** Communicate and document the management legacy for others to build on, and in doing so, inspire others.

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Erosion and Channel Adjustments Following Forest Road Decommissioning, Six Rivers National Forest

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Although watershed restoration through road decommissioning has become common in the last decade, few studies have attempted to investigate the success or failure of such projects. This study examines 117 km (73 miles) of decommissioned roads, including 262 stream crossings, on the Six Rivers National Forest, northwestern California, to quantify erosion and identify failure mechanisms and potential areas for improvement. Although most crossings had experienced some adjustment, erosion was generally minor. The average amount of erosion for stream crossings was 21 m^3 (28 yd^3), which represents 4.5% of the amount of fill excavated. Of this volume, 40% of the erosion was due to channel adjustment and 60% was due to bank failures. Erosion from the roadbed between crossings was very small and was observed only in areas of highly unstable geology. The amount of erosion appears well correlated with the timing and intensity of storm events. Large storm events occurring the first winter after decommissioning produced elevated erosion levels. After several dry winters, erosion was very minor, even from large storm events.

Keywords: *roads, decommissioning, obliteration, erosion*

Introduction

It has long been recognized that roads, particularly roads in steep, mountainous terrain, can have significant impacts on water quality and aquatic ecosystems by: accelerating erosion and sediment loading, altering channel morphology, and changing the runoff characteristics of watersheds (Furniss et al. 1991). Where forest roads are located in steep terrain, mass soil movement is a common mechanism of erosion and sediment delivery (Lyons and Beschta 1983). Also common are road-stream crossing failures that occur when culverts fail to pass wood, sediment or storm discharge. The plugging of culverts may result in the loss of the roadbed at the stream crossing or the diversion of the stream offsite, both of which may generate large erosional features and sedimentation of adjacent water bodies. Road cuts can also intercept groundwater and reroute subsurface water into streams. This increase in stream discharge may result in channel enlargement including downcutting and bank erosion.

On Six Rivers National Forest, northwestern California, roads are the leading source of management-related sediment inputs, predominantly associated with mass wasting features such as shallow debris slides and debris torrents. The majority of road-related erosion and sediment delivery are associated with large storm events that trigger culvert failures, stream diversions, and mass wasting such as debris slides and smaller slumps within the roadbed. With declining road maintenance funding, the risk of road failures and elevated sediment delivery is increasing, particularly in the event of large storms.

In an effort to reduce erosion and sediment delivery associated with forest roads, a road-decommissioning program was initiated in the early 1990s on Six Rivers National Forest. Over the past decade, the forest has decommissioned approximately 341 km (212 mi) of forest roads. Road decommissioning efforts target abandoned and low-use roads with high erosion and sedimentation risks. The focus of road decommissioning efforts has been on improving water quality and aquatic ecosystems through reducing sediment introduced to streams, and on reducing the risk of future sediment delivery from roads in the event of a large storm.

The primary road decommissioning treatments on the Six Rivers has been the removal of culverts and the associated fill in stream crossings, and recontouring the stream crossing to as close to the original channel morphology as possible or practical. Roads were not completely obliterated (i.e., fully recontoured) as is typically done in the Redwood National Park restoration program (Madej 2001), but rather were placed in a free-draining condition. Where areas of instability were evident, road fill between stream crossings was recontoured, but in areas where there were no signs of instability, the roadbed was

Furniss, M.J., Clifton, C.F., Ronnenberg, K.L., eds., 2007. *Advancing the fundamental sciences: proceedings of the forest service national earth sciences conference, San Diego, CA, 18-22 October 2004*. PNW-GTR-689. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

left in place. Generally speaking, the upper to mid slope location of the majority of forest roads on Six Rivers National Forest and the geology in many of the areas was such that leaving the majority of the road prism intact was seen as a low risk and a means to cost-effectively decommission more miles of road. In addition to culvert removal and occasional outsloping of the roadbed, installation of water bars or rolling dips was also employed to make the road free-draining. In some cases, the roadbed was ripped or sub-soiled, or trees were planted to speed up revegetation. In all cases, the ultimate objective of the road decommissioning treatment was to make the road free-draining, maintenance-free, and hydrologically benign relative to future erosion and sedimentation risk.

Because of the relatively new emphasis on road decommissioning in recent years on national forest lands and on private timber lands, little attention has yet been given to understanding the extent of erosion and sedimentation that occurs after a road has been decommissioned. There is a general recognition that there will be short-term effects associated with road decommissioning. These short-term effects are considered small given the long-term gain in reducing the larger sedimentation risk if more roads were to fail during large storm events. However, few studies have quantified the sediment lost due to post-decommissioning erosion and channel adjustments. A recent post-treatment decommissioning study was conducted in Redwood National Park (Madej 2001). Madej found that on stream crossing sites, post-treatment sedimentation was small and the majority of the post-treatment erosion and sedimentation were attributable to treated roadbeds. Regardless of treatment, post-project erosion and sedimentation were low when compared to untreated sites. For the period 1980 to 1997, an average of 50 m^3 (66 yd^3) of sediment delivery per stream crossing occurred (Madej 2001). Klein (2003) conducted a post-treatment erosion and turbidity monitoring study on decommissioned roads in the Mattole River watershed in northern California. Klein reported an average of 11 m^3 (15 yd^3) of sediment delivery associated with restored stream crossings. During the first winter after treatment, erosion and elevated turbidity within the restored stream crossings was common but the erosional responses diminished considerably over the winter sampling period. Dunkley et al. (2004) assessed the effectiveness of road deactivation ('decommissioning') techniques in reducing the incidence of landslide initiations but did not assess the volumes of erosion and sedimentation associated with landslides. On the Clearwater National Forest in Idaho, a study was conducted to assess the short-term total suspended-solid concentrations resulting from stream crossing obliteration (Brown 2002). The Clearwater study determined that turbidity and suspended sediments increased during stream crossing restoration and that total sedimentation could be reduced if sediment traps were installed. No analysis was conducted to determine how long the turbidity and suspended solids lasted after the restoration work ceased.

Project Objectives

In light of the extensive road decommissioning that had occurred over the past ten years on the Six Rivers National Forest and the high likelihood that more roads will continue to be decommissioned in the near future, assessing road decommissioning projects was identified as a critical step that would quantify the extent of post-treatment road decommissioning erosion and sedimentation, and improve future road decommissioning projects through incorporating lessons learned. The objectives of the post-treatment road decommissioning assessment were to:

1. Quantify the amount of fill removed and the amount, types and locations of post-project erosion. Assess the effectiveness of treatments in reducing sediment inputs
2. Identify successful or unsuccessful treatment techniques (e.g., ripping, leaving road prism intact, and so on)
3. Identify criteria that would facilitate predicting when future projects may need special treatments (e.g., stream power, slope gradient, slope position)
4. Identify any limiting factors contributing to less than fully successful road decommissioning

These objectives are aimed at assessing the relative risk of implementing road-decommissioning projects and quantifying the nature of the short-term post-treatment erosion risk. This information is particularly relevant given the extent of threatened and endangered anadromous fisheries within the Six Rivers National Forest and the potential for road decommissioning projects to result in adverse effects on these fisheries and water quality.

Project Area Description

Six Rivers National Forest is located in northern California within the Klamath Mountains and California Coast Ranges Geomorphic Provinces. The Klamath Mountains Province has been uplifted relatively rapidly and is deeply dissected, contributing to the ruggedness of the terrain. Both rugged and gentle terrain is found in the Coast Ranges, and drainage systems are generally smaller in area. Topography throughout the Forest is typically steep (slopes ranging from 30 to 80 percent), well dissected, and forested, although there are extensive areas of grassland in the south and barren areas of ultramafic rock in the north. The large number of older, deep-seated landslides and younger, shallow landslides is due to rapid downcutting by streams through weak bedrock and overlying surficial materials in response to the rapid uplift, as well as the active tectonic environment. Over 90 percent of the high and extreme landslide hazard areas occur adjacent to stream channels on slopes steeper than 65 percent which typically occur in inner gorges of stream channels, recently active landslides, toe zones of deep-seated landslides, and fault zones of weakened bedrock. In general, roads located on slopes steeper than 50% have a greater risk of failure and sediment delivery (USDA 1999, Appendix 2). Roads located within these areas pose a higher risk of erosion and sedimentation during large storm events.

The geology of Six Rivers National Forest is complex and can be categorized in four groups: (1) sedimentary and metasedimentary rocks; (2) metaigneous [or metavolcanic] rocks; (3) ultramafic intrusive rocks; and (4) igneous rocks. The sediments and metasediments include graywacke, shale, schist, and chert of the Franciscan Complex, slate, phyllite and sandstone of the Galice Formation, and pre-Cretaceous metavolcaniclastic rocks of the Rattlesnake Creek and Hayfork Terranes. The metavolcanic rocks are mainly associated with the Galice and Rogue formations or part of the pre-Cretaceous terranes, or occur as isolated blocks in the Franciscan Complex. The ultramafic rocks are predominantly serpentinite, dunite and serpentinized peridotite. The igneous rocks range from diorite and quartz diorite to gabbro, and most occur as relatively small intrusive bodies or inclusions in mélange.

Six Rivers National Forest is characterized by a Mediterranean climate with cool, moist winters and warm dry summers. Precipitation is moderately heavy over most of the forest. It ranges from around 1,270 mm (50 inches) on the middle to southern portion of the forest and up to 3,048 mm (120 inches) on the more northerly portions of the forest. Roughly 90 percent of the total precipitation falls in the six-month period between November and April. Stream runoff is mainly from rainfall, and snowmelt makes up only a minor part of total runoff. The largest storm runoff is usually associated with rain-on-snow events. The relatively high rainfall in combination with steep terrain poses challenges for maintaining forest roads, particularly during large storm events.

To examine the effect of rainfall on decommissioned roads, monthly rainfall from each ranger district was analyzed. Information about individual storm intensities would be more relevant, but this data is not available. Instead, the highest monthly rainfall of the year was used to create an annual maximum series. Rainfall with a return period of 5 years or greater was used to designate that year as a "wet" year. Rainfall return periods were similar to flood discharge return periods for the few stream gages that exist nearby.

Since the decommissioning program began, three large storm events have occurred. Intensity varied from district to district (Figure 1), but most decommissioning sites have experienced at least an 18-year storm. The largest event was the "1997 New Year's Day Flood" which had a return period between 22 and 52 years (Figure 1). Such heavy rainfall should reveal decommissioned sites that are erosion prone or inadequately restored.

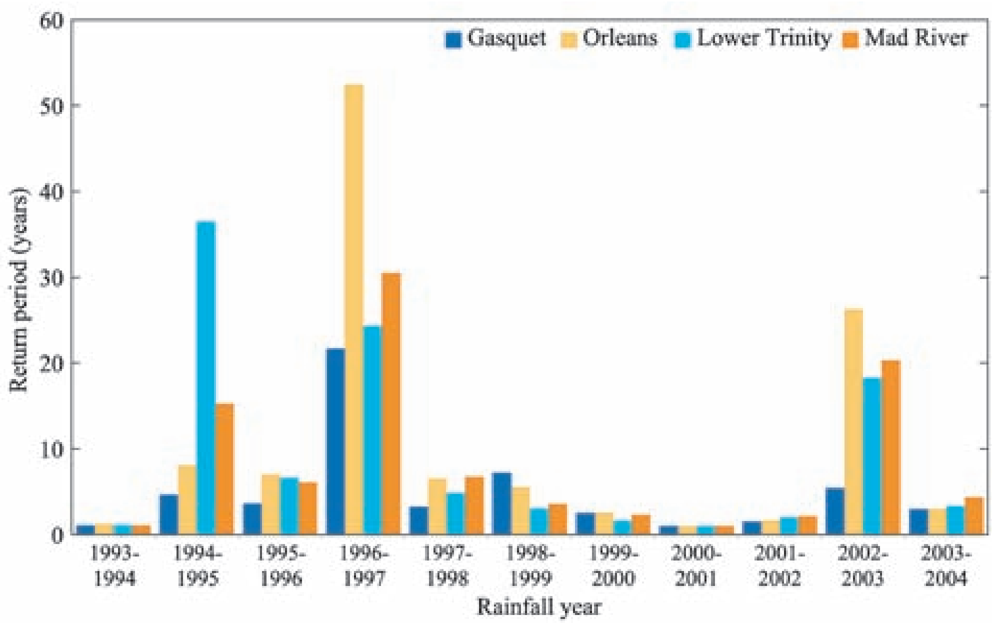


Figure 1: Recent monthly rainfall return periods for the Gasquet, Orleans, Lower Trinity, and Mad River Ranger Districts, coastal northern California ,from 1993 to 2004.

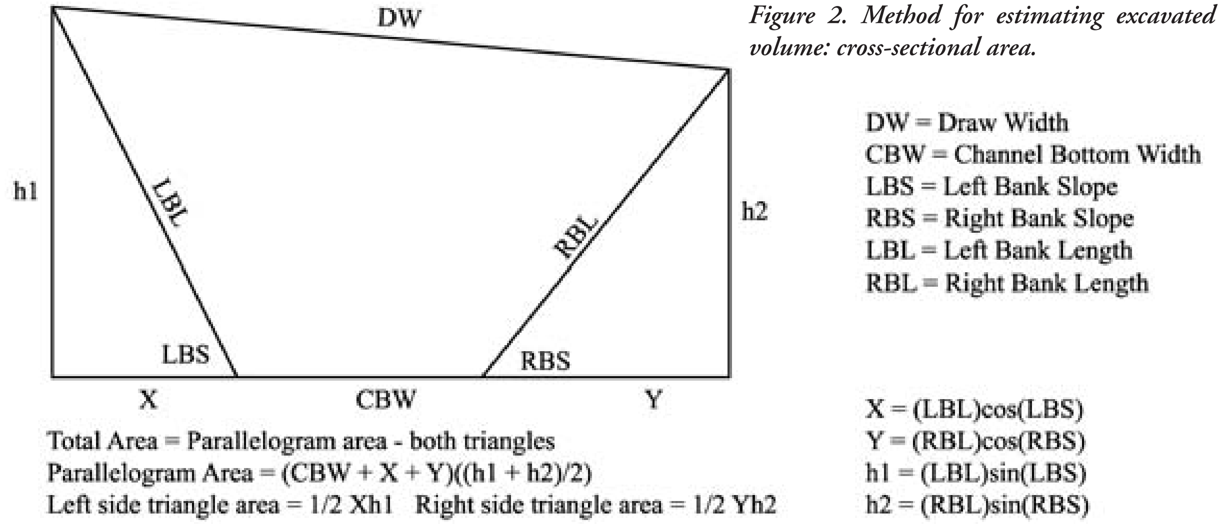


Figure 2. Method for estimating excavated volume: cross-sectional area.

Methods

A total of 117 km (73 mi) of previously decommissioned roads were assessed, or 34% of the total miles of decommissioned road (341 km or 212 mi of road decommissioned). Decommissioned roads were haphazardly selected based on age since treatment; however, attempts were made to get a cross section of different geologic terrains as well as a variety of stream crossing treatment sizes (i.e., large fill volumes versus small fill volumes). The intent of the post-treatment road decommissioning monitoring was to sample as many roads as possible that had weathered large storm events and thereby had treatments that were "tested" by winter storms. Eighty-eight percent of the sampled decommissioned roads had experienced at least three winters of post-treatment adjustment, including storm events with at least an 18-year recurrence interval.

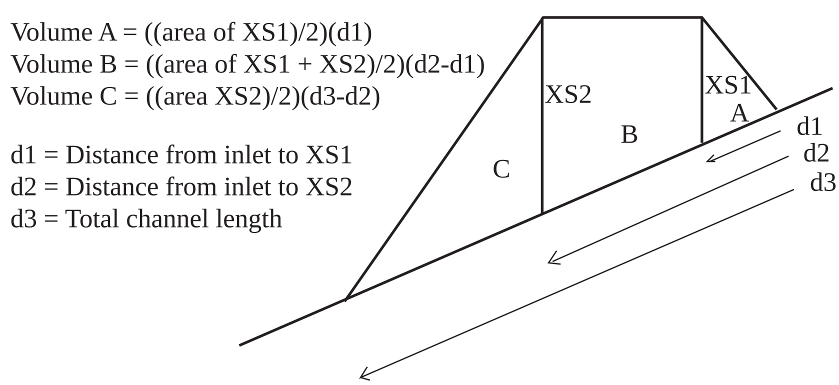
Decommissioned roads were assessed to determine the effectiveness of the treatments at stream crossings as well as the roadbed between the stream crossings. Methods and questions assessed are discussed below.

Estimating Excavated Stream Crossing Fill Volume

The post-treatment road decommissioning monitoring protocol required that the amount of material excavated from stream crossings be measured along with the volume of any post-treatment erosional features. A simplified model of the excavated crossings was used to facilitate rapid measurement of fill volume (see Figure 2 and Figure 3). In using the model, two cross-sections were measured (using a tape and clinometer), along with channel length and slope. The cross-sections were modeled as parallelograms. Total area of the cross-section was calculated by subtracting the area of the two triangles on the sides from the parallelogram area.

This method allowed estimating excavated fill volume for stream crossings that had a significant road gradient going through the channel, yet kept the measurements simple. When measuring the channel bottom width, due to post-treatment adjustments, estimates of the original channel bottom configuration were made to estimate the total fill volume excavated. Total volume for the excavated stream crossing was calculated by scaling the cross-sectional areas by the appropriate distance along the channel (Figure

Figure 3. Profile measurements for estimating fill volume.



3). Cross-sectional area was assumed to be zero at the upstream and downstream end of the crossing.

Most crossings were adequately measured with two cross-sections. In the case of very small crossings, only one cross-section was needed. In such instances, the profile was viewed as a rectangle with sides equal to the cross-section and bottom equal to the total channel bottom length. The upstream cross-section was located where the inboard edge of the old road meets the excavated crossing. The downstream cross-section was placed at the widest point of the excavation. Where significant road curvature exists, excavated fill volume may be slightly over-estimated.

Measuring Post-Treatment Erosional Features

Post-treatment erosional features in both excavated stream crossings and on the roadbed between stream crossings were measured. All visible erosional features were measured using average width, average length and average depth, which yielded estimates of total volume of material eroded. The type of feature was also noted (e.g., channel incisement, slump, gully, rill, debris slide, and so on). Sheet erosion was not measured. When possible, the cause of the erosion was noted and discussed. An estimate of percent delivery of sediment to watercourses from all erosional features was made. For the purposes of this study, all reported erosion volumes within stream crossings were considered 100% delivered sediment.

In addition to measuring the excavated and eroded volume, post-treatment assessments were made to determine if the erosional features had stabilized or were still susceptible to chronic future adjustment and sedimentation. For sites with large post-treatment erosion, evidence as to whether or not poor contract design or implementation was a factor was also assessed.

Post-treatment erosion was compared to the following independent variables: hillslope position, hillslope gradient, stream power, storm return interval, and size of excavation. The intent of the analysis was to identify interactions that might serve to predict when the intensity of road decommissioning design needs to be elevated because the risk of post-treatment adjustments are high. In other words, under what circumstances are the risks of post-treatment erosion and sedimentation high and how can they be reduced?

Results and Discussion

Approximately 117 km (73 mi) of decommissioned roads (or 34% of the total length of decommissioned roads) were monitored for post-treatment erosion (stream channel and sideslope erosion at the crossings, and erosion of the roadbed between stream crossings). The majority of these roads and stream crossings had experienced large storms (18-year or greater return period) during the winters of 1995, 1997 and 2003. High intensity storms were considered a good test of the type and magnitude of post-treatment erosion that occurs on typical road decommissioning projects in the Six Rivers National Forest.

Stream Crossings

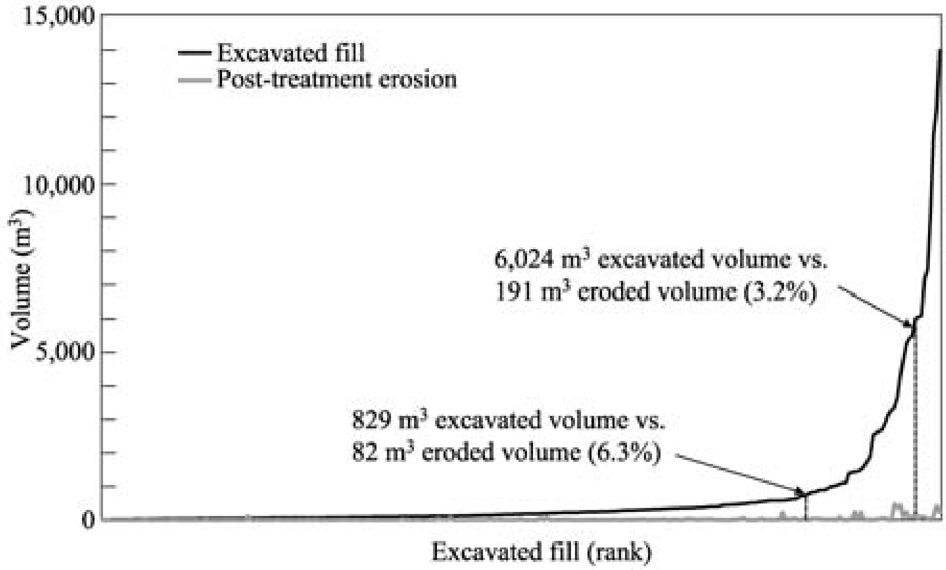
A total of 262 stream crossings were assessed for post-treatment channel erosion. These stream crossings were predominantly perennial streams but intermittent and ephemeral streams were also assessed. Post-treatment stream channel erosion was quite common, and was generally not large when compared to the amount of material excavated during the initial stream crossing restoration. On average, the amount of post-treatment erosion occurring within stream crossings was 4.5% of the total volume of fill excavated, or 21 m^3 (28 yd^3) (Table 1).

Post-treatment erosion on larger stream crossings (greater than 765 m^3 or 1000 yd^3 of fill) was more variable. The average post-treatment erosion on the larger stream crossings was approximately 3.2% of the total fill excavated but varied from 0 to 16%. Large post-treatment adjustments were rarely observed. In approximately 80% of these large sites, post-treatment erosion was less than 4.5% of the total fill excavated or under 111 m^3 (146 yd^3) (Table 1). The majority (64%) of the inventoried stream

Table 1: Stream crossing excavations and post-treatment erosion.

Excavated Stream Crossing Volume (yd^3)	Percent of Stream Crossings (%)	Volume Excavated (yd^3)	Average post-treatment erosion (yd^3)	Range of post-treatment erosion (yd^3)	80% of sites eroded less than # (yd^3)	Percent of excavated fill volume lost to post-treatment erosion (%)
0-400	64	153	6.7	0 to 156	5.7	5.1
400-1000	20	612	21	0 to 284	25.1	3.3
>1000	16	4692	124	0 to 621	146	3.2
All sites	100	967	28	0 to 621	20	4.5

Figure 4. Stream crossing excavation and erosion volumes.



crossings had excavated fill volumes under 305 m^3 (400 yd^3) and these stream crossings had very small amounts of post-treatment channel adjustments and erosion (average of 5 m^3 or 6.7 yd^3). Stream crossings larger than 305 m^3 (400 yd^3) experienced slightly more post-treatment erosion (average of 16 m^3 or 21 yd^3) but these quantities were small compared to the volume of material excavated from the stream crossings.

While the total volume of post-treatment erosion increased with the size of the excavation, the relative proportion of post-treatment erosion compared to fill volume excavated decreased from 5.1% for small stream crossings to 3.2% for large stream crossings (Table 1). Post-treatment channel erosion remained fairly constant regardless of stream crossing size (Figure 4). While occasional large stream crossing restoration sites have significant post-treatment channel erosion, on average the post-treatment channel erosion on these larger treatment sites is small considering the amount of fill removed.

Photo 1: Typical stream crossing erosion due to post-treatment channel incisement.

On Six Rivers National Forest, approximately 40% of measured post-treatment stream crossing erosion was attributable to channel downcutting or widening, and 60% was attributable to channel bank or sideslope failures. Post-treatment channel downcutting or widening was commonly found at most treatment sites (Photo 1) but excessive downcutting may indicate inadequate restoration design or contract implementation (Photo 2). Rills and gullies were only rarely observed on channel sideslopes and usually only associated with a nearby spring. The bulk of channel sideslope failures were attributable to oversteepened slopes and could be a result of inadequate restoration design or implementation (Photo 3). Depending on the size of the stream crossing restoration site, oversteepened slopes led to shallow slumps and small debris slides. Channel sideslope failures are an inherent risk in restoring stream channels, particularly in naturally steep and incised topography, regardless of the quality of contract design and implementation. Nevertheless, in some instances inadequate channel design, such as too narrow a stream channel configuration or too shallow a depth of excavation, resulted in channel incision, which led to oversteepened and unstable sideslopes (Photo 4). The data indicate that while the total post-treatment erosion was small, a greater emphasis on designing and excavating less steep channel sideslopes would likely reduce post-treatment erosion to

Photo 2: Atypical and excessive post-treatment channel incisement (note exposed root across channel indicative of depth of erosion).

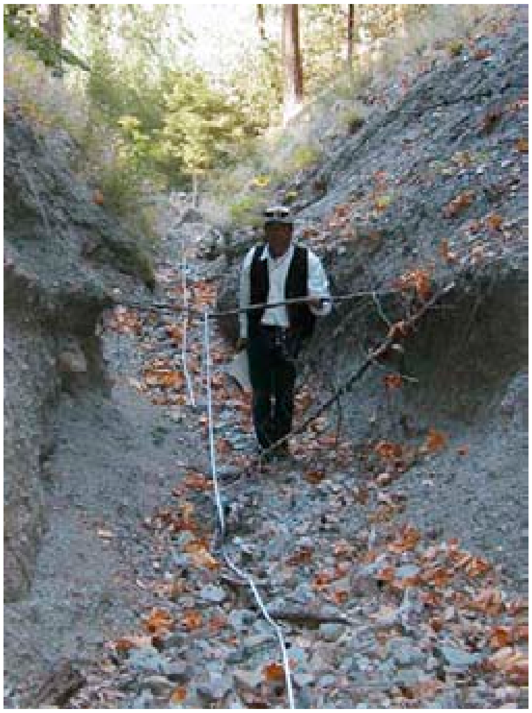
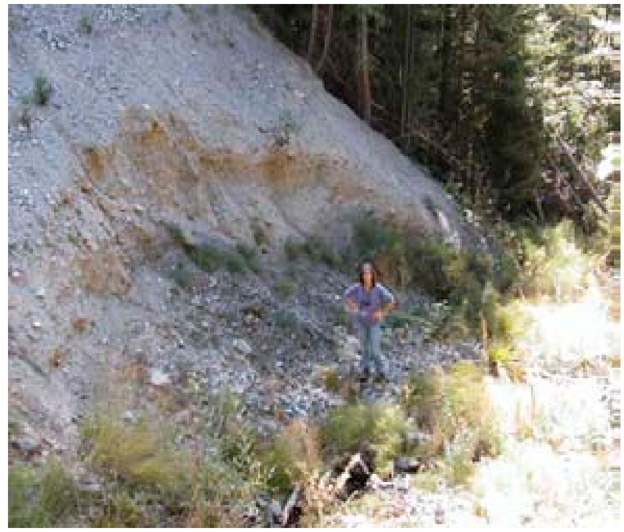


Photo 3: Incipient slope failure due to oversteepened channel side slope.

even smaller volumes, especially in stream crossings that are not topographically constrained by narrow, incised valleys.

Post-treatment erosion on excavated stream crossings is widely recognized as an inherent short-term effect that is offset by larger long-term gains in reducing the risk of major sedimentation resulting from culvert and fill failures. Fill failures and diversions of road stream crossings have been shown to be significant contributors of fluvial hillslope erosion (Best et al. 1995; Weaver et al. 1995). Furniss et al. (1998) assessed stream crossing failures on non-decommissioned forest roads in Washington, Oregon and Northern California and found that after the winter floods of 1995 and 1996, significant portions of road fill were lost due stream crossing failures. Figure 5 illustrates the proportion of stream crossing fill eroded where streamflow overtopped the road. The Furniss et al. data indicate that in approximately 35% of the culvert failures sampled, over 25% of the stream crossing fill eroded, and that 44% of the failures had between 1 and 25% of the stream crossing fill eroded. While the total percentage of storm-related stream crossing fill erosion on non-decommissioned roads varies, it is clear that the proportion lost due to post-treatment road decommissioning erosion is significantly smaller than the erosion that occurs during large storm events. Post-treatment road decommissioning erosion on the Six Rivers varied between 3.2 to 5.1% of the total stream crossing fill volume and was typically considerably less than the volume of erosion that occurs on untreated roads during large storm events.

Photo 4: Channel bank failure due to oversteepened slope and inadequate channel width



A general assumption of stream crossing restoration is that the risk of post-treatment erosion and volume of sediment generated increased with size of the stream channel being restored. Data from this assessment indicate that while the total volume of erosion increased with larger stream crossings, the total volume of material was small compared to the total material excavated (typically 3 to 5%) (Figure 4). Photos 5 and 6 are examples of typical small and large stream restoration sites with very limited post-treatment channel erosion and sedimentation.

Figure 5. Proportion of road-stream crossing fill eroded where streamflow overtopped the road. From: Furniss et al. (1996).

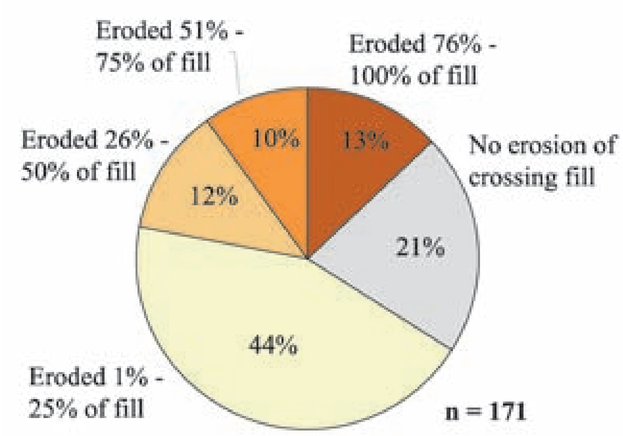


Photo 5: Typical large size restored stream crossing - 5N13B.

Photo 6: Typical small to moderate size stream crossing excavation - Road 2N14H.

Restoration of stream crossings must be carefully planned and executed, but even the best-designed projects have some post-treatment channel erosion. Some of these erosional features can be avoided while others are unpredictable and probably unavoidable. During site excavation, unforeseen conditions may occur and best guesses are made of original channel bottom depths and configurations, only to find out the next year that the channel has downcut, indicating that the original channel was clearly not reached during the initial excavation.

A relatively small proportion of the decommissioned roads (8%) were identified as warranting further monitoring for future channel adjustments and erosion pending the next large storm event. The majority of the decommissioned roads were determined to be in a stable condition and did not pose a significant future sedimentation risk. In others, the short-term impact had largely abated. Sites that warranted future monitoring were mostly associated with roads located in steep inner gorges and large perennial streams (typically 3rd-order or larger) where post-treatment channel erosion had varied between 1 to 15% of the total fill excavated. In these sites, roughly 229 to 459 m^3 (300 to 600 yd^3) of erosion occurred. In general, it is more difficult to minimize post-treatment erosion at decommissioned crossings with deeper channels and higher stream power within the inner gorge. A very small percentage of the sites warranted continued monitoring because of poor contract implementation.

Roadbed

Few surface erosional features attributable to road decommissioning were found on the remaining roadbed between stream crossings. The total volume of all erosional features associated with the 117 km (73 miles) of inventoried roadbed was 2,646 m^3 (3,460 yd^3) (total erosion and associated sediment from restored stream crossings was 9,213 m^3 (12,050 yd^3) or approximately 78% of total post treatment erosion). Roadbed fillslope failures occurred on two roads located in inherently unstable Franciscan mélange terrain (less than 1% of total miles of roads treated). Approximately 2,263 m^3 (2960 yd^3) of fill were associated with post-treatment fillslope failure on mélange terrain and 5% of this material was delivered to adjacent watercourses. The erosional features that produced the greatest erosion were associated with fillslope failures (2,523 m3 or 95%), followed by gullies (76 m^3 or 3%) and cutslope failures (42 m^3 or 1%).

The decision early on in the road-decommissioning program to minimize obliteration and recontouring of the road prism between stream crossings was validated by the relatively small proportion of sedimentation generated from post-treatment roadbed slumps and fillslope failures and by those few failures that occurred being limited to inherently unstable terrain. However, this conclusion should be re-evaluated after a major storm event, such as following a 50-year or greater recurrence interval storm.

Photo 7: Untreated roadbed on decommissioned road.

Photo 8: Outsloping associated with unstable roadbed.

Photo 7 shows a typical untreated roadbed left between restored stream crossings. Photo 8 is an example of road prism outsloping where slope stability was a concern.

Small gullies were the most common erosional feature on the roadbed between stream crossings, but did not account for a large amount of erosion (76 m^3 or 100 yd^3 total). Unlike fillslope failures however, gully erosion resulted in almost 100% sediment delivery to adjacent watercourses. Gully erosion was largely attributable to poor road drainage due to either faulty contract design or incomplete implementation of contract specifications.

Roadbeds between stream crossings were generally not ripped. Rolling dips and waterbars were installed between stream crossings to improve drainage of springs and seeps from road cutslopes. Limited post-treatment erosion was evident as a result of these practices.

Other Post-Treatment Variables

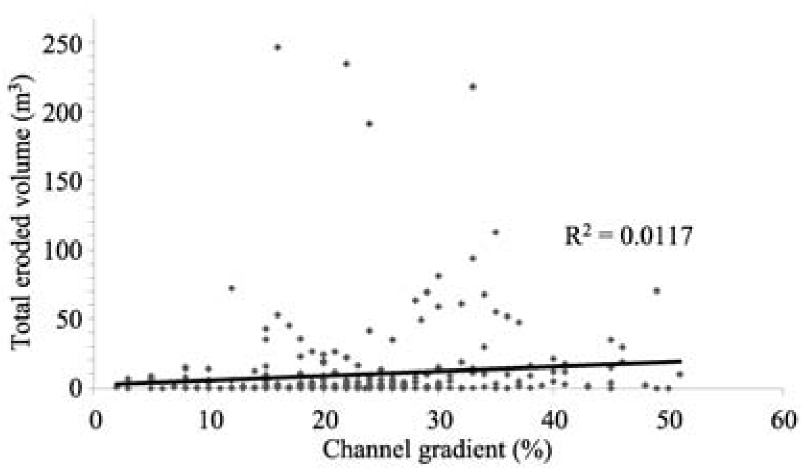
Independent variables such as geology, hillslope gradient, channel gradient, location in the inner gorge, storm history, drainage area, stream power, contract design and contract implementation were assessed to determine whether they influenced post-treatment erosion on decommissioned roads. Due to the high variability of post-treatment erosion within stream crossings, statistical relationships with the variables listed above were not significant. Storm history, geology, drainage area and location in the inner gorge appear to be useful predictors of increased erosion.

The influence of channel gradient on post-treatment adjustments was examined, but no statistical relationships were evident (Figures 6 and 7). We hypothesized that steeper channel gradients would result in more erosion, but this was not supported by the data.

Geology and post-treatment erosion were also evaluated, and some generalizations can be made. All treated sites were classified into five types of parent material: diorite rock, metasedimentary rock, mica schist, sedimentary and metasedimentary rock, and sheared metasedimentary rock. A means test was conducted and diorite and mica schist parent materials showed statistically significant lower post-treatment erosion rates than those sites located in sedimentary and metasedimentary rock (95% confidence interval) (Figure 8).

This finding is counter-intuitive because diorite parent material is generally non-cohesive and highly erodible. Further examination of the data reveals that all of the

Figure 6. Channel gradient regressed against total erosion.



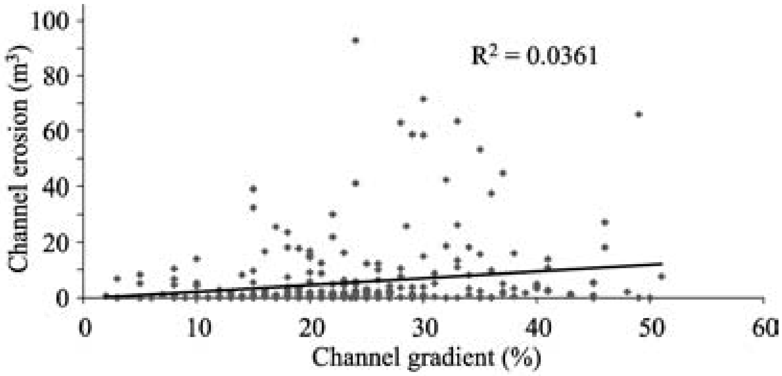
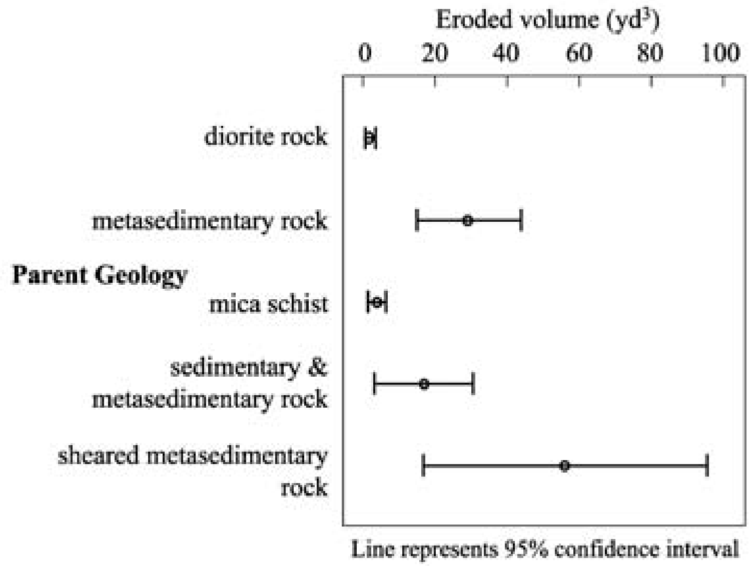


Figure 7. Channel gradient regressed against channel erosion.

Figure 8. Means test between eroded volume and parent material.



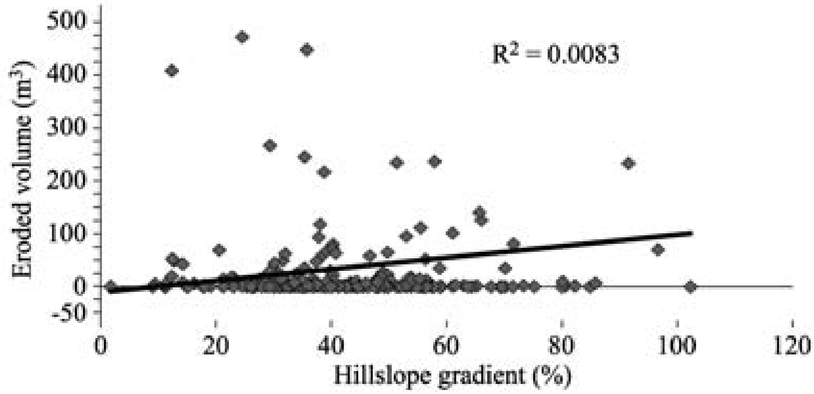
treated stream crossing sites within dioritic parent material are above 1,220 m (4,000 feet) in elevation and may be protected from winter storms due to presence of a seasonal snow pack. Treatment sites located in lower elevation diorite parent material are likely still highly susceptible to post-treatment erosion. (Qualitative observations of post-treatment erosion on low elevation sites in diorite parent material support this hypothesis; however, insufficient time was available to include these sites in this study).

Bedrock geology might also be an influence in post-treatment erosion associated with roadbed fillslope failures. Field data indicated however, that post treatment slope failures on roadbeds were extremely limited and located only in the Franciscan mélange terrain. The slope failures on these sites were not clearly attributable to the road decommissioning and could have resulted from the unstable geologic and geomorphic terrain. Overall, a relationship between post-treatment erosion and differing bedrock geology was not evident in the analysis.

The amount of in-channel erosion observed was compared to excavated volume, drainage area, and hillslope gradient as well as stream power. Hillslope gradient was defined as the average gradient of hillslope through which stream channel dissects and stream power was defined as drainage area times channel slope. No correlation was observed between either hillslope gradient (Figure 9) or stream power (Figure 10) and the amount of observed erosion. This was surprising, especially in the case of stream power which had been found to be a good predictor of erosion in the Franciscan terrain of Redwood Creek by Madej (2001). A multiple regression was conducted on post-treatment erosion, excavated volume, and drainage area on decommissioned stream crossings in Six Rivers. These variables were significantly related ($n = 52$, $r^2 = 0.55$, $p = 0.0001$)

Contract design appeared to influence the amount of erosion at some stream crossings, primarily where excavation did not reach the original channel grade, or where post-treatment channel sideslopes were overly steep. These were generally some of the earliest decommissioning project sites with inadequate pre-project surveys. Standard procedure currently is to survey all but the smallest crossings to ensure good contract design. Therefore, faulty contract design should not be a cause for significant erosion in the future.

Figure 9. Hillslope gradient regressed against eroded volume.



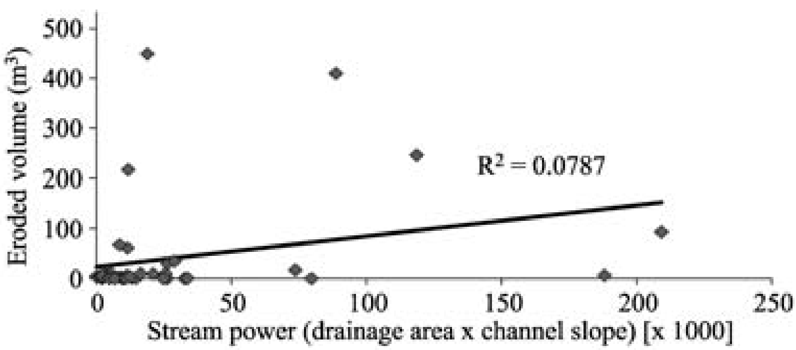
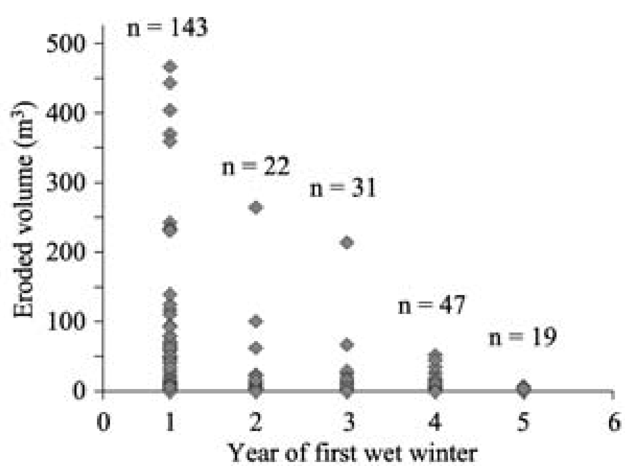


Figure 10. Stream power regressed against eroded volume.

Figure 11. Erosion related to the year of the first wet winter after decommissioning.



Quality of contract implementation did not consistently relate to the amount of post-treatment erosion. In fact, some of the largest erosion was associated with the best-implemented contracts, as determined by the level of on-site inspection during treatments. The large amounts of post-treatment erosion primarily occurred at large or sensitive crossing sites that experienced an unusually wet first winter.

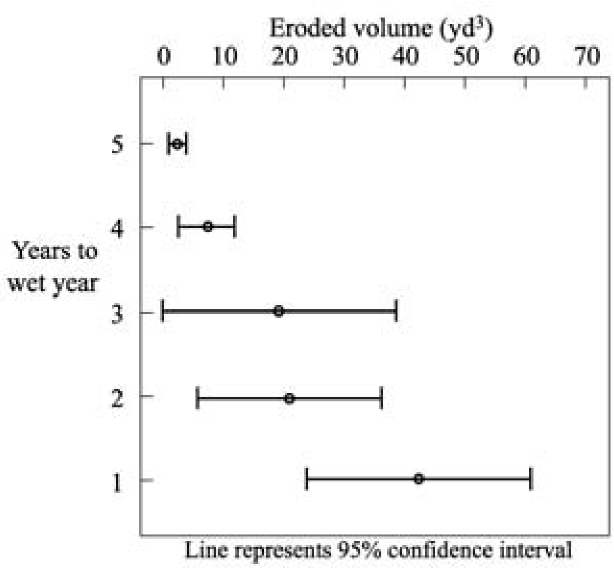
The amount of rainfall, particularly during the first winter, was found to be a good predictor of erosion. Each treatment site was classified into one of five categories reflecting the number of years since the site had experienced a wet winter. For purposes of this analysis, a wet winter was defined as the wettest monthly rainfall occurring with a recurrence interval of 5 or more years. In some cases (such as Bluff Creek), just weeks after completing the decommissioning, a 50-year storm event occurred. This storm produced some of the greatest observed post-treatment erosion, even though the project was well designed and implemented.

Relatively dry winters allow treated sites to revegetate and increase stability to the point where they can withstand a large storm with little erosion. Comparing the post-treatment erosion volumes in relation to time between storm events indicates that after four dry years, erosion from a wet year is minimal (Figure 11). There also appears to be a substantial reduction in erosion after only one dry winter (Figure 11).

While the relationship between time since storm events and post-treatment erosion is clearly visible in Figure 11, statistical analysis of the data show large variability. Comparing post-treatment erosion and years since first wet winter indicated that there was a high variability of erosion in sites that had a greater than 5-year storm event the first year following treatment ($r^2 = 0.35$, $p = 0.001$). This variability is due to lack of data on rainfall intensities of the storms, or knowing whether these storms were associated with rain-on-snow events, or the timing of the storms. Seasonal timing of large storms is important because if they occur in the late fall just after the completion of the decommissioning treatments, the recently treated channel slopes are highly vulnerable due to the unconsolidated nature of the disturbed soils; these disturbed soils become progressively more consolidated as the winter progresses due to the settling and compaction associated with raindrop impact. Despite the weak statistical significance between post-treatment erosion and years between large storms (r^2 = 0.35), a means test revealed there was a significant difference in post-treatment erosion between the sites that experienced a greater than 5-year recurrence interval storm the first year after treatment when compared to sites that had not experienced a storm greater than 5-year recurrence interval four and five years after treatment (95% confidence interval) (Figure 12). Further examination of the sites that experienced a greater than 5-year storm recurrence interval the first year after treatment revealed a significant relationship between the amount of excavated volume and post-treatment erosion (r^2 = 0.59). Sites that are exposed to large storm events close to completion of the treatment have a greater likelihood of experiencing post-treatment erosion than sites that have had at least four to five years to stabilize under milder winter conditions.

The amount of erosion was also correlated to whether the stream crossing was located in the inner gorge or not. Inner gorge was defined as any slope greater than 65% and adjacent to a stream channel. Crossings in the inner gorge produced about 4.5 times as much erosion as crossings not in the inner gorge. The 34 sites located in the inner gorge averaged 89 yd^3 (68 m^3) of erosion per year, where as the 226 sites outside the inner gorge yielded an average of only 20 yd^3 (15.3 m^3) of erosion per year. A means test was conducted and the observed differences between post-treatment erosion within the inner gorge were statistically different (95% confidence interval, $p < 0.001$) from those outside the inner gorge and the observed differences were not a function of sample size. Greater post-treatment erosion within the inner gorge occurred because crossings in the inner gorge tend to be larger, on steeper slopes, and have more water. Faulty contract design or implementation at these inner gorge sites will generally have more severe consequences on post-treatment erosion than at sites with smaller stream crossings in more gentle terrain. In extremely incised and narrow inner gorge stream crossings, the natural topography can severely hamper the creation of stable channel side slopes. In these instances, it must be recognized that the ability to fully reconstruct the stream crossing close to its original morphology without risk of some sedimentation and post-treatment erosion is limited. However, the volume of material saved will likely be much larger than the amount lost due to post-treatment adjustments. Data indicate that in inner gorge areas, where the risk is highest, opportunities need to be explored to reduce the risk of post-treatment adjustment by minimizing overly steepened stream channel sideslopes where possible. While more costly, designing stream crossings so that the fill removal extends to and mimics the gradient of the surrounding valley walls will reduce the risk of post-treatment sideslope failure.

Figure 12: Means test between eroded volume and years to first wet year.



The duration of post-treatment erosion was not assessed in this study, however qualitative observations over many years indicate that the bulk of post-treatment erosion and channel adjustments occurs the first year after treatment and rapidly diminishes over subsequent winters. Klein (2003) conducted a post-treatment erosion and turbidity study on decommissioned stream crossings in the Mattole River watershed, coastal northern California, and found that peak turbidity levels downstream of treated sites occurred as a result of the first few winter storms during the first year but that, by and large, erosional response in the sampling sites diminished considerably over the winter sampling period.

Conclusions

Total erosion from decommissioned roads was found to be relatively minor and not likely to persist. Average post-treatment erosion on stream crossings was 21 m^3 (28 yd^3), which is 4.5% of the fill excavated. This amount is much smaller than the amount of erosion that could occur if the culverts failed during large storm events. Larger crossings produced greater amounts of erosion, but a smaller proportion of the excavated fill. Approximately 40% of erosion was from channel adjustment (primarily downcutting with some widening) and 60% was due to sideslope failures (usually from over-steepened slopes that resulted in shallow soil slumps). Over-steepened slopes in many restored stream crossings were due to inadequate contract design or implementation, but in other sites the over-steepened slopes were due to natural topographic constraints. Leaving the roadbed between stream crossings intact and only outsloping visibly unstable portions of the roadbed was shown to be a viable option in designing road decommissioning projects with limited risk of post-treatment erosion. Erosion from the roadbed between stream crossings was very small and occurred only in unstable mélange terrain. Analysis of data indicated that hillslope gradient, channel gradient, channel sideslope gradient, and stream power were not good predictors of post-treatment erosion. The amount of post-treatment erosion was best predicted by the storm history following treatment. When large storm events occur during the first winter after decommissioning, post-treatment erosion is above average and the amount of post-treatment erosion is influenced by the volume of material excavated. The risk of post-treatment erosion will be considerably less if the site does not experience a large winter storm until 4 or 5 years after treatment.

Post-treatment road decommissioning monitoring indicates that while there is a short-term risk of increased erosion and sedimentation, the amount of erosion is minor when compared to the volume of material removed, and that road-decommissioning treatments are effective in reducing long-term sedimentation risks. Recommendations for future work include assessing the extent and duration of sedimentation effects from decommissioning treatments on local aquatic fauna (e.g., macro-invertebrates), as well as assessing the magnitude of changes to the local hydrology of affected streams.

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Roads in the River: Encroachment, Implications, and Solutions

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In recent years, forest road management issues have focused more frequently on roads within riparian areas. This includes every aspect of managing existing roads, from prioritizing aquatic habitat restoration, to understanding risks and watershed health, to road location, storm damage repair, and road maintenance. Current direction and changes in priority (i.e., Northwest Forest Plan, Aquatic Conservation Strategy), suggest a change in the way that encroachment problems are approached. Watershed analysis and management under the Aquatic Conservation Strategy (ACS) imply an understanding of processes, cause and effect, and managing (reducing or eliminating) hazards in priority areas such as Key Watersheds, riparian areas, and areas adjacent to important aquatic species habitat. Traditional standards of practice, such as bank hardening and revetment construction, can be very effective for protecting infrastructure, but are increasingly viewed as being incompatible with aquatic resource objectives. These techniques are now closely scrutinized, and approaching such problems in the traditional mode invites controversy. Designs and solutions should reflect this change of attitude. Questions now being asked at the planning and design phase include: What do we know about natural conditions, active processes, and the range of natural variability? Can the design at a site emulate local processes or a designated reference condition? Looking at analysis at several scales often provides insights. Examples from the Olympic National Forest, Washington, illustrate these considerations and some of the links between site conditions, physical processes, and the resulting design solutions.

Keywords: *road management, channel geomorphology, aquatic habitat, stream channel, bank hardening*

Introduction

Lands administered by the USDA Forest Service contain considerable areas of steep, mountainous terrain that present a challenge for road managers and designers. Within the steepest and most dissected terrain, the flattest and most stable locations are often along lower valley slopes and in valley bottoms adjacent to streams. Further complicating the situation, the valleys in mountainous regions are often narrow, making road and stream interactions more likely. From a road management perspective, these same valley bottom areas are usually the preferred locations for the most important or highest standard roads. While these areas are preferred for road location, they create conditions where roads are most closely connected to the stream network.

In the past decade, land managers for the Forest Service and other resource agencies have become increasingly concerned with these road-stream interactions in both the long-term and short-term management of the transportation network. Both the Aquatic Conservation Strategy in the Northwest Forest Plan (USDA and USDI 1994), and the National Road Management Policy (USDA FS 1999; Federal Register 2001) address these issues and provide guidelines and direction for management. Such policies suggest that a better understanding of physical conditions and geomorphic processes will result in better management and better decision making. This concept applies to land management at the watershed or larger scale as well as design and implementation decisions at the site or project scale.

Furniss, M.J., Clifton, C.F., Ronnenberg, K.L., eds., 2007. *Advancing the fundamental sciences: proceedings of the forest service national earth sciences conference, San Diego, CA, 18-22 October 2004*. PNW-GTR-689. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Roads in the River Margin

This presentation focuses on problems associated with roads located in and along channel margins. Road washouts and other problems range from simple encroachment to more complex encroachment in an active or changing landscape (Figures 1 and 2). Complex encroachment problems often require a more comprehensive assessment and more complicated or creative design solutions. Site assessments confined to the immediate washout area are often inadequate for determining the best solutions. They may fail to address causal mechanisms, processes that operate at a larger scale, trends, or off-site and long-term impacts. Problems in the most complex or sensitive environments are more likely to encourage solutions that rely on avoidance of the problem.

Figure 1. An example of simple encroachment: Site assessment may be limited to the area at and immediately adjacent to the site. Designs solutions may be limited to the immediate washout area.

Figure 2. Encroachment within an active landscape: North Fork of Calawah River, Forest Road 2923. Assessment included evolving or active slope processes at washout.

Figure 3: The Dosewallips washout. The photos are taken from the 2610 road at the downstream end of the washout, looking upstream. In the left hand photo (a) , the line of coarse rocks near mid-channel indicates the approximate location of the former toe of the road fill. The bank on the right (b) is 20 to 30 m high. The washout is approximately 100 meters long. Photo (a), D. Cenderelli; photo (b), T.E. Davis.

Three examples from the Olympic National Forest are offered to illustrate several of these points. The discussion closes with some thoughts on revetment designs and project development for solutions that are more consistent with natural resource objectives.

Case Example 1: The Dosewallips River Washout

In January 2002, a 100-m section of Forest Road 2610 was washed out by the Dosewallips River (Figure 3). The Dosewallips is a key watershed, a high priority for restoration, protection, and recovery of aquatic species. The watershed has high-value fisheries including a threatened stock of Chinook salmon (*Oncorhynchus tschawytscha*). The watershed upstream of the washout has had minimal timber harvest and has a low road density. The headwaters are within Olympic National Park. The primary road use is recreation traffic; both the national park and the national forest maintain campgrounds beyond the washout, and the national park has trailheads accessing a system of trails into the backcountry.

The Environmental Assessment (EA) following the washout considered a range of alternatives. Initially, the preferred alternative was to re-establish the road in its former location. The design was developed concurrently with the EA and the assessment of potential impacts. Early in the process, several assumptions were made that suggested this was a reasonable course of action. These assumptions included the following: (1) the road had been in this location for 80 years or more; (2) salmon habitat within the main channel adjacent to the washout is rather marginal (coarse, steep, and uniform); and (3) overall salmonid habitat in the upper watershed is of high quality and is functioning naturally.

Because of the high ecological values in the watershed, and questions raised during public review of the draft EA, it became evident that a more detailed analysis was needed. An intermediate level (reach) assessment was conducted in order to better describe the potential long-term and off-site impacts to fish habitat and listed fish stocks (Cenderelli et al. 2003). The reach assessment consisted of a more comprehensive evaluation than the EA, focusing on the following factors:

- Temporal assessment, evaluating change over time using historic air photos dating from 1939
- Geomorphic characterization of the river channel extending upstream and downstream of the washout.
- Hydrologic characterization including flood history and response.
- Characterization of the channel bed sediments
- Characterization of sediment sources, terraces and sources of spawning gravels
- Assessment and characterization of aquatic habitat.

Geomorphic Setting

The unique nature of the washout area was not fully appreciated prior to the reach assessment. The washout is located in an area where the river is incised into a series of glacial outwash and fluvial terraces; four distinct terrace sets were identified and mapped. This section of river was designated the Terrace Transition section. Figure 4 shows the Terrace Transition and adjacent geomorphic types. Table 1 displays some of the characteristics.

The Terrace Transition section and the link to the high quality habitat in the Alluvial Unconfined response reach downstream are important associations in this part of the watershed. A similar association was not found in the upper watershed. Although it is limited to slightly more than one meander wavelength, only about 850 m long, the Terrace Transition section supplies a substantial amount of high quality spawning-sized gravels to areas immediately downstream. The long-term trend has been toward increasing erosion from the bend at the washout, and decreasing erosion at the other high bank in the upper meander bend. Revetment construction would eliminate the source of spawning gravels in the lower bend.

Additional findings from the reach assessment included:

1. Temporal and spatial variability is more significant than initially assumed.
2. The long-term trend in river planform is toward expansion at the downstream meander bend and increasing bank erosion at the washout.
3. The recommended mitigation should emulate the natural processes and links that would be diminished by revetment construction. Encouraging meander development and associated bank erosion with log (large woody debris, LWD) complexes is an appropriate mitigation, although it will not compensate for eliminating the high bank as a source of spawning gravel.

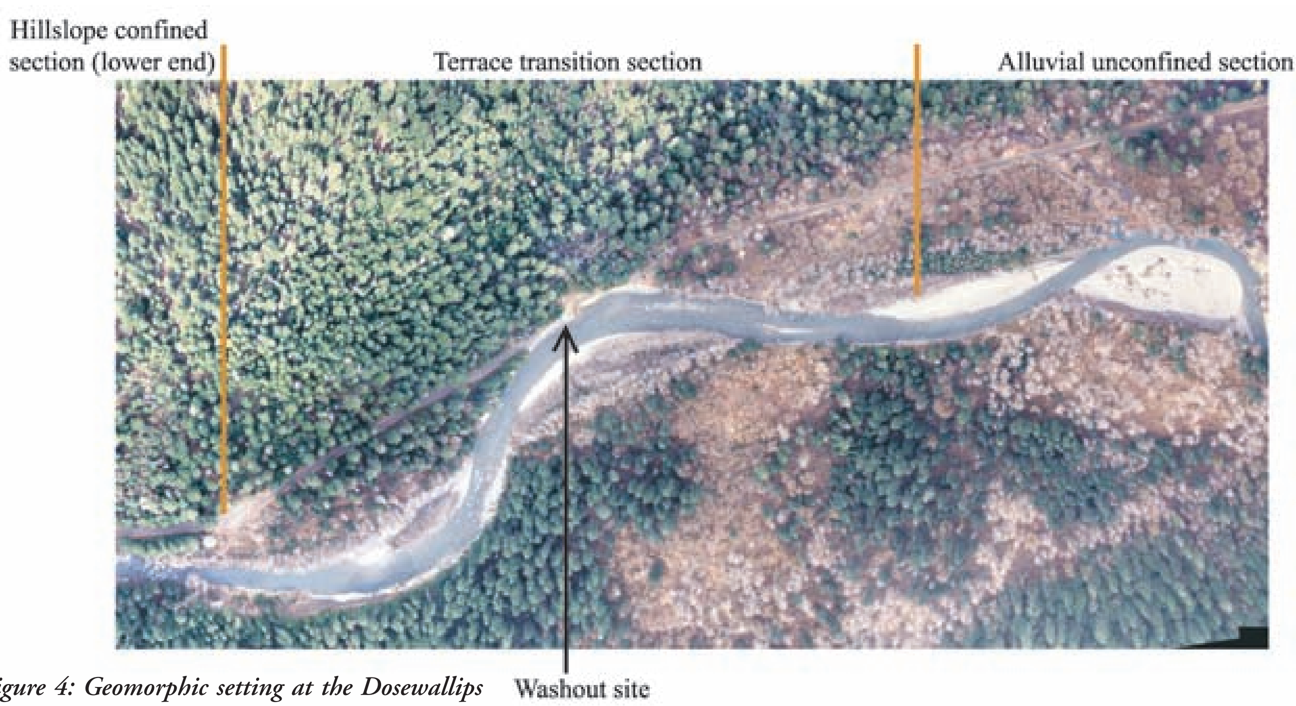

Figure 4: Geomorphic setting at the Dosewallips washout site. Upstream is to the left of the photo.

Table 1: Dosewallips River, characteristics of designated channel geomorphic units.

	Hillslope Confined	Terrace Transition	Alluvial Unconfined
Gradient	2% to 4%	< 1% to 2%	< 1%
Confinement	Confined	Moderate confinement	Unconfined
Bed material	Boulders and bedrock	Cobble and gravel	Gravel
SPF*	Transport	Transport (supply)	Response
Comments	Hard, dominated by non-deformable bed and banks	High sediment supply from adjacent banks; hillslope interaction high	Frequent split channels and abundant wood (log jams); Habitat value is high
Rosgen Class	B1 and B2	F3 to F4	C4

**SPF: Sediment processing function (Montgomery and Buffington 1993)*

Summary of the Dosewallips Example

- Initial assumptions were based on a limited scope, site level assessment.
- An intermediate level or reach assessment was needed to accurately describe potential impacts on fish and fish habitat.
- The relationship between upstream (sediment poor), the washout area (high sediment and spawning gravel supply), and the downstream response reach is more important than conditions at the washout site. The aquatic habitat immediately adjacent to the washout is considered rather marginal.
- Because the original preferred alternative would create substantial adverse impacts at the reach scale, to a resource that is very limited in the watershed (Chinook salmon spawning habitat), it is not consistent with Aquatic Conservation Strategy objectives.

Case Example 2: The Upper Dungeness River, Forest Road 2860

The 2860 Road is an example of simple encroachment, as compared to the setting of the Dosewallips washout. The valley bottom is narrow, but is the only suitable location for a road through this area. The road has been in this location for over 40 years. The channel is steep, coarse and predicted to be rather insensitive to change. The washout site is shown in Figure 5.

Similar to the Dosewallips, the Dungeness is a high value watershed with regard to fisheries, water quality, and watershed restoration. This section of the river supports populations of four species of Pacific salmon. Bull trout (*Salvelinus confluentus*) also occur, and along with the local Chinook salmon population are federally listed as threatened species. It is a popular recreation area, so reducing access is controversial. Significant channel attributes at the washout site are shown in Table 2.

Figure 5: The Upper Dungeness River at the 2860 Road washout. Boulders in mid-channel and the constriction formed by the road encourage accumulation of logs and diversion of flow along the toe of the fill. This has been a chronic problem area.

Table 2: Upper Dungeness channel geomorphic unit characteristics.

Type	Hillslope Confined
Gradient	2% to 4%
Confinement	confined
Bed material	boulders and bedrock
SPF*	transport
Comments	hard, dominated by non-deformable bed and banks
Rosgen Class	B1 and B2

**SPF: Sediment processing function (Montgomery and Buffington 1993)*

High quality Chinook spawning habitat is concentrated 1200 m downstream of the washout, in the area around East Crossing Campground. The channel in this area is a lower gradient unconfined alluvial channel type, classified as Rosgen channel class C3 (Rosgen 1994). It is the first response reach (Montgomery and Buffington 1993) downstream of the washout.

In previous years this road segment was treated with a traditional approach, meaning that washouts and erosion were repaired by armoring the bank. The coarse, steep nature of the hillslope-confined channel adjacent to the site suggested limited need for concern about impacts on aquatic habitat; the need for access dominated the decision-making processes. Site assessment limited to the washout area did not provide information that was compelling enough to change the management of the road. Ultimately, however, it was larger scale considerations and concern for watershed values that governed the decision process. The final decision was to decommission the road and campground and provide alternate access to trails and recreation opportunities in the upper watershed.

The proximity to high-value aquatic habitat, watershed-scale values, and the character of the stream channel through the stream-adjacent road segment directly influenced the design of the decommissioning. An intensive level of road decommissioning was done where the road was most directly connected to the river (Figure 6). In locations where the connection to the river was not as strong, or the impact was interpreted as low, the intensity of decommissioning was reduced.

Figure 6: High intensity decommissioned section through former washout; roadway and all associated fill have been removed. Straw mulch indicates former road and area disturbed by excavation. Two of the log complexes placed for structure and stabilization can be seen on the left. Note the lower intensity of treatment at the far (upstream) end.

Summary of the Dungeness River Example

- The final decision (decommissioning) was based on factors well beyond the site scale, including watershed values and linkages to downstream habitat conditions.
- Interdisciplinary and interagency involvement throughout the project was a key to success, as was extensive contract oversight.
- The final design included high and intermediate levels of road decommissioning and was based on identified risk, site conditions, and interpreted channel sensitivity.

Case Example 3: The Walter Creek revetment, Road 2350, Milepost 9.95

In this example, the repair contract was awarded as a traditional riprap revetment following a simple site investigation. However, during construction, problems were encountered and the project could not be built as designed. Because the problem surfaced during the construction phase, a solution was needed quickly. An interdisciplinary group, including design and construction engineers, a fisheries biologist, the construction contractor and the equipment operator, developed a preliminary solution on-site. The site was quickly re-surveyed and the new design was accomplished the following day. In this example assessment was limited to the immediate washout area.

The solution involved lowering the fill and installing internal reinforcement (reinforced soil slope) to steepen the slope and reduce encroachment. Figure 7 shows this phase during construction.

Figure 7: Construction at Walter Creek. Note the installation of geotextile fabric reinforcement through steepened section of the revetment.

Structure was added along the channel margin, including logs keyed into existing boulders but not into the revetment. The structures were designed to reduce erosional forces on the revetment, but ultimately provided complexity to the channel. The use of logs embedded into the foundation or footprint of the road was avoided because of a concern for decaying logs compromising long-term performance. The slope above the riprap was covered with a turf

Figure 8: Walter Creek Revetment, Rd 2350 milepost 9.95 - photo of completed project.

reinforcement mat, filled with topsoil and planted. The completed project is shown in Figure 8.

Summary of Case Examples

The preceding examples show a range of sites and conditions. They involve changes in approach that span the project development process from assessment to implementation. The list below provides a summary.

- All of the projects started out as conventional riprap revetments.
- All began with assumptions made from a limited (site) level assessment
- All changed substantially and none were implemented as initially envisioned; Walter Creek has been implemented as a riprap revetment although it is not a traditional design.
- The Dosewallips is a complex site in an evolving environment. Potential solutions are complex, expensive, and extend well beyond the limits of the washout. The assessment was comprehensive.
- The Dungeness, by comparison, is a relatively simple encroachment problem involving a more limited assessment, though still extending well beyond site boundaries. The solution was based on issues and values beyond the site level.
- Walter Creek is a much more straightforward example. It involves site level assessment only, and the solution is limited to the washout area. Nevertheless, the design incorporates features not typically found in conventional revetments.

Table 3: Conceptual elements useful for evaluating bank protection designs.

Variable	Habitat Components	Traditional Revetment Designs
Texture	rough	smooth
Variability	high	low/uniform
Hydraulic efficiency	inefficient	efficient
Structure	complex (messy)	simple (neat)
Overall impression	soft	hard

Design Solutions: Some Thoughts on Non-traditional Approaches

Traditional solutions such as riprap revetments are effective techniques that have stood the test of time and should not be abandoned. Design methods such as those developed by the Corps of Engineers (USACoE 1991), the Federal Highways Administration (USDOT FHA 1989) are appropriate starting points for projects involving riprap. However, natural resource professionals and regulatory agencies are calling for more creative solutions that minimize adverse impacts on the stream environment. With this in mind, consider the range of conditions within the variables listed in Table 3.

Several variables in Table 3 are often an objective of, or are affected by, bank protection measures. These variables highlight some key differences between desirable aquatic habitat conditions and traditional riprap design objectives. Column 2 lists conditions with respect to these variables that are often associated with high quality aquatic habitat. It is often rough, highly variable, hydraulically inefficient and structurally complex. These are also components that perform important energy dissipation functions within streams. Column 3 suggests that traditional engineering designs favor opposing conditions with respect to these variables; they tend toward efficiency, uniformity, and predictablility. The stream environment is dynamic and variable, while analysis and design necessitates simplifying assumptions. Incorporating elements that increase variability and turbulence also increases uncertainty, risk, and cost. In the search for more compatible designs, the challenge is to develop an integrated approach that seeks the best compromise between engineering efficiency and natural habitat values.

A Contemporary Design Example: The Big Quilcene Revetment

The Big Quilcene Revetment, shown in Figure 9, offers a fine example of a non-traditional, or some would say a more contemporary, bank hardening design using riprap. Rootwads and short rock spurs have been incorporated along the toe, and soil bioengineering techniques using brush layers and jute matting were used in the upper

Figure 9: Big Quilcene River revetment just upstream of Highway 101. Note the irregular shaped rock toe incorporating rootwads and built to a limited height with brush layers installed above.

section. These techniques are intended to soften some of the effects of riprapped banks, and increase hydraulic roughness.

In this example the height of the rock armor (H) is somewhat lower than recommended in traditional designs. Many newer designs set the top of the rock to the height of lower discharges such as the predicted 20-year recurrence interval flood (Q_{20}), or even lower. Because shear stresses or erosional forces are concentrated near the channel bed, and drop off rapidly toward the water surface, the top of the structure need not be as hard or be designed to resist the maximum shear stress. Closer to the surface, soil bioengineering, plantings, or other soft techniques can be used (USDA NRCS 1992). Designers must be careful to recognize the uncertainty involved in predicting flood height, and therefore the risk involved when basing rock height (H) on lower flow levels.

Conclusions

In many instances, traditional approaches based on simplifying assumptions or a limited scope of analysis have been costly. At complex sites such as the Dosewallips washout, this approach has led to complete redesigns and repeating several steps of the environmental assessment phase or National Environmental Policy Act (NEPA) analysis. Conducting design concurrent with NEPA analysis is risky at these sites.

Many streambank protection projects are still approached in a traditional mode, which is to replace and fortify what was previously there. Approaches for treating road encroachment problems have changed in the last decade, particularly for natural resources management and regulatory agencies. There is an increased emphasis on understanding physical and biological processes and finding solutions that are consistent with the range of natural conditions. Road management in this environment is not business as usual, and assessments and designs should reflect this. Road management agencies, highway departments, and the consultants that often work for them do not necessarily have this philosophy.

The scale of the assessment will often have to be expanded beyond the immediate project area in order to determine the best solutions. Design and on the ground implementation should maximize the use of available structure. Many improved designs use the same components that provide stability in undisturbed stream analogs or nearby reference conditions.

Early interdisciplinary or interagency involvement is valuable, and in some cases is essential, at any phase of these projects. The degree of involvement is directly related to site complexity and to larger scale issues such as watershed values. Involving regulatory agencies after designs have been completed, or only after a problem has been encountered during construction is asking for trouble.

Manuals such as Washington State's Integrated Streambank Protection Guidelines (WDFW et al. 2002) and the Federal Interagency Working Group's Stream Corridor Restoration Manual (FIWG 1998) provide excellent guidance for road management and design along stream and river margins. These guides address habitat impacts, and attempt to integrate an understanding of changes in channel processes into road management and design.

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Road Decommissioning Effectiveness Monitoring Techniques

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National forest road decommissioning techniques are a key tool in effective watershed restoration. Although land managers have been involved in road decommissioning over the past three decades, there is little consistency in road decommissioning monitoring. This document provides a framework for developing and implementing a monitoring plan that responds to the specific needs and unique ecological conditions of each forest.

Keywords: *road decommissioning, effectiveness monitoring, watershed restoration*

Introduction

The Road Decommissioning Effectiveness Monitoring Techniques report presents a framework that an interdisciplinary team (IDT) can use to develop a road decommissioning monitoring program. Additional forms, references and examples of monitoring plans can be found by visiting the links at the end of this document.

As the group that needs this information most is the IDT, this report takes the form of instructions to the team. However, all other readers with interest in the subject will find the information useful.

Several national forests have developed road decommissioning monitoring plans and this report builds on their work. Rather than advocating one method for each monitoring project and budget, this document enables users to select a monitoring technique for each situation.

In the late 1970s, Redwood National Park (RNP) started to decommission unneeded roads. Park geologists tried to reduce the adverse environmental effects of roads and road crossings including erosion, mass wasting, and sedimentation. Techniques to decommission roads evolved from monitoring results. Treatments changed from hand tools and revegetation to dozers and excavators. The same kind of heavy equipment that created the road now decommissioned the road.

At the same time, national forests across the country began decommissioning roads. Flood events that occurred during the 1980s and 1990s also showed the vulnerability of the transportation system and the negative results of poorly designed and located roads.

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Road decommissioning reduces chronic sediment delivery, restores hillslope hydrology and reduces impacts to aquatic, riparian, and terrestrial ecosystems of roads crossings. The Forest Service has different levels of decommissioning treatments to reduce road hazards. Forest Service personnel have learned which decommissioning treatments are effective for different climatic conditions, geology, and soil type. Forest IDTs develop monitoring plans for evaluating the effectiveness of decommissioning treatments.

What is Road Decommissioning?

Road decommissioning is defined as: "Activities that result in the stabilization and restoration of unneeded roads to a more natural state." (36 CFR 212.1, Forest Service Manual 7705 - Transportation System [[USDA FS 2003]]). The Forest Service Manual (7712.11- Exhibit 01) identifies five levels of treatments for road decommissioning which can achieve the intent of the definition. These include the following:

1. Block entrance
2. Revegetation and waterbarring
3. Remove fills and culverts
4. Establish drainageways and remove unstable road shoulders
5. Full obliteration, recontouring and restoring natural slopes

These five treatments give the IDT a range of options for stabilizing and restoring unneeded roads. Watershed Analysis (WA) and Roads Analysis (RA) help determine what treatment level or combination of treatments is appropriate. In some situations blocking the entrance may meet restoration objectives. In other situations, restoring hillslope hydrology may require full obliteration recontouring. Local factors such as climate, geology, topography, soil, and road design and construction also factor into the stabilization and restoration objectives.

Components of a Monitoring Plan for Road Decommissioning

The following steps (adapted from Kershner 1997) will help the interdisciplinary team establish their monitoring plan:

1. Obtain management and leadership support. Monitoring dollars will always be limited, as will available resources to conduct the monitoring. Link monitoring results to management decisionmaking and goals. Identify some linkages from scoping questions in NEPA analysis: What are the commonly asked questions that management has to answer about road decommissioning? Will the monitoring effort provide information that is critical for policy making and reporting to the public? Can the monitoring obtain results in a useful timeframe?

2. Define the participants. Jointly develop the monitoring goals and objectives. Ensure that the team has the technical expertise to set protocols, collect the data, and analyze the data.

3. Determine the overall goal or goals. Use findings in the RA and WA, Land and Resource Management Plan (LRMP) goals, and aquatic conservation strategies, as available and appropriate. The following are sample goal statements from the Aquatic Conservation Strategy for the Northwest Forest Plan (FEMAT 1993)

Maintain and restore the physical integrity of the aquatic system including shorelines, banks and bottom configurations.

Maintain and restore the sediment regime under which aquatic ecosystems evolved. Elements of the sediment regime include the timing, volume, rate, and character of sediment input, storage, and transport.

Maintain and restore the habitat to support well distributed populations of native plant, invertebrate, and vertebrate riparian-dependent species.

These goal statements are broad and general. Although teams often want to further break down the goals, be patient during this step and look at the ecosystem from a broad perspective.

4. Select objectives that fit the goal(s).

A well-written objective statement clearly shows the expected outcome. Make it specific, concise, and most importantly, observable or measurable. Objectives can also be time-specific statements of measurable planned results, responding to pre-established goals that you can find in the WA, RA, or Land and Resource Management Plan (LRMP) for the forest. If specific, measurable objectives are not available, locate indicators of similar "healthy" systems and use these for objectives. Select monitoring objectives that best indicate change and measure them in the locations that are responsive to change. (Kershner 1997)

5. Design monitoring to detect change to: (a) distinguish treatment effects from other variations, and (b) take replicate samples over space and time. Consider the geographic extent of the plan and minimize the variability from site to site, by selecting areas of similar size, geology, morphology, stream discharge, and other unique or important characteristics. Sample number and statistical significance of the monitoring should be included in the initial monitoring design. Use pretreatment inventory data as a benchmark of pre-restoration condition.

6. Prioritize and schedule monitoring activities: identify what needs doing and prioritize it. For example, evaluate cover effectiveness the first year if a mulch or seed mix is a component of the treatment. Monitoring the type of cover for vegetation composition and species dominance may require sustained monitoring over several years. Evaluating the change in riparian vegetation community composition and spatial arrangement at a road decommissioning site may require less intensive monitoring but over a longer duration.

7. Implement the road decommissioning treatment. The FSM 7712.11 identifies five treatment levels for road decommissioning. Depending on the site, a combination of treatments may be implemented.

8. Analyze data and report results. Complete an annual report on the monitoring results and present the findings to the district and/or forest leadership team. Seek opportunities to share the team's findings during field trips with the forest leadership team or other interested groups.

9. Use new information to adapt goals and objectives. "Whether monitoring demonstrates success or failure of outcome predictions, what is learned from monitoring will illuminate analysis and decisionmaking in the future." (USDA 1999)

Monitoring Plan Development

The previous section provided a framework for organizing a road decommissioning monitoring program. Use information from the Watershed and Roads Analysis to identify watershed restoration goals and objectives. Identify restoration goals and objectives and select the appropriate treatments. The monitoring plan provides the feedback mechanism for answering questions on both implementation and effectiveness.

Seek guidance and feedback from forest Line Officer's on questions, activities, resources and schedules. The interdisciplinary team needs the staff for the design, analysis, interpretation and annual reporting of findings to managers and the public.

Designing a Road Decommissioning Effectiveness Monitoring Plan

Designing a road decommissioning effectiveness monitoring plan can be difficult. This section is designed to provide a framework for a team to fully develop each component of a monitoring plan. The four most common monitoring methods currently being used for road decommissioning effectiveness are shared. Depending on the resources available for monitoring, a team can select different methods for different areas. The monitoring level of intensity may vary from year to year and the team may want the flexibility to capture more or less information in a given year.

Table 1 gives examples of goal and objective statements that a team can use as a starting point for items #3 and #4 of Components of a Monitoring Plan. Tables 2 and 3 illustrates a technique to link Watershed and Roads analysis findings to restoration objectives, treatments, and finally, measurable indicators for monitoring treatment effectiveness.

In researching current monitoring methods used by Forest Service, state, or private watershed groups, the following four monitoring methods were repeatedly cited as tools to monitor decommissioning effectiveness:

- Quantitative measurements of channel cross-sections, vegetation, and soil erosion rates.
- Qualitative measurements using Best Management Practices (BMPs).
- Photo-point monitoring using "before" and "after" photographs.
- Tracking spreadsheets that answer who, what, where, how much, and when.

Table 1: Examples of goal and objective statements from forest LRMPs.

Generic Goal Statements	Measurable Objective Statements:
Maintain and restore the sediment regime under which aquatic ecosystems evolved. Elements of the sediment regime include the timing, volume, rate, and character of sediment input, storage, and transport.	Keep ground-covering litter, duff, and/or vegetation on at least 90% of non-rocky riparian areas.
Improve juvenile steelhead habitat to restore runs of summer steelhead.	Roads occupy less than 3% of all near-stream areas within a sub-watershed.
Restore spawning and rearing habitat for summer steelhead in the subwatershed.	Remove identified unneeded crossings to achieve < 2 crossings per mile of perennial stream.
Restore hillslope hydrology and improve infiltration on compacted road prisms.	Increase Channel Bank Stability to obtain an upward trend in stability, with target of 85% stability for reaches.
Restore watershed functions to improve water quality, fish and wildlife habitat, and scenic value	Upward or stable trend in W/D measures, as compared to reference stream data, measured at flat water habitat types.
Maintain and restore habitat to support well-distributed populations of native plant, invertebrate, and vertebrate riparian-dependent species.	Increase structurally complex rearing habitat for juvenile steelhead as measured for deep pools and woody debris frequency in the current administrative policy.
Maintain and restore the timing, variability, and duration of floodplain inundation and water table elevation in meadows and wetlands.	Increase the numbers of juvenile steelhead to meet downstream migrant numbers defined as optimal in state management plan.
Maintain and restore the physical integrity of the aquatic system, including shorelines, banks, and bottom configurations.	Decrease the percentage of fines in spawning gravel to less than 10% during spawning and incubation.
Maintain and restore spatial and temporal connectivity within and between watersheds. Lateral, longitudinal, and drainage network connections include floodplains, wetlands, upslope areas, headwater tributaries, and intact refugia.	Decrease near stream road density to 1 mi/sq mi in key watersheds.
	Decrease soil compaction to less than 5% in near stream areas within a sub-watershed.
	Upward trend in bank angle, with target of 100° average for reaches. Maintain streambanks to ensure the protection of the aquatic systems to which species are uniquely adapted.

Table 2: An example of a table used to illustrate the linkages between watershed process, watershed analysis (WA), and restoration objectives to treatments and monitoring indicators.

Process or Attribute	WA findings and Results	Restoration Objectives	Restoration Treatment	Monitoring Indicator
Channel morphology (width to depth ratio)	Identify the appropriate goal based on findings from WA, RA, and previous inventory or monitoring records.	Identify the specific objective based on channel type classifications.	Link WA, objectives, to identify priority areas. Select decommissioning level that obtains objective	Channel cross sections
Sediment regime	Identify existing sources and change to temporal and spatial scale	Consider direct and indirect indices to include on site and off site effects. Link to regulatory agency direction.	On-site cover techniques including natural mulches and large woody debris	Change in contributing source areas; In stream pool fines; amount of material removed at stream crossing.
Channel and floodplain function	Identify change in channel type as a result of management inputs.	Determine restored channel classification	May include channel stabilization thru redesign	• channel cross sections • streambank erosion • amount of material removed at cross section.
Species composition and structural diversity	Locate PNV information to determine natural species composition.	Identify composition and time frames to achieve goal.	Identify seed and cutting sources for vegetation establishment. Consider risk associated with noxious weeds.	Vegetation monitoring (Releve plots, line or belt transects
Erosion and mass wasting processes	Identify existing sources, and change in frequency and magnitude.	Determine "natural triggers" and reduce management induced triggers.	Restore hillslope hydrology and vegetative recovery.	Change in contributing source areas; in stream pool fines; amount of material removed at cross section

Regardless of which monitoring method or combination of methods is selected, the monitoring team must develop goals and objective statements for the monitoring. Table 1 provides sample goal and objective statements for a monitoring plan. Remember that goal statements are broad and can commonly be found in the LRMP. Objective statements are specific, concise, and measurable, and generally harder to pinpoint. Write objectives from the best data available.

Indicators

Item #5 of the components of a monitoring plan requires that monitoring be designed to detect change. Indicators are the measure or record of change. Select indicators that can be observed and measured. The following are examples of indicators used for road decommissioning monitoring:

1. Channel adjustment both above and below a road crossing
2. Erosion rate changes including surface erosion (existing road prisms) to changes in mass wasting frequency and extent (landslides)
3. Sediment sources associated with roads (chronic vs. pulse)
4. Revegetation of hillslopes and riparian areas to desired species
5. Amount of material removed from crossing(s), and miles of road decommissioned

Some of these indicators are direct indicators of change while others are indirect. Select direct or indirect indicators depending on resource availability (personnel and funding), priority, and treatment type.

Table 2 provides a template for tracking WA findings, and linking restoration objectives to treatments and indicators. The table focuses the monitoring team on determining which process or processes a road modifies. In the first example, the removal of a culvert, ford, or bridge modifies channel morphology at stream crossings. In addition, roads paralleling a stream channel can modify channel morphology by constricting the channel.

Other changes to processes occur with roads crossing meadows. In many cases channels have aggraded above culverts and degraded at the culvert outlet. In meadows, roads can affect channel and floodplain functions. It is not uncommon for channels to change from a Rosgen C Type to an incised gullied channel. The team faces the task of determining how to decommission the road and what type of channel stabilization is necessary. Monitoring treatment effectiveness may focus on recovery of the channel and floodplain. The team must determine the best indicators.

Levels of Intensity of Effectiveness Monitoring

With different intensity levels for conducting effectiveness monitoring, forests use a mixture based on the values at risk, project design, and availability of personnel and resources.

The four monitoring methods commonly used by forests are:

1. Quantitative measurements with repeat evaluation on excavated channel cross sections, vegetative recovery transects, and evaluation of erosion rates on site.
2. Use of BMP evaluation protocols to assess implementation and treatment effectiveness.
3. Photo comparisons of treatments, including key indicators of change in channel cross section and revegetation.
4. Tracking tools, quantifying amount of material removed, length of road decommissioned, and treatment type.

Quantitative Measurements

Quantitative measurements refer to measurements taken in the field such as stream channel dimensions, amount of erosion, and revegetation.

The team and forest management may be implementing road decommissioning with the goal of improving juvenile steelhead (anadromous *Oncorhynchus mykiss*) habitat to restore runs of summer steelhead. However, the team may select as indicators, direct measures of channel cross section, erosion, and revegetation. If the road decommissioning treatment results in a stable stream channel, reduced erosion, and healthy revegetation, the conditions exist for an improved juvenile steelhead habitat.

Several forests use direct stream measurements to evaluate treatment effectiveness.

Common goals for this type of monitoring are to quantify the effectiveness of road decommissioning projects to reduce or eliminate sediment inputs. Additional goals include identifying both successful treatments' techniques and limiting factors. The team must know if treatments are effective for a particular site.

Teams conducting this level of monitoring divide the decommissioning work into three areas: 1. Road prism stabilization; 2. Stream channel excavations; 3. Revegetation and effective soil cover. Road prism stabilization may involve random transects across numerous segments of the treated prism. The team must ask: is there adequate cover to reduce erosion? What is the type and composition of the soil cover? Did the treatment improve infiltration? On a fully decommissioned road the team samples the re-contoured area from the toe of the fill slope to the top of the cut bank. Soil transects can be line-intercept transects or grid and measure bare soil, litter, plants, downed material, rilling, and compacted soil. (San Dimas Technology and Development Center Website, *http://fsweb.sdtdc.wo.fs.fed.us/programs/im/fy04/rdmt/*)

For monitoring stream channel excavations the team has several choices. Obtaining baseline inventory data of the volume of material in the crossing is valuable. Data may be found in the National Environmental Policy Act (NEPA) document or restoration contract. The monitoring questions at road crossings include the amount of horizontal and lateral adjustment of the stream channel, and surface erosion or mass wasting. A longitudinal channel profile and cross sections may be established.

Secondly, an "as-built" longitudinal channel profile and cross-section survey taken immediately after decommissioning and prior to storm events can serve as a benchmark. The design for the removal of the crossing should be based on reference stream channel characteristics. (Harrelson et al. 1994; Rosgen 1996)

Lastly, to expedite cross section measurements the team can use a simplified model of the excavated crossing. Many forests use this model in the inventory phase, modeling the cross section as parallelograms. The team calculates the total area of the cross section by subtracting the area of the two triangles on the sides from the parallelogram area. (San Dimas Technology and Development Center Website, *http://fsweb.sdtdc.wo.fs.fed.us/programs/im/fy04/rdmt/*).

The line intercept transect used on the road prism stabilization can measure surface erosion and effective soil cover. Mass wasting documentation is evaluated during the years after implementation, or if an event occurred that triggered some instability. Data collected for mass wasting is an estimate of size (L x W x D) and amount of material moved. The team can determine how much of the material stayed on the hillslope and how much entered a stream.

Revegetation monitoring goes beyond measurement of effective soil cover to prevent surface erosion, and records the species composition and community types present. Monitoring protocols are available to determine the effectiveness of the treatment on revegetation.

Use protocols that best capture the type of vegetation the area is capable of producing. For example, the Greenline protocol is useful for monitoring meadow or riparian vegetation response to road decommissioning. (Winward 2000) In drier sites other protocols may better capture the species composition and community types present. In forested areas, the Forest Inventory Analysis (FIA) inventory protocols may be used to track changes in vegetation type.

Strengths of the Actual Measurements

When measurement data is linked to specific monitoring questions and succinct objective statements, the effectiveness of the treatment can be assessed. However, with general objectives and poorly defined monitoring questions, the determination is difficult even with actual measurements.

Actual measurements can help separate out and categorize the sample pool by independent variables, such as: bedrock geology, soil type, hillslope position, hillslope gradient, size of excavation, time since implementation, and contract method. The team can more easily manipulate the data to keep independent variables from confounding the results.

The team can take actual measurements for erosion, stream channel adjustments, and vegetation with a variety of proven and effective protocols. Depending on the monitoring plan questions, more emphasis may be given to stream channel adjustments than to erosion from the decommissioned road prism.

Limitations of Actual Measurement Monitoring

To ensure the accuracy of measurements and documentation, all monitoring protocols require training and spot-checking. Personnel need thorough training. To collect good data requires confidence in the use of equipment and a thorough understanding of the assumptions and questions underlying the monitoring plan.

Actual data collection takes more time than photo documentation, tracking, or BMP monitoring, because the crew will not be able to sample as many sites in the available time.

As with all monitoring, the team needs to design the method of data analysis before any data is collected. For actual measurement monitoring, a database may be necessary to expedite analysis of the data. Database development is not difficult, but the IDT must have the necessary skills or access to skills to ensure this step is taken prior to data collection.

Best Management Practices

Best Management Practices (BMPs) are a set of practices, procedures and programs that comply with requirements of Sections 208 and 319 of the Federal Clean Water Act (PL92-500). Section 208 of the Clean Water Act states that the agencies responsible for implementing the State Water Quality Management Plan must be designated as a Water Quality Management Agency (WQMA). In California, the Forest Service has a Management Agency Agreement (MAA) with the State Water Resource Control Board designating the Forest Service as the WQMA for NFS lands in California. BMPs are identified for all land-disturbing projects. Each forest monitors the implementation and effectiveness of the BMPs for road decommissioning. (San Dimas Technology and Development Center Website, *http://fsweb.sdtdc.wo.fs.fed.us/programs/im/fy04/rdmt/*)

Each Forest Service region implements a BMP program. The monitoring reports vary from region to region, depending on what agencies are designated as responsible for implementing the State Water Quality Management Plan. Currently there is emphasis to develop a national BMP effectiveness program that is similar to the Forest Service Region 5 (Pacific Southwest Region) program.

Region 5 BMP Effectiveness Program (EP) monitoring includes the following:

- Annually develop a sample pool of all road decommissioning projects (old and new)
- Conduct an in-office review of NEPA documents, timber sale contracts, and restoration contracts to identify the water quality issues and objectives for the project.
- Conduct a field review comparing the planning document objectives to the on the ground results.
- Using the established protocols for ground cover and revegetation, rilling, compaction, slope failure, and traffic control, complete the data sheet.
- For effectiveness evaluations of stream crossings, use numeric indicators for channel adjustment, including downcutting and lateral channel adjustment. (Refer to attached R-5 BMP form and protocol link, San Dimas Technology and Development Center Website at *http://fsweb.r5.fs.fed.us/unit/ec/water/*

final_bmpep_protocols/Final_BMPEP_Forms-Onsite_Evaluations_06_10_02.pdf)

- Attach photographs to the data sheets at the time of field review.
- Conclude the effectiveness of the treatment with data entry into the BMP database (R5) analysis of the indicators.

Strengths of BMP Monitoring

The BMP format is useful for several reasons. First, review of water quality considerations in the decommissioning plan tells the reviewer what the planning team identified as the water quality values at risk. The office review may also highlight missing information about water quality objectives.

Second, the field review for implementation puts the reviewer at the site, during or shortly after the work is completed. Implementation monitoring can allow for mid-course corrections if the situation requires.

Finally, a second field review within two years after project implementation assesses treatment effectiveness.

Limitations of BMP Monitoring

Limitations to BMP monitoring are training, qualifications and timely evaluations.

The monitoring team should ensure that personnel resources are trained and available to conduct the BMP evaluation. Well-qualified and trained personnel reduce subjectivity and error.

BMP monitoring must occur within two years of implementation. However, if only mild weather conditions prevail during the first two years, they may not test the treatment fully. Consider the climatic factors and design storm the treatment was designed for when monitoring. Some types of problems with road decommissioning results become evident only after a large storm event.

BMP monitoring lumps dissimilar sites and treatments as one. Stratify BMP records by treatment types, geology, climatic regimes, and other variables when designing the monitoring plan.

Photo-Point Monitoring

Photographs or digital photos are a common tool for detecting changes and trends in road decommissioning projects (Hall 2002). Photo monitoring is a simple, cost effective, and reliable procedure that documents the properties of a site. Repeat photos taken from the same location and angle are useful “change indicators” and can be sampled with dot grids to document change in vegetation and other attributes. In addition, photos can augment other more intensive monitoring.

In photographing road decommissioning work it is important to capture the appropriate scale, timing, location, and representative photo points. If this is the selected monitoring tool, or one used in combination with other monitoring, there are some key points that should be included in the monitoring plan to improve photo point monitoring quality.

Identify measurable objectives for photo documentation, including what and where to monitor. Questions related to why, when, and how to monitor should be included as a component of the monitoring plan.

Photo-point monitoring is used for implementation, effectiveness, and trend monitoring, with some attributes being easier to photograph than others. Commonly used indicators include soil cover, streambank stability, vegetative composition and revegetation of riparian areas. Table 3 provides information on the indicator, type of monitoring, and frequency.

Keys to reliable and repeatable photo monitoring:

Hall (2002) outline a useful set of instructions for effective photo point monitoring.

1. Take the photo from the same point, in the same direction each time the photo is repeated. Identify the location with tags or GPS readings to enable anyone to get back to the same site. Take a copy of the photo to the field for the correct settings. Don’t set up a photo monitoring and record keeping system so that only you can get back to the site. A lot of invaluable information has been lost by poorly documented and maintained photo records.
2. If possible, use a camera that documents the date the photo is taken on the face of the photo. Use a white board or a photograph identification form with large letters to identify within the photo what the subject is, and its location.
3. Take the photos on or about the same time of year. Include a consistent tool for scale in each photo. Depending on what you are monitoring the scale will change, meter boards are often used for vegetation and stream bank stability. Select the appropriate tool and maintain consistency.
4. Maintain a photo notebook or use 3 X 5 cards to capture any additional information on the photo. This can be useful if other people are collecting the data. Many monitoring systems are now being designed that link Personal Desk Recorders (PDRs), Global Positioning Systems (GPS) and photographs together.

Table 3: Items to consider when using photo-point monitoring for effectiveness monitoring of road decommissioning treatment.

Indicator	Considerations	Type and Time to Monitor
Channel Adjustment – channel cross section	This indicator is best to be measured directly and the use of photographs is in addition to the before and post treatment data. Photographs during or after an event help us understand what conditions look like during an event which can help us in design. Post event photos can capture any change in channel adjustment as a result of the event.	*Effectiveness:* Good quality photos can be used later in years that are not more intensively monitored and where change does not appear to be significant. *Event:* after storms that may "test" your design. In-channel measurements right after an event may not be feasible.
Soil Cover	If the treatment required a soil cover (mulch or natural) to be applied photos can be used to quantify cover. Use close-up shots of a defined plot that may be 1 square foot in size.	*Implementation:* taken during or immediately after project is completed.
Soil Cover	Photos can be taken each year to evaluate effectiveness of cover.	*Trend and Effectiveness:* should be taken at the same time of year.
Mass Wasting	It is hard to obtain before photos of this unless you have a specific area that you are concerned about. Otherwise most photos will be event driven or effectiveness monitoring.	*Event:* Photos taken after an event help to link weather conditions with effect. *Trend:* On -going monitoring of stream bank conditions or identified unstable areas taken annually can provide information on recovery.
Revegetation of Riparian Areas	The treatment may prescribe a certain number or density of cuttings, transplanting of sod plugs, or native seeding.	*Implementation:* During or right after to identify if the treatment was done correctly.
Revegetation of Riparian Areas	Good monitoring site selection is important since vegetation can increase dramatically. In some cases when vegetation is NOT the objective, it can obscure the indicator.	*Effectiveness:* annually during and or at the close of growing season.

This is a good way to ensure that all the data is together, and that both the data and the photo point can be relocated.

5. Ensure the photo quality is adequate for its intended use. Not all digital cameras are created equal. Adjust the settings to be sure the highest resolution and image size is always used.

Tracking Methodologies

Tracking methodologies are a tool to record completed road decommissioning treatments.

The objective of tracking tools is to record what was done, when it was done, and how much material was removed. The Forest Service tracks annual road decommissioning miles using INFRA (the FS infrastructure maintenance database). Accomplishments may also be tracked with spreadsheets or other database tools. Key information to record in spreadsheets includes the following:

- Date of activity
- Road number
- Road treatment
- Road length
- Number of road crossings treated
- Road crossing volume removed

This information may be recorded by watershed. Records can be obtained from inventory data on the condition of the road and the size of the road crossings. The database can be linked to GIS and photo documentation of each site.

Conclusion

Interdisciplinary teams have several approaches available to monitor road decommissioning effectiveness. Each team needs to consider the goals and objectives of monitoring that are built on findings and assumptions stated in the WA and RA process. Monitoring can answer questions the interdisciplinary team has on the processes that are restored by road decommissioning. For more information on road decommissioning effectiveness monitoring and monitoring forms, go to *http://fsweb.sdtdc.wo.fs.fed.us/programs/im/fy04/rdmt/*

Road Decommission Monitoring Techniques Links

http://fsweb.r5.fs.fed.us/unit/ec/water/final_bmpep_protocols/Final_BMPEP_Forms-Onsite_Evaluations_06_10_02.pdf. Link to Region 5 BMPEP for forms and protocol.

http://fsweb.r5.fs.fed.us/unit/ec/water/water-best-mgmt.pdf. Background information on R-5 BMP authority and procedures.

http://www.stream.fs.fed.us/ Link to Stream Team website

http://www.stream.fs.fed.us/publications/PDFs/RM245E.PDF Link to document on how to establish Stream Channel Reference Sites.

http://www.watershed.org/wmc/index.php - links to Watershed Management Council newsletter and database

http://www.mattole.org/ community based restoration and monitoring efforts.

http://www.cnps.org/archives/forms/releve.pdf - Vegetation Monitoring sample method use Releve' technique.

http://www.cnps.org/archives/forms/releveform.pdf - actual data form

http://www.firelab.org/firemon/pd.htm for information on ECODATA plot inventory.

http://www.fs.fed.us/pnw/pubs/gtr526/ Photo Monitoring tools

http://www.fs.fed.us/pnw/pubs/gtr503/gtr503f.pdf Photo Monitoring tools

http://anrcatalog.ucdavis.edu/pdf/8067.pdf Photo Monitoring for Better Land Use Planning and Assessment - Good resource for why and how to monitor.

http://fsweb.f5.r6.fs.fed.us/aquatics/monitoring/index.shtml Good example of watershed restoration effectiveness monitoring plan.

http://fsweb.wo.fs.fed.us/directives/fsm/7700/ References Transportation System and Roads Analysis process.

http://www.wildlandscpr.org/roads/RRtoolkit.htm Provides information on current wildlife monitoring of road decommissioning projects.

http://fsweb.nris.fs.fed.us/about_us/index.shtml NRIS website information.

http://www.fs.fed.us/rm/pubs/rmrs_gtr047.pdf Provides information on how to monitor vegetation in riparian areas.

http://fsweb.sdtdc.wo.fs.fed.us/programs/im/fy04/rdmt/ Link to San Dimas Technology and Development Center website for road decommissioning. Contains existing monitoring reports and forms by other forests.

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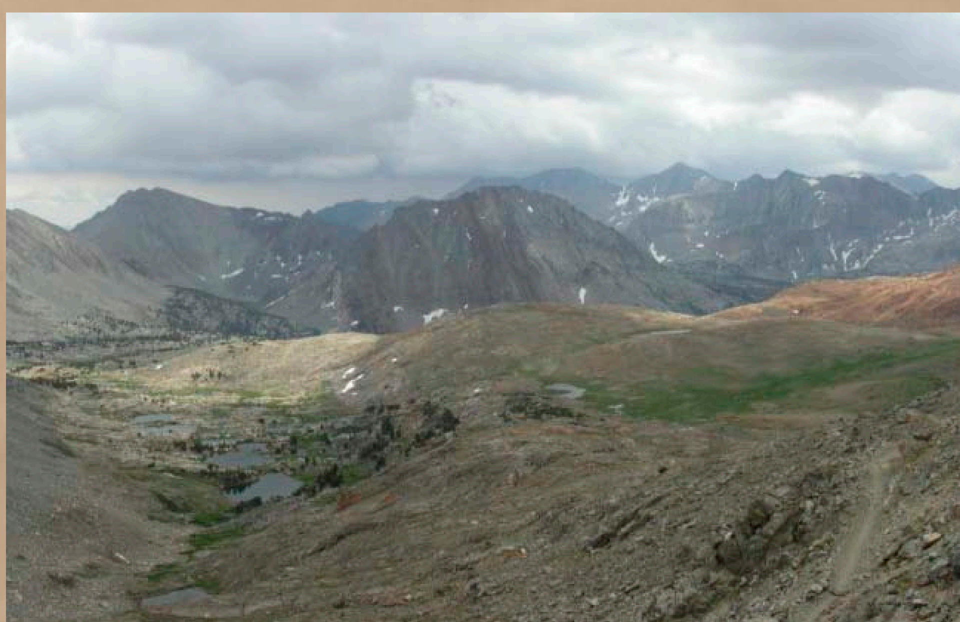
Section 4. Valuing the Earth Sciences
Part 1. Soil



Overleaf:
Pinchot Pass, Kings Canyon National Park, Sierra Nevada, California. Photo by Michael J. Furniss.

Ten-Year Results From the North American Long-Term Soil Productivity Study in the Western Gulf Coastal Plain

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Forest management operations have the greatest potential to reduce soil productivity through altered soil fertility and air/water balance, which are most affected by organic matter removal and compaction, respectively. The objectives of this study were to assess the early growth response to compaction, organic matter removal, and weed control on the ten locations of the Long-Term Soil Productivity study on the Kisatchie, DeSoto, and Davy Crockett National Forests (Louisiana, Mississippi, and Texas). Three levels of compaction (none, moderate, severe) and three levels of organic matter removal (stem only, whole tree, and whole tree plus forest floor) were applied in a factorial design at each site, and half of each treatment plot was kept free from interspecies competition with herbicides. Soil compaction had no negative impacts on tree growth at ten years; most sites responded positively to compaction due to the reduction of shrub understory competition. Removing more organic matter than the stems reduced stand volume on eight of the ten sites by more than 15 percent. This study indicates that harvesting operations that remove tree branches and foliage, and site preparation operations that remove the forest floor, such as site preparation burns, can have negative impacts on long-term soil productivity.

Keywords: *long-term productivity, soil compaction, nutrients, forest practices, guidelines for management, monitoring, vegetation management, loblolly pine,* Pinus taeda *L.*

Introduction

The North-American Long-Term Soil Productivity (LTSP) study began as a collaboration of the National Forest System and Forest Service Research in 1989. The study was founded to answer fundamental questions regarding the long-term consequences of soil disturbance on forest productivity, through carefully designed trials throughout the nation. The originality, scope, and careful design encouraged other partnerships to form among the Forest Service, forest industry, and academia. Fifteen years later, the comprehensive program has over 100 installations in the U.S. and Canada that comprise the world's largest coordinated research network addressing basic and applied science issues of forest management and sustained productivity.

The LTSP program was founded in response to the National Forest Management Act of 1976 (NFMA). The NFMA states that the Secretary of Agriculture must ensure, through research and monitoring, that forest practices do not cause a lasting reduction of the productivity of the land. This mandate was clarified somewhat by the report of a committee of independent scientists (Code of Federal Regulations 1985) that, in part, stated that the Forest Service must monitor the effects of forest prescriptions on "significant changes in land productivity". The Forest Service recognized that clear, scientifically-based definitions of "significant changes in land productivity" and monitoring criteria would be needed to avoid dispute. The term "land productivity" is quite subjective, and can refer to any number of forest attributes and functions. However, at its most fundamental nature, land productivity can be considered a site's capacity to capture carbon in growing plants, i.e., net primary productivity (NPP). Because NPP, the sum of all dry matter produced per unit area per unit time, fluctuates greatly due to climate, stand development, and other factors not related to the

Furniss, M.J., Clifton, C.F., Ronnenberg, K.L., eds., 2007. *Advancing the fundamental sciences: proceedings of the forest service national earth sciences conference, San Diego, CA, 18-22 October 2004*. PNW-GTR-689. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

land, it was also decided that a 15 percent departure from a baseline would be deemed “significant” (USDA Forest Service 1987).

The Forest Service needed some metric other than NPP to monitor, however, because the intensity of effort required to measure NPP makes it impractical under operational monitoring conditions. Tracking stand growth through time, while operationally possible, does not assess soil productivity per se; differences in climate, stocking, genetics, vegetation management, and other practices affect forest productivity without affecting soil productivity (Burger 1996; Powers 2001). An alternative is to relate land productivity to measurable soil processes (Burger and Kelting 1999). The Forest Service adopted this approach, which is based on the following rationale (Powers and Avers 1995):

1. Forest management practices disturb soils
2. Soil disturbances affect soil properties and processes
3. Soil properties and processes determine site productivity

The approach has been used to develop preliminary monitoring protocols (Powers and Avers 1995; Powers et al. 1998; Page-Dumroese et al. 2000) based on the best scientific data available and personal experience. It has also been verified in research settings (Kelting et al. 1999).

Unfortunately, it is impossible to directly measure all soil properties and processes. Therefore, careful experimentation was needed to determine, for each region, what soil properties and processes were most indicative of productivity. Thus, the National Forest System asked Forest Service Research to develop a coordinated study to address these issues. A detailed review of the literature regarding forest management and site productivity determined that the two most fundamental causes of productivity loss following forest management activities were organic matter removal and soil porosity loss (Powers et al. 1990). The review also concluded that scant direct evidence of productivity loss was available, largely because previous studies were not designed well enough to clearly determine cause and effect. Previous studies of soil physical disturbance were confounded by different levels of organic matter removal and weed control, and studies of harvest intensity have been confounded by soil physical disturbance. Many of these studies were further complicated by uncontrolled differences in climate, stocking, and weed competition (Morris and Miller 1994).

Therefore, the founding principles of the LTSP study were that (1) soil is the key factor controlling site productivity that is affected by management, (2) the fundamental measure of productivity is vegetative carrying capacity, expressed as dry biomass accumulation, and (3) removal of site organic matter (slash and/or forest floor) and soil compaction are the most common causes of long-term productivity loss. The LTSP design was chosen to specifically address these problems and focus on the long-term cause and effect relationships between organic matter, soil compaction, and site productivity. The specific hypotheses LTSP was designed to test are shown in Table 1.

Powers et al. (2004) reported on the 10-year findings from selected installations on the southern Atlantic and Gulf coastal plains and in the Sierra Nevada Mountains in California, highlighting major trends. They found that little evidence existed for universal impacts of either soil compaction or organic matter removal, but the presence of understory vegetation caused a clear and widespread reduction in planted tree growth. Within a given region, however, generalized findings may not apply. Scott et al. (2004) reported on the 5-year results from 13 loblolly pine (*Pinus taeda*) sites across the soutern US, and found that results from one site were not necessarily indicative

Table 1. Hypotheses of the Long-Term Soil Productivity Study.

Hypothesis	H_0	H_a
1	Pulse changes in site organic matter and/or soil porosity do not affect the sustained productive potential of a site.	Critical changes in site organic matter and/or soil porosity have a lasting effect on potential productivity by altering soil stability, root penetration, soil air, water and nutrient balances, and energy flow.
2	If impacts on productivity occur from changes in organic matter and porosity, they are universal.	The biological significance of a change in organic matter or porosity varies by climate and soil type.
3	If impacts do occur, they are irreversible.	Negative impacts dissipate with time, or can be mitigated by management practices.
4	Plant diversity has no impact on the productive potential of a site.	Diverse communities affect site potential by using resources more fully or through nutrient cycling changes that affect the soil.

