Flooding, land use, and watershed response in the Blue Mountains of northeastern Oregon and southeastern Washington

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ABSTRACT

The northern Blue Mountains sustained heavy rain and rapid snowmelt in November 1995 and rapid snowmelt over frozen soil in February 1996. The result was multiple record flood events, with February peak flows being more wide-spread and of higher magnitude. In addition to flooding, the storms triggered debris flows and slides on the Umatilla National Forest. These features commonly occurred in the rain-snow transition zone, in saturated loam-clay-ash soil, and on steep slopes (30-80 percent). Debris flows or torrents were the dominate feature, starting as an earthslide and then transporting debris sometimes over a mile. Roading and logging were associated with 37 percent of the observed mass wasting features. High flows and mass wasting combined to produce a variety of channel responses including: scouring of substrate and banks; aggradation of sediment; accumulation of large woody debris; and, lateral channel migration. Fluvial responses appear to differ with elevation and land use intensity. Flood discharge of National Forest streams was estimated using the indirect, slope-area method based on post-flood field evidence. Flood frequencies were then estimated using U. S. Geological Survey regional flood equations. Flood magnitude and frequency varied by watershed with some areas experiencing one or more "100 year" events (Umatilla and Walla Walla) and others experiencing less than a "25 year" event (Tucannon and Wenaha). Flood effects on National Forest investments (instream fish habitat structures and road-stream crossings) were also assessed. Results from field inventories indicate a high rate (73 percent) of instream fish habitat structure survival. Anchored rock weirs had the highest success rate. In roaded watersheds, a sample of culverts at stream-road crossings indicated about 50 percent of the culverts failure. The failure rate varies by watershed, however, from 23 to 95 percent. Culverts failed because of plugging with sediment often causing additional flood damage to roads and streams. Preliminary results indicate variability in watershed response to flooding which is partly attributed to different watershed characteristics and land use intensities. The post-flood assessments will be used to improve understanding of watershed response to extreme hydrologic events and to improve management practices to reduce damage from future high flows.

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INTRODUCTION

After record flooding in late 1995 and early 1996, the Umatilla National Forest initiated a field assessment of flood effects on watersheds. The Forest is located in northeastern Oregon and southeastern Washington (Figure 1). The objectives of this assessment are to characterize and evaluate watershed response to flooding and to measure the effectiveness of management practices during extreme hydrologic events. The flood assessment focused on characterizing the events, inventorying mass wasting features, mapping channel perturbations, estimating flood magnitude and frequency, and evaluating performance of instream fish habitat structures and stream-road crossing culverts. Major findings from this assessment include: 1) highest flooding on many streams since 1964; 2) numerous shallow rapid landslides and debris torrents, many reaching stream channels; 3) substantial channel adjustment in main valley streams in response to high flows and tributary mass wasting; 4) high survival rate of instream habitat structures; and, 5) road culvert failure mechanism was by plugging with sediment, rather than being undersized for flow.

METHODS

This was a two phase flood assessment: 1) a reconnaissance (Phase I) of key areas and features; and 2) an intensive field survey (Phase II) which inventoried and quantified flood effects on hillslopes, stream channels, instream fish habitat structures, and stream-road crossing culverts. The Phase II field survey was followed by an analysis phase which attempted to interpret the relationships between flooding, land use, and watershed response.

Mass wasting features were identified using aerial and ground reconnaissance. Features which displaced greater than 100 cubic yards of material were mapped according to methods described by Leopold et al. (1964) and Costa (1984). During Phase I, the emphasis was on features which impacted roads and human safety. Phase II set out to inventory and map all the large features which were triggered during flooding.

Flood impacts on the stream channel were inventoried and measured by ground survey and Stream Channel Reference Reaches (Harrelson et al., 1994). Flood magnitude and frequency was estimated at ungaged sites using identified high water marks, channel geometry, resistance equations, and USGS regional regression equations (Harris and Hubbard, 1983). Flood impacts on instream fish habitat structures and stream-road crossing culverts were evaluated using U.S. Forest Service Regional protocols. Data were statistically summarized and compared spatially using a Geographic Information System (ARC-INFO).

