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

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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).

M Furniss, C Clifton, and K Ronnenberg, 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.

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.

Literature Cited

Copstead, RL, and DK Johansen. 1998. Water/road interactions: examples from three flood assessment sites in Western Oregon. Washington, DC: USDA Forest Service, Technology Development Program, 98771805-SDTDC. 33 p.

Forman, RT, and D Sperling, eds. 2003. Road ecology - science and solutions. Washington, DC: Island Press. 480 p.

Furniss, MJ, TS Ledwith, MA Love, and SA Flanagan. 1998. Response of road stream crossings to large flood events in Washington, Oregon, and Northern California. Washington, DC: USDA Forest Service, Technology Development Program, 98771806-SDTDC. 42 p.

Havlick, DG. 2002. No place distant. Washington, DC: Island Press. 297 p.

U.S. Department of Agriculture, Forest Service [USDA FS]. 1990. Land and resource management plan. Mountlake Terrace, WA: USDA Forest Service, Mt. Baker-Snoqualmie National Forest1 .

U.S. Department of Agriculture, Forest Service [USDA FS]. 1992. Flooding in West Cascade Mountain river basins - a perspective on the November 1990 flooding in Western Washington. Mountlake Terrace, WA: USDA Forest Service, Mt. Baker-Snoqualmie National Forest.

U.S. Department of Agriculture, Forest Service [USDA FS]. 1999. Road analysis: informing decisions about managing the national forest transportation system. FS-643 Technical Report. Washington, DC: USDA Forest Service.

U.S. Department of Agriculture, Forest Service [USDA FS]. 2000. Recreational and visitor use study. Mountlake Terrace, WA: USDA Forest Service, Mt. Baker-Snoqualmie National Forest.