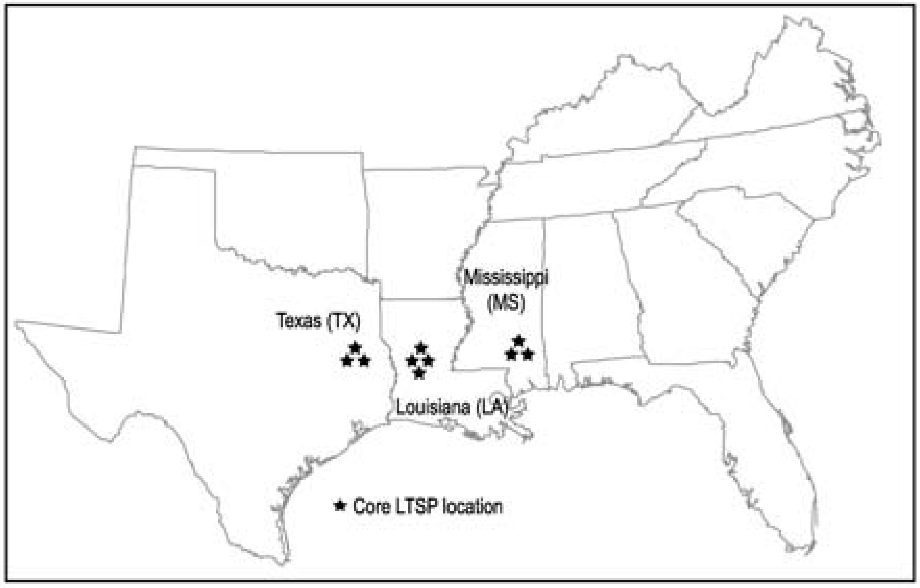


Figure 1. Ten locations of the North American Long-Term Soil Productivity study in the western Gulf Coastal Plain.

of other sites in the same area. Accordingly, the objectives of this paper are to: (1) determine how soil compaction and organic matter removal at harvest and stand diversity after harvest affected the site productivity of loblolly pine at age 10 years in the western Gulf Coastal Plain; and (2) determine soil or site indicators of productivity response to soil compaction and organic matter removal.

Materials and Methods

Study Sites

Ten locations of the LTSP study were installed in the southern United States Gulf Coastal Plain from 1990 to 1995 (Figure 1). All sites are located in the humid-temperate-subtropical Southern Mixed Forest or Outer Coastal Mixed Forest Province (Bailey 1995). Four sites were installed in the Kisatchie National Forest in Louisiana, while three sites each were installed in the DeSoto National Forest in Mississippi and the Davy Crockett National Forest in Texas, respectively. The soils were common Ultisols and Alfisols found on coastal plain uplands and terraces, and were formed from marine and alluvial sediments (Table 2). The surface soils ranged in texture from fine sandy loam to silt loam and overlaid heavier textured subsoils. The understory on the Louisiana and Texas plots was characterized by shrubs and small trees common across much of the southern coastal plain, including sweetgum (*Liquidambar styraciflua*), wax myrtle (*Morella cerifera*), yaupon (*Ilex vomitoria*), and assorted oaks (*Quercus* spp.). The understory in Mississippi was dominated by inkberry (*Ilex glabra*).

Treatments

Nine treatments were imposed in a 3 by 3 factorial design following a clearcut harvest of the existing stand, with organic matter removal and compaction as the main treatment factors and vegetative diversity as a split-plot factor (Figure 2). The three organic matter removal treatments were stem-only harvest, whole-tree harvest, and whole-tree harvest plus forest floor removal. The three levels of compaction were no compaction (no mechanical equipment was allowed on plots during harvesting), moderate compaction, and severe compaction. Severe compaction was defined as 80% of the root-growth limiting

Table 2. General site data for the ten locations of the Long-term Soil Productivity study in the Gulf coastal plain region.

Location	National Forest	Soil Series	Year Established	Previous Stand	Understory
LA 1	Calcasieu RD, Kisatchie NF	Malbis	1990	Loblolly	Grass
LA 2	Catahoula RD, Kisatchie NF	Glenmora	1992	Loblolly	Shrub
LA 3	Catahoula RD, Kisatchie NF	Metcalf	1993	Loblolly	Hardwood
LA 4	Catahoula RD, Kisatchie NF	Mayhew	1993	Loblolly	Hardwood
MS 1-3	Chicksawhay RD, Desoto NF	Freest	1994	Slash plantation	Shrub
TX 1-3	Davy Crockett NF	Kurth	1997	Loblolly/shortleaf	Shrub

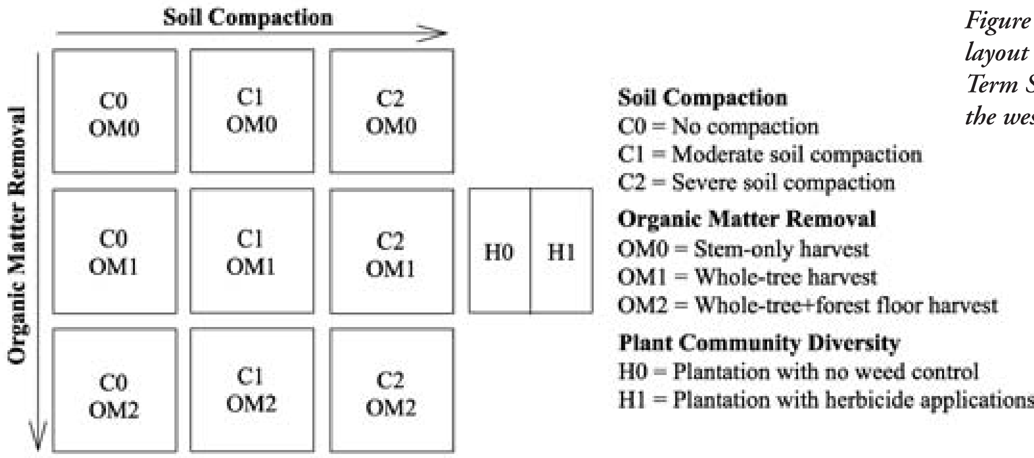


Figure 2. Treatment design and plot layout of the North American Long-Term Soil Productivity study sites in the western Gulf Coastal Plain.

bulk density, as determined from soil texture (Daddow and Warrington 1983). A field-based Proctor test was used to determine load and compaction level relationships at each site. Moderate compaction was defined as the geometric mean bulk density between the no compaction and severe compaction levels. The two experimental compaction levels were induced by pulling a multi-tire road compactor with two levels of ballast across the plots six times (Figure 3). After treatment installation, container loblolly pine seedlings from ten known half-sib families were planted at a 2.5-by-2.5-m spacing. Each 0.4-ha treatment plot was split into two 0.2-ha subplots (Figure 2). One of the subplots was kept clear of competing vegetation by manual removal and directed-spray herbicide applications (primarily glyphosate). Competing vegetation was allowed to grow freely on the paired subplot. Volunteer pines were controlled manually on all plots. Measurement plots were the interior 0.1 ha of each subplot.

Measurements

At age 10 years (age 5 in Texas), we measured tree height and diameter at breast height (dbh) of all pine trees in the 0.1-ha measurement plot with height poles and calipers. Pine volume was estimated using equations from Baldwin and Feduccia (1987). Prior to treatment, five soil samples were collected to 15 cm with a push probe sampler on each of three transect lines across each measurement plot and bulked by transect line. Mehlich III available soil P (phosphorus) (Mehlich 1984) and exchangeable Ca, Mg, and K (calcium, magnesium, and potassium) (Gillman 1979) were determined for each sample on a Hewlett-Packard 8453 colorimetric spectrophotometer[1] and a Perkin-Elmer 2100 atomic absorption spectrophotometer, respectively. Soil carbon was determined on a LECO CNS analyzer and converted to soil organic matter. Soil bulk density samples were collected prior to treatment, at age

Figure 3. Wobble-wheel road compactor and dozer used to compact soils in the western Gulf Coastal Plain Long-Term Soil Productivity sites. Photo by Allan Tiarks.

[1]The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

5 years and at age 10 years, with a custom core extractor from ten random locations throughout each measurement plot in the four Louisiana sites. The sampler extracted a 5-cm diameter by 30-cm length soil core, which was then separated into 0-to-10-cm, 10-to-20-cm, and 20-to-30-cm sections. The soils were dried at 105°C to a constant weight, and bulk density was recorded.

Data Analysis

The main effects of soil compaction, organic matter removal, and stand diversity (competition control) on loblolly pine growth were compared using analysis of variance (ANOVA), and the means were separated using a Duncan's Multiple Range Test at P = 0.10 (SAS Institute 2000). The relationship between soil P and relative productivity was determined with least-squares regression. The influence of compaction level and stand age on bulk density was determined with a mixed-model analysis of variance.

Results and Discussion

Main Treatment Effects on Loblolly Pine Growth

Early stand volume production was generally increased by soil compaction, decreased by whole-tree harvesting, and increased by chemical weed control. Soil compaction increased volume growth in Louisiana and Mississippi by 16 and 24%, respectively (Table 3). It had no impact on volume growth of the pine trees in Texas at age 5. Compaction intensity had no effect. The moderate and severe compaction treatments had the same influence on stand growth in each state.

Organic matter removal had no significant effect on stand volume across the four blocks in Louisiana, but intensive organic matter removal clearly decreased productivity in Mississippi and Texas (Table 3). In Mississippi, the whole-tree harvest and whole-tree+forest floor harvest treatments reduced volume production by an average of 24% relative to the stem-only harvested treatment. In Texas, the whole-tree harvest treatment reduced productivity at age 5 by 26% compared to the stem-only treatment, and removing the forest floor increased this reduction to 65%.

The plantations with simple vegetative communities produced much more timber than the diverse communities. Across the Louisiana and Mississippi sites, chemical control of competing vegetation increased pine productivity by almost 50% compared to the plantations with no chemical weed control (Table 3).

Site-Treatment Interactions and Response to Compaction

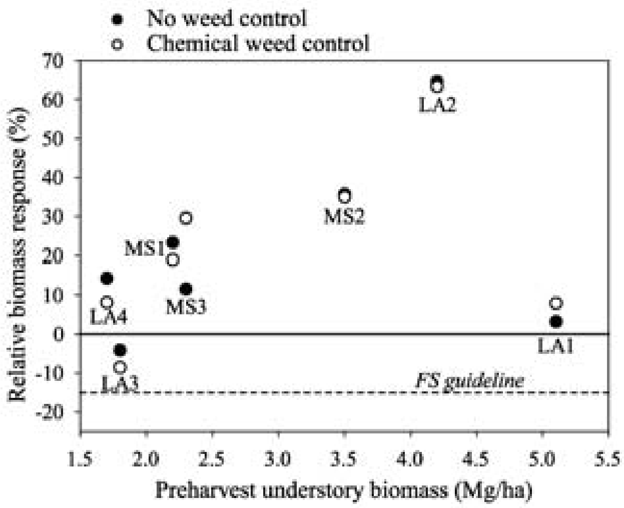
Compaction had the greatest positive impact on the relative volume of loblolly pine on the LA2, MS2, MS3, and MS1 sites (Figure 4), and the positive impact of compaction was related to the quantity and type of preharvest understory (less than 7.6 cm dbh). The LA2, MS2, MS3, and MS1 sites all had a heavy understory of shrub species and small hardwood trees (Table 2). The LA2 site was dominated by wax myrtle, yaupon, and sweetgum. The Mississippi sites were dominated by inkberry. The LA1 site, which had the most understory biomass before harvest, showed no positive response to compaction. The understory at LA1 was almost exclusively grass, due to frequent cattle grazing and prescribed fires. LA1 was also compacted before treatments due to the history of cattle grazing, and the experimental compaction was less effective at changing bulk density at this site (Tiarks et al. 1991). The LA3 and LA4 sites had little understory biomass and showed little response to compaction. These sites, however, had the greatest hardwood biomass (greater than 7.6 cm dbh) of all the sites (data not shown). The LA3 site was the only site to exhibit a negative response to the compaction. The Metcalf soil on LA3 was originally classified as an

Table 3. Stand volume response at age 10 to soil compaction, harvest intensity, and chemical weed control in three replicated LTSP study sites in the western Gulf coastal plain.

Treatment	Stand Volume (cubic meters per hectare) Louisiana	Mississippi	Texas[2]
No Compaction	96b[1]	64b	4.8a
Moderate compaction	115a	79a	5.1a
Severe Compaction	107a	80a	5.1a
Stem-only harvest	111a	89a	6.9a
Whole-tree harvest	102a	66b	5.1b
Whole-tree+forest floor harvest	105a	70b	2.4c
No weed control	83b	62b	4.7a
Chemical weed control	129a	87a	5.3a

[1]Means within a column followed by the same letter are not significantly different at P < 0.10.
[2]Texas data were from age 5.

Figure 4. Average loblolly pine volume response at age 10 on compacted soils relative to the uncompacted soils as a function of the preharvest understory biomass on across the Louisiana and Mississippi Long-Term Soil Productivity study sites.



Alfisol when the study was installed, but was reclassified as a Vertisol. The soil texture at LA3 and LA4 averaged 29% clay in the upper 30 cm, whereas the average clay content of the LA1, LA2, and the MS sites was only 19% in the upper 30 cm.

The positive response of the planted pines to compaction on the sites with heavy shrub-based understories indicates that the understory plants were negatively impacted by compaction. The compaction probably did not have a direct effect on the plants; breaking stems and exposing roots would likely increase sprouting and dominance of these species. Compaction did not have an additive effect with the herbicide treatments. While the herbicide treatments were quite effective on relative loblolly pine productivity on all plots (Table 3), the herbicide application on the compacted plots had no additional impact compared to the uncompacted plots (Figure 4). Therefore, it is likely that the compaction had an indirect impact on the understory plants by increasing soil strength and reducing aeration. The planted pine probably responded because this indirect impact on the soil was not as important as the reduction of competition for resources.

In the early stages of the LTSP study, many foresters and scientists expected the soil compaction treatment to have the greatest negative impact on productivity. Soil physical disturbances are visually unappealing, and evidence of compaction-induced productivity losses in southern pine stands is abundant (Hatchell et al. 1970; Tiarks 1990; Aust et al. 1995; Miwa et al. 2004). One explanation of the lack of negative response may be that we did not achieve enough soil disturbance or the right form of disturbance to have a biological impact on the planted pines. This was definitely the case at the 20-30 cm depth, where the compaction treatments had no impact on bulk density in Louisiana (Table 4). The form of physical disturbance we created (compaction) is only one form of disturbance caused during forest management activities such as logging. Rutting and churning, unlike simple compaction, disturb not only the soil porosity, but they also disturb soil structure and may have a greater impact than simple compaction (Tiarks 1990). While compaction is usually the dominant forest management-induced soil disturbance, these results can not be applied to rutted or churned sites and may explain discrepancies between these data and previous studies.

Another explanation is that these trees are still quite young and only recently attained full canopy closure. Short-term results are not always indicative of long-term results, especially when multiple processes are functioning. For example, while the early productivity of the planted pines was improved by the compaction, it appears this increase was caused by a reduction in understory plants that were more susceptible to changes in soil properties. After canopy closure, when intraspecific competition for site resources will be greater than interspecific competition, soil properties will likely have a greater relative impact on pine productivity than before canopy closure. Essentially, as the stand matures, understory competition will be less important to pine productivity relative to near-surface soil

Table 4. Compaction effect on bulk density at three depths across four LTSP sites in Louisiana immediately after treatment and ten years after treatment.

Depth	Compaction	Bulk Density (megagrams per cubic meter) Age 0	Age 10	Change[2]
0-10	Uncompacted	1.32b[1]	1.26b	-0.07b
	Moderate	1.41a	1.27b	-0.14a
	Severe	1.43a	1.30a	-0.13a
10-20	Uncompacted	1.48b	1.39c	-0.08a
	Moderate	1.54a	1.46b	-0.07a
	Severe	1.56a	1.48a	-0.07a
20-30	Uncompacted	1.51b	1.45c	-0.06a
	Moderate	1.52ab	1.47b	-0.05a
	Severe	1.53a	1.49a	-0.03a

[1]Means within a column and soil depth followed by the same letter are not significantly different at $P = 0.10$.
[2]Discrepancies between the difference of the Age 0 and Age 10 data and the change in bulk density data were due to rounding. All changes in bulk density from age 0 to age 10 were significantly different at $P = 0.05$.

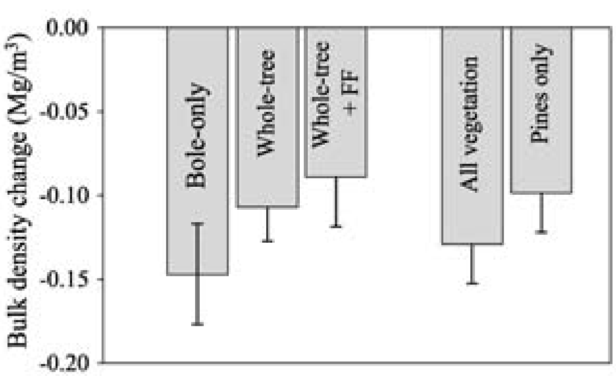
properties. Because of this, we also wanted to assess how well the soil has recovered from compaction to indicate whether long-term responses to compaction would be similar to or different from short-term responses.

Soil Recovery from Compaction

Bulk density in the surface soil at the four Louisiana sites was significantly increased by compaction at all three depths. The degree of compaction had no relative impact; the moderate and severe treatments resulted in similar bulk densities immediately post-treatment at all depths (Table 4). The bulk density of the compacted soils remained elevated over that of the uncompacted soils 10 years after treatment. The recovery of the bulk density was greatest in the surface 10 cm, but was significant at all depths (Table 4). Although recovery was significant at the lower two depths, it did not differ based on compaction intensity (Table 4), organic matter removal, or herbicide application. The surface 10 cm recovered differently depending on the treatment. Whole-tree and whole-tree+forest floor harvesting reduced the bulk density recovery from almost 0.15 Mg/m^3 to about 0.10 Mg/m^3 (Figure 5). Chemical weed control also reduced the recovery by about 0.03 Mg/m^3.

Natural recovery of soils from compaction occurs primarily through three mechanisms (Miwa et al. 2004). The first and generally most important process is shrinking and swelling of 2:1 expanding clays. The second, much less common in the southern coastal plain, is freezing and thawing. The third process is through biological disturbance; root penetration and biopedoturbation. The recovery of the deeper surface layers was unaffected by organic matter removal and chemical weed control. In

Figure 5. Change in bulk density of the surface 10 cm over ten years on the Louisiana LTSP sites as a function of organic matter removal and chemical weed control. Error bars represent one standard error.



the surface 10 cm, however, the recovery was reduced by removing tops and forest floor and by controlling the non-pine vegetation chemically. Removal of the forest floor and weeds may have altered the soil warming and cooling cycles and changed the freeze-thaw dynamics, but these treatments more likely altered bulk density recovery by affecting biopedoturbation. Coarse woody debris serves as a host for many insects and other ground-dwelling organisms (Harmon et al. 1986). Termites decompose the coarse woody debris and transport soil into the decomposing material (Tiarks et al. 1999). This soil juxtaposition caused by organisms is a natural amelioration for soil physical disturbances. The understory control probably lowered the bulk density recovery by reducing the number of fine roots exploiting the surface soil. Prior to canopy closure, the fine roots from the understory were probably much more numerous than the fine roots from the developing pine stand, and therefore had the most direct impact on soil compaction amelioration.

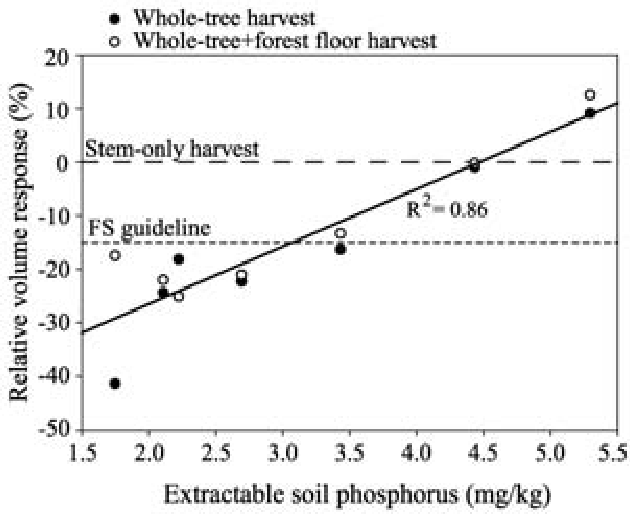
Site-Treatment Interactions and Response to Organic Matter Removal

At age 5 years, productivity loss due to whole-tree harvesting and whole-tree+forest floor harvesting was clearly related to site productivity as measured by the stem-only biomass growth at that time; productivity loss was greatest on sites with the lowest productivity (Scott et al. 2004). However, this measure would not be useful in assessing stands prior to harvest for potential declines.

We studied the relationship between surface soil nutrients and productivity loss. The soils were essentially either fertile or very infertile with respect to calcium, magnesium, and potassium (data not shown), which provided little insight regarding whether or not the harvesting reduced productivity. Soil phosphorus (P) was clearly related to the harvest intensity impact. The linear relationship between preharvest soil P concentrations and the relative biomass response was highly significant ($p < 0.0001$) and explained 86% of the variation (Figure 6). Whole-tree harvesting reduced productivity by 15% or more on the sites with less than 3.1 mg/kg of Mehlich III available P. This is very similar to the 3 mg/kg soil critical level reported for determining sites responsive to P fertilizer (Wells et al. 1973), and may be a good monitoring criterion for determining sites susceptible to productivity loss caused by organic matter removal.

Coastal plain soils, while ranging in texture from coarse sands to heavy clays, have widespread nutrient limitations. While soil N deficiencies are more widespread and have been more of a concern with respect to harvesting intensity, phosphorus deficiencies are common as well across the

Figure 6. Loblolly pine response at age 10 on the whole-tree and whole-tree+forest floor harvested plots relative to the stem-only harvested plots as a function of preharvest available soil phosphorus across the Louisiana and Mississippi Long-Term Soil Productivity sites.



southeastern United States (Allen 1987). Organic matter decomposition and nutrient release is of even greater importance to nutrient availability on weathered soils with infertile parent material. Research from Australia (Farrell 1984) and New Zealand (Smith et al. 2000) has indicated that harvest residues should be maintained on sandy sites to ensure productivity, largely due to reductions in N availability. Soil texture has been considered a primary variable in the role of organic matter and sustained forest productivity (Vance 2000), but data from these loamy Gulf coast LTSP sites show that soil texture is not exclusively indicative of low fertility in this region.

In many commercial harvesting operations in the southern pine region, whole-tree harvesting occurs by default since much of the tree crown biomass and slash is often concentrated near landings, even when efforts are made to redistribute the material through the stand. Therefore, additional care should be taken on soils with low available P to redistribute the slash evenly or consider P fertilization.

Conclusions

The LTSP study is the single largest study of forest management practices and soil productivity in the world. It was designed to help national forest planners meet the letter and spirit of several pieces of legislation by ensuring that forest management practices do not degrade soil productivity. It was also designed to develop and validate monitoring criteria that could be used in planning and monitoring protocols. The national forests and ranger districts in the Gulf Coastal Plain with LTSP installations benefit by having the sites in the planning and monitoring phases. They help in the National Environmental Planning Act (NEPA) process by providing research data on long-term effects. Referencing the LTSP study results adds to the credibility of their NEPA evaluations. The Forests also benefit from the close relationship to Forest Service Research, and vice versa. Several other studies on soil productivity and management have been implemented in the region based on this mutual interaction.

Soil compaction, organic matter removal, and stand diversity all had substantial impacts on the growth of planted loblolly pine across 10 sites in the western Gulf Coastal Plain. Soil compaction had a positive impact on loblolly pine growth at 9 of the 10 sites, but was clearly related to the preharvest understory type and biomass. Sites with shrubby species such as yaupon, wax myrtle, and inkberry benefited from compaction by reducing the understory growth. While we cannot forecast whether the remaining elevation in bulk density on the compacted plots will have a negative effect on overall soil productivity in the future, the 10-year improvements in soil properties suggest that these sites are recovering well from the experimental compaction. Harvesting practices that leave coarse woody debris on site and allow herbaceous and woody plants to grow will generally increase this natural amelioration. Removing tree tops, with or without removing the forest floor, reduced productivity by more than the allowable 15% on 8 of 10 sites. The degree of productivity loss was clearly related to available soil P; sites with less than 3.1 mg/kg of available P lost more than 15% productivity by whole-tree harvesting. Care should be taken on these sites to ensure that logging slash is redistributed evenly across the stand to return the nutrients to the whole stand or fertilization should be considered.

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Soil Compaction Study of 20 Timber-Harvest Units on the Ouachita National Forest

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A soil compaction study was performed on 20 timber harvest units on both rocky (15-35% by volume gravel) and non-rocky (<15% by volume gravel) surface soils of the Ouachita National Forest in Arkansas, to determine if these areas met the USDA Forest Service Southern Region (R8) soil quality standards for compaction and affected area extent. The compaction standard states bulk density cannot increase more than 15% from its natural (undisturbed) level and not more than 15% of an activity area can be adversely affected. Eight of the study units exceeded this standard. These eight units generally contained less than 15% rock fragments in the top 8 inches (20 cm) of soil, and seven of the eight had been harvested during the moist season (December-June) using rubber tire skidders. The non-rocky soil units, when harvested during the dry season (July-November), resulted in about 20-50% less compaction than when harvested during the moist season. Non-rocky soils with a sandy loam surface tended to compact less during dry season but more during moist season equipment operation than the non-rocky loam or silt loam soils. Compaction also averaged about 30-50% less on the rocky soils than on non-rocky soils. On the rocky soils, logging equipment operation during either the dry or moist season did not show a difference, and only native surface roads and log decks tended to have a greater than 15% bulk density increase. Compaction due to timber harvest activities that had occurred at least 15-20 years earlier averaged about 9% bulk density increase for the non-rocky soils and 7% for the rocky soils, and indicated that partial recovery had occurred. An analysis of surface infiltration rates found that a 15% density change resulted in more than 60% reduction in infiltration. This study also found that a 15% density change can be visually determined by change in soil structure.

Keywords: *compaction, bulk density, infiltration, soil structure, soil quality standard*

Introduction

Forest land managers are concerned with soil compaction and its effects on long term productivity of the land. Regionally and nationally there has been growing evidence to support this concern. On the Ouachita National Forest, Arkansas, little previous work has been done to determine the degree and extent of compaction that may occur on our soil types. Because the soils on the Ouachita National Forest are typically rocky, it has generally been concluded that compaction is not a serious problem.

Turton et al. (1997) analyzed compaction on six Phase II Ecosystem Management Research sites on the Ouachita, and found compaction to be significant only on multiple pass skid trails in single tree selection and group selection treatments, where soil rock content was relatively low. They found that those soils with the greater percentages of rock content resulted in lower amounts of soil compaction.

Kluender et al. (1994), in their assessment of impacts of alternative harvesting methods in mixed pine/hardwood stands on six harvest units on the Ouachita NF, found that compaction was significant only on the single tree selection treatment units. They attributed this result to the more concentrated traffic pattern or increased number of passes on fewer skid trails on these units. In another site impact study of five harvest treatments on 23 stands in the Phase II Ecosystem Management Research plots, Stokes et al. (1997) found the percent area extent in primary and secondary skid trails to be 22.4, 21.9, 20.5, 14.6 and 14.3 for the clear cut, seed-tree, shelterwood, group selection and single tree selection harvest treatments, respectively.

Froelich et al. (1980) found that the most critical period for compaction to occur is when soil moisture levels are between field capacity and saturation. This information is essential but still leaves the land manager with unanswered questions and situations when dealing with soil compaction at the operational level considering the various soils on the forest. Our study was designed to further our knowledge

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of compaction, its effects on surface infiltration and its degree and extent on the Ouachita's soils, and relate this to the USDA Forest Service Southern Region (Region 8) soil quality standard for compaction and area extent (UDSA Forest Service 2003). The compaction standard states that bulk density cannot increase more than 15% from its natural (undisturbed) level in the top 20 cm (8 inches) of soil, and that no more than 15% of the unit area can be affected.

Methods

Treatment units were initially selected for their compaction potential. A review of compaction research shows that soils and harvest units that show high amounts of compaction would have been subjected to intense heavy equipment activity, would contain low proportions of rocks, would probably be sandy loam textured soils, and would have been operated on during the moist season when soils would have a greater chance of being moist. Several units were selected that met these criteria. Similar soils and treatment units were also selected that had been harvested during the dry season, or that had a loam or silt loam surface texture, to help determine the importance of operating season or surface texture to compaction. To determine the influence of soil rockiness on compaction, treatment units were also selected that contained moderate percentages of rocks (approximately 15-35% gravel size rocks) in the top 20 cm (8 inches) of soil. Some of these rocky units had been harvested during the moist season and some during the dry season.

The study site soils are of the Carnasaw and Sherless Series. The Carnasaw soil is a clayey, mixed, thermic, Typic Hapludult, 100-150 cm (40-60 inches) deep, overlying soft shale bedrock with small amounts of sandstone. The Sherless soil is a fine-loamy, mixed, thermic, Typic Hapludult that is 50-100 cm (20-40 inches) deep over soft sandstone bedrock with small amounts of shale. For this study, those soils containing from 0-15% (field estimate by volume) rock content in the top 20 cm (8 inches) of soil are referred to as "non-rocky soils", and those soils containing from 15-35% rocks as "rocky soils". The density readings of the rocky soils were corrected for rock content differences among groups, and directly related to their non-rocky counterpart soils. The predominant rock size (which typically accounted for 50-100% of the rock present) was 2-19 mm and consisted mainly of sandstone fragments.

This study was performed on small, 0.8-2.0 ha (2-5 acre) subplots of timber harvest units. Most of the harvest units had been harvested within the past year with a few not yet harvested at time of selection. Treatments included single tree selection, group selection, shelterwood or seed tree harvest with harvest volumes mainly in the 23-35 m^3/ha (4,000-6,000 board foot/ac) range. Random transect monitoring was conducted using a Troxler 3440 moisture/density gauge to determine soil density within the 0-20 cm (0-8 inch) soil depth. Each day of use the gauge was tested for calibration and accuracy. To further validate the accuracy of the moisture/density gauge readings, and note any natural changes in the sample itself, the soil at each reading site was excavated by shovel, and field examined for USDA soil texture, estimated percent by volume rock fragments, and estimated amount of roots or buried debris present for possible gauge reading interference. In addition, an estimate of soil moisture at each reading site was made by feel. To further validate soil moisture readings from the Troxler gauge, selected soil samples of the 0-20 cm (0-8 inch) depth were collected and oven dried for 24 hours at 105°C. to gravimetrically determine moisture content. During the physical examination of each reading site, evidence of soil compaction was also recorded. This included noting changes in soil structure and the degree and depth of this structural change according to the 2002 NRCS Field Book for Describing and Sampling Soils (USDA NRCS 2002).

Random transects were set up using a tape with points measured at 3-m (10-foot) intervals and averaging about 75 sample points per unit. Each transect point was given one of six levels of visual disturbance ratings. These six levels included: undisturbed (or natural); evidence of previous impacts but not disturbed this entry (old disturbance); 1-2 pass tractor logging or other heavy equipment operation; 3 or more pass tractor logging not on the primary skid trail (these multi-pass areas are hereafter referred to as secondary skid trails); primary skid trail; and log deck or native surface road.

Identifying old disturbance sites required assessing such density gauge and field indicators as: (a) a site with a slight soil surface depression made from previous entry tire tracks; (b) a thinner layer of semi-decomposed litter relative to that of the natural undisturbed areas; (c) a change in soil structure from the natural state; and (d) greater density readings with no apparent cause other than prior disturbance. The final determination would typically include a combination of the above indicators with highest priority given to change in soil structure.

Surface infiltration measurements were performed on selected harvest units and sites of known degree of compaction to determine what effect density change may have on infiltration. Each infiltration measurement was made by carefully driving one 15-cm-tall x 10-cm-diameter x approximately 2-mm-thick steel ring, 3-5 cm into the soil by placing a short piece of 2 x 4 wood over the ring and using a 2-pound hammer. Water was then carefully applied to fill the rings while not disturbing the soil surface inside the ring. A period of 30 minutes was given for the water to soak into the soil, with additional water added to the ring and any leakage outside the ring stopped by soil mounding as needed. Readings were then recorded of water draw down inside the ring over time. The final surface infiltration recording was the average of the two or three individual ring recordings, and reduction in infiltration was the difference between those of the compacted sites vs. the undisturbed site infiltration recordings for each unit.

To determine whether bulk density values were different on individual treatment units between levels of disturbance, data were analyzed using one-way analysis of variance (ANOVA). To determine if these bulk density disturbance values were affected by the interaction from soil rockiness, season of equipment operation, or soil texture, data were analyzed using two-way analysis of variance (ANOVA), in which the classification variables of mean bulk density (BD) by texture, season of equipment operation, and soil rockiness were compared with the 'treatment', or disturbance variables. The analysis was conducted using the General Linear Models (GLM) procedure, with comparisons of means among classification and treatment interactions conducted with Sidak's test (SAS Institute 1989).

In instances where mean bulk density of the natural condition varied among classification variables, data were transformed by expressing all BD observations as a percentage of mean natural BD within each classification. ANOVA tests using Sidak's mean comparison test were then performed on the result, essentially a means of testing whether the percentage increases in BD above the natural conditions were significant between classification variables by treatment. Individual unit results are summarized in Table 1, and combined interaction unit results in Table 2.

Results

During this study additional data were collected to examine a number of variables including type of harvest method employed and volume per unit area removed. The analyses of these data were not found to be significant and therefore are not discussed here. Those variables that did prove to be significant included season of equipment operation, soil rockiness class, and surface texture class of the non-rocky soils. The fine sandy loam and loamy fine sand textured surface soils are hereafter referred to as sandy loam textured soils.

Table 1 shows bulk density means by individual harvest unit by two soil rockiness classes (non-rocky = <15%, and rocky = 15-35% gravel rock) where present, as measured against six different compactive disturbance levels. Also represented in this table is the average percent of area receiving 15% or greater soil density increase over that of the undisturbed condition by soil rockiness class, and the overall percent weighted area extent of each unit area receiving 15% or greater density increase from all data when both the non-rocky and rocky classes (if applicable) are combined. As the data show, eight harvest units did not meet the regional soil quality standard for compaction and area extent of impact (Table 1).

Soil Rockiness

Non-rocky soils compacted more, and with less effort, than the rocky soils. Nearly all units containing the rocky soils showed lower bulk density levels and smaller areas of excessive compaction relative to their non-rocky counterparts (Table 1). Of the 16 units that contained only or mostly non-rocky soil (see Table 1), eight exceeded the proposed compaction threshold. In contrast, none of the four units in which half or more of the area was made up of the rocky soils (shaded in Table 1) exceeded this threshold.

When data from these individual units are compared a clearer picture emerges. Figure 1 and Table 2A compare the mean bulk density and percent compaction of all the non-rocky soils to that of the rocky soils by disturbance level. Both the rocky soils and the non-rocky soils show significantly different mean bulk densities at all levels of disturbance, including old disturbance vs. their undisturbed levels. The data also show that rocky soils have significantly lower mean bulk densities than non-rocky soils on primary and secondary skid trails and areas receiving 1-2 equipment passes.

Mean bulk density change for the non-rocky soils, as compared to undisturbed areas, was about 22% on the landings and native surface roads, 19% on the primary trails, 13% on secondary trails, 7% on areas receiving 1-2 passes, and 9% from old disturbance areas. Analysis shows these densities to be different from the natural level at the 95% or greater confidence level. In contrast, the rocky soils show bulk density to be about 19% greater than natural levels on log decks and native surface roads. On primary skid trails, secondary skid trails and areas receiving 1-2 equipment passes this drops to about 10%, 8% and 5%, respectively. The old disturbance averaged about 7% above natural levels for rocky soils. Based on these data, the rocky soils appear to be 30-50% less compactable than the non-rocky soils for primary and secondary skid trails, and areas receiving from 1-2 equipment passes.

Total depth of the compacted soil layer was related to the level of disturbance and rock content of the soil.

Table 1. Comparison of mean bulk density (in g/cm^3) by disturbance level, percent of area receiving greater than 15% increase by soil rockiness group, and percent overall weighted area exceeding the compaction standard of 15% change in bulk density. Shading indicates units where rocky soils predominate.

				Bulk Density Measurements[4] (g/cm^3)						Change in Treatment Area (%)	
Unit ID	Surface texture	Season of operation	Soil rockiness	Undisturbed density	Old disturbance	1 to 2 passes	Secondary skidtrail	Primary skidtrail	Log deck/ temp. road	>15% change in density by class	>15% change in density, total area
1	fsl[1]	moist	non-rocky[3]	1.36a	1.45b		1.47b	1.57c		9	
			rocky	1.36a	1.43b	1.43b	1.41	1.45c		0	4
2	fsl	moist	non-rocky	1.38a	1.41a	1.51b	1.58	1.77c		22	22
3	fsl	dry*[2]	non-rocky	1.35a	1.45b		1.49c	1.52c		2	2
4	fsl	dry*	non-rocky	1.38a	1.44ab		1.47b			0	0
5[5]	fsl	moist	non-rocky	1.37a	1.48c	1.44b	1.50c	1.51c	1.49c	7	7
6	l	dry	non-rocky	1.28a	1.44	1.33b	1.40	1.51c	1.47c	13	
			rocky	1.28a		1.26a	1.33	1.45b		11	13
7	sil	moist	non-rocky	1.33a	1.39a	1.47b	1.50	1.58c		22	
			rocky	1.33a			1.40	1.52b		22	22
8	sil	dry*	non-rocky	1.32a	1.42b	1.41b	1.49c	1.48c	1.61d	6	6
9	l	dry	rocky	1.32a	1.40	1.37b	1.42	1.43bc	1.49c	9	9
10	sil	moist	rocky	1.31a	1.35ab	1.38b	1.44c		1.44c	8	8
11	sil	moist	non-rocky	1.34a	1.41ab	1.41ab	1.42	1.64c		14	
			rocky	1.34a			1.48b	1.41ab		8	11
12	sil	moist	non-rocky	1.34a	1.45b	1.43b	1.52	1.60d	1.65d	24	24
13	sil	moist	non-rocky	1.31a	1.37b	1.43c	1.48		1.55d	24	24
14	l	moist	non-rocky	1.31a	1.40b	1.40b	1.53c	1.55c		32	
			rocky	1.31a	1.30a		1.49			14	30
15	sil	dry	non-rocky	1.31a	1.47	1.4	1.53	1.54		26	
			rocky	1.31a		1.42b	1.47			7	16
16	sil	moist	non-rocky	1.28a	1.40b		1.37b			2	2
17	l	moist	non-rocky	1.30a	1.42	1.39b	1.47			11	
			rocky	1.30a	1.42	1.38b	1.44	1.46c	1.66d	17	13
18	fsl	moist	non-rocky	1.31a	1.45b	1.40b	1.54	1.62c	1.69d	28	28
19	fsl	dry	non-rocky	1.34a	1.45b		1.41b	1.53c		8	8
20	fsl	moist	non-rocky	1.34a	1.50b	1.49b	1.56bc	1.62c	1.74d	40	40

[1] fsl = fine sandy loam; l = loam; sil = silt loam

[2] * indicates that unit was initially operated on when the soil was too wet, and logging operations were temporarily suspended until conditions improved.

[3] Non-rocky = 0-15% by volume gravel in surface 20 cm (8 inches); rocky = 15-35% by volume gravel in surface 20 cm.

[4] Bulk densities followed by different letters are significantly different at P > 0.05. Bulk densities without a letter had too few samples for statistical analysis

[5] This unit was logged using a team of mules instead of a rubber tire skidder.

Table 2. Mean bulk density values (in g/cm³) and significance for four levels of recent disturbance plus old disturbance as measured against undisturbed bulk density.

A. Comparison of non-rocky (0-15% gravel) soils to rocky (15-35% gravel) soils

	undisturbed	1-2 pass	secondary trail	primary trail	log deck/road	old disturbance
non-rocky soil	1.32	1.41	1.49	1.57	1.61	1.44
rocky soil	1.32	1.38	1.43	1.45	1.57	1.42
signif. by soil rockiness:	ns	*	***	***	ns	ns
signif. by disturbance level:	a	b	d	e	f	c

B. Comparison of dry vs. moist season logging on non-rocky soils

	undisturbed	1-2 pass	secondary trail	primary trail	log deck/road	old disturbance
dry season	1.32	1.38	1.47	1.51	1.55	1.45
moist season	1.33	1.43	1.5	1.6	1.67	1.44
significance by season of ops:	ns	**	**	***	***	ns
significance by disturbance level:	a	b	d	e	f	c

C. Comparison of dry vs. moist season logging on rocky soils

	undisturbed	1-2 pass	secondary trail	primary trail	log deck/road	old disturbance
dry season	1.31	1.37	1.42	1.44	1.49	1.41
moist season	1.32	1.39	1.44	1.46	1.61	1.42
significance by season of ops:	ns	ns	ns	ns	*	ns
significance by disturbance level:	a	b	c	c	d	bc

D. Comparison of non-rocky sandy loam vs. non-rocky loam or silt loam soils

	undisturbed	1-2 pass	secondary trail	primary trail	log deck/road	old disturbance
sandy loam	1.35	1.46	1.51	1.64	1.72	1.45
loam/silt loam	1.31	1.38	1.48	1.54	1.56	1.44
significance by soil texture:	ns	**	ns	**	**	ns
significance by disturbance level:	a	b	d	e	f	c

E. Comparison of dry vs. moist season logging on non-rocky loam or silt loam soils

	undisturbed	1-2 pass	secondary trail	primary trail	log deck/road	old disturbance
dry season	1.30	1.36	1.45	1.51	1.55	1.43
moist season	1.32	1.40	1.49	1.55	1.59	1.44
significance by season of ops:	ns	*	**	*	ns	ns
significance by disturbance level:	a	b	d	e	e	c

F. Comparison of dry vs. moist season of logging on non-rocky sandy loam soils.

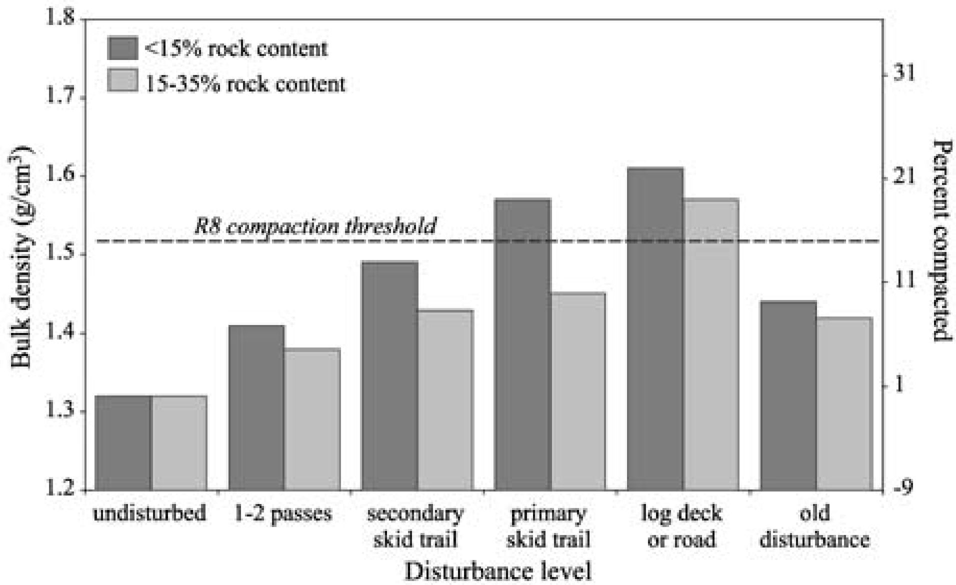
	undisturbed	1-2 pass	secondary trail	primary trail	log deck/road	old disturbance
dry season	1.36	1.46	1.49	1.52	no data	1.45
moist season	1.34	1.46	1.53	1.65	1.72	1.45
significance by season of ops:	ns	ns	**	*		ns
significance by disturbance level:	a	bc	c	d	e	b

G. Comparison of dry vs. moist season of logging on rocky loam or silt loam soils.

	undisturbed	1-2 pass	secondary trail	primary trail	log deck/road	old disturbance
dry season	1.31	1.37	1.42	1.44	1.49	1.41
moist season	1.33	1.41	1.47	1.47	1.47	1.37
significance by season of ops:	ns	ns	ns	ns	ns	ns
significance by disturbance level:	a	b	c	c	cd	b

ns not significant
* significant at P > 0.05
** significant at P > 0.01
*** significant at P > 0.001
different letters following disturbance levels are significantly different at P>0.05.

Figure 1. Comparison of mean bulk density of non-rocky and rocky soils.



From visual observation only the first few inches tended to be compacted where 1-2 passes had been made. On primary skid trails, log decks and native surface roads this compacted layer would typically include the entire 20 cm (8 inches) of soil examined. The rocky soils tended to display a less prominent visual degree and depth of impact as compared to the non-rocky soils for the same levels of disturbance.

Season of Equipment Operation

Twelve of the 20 harvest units monitored were logged during the moist season (December-June), and eight during the dry season (July-November). Of the eight units in Table 1 exceeding the proposed compaction standard, seven were yarded during the moist season. Only one of the eight units harvested during the dry season (unit 15) did not meet the standard.

A review of Figures 2 and 3, and Tables 2B and 2C, shows that the non-rocky soils compact more than rocky soils and season of logging operation significantly affects bulk density on the non-rocky soils, but not for the rocky soils. Moist season logging operation proved to be significant for all recent levels of disturbance for the non-rocky soils, but was not significant at any level of disturbance for the rocky soils. Figure 2 shows mean bulk density for all non-rocky soils data (excluding areas where mule logging was used) by dry or moist logging operating season. This figure clearly indicates that moist season equipment operation results in the greatest change in bulk density. These analyses show changes in mean bulk density to be 20-50% smaller on the non-rocky soils on primary and secondary skid trails, and areas receiving 1-2 passes, when logging operations were conducted during the dry season. On the rocky soils, equipment operation performed during the dry season vs. the moist season showed only a slight and insignificant change in mean bulk density by disturbance levels.

Unit 5 (Table 1) was the only unit harvested not using conventional rubber tire skidders. This unit was logged using a team of mules. The log deck and native surface haul road were driven on by a 2-axle haul truck with a mounted log loader. This unit was one of the five non-rocky soil units harvested during the moist season that met the proposed soil quality standards for compaction. In fact, of the 7% area extent not meeting the compaction standard, more than half was due to old disturbance compaction caused from a previous entry or entries.

The most serious degree and extent of compaction were found on the non-rocky soil units that were harvested when these soils were very moist but not saturated. Examples of this situation were experienced with units 2, 14 and 18 (Table 1). Soil moisture conditions on these units were known to be very moist from personal field observation at the time of equipment operations. Similarly, on units 3, 4, and 8, where harvest activities were first commenced and then halted during very moist soil conditions (near saturated soil moisture) and later completed during the dry season, compaction did not show up as a serious problem. Instead, soil puddling or displacement became the major concern where deep tire tracks had been made earlier when the soils were too moist.

Units 10 and 13 (Table 1) were also harvested during very moist soil conditions. On these units no primary skid trails were present, as the tractor operator would often change trail routes in order to prevent further deep tire

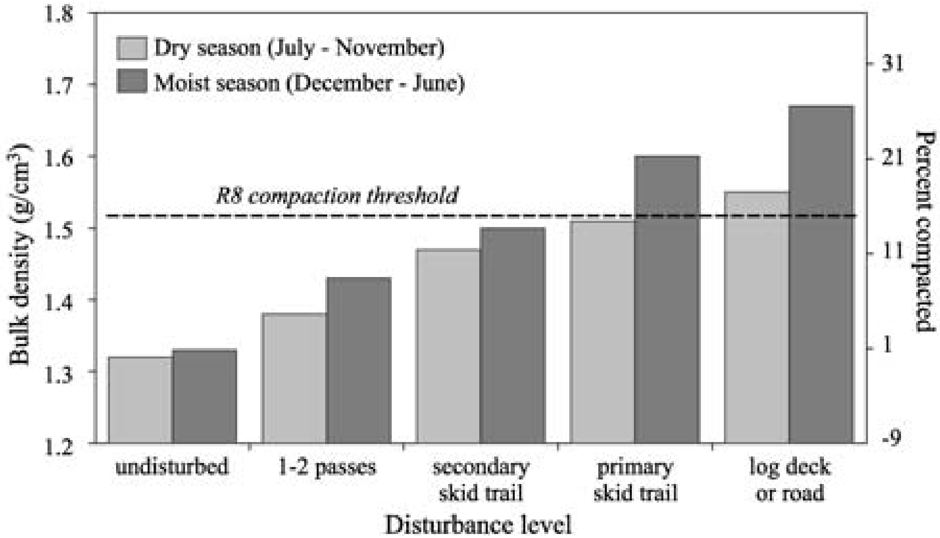


Figure 2. Comparison of mean bulk density of non-rocky soils by season of equipment operation.

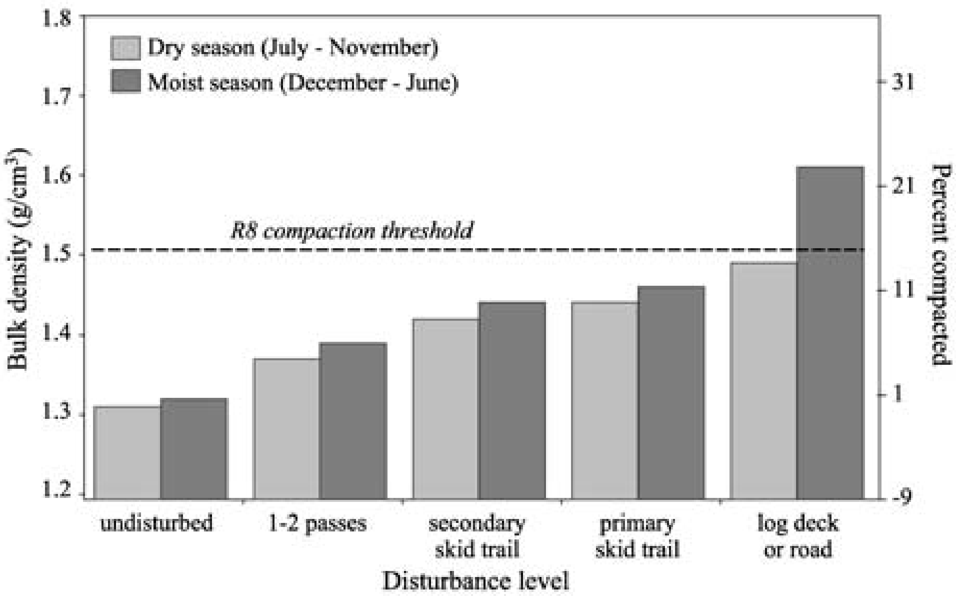


Figure 3. Comparison of mean bulk density of rocky soils by season of equipment operation.

tracks or other obvious damage to the soil resource. This highly dispersed equipment logging practice resulted in a greater area of impacts from the equipment. For unit 13, which contained non-rocky soil, 24% of the area received greater than 15% compaction. Unit 10, a rocky soil, faired much better. Only 8% of the unit area was greater than 15% compacted.

Soil Texture

Changes in surface texture on non-rocky soils affected the degree of compaction (Table 2D). The sandy loam textured soils suffered greater changes in density levels than the loam or silt loam textured soils at all four recent disturbance levels. Analysis shows density changes due to texture are significant for log decks and native surface roads, primary trails, and areas receiving 1-2 equipment passes.

When logging equipment operating season is also considered, the non-rocky loam and silt loam soils, and the non-rocky sandy loam soils, continue to show significant differences in bulk density both by disturbance level and season of operation (Table 2E and F). Moist season logging resulted in significant increases in compaction on primary and secondary skid trails from both textural groups. In addition, there was a significant density increase for 1-2 pass equipment operation for the loam and silt loam soils during moist season operation.

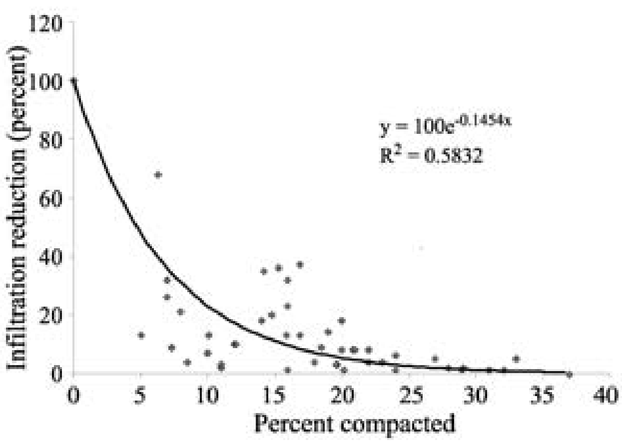
Analysis of all data found the percentage of samples exceeding the 15% compaction standard on loam and silt loam soils by dry season vs. moist season equipment operation to be 0% vs. 2% for 1-2 pass areas, 30% vs. 42%

for secondary trails, and 52% vs. 71% for primary trails, respectively. For the sandy loam soils, the numbers were 0% vs. 10% for 1-2 pass areas, 8% vs. 36% for secondary trails, and 33% vs. 82% for primary trails when logged during the dry vs. moist season, respectively. These data indicate that the sandy loam soils tend to compact less than the loam and silt loam soils during dry season equipment operation, but more during moist season operation. For the rocky soils with loam and silt loam surface textures our data indicated no significant differences by disturbance level between dry vs. moist season equipment operation (Table 2G).

Surface Infiltration

Surface infiltration measurements were performed on both undisturbed sites and selected disturbed sites within units 6, 8, 12, 14, 18 and 20 to determine the relative change in infiltration as a result of density change (Figure 4). Over 50 measurements were recorded from soils with density changes ranging from 5% to greater than 30% relative to the undisturbed density levels. This study found infiltration rates had been significantly reduced. Surface infiltration rates have dropped by over 60% from the undisturbed levels when density levels had increased by 15 percent or more (Figure 4).

Figure 4. Reduced surface infiltration caused by compaction.

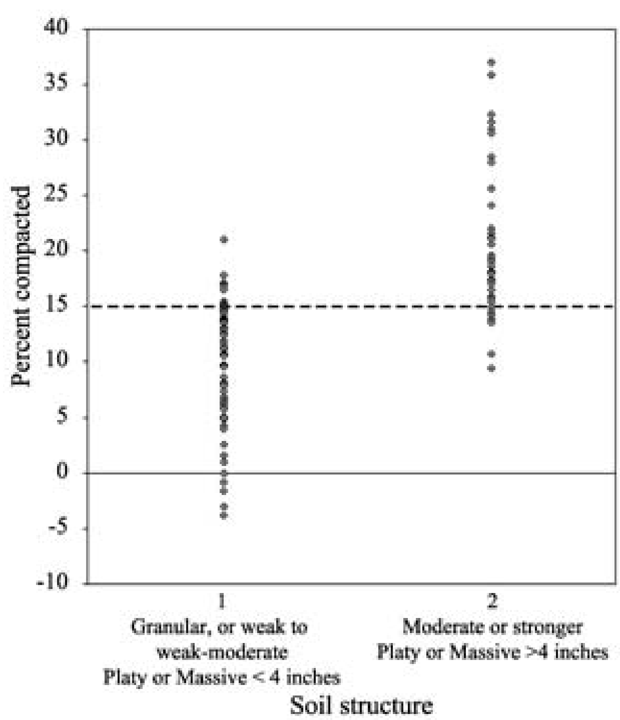


Soil Structure Change vs. 15% Compaction

Physical changes in soil structure were examined, including degree and depth of structural change, to determine if structure could be used to identify a 15% change in soil density. Soil structure had briefly been examined during data collection at all sites, but was more intensely examined on 113 sites during later follow-up work. These follow-up sites included both rocky and non-rocky soils and soils with sandy loam, loam or silt loam textures. On these harvest units the surface soils, in an undisturbed condition were granular in structure, and typically identified as a moderate medium granular structure (USDA NRCS 2002). Those surface soils in a strongly compacted condition (25% density change or greater) nearly always contained a moderate or strong platy structure which typically included the entire 20-cm (8-inch) depth being analyzed.

To determine whether the soil exceeded the Region 8 compaction threshold (15% density increase over the undisturbed level) required more detailed observation of structure. Those soils with a 5-15% density change typically contained a weak or weak-moderate (an inter-grade between weak and moderate) platy or massive structure that was less than 10 cm (4 inches) in total thickness beginning at the surface. In contrast, those soils with a 15-25% density change typically contained a moderate or moderate-strong (an inter-grade between moderate and strong) platy or massive structure that was greater than 10 cm (4 inches) in total thickness (Figure 5). This structure and affected depth combination resulted in a 95% probability of correctly determining whether the soil had either greater than, or less than, a 15% density change. Neither soil rockiness nor soil texture altered this structure or depth combination in relation to change in compaction.

Figure 5. Use of soil structure to determine 15 percent change in bulk density (Region 8 compaction threshold).



Confidence level that 1 ≤ 15% and 2 ≥ 15% density change: P ≥ 0.05

Discussion

We found soil compaction to be a serious concern on some soils on the Ouachita National Forest, especially when silvicultural harvest operations using conventional rubber tire skidder logging equipment are conducted during the moist season, when antecedent soil moisture levels are high. Other studies have also found that moisture condition of the soil itself at the time of heavy equipment operation is the most important precursor to compaction (Day and Holmgren 1952; Froelich et al. 1980; Hatchell et al. 1970). Day and Holmgren (1952) using three different levels of compactive force, found the soil to be 2.4 to 3.0 times more compacted when these forces were applied to moist soil vs. dry soil. Our study comparing moist vs. dry season logging did not show as large a difference. This is probably due to the fact that antecedent soil moisture conditions fluctuate during both moist season and dry season. They tend, however, to remain generally wetter during the moist season and drier during the dry season.

Results from individual units in our study known to have very moist soils during equipment operation (units 2, 13, 14, and 18) indicate that the soils in these units were up to twice as compacted as similar dry units. These very moist soil units would be more in line with Day and Holmgren's (1952) findings above. During very moist soil conditions, equipment logging operations also tended to become more and more dispersed. This is typically done with the good intention of desiring to avoid unnecessary or severe impacts to the soil. This dispersal practice, however, has not worked well to reduce equipment impacts, particularly on non-rocky soils which are most susceptible to compaction, as demonstrated in unit 13 of our study.

Our study found that, for non-rocky soils during moist season equipment logging, a secondary skid trail exhibited about the same degree of change in bulk density as a primary skid trail did on the same soil during dry season logging (Table 3). Both of these mean bulk density changes (14%) are close to exceeding the compaction standard of 15%. Similarly, primary skid trails, log decks and temporary roads were about 50% more compacted during moist season equipment logging vs. dry season logging (Table 3). These findings are in line with those of Hatchell et al. (1970), who concluded that one equipment pass under moist soil conditions was equivalent to four equipment passes under dry soil conditions. The 20-50% decrease in mean density levels from dry season logging (relative to the moist season) found on our non-rocky soils indicates that managing the season of heavy equipment use can be an effective way to help minimize compaction on a forest wide scale.

Our results indicate that soil bulk density increases somewhat proportionately to increasing levels of disturbance. Figures 1-3 show a stair-step pattern of mean

Table 3. Change in mean bulk density (g/cm^3) and percent compaction by disturbance level, by soil rockiness group and season of equipment operation.

Soil Rockiness Group	Dry Season Equipment Operation	Percent Increase in Bulk Density (% compacted)	Moist Season Equipment Operation	Percent Increase in Bulk Density (% compacted)
0-15% gravel rock soils "Non-Rocky"				
Natural (undisturbed)	1.32		1.32	
1-2 passes	1.38	5	1.42	8
Secondary trail	1.47	11	1.50	14
Primary trail	1.51	14	1.60	21
Log deck/road	1.55	17	1.67	27
Old disturbance	1.45	10	1.44	9
15-35% gravel rock soils "Rocky"				
Natural (undisturbed)	1.32		1.32	
1-2 passes	1.37	4	1.39	5
Secondary trail	1.42	8	1.44	9
Primary trail	1.44	9	1.46	11
Log deck/road	1.49	13	1.60	21
Old disturbance	1.41	7	1.42	8

density levels from the natural (undisturbed) levels to the greatest change at the log deck/native surface road disturbance level. On non-rocky soils, mean soil density increased from 5% at 1-2 passes, to 11% on secondary skid trails, and 14% on primary trails under dry season operations, versus 8%, 14% and 21% for these same disturbance levels, respectively, during moist season equipment operations (Table 3). This compares closely with Hatchell's (1970) findings where they found compaction to be twice as great on primary skid trails as on secondary trails on nine treatment units in South Carolina and Virginia.

When considering the use of rubber tire skidders in logging operations, for non-rocky soils we can expect log decks, native surface roads, and primary skid trails to be excessively compacted under most antecedent soil moisture conditions. Under moist soil conditions, however, secondary skid trails may similarly be excessively compacted. As Stokes et al. (1997) have shown from their study on area extent in primary and secondary skid trails for typical silvicultural systems on the Ouachita National Forest, operating logging equipment during dry soil conditions can make the difference if a unit passes or fails the Region 8 soil quality standard for compaction for harvest units having non-rocky surface soils.

We found that surface soils containing between 15-35 percent by volume of gravel rock content resulted in 30-50 percent less density change than soils containing from 0-15 percent by volume gravel rock. These results are in line with an unpublished independent follow-up study by Barkhimer (2000). Barkhimer used a modified Proctor Test to compare two levels of gravel rock content on loam and sandy loam soils collected from the Ouachita National Forest. He found that between antecedent soil moisture levels of permanent wilting point and field capacity, the soils were 0-20% less compactable when 15% by volume gravel rock was added, and 40% to more than 100% less compactable when 35% by volume gravel rock was added to these soils.

For rocky soils, our study found no significant differences between dry season vs. moist season equipment logging (Table 2). Neither season of equipment operation nor soil texture played a significant roll in soil compaction on rocky soils. Mean density levels exceeded the 15% compaction standard only on log decks and temporary roads during moist season logging operations (Table 3). Primary skid trails tended to exceed the compaction standard only under very moist soil conditions. Generally, however, the area extent of soil compaction itself did not exceed the soil quality standard. Other than for very moist soil conditions and high traffic areas such as log decks and temporary roads, the 15-35% rock content of these soils tended to be effective in buffering against excessive compaction. By extrapolating these results to soils containing greater than 35% rock content we would expect even less compaction to occur.

Old disturbance sites exhibiting compaction did not reflect the same lower dry season/higher moist season density fluctuation we typically found with current levels of disturbance (Tables 2 and 3). This is because season of equipment operation during prior entries could not be determined, as these records have long since been discarded. The result is that there is an equal chance this old disturbance could have occurred during either period. We would therefore expect to find little or no change in mean bulk density due to the current season of operation, as was typically the case. Average percent compaction found on old disturbance areas was about 9-10% for the non-rocky soils compared to about 7-8% for the rocky soils (Table 3). This represents an approximate 20% reduction in bulk density change on rocky soils as compared to that found on the non-rocky soils. Although this 20% change did not prove to be significant (Table 2), it is to be expected and supports the above findings that rocky soils are less compactable than non-rocky soils.

Surface infiltration was studied to determine what effect compaction might have on soil infiltration rates on this Forest. This work indicated that a relatively small increase in soil density caused by compactive forces will result in a large decrease in infiltration rate. Surface infiltration drops rapidly from undisturbed soil density levels to almost no infiltration as soil density increased to 25% or greater (Figure 4). This can have a negative impact on both soil productivity and the watershed's natural hydrologic functioning. A reduced infiltration rate can result in less water entering the soil profile for future plant uptake and growth. In addition, water not entering the soil adds to overland runoff, resulting in increased on-site erosion, channel destabilization and downstream flooding.

Our study found some evidence that old disturbance areas have partially self-mitigated since the previous harvest entry. The old disturbance compaction we observed in this study was caused from harvest equipment activities that occurred at least 15-20 years earlier. Old disturbance areas are composed of secondary or primary skid trails and areas that received 1-2 equipment passes. Temporary roads and log decks are not included in old disturbance level findings from this study, as these areas were reused again during the recent entry.

The amount of natural soil bulk density mitigation since the last disturbance can be estimated by comparing the average density change from the three current disturbance mean density levels of the primary and secondary skid trail densities and areas receiving 1-2 passes, to the old disturbance density level. By multiplying this difference by a 15-20 year recovery period, and relating this back to the current old disturbance density level, we estimate it would take from 50-80 years for skid trail soil density levels to recover to near natural density levels. This estimated recovery period is in line with other findings. Perry (1964) estimated a 40-year recovery period for reduced infiltration rates on old compacted woods roads to approach natural rates on a southern Arkansas soil. In the Pacific Northwest, it has been suggested that it would take 100 years or more for compacted areas to recover to near natural density levels (Froelich et al. 1980).

Our study also examined changes in soil structure vs. degree of compaction. Altered soil structure, as a result of compaction, has commonly been used to help determine when a soil has, or has not, exceeded a given compaction standard. Altered soil structure is visible in both degree and extent when examined with a spade. Our intent was to calibrate this structural change, degree and extent with soils on the Ouachita National Forest to equate to a 15% soil density change (our Region 8 soil compaction standard).

This study determined that there is a 95% probability that Ouachita National Forest soils exhibiting a moderate or stronger platy or massive structure, with a total affected depth of 10 cm (4 inches) or greater, equates to a 15% or greater density change. Conversely, those soils exhibiting a granular structure, or, a weak, or weak-moderate (intergrade between weak and moderate) platy or massive structure, with a total effected depth of less than 10 cm (4 inches), equates to less than 15% density change (Figure 5). This structural change information can be used as an indicator in future monitoring efforts in determining whether our forest land management practices meet the Region 8 soil quality standard for compaction.

Conclusion

Soil compaction has been shown to result in a rapid loss of surface infiltration. Compaction has been found to be a concern on the Ouachita National Forest on non-rocky soils where conventional harvest equipment logging occurs during moist antecedent soil conditions. Compaction can be minimized on non-rocky soils by logging during dry soil conditions. On rocky soils, logging during moist soil conditions is not as great a concern, as the soil rock content acts as a buffer to compaction. We have also shown that the Region 8 soil quality compaction standard of 15% density change can be detected visually by noting change in soil structure.

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Monitoring to Improve the Understanding of Herbicide Fate and Transport in the Southern Sierra Nevada, California

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Reforestation efforts on the Sierra and Stanislaus National Forests (California) in the 1990s included use of the herbicide, hexazinone. This herbicide is the most water-soluble and water-mobile of those approved for use under a Regional EIS (Environmental Impact Statement) for vegetation management. To better understand hexazinone movement in soil and water typical of areas being reforested, monitoring at operational units was carried out. Two monitoring efforts are described here. In the first, instrumentation to detect hexazinone in the soil, vadose zone water, and surface water runoff was used to monitor the effectiveness of a stream buffer zone. Initial chemical application was to a 6.1 by 7.6 m test plot upslope from an instrumented area. Water and soil samples were collected after five significant storm events. The following year, an operational chemical application was made to the unit containing this instrumentation. Samples were collected after four significant storm events. Hexazinone was detected in the vadose zone to a depth of 1.8 meters and for a slope distance of 6.1 meters. The difference between the test plot and operational applications was an order of magnitude greater concentration detected in both vadose water and surface runoff. While hexazinone did penetrate into the buffer zone, it was well below concentrations of concern. In the second monitoring effort, on the Stanislaus National Forest, groundwater monitoring wells were installed in selected reforestation units to verify levels of hexazinone entering groundwater and examine its persistence. A total of five monitoring wells were sampled. Wells sampled the unconfined upper aquifer above competent bedrock and typically varied between 2.9 m to 10.1 m in depth. If hexazinone was detected, typically 1 to 2 years had passed between hexazinone application and detection in groundwater samples. While the concentrations generally dropped after initial detection, it took between 2 to 3 more years before it fell below the detection limit. Monitoring demonstrated that hexazinone detected in groundwater was well below the concentration established by the State of California as a water quality goal.

Keywords: *herbicides, monitoring, water quality, groundwater, surface water, soil*

Introduction

The Forest Service Pacific Southwest Region (R-5) (Figure 1) published an Environmental Impact Statement (EIS) in 1974 to address reforestation methods (USDA Forest Service 1988). In the years following, public concern regarding use of herbicides and possible effects of vegetation management on the forest environment changed, as did environmental regulations and the herbicides registered for silvicultural use (USDA Forest Service 1988). A moratorium on herbicide use in the Pacific Southwest Region was instituted in 1984 in response to federal court rulings.

In response to these changes, a final Environmental Impact Statement (FEIS) for vegetation management for reforestation was issued in December 1988 (USDA Forest Service 1988). The Record of Decision (ROD) issued in February 1989 selected an alternative that provided for the limited use of herbicides in reforestation efforts (USDA Forest Service 1989). The ROD reiterated several mitigation measures for herbicide use from Table 2-7 of the FEIS. One of these measures stated, "Do not use hexazinone, picloram, dalapon, or dicamba where they are expected to enter groundwater or surface water, such as when soils are very sandy or have low clay or organic matter contents." A clarifying letter to Forest Supervisors on 30 October 1990 from the Regional Forester noted that this mitigation measure did not mean a zero tolerance

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Figure 1. The Pacific Southwest Region showing the location of National Forests relative to geographic features in California. Note the Sierra and Stanislaus National Forests in the southern Sierra Nevada.

for the stated herbicides entering groundwater or surface water. Rather, a site specific analysis should identify high risk situations where this mitigation would be applied. Another mitigation measure in Table 2-7 of the FEIS stated, "Monitor herbicide residues in soil and ground and surface water to identify patterns of herbicide persistence and mobility at sensitive sites." This direction clearly required monitoring to validate site specific analyses and decisions on hexazinone use.

Of the four chemicals noted in the mitigation measure, only hexazinone was considered appropriate to the treatment prescriptions. Neary et al. (1983) noted hexazinone has high water solubility (33,000 ppm by weight at 25°C), making it likely to move off-site with storm runoff and leach to groundwater. Therefore, it became the focus of concern for much of the groundwater and surface water monitoring on reforestation projects in the southern Sierra Nevada. Earth scientists working on national forests in the southern Sierra Nevada were faced with predicting the pattern for mobility and persistence of hexazinone as input to environmental documents prepared for reforestation projects. They also needed to define locations where hexazinone should not be used in vegetation management prescriptions.

Unit 505 Monitoring – Sierra National Forest

Test Plot Applications

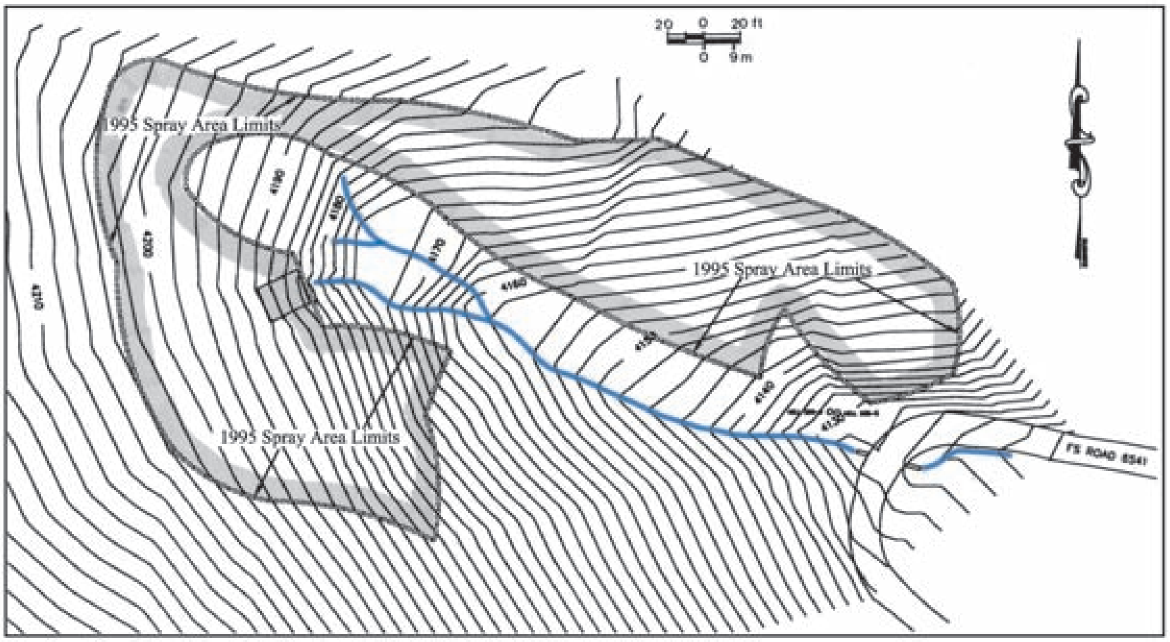
The Sierra National Forest undertook a number of small reforestation projects in the early 1990s. The mixed conifer forests in these areas were generally second-growth, following the cutting of the old-growth during the early 1900s. Harvest of this second-growth forest in the 1980s had occurred partly in response to the combined effect of drought and insect attack. Unlike earlier logging efforts, the recent harvest had included clear-cut units. In some of these harvest units, grass and brush competition significantly hampered re-establishment of conifers in subsequent reforestation efforts. Mechanical methods were not wholly successful in reducing this competition. Herbicide application was then undertaken to improve the success of reforestation efforts.

Buffer zones are a common mitigation to prevent impacts to water quality. In 1993, a question arose about the adequacy of buffer zones applied to Class 4 channels. Class 4 channels are the minor drainage ways that typically channel water into more defined channels only during snowmelt runoff or during intense rain storms. A buffer 7.6 meters on either side of the Class 4 channel centerline was excluded from application of herbicides for individual reforestation projects on the Sierra National Forest. The widespread distribution of Class 4 channels would lead to serious problems in operations to apply herbicides if the buffer zones needed to be wider than 7.6 meters.

A site was chosen in 1993 for an intensive monitoring effort to examine the adequacy of the 7.6-meter buffers on Class 4 channels. This monitoring effort clearly represented implementation of the mitigation measure, "Monitor herbicide residues in soil and ground and surface water to identify patterns of herbicide persistence and mobility at sensitive sites." While scientific literature on hexazinone persistence and mobility was available for the southeastern United States, no studies had been done for the southern Sierra Nevada, and it was questionable whether results from such a different and distant region could be applied to central California conditions.

The chosen site, Unit 505, was one of several herbicide treatment units in an approved vegetation management plan for part of the Bass Lake Ranger District of the Sierra National Forest. Unit 505 lies within the Lewis Creek watershed about 5 km north of the town of Oakhurst, California. The vegetation, slope, and soil present in Unit 505 are representative of many areas where hexazinone was being considered as a treatment option. The elevation is 1340 m, on generally east-facing slopes. Soil mapped as Holland Series overlies the Tonalite of Bass Lake at this

Figure 2. A detailed topographic map showing the outline of the Unit 505 operational area (wide gray shaded border). The alignment of the Class 4 channel is shown in blue. The larger rectangle is the outline of the protective fence with the inner rectangle delineating the application area and instrumented area within the buffer zone.



site. At the beginning of the study, the ground surface was covered by grasses with scattered concentrations of bear clover.

The monitoring plan specified establishment of a 6.1 m by 7.6 m plot (46.5 m^2) for applying hexazinone, adjacent to the upper boundary of the buffer zone of a Class 4 channel (DeGraff et al. 1994) (Figure 2). Transect lines for soil samplings were established within the application area and the adjacent buffer zone in order to determine the concentrations of hexazinone at the ground surface where the herbicide was applied, and where herbicide attached to soil particles might be washed down slope. Leaching to shallow groundwater was evaluated using pressure vacuum lysimeters, consisting of PVC tubes with a ceramic tip, installed on three lines parallel to the slope contour. The first line was at the application plot/buffer boundary, while the second and third lines were placed at 3.1 m and 6.1 m down slope from the boundary, respectively. Along each line, three sets of 0.6-m- and 1.2-m-long lysimeters were installed, with a set in the center of the line and the others 1.5 m to either side of the center set (Figure 3). The exception to this array was along the line placed 6.1 m down slope, where a 1.8-m-long lysimeter was added to this arrangement. Vadose zone water was collected from the lysimeters by placing a vacuum on each one following each storm event. Fluid was extracted two to five days later into sample bottles.

Surface runoff was intercepted at a 4.6-m distance down slope from the application plot/buffer boundary where a stiff plastic barrier was embedded into the soil. The barrier was attached to a pipe that directed the collected surface water into a container housing a 1000-mL sample bottle. After each storm event, the filled or partially filled sample bottle was collected for analysis.

On 15 March 1994, liquid hexazinone was applied to the plot using a backpack sprayer (Figure 4), at the treatment rate of 1.4 kg of active ingredient per 0.4 ha prescribed for the operational treatment of Unit 505.

Figure 3. A view down slope from the application area toward the Class 4 channel that runs from left to right across the background. The clusters of lysimeters are visible on the boundary of the application area and buffer zone and along the line 3.1 m down slope. A black plastic barrier at 4.6 m diverts surface runoff to the surface water sampler.

Figure 4. A view of the monitoring installation in Unit 505 surrounded by a protective fence. The application area is visible in brown following the initial hexazinone treatment.

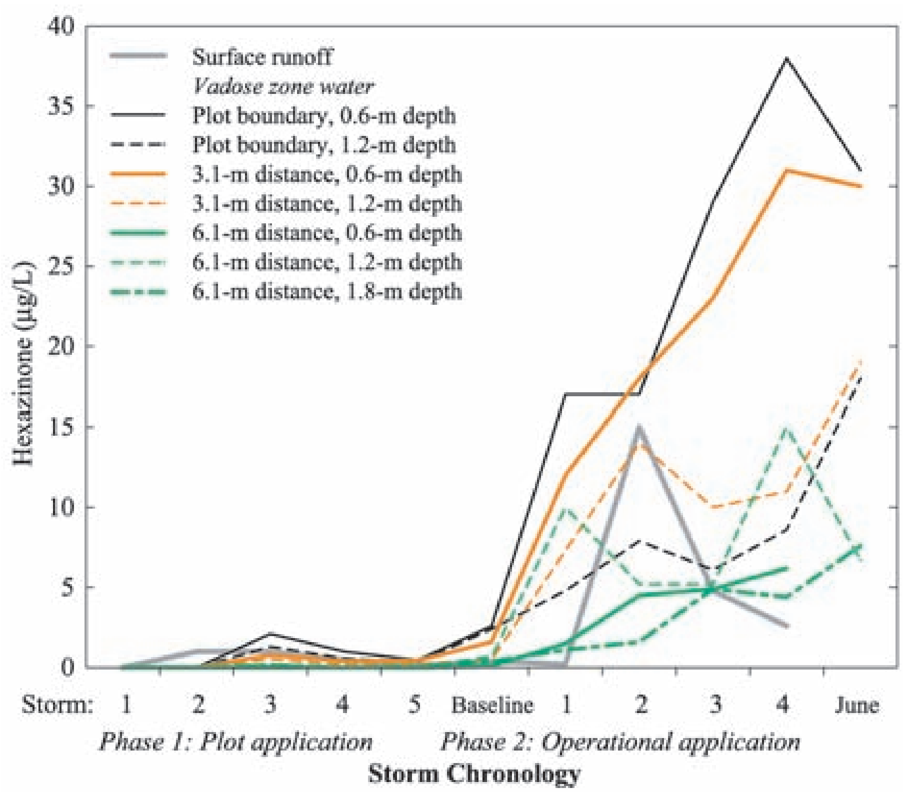
No hexazinone applications had previously occurred in this unit or anywhere else within the watershed where this unit is located. The absence of hexazinone residues was confirmed by sampling of soil transects in the application area and by testing soil excavated during lysimeter installation prior to application.

Five significant precipitation events affecting the application area took place between 15 March 1994 and 31 May 1994. A total of 185.4 mm of precipitation was recorded between these dates at the daily storage gauge located at Batterson Work Center, about 4 km from the site and 1305 m lower in elevation. Daily precipitation totals ranged from 27.9 mm to 2.5 mm, with the events on 24 March, 8 April, and 19 May being generally light rainstorms. Some of these events were preceded by one to two days of lower precipitation. A rainstorm on 23 April continued through 25 April and turned to snow with falling temperatures. The fifth storm event was a thunderstorm on 30 May yielding some intense rainfall.

No hexazinone was detected in surface water after the first storm event on 24 March (Figure 5). The highest concentration in surface water of 1.0 µg/L was found after the second storm on 8 April. The 23 April sample was lost due to breakage during transport. However, the remaining two storm events yielded surface water hexazinone concentrations of 0.49 µg/L on 19 May and 0.11 µg/L on 30 May. It should be noted that the surface water sample for the 19 May storm event was taken earlier from preceding rainfall. The change to snowfall on 19 May resulted in no surface runoff at that time.

No hexazinone was detected in vadose zone water withdrawn from the lysimeters after the first storm (24 March) or the second storm (8 April) (Figure 5). After the third storm (23 April), hexazinone was detected in the 0.6-m lysimeters at the application plot/buffer boundary and in the line 3.1-m down slope, but not at 6.1 m down slope, where the 0.6-m lysimeters are down slope from the surface water intercepting barrier. It was also detected in the 1.2-m lysimeters on the plot boundary, and at the lines

Figure 5. Chart comparing concentrations of hexazinone found in the surface runoff and vadose zone water following plot and operational applications.



3.1-m and 6.1 m down slope. Hexazinone was detected in the 1.8-m lysimeters installed only along the line 6.1 m down slope. As expected for a material leaching into the soil, the concentrations detected at any depth were highest for the points closest to the application area and decreased down slope. Similarly, the concentrations at any particular line of lysimeters decreased with depth. With subsequent storms, this pattern of concentration values persisted but with decreasing concentrations. The highest concentration detected in vadose water was 2.1 µg/L.

Surface soil was collected from both the application area and the buffer zone. Within the application area, soil samples were collected at the beginning of the months of April, May, June and September. Samples were soil plugs 7.6 cm deep, collected along two transects and combined for analysis. The highest 1994 concentrations found in the application area were 910 µg/L (April), 880 µg/L (May), 330 µg/L (June), and 40 µg/L (September). Surface soil sampling within the buffer zone took place along transects aligned at 1.5 m and 3.1m down slope from the application plot/buffer zone boundary. These samples were 2.6 cm-deep plugs of soil collected after the first, third, and sixth storm events. Buffer zone sampling attempted to determine how much hexazinone was transported down slope via attachment to surface soil particles. Hexazinone was detected at 15 µg/L (1.5-m transect) and 13 µg/L (3.1-m transect) in the surface soil of the application area after the third storm. It was not detected in samples taken after the first or sixth storm events. Hexazinone may have been present at concentrations less than 10 µg/L, as the extraction process from soil resulted in this higher detection level than analysis of water samples.

The plot results showed that hexazinone would penetrate at least 4.5 m into the 7.6-m buffer zone in surface water, at least 3.1 m in surface soil, and leach to a depth of 1.8 m at 6.1m into the buffer zone. This demonstrated that a larger quantity of the chemical was moving into the buffer zone than anticipated. Sampling also found higher concentrations of hexazinone in vadose zone water than in surface runoff. However, no concentration detected exceeded the then-current 200 µg/L regulatory limit for hexazinone. This 200 µg/L limit was the State of California adopted water quality goal, and represents the Environmental Protection Agency's lifetime health advisory value (EPA 1988), which represents the portion of an individual's total hexazinone exposure from drinking water, and is meant to limit lifetime adverse health effects due to exposure to carcinogenic substances. The highest detected value within the buffer zone, the 15 µg/L surface soil value, is clearly significantly lower than the State of California regulatory limit for this chemical.

Operational Application

To ensure that plot results represented actual operational results, a second phase of monitoring involved the planned treatment of Unit 505 with hexazinone (Figure 4). The same instrumentation was left in place to monitor surface soil, surface runoff , and leaching into the soil. Treatment of the unit took place on 15-16 March 1995. Again, backpack sprayers were used to apply the hexazinone at the rate of 1.4 kg of active ingredient per 0.4 ha.

Prior to the first storm following treatment, the samples were collected of surface water runoff, soil from transects within the buffer zone, and vadose zone water from the lysimeters. Nearly one year after the plot treatment, surface water runoff was found to have concentrations of hexazinone at 0.9 µg/L, at non-detectable concentrations in surface soil, and at maximum concentration of 2.6 µg/L in vadose zone water. This represented the baseline situation prior to the operational application in March 1995.

Four significant storm events occurred following the operational application of hexazinone to Unit 505, between 20 March and 15 May 2004. As measured at the storage gauge at Batterson Work Center, these storms generated a total of 160 mm of precipitation. Daily totals on 22 March, 17 April, 5 May, and 15 May ranged from 16.5 mm to 30 mm. Rainfall the day preceding the storm peak day ranged from 0 to 17.3 mm.

Hexazinone detected in surface water during the 22 March storm event was at 0.2 µg/L (Figure 5). During the second storm (14 April), the maximum concentration of 15.0 µg/L was found in the surface water sample. The third storm sample (5 May) and fourth storm sample (15 May) were found to have 4.8 and 2.6 µg/L of hexazinone present, respectively.

Hexazinone concentrations in vadose zone water jumped from the maximum pre-application value of 2.6 µg/L to 17 µg/L after the first storm event (Figure 5). It was 18 µg/L after the second storm event. Concentrations increased to 29 and 38 µg/L following the third and fourth storm events, respectively. All the samples extracted from the lysimeters, regardless of depth or position on the slope, were found to have concentrations of hexazinone greater than the those found during the baseline analysis before the first storm event. The distribution of concentrations among the lysimeters at each sampling event was similar to that encountered following the plot application; the values detected at any depth were highest for the points closest to the application area and decreased down slope. Likewise, the concentrations at any line were greatest at the shallowest depth and decreased with depth. The difference between the plot application and the operational application was that while this pattern of concentration values persisted, it was with increasing rather than decreasing concentrations. A general decrease in concentrations of hexazinone was not detected until post-rainy season sampling in June 1995 when the highest concentration had dropped to only 31 µg/L.

Again, transects aligned at 1.5 m and 3.1 m down slope from the application plot/buffer zone boundary were used for surface soil sampling. Samples were collected in the upper 2.5 cm of soil after the first and third storm events, and in follow-up monitoring in June 1995. Unlike sampling after the first storm following plot application, hexazinone was detected in samples taken after the first storm event. The maximum concentration along the 1.5-m transect was 1200 µg/L and along the 3.1-m transect at 20 µg/L. Sampling after the third storm detected hexazinone at 20 µg/L (1.5-m transect) and 30 µg/L (3.1-m transect) in the surface soil of the application area. This dropped to 10 µg/L along both transects in the follow-up sampling done in June 1995.

The concentrations of hexazinone detected after operational application were significantly higher in surface and vadose zone water and in surface soil compared to the plot application. However, the patterns of change in concentrations found over time and space were similar (Figure 5). Hexazinone concentration was highest in the surface water from the second storm event following each application. In the vadose zone, the peak concentrations lagged one to two storms behind the surface water peak, and the pattern of changing concentrations down slope and at depth was similar. Again, the maximum concentration of hexazinone in surface water was about half the maximum concentration detected in vadose zone water. However, the concentrations of hexazinone for both plot and operational applications were below the water quality goal of 200 µg/L, except for one surface soil sample at the 1.5-m transect taken after the first storm event following operational application. Higher concentrations persisted longer in the vadose zone after the operational application than after the plot application.

The Unit 505 monitoring clearly showed that hexazinone in the surface water runoff and on surface soil penetrates a significant distance into the buffer zone for Class 4 channels. It also demonstrates that leaching of hexazinone in the vadose zone water moves laterally down slopes into the buffer zone and vertically to at least a 1.8-m depth. However, it also shows that the concentrations are unlikely to approach or exceed the State of California water quality goal for hexazinone, except for surface soil washed about a meter into the buffer zone during the first storm following operational application.

Post-wildfire Reforestation Monitoring–Stanislaus National Forest

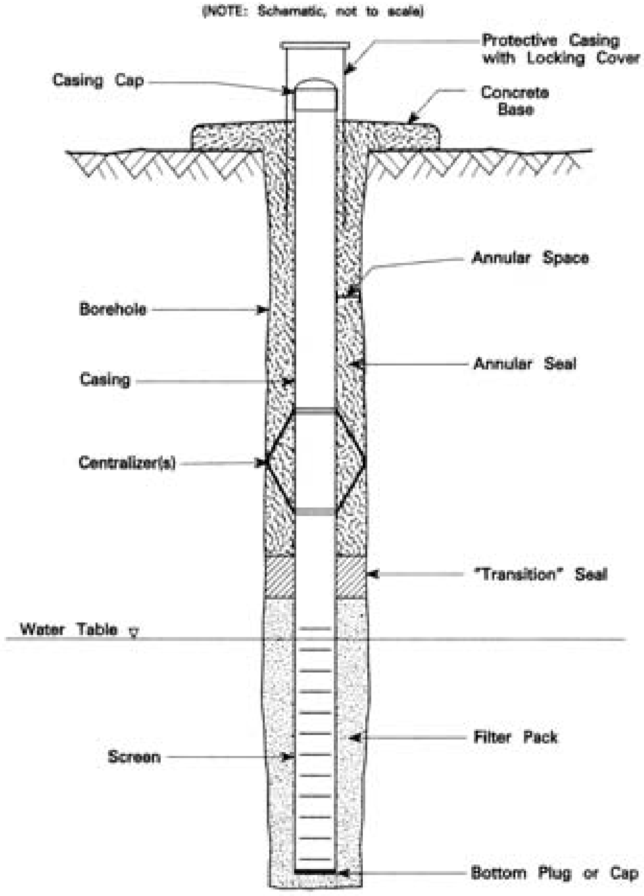
In August 1987, several major wildfires were ignited by dry lightning on the Stanislaus National Forest. These wildfires expanded into each other to create the Stanislaus Complex wildfire that eventually burned 59,489 ha on the Mi-Wok and Groveland Ranger Districts (Frazier and Grant 2003). Reforestation efforts experienced significant problems in grass and brush competition and resulted in plans to use herbicides to improve seedling survival and growth. Public opposition delayed implementation of this work until the late 1990s. Several additional wildfires adjacent to the Stanislaus Complex, such as the Arch Rock and Ruby fires, added more areas in need of reforestation during this time.

Hexazinone was one of the herbicides planned for use in this reforestation effort. Development of the alternatives excluded use of hexazinone on any treatment unit where a reasonable chance existed for it to contaminate existing wells. In order to validate the mitigation measure, "Do not use hexazinone, picloram, dalapon, or dicamba where they are expected to enter groundwater or surface water, such as when soils are very sandy or have low clay or organic matter content," monitoring of both water sources was undertaken.

Logistical and physical conditions constrained the location of groundwater monitoring. Where possible, groundwater and surface water monitoring was co-located to demonstrate whether concentrations of hexazinone in surface water were strictly due to surface runoff or included a base flow concentration from groundwater. Efforts were made to identify monitoring sites within each major drainage of the project area where units to be treated with hexazinone were located. A major physical constraint on final selection was whether a road existed to allow the drill rig to install a groundwater monitoring well at the down slope end of the treatment unit.

Monitoring wells were installed to enable sampling of groundwater at the base of the unconfined upper aquifer extending from the ground surface to the base of the overlying regolith. This permitted installation of the monitoring wells using a hollow-stem auger. Drilling would cease at auger refusal when it penetrated to the regolith-rock interface. The drill hole was logged, as was the installation of the monitoring well. Each monitoring well was a 5.1 cm diameter well cased with a combination of PVC pipe and stainless steel screening (Figure 6). Wells were installed to the standards for monitoring wells promulgated by the California Department of Water Resources Department (CDWR 1991).

Figure 6. A schematic diagram illustrating a typical monitoring well installation and its main components (CDWR 1991). Wells used on the Stanislaus National Forest were too shallow to require a centralizer.



On the four reforestation projects, a total of twelve groundwater monitoring wells were installed. While most monitoring wells were drilled in areas of granitic bedrock, several were within volcanic or metamorphic bedrock areas. Of the twelve wells, one was destroyed by reforestation work after its initial baseline sampling took place. Seven others were rendered unusable because of a decision to modify the treatment by omitting use of hexazinone, or due to lack of sufficient rainfall following application for mobilizing hexazinone.

Groundwater was sampled from each well using a bailer (Figure 7). Bailers were dedicated for each well to avoid cross-contamination, and water present within the well casing was purged prior to taking a sample. The volume of water present was determined by using an electric water level indicator to measure the depth to water. Calculations would then determine how many times the bailer would have to be used to remove the entire stored volume. The temperature and pH of the water was taken prior to starting the purge and after the first and second purges were completed. Typically, the temperature dropped and a shift in pH was noted between the pre-purge and first purge values. If the second purge values were identical to those after the first purge, it was concluded that a water sample would be representative of the groundwater present around the well screen. In some instances, a third purge was done because of continuing differences in temperature and pH. Following purging of the well, a water sample was collected using the bailer and placed in 1000-mL glass bottles provided by the commercial laboratory where the samples would be taken for analysis. Duplicate samples were included among those collected from different wells to provide a check on laboratory analysis. The bottles were placed in cooled chests and transported to the laboratory to avoid exceeding the appropriate hold time prior to analysis. The same analysis laboratory was used for all the samples taken from the Stanislaus National Forest projects.

For any particular monitoring well, groundwater sampling took place just prior to the initial application of hexazinone to the treatment unit. This provided a baseline to demonstrate that hexazinone was not already present in the groundwater. Initial post-treatment sampling took place after the first major storm event following application of hexazinone. A major storm was defined as one that provided fifty or more millimeters of rainfall to the unit. In subsequent years, samples were collected in the spring following the winter rainy season, or after snowmelt took place, depending on the elevation of the monitoring well location.

Figure 7. The senior author (DeGraff) purging monitoring well BS-45 with a bailer on the Stanislaus National Forest. A second bailer is used to collect the sample after well purging. A housing installed flush to the ground surface protects the well between sample events. See Figure 6 for details.

Among the four wells successfully used to sample groundwater, hexazinone was not detected at concentrations that approached, much less exceeded, the State of California water quality goal of 200 µg/L (Table 1). It should be noted that the Environmental Protection Agency revised its health advisory during this period. This resulted in the State of California easing its water quality goal for hexazinone to 400 µg/L. The rate of application for hexazinone, in pellet form, for the treatment units where the groundwater monitoring wells were sited varied from 33.6 to 41.4 kg/ha.

Hexazinone was not detected during the year of application in any of the monitoring wells (Table 1). For wells where application was ground based, it was detected in the first year following application (second year sampling). For wells where aerial application took place, hexazinone was not detected until the second year following treatment (third year sampling). However, the sample size is too small to make any inference from this observation. What is not surprising is the delay before detectable amounts of hexazinone were found in groundwater samples. Neary et al. (1993) had noted that movement of hexazinone in shallow groundwater took from months to a year following hexazinone application before detection. Based on the Stanislaus National Forest sampling, hexazinone demonstrated multi-year persistence, lasting from one to four years following detection. Again, this is too small a sample upon which to base broad conclusions.

Conclusions

Both the Unit 505 monitoring and post-fire groundwater monitoring well results demonstrate that hexazinone used in reforestation efforts in the southern Sierra Nevada does enter unsaturated and saturated groundwater zones. Monitoring to date does not find those detected concentrations approaching or exceeding the initial State of California water quality goal of 200 µg/L or the later less restrictive value of 400 µg/L.

On the Sierra National Forest, Unit 505 monitoring demonstrated that hexazinone can penetrate a significant distance into the 7.6-m buffer on either side of a Class 4 channel centerline. The detectable concentrations are a full magnitude lower than the State of California water quality goal. The pattern of mobility at these sensitive sites clearly shows peak concentrations of hexazinone in surface water following the first storm event and a gradual rise to peak concentrations of hexazinone in the vadose zone water after several storm events.

On the Stanislaus National Forest, monitoring well results yielded persistence information that has implications for groundwater monitoring in future reforestation projects. Plans for monitoring of the saturated groundwater zone should extend for two years of sampling following the year of application to ensure detection of hexazinone. Once detected, hexazinone will likely persist for one to four more years.

Monitoring for herbicide impacts to groundwater requires a significant commitment of time, personnel and funding. However, monitoring information is important to improving project design and demonstrating expected performance to a sometimes skeptical public.

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Table 1. Well number, application data, and detected concentrations of hexazinone (in µg/L) for monitoring wells used on Stanislaus National Forest reforestation projects.

Well	Application Method	Application Rate (kg/ha)	Concentration of Hexazinone (in µg/L) for Year 1	2	3	4	5	6	7
MW 26-12	Ground broadcast	34.7	ND	**2.6**	**3.1**	*NS*	**0.56**	**0.44**	ND
MW 26-21	Ground broadcast	41.4	ND	**0.99**	**2.2**	**0.16**	ND	---	---
MW 26-56	Aerial broadcast	33.6	ND	ND	**0.29**	**0.76**	**0.71**	ND	---
MW BS-45	Aerial broadcast	33.6	ND	ND	**0.17**	**0.28**	ND	---	---

ND - substance absent or below detection limit of test
***NS* - no sample taken**

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Section 4. Valuing the Earth Sciences
Part 2. Geology

Overleaf:
Beartooth Range, Gallatin National Forest, Montana.
Photo by Pete Bengeyfield.

Jökulhlaup in the Wind River Mountains, Shoshone National Forest, Wyoming

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A jökulhlaup burst from an ice-dammed lake at the head of Grasshopper Glacier in the Fitzpatrick Wilderness of Wyoming's Wind River Range during early September 2003. The 12-hectare lake drained an estimated 3.2 million cubic meters of water, down slope, underneath the glacier, and down tributary valleys into the Wind River valley. The outburst flood was recorded at a USGS gage (06221400; drainage area 245 km^2) on the Dinwoody River approximately 33 km downstream from the ice-dammed lake. Jökulhlaups can be triggered by volcanic, seismic, and meteorologic events, and perhaps by climatic warming. Satellite images of the Wind River Mountains show dramatic recession of the glaciers since 1986. Work by Naftz et al. (2002) on the Upper Fremont Glacier (10.5 km south of Grasshopper Glacier on the Continental Divide) shows a warming trend and temperature increase of 3.5°C at high elevations over the past fifty years. It is likely that the Grasshopper Glacier jökulhlaup was triggered by local conditions within the glacier and the outburst lake created by this climatic warming trend. Reconnaissance surveys in the summer of 2004 characterized the geomorphic effects and addressed the hazards associated with the jökulhlaup. Five distinct sedimentation patterns formed in reaches of the river downstream from the glacier. Outburst floods in the Wind River Range will probably recur in the near future, as the glaciers continue to recede.

Keywords: *channel geomorphology, flood processes, geology/geomorphology, glaciation, hydrologic processes, sedimentation, streamflow, woody debris*

Background

A jökulhlaup, or glacial outburst flood, burst from an ice-dammed lake at the head of Grasshopper Glacier in Wyoming's Wind River Range during early September 2003. The 12-hectare lake drained an estimated 3.2 million cubic meters of water downslope, underneath the glacier, and down tributary valleys into the Wind River valley. The outburst flood was recorded at a USGS stream gage (06221400; drainage area 245 km^2) approximately 33 km downstream from the ice-dammed lake. During the period 1956-2001, annual peak snowmelt flow at the gage averaged 23 cubic meters per second (range 14-42 cubic meters per second). On 9 September 2003, the gage recorded a peak of 36.5 cubic meters per second, which rose from a base flow of 7 cubic meters per second on 6 September (Figure1).

Grasshopper Glacier lies on the Continental Divide between high-level erosion surfaces and the eastward-facing cirque walls of the mountain front. The glacier, which flows from south to north, drops 2.8 km from approximately 3647 m down a slope of 0.11 to its snout at 3435 m elevation. Grasshopper Glacier is presently about 2.5 km wide and covers approximately 364 hectares. The catchment of the outburst lake is at most 2.8 km^2, and only a small remnant of the glacier remains in the cirque above the lake. Ice at the margin of the lake is 18-21 m thick. (Figure 2)

The Grasshopper Jökulhlaup

The outburst flood entrained subglacial sediment as it flowed for 2.8 km beneath Grasshopper Glacier. The sediment-laden flood then followed the steep, narrow valley of Grasshopper Creek to the Downs Fork and its confluence with Dinwoody Creek. Here, where the valley widens in a broad u-shaped glacial valley, the flood ponded in an ephemeral lake at the low gradient Downs Fork Meadows 13 km downstream. The flood then continued to step down the valley for another 23 km, to Mud Lake, the gage site, the Dinwoody Lakes, and on to the Wind River. Along most of this route, the flood

Furniss, M.J., Clifton, C.F., Ronnenberg, K.L., eds., 2007. *Advancing the fundamental sciences: proceedings of the forest service national earth sciences conference, San Diego, CA, 18-22 October 2004*. PNW-GTR-689. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Figure 1. Grasshopper Glacier is located in the Fitzpatrick Wilderness, on the Shoshone National Forest, in the Wind River Range about 30.5 km south of Dubois, Wyoming. The USGS stream gage site on Dinwoody Creek is located at the eastern margin of the watershed on the Wind River Indian Reservation. Dinwoody Creek crosses Wyoming Hwy. 287 downstream of the gage site, and is tributary to the Wind River. Map base is USGS topographic series Thermopolis Sheet 1:250,000.

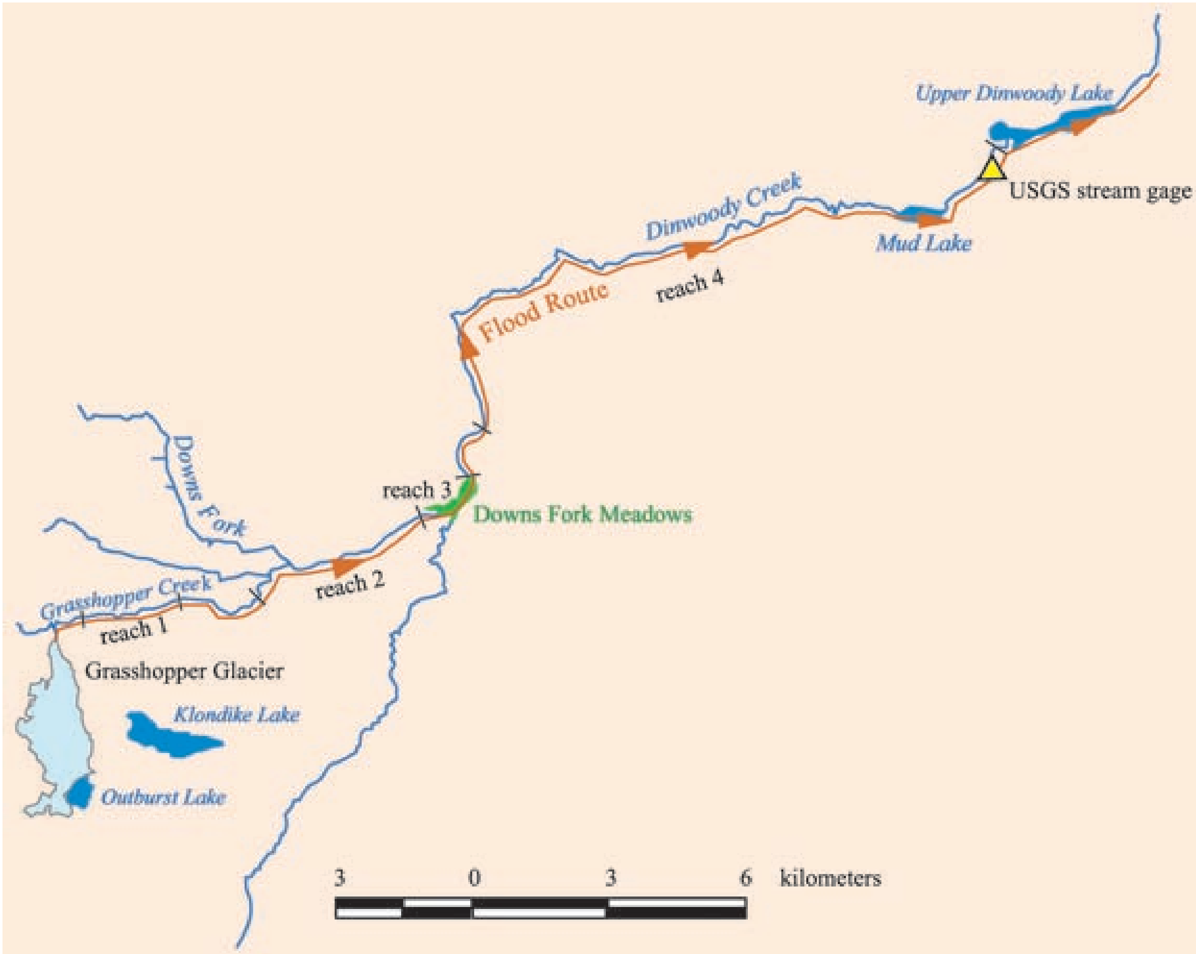

Figure 2. Ice-dammed lake that drained from head of Grasshopper Glacier. The view is to west. The lake drained beneath glacier to the north, and flooded to the north then east down the drainage of Grasshopper Creek, to Downs Fork Creek, and to Dinwoody Creek.

traversed glaciated terrain of granites, migmatites, and gneiss. Paleozoic sedimentary rocks crop out near Mud Lake.

Aerial surveys about two weeks after the flood showed the jökulhlaup had deposited bedload in apparently braided channels from the head of Grasshopper Creek down to the confluence with the Downs Fork. Floodwaters scoured the abutments of the Downs Fork Bridge, then overtopped the bridge and deposited large woody debris, creating a debris jam on the bridge. Suspended sediment roiled through the ephemeral lake at Downs Fork Meadows. When the lake level subsided, 0.6-1.5 m of granitic silty sand were deposited over an area of approximately 28 hectares. Suspended sediment transport continued down Dinwoody Creek, where 1-meter-high standing waves were observed. The creek avulsed from its pre-flood meandering course through the meadow, creating numerous overflow channels, and filling the pre-flood channel with sediment. Downstream nearly 33 km from the outburst lake, Mud

Lake practically filled with sediment. Fine sediment was carried into the Dinwoody Lakes, and was still present in Dinwoody Creek (where it crosses Wyoming Highway 287) at unusually high levels in mid-November 2003.

Jökulhlaups have been attributed to volcanic, seismic, and meteorologic triggers (Cenderelli and Wohl 2001, 2003; Walder and Costa 1996). The warmer summers and shorter, warmer winters likely to accompany climatic warming may also increase the incidence of jökulhlaups as glacial ice melts and thins more rapidly. No direct correlation was found between regional meteorologic or seismic events and the Grasshopper Glacier jökulhlaup, but the jökulhlaup did occur during unseasonably warm weather in the fifth year of a severe regional drought.

The rapid recession of glaciers worldwide is well documented. Satellite images of the Wind River Range (courtesy of Sky Truth, John Amos) show particularly dramatic recession since 1986. Work by Naftz et al. (2002) on the Upper Fremont Glacier, 10.5 kilometers from Grasshopper Glacier, indicates a warming trend and temperature increases of 3.5 degrees Celsius at high elevations in this region during the past 50 years. It is hypothesized that accelerated warming in the high elevation areas of the Wind River Range, as documented in the ice-core record, caused melting and recession of the glaciers, producing increased meltwater which eventually filled the ice-dammed lake perched on the bedrock floor above Grasshopper Glacier, and caused the glacial outburst flood (Naftz et al. in press).

Field reconnaissance surveys conducted in summer 2004 recorded the geomorphic effects of the jökulhlaup as the flood eroded, transported, and deposited sediment and shaped the river and its valley along the flood route. From the draining of the ice-dammed lake (Figure 2) and subglacial entrainment of sediment, five distinct sedimentation patterns were documented in reaches downstream from the glacier. These five reaches are characterized in a downstream direction by: 1) "outwash" deposition of expansion bars; 2) log jams, stream bed aggradation and overbank deposition; 3) channel avulsion and aggradation, and deposition from ponding in an ephemeral lake; 4) in-channel depositional filling of riffles and pools; and 5) silt and clay deposition in lakes and irrigation systems. Also in a downstream direction, median grain size progressively decreased from boulders to cobbles at the expansion bars, to gravels, sands, silts and clays toward the gage site.