1995-1996 FLOOD EVENTS

Two major storm and flood episodes occurred in the winter of 1995-1996; the first in late November and second in early February. Higher than average fall rains, followed by heavy wet snowfall in late November, and rapid warming caused localized flooding in the foothills of the Blue Mountains. On November 28, 1995 the highest recorded flood on the upper Umatilla River caused localized damage to Forest roads, trails, and campgrounds.

Precipitation continued above average in January with heavy snow accumulations in the mountains and foothills. A week of intense cold at the end of January was followed by a series of warm subtropical storm surges bringing more rain and snow and leading to Region-wide flooding by the week of February 5th, 1996. Record floods again were observed on the upper Umatilla, and on other stream and river systems of the northern Blue Mountains.

Four counties in southeast Washington and two counties in northeast Oregon were declared federal disaster areas. The last comparable flood of this size and geographic extent occurred in the winter of 1964-1965.

MASS WASTING INVENTORY

The objectives of this component are to inventory shallow rapid debris flows and slides, triggered during flooding, to determine the physical controls (geology, soil, and slope) and influences of land use. A total of 67 mass wasting features were mapped, each displacing greater than 100 cubic yards of material, in 12 stream systems. Overall, debris flows (classified as debris torrents) were the dominant feature (72%). The dominate geology in the sampled area is Columbia River Basalt formations, commonly displaced by north-west trending faults (Whiteman et al., 1994).

The features typically occurred in sandy loam soil, consisting of basal clay lenses, on moderate to steep slopes (30-80%). The majority of mass wasting features entered an active channel; less than 10% remained on the hillslope (Figure 3). Based on reconnaissance and detailed field mapping, this is typical of mass movements on the Forest. Small landslides converge on low-order drainages, gain momentum, and move rapidly downslope as hyperconcentrated flows often reaching the main channel. In the inventoried area, 27% of features were caused by road failure, 10% occurred in clear-cut harvest units, and 63% had no direct association with land use . The major contributing factor causing failure appears to be super-saturation of soils in the transient snow zone.

STREAM CHANNEL RESPONSE

The objective of this component is to characterize floodplain and stream channel response to record floods. Permanent monitoring sites, defined as Channel Reference Reaches, quantitatively document channel morphology and bedload distribution. In addition, these sites are used to estimate flood magnitude and frequency on ungaged stream segments.

A total of 29 Channel Reference Reaches were surveyed on 6 different stream systems. Each site consists of: 1) 2-3 stream cross-sections; 2) longitudinal profile; and 3) pebble count. High water marks were identified and surveyed at each cross-section. Evidence used to determine the high water mark include: 1) scour line; 2) highest point of fine sediment; 3) debris trapped in vegetation; and 4) any other obvious feature resulting from flooding.

Channel perturbations were greatest in high order stream segments (i.e, > 4^{th} order) below 4000 feet in the transient snow zone. Common channel responses include: 1) scouring of substrate and banks; 2) accumulation of large woody debris; 3) aggradation of bedload; and 4) lateral channel migration.

ESTIMATING FLOOD MAGNITUDE AND FREQUENCY

This component of the assessment used the indirect slope-area method (Baker, et al, 1988; Hedman and Osterkamp, 1982; Wahl, 1984) and U.S. Geological Survey regional flood equations (Harris and Hubbard, 1983) to estimate flood magnitude and frequency at ungaged Channel Reference Reaches.

At Channel Reference Reaches, high water marks were surveyed at channel cross-sections. Using the area and slope of a given cross-section, flood discharge was estimated using Manning's Equation.

$$Q = 1.49/n[AR^{2/3}S^{1/2}]$$

n*= Manning's roughness coefficient; R = hydraulic radius; S = water-surface slope; A = cross-section area

*Manning's roughness coefficient was estimated two ways: 1) from low flow measured velocity; and 2) from standard tables (Chow, 1959). Typical n values used in the equation at low and high flow are 0.08 and 0.02, respectively.