Table 1. Summary of characteristics of studied reaches of Grasshopper Creek.

Reach	Distance Below Glacier (km)	Average Valley Gradient	Figure
1	4.2 - 6.1	0.045	3
2	8.2 - 13.2	0.025	4
3	13.2 - 15.3	0.013	5
4	16.7 - 21.2	0.025*	-
5	32 - 38.6	NA	-

**in depositional areas*

Outwash deposition of expansion bars occurred in the most upstream reaches (Table 1) of Grasshopper Creek (Figure 3; Reach One: 4.2 km to 6.1 km; distance measured from outlet of outburst lake at head of the glacier). Valley slope averages about 0.045. Bar deposition spread out across the entire valley bottom, up to 0.2 km wide and 1.4 m high. Log jams, stream bed aggradation, and overbank deposition occurred in a lower-gradient reach with 0.025 average slope (Reach Two: 8.2 km to 13.2 km distant from the outburst lake). Sixteen log jams were recorded that persisted in the valley at the time of the survey. The largest

Figure 3. Expansion bars deposited by flood in upper reaches of Grasshopper Creek. The view is upstream.

Figure 4. One of the many log jams on the Downs Fork. The view is downstream

log jam was at a maximum up to 12 m wide down the length of channel, 35 m across the width of channel, and up to 3.5 m high from the channel bed (Figure 4). At the Downs Fork bridge, large woody debris had been removed in order to "save the bridge". Channel avulsion and aggradation, log jams, and deposition of suspended load in an ephemeral lake occurred in the Downs Fork meadow area, with 0.013 average slope (Reach Three: 13.2 km to 15.3 km) (Figure 5). In-channel depositional filling of riffles and pools occurred below Dinwoody Falls, to below Shangri-La Meadows, and on to the lower reaches of the Dinwoody valley (Reach Four: 16.7 km to 21.2 km and beyond). Slopes averaged 0.025 at depositional areas of these reaches. Silt and clay deposition in lakes and irrigation systems occurred in the lower reaches of the Dinwoody valley at Mud Lake, the Dinwoody Lakes (Reach Five: 32 km to 38.6 km), and irrigation canals and ditches that traverse the lower Dinwoody River to the Wind River floodplain.

Conclusions

No known fatalities, and only minor structural damage to the Downs Fork bridge and disruption of the Downs Fork outfitter camp, occurred in the Fitzpatrick Wilderness as a result of the jökulhlaup. There is an increased flood risk in the upper reaches of the flood area due to aggradation of stream channels. Log jams that formed during the flood created significant geomorphic effects on the river valley. The flood produced a local impact on irrigators of the upper Wind River Indian Reservation, not only due to the siltation of irrigation ditches, but also due to the diminishing glacial reservoirs which the irrigators rely on for late-season irrigation. It is likely that continued warming and melting of glaciers in the Wind River Range will result in future and perhaps more frequent outburst flood events.

Figure 5. Aerial view of Downs Fork Meadows in late September 2003, showing extent of flood deposition in ephemeral lake, channel avulsion, and overbank flows. Left is downstream.

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Reclamation, Remediation, and Hydrologic Monitoring of the Minnie Mine and Mill Site, Okanogan County, Washington

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The Minnie mine, a small cyanide heap leach gold mine near Carlton, north-central Washington was abandoned in the early 1990s. The presence of cyanide and heavy metals in the heap and process waters necessitated a series of removal and remediation actions taken by the US Forest Service under CERCLA and a parallel state law, the Model Toxic Control Act. Some contaminated fluids were batch treated using conventional methods and disposed of by land application (controlled distribution of treated solutions over a specified land area). An innovative pilot-scale In-line System process was successfully used to treat free and complexed cyanide in 45,000 liters of process pond sludges. A soil cap was constructed over arsenic-contaminated, spent ore heap materials to isolate them from people and wildlife. Suction lysimeters were installed below these solids, along with monitoring wells up- and down-gradient, to monitor potential arsenic mobilization. The capped heap, mine pit and associated disturbances were reshaped and successfully revegetated. Eight years of monitoring shows no significant down-gradient arsenic mobilization at the site.

Keywords: *mine restoration, hydrology, groundwater quality, pollution, costs, CERCLA, MTCA*

Introduction

This paper describes the successful efforts to restore the abandoned Minnie mine and millsite in north-central Washington (Figure 1) and to remediate hazardous wastes associated with the site. The paper also highlights the unanticipated efficiency and cost impacts resulting from compliance with parallel federal and state cleanup laws.

Beginning in 1983, Cordilleran, Inc., operator of the Minnie mine, initiated cyanide heap leach technology to recover gold and silver from oxidized quartz-sulfide ore mined in a small open pit located on National Forest System Lands. This operation resulted in the placement of approximately 6,300 metric tons of crushed and cement-agglomerated ore upon a 26 m by 36 m pad underlain by a 30-mil polyvinyl chloride (PVC) geomembrane liner and compacted soil. Pregnant (gold-bearing leachate) and barren (stripped and recycled fluid) process ponds constructed adjacent to this pad were about 15 m by 15 m, by 2.5 m deep, with a capacity of approximately 280,000 liters of ore heap leachate each (Figure 2). Ponds were double lined with 36-mil Hypalon liners separated by geotextile fabric and a leak detection monitoring system. A small carbon absorption/electrowinning plant was constructed to recover precious metals from the leach solutions.

The operator discontinued heap leach operations by early 1986, but site closure implementation was delayed. Due to corporate reorganization and lack of funds, the company was searching for a buyer that was interested in restarting operations. Meanwhile, it became necessary to treat and pump process pond fluids to reduce cyanide concentrations and avoid spring-time overtopping of the ponds. Cordilleran completed some emergency work but their cash problems continued. The Forest Service's goal during this period was to work toward final site closure while maintaining safe conditions and holding the operator responsible for all costs. When it became apparent that the owner was unable to comply with their operating plan, the agency completed site work that was necessary to protect ground water, wildlife, and human health. Repayment agreements were executed by the claimant to compensate the USDA Forest Service for the cost of that effort. A buyer for the mine never materialized and eventually the claimant declared bankruptcy; the Forest Service inherited sole responsibility for cleanup in late 1990 and the operation's $7,200 reclamation bond was forfeited.

Site remediation was complicated and delayed by the interaction and perceived differences between parallel Federal and state environmental cleanup laws; the Comprehensive Environmental Response, Compensation and Liability Act, as amended (CERCLA or "Superfund", 42 USC §§ 9601) and Washington Model Toxics Control Act (MTCA, Chap. 70.105d Revised Code of Washington [RCW}). Washington Department of Ecology manages

Furniss, M.J., Clifton, C.F., Ronnenberg, K.L., eds., 2007. *Advancing the fundamental sciences: proceedings of the forest service national earth sciences conference, San Diego, CA, 18-22 October 2004*. PNW-GTR-689. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Figure 1. Minnie mine facilities: (h) processed ore heap, (l) pad liners, (p) pregnant process pond, (b) barren process pond, (r) recovery plant. Photograph taken after the 1985 Minnie wildland fire (unrelated to the mine operations).

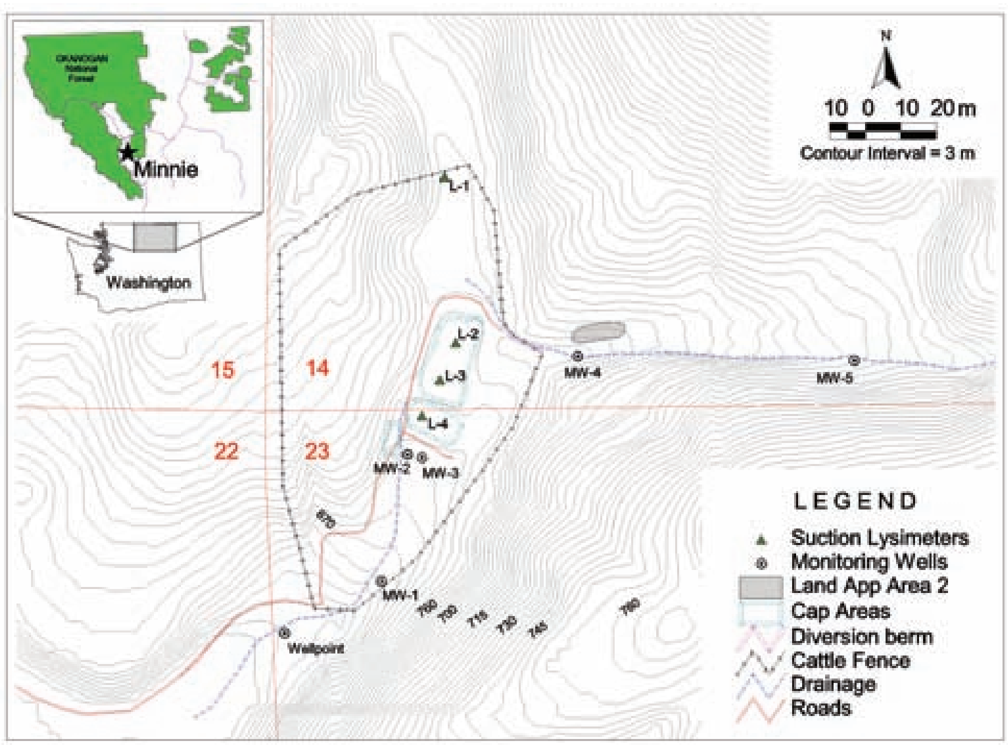


Figure 2. Minnie mine site location.

the MTCA program. Considerable time and energy were invested to resolve issues of authority and even report formats. While the Forest Service initially attempted to satisfy the intent of MTCA using CERCLA documents, the agency eventually produced two sets of documents for the final removal actions.

CERCLA/MTCA Process and Reports

The National Oil and Hazardous Substances Pollution Contingency Plan (NCP, 40 CFR 300) sets forth procedures for undertaking CERCLA cleanup actions and defines federal agency roles, including the Forest Service. Regarding abandoned mines, the process begins with a site assessment, which determines if a release or threat of a release of a hazardous substance has occurred. This step usually generates two reports, a Preliminary Assessment (PA) and a Site Inspection (SI), both of which document conditions at the site and the evidence of the threat or actual release of hazardous substances. If a release is evident, a Potential Responsible Party (PRP) search is conducted and documented. This step looks for parties that may be responsible for the contamination and that could participate in and pay for any cleanup actions. Cleanup response may take the form of a Removal or Remedial Action. Most Forest Service mine responses use the Removal process. Such responses demand simple to moderate levels of analysis and may be time critical in nature. Remedial action responses are typically evoked for large, complex projects that require lengthy, detailed study or those promoted to the National Priorities List (NPL) by US Environmental Protection Agency (EPA). Both processes analyze alternative response approaches and provide for public input consistent with the level of complexity. For Removals this is documented in an Engineering Evaluation/Cost Assessment (EE/CA) and for Remedial Actions, a Remedial Investigation/Feasibility Study (RI/FS).

Regulations implementing MTCA are organized under Washington Annoted Code (WAC) Chapter 173-340. These regulations outline a process which parallels CERCLA. Under MTCA an Initial Investigation and Site Hazard Assessment replace the PA/SI. All cleanup actions are documented in a Remedial Investigation/Feasibility Study (RI/FS) under MTCA.

Environmental Concerns

Initial site concerns revolved around the presence of highly toxic free cyanide and cyanide complexes in the process fluids and processed ore heap. Heavy metal contaminants, especially arsenic, cadmium and mercury, later became more prominent in the cleanup strategy.

Short Term Risks

Shortly after mine operations ceased several immediate risks became evident. Warm summer conditions favoring evaporation tended to concentrate cyanide in the process pond fluids and natural buffering reactions decreased heap and fluid pH. The combined effect was to increase the off gassing of hydrogen cyanide (HCN) to the atmosphere (Smith and Mudder 1991) thus increasing risk to nearby wildlife and humans. A substantial number of bird and bat carcasses were discovered around the ponds in July 1986.

Because precipitation on the heap continued draining to the pregnant process pond, fluid volume accumulated over time. Spring melting of winter snows on the heap sometimes threatened to overfill the ponds, spilling contaminated fluids and menacing ground water.

Long Term Concerns

Investigations at the site revealed several tasks that must ultimately be addressed:

- The treatment of contaminated process fluids and sludges accumulating in the process ponds;
- The treatment of cyanide in the processed ore heap;
- The potential for ground water contamination from pad-liner or pond leaks and from leaching of processed and unprocessed ore materials and land application soils;
- Physical reclamation of the mine and millsite facilities; and
- Long-term protection of remedial structures and reclamation efforts from storm and surface water runoff and erosion.

Restoration and Remediation

Treatment of Processed Ore Heap

The PVC liner from a second, unused pad was pulled over the exposed heap in November, 1986 to limit precipitation influx to the process ponds, which were in danger of overtopping at the time. This cover was removed one year later to facilitate heap washing and neutralization. No analyses of the processed ore heap material are available from that time, but a qualitative field test of leachate draining from the heap in August 1988 indicated >100 ppm free cyanide (CN_{Free} = unbound CN^- & HCN). By April 1989 CN_{Free} in the heap averaged about 10 mg/kg with a maximum value of 28 mg/kg. Because of contaminated drainage from the heap, it was clear that treatment of the heap solids and decommissioning of the pad was a prerequisite to the final treatment and disposal of process fluids and pond sludges.

Treatment of heap solids was accomplished over an extended time period by natural oxidation processes, influx of rain and snow melt and by circulation of neutralized process fluids and fresh water. Natural degradation of cyanide complexes was facilitated by periodically stripping the detoxified surface layer (0.7-1.0 m in depth) from the heap. The new surface was then ripped to improve overall permeability. Stripping was cost effective at the Minnie due to the relatively small size of the heap. Surface layers were removed three times between October 1989 and April 1991. The compliance standard for solids removal and final treatment was 10 mg/kg amenable cyanide (CN_{Amen}) which represents the difference between total cyanide (CN_{Total} = free + complexed CN) measured before and after alkaline chlorination treatment (USDA FS 1992). Heavy metals in the heap also had to meet RCRA (Resource Conservation and Recovery Act) solid waste criteria. Following compliance testing, the remaining heap lift and the synthetic heap liner were machine ripped to sever their hydraulic connection to the process ponds.

Treatment and Disposal of Process Fluids

Process fluids are here defined to include all solutions or supernate that report to and reside in the pregnant and barren process ponds. The operating plan called for working solutions containing 0.025 percent or 2500 ppm CN_{Total}. Dissolved constituents in these solutions varied between the two ponds and during the treatment procedures. Analysis of pregnant pond solutions in 1986 indicated 1200 ppm weak acid dissociable cyanide (CN_{WAD} = CN_{Free} + weakly bound CN complexes). Process water quality is described in Appendix A.

Fluid treatment was initiated by the operator in 1986. The intent was to detoxify the ponds and heap and dispose of excess fluid under their state waste discharge permit by land application. Alkaline chlorination (Smith and Mudder 1991) was selected by the operator to accomplish cyanide neutralization because of its relative simplicity both in technique and reagent use. This method involved the careful mixing of calcium hypochlorite ($Ca[OCl]_2$)with the pond solutions while maintaining a pH of 10.5-11.5. The hypochlorite converts CN_{WAD} to non-toxic cyanate (CNO).

Neutralization of pond fluids continued intermittently until 1993 in coordination with heap detoxification and stripping operations. Treated process fluids were land applied under Cordilleran's default National Pollutant Discharge Elimination System (NPDES) permit on two occasions and over two areas (Appendix A). The operator's discharge permit was cancelled in 1990. Washington Dept. of Ecology imposed more stringent discharge standards thereafter, which were not attainable using alkaline chlorination and sulfide precipitation (see discussion below). Consequently, the final 103,000 liters of neutralized process fluid, designated as a dangerous waste under state law (WAC 173-303) because of elevated mercury levels, was eventually trucked to a permitted treatment/discharger on Puget Sound in October 1993.

Fluid treatment at the Minnie was complicated by: (1) continued inflow of contaminated water from the heap; (2) ongoing chemical interaction with the sludges; (3) the need to prevent overtopping of the ponds; (4) high chlorine consumption; and (5) elevated mercury levels. Chlorine consumption was very high for Minnie process pond cyanide detoxification; an estimated 15-28 kg of chlorine for each kg CN_{WAD} oxidized. Early lab tests indicate 8-13 kg of chlorine would be needed for each kg of CN_{WAD} oxidized. Excessive chlorine consumption may have resulted because of inadequate reaction monitoring, reaction with sludge components, or the presence and oxidation of thiocyanide in the fluid (Smith and Mudder 1991). The operator reported copper and mercury concentrations in treated water as high as 400 and 7 ppm, respectively. The alkalinity maintained during treatment assisted in the precipitation of heavy metals present in solution as hydroxides. Sodium sulfide was mixed in the ponds as a polishing step (Smith and Mudder 1991), especially to precipitate and further reduce dissolved mercury concentrations.

Minnie ore typically contained low mercury concentrations (Appendix A). However, elevated mercury was found in the process waters and the upper part of the heap after it was washed with treated process waters. Because of the large volume of treatment reagents used it is believed that trace amounts of mercury present in the calcium hypochlorite may have accumulated during the neutralization process.

Treatment and Disposal of Process Sludges

Process sludges are defined as the low-density solids which accumulated in the pregnant and barren process ponds since their installation. Included are various incompletely dissolved chemical reagents used during operations and treatment, detrital sediment originating from the heap, chemical precipitates, dust and vegetative matter and accompanying interstitial fluids. Approximately 45,000 liters of sludge remained in the ponds after all process fluids had been removed. Chemical and Toxicity Characteristics Leach Procedure (TCLP) analyses for the sludge solids portion are displayed in Appendix A. The values indicate high levels of cyanide and heavy metals in the sludge. TCLP extracts also exceed ground water standards for cyanide and most heavy metals.

The sludge EE/CA decision (USDA FS, 1993) supported the removal and transport of process sludges as a hazardous substance to a Resource Conservation and Recovery Act (RCRA) Class C Licensed Treatment/Storage/Disposal facility (TSD). However, cyanide levels in these materials exceeded the TSD's screening values (570 mg/L $CN_{T,}$ 30 mg/L CN_{WAD}). Rather than transporting the sludge to a more distant TSD which had additional treatment capabilities and approximately doubling disposal costs, the Forest Service chose to treat the sludge using alkaline chlorination. Assisted by the USDI Bureau of Mine's scientists, the Forest Service designed and constructed a unique, pilot-scale In-Line System (ILS) to successfully treat the process solids (Figure 3). Details of the design and use of the ILS are described by Lentz and Knott (1997). Following reduction of cyanide concentrations the sludges were transported by a licensed Hazmat contractor to the TSD in September 1993 (Figure 4). Pond liners were cleaned, examined for tears or punctures, tested and removed to a land fill as solid waste.

Figure 3. ILS design for sludge treatment.

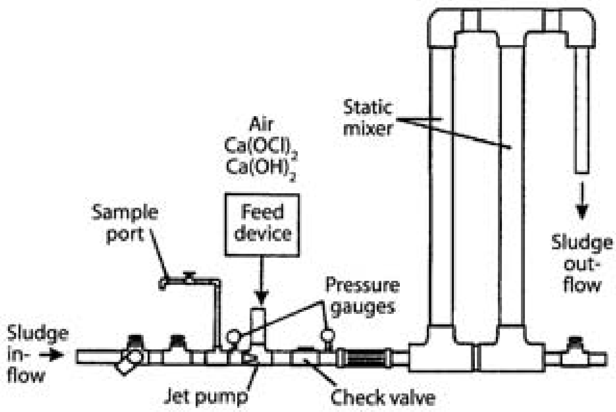


Figure 4. Following reduction of cyanide concentrations the sludges were transported by a licensed Hazmat contractor to the TSD in September 1993.

Evaluation of Ore, Heap, Process Plant, Land Application and Sub-liner Soils

A soil sampling program was developed for soils beneath or adjacent to the various mine facilities to evaluate compliance with MTCA screening levels. A total of 51 samples were analyzed: 12 beneath the heap liner; 14 beneath land application #1; 6 beneath land application #2; 15 beneath the process ponds; three from the recovery plant and three from beneath the unprocessed ore stockpile. Appendix A summarizes sampling data. Soil samples were screened against MTCA Method B soil formula values while TCLP tests were compared to MTCA Method B ground water formula values (Olympus Environmental, Inc. and USDA FS 1994a).

Process Ponds and Plant. Observations of the upper and lower synthetic pond liners and the intervening fiberglass mat (leak detection layer) showed no evidence of significant leakage through either liner. Three small, circular white stains found on the fiberglass mat may have been caused by pinhole-sized holes in the upper liner. A 2.5-cm-long tear in the lower liner (pregnant pond) about midway up the leak detection monitoring pipe (20 cm diameter PVC) was attributed to a sharp edge on the pipe. Eight centimeters of bark mulch underlying the lower liners was dry and unoxidized except for a small area around the tear which showed dark discoloration. This may have been caused by surface water moving along the leak detection pipe. Soil samples taken beneath this point and at other points beneath the ponds and at the processing plant showed no cyanide and less than screening or background levels of heavy metals. However, all but two of these samples exceeded the 1.3 ppm screening value for arsenic. For comparison, local background for soil arsenic was determined to be 26 ppm (90 percentile upper confidence limit).

Processed and Unprocessed Ore. Processed and unprocessed ore materials contained elevated metals, especially zinc, copper and arsenic, when compared to background. Nevertheless, only arsenic exceeded screening levels in these samples. The final heap samples (1993) all contained less than 0.5 ppm CN_{WAD}. TCLP leachate from processed ores exceeded ground water screening criteria for arsenic, cadmium lead, zinc and mercury (Appendix A). TCLP was run on one unprocessed ore sample. No screening levels were exceeded but the analysis did not include arsenic and lead. It is presumed that the TCLP for arsenic would have exceeded the ground water screening level.

Limited direct observations of the in situ synthetic liner found it to be in good condition where it had remained covered beneath the heap. But deterioration of the PVC was noted where it was exposed to the atmosphere, direct sunlight and mechanical impact or strain by 1990, about 7 years after installation. Some leakage was evident at the liner-outlet pipe seal. Analysis of soil underlying this connection showed substantially elevated metals compared to all other samples taken from beneath the heap liner. (880 ppm arsenic compared to 17 ppm average). All other sub-liner samples showed metal concentrations below screening levels or background. One sample exceeded the 1.3 ppm arsenic screening value.

The potential for acid rock drainage (ARD) from both processed and unprocessed ore is deemed low. Minnie mine ore is largely oxidized, containing few iron sulfide minerals. Moreover, the ore is associated with an acid-neutralizing calcium carbonate host rock (marble). Static ARD testing (modified acid base accounting) demonstrated a net neutralizing capacity of the ore, its neutralization potential/acid potential ratio or NP/AP being 9 (NP/AP ratios of 3 or greater are considered non-acid forming; USEPA 1994).

Land Application Areas. Compliance soil sampling revealed above-background levels of zinc, copper, arsenic and mercury in Land Application Area 1. Only arsenic was found to exceed the 1.3 ppm screening level. All CN_{WAD} concentrations were less than 0.5 ppm. Because Area 1 lies on mine waste rock the elevated metals may in part be attributed to background concentrations. Metals concentrations analyzed in Land Application Area 2 soils were all at or below background values. But again, arsenic exceeded the MTCA screening level.

Remedial Action and Reclamation

Final remediation and reclamation construction activities at the Minnie were completed in May 1995. The reasoning for and selection of the remedial action at the site is described in the Minnie Mine Soils EE/CA (USDA FS 1994) and the Phase I & II RI/FS (Olympus Environmental, Inc. and USDA FS 1994a, 1994b). Remedial Site work included the following activities:

- Removal of the unprocessed ore stockpile to the depressions occupied by former process ponds.
- Grading of unprocessed and processed ore storage areas and Land Application Area 1
- Distribution and mixing of ~2.2 metric tons/ha agricultural lime across the above arsenic-impacted areas to modify soil pH
- Excavation of clean native soils from an adjacent borrow area
- Distribution of native soils forming a gently sloping (<10 percent grade), 0.5-m-thick water storage cap over arsenic-impacted areas
- Installation of soil moisture sensing (gypsum blocks) and pore water sampling equipment
- Compliance sampling of cap soils
- Seeding cap of soil with native grass species
- Maintenance of the existing storm water diversion ditch/dike (as needed)

The purpose of the soil cap was two fold: (1) To isolate people and wildlife from contact with or ingestion of elevated arsenic, and to a lesser degree cadmium, found in the ore materials and land application area; and (2) to minimize infiltration of meteoric water into and through the contaminated soils. The later was based upon the capacity of the soil cap to store annual precipitation and snow melt and release it through evapotranspiration. EPA's Hydrologic Evaluation of Landfill Performance (HELP) model (Schroeder et al. 1986) was used to evaluate the cap design. The HELP model estimated a net annual infiltration rate of 2.5 cm/yr issuing from the base of the contaminated soils.

Soil pore water monitoring required the installation of four suction lysimeter/gypsum moisture block sets (Figure 5): one background station, one beneath the unprocessed ore, and two beneath processed ore material (Figure 2). Each set include identical primary and backup installations.

Other Reclamation Activities. Coincident with the remediation construction activities were other site reclamation efforts (Knott and Lentz 1996). The small open pit, waste rock and overburden stockpiles, the main haul road and a number of exploration cuts, pits and roads were reshaped and reseeded (Figure 6). The pit excavation was partially backfilled with waste rock and the remaining waste rock recontoured to blend with surrounding terrain. Approximately 300 linear meters of road was reclaimed by pulling back the fills into the road cut and recontouring. Approximately 3.2 hectares of total disturbance was graded and reshaped to blend with surrounding terrain and all areas reseeded with a native-species-dominated mix. Figure 7 shows the recent condition of the site.

Figure 5. Suction lysimeter installation (a), lysimeter/soil moisture block (b), and field installation (c). This typical lysimeter was used to monitor pore water beneath the processed and unprocessed ore storage areas.

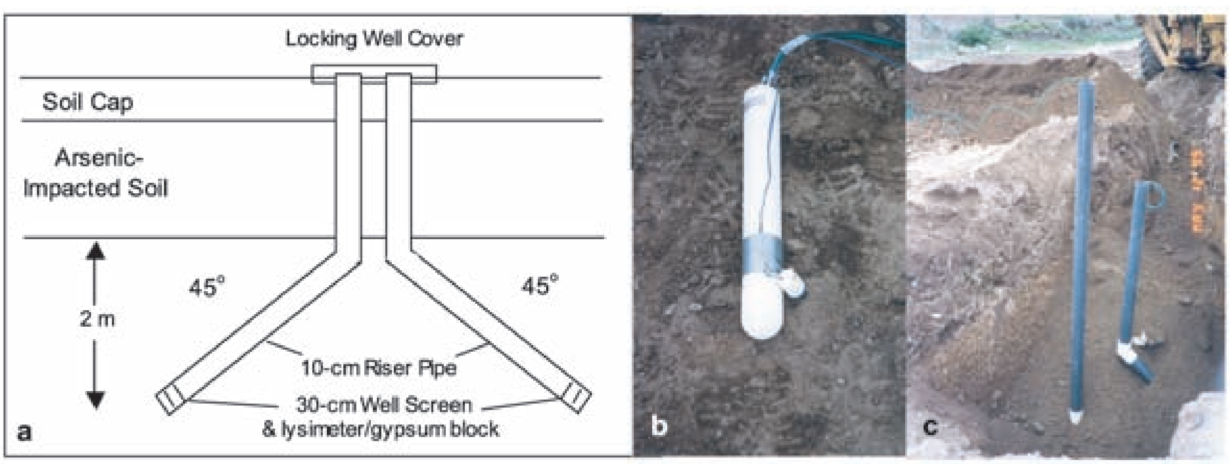


Figure 6. Comparison pre-cleanup disturbances (a) and final cap construction (b).

a

b

Site Monitoring

Monitoring requirements were designed to evaluate both cap construction and cap function. The upper 0.5 m of the cap were to meet MTCA Method A cleanup standards for arsenic (≤ 20 mg/kg) and MTCA Method B standards for cadmium (≤ 40 mg/kg). A level of 20 mg/kg arsenic was approved as the target criterion deemed to meet both metal standards. The cap and the diversion ditch and berm would be monitored for potential damage caused by erosion or deep-rooted vegetation. Background and under-cap soil pore water would be monitored, and when arsenic was present, arsenic concentrations to be determined quarterly for at least two years. Should under-cap soil pore water arsenic concentrations exceed those in the background lysimeter or, when no background sample was available, if under-cap soil pore water arsenic concentration exceeds 5 ppb arsenic, then sampling would be increased to monthly to collect statistically significant data, and the site Cleanup Action Plan (CAP) would be reopened and re-evaluated as necessary. A private drinking water well (1 mile [1.6 km] down gradient of site) was to be monitored semi-annually for 2 years.

Five up- and down-gradient ground water monitoring wells installed by the Forest Service in 1991 (Figure 2) were also monitored and sampled in conjunction with that of the suction lysimeters. A deeper, down-gradient piezometer well ("wellpoint" in Figure 2) installed by a previous operator was also monitored. Lastly, the Forest Service installed a weather station and regularly collected site weather data.

Early sampling results were evaluated in a 1995 Minnie Mine Millsite CAP Construction Report (Olympus Environmental, Inc. and USDA FS 1995). Preliminary analysis indicated background arsenic soil moisture concentrations of 11.35 mg/L, a value significantly greater than the site cleanup criterion of 5.0 µg/L arsenic. MTCA allows the use of natural background in place of the Method A cleanup standard (WAC 173-340-700(4)(d)). Therefore, the intent of the monitoring program became the collection of sufficient data to make a statistical comparison between background concentrations of arsenic and arsenic concentrations in down-gradient monitoring wells and suction lysimeters (Olympus Environmental, Inc. and USDA FS 1995).

Monitoring of the Barnett well was discontinued after approximately two years because of low arsenic concentrations in that well and in monitoring wells closer to the site.

Monitoring Results

Site monitoring results, interpretations and conclusions are discussed in detail in the Minnie CAP Monitoring Report (USDA FS 2003). Approximately eight years of monitoring (1995-2003) detected no visible evidence of structural failure or significant erosion of the soil cap. A large, summer storm event occurred in June 1998 that tested the up-stream diversion channel. This event caused deepening of the channel but did not compromise the integrity of the armored channel berm.

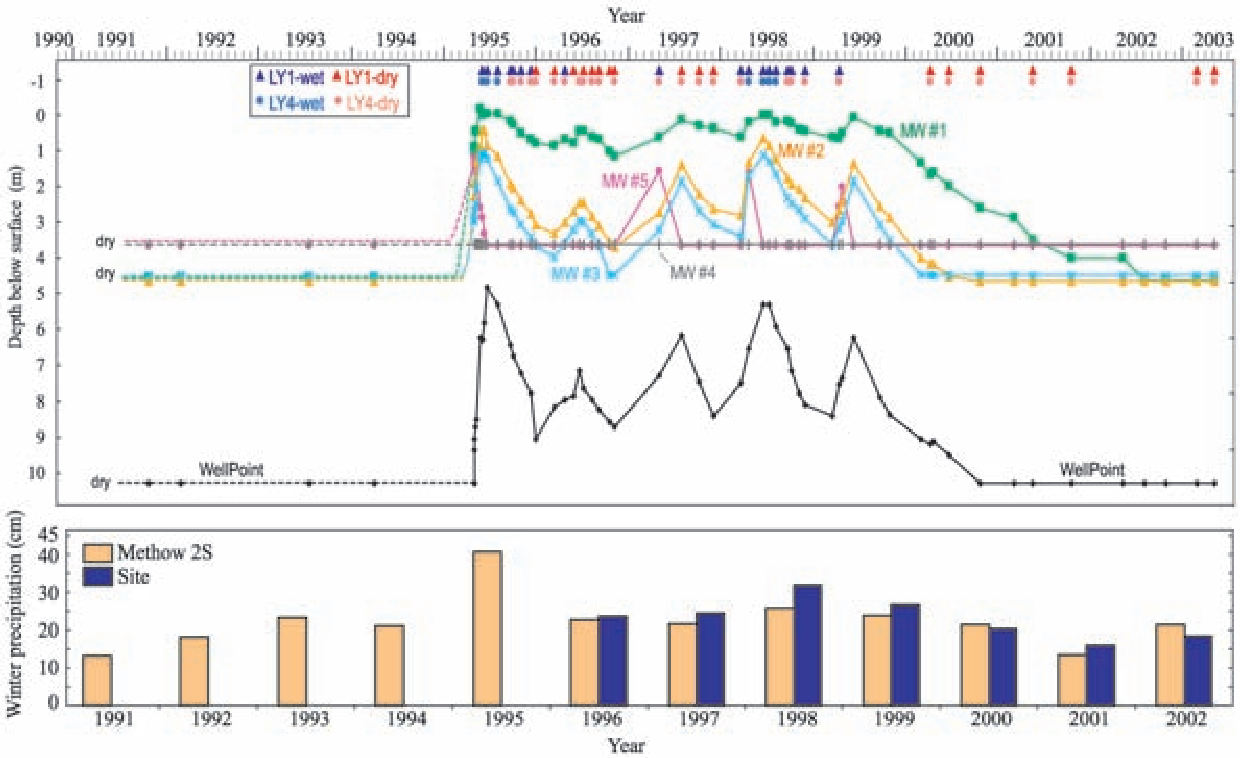
Revegetation of the soil cap and surrounding area was accomplished early and is successfully propagating (Figure 7). The CAP requirement to limit deep-rooted vegetation on the soil cap was rescinded by Washington Dept. of Ecology in 2001. Mowing of cap vegetation was therefore discontinued and sage brush has become a significant component of the cap plant community.

General Observations. Figure 8 summarizes water levels over the time period of documented observations. The condition ("wet" or "dry") of lysimeters L-1 (background) and L-4 is shown for comparison. Total winter precipitation from the nearest climatological station (Methow 2S) and the site (1995-2003) is also displayed. Monitoring data support the following general observations:

1. An anomalous occurrence of surface water and high groundwater levels at the site existed between 1995 and 2002. The change of surface and ground water manifestation was associated with unusually heavy winter (1994-95) precipitation, the first heavy precipitation year since the upper part of the drainage was denuded of timber by an August 1985 wild land fire (Figures 2 & 8).
2. Correlation of monitoring well data indicates down-drainage ground water movement on and above the bedrock/glacio-alluvial sediment interface at rates of 6-8 m/day.
3. Samples could not be drawn from the suction lysimeters when the lysimeter cups were found to be dry (i.e., when soil surrounding the lysimeter cups was unsaturated).
4. Few samples were available from L-2 and L-3, suggesting rapid transit of the spring snow melt wetting front and limited time of saturation.
5. Samples were available in L-4 only when water levels in down-gradient monitoring wells were high (within 1.3 m of the surface in MW-2).
6. Due to the return of subsurface water to normal levels it is unlikely that additional water samples will be available from L-4 or the other lysimeters.
7. The lack of observed ground water in MW-4 suggests the presence of a buried paleochannel which underlies glacio-alluvial deposits south of the existing valley .
8. The gypsum soil moisture blocks did not operate as intended. The purpose of these blocks was to help identify when adequate soil moisture was present for

Figure 7. Established site vegetation.

Figure 8. Comparison of Minnie mine ground water levels with lysimeter status and winter (Oct-Apr) precipitation.



sample collection. However, in practice, soil moisture readings were consistently in the 90-97 percent range whether or not soil moisture samples could be drawn from the lysimeters. Lower moisture readings were not obtained until June 2000 and may be due to moisture block deterioration rather than actual changes in soil moisture (life expectancy is advertised at 3-5 years under irrigated soil conditions).

9. Arsenic levels in L-4 show a decreasing trend with time (Figure 9).

10. Good correlation of arsenic values in L-1 and L-4 suggests that a significant portion of the arsenic in L-4 pore water can be attributed to background arsenic levels (Figure 10).

Compliance. Compliance statistics for the Minnie monitoring stations are summarized in Table 1. Compliance requires that the 95 percentile upper confidence limit (UCL) for arsenic be less than the cleanup level, that no sample value is more than twice that standard, and than less than 10 percent of the values exceed the cleanup level. Soil sampling verified compliance with these stipulations when compared to the 20 mg/kg arsenic cap standard (Appendix A).

Figure 9. Arsenic trends in lysimeter L-4, soil pore water.

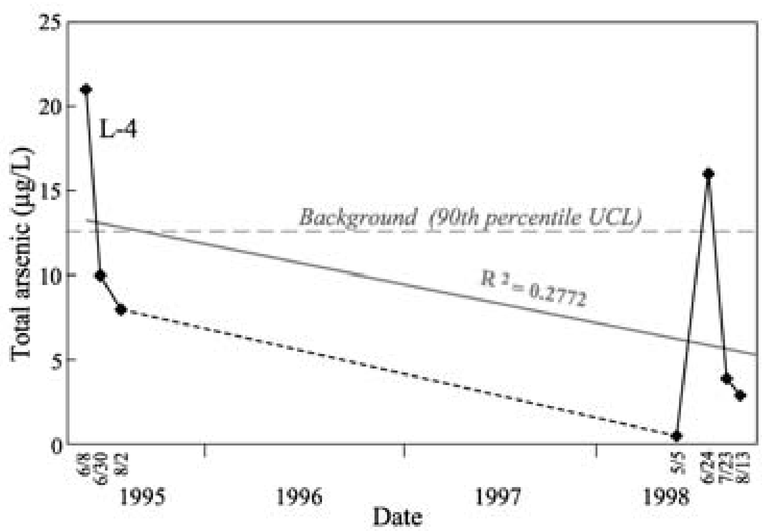
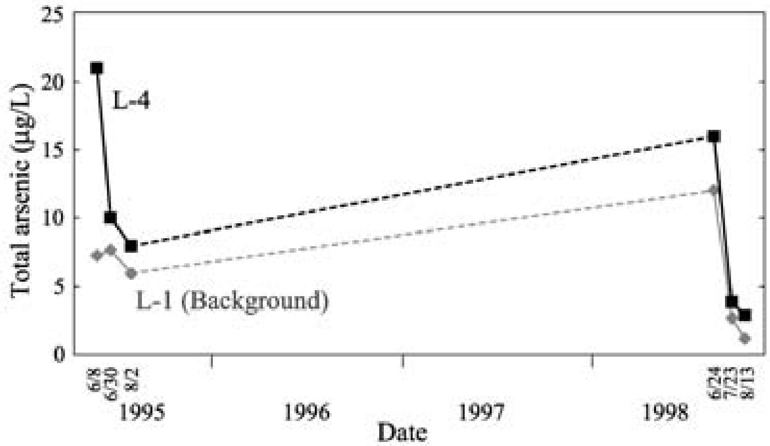


Figure 10. Correlation of arsenic values in lysimeters L-1 and L-4.



Statistical analysis of 21 background samples gives a site background value (90th percentile UCL) for arsenic in soil pore water of 12.69 μg/L. This value becomes the cleanup level for the suction lysimeters and monitoring wells.

Suction lysimeters L-2 and L-3 can not be tested statistically for compliance due to the lack of available soil pore water samples from these down-gradient points. One or no samples were collected from these stations, respectively. The single sample from L-2 showed arsenic concentrations of <1 ug/L. The apparent lack of soil moisture at these lysimeters implies compliance with soil pore water standards.

Down-gradient compliance points statistically evaluated include L-4, MW-1, MW-2, MW-3 and the Barnett well. The 95 percentile UCL for arsenic in monitoring wells MW-1, 2 and 3 were all below the 12.69 μg/L background and no samples exceeded that value.

Only seven soil pore water samples were available from lysimeter L-4. The statistical distribution of the data is lognormal and the lognormal mean, 11.07 μg/L, is below the background standard of 12.69 μg/L. However, due to the value range and small number of samples MTCAStat calculated a 95th percentile of 57.9. None of the sample values exceeded twice the background standard (25.38), but two of the seven or 29 percent exceeded background. MTCAStat estimates that some 226 samples would be necessary to obtain an upper confidence limit (UCL) of 12.5 μg/L (below background). Based upon sample availability during the past eight years this would amount to many decades of additional monitoring.

Four compliance samples from the Barnett well were available for statistical analysis. The lognormal mean for arsenic in these samples is 1.40 μg/L. No sample values exceeded background. The upper confidence limit, determined using the data set's maximum value, is 1.70 μg/L The UCL falls below the current state drinking water standard (10 μg/L) and the site's background value.

Table 1. Summary of arsenic compliance statistics for Minnie ground water monitoring samples.

Station	n[1]	Mean	Median	UCL[2]
Background	21	6.03	5	12.69
Down Gradient				
L-2	1	NA	NA	NA
L-3	0	NA	NA	NA
L-4	7	10.3	9	57.9
MW-1	22	1.73	1	2.55
MW-2	21	1.46	1	2.1
MW-3	8	2.28	2	4.33
Barnett Well	4	1.35	1.35	1.73

[1]Number of samples
[2]Upper Confidence Limit; 90th percentile for background and 95th for compliance.

Discussion. Except for suction lysimeter L-4, arsenic in all down-gradient ground water monitoring stations complies with the background standard of 12.69 μg/L. Nonetheless, the lognormal mean of arsenic concentrations in L-4 samples is below the background standard. Considering these data and the following observations the Forest Service believes that the site cleanup is protective of human health and the environment and has resulted in little or no impact to ground water quality.

Despite arsenic spikes in soil pore water from lysimeter L-4 arsenic concentrations in all down-gradient monitoring wells have lognormal means of 1.47 to 2.33 μg/L and comply with site background and the new 10 μg/L drinking water standards. Arsenic in L-4 soil pore water is decreasing, indicating diminishing availability of soluble metal in the capped material. A substantial portion of arsenic in the L-4 soil pore water can be attributed to background levels. The contribution from capped areas to ground water flow beneath the site is very small (0.04 percent) relative to the entire drainage basin. If arsenic is being mobilized down gradient of L-4 there is no indication that it has reached the nearest monitoring well, MW-2 (100 feet down gradient), after eight years of unusually high groundwater flows (Table 1).

Based upon the monitoring results regular soil pore water monitoring at the Site was discontinued. However, if site groundwater levels rose again before 2006, sampling and arsenic analysis would resume. The Forest Service would continue to inspect the site to assure the integrity of the cap and related facilities both on an annual basis and after any unusual storm events.

Site Cleanup Costs

Final site cleanup costs totaled approximately $302,000. These costs are summarized by work type in Table 2. Physical remediation and reclamation work accounts for about fifty percent of the total cost. MTCA and CERCLA analyses and report preparation account for most of the remainder. A little more than half of the physical cleanup costs are attributable to the expense of the transporting process fluids and sludges classified as hazardous waste. MTCA compliance was a major cost item for the project.

Total costs by far exceeded monies collected from the reclamation surety ($7,200) and the collection agreements ($10,000). The discrepancy is, in large part, due to the unplanned costs associated with a CERCLA/MTCA cleanup and the divergence between the closure requirements originally approved in the mine operating plan and the actual cleanup implementation. However, process fluid detoxification costs were substantially underestimated and some tasks, such as dealing with potential process sludge, were overlooked completely in the initial mine permitting. These mistakes were recognized early during the cleanup process and the lessons relayed to other minerals administrators working in the field (Knott and Lentz 1990).

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Table 2. Summary of Minnie mine cleanup costs.

Physical Remediation/Reclamation		$145,000
Pre-CERCLA fluid trtmt/disposal (416k liters)	$ 15,000	
Sludge trtmt/remov/trnspt/disposal (45k liters)	$ 60,500	
Fluid/liner remov/trnspt/disposal (103k liters)	$ 36,500	
Misc. reclamation	$ 9,000	
Cap const/lysimeter installations	$ 24,000	
Subtotal	$145,000	
CERCLA study/documentation		$ 17,000
MTCA study/documentation		$134,000
Post construction monitoring		$ 6,000
Total		$302,000

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See following three pages for Appendix A.

Appendix A. Summary of Minnie mine sample analyses. Metals tested for are shown as their chemical symbol. As = arsenic, Ba = barium, Cd = cadmium, Cr = chromium, Cu = copper, Pb = lead, Ag = silver, Zn = zinc, Hg = mercury, Se = selenium, Na = sodium, Ca = calcium, Fe = iron, Mg = magnesium, K = potassium; CN = cyanide.

	SOLIDS DATA (ppm unless otherwise indicated)																		
AREA TESTED	As	Ba	Cd	Cr	Cu	Pb	Ag	Zn	Hg	Se	CN_{Free}	CN_{WAD}	CN_{Total}	pH	Na	Ca	Fe	Mg	K
Ore Materials																			
Processed Ore																			
8/29/1989																			
no. of analyses												0							
minimum												1							
maximum												22							
average												10.2							
8/10/1992																			
no. of analyses												14							
minimum												0.4							
maximum												18							
average												3.8							
10/27/1993																			
no. of analyses	8	8	8	8	8	8	8	8	8			8							
minimum	690	100	26	34	620	120	5.7	4900	1.2			<0.5							
maximum	1800	140	91	45	810	240	14	6900	3.7			<0.5							
average	1084	124	42	40	726	178	9	5925	1.7			<0.5							
Unprocessed Ore																			
no. of analyses	4	1	4	3	4	4	2	4	1	2									
minimum	420	170	5.2	15	150	130	2.2	480	0.14	<3.0									
maximum	640	170	7.8	20	240	200	6.2	910	0.14	<3.4									
average	492.5	170	6.45	18	180	162.5	4.2	630	<0.002 - 0.14	<3.4									
Process Pond Sludge																			
6/15/1992																			
no. of analyses	4	0	4	4	4	4	4	4	4	4	1	1	1	1	4	4	4	4	4
minimum	317		389	<35	0.8	<65	58	4.4	0.05	<0.3	94	280	860	9.62	0.4	19.6	0.6	4	0.1
maximum	1510		618	95	2.7	<93	554	5.2	0.096	<0.3	94	280	860	9.62	0.8	22.7	2.6	8.7	0.5
					weight %			weight %							weight %	weight %	weight %	weight %	weight %
Subliner-facility Soil Samples																			
Site Background																			
no. of analyses	12		17	4	17	17		12						2					
minimum	3.2		0.7	11	19	3.3		224						7.8					
maximum	54		2.3	39	100	21		170						8.2					
average	12.7		1.2	25	36.4	7.8		55.6											
90 percentile (MTCA UCL)	26																		
Beneath Heap Liner																			
no. of analyses	11	12	12	12	12	10	12	11	12			3							
minimum	5.4	61	0.6	8.2	37	0.21	0.45	27	<.07			<0.5							
maximum[1]	880	140	41	28	540	140	4.6	5100	1.3			<0.5							
average[2]	17	84	3	10	53	4	0.45	76	0.1			<0.5							

[1]These values come from the soils beneath the outlet pipe leak
[2]Average excludes anomolous sample near outlet leak

Appendix A (page 2 of 3). Summary of Minnie mine sample analyses.

AREA TESTED	As	Ba	Cd	Cr	Cu	Pb	Ag	Zn	Hg	Se	CN_{Free}	CN_{WAD}	CN_{Total}	pH	Na	Ca	Fe	Mg	K
								SOLIDS DATA (ppm unless otherwise indicated)											
Ore Materials (cont.)																			
Beneath Land App 1 (small area west of MW-2)																			
no. of analyses	12	8	14	14	14	14	1	14	14	6		6							
minimum	0.22	100	0.8	5.5	28	3.3	0.9	35	0.001	<3.7		<0.5							
maximum	160	190	6.9	54	130	58	0.9	1300	0.8	<3.7		<0.5							
average	44	139	2.4	26	63	11	0.9	280	0.18	<3.7		<0.5							
Beneath Land App 2 (small area north of MW-4																			
no. of analyses	6		4	6	6	6		6	6	6									
minimum	3		0.7	5.9	17	3		30	<0.09	<3.7									
maximum	22		1	1	3	5.5		42	<0.09	<3.7									
average	10		1	8	23	4.5		33	<0.09	<3.7									
Process Building Area																			
no. of analyses	3	3	3	3	3	3	3	3	3			3							
minimum	4.6	100	0.8	11	42	<2.2	<0.44	39	<0.08			<0.5							
maximum	7.6	150	0.9	12	54	<2	<0.44	48	<0.08			<0.5							
average	6.5	133	0.9	11	50	<2.2	<0.44	44	<0.08			<0.5							
Cap Compliance Samples																			
no. of analyses	42																		
minimum	1.3																		
maximum	26																		
average	6.05																		
95th percentile	7.56																		
								TCLP DATA (mg/L dissolved)											
Screen Value[3]	5E-05	1.12	0.008	0.08	0.592	0.005	0.048	4.8	0.002	0.08		0.32							
Unprocessed Ore 11/19/1992	<0.1				<0.1			0.7	<0.002	<0.1									
Processed Ore 11/27/1993																			
no. of analyses	4	4	4	4	4	4	4	4	4	0		1		0					
minimum	0.079	0.71	0.12	0.005	0.24	0.034	0.005	20	0.002	0		0.07		0					
maximum	1.1	0.85	0.14	0.01	0.32	0.054	0.01	33	0.01	0		0.07		0					
average	0.8	0.8	0.14	0.008	0.28	0.040	0.009	27	0.005	<.005									
no. of exceedences	4		4		0	4	0	4	4	4		0		0					
Process Pond Sludge 6/15/1992																			
no. of analyses	3		3	3	3	3	3	3	1	1	1								
minimum	0.25		0.04	0.03	163	0.086	1.99	5.85	0.99	<.005									
maximum	1.21		2.4	0.1	294	0.165	13	729	0.99	<.005									
average	0.84		1.56	0.06	243	0.112	9	480	0.99	<.005	150								
no. of exceedences	3		2	1	3	3	3	3	1	0									

Metals tested for are shown as their chemical symbol. As = arsenic, Ba = barium, Cd = cadmium, Cr =chromium, Cu = copper, Pb = lead, Ag = silver, Zn = zinc, Hg = mercury, Se = selenium, Na = sodium, Ca = calcium, Fe = iron, Mg = magnesium, K = potassium; CN = cyanide.

[3]From MTCA Method B Gnd Water Criteria

Appendix A (page 3 of 3). Summary of Minnie mine sample analyses. Metals tested for are shown as their chemical symbol. As = arsenic, Ba = barium, Cd = cadmium, Cr =chromium, Cu = copper, Pb = lead, Ag = silver, Zn = zinc, Hg = mercury, Se = selenium, Na = sodium, Ca = calcium, Fe = iron, Mg = magnesium, K = potassium; CN = cyanide.

	PROCESS FLUIDS ANALYSES (mg/L total constituent)																		
AREA TESTED	As	Ba	Cd	Cr	Cu	Pb	Ag	Zn	Hg	Se	CN_{Free}	CN_{WAD}	CN_{Total}	pH	Na	Ca	Fe	Mg	K
Barren Pond																			
11/14/1986	<3	<0.1	<0.04	<0.4	490	<1	5.6	250	8.6	-	10	-	340		4700	1300			
10/8/1987 (1st Land App.)	0.08	0.05	0.007	<0.01	1.9	<0.02	0.23	0.99	0.091	5.36		<0.05		11.2	5500				
Pregnant Pond																			
11/14/1986	<3	<0.1	2.9	<0.4	510	<1	10	350	1.7	-	10		1200		2100				
9/21/1989 (2nd Land App.)	0.08	0.05	0.01	<0.02	4.8	<0.01	0.2	-	0.0034	<0.1		0.05		8.6	500				

The Role of Geology in Sediment Supply and Bedload Transport Patterns in Coarse-Grained Streams

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This paper compares gross differences in rates of bedload sediment moved at bankfull discharges in 19 channels on national forests in the Middle and Southern Rocky Mountains. Each stream has its own "bedload signal," in that the rate and size of materials transported at bankfull largely reflect the nature of flow and sediment particular to that system. However, when rates of bedload transport were normalized by dividing by the watershed area, the results were similar for many sites. Typically, streams exhibited normalized rates of bedload transport between 0.001 and 0.003 kg s^{-1} km^{-2} at bankfull discharges. Given the inherent difficulty of obtaining a reliable estimate of mean rates of bedload transport, the relatively narrow range of values observed for these systems is notable. While many of these sites are underlain by different geologic terrane, they appear to have comparable patterns of mass wasting contributing to sediment supply under current climatic conditions. There were, however, some sites where there was considerable departure from the normalized range of values. These sites typically had different patterns and qualitative rates of mass wasting, either higher or lower, than observed for other watersheds. The gross differences in sediment supply to the stream network have been used to account for departures in the normalized rates of bedload transport observed for these sites. The next phase of this work is to better quantify the contributions from hillslopes to help explain variability in the normalized rate of bedload transport.

Keywords: *bedload transport, sediment supply, mass wasting*

Introduction

Differences in the underlying lithology of watersheds cause variation in the stability of the landscape and, hence, variation in the modes of sediment supply to a stream channel. While the rate and patterns of coarse sediment transported in gravel bed streams reflect many watershed factors (e.g., climate, land use, natural disturbances) the characteristics of materials supplied from hillslope and in-channel sources are of particular importance. Specifically, the size of material, the rate and volume of sediment delivered, the timing of delivery relative to high flows, and the periodicity of failures, all influence sediment supply and the stream's ability to transport sediment delivered from adjacent hillslope erosion. In areas where mass wasting processes and rates are largely comparable, one might expect similarity in the rate and patterns of sediment transport.

The primary purpose of this paper is to compare and contrast rates of bedload transport measured at bankfull discharges for a number of stream sites on national forest lands in Colorado and Wyoming. Bankfull discharge, or the flow that just fills the channel banks, was used as a reference point so that transport rates at a common discharge scaled to the size of the channel could be compared. Because comparisons are made between watersheds of varying size, the data are normalized by dividing the rate of bedload transport by the area of the drainage basin. Similarities and differences between these normalized values are discussed, using examples to compare and contrast the relationships and relate them to gross differences in geologic terrane and associated patterns of mass wasting. Specifically, the paper is divided into the following three areas:

- Commonalities in the normalized rate of bedload transport for several sites in central Colorado and southern Wyoming. These areas are underlain primarily by granite, gneiss, and schist, and have relatively low rates of mass wasting relative to those that have occurred in the past (Caine 1986).
- Substantial departure in normalized rates of transport observed in watersheds underlain by extrusive volcanic and granitic terrane on the San Juan National Forest in southwestern Colorado. Here, the normalized values are among the highest and lowest observed in this series of comparisons and are linked to gross differences in observed mass wasting patterns.
- Variations in transport rates observed at two sites in the Gros Ventre Range in western Wyoming. While

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both sites are underlain by deformed sedimentary formations common to this area, there are distinctive differences in patterns of mass wasting between these two watersheds that can be used to explain substantial variation in observed rates of sediment transport.

Study Areas

All of the study sites are located on streams where the USDA Forest Service or the U.S. Geological Survey have initiated studies on sediment transport over the past 10-20 years. The streams are located within either the Middle or Southern Rocky Mountain provinces (Hunt 1974) and are tributaries to the Snake, Platte, Colorado, Arkansas, and San Juan Rivers (Figure 1). Most sites are located near presently- or historically-operating gaging stations and represent a range of channel sizes and types (Ryan et al. 2005). Drainage areas range from 2.9 to 230 km^2 and the sites are between 2000 to 3000 m in elevation. Channels are characterized by moderate to steep gradients (0.01 to 0.05 m/m). The median grain size of the bed surfaces range from very coarse gravel to coarse cobble sizes that are poorly to very poorly sorted (Ryan et al. 2005). Channel types include step-pool, plane-bed, pool-riffle, and one moderately braided site (Table 1).

The lithology of the studied areas is quite diverse (Tweto 1979; Love and Christiansen 1985) (Table 1). Most of the sites are underlain by granite, gneiss, and schist bedrock while other streams flow through areas with sedimentary formations including sandstone, conglomerate, and limestone. The East Fork San Juan and Silver Creek, in southwestern Colorado, are underlain by complex volcanic formations consisting of layered lavas flows. Nearly all of the sites have been glaciated and are

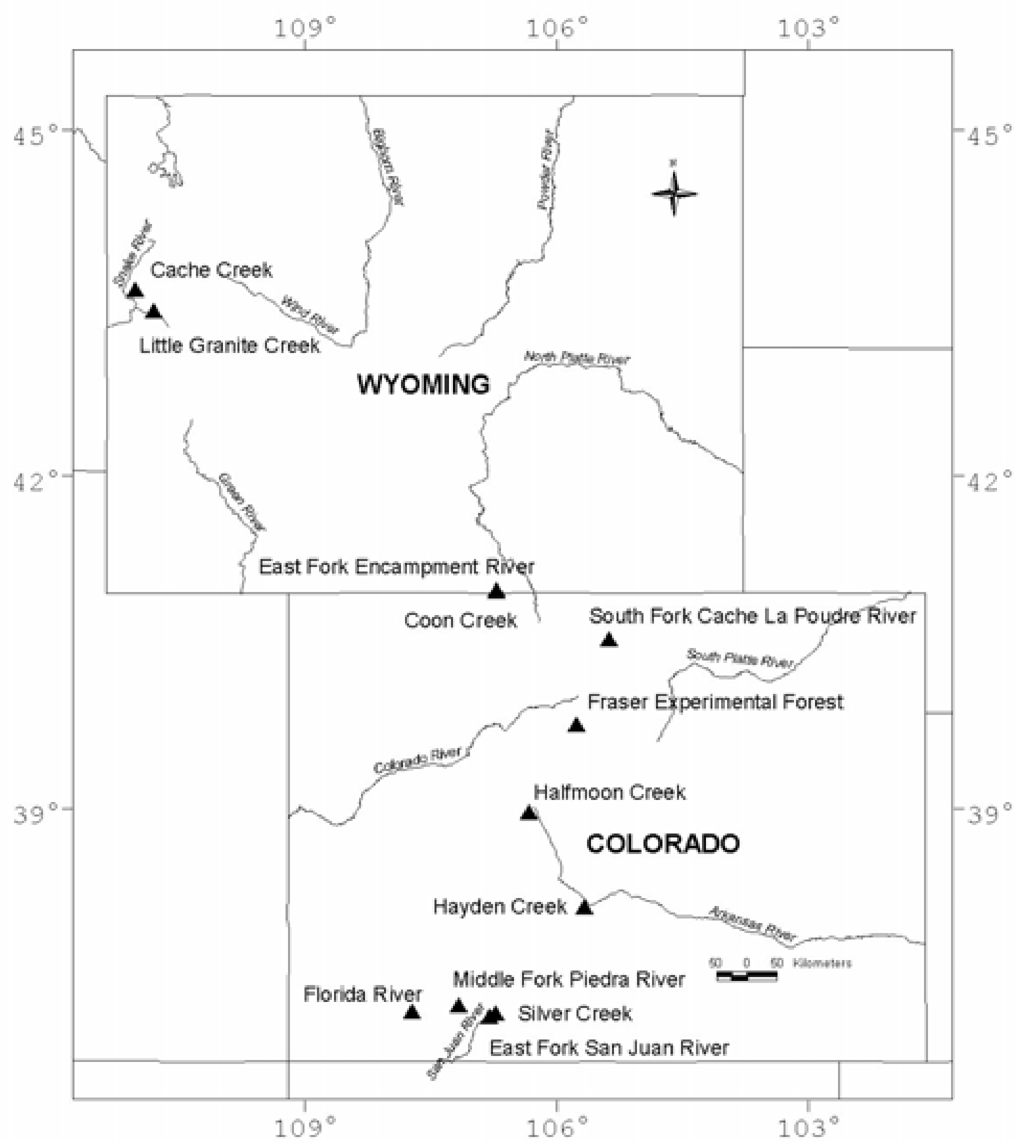


Figure 1. Map of study sites located in Colorado and Wyoming. Eight of the sites are located within the Fraser Experimental Forest, including St. Louis Creek sites 1-4, 4a, and 5, East St. Louis Creek, and Fool Creek.

Table 1. Watershed and channel characteristics.

Site	Channel Type	Management History	Drainage Area (km^2)	Bankfull Discharge $Q_{1.5}$ (m^3/s)	Transport Rate at Bankfull (kg/s)	Primary Lithology	National Forest	State
St. Louis 1	step-pool	diversion	55.6	4.41	0.115	gneiss/granite	Arapaho-Roosevelt	CO
St. Louis 2	plane	diversion	54.2	4.75	0.077	gneiss/granite	Arapaho-Roosevelt	CO
St. Louis 3	riffle	diversion	54.0	4.59	0.104	gneiss/granite	Arapaho-Roosevelt	CO
St. Louis 4	plane	free-flowing, pristine	33.8	3.61	0.048	gneiss/granite	Arapaho-Roosevelt	CO
St. Louis 4a	riffle	free-flowing, pristine	33.5	3.37	0.053	gneiss/granite	Arapaho-Roosevelt	CO
St. Louis 5	step-pool	free-flowing, pristine	21.3	2.63	0.021	gneiss/granite	Arapaho-Roosevelt	CO
E. St. Louis Cr.	step-pool	free-flowing, pristine	8.0	0.86	0.013	gneiss/schist	Arapaho-Roosevelt	CO
Fool Cr.	plane	free-flowing, harvested	2.9	0.30	0.010	gneiss/schist	Arapaho-Roosevelt	CO
Little Granite Cr.	plane	free-flowing, pristine	54.8	5.95	0.137	sedimentary	Bridger-Teton	WY
S.Fk. Poudre R.	riffle	free-flowing, some private ownership	231.0	11.44	0.283	gneiss/granite	Arapaho-Roosevelt	CO
Coon Cr.	plane	free-flowing, harvest, tie-driven	16.7	2.77	0.031	gneiss/granite	Medicine Bow-Routt	WY
E.Fk. Encampment R.	plane	free-flowing, historical harvest, tie-driven	9.1	1.45	0.007	gneiss/granite	Medicine Bow-Routt	WY
Halfmoon Cr.	riffle	free-flowing, historical harvest	61.1	6.23	0.240	gneiss/granite	Pike-San Isabel	CO
Hayden Cr.	plane	free-flowing, harvest	46.5	1.92	0.044	sedimentary	Pike-San Isabel	CO
Cache Cr.	plane	free-flowing, pristine	27.5	1.84	0.004	sedimentary	Bridger-Teton	WY
E.F. San Juan R	riffle-braided	free-flowing, some private ownership	166.0	15.66	4.742	volcanic	San Juan	CO
Silver Cr.	plane	free-flowing, pristine	15.7	1.30	0.305	volcanic	San Juan	CO
Upper Florida R.	step-pool	free-flowing, pristine	115.0	14.50	0.023	granite	San Juan	CO
M. Fk. Piedra R.	riffle	free-flowing, pristine	86	10.05	0.308	volcanic/sed.	San Juan	CO

mantled by till and glacial outwash correlative of Bull Lake and Pinedale aged deposits (e.g., Nelson and Shroba 1998). At many sites, hillslopes are relatively stable under the current climatic regime and vegetative cover, though there is evidence of active mass wasting in the past (Caine 1986). Exceptions include Little Granite Creek, in western Wyoming, where there are active, deep-seated earthflows, and the sites underlain by volcanic formations, where debris chutes and ravel from unstable terrain deliver materials directly to the stream system (Ryan 2001).

Runoff at all of the studied sites is strongly influenced by the melting of snow in spring (Jarrett 1990), though the timing of the annual peak varies between sites. Peak discharge occurs typically from early May to late June and low flow occurs in January or February. A second peak discharge can occur in late summer at the sites in the San Juan Mountains in southwestern Colorado, due to the influence of the Arizona monsoon. Most of the study sites are free-flowing, though three of the Fraser Experimental Forest sites are located in channels from which an average of 40% of the total annual flow is diverted (Ryan 1994). However, water is rarely diverted from these sites at high flow when bedload is usually sampled. Small portions of flow at East Fork San Juan and South Fork Cache la Poudre sites are diverted for household or agricultural purposes upstream of the study sites. Some of the watersheds have been deforested to different degrees (e.g., Troendle and King 1985; Troendle et al. 2001) and a few of the channels were tie-driven in the historical past (Young et al. 1994) (Table 1). Other watershed areas have been selectively cut, the extent to which is either relatively minor or unknown.

Methods

Discharges used in flow frequency analyses were gaged either by the U.S. Geological Survey or the Forest Service. For the purposes of this analysis, the bankfull discharge is approximated using the 1.5-year return interval flow from Log Pearson type-III analysis (U.S. Interagency Advisory Committee on Water Data 1982). Previous work from these sites indicates that this value is a suitable approximation for the discharge that just fills the channel to its active floodplain (Ryan et al. 2005). Watershed area was obtained either from the metadata included with U.S. Geological Survey gaging data or was digitized from 1:24,000-scale topographic maps.

Bedload was measured using hand-held pressure difference samplers, such as a Helley-Smith bedload sampler (Helley and Smith 1971) or an Elwha sampler (Childers et al. 2000). Bedload was sampled once or twice daily over several weeks during snowmelt runoff using the Single Equal Width Increment (SEWI) method (Edwards and Glysson 1998). Bedload samples were dried and sieved using standard sedimentological methods (Folk 1968). Rate of transport was calculated using the total weight of the sample (in kg) divided by the total sampling time (number of verticals and time in seconds) and width of the sampler (in m) to obtain the unit bedload transport rate (kg m^{-1} s^{-1}). This value is multiplied by the width of the channel (m) to obtain the mean transport rate through the channel cross-section (in kg/s). The datasets used for developing bedload rating curves for individual sites contain between 40 and 200 pairs of flow and bedload observations. Bedload rating curves were developed from these data, and were then used to estimate the mean rate of bedload transport for the bankfull discharge. Additional information on these rating curves is available in Ryan et al. (2005).

Geologic type and patterns of mass wasting were evaluated at a relatively coarse scale. Geologic type was determined from published data and geologic maps available for individual areas. Patterns of mass wasting were determined from field reconnaissance or aerial photography and published maps, as available.

RESULTS

Commonalities in Normalized Values

Measured (or dimensional) rates of bedload transport typically vary between sites, indicating that individual stream systems exhibit their own "bedload signal" where the rate and size of materials transported largely reflect the nature of flow and sediment particular to that system. Moreover, it was observed that for sites within the same watershed, increases in sediment loads moving from small tributaries to larger channels were fairly predictable. In the St. Louis Creek watershed, there was about an order of magnitude increase in the rate of transport moving from a small watershed (East St. Louis Creek, drainage area about 5 km^2) to lower St. Louis Creek (St. Louis 1; about 50 km^2) (Figure 2). The normalized rate of bedload transport at bankfull for these eight stream sites was on average 0.0018 kg s^{-1} km^{-2} (standard deviation + 0.0008) (Figure 3). By comparison, when transport rates measured at additional sites were normalized by watershed area (Figure 3), many exhibited about the same level of bedload transport per unit area at the bankfull discharge as observed for the St. Louis Creek sites. These normalized values ranged from about 0.001 to 0.003 kg s^{-1} km^{-2}. Given the inherent uncertainty in the estimate of bedload transport associated with gravel bed streams, similarity among a number of sites is noteworthy. This suggests that the transport rate is fairly predictable within and between watersheds with similar flow, sediment, and supply relationships, and that drainage area can be used to help predict rates of sediment transport for an individual site. There were, however, several notable exceptions from this range of values, including the relatively high rates of transport from the East Fork San Juan River and Silver Creek (about 0.025 kg s^{-1} km^{-2}) and the relatively low rates from Cache Creek and the Florida River (about 0.0002 kg s^{-1} km^{-2}). While these exceptions may be attributed to a number of factors, it was noted that there were distinct differences in patterns of mass wasting in these watersheds that would cause variation in sediment supply to the stream system and associated differences in rates of bedload transport. This is explored in greater detail below.

San Juan Sites, Southwestern Colorado

It is worth noting that data for all of the sites in the San Juan area (East Fork San Juan, Silver Creek, Middle Fork Piedra, and Florida River) were collected using a pressure-

Figure 2. Relationship between estimated transport rate at bankfull discharge and drainage area for main stem and tributaries to St. Louis Creek, Fraser Experimental Forest.

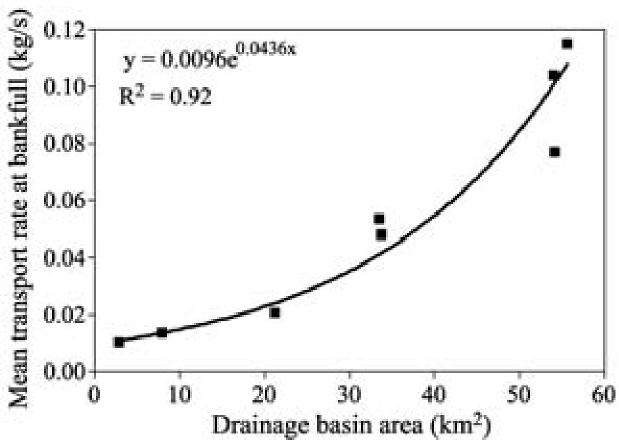
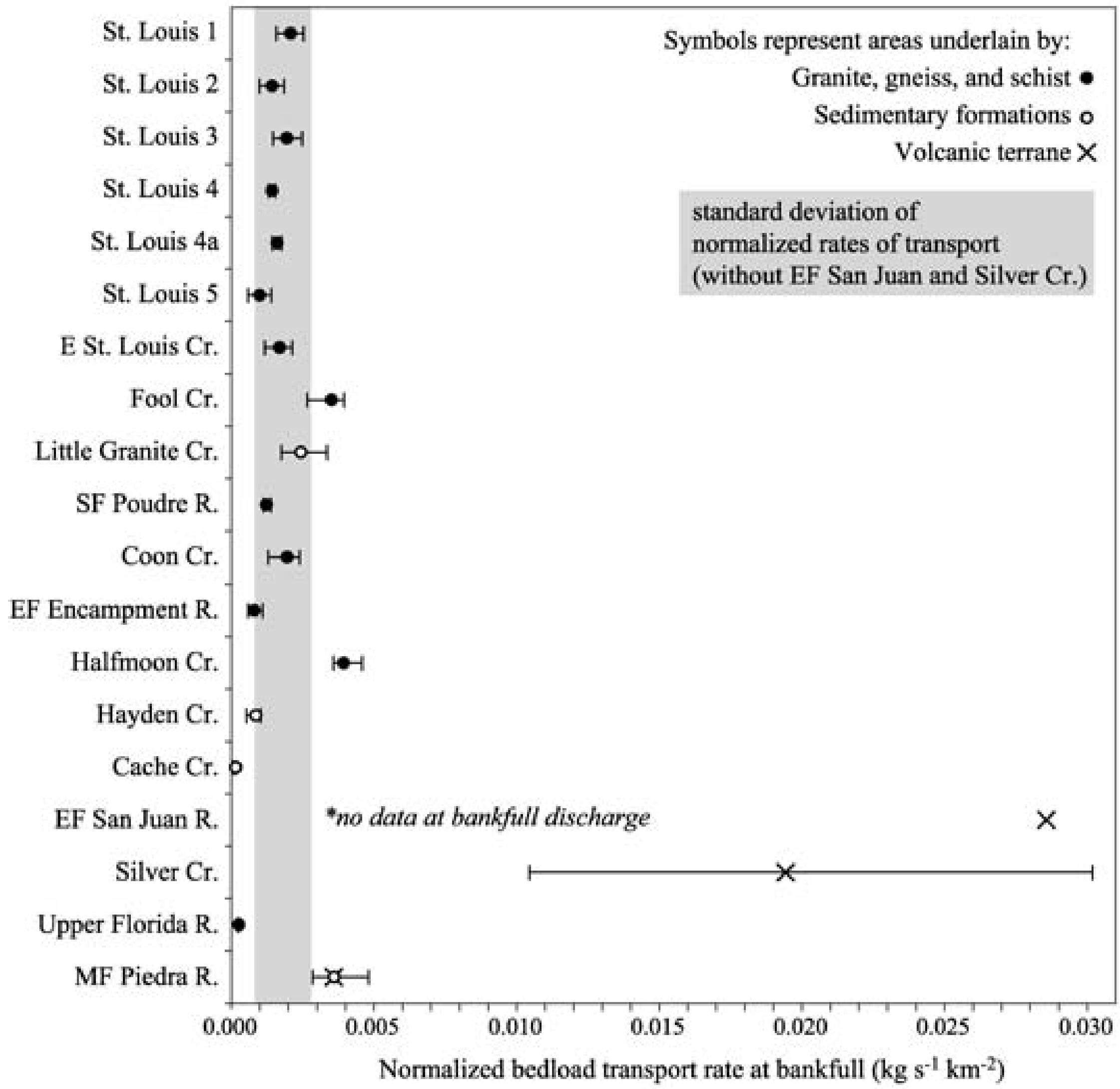


Figure 3. Normalized rates of bedload transport for 19 sites in Colorado and Wyoming measured between 1982 and 2001. Data were normalized by dividing the estimated rate of bedload transport at the bankfull discharge (and calculated 95% confidence limits) against the drainage area upstream of the sampling site. The black circles represent areas underlain by granite, gneiss, and schist, open circles represent areas underlain by sedimentary formations, and crosses represent areas draining volcanic terrane. The Middle Fork Piedra lies on a transition between volcanic and sedimentary bedrock and so two symbols are used. The area in gray represents the standard deviation of the normalized rates of transport, exclusive of the East Fork San Juan and Silver Creek sites. No confidence limits could be estimated for the East Fork San Juan site because there was no data at bankfull discharge. The wide error bars observed for the Silver Creek data are attributed to probable hysteresis effects observed in the dataset (Ryan 2001; Ryan et al. 2005).



difference sampler with a larger opening (4 x 8 inches; 10 x 20 cm) than deployed at the other sites (3 x 3 inches; 7.6 x 7.6 cm). This could explain, in part, lower rates of transport observed elsewhere (Figure 3) if the smaller sampler has a low capacity relative to the rate of bedload transport. However, not all sites where the larger sampler was used exhibit elevated rates of normalized bedload transport. Data from the Florida River indicate low normalized rates of transport, while data from the Middle Fork Piedra site suggest slightly elevated values, though not to the levels observed at East Fork San Juan River and Silver Creek (Figure 3). Hence, the differences in normalized rates of transport from these sites cannot be attributed simply to sampler type, but more likely reflect differences in sedimentation processes in the watersheds (Ryan et al. 2005).

As a causative explanation for the differences in normalized rates of bedload transport, it was observed that the San Juan sites have distinctive modes of sediment supply linked to the instability of the extrusive volcanic bedrock (Tertiary) and to the relative stability of the granite formations. In Silver Creek, precipitous, unstable hillslopes impinge on the steep tributary, and materials from active debris/avalanche chutes are delivered directly into the channel. The channel becomes an effective conduit for transporting the delivered sediment, particularly on the rising limb of the seasonal hydrograph after the overwinter sediment supply has accumulated in the channel. Transport rates are at times high, though irregular, in this system (0.002 - 0.031 kg s^{-1} km^{-2} at bankfull), reflecting the episodic nature of the sediment supply (Ryan 2001). Sediment moved by Silver Creek and other tributaries is deposited downstream in a wide valley bottom with a braided to plane-bed channel (East Fork San Juan) that also has high rates of transport (about 0.029 kg s^{-1} km^{-2} at bankfull). This value is on the same order as the mean normalized rate observed for Silver Creek (Figure 3). The similarity in rates of transport between these two sites is likely a systematic effect, determined by sediment supplied by the upper sites (such as Silver Creek) to the mainstem.

By contrast, observed rates of sediment transport are quite low (0.0002 kg s^{-1} km^{-2}) at the Upper Florida River site. This watershed is underlain by stable granitic terrane and the channel upstream of the site flows over bedrock, signifying a relatively low supply of sediment. The primary source of material in this system is from the channel beds and banks, as there were few observed external sources of sediment, such as active landslides, upstream. Sand and fine gravel, originating from sand and gravel patches interspersed between very large particles, are transported over a largely stable, interlocking boulder and cobble bed. Because of the relative stability of the channel bed, widespread entrainment is unlikely to occur over a majority of the channel surface (Ryan 2001). Hence, the low normalized rate of sediment transport is likely due to low supplies of sediment that characterize the Florida River watershed.

Gros Ventre Range Sites, Northwestern Wyoming

The series of comparisons from St. Louis Creek and other sites in Colorado and Wyoming suggest the existence of common normalized bedload transport rates for areas underlain by similar geologic terrane. However, there can be substantial differences in sediment supply in areas where the geologic terrane is spatially variable over short distances. As an example, transport rates and patterns of mass wasting from two sites in the Gros Ventre Range in northwestern Wyoming are compared. The geology of the Gros Ventre Range consists primarily of Paleozoic and Mesozoic sedimentary rock formations, many of marine origin (Love and Christiansen 1985). These formations are highly deformed and relatively unstable. As a result, parts of the Gros Ventre Range are characterized by some of the highest densities of landslides in the United States (Wyoming State Geological Survey 2001). The area is also influenced by active faulting and a relatively high likelihood of earthquakes (Case and Green 2000). Hence, one might expect that channels draining watersheds in the Gros Ventre will exhibit high rates of sediment transport due to potentially large supplies of sediment from active mass wasting. Yet, measured rates of bedload transport from two sites in this range suggest otherwise. Normalized rates of transport from Little Granite Creek (0.0025 kg s^{-1} km^{-2}) are on the high end of the range while the rates from Cache Creek (0.0001 kg s^{-1} km^{-2}) are the lowest measured in this study. An evaluation of mass wasting patterns from the two watersheds (Wyoming State Geological Survey 2001) shows about five times the number of landslides in Little Granite Creek (118) compared to Cache Creek (23). Inspections of aerial photographs and field reconnaissance show that many of the slides in both watersheds are of the large, slow-moving, earth flow-type that often involves entire an entire hillslope (Varnes 1978). Several of the large slides identified in Little Granite Creek were observed to impinge directly on stream channels. Where these slides impinge, the toeslopes are actively raveling and the channel is pushed to the far side of the valley bottom, creating a second set of slides where the hillslope is undercut. These slides are a chronic source of sediment in this watershed, as materials deposited from the erosional faces are reactivated during high runoff. Moreover, the upper portion of the Little Granite watershed was glaciated and there are several currently active sources of sediment from glacial debris. While the upper watershed is a potential source of bedload in this system, much of the glaciated material comes off in suspension, as Little Granite Creek has an exceptionally high suspended load relative to bedload (Ryan and Emmett 2002). By contrast, there appear to be fewer chronic sources of sediment in Cache Creek, which flows through a largely stable inner gorge over most of its length above the sampling site near a U.S. Geological Survey gaging station. Hence, differences in the normalized rates of transport observed for these two sites are likely linked to variation in geologic controls, gross differences in the patterns of mass wasting, and inherent differences in sediment supply from the two watersheds. Therefore, one should be cautious in applying the sediment transport relationships even in watersheds draining similar geologic terranes without considering localized differences in sediment supply that potentially influence rates of sediment transport.

Discussion

Results from this comparison of normalized rates of bedload transport suggest that streams in many of our watersheds exhibit comparable rates of sediment transport per unit watershed area at bankfull discharges (ranging between 0.001 and 0.003 kg s^{-1} km^{-2}). Variability in the range of these normalized values may be attributable to land use effects or recent disturbances, though this was not directly assessed in this work. However, given the inherent difficulty in obtaining reliable estimates of mean rates of bedload transport, the relatively narrow range of values observed for these systems is noteworthy. One might expect such similarity in watersheds with comparable rates of sediment supply (e.g., landslides, bank collapse, and stream bed entrainment). Other recent work on bedload transport supports the idea of similarity in processes for channels in inland western mountainous terrain, such as correspondence in dimensionless sediment transport relationships (Troendle et al. 2001) or comparable ranges of flow at which the onset of coarse sediment transport occurs (phase II) (Ryan et al. 2002; Ryan et al. 2005).

While the relatively narrow range of values suggests that many of these gravel bed systems behave in a in a similar way, the analysis also identified sites where there was substantial departure. Generally, when sediment supplies were abundant, the normalized rates of bedload transport were substantially greater than when sediment was restricted. Areas with active mass wasting from unstable landscapes, such as a volcanic terrane in the San Juan Range, had rates of normalized bedload transport that were about an order of magnitude greater than the average. By contrast, areas in relatively stable landscapes exhibited rates of normalized bedload transport that were about an order of magnitude lower. As a caveat, while this series of comparisons suggests that scaled rates of bedload transport may be transferable across watersheds in similar geologic settings, one does need to consider localized influences that contribute to differences in sediment supply before applying the sediment transport relationships broadly.

The relationships between sediment supply and normalized transport described in this paper were qualitative, relying on broad classes to describe mass wasting patterns (high, medium, or low). The next phase of this work will focus on better quantification of sediment supplied from different sources, to help in explaining variability in the normalized rate of bedload transport. Natural levels of materials transfer and the relative importance of different modes of sediment production in a watershed can be assessed through a sediment source analysis (Reid and Dunne 1996). Such an analysis can be complex, requiring field identification of a range of sources, including large landslides, instream sedimentation, and sediment contributed by different land management practices. However, such assessments are necessary in order to better define the relationships between sediment supply and transport, and to improve our capability to predict rates of bedload transport.

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A River Runs Underneath It: Geological Control of Spring and Channel Systems and Management Implications, Cascade Range, Oregon

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Long-term sustainable management of Cascade Range watersheds requires an understanding of water sources and discharge patterns from tributary streams, particularly those sourced in large-volume cold springs of the High Cascades geologic province. Focusing on the McKenzie River watershed, measurements of discharge and stream temperature combined with laboratory analysis of spring water isotopes improve our understanding of spatial and temporal recharge and discharge patterns. Summer streamflow in the McKenzie is dominated by water from approximately ten spring-fed streams, which maintain 4 to 7°C spring water temperatures and relatively steady flow throughout the summer. In winter months, streams in the Western Cascades geologic province respond rapidly to rain and rain-on-snow events and become the major water source to the McKenzie River. Spring-fed streams also respond to precipitation events, but show muted and delayed hydrograph peaks. Summer flow behavior varies among springs, even between those that are located near each other. Isotopic data reveal that recharge to large springs occurs between 1300-1800 m in elevation, which is coincident with geologically young lava between McKenzie and Santiam Passes. Recharge elevations also suggest some disagreement between recharge areas and topographic watersheds of the springs. Because of their importance to summer streamflow, water quality, and habitat in the McKenzie River basin, water resources decision-making must differentiate between spring-fed and runoff-dominated streams.

Keywords: *streamflow, groundwater processes, geology/geomorphology, springs, water temperature, Oregon Cascades*

Introduction

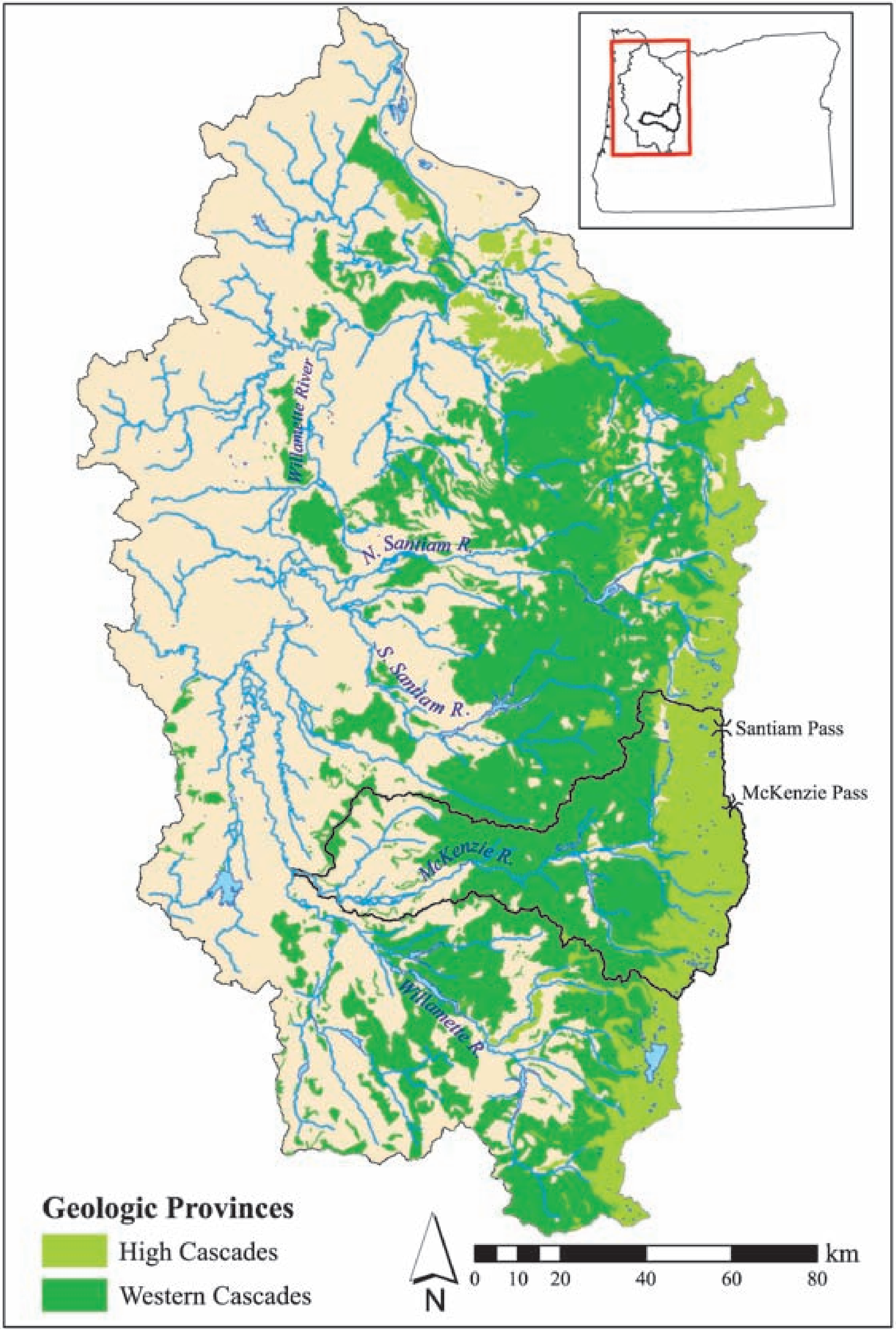
The Willamette River basin is home to 70% of Oregon's population, and while the McKenzie River watershed covers less than 12% of the basin's area, it provides almost 25% of the Willamette River's water during low flow periods (PNWERC 2002). The McKenzie watershed includes threatened and endangered fish runs, a complex system of federal and private dams for flood control and hydroelectric power generation, and Oregon's second largest city (Eugene), which draws 10 billion gallons (37.8 billion L) of drinking water per year directly from the river.

Furniss, M.J., Clifton, C.F., Ronnenberg, K.L., eds., 2007. *Advancing the fundamental sciences: proceedings of the forest service national earth sciences conference, San Diego, CA, 18-22 October 2004*. PNW-GTR-689. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Recent analyses show that the Cascade Range is particularly sensitive to current and projected climate warming trends, specifically reduced snow accumulation and earlier spring melt, leading to a decline in summer streamflow (Service 2004). By 2050, Cascade snowpacks are projected to be less than half of what they are today (Leung et al. 2004), potentially leading to major water shortages during the low-flow summer season. Although not yet as contentious as the Klamath River to the south, the stage is set in the Willamette basin for significant future conflicts and demands for water.

Despite the importance of the McKenzie River's water to the region's quality of life, geologic and climatic controls on patterns of streamflow have been poorly understood. The watershed of the McKenzie River lies primarily within two distinct geologic provinces: the High and Western Cascades (Figure 1). The High Cascades are known for their active composite volcanoes and extensive Quaternary basaltic lavas, while the Western Cascades are the products

Figure 1. Forty-two percent of the McKenzie River watershed lies within the High Cascades geologic province, the most of any major Willamette River tributary. Geologic classification is based on mapping by Sherrod and Smith (2000).



of Tertiary volcanism, and have been extensively faulted, weathered, and dissected (Conrey et al. 2002). The Western Cascades have well-developed drainage networks and watersheds dominated by shallow-subsurface, runoff-dominated flow (Harr 1977), while in the High Cascades large areas lack drainage networks and many of the streams are fed by springs. Preliminary hydrograph analyses indicate that High Cascades streams show much more uniform flow and temperature through time compared to Western Cascades streams (Tague and Grant 2004). These differences have significant implications for water quantity and quality in headwater streams and for larger rivers, such as the McKenzie and Willamette, where both High and Western Cascades streams contribute to flow.

This research represents a systematic attempt to quantify volumes and sources of discharge in the McKenzie River basin. The overall goal of the project was to provide a more complete picture of flow contributions to the McKenzie River, for use in planning the sustainable long-term water management of the basin. Our objectives were to identify sources of summer streamflow to the upper McKenzie River, obtain continuous discharge records for large spring-fed streams, and use isotopic information to characterize groundwater recharge patterns.

Our field campaign focused on the upper McKenzie River basin, defined as the 2409 km^2 watershed upstream of the USGS gage at Vida. This area encompasses all of the High Cascades geology in the basin, as well as two Western Cascades tributaries with Corps of Engineers flood control reservoirs. USGS stream gages operate at four locations on the mainstem of the McKenzie River and on the tributaries Blue River, Separation Creek, Smith River, and the South Fork of the McKenzie. The USGS gages for the McKenzie River at Clear Lake and Separation Creek include a substantial spring-fed component, but do not represent a pure spring signal.

Methods

In summer 2003, discharge was measured at all McKenzie River tributaries flowing from areas of High Cascades geology. These data, combined with knowledge of some spring locations, allowed us to identify all of the major sources of summer streamflow to the upper McKenzie River. Fourteen streams were selected for continuous gaging (Figure 2), and Trutrack[1] capacitance rod water stage and temperature recorders were installed during July 2003. These streams included nine spring-fed streams, four runoff-dominated streams, and one ephemeral spring-fed stream. Selected spring-fed streams included all of the major ungaged springs that are tributary to the McKenzie River. Runoff-dominated streams were selected because they were tributary to or provided a reference site in close proximity to spring-fed streams.

Discharge measurements were made at a variety of stages in order to develop rating curves for each site, following standard USGS procedures. These curves allow interpolation from stage to discharge and result in daily hydrographs for the streams. Discharge was directly measured between four and 18 times at each site, depending on flow variability. Despite repeated measurements, peak flows had to be extrapolated from the rating curve for each site. Where there is not sufficient confidence in such extrapolations, hydrographs are truncated in high flow periods.

In mountainous regions, the isotopic composition of precipitation varies in a systematic way with elevation (Dansgaard 1964). The isotopic composition of spring water can be projected to the elevation at which precipitation has a comparable composition. Recharge elevations estimated by this method represent precipitation-weighted averages and have an error of ±60 m due to analytical uncertainty, plus some uncertainty associated with the altitude-isotope relationship. Spring water samples were analyzed for hydrogen and oxygen isotope ratios (δD and $\delta^{18}O$, respectively) at Lawrence Livermore National Laboratory. Isotopic composition of the water was compared to a published altitude-isotope relationship for the Oregon Cascades (Ingebritsen et al. 1994).

Spring water samples were also analyzed at the University of Waterloo (Waterloo, Ontario, Canada) for tritium, a radioactive hydrogen isotope with a half life of 12.43 years. Tritium in the groundwater system indicates that it has been recharged within the last ~50 years (Clark and Fritz 1997). Tritium concentrations were greatly increased in the atmosphere as a result of nuclear weapons testing in the 1950s and 1960s, but by the 1990s atmospheric tritium activities had approximately returned to pre-bomb levels.

Results

During 5-7 August 2003, discharge measurements were made on High Cascades tributaries to the McKenzie River (Figure 3). Discharge of the McKenzie River at Vida was 50.7 m^3/s on 7 August 2003. According to our measurements, 83% (42.3 m^3/s) of this flow came from spring-fed streams. By combining locations from this project and the USGS, over 97% (49.4 m^3/s) of the flow in the McKenzie River was measured, despite neglecting most tributaries flowing from Western Cascades geology.

[1]The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Figure 2. Gaging sites are located on spring-fed and runoff-dominated streams in the upper McKenzie River watershed. Indicated big springs have more than 0.85 cms average annual discharge.

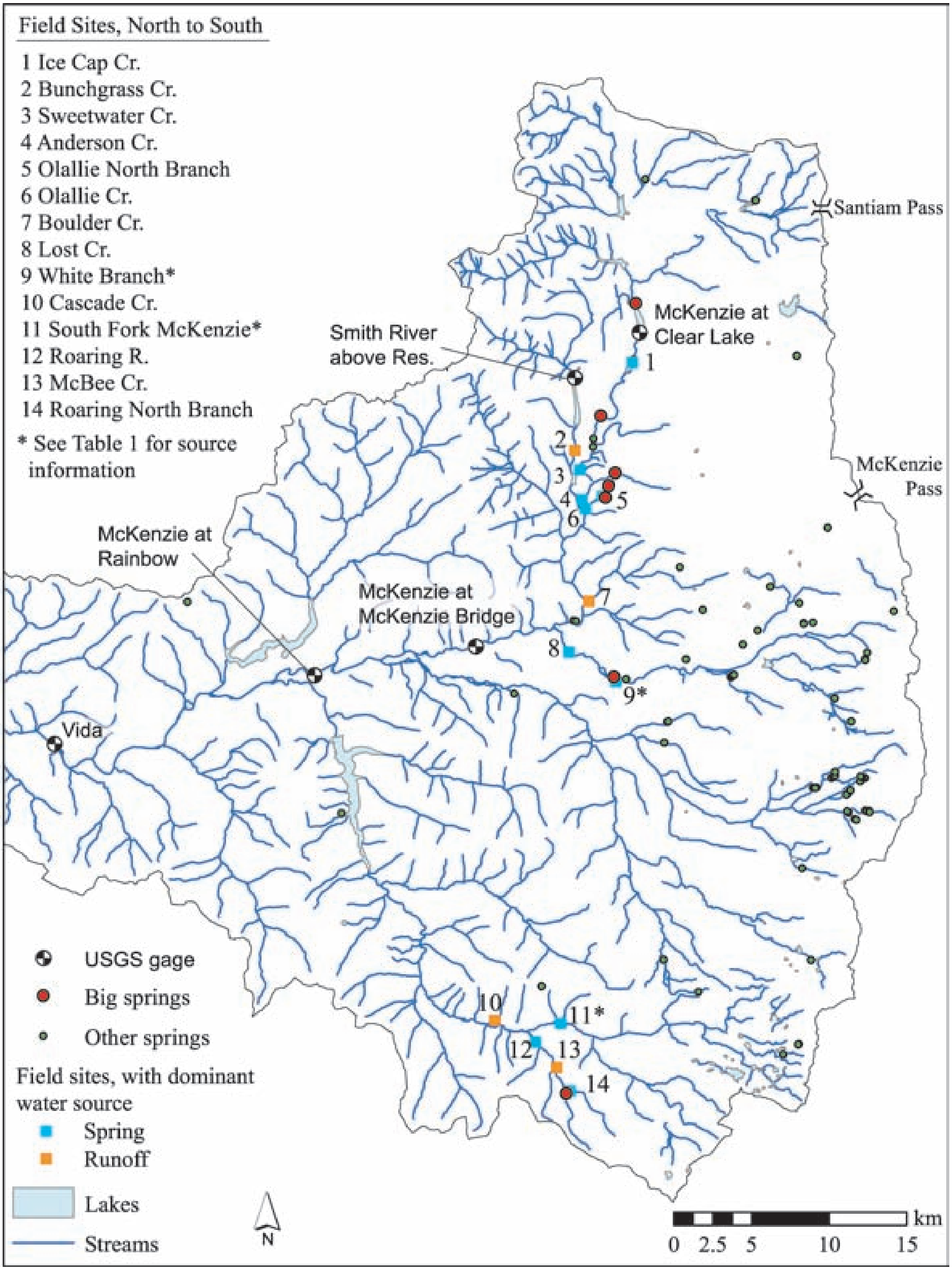


Table 1. Summary of characteristics of discharge measurement sites. For more detailed information on groundwater patterns, see Jefferson et al. (2006).

Site Name	Dominant Water Source	Mean Water Temperature (°C)†	Std Dev. (°C) †	Daily Discharge (m^3/s) 5 August 2003
Anderson Cr.	Spring	4.7	0.9	0.61
Boulder Cr.	Runoff	8.3	3.7	0.0061
Bunchgrass Cr.	Runoff	6.6	3.6	N/A
Cascade Cr.	Runoff	7.0	3.1	N/A
Ice Cap Cr.	Spring	4.5	0.2	N/A
Lost Cr.	Spring	6.9	0.3	5.8
McBee Cr.	Runoff	6.4	3.0	0.021
Olallie Cr.	Spring	5.0	0.1	4.7
Olallie North Br.	Spring	4.7	0.0	1.6
Roaring River	Spring	5.4	0.7	2.7
Roaring North Br.	Spring	4.3	0.1	0.79
South Fork McKenzie	Spring likely - location unknown	5.9	1.8	2.3
Sweetwater Cr.	Spring	N/A	N/A	N/A
White Branch	Ephemeral spring	6.1‡	1.9‡	0.11

† For period of record between 10 July 2003 and 31 March 2004.
‡ For period when stream has flowing water.

Reservoir supplementation accounted for ~10% of the flow at Vida. Without this supplementation, spring-fed streams would provide 93% of the flow in the McKenzie River.

This campaign of discharge measurements indicated that all major springs discharging into tributaries of the McKenzie River were accounted for in the gaging scheme described above. There is considerable accretion of groundwater directly into the mainstem of the McKenzie River between Clear Lake and Trail Bridge Reservoir (Stearns 1929), but direct discharge measurements are unattainable. The difference in discharge between the USGS gages at Clear Lake and Trail Bridge Reservoir minus the discharge of Smith River and Bunchgrass Creek can be attributed to this groundwater accretion. During August 2003, 10.3 m^3/s of groundwater were added to the flow of McKenzie River in the Clear Lake to Trail Bridge Reservoir reach. Additionally, there are small springs in the watershed which discharge water to the surface where it quickly infiltrates back into the ground, while other springs discharge into closed-basin lakes, where their water either evaporates or recharges the groundwater system.

Considerable differences were observed between the hydrographs of spring-fed and runoff-dominated streams in the McKenzie River watershed (Figure 4). Peak flows were 1.5 to 2.7 times greater than low flows on spring-fed steams, whereas for runoff-dominated streams peak flows were approximately 30 to 1000 times greater than low flows. Hydrographs of spring-fed streams also showed little recession during the summer, as compared to those of runoff-dominated streams. Comparison of flows from summer 2003 to spot discharge measurements in 2001-2002, and to irregular measurements from the 1910-1926 (Stearns 1929) suggests that springs have less interannual variability than runoff-dominated streams.

Two major peak flow events are represented in the gaging record: 13-14 December 2003 and 29 January 2004. The spring-fed streams exhibit a delayed peak flow compared to runoff-dominated streams, and this cannot be completely explained by elevation or watershed area. For example, all four runoff-dominated streams had their peak flow on 29 January 2004, but the spring-fed streams reached their peak flows on 30-31 January. Anderson Creek showed almost no response to rain events, while the bigger spring-fed streams showed some responsiveness. Some of this responsiveness may be due to gaging location, as the Roaring and South Fork sites are downstream of runoff-dominated tributaries.

Springs feeding the same creek exhibited different dynamics during the summer period, as illustrated by Olallie Creek and Roaring River (Figure 4, Table 1). Olallie North Branch rises through July and August and drops off in September, while downstream on Olallie Creek, below the confluence of the north and south branches, Olallie Creek exhibits a slight recession throughout the summer as well as greater fluctuations. This recession is similar to the stage record at Olallie South Branch (not shown), which contributes most of the flow to Olallie Creek. Thus,

Figure 3. By combining data from USGS gages and sites measured for this research, 97% of discharge in the McKenzie River at Vida can be apportioned. Discharges in the McKenzie River and its tributaries on 5-7 August 2003 are schematically represented by the thickness of each line. Distances are not to scale.

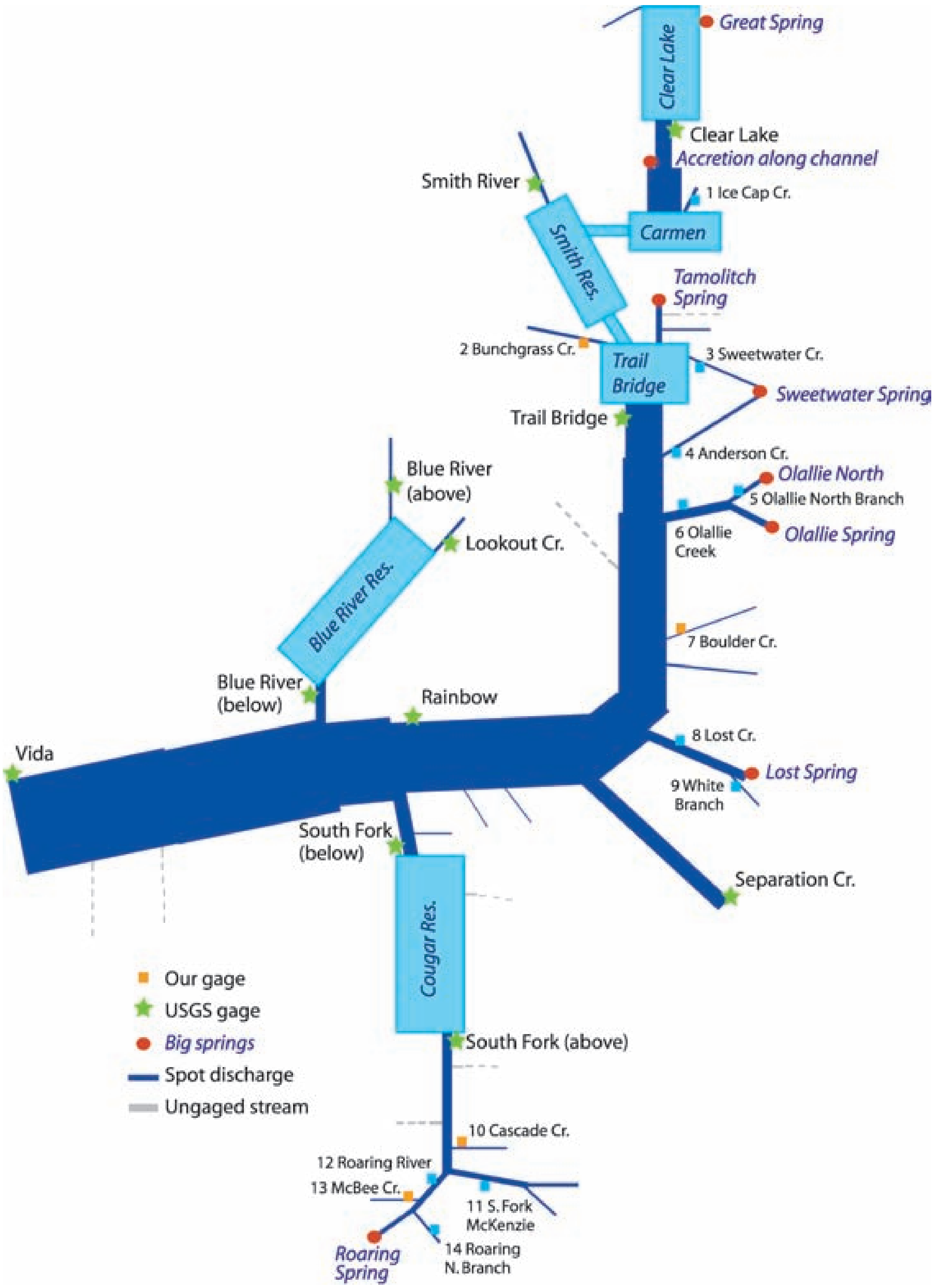
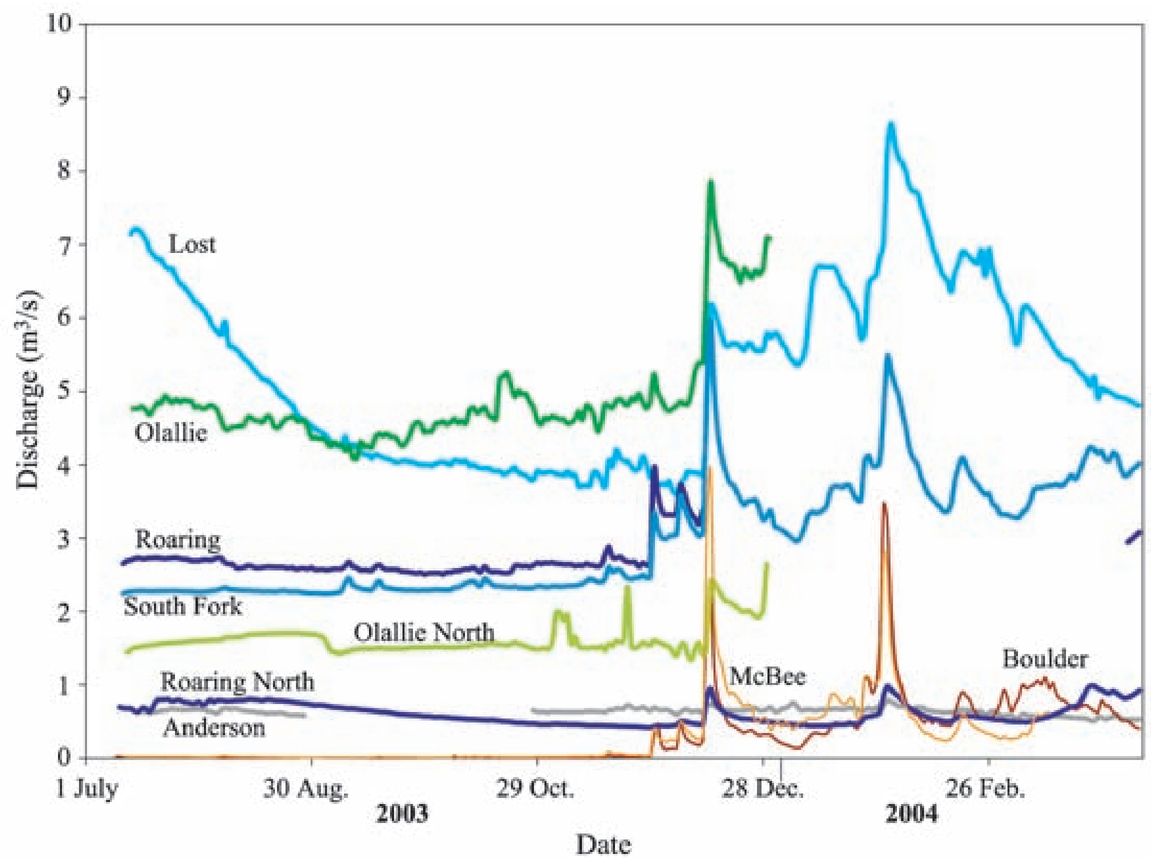


Figure 4. Spring-fed streams (thick lines) display less seasonal fluctuation and muted event response compared to runoff-dominated streams (thin lines), as exhibited by these hydrographs for 9 July 2003 to 7 April 2004. Olallie Creek and Olallie North hydrographs are truncated where there is low confidence in extrapolated discharge values. Other missing data are the result of instrument failure.



although the two branches are sourced in springs less than one kilometer apart, their summer flow behavior differs. Between 15 August and 15 September 2003, discharge from the north spring on Roaring River declined 0.15 cms, while flow at the downstream gage dropped only 0.04 cms. Increased flow from Roaring Spring (south branch) must account for the discharge measured downstream.

White Branch Creek, as measured near its confluence with Lost Creek, appears to be controlled by an ephemeral spring (Figure 5). It exhibits markedly different discharge dynamics than either spring-fed or runoff-dominated streams, despite its spatial proximity to perennial Lost Spring. The stream had a very steep recession in July-August and again in March, each time resulting in a completely dry channel. The stream did not respond to the 13-14 December peak flow event, and exhibited a five-day delay in peak flow for the end of January event. Throughout the vagaries in discharge, water temperature remained nearly constant between 6.5 and 6.7°C, within the range exhibited by Lost Spring. Only when discharge was below ~0.1 m^3/s did significant temperature fluctuations occur.

Water temperature trends also exhibited differences between spring-fed and runoff-dominated streams (Figure 6, Table 1). Temperature measured directly at springs was nearly constant throughout the year, while streams showed fluctuations likely due to cooling or heating from the surrounding air mass. However, spring-fed streams showed much smaller variation in temperature both seasonally and daily than did runoff-dominated streams.

Water samples for five springs were analyzed for tritium, and results ranged from 2.9 to 6.1 tritium units, indicating that the groundwater had been recharged within the last 50 years (Clark and Fritz 1997). Recharge elevations, based on isotopic composition of spring water samples, are at substantially higher elevations than the springs are discharging (Figure 7). The recharge elevations for the springs are concordant with the elevation of extensive young lava flows between McKenzie and Santiam Passes (Figure 2). Springs providing discharge to tributaries of the South Fork of McKenzie also recharge in this elevation range (1325-1825 m), despite less extensive areas of young lavas. Recharge elevations inferred by isotopic methods

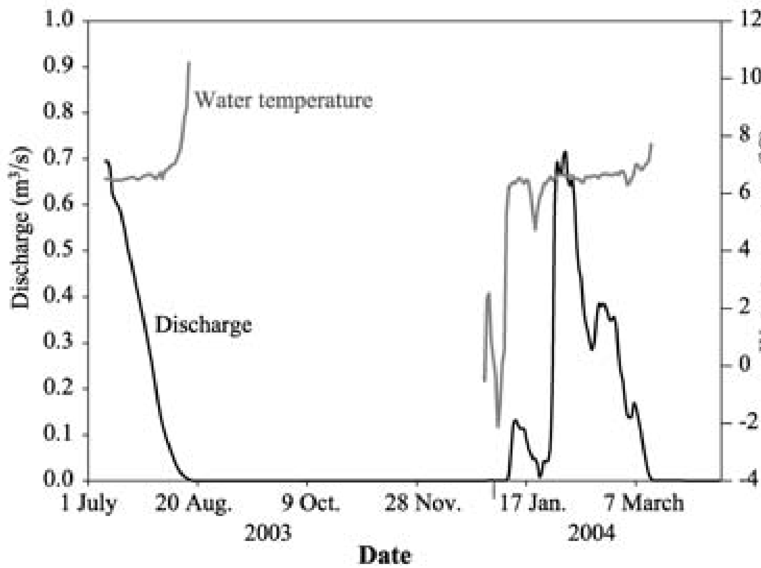


Figure 5. White Branch Creek is fed by an ephemeral spring, and its hydrograph and temperature history are dissimilar to other spring-fed or runoff-dominated streams. White Branch, as measured near Oregon Highway 242, had no water in its channel from 19 August to 25 October 2003 and from 16 March 2004 until the end of the analysis period.

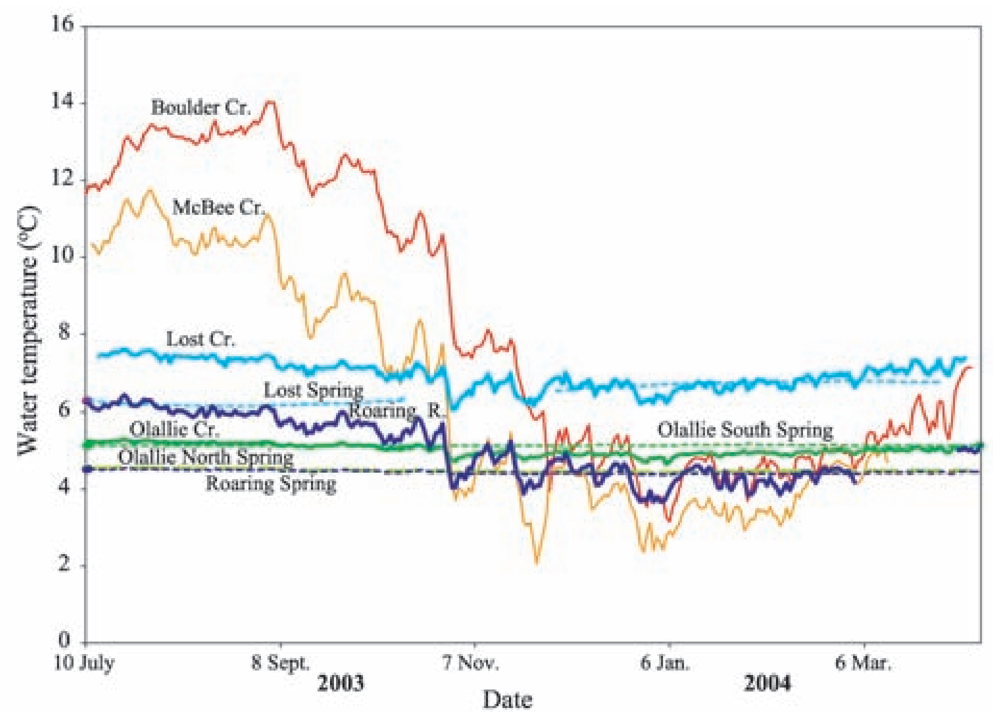


Figure 6. Water temperatures in springs (dashed lines) and spring-fed streams (thick lines) exhibit less variability than temperatures of runoff-dominated streams (thin lines). Water temperature at springs measured by Hobo Water Temp Pro sensors, and in streams, temperature was measured using Hobo or Trutrack sensors.

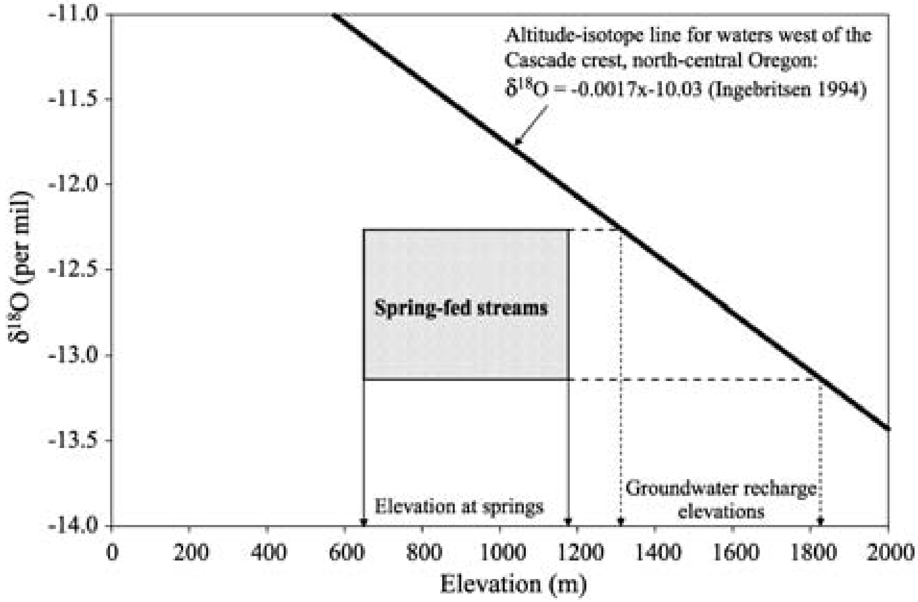
indicate that topographic watersheds may not be providing evenly distributed recharge to the groundwater system. In at least one case, the inferred average recharge elevation is greater than the maximum elevation in the topographic watershed, requiring significant recharge from outside its boundaries.

Discussion and Management Implications

Spring-fed streams are the dominant source of summer streamflow in the upper McKenzie River, and this flow is sourced from less than ten discrete areas in the watershed. Most of these springs occur on federal land, requiring local and federal water resources agencies to cooperate in their management and protection. The discrete nature of the source areas of water in the McKenzie suggests a number of implications for management.

Maintaining the high water quality of the springs and spring-fed streams requires consideration of several distinct environments: a) the springs themselves; b) the extensive, but often cryptic or unknown area upstream of the springs contributing flow to the springs; and c) channel and riparian areas bordering spring-fed streams. Each of these environments can potentially have different ownerships (public or private), management allocations, impacts, and consequences for water quality. We are only beginning

Figure 7. Mean recharge elevation for the springs can be determined by projecting their isotopic composition onto the altitude-isotope line. On average, the springs are recharging almost 800 m higher in elevation than they are discharging.



to understand the interplay of these environments and potential impacts of human and land use activities on each. Specifically, the effects of human activities and natural disturbances in recharge areas on spring water quantity and quality are not well understood. For example, most large springs in the McKenzie drainage are located on national forest lands, and are included in riparian reserves under the Northwest Forest Plan (USDA and USDI 1994). This affords a relatively high degree of protection against forest-harvest and road-building activities. However, source areas that contribute to the springs may or may not be included in riparian or other reserve or protection categories, since groundwater systems are not explicitly included in the Northwest Forest Plan. Whether land-use activities, including forest harvest, recreation, fire suppression, and fuels management, affect the flow in springs remains an open question.

Recharge elevations are significantly higher than spring locations and suggest some discordance between recharge areas and topographic watersheds. These findings emphasize the importance of further investigation into recharge area geometry, the question of whether specific portions of the landscape provide a disproportionate share of recharge to the groundwater system, and what effects human activities in source areas may have on streamflow and water quality.

It is not clear whether highlighting the location of springs (i.e., on maps or through media) will contribute to their future protection or degradation. Many springs are quite sensitive ecologically, with extensive wetland vegetation, unique habitats, and undeveloped access, and would probably be degraded by extensive human use. On the other hand, some springs are on well-developed trail systems and appear to have been quite resilient to the effects of nearby recreational uses.

Despite their importance to water supply during low flow seasons, none of the springs and few of the spring-fed streams have established long-term monitoring facilities (i.e., USGS gages). While spring-fed streams provide more consistent flow than runoff-dominated streams, they do experience higher flows in response to rain and rain-on-snow events. Thus, adequate gaging of these systems is still important for reservoir management planning. A small number of discharge measurements might be sufficient to characterize summer streamflows in spring-fed streams, but winter flows cannot be assumed to be static. Furthermore, differences in flow dynamics between spring-fed streams, even those in close proximity to each other, preclude generalizing measurements from one spring system to others.

Stream temperature, an important habitat criteria for bull trout (*Salvelinus confluentus*) and other species, is generally lower and more stable in spring-fed than runoff-dominated streams, suggesting that conservation efforts for some species might be concentrated in spring-fed streams. At a minimum, the relationship between ecosystem structure and function in spring- versus non-spring streams should be investigated, as this may have implications for regulatory standards affecting water quality and forest management.

Post-1950 groundwater recharge dates imply that the groundwater system is being actively recharged, probably in balance with the amount discharged at springs annually. This suggests that spring water may be susceptible to contamination by atmospheric deposition or chemical spills in recharge areas. Contamination of spring water may appear several years after a spill and the effects may last for decades. Finally, a change in the overall amount of precipitation falling on the Cascades would probably have an impact on spring discharge within a few years, but a change in seasonality or form of precipitation may be less significant for spring-fed streams than for runoff-dominated streams.

Because of their importance to summer streamflow, water quality, and habitat in the McKenzie River basin, water resources decision-making must differentiate between spring-fed and runoff-dominated streams. This will require cooperation between local and federal organizations, continued assessment of long-term behavior of spring-fed streams in light of climate variability and change, and more investigation into how human and natural impacts on recharge areas could affect groundwater quantity and quality.

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Hubbard Glacier, Russell Fiord, and Situk River: A Landscape in Motion

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Hubbard Glacier, Russell Fiord and the Situk River near Yakutat, Alaska are glacial terrains and forelands in a constant state of motion. The area is an extremely active and dynamic landscape with an advancing tidewater glacier (10 km wide at tidewater), two major seismic faults, and a maximum net isostatic uplift rate of 0.44 cm/yr. The southern end of Russell Fiord is confined by a terminal moraine whereas the northern end of the fiord flows into Yakutat Bay. In 1986 and 2002, the advance of the Hubbard Glacier blocked the northern of the Russell Fiord from Yakutat Bay, temporarily creating Russell Lake. Subsequent failure of the ice or moraine dams in 1986 and 2002, respectively, produced the two largest glacial outburst floods in historic times. Both of these dams failed before the lake had risen to an elevation that would have caused it to spill over the terminal moraine at the southern end of Russell Fiord into the Situk River drainage. In 2002 the Tongass National Forest commissioned an interagency technical team to investigate the implications of the Hubbard Glacier completely closing Russell Fiord and rising lake levels overtopping the moraine at the southern end of Russell Fiord, forcing flow into the historic Situk River channel. Complete closure of Russell Fiord has major economic and safety issues affecting the City of Yakutat. The Situk River provides world class sport, subsistence and commercial fishing, which drives and supports the majority of the Yakutat economy. A sustained closure of the Hubbard-Russell ice dam will increase average daily flows in the Situk River from the current 3 to 11 cubic meters per second (cms) to over 566 cms if Lake Russell overtops the moraine, resulting in significant short and long-term changes to the river ecosystem. Hydrologic and geomorphic analyses of potential overflow scenarios were performed using data obtained from field and remote sensing technologies. The results and methods used to perform the analyses are discussed.

Keywords: *glaciers, LIDAR, flood modeling, geophysical survey, floods, ice dam stability, jokulhlaups, glacial outburst floods*

Introduction

During the last 7,000 years, Russell Fiord in southeast Alaska has experienced cyclical ice damming by the Hubbard and Nunatak glaciers, forming a large lake that redirects outflow into the Situk River near Yakutat, Alaska. These cyclical events have continually altered the land and subsistence lifestyles of the local indigenous people (Tlingit). Oral traditions (deLaguna 1964) and geologic evidence (King 1995; Barclay et al. 2001) indicate that the last major ice dam failure occurred in the mid 1800s, transforming the Situk River into the present river system. The Hubbard Glacier most likely began re-advancing prior to 1791 (Barclay et al. 2001) forming temporary ice dams that created Russell Lake in 1986 and 2002. Future Russell Lake ice dam events could once again force major environmental and economic changes on the inhabitants of the area.

Background

The Yakutat forelands and coastal mountains are one of the most geologically active areas on the North American continent. Nestled in the immense landscape near the mouth of Yakutat Bay is the small community of Yakutat (Figure 1). Yakutat's economy is almost entirely based on sport, commercial and subsistence fishing on the Situk River. Continued advance of Hubbard Glacier and potential permanent closure of Russell Lake, at sometime in the future, would have severe social and economic consequences for the residents of Yakutat and its outlying area. These concerns have spurred numerous studies during the 1986 and 2002 closures to better understand the geologic, hydrologic, biologic, and sociologic implications of such a major disturbance on the community and surrounding environment. During the 2002 Russell Fiord

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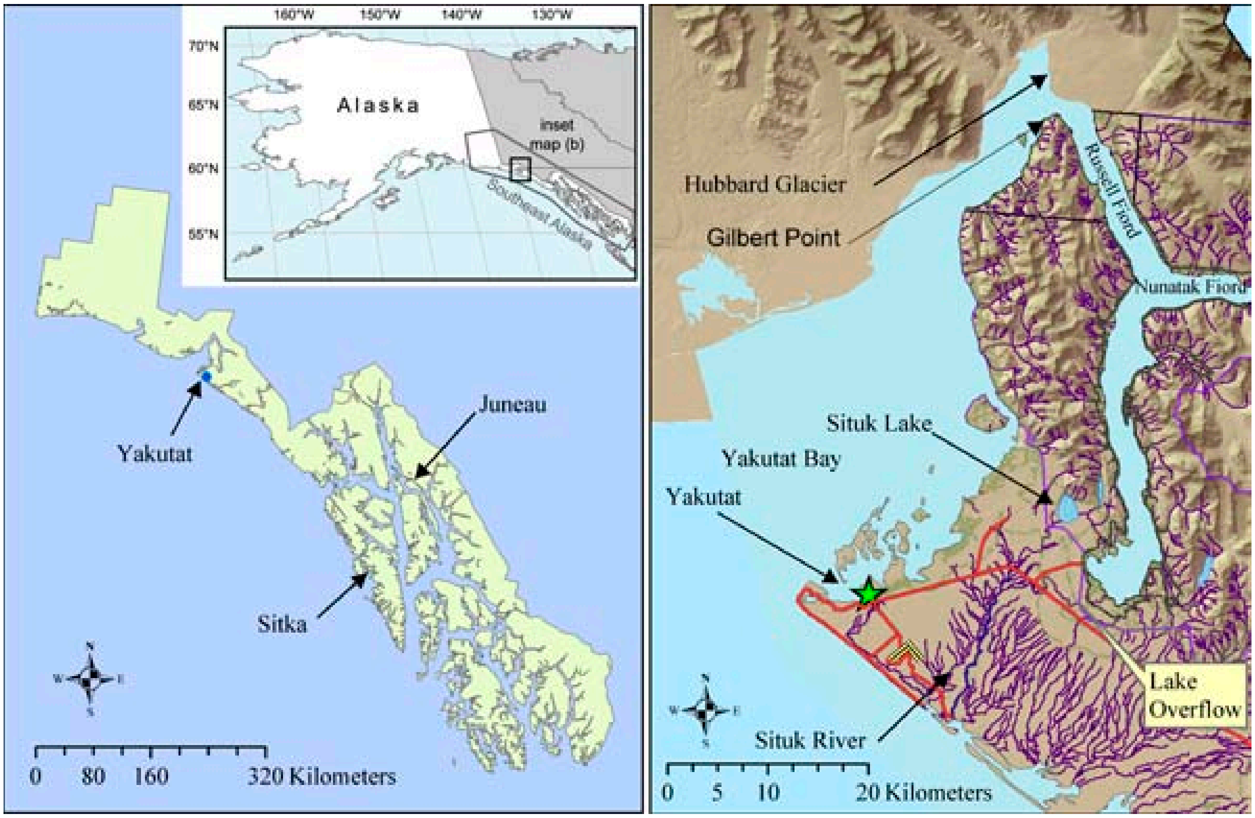
Figure 1. Vicinity maps showing southeast Alaska and the Yakutat area.



closure, the USDA Forest Service, Tongass National Forest (lead agency) convened an interagency interdisciplinary team that included the Forest Service, US Geological Survey, Alaska Department of Transportation, National Park Service, University of Alaska and Army Corps of Engineers, to assess the affects on the Situk River and the Community of Yakutat. The work of the interagency team is ongoing and this paper reflects current and pending work completed to date. During the 1986 closure, a Forest Service team of technical specialists completed a floodplain analysis on potential inundation levels for the Situk River caused by the new Russell Lake and some possible diversion alternatives. The focus of the 2002 technical team was to update previous studies with more current information; perform stability analysis of the terminal moraine and ice dam; and determine feasibility of diversion alternatives. The results of these and future studies will address the following questions:

1. Will all flow from newly formed Russell Lake flow into the Situk River?
2. If flooding occurs, what are the risks to the community or to existing infrastructure?
3. Are the 1986 flow and floodplain assessments valid?
4. Is it feasible and by what method could Russell Lake be diverted into another drainage system?
5. Is the terminal moraine at the lake outlet stable?
6. Will the ice dam forming Russell Lake be persistent and stable at the next closure?

Geology

Glaciation

Most of the Yakutat Forelands landscape was formed from glacier outwash and moraine deposition processes within the last 1,000 years (Shephard 1995). Radiocarbon dates from debris buried in glacial outwash deposits indicate that there were at least two periods of recent advance, between the 13th and 19th centuries, by glaciers originating in the Barbazon Range east of Yakutat. The Nunatak Glacier (Figure 1), advanced to within 6 miles (9.7 km) of the head of Russell Fiord during the early 1800s, resulting in the most recent overflow of glacial Russell Lake into the Situk River system (King 1995). By the late 1890s, the Nunatak Glacier had retreated out of Russell Fiord (Gilbert 1904; Tarr 1909). The Hubbard terminus in 1895 was located about 2.4 km back from Gilbert Point (Figure 1) and the mouth of Russell Fiord (Trabant et al. 1991). Over the last century, Hubbard Glacier, currently the largest tidewater glacier in North America, has been strongly advancing while other glaciers in the area have continued to retreat (Trabant et al. 2003).

This advance-between 15 and 46 m per year-is likely to continue regardless of short-term climatic influences (Trabant et al. 2003).

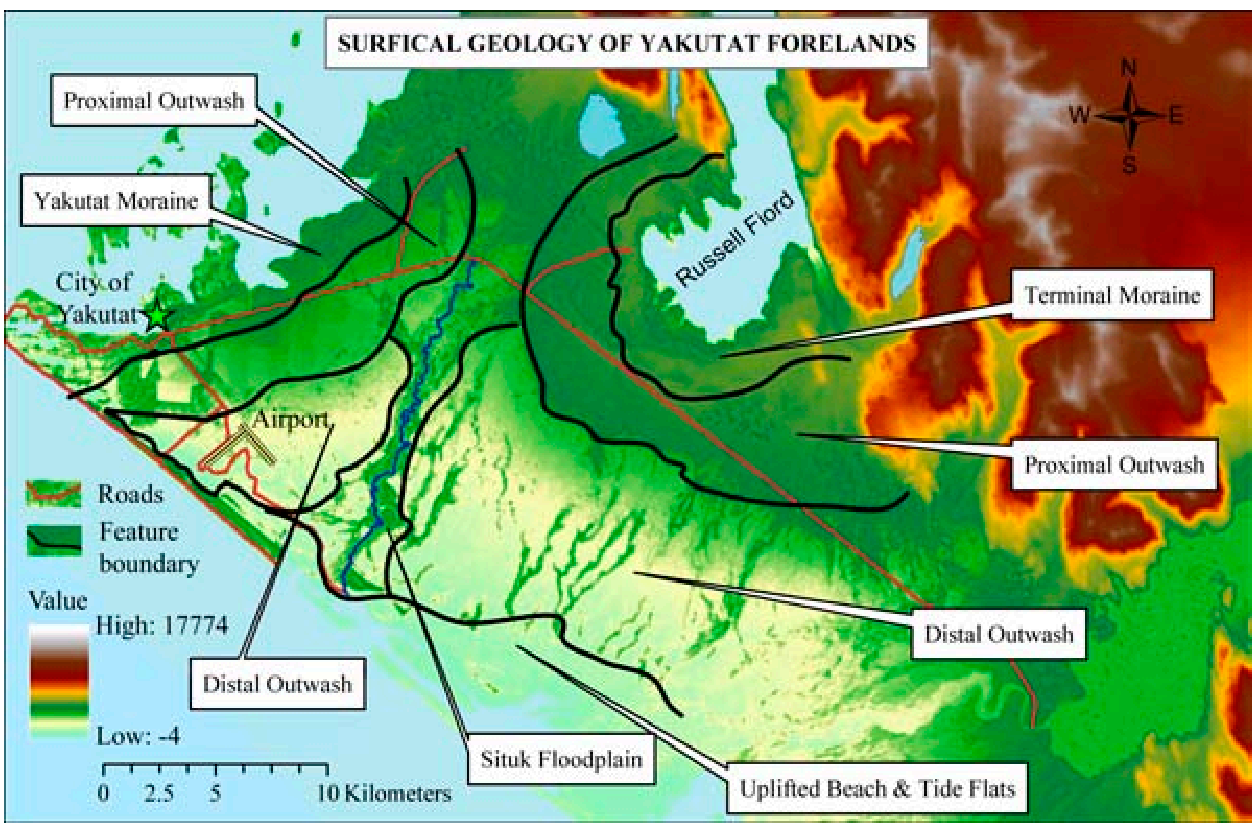
Over the last 20 years, seasonal advance of Hubbard Glacier has twice blocked the entrance to Russell Fiord, temporarily creating a large freshwater lake, Russell Lake. A shallow bedrock sill near the mouth of Russell Fiord allowed narrow fingers of ice and moraine deposits to close off the entrance to the fiord in 1986 and again in 2002. Russell Lake filled at an average rate of 0.2 m per day (Trabant et al. 2003) during the summer and early fall. In 1986, Russell Lake reached a maximum level of 26 m above sea level (maximum lake elevation in 2002 was 15 m) (Trabant et al. 2003). The incipient lake was strongly stratified by a freshwater-saltwater salinity gradient. The lower saltwater layer would have become anoxic (with no dissolved oxygen) in less than two years (Reeburg et al. 1976). However, the upper layer would be capable of supporting freshwater zooplankton and fish communities. A combination of hydrostatic pressure from the lake, erosion of the ice-moraine plug, and seasonal calving of the ice front resulted in catastrophic failure of both ice dams, producing the two largest outburst floods on record worldwide, 112,418 cms on 8 October 1986 and 52,386 cms on 14 August 2002 (Trabant et al. 2003).

Landscape Characteristics

The Russell-Situk watershed encompasses three major ecological subsections: Saint Elias-Fairweather Icefield, Puget Peninsula, Yakutat-Lituya Forelands (Nowacki et al. 2001). Headwaters in the Saint Elias Icefield reach elevations of over 2,743 meters. This ice mass covers 907 km^2 and feeds the Hubbard, Variegated, Nunatak, Hidden and Fourth glaciers. These mountain glaciers all terminate at or near sea level in Russell Fiord. The Puget Peninsula is a rugged mountain range that forms the western boundary between Russell Fiord and Yakutat Bay. Most of this area is barren rock with patches of alpine sedges, forbs and low shrubs. Lower mountain slopes have a dense cover of alder-willow shrub communities and isolated stands of black cottonwood (*Populus trichocarpa*) and Sitka spruce (*Picea sitchensis*). Russell Fiord covers an area of 199 km^2. The fiord has steep walls except for small river deltas and alluvial fans associated with the inlets of glacial rivers including Beasley Creek. These short glacial and steep mountain-slope stream segments provide very limited resident and anadromous fish habitat.

The Yakutat-Lituya Forelands is a low relief coastal plain formed by unconsolidated glacial outwash, moraine and recent fluvial deposits (Figure 2). This area has also been heavily influenced by isostatic rebound, tectonic uplift

Figure 2. Geologic map of glacial deposition, uplifted beach, and moraine features in the Yakutat area.



and subsidence, and long-shore ocean sediment transport and deposition. Vegetative cover is predominantly early successional spruce-hemlock forest and extensive bog wetland plant communities along Russell Lake (Shephard 1995).

The Russell terminal moraine (Figure 3) is a 1.6- to 3.2-km-wide deposit of unsorted glacial debris, ranging from silt- to boulder-sized glacial deposits. It extends from the south shore of Russell Fiord to the Forest Highway (FH) 10 crossing on Old Situk Creek. These better drained ablation tills are covered with a dense spruce-hemlock forest. Another, roughly 3.2-km-wide band of spruce-hemlock forest on gently sloping, proximal outwash deposits extends further to the south. Ephemeral streams exist throughout the proximal outwash zone. These outwash deposits consist mainly of highly permeable cobbles and coarse gravels (Shephard 1995).

The forelands contain numerous highly productive anadromous fish streams with the Situk River being the most prominent of these systems. Until about 1850, the Old Situk River-Situk River corridor (Figure 4) was the historic outlet to glacial dammed Russell Lake (de Laguna 1964). Narrow bands of cottonwood, alder, and conifer forests occur along current and abandoned floodplain terraces of the Situk River and its major tributary channels. Tree ring analysis of dominant conifers in the floodplain indicates that these trees were established shortly after the 1850 ice dam failure that drained historic Russell Lake (Clark and Paustian 1989).

The distal outwash (Figure 2) covers the bulk of the forelands adjacent to the Situk River corridor. This area is covered by fine-textured glacial-outwash sediment (gravel, sand, and silt). The water table is at the surface most of the year, forming the vast wetland fens and bogs in this area (Shephard 1995). Numerous small, palustrine streams initiate along the interface between the proximal and distal outwash zones.

Uplifted tidal flats and beach ridge landforms occur along the Gulf of Alaska coastline. This area, including the Situk-Arnkalin River estuary and Black Sand Spit (along the mouth of the Situk River), has recently been modified by earthquake, isostatic rebound and coastal erosion/deposition processes (Shephard 1995). The Yakutat area has had five major earthquakes since 1899, resulting in up to 15 m of uplift in portions of Yakutat Bay (Combellick and Motyka 1995). This tectonic activity altered groundwater tables and probably had long lasting effects on groundwater exchange with stream segments in affected areas. Isostatic rebound has also occurred over a much longer time span but may have resulted in more extensive changes to the lower forelands. Coastal areas near Yakutat have risen at a rate of 0.5 cm per year since 1940 (Savage and Plafker 1991). Portions of former perennial streams, such as Ophir Creek (adjacent to City of Yakutat), have become intermittent over the last few decades. Radiocarbon analysis of buried organic horizons exposed in stream banks indicates that uplifted beaches and tidal basins near the Situk River mouth were formed within the last 150 years (Shephard 1995). Long-shore transport and deposition of sediment derived from large glacial rivers is another significant agent of coastal change. Expansion of Black Sand Spit has pushed the mouth of the Situk River 2.4 km to the northwest over the last 50 years (Shephard 1995).

Figure 3. Oblique aerial view of the Russell terminal moraine. Note the parallel sequence of moraine ridges bisected by relic glacial drainage paths. The high water level from the 1986 ice dam event is marked by the band of dead trees along shoreline of Russell Fiord.

Figure 4. Oblique aerial view of the Old Situk River–Situk River corridor.

HYDROLOGY

Unique landscape and climatic factors strongly influence major hydrologic events in the Russell-Situk watershed. The Yakutat area has a wet, cool, maritime climate

Figure 5. Russell Lake (circa 1986) looking north toward Hubbard Glacier.

typical of southeast Gulf of Alaska coast. Average annual temperature at the Yakutat NOAA weather station is 4°C . Typical mean air temperature is in the 0-5°C range during winter and 10-16°C during the summer. Normal annual snowfall is 510 cm at the coast, with a maximum of 10.2 m recorded in the winter of 1975-76. Average annual precipitation in Yakutat is 380 cm. No climatic data are available for the Russell Fiord and Saint Elias Icefields; however, annual precipitation is estimated to be between 410 cm and 559 cm. Except for periods during the summer months, precipitation in the icefield portion of the Russell Lake watershed falls as snow.

Almost 50% the Russell Lake watershed area (Figure 5) is covered by permanent snow and ice fields. Runoff into glacial Russell Lake is greatest during maximum snow and glacier melt in the summer months, and decreases considerably during the remainder of the year.

Russell Lake

The USGS lake gage at Marble Point, operated during the 1986 and 2002 ice-dam closure events, measured an average lake inflow rates from 425 cubic meters per second (cms) to 538 cms (Trabant et al. 2003; Neal 2004). A large portion of the Russell Lake watershed area is lake surface (11%) and rock or shallow alpine soils (30%), characteristics that result in rapid runoff during high intensity summer rainfall. Large spikes in the lake inflow hydrograph, as high as 2,605 cms, occurred in response to short-duration, high-intensity, summer rainfall events in August of 1986 and 2002. Rainfall intensities for these two events approached the maximum 24-hr and 12-hr August rainfall records (14 cm and 8 cm respectively) for the Yakutat weather station. It is interesting to note that even though these rainfall events were of similar intensity and duration, the peak lake inflow rate observed in 2002 was almost double the peak inflow rate in 1986. These data suggest that factors such as moraine/ice dam leakage, variability in basin rainfall distribution, or englacial runoff from Hubbard Glacier may significantly influence short-term inflow rates to Russell Lake.

Russell Lake inflow rates for selected return intervals (Table 1) were calculated using two approaches: 1) regional equations, based on basin characteristics (Curran et al. 2003); and 2) a regression model, based on 2002 lake gage data correlated to stream gage data from Situk River and Ophir Creek (Neal 2004). Russell Lake peak inflow estimates were also derived using regional equations (Curran et al. 2003). Regional equation variables include: total basin area (1,927 km^2), annual precipitation of 559 cm, and minimum January temperature of -9°C. The regression equation contains a percent of lake in the basin, set to a value of one to remove lake storage effects. Results of the both methods are listed in Table 1. It is important to note that the Russell watershed characteristics are significantly different from watershed characteristics of gaged basins used in the development of the regional regression equations, increasing the uncertainty and reducing the reliability of these inflow rates.

Neal's regression approach used lake-gage data from 16 July to 13 August 2002 when leakage from the moraine/ice dam was observed to be minimal. Stream gage data from eleven Ophir Creek and Situk River peak flow events (between 15 May and 15 October for water years 1991-2002) were used to develop a synthetic Russell Lake inflow hydrograph (Table 1) (Neal 2004). Neal's synthetic peak discharge estimates (Table 1) are much higher than peak flow estimates derived from the USGS regional equations. These estimates represent a best approximation for the range of peak Russell Lake inflows given limitations in the available data used to derive both sets of predictions.

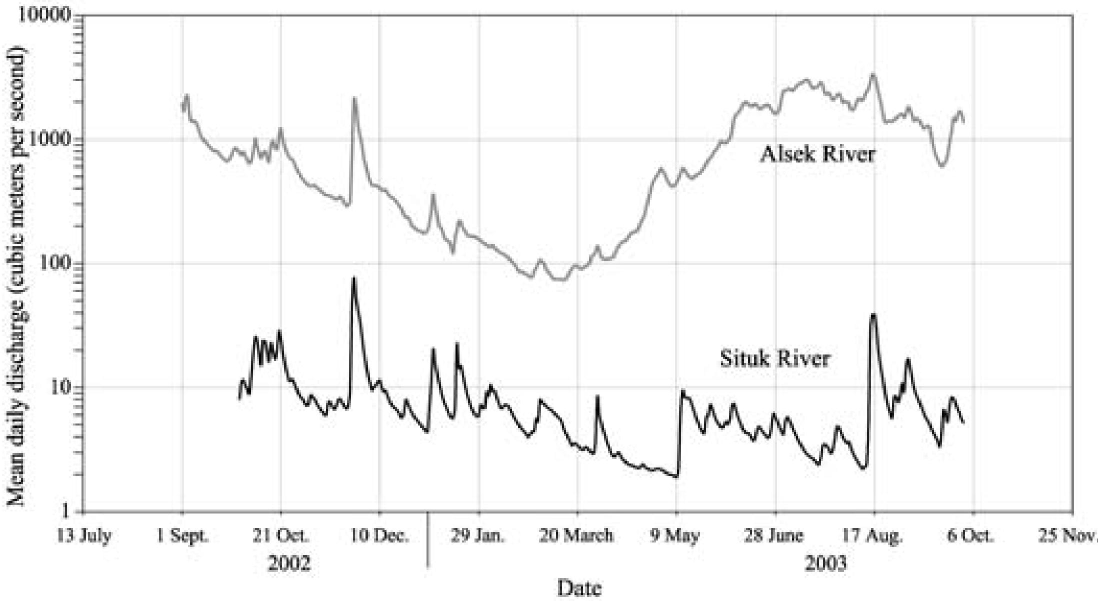
Situk River

The headwaters of the Situk River (Figure 1) emanate from the Puget Peninsula, Mountain Lake, and Situk Lakes. Major tributaries are the Old Situk River, draining

Table 1. Russell Lake inflow predictions from regression model and regional equations (after Neal 2004).

Recurrence Interval (yrs)	Synthetic Model Discharge (cms)	Regional Equations Discharge (cms)
2	4,171	2,163
50	6,397	4,078
100	6,759	4446

Figure 6. Mean daily flow hydrograph for the Alsek River and Situk River in cubic meters per second.



the Russell Moraine (also the historic overflow channel from Russell Lake) and West Fork Situk River, that drains the Redfield Lakes and the eastern portion of the Yakutat Moraine. Numerous small palustrine streams enter the Situk along the distal outwash plain. Ophir-Tawah Creek and Lost River are the most prominent tributaries in the lower Situk River watershed.

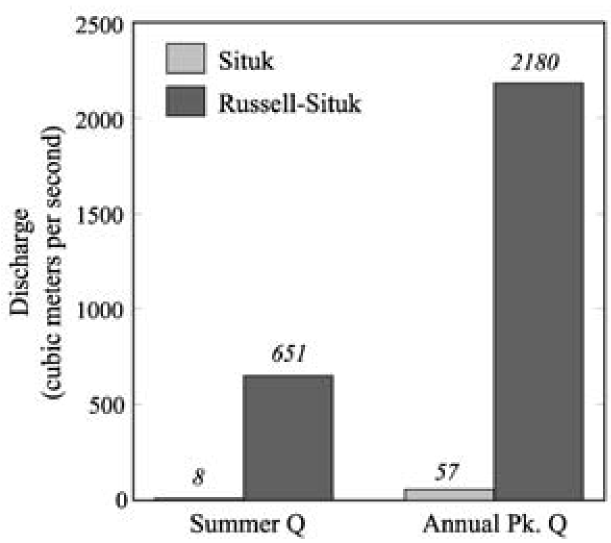
Peak flows in the middle Situk drainage basin (93 km^2) are generated by prolonged periods of high rainfall in the fall and early winter (Figure 6). Base flows are relatively stable during the remainder of the year. Groundwater derived from the moraines and proximal outwash landforms are a major component of river base flow. Storm hydrograph peaks, however, have a relatively short duration of 1 to 3 days.

The basin area for the entire Situk River drainage would increase from 215 km^2 currently, to over 2,072 km^2 with the addition of the Russell Lake basin area (Clark and Paustian 1989). Future Russell Lake overflows into the Situk River drainage will result in the dramatic changes of a one hundred-fold increase in average summer river discharge to the Situk River flow regime (Figure 7). Figure 6 contrasts seasonal hydrographs for the middle Situk stream gage and a nearby stream gage on a large glacial river, the Alsek River. The Alsek River is a much larger watershed and has lower annual precipitation, but has a geologic setting similar to Russell Lake. Glacially dominated runoff from Russell Lake will also shift peak flow timing in the Situk from the fall and winter months to the summer season (Figure 6).

Mean summer discharge in the Situk is currently between 5.7 and 8.5 cms. In contrast, Russell Lake gage measurements from 1986 and 2002 indicate that summer flows in the Situk River associated with the greatly expanded Russell-Situk drainage basin will be between 425 and 850 cms (Figure 7). Maximum daily peak discharge measured for the Situk River (from 1988 and 2004) is 92 cms. Annual peak discharge (2.33-year flood frequency) for Russell-Situk watershed is predicted to be 2,186 cms (Miles 2004).

Groundwater tables in the distal outwash zone of the lower Situk River watershed are within 1 m of the surface. A series of dry gravel borrow pits along FH 10 indicates that water tables are relatively deep in the proximal outwash zones. Proximal outwash and some moraine deposits are

Figure 7. Comparison of the current Situk River streamflow with the predicted Russell Lake-Situk River flow.



well drained, however, kettle ponds and bogs are common in depressions that have been sealed by silt deposits and fine organic material (Shephard 1995).

Due to the heterogeneity of moraine deposit sediments, permeability changes both laterally and vertically. The terminal moraine at the head of Russell Fiord has seen several glacial advances (shown in Figure 3 as parallel ridges) and retreats with associated lake formation. We speculate that these glacial advances and retreats have contributed fine materials (silt and rock flour) to the subsurface moraine material, greatly reducing hydraulic conductivity of the moraine or making it impermeable, similar to a clay plug in an earthen dam. Although field observation along the Russell Lake side (northwest corner) of the moraine face validates this assumption, additional geophysical data is required to verify consistency across the moraine.

Monthly groundwater levels are stable for much of the year, with the exception of depressed levels in June and July, which correspond to low rainfall and minimal snow pack inputs (Clark and Paustian 1989). Segments of small palustrine and floodplain tributaries (including Ophir Creek) become intermittent during short summer droughts.

The Old Situk River channel was the historic outlet of glacial Russell Lake for an unknown period of time during the early to mid 1800s. Oral history accounts of the Tlingit Indians (de Laguna 1964) and dendrochronology data from the Situk flood plain and shoreline of Russell Lake (Clark and Paustian 1989; King 1995) indicate that the Nunatak Glacier ice dam failed around 1850, severing the Situk watershed connection with the Russell Lake watershed. The 1800s ice dam location (approximately 10 km from the head of Russell Fiord) resulted in a much smaller lake (and smaller watershed area), than was associated with the 1986 and 2002 dams at Gilbert Point near the mouth of Russell Fiord (King 1995). We speculate that runoff volumes from the Old Situk Notch, which formed the relic Situk floodplain channels (Figure 4) prior to the Nunatak ice dam failure, are potentially an order of magnitude smaller than the runoff volume that would result from a semi-permanent Hubbard Glacier ice dam located at Gilbert Point.

Terrain Modeling

Data Acquisition

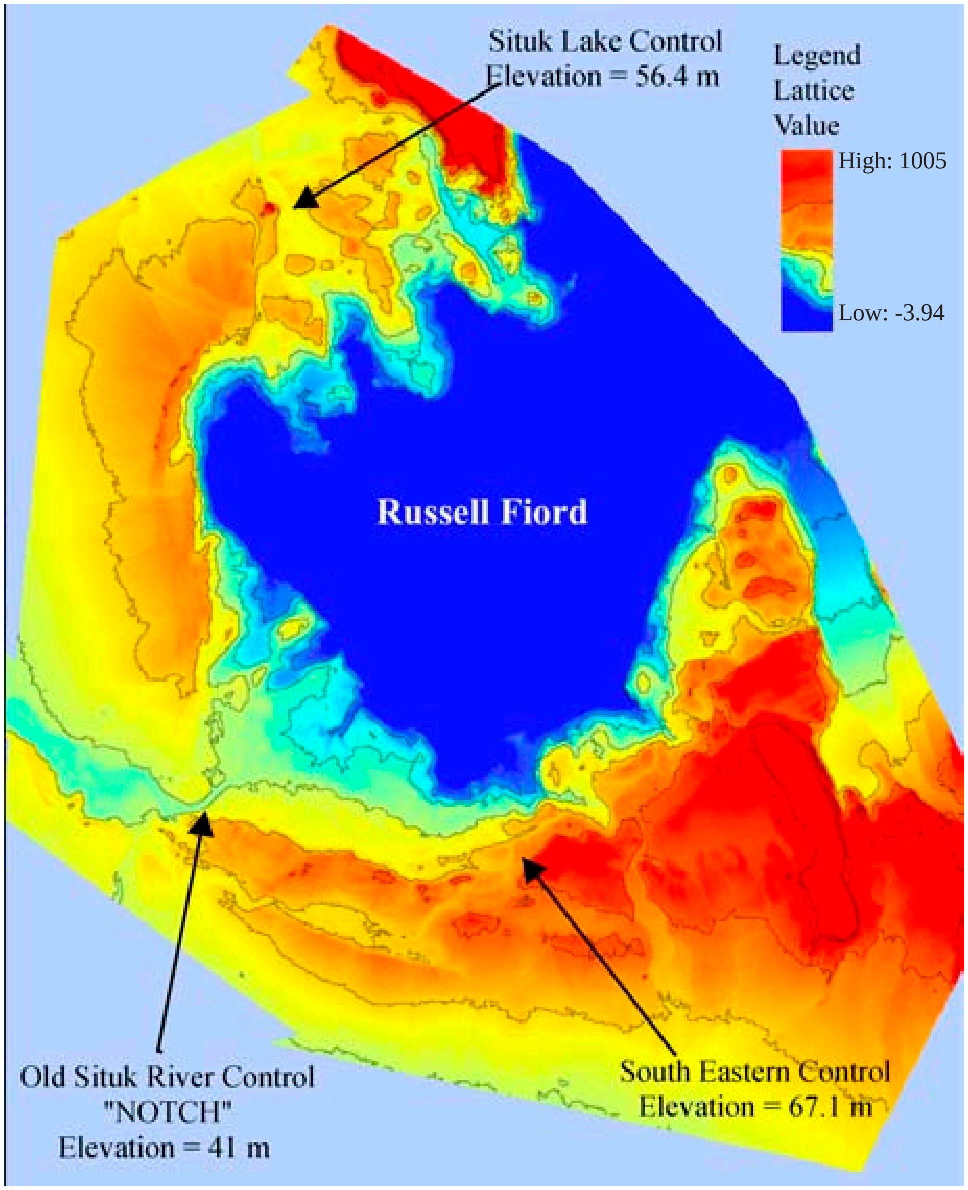
One of the keys to modeling Old Situk-Situk River flood plain characteristics is accurate elevation data. Terrain on the forelands has very low relief and is composed primarily of bogs and fen complexes with grass and sedge of various heights (Shephard 1995). Most streams have a riparian corridor consisting of dense Sitka spruce, willow, and devils club (*Oplopanax horridus*). The terminal moraine and proximal outwash is heavily forested with Sitka spruce and *Vaccinium* understory. Vegetation influence is always an issue in determining true ground elevations especially in areas of dense vegetation. The original 1986 floodplain assessment relied on elevation data generated by USGS using analytical photogrammetric methods from air photos flown during leaf on conditions. The ability to get sufficiently dense and accurate data reflecting actual ground elevations and not the top of vegetation with this type of technology is difficult and a potential source of modeling error, which becomes more significant in areas of very low relief.

A test flight using LIDAR (Light Detection and Ranging) technology was made in 2002 to determine if accurate elevation data could be obtained along the Situk River during leaf-on conditions. LIDAR data provides a quick way of obtaining and mapping elevation data in terrain that is logistically difficult to access. LIDAR uses a tagged laser pulse that records the return time of the laser pulse and keeps track of the airplane position and orientation (roll, pitch and yaw), yielding elevation data that is accurate to 15 cm vertically and 1 m horizontally. To validate the LIDAR elevation data, survey grade GPS controls were established to test profiles surveyed along the river corridor on the forelands and terminal moraine. All survey data were transformed into the same coordinate system (NAD 27 NGVD 88). The ground surveyed profiles were very similar to those produced by the LIDAR data. The elevation accuracy between the two data sets (Table 2) led to the acquisitions of LIDAR data for the entire Situk River floodplain and remaining areas around the terminal moraine. The data was processed with a vegetation removal algorithm similar to the method described by Haugerud and Harding (2001) to remove ~99% of the vegetation points. Although this is an automated procedure, some additional manual processing may be necessary to remove vegetation anomalies along the dense riparian corridors. The ASCII ground point files of the LIDAR data were so dense that further thinning by gridding the points was necessary for the floodplain inundation models to be continuous from the ocean to

Table 2. Comparison of LIDAR elevations to ground surveyed profiles.

Location	Mean Difference (m)	Std. Dev. (m)	RMSE
Old Situk River Notch	-0.31	0.41	0.16
Section 10 on Forelands	-0.30	0.31	0.03

Figure 8. LIDAR derived DEM showing outflow controls for historic Russell Lake.



Russell lake boundary conditions. The LIDAR data was dense enough to show all of the geomorphic expression of the moraine and floodplain landscapes (Figure 8).

LIDAR data acquisition was difficult due to the remoteness of the project area, poor weather (low cloud ceiling and precipitation), and LIDAR operator flight requirements (minimum of 1000 m above ground level). These difficulties, in addition to needing a dedicated helicopter for ground surveys and the urgent need for data, drove costs higher than normal for both LIDAR and ground surveys (Table 3). Further LIDAR data collection efforts are planned to obtain elevation data across the forelands to determine the feasibility for creating diversion channels.

Table 3. Survey accomplishments and costs for LIDAR and ground surveys.

Year	Ground survey (km)	Ground survey costs (2004$)	LIDAR Area (hectares)	LIDAR costs (2004$)
2002	19	$275,000	12484	$89,000
2003	-	-	20914	$151,000

Lake Flow Controls

One of the purposes of the LIDAR survey was to obtain detailed topography along the terminal moraine to map all potential overflow points. All previous assessments have mentioned only the Old Situk River Notch as the main lake outlet control. The Old Situk Notch was validated as the outlet control, however, the LIDAR survey also revealed additional control elevations of several historic Holocene outlets that contain underfit streams (streams too small to have carved their valleys). Three main Holocene lake level controls are identified (Figure 8). The identification of these other spillways is important in understanding their relations to maximum projected lake level since the current lake size (and inflow volume) is approximately double that of the last closure.

To identify historic Holocene lake controls, the LIDAR data were transformed into a lattice grid in ESRI ArcInfo[1] . The grid was then incrementally assessed using the analysis map query tool in ESRI ArcView to develop coverages that show all elevations greater than a given elevation. This process was repeated every 1.5 m until the major overflow controls were identified. The control areas (Figure 8) were then evaluated using terrain modeling software (Spectra Precision TERRAMODEL V 9.7 2000). The model's gridding process averages elevation from the point coverages to form an equally spaced set of gridded elevations. This process can slightly alter the actual control elevation. The LIDAR points were recontoured in TERRAMODEL to compare the results. As the exact location of the LIDAR points on the ground cannot be controlled due to vegetation point removal, track and swath spacing, and collection of the LIDAR sensor, the overflow elevations reported are based on the ArcView analysis with potential lower limit elevations developed in TERRAMODEL. Both methods produced similar results. Overflow and lowest possible elevations were determined for each lake control. For the Old Situk River control, values were 41 m and 40.2 m, respectively; for Situk Lake control, 56.4 m and 55.2 m; and for the southeastern control, 67.1 m and 66.5 m.

The terrain modeling results show that all outflow from Russell Lake will drain through the Old Situk River control notch when the lake levels rise above 41 m. Our floodplain analysis evaluated discharges of 566 cms for normal flow, 2186 cms for a 2.33-year flood, 4446 cms for a 100-year flood, and 6796 cms for the maximum flood, and produced estimated lake levels of 45.3 m , 49.2 m, 52.6 m, 54.6 m respectively. These estimates are well below the 56.4 m Situk Lake elevation control; therefore this outflow location will not affect Situk Lake or the 10 km of prime salmon & steelhead spawning and rearing habitat in the upper Situk River drainage (because these areas are above the mainstem junction with the Old Situk River channel).

[1]The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Hydraulic Flood Modeling

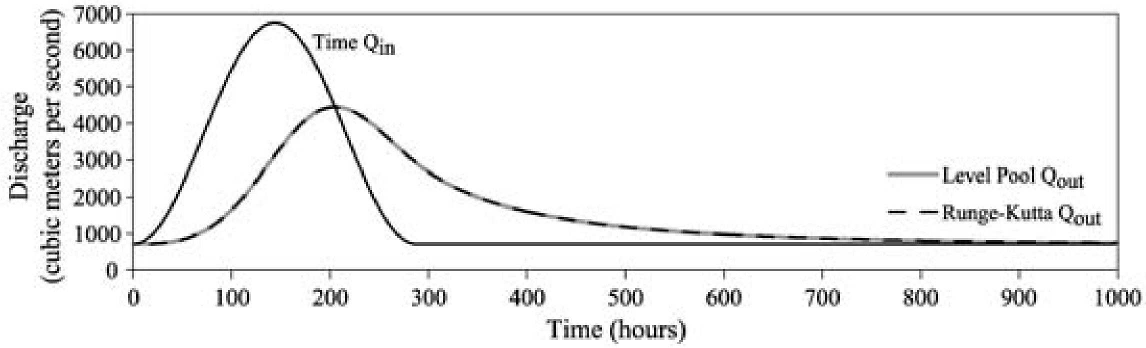
Hydraulic flood modeling was done in order to identify floodplain inundation limits with improved elevation data and determine lake levels and potential overflow points along the terminal moraine. A flood assessment of this magnitude is difficult to predict because of continual changes in channel characteristics (width, depth, shape), and the effects of roughness (form roughness, log jams) as flow progresses from initial overtopping of the moraine to some point in the future when a more stable system will develop. The geomorphic expression of the old Situk River on the proximal and distal outwash provides anecdotal evidence of historic flood limits. However, historic Russell Lake was believed to be 50% smaller than the current lake and watershed area. This factor will increase projected lake overflow volume to the Situk River corridor.

Russell Lake Outflow and Reservoir Routing

Once the lake level reaches 41 m above mean sea level, water will overtop the Old Situk River spillway. The volume of lake outflow is controlled by the height of the water above the spill crest. For the analysis, a stage-discharge relationship was developed assuming the spillway is a rigid boundary. The elevation and spillway geometry of the Old Situk River control should be sufficient to handle outflow from Russell Lake, preventing the lake from rising to an elevation that would cause outflow to occur at the Situk Lake control (Figure 8). The Old Situk River control has the capacity to convey a discharge of 7100 cms, which is 1.6 times greater than the estimated 100-year flood discharge.

Lake systems provide a storage function for inflow hence Lake outflow = inflow - storage. The elevation rise in a lake is a function of hypsometry (storage volume versus elevation) and inflow. The amount of storage for various floods needed to be calculated to determine peak outflow rates. An inflow hydrograph is the first step in the analysis; the shape and duration of this hydrograph greatly affects the model results. No inflow hydrograph existed, so a synthetic hydrograph was developed. The storm history of the Yakutat area and simulated hydrographs developed by the USGS inflow study (Neal 2004) indicated that a time to peak flow of four to six days for a "standard" was a reasonable assumption (Miles 2004). A base flow of 708 cms with six-day duration to peak inflow was used in a simple sine function to develop the shape of the inflow hydrograph. Two methods of reservoir routing (Runge-Kutta and Level Pool) were used with the data from the inflow hydrograph, lake hypsometry and outflow stage discharge relationship resulting in similar outflow

Figure 9. Russell Lake Inflow and Outflow Hydrograph for the 100-year flood.. Both the Level Pool and Runge - Kutta methods which predict similar results and are not visible separately on this graph. (Miles 2004) Qin is the inflow rate and Qout is outflow rate.



hydrographs (Figure 9) (Miles 2004). Flood routing results are shown in Table 4 (Miles 2004).

Flood Modeling

Computer open-channel flow models assume a "rigid" boundary. This rigid boundary assumes that the channel bed and margins do not mobilize or erode, changing shape with discharge. In the case of the Situk River, the distal outwash is unconsolidated fine-grained gravel and sand. Depending on flow stage, a portion or entire channel sections will be mobilized and margins will erode until the system reaches some form of "dynamic equilibrium". The modeling done to date assumes a rigid boundary, which will produce higher water levels compared to the existing topography than the likely future channel due, to incision and channel formation. Our current intent is to identify potential impacts on public safety and infrastructure, and note areas of where mobile bed conditions may exist. Two models were used to evaluate flood characteristics on the Situk: the dimensional steady state flow model HEC-RAS V3.1 from the U.S. Army Corps of Engineers (US ACoE 2003), which assumes average flow velocities perpendicular to the cross sections evaluated; and the two-dimensional flow model SMS/Flo2DH (BYU and FHA 2004), from Brigham Young University and the Federal Highway Administration, a finite element analysis that solves for flow in the horizontal plane assuming vertically averaged flow velocities for each element.

Table 4. Flood routing analysis (after Miles 2004). Routed outflow discharge results indicate a significant storage capacity in Russell Lake that substantially attenuates inflow peak discharge.

Recurrence Interval (years)	Inflow		Outflow	
	cms	cfs	cms	cfs
2	4,171	147,300	2,107	74,400
2.33 (mean annual)	4,332	153,000	2,186	77,200
50	6,397	225,900	4,174	147,400
100	6,759	238,700	4446	157,000

Modeling Assumptions

The channel cross sections used in modelling were based on the existing topography and assumed to be rigid. Even though both lateral and vertical scour is expected, the amount of channel scour cannot be reliably estimated until geotechnical drilling verifies the subsurface material characteristics of the bounding channel walls and bed. Roughness of the channel greatly effects water surface elevation. It is anticipated that log jams will form randomly through the system, causing large fluctuations in roughness. Current predictive capabilities have high uncertainty, so estimates of roughness are based on operator experience, and assume that a portion of the woody debris has been removed by high water (Miles 2004). Both models require inputs of boundary conditions. The upstream boundary condition is the outflow from Russell Lake and the downstream boundary condition used is the high tide line at ~3 m above mean sea level, where the Situk River meets the Gulf of Alaska. Both programs are capable of unsteady flow analysis, when discharge varies over time. To reduce the complexity of the model, a simplified steady state (constant) flow for peak flows was assumed. Peak flow is expected to occur for an adequate length of time, making steady flow a reasonable assumption (Miles 2004). No attenuation of peak flows was used in the model, providing a conservative analysis due to public safety concerns for Yakutat.

Model Results

The HEC-RAS model was based on seventy-eight cross sections over a 35 km (21.6 mi) length of channel. For all the flows modeled (Q_2 to Q_{100}), the Situk River control acts as a spillway using its current channel configuration,

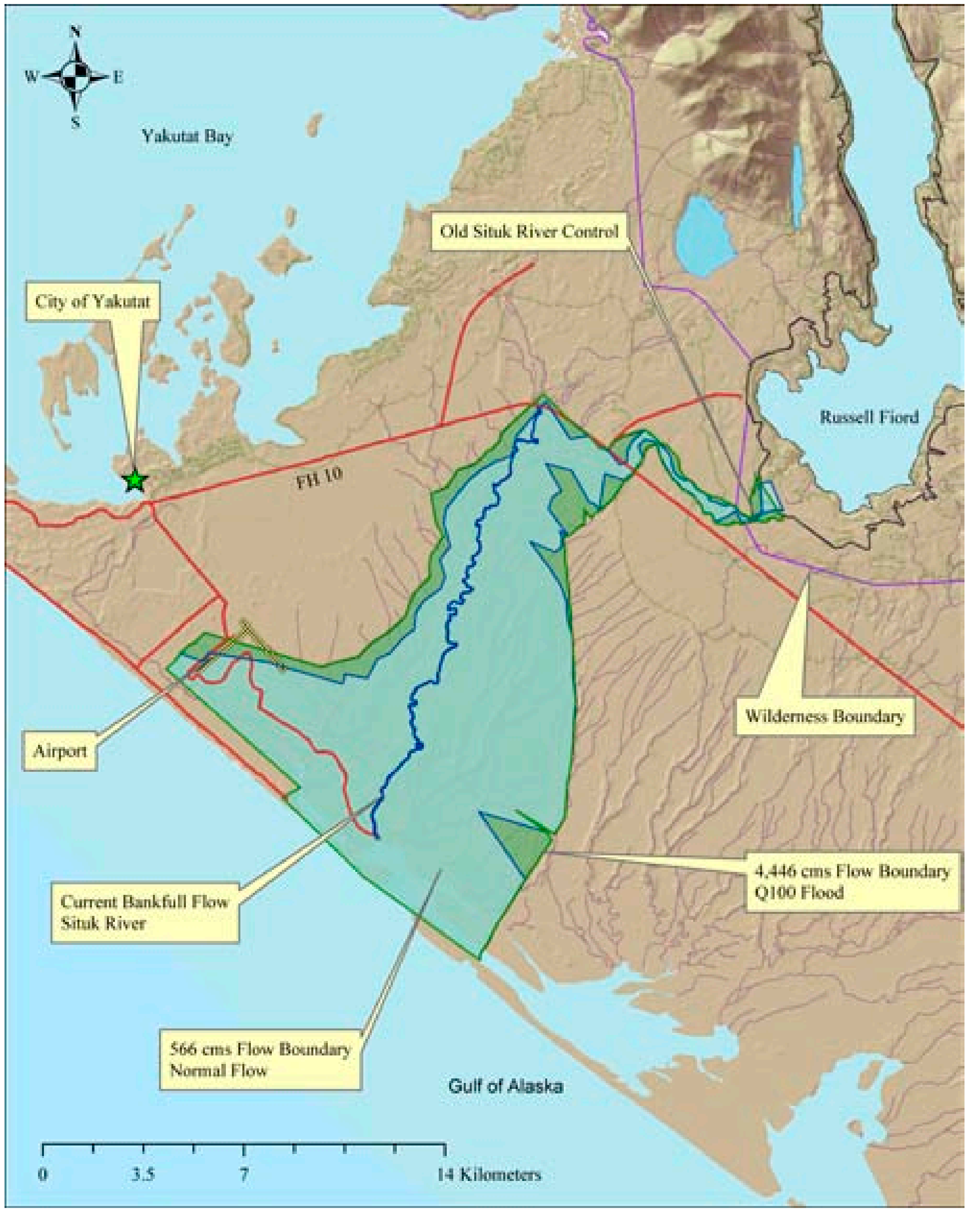


Figure 10. Floodplain inundation map based on HEC-RAS modeling and a rigid boundary assumption.

with the actual hydraulic control being approximately 732 m (2400 ft) downstream (Miles 2004). Along the Situk River control segment, the model produced supercritical flow (Froude # = 1.1 to 1.5) with extremely high velocities of Q_2 = 7.6 m/s and Q_{100} = 10.1 m/s. The two short segments of the Situk River that had supercritical flow are narrow and deeply incised sections within the moraine. These zones of supercritical flow are expected to change channel configurations from scour due to high velocities and water surface slopes. All other sections of the Situk River are, as expected, in subcritical flow regime.

Floodwaters exit the proximal outwash onto the forelands approximately 8 km (5 mi) downstream of the Old Situk River control immediately below FH10 (Figures 1 and 4). At this point topography changes, rapidly becoming less confined with well developed floodplains further downstream. In this area, floodwaters inundate the floodplain to varying widths, depending on magnitude of the flood. For the 2-year (Q_2) and 100-year (Q_{100}) flood return intervals, widths ranged from 0.6 and 1.3 km at FH10, to 7.5 and 8.0 km approximately 9.7 km (6 mi) upstream of the Situk outlet, and 14.4 km (9 mi) for both flows at the mouth of the Situk River (Miles 2004). (Figure 10)

To construct the SMS/Flo2DH model, the dense LIDAR data required "weeding" to a 15-m (50-ft) spacing and required the river corridor to be divided into three sections with a total of 27,000 elements and 56,000 nodes (Miles 2004). Only the Q_{100} flood (4446 cms) was analyzed with the 2-D model, and surface water elevations predicted were similar to those of the HEC-RAS Model (Table 5). The model could not predict a stable solution for a short

Table 5. Comparison of computed water surface elevations at selected sites (Miles 2004).

Location	River Station	Ground Elevation (m)	HEC_RAS $Q_{2.33}$ (m)	HEC_RAS Q_{100} (m)	Flo2DH Q_{100} (m)
Outlet	448.4	- 1.8	3.0	3.0	3.0
Threshold Runway 2	3210.1	3.4	Dry (3.1)	Dry (3.3)	4.6
Threshold 29	5917.2	5.6	5.6	6.1	Dry (5.5)
Mid Yakutat Forelands	6436.3	3.9	5.9	6.4	6.0
Mid Yakutat Forelands	10745.3	7.3	9.2	9.8	10.4
Situk-Old Situk confluence	21785.5	17.3	20.3	21.0	20.3
Forest Highway 10	26068.8	26.3	29.6	30.7	30.3
Area below lake control	32776.2	36.5	40.8	43.5	NC
Russell Fiord	34830.0	NA	49.2	52.6	52.6

915-m section of river immediately above FH10, because of rapidly varied flow conditions and multiple flow paths (Miles 2004).

Geophysical Surveying

Because outflow from Russell Lake will drain through the Old Situk River control notch, it was important to better characterize the subsurface conditions of this feature. In summer 2003, preliminary seismic and ground penetrating radar (GPR) surveys were conducted in the Old Situk River control notch. These surveys were intended to determine if the methods used could differentiate the thickness of the armored channel, fine-grained unconsolidated materials, and potential bedrock surface. The "Notch" is located within the Russell Fiord wilderness boundary, precluding the use of helicopters and all-terrain vehicles. Seismic and GPR surveys were used because the equipment is portable by backpack, and the methods required minimal ground disturbance and vegetation clearing. No calibration data were obtained from drilling because of limited access through the wilderness and funding constraints. This is a concern, because the geophysical assessment is based on interpretation of remotely sensed images, mapped stratigraphy near the southern portion of Russell Fiord (King 1995; Tarr 1909), observed exposures of sediments and surficial armor in the Old Situk channel, and limited drill data on the forelands near Yakutat (Yehle 1979).

The Russell Fiord terminal moraine is geologically complex, since it was probably formed by both tidewater and terrestrial glaciers. This complexity means a single survey method often may not be suitable to characterize the moraine and outwash areas, hence the decision to use both seismic and GPR techniques. Each technique has limitations and strengths, and using both geophysical techniques will improve the subsurface interpretation, as data from each can be compared and correlated.

Ground Penetrating Radar

GPR measures the contrast in dielectric properties of the subsurface materials through which electromagnetic waves of a given frequency (radio waves at 25 MHz to 1 GHz) travel (Philip 2004). As the electromagnetic waves propagate through the subsurface materials, some of the waves are reflected and absorbed, while the remaining waves are transmitted at boundaries between layers of materials that differ in physical properties and dielectric constants. Image resolution and penetration depth vary depending on the antennae frequency with greater penetration depth occurring at lower frequency antennas (25 MHz - 50 MHz) and increased image resolution occurring at higher frequency locations (500 MHz - 1 GHz) (van Overmeeren 1994). A MALA Geoscience RAMAC GPR system with Groundvision V1.3.6 software was used to record and process the data with 50 MHz unshielded antennas for maximum penetration because the unknown depth to bedrock in the notch area. Radio waves pass readily through geologic materials with low dielectric constants such as sands and gravels, while materials with high dielectric constants such as clay-rich layers can attenuate or block the signal entirely (Philip 2004). When large contrasts in dielectric constants exist, strong reflections are observed. This is the primary means of identifying subsurface features, but GPR becomes limited with depth because of reduced signal strength and resolution (Figure 11).

Deriving the GPR wave velocity allows conversion of travel time to depth and development of subsurface stratigraphic models (Philip 2004). Wave velocity in a subsurface materials can be described by the following equation:

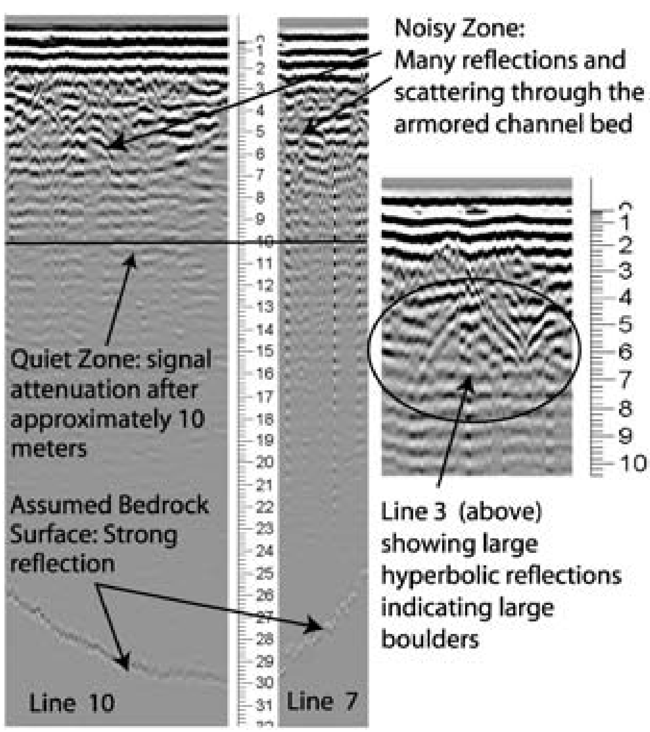
$$V = \frac{C}{\sqrt{e_r}}$$

where: V = velocity (m/s); C = speed of light in free space (m/s); e_r= relative dielectric constant.

Since e_r is unknown, a common midpoint survey was used to determine velocities. The transmitter and receivers are placed around a common midpoint, a measurement is taken and the transmitter and receiver are moved apart incremental distances until several data points are collected. A plot of T^2 vs. X^2 (2-way return time versus distance) is constructed and the slope of a best-fit line yields the squared wave velocity (Beres and Heini 1991). Four common midpoint surveys were performed with an average derived velocity of 64 m/µs with a standard deviation of 5.5 m/µs. This average velocity was used to calibrate the radar images in Groundvision V1.3.6, to determine the depth to reflection events along the GPR survey lines.

Ideally a continuous GPR survey line length should be five to ten times the depth to the surface of interest (bedrock). This was not possible because of the dense Sitka spruce stand in the Old Situk River control survey area. Twelve GPR transects varying from 10 to 40 m where surveyed. The Old Situk channel bottom is very rough, with a predominately boulder armored surface (Figure 12). This type of material made it difficult to find transects where full antenna contact could be made with the ground.

Figure 11. Ground penetrating radar images showing three distinct zones including an upper noisy zone of boulder armor, a quiet middle zone and a lower bedrock surface.



Seismic Refraction

Seismic refraction has been used successfully in various environments and conditions to measure the depths of materials and locations of the subsurface interfaces for engineering, mining and research applications. Seismic wave refraction is the travel path of acoustic waves through an upper medium, along an interface at a critical angle, and back to the surface. These interfaces are interpreted as different materials or changes in density. The propagation of acoustic waves through different mediums follows Snell's law of light refraction, which describes the geometry of wave travel paths, allowing standard techniques to recover layer velocities and depths (Philip 2004).

Seismic data are processed by taking the first arrival of the signal for each geophone, and plotting the return time from acoustic source (sledge hammer) to geophone versus the distance the wave traveled from the acoustic source. The inverse slope of the return time versus distance plot allows the determination of seismic wave velocities through the layers of material.

An acoustic source was applied to both ends of the transects to obtain forward and reverse shot data. This is a standard procedure to test for asymmetric travel times and lateral velocity changes as well as any dip angle of different material layers. A Geometrics SmartSeisSE 12-channel seismograph was used to collect seismic refraction data with Geophone spacing that ranged from 1.5 to 5 m, depending on terrain and length available for each survey transect. Data was processed with SIPWIN software from Rimrock Geophysics. This software allows the operator to input multiple spreads, acoustic source locations, and reverse lines.

Geophysical Survey Results

The GPR images show numerous reflections in the first several meters of depth, followed by a marked absence of reflections below 10 m. Large hyperbolic reflections (Figure 11) indicate large boulders in the channel subsurface that are probably similar in nature to those observed on the channel surface, and located 5 to 7 m below the channel surface. Below 10 m, signal strength is markedly weaker (Philip 2004). Though there is no clear location of the boundary, this signal attenuation is most likely caused by a clay-rich conductive layer. This clay-rich layer corresponds with the upper stratigraphic sections mapped by King (1995) in the lower Russell Fiord area that contained thinly laminated clay, silt, and sand layers at approximately the same depth. A strong reflection is shown in all GPR images at approximately 30 m below the Old Situk River control. The shape and location of this reflector is consistent

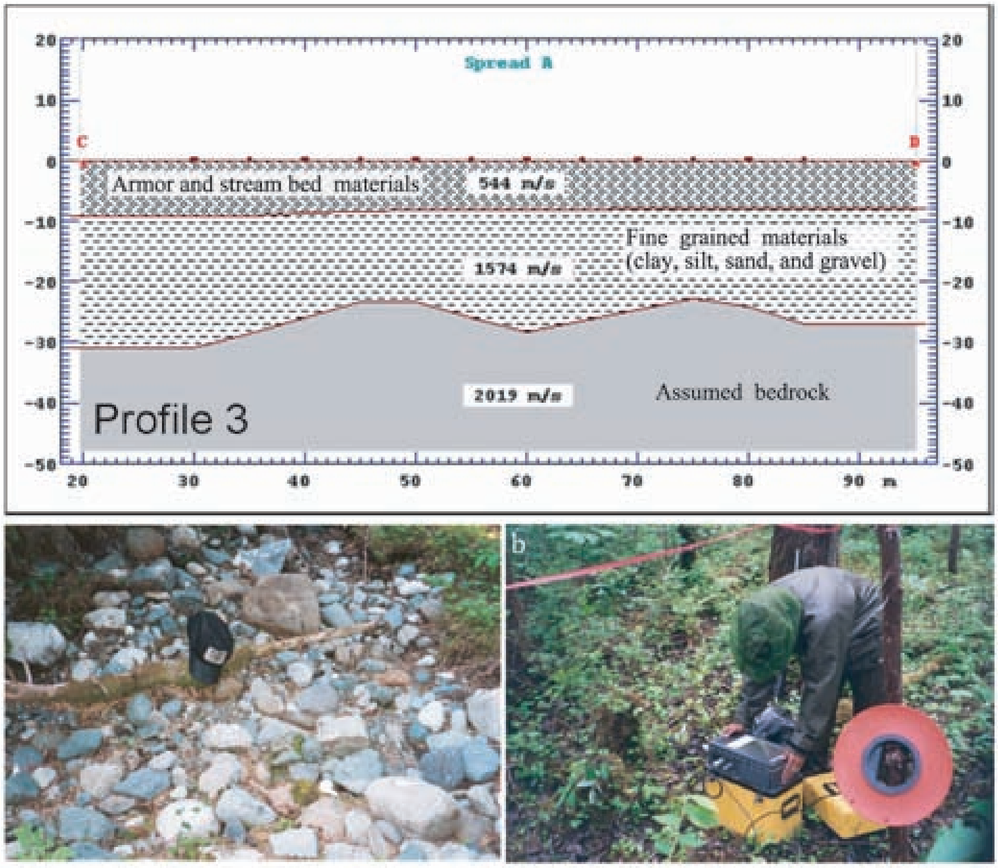


Figure 12. Seismic refraction 3-layer results with recording equipment and existing surface conditions
(a) left – Boulder / cobble armored channel bottom in the Old Situk River Notch. Heavy armor and rough surface of historic channel bottom made GPR surveying difficult and limited in scope.
(b) right – Geometrics SmartSeisSE 12-channel seismograph.

through several of the images and was interpreted as bedrock (Philip 2004). The beginning of Line 7 is nearly coincident with the end of Line 10 in the field (Figure 11) and the radar images show the bedrock reflector at the same depth at this location. The presence of this bedrock reflector is consistent across other GPR lines that cross one another. However, drilling on the moraine demonstrated that the suspected bedrock turns out to be a massive fresh water saturated silt layer of glaciolacustraine origin. The silts are slightly plastic and the high water contentand silt layer gave the strong reflection. It is important to verify and calibrate your remotely sensed data with borehole data to make it more reliable for analytical use.

The seismic data showed results similar to the GPR. The 2-layer partitioning of the data shows a change in density at ~15 m of depth. Only two seismic transects were long enough to give reasonable travel times to derive a three-layer solution. Images generated from three-layer seismic refraction data show refractors occurring at about the same depths, 10 and 30 m (Figure 12). The calculated velocities for the upper layer are <1000 m/s, and range from 1500 to 2800 m/s for the next lower layer. Calculated velocities are within acceptable ranges for near-surface sand, gravel, and clay bodies (Reynolds 1997). The lowest layer of the three-layer seismic case include a refractor around 30 m in depth. The velocities derived for the third layer are 2019 m/s and 4,444 m/s, which are reasonable value for bedrock velocity.

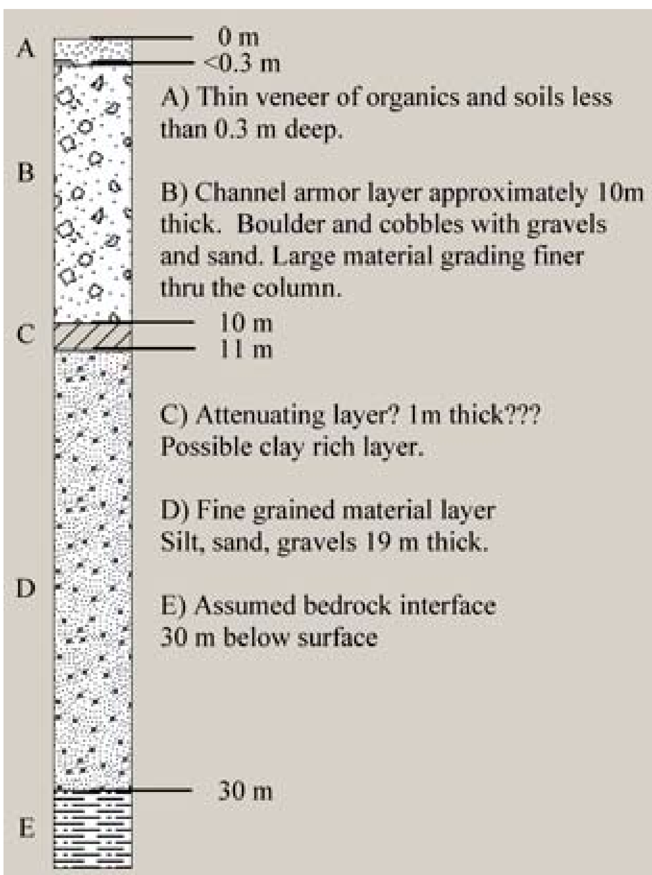
Both GPR and seismic had strong returns occurring in each survey line around 30 m below the surface. The agreement of this layer between GPR images suggests lateral continuity of the strong bedrock reflection, both in the area of high survey concentration and at those survey lines farther west and south (Philip 2004). There is a 1-m change in elevation of the GPR reflector over distances less than 40 m, indicating that reflection occurring as result of interaction with the water table is unlikely, because the slope is too steep for a water table surface (Philip 2004). Field observations in the Old Situk River Notch show evidence of perched water tables within the first few meters of the surface that were not identified on the GPR images because these surfaces were located within the noisy (ground-coupling) zone.

At this point the remotely sensed images are uncalibrated, since no drilling data were collected concurrent with the geophysical surveys. Stratigraphic interpretation is speculative at this time until actual drill data are collected at the Old Situk River control. These preliminary interpretations should not be solely used to make a final determination on terminal moraine or lake control stability. This determination will require a more intensive geotechnical investigation. The general stratigraphic interpretation provided (Figure 13) is based on current data obtained from field observations, geophysical surveys and research literature.

Layer A (0 - 0.3 m) (Figure 13) is the organic and soils layer, containing forest duff, minor soil development and root mass; Layer B (0.3 - 10-12 m below surface) consists of sediments ranging in size from sand to boulders with large boulder present at an 8 m depth; Layer C (10 - 11 m or possibly greater) is interpreted as a clay-rich layer; Layer D (11- ~30 m) is composed of unconsolidated silt, sand, and gravel; and Layer E (30 m or greater) is interpreted as bedrock.

This stratigraphic interpretation is similar to the general pattern mapped in an exposure 10 km northeast of the Old Situk River control by King (1995). No bedrock was found in that particular stratigraphic section, however bedrock was observed in a waterfall on the northwest portion of the terminal moraine along with suspected bedrock ridges (not verified in the field) along the southeastern portion of the terminal moraine. Also, 14 km downstream from the Old Situk River control the depth to bedrock was 64 m below the surface, supporting the bedrock interpretation at 30 m below the surface from the GPR reflections and seismic refractions.

Figure 13. Interpreted stratigraphic column at Old Situk River control. (Modified from Philip 2004).



Conclusions

Based on the current body of work, we have addressed the following questions:

1. Will all flow from newly formed Russell Lake flow into the Situk River?

The recent modeling work assuming rigid channel boundaries indicates the Old Situk River has the capacity of 7,100 cms before flowing into the Situk Lake overflow. This is 1.6 times the 100-year flood which is assumed close to a 500-year event. If the Old Situk channel were to become clogged with icebergs, water may elevate to a point where some spillover occurs. It is anticipated that most ice will pass through the Old Situk River control or ground out before entering the channel.

2. If flooding occurs, what are the risks to the community and existing infrastructure?

All hydraulic modeling from the recent studies indicates minor impacts on the Yakutat airport area. However, the uncertainty related to debris dams formed during initial overflow or long term lateral migration of the new Situk channel would increase the risk to the airport. These risks can be mitigated by revetment protecting the airport (Miles 2004). All cabins or improvements along the Situk River would be lost during the initial flood.

3. Are the 1986 flow and floodplain assessments valid?

Results from recent work indicate slightly wider inundated areas and water levels than the 1986 study. The recent work indicates low lying portions of the airport could see some inundation at peak flow events. Elevations for the Old Situk River control determined by the 1986 study are within an acceptable margin of error from those determined by the 2002 surveying and LIDAR terrain modeling.

4. Is it feasible and by what method could Russell Lake overflow be diverted into another drainage system?

Additional studies are required to determine feasibility of a channel diversion. The Forest Service and Corps of Engineers (COE) are in the planning stages of a feasibility study, however the moraine stability study is required before feasibility assessment can commence.

5. Is the terminal moraine at the lake outlet stable?

Since flows will be larger than the previous channel forming flows, we anticipate that channel will laterally scour: To what extent is uncertain without additional geotechnical drilling and remotely sensed subsurface data. Additional work is scheduled in 2005.

6. Will the ice dam forming Russell Lake be persistent and stable at the next closure?

At this point in time we do not know when the glacier will close off. An ice stability study is in the planning stages by the COE.

Future Work

Additional work is needed to examine the stability of the terminal moraine and other lake outlet controls, moraine/ice-dam permanence, and feasibility of a diversion channel to protect the economic integrity of the City of Yakutat. Currently the USDA Forest Service is the lead agency in charge of the project. A memorandum of agreement is being negotiated between the Forest Service and the Army Corps of Engineers (COE) to determine the feasibility of constructing a diversion channel and assessing the stability of the Hubbard Glacier ice dam and moraine.

Ice-Dam Stability

Understanding moraine and ice dam stability is an important consideration before expending large amounts of capital for a diversion project. The 1986 and 2002 damming events were relatively short lived (~3 months) and the configurations of each dam were different. The 1986 ice dam was made almost entirely of ice with small moraines at the edges. The 2002 dam was primarily composed of sediment accumulating in front of the glacier, forming a large terminal push moraine (Figure 14) that continued to build at the same rate the lake level increased. The 1986 and 2002 dams also failed in different manners. The 1986 ice dam experienced a structural failure with rapid calving around the seaward glacier face just before the ice dam broke apart. The 2002 moraine and ice dams failed when the lake overtopped and rapidly eroded the moraine, causing the dam to fail. The moraine dam was overtopped when a storm caused lake level to rise 1.5 m in two days, exceeding the growth rate of the moraine. The formation and failure mechanisms for each of these glacier dams are extremely complex, but provide the important variables that need to be considered when assessing future occurrences and developing mitigation measures.

Ice dam stability is a function of: 1) sediment accumulation around the dam, which reduces the amount of calving; 2) mass of the dam (thickness and height); 3) hydrostatic pressure in the lake, which determines the force acting on the dam and flotation of the dam; 4) bed topography and composition beneath the dam, which determines glacier mobility and subglacial outflow; 5) degree of ice fracturing and interconnectedness of the crevasse system, which determines englacial outflow; and 6) the rate of glacier advance. To better address ice dam stability, additional data will need to be collected that includes bathymetry to monitor sediment accumulation, subacoustic profiling to determine sediment thickness and bed topography, and full waveform LIDAR to characterize the crevasse system. Data collection is currently being planned and will begin in 2005 if funding is available.

Moraine and Lake Control Stability

To address public safety issues from moraine failure or catastrophic incision of the Old Situk River control spillway during large storm events, additional geophysical analysis and geotechnical drilling are required. The USFS and COE are developing plans to collect and assess this data in 2005. Geotechnical drilling, GPR and seismic surveys will be used to characterize the materials (size, composition, distribution, and permeability) of the Russell moraine in order to model the response of those materials to extreme events.

Figure 14. Oblique aerial view of 2002 moraine dam and outflow channel from Russell Fiord. (a) Entire moraine dam and overflow channel; (b) Ice choked channel with glacier face and dam.

Diversion Feasibility

An overflow of Russell Lake into the Situk River will have severe immediate economic consequences to the Yakutat economy, which is almost entirely driven by commercial and recreational fishing on the Situk River. At the request of the City of Yakutat, Alaska congressional delegation, and the Governor's office, the USFS and COE will perform a study to assess the feasibility of constructing a diversion channel. Preliminary work identified several diversion options including: 1) constructing a narrow trench in which the stream is allowed to erode and develop into a self formed channel; 2) designing and constructing a 16.3-km channel from the terminal moraine to the ocean; and 3) boring a 4.8-km diversion tunnel through the mountains that divide Yakutat Bay from Russell Fiord. The magnitude and extremely high costs of a project of this scope warrant a thorough and detailed assessment to determine the feasibility of the different diversion options. The diversion feasibility study will involve design and layout of various channel options, hydraulic modeling of flood events in the new proposed locations, and improved cost estimation. The work will commence in 2005 if funding is available.

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Photo credits: All photos were taken by Tongass National Forest employees during the course of their work.

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Section 4. Valuing the Earth Sciences
Part 3. Air

Overleaf:
Meadow near Thompson Reservoir, Fremont National Forest, south-central Oregon. Photo by Bruce McCammon.

Using the Critical Load Concept to Protect Ecosystems From Acidification

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Sulfur and nitrogen in the atmosphere are major components of acid deposition, and the anthropogenic contribution to these pollutants comes primarily from burning fossil fuel. A *critical load* is a threshold for the loading rate of an air pollutant, such as sulfur or nitrogen, above which a specific deleterious effect may occur. When critical loads are exceeded, loss of acid neutralizing capacity, stream and soil acidification, nitrogen enrichment and direct toxicity can result. Thus, elevated levels of sulfur and nitrogen can have a cascading effect on aquatic and terrestrial resources. Scientific information on ecosystem response to pollutant loading is the basis for calculating a critical load. However, policy decisions must be made to identify the levels of protection desired for selected resources within specified timeframes, and these levels are called *target loads*. Once these policy decisions have been made and the critical and target loads have been calculated, land managers are able to clearly communicate the effect of air pollution on the resources they manage. In this manuscript we present examples showing how Forest Service land managers can use the critical load concept as a communication tool and to protect natural resources from air pollution effects.

Keywords: *air pollution, acid deposition, critical load, atmospheric deposition, ecosystem thresholds*

Introduction

Overviews about acid deposition in the United States have been published by the Ecological Society of America (1999), the United States Environmental Protection Agency [USEPA] (2001), and Hubbard Brook Research Foundation (Driscoll et al. 2001a). While sulfur (S) emissions have declined in the eastern United States, especially in the northeast, nitrogen (N) deposition has continued to increase in the west. Furthermore, ecosystems have been slow to respond to declining emissions. This discussion concerns critical loads for sulfur and nitrogen; however, critical loads are also being calculated for ozone and other compounds.

Air pollutants can travel hundreds to thousands of kilometers before deposition and ecosystem degradation occurs. Therefore, the concerns for acid deposition are local, regional, national and international. Lessons applicable to the United States are being learned from approaches adopted by the European Union, i.e., the International Cooperative Programme on Modelling and Mapping of Critical Loads and Levels and their Air Pollution Effects, Risks and Trends (ICP Modelling and Mapping). In recent years, U.S. partnerships have been expanded to include joint monitoring programs with Canada (Committee on the Environment of the Conference of New England Governors and Eastern Canadian Premiers 2001).

USDA Forest Service Program Responsibility

The Air Resource Management Program of the Forest Service has the responsibility to evaluate resource conditions and to advise decision-makers about the existing and potential effects of air pollution on natural resources. This includes effects on flora, fauna, soils, cultural resources such as petroglyphs and pictographs, geochemistry, water, and visibility. Impacts are predicted for individual ecosystem components and whole ecosystems, often using mathematical models. The Air Resource Management Program also recommends goals and objectives for resource management, and ensures that monitoring programs are designed and implemented.

The program often focuses on specific wildernesses, known as Class I areas, because the Clean Air Act provided special protection for these lands. Class I areas include all international parks, national wilderness areas that exceed 5,000 acres (2023 ha) in size, national memorial parks that exceed 5,000 acres (2023 ha) in size, and national parks that exceed 6,000 acres (2428 ha) in size, and

Furniss, M.J., Clifton, C.F., Ronnenberg, K.L., eds., 2007. *Advancing the fundamental sciences: proceedings of the forest service national earth sciences conference, San Diego, CA, 18-22 October 2004*. PNW-GTR-689. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

that were in existence on 7 August 1977. Federal Land Managers (FLMs) have received Congressional direction to "err on the side of protecting the environment" when implementing the Clean Air Act requirements (Senate Report #95-127, 95th Congress, 1st Session, 1977). Critical loads can assist in this effort by helping us clearly communicate the effects of air pollution on resources.

Federal Land Managers have developed consistent methods for protecting resources from air pollution that include developing critical loads. These interagency methods were published as the Air Quality Related Values Workgroup (FLAG) Phase I Report (National Park Service 2000). Accordingly, the FLMs have agreed to:

- Protect the most sensitive resources;
- Ensure no unacceptable change to the resource;
- Use the best science available;
- Develop methods for establishing critical loads;
- Calculate critical loads for areas with adequate information;
- Review and update critical loads; and
- Develop strategies to obtain needed information for other areas.

The Critical Load Concept

A critical load is the amount of pollution delivered to an ecosystem that will not cause harmful changes to physical, chemical, or biological factors (Nilsson and Grennfelt 1988). It is often expressed as kilograms of pollutant per hectare per year (kg ha^{-1} yr^{-1}). The critical load quantifies a cumulative effect to an ecosystem receptor, rather than the effect of single sources of pollution. Loading rates for S and N that are greater than the critical load result in acidification or nutrient enrichment, and are not sustainable.

Critical loads are scientifically determined, and are usually calculated using steady-state or dynamic mathematical models. Examples of steady-state (mass balance) models for acidification are the first order acidity balance (FAB) model (Henriksen et al. 2002) and the Steady-State Water Chemistry (SSWC) model (Aherne et al. 2004). Dynamic models for acidification include Model of Acidification of Groundwater in Catchments, MAGIC (Cosby et al. 1985; Wright 2001) and PnET-BGC, a biogeochemistry model that simulates nutrient cycling, including soil processes such as weathering, cation exchange, adsorption and solution chemistry (Groffman et al. 2004).

The Forest Service, National Park Service and Fish and Wildlife Service have begun calculating critical loads for terrestrial and aquatic ecosystems. These calculations are site-specific (i.e., designed for individual terrestrial and aquatic ecosystems rather than large geographic areas) and apply to the most sensitive resources. Critical loads can also be empirically determined based on field observations showing ecosystem changes or experimental studies that define a dose-response relationship for resource conditions under background or "natural" loading rates compared to conditions under current and predicted (future) loading rates.

A target load is selected to incorporate agency policy, and is similar in concept to a desired future condition. Target loads could be higher or lower than critical loads based on political, economic, social, geographic, or temporal considerations. Intermediate target loads above critical loads could be applied where deposition levels far exceed critical loads (often in the east). Target loads that are more protective than critical loads can prevent degradation in more pristine environments (often in the west), or provide a safety margin for wilderness protection.

Critical and target loads are being used to communicate how pollution is currently affecting natural resources. They are also used to convey what is needed to protect resources that can be affected by air pollution in the future, and to restore resources that have been degraded. These needs can include goals for emission reductions, specific control technologies and mitigation measures.

Discussion

The Forest Service Air Program is concerned about the deposition of nitrogen, sulfur, metals and other toxic substances to both aquatic and terrestrial ecosystems. This concern is due to current conditions and increases in population, energy development and air quality permit activity (and thus subsequent emissions). Acid deposition has contributed to or caused chronic stream acidification from New England into the southern Appalachian Mountains (Driscoll et al. 2001b). It contributes to soil nutrient changes such as calcium and magnesium leaching, or aluminum mobilization, and causes stream acidification (Herlihy et al. 1993). Acid deposition has also affected tree growth in spruce-fir forests. Examples of how acid deposition affects forest resources in the eastern and western United States are presented below.

Case Studies: Eastern U.S. – Chronic Acidification

Historically high deposition, combined with watersheds having low buffering capacity, has resulted in stream acidification and likely changes in soil nutrient status in parts of the eastern United States, including the mountains of Virginia and West Virginia. In some cases of chronic stream acidification, limestone sand (calcium carbonate) is being added to the water as a temporary way to neutralize the acids so that aquatic life won't be precluded, but it does not solve the problem of high sulfur loading rates. Liming is a common occurrence in West Virginia, and the Forest Service has limed headwater streams in St. Mary's Wilderness in Virginia. Liming, especially in a wilderness area, could be controversial, but the decision is generally made based on a desire to maintain the aquatic biota until sulfur loading is reduced through air regulations.

As a result of acidification, soil chemistry is also degraded and aluminum is mobilized in soil solutions. Nutrient cycling is affected by the leaching of nutrients such as calcium and magnesium, and there is interference with calcium uptake and other root functions. Soil nutrient change may lead to changes in vegetation growth and reproduction (Shortle and Smith 1988; Shortle et al. 1997; Lawrence et al. 2005).

Case Studies: Western U.S. – Episodic acidification, N enrichmen

Episodic acidification is defined as "the short-term decrease of acid neutralizing capacity from a lake or stream. This process has a time scale of hours to weeks and is usually associated with hydrological events" (Irving 1991). Thus, it refers to pulses of acidic input that generally are infrequent, but may cause severe damage. In watersheds where snowmelt is the dominant source of water, episodic acidification most likely would occur during early snowmelt, perhaps before ice-free conditions. This can adversely affect the most acid-sensitive aquatic biota, especially early life stages or reproducing individuals. Some phytoplankton and diatom species are very sensitive to pH and water chemistry, and occur only within a small range of pH or ionic concentrations (Mason 1992). Also, snowmelt can flush aquatic systems rapidly, causing an abrupt change in water chemistry or aquatic biota. Episodic acidification can result in an increase in inorganic-monomeric aluminum concentration, which can be toxic to aquatic life. Headwater streams, vernal pools, and high-elevation lakes with low buffering capacity are particularly susceptible to episodic acidification (Baron et al. 2000).

Fenn at al. (2003) provide an overview of the effects of eutrophication and nitrogen saturation in the western United States. Increases in nitrogen deposition and resultant changes in the nitrogen cycle can affect forest growth, health, and carbon sequestration. Since many aquatic ecosystems in the west are nitrogen limited or co-limited, small additions of nitrogen can increase primary production, especially in high elevation lakes. Lichens, diatoms and nitrate concentrations in water are especially sensitive to nitrogen enrichment. Nitrogen saturation means that ammonium and nitrate concentrations exceed demand, and this affects soil and plant calcium to aluminum ratios, aluminum toxicity, and leaching of base cations. Calcium depletion may affect the ability of trees to withstand stress, decrease the rates of decomposition and other microbial processes (Fenn et al. 1998).

Case Studies: Western US – Rocky Mountains

In 1993 the Rocky Mountain Region of the Forest Service certified impairment of visibility and aquatic ecosystems of Mt. Zirkel Wilderness, Colorado, due to emissions from local power plants. This led to a reasonable attribution study of visibility impairment in 1996-1997. This type of study is designed to identify the sources of air pollution that are affecting a particular site or area. The results of the reasonable attribution study led to revision to the long-term strategy portion of Colorado's State Implementation Plan (SIP) for Class I Visibility Protection, and most importantly, to new control strategies and emission reductions. Although the critical load had not been calculated, direct observations of aquatic chemistry supported the certification of impairment (Turk and Campbell 1987). The background information for certification noted the following conditions:

1. High elevation location along the Continental Divide - elevations of the Mt. Zirkel Wilderness range from 2,256 to 3,712 m and include alpine and subalpine lakes;
2. Watersheds composed of non-reactive bedrock with slow weathering rates;
3. A minimum of 18 lakes in the Mt. Zirkel Wilderness with observed alkalinity < 50 μeq/L, and some lakes with < 10 μeq/L;
4. Precipitation chemistry with higher concentrations of sulfur and nitrogen than background-- evaluation of sulfur isotopes indicate that local sources contribute to this condition;
5. Presence of acid-sensitive amphibians, salmonids and other biota;
6. Conceptual modeling that indicated a loss of buffering capacity had probably occurred in some lakes within the Mt. Zirkel Wilderness;
7. Potential for episodic acidification during snowmelt;
8. Potential response of aquatic ecosystems to increases in acid deposition; and
9. Proximity to sources of nitrogen and sulfur that can be transported to the wilderness by prevailing winds. This included the electric-generating stations in Hayden and Craig, CO, located west and upwind of the wilderness, and sources located at greater distances.

If critical loads were established for Mt. Zirkel Wilderness, then comparisons could be made to deposition loading rates that result from emission reductions. This would facilitate tracking progress toward the desired future condition.

Rocky Mountain National Park has also suffered impacts of atmospheric deposition. The effects of nitrogen deposition on terrestrial and aquatic systems have been subtle, yet critical loads may currently be exceeded (Williams and Tonneson 2000; Wolfe et al. 2003). High elevation watersheds have nitrogen saturation and therefore high nitrate concentrations in surface waters and soils. Changes in hydrogen ion concentration over time and an excess of nutrients during the growing season have occurred. Changes that have been observed in alpine lakes in the park include a shift in phytoplankton species and productivity and a shift in diatom community species compared to 50 years ago (Wolfe et al. 2002). The increase in nitrogen emissions can be attributed to population growth and the associated emissions (transportation, industrial, power generation and agricultural) east of the Colorado Front Range.

How Forest Service Managers Can Use Critical Loads and Target Loads

Critical loads are a way to quantify current resource conditions in terms that many audiences can understand. Some people may understand the concept of exceeding a threshold better than they can understand changes in ecosystem function due to anthropogenic pollution. The target audiences for communication about critical loads include our own decision makers, the regulatory community that sets the rules for controlling air pollution, the regulated entities, and the public whose support is needed for positive change to occur.

A primary use for the critical load concept is in the Clean Air Act's New Source Review process for evaluating permit applications to modify or build sources of air pollution. Critical loads can be used to determine how wilderness conditions would be affected by the new emissions, and to make recommendations to permitting authorities, including states, EPA and tribal governments. Another potential application for the critical load concept is land management planning. Critical loads could be incorporated into goals or objectives in Forest Plans or amendments. Progress toward meeting critical loads could be reported in assessments of resource conditions. For example, the Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA) requires the Secretary of Agriculture to conduct an assessment of the Nation's renewable resources every 10 years. Critical loads could also be used to evaluate project impacts, including cumulative effects, in the National Environmental Policy Act (NEPA) process.

Since critical loads are important tools for evaluating potential impacts from new sources of air pollution, states could adopt them in their State Implementation Plans that describe how clean air will either be achieved or maintained according to national and state standards. Regional Planning Organizations (RPOs) for air pollution control could use critical loads to help measure the rate of progress toward more natural visibility conditions. Current RPOs include the Western Regional Air Partnership (WRAP), Central States Regional Air Planning Association (CENRAP), Midwest Regional Planning Organization, Mid-Atlantic/Northeast Visibility Union (MANE-VU), and the Visibility Improvement State and Tribal Association of the Southeast (VISTAS).

Aquatic Critical Loads

Various regions of the Forest Service have been using the Model of Groundwater Acidification in Catchments (MAGIC) in their efforts to protect ecosystems from air pollution. For example, the MAGIC model was used to evaluate the effects of increasing sulfur deposition on lakes in the Absaroka-Beartooth Wilderness and the Selway-Bitterroot Wilderness of Montana, and to develop critical and target load relationships for Class I areas in North Carolina and West Virginia.

The MAGIC model simulates chemistry of soil solution and surface water to predict average ion concentrations per month and year. It is also being used to help managers establish target loads (Table 1). For example, assume that an acid neutralizing capacity (ANC) of 50 μeq/L indicates no harmful effects occurring to the aquatic ecosystem, and that current sulfur deposition rate is at 10 kg S ha^{-1} yr^{-1}. Site A has current stream chemistry that is well below the pre-1900 condition, indicating that degradation has occurred. A future stream ANC of 50 μeq/L would not restore this system to "natural" conditions, but would allow most aquatic biota to live in the stream. The target load for Site A varies from 1-6 kg ha^{-1} yr^{-1} depending on how quickly recovery is desired. To improve from a current ANC of 7 μeq/L to 50 μeq/L (on the way toward the baseline ANC of 91 μeq/L) by the year 2040, would require deposition to be reduced from the current loading rate of 10 kg S ha^{-1} yr^{-1} to 4 kg S ha^{-1} yr^{-1}.

For site B, stream ANC is less than "natural," but still above 50 μeq/L, indicating that aquatic biota can survive. In this situation more deposition can be tolerated and the ANC will still remain above 50 μeq/L. In both Sites A and

Table 1. Sample target loads, in kg sulfur (S) ha^{-1} yr^{-1}, to meet desired future conditions of stream Acid Neutralizing Capacity (ANC). In this example, the current loading rate is 10 kg S ha^{-1} yr-1 and target ANC is either 20 or 50 μeq/L. Note that for Site A to improve from a current ANC of 7 μeq/L to 50 μeq/L (on the way toward the baseline ANC of 91 μeq /L) by the year 2040, would require deposition to be reduced from the current loading rate of 10 kg S ha^{-1} yr^{-1} to 4 kg S ha^{-1} yr^{-1}.

Stream ANC (μeq/L)			Target Load for Sulfur (kg S ha^{-1} yr^{-1}) for ANC = 20 μeq/L			Target Load for Sulfur (kg S ha^{-1} yr^{-1}) for ANC = 50 μeq/L		
Site	Pre-1900	Current	Year 2020	Year 2040	Year 2100	Year 2020	Year 2040	Year 2100
A	91	7	5	8	9	1	4	6
B	82	60	43	26	13	15	10	7
C	60	21	2	3	3	6	9	13

B if the desired future condition of ANC is less than 50 μeq/L, then more deposition could be tolerated.

For the stream at Site C, ANC is only slightly above 50 μeq/L in a natural state, and the current ANC has deteriorated to 21 μeq/L. Depending on how long we are willing to wait for recovery, deposition would have to be reduced from 10 kg S ha^{-1} yr^{-1} to between 2 and 9 kg S ha^{-1} yr^{-1}.

The Pacific Northwest Region of the Forest Service has initiated a five year study, the Cascade Wilderness Lakes Project, to calculate critical loads for aquatic ecosystems. The CE-QUAL-W2 model will be modified for biological processes and dilute lakes to calculate the critical loads of ammonia, nitrate and hydrogen ion. CE-QUAL-W2 is a hydrodynamic model developed by the US Army Corps of Engineers (Wells 1997). It is a two-dimensional model for various temporal and spatial scales. The revised model will characterize hydrologic, biologic and chemical variables of the lakes. First the water budget will be calculated. Then the conservative ions such as chloride and the reactive ions such as nitrate, ammonia and phosphate will be incorporated. The major biological components that affect the reactive ions include phytoplankton, zooplankton, benthos, and fisheries. CE-QUAL-W2 incorporates hydrodynamic factors that most acid-rain related models do not, and also includes critical biological processes. Thus, both acidification and eutrophication will be modeled.

The Pacific Southwest Region of the Forest Service is developing a screening procedure for identifying acid-sensitive lakes based on catchment characteristics. This project includes predicting ANC for high-elevation lakes in California's Sierra Nevada mountains using conceptual and general linear models (Berg et al. 2005). The catchment characteristics being studied are: catchment-to-lake area ratio, lake perimeter-to-area ratio, carbonate lithology, lake headwater location, and geochemistry.

Terrestrial Critical Loads, Cooperation with Research Scientists

Air Program Managers from National Forest Systems are cooperating with scientists from Forest Service Research to better quantify critical loads. One project is developing a protocol for estimating terrestrial critical loads in Class I areas and collecting essential data at an eastern and western demonstration site. The purpose of this project is to summarize the methods available for calculating terrestrial critical loads and to form a strategy for estimating critical loads in all Class I areas. The eastern demonstration site is at Fernow Experimental Forest, West Virginia, in the Monongahela National Forest. This site contains high elevation spruce-hardwood forest, and receives loading rates of approximately 8 kg N $ha^{-1}yr^{-1}$ and 18 kg S $ha^{-1}yr^{-1}$. The western site is Kings River located in the Sierra National Forest of California. The effects of nitrogen deposition from San Joaquin Valley sources on ponderosa pine (*Pinus ponderosa*), Sierran mixed conifer, fir, and alpine meadows are a concern. We hope that this collaboration will result in a broader network of air pollution study sites that is linked to the Forest Health Monitoring Program. Once the critical loads are calculated and entered into a spatial database, a map of critical loads for federal lands could be generated.

Conclusion

Critical loads are exceeded when episodic or chronic acidification has been documented or nutrient enrichment is occurring. Where critical loads are not exceeded, antidegradation is a concern, especially since the Wilderness Act states that wilderness is to be "protected and managed so as to preserve its natural conditions." It is possible that unacceptable effects may occur when critical loads are approached, if uncertainties have not been quantified or a safety margin has not been incorporated.

Three things are needed to enable federal land managers to move forward with the critical load concept. First, we need to acquire site-specific data for soil chemistry, water chemistry and deposition rates. Second, decisions have to be made regarding the empirical data or models used to calculate critical loads. Finally, we need to complete the demonstration projects that are currently underway to collect data to populate a variety of models that can be used to calculate critical loads. Although the Air Resource Management Program is currently funding collaborative projects with Forest Service Research and Development to implement the critical loads concept, additional cooperation with researchers will be required to establish critical loads for all Class I areas.

Scientific information on ecosystem response to pollutant loading is the basis for calculating a critical load. However, policy decisions must be made to identify the levels of protection desired for selected resources within specified timeframes, the target load. Once critical and target loads have been calculated, land managers will be able to clearly communicate the effect of air pollution on the resources they manage.

Critical and target loads can be used to better communicate how pollution is affecting natural resources and what is needed to protect and restore them. The audiences for this communication are:

• Our own decisionmakers;

• The regulatory community that sets the rules for controlling air pollution; and

• The public whose support is needed for positive change to occur.

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The Potential Effects of Acid Deposition: What's a National Forest To Do?

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The mid-Atlantic region, in which the Monongahela National Forest lies, receives some of the highest rates of acidic deposition in the country. As a result of the substantial acidic inputs and growing public concern with the problem, the forest is addressing this topic in its current forest plan revision as it relates to potential effects to water quality, aquatic habitat, soil nutrient status, and forest productivity. Plan revision is approximately fifty percent complete, and the revision team is now in the initial stages of designing a multi-level monitoring plan to collect and compile data to evaluate short- and long-term effects of continued deposition and land management activities on soil and water resources. This paper briefly describes the state of the science of acidic deposition effects on land productivity, and their management implications for the Monongahela. Additionally, risk assessment analyses for the forest and monitoring strategies to continue data collection and database expansion are described. Preliminary soil chemistry data from watersheds highly sensitive to acidic inputs and base cation loss on the Monongahela National Forest are presented to illustrate the importance of including this problem in forest plan revision and project level planning, and to show how the team incorporated available data in its decision processes.

Keywords: *acid precipitation, air pollution, calcium, soil productivity, resource management*

An Introduction to Acidic Deposition and Its Effects

Acid deposition occurs when sulfur dioxide and nitrogen oxides react with water and oxygen in the atmosphere to form acidic compounds, which then fall to earth in either a dry or wet form (EPA 1998). The northern half of West Virginia has long been recognized as an area of high acid deposition. Total annual sulfur deposition on the Monongahela National Forest is the late 1980s ranged from 19 kg/ha at the lower elevations, to 26 kg/ha at high elevations (Adams et al. 1991). Few areas of the United States showed higher sulfur deposition than was found on the Forest. Current monitoring results show that wet sulfate deposition has decreased 29 percent in the mid-Atlantic region as the Acid Rain Program emission reductions have been implemented (EPA 2004). In fact sulfur deposition at Parsons, West Virginia (a lower elevation monitoring site) was down to 12 kg/ha in 2000 (*http://www.epa.gov/castnet/charts/par107ts.gif*, accessed February 2006).

Bases, such as calcium and magnesium, are also found in atmospheric deposition, and these compounds could help offset some of the negative effects of acid deposition. However concentrations of bases in atmospheric deposition have also decreased. For example, at Parsons, West Virginia, annual calcium deposition has decreased from about 4 kg/ha in 1979 to just over 1 kg/ha in 2003 (*http://nadp.sws.uiuc.edu/trends/trendRequest.asp?site=WV18*, accessed February 2006).

Soil acidification can be seen as a balance between acid inputs and mineral weathering (Binkley et al. 1989). Therefore, when soil acidifying processes (such as acid deposition and forest growth) exceed mineral weathering inputs of base cations, acidification occurs.

Changes in soil chemistry are difficult to quantify due to the long periods of time over which they occur, the complexity of the factors controlling them (Markewitz et al. 1998), and the inherent spatial heterogeneity of soils. A study of soil acidification in the Calhoun Experimental Forest in South Carolina using soil data from 1962 to

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1990 showed that the upper 60 cm of soil acidified at an accelerated rate due to acidic deposition while the naturally acidifying processes of biomass accumulation, root and microbial respiration, and organic matter incorporation also occurred (Markewitz et al. 1998).

Soil acidification increases cation leaching, decreases soil pH and base saturation, increases the N content of trees, and negatively affects many biological processes (Adams and Kochenderfer 1999). Adams (1999) found that Ca losses were particularly large when a forest soil becomes acidified. A nine-year acidification study at Bear Brook watershed in Maine showed accelerated loss of base cations from the soil, which subsequently leached into streams (Fernandez et al. 2003). Base cations also are removed from the soil by plant uptake, leaching, and harvesting (Gbondo-Tugbawa and Driscoll 2003).

The major base cations in atmospheric deposition, soils, and geologic materials are Ca^{+2}, Mg^{+2}, Na^{+}, and K^{+}. Of these Ca and Mg typically provide the greatest contribution to buffering because they usually are more abundant than K and Na and they possess a greater positive charge. Mineral weathering of soil and geologic materials control base cation availability over the long term, but the major short-term sources of base cations to soil are litter fall and atmospheric deposition (Johnson and Todd 1990; Jenkins 2002). Slope position affects base cation supplies because litter accumulates more on lower slope positions than on higher ones (Johnson and Todd 1990).

The National Acid Precipitation Assessment Program (NAPAP 1998) indicated that base cation depletion may affect the health of forest ecosystems. The health of eastern hardwood forests has not yet shown adverse effects from acid deposition on a broad scale (NAPAP 1998). However, mortality and decline of red spruce (*Picea rubens*) at high elevations in the Northeast have been significant and provide the greatest evidence of forest damage by acidic deposition (NAPAP 1998). Sugar maple (*Acer saccharum*) is also a species of concern (Likens et al. 1996; Bailey et al. 2005), since it is particularly sensitive to decreases in Ca and Mg soil pools.

Existing Conditions on the Monongahela National Forest

Aquatic Resources

The Monongahela National Forest (MNF) is the fourth largest national forest in the northeast and contains the headwaters of five major river systems: the Monongahela, Potomac, Greenbrier, Elk, and Gauley Rivers. Twelve river segments on the MNF are being studied for potential classification in the National Wild and Scenic Rivers System. Rivers and streams across the forest include more than 900 km of coldwater trout streams and provide an additional 200 km of warm water fishing. Although the State of West Virginia manages many stream segments as put-and-take trout fisheries with seasonal trout stocking, some estimates suggest 90% of West Virginia's native brook trout (*Salvelinus fontinalis*) streams occur on the MNF.

Healthy, reproducing trout populations and their associated communities have various habitat requirements. Water quality in rivers and streams is an important consideration when establishing management priorities on the forest to provide for the maintenance of healthy aquatic ecosystems. Water chemistry is one component of water quality and represents a fundamental building block for aquatic communities. For example, harmful effects to certain aquatic organisms, such as reduced reproduction, begin to occur as pH values in streams fall below 6.0; detrimental effects, such as mortality, begin to occur as pH falls below 5.0. Also, values less than 50 for acid neutralizing capacity (ANC) indicate a stream system is acid sensitive, values less than 25 suggest a system likely experiences episodic acidification during storms, and negative ANC values indicate a system is already acidic (*http://www.dep.state.wv.us*).

Water chemistry of streams and rivers is the by-product of dynamic nutrient pathways and chemical processes occurring within the contributing watershed environment-atmospheric, terrestrial, and biological. The significance of water chemistry is perhaps no more apparent than in aquatic ecosystems composed of diverse geology, particularly when these systems are exposed to acid deposition. Watersheds across the MNF exhibit a wide range of surficial geologies that have variable capacities for neutralizing acid inputs.

In 2001, the MNF initiated an effort to establish forest-wide monitoring of water chemistry properties in streams across the forest. Sample sites were strategically located to allow monitoring efforts to increase the level of understanding of the relationships between water chemistry and various local environmental factors including the geologic composition of contributing watershed areas, rates of acid deposition, and supported aquatic communities. Results of water chemistry monitoring from fall low flow and spring high flow sampling demonstrated a high degree of variability between sample locations and sample periods, as expected. For example, measures of pH ranged from 3.88 to 8.2 (mean = 6.8) during fall 2001 samples (low flow conditions) and from 3.73 to 8.55 (mean = 6.4) during spring 2002 samples (high flow conditions). Measures of ANC ranged from -166 to 2868 (mean = 407) during fall 2001 samples and from -195 to 1599 (mean = 135) during spring 2002 samples.

Variation in measures of pH and ANC between sample locations was largely explained by the variable capacity of a watershed's geology to neutralize acid inputs. Variation in measures of pH and ANC between sample periods at a given site was largely explained by the different stream discharge conditions. Except where acid mine drainage is an issue, water samples collected at low flow conditions during the late summer to early fall period are typically expected to exhibit higher pH and ANC values due to the greater influence of groundwater on stream flows, as compared to spring high flow conditions when direct inputs from melting snow and precipitation (i.e., acid rain) have greater influence.

State water quality monitoring programs are also documenting cases of stream acidification in West Virginia. In an attempt to mitigate impacts of stream acidification on native trout streams and the recreational fishing opportunities they provide, the state has developed and refined a program to treat acid impaired streams with limestone sand. Limestone sand is currently being applied to acid impaired streams on the forest and across the state to help neutralize acidity. Forest monitoring results show water chemistry downstream from treatment areas exhibits notable increases in ANC, pH, and Ca when compared to untreated water upstream. Although this action helps mitigate against many symptoms of stream acidification within the effective stream treatment zone, it does not affect the underlying cause of the condition to address risks to aquatic and terrestrial ecological processes and functions that extend beyond the treatment zones (McClurg et al. 2004).

Parent Materials

Soils of the MNF have developed from sedimentary rocks and are divided broadly into two zones that have different soil patterns, the Allegheny Plateau Province and the Appalachian Ridge and Valley Province. The Allegheny Plateau Province has relatively flat-lying bedrock. Soils on the Plateau are characterized by high moisture content, thick humus, acidic conditions, and low nutrient levels. Timber productivity in this region of the forest is more a function of soil moisture than fertility. In the Ridge and Valley Province, bedrock is folded, faulted, and fractured. Rock outcrops and escarpments are common. Soils are often shallow, shaley, droughty, and not highly productive. Most MNF soils exhibit moderate to severe erosion potential, and high hazard areas exist in areas of shale and limestone.

Elevation on the MNF ranges from 274 m to 1482 m. Rain shadow effects caused by slopes of the Allegheny Front result in an average of 153 cm of annual precipitation on the west side of the MNF and about half that amount on the east side. Soils develop under mesic and frigid climatic temperature regimes where annual air temperature is 9°C. Frigid soil temperatures usually exist above 915 m. The mountainous landscapes on the MNF result in steeply sloping topography, with many areas having slopes of 30% or greater.

Soils on the MNF have been subject to the effects of abusive cutting and burning in the late 1800s and early 1900s. Logging without regard to resource protection contributed to damaging floods, severe erosion and topsoil loss, and pollution of streams. Severe fires further increased erosion by burning so hot that soil carbon was lost to the atmosphere. Soil productivity in some areas on the MNF is irretrievable in human time frames. Although there has been some recovery for the soil resource during the past century, many forest soils on the MNF still have only thin surface horizons, which now limit their ability to neutralize acidic inputs.

Air Quality

Historic atmospheric deposition, particularly of SO4 (sulfate), from the Ohio River Valley and other Midwestern areas has contributed to acidification of streams and could affect soil productivity in parts of the MNF. Evidence of nutrient depletion in certain soils on the MNF has been found (Jenkins 2000; Schnably 2003; C. Sponaugle personal communication). Sulfate also is a primary contributor to visibility impairment or regional haze.

Sulfates are formed from atmospheric emissions of SO_2 (sulfur dioxide) from power plants and other industrial sources. The MNF receives industrial emissions primarily from sources in Ohio, Pennsylvania, Indiana, Illinois, and West Virginia. These states continue to produce some of the highest sulfur dioxide emissions in the nation, despite significant emissions reductions made during the 1990s. The combination of high emissions and limited buffering capacity of certain geologies and soils on the MNF have increased stream water acidity and possibly contributed to soil nutrient depletion.

The 1990 Clean Air Act Amendments (CAAA) Acid Rain provision mandated significant reductions in SO_2 emissions in the 1990s. The greatest percentage decreases in atmospheric SO_4 concentrations occurred in the eastern states north of Tennessee and North Carolina, and the highest absolute decrease (73%) occurred at the Bearden Knob air monitoring station on the MNF (often referred to as Dolly Sods in the literature) (Malm et al. 2000). These reductions are attributable to large reductions in SO2 emission at sources upwind from the MNF (between 1990 and 1999: Indiana: -44%, Ohio: -35%, West Virginia: -34%, Kentucky: -29%, and Illinois: -13%). In these five states, SO_2 emissions decreased by 2.5 million tons between 1990 and 1999.

Downward trends in SO_2 emissions and SO_4 deposition will affect MNF resources positively; however, they may not be enough to reverse all of the degradation that already has occurred.

According to modeling projections made by the Southern Appalachian Mountains Initiative (2002), reductions in SO_2 emissions resulting from the 1990 CAAA will not be enough to restore the chemistry of acidified streams to levels where aquatic life can thrive. Additional emission reductions will be needed to restore acidified streams and natural atmospheric visibility conditions.

The Occurrence of Acid Conditions and Acid Sensitivity on the MNF

Soil water and stream acidification are real phenomena that have been shown to occur in West Virginia. Long-term, increasing losses of base cations to stream water due to ambient acid deposition have been documented in stream water on a control watershed in the Fernow Experimental Forest, which is located in the MNF (Edwards and Helvey 1991). Other watersheds on and near the Fernow Experimental Forest that have been artificially acidified with S and N to determine effects on soils and stream water have shown mobilization of base cations in soil and consequent leaching to stream water and substantial reductions in the acid-neutralizing capacity of soil water (Edwards et al. 2002a, 2002b).

Otter Creek Wilderness is one of the most popular recreation areas in the MNF, and because it also is designated a Class I area[1] it has been intensively monitored to characterize the extent of acidic water, soils, and geology. Approximately 71 percent of the Otter Creek Wilderness is underlain by geologic material of the Pennsylvanian Epoch. The dominant geology is the Pottsville Group, which generally has very acidic strata. Many of the sandstones associated with Pottsville geology are resistant to weathering, and weathered materials produce very acidic soils with pH values ranging from 3.5 to 4.6. Only small base cation reserves exist to be weathered to the soil, so there is little to no acid-neutralizing capacity available (Jenkins 2002).

Total Ca and Mg levels measured in high-elevation soils underlain by Pennsylvanian geologic material in Otter Creek range from 513 to 1095 kg/ha and 3896 to 6662 kg/ha, respectively (Jenkins 2002). Total soil reserves of these base cations are much less than those in similar forest ecosystems. For example, Mann et al. (1988) and Federer et al. (1989) calculated average total stores of Ca in other Northeastern forest soils to be approximately 4 to 20 times greater than those in Otter Creek. Otter Creek soils also have elevated aluminum, which poses a threat to forest productivity and exacerbates soil nutrient deficiencies (Jenkins 2002). Jenkins (2002) found that most of the soils studied from Otter Creek have a Ca:Al molar ratio of less than 0.2 along with a base saturation of the effective cation exchange capacity (BSECEC) of less than 15%. This was interpreted to mean that these forests are at about a 100% risk for decline based upon work by Cronan and Grigal (1995). High Al concentrations are present in soils supporting declining spruce stands in northeastern United States and are commonly thought to inhibit Ca uptake and transport (Shortle and Smith 1988). Red spruce (Picea rubens) is a dominant tree species growing in the high elevation soils of Otter Creek Wilderness, and it is an important ecosystem component for several rare or listed species on the MNF.

While Otter Creek has been intensively monitored, more widespread continuous monitoring of soils around the MNF has taken place since before the 1970s through cooperative efforts between the USDA - Natural Resource Conservation Service (formally the USDA Soil Conservation Service) and the MNF to develop and publish county soil survey reports. While the data are not complete and the soil pits from which the data were obtained were not always located in areas of interest to the MNF, the soil data were collected across multiple geologies over time and are very useful in helping to assess soil productivity.

Since 2001, additional intensive soil data collection continues to be done outside of Otter Creek Wilderness to develop baseline soil chemistry data across the MNF, especially in areas assessed by the Soil Nutrient Sensitivity Map (described in the next section) to be highly sensitive to acidification. More than 500 soil samples have been collected across varying soil types, landscape positions, and varying aspects and analyzed for physical and chemical characteristics. Preliminary results show that soils in sensitive areas are affected adversely by acid deposition.

[1] The Clean Air Act Amendments (CAAA) of 1977 established the prevention of significant deterioration (PSD) program. These amendments designated specific Wildernesses and National Parks over a certain size as Class I areas. These federally mandated Class I areas are provided with an additional measure of protection under Title I, Part C of the CAAA, which states that one purpose of the Act is "to preserve, protect, and enhance the air quality in national parks, national wildernesses". Further more, the PSD regulations charge the federal land manager with the "affirmative responsibility to protect the air quality related values (including visibility) of any such lands," and to consider "whether a proposed source or modification would have an adverse impact on such values" (40 CFR 51.166 (p)(2)).

Base saturation values often are below 15 percent and Ca:Al ratios are less than 1.0 for soils found on ridgetops and benches. Some south-facing cove soils have soil Al levels that might indicate possible toxicity for vegetation. The data are just now becoming available and the interpretations should be ready for the 2006 forest-wide monitoring report.

Approaching Acidic Deposition Effects in Forest Plan Revision

Soil Nutrient Sensitivity

Acidic deposition and its effects on soil productivity arose as a new issue during the scoping phase of Forest Plan Revision in 2003. After a review of the literature, discussions with research scientists, and discussions with internal interdisciplinary team members, the issue was brought forward as a primary issue during Forest Plan Revision. Soil productivity issues and mitigations on disturbed lands were addressed in the Standards and Guidelines of the 1986 Monongahela National Forest Land Management Plan (USDA Forest Service, p. 79 and Appendix S), but there was no consideration of soil productivity losses caused by base cation depletion on undisturbed soils.

To address this issue in the forest plan revision, areas on the MNF susceptible to potential effects of acid deposition first were identified and mapped using a multi-step process. The initial map data layer in the analysis was the geology layer; geology was ranked as high, medium, or low sensitivity based on the geochemistry from county geology documents and personal knowledge of MNF geologists. Geology known to have substantial sources of alkalinity was assigned low sensitivity because it could provide a reasonable level of buffering capacity to soil. Geology known to have only trace amounts of alkaline producing minerals was rated as high sensitivity. Geology known to have a moderate amount of alkaline producing minerals or interbedded seams of calcite or alkaline shale received a rating of medium sensitivity due to the uncertainty about the amount of weatherable alkaline minerals or the depths of the material from the rooting zone.

The second map data layer included in the analysis was the stream layer of the MNF. Streams were analyzed for water quality impacts from acid rain and mine drainage using the current 303d listing from the state (*http://www.dep.state.wv.us*). Sources of acidity were identified in the stream layer. The correlation between geology and stream water quality is strong. Where high geologic sensitivity exists on the MNF, acid rain impaired streams are present. Some streams flow through areas of low sensitivity but remain impaired due to the large effect from upstream geochemistry, soil chemistry, and precipitation chemistry.

The third map data layer was SO_4 deposition across the MNF. Deposition data were generated by Dr. James Lynch at The Pennsylvania State University. Areas of the MNF that received high amounts of wet SO4 deposition rates were identified with this map layer (Figure 1). Other forms of SO_4 deposition also occur which are not depicted in this map, such as dry deposition and fog deposition. Some experts estimate that dry deposition may be at least as much as the wet deposition totals. Fog deposition is often not even accounted for in measurements and may be greatly underestimated at the higher elevations. Therefore, this map captures only a portion of actual deposition rates.

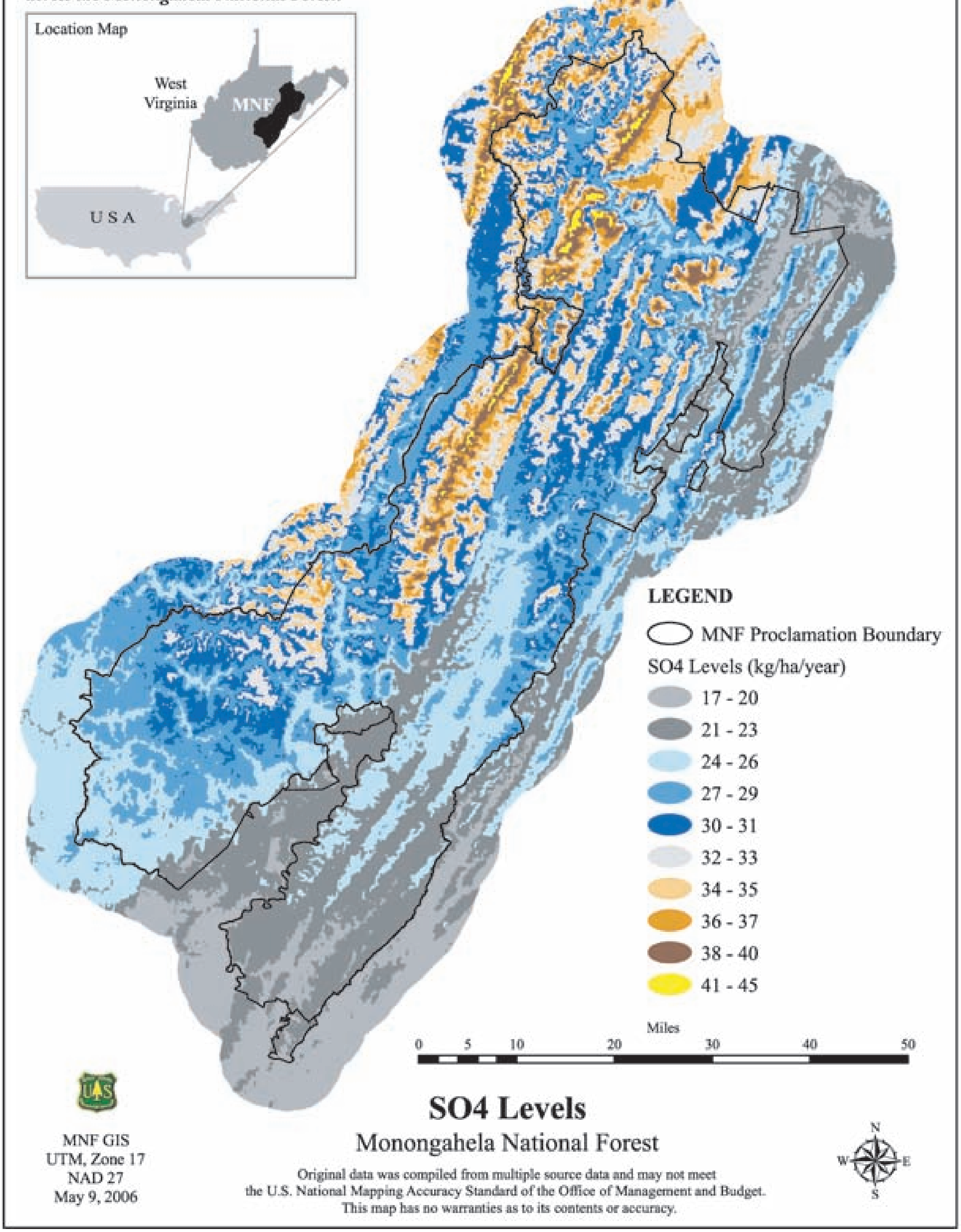
The combination of these three analysis layers provides an overall picture of acid deposition sensitivity across the MNF (Figure 2). In general, an area with highly sensitive geology, high rates of sulfate deposition, and acid rain impaired streams would indicate potential soil productivity problems in the surrounding watershed. An area with moderate sensitivity, high rate of sulfate deposition, and a non-acid impaired stream may indicate an area that may not be susceptible. However this area would require an assessment of any monitoring data and a site visit by a specialist. This acid deposition sensitivity layer (Soil Nutrient Sensitivity Map) is being used at the Forest Plan Revision level, the forest-wide level for analyses, and at the watershed assessment level.

Forest-wide Monitoring

While the Soil Nutrient Sensitivity Map provides a useful way to estimate a soil's sensitivity to acidic inputs or acid-causing situations (i.e., a risk assessment), the map does not provide a direct measure of soil productivity, which is very important for forest level management. Soil productivity can be predicted using available soil chemistry and acid deposition data. The MNF currently is deciding on the approach that it will take to assess soil productivity from a Forest Plan perspective. These decisions have not been finalized, but from the general direction of approach it now appears that following the initial risk assessment determined from the Soil Nutrient Sensitivity Map, specific chemical analyses of soil and water will be required for areas at high risk of nutrient depletion before management activities that might remove base cations are approved (e.g., timber harvesting or ground disturbance). Currently

Text continues on page 435.

Figure 1. Wet sulfate deposition levels across the Monongahela National Forest.



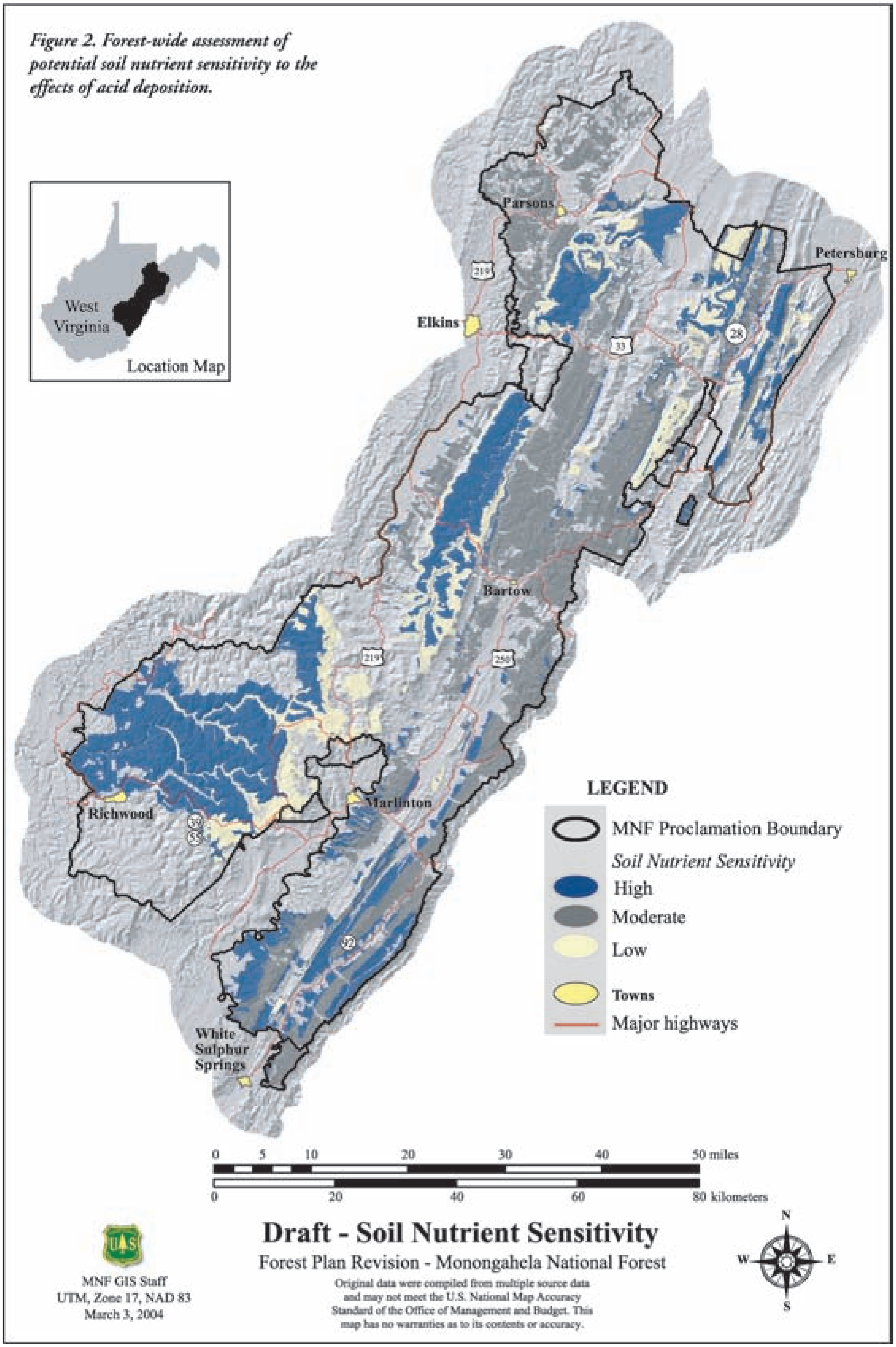


Figure 2. Forest-wide assessment of potential soil nutrient sensitivity to the effects of acid deposition.

the chemical criteria being considered for monitoring soil productivity of sensitive areas are: 1) soil Ca:Al ratios; 2) soil base saturation; 3) effective cation exchange capacity of the soil; 4) acid neutralizing capacity (ANC) of the stream water within subwatersheds (Hydrologic Unit Code [HUC] levels 6 and 7); and 5) the presence or absence of vegetative indicator species in the understory.

Critical Loads

Ultimately, the ability to calculate an array of critical loads with regard to acidic deposition and forest management alternatives is the goal that the MNF would like to achieve; critical loads provide quantitative answers to the "So what do soil conditions or acidity mean in terms of forest management?" question. A critical load is that amount of pollution below which no adverse impacts will occur. Currently, the MNF does not have all the necessary data to determine critical loads for the many combinations of deposition, geology, soil, and water chemical characteristics present on the MNF. Data collected within the MNF's various resource staff areas, routine monitoring programs, and data that will be collected as a result of the monitoring program set forth in Forest Plan Revision will be used to evaluate and refine current conditions using the Soil Nutrient Sensitivity Map and eventually to develop critical loads. The necessary stream, soil, and soil water data have been collected from a few sites on the MNF to calibrate the MAGIC Model (Model of Acidification of Groundwater in Catchments), which will be used to calculate critical loads. Determination of critical loads for the many types of sites on the MNF will provide a tool that land managers can use to better protect resources; land managers then can assess how various land management alternatives might affect desired future conditions based on an array of critical loads. At the regional or national scale, policy makers can use critical loads to determine what levels of pollutant reductions would be needed to achieve desired future conditions on larger landscape or at regional scales.

Other National Forests in Region 9

Many forests in the northeastern portion of the eastern region of the US Forest Service (areas east of the Ohio River basin and northeast of the Great Lakes) are experiencing similar effects on resources from acid deposition. The White Mountain National Forest, in New Hampshire and Maine, has assessed resource effects of acid deposition and has developed a scientific approach to effects monitoring and management of those affected resources. Research at the Hubbard Brook Experimental Forest, located in the White Mountain National Forest, indicates that long-term depletion of forest soil Ca could affect forest productivity, health, or composition, particularly of red spruce and sugar maple (Federer 1989). Currently, the Green Mountain National Forest in Vermont is assessing soil productivity in relationship to acid deposition sensitivity.

Studies on the Kane Experimental Forest and the Allegheny National Forest in northwestern Pennsylvania show that sugar maple is sensitive to soil Ca levels (Bailey et al. 2004; Horsely et al. 2000). Soils in this region have parent materials formed from the same Pottsville geologic formation underlying the Allegheny Plateau. These Pottsville-derived soils are naturally highly acidic and Ca deficient. In this area of Pennsylvania, Ca depletion has led to significant mortality of sugar maple in large areas when other pre-disposing factors, such as drought and insect infestation have been present and have served to exacerbate mortality.

Conclusion

Acid deposition is a real issue for the MNF. The relationships between air, water and soil chemistry are not always clear; however, science has shown links and associated effects. The results from forest stream monitoring sites are supported by the acid sensitive geology classification developed by combining data from the US Geological Survey with information on rates of acid deposition from the 2002 Southern Appalachian Mountain Initiative Report. That is, water chemistry monitoring on the forest indicates poor water chemistry buffering in aquatic systems located in contributing watershed areas dominated by geologies classified as higher acid sensitivity, and in some cases those systems dominated by a combination of moderate and higher acid sensitive geologies. Soil productivity monitoring is providing additional information, which will lead to the ability to model long-term cumulative effects in watersheds. This data will ultimately help land mangers answer questions about the potential long-term effects of management activities in highly sensitive areas and the forest's ability to achieve future desired conditions.

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Methylmercury Contamination:
Impacts on Aquatic Systems and Terrestrial Species, and Insights for Abatement

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Methylmercury (MeHg) is one of the most widespread waterborne contaminants, and through biomagnification processes has commonly been found in prey fish at concentrations toxic to piscivorous birds and mammals. In USEPA's National Fish Tissue Survey, the Lowest Adverse Effect Concentration of 0.1 g/g wet weight was exceeded in 28% of total samples and 86% of predatory fish samples (USEPA 2002). Evidence suggests that more than a quarter of all mature fish contain methylmercury concentrations above this level. This review focuses on the leading anthropogenic sources of mercury to aquatic systems, through atmospheric deposition and the environmental dynamics of the mercury methylation process in aquatic sediments. The results of extensive mercury monitoring studies are discussed, as well as the reproductive and behavioral impacts on birds and mammals feeding on fish exhibiting realistic contaminant concentrations. Recommendations are provided for continued research and the abatement of methylmercury concentrations in fish through forest management practices.

Keywords: *mercury deposition, methylmercury, sulfate reducing bacteria, aquatic sediments*

Introduction

Methylmercury (MeHg) is one of the most widespread waterborne contaminants (USGS 2001a; UNEP 2002; USDHHS and USEPA 2004). Unhealthful levels of MeHg in fish have led to the issuance of fish consumption advisories by at least 46 states (USEPA 2004). The generation, bioaccumulation, and biomagnification of MeHg within aquatic systems has been studied for decades, following the identification of severe neurological and teratogenic impacts to humans associated with the consumption of contaminated fish in Minimata Bay, Japan in the 1950s (Eisler 1987; Ninomiya et al. 1995). MeHg has been linked to potential reproductive and immune system effects in humans and wildlife (Wiener et al. 1996; USEPA 1997d; Round et al. 1998). To protect human health, the U.S. Environmental Protection Agency (USEPA) has set a generalized, default fish tissue mercury residue criterion for freshwater and estuarine fish at 0.0175 mg per kg of fish per day (USEPA 2001). With regard to management of Forest Service lands, MeHg is recognized to be a significant risk to the viability of natural systems associated with aquatic resources (Hammerschmidt et al. 1999, 2002; Gnamus et al. 2000). Of the over 40.4 million ha (100 million acres) of freshwater wetlands within the conterminous United States, over 20.2 million ha (50 million acres) were determined to be forested wetlands, as well as 10.0 million ha (25 million acres) of emergent wetlands and 7.3 million ha (18 million acres) of shrub wetlands (Dahl 2000). While National Forest lands represent only eight percent of the contiguous United States, they contribute 14 percent of the runoff (USDA FS 2000). National Forests and Grasslands contain over 240,000 km (150,000 miles) of streams and 1 million ha (2.5 million acres) of lakes (USDA FS 2004). Anglers spent nearly 50 million days fishing on National Forests in 1996, and generated US $2.9 billion (NFF 2004). Clearly, the Forest Service has a large stake in the study, prevention, and possible abatement of mercury contamination within the nation's waters.

This review focuses on the primary anthropogenic source of mercury ultimately affecting aquatic systems - coal combustion. Much smaller contributions from wildland fire, associated with Forest Service land management activities, will share that focus. Also discussed are: subsequent mercury deposition to aquatic systems, dynamics of conversion to MeHg within fresh water aquatic sediments, impacts on aquatic and terrestrial species, proposed controls and regulatory initiatives, and suggested mitigation measures.

Sources

The bulk of MeHg within natural systems originates from methylation of atmospherically deposited mercury

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species by sulfur reducing bacteria within aquatic sediments (USEPA 1997d). Long thought to originate from mercury-laden industrial point source effluent, mercury contributions from geological processes, or both, MeHg contamination has more recently been portentously linked to long-term, long-range transport of emissions from fossil fuel combustion sources throughout the industrialized world (USEPA 1997b, 1997d; UNEP 2002; Bullock 2004). Despite the uncertainties involved in determining emission inventories, it is widely accepted that anthropogenic emissions have increased relative to natural sources since the beginning of the industrial period (Fitzgerald et al. 1998). This has resulted in atmospheric deposition of elemental and oxidized mercury species, even in remote areas (Rasmussen 1994; Sorensen et al. 1994; Morrison and Watras 1996; Eisler 1998; Fitzgerald et al. 1998; USGS 2000; St Louis et al. 2001; Blett 2002; MPCA 2004). Concern exists that most National Forest lands are characterized by relatively remote freshwater systems, many showing signs of MeHg contamination (USDA FS 2000).

The burning of fossil fuels, primarily coal, is the best characterized and most dominant anthropogenic source of mercury emissions (USEPA 1997d; Seigneur et al. 2003), representing over 30% of mercury emissions from domestic sources and 29% of global anthropogenic emissions (Seigneur et al. 2004). Approximately 40% of the 68 metric tons (75 tons) of Hg from the coal burned domestically remains in the ash and scrubber residues, while 60% is emitted to the atmosphere (ICR 2000). The ratio of mercury deposition from international and domestic sources varies considerably by location within the United States (Bullock 2004). It is estimated that North American anthropogenic emissions account for only 1.5-3% of global emissions (Bullock 2004; Seigneur et al. 2004). However, modeling studies estimate that 95-96% of mercury deposition in the eastern United States and 88-90% in the western United States comes from anthropogenic sources (Levin et al. 2000; Bullock 2004).

Comparing estimates of long-term accumulation rates of total mercury within soil of northwestern Ontario to measured flux rates within litterfall and throughfall, St. Louis et al. (2001) found they were similar, suggesting that inputs of total mercury originated from atmospheric deposition. Hanisch (1998) indicated that 40% of mercury deposition could be attributed to anthropogenic sources. Short range modeling data reported by USEPA (2001), using the ISC-3 model, indicated that from 7-45% of primary, inorganic mercury (Hg^{II}) emissions, originating from eastern U.S. sources with relatively lower stacks, are deposited within 50 km of their source. Similar western source emissions were modeled at rates from 2-38%. Regional differences were attributed to differing frequencies of precipitation events. Round et al. (1998) reported that most mercury emissions from taller stacks, including elemental mercury (Hg^0) oxidized to Hg^{II}, are deposited within 1000 km of the source. Electric utilities are recognized as the largest single source category of mercury emissions in North America (Seigneur et al. 2004), but several other source categories are known to emit large amounts of mercury (Dvonch et al. 1999).

There are distinct regional differences across the United States with respect to mercury input values per 1012 Btu for various coal types (ICR 2000; USGS 2001b). Initially, it may be assumed that the environmental impact of mercury emissions from the burning of any given coal type may be a factor of its mercury content relative to its Btu value. In addition, the ratio of various mercury species within combustion source emissions will influence the percentage of mercury initially available for methylation within natural systems (Seigneur et al. 2004). Within 14 regions, the USGS (2001b) lists Gulf Coast lignite as exhibiting the highest mercury to Btu value (20 lb Hg per 1012 Btu [9 kg Hg per 293 million kwh]) followed in order of magnitude by coal from the northern Appalachian, southern Appalachian, western interior, Fort Union, and Pennsylvania anthracite deposits. ICR (2000) data, based strictly on reported values from the utility sector, found similar regional rankings, but significantly lower mercury to Btu ratios.

While anthropogenic emissions of oxidized and elemental mercury are widespread, they are only a fraction of total global contributions (Grumet 2000). Seigneur et al. (2003) and Lindberg and Stratton (1998) identified speciation ratios of anthropogenic emissions (the relative fractions of Hg^0, Hg^{II}, and particulate mercury or Hg^P), as critical to the environmental fate of that mercury. Anthropogenic emissions vary widely in the percentage of Hg^0, Hg^{II}, and (Hg^P) forms, with Hg0 representing the vast majority of the worldwide atmospheric mercury load (USEPA 1997c; Round et al. 1998). Hg0 remains in the atmosphere for up to a year (USEPA 1997c). Conversely, Hg^{II} species, whether emitted as primary pollutants or transformed within the atmosphere from Hg^0, are much more water soluble, more easily deposited during rain events (Seigneur et al. 2003), and are principally the mercury species which undergo methylation within natural systems (USEPA 1997a). Seigneur et al. (2003) reported that up to 50% of Hg^{II} species were depleted by rainfall, whereas less than 10% of Hg^0 species were depleted. An elevated mercury deposition pattern, associated with summertime thunderstorms, became evident at ten sites across Florida in periods ranging from 2 to 5 years (Guentzel et al. 2001). This was estimated to be >50% of the mercury deposition in southern Florida. During a single summer rain event, a northern Wisconsin monitoring station received two thirds of its annual mercury load (L. Bruss, Section Chief, Wisconsin DNR–Bureau of Air Management, Personal communication, 2003).

2003). The propensity of atmospheric Hg^{II} to be depleted by rainfall, and the indication that vegetation may act as a sink for Hg^{II} species, suggests that elevated ecosystem exposure to Hg^{II} may be possible near a major mercury emitter (Lindberg and Stratton 1998). Table 1 lists mercury particle speciation profiles for a number of anthropogenic source categories.

While a number of studies have markedly increased our understanding of both total Hg and MeHg cycling within forested watersheds (Bishop et al. 1998; St. Louis et al. 2001; Hintelmann et al. 2002; Munthe and Hultberg 2004), few studies address the role of wildland fire in mercury cycling. One of the more spectacular examples of gaseous mercury transport within the plume of a large wildfire occurred during July 2002, when researchers using carbon monoxide (CO) as a tracer of a plume originating from a series of boreal wildfires in northern Quebec calculated a strong correlation between mercury levels and CO at Harvard Forest in western Massachusetts (Singler et al. 2003). Average flux rate for these boreal fires was determined to be 1.5 μg Hg per hectare, resulting in an annual Canadian wildfire emission rate of 3.5 metric tons Hg, equaling 30% of average Canadian anthropogenic emissions. Singler et al. estimated annual global boreal wildfire emissions to be 22.5 metric tons.

Table 1: Emission speciation profiles for various anthropogenic mercury source categories. Adapted from Round et al. 1998, with biomass fire data taken from Friedli et al. 2003.

	Speciation (%)[a] of Mercury Emissions		
Source Type	**Hg^0**	**Hg^{II}**	**Hg^P**
Electric utility fossil fuel boilers	50	30	20
Non-utility fossil fuel combustion	50	30	20
Municipal waste combustion	20	60	20
Medical waste incineration	20	60	20
Chlor-alkali factory	70	30	0
Other point sources[b]	80	10	10
Biomass fires[c]	>95	negligible	<5
Area sources[d]	100	0	0

[a] Hg^0 symbolizes elemental mercury; Hg^{II} symbolizes divalent, oxidized mercury; Hg^P symbolizes particulate mercury.

[b] Includes residential boilers, sewage sludge incinerators, wood-fired facilities, lime manufacturing, mercury compounds production, cement manufacturing, and secondary mercury production. However, a number of potentially important source categories (such as refineries) are not included because emissions estimates for these sources are currently lacking.

[c] From Friedli et al. 2003.

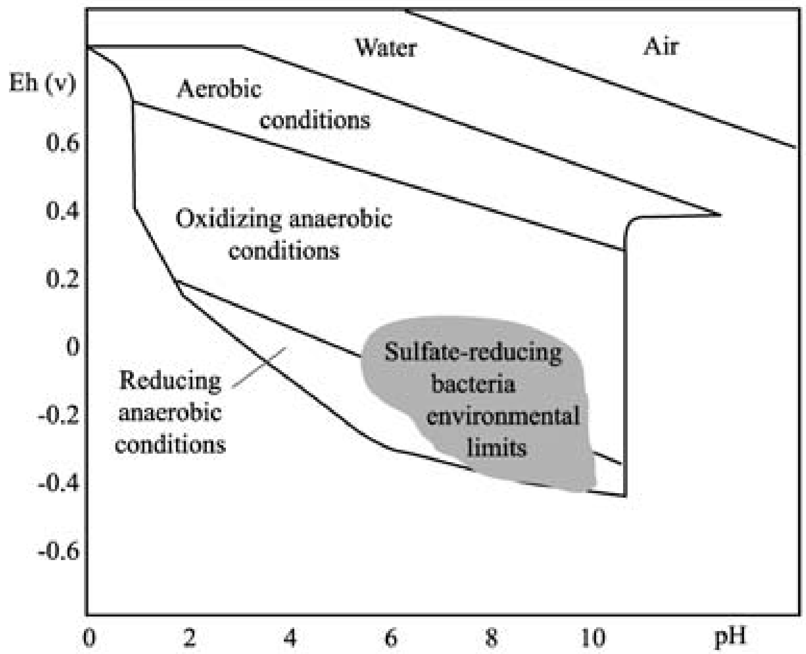
[d] Because most area sources do not involve combustion sources, emissions were assumed to be 100% Hg^0 for this source category. However, a small (but presently unknown) fraction of area source emissions may be in divalent or particulate forms.

Using fuels from across the United States, Friedli et al. (2003) demonstrated in the laboratory that nearly all mercury from biomass fires may be emitted as elemental mercury. Friedli et al. also sampled smoke from a small wildfire with a research aircraft, and determined that wildfires may emit a larger percentage of Hg^P than was determined from laboratory studies. This additional particulate mercury was likely released from fire-heated soils. Mercury concentrations ranged from 14 - 71 μg Hg/kg (dry mass) fuel for the laboratory burns and 112 μg Hg/kg for the wildfire. It is evident that forests act as sinks for atmospheric mercury, and wildland fire emissions contain mercury deposited on and incorporated in fuel, as well as that which may be released from fire-heated soil (Friedli et al. 2003). Forest Service researchers are currently researching mercury mobility and accumulation in fish responding to wildland fire in the Boundary Waters Canoe Area of northern Minnesota's Superior National Forest (Kolka 2003). There is also some evidence that mercury may be mobilized during soil disturbances from construction of logging roads or large fire breaks (Munthe and Hultberg 2004).

Environmental Dynamics

Sulfur reducing bacteria within aquatic sediments are ubiquitous, and are recognized as the primary agent of mercury methlyation within aquatic systems (Wetzel 1983; King et al. 2002; Bates et al. 2002). Benoit et al. (1999) postulate that the presence of mercury complexes such as cinnabar (HgS), the dominate neutral mercury complex in sulfidic sediment pore waters, mediates bacterial methylation of mercury by passively diffusing across bacterial membranes, and being used in sulfate reduction/ mercury methylation reactions. Other researchers point to precipitation of relatively insoluble HgS, decreasing mercury availability, and inhibiting MeHg production (Gilmour et al. 1998; King et al. 2002). Gilmour et al. also determined that those areas with sediments exhibiting high sulfur reduction rates were characterized by lower relative sulfate levels, and thus lower levels of sulfide inhibiting methylation. Wetzel (1983) reported the conditions within aquatic sediments, relative to redox potential, supporting the presence of sulfur reducing bacteria, and therefore also mercury methylation (See Figure 1). Ultimately, translocation of easily-soluble MeHg out of the sediments

Figure 1: Environmental limits of sulfur reducing bacteria in aquatic sediments. Based on Wetzel (1983).



leads to its biomagnification within higher trophic levels (USEPA 1997d).

Due to the relative abundance of anaerobic sulfur reducing bacteria in associated sediments, wetlands and those lakes characterized by large shoal areas appear to generate methylmercury at greater rates than other freshwater systems (Sutton 1998; King et al. 2002). In addition, flooding appears to initially and significantly increase the production and export of MeHg (Kelly et al. 1997; Gerrard and St. Louis 2001) and its bioaccumulation (Paterson et al. 1998). Based on this evidence and Wetzel's (1983) indication of optimal redox conditions, the avoidance of flooding and the minimization of anthropogenic water level manipulations may offer a means to minimize MeHg production, even within existing lakes and wetlands.

Several factors independent of mercury depostion are associated with MeHg concentrations in fish. Abiotic factors include an increase in dissolved organic matter (Sorensen et al. 1990; Babiarz et al. 2001) as associated with increased leaf fall and subsequent algal blooms (Balogh et al. 2002), fluctuation of lake levels (Wiener et al. 2002), and higher sulfate-laden inflow to shallow waters (Gilmour et al. 1992, 1998; Sutton 1998; Harmon et al. 2003; Jeremiason et al. 2003; MPCA 2004). In addition, proximity to geothermal vents, land disturbance events, and major sewage treatment plants (Sutton 1998) and some mining operations (Wiener et al. 2002) are also associated with higher MeHg levels in fish.

It is unclear how pH within the water column affects MeHg levels. Sorensen et al. (1990) determined pH was negatively correlated with fish MeHg levels, contrary the Sorensen et al. literature review and that of Sutton (1998). This discrepancy could be related to the inclusion of deeper lakes in the Sorensen et al. study. HgS nodule precipitation occurs readily under reducing conditions within the deeper areas of hypolimnetic waters, decreasing the amount of mercury available for methylation. However, if pH is high within these hypolimnetic waters, Hg can become soluble and so available for methylation (Sutton 1998).

On her comprehensive website, Sutton (1998) reported that ideal lake conditions leading to high levels of mercury methylation include: high sulfate levels, shallow well-mixed lake waters, deep lakes with a high pH, or lakes with large shallow areas. Hurley et al. (1995), in their study of 39 river sites within Wisconsin, found MeHg generation rates were positively correlated with the percentage of wetlands within a hydrologic unit, and were highest within watersheds containing greater percentages of wetland/forest sites relative to agricultural/forest sites or agricultural only sites. In their study of 80 lakes in remote northern Minnesota, Sorensen et al. (1990) also found the significant ($|r| > 0.90$), water related and positively correlated predictor variables: Al (aluminum), low sediment acid neutralizing capacity (ANC), percent of watershed in forest, lake surface area, and watershed area. High Al and low ANC have also been associated with lakes sensitive to acid deposition (Adams et al. 1991).

As part of the comprehensive METAALICUS study, Hintelmann et al. (2002) found that in a boreal forest, the initial mobility, and so the ultimate bio-availability of mercury received through wet and dry deposition, decreased markedly in a short time through methylation relative to the larger pool of stored mercury, suggesting that there may be rapid decline in rates of MeHg bioaccumulation in fish if mercury deposition is reduced. Hintelmann et al. further suggest that this decline could take less than 10 years, although WDNR (1999) suggests 15-20 years. Potential exists for land managers and air quality regulators to influence the abatement of mercury and sulfur deposition to aquatic systems, and so abate MeHg concentrations within these systems. However, the mercury isotope marker in the Hintelmann et al. study was bound to vegetation to a much higher degree than native mercury, suggesting there may be a time delay before atmospherically derived mercury enters the mercury soil pool, and therefore before that soil pool would respond to changes in deposition.

General knowledge of the factors that contribute to MeHg bioaccumulation would not be complete without noting that abiotic and biotic MeHg degradation pathways exist within natural systems, mitigating MeHg toxicity. In addition to the abiotic processes of MeHg photodegradation in lakes (Seller et al. 1996), these include production of HgS within soil pore water (Benoit et al. 1999), and dissolution of HgS in the presence of humic and fulvic acids (Ravichandran et al. 1998). Various aerobic and anaerobic microbial populations are known to possess enzyme degradation systems that react with mercury species. These systems impart to the host some resistance to the toxic effects of MeHg, and result in the cleaving of MeHg, forming CH4 and HgII. Some bacteria possessing a more "broad spectrum" resistance have the ability to further reduce HgII, forming volatile, elemental mercury (Marvin-Dipasquale et al. 2000). However, the evident widespread bioaccumulation and biomagnification of MeHg suggests that these degradation mechanisms do not dominate within aquatic sediments.

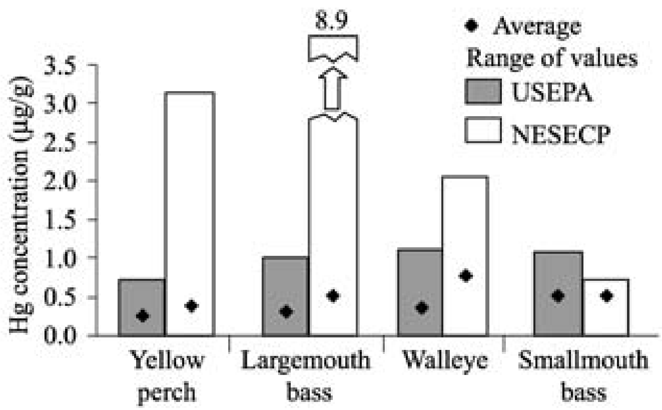
Of particular concern to the Air and Watershed Programs of the Forest Service is the correlation between the presence of sulfates and MeHg production within wetland systems. An example of note is the repeated and long-term applications of sulfur-rich agricultural fertilizers on the sugarcane fields of southern Florida, resulting in significant MeHg loadings to fish and birds downstream, within the Everglades wetland system (Bates et al. 2002). Conversely, in their study of total mercury bioaccumulation in fish, the United States Geological Survey (USGS 2001a) found a significant negative correlation of mercury bioaccumulation with sulfate in water within 20 river basins nationwide. However, nearly all collection sites were within larger streams, and it is unclear how these collection sites relate to their associated wetland systems or sulfate inputs. Preliminary results of an ongoing study within a two-hectare wetland by researchers on the Marcell Experimental Forest in northeastern Minnesota (Jeremiason et al. 2003; MPCA 2004) clearly demonstrate an increase in peat pore water MeHg concentrations following sulfate addition. While sulfate concentrations decreased following its addition, MeHg concentrations rose until pore water sulfate levels were depleted, corresponding to the findings of the USGS (2001a) that the presence of acid volatile sulfide within sediment pore water will signal the reduction of available sulfate, and thus the reduction in the production of MeHg. Most significantly for this review, further study is needed to quantify an abatement of mercury levels in fish which could stem from reductions in industrial sulfur dioxide emissions, and subsequent sulfate deposition.

Effects on Wildlife

MeHg concentrations generally increase with trophic level and with increased size and age of a given organism. Fish eventually sequestered MeHg in skeletal muscle, reducing exposure to the central nervous system (Wiener et al. 2002). Haines (1996) reported mercury concentrations in wild freshwater fish populations in 125 randomly selected lakes in Maine commonly exceeded 1 μg/g wet weight, the United States Food and Drug Administration's action level, or that level deemed unfit for human consumption (USDHHS and USEPA 2004). Half the samples from the Haines study exceeded 0.5 μg/g. USEPA's two-year, National Fish Tissue Study found concentrations exceeding 1 μg/g in only eight of 282 composite samples of predatory, freshwater game fish distributed across the United States, while the highest concentration in the 237 composite samples of bottom dwelling fish was 0.531 μg/g (USEPA 2002, 2003). However, more than 28% of the total samples exceeded 0.1 μg/g, with over 86% of predatory fish exceeding this level. Levels exceeding 1 μg/g were also common as reported in the Northeast States and Eastern Provinces' comprehensive mercury study (Tatsutani 1998), with largemouth bass (*Micropterus salmoides*) reaching 8.94 μg/g. As in all studies reviewed, predatory fish exhibited the greatest mean and maximum mercury values. Figure 2 compares data from the USEPA and Tatsutani studies.

Numerous laboratory studies have established a link between the ingestion of MeHg at sublethal levels and subtle visual, cognitive, and neurobehavioral deficits in small mammals (Wiener et al. 2002). In addition, controlled experiments with mink (*Mustela vison*) and otter (*Lutra canadensis*) have established that dietary MeHg concentrations of 1 μg/g lead to death in less than a year. In their critical review, Wiener et al. reported numerous reproductive and behavioral effects on wild avian and mammal populations associated with ingestion of realistic

Figure 2: MeHg concentrations in predatory fish: A comparison of the USEPA and NESECP studies



concentrations MeHg. For example, neurotoxic effects from sublethal exposure of eggs to MeHg can result in reduced prey capture efficiency and competitive ability of grayling (*Thymallus arcticus arcticus*) three years after exposure. MeHg content of eggs is strongly related to concentrations of the maternal fish. Tan (2003) attributes reproductive effects, based on gender, to disruption of endocrine systems by MeHg. Kamman and Burgess (2004) suggest that, in the northeastern United States, the widespread occurrence and mercury uptake characteristics of brook trout (*Salvelinus fontinalis*) and particularly yellow perch (*Perca flavescens*) may make them preferred subjects for monitoring of mercury impacts on natural systems.

While the scientific community has focused on affected salt and freshwater aquatic processes and species, wild piscivorous birds and mammals receive a greater exposure to mercury than any other receptor (USEPA 1997d). Few studies have addressed impacts on these species (Haines 1996; USEPA 1997d). Wiener et al. (2002) reported impaired reproduction in wild merlins (*Falco columbarius*), common loons (*Gavia immer*), wood storks (*Mycteria americana*), and common terns (*Sterna hirundo*) associated with ingestion of aquatic prey exhibiting elevated body burdens of MeHg. Eisler (1987) established a Lowest Observed Adverse Effect Concentration (LOAEC) of 0.1 µg/g wet weight for MeHg contaminated food fed to mallards (*Anas platyrhynchos*). Wiener et al. (2002) suggested that mercury in feathers is an indicator of mercury in other avian tissues, and Evers et al. (1998) indicated that common loons can reduce their body burden during the winter molt. Evers et al. (2003) found that common loon egg volume declined significantly as egg-Hg concentrations increased, while mercury levels in common loons were higher at eastern North American sites relative to western. In general, common loon eggs appear to be suitable indicators of MeHg availability on lakes with territorial pairs. Gerrard and St. Louis (2001) also reported adverse impacts on reproductive success of wild tree swallows (*Tachycineta bicolor*) associated with elevated aquatic MeHg levels.

Data reported for six terrestrial species rated relative rank of exposure as: Kingfisher > otter > common loon = osprey = mink ≥ bald eagle, setting reference doses for MeHg in avian and mammalian wildlife at 21 and 18 µg/ kg body weight per day, respectively (USEPA 1997d). Table 2 lists the percent of species range overlapping with regions of high mercury deposition and a generalized wildlife criterion, defined as the concentration in water that, if not exceeded, protects avian and mammalian wildlife taken from these waters. It should be noted that mercury in birds and mammals is considered to be almost exclusively in the form of MeHg.

Table 2. Impacts of methylmercury on selected bird and mammal species' ranges, with the wildlife criterion as measured in water and body tissue for each species. Data from USEPA (1997d).

Species	Percent of Range Affected	Wildlife Criterion in water (pg MeHg/L)	Kg body wt. / Kg ingested / day
Kingfisher *Ceryle alcyon*	29%	27	0.50
Mink *Mustela vison*	35%	57	0.22
Loon *Gavia immer*	40%	67	0.20
Osprey *Pandion haliaetus*	20%	67	0.20
River otter *Lutra canadensis*	38%	42	0.16
Bald eagle *Haliaeetus leucocephalus*	34%	82	0.11
Florida panther *Puma concolor coryi*	100%	NA	NA

Gnamus et al. (2000) linked mercury deposition on terrestrial plants to food intake by roe deer (*Capreolus capreolus*). A Florida panther (*Puma concolor coryi*), thought to have died of MeHg poisoning, was found to have a concentration of total mercury in its liver of 110 μg/g (Roelke 1990). Due to the numerous uncertainties involved in field experiments, more studies are needed for definitive determinations regarding effects on wild fish-eating birds and mammals.

Hopefully, the decrease in overall body burdens of mercury in Wisconsin's adult common loons from 1992-2000 (Fevold et al. 2003) represents the effectiveness of recent emission reductions associated with more stringent SO_2/acid rain regulations for coal-fired utilities.

Emission Controls

Mercury control strategies acceptable to the regulated community have been difficult to establish because of both the political issues involved and the uncertainties in the emission inventories of mercury species (Bruss 2003). However, as a result of more recent understanding of the sources and impacts of mercury deposition, USEPA, Canada, and several states have sought tighter controls on emission sources (WDNR 1999; EIA 2001). After a long and contentious review process, USEPA released its final Clean Air Mercury Rule on 15 March 2006, instituting a cap and trade program for coal and oil based power plants, over the protests of critics who sought the more stringent Maximum Achievable Control Technology standard for those sources.

As previously stated, mercury plume speciation varies greatly relative to source category (Round et al. 1998), and is an important factor in the control of mercury emissions (Laudal 2001). Coal plume mercury speciation at the inlet of particulate control devices was found to depend on the inlet temperature and the chlorine and calcium content of the coal burned (Senior 2001). For example, emissions of chlorinated HgII compounds (e.g., mercuric chloride) can be captured with particulate control devices at high efficiencies (Laudal 2001; Senior 2001), while calcium within coals can reduce the beneficial oxidizing effect of chlorine (Benson 2003). This is evident in tests performed on western coals that are low in both chlorine and calcium. However, Hg^0, representing the dominant species emitted, is not well controlled by scrubbers or other particulate control devices (UNEP 2002). Finally, Hg^P species are obviously well controlled by particulate controls.

A reading of EPRI (2004) and USEPA (1997e) suggests mercury control strategies for coal-fired sources can be divided into two general categories: (1) Fuel controls, including the burning of high ranking (high Btu) coal, burning low mercury coal, coal washing (which may reduce mercury levels by 50%), and use of alternative fuels such as natural gas; and (2) Flue gas controls, of which there are currently two leading contenders. Flue gas controls include activated carbon injection (ACI), followed by a particulate collection device, or a compact baghouse (fabric filters) added after use of an electrostatic precipitator (ESP) (EPRI 2004). A combination of these flue gas control technologies, employing ACI between the baghouse and the ESP, has been shown to be most effective under some circumstances. However, mercury removal efficiencies from the burning of lignite coal were shown to be poor (0-9%) for both ESPs and fabric filters (Sjostrom et al. 2004). As a general rule, traditional SO_2 controls also remove some Hg^{II}. The nature of mercury control strategies is too complex to be comprehensively reviewed here. For a more thorough review, inclusive of multiple source categories and technologies, see USEPA (1997e).

Conclusion and Future Research Needs

The impacts and dynamics of mercury within natural systems are still not fully understood. Recommended areas for future research that could productively contribute to this understanding include:

- Effects of soil disturbance and wildland fire on translocation of mercury relative to watershed conditions.
- Physiological and behavior effects of realistic levels of MeHg on wild populations of birds and mammals.
- Effects of sulfate deposition on in-situ mercury methylation rates under various watershed conditions.
- Relationship between acid deposition and mercury methylation rates.

For many years, comprehensive program integration has been a Forest Service goal, whether in the collection and management of data, as with recent developments within and linkages between multiple databases (e.g., the Natural Resource Information System, NRIS, and the Forest Service infrastructure inventory database, INFRA), or in the implementation of project-level management decisions. The avoidance or abatement of mercury levels in wildlife species offers an opportunity to more completely reach that goal. The following recommend actions, if implemented, could provide forest managers involved in the fields of air resources management, wildlife management, recreation, timber management, and watershed improvement, opportunities to better understand the impacts and dynamics of mercury within the natural systems they manage:

1. Monitor mercury levels in water and wildlife, as linked to implementation, effectiveness, and validation monitoring associated with various forest land management activities (e.g., management of sedimentation associated with timber harvest).

2. Rank wetlands and lakes as to their potential for elevated MeHg production rates.

3. Minimize water level manipulations of lakes and wetlands to minimize mercury methylation rates within aquatic sediments.

4. Minimize sedimentation associated with land disturbance activities.

5. Manage fish species relative to risk factors associated with proximity of mining operations, lake morphology, and landscape ecology (e.g., avoid managing for top predators in areas of high risk).

6. Comment to state and federal air regulatory officials to maximize controls on industrial mercury and sulfate emission rates near forest boundaries.

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Section 4. Valuing the Earth Sciences
Part 4. Water

Overleaf:
River on the Carson National Forest, northern New Mexico. Photo from USDA Forest Service.

Short History of Watershed Management in the Forest Service: 1897 to 2100

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Congressional direction for administration of the forest reserves, now called national forests, began in 1897 with passage of the Organic Administration Act. One of the defined purposes for which forest lands were set aside from settlement was "securing favorable conditions of water flow." Subsequent passage of over 25 other federal statutes further defined watershed management on these lands, and federal courts have interpreted these laws since 1908 in ways that sometimes expanded, sometimes contracted, delegated authorities. The Research Branch began watershed experiments in 1910 at Wagon Wheel Gap, Colorado, and has since expanded to 24 research watersheds. The contributions of certain individuals, the 1930s Civilian Conservation Corps, the barometer watershed program in the 1960s, and the State and Private Forestry suite of watershed technical assistance are discussed. Finally, possible future watershed management scenarios in the Forest Service in the years 2050 and 2100 are briefly discussed.

Keywords: *watershed management, barometer watersheds, research watersheds, history*

Beginnings: 1897-1911

When the first forest reserve (Yellowstone) was proclaimed in 1891, President Harrison was trying to stop exploitation and destruction of the forests adjacent to Yellowstone National Park – nothing more. No direction was provided to the General Land Office personnel responsible for administering this piece of the public domain, nor was much money appropriated for it. Other forest reserves established from 1892 to 1897 suffered from the same lack of consistent direction. Foresters in the federal Bureau of Forestry were fearful of the consequences and supported efforts in the Congress, led by Senators A. S. Paddock and R. Pettigrew and Congressman T. R. McRae, to obtain passage of a bill that would put the federal forest lands on a course of purposeful and professional management (Steen 1976). The answer was what is known today as the Forest Service Organic Administration Act of 1897.

Gifford Pinchot, then an employee of the Bureau of Forestry, was the first professional forester in the United States. He had studied in France and had read George Perkins Marsh's 1864 landmark monograph *Man and Nature: Or, Physical Geography as Modified by Human Action*. He was also greatly influenced by Marsh's conclusions that many civilizations had vanished as a result of abusing their watersheds to the point where severe erosion and polluted water supplies deprived them of necessary resources for their survival. Pinchot hired other college educated professionals able to put American forest conservation on a solid footing, and who were capable of persuading local settlers to accept wise use of forest resources and the need to obtain special use permits prior to removing timber, grazing livestock, building dams, and conducting other activities on the national forest reserves.

In 1898 the Department of the Interior's General Land Office (GLO) made its first timber sale on a forest reserve. The Homestake Mining Company purchased 15 million board feet (35396 m^3) of timber on the Black Hills reserve (South Dakota) at one dollar per thousand board feet (Fedkiw 1998). By 1901, the GLO and the USDA Division of Forestry were sharing the management of the forest reserves, with the GLO patrolling them for trespassers and the foresters providing technical advice. In 1902, Interior issued its Forest Reserve Manual. When the reserves were transferred to the Department of Agriculture in 1905, the Forest Service quickly issued its own Use Book which had stated objectives of the forest reserves as … "preserving a perpetual supply of timber for home industries, preventing the destruction of forest cover which regulates the flow of streams, and protecting local residents from unfair competition in the use of forest and range." (USDA Forest Service 1905)

Raphael Zon was one of Pinchot's hired professionals. Born in Russia and an immigrant into the United States in the 1890s, Zon was a key figure in establishing and continuing the watershed experiments on the Rio Grande National Forest at Wagon Wheel Gap, Colorado, from 1910 to 1926 (Schmaltz 1983). The experiment in clearcutting one small watershed while leaving an adjacent, similar watershed uncut, to test whether stream flows

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were changed by the logging after seven years of baseline monitoring of both drainages was the first time in the world that such a scientific experiment was undertaken. The controversy derived from questions on the relationship between forests and rainfall, and the best way to control floods: reforestation of denuded watersheds, or building dams and levees? Pinchot and most foresters advocated reforestation, while Hiram Chittenden of the Army Corps of Engineers (CoE) strongly advocated a structural approach to flood control. To win this argument, in July of 1910 the Forest Service appointed C.R. Tillotson, while the Weather Bureau, then part of USDA, appointed B.F. Kadel to initiate the Wagon Wheel Gap experiments. After 16 years of careful measurements were completed, it took the personal involvement of Zon to work with Carlos Bates, in charge of the Wagon Wheel Gap work at the time, and his counterpart, A.J. Henry of the Weather Bureau, to produce the final report in 1928 on the results of the experiment, after disagreements arose between the two men as to the significance of the results (Bates and Henry 1928).

In 1908, President Theodore Roosevelt's Inland Waterways Commission reported on its survey of U.S. waterways for commercial navigation and other water resource uses and problems. Pinchot was a member of this commission. Modeled after the successful 1905 Forest Conference, Pinchot hoped this commission would lead to the establishment of a national, federal policy for managing water resources in the United States. Indeed, the commission recommended that both local and national benefits of a water policy be considered as well as costs; that plans for improving waterways should consider all of the uses of water including flood control, water power, irrigation and pollution control; and that a national waterways commission be created to coordinate the work of the Corps of Engineers, the Reclamation Service, USDA's Forest Service and Bureau of Soils, the Bureau of Corporations, and other concerned federal agencies in making multiple-purpose plans for waterways in cooperation with state and local governments. (USDA Economic Research Service 1972). However, the commission's report failed to spur creation of a national water policy largely because it would have usurped 50 years of western states' water laws, customs, and policies, and these states would have none of that! One other result of this commission and the National Conservation Commission of 1909 was increased discussions within the Congress that resulted in passage of the Weeks Act in 1911. This Act provided authority to the Forest Service to purchase lands in the eastern United States, in watersheds whose water supplies were needed to preserve river navigability. The Act also created the National Forest Reserve Commission and provided that the Secretary of Agriculture, in cooperation with Interior's U.S. Geological Survey, could recommend for purchase such lands in the watersheds of navigable streams needed to regulate water flow. This Act is responsible for the eventual acquisition of 25.3 million acres (10.2 million ha) in the East as national forests (USDA Forest Service 2003).

Custodial Era: 1911-1945

Between 1911 and 1945, the Forest Service was largely focused on the acquisition and reforestation of abandoned and abused watershed lands in the East and Midwest; establishment and expansion of the Research Branch in 1915; passage of a few new laws such as the Clarke-McNary Act of 1924; and the work of the Civilian Conservation Corps (CCC). Many Forest Service employees, including Chief Henry Graves, enlisted in the Army Expeditionary Force during World War I, where they served in Europe setting up sawmills and acquiring timber needed for trench walls, railroad ties and other purposes.

The National Waterways Commission was authorized in 1917 to coordinate the work of all federal agencies with water resource responsibilities on preparation of nationwide multiple purpose plans, either by the federal government alone, or in cooperation with states and localities. The commission members were never appointed due to World War I, and in 1920 the Federal Power Act expressly repealed the 1917 law that created the commission. A Forest Service engineer, O.C. Merrill, helped Congressional staffers write the Federal Water Act in a manner that served the public interest, rather than the many land speculators then buying many of the best hydropower sites on private lands.

The Research Branch did almost all of the watershed work for the Forest Service until the CCC was established in 1933. Even while Wagon Wheel Gap was still operating, other watershed and soil erosion research was begun in Utah, Arizona and California. Harold Croft, Charles Hursh, and others whose names are now lost, were some of the first soil or water scientists hired by the agency in the 1910s and 1920s. In 1917, Research produced one of the first soils reports, and in 1928, a well written report on the role of forests in watershed management was issued (Shepard 1928).

Edward Munns served in the Chief's Office from 1923 to 1951, as the modern equivalent of the director of watershed research, where he played a key role in maintaining the agency's focus on scientific research of many soil and water issues. He helped establish the experimental forests, watersheds and laboratories at Coweeta (NC), Fernow

(WV), H.J. Andrews (OR), Fraser (CO), South Umpqua (OR), San Dimas (CA), Teakettle (CA), Manitou (CO), Sierra Ancha (AZ), Calhoun (SC), Delta (MS), Koen (AR), Santee (SC) and Tallahatchie (MS), which have cumulatively contributed much knowledge about how mountain watersheds behave. He also recruited many of the research hydrologists and soil scientists who worked at these experimental areas, and insured their growth and survival when times got tough during the Great Depression and World War II. Munns was also successful in getting the CCC enrollees to help build the research laboratory infrastructure at many of these locations between 1933 and 1942, including access roads, measuring weirs, lab buildings, and telephone lines (Otis et al. 1986).

Chief Forester Pinchot created a separate State and Private Forestry Branch in 1908 to render assistance to private forest landowners, in cooperation with USDA's Bureau of Entomology for pest control work and with the Bureau of Plant Industry on forest tree diseases, among other tasks (Williams 2000). The 1911 Weeks Act expanded the scope of this work to include firefighting on all land ownerships. The Clarke-McNary Act of 1924 expanded the Weeks Act to improve conditions on private forest land, and modified taxation policy to favor retention of forests.

In 1939 the Chief established a Division of Watershed Management within the National Forest System (NFS) Branch with Gordon Salmond as Director. Mr. Salmond served in that position until he retired in 1961. None of the 13 subsequent directors of this staff have served as long as he.

In 1949, Congress passed the Federal Classification and Pay Act which authorized the Civil Service Commission to create the job classification system in use today in most federal agencies. Prior to this Act, it was very difficult to assess how qualified applicants were for many technical job series, such as hydrologists, geologists or soil scientists, and to keep track of how many people in each job series were employed by federal agencies.

Development Era: 1945-1969

Demand for timber to build homes and other needs for returning GIs skyrocketed after World War II. Clear-cutting became normal practice on many national forests, and access roads were built to move the logs to the mills. Forest Service watershed research was maintained, but not expanded, until the 1960s. The most significant watershed developments during these 25 years included establishment of the barometer watershed program starting in 1962, and greatly accelerated hiring of soil, water and geology specialists in many Forest Service Regions and Research Stations, as a result of the McIntire-Stennis Act in 1962 which greatly expanded university-based forestry research at land-grant institutions (Glazebrook 1969; Steen 1998).

Barometer watersheds were intended to apply results from small experimental watersheds to larger basins, where typically a fuller set of multiple uses of land and resources were in place, so that effects on water quantity and quality could be determined. Some 24 barometers, ranging in area from 24,000 to 189,000 acres (9,700 to 76,500 ha) and representing 24 hydrographic provinces in 18 states were selected, instrumented, and staffed by 1970. A few fulfilled their original intent, but most never did for a variety of reasons that are more fully covered in a paper by Larry Schmidt and Byron Beattie in this publication.

The barometers were successful in helping justify the need for more agency hydrologists and hydrologic technicians. Probably close to 50 of these professionals worked at some point in their career on a barometer watershed. I was one of them, and my experience on the Lake Creek barometer in Colorado in 1969 was a very valuable training opportunity.

The Forest Service also hired more soil scientists in the 1960s to do soil surveys in cooperation with the then-Soil Conservation Service, now Natural Resources Conservation Service (NRCS). The national Soil Survey program was initiated in 1961 under John Retzer's leadership in the Washington Office. Many Soil Conservation Service soil scientists transferred to the Forest Service in the 1960's, bringing their expertise with them.

The 1954 Small Watershed Program (P.L. 83-566) expanded Forest Service authority to include flood prevention on farmland watersheds less than 250,000 acres (101,000 ha) in size by means of structures, upstream protection measures, and livestock controls. The Forest Service has worked with USDA's NRCS and Agricultural Research Service, the Army Corps of Engineers, the states, and local entities to implement these projects on NFS lands. Funding for maintaining these structures has diminished over time and there is a growing need to repair, replace or de-commission some of these structures as they approach the end of their design life.

The 1960s also brought the seeds of the environmental movement, with passage of the Multiple-Use Sustained-Yield Act of 1960, the Wilderness Act of 1964, the Jobs Corps Act of 1964, the Wild and Scenic Rivers Act of 1968, and the grand-daddy of them all – the National Environmental Policy Act (NEPA). These statutes, plus U.S. Supreme Court decisions involving reserved water rights from 1908 through 1963, portended that watershed management of the national forests and grasslands was about to change in the 1970s.

Environmental Era: 1970-1990

The year 1970 saw the passage of NEPA, the Youth Conservation Corps Act, and creation of the U.S. Environmental Protection Agency (USEPA), all of which helped change watershed management in the Forest Service. NEPA certainly created many more specialist jobs in the Forest Service at all levels within the NFS Branch, and improved the quality of land use decisions in ways that have lessened adverse impacts on the environment. The Youth Conservation Corps program provided new opportunities to educate young people about the environment and for them to learn job and life skills that have served them well (Figure 1). Some valuable soil and water improvement work has been accomplished by this program.

The USEPA has certainly changed water and air quality management in the Forest Service through their many rules, regulations, requirements, and interactions. We in the Forest Service often underestimate the amount of change that USEPA has brought about in this nation, including how NFS lands and natural resources are actually managed. Both the Clean Water Act of 1972, as amended, and the Clean Air Act of 1977, as amended, have resulted in the hiring of more Forest Service hydrologists and air quality specialists to work on evaluating likely effects of proposed resource extraction activities upon water and air quality and identifying mitigating measures for those activities. For example, the number of hydrologists went from 76 in 1970 to 203 in 1980, and 225 in 1989, while the number of air quality specialists increased from none in 1970, to 10 in 1980, to 22 in 1989 (USDA Forest Service 1970, 1980, 1989). Improvements in both water and air quality have resulted from these specialists' efforts in local areas.

The Bitterroot National Forest clear-cutting and terracing controversy, together with the District and Appeals Courts' decisions in the Monongahela National Forest case, led to Congressional hearings, passage of the National Forest Management Act (NFMA), and greatly restricted the size of clear-cuts on NFS watersheds in the mid 1970s. They also caused a large expansion in water quality monitoring of logging and road construction activities by hydrologists. In the Northern Region, several forest hydrologists developed "Hydrologic Cutting Guides" as a tool to assess water yield changes; they were fairly effective and other regions adopted modified guides as well. A major report, An approach to water resources evaluation of non-point silvicultural sources (A procedural handbook), also known as WRENSS (USEPA 1980), was issued as a tool for controlling non-point sources of water pollution from silvicultural activities. It had limited utility, because the data input needs were too large and complex, the handbook itself was 861 pages long, and the computer had not yet matured as a usable tool at the forest level.

The first inter-disciplinary teams were formed in early 1971 as a mechanism for implementing NEPA at the project level scale; almost all of them included soil, water, and geology expertise, as well as forestry/silviculture, fire, engineering and landscape architecture skills. I was part of the first team formed in Region 2, the Rocky Mountain Region. The previous multiple use surveys gave way to unit planning by these teams. There was a large degree of freedom to develop data collection and analysis methods,

Figure 1. The Youth Conservation Corps doing stream stabilization work on a national forest in the 1980s. Photo from the Forest Service achives.

write reports, and participate as an equal or almost equal member of the team as long as the team leader and other members were willing to operate in that manner. By 1973, a few national forest teams were starting to develop forest-wide land use plans, some of which went beyond the forest boundaries and eventually led to at least one forest supervisor losing his job. These early teams broke the ground for later planning teams that were helping implement long-range planning requirements of the Resources Planning Act and NFMA. They also certainly showed many line officers the value of hiring soils, water, geological and air specialists.

The year 1978 saw passage of the Cooperative Forestry Assistance Act and issuance of the Mimbres water rights decision by the U.S. Supreme Court. This Act expanded the suite of technical and cost-sharing assistance programs that the Forest Service could deliver for private forest landowners and state foresters, including new soil and water stewardship programs. In addition, Title IV of the Agricultural Credit Act of 1978 authorized the Secretary of Agriculture to undertake emergency measures for runoff retardation and soil erosion prevention to safeguard lives and property from floods, drought, erosion after fire, or other natural occurrences that caused watershed impairment. The Mimbres decision restricted the scope of federal reserved water rights under the 1897 Organic Act to the minimum needed to secure favorable conditions of water flow, or for sustained timber supplies. In dicta, the Supreme Court dismissed reserved rights claims for recreation, grazing, and fisheries under the Multiple-Use Sustained-Yield Act of 1960.

To encourage technology transfer, agency hydrologists published an important summary of forest watershed management knowledge (Anderson et al. 1976) and convened national meetings at Grand Targhee in 1974, and Atlanta in 1978. These were the first meetings of mostly field based hydrologists, and contrasted markedly with the 1955 soil and water meeting in Denver which consisted entirely of 85 Washington Office and Regional Office based personnel. Some 83 hydrologists and hydrological technicians attended the Targhee meeting (82 men and 1 woman), while 130 attended the Atlanta meeting (119 men and 11 women). Both meetings were very successful in accomplishing their networking and technology transfer objectives. They helped set the stage for the following era and the 1992 FS National Hydrology Workshop in Phoenix.

Planning and Ecosystem Management: 1980-Present

Development of the initial round of Forest and Resource Plans based on the 1979 planning regulations that followed passage of NFMA engaged almost every physical scientist or practitioner during this period. As a result, very few new watershed initiatives were undertaken and some of those started in the 1960s, like the barometer watershed program and many water quality monitoring efforts, were terminated. There has also been a slow but steady decline in inflation-adjusted Forest Service watershed administration and research funds in this period.

Several important watershed events did occur. The Forest Service and USEPA cooperated in a massive water quality sampling effort in 1985 as part of the National Acid Precipitation Assessment Program. Over 2,000 remote lakes, often in wilderness areas, were sampled during their fall overturn period, under often difficult weather and logistical conditions, for their vulnerability to acidification from deposition of atmospheric pollutants. Limited, concurrent sampling by USEPA personnel in helicopters that landed on the lakes within minutes of the Forest Service ground-based crews that rafted out to the deepest part of the lakes proved that the Forest Service crews did a superb job of their sample collection, preservation, and transfer of samples to mobile labs set up at nearby airports within four hours of sample collection. This effort greatly increased the trust that USEPA had in Forest Service personnel.

Also in 1985, Data General mainframe computers were installed at almost all agency offices. This network allowed better communication among employees and sharing of ideas, methods, draft papers and data. They also allowed batch processing of large data sets using FORTRAN. Both were significant improvements over earlier dumb Typagraph terminals and tiny CPU processors.

The number of watershed councils and other ad hoc committees devoted to improving some aspect of watershed management has blossomed during this period. They are trying to accomplish what earlier federal river basin planning commissions and groups never could: application of real solutions to local problems of water quantity, quality, or both.

The year 1992 saw the New Perspectives and PACFISH initiatives, and the Appeals Reform Act. President Clinton's Northwest Forest Conference in 1993 and the Ecosystem Management Conference in 1994 also changed how watershed management is practiced by the agency by greatly expanding the number of stakeholders and the planning processes used to make a decision. In 1997, Chief Mike Dombeck introduced the "Collaborative Stewardship" term to describe his vision of working together with many partners to accomplish the "Taking care of the land and serving people" mission statement of the agency. Watershed management is embedded within the collaborative stewardship terminology. The late 1990s also saw an interagency, inter-disciplinary team effort led by this author to develop agency policy, and technical and legal guidance for managing the ground water resources of the national forests and grasslands. This effort is expected to be completed in 2005.

The large wildfires of 2000 and 2002 led to creation of the National Fire Plan and passage in 2003 of the Healthy Forests Restoration Act (HFRA) by Congress. This Act could result in a shift of soil, water, geology and air resources expertise toward work on planning and execution of projects designed to reduce woody fuel accumulations in the wildland-urban interface zone. The Act also provides for small increases in watershed expertise in state forestry organizations.

Future Prognosis: Present to 2100

This section is based upon an evaluation of current demographic, societal and natural resource trends projected into the future. Since the future is really unknowable, these projections represent a mix of subjective and some objective views of the author and others. Only time will tell if any of these projections or views were correct; they are intended to stimulate discussion now.

The population of the United States in the 2000 Census was 283 million. The Population Reference Bureau projects that number to be 422 million in the year 2050 (Haub 2003). I estimate it could be 650-700 million in the year 2100. Not only will the absolute numbers be higher, but the average population is projected to grow steadily older, richer, healthier, and more ethnically diverse and urbanized (Cetron and Davies 2003). All of these factors, plus future legislation and court rulings, will affect the commodities and amenities Americans expect from their national forests and grasslands.

By the year 2040, the 1990 RPA Water Situation report (Guldin 1989) predicts water supply shortages in many parts of the southwestern U.S., depletion of groundwater in California, Nevada, Utah, and growing shortages in eastern and midwestern states. Projected changes in freshwater withdrawals for public and domestic uses from 2000 to 2050 could rise 85 percent, industrial and commercial uses could increase 71 percent, and irrigation could decline by nine percent in the west coast states of California, Oregon, Washington, and Idaho (Houston et al. 2003) The amount of cropland being irrigated in the East and South is growing rapidly (Hutson et al. 2004) and is likely to cause more rivers to become partially or totally dewatered in the future unless state water rights laws are changed to prevent it. Based on the rate of change in western states water rights laws, the chances of the eastern states upgrading their laws appear “iffy” at best in my opinion.

By 2050, water quality effects from non-point sources of pollution typically found on NFS lands are expected to approximate today’s conditions. It is very difficult to make large improvements in what are often small amounts of pollutants resulting from current land uses in forested watersheds, compared to the large amounts of eroded sediment from colonial farming practices that still clogs many eastern waterways. Drinking water will become more costly to consumers and the amounts of reclaimed wastewater will also have to increase to partially solve local shortages of water for non-potable uses. Today’s challenges arise from hardrock mining, oil and gas and coal-bed methane extraction, suburbanization of forested areas, and atmospheric deposition of acidic precipitation and other pollutants. Effective solutions have been difficult to implement for these types of land uses or sources; nevertheless, these parts of what has been dubbed the “Restoration Economy” (Cunningham 2003) will continue to grow rapidly. Forest Service soil scientists, geologists, hydrologists, and air resource specialists employed in 2050 will need to devote increasing shares of their time and attention to tackling these problems over future decades, and there will be fewer of these experts than at present.

By 2100, it is quite possible that the national forests and grasslands will be used primarily for recreation, other amenity values, and for water production. The amounts of timber harvesting, livestock grazing, and oil, gas, and mineral production could decrease greatly. The number of special use authorizations is expected to increase from today’s 75,000. Unfortunately, as these numbers grow, the general public’s access to their public lands continues to diminish since each of these authorizations essentially becomes a separate in-holding and more expensive and troublesome for the agency to administer. Water shortages will continue in the same basins as in 2050. A better water rights marketplace will develop by 2100 that will allow more transfers of agricultural water rights to ever-growing communities at lower unit transaction costs than in 2000.

Satellites will monitor air, soil, geological and water resources continuously by 2100. They will feed this data into large data warehouses where the few remaining agency specialists will use it to develop contracts for private sector firms of resource specialists to bid on to do the actual watershed analysis work for NFS lands. Since federal pay in 2100 could be much lower than the private sector for similar work, I think there will be fewer physical science practitioners in the Forest Service in 2100 than there were in 2000. It is also possible that there will be fewer NFS acres in 2100 than there were in 2000, as land ownership consolidation continues unabated and Water and Conservation Fund monies dry up. There has been, and will continue to be, pressure from individuals, corporations, and perhaps states and the Congress to dispose of federal forest lands for various other needs or wants just as in the 1800s and in the 1930s, when federal forest land acreage actually declined. I certainly hope that I am wrong about this.

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The Marginal Economic Value of Streamflow From National Forests: Evidence From Western Water Markets

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Evidence from over 2,000 water market transactions that occurred in the western U.S. over the past 14 years (1990 through 2003) was examined to learn who is selling to whom and for what purpose, how much water is involved, and how much it is selling for. Roughly half of the transactions were sales of water rights; the rest were water leases. The transactions show that the price of water is highly variable both within and between western states, reflecting the localized nature of the factors that affect water prices. Ideally, if water market prices or valuation studies are to be used to help determine the marginal value of water from specific areas such as national forests, information from local markets or local studies should be used. Lacking site-specific value information, only rough estimates are possible.

Keywords: *water value, streamflow, economic value, water markets*

Introduction

The economic value of a good or service is indicated by a willingness to sacrifice other goods and services in order to obtain or retain it, and is typically measured in money terms, usually as willingness to pay (WTP). WTP may be determined for changes in the quantity, quality, or timing of water. This paper deals with the value associated with water quantity, specifically the quantity of streamflow.

The value of a small change is what economists call marginal value. Estimates of marginal value are useful in analyzing policies that cause relatively small changes, such as changes in streamflow resulting from vegetation management. Of course, even small changes in streamflow may have numerous additive downstream effects. For example, an acre-foot of streamflow increase may first be used by recreationists, next pass through a hydroelectric plant, then be diverted to a farm, and finally be diverted to a city, all the while helping to dilute wastes and enhance fish habitat. The aggregate value of a change in streamflow is equal to the sum of its values in the different instream and offstream uses to which the water is put during its journey to the sea (e.g., Brown et al. 1990). For the general case, the aggregate value of a small change in streamflow (V^*) is given by:

$$V^* = \sum_i \alpha_i \beta_i V_i$$

where i indicates a water diversion or instream use location; α_i is the proportion of the marginal acre-foot that reaches a use i (water that is not consumed upstream) ($\alpha \leq 1$); β_i is the proportion of the marginal acre-foot reaching use i that arrives when it actually can be of use ($\beta \leq 1$); and V_i is the value of the marginal acre-foot in use i assuming the water is put to use ($V \geq 0$).

The task of estimating the marginal value of streamflow from a national forest thus consists of estimating the V_s and their respective αs and βs. Our focus here is on V_i.

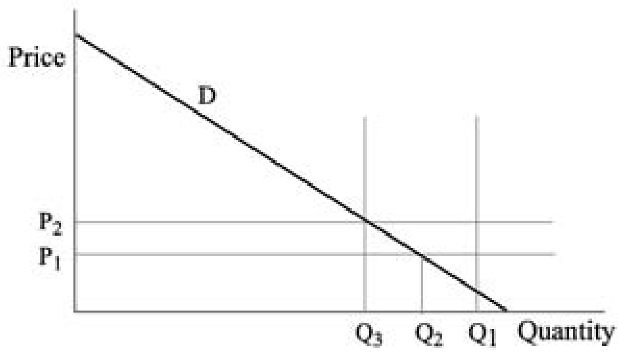
There are two basic approaches to estimating the marginal value of water: employing economic valuation methods and observing water market prices. The suite of valuation methods (Gibbons 1986; Young 1996) was developed because markets for goods like water were uncommon and, when present, rarely competitive. However, water market activity has increased in recent years, raising hopes that water markets can offer useful estimates of water value. This paper presents evidence from water market transactions in the western United States.

To review how price is related to marginal value, consider the case of offstream uses depicted in Figure 1. If demand (i.e., marginal WTP) for water at a point of use is represented by D, Q_1 is the total quantity of streamflow available, and P_1 is the cost of transporting (e.g., pumping) the diverted water to the point of use, then users desire to divert Q_2 units. Here the net marginal value of the diverted streamflow (V) is P_1-P_1 = 0 per unit. Alternatively, if water supply were constrained at Q_3, Q_3 units would be diverted. At a diversion of Q_3 units, the marginal value of delivered water is P_2, and $V = P_2 - P_1$. If a competitive market for streamflow existed in this location, the market price would be P_1, and if a competitive market for delivered water existed its market price would be P_2.

Furniss, M.J., Clifton, C.F., Ronnenberg, K.L., eds., 2007. *Advancing the fundamental sciences: proceedings of the forest service national earth sciences conference, San Diego, CA, 18-22 October 2004*. PNW-GTR-689. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

This example thus illustrates two points: (1) streamflow has value at the margin only when there is not enough of it to meet all demands; and (2) if the price includes consideration for storage or delivery, it may overstate the marginal value of streamflow.

Figure 1. Marginal value of offstream diversion.



Water Markets

Water has become scarcer as population, economic growth, and changing values in the West have increased demand for water (Gillilan and Brown 1997). Where institutions allowed it and transaction costs were not excessive, the growing scarcity often brought willing buyers and sellers together in what is called a water market. The term "water market" lacks a precise definition, but once a few voluntary trades of water of relatively common physical and legal characteristics occur, it is said that a water market has developed.

Water markets require a well-administered system of transferable water rights. The doctrine of prior appropriation that underlies water law across the West allows for clearly defined and transferable water rights, and state agencies or the courts administer and enforce those rights, although the states differ in how they implement the doctrine and administer the water rights systems (National Research Council 1992).

Water market activity may be limited by physical and legal constraints. Physical constraints on water trades, such as uneven water availability and lack of access, are eased by such structures as diversion dams, canals, and storage reservoirs, which extend spatial and temporal control over water delivery. Legal constraints on water sales often exist, perhaps due to state law (e.g., constraints on moving water to another basin, or constraints on the availability of instream flow rights) or federal guidelines for specific water development projects. As scarcity has intensified, some constraints on water markets are being loosened (North 1990; Loomis 1992).

If water in a water short area were freely traded in an efficient market, water would be reallocated via trades to the point where each user was consuming at the point where the marginal values in all uses were identical (e.g., the marginal value in irrigation would be equal to the marginal value in municipal use or in instream recreation). In this ideal world, a single market price would emerge that would indicate the marginal value of raw water in that market area. However, in the real world, even in those locations where water markets exist, water rarely trades so easily or completely. Two reasons for this are lack of a homogeneous product and lack of market competitiveness.

Lack of homogeneity is a natural consequence of how the prior appropriation doctrine accommodates the stochastic nature of streamflow. The doctrine deals with shortage by assigning priorities to water rights and temporarily canceling permission to divert based on those priorities, beginning with the most junior right and moving as far up the list of priorities as needed to assure delivery to more senior rights. Each individual right may have a unique priority date. Senior rights are worth more than junior rights because senior rights face less risk of shortage. If each right is unique, homogeneity of product is compromised. However, within the overall structure of prior appropriation there exists a quite different approach know as fractional flow rights (Eheart and Lyon 1983). With such rights, all users have equal priority, and shortage is accommodated in a given time period by lowering the allowable diversion for all users. The use of fractional flow rights is common in mutual ditch companies and some water conservancy districts, wherein water is owned as shares of the total amount available (Hartman and Seastone 1970). Within such an organization all members essentially have the same priority, and the effect of a flow increase available to the organization is distributed to the members in proportion to the number of shares each owns, thus providing homogeneity of product. Many of the more active water markets deal in shares of such a company or district.

A fundamental tenet of neoclassical economic theory is that competitive markets yield prices that reflect the true marginal economic value of the good being traded. Competitive markets have many buyers and sellers, do not artificially restrict price or ability to trade, have low transaction costs, allow an easy flow of information about prices and potential trades, and internalize all relevant costs and benefits of the transaction. Water markets typically fall short on one or more of these requirements. Many markets areas are so small that sellers and buyers are few. In others, laws, regulations, or customs limit price. In many water markets transaction costs are substantial, involving administrative and legal requirements. In many markets information is not readily available. And externalities (effects on individuals not party to the exchange) commonly exist, especially in the form of changes in water quality and instream flow (Howe et al. 1986; Saliba 1987). Some of these restrictions on the competitiveness of the market (e.g., a limited number of sellers) may elevate the price relative to the price that would be established in a purely competitive market, whereas others tend to depress the price (e.g., government subsidies, transaction costs, regulations or customs). Many of the restrictions, such as transaction costs, will also tend to limit the number of trades.

Studies of water markets have usually focused in detail on one or a few specific markets (e.g., Hartman and Seastone 1970; Saliba et al. 1987; Michelsen 1994; Howe and Goemans 2003). Only with a detailed examination can the numerous characteristics of the individual markets be given their due consideration. This study, in contrast, takes a broad look across the western United States, emphasizing geographical scope rather than in-depth focus (see also Brown 2006). This "big picture" approach offers a look at how water prices in general have changed over the past few years and how they differ across locations or across the purposes for which the water was purchased.

When water is sold in the West, either a water right changes hands or use of the right is essentially leased for a period of time. Ownership of a water right conveys access to a specified quantity of water in perpetuity, subject to particulars such as priority, timing, and location. With a water "lease" as used herein, the holder of the right agrees to deliver, or allow the buyer access to, a certain quantity of water over a stated time period, subject to conditions such as timing of access and location. One-time transfers of water (essentially short-term leases) are sometimes called "spot market" trades or "rental" transactions. This paper reports on both sales and leases of water rights.

Methods

The broad-scale examination of water prices reported here is made possible by the Water Strategist and its predecessor the Water Intelligence Monthly, published by Stratecon, Inc., of Claremont, California, which have summarized many of the available western water market transactions in reports released on a monthly or quarterly basis. Fourteen years of transactions reported by these publications (1990-2003) were tabulated to provide the estimates of the price of water described here. It is important to note that these publications did not report on all the transactions that occurred. Especially in the case of water leases, large numbers of trades were not summarized. Neither are the included transactions a random sample. Thus, the current report indicates the nature, but not the breadth or precise character of western water trades.

Each water transaction entry in the Water Strategist or Water Intelligence Monthly briefly summarizes one or more actual trades. The entries do not allow a full understanding of what influenced the price, and are not always consistent in how the transactions are described (perhaps because some information was not available). Nevertheless, most of the entries provide sufficient information for a rudimentary analysis of the factors influencing water market prices, and together they form the most comprehensive set of information available about water market trades in the western United States.

The entries typically include buyer, seller, purpose for which the water was purchased, type of transaction (whether purchase or lease of a water right), and the source of the water (surface water, ground water, effluent, or potable water). Buyers and sellers are categorized herein as one of the following: (1) municipality; (2) irrigator (farmer or rancher); (3) private environmental protection entity (e.g., public trust concern, or private entity such as the Nature Conservancy); (4) private entity providing water to many users, such as a water "district," "association," or "company," referred to here as a "water district"; (5) public agency (federal or state government agency, conservancy district, or other water "authority"); (6) other entity (e.g., power company, mining company, developer, investor, country club, feedlot, individual homeowner); or (7) several entities (when several buyers or sellers of different types were listed, such that the transaction could not be neatly assigned to one of the other categories.

The purpose of the transaction was characterized as one of the following: (1) municipal or domestic (including commercial and industrial if serviced by a municipality, and golf courses and other landscape irrigation); (2) agricultural irrigation; (3) environmental (e.g., instream flow augmentation); (4) other (e.g., thermoelectric cooling, recreation, mining, aquifer recharge, augmentation of flows leaving the state per court order, supply to individual businesses such as feedlot or manufacturing plant, an investment of undefined characteristics, unspecified); or (5) several (several purposes, such that the transaction could not be neatly assigned to one of the other categories).

Some entries covered several related transactions. For example, several sellers or several buyers, or both, may have been included in the entry. Or several transactions within the same market may have been listed together in the same entry. Such entries were broken down into separate cases for analysis if distinct prices were listed and different categories

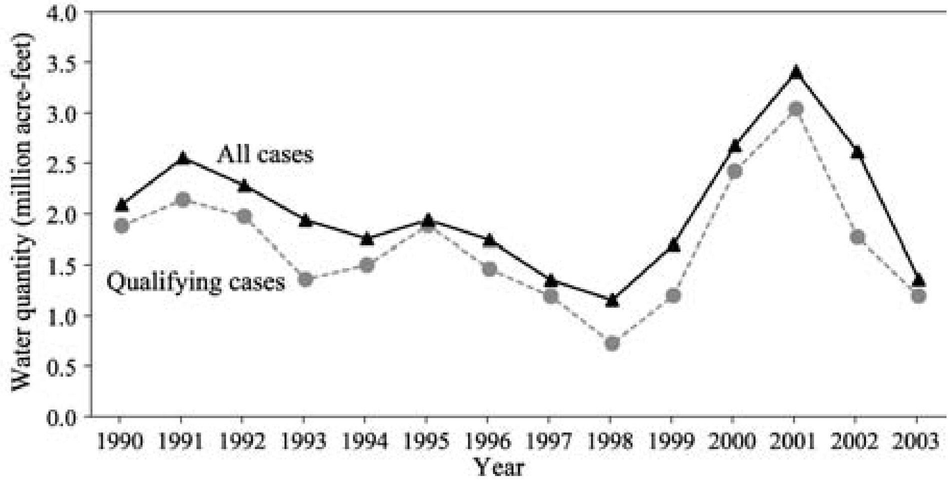


Figure 2. Trends in total number of acre-feet transferred .

of buyers, sellers, or purposes were involved. After this disaggregation process, a total of 2,447 transactions were available for the 1990-2003 period.

The Colorado Big Thompson (CBT) market is the most active market for water rights in the West, with up to 30 or more purchases per quarter by municipalities alone. It is also a market about which market information is readily available. The entries listed 949 CBT trades over the 14 years. Because the sale price for CBT shares differed little among trades completed during a given month, and because the volumes traded were typically small (averaging 40 acre-feet), all CBT transactions of a single purpose within a given month were tabulated as one case for analysis in order to avoid having CBT transactions overwhelm the summary statistics. This aggregation process left a total of 228 CBT cases for the 14-year period, and thus a total of 1,726 cases (2,447 - 721 CBT transactions consolidated) for analysis.

Of these 1,726 cases, 349 were omitted from further analysis because key information was missing (such as price or amount of water transferred), something other than raw water (i.e., effluent or treated water) was involved, the price included payment for things other than water (e.g., land), or the transaction was not a market sale (e.g., it was an exchange or a donation). Thus, 1,377 qualifying cases (1,726 - 349 missing information) were left for analysis. Figure 2 shows the total water volume by year of the qualifying cases and the full set of cases.

Prices, expressed on a per acre-foot basis, were adjusted to year 2003 dollars using the consumer price index. Prices for water rights were converted to an annual basis using a 3% interest rate, which is approximately the mean annual growth rate in real gross domestic product over the past 20 years in the U.S. Although mean prices are also reported, this analysis emphasizes median prices, which more accurately indicate the price of a typical water sale when the price distributions are skewed.

Prices paid for untreated water often include reimbursement for water management, including such services as storage and conveyance, in addition to the cost of the raw water in the stream. Such prices are analogous to P_2 in Figure 1 given supply at Q_3. Because our primary interest is in the value of streamflow, costs of water management were not included in the price when such costs could be separated out. However, storage and delivery services are so commonly a part of water transactions that such services were often not even mentioned in the entries. Most prices reported here probably include some consideration for the value of water management services.

Results

All results reported here are based on the 1,377 cases meeting the criteria for further analysis explained above. Figure 3 shows the number of cases by a convenient geographic breakdown, climatic division (*www.cdc.noaa.gov*). Fourteen states have qualifying cases (all states in Figure 3 except North Dakota, South Dakota, and Nebraska). Three climatic divisions within these states have over 75 cases: division 4 in northeast Colorado, including Denver, Fort Collins, and other cities along the northern Front Range; division 5 in California, capturing the southern (San Joaquin River) portion of the Central Valley and on down to the Bakersfield area; and division 10 at the southern tip of Texas, along the Rio Grande as it enters the Gulf near Brownsville. Nine climatic divisions had between 26 and 75 cases-three in California, two in Texas, and one each in Arizona, Colorado, Idaho, and Nevada. Thirteen climatic divisions had between 11 and 25 cases, and 43 had from 1 to 10 cases. Another 44 climatic divisions in the 14 states had no cases.

Figure 3. Number of cases meeting criteria for analysis of market prices, 1990-2003, by climatic division (divisions are numbered independently within each state).

Quantity of Water Sold

A median of 804 acre-feet was transferred per case (the mean is 17,234 acre-feet). Table 1 lists the volume transferred by state. Three states (Arizona, California, and Idaho) account for 75% of the water transferred.

In all years much more water has been transferred via leases than via rights (Figure 4), which reflects in part the fact that water transfers are easier to agree upon and arrange on a temporary than on a permanent basis. The median lease size over the 14 years is 6000 acre-feet per case, compared with 110 acre-feet for water rights cases. There is considerable annual variation in amount of water transferred for both types of transactions, but no apparent relation between the two trends (R = 0.13).

Ten percent (141) of the cases involve groundwater, with the remainder (1,236) being of surface water. However, only 4% of the water transferred in these trades has been ground water, as suggested by the fact that the average water volumes per case are 6,679 acre-feet for groundwater and 18,438 for surface water.

Table 1. Western water market activity and prices by state, 1990-2003 (both leases and rights, price in year 2003 dollars per acre-foot per year).

	Number of cases	Volume	Price			
	(N)	(1000 acre-feet)	Mean	Median	Min*	Max
Arizona	86	7,910	51	48	0	115
California	294	8,104	96	66	0	1,000
Colorado	427	443	133	81	1	630
Idaho	64	2,802	15	6	0	251
Kansas	16	11	40	48	13	54
Montana	5	15	20	6	2	56
New Mexico	59	525	77	55	1	607
Nevada	69	1,299	125	106	6	375
Oklahoma	3	81	246	118	46	575
Oregon	43	261	31	9	1	302
Texas	207	1,376	104	28	7	2,258
Utah	43	122	34	16	5	165
Washington	25	563	70	32	3	343
Wyoming	36	219	37	40	3	93
All	1,377	23,731	96	56	0	2,258

** Cases with a $0 price were not included. $0 indicates rounding of a very low price.*

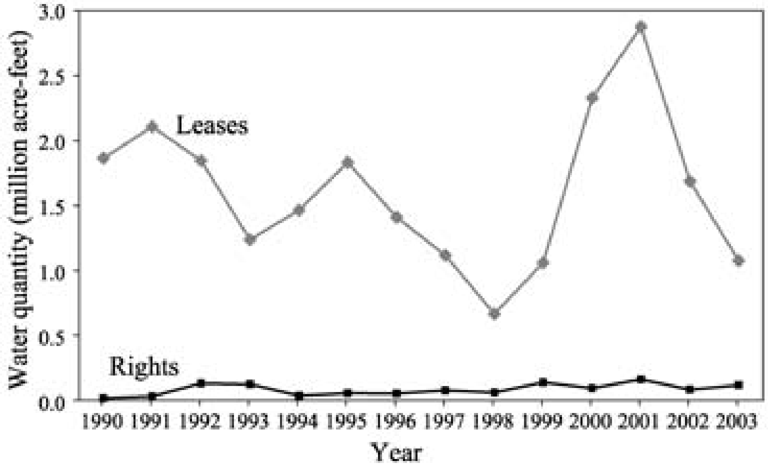


Figure 4. Trends in total quantity of water transferred (qualifying cases only).

Price of Water

A quick look at Table 1 reveals at least three findings of interest about water prices. First, mean prices exceed median prices for the complete set of cases (a mean of $96 per acre-foot per year versus a median of $56) and for all but two states. Second, the range in price is substantial for each state, with most minimums near $0 and maximums typically in the $100s (the maximum of $2,258 is for a lease by a mining company). Clearly, water changes hands at a variety of prices. Third, the median prices vary substantially among the states, ranging from below $10 in Idaho and Oregon to over $80 in Colorado and Nevada (ignoring Oklahoma and Montana because of their small numbers of cases). There is no apparent relation between number of cases and median price. Also of note is that water trades are much more common in some states (e.g., California and Colorado) than others (e.g., Montana and Oklahoma). Water scarcity no doubt plays some role in determining the number of trades, but institutional and legal differences are probably the most important factors affecting sale frequency among the western states.

To begin to understand the reasons for the range of median prices, consider Table 2, which summarizes the sales by type of transaction, either a lease or a perpetual right. Over all states, the median price for leases ($47 per acre-foot per year) is about two-thirds that of rights ($72) given the 3% interest rate for annualizing prices of rights. However, the median price of leases exceeds the median annualized price of rights in most states. The overall superiority of median water rights prices results largely from the fact that 56% of the water rights cases are for Colorado, a state where the median price of water rights far exceeded the median price of leases. Fully 216 (59%) of the 369 water rights cases for Colorado are of CBT shares, and another 129 (35%) are for other water rights along the northern Front Range within or near the area of the Northern Colorado Water Conservancy District where CBT shares trade (in climate division 4, Figure 3). Also of interest is that for 10 of the 14 states the number of lease cases exceeded the number of rights cases. The exceptionally high number of water rights transactions in Colorado reflects the relative ease with which such transactions can be accomplished and the strong demand for secure water supplies by the fast-growing cities along the Front Range.

Table 3 summarizes the cases by the purpose for which the water was purchased. Over half (739) of the purchases were for municipal purposes, another 23% (321) were for irrigation, and 11% (150) were for environmental purposes. The median price paid for municipal uses ($77)

Table 2. Western water market prices by state and type of transaction, 1990-2003 (year 2003 dollars per acre-foot per year).

	Leases		Rights	
	N	Median ($)	N	Median ($)
Arizona	48	58	38	40
California	250	68	44	37
Colorado	58	18	369	84
Idaho	49	8	15	3
Kansas	11	50	5	16
Montana	5	6	0	
New Mexico	29	55	30	76
Nevada	4	83	65	109
Oklahoma	2	347	1	46
Oregon	34	9	9	7
Texas	159	29	48	24
Utah	11	7	32	17
Washington	21	37	4	13
Wyoming	34	40	2	43
All	715	47	662	72

Table 3. Western water market prices by purpose of buyer, 1990-2003 (both leases and rights, year 2003 dollars per acre-foot per year).

Purpose	N	Mean ($)	Median ($)	Min ($)#	Max ($)
Municipal	739	118	77	0	1607
Irrigation	321	46	28	1	490
Environment	150	56	40	0	450
Other	105	180	62	2	2258
Several	62	51	56	2	190
All	1377	96	56	0	2258

 # Cases with a $0 price were not included. $0 indicates rounding of a very low price.

was nearly three times that paid for irrigation water ($28) and nearly twice that paid for environmental purposes ($40). Purchases for municipal purposes tended to be of water rights (453 cases involving rights versus 286 for leases), suggesting that municipalities desire-and are able to pay for-dependability of supply. Purchases for irrigation and environmental purposes tended to be of leases.

For the three principal purposes for which water was purchased (municipal supply, irrigation, and environmental protection), there is a wide range in median price across the states (Table 4). The overall median price paid for municipal water ($77 per acre-foot per year) is heavily influenced by sales in Colorado, where the median price of the 250 cases is $88. Other states with both high median prices for municipal purposes and a substantial number of cases are California (median of $96), Nevada ($110), and Wyoming ($77). Excepting Colorado, the median price of the remaining 489 sales for municipal purposes is $57. The overall median price paid for irrigation water ($28) is also heavily influenced by Colorado, which had over one-third of these cases and a median price of $72. Other states with a substantial number of cases include California (median of $45), Idaho ($4), and Texas ($24). Excepting Colorado, the median price of the remaining 211 cases for irrigation purposes is $16. Among purchases for environmental purposes, states with the highest median prices and with at least ten cases are California ($64), Colorado ($20), Idaho ($8), Oregon ($26), and Washington ($32).

Table 4. Western water market prices by state and purpose of buyer, 1990-2003 (both leases and rights, year 2003 dollars per acre-foot per year).

	Municipal		Irrigation		Environmental	
	N	Median ($)	N	Median ($)	N	Median ($)
Arizona	47	48	12	45	5	45
California	149	96	66	45	51	64
Colorado	250	88	110	72	19	20
Idaho	5	6	31	4	19	8
Kansas	14	48	2	51	0	
Montana	0		1	6	3	2
New Mexico	26	77	4	50	10	47
Nevada	59	110	0		7	43
Oklahoma	3	118	0		0	
Oregon	0		20	8	19	26
Texas	141	26	40	24	0	
Utah	28	20	13	7	2	40
Washington	3	40	5	17	15	32
Wyoming	14	77	17	5	0	
All	739	77	321	28	150	40

Who Sold to Whom, and for What Purpose?

Irrigators are the sellers in 38% (531) of the cases (Table 5), not counting when they might appear among the 222 cases involving several sellers. Public agencies are the sellers for another 16% (224) of the cases. These public agency sales include those involving State Water Project or Central Valley Project water in California, Central Arizona Project water in Arizona, and water managed by the U.S. Bureau of Reclamation in many states, including Colorado, Oregon, and Wyoming. Nearly all public agency sales were leases.

Municipalities were the most common buyers of water, accounting for 27% (375) of the cases (Table 5), not counting when they might appear among the 206 cases involving several buyers. Other active buyers were public agencies with 17% (234) of the cases, farmers with 15% (204) of the cases, and water districts with 13% (183) of the cases.

Trends in Occurrence and Price

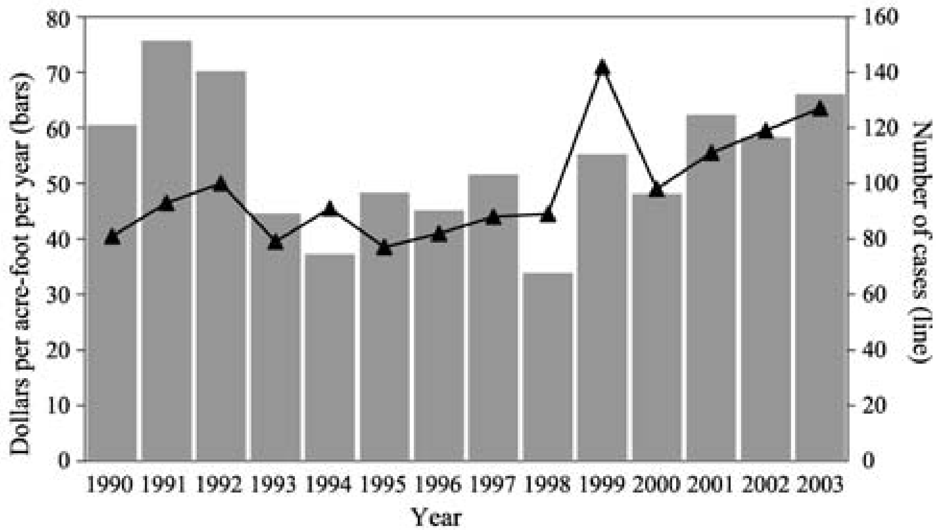
The number of cases per year (across all states and purposes) ranges from a minimum of 77 in 1995 to a maximum of 142 in 1999 (Figure 5). Recent years show an increase in the number of cases (over the 14 year period, the four highest numbers of cases occurred in 1999, 2001, 2002, and 2003); the overall increasing trend is statistically significant at the 0.05 probability level based on the Mann-Kendall test for time trends (test statistic = k = 2.56). Examining sales of leases and rights separately reveals that the number of leases has increased substantially over the past 14 years (k = 3.60), whereas the numbers of sales of rights show no trend (k = -0.49).

The median price per year (across all states and purposes) ranges from $34 in 1998 to $76 in 1991 (Figure 5). No overall trend is evident (k = 0.24). However, looking

Table 5. Number of western water market trades from seller to buyer, 1990-2003 (both leases and rights).

Seller	Buyer							Total
	Municipality	Irrigation	Environmental	Water district	Public agency	Other	Several	
Municipality	26	8	0	7	18	6	4	69
Irrigator	175	96	10	60	95	40	55	531
Environmental	1	0	1	0	1	0	0	3
Water district	21	19	1	38	32	8	16	135
Public agency	39	48	1	32	46	18	40	224
Other	60	12	1	26	22	68	4	193
Several	53	21	0	20	20	21	87	222
Total	375	204	14	183	234	161	206	1377

Figure 5. Trend in median price of water, all water uses (includes both leases and rights, year 2003 dollars).



separately at sales of leases and rights reveals that the median price of rights has increased significantly (k = 2.07), whereas the price of leases has not (k = 0.00). Colorado, especially the Front Range area, is largely responsible for the overall increase in the price of water rights.

Price Differences Across Markets

Space constraints preclude presenting details here about individual water markets. An analysis of separate markets revealed the following findings. First, prices at a given time can vary considerably even among markets located quite close to each other. Such markets often differ in local economic conditions, availability of alternative supplies (such as groundwater as a supplement for surface water), extent of water distribution infrastructure, and past decisions to obtain secure surface water rights. Second, prices in competitive markets can change dramatically over time in response to development pressures or weather cycles. Third, prices of leases in many markets are heavily influenced by administrative criteria, and thus not competitively set (exceptions to this observation include the Texas Rio Grande lease market). Fourth, water rights are typically sold in relatively competitive situations where the prices are determined by individual negotiations between buyer and seller.

Conclusions

Analysis of the trades reported by Stratecon allows the following general statements (which may not represent the full population of western trades):

1. The incidence of water market trades is geographically variable. Markets are very active in a few areas of the West, but most areas apparently had few trades over the past 14 years. Although three states (California, Colorado, and Texas) account for three-fourths of the qualifying sales, even in these states some areas had very few trades.

2. In a given year, at least ten times as much water changes hands via leases as changes hands via sales of water rights. The median size of leases is over 50 times that of water rights sales.

3. Across the western states, the median price of water is highly variable, with Colorado and Nevada having the highest medians, and Idaho and Oregon having the lowest medians, when sales of leases and rights are combined. However, the price of water is also highly variable within every state, reflecting the particular physical and legal characteristics of individual water markets. This variability makes it risky to transfer a value from one location to another, thus complicating the process of benefit transfer.

4. Among the major purposes for which water was purchased, purchases for municipal uses have the highest median price ($77) and account for over half of all trades. Purchases for agricultural irrigation and environmental protection have lower median prices (roughly $35).

5. Purchases for municipal purposes have tended to be of water rights, whereas purchases for irrigation, environmental, or other purposes have tended to be of leases.

6. Irrigators were the sellers in about 40% of the transactions. Public agencies, such as federal agencies managing large water storage and delivery projects, were the sellers in another 16% or so of the transactions. Municipalities were the most common buyers, accounting for about 30% of the transactions. Other common buyers were farmers, public agencies, and water districts.

7. Across all cases, the median price of leases in real terms showed no consistent trend over the past 14 years, whereas the median price of water rights showed an upward trend.

Water market activity in aggregate offers a broad and rich understanding of the value of water. Water values can be substantial, but because they also are highly variable both geographically and temporarily, care must be used in applying water market prices to analyze policies affecting streamflow.

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An Army of Watershed Specialists: Good Working Relationships Encourage Everyone to Value Watersheds

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By developing strong personal relationships, physical scientists can get the field-going people in their sphere of influence to do the best job possible for the sake of watershed health. In order to accomplish a large workload with limited resources, it is valuable to use the entire workforce to find, report, and improve unacceptable watershed conditions. When there is mutual respect among hydrologists, timber sale administrators, engineers, and other Forest Service disciplines, the watershed is the biggest winner, because those employees can act as recruits in the "watershed army". To recruit this army, hydrologists need to listen to the needs and challenges of their coworkers. This active listening promotes additional communication between watershed specialists and people who can help improve watershed conditions. When scientists participate in cooperative work to meet agency objectives, this proves their commitment to accomplishing the entire job, and fosters a cooperative spirit within the entire organization. Finally, after the army has been enlisted and beneficial watershed work has been accomplished, those employees need to feel appreciated, in order to encourage them to continue to fight for improved watershed conditions. When all Forest Service employees are interested in being good watershed stewards, the effectiveness of a single physical scientist can be multiplied.

Keywords: *resource management, partnership, restoration*

Introduction

Hydrologists are a relatively scarce resource in the Forest Service, with large areas of responsibility and huge workloads. In order to maximize their effectiveness, watershed specialists can enlist other employees to help them care for the land, and accomplish more resource improvement objectives in a time when personnel and funding are dwindling. Building strong personal relationships and working together are the way to get the entire job done.

This paper contains case studies from the North Zone of the Black Hills National Forest, South Dakota, and ideas on how physical scientists can work with their fellow employees to maximize watershed benefits. A hydrologist may think, "I'm the hydrologist, and that's all I do". However, by thinking more broadly, and doing everything possible to build solid relationships with the other people on a district, zone, or forest, scientists can be more effective. No one can do everything on his or her own. The Black Hills in an active forest that has many timber sales, fuels projects, recreation activities, land transactions, mineral operations, and grazing allotments. All of these actions have the potential to affect watershed resources. In order deal with this level of activity, and build good relationships, a watershed specialist should listen to the concerns and challenges facing their coworkers, demonstrate respect and understanding for other people's jobs and viewpoints, communicate watershed concerns while participating in work that is mutually beneficial to all, and appreciate work that is done in order to achieve a better outcome for watershed values.

Case Studies

Mud Bogging

Fresh out of graduate school, I was relatively new to the Forest Service, new to the job, and definitely new to the Black Hills. I didn't know what was happening on the ground, and didn't even really know what could happen out there.

For example, our Law Enforcement Officer (LEO) notified me of a situation where ATVs (all-terrain vehicles)

Furniss, M.J., Clifton, C.F., Ronnenberg, K.L., eds., 2007. *Advancing the fundamental sciences: proceedings of the forest service national earth sciences conference, San Diego, CA, 18-22 October 2004*. PNW-GTR-689. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Figure 1. ATV ruts in Johnston Gulch. Photo by Ken Boerman.

Figure 2. Johnston Gulch condition before signing and enforcement. Photo by Ken Boerman.

Figure 3. Johnston Gulch condition after signing and enforcement. Photo by Ken Boerman.

and 4X4s had been mud bogging in a Black Hills riparian area (Figure 1). He knew this was a problem, and because he and I had communicated with each other on occasion, he knew who to contact about it. We talked more and I listened to his past experience with this kind of activity and how to stop it. I expressed to him that this was a priority area to address, and he agreed to do some enforcement work at this site. During a stakeout on Easter weekend (11 April 2004), he caught someone in the act of destroying this meadow, and issued a citation. LEOs are very busy, with more enforcement work than they could ever handle, but because we talked, and because he felt that some enforcement could make a difference at this site, we put some time and effort into patrolling this area and posting some closure signs.

Before we took any signing or enforcement measures, this area did not meet riparian objectives (Figure 2). Upstream from the photographed area, a hand-excavated trench diverts water flow out of the natural drainage channel and onto the road surface. ATVs and full-size 4x4 vehicles have driven along this road, and through this wet meadow, intentionally looking for ways to make more tracks. Fortunately, after the LEO issued a few citations, and our Recreation Staff Officer talked to some of the local off-road clubs, people have left this spot alone, and conditions are improving. In this case, lots of eyes looking for problems found an area that was in trouble, and some cooperative work helped turn things around. As a new hydrologist in a new place, I could not know everything. However, with a little help from people in the field, we were able to improve conditions at this site (Figure 3).

Snowmobile Trail Erosion

In order to cover more ground, and accomplish more resource improvement, I enlisted the help of our engineers. They are looking at roads all the time. Since connected disturbed areas associated with roads are the main source of damage in all regions (USDA 2001), it makes sense to get more people to look at water/road interactions. By communicating my concerns and participating in joint field visits, I was able to understand the complete situation, and work cooperatively to find a solution.

After using GIS to find locations where roads overlap with perennial streamcourses, and conducting site visits to find evidence of direct sediment contributions, I contacted the engineers about rills in the fillslope of the road, and the resulting sediment plumes in the creek. Spearfish Canyon is one of the few major perennial streams on the Northern Hills District. It is a popular fishing destination with resident brook trout (*Salvelinus fontinalis*) and is one of the most visited canyons on the forest. Once I shared my concerns with the engineers, one of them brought some additional details to my attention.

Although the majority of the erosion and sedimentation problems in the Black Hills are the result of heavy summer thunderstorms, this problem was the result of snowmelt along the snowmobile trail. This road is closed in the winter, and groomed as a snowmobile trail. This grooming creates packed snow conditions on the surface of the road, and large snow berms along the sides of the road. In the spring, melting snow generates water that flows down the surface of the road, since the berms prevent water from flowing into the ditch or shedding off the road. This trapped flow gathers volume and energy as it continues downhill, forming small gullies in the road surface. Eventually, the water reaches the end of the melting snow berm, and cuts a deeper gully in the fillslope as it falls off the side of the road, and down to the creek, at the bottom of the fillslope. Because of our good working relationship, and because these conditions affect the integrity of the road as well as the stream, the engineers and I worked together with the recreation specialist to solve this problem.

The road is constructed with lead out ditches that route water and sediment through filter zones before it reaches the creek. To allow the snowmelt to access these lead out ditches, changes can be made to the snowplowing techniques used by the snowmobile trail grooming machines. The berms can be broken up by “snow ditches” or plowed openings in the berm. This allows snowmelt to escape the road surface, and flow into the filter strips, before it concentrates and generates enough volume and energy to start eroding the road surface and fillslope. Therefore, it reduces the amount of sediment reaching the creek. With this as an example of cooperative success between engineers and hydrologists, future work can be done, where hydrologists or watershed crews can report on road maintenance problems, and engineers can find and repair watershed problems at damaged sites.

Timber Sale Best Management Practices

Large timber sales can be difficult to survey with only one person. If other district personnel fail to look for the same problems that I look for, something will certainly be missed. That is why it is ideal to work with the other people on the districts to spot potential problems and take the necessary measures to avoid creating them in the first place.

Heavy mechanical vehicles dragging logs on a steep slope adjacent to a creek could result in excessive sediment delivery to the creek. However, to expedite emergency vegetation treatment, a special law passed by congress exempted 8,000 acres (3,240 ha) on the Black Hills National Forest from the environmental analysis requirements of the National Environmental Policy Act (NEPA). Because of this exemption, I didn’t get the opportunity to identify a potential trouble spot on one of the timber sale areas. Fortunately, sale prep foresters and sale administrators – looking for the same kind of problems that I look for – brought this to my attention before the sale was even sold. They recognized the risks of operating within a few feet of a creek. The law also exempted this area from compliance with Forest Plan Standards and Guidelines, including those designed to protect soil and water quality. Despite this, the foresters and administrators still asked for my advice on how to reduce the risk to water quality.

After several site visits and weeks of proposals and counter proposals, we reached an agreement to reduce potential impacts on water quality. Logging operations were conducted over the snow and with frozen soil conditions, to reduce soil damage and loss of ground cover. Landings were designated and placed in locations away from the stream, or in places where potential runoff would be filtered through remnant riparian and streamside vegetation. Some steeper sections of the sale were dropped, since they could not be accessed in frozen soil conditions, and couldn’t be operated on during dry conditions without causing unacceptable soil damage. Finally, temporary bridges were used at pre-selected locations to enable harvest operations on the far side of the creek without damaging streambanks or building new roads. By working together to put necessary mitigation measures in place, large problems can be avoided.

Listen, Communicate, Participate, Appreciate

Listen

In order to encourage other Forest Service employees to bring problems forward, it is important to listen and show interest in their work. Listening to people and the challenges that they face helps develop trust and fosters cooperative relationships. These relationships are further strengthened by a constructive, not antagonistic, expression of needs by all sides. By presenting watershed needs and concerns, instead of simply saying, "No, you can't do that", people are given a chance to come up with their own solutions. This solution-oriented mindset gives people incentive to work together to find the best fit for all.

Communicate

When we communicate, we realize that none of us want degraded watershed conditions. Excessive streambank erosion is something Range Conservationists should be willing to bring forward, whether it's caused by overgrazing or not. Communication is the key to this. When watershed specialists talk about why it is important to reduce streambank erosion, and range specialists talk about management techniques that can be implemented, a dialogue is maintained that can lead to tangible improvements. Without such dialogue, the effort to improve watershed conditions receives only a fraction of the attention necessary to create change.

Participate

One way to get people to work with each other is to participate with them on the task at hand. This includes engineering route reviews, timber sale unit inspections, grazing evaluations, and other types of projects. When hydrologists participate in reviews like these, they can learn more about what it takes to do each job in the Forest Service. This greater understanding can put their job into better perspective. Participation can also provide an interactive opportunity to explain the challenges of managing the watershed resource. It's another way to foster good relationships.

Hydrologists that participate in fire fighting or fuel reduction work may be able to motivate their local fire organization to help them for project work, like spreading mulch after a wildfire, or monitoring efforts, like looking for damaged or ineffective travel management structures. As engines are patrolling for fires, fire fighters can look for road closures that are not working, repair them when possible, or report them for later repair. In this way, employees can work together to improve road conditions, and reduce the impacts that damaged roads can have on watershed values.

Appreciate

The amount of cooperation I receive increases dramatically with the amount of appreciation I express. Once people demonstrate a willingness to help and take steps to protect or improve watershed conditions, it is important to show appreciation for that work. Constructive cooperation with people can encourage them to help more. Giving credit where credit is due, with a personal "thank you", or a public expression of gratitude, motivates people to be advocates for the watershed. Nominating employees for spot awards is another great way to express well-deserved appreciation.

Sometimes, there are outliers, and no matter how willing and cooperative a watershed specialist may be, some employees may not want to cooperate toward achieving watershed goals. It must be understood that there will always be people like this. However, these attitudes should not keep hydrologists from attempting to connect with people, build solid working relationships, and engage them in a constructive dialogue.

Conclusion

Watershed management in today's environment takes an army of watershed specialists. It is important to make a concerted effort to get to know the field-going personnel in an office. These are the people who can have the greatest impact on the ground. Listen to their points of view. Hear and understand their day-to-day concerns. Cooperate in helping them get their jobs done. When a watershed issue needs to be addressed, explain these concerns in a way that gives people incentive to help solve problems, instead of just shutting them down. Participate in the work that needs to be done, including any fieldwork that demonstrates an interest in working toward a common goal, not just a hydrology goal. Finally, make sure to appreciate the hard work that people put forth for the watershed resource. By following these steps, an army of many can be recruited to fight the watershed battle, instead of fighting it as an army of one.

Acknowledgements: I would like to thank Monte Williams for guiding me to conduct myself in a way that fosters cooperation. I would also like to thank the employees of the Black Hills National Forest, who work to improve watershed conditions every day.

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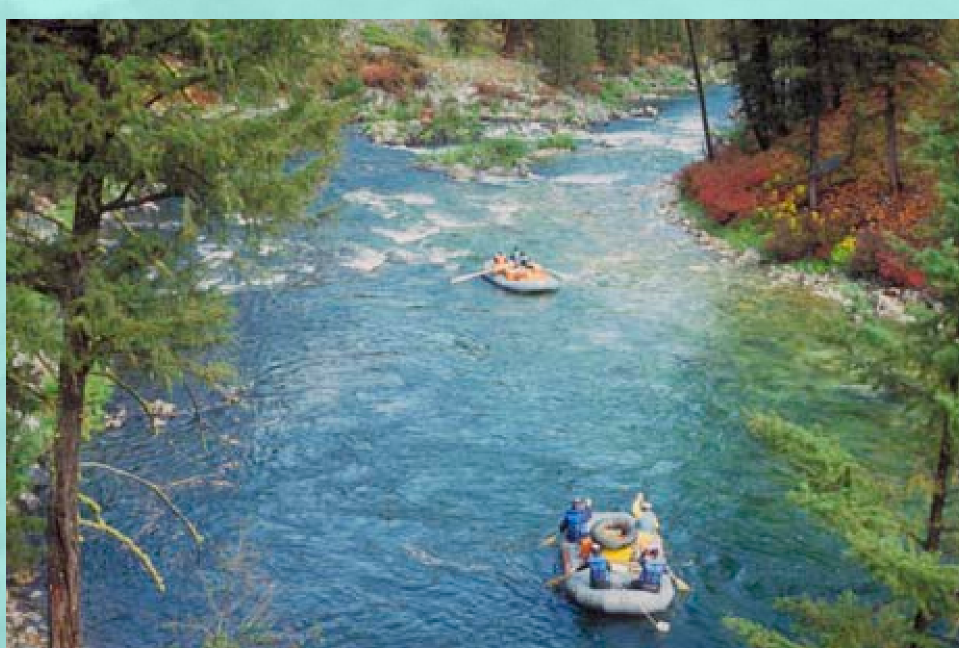
Section 5. Partnership and Collaboration



Overleaf:
Rafters floating the Middle Fork of the Salmon River, Salmon-Challis National Forest, east-central Idaho. Photo by Jay Craig, 1982.

Forest Sustainability Criteria and Indicators: A Common Language for the 20 States Served by the Northeastern Area

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The USDA Forest Service, Northeastern Area State and Private Forestry (NA) and the Northeastern Area Association of State Foresters (NAASF) are working collaboratively with the Northeastern Forest Resource Planners Association to integrate concepts of sustainable forest management into USDA Forest Service State and Private Forestry policies, monitoring and management programs, and technology transfer activities. A key component of this effort is built around a framework for measuring sustainability using sustainability indicators distributed among seven sustainability-related criteria. These criteria highlight important aspects of the conservation and management of biodiversity, forest productivity, forest health, forest soil and water resource quality, global carbon cycles, the social and economic benefits of forest use, and the status of the legal, institutional and economic framework that affects forest resource management. This framework was adopted from an international system referred to as the Montreal Process criteria and indicators (C&I). Components of the Northeastern Area effort to date include: (1) a C&I-based report on the status of forest health and sustainability in the 20-state region; (2) a sourcebook on C&I; and (3) selection of indicators to track at regional and state scales; and (4) a forest sustainability information clearinghouse. For more information, see the NA Sustainability Web Site: *http://www.na.fs.fed.us/sustainability*.

Keywords: *sustainability, indicator, biodiversity, forest productivity, forest health, forest use, forest policy, forest research, water quality, Northeastern Area*

Introduction

Physical scientists help manage forests in a sustainable manner. A sustainability challenge, not fully met, is to integrate the fundamental knowledge of physical systems and their management with knowledge and activities occurring in the biological, social, economic and political realms. The USDA Forest Service, Northeastern Area State and Private Forestry (NA) and the Northeastern Area Association of State Foresters (NAASF) are working collaboratively with the Northeastern Forest Resource Planners Association (NFRPA) to integrate concepts of sustainable forest management into forestry policies, monitoring, management, and technology transfer programs. One focal point for this effort is the use of a framework of criteria and indicators of forest sustainability within their jurisdictions. The Northeastern Area includes the 20 states from Maine to Minnesota, south to Missouri, and east to Maryland.

Furniss, M.J., Clifton, C.F., Ronnenberg, K.L., eds., 2007. *Advancing the fundamental sciences: proceedings of the forest service national earth sciences conference, San Diego, CA, 18-22 October 2004*. PNW-GTR-689. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

The Criteria and Indicators Framework (C&I)

A criterion is a broad goal or category that reflects public values and scientific principles. An indicator is a measure of a criterion. Indicators can be quantitative or qualitative variables that, over time, will indicate positive or negative trends toward sustainability.

The C&I framework was developed in an international forum (Montreal Process Working Group 2001) and used in the United States to prepare the recent National Report on Sustainable Forests 2003 (USDA Forest Service 2003). It consists of sustainability indicators distributed among seven criteria that highlight important aspects of forest conservation and management including: (1) the conservation and management of biodiversity; (2) forest productivity; (3) forest health; (4) forest soil and water resource quality; (5) global carbon cycles; (6) the social and economic benefits of forest use; and (7) the status of existing legal, institutional and economic systems.

NA, NAASF, and NFRPA are using this framework to build a common understanding and language of sustainability with stakeholders and the general public. C&I components of the sustainability effort to date include: (1) a C&I-based report on the status of forest health and sustainability in the 20-state region; (2) selection of indicators for on-going at regional and state sustainability monitoring; (3) development and maintenance of a forest sustainability information clearinghouse; and (4) a book that introduces the benefits and challenges associated with the use of C&I.

Forest Sustainability Assessment for the Northern United States

An indicator-based assessment can introduce the many facets of sustainability to the general public; contribute to informed discussions of the appropriate balance among ecological, social, and economic considerations; and provide a mechanism to track general information with regard to sustainability. To this end, NA and NAASF began work in 1999 on a Forest Sustainability Assessment for the northern United States that is being prepared for digital publication right now (will be available at *www.na.fs.fed.us/sustainability*). The effort was intended to build on the base of information provided through the USDA Forest Service's Forest Inventory and Analysis (FIA) and Forest Health Monitoring Programs (FHM), and to provide insight into which federal, state and private inventory and monitoring programs, technical reports, journals, and other publications were relevant to this effort.

The assessment provided hands-on experience working with the C&I on a regional scale. It involved compiling data across state borders with the associated issues of data gaps and inconsistencies in terminology, inventory methods, and data and cartographic resolution. To add to the FIA and FHM program data, USDA Forest Service Research, the Natural Resource Conservation Service and The Nature Conservancy mined organizational databases for information specific to our needs. Existing Resource Planning Act [RPA] assessments and information from the national report on sustainable forests (USDA Forest Service 2003) were all critical sources of information. Over the course of the assessment, indicator related information has become more accessible through the Internet.

The technical report is currently being prepared for digital publication (available at *www.na.fs.fed.us/sustainability*). Keys points derived from the technical report were published in 2003 in Sustainability Assessment Highlights for the Northern United States (Carpenter et al. 2003).

NA and NAASF Base Indicators.

NA and NAASF have agreed to provide historical and current information on 18 specific indicators that can provide a strong base for state, multistate and area sustainability assessments (Table 1). These base indicators are derived from those in the international C&I framework, to insure linkage with national and international efforts. They span all seven international criteria, but are intended for use at regional and state scales. They were chosen because of their perceived utility by a wide range of stakeholders. There are some data gaps associated with this set of indicators, and data inconsistencies across state boundaries that will be worked out over time. The process used to select the indicators is documented in a publication, NA/NAASF Base Indicators of Forest Sustainability: Metrics and Data Sources for State and Regional Monitoring (USDA Forest Service 2003).

NAASF recommended that the indicators be used as the core of NA-wide forest sustainability C&I assessment reports that are planned to occur every five years, at a minimum. The base indicator information will be posted online, and NA will be responsible for ensuring the currency of the information. Benefits of online indicator reporting include the ability to post new data as soon as it becomes available, rather than waiting a full reporting period; providing stakeholders with easy access to data; and the ability to query data sets to retrieve graphs, download data, and generate summary reports.

Sustainability Clearinghouse Activities

As part of the overall initiative, NA serves as a clearinghouse for information and inquiries regarding sustainability from state forestry agencies, the Forest Service, other public agencies, nongovernmental groups, and stakeholder groups. The clearinghouse helps raise awareness about sustainability and NA/NAASF sustainability efforts. It helps in uncovering opportunities to integrate regional, national, and state work. A key component of the clearinghouse is the Northeastern Area's Sustainability Program Web site (*http://www.na.fs.fed.us/sustainability*). The site provides information on national, regional, and local sustainability assessments, strategic and state forest resource planning, sources of ecological classification and mapping, forest certification, and up-to-date information on the status of the NA/NAASF sustainability efforts. For example, because the C&I framework spans the fields of physical, biological, social, economic and political, science, management, and policy, it can seem overwhelmingly complex on first introduction. To reduce the learning curve, a publication is available on the Website called Sourcebook on Criteria and Indicators of Forest Sustainability in the Northeastern Area (USDA Forest Service 2002). This publication outlines the basic use of C&I to assess forest sustainability, summarizes information on the development and use of C&I by various organizations and agencies, provides a list of recommended resources, and presents information on the NA, NAASF, and NFRPA sustainability work. It is intended as a starting point for states and other organizations to help guide their efforts to use criteria and indicators for assessing forest sustainability. Up-to-date displays of the base indicator information will be a major feature of the clearinghouse Website.

Next Steps for C&I Effort

Over the next several years, the effort will focus on four areas: (1) focusing on data issues and gaps in information needed to address the 18 base indicators; (2) developing the base indicator on-line clearinghouse; (3) increasing awareness of the C&I framework and the base indicator web site through education and training; and (4) development of the first five-year assessment that incorporates the 18 base indicators.

The on-line clearinghouse is currently being developed to provide indicator reports with user-friendly graphs, maps, and tables at regional, state and other scales, where appropriate. The target audience includes state foresters, planners, policymakers, other natural resource professionals, and people doing strategic planning. Where possible, data will be displayed to show trends over time and users can download data tables. It will also have links to the data sources and to additional information and resources.

Summary

The USDA Forest Service, Northeastern Area, State and Private Forestry and the Northeastern Area Association of State Foresters share a commitment to the sustainable management of forests. They have determined that criteria and indicators provide relatively complete, accurate, and unbiased information on forest conditions, the factors that influence forest conditions, and the way changes in forest conditions affect the benefits derived from forests. Thus, a suite of 18 indicators consistent with the C&I framework have been adopted by the USDA Forest Service, Northeastern Area and the Northeastern Area Association of State Foresters. They are intended to provide a base of comparable information across state borders through state and regional assessments, and are a valuable means of tracking the effectiveness of agencies' programs and policies (USDA Forest Service 1999).

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Beyond Boundaries: Resource Stewardship in the Skagit River Basin–Communities and National Forests in Partnership

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This publication is about people, place, and partnerships – a story of relationships among the Forest Service, communities, and organizations in the Skagit River basin in western Washington. It's about the power of partnerships to help conserve and restore resources when people are inspired and motivated to push beyond boundaries and work together. The partnership story as it plays out in the Skagit involves many people, resources, and issues. A common thread to the stories in this document is the Pacific Northwest salmon, currently in decline. The large and relatively intact Skagit River watershed is widely recognized as a critical stronghold for wild salmon in Puget Sound and a key to salmon recovery efforts. The push to protect and restore salmon affects every aspect of life here, galvanizing local conservation efforts and fostering controversy. But every region has its own resource conflicts and its own opportunities to build the relationships that can lead to solutions. Partnerships can help accomplish work, but partnering is as much about building relationships as it is about outcomes. We explore what the Forest Service can bring to the partnership table, share some of what we've learned about partnerships through stories of and by our partners, and discuss some of the stewardship and partnership challenges that lie ahead. The overriding lesson that we want to share is that partnerships can work and can help provide a foundation for effective resource stewardship.

Keywords: *partnerships, stewardship, salmon, salmon recovery*

This document should be cited as:
Movassaghi, G.; Carr, M. 2001. Beyond Boundaries: Resource Stewardship in the Skagit River Basin-Communities and National Forests in Partnership. Sedro-Woolley, WA: USDA Forest Service, Mt. Baker-Snoqualmie National Forest. *http://www.fs.fed.us/r6/mbs/*. 28 p.

Beyond Boundaries:
Resource Stewardship in the Skagit River Basin

COMMUNITIES AND NATIONAL FORESTS IN PARTNERSHIP

USDA

Mt. Baker-Snoqualmie National Forest

OCTOBER 2001

Prologue

This publication is about people, place, and partnerships—a story of relationships among the Forest Service, communities, and organizations in the Skagit River basin in western Washington. It's about the power of partnerships to help conserve and restore resources when people are inspired and motivated to push beyond boundaries and work together.

The Mt. Baker-Snoqualmie National Forest is located in a unique and inspiring place, largely wild, yet within a stone's throw of major metropolitan areas. The convergence of abundant natural resources and 5.5 million people creates an environment that is on the one hand passionately prized, and on the other hand threatened by increasing pressures and conflicting demands on natural resources. This climate has fostered abundant opportunities for developing partnerships that push beyond geographical, legal, administrative, political, and personal boundaries to find effective solutions.

Partnerships can help accomplish work, but partnering is as much about building relationships as it is about outcomes. Working in partnership is a way of thinking and engaging with others. It is a way of building trust and facilitating the process of joint problem-solving. Partnerships take hard work, but the results usually outweigh the difficulties as long as partners share mutual interests and remain true to their own values and capabilities.

The partnership story as it plays out in the Skagit involves many people, resources, and issues. A common thread to the stories in this document is the Pacific Northwest salmon, currently in decline. The large and relatively intact Skagit River watershed is widely recognized as a critical stronghold for wild salmon in Puget Sound and a key to salmon recovery efforts. The push to protect and restore salmon affects every aspect of life here, galvanizing local conservation efforts and fostering controversy.

Every region has its own resource conflicts and its own opportunities to build the relationships that can lead to solutions. The lesson that we want to share is that partnerships can work and can help provide a foundation for effective resource stewardship. We hope that Forest Service staff and others will see similarities to their own situations and find our collective partnership experiences useful.

This is our story, on this landscape, but it is part of a bigger picture. Nurturing partnerships at all levels will become even more important as emerging issues reach across regional, national, and global boundaries. It will be essential not only to have partners but to be partners in the important work of caring for the land and serving people.

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"Ecological understanding is a cultural imperative for each of us… And what better place to begin that deeper appreciation than in the place we live. From such appreciation can come wise decisions and actions to preserve and protect what is left of the Puget Sound basin's natural beauty and wild, self-sustaining life in variety."

– *A.R. Kruckeberg, The Natural History of Puget Sound Country*

An Extraordinary Place

Livelihoods and Lifestyles

- Farming/Agriculture
- Logging/Wood Products
- Fisheries (commercial)
- Manufacturing & Construction
- Trades, Services, Schools
- Government
- Tourism-Related Businesses
- Camping
- Recreational Fishing, Hunting
- Watchable Wildlife
- Horseback Riding
- Water Use
- Power Generation

The symbols and graphics represent only a sampler of some of the major natural resources, human uses, and stewardship challenges in the Skagit River basin

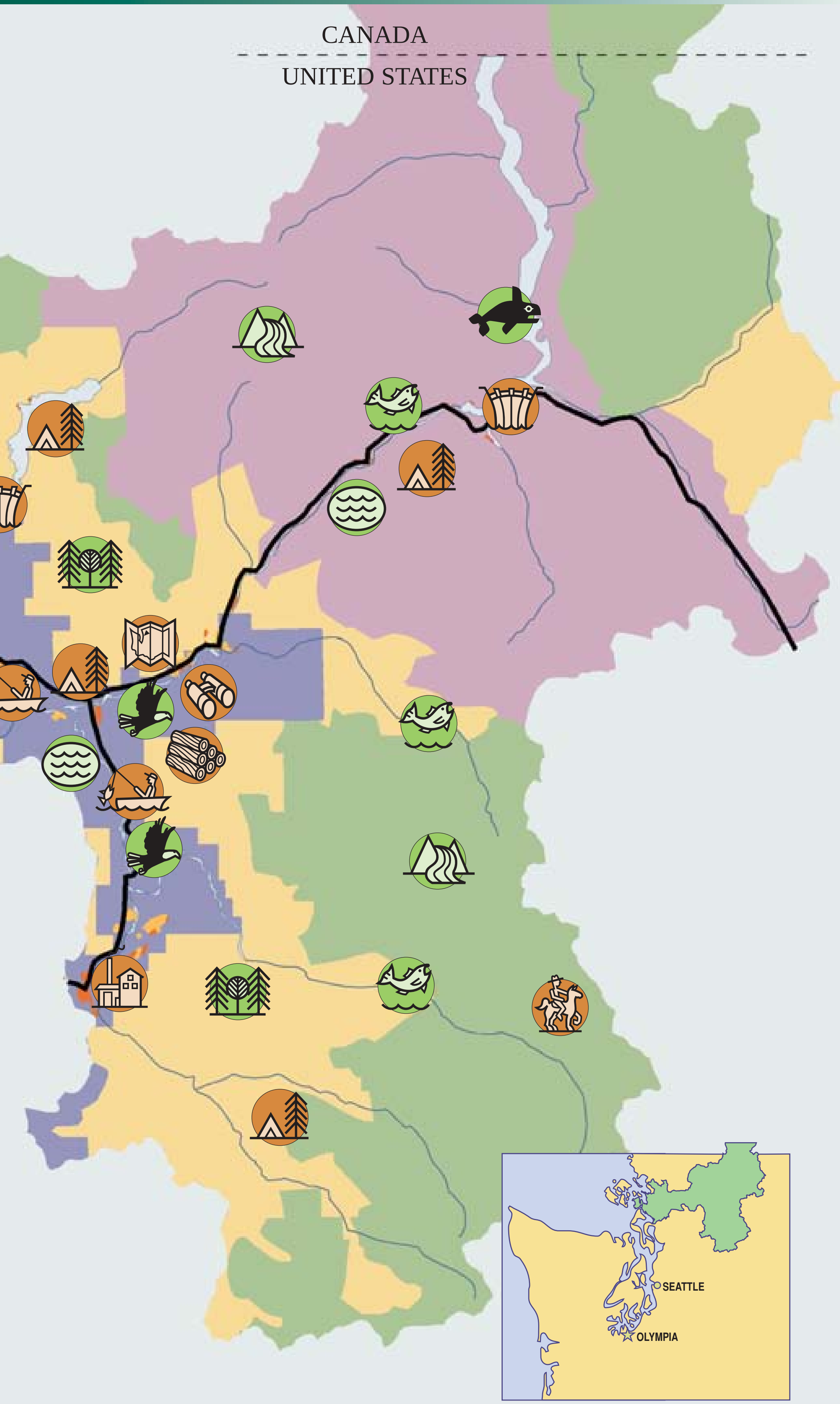
" The Skagit is one of the great rivers of North America. The river and its tributaries are the focus of life and energy for more than 1.7 million acres of the North Cascades - one of the most rugged mountain ranges in North America. Containing hundreds of glistening glaciers, tumbling waterfalls, rushing creeks, soaring eagles and spawning salmon, the Skagit is the largest watershed in the Puget Sound Basin...."

– Weisberg and Riedel, From the Mountains to the Sea, 1991

The Skagit River basin provides the setting for the stories we are telling here. This extraordinary place has inspired and motivated an uncountable number of strong and diverse partnerships.

The Skagit appears largely natural and undeveloped in its sweep from the peaks of the North Cascades to the open waters of Puget Sound. The largest river in the region, the Skagit is one of the few rivers to support five types of salmon as well as seagoing trout. With its numerous tributary streams, high mountains, deep canyons, broad floodplains, estuaries, forests, fields, and farms, the Skagit retains a wealth of environments vital to fish, wildlife, and humans alike.

Over the past century, increasing human uses and competing demands on the Skagit's natural resources have presented a daunting challenge in the effort to maintain naturally functioning ecosystems. At stake are not only the survival of the region's salmon, forests, waters, wildlife, and wild places, but also the cultural identities, family heritages, lifestyles, and livelihoods of the people whose lives are so intimately linked with this landscape.



Landscape and Resources

Landscapes/ uses/ownership

- Farmland
- Wilderness
- Estuary/wetlands
- National Park
- National Forest
- State & Private Lands
- Towns/Urban Areas

Wild inhabitants and resources

- Fish
- Water
- Forest
- Waterfowl
- Eagles
- Elk
- Glaciers
- Human Cultural/ Historical Places

The symbols and graphics represent only a sampler of some of the major natural resources, human uses, and stewardship challenges in the Skagit River basin

The Forest Service in the Skagit

The Forest Service stewardship mission, Caring for the Land and Serving People, has long been served by formal and informal partnerships. Collaboration with others in firefighting, commodity production, conservation, and other resource management efforts has reinforced the notion that we are not just 'The Government'. Rather, the Forest Service is people—people who live in and build relationships within their communities to address shared resource management concerns.

The Forest Service mission is becoming ever more challenging as we strive to maintain functioning ecological systems in light of the accelerating and sometimes conflicting needs and demands of a diverse public. Our broadly defined role of resource steward increasingly relies on partnering. Successful resource stewardship requires: (1) working cross functionally within the agency, (2) coordinating programs with other federal agencies, and (3) going beyond geographical and administrative boundaries to develop partnerships of mutual interest with individuals, organizations, tribes, agencies, and communities.

The Skagit River basin has a long history of people working together, on a wide range of resource management issues. The Forest Service has a stake in the condition of the entire landscape, since the resources we manage both affect and are affected by activities outside national forest boundaries. Key management decisions and resource concerns have provided both opportunities and mandates to work cooperatively (see box below).

As a partner, the Forest Service is sometimes viewed as having capacity and resources unavailable to many grassroots organizations, nonprofits, or individuals. We do have specialties to offer (see sidebar), but our partners also contribute much that may be unavailable to us: different kinds of experience, expertise, and enthusiasm; established programs; or the ability to lobby Congress and fundraise. For the Forest Service in the Skagit, the process of partnering enables us to work together more effectively for the benefit of the resources we care for in common.

How did we get here?

Key resource management decisions and concerns have motivated the Forest Service to form resource-based partnerships. A few include:

- ***The Skagit Wild and Scenic River was designated—but left unfunded—in 1978. Because about half of the Wild and Scenic River is in non-federal ownership where the Forest Service has no regulatory authority, we had the opportunity early on to work cooperatively with other agencies and jurisdictions to protect the values for which the river was designated.***
- ***In the late 1980s, concern over the impact on fish habitat from increased sedimentation due to roads compelled the Forest Service to work with partners to develop a basin-wide approach to watershed restoration.***
- ***Implementation of the 1994 Northwest Forest Plan, along with current salmon recovery efforts, have created the need for the national forest to become more involved in basin-wide partnerships.***

"Watersheds are complicated biological systems. This fact, coupled with the diversity of ownerships, jurisdictions, social interactions and regulations, makes for highly complex problem solving. Success can be achieved only with collaboration and good communication at all levels of government and with key interests engaged and working together."

– John Phipps, Forest Supervisor, Mt. Baker-Snoqualmie National Forest

Pacific Coast Watershed Partnership

The Mt. Baker-Snoqualmie National Forest participates in the Pacific Coast Watershed Partnership (PCWP), one of 12 national Large-scale Watershed Restoration Demonstration Projects funded by the Forest Service. The purpose of the program is to change the way the Forest Service approaches watershed management—from concentrating watershed restoration efforts within national forest boundaries to exploring the use of holistic large-scale watershed restoration partnerships.

The PCWP and the other demonstration projects emphasize collaboration: with the people whose livelihoods depend on the watershed, with those who simply cherish the land, and with organizations striving to create a vigorous self-sustaining landscape. The partnership projects show how the Forest Service and communities can work together rather than in conflict, building connections between ecological and economic health. The projects highlight places where local and regional efforts, driven by common visions and goals, are: reflecting public values, integrating watershed restoration efforts, using science, fostering learning-by-doing (adaptive management), restoring and enhancing habitats of species at risk, and protecting and improving watershed conditions.

What The Forest Service Brings to the Partnership Table

Land and Resources, and their Management

- Land base
- Infrastructure (roads, trails)
- Facilities (campgrounds, buildings)
- Terrestrial and aquatic habitats
- Cultural and historical places
- Natural sites and settings
- Sustainable resource products
- Land management strategies, practices, and experience

People, Processes and Programs

- Familiarity with processes and procedures
- Experience with regulatory requirements
- Interdisciplinary and multi-resource perspectives
- Established outreach programs
- Staff with technical expertise and local ties
- Institutional longevity
- Regional, national, and international links and perspectives

Expertise and Technology

- Access to scientific research
- Place-based knowledge
- Ability to collect, store, analyze data
- Technology development and transfer
- Training opportunities
- Inventory and monitoring
- Clearinghouse for information

Asset Leveraging

- Grants and donations
- Community assistance
- Seed money and matching funds
- Challenge cost-share dollars

Services

- Recreation experiences
- Conservation education
- Visitor orientation and information
- Interpretive services
- Public safety efforts (e.g. fire, flood)

A Web of Partnerships

What We've Learned

Build partnerships smartly

We can neither do it alone nor do it all. Partners bring different strengths and contributions—know your strong points, so you can complement each other's skills and build a smart partnership that makes the most of what everyone has to offer to achieve mutual goals.

Partnerships are relationships

Partnerships that last and accomplish the most are built on personal relationships, trust, flexibility, and caring about common concerns and mutual interests. Each partner should be able to work toward both their own individual goals and the shared goal. While partnerships are about mutual interest they may not always be of direct or equal benefit to each.

Partnerships are place-based

People have a passion about their place—where they live, recreate, and work. The strongest partnerships are based in places people care about, reflecting their culture, heritage, livelihoods, and quality of life. Because each place is unique, each partnership is unique.

This section introduces just a few of the many different projects in which the Forest Service has partnered in the Skagit River basin. The stories are organized around six types of stewardship goals important here today–watershed restoration and salmon recovery, habitat protection, education, recreation, community development, and assessment and monitoring.

Our partnerships vary in form and size, from informal information sharing with a few constituents, to long-term, intensive programs. They are always in flux–some collaborations grow stronger over time, while others taper off or alter their form as needs and players change. The web of Skagit partnerships is wide and deep–some are individuals, agencies, or organizations, while others involve multiple agencies and groups under a larger umbrella, such as a watershed council. In many cases a single organization is involved in different types of projects, playing diverse roles and bringing varying contributions and needs to different endeavors.

Why Partnerships?

Partnerships make sense because ecological, social, and economic issues and concerns are impossible to tease apart or keep within boundaries, especially when working at a landscape scale. A partnership approach also is wise given the increasing pace of development, declining budgets, expanding agency mandates, changing societal values and expectations, increasing scientific information and awareness of the complexities of natural systems, and a broadening desire among national forest users and neighbors to participate meaningfully in forest management. Through their diversity and flexibility, partnerships can lead to more creative ideas, better decisions, and ultimately better conditions on the landscape.

"We cannot do it alone. The issues are too broad, the land base too large, and the resources too scarce."

– Mike Dombeck, former Chief of the Forest Service

What We've Learned

We can and must work across boundaries

All kinds of boundaries—geographical, legal, administrative, organizational—need to be crossed or bridged to see the bigger picture, work at a broader scale, take a longer-term perspective.

Partnerships aren't the easy way

Partnerships take a lot of time, effort, commitment, and energy, to be successful over the long term. Partnerships aren't always the right choice (e.g., where there is an apparent conflict of interest). Some partnerships just don't make it.

Monitoring and feedback are essential

Without monitoring our progress (both on the land and within our partnerships) we can't measure the benefits of our actions; we need frequent reporting, both formal and informal. We need to reward and recognize partners and their achievements, large or small.

Partnerships can benefit all aspects of Forest Service work

Good collaboration reaps good relationships and good will. We all get more work done, achieve more of our natural resource agenda, and jointly solve problems through partnerships.

Partnership Activities: Watershed

Watershed restoration is a cornerstone of Forest Service management direction in the Pacific Northwest, where declines in fisheries and water quality have resulted from the disruption of natural systems. We strive to understand and restore natural physical and biological processes, as well as places important to local communities, through such activities as unblocking fish passages, reducing sediment in streams, or revegetating riparian areas.

Until the 1990s, watershed and fish habitat improvement projects often focused on a single site or target species. But restoring whole watersheds and ensuring species recovery requires a broader approach. Since the mid 1990s, a watershed scale approach to restoration has been used in the Skagit, creating both incentive and opportunity for extensive partnership efforts.

Who Among Us Would Argue Against Working Together?

Salmon once swam the Skagit River by the millions, but today salmon and trout are found in only a fraction of those numbers. There are many causes for the decline and many opinions about potential solutions. However, few would argue that for restoration actions to be effective, they must be coordinated across landownership and jurisdictional boundaries, to involve all those who have a stake in healthy watersheds.

Early in the 1990s, several organizations in the Skagit began meeting informally on sub-basin and watershed scale issues. Over time, these groups evolved as people became familiar with each other and the interconnected nature of their interests and concerns. The Forest Service helped to coordinate informational meetings among agencies and organizations as part of the interim watershed assessment process under the Northwest Forest Plan. By 1997, these relationships were formalized as the Skagit Watershed Council, an umbrella organization of 38 members with disparate interests, missions, and philosophies but with one overriding common interest: the restoration of the Skagit River watershed and its resident salmon.

The Skagit River basin is recognized as supporting the best remaining habitat for wild salmon in Puget Sound. Council members feel strongly that protection and restoration of these salmon stocks are vital to recovery throughout the region. The council supports voluntary restoration and protection of salmon habitats and the natural processes that form and sustain them. Through collaboration, technical assistance and education, the council seeks to fulfill its mission, which is to understand, protect, and restore the

Restoration

"We are together because we know that this inclusive approach is our only hope, the only way to ensure abundant salmon in this river system in the future."

– Shirley Solomon, Skagit Watershed Council Chairperson

production and productivity of the Skagit and Samish watersheds in order to support sustainable fisheries. The Forest Service supports the work of the council with contributions of staff time and financial assistance.

Among the tangible results of this partnership effort is the councils' highly regarded restoration strategy. The council has adopted the strategic approach of using the best science available to identify target areas for restoration and protection that are biologically important for salmon recovery and protect the best habitat first, and to complete those projects that are most cost-effective.

Less visible but equally important are the relationships and history of working together that have developed. Still, Council Chairperson Shirley Solomon suggests that building consensus around controversy among groups who might otherwise have little in common has been no easy task: "Who among us would argue against working together? But actually working together in a way that gets things done is not particularly easy, especially in a partnership of the big tent variety that this council represents. Interests and world views cannot but collide at times."

Buffering those collisions will be critical for future successes. "The council currently functions as the hub for coordinating watershed restoration and salmon recovery efforts in the basin," said Dave Pflug Seattle City Light Fisheries Biologist and council member. "But the history of watershed councils is that they have a five year life-span. The challenge is to keep the council alive so that we continue to have a mechanism for collaboration on these vital issues."

A Sampler of Other Watershed Restoration Partnerships

MAJOR PARTNER

Seattle City Light

The City of Seattle (which owns and operates 3 major hydroelectric dams on the Upper Skagit River) has developed an Early Action Plan to address Endangered Species Act concerns and help in species recovery. Implemented through the Skagit Watershed Council, SCL provides funding to protect and restore high quality habitat in watersheds where the city has an interest.

MAJOR PARTNER

Skagit Fisheries Enhancement Group

The SFEG has supported several restoration projects on National Forest System land and played a major role in the implementation of the Skagit Watershed Council Restoration and Protection Strategy.

MAJOR PARTNER

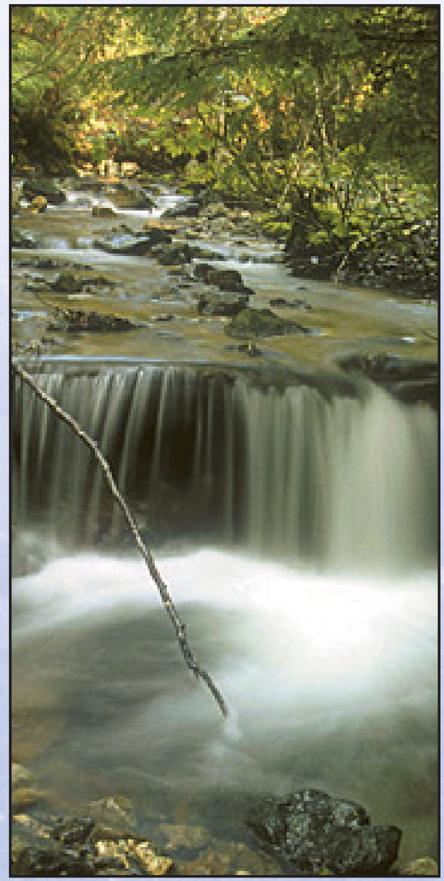
Skagit County

The national forest and Skagit County have partnered on several fish passage improvement and flood repair projects both on and off National Forest System land.

Partnership Activities: Habitat Prot

Protecting habitats for all living things, including people, is a key focus of resource stewardship. Forest Service management emphasis has shifted in recent decades from a focus on habitats for individual species, to protecting whole landscapes and their numerous habitats that support species native to the system.

Where resources are relatively intact, such as in the Skagit, it is less expensive and more feasible to protect high quality habitat than to fix problems in the future. We won't succeed through regulation alone, but rather through working together, having a commitment and ownership in the outcome. Land acquisition and habitat protection efforts throughout the Skagit River basin feature agencies and organizations sharing strategies, priorities, and funds. The Forest Service engages in partnerships to manage habitats in an ecosystem context, rather than piece by piece.



Skagit River Bald Eagle Natural Area

Each November, a remarkable interaction plays out on the forested riverbanks of the Upper Skagit River: the return of spawning runs of salmon and hundreds of hungry bald eagles. The primary setting for this natural drama is an 8,000-acre natural area created by a unique partnership between a private nonprofit conservation organization and several cooperating local, state, and federal agencies and organizations.

Since 1976, the Skagit River Bald Eagle Natural Area (SRBENA), under the management of The Nature Conservancy (TNC), has protected habitat for one of the largest wintering populations of bald eagles in the lower 48 states. This multi-partner conservation effort began with a focus on the preserve, but quickly expanded to work at the landscape or watershed scale.

"The aim of this approach—looking at the entire Skagit watershed and devising strategies to protect the areas of highest quality habitat—is to protect not only eagles, but salmon and all other species in the watershed," says TNC's Bob Carey. "That requires several things, including working closely with our partners."

In this case, the partners include the Forest Service, the Washington Department of Fish and Wildlife, the National Park Service, the Skagit Watershed Council, the U.S. Fish and Wildlife Service, the Skagit Land Trust, Seattle City Light, and The River Network.

The SRBENA not only provides protected land but also serves as a hub for conducting critical scientific and educational activities involving local communities. During the eagle

tection

"What's noteworthy here is the way we're all building on each other's work. In an area where there are so many different landowners, it's essential that we work together and that we focus on what's most ecologically significant."

– Bob Carey, The Nature Conservancy

wintering period, TNC naturalists and other partners conduct a weekly bird census, give guided tours of the area, and make presentations to local school and community groups. The Forest Service, as Skagit Wild and Scenic River manager, helps manage human disturbance during eagle wintering season through voluntary timing restrictions on river use and volunteer Eagle Watchers who focus visitor use in designated areas.

Thanks to TNC and its partners, land is protected for eagle roosting in winter, participation of community members in volunteer programs is on the rise, and thousands of people attending the annual Upper Skagit Bald Eagle Festival are learning about bald eagle habitat and management needs. Bob Carey attributes much of SRBENA's success to its strong partnerships.

"The idea is not to buy large areas within the watershed," Bob explains. "We have neither the resources nor the desire to do so. Rather, the objective is to work cooperatively with both private landowners and public partners to protect the most ecologically important parts of the watershed and to ensure that natural processes still unfold and a functioning landscape is maintained."

Changing resource values and declining partnership funding are among the challenges facing SRBENA and other partnership efforts that seek to gain protection for large areas and natural processes. More landowners and stakeholders need to be involved if landscapes from ridgetops to estuary are to be connected and conserved.

A Sampler of Other Habitat Protection Partnerships

MAJOR PARTNER

Skagit Land Trust

The Skagit Land Trust has worked with the national forest to prioritize acquisition of high quality riparian habitat including a recent purchase of 15 acres at the confluence of Diobsud Creek and the Skagit River. This parcel has over 900 feet of forested shoreline, providing pristine habitat for bald eagles and 4 species of wild salmon.

MAJOR PARTNER

Seattle City Light

Seattle City Light's land acquisition program purchases land in the upper Skagit basin in an effort to improve connectivity and provide habitat as mitigation for the impacts of the Skagit Hydroelectric Project.

MAJOR PARTNER

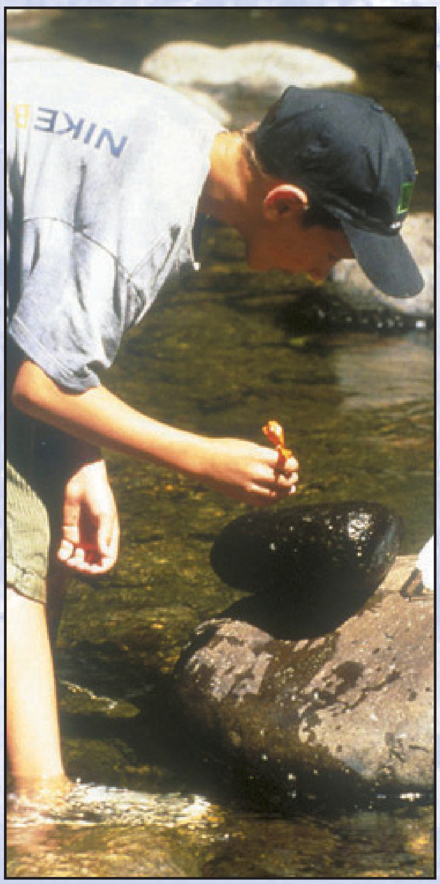
River Network

The River Network secures properties of interest in partnership with other organizations to achieve mutually agreed upon conservation goals. In the Skagit they have been instrumental in facilitating acquisitions that were later sold to the Forest Service.

Partnership Activities: Education

Effective conservation education helps people understand their environment and how it relates to their daily lives. Such education instills awareness and concern, especially among younger members of society, and provides people of all ages the tools they need to participate effectively in stewardship of natural and cultural resources.

The Forest Service embraces education both as an effective tool to achieve stewardship goals and as a way to learn from the unique knowledge, advice, and values of local people. An extensive partnership network has developed across the Skagit River basin, providing abundant opportunities for effective and comprehensive educational efforts. The national forest's contributions often center on: (1) providing a place in which outdoor education can occur, (2) translating and providing accurate and timely scientific and technical information, and (3) providing financial support to ongoing educational activities and programs.


Natalie Fobes

Skagit Watershed Education Project

The plea from local teachers was loud and clear: "It's easier to find out information about the Amazon than about the river outside our classroom windows!"

Their voices reached the ears of the North Cascades Institute (NCI), a non-profit educational organization committed to connecting people, nature, and community in the Pacific Northwest. Their response: creation of the Skagit Watershed Education Project, or SWEP.

All seven school districts signed on for the program, which focuses on creating a sense of stewardship for the Skagit River basin. Integrated classroom and field activities are designed around the entire watershed, with an emphasis on the relationship between a healthy watershed, a healthy fisheries population, and healthy communities.

SWEP began in 1990 as a partnership between the schools and NCI, but within a few years, as national forest management focus shifted more to the watershed level and to the growing need for conservation education, the Mt. Baker-Snoqualmie National Forest joined in. The partnership has since grown to encompass several other collaborations between the forest and NCI.

"It was great timing," says NCI's Tracie Johannessen. "We had been able to get the program off the ground and developed an ongoing relationship with the schools, but it

"We all learned that to be a good partner you don't go out to find someone to do what you need done. You go out and take a look around to see what's going on and how your message can fit in."

– Tracie Johannessen, North Cascades Institute

was hard for us to get enough staff to cover all the field trips. The Forest Service had a common interest and was able to provide funding and staff assistance. It's a great relationship."

What makes this partnership work? "It's all about flexibility," says Tracie. "It's about being cooperative, having a give and take, playing to each other's strengths."

Other reasons for success hinge on the program's inclusiveness—involving students, teachers, parents, landowners, natural resource managers, Skagit River Tribes, and business interests who recognize the value of education in ensuring the health of the Skagit basin.

The SWEP program reaches more than 750 elementary school students and their parents annually. Watershed education continues to gain momentum and attention as a vehicle for the integration of community and schools. The program has received national recognition and now has more than 40 partners.

A challenge for SWEP is to stay ahead of the curve, anticipating and aligning program objectives with changing community and partnership needs. Trying new approaches, organizing in new ways, learning, and adapting will continue to help this partnership thrive.

A Sampler of Other Education Partnerships

MAJOR PARTNER

Upper Skagit Bald Eagle Festival

The Forest Service helps the Eagle Festival organize and staff the Bald Eagle Interpretive Center. The annual Eagle Festival provides project leadership; the national forest assists with funding, materials, supplies, and River Rangers to lead interpretive programs.

MAJOR PARTNER

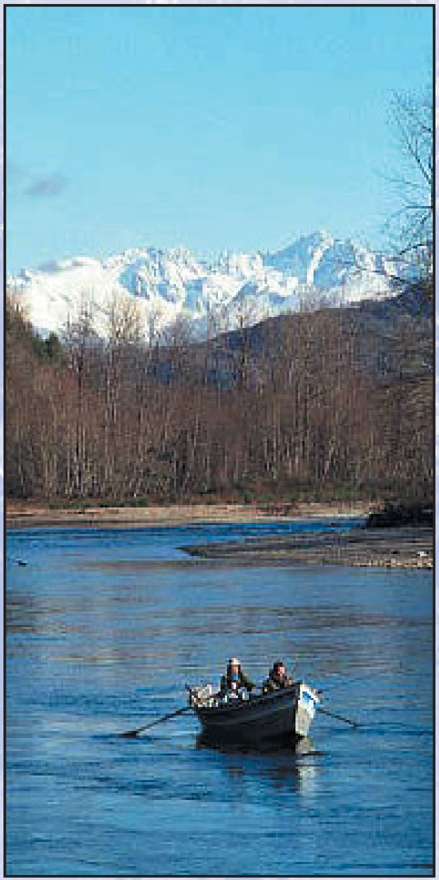
Local Schools

In 2001, 26 students of Ms. Korn's 6th grade class from Central Elementary School in Sedro-Woolley, Washington, monitored the survival of trees planted in newly acquired lands along the Skagit River. The children used their math and science skills collecting and analyzing data about tree growth and survival and shared their findings on the school website.

Partnership Activities: Recreation

A key element of resource stewardship is protecting and facilitating uses of natural and scenic sites, settings, and landscapes, which serve to nurture individual needs and values. But a dramatic increase in recreation, tourism, and travel in the Pacific Northwest, coupled with a continued decrease in regional recreation funding, has resulted in overcrowding, poor facility conditions, and degraded forest settings.

The outstanding natural environment of the Skagit River watershed supports a wide array of year-round recreational opportunities, from hiking, fishing, and boating, to snow sports, mountain climbing, and wilderness experiences. Most of these types of recreation are available on the Mt. Baker-Snoqualmie National Forest and adjacent public and private lands. The forest works with partners to ensure the integrity of the outdoor recreation experience while emphasizing watershed and wildlife habitat protection, restoration, and enhancement.



Wildcat Steelhead Club: For the King of All Sportfish

Fishing for certain sportfish often takes on mythic proportions when the stories are told. Recreational fishing has long been celebrated as an opportunity to relax in a natural setting while meeting the challenge of outsmarting the fish. The Skagit River steelhead is one of those mythic fish, and the Wildcat Steelhead Club was formed in 1936 to promote the enjoyment of fishing for all fish, but particularly the steelhead.

In its early days, club members focused on advancing the recreational activities of fishing and hunting in area rivers and in the high country. But in recent years as the numbers of fish have declined and the conflicts over dwindling stocks have risen, members have expanded their concerns to habitat protection and other issues vital to their form of recreation.

"Sadly, today with overall declines in local fish stocks, club members spend more time arguing over fisheries harvest issues and lobbying for the sport fisher's share of the catch, than they do out on the river," says club member Ron Tingley.

The club sponsors an annual river clean-up day, works for the betterment of local hatcheries, and disperses salmon carcasses in small streams to replenish natural nutrients. The Forest Service, the Steelhead Club, and others partnered on the development of eagle watching sites along the river to focus visitor use and help mitigate disturbance of eagles during winter. In these and other ways, club members work in partnership for the protection and enhancement of the river and its resources

"I grew up on the river, and fishing was part of daily life along the river. The funny thing is, my father, who ran tugboats up and down the river every day, never fished, he said it was too easy."

– Ron Tingley, Wildcat Steelhead Club

Sometimes the interests and needs of the partners don't quite align, straining the relationship. In its role as Skagit Wild and Scenic River manager, the Mt. Baker-Snoqualmie National Forest may make management decisions that conflict with the club's interests as river users. For example, when the Forest Service limited fishing on the Skagit during bald eagle winter feeding times, the fishing community and the club found themselves at odds with agency decisions.

But club members are hopeful that their concerns about habitat and fisheries can also be addressed through local collaborative processes embodied by the Skagit Watershed Council, of which both the Steelhead Club and the Forest Service are members. Keenly aware that habitat isn't the only factor affecting the sustainability of salmon stocks, club members feel strongly that in order to be effective they need to be involved in cooperative local efforts to restore the fisheries resource on the rivers they care about.

Speaking to the challenge of achieving salmon and steelhead recovery in the face of continuing fishing pressure, Ron says, "Politics is getting in the way of listening to what science is trying to tell us."

Challenges for recreational partnerships include not only addressing political realities, but also gaining awareness that although interests may diverge, resolving the conflicts can help build stronger partnerships, which in turn can help resolve future conflicts.

A Sampler of Other Recreation Partnerships

MAJOR PARTNER

Washington Trails Assn., Sierra Club, Audubon Society, Skagit Alpine Club, Mt. Baker Alpine Club

These organizations volunteer many hours to reduce the national forests' backlog of trail maintenance. With their assistance the forest accomplishes 20–30% more trail work annually.

MAJOR PARTNER

Skagit County Parks and Recreation

The Forest Service administers a county grant for the Snopark program and snowmobile trail grooming on Forest Service roads.

MAJOR PARTNER

Pacific Northwest Trail Association

The SKY (Service Knowledge Youth) program is a collaborative effort between school districts and private partners to provide high school students with an outdoor-based work experience blended with academic instruction. SKY is working with the Forest Service to develop a program for high school students to work on trails.

MAJOR PARTNER

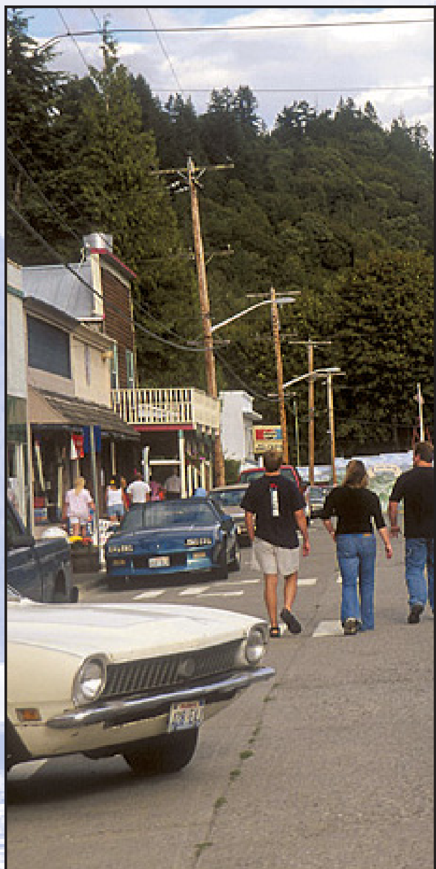
North Cascades Institute

In 1993, NCI and the Forest Service created the Eagle Watchers program to help manage the convergence of wintering bald eagles and the tourists who flock to watch the birds along the Skagit River. Volunteers inform thousands of visitors about bald eagles, salmon, and related habitat and management issues.

Partnership Activities: Community

Effective stewardship of the national forest supports—and depends on the support of the communities of which the Forest Service is a part. Rural communities can participate more meaningfully in the management of their national forests when they have the technology and the capability to do so. The Forest Service has both directives and incentives to encourage partnerships with our rural communities and tribes, especially those affected by declines in timber harvest and salmon populations in the Pacific Northwest.

The Mt. Baker-Snoqualmie National Forest is considered an ‘urban forest’ because of its proximity to the Seattle–Vancouver metropolitan area, but many of our staff live and work in rural communities. Our rural community partnership efforts focus on extending technology, expert assistance, professional knowledge, and resources to help small communities whose economies and lifestyles are tied to natural resources meet their economic, social, and environmental goals.



Concrete, Washington: On the Road Again

Sometimes it takes a couple of starts before you end up on the right road. When the upper Skagit Valley town of Concrete created its first Community Action Plan in 1994, the direction seemed to point toward tourism as the destination that would help them recover from economic downturns related to forest resource issues. Tourism was a logical choice given the town’s scenic location at the gateway to the North Cascades.

Determined to get where they were going on their own, the town bypassed planning help from an outside nonprofit organization, Northwest Small Cities Services. Community leaders applied for Forest Service funds to begin downtown improvements to attract more tourists. They found themselves confronted by an unexpected roadblock—turned down for the grant in part because their action plan didn’t address major water and sewer improvements, and in part because their reluctance to accept outside help or take on debt may have been interpreted as an inadequate level of local commitment.

After going back to the starting line, community leaders accepted a partnership with Northwest Small Cities Services. Members of the community formed a team with the Forest Service, the town council, and other state and federal agencies, to prepare for and work with others at the 1996 Northwest Timber and Salmon Communities Symposium to develop a new plan of action. This time the focus broadened to emphasize infrastructure

y Support

> ***"Today, more than ever, we are committed to working in partnership with others, in the public and private sectors, who are trying to facilitate locally led changes that benefit both the land and rural communities."***
>
> *– A Strategic Plan for the USDA Forest Economic Action Programs, September 2000*

improvements, not only to meet their own residents' needs but also to increase the potential for development of all kinds and to meet newly emerging state regulations for water quality and growth management. This time around, tourism development was still identified as a goal, but one further in the future.

The most long-lasting impacts from this partnership effort have been the changes in community attitude—from a long tradition of independence to a willingness to work with partners, and from a feeling of uncertainty to an awareness of their own power to address problems that had seemed beyond their capacity to solve. In the process of accepting and nurturing relationships with others, the community has actually become more self-sufficient.

The Forest Service's role in Concrete's journey has evolved to focus more on helping with strategic planning and some design and engineering consulting. The town has numerous challenges ahead as they work toward a strengthened and more diverse economy enhanced by their proximity to abundant natural resources.

"The initial process did what it was supposed to do—launch the town onto its feet," says forest environmental coordinator Karen Nolan, who worked alongside Concrete throughout the initial planning process. "They're pretty much in control of their own future."

A Sampler of Other Community-Building Partnerships

MAJOR PARTNER

Town of Darrington

Forest Service employees initiated and helped plan and construct the Kids' Place Early Learning Center in Darrington, as well as a kiosk and restrooms for the community park.

MAJOR PARTNER

Economic Development Association of Skagit County

The Skagit Wood Products Project is a non-profit organization assisting small value-added wood product businesses in northwest Washington. Partnership funding helped with early feasibility studies and planning.

MAJOR PARTNERS

Samish Indian Nation, City of Burlington, Stillaguamish Tribe of Indians

Forest Service funds have helped with numerous community projects including: the production of the Samish Nation's five-year economic development plan, the development of the Burlington Farmers' Market, and the launching of the BankSavers Business Startup Project for the Stillaguamish Tribe of Indians.

Monitoring and evaluation, with feedback to the assessment and planning processes, are key to the success of resource stewardship. Unless we learn from our efforts and become aware of what works and what doesn't, millions of dollars may be wasted on misguided attempts to manage multiple resources and improve resource conditions across the landscape.

Science can provide not only technical information but also a common language to start discussion among those with different viewpoints. Effectively engaging in such dialogue requires a long-term commitment of resources, technical expertise, and extensive local knowledge. The Forest Service has long been a storehouse of technical and scientific data about individual species as well as ecosystem functions and processes, while tribes, communities, and organizations are storehouses of local wisdom and experience on the land. Successful resource stewardship requires partners with complementary skills and capacities to maintain a commitment to assessment, monitoring, and evaluation.

Dick Knight

Is Good Science Enough?

In the Puget Sound region, local Indian tribes have not only a vested interest in the survival of salmon, but also a legal right to the assurance of the salmon's continued existence. Tribal scientists consequently have played a major role in salmon recovery efforts. The Skagit River basin is home to several treaty Indian tribes: the Swinomish, Upper Skagit, and Sauk-Suiattle. Together they formed a partnership known as the Skagit System Cooperative (SSC), a natural resources consortium that addresses fisheries management issues.

For the tribes, fisheries management is not merely a technical exercise concerning another creature or piece of real estate. It is about maintaining opportunities for the exercise of ceremonial, subsistence, and commercial rights to harvest fish. Under the Treaty of Point Elliot (1855) the Puget Sound Tribes retained the "right of taking fish at usual and accustomed grounds and stations," and they are making a concerted effort to restore sustainable fisheries for future generations.

SSC recognizes the need to use the best available science to evaluate the effects of human activities on salmon and their habitats and to develop strategies to reverse the decline of the species. The Research and Restoration Program of SSC has been involved in studies of historical habitat loss, current habitat condition assessment, stock status assessment, development of recovery strategies, restoration projects, and monitoring and evaluation. The Mt. Baker-Snoqualmie National Forest, the Skagit River Indian Tribes, and others have been working

"We are now entering a new era, in which science and scientists—along with managers and stakeholders—will be intimately and continuously involved with natural resource policy development.... However, we are still very much at the stage of learning how the scientific, the technical, and the social can be integrated".

– Jerry Franklin, biologist, in Science Findings May 2000

collaboratively on these issues for the past 15 years.

The SSC believes that good science should lead to good management decisions, particularly with regard to a strategic approach to implementation of restoration projects. Because SSC works for the benefit of the fisheries interests of the Skagit Tribes, their work is a contribution to cultural survival. "For the first time, all groups interested in salmon restoration in the Skagit River basin can sit down at the same table and begin to identify what needs to be done to bring our salmon back," says Lorraine Loomis, of the Swinomish Tribal Senate.

Inventory, assessment, monitoring, and research conducted by SSC and others, including the Forest Service, in the Skagit Basin have provided a working knowledge of the functions and processes of the Skagit River system. This knowledge forms the basis for the Skagit Watershed Council's Habitat Protection and Restoration Strategy and has guided development of procedures for its implementation.

The success of these collaborative efforts in restoring salmon will test the effectiveness of our scientific theories. "The public expects that there will be measurable benefits from expenditures for stewardship activities," says Dave Pflug, fisheries biologist with Seattle City Light, another partner in assessment activities. "We need to be able to measure these benefits, at the watershed scale, and provide information to the public and feedback to the planning process."

A Sampler of Other Assessment, Monitoring and Evaluation Partnerships

MAJOR PARTNER

North Cascades National Park

Skagit River Stewards is a volunteer monitoring program coordinated by the Forest Service and North Cascades Institute in partnership with North Cascades National Park and the Skagit Fisheries Enhancement Group (SFEG). Volunteers collect aquatic insects (which are indicators of stream health). Data are used by the national forest to monitor the conditions in the Skagit Wild and Scenic River, by the national park to develop a regional index of aquatic conditions, and by the SFEG to measure the success of stream restoration projects.

MAJOR PARTNER

Skagit Chinook Work Group

This coalition of agencies and organizations is developing a limiting factors analysis and recovery strategy for the six Skagit chinook salmon stocks.

MAJOR PARTNER

Washington Department of Fish and Wildlife (WDFW)

The WDFW has conducted assessments of off-channel habitat and fish-passage blocking culverts on streams throughout the Skagit Basin. In addition, the WDFW monitors the status of all fish stocks in the basin.

Looking Ahead: Stewardship Cha

"If we assume that biodiversity is worth conserving, it is far less clear how we go about actually conserving it. How do you take the whole world into account?"

– Science Findings, November 2000

The need to establish and nurture relationships with stakeholders in management issues will only expand in the future as the stewardship challenges developing in our local communities take on regional, national, and global proportions. Working beyond geographical and administrative boundaries will become critical to achieving resource goals at multiple scales. Monitoring our progress, both on the land and in our partnerships, will also be an essential element to achieve our mission over the long term.

Crossing Management Boundaries in North Cascades National Park

A national park that is also designated wilderness might seem an unbeatable way to protect a sensitive landscape and its inhabitants forever. But North Cascades National Park (NCNP), a gem at the mountainous headwaters of the Skagit River, illustrates that even undeveloped lands are closely connected to the world around them—that ecological challenges cross boundaries and so must their solutions.

"Administrative boundaries are invisible to the migratory species that travel through and to many other habitats, which may be degraded or threatened with development or alteration," notes Bruce Freet of the NCNP. " Air pollution also crosses boundaries, coming into the national park system, in the form of acid rain or persistent organic pollutants. These can affect the water quality of the park's lakes, streams, and glaciers, which are critical to the water budget for the entire Skagit River watershed."

Addressing such challenges at the NCNP involves broadening the boundaries to work at multiple scales and with various partners. NCNP and its national recreation areas are known together as the North Cascades NPS Complex (NOCA). The NOCA complex itself is part of a larger network of seven national park system areas known as the North Coast and Cascades Network, which facilitates work at the local level while linking the NCNP with other ecoregions including Southeast Alaska/British Columbia and north coast California/Oregon.

The national park system has the dual and sometimes conflicting mandate of providing for public enjoyment and protecting resources

llenges

Challenging stewardship issues include:

- Habitat fragmentation
- Water quality and quantity
- Introduction and spread of exotic plants and animals
- Recreation demands
- Energy use
- Preservation of farmland and open space in the face of increasing urbanization
- Additional listings of endangered species, declining fisheries, and other species losses
- Ecological literacy for an engaged and knowledgeable public
- Maintaining a connection to the land and natural resources in our daily lives
- Lack of resources to complete needed plans: decreasing staff and funding levels
- Political influences in natural resource management, which may conflict with science and with biological or ecological needs
- Continued threats to sustainable populations.
- Implications beyond our boundaries: air pollution, loss of biodiversity, displacing our environmental problems to other parts of the world

for future generations. In the late 1990s as science and resource management co-evolved, the priority tipped more toward resource protection. The shift created new challenges, including funding and a need to monitor progress. In 2001, NCNP embarked on a long-term ecological monitoring program to evaluate the status and trends over time of the natural resources that the park is mandated to protect. Developing and implementing monitoring strategies and activities necessary to deal with cross-boundary issues has led to close partnerships with research institutions, agencies (including the Forest Service), and many others.

"Monitoring natural conditions at multiple scales and time frames can provide insight into the range of natural variability," says Freet. "The results provide reference conditions for more heavily developed or altered landscapes outside the park boundaries. Scientists can use conditions in the park to assess changes from historical conditions and set goals for restoration."

Ecological monitoring will provide valuable information that allows the NCNP to serve as a barometer of conditions within and beyond the Skagit watershed. This long-term monitoring, with occasional research, may provide a window into the complexity of local and global ecosystems and an opportunity to show the essential connection of our actions and intentions, beyond boundaries and over time.

Definitions

Society's evolving views of ecology, conservation, stewardship, and partnership have contributed to an emerging perspective on the vital role of partners in managing resources across boundaries, at landscape scales such as river basins.

Resource Stewardship ~ An approach to resource management that considers ecological, economic, and social/cultural factors in deciding appropriate protection and uses of natural resources. Guiding principles are:

* The **interconnectedness** of communities of living things and the physical environments in which they interact. *Effective stewardship requires reaching across political or jurisdictional boundaries to collaboratively achieve common goals in a particular place and time.*

* **Sustainability** of watersheds, forests, rangelands, and communities—taking no actions that would limit future land management options.

Partnership ~ A type of collaboration built on personal relationships and mutual interest, in which people, organizations, and/or institutions voluntarily work together toward common goals that are consistent with their individual values, objectives, and resources. *Effective partnerships are synergistic, allowing more to be accomplished than would be possible with everyone working alone.*

Looking Ahead: Partnership Chall

"That so many geese would crowd together on a single farm field indicates that wildlife friendly farming has worked. What is worrisome though, is the unrelenting development pressure that is turning agricultural expanses into slivers of property."

– Ducks Unlimited website

The partnership approach to problem solving will become increasingly important, yet ever more challenging in the future. As resource conflicts increase, it will take more and more effort to foster the trust and understanding that are critical to solving problems. It will take strong personal relationships to get past the inevitable stumbling blocks. And it will be important to be able to anticipate the changes that may affect our ability to do good work as partners.

In the long haul, partnership challenges for the Forest Service resemble those confronting all interpersonal relationships.

Ducks Unlimited

Expanding Partnership Boundaries on the Skagit Delta

While far downstream of national forest borders, estuary habitat has become part of the partnership story for the Mt. Baker-Snoqualmie National Forest because this habitat has been identified as a limiting factor in salmon recovery. The Skagit River delta is extremely important to juvenile salmon, which spend time there to feed and acclimate to salt water. The delta also provides habitat for 80 percent of the wintering waterfowl in western Washington, some of which also use habitat on National Forest System land.

In the Skagit, as in much of Puget Sound, most of the natural wetland habitat was diked and dredged at the turn of the last century, replaced by farm fields. Over time the waterfowl have adapted to the farmlands as a food source (salmon have not been as successful), but today farms are subject to increasing pressures. Loss of farmlands and remaining wetlands is threatening habitat for wintering waterfowl, migrating salmon, and the agrarian economy in the Skagit Valley.

"While restoration of Puget Sound's estuaries is essential for the survival of chinook and other wild salmon, it also provides myriad benefits for birds and wildlife as well as for human recreation and enjoyment of nature," according to People for Puget Sound, a conservation organization dedicated to renewal of the region's estuaries. Ducks Unlimited (DU), a major partner in the Pacific Coast Watershed Demonstration Project, is another key player in efforts to protect the estuary and ensure that sufficient habitat and food remain to support the life stages of migrating waterfowl and other wetland birds as well as salmon.

Challenging partnership issues include:

- Communication and follow-through
- Maintaining real personal commitments to make partnerships work over time
- Keeping issues and relationships alive as conditions and expectations change and individual partners or staff move on
- Engaging diverse communities of place and interest
- Expectations and accountability
- Learning how to assess when conflicts are just not resolvable
- Having all people in the Forest Service trained and experienced in working as partners, both within and outside the agency
- Supporting people in developing and sustaining partnerships
- Competition among each other for resources and the need to be strategic with limited resources.

Biologist Lorna Ellestad, a third generation Skagitonian, formerly represented DU in the Skagit. Lorna has built strong relationships with the farming community, working to alter farming and drainage practices on marginal lands, creating higher crop yields and providing benefits to wildlife. "The value of these resources compels us to action," she says. "We couldn't do better work for the resource in any other place in Puget Sound."

Increasingly DU is attempting work salmon-friendly designs into its wetland and waterfowl improvement strategies, part of an effort to keep farm-friendly issues in the limelight while expanding awareness to embrace the challenge of salmon recovery. While not always in agreement with the single species focus, DU seeks to build agreement on the broader ecosystem stewardship issues including protection of rural areas from development and restoration of natural processes and functions that benefit all species.

Driven by her passion for this place, Lorna worked tirelessly to create win-win situations for the farmer and the resource. But farmers are increasingly overwhelmed by development pressure, growth management restrictions, high fuel prices, and low food prices. The inherent tug-of-war between natural resources and human needs is making it tougher to keep partnerships going.

Keeping partnerships alive into the future will require finding creative ways to support the goal of diverse and functional habitats in the Skagit River basin. For the Forest Service, moving beyond our boundaries to include partnerships in the Skagit River delta is one way we hope to address this key challenge.

Partnership Tips

Partnerships are:

Relationships—based on
- mutual trust
- honesty
- understanding
- flexibility
- open communication
- constructive conflict resolution

A way to achieve a common goal
- not a way to farm out your own work
- not just about your agenda, but about mutual interests

For the long term
- Be ready for change

Partnerships need:

Clearly defined goals, tasks, responsibilities
- be true to your own mission and values but...
- work toward the common goal

The right mix of partners
- skills
- resources
- stakeholders

Organizational support
- commitment
- accountability

A clear way to measure progress and success
- Reward the small achievements
- Monitor, learn, adapt

Partnerships must overcome:

Time and resource limitations
- be selective about how much to tackle
- avoid burnout

Barriers and Boundaries
- turf battles
- adversarial approach
- red tape
- negativity

Partners and References

Selected Partners in the Skagit

The following are a few of the major partners with whom the Forest Service has worked on substantial projects and programs over the past 15 years. Innumerable other individuals, organizations, and agencies have been partners in the Skagit, working together to conserve and restore natural resources.

Backcountry Horsemen

Crown Pacific
http://crownpacificpartners.com/

Ducks Unlimited
http://www.ducks.org/news/pacific_nw_part_2.asp

Economic Development Assoc. of Skagit Co.

National Marine Fisheries Service

Natural Resources Conservation Service
http://www.wa.nrcs.usda.gov/nrcs/

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http://www.fs.fed.us/r6/mbs/

The Roger Rule for Restoration Partnerships

- We are all in this boat together, acting in good faith.
- We are engaged in developmental work so we don't always know exactly how to get where we want to go.
- We will undoubtedly encounter Class IV rapids.
- When we do, if we don't all pitch in and help, our boat will sink.

-Roger Nichols, Forest Service geologist

"Our goal of restoration and protection of salmon habitat in this basin will not come easy. It will take science and story, on-the ground progress, plus solid planning and evaluation. It will also take time and resources and the goodwill of the entire community.""

-Skagit Watershed Council Chairperson Shirley Solomon

"Stewardship of habitat [was then and] remains today divided among many landowners, each with a different perspective on risks and values associated with natural ecosystems. In addition, most of the habitat in the United States is privately owned and not subject to similar management goals and policies."

- Ross Kiester in Science Findings November 2000

"We recognize that some of our individual objectives will be met through the partnership, while other objectives will have to be met some other way."

-Tracie Johanessen, North Cascades Institute

USDA United States Department of Agriculture

Forest Service

Ecological Management Decision Support Model of the Applegate River Basin

Mike Mathews
Bureau of Land Management, Medford District, Medford, Oregon

The Ecological Management Decision Support Analysis of the Applegate River sub-basin of the Rogue River basin in southwest Oregon resulted from an integrated effort to develop a watershed health assessment tool. The Rogue River Basin Technical Team, an interagency group formed with the cooperation of 25 federal and state agencies, assessed and identified priority restoration work needed across the 33 sub-watersheds in the Applegate sub-basin. The analysis relied primarily on the Ecosystem Management Decision Support model, which evaluated 11 indicators of watershed health. When fire risk was included in analyses, 29 of the 33 were rated in poor health. Excluding fire, 21 sub-watersheds were rated in poor health. Federally managed areas contained 9 of 12 healthy watersheds. Based on instream conditions (four indicators), 25 of 33 sub-watersheds received poor scores. Across the Applegate basin, all floodplains received poor health scores for function. Generally, the upper reaches of the watershed were in better health than the low gradient areas that have the highest potential for structural and biological diversity. Recommendations for restoration differed by elevation and ownership. Accomplishing restoration priorities in the low gradient areas may be complicated due to the predominance of private ownership in those areas. Although this report is directly applicable to the Applegate sub-basin, the ecosystem indicators evaluated, the relationship between indicators, cumulative effects, and rationale used to prioritize restoration health are appropriate throughout the Rogue River basin.

Keywords: *ecosystem modeling, GIS, watershed health, landscape planning, restoration, collaboration*

Introduction

The Applegate River sub-basin is a 4th-field watershed tributary to the Rogue River basin in southwest Oregon. Traditionally, assessments and restoration planning in the Rogue River and its tributaries have been fragmented, conducted by various agencies or watershed councils. While these assessments provide a useful tool for project level planning, they do not provide priorities at larger scales. Additionally, the disparate efforts have not engaged all land managers in the watershed or incorporated limiting conditions across the landscape, reducing the efficacy of restoration efforts. To coordinate watershed restoration efforts, the Southwest Oregon Provincial Interagency Executive Committee (PIEC) and the Southwest Interagency Group (SWIG) comprising 25 federal and state agencies in the Rogue River basin signed a Memorandum of Understanding (MOU) to develop a basin-scale approach to watershed restoration. To accomplish this task, the agencies formed the Rogue River Basin Technical Team (hereafter referred to as 'the team'; see acknowledgements for members), representing various agencies and skills, to identify and prioritize restoration work needed across the 33 sub-watersheds in the Applegate sub-basin.

A functioning, healthy watershed has the structure, products and resources needed to support productive natural systems (Kolb et al. 1994). Specifically, a healthy watershed is defined as one that has: the physical structure, biotic resources and trophic (energy) levels that support productive systems; the capacity to quickly recover from episodic disturbances at the landscape scale; and the presence of a diversity of habitats for native species.

Based on these definitions of watershed health, the team selected eleven indicators to evaluate conditions in the Applegate River sub-basin. The indicators represent upslope, riparian, and in-channel processes as well as current aquatic conditions. Seven indicators define key processes that directly and indirectly influence aquatic conditions; these are causal process indicators. Process evaluation facilitates the understanding of linkages between the upslope, riparian and aquatic systems and provides insights to cause and effect relationships. Four of the eleven indicators are response indicators and represent current aquatic conditions. Table 1 lists the processes, respective indicators and variables used to measure the indicators.

Furniss, M.J., Clifton, C.F., Ronnenberg, K.L., eds., 2007. *Advancing the fundamental sciences: proceedings of the forest service national earth sciences conference, San Diego, CA, 18-22 October 2004*. PNW-GTR-689. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Table 1. Watershed processes and indicators (Whitall et al. 2004)

Process	Indicator(s)	Variables
	Causal Indicators	
Water delivery	Terrestrial Vegetation	• Diameter • Species • Crown closure • Canopy layers
Sediment yield	Terrestrial Vegetation Erosion	Same as above • Roads in riparian areas • Roads on slopes >30% • Roads crossing streams with gradients 25%
Fire risk	Terrestrial Vegetation	• Diameter • Species • Crown closure • Canopy layers
Streamside shade	Riparian Vegetation (within 30 m of stream)	• Species • Diameter • Crown closure
Large wood delivery to streams	Riparian Vegetation (within 30 m of stream)	• Canopy layers • Species • Diameter • Crown closure
	Wood Removal	• Roads in riparian areas
Channel processes	Floodplain Connectivity	• Entrenchment of low gradient (<3%), with valley bottoms having a valley width index of greater than 2.2
	Bank Stability	• Roads in riparian areas
Aquatic community	Fish Passage Water Availability	• Percent of watershed upstream of fish barrier • Undetermined
	Response Indicators	
Aquatic conditions	Water Temperature Key Pieces of Large Wood Fine Sediment Deposition Pool Habitat	• Water temperature • Number of pieces of large wood per mile • % fine sediment in riffles • Pool frequency

Causal processes data used were derived from spatial GIS data sets including roads, streams, DEMs, and satellite imagery. For current aquatic conditions, Oregon Department of Fish and Wildlife and the USDA Forest Service aquatic habitat surveys provided data sets. Team members used their collective local experience to assign rating criteria, develop ecosystem relationships, and evaluate results.

Model

The Ecosystem Management Decision Support (EMDS) model (Reynolds 1999) was selected to evaluate conditions at multiple scales. EMDS integrates GIS, used to store and display data, with Netweaver. Netweaver is the knowledge base that reflects the team's understanding of indicators and their cumulative condition to define watershed health and is founded on a combination of thorough literature review and the team's collective professional experience. This data set provided the reasoning to assign condition ratings to each indicator, and to describe the relationships between indicators.

The Netweaver knowledge base contains two key design features to evaluate watershed health. First, evaluation curves assign condition ratings to each indicator. Secondly, the model establishes relationships between indicators used to synthesize individual scores to generate a watershed health score.

The knowledge base evaluates the condition of each indicator using a set of curves, known as evaluation curves. These curves evaluate the proposition: "This watershed is in good health". Indicator scores range from +1, the indicator supports the healthy watershed proposition, to -1, the indicator does not support the proposition. Figure

Table 2. Indicators and evaluation criteria.

Indicator	Variables	Determination*
	Causal Indicators	
Terrestrial Vegetation	• Diameter	• 0” = -1; 10” = 0, 30”= +1
	• Species	• Hardwood = 0; Mixed and conifers = +1
	• Crown closure	• <10% = -1; 10-20% = 0; 50% = +1
	• Canopy layers	• 1 = 0; >1 = +1
Riparian Vegetation	• Species	• Hardwood and mix = 0; Conifer = +1
	• Diameter	• <5” = -1; 5-15”= 0; >30”= +1
	• Crown closure	• <5% = -1; 10-20% = 0; >60 = +1
LWD recruitment	• Ratio of mi. rd. to mile of stream	• 0 = +1; 0.4 = -1
Roads in Riparian Zone	• Mi. of rd. per sq mi on slopes 60+%	• 0 = +1; 1 = -1
Roads on Steep Slope	• # roads crossings/ sq. mi. over streams with slopes 25+%	• 2 = +1; 4 = -1
Road-stream Crossing	• Species	• Hardwoods= 0; Mixed and conifers= +1
Riparian Vegetation-	• Diameter	• <5” = -1; 5-15”= 0; >30”= +1
Shade	• Crown Closure	• <30% = -1; 70% = 0; 90% = +1
Floodplain Connectivity	• Canopy Layers	• Single = 0; Multiple = +1
	• % of low gradient valley bottom streams	• 50% = -1; 10% = +1
	with an entrenchment ratio < 2.2	• 0 = +1; >20%= -1
Fish Passage	• Percent of watershed upstream of fish barrier	• 0.25 = +1; 0.75 = -1
Water Availability	• Ratio of consumptive water use to natural august flows	• Range subdivided into thirds: Cooler 1/3 = +1; Middle 1/3 = 0; Warmer 1/3 = -1.
	Response Indicators	
Water Temperature	• 7-day maximum water temperature in relation to range of recorded temperatures of similar watershed size	• 8 = -1; 18 = 0; 29 = +1
Key Pieces of Instream Wood	• Number of pieces of large wood/mi.	

** Rating: +1 represents full support of the proposition (the watershed is in good health); 0 represents moderate support, undetermined; -1 represents no support for the proposition. With score values along the Y-axis(from -1 to +1) and existing condition along the X-axis, the points are to be connected creating a graph depicting value/score relationship.*

1 displays an evaluation curve for the indicator pool frequency expressed as number of channel widths between pools. Table 2 lists all indicators and the values used to generate evaluation curves.

The ability to assign a range of values has a distinct advantage over procedures using a dichotomous choice, such as either good or bad. Threshold values that distinguish between healthy or unhealthy rarely exist in natural systems. Rather, there is a gradient of conditions existing between the two extremes; this gradient is captured in the rating curves. The curves provide a more accurate expression of our knowledge by expressing the full spectrum of conditions.

In this study, the EMDS model assesses causal processes health and instream response conditions independently, and uses a hierarchal evaluation. The framework for the model that expresses scoring and relationships is the

Figure 1. Pool frequency evaluation curve.

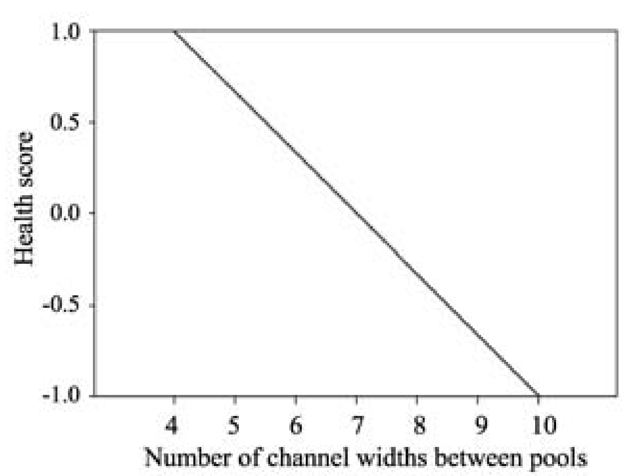
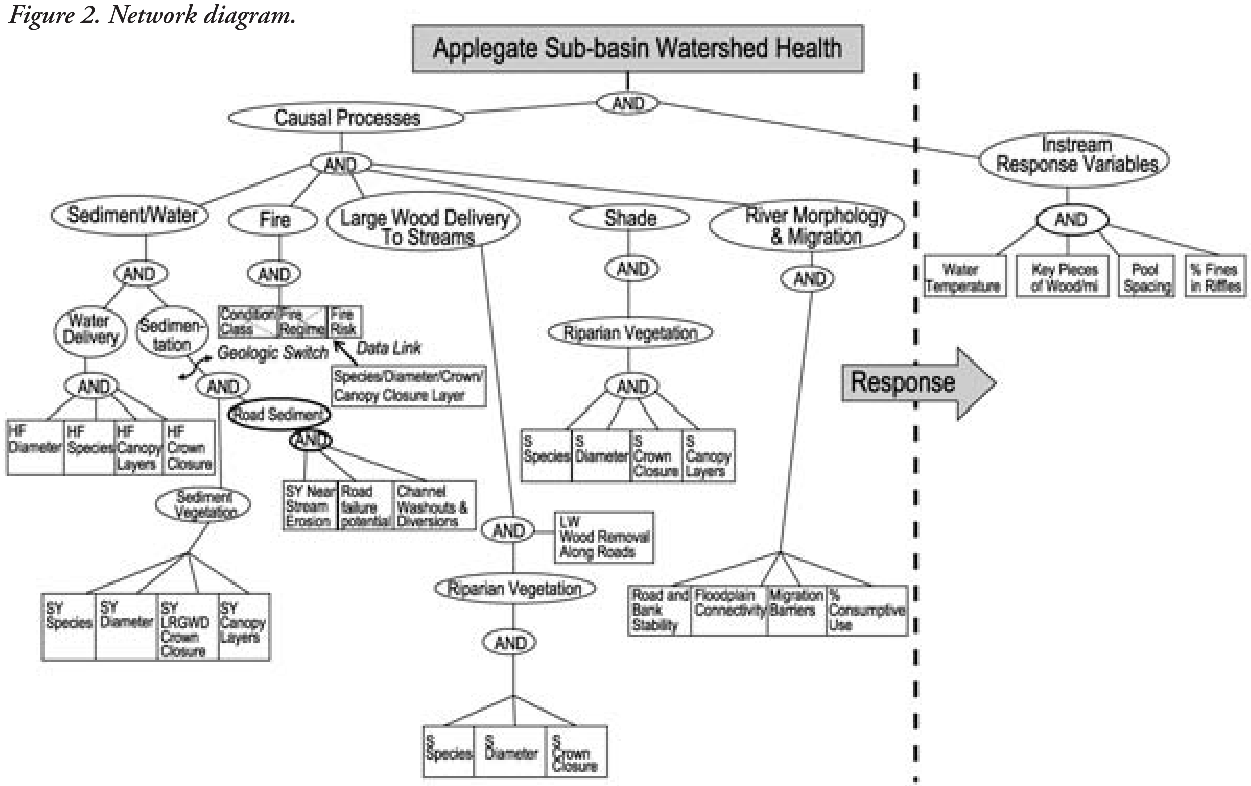


Figure 2. Network diagram.



network diagram (Figure 2). The lowest tier of information, represented by indicator scores, is synthesized providing an interpretation of a watershed process. Each watershed process is then integrated to establish watershed scale evaluation. For example, large wood delivery to streams is the combination of vegetative conditions (species, diameter, and crown closure) and wood removal along roads. The wood delivery to streams is synthesized with all related processes (water delivery, sediment yield, fire risk, streamside shade, large wood delivery, channel-floodplain connectivity, and aquatic connectivity) to generate causal processes health. Aquatic condition health is determined by combining indicators for instream large wood, water temperature, fine sediment, and pool frequency.

The separation of processes and response in the model offers the opportunity to substitute knowledge of process information for current instream condition and vice versa. Namely, if instream wood levels are not known, conditions can be inferred by the condition of wood recruitment and removal processes. Conversely, information on current instream wood levels reflects the process of wood recruitment. Thus, watershed health can be determined by either process-based or response-based conclusions.

Results

Due to the transparency of the model, as the evaluation curves, data input and network diagram were agreed upon prior to output results, outputs were deemed reasonable and defensible during peer review. Additionally, the Applegate River sub-basin maintains a strong collaborative monitoring program, providing a means to verify EMDS model output. When compared to monitoring data, model outputs accurately reflected observed conditions at the 6th-field sub-watershed level.

Recognizing that fire risk was high across the basin, influencing scores for all 33 sub-watersheds in the Applegate River watershed, results of causal processes were examined including and excluding fire. With the inclusion of fire risk, 29 of the 33 sub-watersheds rated in poor health. Excluding fire, the analysis rated 21 sub-watersheds in poor health. Of the 12 sub-watersheds rated healthy, nine are located above Applegate Reservoir where federal management predominates.

While the risk of fire influenced negative scores for watershed health, loss of floodplain connectivity and migration barriers led to poor health scores in all but three sub-watersheds below Applegate Reservoir. Other indicators lowering watershed processes health scores included high numbers of road/stream crossings and roads in riparian zones.

Similar to causal processes, instream conditions were generally in poor health, with 25 of the 33 sub-watersheds in the Applegate sub-basin receiving negative scores. Only five showed support for healthy watershed conditions. A lack of large wood and associated lack of pool habitat were primarily responsible for poor aquatic conditions. Large woody debris functions to dissipate energy, store sediment, form pools, and provide cover and velocity refugia. In the absence of wood, channel processes become simplified, reducing channel complexity. Combined with a system-wide loss of floodplain connectivity, which provides off-channel habitat and pool formation, pool and rearing habitat has greatly decreased in both moderate gradient and low gradient channel reaches.

Cumulative Effects

At the Applegate River watershed scale, the results show that 100% of the 6th-field watersheds received a poor health score for floodplain connectivity. Seventy-five percent of the watersheds received a poor rating due to lack of large woody debris and pool frequency, while 60% received a negative score due to fish migration barriers.

A number of indicators, when examined together, can reveal cumulative effects that are integral to establishing restoration priorities. Whitall (2004) identified four particularly important process/condition interactions that greatly reduce watershed health and resiliency:

(1) ***Water temperatures and fish migration barriers.*** Flows in salmon spawning areas, typically in the lower gradient reaches, become low and warm during the summer months. Juvenile fish, with the presence of barriers, are unable to access cooler water, resulting in poor survival.

(2) ***Sediment yield and key pieces of wood per mile.*** Large roughness elements create complexity by sorting and storing sediment, as well as providing areas of quality habitat. In the absence of large wood, sediment deposits uniformly across the bed surface.

(3) ***Key pieces of wood per mile and floodplain connectivity.*** The principle mechanisms for pool formation are large wood in moderate gradient reaches and lateral channel movement, both of which create sinuosity in lower gradient reaches. Losing both large wood and meandering creates a lack of complex habitat throughout the length of the stream (i.e., longitudinal profile).

(4) ***Floodplain connectivity and water availability.*** Lowering channel bed and water surface elevations can drastically reduce the adjacent water table. Maintenance of the water table within riparian zones is necessary to preserve wetlands and diverse riparian vegetation.

A third of the Applegate sub-watersheds received a negative score for water temperature/migration barriers and floodplain connectivity/water availability indicator pairs. Negative scores for the indicator pairs of sediment yield/instream large wood, and instream wood/floodplain connectivity were found in 25% of the sub-watersheds.

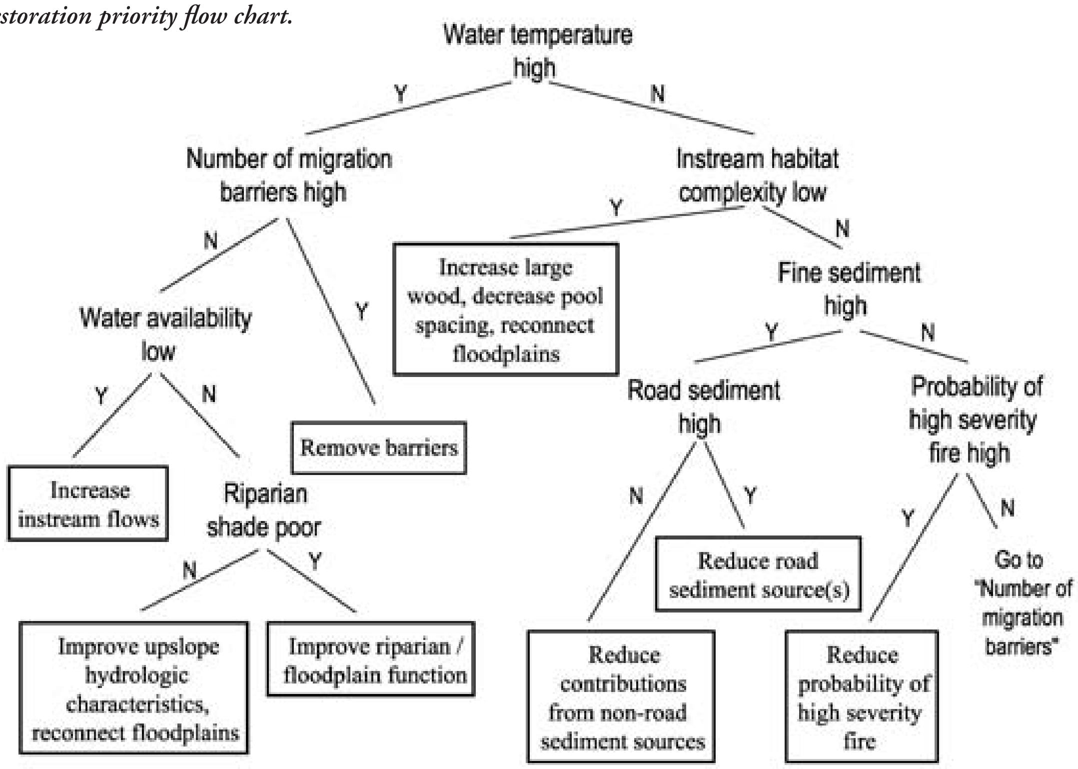
Across the Applegate River watershed, the upper reaches afford better watershed health conditions. The team determined that the lower gradient valley bottom reaches fail to support healthy watershed conditions. These low gradient valley bottoms provide the highest potential structural and biological diversity. Healthy stream channels in low gradient systems contain side channels, alcoves, pool-riffle sequences, undercut banks, off-channel wetlands, and gravel bars. Low gradient floodplain areas also provide conditions for diverse riparian plant and animal species. For a number of species, including coho salmon (*Oncorhynchus kisutch*) and steelhead (*O. mykiss*), unhealthy conditions of the valley bottoms contribute to population declines and inhibit the opportunity for recovery.

Recommendations

Based on the results of the analysis, the team developed a flow chart identifying restoration needs in the Applegate River sub-basin (Figure 3); this chart could apply equally to many watersheds in southwest Oregon. In sub-watersheds with poor water temperature, restoration actions should focus on removing barriers to allow free movement of cold-water aquatic organisms to thermal refuge areas and increasing base flows. Other restoration actions, though potentially needed, will provide little benefit until water temperature conditions are addressed. In those watersheds with reasonable or good water temperatures, restoration actions should be directed at providing high quality structural habitat (i.e., complex cover, pools, and off channel habitat) and reducing sediment where appropriate. A combination of road improvements and placement of large wood in channels in watersheds with significant increases in erosion is recommended. In the short term, wood provides flow velocity complexity, creating scour and sorting of gravel, partially mitigating high sedimentation rates. Long-term restoration may require road and culvert improvements or removal. Re-establishing healthy riparian vegetation, particularly conifers, and providing the stream access to its floodplain will reduce erosion and contribute to increased habitat complexity.

Final recommendations followed a trend with ownership and elevation. In the upper watershed areas, predominately managed by federal agencies, increasing large woody debris and reducing roads in the riparian zones were the top recommendations. Channel types in the federal land allocations typically have moderate to high gradients with little floodplain development and maintain full surface flows throughout the summer. However, wood removal practices combined with riparian harvest have left many channels lacking large instream wood. In the low gradient

Figure 3. Restoration priority flow chart.



reaches, improving water temperature, instream barriers and floodplain functions were the most frequently recommended actions. Consumptive uses and alteration of channel courses via direct modification have reduced both shade and streamflow volume, leading to increased water temperatures. When these effects are added to instream barriers that prevent migration, there is a basin-wide reduction in salmonid rearing habitat.

The EMDS analysis successfully identified restoration priorities for both moderate- to high-gradient and low-gradient areas of the Applegate River sub-basin. Accomplishing the restoration actions may be problematic, particularly in lower-gradient areas where private ownership predominates. Cooperation and collaboration among agency managers, watershed councils, and local landowners will be necessary to meet these objectives.

Acknowledgements. This manuscript summarizes the collaborative work conducted by the Rogue River Basin Technical Team. The team represents a wide range of expertise and skill profiles necessary to accomplish watershed scale planning. Cindy Ricks-Meyers, geomorphologist for the South Coast Watershed Council; Brian Barr, fisheries Biologist from the World Wildlife Fund; Dr. Tom Atzet, retired ecologist from the Rogue-Siskiyou National Forest; Debbie Whitall, policy analyst from the Washington Office of the Forest Service; and Mike Mathews, hydrologist from the Medford Bureau of Land Management developed the watershed health model and restoration strategies.

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Klamath Adjudication–Lessons Learned

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Beginning in 1990, the Forest Service and the U.S. Department of Agriculture, Office of General Counsel (OGC) became intensely engaged in developing federally reserved claims to be filed in the Klamath River basin water rights adjudication. With no data and no inventory of water uses on the three forests in two regions covered by the adjudication, the Forest Service and OGC began what looked at first to be a monumental task. Not only were claims developed, but also the underlying hydrologic information and analysis tools to support such claims. In addition, a unique instream flow protection claim pursuant to the Organic Act was developed. After claims were filed, the Forest Service, OGC, and U.S. Department of Justice (USDOJ) presented preliminary evidence to the Oregon Water Resources Department (OWRD) to assist in its preliminary determinations of the validity of the Forest Service water right claims. After the preliminary evaluations were issued by OWRD, various claimants and water rights holders in the Klamath River basin filed over 1000 objections to Forest Service claims. The Forest Service and OGC met with the various objectors and were able to resolve all objections without contested hearings. This paper discusses the steps taken to assure success in this most contentious of situations, and lessons learned in conducting such complex litigation.

Keywords: *water rights, adjudication, instream flow*

History

The Klamath Basin Adjudication was initiated in 1975 to quantify all federally reserved water rights and state law based rights prior to the date of the Oregon Water Code, 24 February 1909, on the waters of the Klamath River and its tributaries, located in the state of Oregon. Shortly thereafter, litigation between the State of Oregon and the Klamath Tribe (Tribe) was started over whether the Tribe retained a water right after sale of former reservations lands, and if so how much.

The Federal Courts, through the Adair decisions issued by the United States District Court for the District of Oregon and the 9th Circuit Court of Appeals, held that the Klamath Tribe retained a water right initially reserved under its treaty of 1868, but left to the State of Oregon adjudication proceedings the determination of the quantity of that right. (United States v. Adair, 478 FS 336 (Dist. OR 1979) aff'd 723 F.2d 1394 (9th Cir. 1983)).

The State of Oregon issued a notice to the federal government, requiring that federally reserved claims be filed by 1 February 1991. The United States then filed its own action against the State of Oregon, challenging the adequacy of the procedures in the Adjudication, arguing the procedures did not meet the requirements of the McCarran Amendment. The United States lost its challenge of procedural issues. However, the Court held that the United States could not be required to pay filing fees to the State of Oregon.

Challenges of the Adjudication

Pursuant to federal case law, when Congress reserves land from the public domain, such as for a national forest, a reservation of water to fulfill the purposes of the reservation is implied.

Obtaining federally reserved water rights for the Forest Service in the Klamath Basin Adjudication was a challenge. The State of Oregon had never before granted federally reserved water rights in any of its adjudications. The listing of fish species as threatened and endangered was just beginning in 1990. The public in the Klamath River basin was generally suspicious of the federal government, with some ranchers warning that the granting of instream reserved rights was just a veiled attempt to stop all irrigation in the basin.

Early on, the Forest Service arranged a meeting with the Director of the Oregon Water Resources Department (OWRD). In this meeting the Forest Service explained the benefits of instream rights that might be granted, including the benefit to maintaining and enhancing habitat of recently listed fish species. This meeting helped to

Furniss, M.J., Clifton, C.F., Ronnenberg, K.L., eds., 2007. *Advancing the fundamental sciences: proceedings of the forest service national earth sciences conference, San Diego, CA, 18-22 October 2004*. PNW-GTR-689. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

convince OWRD that Forest Service instream rights might help soften the impact of the listing of fish species under the Endangered Species Act, and gained the Forest Service considerable credibility.

Through the process, the Forest Service had to deal with this laundry list of challenges:

1. Determining what rights the Forest Service should file, and on what theories.
2. Hydrology – How much water is there in the Klamath River basin, how to calculate those flows, and what to do about the lack of flow data in the basin.
3. Klamath Tribal Claims – as outlined in the Adair decisions, discussed earlier.
4. Endangered Species Act and listed species in the Klamath River basin – How would the listing of fish species effect operation of Federal irrigation projects in the Klamath River basin?
5. Bureau of Reclamation/Klamath Irrigation Project – who owns the water right for lands in the project area: Bureau of Reclamation, the irrigation districts, or the private land owners.
6. Operation of the Klamath Irrigation Project and priorities among the irrigators.
7. Downstream fisheries.
8. Walton irrigation rights – claimed by individuals owing lands formerly owned and farmed by Tribal members.
9. The Klamath Compact, between the states of Oregon and California, governing management of this two-state basin.
10. Claim of the Klamath Tribe for return of former reservation lands.
11. Downstream Tribes – Hoopa and Yurok – They claim their treaty right to salmon harvest is not being met.
12. Dealing with the many differences of opinion and direction among the group members – Bureau of Reclamation, Fish and Wildlife Service, Bureau of Land Management, National Parks Service, Bureau of Indian Affairs, Klamath Tribe and the Forest Service, plus the U.S. Department of Justice.
13. Filing Claims – Based on these Acts of Congress; Organic (instream favorable conditions, instream fire, consumptive), Wild and Scenic Rivers, Wilderness, and Multiple Use Sustained Yield (MUSY).
14. Coordinating science and its application to the claims.
15. Working with the State on the actual mechanics of filing claims – compiling maps, land status documents, consumptive claims by sub-basin.
16. Alternative Dispute Resolution process – what could be gained in that forum.
17. Litigate or Settle

The above issues all had to be analyzed and addressed while developing the claims. Many times the team had to change or modify direction as analysis was evolving.

No other Forest Service region had yet been successful in an adjudication that could provide any guidance, though there were other adjudications at similar stages. Region 6 of the Forest Service (the Pacific Northwest Region) chose to use and develop its own expertise and responses to the challenges listed above.

Results

1. The Forest Service collected all data to support its claims. Now that data is relied upon by almost all other claimants and OWRD. This includes sediment data, flow and stage readings, and habitat rating curves.
2. The Forest Service developed a favorable conditions of flow claim theory and hydrograph that meshed with the hydrology and needs of the Forest Service in the Klamath River basin.
3. Over 1000 instream nonconsumptive and consumptive claims were filed by the Forest Service in a timely manner.
4. The Forest Service quantified fisheries flows. The results are used by the forests for planning purposes; however, MUSY Act-based claims were withdrawn because of prior unfavorable case law.
5. The Forest Service created fire suppression instream claims pursuant to the Organic Act, which were granted by OWRD, resulting in the awarding of almost the same flow amounts as the MUSY fisheries claims that were later withdrawn. This type of claim was first filed in Oregon, and exhibits the creativity of the team in claiming water for National Forest purposes.
6. Over 1000 objections to FS claims were filed by private parties. All objections were settled by the Forest Service without compromising legal and management objectives.

Lessons Learned

In going through this more than ten-year process, the Forest Service and OGC personnel working on the case came up with the following lessons and pearls of wisdom to share with anyone starting work a water rights adjudication:

1. Know your objectives – it keeps the team from being sidetracked, and wasting time and resources.

2. Listen for understanding – you may learn from so-called opponents and see you have more in common than you suspected.
3. Be truthful – it helps gain credibility when trying to resolve differences.
4. Share information – again, it illustrates that there are no ulterior motives.
4. Work towards common goals – understand other claimants' motivations.
6. Cooperate – again, helps gain credibility.
7. Be helpful – it helps to shorten the process.
8. Know your partners' objectives, policies, rules and regulations.
9. Know your opponents' objectives, policies, rules and regulations.
10. Don't lose sight of your agency's objectives.
11. Don't depend on others, i.e., tribal rights on FS lands.
12. Make sure your attorneys understand your science.
13. Don't be afraid to get the lawyers out of the room and talk about what is on the ground.
14. Expertise can and should be local – parties don't like persons outside the area telling them about their areas of expertise.
15. Don't be afraid to come up with your own science.
16. Again, know and keep sight of your objectives – this cannot be repeated enough.
17. Be realistic with your claims – claim just what is needed for forest purposes.
18. Don't be afraid to branch out and be creative when drafting water right claims.
19. Respect the opinions of others.
20. Don't panic; if you are moving forward you will compete the tasks – break down the tasks into smaller, achievable items.
21. Large negotiations don't necessarily solve all issues, but they can solve small issues.
22. The lawyers' objectives may not be the same as yours – keep them focused on the agency's goals.
23 Don't make assumptions.
24. Use time in meetings with the public to educate them on Forest Service goals, benefits to the public and the limits of Forest Service authorities.

Conclusion

Though the Klamath Adjudication is a few years from receiving a final order from the Director of OWRD because of the time needed to address the reserved claims of other federal agencies, the reserved claims filed by the Forest Service have been resolved, and the Director will be issuing virtually all reserved claims filed by the Forest Service. When the final order of the Director of OWRD is issued, it will grant to the Forest Service water rights reserved under the Organic Act for favorable conditions of flow, fire suppression flows and administrative consumptive uses; instream flows for Wilderness Act purposes; and instream flows for Wild and Scenic River Act purposes.

The effort in the Klamath Adjudication was successful because Region 6 Forest Service personnel did not try to solve all issues in the Klamath River basin. General stream adjudications can be successful in meeting Forest Service water needs if the agency concentrates on its specific objectives and direction, as well as mapping out a reasonable strategy. The key to resolving objections and issues with other claimants is being open to scrutiny and the sharing of information.

The Coastal Initiative: Innovative Partnerships to Restore Watersheds

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The Siuslaw National Forest watershed restoration program depends on partnerships, both programmatic and strategic: this paper highlights two of them. The Coastal Initiative, 1998-present, is a cooperative agreement between the Siuslaw National Forest and the local Resource Conservation and Development District. As of this writing, this holistic program has involved twenty-one projects encompassing all aspects of restoration including project planning and design, environmental education, monitoring, and implementation. The success of the Coastal Initiative lies not in isolated projects, but in its multi-faceted approach to implementing a program in which local groups identify local needs. The Karnowsky Creek Restoration began when the local watershed council introduced the concept of a "charette" or rapid restoration design involving graduate students, followed by a participatory bimonthly design review. The Forest Service provided paid staff time, but partnerships with the watershed council and Soil and Water Conservation District contributed private foundation monies and state funds toward completion of the project. Each partner was integral to the success of the project. An $81,000 commitment by the Forest Service leveraged $350,000 in contributions from partners – a 1:4 match. The partners are now implementing contracts on federal lands.

Keywords: *watershed restoration, collaboration, partnerships*

A new management philosophy, declining forest budgets, and the need to recover aquatic species, have encouraged a variety of partnerships to facilitate watershed recovery. This paper highlights several partnerships that helped us grow as a forest, as a program and as a community.

The Northwest Forest Plan (1994) and the Oregon Plan for Salmon and Watersheds (1997) were two important policy documents that initiated a change in the management philosophy of the Siuslaw National Forest, and organized community involvement in local watershed issues through watershed councils. Both of these policies emphasized the need to recognize that everything in the watershed is connected, and that understanding limiting factors throughout the whole watershed, from the ridges to the estuary, is a crucial component of land management. In response to both of these policies, watershed analyses were being done on both federal and private lands.

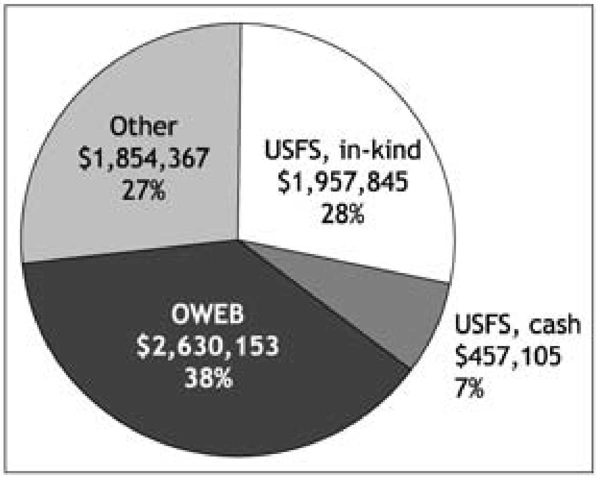
Watershed analysis on the central Oregon Coast documented, for the first time, that while about 85% of perennial stream miles were on national forest land, approximately 80% of coho salmon (*Oncorhynchus kisutch*) spawning and rearing habitat was on private lands below or adjacent to national forest boundaries. It was readily apparent that if the national forest system was going to be actively involved with salmon recovery, we needed to do two things: protect and restore uplands for water quality and quantity, and work with landowners throughout the watershed on stream habitat improvement on low gradient, unconfined stream systems. To accomplish the latter objective, the Siuslaw National Forest needed to work with those entities that already had local contacts, specifically local Soil and Water Conservation Districts, Resource Conservation and Development Districts, state agency personnel, and watershed councils, which were made up of local landowners.

Existing budgets were rapidly declining, as a result of reduced timber harvest activities on federal lands and a higher proportion of the remaining budget was covering salary and overhead costs, so it was clear that appropriated Forest Service funding would be insufficient for the amount of restoration work that needed to be done. Only about 20% of the forest's appropriated fisheries and watershed funding was available for restoration project implementation. We needed to seek supplemental funding elsewhere.

Watershed restoration is not a task that any one entity can take on by itself. There are many groups, both governmental and non-governmental, already actively working to restore conditions for a variety of natural resources, but particularly for coho salmon recovery in coastal watersheds. Many of these groups have common objectives; however, none of them individually has the funding or the technical ability to accomplish large watershed restoration projects. The Siuslaw Watershed Council convenes monthly meetings of many local groups interested in watershed restoration. Over the

Furniss, M.J., Clifton, C.F., Ronnenberg, K.L., eds., 2007. *Advancing the fundamental sciences: proceedings of the forest service national earth sciences conference, San Diego, CA, 18-22 October 2004*. PNW-GTR-689. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Figure 1: Six years of partnership funding on the Siuslaw National Forest.



years, considerable trust and respect has developed among participants. Two or more partners often work together, drawing on the skills of each organization to accomplish shared restoration goals. True collaboration exists not when we seek approval for work we already have planned, attempt to get someone else to do our work for us, or tell someone else what they should be doing, but when the funding, skills, and advice of each group present combine to complete restoration assessments and projects efficiently and in a technically sound manner.

The benefits of developing strong partnerships can easily be portrayed in economic terms. Through these collaborations, between 1999 and 2004, approximately $6.9 million was spent on restoration in the Siuslaw River basin (Figure 1). Direct USFS funding was only 7% of the total; another 28% was in USFS donated salary and supplies (usually large logs for in-stream structures). Partners provided 66% of the funds for restoration with the single largest contribution (38%) coming from the State of Oregon Watershed Enhancement Board.

Working with partners is a huge, long-term commitment, and it requires constant maintenance to succeed. For the Forest Service, internal commitment from the Forest Supervisor, the District Rangers, and the local district staff is essential for partnerships to succeed. And nothing can move forward without the involvement of the contracting and grants and agreement staff; their working knowledge of all the laws and regulations can either keep the process running smoothly or bring everything to a grinding halt. Often partners can apply pressure to ensure this internal support if you cannot obtain it yourself-don't hesitate to ask them for help.

A large variety of tools enable the Forest Service to work with the public and other agencies. First, natural resource specialists should have a working knowledge of all the internal authorities that allow the creation of various types of partnerships. Table 1 lists the agreements and authorities. It's worthwhile to take training about partnership mechanisms, as knowing the ins and outs of those tools will allow you to help guide possible partners through the potentially-daunting paperwork required to set up the agreements. Make it as easy as possible for them to become involved by taking on the burden of the application process yourself. Ask someone to tell you more about the programs on this list if you think they may be appropriate for the project you want to implement.

Second, there are many programs external to the Forest Service that are available for landowners, and often for federal lands if applied for through a partner, that can contribute funding for your projects. Table 2 lists some

Table 1: Agreements and authorities available to Forest Service employees to facilitate partnership development.

Partnership type	Mechanism
Exclusive benefit of the government	Procurements Cost-reimbursable agreements
Support someone else's program	Federal financial assistance Cooperative Agreement / Grant Joint Venture Agreement
Cooperative programs	Memorandum of Understanding Participating Agreement Collection Agreement Challenge Cost-share Agreement INTERagency agreement INTRAagency agreement

Authorities: Wyden Authority, Stewardship Authority

Table 2: Programs providing potential external funding for watershed restoration projects.

Agency	Programs
USDA Natural Resources Conservation Service and the Farm Service Agency	Wetland Reserve Program Wildlife Habitat Incentive Program Conservation Reserve Program Conservation Reserve Enhancement Program Environmental Quality Incentive Program
US Fish and Wildife Service	Partners for Wildlife Coastal Wetland Reserve Program
National Oceanic and Atmospheric Administration	Community Restoration Programs
State Department of Forestry (Oregon)	Forest Land Enhancement Program Forest Resource Trust Forest Stewardship Plan
Non-profit groups (e.g, National Forest Foundation)	Community Assistance Program Matching Awards Program
Other	Easements Exchanges Acquisitions Tax incentives

of the programs, many nation-wide, some state-specific. Find out what is available in your own area. A third critical component of watershed restoration is obtaining funding through grants. Hundreds of organizations have funding available for environmental restoration. However, there are a few things to know about writing successful grants. You stand a better chance of success if you make an effort to participate on boards of local non-profit groups, or volunteer to be on grant review teams, to develop honest and reliable relationships with potential backers. Get to know the source of funds for which you are applying, make a personal contact, explain your idea, and find out whether your project is something they are interested in before you begin to fill out the grant application. Invite potential funders out to your project site, along with your partners. Let your partners do the talking - they make a bigger impression. Then, if you get the grant award, be sure you do what you said you were going to do, make sure your project is technically sound, market the results and always give credit to the funding organization.

Enough of the abstract: how about some real examples of successful watershed partnerships?

The Coastal Initiative and Karnowsky Creek projects are two partnerships developed by the Siuslaw National Forest to accomplish a complex of watershed restoration projects in the Oregon Coast Range.

The Coastal Initiative

The Coastal Initiative, a Cooperative Agreement between the Siuslaw National Forest and Cascade Pacific Resource Conservation & Development District, Inc. (CPRCD), has helped the forest develop outreach to existing local organizations and build capacity to further their on-going efforts. Through this agreement, the USFS supplied both analytical and technical project implementation skills while capitalizing on the contacts that already existed between landowners and these other local groups. The cooperative agreement and several amendments enabled us to have multiple on-the-ground restoration or outreach and monitoring projects active simultaneously. Twenty-one separate projects were included in the Coastal Initiative I 1998-2003. With the Coastal Initiative II 2004-present, fourteen projects are already authorized (Figure 2). The ability to amend the existing agreement on an on-going basis makes the initiative flexible and responsive to local community needs.

The Coastal Initiative pools financial, technical, and social resources to accomplish its objectives. The project is economical and cost effective: with only a 10 % overhead charge, the CPRCD is responsible for project recruitment, landowner agreements, contracts, fiscal management, monitoring and reporting.

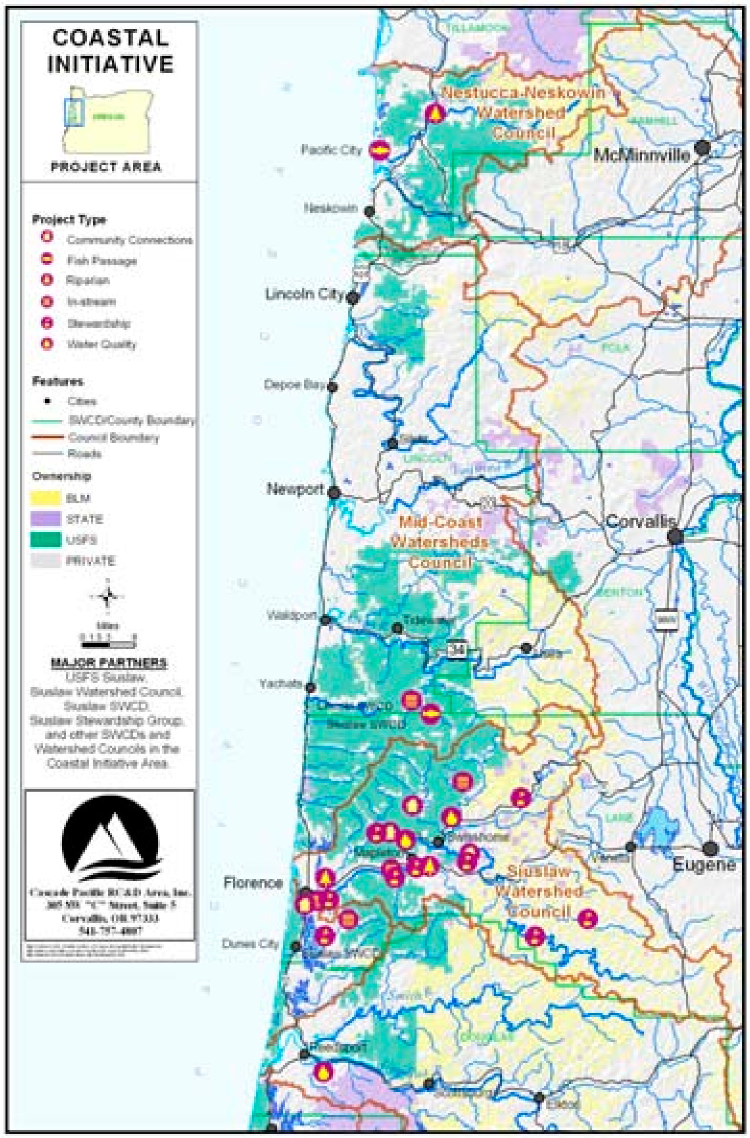


Figure 2. Coastal Initiative sites and types of projects.

Restoration of tidal flow onto an estuarine wetland that has been farmed for over 70 years improves salmonid rearing habitat.

When we first began soliciting outside funding for projects, we found that the single greatest limiting factor in applying for grants is the inability to fund project designs-no granting group will pay for the design, yet they want to see the design before they will approve the project. The Coastal Initiative employed two successful methods to design projects. The first method provided a competitive grant to a local contractor to design stream restoration projects. The grant required the contractor to submit the final design (approved by the local watershed council technical team) in the form of a grant application. The first project of this type designed eight stream restoration projects for $8,000, which in turn brought in additional implementation grants amounting to $250,000. This project was not only successful in obtaining implantation grants, but also in increasing the project design capability of the local community. Since that initial grant, two more projects of this type have been authorized and are on-going. One unexpected benefit of this method is that local contractors are known and trusted in the community and they can often work with landowners whom state and federal agency personnel cannot easily approach.

The second way the Coastal Initiative has found to accomplish project design is to hire an interdisciplinary team of graduate students for an eight-week internship managed by the local watershed council. This student-led project provided graduate students with the challenges of a real-life restoration design opportunity, working in cooperation with local community members and agency representatives (Figure 3). The students bring a freshness, enthusiasm, solid academic background, and phenomenal computer and graphic skills to the project. They respect local input, and through the interactive process of reporting back to an advisory committee every two weeks, they engage community interest and incorporate knowledge that agency staff might not have had time to gather. The

Figure 3. Students from the Mapleton Schools planting native plants from seeds they have collected and grown as part of the Natural Resources curriculum. Funding for the greenhouse came from the Coastal Initiative.

final restoration project design is an easy-to-read document emphasizing graphic design, which is used as a marketing tool to acquire grants. The document content exemplifies the value of stakeholder involvement and partnerships in formulating a successful project design that engages community participation from concept through implementation. Two projects of this type have been completed under the Coastal Initiative. One project was successful in bringing in $450,000 for implementation of the plan; the other, still in phase one, was granted $125,000 for implementation within three months of the final design.

In addition to the above-mentioned projects, the Coastal Initiative has included water quality monitoring, in-stream habitat improvement, education and outreach, fish passage improvement and riparian and tidal wetland restoration. All of these projects filled an important gap in funding to local communities, strengthened local programs, and accomplished technically sound watershed restoration. By being a part of these projects, the Forest Service has increased community trust and support, has been able to identify and propose local projects to restore watershed conditions, and has highlighted data gaps, particularly in the area of water quality.

The Karnowsky Creek Project

Karnowsky Creek was purchased by the Siuslaw National Forest from a private landowner in 1992. When the Northwest Forest Plan was signed, it was apparent to the district that grazing land use occurring in the valley was not in line with current management direction. With encouragement of the Siuslaw Watershed Council, a group of students were brought in to develop a restoration strategy for the area. With the student-generated Karnowsky Creek Restoration design in hand, the watershed council and the Forest Service collaborated to develop a grant proposal for its implementation. The watershed council submitted the grant to the National Forest Foundation to fund the riparian restoration portion of the project, but a watershed council executive board member unexpectedly blocked submittal of the application to the State of Oregon Watershed Enhancement Board (OWEB), stating that he did not support state funding being spent on federal land. However, because the community was integrally involved with the design of the project from the concept phase onward, they felt great ownership in the project and wanted to see it move forward. The local Soil and Water Conservation District then submitted the grant to OWEB. The Forest Service didn't even know these discussions were occurring, but the strength of community investment kept the project going. Both grants were successful in acquiring the funds needed to do the restoration work. Meanwhile the Forest Service completed the necessary environmental documentation. Each partner was integral to the success of the project: a true spirit of collaboration. In this project an $81,000 commitment by the FS leveraged $350,000 in contributions from partners for implementation - a 1:4 match.

Implementation of the Karnowsky Creek restoration continued the unique partnership developed in the initial phases of the project. The Forest Service facilitated the necessary working agreements with the Siuslaw Soil and Water Conservation District (SWCD) and the Siuslaw Watershed Council, resulting in a Memorandum of Understanding that set up a Karnowsky Creek Board of Directors to enhance communications and oversee all activities that occurred within the Karnowsky Creek Valley. Participating agreements with the Siuslaw Watershed Council, the Siuslaw SWCD, and the Siuslaw National Forest enabled the partners to do projects on national forest lands. As a result, the watershed council hired a contractor and facilitated development of the riparian planting design, site preparation, planting, maintenance and monitoring of all riparian species. In addition, the SWCD hired a local contractor to do all road access, stream reconstruction and ditch filling, and hired a monitoring coordinator to facilitate local school involvement in project monitoring. A Forest Service employee was on site to inspect work done by the contractor. The collaboration has been phenomenal, each organization feels ownership in the work that has been done to restore Karnowsky Creek, and we all acknowledge that the project would not have been possible without the enormous contributions of all involved.

It takes innovation, enthusiasm and dedication to engage partners in a whole watershed restoration program. Personalities can be as varied as they are strong willed. Finding and working from common ground, forging alliances wherever necessary, and capitalizing on the skills and knowledge that each group and individual brings to the table is critical to success. The strong partnerships on the Siuslaw have been recognized internationally, receiving the 2004 Thiess International Riverprize for high quality river basin management. The Siuslaw National Forest will continue to be a part of the team that earned that recognition, in the interest of restoring watershed conditions, building strong communities, and fostering a positive relationship between local people and their environment.

The Pathfinder Project:
A Collaborative Effort to Provide for Instream Flow Management

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The Pathfinder Project was a pilot effort initiated by the USDA Forest Service Washington Office and hosted by the Grand Mesa, Uncompahgre and Gunnison National Forest (GMUG) from 2000 thru 2004. Water users, state water officials, local watershed coalitions and conservation organizations met and worked together with the forest to determine how best to provide for instream flow needs in the Forest Plan, while recognizing historic needs and existing laws. Technical work and field investigations involving examination of water rights, diversion points, basin hydrology and comparison of instream flow quantification models were key components and are addressed in this paper. The results of this collaborative effort produced a product different than that envisioned by the Forest Service, but provided a useful critical public perspective on instream flows early in the planning process. The Pathfinder Project has been used as an example of cooperation between the state of Colorado and the Forest Service, in an effort to find common ground on an issue of long standing conflict.

Keywords: *water rights, instream flow, stream diversions, R2Cross method, collaboration, GMUG*

Introduction

Conflicts over water, particularly in the arid western United States, have been and will continue to be a key resource allocation issue facing both elected officials and policy makers. There are many facets to this subject, with instream flows being just one. In states where water is controlled by the doctrine of prior appropriation, water use is considered to be a property right and falls primarily under the jurisdiction of the states. This situation presents huge challenges for federal land management agencies.

In Colorado, instream flow uses are generally looked upon as secondary to consumptive uses, or those uses which capture and control the stream in order to put it to beneficial use. Additionally, instream flows are often very junior to long established agricultural, industrial and municipal uses. The Forest Service must comply with a host of federal laws that direct it to protect the environment and sustain ecosystems. Therein lays the conflict, because without water in stream channels it is impossible to sustain ecosystems.

Colorado has been a real battleground over federal vs. state interests in water. In order to provide water for national forest purposes, the Washington Office was interested in exploring alternatives to litigation, which has historically been costly and less than fully successful. The Pathfinder Project was a Washington Office initiative intended to learn if collaboration could be used as a way to share ownership in water issues and perhaps cut through the contentious and entrenched positions that surround water issues in Colorado. Because the Grand Mesa, Uncompahgre and Gunnison National Forests (GMUG) were initiating a Forest Plan revision, which provides the framework for determining resource management objectives and authorized uses of the national forest, the GMUG was selected as an excellent candidate to test a collaborative process. Water users, state water officials, local watershed coalitions and conservation organizations were brought together for the purpose of assisting the forest in determining how best to provide for instream flow needs in the Forest Plan, while recognizing historic needs and existing laws.

The GMUG is located in western Colorado (Figure 1). These national forest lands are the headwaters for and control about 60% of the Gunnison River basin, which is the largest tributary to the Colorado River within the state. Annual water production is on the order of 2.9 million acre-feet (3,576 million cubic meters), which flows down 3500 miles (5,600 km) of streams. There are 162 reservoirs and 212 ditches authorized by special-use permits or easements on the forests. The Grand Mesa National Forest

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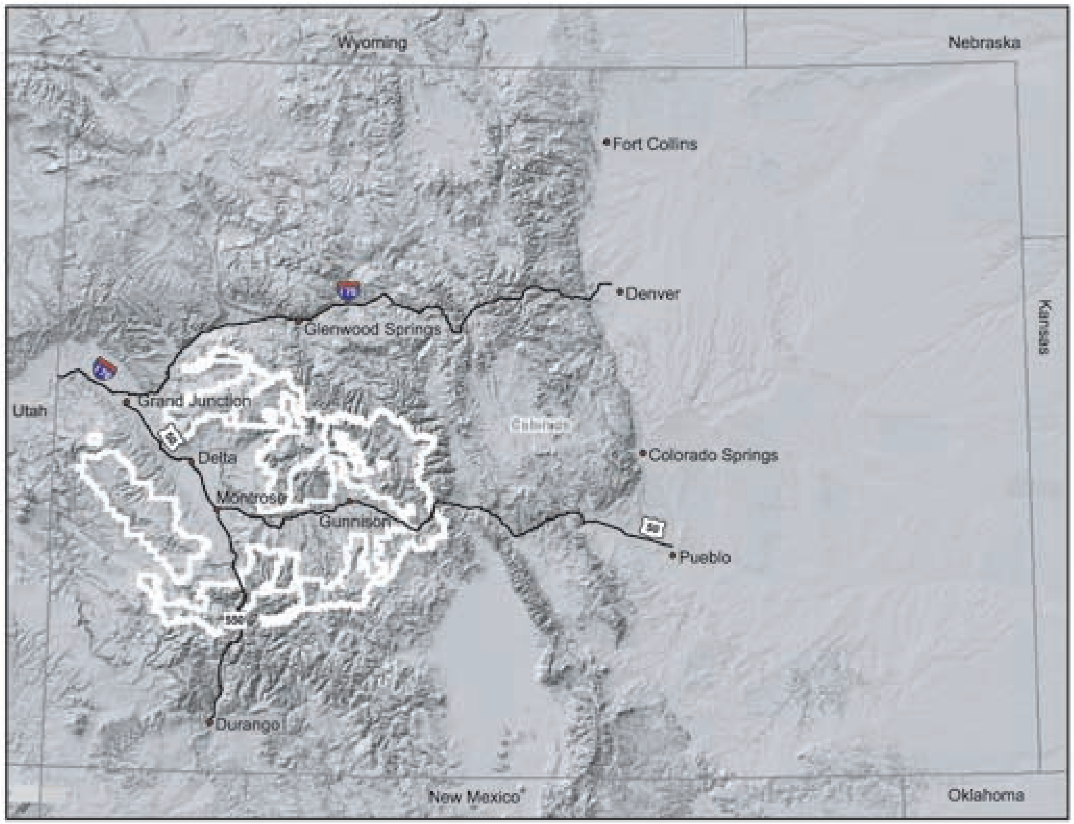
Figure 1. Location of the Grand Mesa, Uncompahgre, and Gunnison National Forests in Colorado.



has more water related facilities authorized than any other national forest in the nation.

Over an approximately three-year period the forest used the extra funding provided by the Pathfinder initiative to undertake a considerable effort to gather and analyze hydrologic data, conduct field investigations and develop both tabular and spatial databases needed to support the project. The efforts can be categorized into four groups. Components of these efforts occurred simultaneously and were often inter-connected. These were:

1) Characterization of flows and basin water yields for the forest;
2) Site investigations of diversion points on the forest;
3) Acquisition of private water right records for locations on the forest; and
4) Comparison of instream flow quantification methodologies and application to a study site on the forest.

A key component of our dialog centered on Colorado's existing instream flow program, which was first adopted by the state legislature in 1974. An issue, which surfaced repeatedly in our citizens work group, questioned whether the state's program, which is based upon protection of "minimum flows necessary to preserve the natural environment to a reasonable degree" (CWCB 1993), can or should be relied upon to meet the more stringent federal environmental legislative mandates of the national forest. The highlighted streams on the map indicate instream flow rights held by the state for streams on the GMUG (Figure 2). Instream flow rights established and held by the state are often very junior, and in some circumstances do not provide any water to the stream, particularly during periods of critical water shortage.

Characterization of Flows and Basin Water Yields for the Forest

In conjunction with the United States Geological Survey (USGS) Water Resources Division, we analyzed existing flow records so that we could better understand the hydrology of our streams. All USGS gage site records, both active and abandoned, were reviewed. Sites were selected that were located on the National Forest or within a few miles of the boundary. Sites with fewer than three years of record were discarded as were those where stream flows were regulated. A total of 60 stations were selected. For all stations with ten or more years of record, an instantaneous peak-flow frequency analysis was performed using the log-Pearson type-III distribution. To the standard set of return intervals, we added the 1.5-year flood, often used to approximate bankfull discharge. The daily mean low-flow and high-flow frequency analysis for 1, 3, 7, 15, 30, 60, 120 and 183 consecutive days was calculated. For all stations with three or more years of record, flow

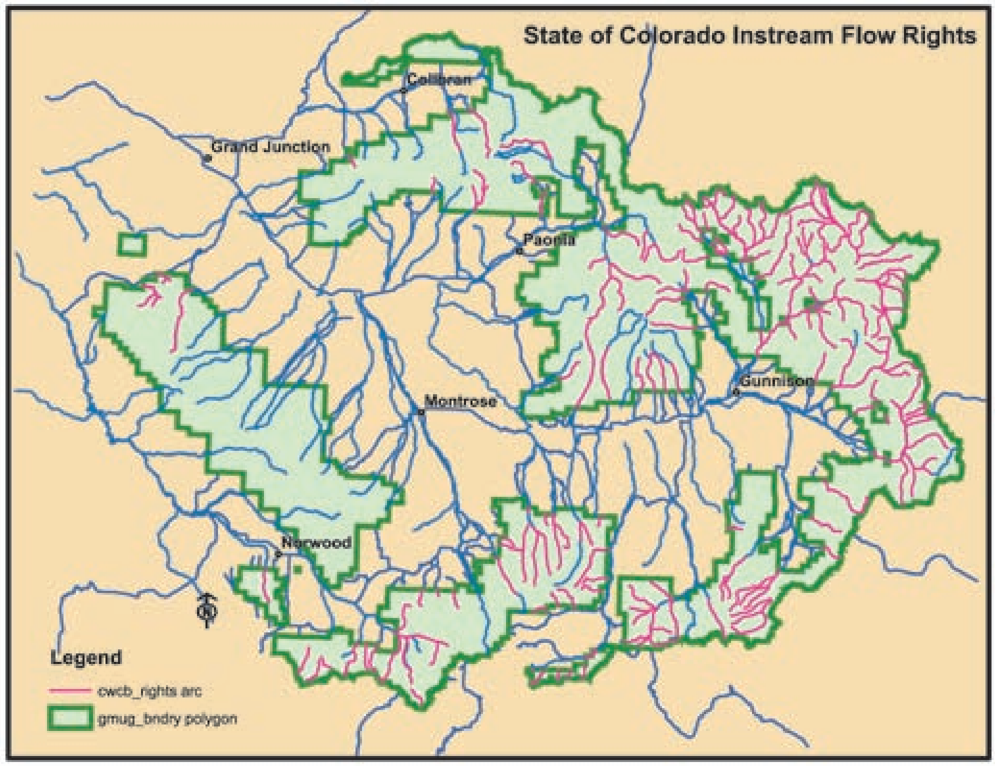


Figure 2. Colorado Water Conservation Board existing instream flow rights on the GMUG.

duration curves using daily means were generated for both an annual and monthly basis (Kuhn 2003).

It was recognized that a lack of long term flow data for headwater streams in the study area would be problematic. In an effort to address this information gap, we selected five sites distributed across the forest for pairing with one or more long-term USGS sites that share hydrologic similarities. Simultaneous discharge measurements taken at the paired sites over a minimum of one full hydrologic cycle were used to estimate monthly streamflow characteristics. In order to get a good representation for the range in flows, sampling was done more frequently during the rising and falling limbs of the hydrograph and less frequently during baseflow periods. At two of the sites, we established continuous water level recorders that allowed us to estimate mean daily flows. The alteration of flow pattern and inundation of the water level recorder due to repeated invasion by persistent beavers (*Castor canadensis*) resulted in the abandonment of one site.

For those basins with no gaging data, we estimated natural streamflow characteristics using published regression equations for western Colorado (Kircher et al. 1985)

Figure 3 is an example of one of the products that was developed from the analysis of flow data. Relative water yield was calculated using mean daily flows projected at the mouth of each watershed. While mean annual flow values are related to basin size, they are primarily influenced by annual precipitation, geology and basin morphology. This information was useful in helping to focus our efforts on watersheds where conflicts may occur with existing diversions or where future water development projects might be expected. In other words, where diversions exist in drier basins, the potential for diminished flow issues is more likely, and similarly, those basins that have greater water production are potentially better suited for future water development demands.

Site Investigations of Diversion Points on the Forest

The field inventory of physical diversions was an interesting and revealing exercise. Our diversion inventory sites were identified by compiling location and attribute information from both Forest Service permits and state water right records. Even though all the structures we visited were under some type of federal authorization, there was often only limited information in our files. We found that in some cases it had been 20 or more years since there was a documented site visit. Our inventory was not sophisticated and did not attempt to quantify flow impacts directly. We employed a two-person crew for three summers, and they inventoried 246 different diversions. The primary attributes recorded were: structure type; evidence of use; maintenance issues; appearance of fish in the stream at the point of diversion; notation of flow measurement devices and channel morphology characteristics, both above and below the diversion point. During the site visit, an estimate was made of the percentage of the stream that was diverted. The estimate of

Figure 3. Relative water yield of watersheds on the GMUG National Forest.

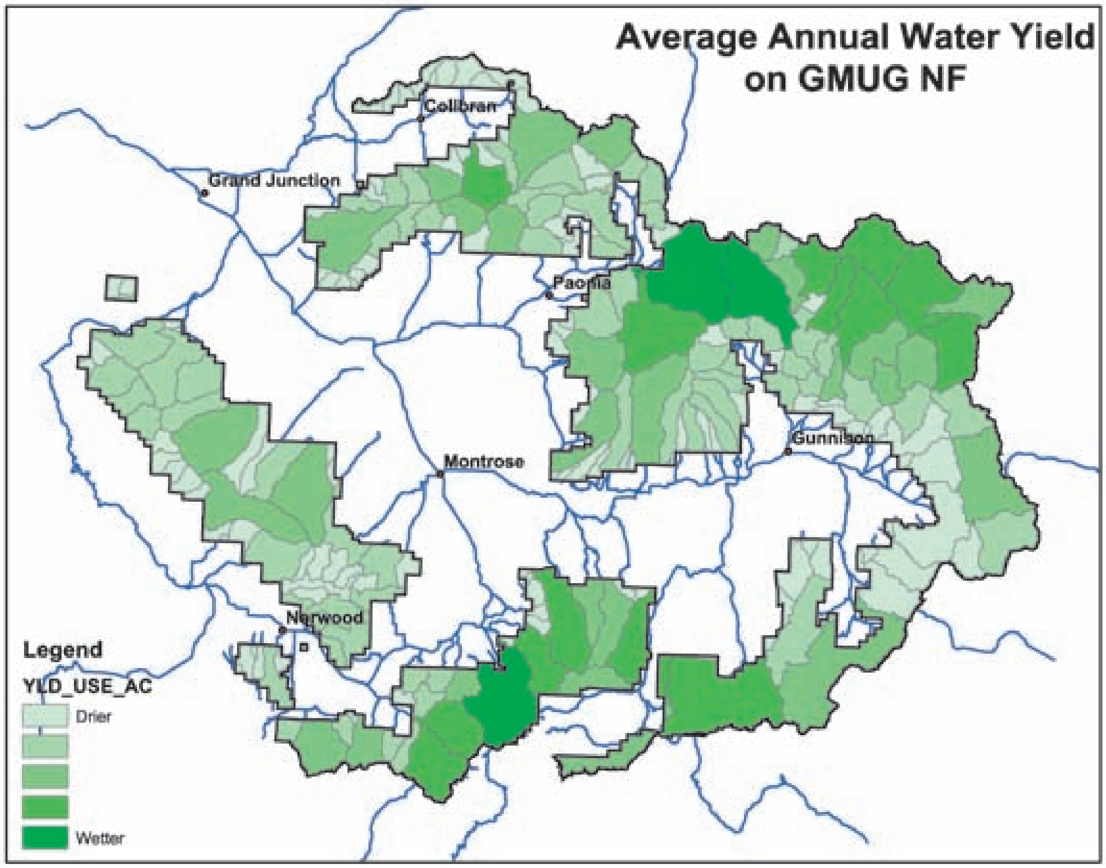
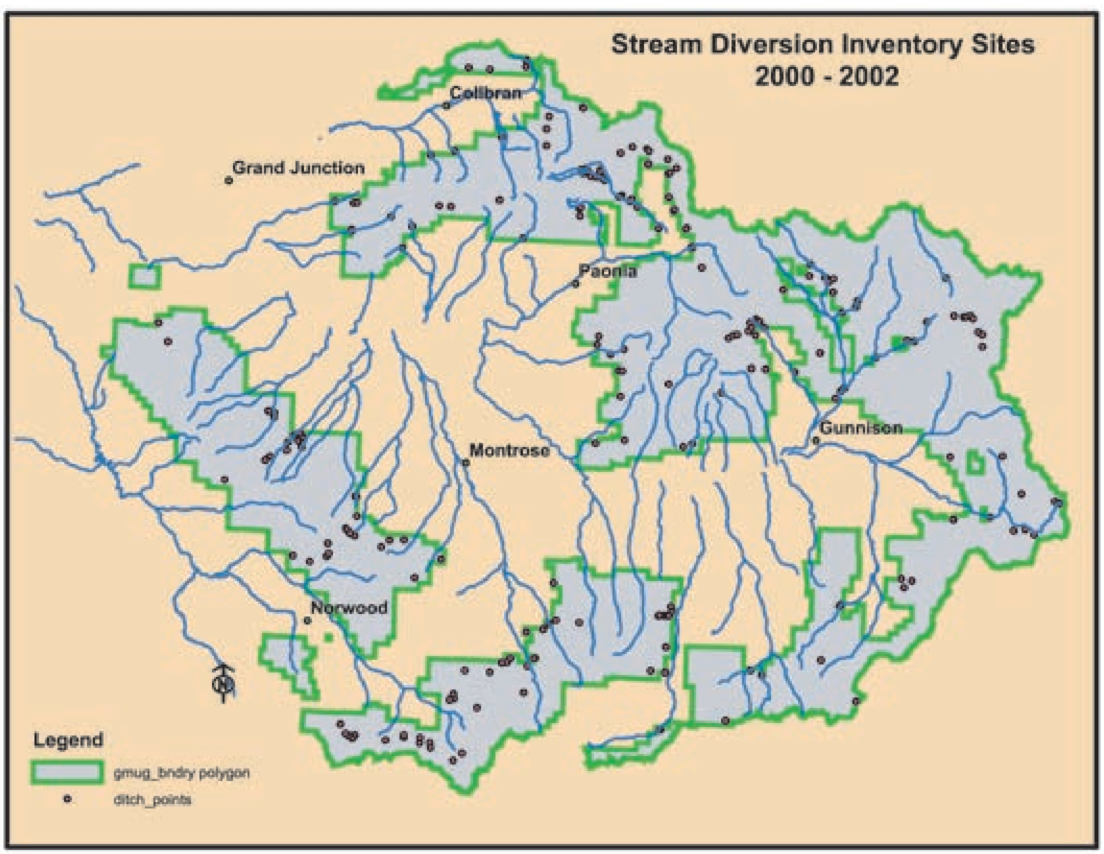


Figure 4. Stream diversion inventory sites on the GMUG NF, 2000-2002.



stream diversion was a key piece of data and was used later to prioritize diversions of concern. However, since our inventory was a one-time visit the estimate on diversion percentage and how it could be used was limited. Digital images were taken and Global Positioning System (GPS) coordinates obtained. This information was used to create a GIS point coverage of diversion sites on the forest with active hotlinks to the digital images (Figure 4). The data from field sheets was used to create a Microsoft Access™[1] data table, which enabled us to sort and query the data. We had enthusiastic support from our lands staff, who recognized that this inventory was going to be very beneficial in evaluating "Ditch Bill" easements and development of operation and maintenance plans. This work proved to be very useful in defining thresholds of concern when used in combination with assigned flow-dependent values and streamflow data for specific basins.

A number of the diversions were well-designed, permanent concrete structures, but most were primitive and made of wood, rock and plastic. Many structures were probably reconstructed, if not every year then every few years, either by hand or with equipment in the channel. Many were barriers to fish passage and virtually none prevented movement of fish into the ditch. While most would be considered small diversions, taking less than 25% of the flow, a few virtually dried up the stream. Most diversions were located within a mile of the forest boundary, but a few were located in the headwaters and were usually associated with a trans-basin diversions or private land inholdings. The farther up in the watershed the original point of diversion was located, the more likely the water transport facility consisted of a series of diversions, ditches and natural channels used to move water to the desired place of use.

Acquisition of Private Water Right Records for Locations on the Forest

The GMUG National Forest has been the source of water for use in surrounding communities and agricultural/industrial uses for more than 100 years. A significant number of water rights were established prior to the creation of the Forest Reserves. There are in excess of five hundred private water rights associated with diversion structures on the GMUG. Each point in Figure 5 represents the location of a private decreed water right.

Electronic water rights records where obtained from the state of Colorado Engineer's Office and used to extract information such as location, type of right (conditional or absolute), quantity and priority. In addition, we obtained records of actual diversions. This was extremely useful in separating a decreed water right flow amount, which is often inflated, from what has been historically diverted. Early in the process we experimented with an examination

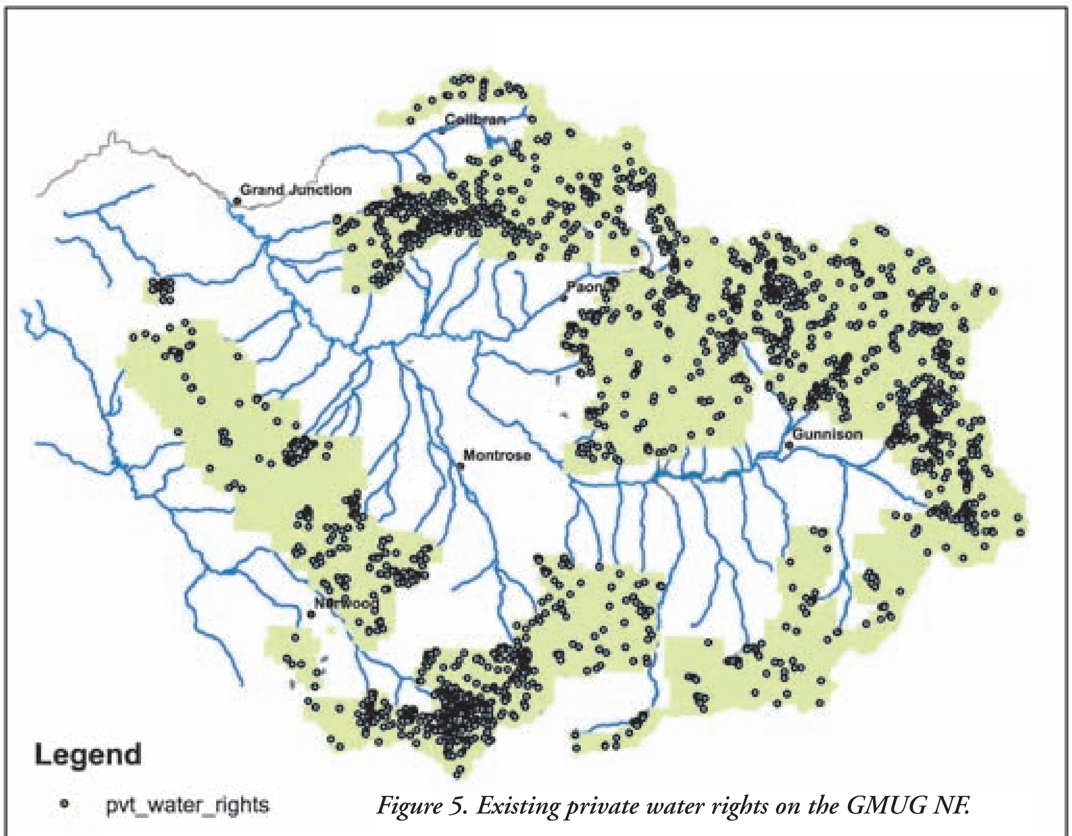
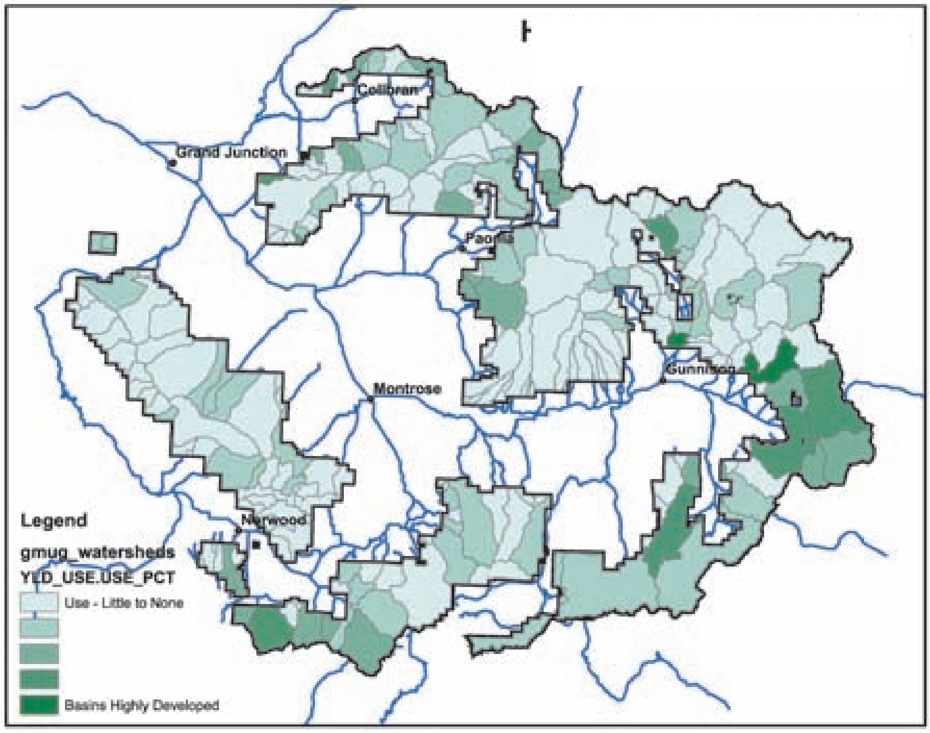


Figure 5. Existing private water rights on the GMUG NF.

[1]The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Figure 6. Historic water withdrawals on the GMUG NF.



of water storage and release records, but quickly learned that correlating reservoir operations with stream flows was a very a complicated accounting problem. As a result, we abandoned the idea of addressing the effects of storage facilities and focused primarily on historic stream diversions.

Given our ability to predict native stream flows and with some indication of how much water is being diverted off for human uses, we were able to estimate how much water is being left in the streams. A determination on whether or not that is enough water to fulfill national forest purposes and public expectations really depends upon the site-specific situation and was not something we could answer in the context of a forest-wide assessment.

Using the information gained from our evaluation of basin hydrology and gaging records, we were able to make projections of basin water yields. When combined with water diversion records associated with identified diversion points, we were able to portray the scale of water withdrawals on the forest as a percentage of yield. (Figure 6) This served as a good communication tool with our working group and the public, and indicated which of our basins are heavily impacted by water diversions. The effects of storage are not considered. The percent of basin yield that was captured and diverted was calculated, whether there were one or many points of diversion. Several basins on the forest have more than 50% of their annual yield captured and removed from the stream, with the largest proportion being 70% of annual yield.

Comparison of Instream Flow Quantification Methods

The West Willow Creek study was intended to look in detail at a representative forest stream and compare several popular instream flow estimation methods. West Willow Creek (Figure 7) is a stream with high flow dependent values, typical in size and morphology of many headwater streams and one with no existing diversions above the study site. The West Willow Creek Study was a joint effort between the Forest Service, Colorado Water Conservation Board and Colorado Division of Wildlife. The field work was done by our integrated team, the hydrology work was done by the Forest Service, and Miller Ecological Consultants did the PHABSIM modeling.

Five methods were examined in detail. The Colorado R2Cross Method (Nehring 1979; Espegren 1996) used by the Colorado Water Conservation Board is based on one or more cross sections and the hydraulic modeling and selection of established width, depth, and velocity criteria intended to provide for "reasonable" protection of aquatic resources. The modified Tennant Method (Tennant 1976), which is based on a percentage of mean monthly flows, is intended to mimic the form of a natural hydrograph. The Wetted Perimeter Method (Nelson 1980; Stalnaker et al. 1995) is obtained by graphing discharge versus wetted perimeter and selecting the inflection point. The Physical Habitat Simulation Method (PHABSIM) requires establishment of multiple cross sections and is resurveyed at different discharges. It results in a determination of the

Figure 7. Field work on the West Willow Creek study.

weighted usable area according to fish species and life stage (Milhous et al. 1989). These four methods are designed to estimate the flows necessary to sustain fish populations. The fifth method used was developed by the U.S. Forest Service with the objective of estimating flows necessary to move sediment and maintain channel morphology (Schmidt and Potyondy 2004). This method requires a determination of bankful discharge and the 25-year return interval flow. Table 1 (see next page) summarizes the characteristics of each method and their strengths and weaknesses.

Using our water level recorder and the 20 discharge measurements we made over a two-year period, a correlation was established between the West Willow site and a nearby USGS gage, and estimates of mean daily flow values were derived. The mean annual peak is approximately 22 cubic feet per second (cfs) (0.62 cubic meters per second [cms]) and the mean base flows are 3 to 4 cfs (0.085 to 1.13 cms). Bankful discharge is estimated at 17.5 cfs (0.5 cms).

Upon completion of fieldwork and analysis of the data, we compared the resulting protection flows that were determined from either application of standards or interpretation by staff. These results were overlaid on the mean annual hydrograph, which was synthesized by correlating short term mean daily flow records at our study site with long term records at a nearby USGS gaging site (Figure 8).

The Tennant method tracks the hydrograph well, as expected. Applying the standards used for R2Cross resulted in a 1.6 cfs (0.045 cms) winter flow and 2.6 cfs (0.074 cms) summer flow protection recommendation. Interestingly in this case, the Wetted Perimeter (5.7 cfs [0.16 cms]) and PHABSIM (5.0 cfs [0.14 cms]) flows were very similar. PHABSIM could be interpreted for seasonal variability but to date this has not been done for this study. In order to provide for sediment transport and periodic disturbance of sufficient magnitude to maintain fluvial processes, flows would need to be protected once they exceed 80% of

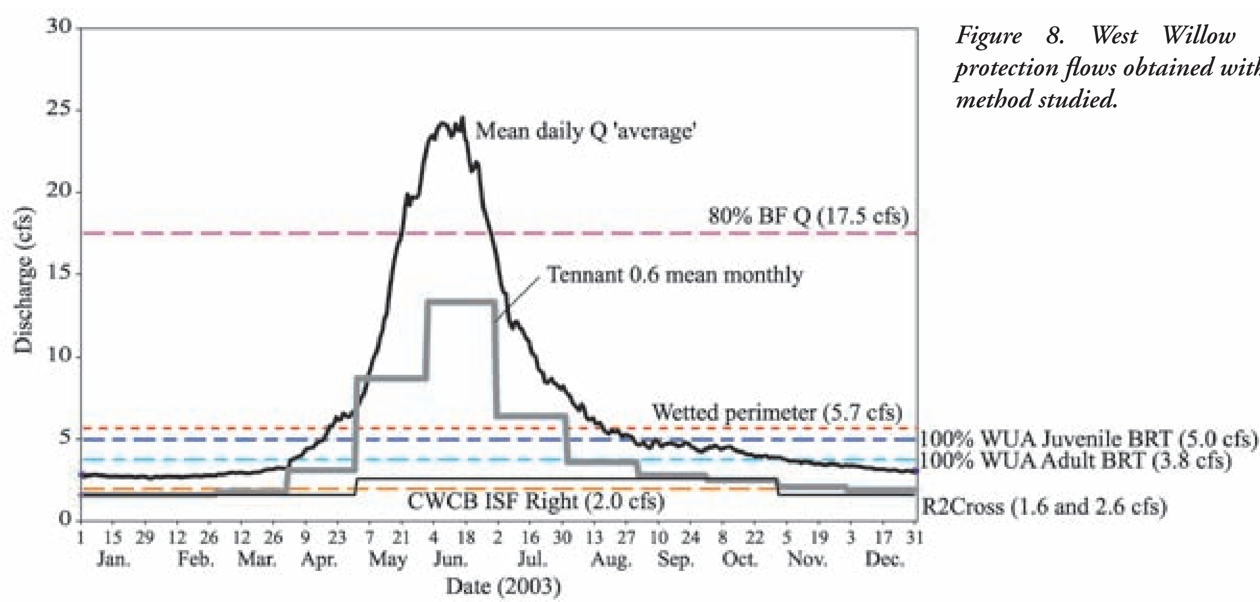


Figure 8. West Willow Creek protection flows obtained with each method studied.

Table 1 - Comparison of instream flow quantification methods.

A. General Characteristics of ISF Methods

	Hydrology Based	Field Based	Existing Standards	Time/Cost Efficiency
R2X	No	Yes	Yes	Moderate
PHABSIM	No	Yes	No	High
Tennant	Yes	No	Yes	Low
Wetted Perimeter	No	Yes	No	Moderate
Channel Maintenance	Yes	No	Yes	Moderate

B. Pros and Cons of Each Methodology

R2Cross

Pros	Cons
Data gathering in short period of time	Modeling limitations - Current version of R2X doesn't allow Manning "N" to vary with changes in modeled flows (modeling accuracy constrained to 0.4 to 2.5 times measured flow)
Inexpensive	Only addresses in-channel fishery needs, mostly used for trout
There are accepted standards	No flexibility of standards
Data and results are reproducible	Doesn't address out-of-channel needs or invertebrates
Looks at "reasonable protection" of trout	Doesn't' address pools w/in Manning's equation (assumes that maintaining riffle habitats will also maintain pool habitats)
Institutionally accepted by the State of Colorado	TU says amounts are too low
R2Cross-based ISF recommendations have been used by the state to "preserve the natural environment to a reasonable degree" since 1973.	Doesn't deal with flushing flow or channel maintenance
	Doesn't deal with impacts of changes of velocity on fish (is not an issue on Willow Creek, is an issue on the GMUG)
	Have we been able to calculate if R2X provides a "reasonable level of protection" since the 1979 standards setting?

PHABSIM

Pros	Cons
Very adaptable/more variables	Labor intensive/ expensive
Deals with habitat types other than riffles	"Illusion of technique"
Deals with life history of fish species	No relationship between WUA and fish
Facilitates looking at tradeoffs of different flows	Takes 1 year to develop data
Learn more about the stream	No standards - difficult to defend in legal arena
Useful where we need more detailed analysis (in a high conflict area, may be a useful tool)	Difficult to interpret results
	Difficult to apply across all of the GMUG
	Consistency of analytical technique--the different variables can lead to subjectivity

Tennant (Montana Model)

Pro	Con
Inexpensive	No clear standards
Don't have to go to field	Relies on professional judgement
Ball park answer	May not have records, rely on empirically derived estimates which may be inaccurate
Accounts for full range of flows	
Based on actual records, where they exist	
Commonly used/easily applied	

Table 1 continues on next page.

Table 1. (continued)

Wetted Perimeter

Pro	Con
Can be evaluated with data using several hydrologic models	Inflection pt. can be subjective based on channel type
	Requires fieldwork
	Is a single flow recommendation rather than a two stage one
	No biological component

USFS Channel Maintenance Method

Pro	Con
Looks at channels maintaining the system, moving the sediment, plus benefits to habitat	This process may not necessarily create a "healthy" stream
Has side benefits related to over bank flows and recharging banks/ground water	Difficult to administer
Simple model	If you have in system storage there is more difficulty in meeting flow requirements
Easy to calculate discharge requirments until bank full level level is exceeded	Not as applicable below dams for determining flow releases
Greater applicability to some stream types	Above bank full flows discharge levels difficult to determine
Has very specific standards	Some stream types not applicable
	Works best where sufficient flow data exists to conduct frequency analysis

QBF (bankfull discharge), which is 14 cfs (0.40 cms), and protection would continue until flows exceeded the 25-year flood event (61 cfs [1.7 cms]).

The consequences of instream flow protection on limitations to potential channel storage projects are presented in Table 2. This table displays West Willow Creek's total average basin water yield of 4,986 acre-feet (6,147,738 m^3) and the amounts and percentage of yield that would still be available above protection levels and therefore available for storage. The values range from a low of 21% of annual yield when the objective is to provide for both channel maintenance and adult brown trout (*Salmo trutta*) habitat needs, to a high of 69% of the annual yield when protection is based upon standards used in R2Cross.

Collaborative Process

The Pathfinder project involved a lengthy collaborative process. True collaboration involves meaningful dialogue between stakeholders and differing points of view provide for a broader approach to management options. While total agreement is rare, the outcome of collaboration is a function of many minds rather than a few. The "front loading" of stakeholder involvement is a departure from the traditional federal agency process where agency scientists and specialists work out a plan or system of strategies then release the results to the public for review. Collaboration early on, brings issues to the forefront sooner rather than later. It attempts to address a full array of concerns, build consensus, and have participants attain a level of ownership in the outcome. Key to any collaborative approach is a group of stakeholders committed to the process, the outcome, and representative of a large array of public perspectives.

The Pathfinder Steering Committee began meeting in May 2000. The Steering Committee was a diverse group of individuals representing the perspectives of organizations or entities concerned with water-resource use and management on national forest lands, private water users, local water purveyors and managers, state regulatory and management interests, and conservation and environmental perspectives. Individual participants and their organizations included: Reeves Brown (Club 20), Charlie Stockton (Ute Water), Peter Kasper (Overland Ditch and Reservoir Company), Steve Glazer (High Country Citizens Alliance), Stan Irby (rancher), John Trammell (Trout Unlimited), Nathan Fey (San Miguel Watershed Coalition), Dan Merriman (Colorado Water Conservation Board), Wayne Schieldt (Colorado Division of Water Resources), Ron Valvarde (Colorado Division of Wildlife), Bob Storch and Carmine Lockwood (U.S. Forest Service). This group held 45 meetings and conducted several public outreach efforts to address instream flow issues and management for the GMUG.

Over time, the interest of the Steering Committee became clear and they focused much of their work addressing two major perspectives on providing for instream flows: (1) Bypass flows, meaning a federal action that imposed regulatory control by administratively requiring a

Table 2. Water available for withdrawal in West Willow Creek.

	Flow Protection		Necessary for Instream Flows (AF and % of total)	Available for Development (AF and % of total)
Average Basin Yield = 4986 AF				
Existing CWCB ISF Claim	2.0 cfs Jan - December		1450 (29%)	3536 (71%)
R2X Method	1.6 cfs Nov - April 2.6 cfs May - Oct		1526 (31%)	3460 (69%)
Tennant Method	Jan. - 1.6 cfs Feb. - 1.6 cfs March 1.8 cfs Apr. - 3.1 cfs May - 8.7 cfs June - 13.3 cfs	July - 6.4 cfs Aug. - 3.6 cfs Sept. - 2.8 cfs Oct. - 2.5 cfs Nov. - 2.1 cfs Dec. - 1.9 cfs	2977 (60%)	2009 (40%)
Wetted Perimeter	5.7 cfs, Jan - Dec		3118 (63%)	1868 (37%)
PhabSim (Juvenile) Method	5.0 cfs, Jan - Dec		2941 (59%)	2045 (41%)
PhabSim (Adult) Method	3.8 cfs, Jan - Dec		2526 (51%)	2460 (49%)
Channel Maintenance*	14 cfs, 21 May - 21 June		1687 (34%)	3299 (66%)
R2X + BF Method			3009 (60%)	1977 (40%)
PhabSim (Juvenile) + BF Method			4239 (85%)	747 (15%)
PhabSim (Adult) + BF Method			3917 (79%)	1069 (21%)

Time of flow protection varies in accordance with availability of flows exceeding 80% bankfull Q. During low flow years, no water would be allocated for channel maintenance.
Calculations are based upon a synthesized mean annual hydrograph correlated between the study site and adjacent long-term USGS gaging sites.

needed volume of water to by-pass the diversion structure or that require specific releases from storage facilities to provide downstream flows; and (2) Colorado instream flow rights that reserve a baseline flow rate to protect the environment to a "reasonable degree". The Steering Committee determined that an array of existing "tools" or mechanisms could be used to provide some level of instream flow protection or enhance stream flows in Colorado. (Table 3) They further found that in order to achieve cooperation and coordination between the various stakeholders involved in water use and water management, it was critical to implement these tools in a tiered approach, meaning that some tools are more acceptable and easier to implement if they follow an order of implementation.

Within the Steering Committee, the perspectives on these two procedures to provide for instream flow had varied acceptance. For example, the state of Colorado asserted that the Forest Service does not have the legal authority to impose bypass flows on a decreed water right. In contrast, some stakeholders held that bypass flows are the "price" of doing business on national forest land, or that imposing bypass flow requirements was the most effective means to protect instream flows on public lands.

The consensus of the Steering Committee was to use an array of options or strategies rather than focusing on one solution. First was to focus on cooperative efforts - voluntary actions that provide for better operations and management of water and then, if resource protection needs are not met, to move to more coordinated efforts - actions that involve multiple participants, call on differing authorities and institutional programs. A last resort would be to take unilateral federal action and impose bypass flow requirements or acquire water through condemnation. This process of tiered implementation is important, and if done in a progressive manner, a full array of opportunities to provide for instream flows would have been considered by the Forest Service before there was a need to move into the more regulatory actions where bypass flow requirements are imposed on water users.

Management Strategies

The tiered implementation of tools was captured in a management strategy matrix (Table 4, p. 524). This

Table 3. Tools for instream flow protection.

Forest Service Management Options	Cooperative or Partnership Approach Options	CWCB's Instream Flow Program Options
1. Inventory and consult with permittee on water rights, water uses, and permits.	11. Assist Colorado Water Conservation Board (CWCB) and State Engineer in monitoring and protecting existing ISF rights on GMUG National Forests (NF)	21. Pursue opportunities offered by CWCB ISF Program
2. Negotiate permit conditions for instream flow purposes on new water development.	12. Work with CWCB to recognize the NF land and resource management objectives and quantification methods for streams on the Forest may differ from the objectives and methods CWCB currently provides.	22. Seek CWCB agreement to appropriate or acquire needed flows on NF lands.
3. As a permit condition, limit diversions to decreed amounts when needed, seasonally.	13. Investigate voluntary re-operation alternatives with existing diversion permit holders to meet FS and permittee objectives.	23. Encourage CWCB to file on USFS flow recommendations the year they are made.
4. Implement channel and fish habitat improvements to compensate for lower flows when a determination has been made that such improvements have biologic merit.	14. Seek voluntary agreement with new applicants to develop operational plans to meet FS and applicant's objectives.	24. Establish legal, shared property ownership with the CWCB for acquired ISF rights on NFS lands.
5. Consider other forest practices that influence stream flows, such as vegetation management.	15. Consider new and expanded storage with participation by the USFS for instream flow purposes (which include the Forest Service appropriating or acquiring an interest in the water rights).	25. Encourage CWCB to file on peak spring flows and shoulder flows under ISF Program to allow for recharge of groundwater and to maintain riparian and off-channel habitat.
6. Use land and water acquisition programs and water right purchases to obtain water rights that could be converted to instream flow (ISF) rights.	16. Consider off-channel storage for later release.	26. Encourage the State Legislature to expand the CWCB ISF program to include recreational, scenic, and aesthetic uses.
7. Ensure that water rights acquired as part of an USFS acquisition or exchange are incorporated into the Forest water right inventory.	17. Provide State Engineer with documentation on water rights not being used.	27. Identify stream segments currently limited by availability of water for ISF protection and improvement.
8. Protect water rights held by USFS.	18. Initiate educational program for water conservation and promote/facilitate delivery and application efficiencies.	
9. Expand USFS efforts to inventory and assess the aquatic and riparian resources on GMUG NF.	19. Establish ISF management objectives for watersheds on the GMUG NF.	
10. Practice good watershed and streamside management to deliver sufficient quantity and quality of water to meet downstream and forest uses.	20. Work cooperatively with local governments to establish Recreational Instream Channel Diversion (RICD) on stream segment(s) located on NFS lands.	

matrix of strategies looks at implementation by working in two directions. First, streams were categorized into four diversion classes. These four categories are: no diversions; zero to 25% diverted; 25 to 50% diverted; and over 50% diverted. The tools or strategies were identified for implementation moving from top to bottom of the matrix in a tiered approach based on the resource or water use objectives. Those objectives and values included water rights (recognizing existing rights), flow regimes, future water development, recreation, restoration, and water quality.

Implementation strategies are progressive in their approach. As water use increases, the protection objectives become more intensive. The implementation strategies also vary depending upon the instream flow objectives or values being managed for.

To evaluate the effectiveness of the strategies outlined in the matrix, the Steering Committee conducted a paper exercise where we tested the process using some real-world hydrologic conditions and water use situations. Each time the test showed that there were at least one or two points along the implementation process where instream flow needs could be met provided there was some level of agreement between the entities involved to use the tools. If not, then the tool of last resort was the final tier of action and the Forest Service would have to take unilateral action (requiring bypass flows) to provide the necessary resource protection.

With the tests completed and input from the public and those agencies, entities, and organizations represented by the Steering Committee, a Steering Committee Report, Strategies for Instream Flow Management, was finalized in May 2004. This report is available at the Grande Mesa, Uncompahgre and Gunnison National Forests Website, *http://www.fs.fed.us/r2/gmug/policy*.

The Steering Committee Report is written from the stakeholders' perspective to detail strategies and processes that could be used by the Forest Service to protect or provide for instream flows on national forest lands. It relies on existing procedures, programs, regulations and laws to manage for instream flows. It focuses on cooperation and coordination before unilateral action by the Forest Service is suggested. It is intended to provide the Forest Service with a possible strategy or template to address instream flows in the Forest Plan revision.

This Steering Committee Report is not a Forest Service document, nor does it represent a final decision by the GMUG National Forests on instream flow management, but it is a workable strategic plan for instream flow management in Colorado.

The Pathfinder Project will provide forest planners with possible instream flow objectives, desired conditions for water development, and tools that may work as standards and guidelines for instream flow management.

Conclusions

The technical aspects of this project have afforded us an opportunity (funding and priority) to gather related hydrologic data and do a kind of analysis that is not typically done. This has proven to be beneficial for uses beyond our instream flow needs deliberations. It has allowed us to improve our understanding of the water resources that shape the local environment. That understanding may prove to be most the lasting benefit of what this project set out to accomplish. The analysis process was a challenging blend of field hydrology, statistical analysis and GIS work.

Did collaboration accomplish our goals? Yes and no. The key benefits of the process have proven to be the relationships we have developed with the stakeholders, and in particular with their representatives on the Steering Committee. The Pathfinder Project has developed a level of trust among the parties involved that has already carried over into other projects, and that can with trust, cooperation and coordination, continue into the future.

The Forest Service now has an approach and strategy that can be incorporated into the Forest Plan Revision process for instream flow management and water management that comes to the agency with a level of support from our stakeholders and the public that we could not have developed in the more traditional plan review process.

The Pathfinder Project was a major time commitment for the forest involving almost four years of effort. The results of the collaborative effort produced a product that wasn't exactly what was envisioned by the Forest Service when it embarked on this project. That is the nature of a collaborative efforts, and they frequently take on the focus and concerns of the stakeholders and participants rather than agency expectations. Collaboration however provides a critical public perspective early in the process rather than at the end of the planning cycle, which is most useful to any public agency.

Acknowledgements. The Pathfinder effort began in May 2000 and was intended to be a collaborative effort that was built upon technical and scientific information. The work that was accomplished would not have been possible without the efforts of the following individuals. Jonathan Ferree (USFS), Warren Young (USFS), Chris James (USFS), Matt Sutton (USFS), Heather Eckman (USFS), Eric Eckman (USFS), Matt Welsh (USFS), Kathy Pagano (USFS), Gerhard Kuhn (USGS), Jay Skinner (Colorado Division of Wildlife), Greg Espegrin (Colorado Water Conservation Board) and Bill Miller (Miller Ecological Consultants, Inc).

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Table 4. Instream flow management matrix for Grand Mesa, Uncompahgre and Gunnison National Forest watersheds.

	No Recorded Diversions		0 to 20% Diverted of Annual Yield	
	Species of Concern	No Species of Concern	Species of Concern	No Species of Concern
	GOAL I: Preserve existing natural flows for the benefit of species of concern, ecosystem integrity and reference conditions.	GOAL II: Protect hydrologic flow regimes needed to maintain baseline values.	GOAL III: Maintain existing flow conditions for the benefit of species of concern and ecosystem integrity.	GOAL IV: Establish and/or maintain a reasonable balance between consumptive and non-consumptive uses of water resources on the forest.
Water Rights	OBJECTIVE I. A: Preservation of these watersheds will be the Forest Service's top priority for the conservation of species of concern TOOLS: Tier I: 9, 10, 19, 21, 22, 23, 25 Tier II: 12 Tier III: none	OBJECTIVE II. A: Instream flow volumes, including peak flows and timing regimes shall not be reduced to the extent that existing baseline flow-related values are unacceptably impacted or degraded within a sixth level watershed (HUC) TOOLS: Tier I: 10, 19, 21, 22, 23, 25 Tier II: 6 Tier III: none	OBJECTIVE III. A: Recognize existing legal water uses TOOLS: Tier I: 1 Tier II: 7, 8, 17 Tier III: none	OBJECTIVE IV. A: Recognize existing legal water uses TOOLS: Tier I: 1 Tier II: 7, 8, 17 Tier III: none
	OBJECTIVE I. B: Recognize conditional water right TOOLS: Tier I: 1, 17 Tier II: none Tier III: none	OBJECTIVE II. B: Recognize conditional water rights TOOLS: Tier I: 1, 17 Tier II: none Tier III: none	OBJECTIVE III. B: Recognize conditional water rights TOOLS: Tier I: 1 Tier II: 7, 17 Tier III: none	OBJECTIVE IV. B: Recognize conditional water rights TOOLS: Tier I: 1 Tier II: 7, 17 Tier III: none
Stream Flows	OBJECTIVE I. C: Achieve flow regimes that maintain self-sustaining populations of species of concern TOOLS: Tier I: 9, 10, 21, 22, 23, 25 Tier II: 4, 6 Tier III: none	OBJECTIVE II. C: For those segments identified in cooperation with the DOW as potentially providing high value habitat for reintroduction of species of concern, pursue protection efforts TOOLS: Tier I: 10, 19, 21, 22, 23, 24, 25 Tier II: 4, 18 Tier III: none	OBJECTIVE III. C: Achieve flow regimes that maintain self-sustaining populations of species of concern TOOLS: Tier I: 9, 10, 21, 22, 23, 25 Tier II: 4, 5, 6, 13 Tier III: Unilateral federal actions	OBJECTIVE IV. C: Ensure instream flows necessary to sustain baseline ecological values TOOLS: Tier I: 9, 10, 21, 22, 23, 25 Tier II: 4, 5, 6 Tier III: Unilateral federal actions
Water Development	OBJECTIVE I. D: Entertain future water development only when the action can be determined to have an insignificant impact on flow regimes necessary for the conservation of species of concern TOOLS: Tier I: 2, 3, 10, 11, 19 Tier II: 18 Tier III: none	OBJECTIVE II. D: Accommodate future water development requests when a high level of ecosystem protection can be ensured TOOLS: Tier I: 3, 11, 21 Tier II: 2, 18 Tier III: none	OBJECTIVE III. D: Entertain future water development requests when a high level of population protection and habitat protection can be ensured TOOLS: Tier I: 2, 3, 4, 19 Tier II: 14, 15 Tier III: none	OBJECTIVE IV. D: Accommodate future water development so long as baseline recreational and ecological values are not precluded TOOLS: Tier I: 3, 15 Tier II: 2, 4 Tier III: none
Recreational	OBJECTIVE I. E: Protect appropriate instream flows so that recreational uses (high use areas/unique recreation attractions) are not precluded by future water development TOOLS: Tier I: 10, 11, 15, 20 Tier II: 12, 18, 25, 26 Tier III: none	OBJECTIVE II. E: Protect appropriate instream flows so that recreational uses (high use areas/ unique recreation attractions) are not precluded by future water development TOOLS: Tier I: 4, 10, 15, 20 Tier II: 12, 24, 25, 26 Tier III: none	OBJECTIVE III. E: Protect appropriate instream flows so that recreational uses (high use areas/ unique recreation attractions) are not precluded by future water development TOOLS: Tier I: 1, 4, 10, 15, 20, 26 Tier II: 12, 24, 25 Tier III: none	OBJECTIVE IV. E: Protect appropriate instream flows so that recreational uses (high use areas/ unique recreation attractions) are not precluded by future water development TOOLS: Tier I: 1, 4, 10, 15, 20, 26 Tier II: 12, 24, 25 Tier III: none
Restoration				
Water Quality	OBJECTIVE I. G: Recognize Forest Service obligation to comply with provisions of the Clean Water Act (303(d)) as it relates to instream flow TOOLS: Tier I: 10 Tier II: 2 Tier III: none	OBJECTIVE II. G: Recognize Forest Service obligation to comply with provisions of the Clean Water Act (303(d)) as it relates to instream flow TOOLS: Tier I: 10 Tier II: 2 Tier III: none	OBJECTIVE III. G: Recognize Forest Service obligation to comply with provisions of the Clean Water Act (303(d)) as it relates to instream flow TOOLS: Tier I: 10 Tier II: 2, 3 Tier III: none	OBJECTIVE IV. G: Recognize Forest Service obligation to comply with provisions of the Clean Water Act (303(d)) as it relates to instream flow TOOLS: Tier I: 10 Tier II: 2, 3 Tier III: none

Table 4. (continued)

20 to 50% Diverted of Annual Yield		Greater Than 50% Diverted of Annual Yield	
Species of Concern	**No Species of Concern**	**Species of Concern**	**No Species of Concern**
GOAL V: Maintain existing flow conditions for the benefit of species of concern and ecosystem integrity.	GOAL VI: Establish and/or maintain a reasonable balance between consumptive and non-consumptive uses of water resources on the forest.	GOAL VII: Maintain existing flow conditions for the benefit of species of concern and ecosystem integrity.	GOAL VIII: Establish and/or maintain a reasonable balance between consumptive and non-consumptive uses of water resources on the forest.
OBJECTIVE V. A: Recognize existing legal water uses TOOLS: Tier I: 1 Tier II: 7, 8, 17 Tier III: none	OBJECTIVE VI. A: Recognize existing legal water uses TOOLS: Tier I: 1 Tier II: 7, 8, 17 Tier III: none	OBJECTIVE VII. A: Recognize existing legal water uses TOOLS: Tier I: 1 Tier II: 7, 8, 17 Tier III: none	OBJECTIVE VIII. A: Recognize existing legal water uses TOOLS: Tier I: 1 Tier II: 7, 8, 17 Tier III: none
OBJECTIVE V. B: Recognize conditional water rights TOOLS: Tier I: 1 Tier II: 7, 17 Tier III: none	OBJECTIVE VI. B: Recognize conditional water rights TOOLS: Tier I: 1 Tier II: 7, 17 Tier III: none	OBJECTIVE VII. B: Recognize conditional water rights TOOLS: Tier I: 1 Tier II: 7, 17 Tier III: none	OBJECTIVE VIII. B: Recognize conditional water rights TOOLS: Tier I: 1 Tier II: 7, 17 Tier III: none
OBJECTIVE V. C: Achieve flow regimes that maintain self-sustaining populations of species of concern TOOLS: Tier I: 9, 10, 21, 22, 23, 25 Tier II: 4, 5, 13, 15, 17 Tier III: Unilateral federal actions	OBJECTIVE VI. C: Ensure instream flows necessary to sustain baseline ecological values TOOLS: Tier I: 9, 10, 21, 22, 23, 25 Tier II: 4, 5, 6, 13 Tier III: Unilateral federal actions	OBJECTIVE VII. C: Achieve flow regimes that maintain self-sustaining populations of species of concern TOOLS: Tier I: 9, 10, 21, 22, 23, 25 Tier II: 4, 5, 6, 13, 16 Tier III: Unilateral federal actions	OBJECTIVE VIII. C: Pursue instream flows necessary to sustain baseline ecological values TOOLS: Tier I: 9, 10, 21, 22, 23, 25 Tier II: 4, 5, 6, 13 Tier III: Unilateral federal actions
OBJECTIVE V. D: Entertain future water development requests when a high level of population protection and habitat protection can be ensured TOOLS: Tier I: 2, 3, 4, 19 Tier II: 14, 15 Tier III: none	OBJECTIVE VI. D: Accommodate future water development so long as baseline recreational and ecological values are not precluded TOOLS: Tier I: 3, 15 Tier II: 2, 4 Tier III: none	OBJECTIVE VII. D: Do not entertain future water development requests if it would contribute to degradation that causes loss of species viability TOOLS: Tier I: 2, 3,14 Tier II: 15, 16 Tier III: none	OBJECTIVE VIII. D: Scrutinize future water development to avoid unacceptable impairment of baseline recreational and ecological values TOOLS: Tier I: 3, 4, 15 Tier II: 2 Tier III: none
OBJECTIVE V. E: Protect and/or enhance appropriate instream flows so that recreational uses (high use areas/ unique recreation attractions) are not precluded by future water development TOOLS: Tier I: 1, 4, 10, 15, 20, 26 Tier II: 3, 6, 12, 16, 18, 24, 25 Tier III: none	OBJECTIVE VI. E: Protect and/or enhance appropriate instream flows so that recreational uses (high use areas/ unique recreation attractions) are not precluded by future water development TOOLS: Tier I: 1, 4, 10, 15, 20, 26 Tier II: 3, 6, 12, 16, 18, 24, 25 Tier III: none	OBJECTIVE VII. E: Protect and/or enhance appropriate instream flows so that recreational uses (high use areas/ unique recreation attractions) are not precluded by future water development TOOLS: Tier I: 1, 4, 10, 15, 20, 26 Tier II: 6, 12, 16, 18, 24, 25 Tier III: none	OBJECTIVE VIII. E: Protect and/or enhance appropriate instream flows so that recreational uses (high use areas/ unique recreation attractions) are not precluded by future water development TOOLS: Tier I: 1, 4, 10, 15, 20, 26 Tier II: 6, 12, 16, 18, 24, 25 Tier III: none
OBJECTIVE V. F: For those segments identified in cooperation with the DOW as potentially providing high value habitat and/or recovery sites pursue restoration efforts to improve flow and habitat conditions TOOLS: Tier I: 2, 3, 11, 13, 15, 21, 22, 23, 24, 25 Tier II: 4, 5, 6, 7, 12, 16, 18 Tier III: Unilateral federal actions	OBJECTIVE VI. F: Consider restoration of baseline values where evaluation has concluded that restoration is needed. TOOLS: Tier I: 1, 3, 5, 6, 10, 11, 13, 19, 21, 22, 23, 24, 25 Tier II: 4, 7, 18, 27 Tier III: Unilateral federal actions	OBJECTIVE VII. F: For those segments identified in cooperation with the DOW as potentially providing high value habitat and or recovery sites pursue restoration efforts to improve flow and habitat conditions TOOLS: Tier I: 2, 3, 6, 13, 15, 21, 22, 23, 24, 25 Tier II: 4, 5, 7, 12, 16, 18 Tier III: Unilateral federal actions	OBJECTIVE VIII. F: Seek restoration of baseline values where evaluation has concluded that restoration is needed. TOOLS: Tier I: 1, 3, 5, 6, 10, 11, 13, 19, 21, 22, 23, 24, 25 Tier II: 4, 7, 18, 27 Tier III: Unilateral federal actions
OBJECTIVE V. G: Recognize Forest Service obligation to comply with provisions of the Clean Water Act (303(d)) as it relates to instream flow TOOLS: Tier I: 10 Tier II: 2, 3, 5 Tier III: none	OBJECTIVE VI. G: Recognize Forest Service obligation to comply with provisions of the Clean Water Act (303(d)) as it relates to instream flow TOOLS: Tier I: 10 Tier II: 2, 3, 5 Tier III: none	OBJECTIVE VII. G: Recognize Forest Service obligation to comply with provisions of the Clean Water Act (303(d)) as it relates to instream flow TOOLS: Tier I: 10 Tier II: 2, 3, 5 Tier III: none	OBJECTIVE VIII. G: Recognize Forest Service obligation to comply with provisions of the Clean Water Act (303(d)) as it relates to instream flow TOOLS: Tier I: 10 Tier II: 2, 3, 5 Tier III: none

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Cooperative Forest Watershed Management in Maryland: Watershed Restoration Across Land Ownerships

Anne Hairston-Strang
Maryland Department of Natural Resources, Forest Service, Annapolis, Maryland

The Maryland Department of Natural Resources Forest Service has worked cooperatively with USDA Forest Service Northeastern Area State and Private Forestry to develop a forest watershed management program that covers public and private land. Maryland has 41% forest cover state-wide, predominantly privately owned. The forest watershed program spans riparian forest buffer restoration, drinking water reservoir watershed management, forest harvesting Best Management Practices (BMP) assessment, and targeted watershed activities. Progress has included 1722 km of riparian forest buffers planted since 1996, statewide forest buffer survival estimates increasing from 60% of planted seedlings in 2000 to 78% in 2002, a comprehensive forest conservation plan for 7,225 ha of forest surrounding the Baltimore, Maryland, drinking water supply, developing the Potomac Watershed Partnership with five other major partners in the region, and assessing harvesting BMPs in the state in collaboration with the Northeast Area Regional BMP Assessment Protocol.

Keywords: *Aquatic/riparian; watershed restoration, watershed management, timber harvesting BMPs*

Introduction

The Maryland Department of Natural Resources Forest Service established a watershed forest management program in 2001 to better encourage the use of forests and forestry to improve watershed condition in the state. The USDA Forest Service State and Private Forestry has been an important resource for technical and financial assistance in developing an effective program. The design for a watershed program depends on conditions in the watershed. Some of the major resources and stressors in Maryland are covered briefly here as context for Maryland's watershed forestry efforts.

With 5 million people, Maryland is the fifth most densely populated state in the nation and has 41% forest cover. Maryland lacks any national forest land, although neighboring states to the south, west, and north have substantial national forests. Maryland does have state forests and parks, national park land, national wildlife refuge land, military bases, and state natural resource management areas that include significant forested areas and provide long-term forest conservation. Maryland also benefits from a close partnership with USDA Forest Service Northeastern Area State and Private Forestry, an important connection in a state where forestland is 76% privately owned. Maryland lies in the middle of the Chesapeake Bay watershed, and is heavily involved in the regional program to reduce nutrients and improve living resources in the Chesapeake.

The areas with the most extensive forests are in the mountains in the western portion of the state and on the coastal plain in southern Maryland and the lower Eastern Shore (Figure 1). Piedmont areas in the central portion of the state (Baltimore/Washington, DC, corridor and concentrations of agricultural lands) have the least forest cover. The forest products industry is the fifth largest in the state, and many small mills and secondary manufacturing facilities provide demand for wood. However, in many areas of central and southern Maryland, population density and small parcel sizes limit the likelihood of active management for any reason, even timber stand improvement, wildlife, or water quality (Figure 2).

Baltimore, Washington, DC, and several smaller communities draw substantially on surface water reservoirs for drinking water, which goes through water treatment facilities before delivery. Even outside of the reservoir systems, many areas rely on rivers and streams for drinking water sources. Many watersheds in central Maryland are substantially developed and bear the effects of land use changes in loss of function in streams.

In a recent study in Montgomery County in the Maryland Piedmont west of DC, Goetz et al. (2003) quantified the relationship between impervious surfaces, forest buffers, and forest cover (Figure 3). They found

Furniss, M.J., Clifton, C.F., Ronnenberg, K.L., eds., 2007. *Advancing the fundamental sciences: proceedings of the forest service national earth sciences conference, San Diego, CA, 18-22 October 2004*. PNW-GTR-689. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

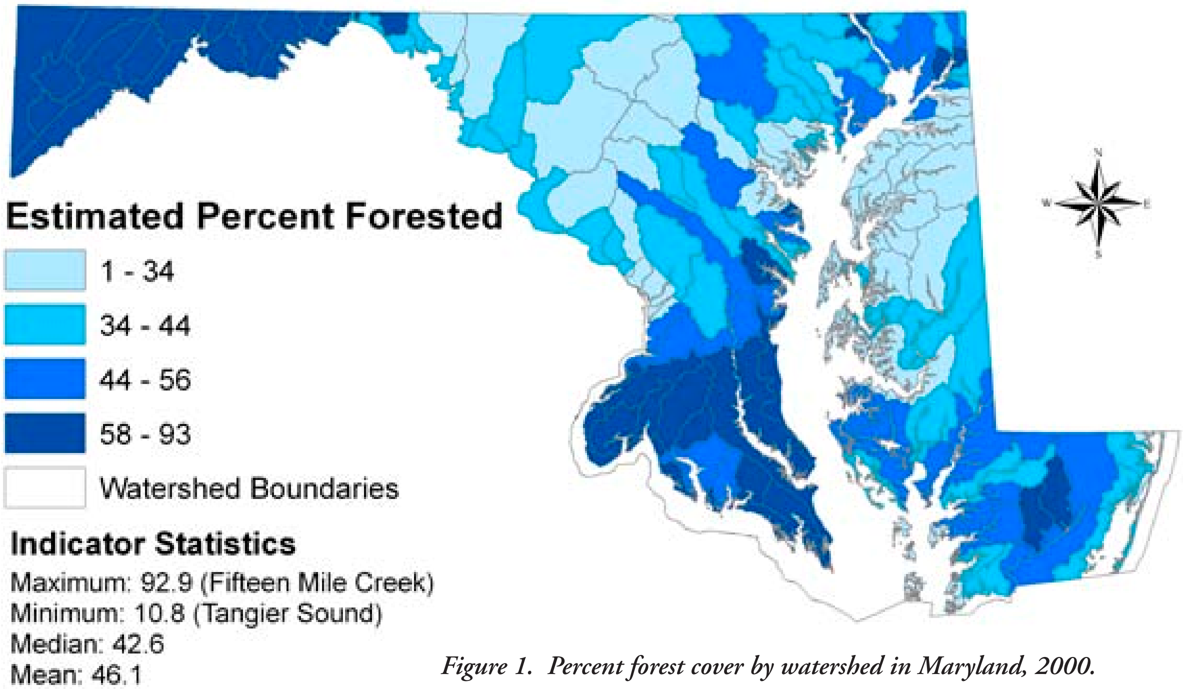


Figure 1. Percent forest cover by watershed in Maryland, 2000.

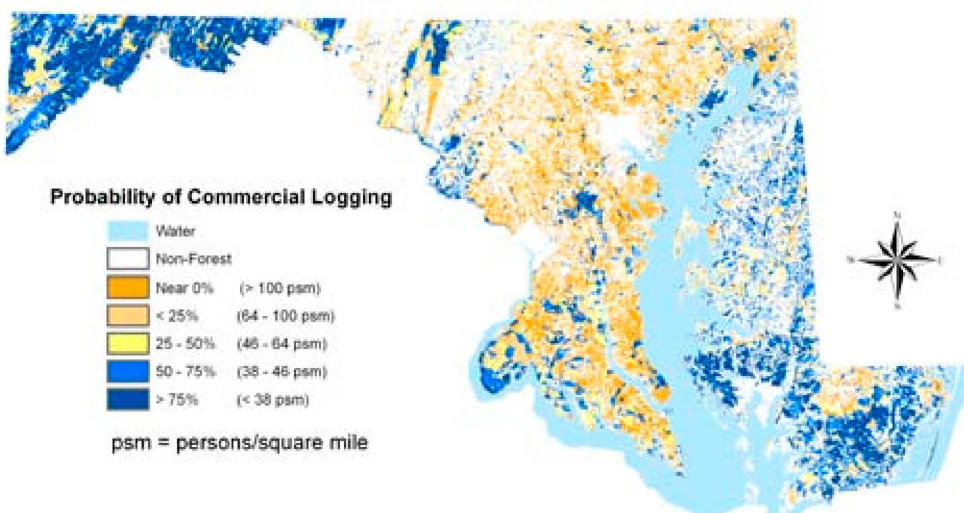


Figure 2. Probability of commercial logging of forests in Maryland as predicted from population density.

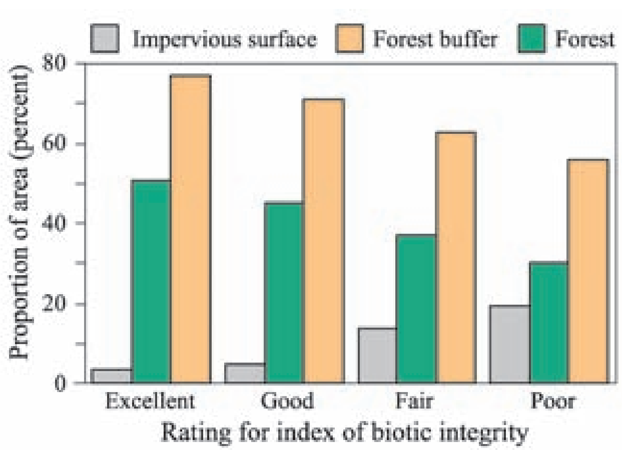


Figure 3. Percent of impervious surfaces, forest cover in watershed, and forest buffers for streams receiving excellent, good, fair, or poor ratings for an index of biotic integrity based on benthic macroinvertebrate composition.

the closest relationship to the Index of Biotic Integrity (IBI) for benthic macroinvertebrates was with impervious surface percentage, and the next closest with forest buffers. Forest cover in the entire watershed was the least closely linked but still important. In a range of watersheds from mostly rural to intensely urban, there were no streams with "excellent" IBI rankings except where watersheds had less than 6% impervious surface and more than 65% forest buffer. Even "good" IBI ratings were found only where impervious surfaces were less than 10% of the watershed and where more than 60% of the streams had forest buffers.

Within the context of extensive population and still significant forested areas, the Maryland Forest Watershed Program currently has four concentrations:

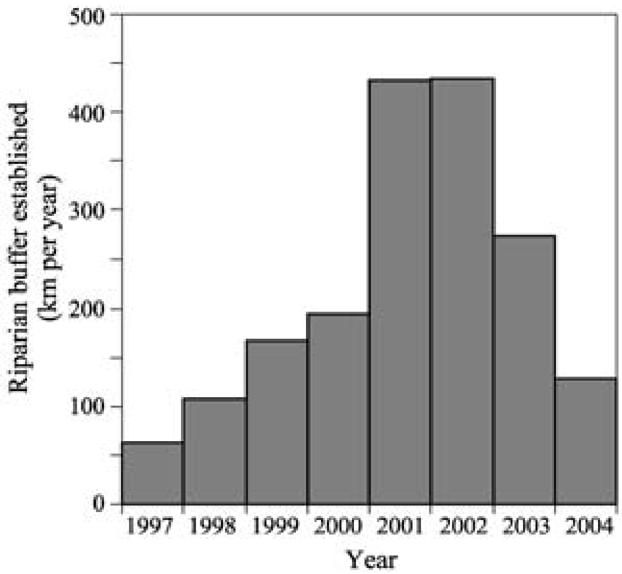
- Riparian forest buffers
- Forest management to protect drinking water reservoirs
- Watershed partnerships
- Forest harvesting Best Management Practices (BMP) assessments.

Riparian Forest Buffers

Streamside areas are an essential focus for watershed health because their influence on streams is great in comparison to their area. Forests are a preferred riparian land use because they help prevent nutrient input to streams and foster greater instream nutrient processing (Sweeney et al. 2004), in addition to providing riparian and aquatic habitat. Riparian forest buffers (RFBs) have been part of Maryland's forestry program since 1987. They became a focus in 1996, when the Chesapeake Bay goal of 3235 km (2010 miles) of new RFBs created by the year 2010 was adopted, recognizing the importance of buffers for improving water quality and habitat. Maryland committed to 965 km towards that goal. The Conservation Reserve Enhancement Program (CREP), authorized in the 1996 Farm Bill, became the major tool in expanding the rate of buffer creation. From an average of 19 km of buffer per year prior to 1996, buffer creation increased more than ten-fold (Figure 4). Expanded benefits under CREP stimulated even more increases, but later decreases in payment rates and eligibility saw rates fall off.

Maryland established 1,722 km (1,070 miles) of RFBs between 1996 and July 2004, about 2.6% of the state's riparian miles. The summaries sound simple, but the order-of-magnitude and greater increases required ramping up activities in a number of service arenas, including landowner assistance, training for resource professionals, supplying native hardwood seedlings, making planting machines available, and finding or training skilled contractors. Efforts

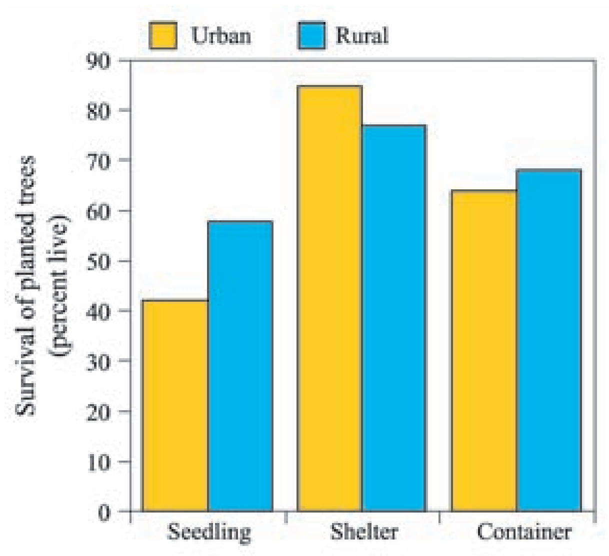
Figure 4. Kilometers per year of riparian forest buffers established in Maryland.



were also made to assess overall survival of seedlings, contribution of natural regeneration, and effect on stream and riparian functions. USDA Forest Service support was essential in expanding capabilities and funding training and buffer assessments through state grants, including the Potomac Watershed Partnership.

Seedling survival was assessed using a consistent statewide method in 2000 (Pannill et al. 2001) and 2002. Survival increased from an average of 60% in 2000 to 78% in 2002, attributed to increased maintenance efforts. Natural regeneration was not consistently present, but was significant on many sites, with one-third of trees being volunteers in the 2000 survey and one-quarter in 2002, even with increasing mowing and spraying to favor planted trees. Monitoring of riparian plantings as part of the Potomac Watershed Partnership found 87% average survival through 2003. The surveys were also used to assess stressors on survival. The top three factors affecting survival were weed competition, drought, and deer browse. Weed competition was by far the greatest, with noxious or invasive species being common, but not usually dominant, on newly planted sites. Deer damage is especially problematic in the middle portion of the state, where the proportion of a third forest, a third farm, and a third developed land proves to be the recipe for large deer herds with low hunting pressure. As a result, tree shelters were commonly recommended, and proved beneficial to survival (Figure 5). Other stress factors that were less common but problematic where present were insects, beavers, voles, and mice. Particularly on urban sites, mechanical damage from weedeaters and mowers took a toll on tree survival.

Figure 5. Percent survival of planted trees in riparian forest buffers in Maryland, 2000.



Forest Management for Protection of Drinking Water Reservoirs

Land management in watersheds draining into reservoirs used for public drinking water greatly affects water quality and treatment costs for water supply. Maryland DNR Forest Service has partnered with municipal water suppliers in developing forest management plans for lands immediately surrounding reservoirs. Baltimore City's reservoirs were established starting before the turn of the 20th century, and the landscape surrounding the water supply has changed dramatically in the 100+ years since (Figure 6). Urbanization now affects a major portion of the Loch Raven watershed. The reserved lands immediately adjacent to the watershed are now even more critical for appropriate management, as are buffer reforestation efforts along tributaries throughout the watersheds.

A comprehensive forest conservation and management system was developed for the 7,225 ha of forested lands owned by Baltimore City around its three reservoirs, based on the city's hierarchical goals of water quality, biodiversity and recreation, and emphasizing restoring forest resilience. Issues that emerged as significant for the City's primary goal of water quality included a dearth of regenerating seedlings for sustainable forests, extent of recreational use including mountain bikes and off-road vehicles (ORVs), excessive area in roads and damaged stream crossings, and forest stands currently susceptible to windthrow. The management approach includes deer exclosures on parts of regeneration cuts to demonstrate the effect of excessive deer browse, gradual stand conversion to more windfirm stand types, and management of shallow soils near nutrient sources to encourage rapid growth and nutrient uptake. A complementary watershed-wide analysis of land critical to reforest or conserve was completed, funded by USDA Forest Service. It developed better information on stream networks and forest distribution, and identified priority lands for conservation and restoration.

Watershed Partnerships

Maryland forestry watershed partnerships range in scale from the Chesapeake Bay Program, covering a good part of the Mid-Atlantic region, to the Potomac Watershed

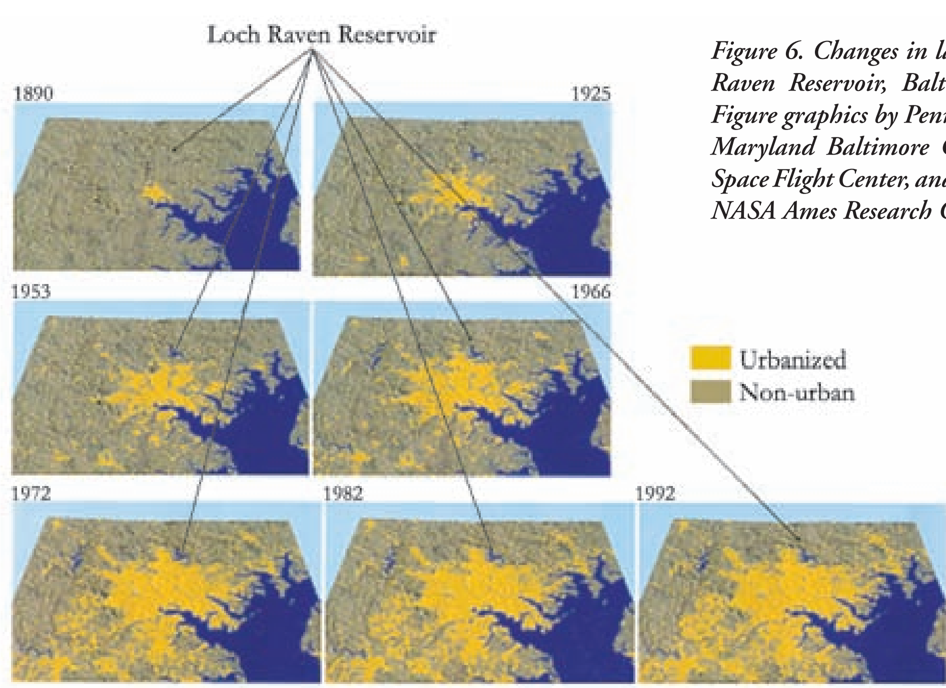


Figure 6. Changes in land use surrounding Loch Raven Reservoir, Baltimore, MD, 1890-1992. Figure graphics by Penny Masuoka, University of Maryland Baltimore Campus, NASA Goddard Space Flight Center, and William Acevedo, USGS, NASA Ames Research Center.

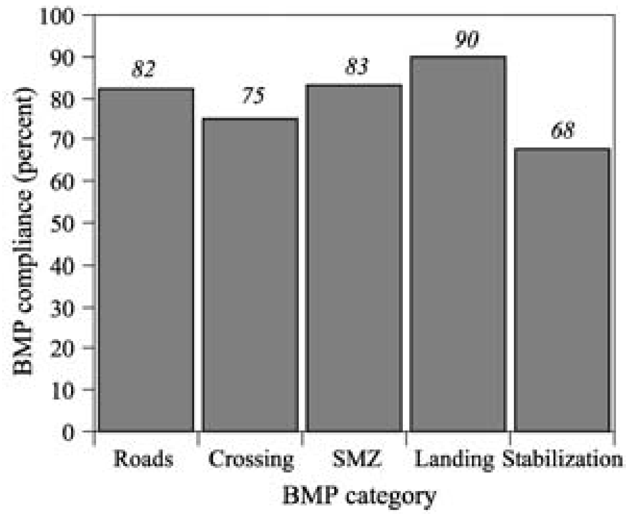
Partnership with surrounding states, and the Special Rivers Chesapeake Bay Implementation Grant, focusing on four areas within Maryland. The Potomac Watershed Partnership (PWP), used as an example here, is one of the large-scale, community-based watershed restoration efforts initiated with USDA Forest Service funding. PWP partners include Virginia Department of Forestry, Pennsylvania Department of Environmental Protection, Ducks Unlimited, George Washington/Jefferson National Forest, and Potomac Conservancy. The focus watersheds in Maryland were selected based on priority watersheds with the lowest proportion of forest buffers, using information from the state's Clean Water Action Plan. The PWP is our best effort at integrating the range of forestry services, including forest stewardship, forest fire risk reduction, monitoring of RFB survival and effectiveness, and urban forestry, on a watershed basis. It provides the focus and framework for expanding landowner services for forest stewardship and buffer restoration, coordinating monitoring of buffer restoration, minimizing risk from damaging wildfires, and increasing community forestry projects in an area of the state that has particular need for watershed improvement.

Examples of projects that draw on the synergy of multiple partners focused on mutual objectives, include the Growing Native project, a volunteer seed collection that also spreads the message about need for watershed restoration, and a recent conservation landscaping project that pulled together information on rain gardens (vegetated infiltration areas), native plants, and fire-resistant landscaping. The partnership helps expand horizons and focus resources on common goals.

Harvesting BMP Assessment

Forests provide one of the least-polluting land uses in the watershed, a circumstance that relies on appropriate use of BMPs during periodic harvesting. Maryland is cooperating with Northeastern Area State and Private Forestry on a regional assessment of harvesting BMPs developed by Maine Forest Service. The regional protocol allows comparison across state lines and focuses on sediment delivery pathways and quantifiable measures. Maryland will be doing 80 samples statewide, with the samples being defined from stream crossings as called for in the protocol. Maryland is particularly interested in this approach to harvesting BMP assessment because it could be used to support Total Maximum Daily Load development (rather than assigning disproportionately large sediment sources to poorly documented timber harvesting), and Chesapeake Bay Program nutrient reduction modeling and tracking.

Figure 7. Implementation rates for forest harvesting BMPs in Maryland, 1995.



Maryland has completed previous studies on BMP use, for effectiveness and implementation rates. A paired watershed study with a one-year calibration period was conducted from 1995 to 1999 in the Piedmont physiographic province (Pannill et al. 2000). It assessed effects of forest harvesting using standard state BMPs on stream benthos, temperature, and suspended sediment, none of which were found to differ significantly following harvest. For BMPs to work as intended to protect water quality, they have to be widely applied. Maryland did a statewide survey of BMP implementation in 1994, and found an average 82% application rate, with the steeper western portions of the state having greater difficulty in maintaining BMP compliance (Figure 7). The 2004-2005 assessment will update statewide BMP implementation rates.

Summary

Forests play an important role in watershed health throughout Maryland. The Maryland Department of Natural Resources Forest Service has worked cooperatively with USDA Forest Service State and Private Forestry to develop a forest watershed program that emphasizes using forests and forestry to improve watershed condition. The state has made significant advances in riparian forest buffer restoration and forest watershed management approaches for drinking water reservoirs. Maryland is using and assisting with the development of a regional harvesting BMP assessment protocol that may prove useful for state water quality modeling and Chesapeake Bay reporting. Watershed partnerships at several different scales are being used effectively to increase coordination and focus attention on geographic areas and activity types that improve watershed health. These advances have occurred during a time of shrinking state budgets and staff. The leadership, technical assistance, training coordination, and financial support of Northeastern Area State and Private Forestry have been critical to expanding the state's program in watershed forestry and increasing the use of forestry as a solution to non-point source pollution.

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II. Poster Abstracts

Overleaf:
South Fork Clearwater River, just upstream of Cottonwood Creek, near Stites, Idaho. The Nez Perce National Forest manages approximately two-thirds of the upper South Fork subbasin, and has been actively involved in subbasin-wide monitoring, assessments and restoration plans, including the reach pictured. Photo by Nick Gerhardt.

Poster Abstracts From
Advancing the Fundamental Sciences:
the Forest Service National Earth Sciences Conference
San Diego, CA, 18-22 October 2004

Excavator Subsoiling Applications: Integration of Subsoiling with Grapple Piling and Road Obliteration

J. Archuleta, and M. Karr

Erosion occurs from the exposure of soil to the effects of wind, water, and gravity. When soil is compacted, these forces may be exacerbated. By slowing or inhibiting vegetative growth, moisture infiltration and soil development, compaction can maintain erosion on gentle topography. Some land managers intend for nature to treat compaction, spending their limited watershed restoration funds on other treatments, while others choose the expensive proposition of subsoiling compaction. However, evidence of the longevity of compaction can be found in the unmanaged and abandoned portions of the historic Oregon Trail, a testament to the endurance of the problem. On the Umpqua National Forest, two implements were developed to combine the needs of multiple project objectives with subsoiling treatments. The implements are available for any make of excavator of suitable size for this type of heavy duty work. Combining grapple piling and subsoiling has been shown to produce results equivalent to any subsoiling operation, at a minor cost afforded through reduced piling production and minimal financial cost to the project. The primary benefit of this treatment is related to its use of available organic matter. Often by the time subsoiling is done, all available organic material has been disposed of during prior harvest slash disposal activities, leaving no material available for effective ground cover after subsoiling. By combining harvest slash disposal, road obliteration and subsoiling, use of these implements reduce the lag time between impact, restoration and restored soil productivity.

Application of Water and Sediment Models in Hydropower Relicensing

Margaret Beilharz

Hydropower Relicensing provides an opportunity for the Forest Service and other parties to make decisions about water storage and use at hydropower projects. Because these decisions are codified for a 30- to 50-year time frame in the License to Operate issued by the Federal Energy Regulatory Commission, they have major long-term consequences for the health of the watershed and rivers. The decisions must be based on "substantial evidence," which commonly includes the results of instream flow, reservoir and sediment transport models. The decisions are often arrived at by collaborative groups of the hydropower industry, federal, state, and county agencies, and NGOs, who learn to interpret the results of the models in order to discuss the environmental and other consequences of the projects. Standard and project-specific models are applied to a variety of project configurations, by a variety of consultants, resulting in evolutions of the models to fit the needs. These projects range in size from steep headwater streams with operating ranges as low as 100 cfs, to the Hells Canyon Complex on the Snake River, with an operating range of up to 30,000 cfs. An overview of the application of models, their benefits and pitfalls will be discussed. We include description of: Instream flow models - PHABSIM, River2D, Expert Habitat Mapping; Reservoir operation models - CHEOPS, HYDROPS, HEC-5, project specific models: Channel and sediment models - Mike11, Mike21, HEC-RAS, SAM, and others.

Furniss, M.J., Clifton, C.F., Ronnenberg, K.L., eds., 2007. *Advancing the fundamental sciences: proceedings of the forest service national earth sciences conference, San Diego, CA, 18-22 October 2004*. PNW-GTR-689. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Detecting Water Yield Increase in a Downstream Direction

Gregory S. Bevenger

Streamflow was measured at the mouth of two sub-watersheds of the North Fork Shoshone River drainage to monitor effects of the 1988 Clover-Mist Fire. The sub-watersheds were Jones Creek (19 mi^2), which was completely consumed by the fire, and Crow Creek (12 mi^2), which was not burned. Troendle and Bevenger (1996) analyzed the stream flow data and demonstrated that seasonal water yield in Jones Creek was, on average, 5.4 inches greater than Crow Creek. Though this was not a true paired watershed study, they concluded there was strong circumstantial evidence that the difference in yield can be attributed to fire effects. The Clover-Mist Fire, in total, resulted in a stand-replacement burn of 13% of the North Fork Shoshone River drainage (as measured from a USGS gage located near the mouth of the drainage and having a watershed area of 699 mi^2). In 2002, Shoshone National Forest staff conducted a watershed assessment of the North Fork Shoshone River drainage. One item they assessed was whether the apparent water yield increase resulting from the Clover-Mist Fire could be detected at the USGS gage, which is 35 miles downstream of the burn area. Analysis of pre- and post-fire streamflow indicates the water yield increase is not detectable ($p = 0.586$) at this scale. There is uncertainty whether this is due to distance from the burn or to the fact the gage was moved in 1988 to accommodate expansion of a reservoir that flooded the original gage location, which had a watershed area of 725 mi^2.

Land Type Associations of Weber County, Utah

Jeff Bruggink, DeVon Nelson

A land type association inventory of Weber County, Utah, was made primarily to support county planning and as an example of ecological land classification for county planners and others who could benefit from information gathered by this approach. The inventory was made by visually delineating, describing and interpreting 13 land type associations on satellite imagery using personal knowledge and field observations supplemented by existing resource reports. The inventory proved to have limited application to the present, residential level of planning in the county, but has considerable promise as the bridge between the current widespread use of land classification on national forest lands and its possible use on lands of other jurisdictions. We broke new ground by making a county level LTA inventory. This kind of survey is not uncommon on National Forest land nor are more general subsection maps new to the state. We know such inventories are widely used in other parts of the country. In Utah, detailed, individual resource maps, e.g., soils, vegetation and geology, cover much of the state and are essential for some uses, but their number, diversity, and detail can lead to confusion among planners and local officials if the need is for an overview of a large land area. This inventory was aimed at the gap between the generalizations of the subsection maps and the detailed, single resource inventories. It will take some time to determine the value of land type associations to local planning but we now have an example we can use to reach out to this vital level of government.

Forest Practice Changes in Response to Soil Protection Guidelines on the Umatilla National Forest

Craig R. Busskohl

Standards and guidelines for forest soil protection were established in the Pacific Northwest Region of the US Forest Service in the 1980s in response to site impacts of random, nonsystematic logging practices and site preparation. Extensive and intensive soil disturbance was common, with measurable effects on reforestation success, growth and erosion rates. The Umatilla NF adopted the regionally developed standards in the Forest Plan of 1990. Harvest systems and site preparation techniques used on the Umatilla NF have changed dramatically from the late 1980s to early 2000s. Monitoring results measuring soil impacts affecting soil productivity have changed concurrently. BMPs and other control measures have produced reductions in erosion potential due to exposed mineral soil. This poster illustrates changes in practices and monitoring data from 1990 to 2003 as they apply to standards and guidelines for detrimental soil conditions.

Low-water Crossings and Channel Functions: What Works and What Doesn't

Kim Clarkin, Suzan Hixson, Gordon Keller, Terry Warhol

A wide variety of low-water stream crossing structures have been built on low-volume forest roads throughout the country with the primary objectives of traffic access and cost efficiency. Fords and vented fords are low-profile structures that may not obstruct stream channels as completely as a standard culvert/road fill installation. Nonetheless, they are still rigid structures in a dynamic system. Depending on their design, they can have most of the same detrimental effects as traditional culverts, including promoting upstream aggradation, bank erosion, and downstream scour. In aquatic habitat, they often pose a barrier to aquatic species. This poster summarizes the results of a review of numerous low-water crossings, including some low-water bridges, in national forests throughout the country. Many older structures do not meet the modern objective of maintaining channel functions, even though they may have been modified over time as problems became evident. Much can be learned from these structures about how not to locate and design a low-water crossing. Other structures incorporate design elements that go a long way toward achieving minimum interference with channel processes. Many are designed specifically to function in extremely dynamic conditions, such as in debris torrent or alluvial fan channels, desert and other flashy hydrologic regimes, or where debris jams, ice jams, or overbank flooding are frequent. The poster will illustrate some of the structural design elements - both successful and unsuccessful - that have been used to deal with these conditions in different valley and channel types.

Hemlock Dam Removal–The Issues and the Story So Far

Bengt Coffin

The Forest Service is working on an Environmental Impact Statement to evaluate options for improving fish passage and water quality at Hemlock Dam. The 22-foot high dam is located on Trout Creek, a tributary to the Wind River on the Gifford Pinchot National Forest in Washington state. Hemlock Dam is a USFS dam that was constructed to provide irrigation water to the Wind River Nursery. The nursery was closed in the mid 1990s, and since that time the only purpose of the dam is to provide a recreational lake behind it for summer use. The Forest Service is proposing to remove the dam, but is considering a range of alternatives at the site including leaving the dam in place and improving fish passage there.

Protecting and Restoring Riparian Area Structure and Function Along Forest Highways and Low-Volume Roads

James E. Doyle and Roy Jemison

Transportation corridors have had profound effects on riparian area structure and function in the United States as well as abroad. With over 600,000 km of system roads to manage across the United States, protecting and restoring habitat in riparian areas along these roads has become a priority long-term management need for the US Forest Service. Beginning in 1999, the US Forest Service, in partnership with other federal agencies and non-government natural resource organizations, initiated a multi-year project to evaluate efforts for protecting and restoring riparian area values affected by roads. Through field evaluations in various ecoregions of the United States, this interdisciplinary team of hydrologists, soil scientists, civil engineers, and fish and wildlife biologists identified and documented the most effective of these restoration efforts. In addition, the most effective road best management practices (BMPs) applied to protect riparian area values were documented. The team also conducted literature searches to augment these field reviews. Road-related restoration treatments reviewed included road outsloping, retaining walls, revegetation, soil bioengineering, landslide mitigation, invasive species control, low-water crossings and fords, culverts, bridges, wildlife crossings, fish passage, beaver pond maintenance, wetland maintenance, and channel modifications. Besides Forest Service funding, this project was supported by national funds from Department of Transportation-Federal Highway Administration, Department of Interior-Bureau of Land Management, and the Environmental Protection Agency. Other partners contributing professional services included the Department of the Interior-Fish and Wildlife Service, Department of Agriculture-National Resource Conservation Service, National Marine Fisheries Service, Army Corps of Engineers, Ducks Unlimited, and Trout Unlimited. Total cost of this project over a three year period was about $150,000. After two and a half years of field and literature reviews, the project identified and documented 24 treatments and techniques currently being used across the country to either protect or restore riparian areas associated with Forest Service highways and roads. This poster highlights the findings and results of this project.

Movement of Sediment Associated with Lowered Reservoir Levels in the Rio La Venta Arm of the Presa Netzahualcoyotl, Chiapas, Mexico

Juan de la Fuente, Bonnie Allison, Saul Bezares, Sue Hilton, Tom Lisle, Alisha Miller, Brenda Olson, Rebecca Quinones, Jose Velasquez

A joint sedimentation study is currently underway at Netzahualcoyotl reservoir in Chiapas, Mexico, involving the Comision Nacional de Areas Naturales Protegidas (CONANP) of the Secretaria de Medio Ambiente y Recursos Naturales and the US Forest Service. The reservoir is adjacent to Reserva de la Biosfera, Selva El Ocote, administered by CONANP. Study goals are to provide watershed managers with strategies to protect the resources of Rio La Venta canyon. The Rio La Venta arm of the reservoir is incised into karst terrain, with near-vertical limestone walls up to 300 meters high. The canyon is fed by two rivers, Rio La Venta and Rio Negro, and is surrounded by pristine tropical forest. The majority of the sand and fine gravel entering the reservoir originates in the headwaters of the two rivers, which are underlain by granitic rock. Rapid sedimentation of the canyon poses a threat to the aquatic ecosystem. Longitudinal and transverse profiles were surveyed in March 2002, and repeated in April 2003 when the reservoir level was 15 meters lower, and again in February 2004. The 2002 longitudinal profile shows an inflection from a slope of 0.0017 to one of 0.0075 at 7.2 km downstream of the mouth of Rio Negro. In 2003, the two slopes remained the same, but the bed lowered 5 meters and the inflection point moved downstream 2.3 km. Data from 2004 are being processed. Initial findings suggest that by managing reservoir levels, sediment accumulation in the gorge can be controlled to meet specified goals.

Turbidity Threshold Sampling in Watershed Research

Rand Eads, Elizabeth Keppeler, Jack Lewis

When monitoring suspended sediment for watershed research, reliable and accurate results may be a higher priority than in other settings. The timing and frequency of data collection are the most important factors influencing the accuracy of suspended sediment load estimates, and, in most watersheds, suspended sediment transport is dominated by a few, large rainstorm events. Automated data collection is essential to effectively capture such events. Continuous turbidity measurements can reveal sediment pulses unrelated to discharge and can be used in real-time to govern the collection of pumped physical samples. While turbidity cannot replace suspended sediment concentration, it can be a tremendous asset as an auxiliary measurement. The turbidity threshold sampling method has been used since 1996 at the Caspar Creek Experimental Watershed in northern California where it is now being used at 21 gaging stations. Sample collection is distributed over the range of rising and falling turbidity values during each significant turbidity peak. A data logger records discharge and turbidity at frequent time intervals and activates a pumping sampler when specified turbidity conditions are met. The resulting set of samples can be used to accurately determine suspended sediment loads by establishing a relation between sediment concentration and turbidity for any sampled period with significant sediment transport, and applying the relation to the continuous turbidity data. The approach can be used in general for other target and surrogate variables and is thereby useful for a wide range of water quality issues.

Monitoring of Stream Channel Cross Sections on the Chequamegon-Nicolet NF

Sara Eckardt and Dale Higgins

Permanent cross-sections have been established on several streams in the Chequamegon-Nicolet National Forest to monitor the effects of channel restoration and culvert replacement over time. In recent years, Wisconsin trout stamp funds have been used to restore wide (20-30 ft), shallow, C type channels by narrowing (10-12 ft) and deepening the thalweg to create low width/depth E type channels that provide better habitat for adult trout. Following such work on three streams, 40 permanent cross-sections were established to determine if the new channel dimensions would remain stable over time. Five to eight years of data for these streams indicate most cross-sections have become 0.5-3.0 feet wider, the bed has aggraded 0.1-1.0 feet and the newly constructed floodplain, which is usually below the level of the adjacent floodplain, has aggraded 0.2-0.8 feet. Eleven permanent cross-sections have been established at three stream crossings and measured for 1-4 years. All had elevated or under-sized culverts that caused upstream aggradation mostly of sand. The cross-sections are helping to characterize and quantify the extent of channel adjustment and restoration associated with culvert replacements.

The 1997 Flood in Northern California: Applications to Refining Landslide Hazard Assessments in the Klamath Mountains North-Central California

Don Elder, Juan de la Fuente, Polly Haessig

The effect of human activities on landslide rates is a key issue in the management of western forests. In the Klamath Mountains of northern California, sedimentation has been identified as a key issue relative to anadromous fish habitat, and landslides contribute most of the sediment to the stream system (about 90% in the Salmon River sub-basin). On the Klamath National Forest, a simple empirical model is currently used for estimating future sediment delivery. It uses GIS coverages (bedrock, geomorphology, roads, and others) and a concept of geomorphic terranes, lands expressing similar slope processes and similar landslide rates. A landslide rate is assigned to each terrane for undisturbed, harvested or burned, and roaded conditions. These rates are based on air photo/field inventories of landslides that occurred in the Salmon River basin from 1965-1975. The model is used to predict future sediment delivery by geomorphic terrane under various roading and vegetation management scenarios, assuming a 1965-1975 type climatic episode. The 1997 flood was used to test the predictive ability of this model. It was found that undisturbed land produced 34% of the volume in 1997 compared to a model prediction of 39%. For road corridors, it was 40% versus the model prediction of 39%, and for harvested or burned lands, it was 27%, versus 21%. The model over-predicted total sediment volumes several fold for each of the land use categories. For undisturbed land, modeled rates were 3.3 times higher, harvested land rates were 2.6 times higher, and road corridor rates were 3.0 times higher.

Monitoring in the Upper South Platte Watershed, Colorado: Before and After Wildfire

Deborah Entwistle, Lee MacDonald, Kevin Bayer, Ken Kanaan, Jennifer Hall

The Forest Service has long been in need of methods of watershed monitoring that are cost-effective and produce useful products in a timely manner. Various monitoring methods have been used in the Upper South Platte River watershed in conjunction with the Upper South Platte Watershed Protection and Restoration Project. In 2001, multiple small sub-watersheds were instrumented to collect erosion data at the hillslope scale, small catchment scale, and sub-watershed scale. Stream monitoring has included repeat cross section surveys, pebble counts, bank stability surveys, and monthly water quality sampling. This work has been conducted collaboratively by the US Forest Service and Dr. Lee MacDonald and his graduate students at Colorado State University. In late spring of 2002, the Schoonover and Hayman Fires burned approximately 140,000 acres in the Upper South Platte watershed, including a large percentage of the monitoring sub-watersheds. This presented a unique opportunity, as the erosion monitoring sites could now be used to monitor effectiveness of various Burned Area Emergency Response (BAER) treatments. The hillslope plots have been treated with a variety of BAER treatments, and the water sampling program was also expanded to include several streams within burned areas. New monitoring programs have also been added after the fires; these include the use of erosion bridges, ground-cover transect surveys, and photo point monitoring in BAER treatments and salvage timber sale units. The results of all of these monitoring projects will be used to evaluate the various management practices as well as the monitoring methods themselves.

Improving Project-Level Soil Interpretations With Geospatial Technologies

Don Fallon, Eric Winthers, Haans Fisk

Soil interpretations are arguably the most important information derived from a soil survey. However, the development of soil interpretations, through the traditional methods of observation, characterization, and interpretation generation based on map unit and component concepts, needs to be revised to include readily-available geospatial data. Since the majority of soil and ecological unit mapping on western national forests is at an order-three level (associations and complexes), component-level interpretations can, at best, only be represented at the map-unit level. Through the use of remote sensing and GIS technology, generation and display of soil interpretations at larger scales (project level) may be possible. Geospatial technologies have been used to depict individual components within map units and spatially refine specific interpretation ratings. For instance, fundamental interpretation criteria, based on slope or aspect, can be derived empirically from topographic data to increase the usefulness and precision of soil interpretations within map units. Once the process is established, a step-wise approach to derive interpretations geospatially could result, further reducing inventory analysis costs and enhancing soil interpretations at the project level.

A Simplified Nitrogen Deposition Collector: A Tool for Evaluating Ecological Impacts

Mark E. Fenn

Quantification of atmospheric nitrogen (N) inputs is needed to determine areas at risk from air pollution. In most areas adequate data on N deposition are lacking, largely because of the difficulty of measuring dry deposition fluxes of the array of nitrogenous pollutants. This problem can be circumvented by measuring nitrate and ammonium in throughfall. Throughfall is the hydrologic flux of compounds from vegetative canopies to the ground during precipitation events. Tree canopies function as natural and effective "filters" of atmospheric pollutants. Thus the transfer of N pollutants from the canopy to the forest floor is an important measure of N deposition and can be effectively used to evaluate air pollution loading to the ecosystem. We describe a greatly simplified method of collecting nitrate and ammonium in throughfall or precipitation. This approach uses ion exchange resin (IER) columns which adsorb N from throughfall solutions. We found that collectors can be employed in the field for as long as a year. Such infrequent sample collection reduces analytical and logistical costs. This method has made it possible to define N deposition gradients in the Sierra Nevada and in the San Bernardino Mountains and to determine thresholds of N deposition that elicit ecological changes such as N saturation conditions. Effects include increased nitrate in soil and streamwater, changes in nutrient cycling and carbon sequestration, increased N fertility, stand densification, and soil acidification. IER collectors provide a useful tool for monitoring N deposition in remote areas and will foster greater understanding of N deposition impacts.

FishXing 3.0: Software and Learning Systems for Fish Passage Through Culverts

Michael Furniss, Susan Firor, Antonio Llanos, Kathleen Moynan, Michel Love, Jeff Guntle, and Robert Gubernick

Culverts at road-stream crossings are traditionally designed for hydraulic efficiency, assuming this will yield a cost-effective design. However, this singular objective often produces adverse environmental effects. Poorly designed stream crossings frequently become barriers to fish and other aquatic organisms, resulting in the fragmentation of habitat essential for their viability and long-term survival. The scale of the problem is immense, with hundreds of thousands of culverts installed on fish-bearing streams in North America alone. Assessment and design of culverts for fish passage is a flow-dependant problem involving knowledge of both hydraulics and fisheries biology. FishXing is an interactive software package for use in culvert design and the assessment of fish passage conditions. FishXing identifies the types and locations of potential barriers across a range of flows by modeling fish swimming and leaping abilities against culvert hydraulics. The model has proven useful in identifying specific fish passage limitations, leading to the removal of numerous barriers. As a design tool, FishXing accommodates the iterative process of designing a new culvert to provide passage of fish and other aquatic species.

Managing Low-Water Crossings on Roads

Leslie S. Gonyer

This poster presentation will present work that is being done on the Black Hills National Forest to harden low water road/stream crossings with concrete mats. It will outline different alternatives that are available to address the problem, including closing the road and rebuilding the stream banks. Closing the road is not always an option and mitigation of the crossing is required to minimize the impact on the stream and watershed. The information will be presented through limited text and photographs display before and after pictures. Low water road-stream crossings can affect the stream and aquatic resources. Impacts include a continual supply of sediment to the stream and widening of the stream. The supply of sediment comes from erosion of the banks and stream channel each time a vehicle crosses. The widening of the stream provides for increased water surface area that allows for additional absorption of solar radiation during the summer, which can elevate stream temperature. One could argue that one crossing in itself is not very significant, but each crossing contributes to the cumulative impacts on the watershed and stream.

Abandoned Mine Inventory, Assessment, and Restoration: Case Studies on the Klamath National Forest, California

Polly A Haessig, Edward K. Rose, Don Elder, and William Snavely

The Klamath Mountains Province has a long mining history and many abandoned mines. National Forest abandoned mine land (AML) programs locate and identify mine hazards and restoration opportunities. Assessment of AML is also critical in property evaluations for land acquisitions and exchanges. Problems associated with AML on Forest lands include unsafe mine openings, erosion and mass wasting of mine waste materials, threatened failure of relict impoundment structures, acid mine drainage, abandoned drums containing hazardous materials, and unneeded or sediment-producing roads. Geologists, engineers, and other earth scientists work closely together in the process of field inventory, hazard assessments, ranking and prioritization of sites, site investigation, proposal development, NEPA analysis, and project implementation. Partnerships with other agencies are used to: expand the framework of knowledge; accomplish more restoration particularly on mixed-ownership sites; and increase opportunities for implementation funding. An interdisciplinary approach using other skills in related sciences of botany, fisheries, wildlife, and archeology is used to ensure long-term rehabilitation of sites and to protect resources. Case studies are presented on various Klamath National Forest AML sites including: (1) mine adit gating & wildlife habitat improvement; (2) sediment tailings dam removal and channel stabilization; (3) contaminant removal; (4) mine waste stabilization and containment; and (5) mine road repair and stormproofing.

Applying Hydrology to Forest Management–Examples Over a Career

William F. Hansen

Rainfall, streamflow and other hydrometeorologic records are available at various densities across most of the United States. Understanding and applying the hydrologic record is a valuable consideration when dealing with the variety of conditions and activities common to most national forests. This poster provides examples of how the hydrological record was applied to various scales from landscape planning to site-specific work. Understanding the frequency, risk, duration and extent of hydrologic events leads to a better understanding of how water functions as it moves from the hillslope to the stream, or is delayed in soils or wetlands. The tools available today make assembling and analyzing hydrologic records easier. Records need to help characterize changes with respect to scale from hillslopes to valleys. However, an appreciation of the data may be lost when dealing with only the numbers. The goal is not amassing and compiling numbers for an answer. Learn to appreciate the data themselves, including the methods and other collecting specifics, their limits and conditions. Breathe data in, let it out. Does it make sense? Hydrologic field indicators such as channel measurements, flood deposits, soils, landforms, plants and land uses can help verify a record or provide as basis for adjusting estimates. Specific examples will be taken from experience in Missouri, Oregon, California, South Carolina, Georgia, Texas, and Puerto Rico. Hydrologic analysis was applied to specific but normal forest management decisions or activities such as culvert sizing and spacing, type of stream, stream crossings, landslide and gully treatments, water right needs, channel stabilization, wetland restoration, timber harvesting, pesticide applications, forest conversion to other uses, nutrient cycling, pollutant loading, emergency watershed protection, and burned area emergency rehabilitation projects. Management styles have changed over the last 33 years. Decision makers may be more receptive, but decisions still depend on the strength of the arguments. Some decision makers are easier to influence than others. Providing clear options with full disclosure of risk and effects should lead toward better management decisions. The question today is not always whether hydrology is a consideration, but to what degree and under what circumstances will it be an overriding consideration. Some activities do fine with default forest standards including best management practices. However, in impaired or unstable systems, or under unusual intensities of management, added consideration may be necessary.

Guidance for Intermountain Region Hydrology Specialist Reports–Field Review Notes, Technical Assessments, and NEPA Specialists Reports

Ronnie-Sue Helzner and Sherry Hazelhurst

As new professionals and technicians have entered our workforce, the Ashley National Forest (Utah and Wyoming) found a need to provide some guidance on information and data considerations for compiling various hydrology specialist reports. Region 4 adapted the Ashley's guidance with comments from other forests to create a general guidance document for all forests in the region. Many of the ideas, topics, and principles extend beyond our specialty and region. We would like to share our "living" document, available via website, with others. It may be useful to 1) new employees seeking guidance and examples, 2) supervisors and line officers responsible for training or mentoring new staff, and 3) experienced specialists looking for new ideas or ways to improve documents. The poster will summarize the document with an outline, example links, and business cards with an fsweb site for downloading (http://fsweb.ashley.r4.fs.fed.us/planningweb/templatesindex.shtml).

The Rebirth of a Stream–the Enchanted Valley Stream Restoration Project

Johan B. Hogervorst and Barbara Ellis-Sugai

The Enchanted Valley Stream Restoration Project was completed in summer 2002, and involved the reconstruction of over one mile of meandering stream channel in a low gradient valley on the Central Oregon Coast. The original stream channel had been moved to the side, straightened and diked to accommodate agricultural use over the last century. After the original relocation, the straightened channel cut down into the valley floor, increased in velocity and began eroding its banks, becoming a problem for both downstream water quality and fish habitat. The primary focus of the project was to restore wetland and floodplain function that once provided high quality rearing habitat for coho salmon (*Oncorhynchus kisutch*) in Enchanted Valley. To accomplish that goal, a new meandering channel was built in the middle of the valley. The new channel was constructed in 1999. The old ditches were plugged, and the water was diverted into the new channel in 2000, giving the willows and other vegetation planted on the banks a year to grow. Riparian and floodplain vegetation restoration continued in 2001 and 2002 with the planting of a variety of trees and shrub species. Large wood was placed in the new stream. Results: Spawning surveys from 2003 show a five-fold increase in returning adult coho salmon since the early 1990s. Last year was the first year that adults returned to the restored channel. Surveys in other local streams in 2003 did not show the same level of increase.

Mapping Air and Natural Gas Resources–the Management Value of Integrating Disparate Information

Melody R. Holm, Jeff Sorkin, and Janice Wilson

Rapidly expanding development of natural gas resources in the greater Rocky Mountain region is requiring more effective integration of the physical and biological sciences. With large areas of development come types and levels of effects not previously encountered with smaller, more confined development projects. Ironically, one of the reasons for growing demand for natural gas is its environmentally desirable clean-burning nature, while at the same time, effects of production and transportation of the resource on other resources are a growing concern. Of particular concern are effects on air quality, specifically impairment of visibility in Federal Class I areas and atmospheric deposition in sensitive areas. A developing series of GIS maps (currently Wyoming and Colorado) depict the geographic relationship among existing production, permitted emission sites (gas compressors), areas of future production potential, sensitive areas (particularly Class I areas), and air monitoring sites. These maps provide for more informative and accurate prediction of effects of development activity on air quality. Initial maps of production, future potential, land ownership, Class I areas, and monitoring sites revealed some surprising relationships that will facilitate managing and planning for existing and future development. This poster presents representative GIS maps that illustrate the management value of integrating seemingly disparate information related to air resources and development of fossil energy resources.

The Effectiveness of Aerial Hydromulch on the Cedar Fire in Controlling Water Movement and Erosion

Ken Hubbert, Pete Wohlgemuth, and Pete Robichaud

The Cedar Fire consumed 272,318 acres, resulting in the loss of 14 lives and 1,483 residences burned. Aerial hydromulch treatments were prescribed by the BAER team in the upper Puetz Valley/Viejas Mountain area of southern California. Our objective was to monitor the effectiveness of aerial hydromulch, applied as a 100% treatment and as a 50% strip treatment, in controlling hillslope water movement and erosion. A total of 56 silt fences were installed and were divided between three units with adjacent untreated controls: 1) Capitan Grande Indian Reservation (100% treatment), 2) granitic parent material in the upper Puetz Valley (strip treatment), and 3) gabbroic rock in the upper Puetz Valley/Viejas Mountain area (strip treatment). Five plant cover quadrats were located at each silt fence to measure cover. Three channel check dams were also constructed to measure sediment yield and peak discharge in three small watersheds located on granitic parent material. Five rain gages were installed. The mean mid-March rainfall total was 165 mm. Rock cover in the gabbroic parent material was 25% as compared with less than 2% in the granitic. Hillslope sediment yields (on a tons/acre basis) were: control gabbroic = 1.20; strip gabbroic = 0.58; control granitic = 2.72; strip granitic = 0.67, and 100% granitic = 0.33. Sediment yields (tons/acre) within the channels were: control = 4.53, strip = 4.49, and 100% = 1.66. On both granitic and gabbroic parent materials, both the 50 and 100% hydromulch treatments were effective in reducing both channel and hillslope sediment yields.

Energy Development in the Eastern United States and Air Pollution Impacts on Aquatic and Terrestrial Resources

Cindy Huber, Chuck Sams, and Andrea Stacy

Energy development has increased dramatically in the eastern United States in recent years, in response to increasing energy demands by the public. Energy consumption is increasing at a faster rate than population growth in the US. One of the byproducts of supplying energy is air pollution. Nitrogen oxides, sulfur dioxide, volatile organic compounds and hazardous metals are some of the pollutants that enter the atmosphere. Whether energy development occurs on national forests or other public and private lands, resulting air pollution can affect forest resources as it disperses across the landscape. Coal-fired power plant development in the East will be used to demonstrate the air quality issues currently facing national forest managers. GIS products will be used to show the spatial relationship between projected development and emissions and national forest resources sensitive to air pollution. Linkages will be discussed between emissions of these pollutants and associated impacts on aquatic and terrestrial resources.

Using BARC for Fire Disturbance Analysis

Kevin Hyde

Severe erosion commonly follows intense wildfires throughout the Mountain West, altering stream channel morphologies and aquatic habitats, and threatening human life and property. These hazards can lead to large financial expenditures to assess and mitigate impacts. We therefore need to explicitly identify locations of highest post-fire erosion potential. Satellite-derived burn severity mapping, now referred to as Burned Area Reflectance Classifications (BARC), was used to quantitatively describe and explain post-fire gully rejuvenation triggered by intense rainfall following the Bitterroot, Montana fires of 2000. Vegetation disturbance was mapped in a GIS by means of an innovative metric, the Vegetation Disturbance Distribution Index (VDDI). Gully rejuvenation occurred in 66 of the 171 drainage basins examined. The mean VDDI value for gullied basins was very high compared to non-gullied basins. The degree and extent of vegetation disturbance was more important than any other landscape variable in predicting the incidence of gully rejuvenation. BARC mapping quantifies the difference in green before and after wildfires and thereby serves as a proxy for the magnitude of vegetation disturbance. Using BARC to generate VDDI values provides a rapid and repeatable means to assess the risk of severe erosion following wildfire. This model may prove to be useful for Burned Area Emergency Rehabilitation team assessment, and the planning, implementation, and monitoring of burned area recovery treatments.

Lichen Air Quality Biomonitoring Partnership on the Salmon-Challis National Forest

Gary L. Jackson and Larry St. Clair

The Salmon-Challis National Forest occupies approximately 4.3 million acres in east-central Idaho. The forest lies in a transition zone between the maritime climate of western Idaho and the continental climate of southeastern Idaho. During the spring and summer seasons, precipitation results from convectional storms moving up from the Gulf of Mexico and the California coast; during the winter, weather patterns develop from the Pacific Northwest. A lichen air quality biomonitoring program was initiated in 1988 in conjunction with Brigham Young University, Provo, Utah. In 1993 a Challenge-Cost Share agreement was put in place to sustain a long-term lichen air quality biomonitoring program. Since 1988 more than 300 lichen species have been identified from 85 sites. This project represents one of the largest and most comprehensive lichen air monitoring programs in North America. Lichen species were first collected for elemental analysis in 1988. Initially, two sites were established, one at Golden Trout Lake (8153 feet) and one at Garden Creek (3400 feet). Both sites were re-sampled in 1993. Between the sampling periods, Golden Trout Lake showed a 32% decrease in sulfur; 70% decrease in copper; and 26% decrease in lead. Likewise, Garden Creek showed a 42% decrease in copper; a 28% decrease in lead with a slight increase in sulfur. The 1988 samples were analyzed using "atomic absorption" methods and the 1993 samples by "PIXIE" methods. The sulfur value at Garden Creek was 0.039%, a concentration well below background levels (0.2 percent).

Restoration of Bluewater Creek Riparian Rangeland Meadow in the Zuni Mountains of Western New Mexico

Roy Jemison

Riparian areas within rangelands of the southwestern United States are centers of high biodiversity. Despite the small size of these areas, when compared to surrounding uplands, they can support greater diversities of plant and animal species. Stands of willow and other woody vegetation in high elevation riparian areas play important roles in maintaining healthy watersheds. Such vegetation stabilizes bank and channel structures of streams, slows water movement downstream, and helps maintain good water quality. Riparian systems provide crucial habitat for native species of birds, fish, amphibians and small mammals. Historically, large numbers of cattle and sheep grazing in these areas eliminated many of these habitats. Although grazing is controlled now, it is felt that current grazing pressures may be keeping native vegetation from re-establishing. The Cibola National Forest in western New Mexico successfully restored riparian vegetation to a stretch of Bluewater Creek (south of Bluewater Lake) over a 10- to 15-year period. Activities that contributed to the success included replanting of native willows (*Salix* spp.), fencing to control cattle, and beavers (*Castor canadensis*). The restored area has increased use by birds, mammals, and people. In 2003, forest personnel began restoration work along Bluewater Creek in the area upstream and adjacent to the area restored earlier. Lessons learned during the first restoration project are being used. Modified and new techniques will also be incorporated as appropriate. A monitoring program is also being conducted with the current restoration activities to document changes in environmental factors as a result of restoration activities.

Relationships Between Hydrology, Exotic Plants, and Woody Fuel Loads in the Middle Rio Grande of New Mexico

Roy Jemison

Management options to reduce the risk of wild fires in the Bosque (riparian zone) of the Middle Rio Grande in New Mexico are being investigated. The Bosque, one of the longest and most contiguous riparian zones in the western US, developed under a much different river flow regime and land uses than exist today. River regulation and flood control, with diversion dams, levees, and fire suppression, have decoupled the self-perpetuating and self-sustaining terrestrial biotic community from the water on which it depends. Elimination of flooding, lowered water tables, and lack of naturally occurring cool fires have allowed exotic plants to establish and thrive in monotypic vegetation types as well as beneath cottonwood (*Populus* spp.) overstories. Salt cedar (*Tamarix ramosissima*) and Russian olive (*Elaeagnus angustifolia*) have formed thickets that are almost impassable without the use of mechanized equipment. The presence of exotic woody plants increases the risk of fire near the river communities of Albuquerque, Socorro, Bernalillo and several Pueblos, reduces opportunities for recreational use of river woodlands, and contributes to the loss of native plants. For example, woodlands dominated by a cottonwood overstory and exotic understory, when burned, typically return as exotics only. In collaboration with landowners and managers, Forest Service scientists are testing methods to reduce and control the build up of exotic fuels in the understory. Relationships between water management, exotic plant distributions, and fuel loads on the middle Rio Grande will be described in this poster along with the current management and research practices that address the identified problems.

Beyond Statistics: Landscape Controls That Mask Apparent Effects of Harvest Activities on Soil Saturation
Adelaide Johnson, Kellie Vache, and Rick Edwards

Observations of peak water table heights in 56 groundwater-monitoring wells at two study locations (Hanus and Portage, southeast Alaska) suggest that soil saturation levels on hillslopes differed significantly with harvest intensity only at Portage Bay following 25, 75, and 100% harvest. For example, before the forest at Portage Bay was cut by 100%, the average rainfall needed for 50% saturation of the soil was 54 mm, but after clearcutting soils reached 50% saturation with only 21 mm. We hypothesize that Hanus Bay sites lacked statistically significant differences in levels of saturation following harvest due to several factors: 1) location, size, and landform of areas contributing to wells, and 2) number, species, size, and density of trees in relationship to wells for pre- and post-harvesting conditions. To test these hypotheses, we developed a simple hydrologic model to predict saturation. Model results were tested with existing records of saturation for various levels of rainfall.

Modern Stromatolites and Benthic Phototrophs in Ultra-Oligotrophic Waldo Lake, Oregon
Al Johnson

Waldo Lake is located in the Willamette National Forest near the crest of the Cascade Range. The 6,298-acre lake is 420 feet deep and is one of the largest natural lakes in Oregon. The lake is regarded as one of the most oligotrophic lakes in the world. Investigators have reported the water to be extremely dilute and chemically similar to distilled water, with reported values of phytoplankton primary production and concentrations of chlorophyll a among the lowest ever found in a freshwater lake. Previous studies have noted the importance of benthic primary production in the lake. Over the last several years, personnel from the Willamette National Forest have participated in investigations of areas < 20 m in depth including studies of the benthic microbial community. Cyanobacteria including many nitrogen fixing species were found to compose a large portion of the biomass of this zone. These cyanobacteria along with a variety of eukaryotic algae form microbial communities covering benthic surfaces. Primarily through the trapping and binding of sediment, these benthic microorganisms have formed modern stromatolite structures over extensive portions of the lake < 7 m in depth. Previous studies of other freshwater lakes have reported the formation of modern living stromatolites in calcareous lakes. Waldo Lake is likely a rare or unique example of modern stromatolite formation in a freshwater lake under ultra-oligotrophic conditions. Further studies of these stromatolite formations are in progress as part of an overall scientific study plan of this extraordinary lake.

Low-Volume Roads Engineering Best Management Practices Field Guide
Gordon Keller and James Sherar

Over the past several years the US Forest Service and US Agency for International Development (USAID) have been working with Virginia Tech on the publication of a roads "best practices" guide titled "Low-Volume Roads Engineering Best Management Practices Field Guide". This Roads BMP Guide was produced to provide an overview of the key planning, location, design, construction, and maintenance aspects of roads that can cause adverse environmental impacts and to list key ways to prevent those impacts. Best Management Practices are techniques or design practices that, when applied, will prevent or reduce pollution and maintain water quality. Roads often have major adverse impacts on water quality, and most of those impacts are preventable with good location, engineering and management practices. This Guide presents many of these desirable practices, with the use of many photos, drawings, and designer aids. Most of these BMPs are sound engineering practices, and are cost-effective because they prevent failures and reduce maintenance needs and repair costs. Key objectives of Roads Best Management Practices include the following:

- Protecting sensitive areas and water quality, and reducing sediment transport off roads;
- Maintaining natural channels and passage for aquatic organisms;
- Controlling surface water and stabilizing the roadbed driving surface;
- Controlling erosion, stabilizing slopes and reducing mass wasting; and
- Stormproofing and extending the useful life of the road.

This poster will include examples of practices in planning and design, roadway surface drainage, drainage crossings, slope stabilization and erosion control used to achieve the above objectives.

Lessons Learned Between BAER Assessment and Implementation on 2003 Southern California Fires

Allen King

The southern California fires of October 2003 burned 750,000 acres within a few weeks, including portions of four major fires on three national forests. Geologists and geotechnical engineers made significant contributions to BAER assessment teams evaluating geologic hazards, defining risks to humans, watersheds and infrastructure, and recommending treatments to reduce risks. Implementation of those treatments provided many challenges as BAER implementation teams installed some of the recommended treatments, modified others, and created new treatments. As winter storms hit burned areas, sixteen people were killed on the San Bernardino NF by the December 2003 Christmas storm. New in-channel debris dams on the Piru Fire were destroyed by the February 2004 storms. Roadwork in the Sespe Oil Field greatly improved traffic flow, but some construction practices caused additional drainage and sedimentation problems. "Before and after" photo monitoring provides many lessons learned, related especially to accurately understanding and interpreting current geomorphic processes, water flow dynamics, and climatic conditions specific to the burned area being studied. What works in New Mexico or Idaho doesn't automatically work in southern California. Many of the lessons learned raise questions about how many times we need to re-learn the same lessons and how can we change old practices that don't reflect BMPs. Some suggestions will be offered.

Modeling the Role of Evapotranspiration in the Unsteady State of the Groundwater Regime in Watershed-Scale Projects

Tom Koler

Forecasting the slope stability of hillslopes at a watershed scale has been successfully completed in industrial timberlands in northern California. The fundamental equations include the infinite slope equation for time-series evaluation and nested code for measuring changes in normal effective stresses in response to fluctuations within the hydrologic cycle. A focus was placed on the evapotranspiration loss from the harvest of redwood stands. Results from this study show the effectiveness of applying this science in the decision-making process for timberland watershed management.

Influence of Prescribed Fire on Fish and Streamwater Mercury Concentrations

Randy Kolka, Jason Butcher, and Trent Wickman

Because of its persistence and wide dispersal in the environment and its ability to bioaccumulate in organisms, mercury (Hg) is a contaminant of great concern. Although scientists are beginning to understand the Hg cycle in forested systems and the important Hg species that lead to bioaccumulation in the food chain, little is known about the role of fire in Hg cycling processes. The North Central Research Station and the Superior National Forest have started to fill these data gaps by establishing a plan to monitor mercury changes during fuel reduction efforts in northeast Minnesota. The Larch Lake watershed, part of which is located in the Boundary Waters Canoe Area Wilderness, is included within an area of the forest where fuel reduction efforts are taking place in response to a major blowdown event that occurred in 1999. The Larch Lake watershed is a 2100 ha headwater system; approximately 40% of the watershed has been recently managed with prescribed fire, with another 30% planned for similar fuel reduction treatments. Total and methyl-Hg in water were measured along with standard physicochemical variables both pre- and post-treatment. Tissue Hg concentrations in young-of-year smallmouth bass (*Micropterus dolomieu*) were also analyzed for the pre-burn (baseline) period; post-burn samples will be taken for a several-year period after treatment to understand any potential bioaccumulation timelines. These data will provide a better understanding of how prescribed fire in the Larch Lake Watershed affects the magnitude and timing of Hg delivery to streams, lakes and fish.

Influence of the Intensity of Silviculture on Soil Carbon

Randy Kolka, Rachel Tarpley, Marty Jurgenson, and Brian Palik

A primary goal of silviculture is manipulation of forests to produce fiber, while sustaining the ecological systems that drive this production. Unfortunately, we know little about tradeoff responses between fiber production and soil physical properties governing productivity, across gradients of silvicultural intensity. Maintenance or enhancement of soil carbon pools is one indicator of productivity. Moreover, the effect of silvicultural intensity on soil carbon has implications for the mitigation of greenhouse gases. In this study we assessed soil carbon pools across a gradient of red pine (*Pinus resinosa*) growing stock at the Cutfoot Experimental Forest in North Central Minnesota. The replicated study treatments include five levels of growing stock (60, 80, 100, 120, 140 ft^2/ac) maintained through repetitive commercial thinning in extended rotation stands.

Since study establishment in 1949, within 85-year-old stands, there have been seven commercial harvests. The experimental forest also contains old-growth stands (130+ years old) with no history of harvesting since initiation. Soil carbon was sampled across the gradient in 2003. In this poster we will present the result of our analyses.

Application of a LIDAR-Generated Digital Elevation Model to Active Landslide and Geomorphic Process Mapping and Interpretation

Benjamin R. Kozlowicz and Mark E. Smith

Six Rivers National Forest has acquired a 10-foot (3-meter) LIDAR generated digital elevation model (DEM) for most of the Willow Creek basin, Lower Trinity RD. Such dense, accurate topographic data can aid in the identification of landforms and surface process zones and can be used to quantify some geomorphic processes. We use this data to estimate the volumes and delivery rates of active, shallow debris slides mapped on sequential aerial photos for sediment budgeting. These volume estimates are then compared to estimates from field surveys using a laser rangefinder. The results of this and previous studies are used to develop area to volume ratios for shallow debris slides in different geologic and geomorphic units. These relationships are applied to the forest-wide active landslide inventory of over 11,000 features. In addition, we use the 3-meter LIDAR DEM to aid in interpreting 1:24,000-scale geomorphic processes and in assessing the relative activity of deep-seated landslides.

Native Plants and Fertilization Help to Improve Sites and Stabilize Gullies on the Sumter National Forest

Dennis L. Law and William F. Hansen

The Sumter National Forest (South Carolina) lands were acquired in the early 1930s under the Weeks Law to provide sustained timber and improve soil productivity. Most areas were severely eroded and depleted of nutrients due to past farming practices. Soil productivity was drastically lower and approximately 20,000 acres of actively eroding gullies and galled barrens dissected the area. Reforestation and active stabilization measures have been used to help restore the landscape. However, some gullies and galled barren areas continue to produce sediment at excessive rates. Trees and other vegetation present on severely eroded lands are often sparse and in poor health. Surface erosion and productivity problems have been reduced or eliminated on most of the treated areas. A variety of techniques have been used to treat gullies, such as soil ripping, disking, fertilizing, seeding and mulching, but this poster will focus on activities involved with using native plants and fertilization. A multi-agency agreement was developed with the South Carolina Native Plant Society, Tall Timbers, Clemson University, county, state and federal agencies to assist in providing cost and technical sharing of native plant information. The poster will highlight pictures of soil recovery efforts. Efforts have included increased cooperation among agencies with over 1,000 person days of volunteer time. The information will show how native plants are collected within the ecotypes and grown in both nursery and field conditions for use on gullies and other disturbed or barren areas.

Coordinated Interagency Response to the Aspen Fire

Robert E. Lefevre, Salek Shafiqullah

The Aspen Fire of June-July 2003 burned 84,750 acres including 330 residential and business structures in and adjacent to the Coronado National Forest in southeastern Arizona. A Burned Area Emergency Response team assessed the fire, prescribed treatments, and implemented them in the burned area. In addition, 7 federal agencies, 6 state agencies, 16 county agencies, and 7 local agencies and utilities began to plan and act before the fire was contained to minimize damage due to accelerated erosion and flooding that was expected across the multiple ownerships. The events leading up to the Aspen Fire that contributed to the exceptional coordination including seven large fires on the Coronado National Forest in 2002 and five large fires in 2003 prior to the Aspen Fire as well as the experience of state and federal agencies following the Rodeo-Chedeski Fire in 2002 are described. Values at risk and burn severity mapping are summarized. The coordinated response including on-the-ground treatments of seeding, mulching, channel clearing, and road drainage improvement are described, and the results of monitoring the efforts are reported. The continued efforts to keep the public aware of potential accelerated erosion and flooding are also reported.

Ecological Classification, Organic Layer, and Large-Scale Prescribed Fire Monitoring on the Superior National Forest

Barb Leuelling and Jeff Tepp

The Superior National Forest (Minnesota) was one of the first national forests to initiate an Ecological Classification System (ECS) in the early 1960s, now known as Terrestrial Ecological Unit Inventory (TEUI). It was pioneered by Don Prettyman in response to FS Manual Direction 2535 to provide baseline information for barometer watersheds. Located within the Boundary Waters Canoe Area Wilderness (BWCAW), this inventory was meant to be a "representative area" to identify changes over time in soil and water from management-caused activities or natural events. From 1965-1990, landtype phases (LTPs) were mapped on national forest land based on combined factors such as climate, geology, landform, soils, vegetation, and hydrology. The Superior National Forest is now concentrating efforts on converting legacy data to electronic format, transferring mapping to GIS format, and developing a TEUI intranet website. TEUI information is being used to conduct monitoring of mechanical and burn treatments to salvage and restore a 500,000-acre blowdown event on the forest in 1999. The monitoring includes about 12,000 of 88,000 planned prescribed burn acres within the BWCAW. This may be the first "implementation prescribed burn monitoring" on a large natural event where lightning-ignited fires were a part of its history, and is designed to assess effects of prescribed burning on the organic layer of shallow to bedrock sites. Monitoring and mercury research on the forest may help answer questions concerning the role of the organic layer: oxidation of the organic layer during natural/prescribed fire events or its accumulation over time in the absence of fire.

Effects of Forest Management in the Caspar Creek Experimental Watersheds

Jack Lewis, Elizabeth Keppeler, and Tom Lisle

Caspar Creek Experimental Watersheds were established in 1962 as a cooperative effort between the California Department of Forestry and Fire Protection and the USDA Forest Service Pacific Southwest Research Station to research the effects of forest management on streamflow, sedimentation, and erosion in the rainfall-dominated, forested watersheds of north coastal California. The project has evolved from a simple paired watershed study into one of the most comprehensive and detailed investigations of its kind. In 1962, weirs were installed for measuring streamflow and sediment loads on the North and South Forks of Caspar Creek. From 1971 to 1973, 50% of the timber volume in the South Fork was selectively cut and tractor yarded, and the untreated North Fork was retained as a control. In 1986, thirteen new gaging stations were installed in the North Fork basin and three unlogged tributaries served as controls when 48% of the North Fork basin was clearcut and cable yarded between 1989 and 1991. Ten new gaging sites in the South Fork will be used to assess impacts of selective harvest and road rehabilitation on tractor-logged terrain. The scope of research in the watershed has expanded beyond hydrological studies to include geomorphological, ecological, silvicultural, and biological investigations.

Restoration of Cherry Creek–Lessons From a Southwestern Stream

Grant Loomis and Tom Moody

Large stream systems, composed of a small baseflow channel lined by a narrow greenline of riparian vegetation bordered by barren gravel and cobble bars are not uncommon in the Southwest. The elevation of the surfaces of the gravel and cobble bars above the water surface elevation of the baseflow channel makes natural recruitment of riparian vegetation on these surfaces difficult and leaves these systems vulnerable to scouring by even relatively frequent floods. In an effort to raise the level of stability of these systems, a demonstration channel restoration project was implemented on Cherry Creek on the Tonto National Forest in Arizona. The project attempts to create a channel that can transport the water and sediment of the watershed while at the same time maintaining the level of floodprone surfaces at an elevation that permits natural recovery of riparian vegetation. This poster will discuss some of the hydrologic challenges involved in design of the channel and some of the uncommon restoration methods used in the reconstruction.

Characteristics of Peak Flow Return Intervals for Small Drainage-Area Watersheds of the Southern Cascades of Eastern Oregon: Implications for Culvert Sizing

Walt Lucas

The equations for the magnitude and frequency of floods in Oregon used by the USGS have high standard errors for return interval values in two regions of Eastern Oregon. They assume that hydrologically similar sites were nested or adjacent, regardless of size. However, the large drainage area watersheds include diverse climatic zones where precipitation could vary from less than 20 inches year falling primarily as rain, to areas of over 60 inches of precipitation that is largely released as snowmelt. Consequently, the relative importance of the geomorphology, climate, and size could vary significantly, causing some of the large errors in the estimates. This work tries to reduce some of that error. Data from ten FS gages with over eight years of record is used to refine the magnitude-frequency relationships for a more uniform environment, where drainage area was between 4 and 50 square miles, minimum basin elevation was above 4200 ft and precipitation zones ranged from 25 to 60 in and were strongly influenced by snowmelt. Extending the relationships out to the 100-year return interval results in different discharge estimates, which have implications for culvert sizing.

Effects of Pine-Bluestem Restoration on Soil Quality on the Ouachita National Forest and Implications for Improved Air Quality and Watershed Condition

Ken Luckow and Hal Leichty

Thinning, midstory reduction and frequent (three- to four-year interval) prescribed fire have been used to restore the shortleaf pine-bluestem ecosystem. During 1997, 1998 and 1999, soil and foliar nutrient data were collected from three shortleaf pine-bluestem (*Pinus echinata*/*Andropogon* spp.) stands that have undergone restorative treatment for the past 18-20 years, and three untreated control stands. The analyses indicate soil quality has been improved in the pine-bluestem treatment stands as compared to the control stands. In the treatment stands soil pH has increased from 4.96 to 5.34; percent organic matter and cation exchange capacity have each increased by about 10%; percent base saturation by 15%; calcium by 60%; and total N and C by about 11% and 31%, respectively. In addition to improved soil quality, both air and water quality and watershed condition are indirectly benefiting from the pine-bluestem treatment stands by an increased soil buffering capacity and from added sequestration of C. The analysis indicate a net soil C increase of 0.20 tons ac^{-1} y^{-1} in the treatment stands, which equates to the removal of 1,500 pounds of atmospheric carbon dioxide ac^{-1} y^{-1}. Increased levels of Ca and organic matter in the treatment stands are beneficial in reducing the negative effects caused by atmospheric acid deposition on watershed condition and water quality, by providing a more effective soil buffering capacity to retain and neutralize acids.

How to Lighten Your NEPA Workload

Tom Mainwaring and Carl Leland

Forests today face ever-increasing NEPA workloads. Combined with staff and time limitations, it has become increasingly difficult for forests to meet project workload requirements and timelines with existing staff and budgets. Use of an enterprise team provides an "in-house" solution to meeting workload requirements within existing budgets, without the commitment to additional full-time personnel. An enterprise team is a group of Forest Service employees functioning as an established business within the agency, providing needed skills and services.

The Timber Experts and Measurements Services (T.E.A.M.S.) team specializes in providing project planning, project implementation, and quality control services to forests nation-wide. T.E.A.M.S. can provide full IDT NEPA contract services such as EAs, EISs, Landscape and Watershed Assessments, or it can provide staff on an individual resource basis, such as a soil scientist, hydrologist, geologist, or interdisciplinary team leader. Implementation services include project layout, quantity determination, contract preparation and appraisal, and BAER services. Quality control includes contract administration, checking cruising and scaling, and product accountability audits. T.E.AM.S. specializes in fire, wind storm, insect emergencies, and large complex projects that forests and other clients typically do not have the time or staff to complete. T.E.AM.S. ability to provide a full range of services, from a complete IDT to staff for a single resource, allows maximum flexibility to forests in determining how to best meet workload and budget requirements.

Quantifying Measurement Error for Accurate Testing of Channel Cross-Sectional Change

Daniel A. Marion

Channel change over time or between different locations is frequently assessed using cross-sectional variables like top width or hydraulic depth. For a given cross-sectional variable, the apparent difference between any two surveys is actually composed of two parts: that part representing the actual difference; and that part resulting from the combined errors associated with using different personnel to make measurements and the variation inherent in the measurement method itself. This latter part can be termed measurement error. To statistically test the actual change in cross-sectional variables between any two surveys, the measurement error must be determined. Measurement error is evaluated by doing repeat measurements (replicates) of randomly selected cross sections on the same day, but rotating survey personnel so that each performs a different job. It is quantified using the standard error of the mean. The standard error is computed for each variable of interest by determining the variable value for each replicate separately, computing the mean of the paired values, and then computing from multiple replicate surveys the standard error of mean. Using data from high-gradient streams in the Ouachita Mountains of Arkansas, I give an example showing how the standard error is computed and used to test changes in cross-sectional area, wetted perimeter, and hydraulic depth. I speculate that measurement errors would vary significantly between channels that differ substantially in substrate size and cross-sectional shape.

Ecosystem Mapping and Soil Survey in the Western Upper Peninsula of Michigan

Sarah E. Mase

The Ottawa National Forest was an early pioneer in ecosystem mapping using the nested hierarchy of ecoregions. Beginning in the 1980s, the Ottawa began mapping ecological landtype phases (LTP) at the 1:15840 scale, using the Land Type Association map to define mapping areas and legends. Components of LTP mapping include soil, landform, and potential natural vegetation. The Ottawa has used both LTA and LTP information in Forest Planning and project design over fifteen years. As a cooperator in the National Cooperative Soil Survey (NCSS), the Ottawa incorporated those standards into LTP mapping, including annual field reviews with oversight and correlation by a Natural Resource Conservation Service (NRCS) State Soil Specialist. In 1998, NRCS initiated soil surveys in Ontonagon and Gogebic Counties. The two counties comprise over 1.5 million acres; about a third of the area is National Forest System lands. Cooperation, technical advances, and databases such as NASIS (the National Soil Information System) and TERRA (the Forest Service's Natural Resource Information System [NRIS] application for soil data), and working relationships between the agencies enabled a vision of a seamless inventory to evolve. Working together on soil-site mapping in an atmosphere of mutual respect, concepts of both systems have been incorporated. Data and mapping from both agencies are contributing to a seamless inventory and added interpretive applications across the continuously forested landscape of the western Upper Peninsula of Michigan.

Geomorphic and Hydrologic Effects of High-Elevation Summer Storm Events

Alisha Miller, Tuli Tannaci, Juan de la Fuente, Abel Jasso, and Steve Bachmann

Two Northern California summer storm events during July and August 2003 resulted in high elevation debris flows on the slopes of Mount Shasta, Mount Eddy, and West Haight Mountain in Siskiyou County. The storm effects were exacerbated by glacial melt and significant snow pack above 8,000 feet on Mount Shasta, which experienced fourteen debris flows on its south and east flanks resulting in numerous plugged culverts and water quality degradation in the McCloud River, Lake McCloud, and McCloud Arm of Shasta Lake. Two debris flows occurred on Mount Eddy along with extensive rilling and gullying. Water quality concerns were raised for five alpine lakes on Mount Eddy due to the influx of sediment, with several of the lakes remaining discolored at least into September. Three stream crossings were damaged by a debris flow on the north side of West Haight Mountain. Because high elevation slopes are buffered with snow through much of the year, summer storm events are important for sediment production and transport processes and stream channel morphology. These events typically occur when rivers are at low flow and incapable of flushing sediment through the system. The occurrence of summer storm events needs to be considered during planning of land management activities, including road construction or maintenance, timber harvest, prescribed fire, and other ground disturbance activities. A better understanding of summer storm events, their temporal and spatial distribution, and their effects could be reached through improved cooperation between earth and atmospheric sciences and sharing of information between forests.

A Comparison of Northern California Sediment TMDLs

Alisha Miller and Juan de la Fuente

Many California rivers and streams have high sediment loads due to a combination of anthropogenic and natural factors. Sediment is one of the pollutants addressed with the Total Maximum Daily Loads (TMDL) Program established by the Clean Water Act and administered by the Environmental Protection Agency (EPA). A TMDL is a three step process of identifying water quality concerns, identifying pollution sources, and determining the load reductions and abatement actions necessary to restore the water body. For sediment-impaired rivers, an important part of the TMDL process is to determine natural sediment production and land management-related contributions through a sediment source analysis. Sediment source studies attempt to estimate the volume of sediment coming off of the hillslopes and being delivered to the river system. These studies typically use varying combinations of aerial photograph interpretation, extrapolation based on field sampling, and literature references. We compared sediment TMDLs completed for Northern California rivers and streams, along with several other sediment studies. The comparison was complicated by the wide variability in study methodologies, including sediment source categories (natural versus anthropogenic), data collection techniques, units of measure, and study time periods. Considering the implications TMDLs have for land management, the associated sediment analyses need to be standardized. Ideally standardization should be universal, but it would also be valuable for analyses of national forest watersheds. We offer suggestions on standardization of key elements of sediment source analyses to allow for a more concise evaluation of each TMDL and simplify comparisons of TMDL findings.

Stream Restoration at Road Crossings in Wisconsin

Jim Mineau and Dale Higgins

Poorly designed road-stream crossings can affect water quality, stream morphology and fish passage in northern Wisconsin. Sediment is the most significant water quality impact, and frequent failures are the largest source of sediment, followed by road surface and embankment erosion. Aggradation is the most common morphological impact. Downstream aggradation is often associated with coarse sediments from frequent failures. Most upstream aggradation consists of muck, silt and fine sand that accumulate because culverts are set too high or are undersized. Since 1998, the Chequamegon-Nicolet NF has replaced over 90 stream crossings through the Ten Percent program. These crossings have been designed to restore channel morphology, provide fish passage, improve safety and reduce maintenance. A protocol for survey and design has been developed to accomplish these objectives. Culverts are sized to pass the 100-yr flood, which is estimated from USGS regional regression equations and occasionally checked with other techniques. The road, culvert, stream thalweg, and at least four channel-floodplain cross-sections (two up and two down) are surveyed in the field. The thalweg survey is used to identify channel morphology impacts and to specify the new culvert elevation. The remaining data are used in Hec-Ras to hydraulically model the existing and proposed culverts. Other key design and construction techniques include stream diversion during construction, compaction, road surfacing, riprap and locating the low point of the road profile to one or both sides of the culvert.

The 1997 Flooding in Two Northern California Klamath National Forest Streams: Geomorphic Effectiveness and Sediment and Large-Wood Budgets

Zackary J. Mondry

The 1997 "New Year's Day" flood produced a range of effects in valley bottoms across the Klamath National Forest in northern California. I assessed flood disturbance in two adjacent basins (drainage area ~35 km^2) having similar bedrock, geomorphic terrane, and land-use characteristics. I examined valley bottom forests and morphology with pre- and post-flood air photos, and with cross sections, and constructed flood sediment and large wood budgets. I then linked event disturbance to volumes of sediment and large wood input during the flood, at the reach scale. Major landsliding in one basin produced large debris flows and downstream debris floods that stripped riparian forests and mobilized floodplain deposits along the entire valley network (~10 km). Large headwater landslides and debris flows also affected the second basin, but disturbance was patchy and decreased downstream as sediment and large wood were deposited at valley bends, impingements, and on unmobilized floodplains. The degree of valley bottom disturbance increases with the volume of sediment delivered to reaches during flooding, and may also increase when greater volumes of large wood are input to reaches lacking valley bends or mature conifer trees that promote deposition. Intermediate-level disturbance increased valley system complexity. In managed Klamath Mountain basins, debris flows commonly originate by landsliding from roads or deforested hillslopes. Such debris flows may have insufficient mature conifers to moderate run-out distance or to promote complexity in receiving channels. These debris flows are more likely to simplify downstream valley forests and morphology and convey flood disturbance to larger systems.

Drought, Storms, and Streamflow and Stream Temperature Monitoring on the Coconino and Prescott National Forests, Northern Arizona

Zackary Mondry

Prolonged drought across the US Southwest has sharpened concerns regarding the availability of water for consumptive uses, and drought effects on forest health and wildfire potential. Of special concern to watershed managers are the impacts of drought on water availability to sustain aquatic and riparian habitats, and effects on associated fish and wildlife species. In support of instream flow water rights programs, the Coconino and Prescott National Forests are monitoring stream flow with instantaneous measurements at some 14 streams. Flow monitoring began in earnest in the summer of 1998, and most sites were previously ungaged. Additionally, I began collecting stream temperature data with Tidbit data loggers in the summer of 2002, and now have temperature data from nine streams across the Coconino NF. Many of these streams were also monitored for stream flow by the FS or USGS (continuous records) during this time. The period from September 2001 through May 2002 was the driest on record dating back to 1898 in northern Arizona. However, storms in September 2002 and February and March of 2003 produced overbank flows along many streams in northern Arizona. Stream flow and stream temperature data are presented, and some effects of weather patterns and storm events on flow rates and stream temperatures are illustrated. For example, temperature depressions can help constrain the onset and duration (but not magnitude) of spring run-off events in streams lacking continuous flow records. These data also provide a baseline to monitor future impacts on water resources from drought and consumptive uses.

Evaluation of Habitat Variability, Channel Changes, and the Effectiveness of Restoration Projects in an Eastern Washington Stream

Mark Muir, Susan Bolton, Robert Wissmar, and Pete Bisson

The purpose of this study was to evaluate habitat variability (1990-2001), channel changes (1994-2001) and the effectiveness of restoration projects (1986-2002) in the Little Naches river, Washington. An adjacent, relatively undisturbed river was used as a reference of natural conditions and processes. Response or pool-riffle reaches were surveyed in both study streams. Between 1990 and 2001, Little Naches response reaches showed an increase in pool habitat, large woody debris [LWD] and surface area comprised of spawning-sized gravels, while the percent of embedded stream length decreased. Cross-section surveys revealed localized channel migration, LWD recruitment and pool formation in the most altered and confined reach. The observed habitat and channel changes in the Little Naches River appear closely related to flood events, rather than management or restoration projects. The effectiveness of in-stream structures varied with structure type, location in the channel and channel type. In-stream structures were not effective at creating or maintaining habitat in the long term, particularly in active response reaches. Although habitat conditions in the Little Naches River appear to be improving, they are still quite different from reference reaches, which exhibited a more complex array of habitat for both juvenile and adult salmonids. Pool habitat, side channel habitat and LWD were all more abundant in reference reaches. Pools in reference reaches also had more total cover, deeper residual depths and were more often associated with meander bends. The observations and results of this study can help offer insight and guidance to future restoration efforts within the Little Naches watershed.

Tools to Evaluate the Effect of ATVs on Soil Physical Properties

Carolyn Napper

The US Forest Service started a study to determine the potential impacts of All Terrain Vehicles (ATVs) on National Forest Lands and Grasslands. The objective of the study is to look at different types of ATV equipment (different weights, tires, suspensions) and evaluate changes in soil physical properties on both existing ATV routes and uncompacted soils. The study is done in partnership with six national forests across the country and the Rocky Mountain Research Station. Key soil indicators used include soil bulk density, rut depth, soil moisture, trail width, soil displacement and erosion. ATV equipment types include sport and utility models with original equipment manufactured tires and after market tires. Data gathering methods include visual observations to define condition classes of low, moderate and high with actual soil measurements of rut depth, trail width, soil bulk density, soil moisture and erosion. Photographic documentation is used to help define condition classes and provide a reference for completing the condition class rating. The findings of the study will be released once the study is completed but the tools and methodology used can help physical scientists in their evaluation and management of ATV use.

Impacts of an Historical Wildfire on Hydrologic Processes: A Case Study in Arizona

Dan Neary

An opportunity to study the impacts of a watershed-scale fire on hydrologic processes in a ponderosa pine (*Pinus ponderosa*) forest ecosystem of the Southwest presented itself following the devastating Rodeo-Chediski fire of June-July 2002, which burned a total of 462,606 ac in north-central Arizona. Streamflow regimes, erosion-sedimentation processes, and other hydrologic and ecological characteristics are being measured on two watersheds to assess the short- and long-term impacts of this historical fire. Findings to date with respect to post-fire changes in soil and water resources are reported upon in this poster.

Regulatory Tools for Watershed Management

Karen Nelson

The U.S. Army Corps of Engineers has regulatory roles designed to help protect the biological, chemical, and physical integrity of waters of the United States. The activities requiring authorizations in the form of a permit include placement of fill, bioengineering streambank treatments, docks, piers, and other structures, in waters of the United States. Regional permits, developed by coordinating with federal, state, and local agencies, cover numerous relatively minor activities and are tailored to the geographic nuances of our regions. Information on nationwide, regional, and individual permits will be available. Permitting requires the balancing of environmental protection with economic development. Mitigation is permitted for losses of water resources when all practical efforts to avoid wet areas have been applied. Failure to seek or comply with a Department of Army permit may result in civil penalties. We will show the Army Corps of Engineers jurisdictional boundaries for both Section 404 of the Clean Water Act, and Section 10 of the Rivers and Harbors Act. Information on permit processes and mitigation information associated with work in waters of the United States will be provided. The poster educates people about the Corps role, rules and laws, applicable for working in waters of the United States, and the resources used to monitor and verify permit compliance.

Spatial Data Analysis of Soils Within the Kisatchie National Forest Using Geographical Information Systems

John C. Novosad, Wayne H. Hudnall, and Jacqueline A. Prudente

The Kisatchie National Forest (KNF, Louisiana) maintains designated trails within the forest for off-road vehicle (ORV) use, but many ORV users create their own trails, causing soil erosion and rutting problems. To help guide the management of this use, a spatial data analysis of the soils within the KNF was performed using geographical information systems (GIS). The objectives were to summarize and present the spatial distribution and nature of the soil resource in a thematic format and to identify areas that are suitable and unsuitable for ORV use with the map overlay procedure in GIS. Results reveal that soils within the Kisatchie Ranger District (KRD) with potential for severe erosion are located on sloping areas, and soils that have the potential for severe rutting are located on upland flats and floodplains. Problem soils–soils with potential for severe erosion or rutting–were identified. These soils are loamy, poorly drained and very slowly permeable, or sandy and well-drained but located on sloping areas. Designated and user-created trails crossed streams and traversed problem soils. Based upon the results of the spatial data analyses of soil suitability, the entire KRD is unsuitable for ORV traffic. Traffic should be restricted on this district to allow damaged sites to recover from the damage that has occurred. The USFS has temporarily closed the KRD to ORV traffic during wet conditions based upon this recommendation.

Streamflow Analysis of the Little Popo Agie River Near Lander, Wyoming

Liz Oswald, Greg Bevenger, and Laurie Porth

The simplified water balance equation Q = P - ET, where stream flow discharge is equated to precipitation minus evapotranspiration, was evaluated to determine whether discharge from the 125-square-mile Little Popo Agie River watershed (central Wyoming) has changed over time. The analysis was made as part of the Little Popo Agie River (HUC 1008000301) Watershed Assessment conducted by Shoshone National Forest staff in 2003. The objective of the analysis was to determine whether forest management activities or the lack thereof (such as timber harvest and prescribed burning) or wildfire, are having an effect on the water balance. Double-mass analysis, following the methods of Anderson (1955), was used with local and regional data from the Natural Resource Conservation Service, the National Weather Service, and the United States Geological Survey. The analysis involved identification of stable snow survey, precipitation, and stream gaging stations that would be suitable as references for 1 April snow water equivalence, average annual precipitation, and seasonal (April through September) stream flow, respectively. The reference information was then compared with the Little Popo Agie River (USGS site 06233000) seasonal stream flow record. The results show no detectable change in stream flow for the period of record (late 1940s to 2003) leading to two possible conclusions: 1) management activities on the national forest have not had a significant effect on the water balance; or 2) if there has been an effect, it is not detectable at the Little Popo Agie stream gage.

Ground-Penetrating Radar and Seismic Refraction as Tools for Characterizing Aquifer Properties in Recently Active Glacial Moraine Settings, Tongass National Forest, Alaska

Noel S. Philip, Steven D. Sheriff, and Robert A. Gubernick

Ground penetrating radar (GPR) and seismic refraction surveys were conducted at a critical location on a glacial moraine near Yakutat, Alaska. Observations of the aquifer material on the moraine were made from exposures at the surface and from shallow excavation. The near-subsurface moraine material is composed of clean sand and poorly sorted gravel, with boulders having a major axis >1 m. Seismic data acquired at the moraine show a subsurface depth to refractor of ~10-16 meters at the moraine. GPR data show a strong reflection at ~25-30 m depth. The expected results from the surveys should allow a reasonable geometric model of the subsurface to be made within a 10% estimated resolution of depth. Further applications of the data set and extrapolated properties of the subsurface should lead to a reasonable conceptual model of hydrogeologic units and general flow regime. The subsurface model will prove valuable during the next cyclical closure of Russell Fjord by Hubbard Glacier, the water body bordering the glacial moraine to the north.

The Stream Systems Technology Center

John Potyondy

This poster will present information about the Stream Systems Technology Center, a national technical service center of the Washington Office Watershed, Fisheries, and Wildlife Staff located at the Rocky Mountain Research Station. The poster highlights technology transfer products STREAM has produced to help the field do their job better. The STREAM charter, operating philosophy, and primary objectives are presented, and STREAM staff are introduced. Examples of resources available from STREAM designed to help physical scientist do their job better are given. This includes information about the STREAM Webpage (*www.stream.fs.fed.us*), the Stream Notes newsletter, technical information and training resources, videos, DVDs, publications, and new technology. The National Stream Systems Technology Center is a unique example of collaboration between the National Forest System and Research and Development to make research findings and other information readily available to field specialists.

Monitoring Soil Erosion Following Wildfires in North-Central Washington State

Kenneth J. Radek

Several large wildland fires, caused by lightning storms, occurred in the North Cascades of Washington, on the Okanogan National Forest, in 1992 and 1994. Concerns about the potential for soil erosion led to a monitoring project. Severely burned sites were identified and treated on two of the fires to reduce soil erosion. Soil erosion plots were established on three of the 1994 fires and the 1992 fire to evaluate the amount and duration of soil erosion. Two methods were used to estimate soil loss. One method used metal troughs on small plots to trap soil movement. The second method used erosion pins or stakes to measure soil loss or accumulation. Onsite erosion measurements were conducted for seven years after the wildfire. Erosion rates were highest in 1995, when high intensity storms occurred in the spring and early summer. Normal spring runoff did not appear to cause increases in erosion. Erosion diminished somewhat on most plots following the 1995 event. By the fall of 2000 most of the plots had an adequate vegetative ground cover where soil erosion had diminished or was non-existent. Natural vegetative recovery of groundcover species was key to reducing erosion as time progressed.

Climate Variability and Change in the Southern Appalachians

Mark S. Riedel

Global warming and climate change may cause significant potential impacts to all of life as we know it. While there has been a wealth of research documenting trends and patterns in global and regional climates, debate within the scientific community still rages as to the existence, magnitude, duration and potential causes of these phenomenon. For example, only recently have we recognized that, given historical global climate patterns, much of the global warming trend we are experiencing appears to be natural. Within this context, long-term climatologic records from Coweeta Hydrologic Laboratory (1934 to present) are presented. From these data it is evident that there is a significant amount of natural climatic variability in the southern Appalachians. The natural variability is closely linked to fluctuations in the North Atlantic Oscillation (NAO). For example, the record drought in the southeastern United States, while extreme, was not unusual given historical patterns of alternating wet and dry cycles. These cycles are characteristically preceeded by phase shifts in the NAO. The breaking of the drought by Hurricane Isidore and Tropical Storm Kyle (Sept. 2002) was also consistent with past drought cessation in this region. Apparent trends toward cooler and wetter conditions for this region are consistent with observed behavior in the NAO. While the highly variable nature of climate in this region makes it difficult to identify climate trends, nighttime temperatures (minimum daily) have increased over the past fifty years.

Estimating Impacts of Cattle Grazing on Stream Sediment Budgets

Mark S. Riedel, Kenneth N. Brooks, and Elon S. Verry

Streams in the Nemadji River Watershed of east-central Minnesota are deeply incised in lacustrine clay and glacial till. Due to "recent" glacial activity (~10,000 years before present) and resultant geologic uplift, this region is quite erosive. Indeed, the Nemadji River is the largest source of fluvial sediments to Lake Superior (on both mass and per unit area bases). While natural land cover was dominated by coniferous forests, riparian areas were commonly used for grazing by the late 1800s. To determine the impacts of grazing on sediment yield, we compared morphology and sediment budgets of streams having forested and grazed riparian areas. We surveyed numerous cross-sections on representative study streams over a three-year period. Grazed streams were generally larger, shallower (increased width depth ratio) and straighter (decreased sinuosity) than forested streams. The highly variable riffle-pool structure of forested riparian areas was lost to sedimentation and replaced by relatively uniform profiles in the grazed streams. Using watershed scale sediment budgets and channel morphology, we computed sediment budgets for each study reach. We then computed the minimum amount of erosion necessary to change the morphology of a "typical" forested stream to that of the grazed streams. We estimate that grazing only 0.01% to 0.1% of the riparian areas increased annual sediment yields by 2% to 9%, over a relatively short period (the grazed streams appear to have stabilized) following the introduction of cattle. While significant locally, these values are orders of magnitude lower than sediment yields from prevalent mass wasting.

Gradient Analysis of Soil, Vegetation, and Climate on the Tonto National Forest

George T. Robertson and W.H. Moir

Ecological site description (ESD) plots contain approximately 150 data elements (mostly soil and vegetation data) that are used in gradient analysis on the Tonto National Forest, Arizona. These ecological data and climate data from NOAA weather stations characterize life zones along a climatic gradient that ranges from low elevation Sonoran desert to high elevation coniferous forests. Gradient analysis is the process used to integrate soil and vegetation with climate. To determine climatic relationships between soils and plant communities, weather station (WS) data are embedded within each life zone. This is accomplished by describing vegetation at or near acceptable weather stations. By including climate data in ordinations, we now see how climatic features, soils and vegetation are distributed within and among life zones. A robust ordering program known as Non-parametric Multivariate Analysis (NMS) in PC-ORD version 4.0, arranges or ordinates ESD and WS data into life zones. NMS is a standard gradient analysis technique developed for analysis of complex, multivariate ecological data. Computer ordination is not by itself definitive in arranging vegetation and soils data along a climatic gradient. Therefore, the final gradient will combine our field knowledge with ordination results.

Rehabilitation of the Left Hand Canyon Dispersed Recreation Area

Theresa Stevens Savery

This project is located on the Arapaho-Roosevelt National Forests, Boulder, Colorado. The Left Hand Canyon Dispersed Recreation Area is an area that has received heavy off-highway vehicle (OHV) recreation use for several decades. **Left Hand** Canyon is in the **Left Hand** Creek Watershed, which is part of the drinking water supply in the Northern Colorado Water Conservancy District, serving millions of people on the Front Range of Colorado. The OHV use had become unmanaged and users were developing new OHV trails weekly. The proliferation of trails caused substantial vegetation and soil loss. This use resulted in the development of several headcuts and gullies ranging from 5 ft to 30 ft deep in a meadow called the "playground" by the recreating public. These gullies had become a main source of sediment in the **Left Hand** Creek Watershed. In 2003 and 2004 the Arapaho-Roosevelt National Forests entered into a partnership with Trail Ridge Runners, Wildlands Restoration Volunteers, and Walsh Environmental to design a restoration project for the "playground" to reduce the amount of erosion and sedimentation occurring in the **Left Hand** Creek Watershed. In April of 2004 the restoration project was implemented through the leveraging of the grant money and the forest was able to restore approximately 14 acres with the help of over 100 volunteers. This poster presentation will show the condition of the recreation area before and the dramatic change after the restoration project and display the efforts of the partners involved. Without the partnerships this project would not have succeeded.

Long-Term Soil Productivity of Western Gulf Coast Loblolly Pine Stands

D. Andrew Scott, John Novosad, and Rodney Peters

Forest management operations have the greatest potential to reduce soil productivity through altered soil porosity and fertility, which are most affected by compaction and organic matter removal, respectively. The objectives of this study were to assess the 10-yr growth response to compaction and organic matter removal and the soil recovery from compaction. We measured tree volume and soil bulk density on four sites in the Kisatchie National Forest in Louisiana and three sites in the DeSoto National Forest in Mississippi as part of the USDA-FS Long Term Soil Productivity project. Three levels of compaction (none, moderate, severe) and three levels of organic matter removal (bole only, whole tree, whole tree and forest floor) were applied in a factorial design at each site, and half of each treatment plot was kept free from competition using herbicides. Soil compaction had no negative impacts on tree growth at ten years, partly due to the rapid recovery of the surface soil from the applied compaction. Removing more organic matter than the boles-only reduced stand volume on five of seven sites by 15 to 30%. This study indicates that harvesting operations that remove tree branches and foliage and site preparation operations that remove the forest floor can have negative impacts on long-term soil productivity.

The Dosewallips Washout: A Reach Analysis Case Study to Evaluate Road Management Solutions and Consistency With the Aquatic Conservation Strategy (ACS)

Bill Shelmerdine and Dan Cenderelli

During the flood of January 2002 approximately 95 meters of Forest Road 2610 on the Olympic National Forest, Washington, was washed out. The Dosewallips River is a key watershed and contains several species of Pacific salmon including the Endangered Species Act (ESA) listed Puget Sound Chinook salmon (*Oncorhynchus tshawytscha*). Over the following 15 months, an interdisciplinary analysis was conducted in order to determine the best solutions for providing access beyond the site. The preliminary assessment suggested that reconstructing the road in its original location, now within the channel of the river, was the preferred solution. Traditional bank hardening methods along with more contemporary structures such as log complexes would be employed. After the initial evaluation it was decided that a more detailed reach analysis was warranted. The analysis concluded that a number of physical and hydrologic processes would be altered if the original preferred alternative were implemented. Analyzing the site in more detail and expanding the scope of the analysis upstream and downstream of the site provided a much better understanding of watershed conditions, processes and potential impacts. Based on the new information, reconstructing the road in its former location was determined to be inconsistent with the Northwest Forest Plan Aquatic Conservation Strategy (ACS) and the alternative was dropped from further consideration. A significant conclusion of this analysis is that traditional approaches and cursory analysis may provide incomplete or misleading results if the scope of assessment is too narrow.

The Olympic National Forest Road Management Strategy–Aquatic Risk Assesment

Bill Shelmerdine, Robert Metzger, Scott Hagerty, and Robin Stoddard

Over the last couple of decades the Olympic National Forest (Washington) has completed numerous road maintenance, stabilization, and decommissioning projects to help restore aquatic conditions. Available funding for such work is far below what is required, resulting in the need to prioritize activities. In 2000 the forest completed a forest-wide Road Maintenance Strategy (RMS) to help us prioritize road treatments to meet multiple resource objectives. The RMS provides a forest-wide framework for integrating road management and watershed restoration. By rating each road based on access needs and potential resource risks, the RMS provides a science-based approach to resource management decisions. Aquatic risk is a critical component of the RMS. Aquatic risk assessment was based heavily on findings from many of our recent watershed analyses. Elements used to determine aquatic risk include: geologic hazard; proximity (delivery) to fish habitat; stream crossing density; riparian zone-stream proximity; and upslope hazard. Aquatic risk is GIS generated and is consistent across the forest. Experience indicates that the aquatic risk assessment is particularly accurate and useful and is a reliable predictor of conditions found on the landscape.

Keeping Water on the Land Longer

Janice Staats

The longer water remains on the land before running off, the more productive that land will be. There are many ways to keep water on the land longer in and near streams. One approach involves working with individuals, institutions and communities to create a common understanding of what riparian-wetland areas need to function properly, and what that means relative to how quickly water moves over and through the land. Through the Creeks and Communities strategy, the USDI Bureau of Land Management and USDA Forest Service, in partnership with the USDA Natural Resources Conservation Service, are helping to create this common understanding by bringing together people of diverse interests and backgrounds to explore the physical attributes and processes (i.e., the interaction of soil/landform, water, and vegetation) that produce values such as clean water, habitat, and other benefits. The concepts of physical function, as outlined in the Proper Functioning Condition (PFC) assessment method, provide this foundation. The PFC method also serves as a communication tool, providing common terms and definitions. By incorporating technical information into collaborative processes, the Creeks and Communities strategy works to ensure that elements of the fundamental sciences are not only incorporated, but help structure the dialogue. This enables diverse stakeholders to craft a common vision that supports the recovery and maintenance of the physical functions that produce important, but often conflicting, public values. As a result of this learning process, people are rediscovering that the largest fresh water storage area in the world is not a lake or reservoir, it is the soil.

Forests on the Edge: Projecting Housing Development on Private Forests Across America's Watersheds

Susan Stein, Mark D. Nelson, Dave Theobald, Ronald E. McRoberts, and Mike Eley

The private working land base of America's forests, farms and ranches is being lost at an increasing rate by conversion to suburban uses. These lands are being converted at the rate of nearly 800,000 acres per year or more than 4,000 acres per day. These trends are affecting the future of private working landscapes and the important habitat and ecological services that they provide. To better understand the contributions of America's private forests to timber, wildlife and water, as well as pressures from development and other ecological factors such as fire, air pollution and insects and disease, the USDA Forest Service has sponsored the "Forests on the Edge" project. This project uses GIS techniques to produce a series of maps of pressures and opportunities on America's private forests for the lower 48 states. Cooperators in this effort include the Forest Service North Central, Southern, and Pacific Northwest Research Stations of the USDA Forest Service, as well as American Farmland Trust and Colorado State University. Phase I of the project has identified watersheds containing substantial forest cover that are likely to experience development pressures, by integrating digital data layers depicting private forest cover and housing density projections out to 2030.

Automated Water Quality Monitoring in the Clackamas River Watershed, Mount Hood National Forest

Ivars Steinblums

The Clackamas River is a public water supply with its source on the Mt. Hood National Forest, serving approximately 175,000 people in the Lake Oswego, Oregon City, and Clackamas areas near Portland, Oregon. Municipal water suppliers expressed a need for real-time turbidity data for the Clackamas River near the Mt. Hood National Forest boundary so they could have early warning of high instream turbidity during storm events. There was also public concern about the potential effects on drinking water quality from the Eagle Creek Timber Sale located on a tributary of the Clackamas River. Automated YSI water quality monitoring sondes were installed on the Clackamas River (December 1999) and Eagle Creek (December 2001) to continuously monitor water temperature, turbidity, conductivity, and pH. Real time water quality data is available via telephone for the Clackamas River monitoring station, with an additional capability to provide early warning by telephone if a pre-set turbidity threshold is exceeded. Monitoring data at the Eagle Creek monitoring site is stored internally for later retrieval and analysis. This poster will display installation methods, operation, and monitoring results and analysis for Clackamas River and Eagle Creek continuous water quality monitoring stations on the Mt. Hood National Forest.

Soil Moisture Monitoring at SNOTEL Climate Stations on National Forest Lands in Oregon and Washington

Sheila Strachan

The Natural Resource Conservation Service Snow Survey program has traditionally monitored mountain snowpack and precipitation for streamflow forecasting. Soil moisture probes have been installed at 17 SNOTEL sites on national forest lands in Oregon and Washingotn. Data are transmitted in real time via the SNOTEL meteor burst telemetry network to the NRCS National Water and Climate Center in Portland and posted on the web for user access. NRCS hydrologists plan to use soil moisture monitoring data to improve their water supply forecasts. Soils that are extremely dry prior to fall snow accumulations are expected to absorb more spring snowmelt, reducing streamflows. The soil moisture profile varies greatly with site and soil type. The Lapine soil on the Winema National Forest (Oregon) is forming in deep air-fall tephra deposits from Mt. Mazama. Soils may never reach saturation and dry out very quickly following snowmelt. In the Wallowa Mountains of Eastern Oregon, the influence of groundwater is apparent at the Mt. Howard SNOTEL site. The Angelpeak soils at Mt. Howard have a deep, ashy over loamy skeletal particle size and are considered well drained. Soil moisture at the 20 inch and 40 inch sensors has been greater than expected since the August 2003 installation.

An Application of the Hillslope Erosion Model (HEM) to Determine Erosion Predictions and Interpretations for Terrestrial Ecosystem Survey (TES)

Steven Strenger, Steve Sebring, and Wayne A. Robbie

The Hillslope Erosion Model [HEM] is primarily designed to predict sediment yield in tons/acre or tonnes/hectare from a particular rainfall frequency such as a 2-year, 24-hour rainfall event. Erosion predictions and interpretations made in the US Forest Service, Southwest Region, however, are based upon temporal soil loss per unit area in tons ac^{-1} y^{-1} or tonnes ha^{-1} y^{-1}. The HEM input values are slope gradient, slope segment lengths, cover percentages and runoff volume. Average slope gradient and cover percentages are obtained from data summarized in Terrestrial Ecosystem Survey [TES] reports and databases. Slope segment length is obtained on-site or from topographic maps. The runoff volume value used in the HEM is derived from the SCS Curve Number

Method. For most curve numbers used in the Southwest, a rainfall of one inch or more is required to produce runoff and resulting erosion. NOAA weather stations provide data on the number of days per year rainfall is equal to or greater than one inch. Data is also provided on the maximum recorded rainfall for each day of the year. By knowing an average rainfall amount equal to or exceeding one inch, the number of days per year this occurs, average slope gradient, slope segment lengths and average cover percentages, average annual erosion rates can be estimated and interpretations made for TES map unit components using the HEM.

A Comparison and Evaluation of Stream Substrate Embeddedness Techniques

Traci L. Sylte

"Embeddedness" or "cobble embeddedness" are terms used to describe fine sediment deposition surrounding larger surface substrates, and have been used as an indicator of substrate habitat conditions. Despite considerable controversy in the early 1990s on its validity, embeddedness remains a measure employed in various studies across the nation and in some regulatory environs. Although descriptions and protocols have emerged in high profile publications, the meaning of embeddedness and its metric are commonly misunderstood, and most documentation necessary for field application of measured embeddedness methodology exists in gray literature or office files. Fundamental problems exist in one methodology and errors and inconsistencies occur between guidance documents. Although measures from the various techniques are typically accepted to accurately portray embeddedness, statistical variance between methods was significant, and was substantially larger than variance between controlled, similar sites. Embeddedness varied by method, calculation technique, streambed composition, and observer. Embeddedness was found to be only weakly correlated with other common bed surface measures. A combination of physical processes are likely responsible for conditions referred to as embeddedness, and predicting embeddedness with any one variable, or linking it directly to biological criteria, is unlikely and not feasible at this time given the current level of understanding and measurement methods. Although very worthy in concept, this study suggests that embeddedness determinations should be used only for general characterization purposes at this time. However, potential exists for methodology improvement, and suggestions for further research and application development are offered.

Dunham Creek Rehabilitation: Early-Day Riparian Harvest Gone Bad-The Consequences, the Remedy, and Highlight for Riparian Health Management First and Foremost

Traci L. Sylte

Photos help recollect the story of almost a mile of riparian harvest in the mid-1960s in Dunham Creek, a tributary of Montana's Blackfoot River basin. Then, a road and bridge bisected the area, where activities targeted large spruce trees and spanned the entire valley bottom. Shortly after removing all trees and understory, the high bedload, C4 stream unraveled. During the early 1970s, well-intentioned stabilization attempts channelized, bermed, and reshaped the channel into a trapezoidal character. In 1998, remnants of the berms existed, the bridge had washed out, bank erosion was magnitudes above natural levels, the channel was braided and 150 feet wide in many locations, and sediment loads threatened fisheries and downstream facilities. Although slowly recovering, projections of attaining natural stability were 50-100 years into the future, which was unacceptable to multi-entity bull trout (*Salvelinus confluentus*) recovery efforts in the basin. With funding, collaboration, or both from at least eight entities, Lolo National Forest water resource personnel designed and implemented a detailed rehabilitation plan that will stabilize the reach for at least 10-15 years until vegetation is re-established. To foster favorable stream values, the District Ranger decided to use an alternative travelway and abandon the existing road and bridge. Today, the project highlights the importance of considering riparian values first and foremost in all management activities and how trained personnel can successfully employ Rosgen's geomorphic and other environmental river mechanic design approaches in a very cost-effective manner. After several high flow events, the stream is functioning as intended and studies have already shown increased fish populations.

Analysis of Relationships of Stream Shading vs. Vegetation Density and Spectral Radiance

Bárbara Gutiérrez-Teira, Charles H. Luce, and David Nagel

Solar radiation is the dominant factor controlling stream temperatures. Attempts to evaluate or model stream temperature patterns and impairment over river basins require estimates of shade for extensive areas. It is generally not feasible to collect such information from the ground, and methods are needed to estimate shade from remotely sensed data. As a first step to develop a shade model, we analyzed the relationships between shade values in specific stream reaches and vegetation density, and between shade and remotely sensed imagery values. Shade is evaluated through solar radiation, obtained with hemispherical canopy photos at each site. Reflectance values from Landsat Thematic Mapper imagery were obtained and different combinations of values from different bands, together with known vegetation indices, are correlated with total radiation. Although the main purpose of these relationships is to obtain an average that can be extrapolated to greater areas, the results are not as reliable as needed for the mapping, mainly due to the great ratio between the pixel size and the area sampled by the hemispherical photography. Other alternatives such as spectral unmixing are explored.

Sediment Transport and Production From Two Small Watersheds in Central Idaho

Robert Thomas, John King, Robert Kenworthy, and Nick Gerhardt

Sediment production from forested watersheds is useful to land managers in evaluating the effects of management activities or natural events, comparison of different watersheds, evaluating and refining existing models and tools, and determining channel maintenance streamflow requirements. Sixteen years of bedload and suspended sediment transport and seasonal (1 April to 30 September) streamflow data were used to estimate annual sediment production for two small watersheds in central Idaho on the Nez Perce National Forest. Missing streamflow records (1 October to 30 March) were estimated using regression relationships with a downstream USGS gaging station. A locally weighted regression technique (LOESS) was used to develop relationships between logarithms of sediment transport and logarithms of stream discharge. The LOESS relationships were used with the mean daily streamflow records to estimate annual sediment production. This approach resulted in relationships with less variance and smaller bias correction factors than more traditional techniques. We evaluate and discuss time trends in sediment production and compare our sediment production estimates with predictions from a sediment yield model (NEZSED) used as a planning tool by the Nez Perce National Forest.

Integrated Forest Plan Monitoring Program: Tongass National Forest Riparian and Aquatic Synthesis

Julianne Thompson and Emil Tucker

Since 1997 resource managers on the Tongass National Forest, southeast Alaska, have struggled to address at least nine separate forest plan monitoring questions through a dozen or more discrete protocols pertaining to watershed resources (soils, wetlands, riparian areas, streams, water quality, and fish). A few protocols have several years of data, some are still in pilot or development stages, and other protocols specifically listed or inferred in the Forest Plan have been ignored. This aquatic synthesis considers the forest plan monitoring questions as an integrated package of watershed monitoring that includes stream, riparian, and upland response indicators (both biological and physical). Stream, riparian, and upland attributes will be monitored in watersheds throughout the Tongass National Forest. These watersheds include a set of case-study watersheds that will be instrumented and intensively monitored as well as a subset of existing monitoring sites tracking physical and biological response indicators that will be periodically remeasured. By aggregating existing projects and focusing our sampling efforts, the riparian synthesis will allow us to tease apart anthropogenic effects on the proper functioning condition of small watersheds from the dynamic disturbance regime naturally present in these young post-glacial systems, and to evaluate ability of the standards and guidelines set out in the forest plan to insure the continued health of our watershed resources. Our presentation focuses on the development of the riparian and aquatic synthesis, the complexities of watershed monitoring in a remote and dynamic rainforest environment, and preliminary information after the first season of instrumentation.

Real-Time Smoke Monitoring–Current Instrument Evaluation and Telemetry Systems

Andy Trent

One mission of the USDA Forest Service, Missoula Technology and Development Center (MTDC) is to evaluate commercially available, real-time, particulate monitors. These monitors provide forest managers, fire and air quality specialists with information on smoke concentrations generated from burning biomass. Airborne particulates, especially those particles smaller than 2.5 microns in diameter ($PM_{2.5}$), pose potential health, visibility, safety and nuisance problems. Measurement of these airborne particulate concentrations is very important to the Forest Service and other land managers as the use of managed forest and rangeland burning increases. Recently, MTDC conducted an evaluation of several new real-time particulate monitors. Included were the E-BAM and E-Sampler manufactured by Met One Instruments, Inc. and the Dataram 4, manufactured by Thermo Electron Corp. The key items of the evaluation were determining the accuracy of each monitor when measuring or estimating smoke concentrations, comparing results from like instruments (inter-instrument comparison), reliability, operational characteristics such as portability, power requirements, data collection, and cost. Additionally, a satellite telemetry system has been developed to transmit data from each instrument to display the smoke concentration data in near real-time on a Web page. The Interagency Real-Time Smoke Monitoring Web page displays the smoke concentration data, along with any other meteorological data associated with the monitor. The Web page also displays historical information for each monitor. The telemetry system uses the ORBCOM low-orbiting satellite system to transmit the data.

Effects of Prescribed Fire on Mercury Concentrations in Water and Fish in the Larch Lake Watershed, Superior National Forest, Minnesota

Trent R. Wickman

Because of its persistence and wide dispersal in the environment and its ability to bioaccumulate in organisms, mercury (Hg) is a contaminant of great concern world-wide. Although scientists are beginning to understand the Hg cycle in forested systems, little is known about the role of wildland and prescribed fire in the Hg cycling processes. The North Central Research Station and the Superior National Forest, Minnesota, have started to fill these data gaps by establishing a plan to monitor mercury changes during fuel reduction efforts in northeast Minnesota. The Larch Lake watershed, partially located in the Boundary Waters Canoe Area Wilderness, is in the process of fuel reduction efforts in response to a major blowdown event that occurred in 1999. The Larch Lake watershed is a headwater system of about 2100 hectares in size. Almost the entire watershed is planned to be, or has been, burned. Total and Methyl Hg in water were measured along with standard physicochemical variables both pre- and post-treatment. Stream sampling was also intensified during the spring snowmelt following the most recent treatment. Tissue Hg concentrations in young-of-year smallmouth bass (*Micropterus dolomieu*) were also analyzed for the pre-burn (baseline) period; post-burn samples will be taken for a several year period after treatment to understand any potential bioaccumulation timelines. These data will provide a better understanding of how Hg is delivered to streams and lakes, how long it takes Hg to accumulate and then decline in organisms within the watershed, and the management implications of these findings.

State Water Quality Exceedence: Fecal Coliform and *E. coli*

Kirk Wolff

Currently, within the US Forest Service Region 2 (Rocky Mountain Region) there are three stream segments in Wyoming listed on the State 303d list for exceedance of fecal coliform/*E. coli* bacteria. One stream is on the Big Horn NF. On the Medicine Bow NF within the Pole Mountain grazing area there are two stream segments which have exceeded state water quality standards for fecal coliform/*E. coli* for the last two years. On the Routt NF in northwestern Colorado we sampled water samples from three streams on three different grazing allotments for *E. coli* bacteria and analyzed them in-house. We sampled streams on the Routt because of public comments on our scoping documents during the NEPA phase of AMP revisions and because of the ongoing fecal coliform results on Pole Mountain. We had limited data or out-dated information on this water quality parameter, so we purchased the equipment to do our own analysis for the Routt based upon EPA guidelines. The results of this lab analysis have shown exceedence in *E. coli* on two of the streams. We have been in contact with the Colorado Water Quality Control Division since we became aware of the situation. A BMP monitoring field trip is planned in early June with the Colorado agency and the FS to review grazing and riparian BMPs within one of these allotments. Colorado has no interest in listing these streams on the state 303d list. Their perspective is different from the Wyoming Department of Environmental Quality (WYDEQ). On the Medicine Bow NF in Wyoming we have been working with grazing permittees, the WYDEQ, multiple Conservation Districts, and other interested stakeholders. We are in the process of developing a new monitoring plan based upon last summer's results with the stakeholder group. The dialogue has been started for doing a watershed management plan with the local conservation district. In the interim, a local environmental group, Biodiversity Conservation Alliance, has issued a Notice of Intent to sue. The forest has been working with Office of the General Council and Department of Justice lawyers. There is no definitive DNA test that can be performed to determine the source of *E. coli* bacteria. Potential candidates are all warm blooded organisms. We feel that this is an emerging issue that has the capability to adversely affect domestic livestock grazing on NFS land throughout the West.

Development of ELTP Layer for the Hoosier National Forest, Southern Indiana

Andrey V. Zhalnin, George R. Parker, and Patrick C. Merchant

One of the critical components of decision making in natural resource management is ecological information. The US Forest Service adopted a national ecological classification hierarchy in 1993 with the ELT (ecological land type) and ELTP (ecological land type phase) forming the lower levels of the hierarchy. This study examines the potential of computer mapping ELTPs for the Hoosier National Forest (HNF) located in southern Indiana. An extensive ELTP sampling was performed in 2001 and 2002 within the four units of the HNF that are situated within the Brown County Hills and Crawford Upland subsections according to the eastern United States classification. We developed an ecological classification for the forest in 1993 that includes six ELTs and sixteen ELTPs total for both subsections. Another study mapped the forest ELT layer based on physiographic conditions using GIS tools. The most important factors affecting classification at ELTP level were soil A-horizon depth and vegetation composition. We hypothesized that ELTPs can change within a single ELT map unit, vary spatially from region to region, or both. We performed an extensive ELTP sampling to find possible correlations with landscape physiography as well as to refine classification, throughout all four units of HNF in 2001 and 2002. Analysis shows a correlation between soil survey mapping units and some ELTPs, which aids in prediction of spatial distribution of ELTPs. Results produced an ELTP map for the HNF as well as providing the basis for development of Land Type Associations (LTAs) using a “bottom-up” approach.

Section III. Index to Authors

Volume I comprises pages 1-288; Volume II comprises pages 289 and above.

Section IV. Conference Organizers and Producers

Advancing the Fundamental Sciences
A Conference for Forest Service Physical Sciences
October 18-22, 2004, San Diego, CA

Steering Committee: Bruce McCammon, Chair; Bonnie Ilhardt, Co-Chair; Steve Glasser, and Russell LaFayette

Registration: Sherry Hazelhurst, Chair; Connie Athman, Timothy Evans, and Lori Wilson

Website: Michael Furniss

Posters: Steve Howes, Chair; Joni Brazier, Connie Carpenter, Dave Dechane, Betsy Reifenberger, and Ruth Tracy

Technical Program: Wayne Robbie, Chair; Courtney Cloyd, Rich Fisher, Mike Furniss, Polly Hays, Jack Holcomb, Steve Howes, Mike Linden, Ivars Steinblums, and Al Todd

Awards & Events: Trish Carroll, Chair; Courtney Cloyd, Michael Collette, Michael Furniss, Steve Glasser, Chris Knopp, Mike McNamara, John Rector, Ken Roby, Wes Smith, Robin Stoddard, John Thornton, and Mark Weinhold

Proceedings: Michael Furniss, Chair; Catherine Clifton, and Kathryn Ronnenberg; Jeff Guntle, CD-ROM

Pinchot Institute for Conservation: Stephanie Kavanaugh, Jennifer Becker, and YenieTran

"The Life and Times of Forrest Stump": Karen Bennett (Angry Citizen), Corrine Black (Sally Mander [ID Team Wildlife]), Jerry Boberg (Bob Dylan), Joni Brazier (Coffee Person), Trish Carroll (Thought Bubble Lady), Alan Clingenpeel (FS Employee & Bernie Stokes [ID Team Fire]), Carolyn Cook (ID Team Leader), Mike Derring (Clint Eastwood), Mark Fedora (Yogi Berra), Michael Furniss (Forrest Stump; writer; montage music), Bob Gubernick (Woody Grove [ID Team Forester]), Polly Hays (Flo), Roy Jemison (Dr. Uncertainty), Terry Kaplan-Henry (Mary Mayor), Chris Knopp (News Anchor & Smokey Bear; writer), Russel LaFayette (Venue Liason), Bruce McCammon (slideshow production), Mike McNamara (The Minstrel; writer), John Rector (shotgun mike), Ken Roby (writer; FloMo Commercial Announcer & video testimonials), Kathryn Ronnenberg (Director, scenic backdrops, photo montages, writer), David Salo (Chip Stone [ID Team Archeology] & Smokey Bear), Larry Schmidt (Frank Cyprinid), Wes Smith (Stage Manager), Adam Solt (Stage Manager), Brian Staab (Eddie), Robin Stoddard (Stranger at the Bus Stop, props and wardrobe) Traci Sylte (Ranger Jane), John Thornton (Walter Aware, Sleepy Pete, Spock), Al Todd (Hank Lakewood), Mark Weinhold (Ranger Dan; writer)

Section V. Manuscript Reviewers

The following people made significant contributions to the Proceedings as technical manuscript reviewers. Sixty-two manuscripts were each independently reviewed by two or more subject matter experts. Their time and expertise in providing careful review, critique, and constructive comments added greatly to the quality and credibility of the final proceedings.

Thomas Bailey
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Robin Beebee
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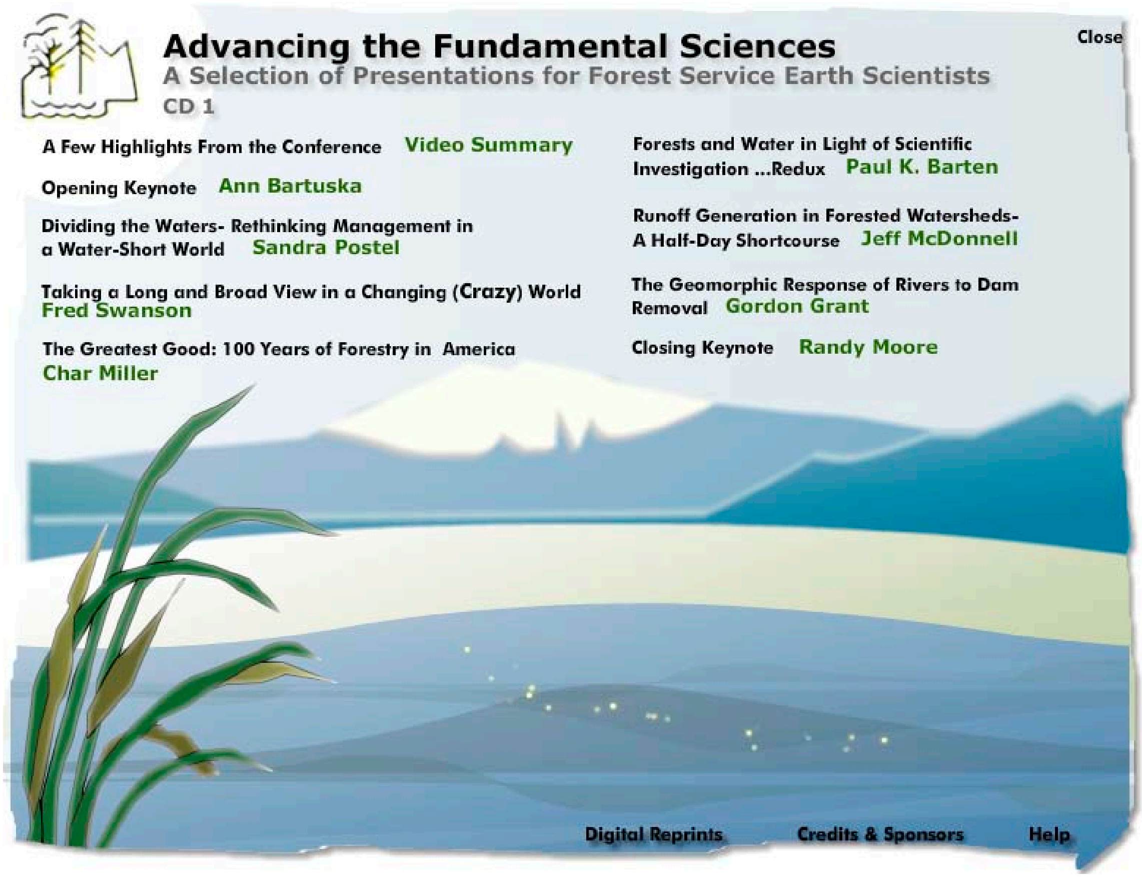
Randy L. Davis
Jerry DeGraff
Sharon M. DeHart
John DePuys
Adam Dresser
Deborah C. Entwistle
Francisco Escobedo
Mark Fedora
Jennie Fisher
Rich Fisher
Suzzanne Fouty
Alan J. Gallegos
Dave Halemeier
Valdon Hancock
Ken Heffner
Cindy Huber
Roy Jemison
Mark Jensen
Tommy John
Mikeal Jones
Steven R. Johnson
Gary Ketcheson
Gregory A. Knight
Randy Kolka
Russell A. LaFayette
Rodney Lentz
Mike McNamara
Cheryl Mulder
Liz Oswald
Rick Patten
Steve Paustian
John Potyondy
Sandra Ryan-Burkett
Chuck Sams
Theresa Savery
Margret Smart
Ivars Steinblums
Ruth Tracy
Sandra Wilson-Musser
Desi Zamudio

Section VI. Contents of Multimedia CD-ROM

About the Advancing the Fundamental Sciences Portable Electronic Presentation CD

The CD in the inside back cover is an interactive learning resource that presents many of the Conference plenary talks and two of the workshops in an electronic format. The format provides for interactive access: you may watch them start to finish, or just the parts that most interest you.

A help screen is available from the home page to assist you with navigating the presentations.



The CD runs on both Windows and Macintosh compatible machines. This CD content can also be found online at http://www.stream.fs.fed.us/afsc