Using the USGS equations, the discharge (Q) of a given flood frequency was calculated for ungaged sites. The equations use drainage area (A), mean annual precipitation (P), and a temperature index (TI) (mean minimum January temperature). The equation for a 100-year event in the north central region of Oregon is as follows:

$$Q_{(0.01)} = 0.00863A^{0.69}P^{0.35}TI^{2.86}$$

To test the accuracy of this approach, the two methods were compared to measured flood discharge at a representative stream gage site (Table 1). The percent difference was less than 10%; therefore, the methods were assumed to be reasonable. Manning's Equation was used to calculate flood discharge since it provided the greatest accuracy. Results from the USGS method were then used to approximate a return interval of the calculated flow.

Table 1. Comparison of measured to estimated flood magnitude SF Walla Walla River (OWRD Gage # 14010000)

	Measured*		Method	Used*	
Frequency	Gage	USGS	%Diff	Mnngs	%Diff
$Q_{(0.01)}$	3040	2828	7.0	3042	0.1

*discharge in cubic feet per second

Tables 2 and 3 show discharge estimates for field survey sites in the Umatilla and South Fork Walla Walla Rivers.

Table 2. Discharge estimates at field survey sites, South Fork Walla Walla River

SF Walla Walla River					
			Method Used*		
Site	Elev.	Area	USGS**	Mnngs	Unit Q^
SFWW-1	2080	61.4	2828	3042	50
SFWW-3	2400	49.4	2434	2550	52
SFWW-5	2740	31.4	1782	1550	49
*discharge in cubic feet per second					
**calculation for 100-year event					
^unit discharge in cubic feet per second per square mile					

Table 3. Discharge estimates at field survey sites, Umatilla River

Umatilla River					
			Method Used*		
Site	Elev.	Area	USGS**	Mnngs	Unit Q^
UMA-1	2300	91.4	3723	4967	54
SFUMA-1	2340	60.0	2735	3029	50
SFUMA-4	2580	44.2	2215	2400	54
SFUMA-6	2680	23.6	1435	1523	65
*discharge in cubic feet per second **calculation for 100-year event ^unit discharge in cubic feet per second per square mile					

From the estimates it appears that each of the sites sustained about a "100 year" flood event, however, the error associated with this USGS (i.e., "100 year" event) equation can range from plus 119 to minus 54 percent (Harris and Hubbard, 1983). As a result, these calculations must be taken as rough estimates of flood frequency. Overall, flood frequencies estimated for National Forest watersheds in the northern Blue Mountains varied from less than a "25 year" event on the Tucannon and Wenaha Rivers to "100 year" events on the Umatilla and Walla Walla Rivers (Figure 1).

MANAGEMENT INTERACTIONS

The objectives of this component are to determine: how land uses influence watershed response to flooding; how investments such as instream fish habitat structures and road systems performed during flooding; and, what changes in management practices are needed to reduce damage from future events.

INSTREAM STRUCTURE INVENTORY

The objectives of the instream structure inventory are: 1) determine post-flood survival rate of instream fish habitat structures; 2) evaluate structure characteristics that influence structure durability; and 3) provide recommendations for structure design.

A total of 217 structures were inventoried in 6 stream systems. Post-flooding, 73% of the structures were in-place. Survival rate varied, however, between individual stream systems with larger streams having a high survival rate (80%), whereas smaller, low order streams, had a lower survival rate. The findings are partly attributed to poor channel stability in the small stream systems in the survey.

Findings and Recommendations:

- A high rate of structure survival or "durability";
- expect some structures to move or shift during high flow events;
- design structures which work with fluvial processes, not against; and,
- limit use of "rigid" structures (e.g., cabled log-rock weirs).

STREAM-ROAD CROSSING INVENTORY

The objectives of the stream-road crossing inventory are: 1) determine the mechanisms that caused stream-road crossing failure; 2) document watershed, stream, and crossing characteristics that influenced crossing failure or survival; and 3) provide design recommendations to improve crossing survival and reduce damage to roads and streams.

A sample of 86 culverts found that 51% failed during flooding, however, failure rate varies by watershed. Culverts in the Umatilla River watershed had a 5% failure rate compared to the Tucannon River watershed which experienced a 95% culvert failure rate. Results also indicate debris and coarse sediment caused the majority of culvert failure, rather than undersizing for flow. There is a close association between upslope mass wasting and culvert failure; for example, the Tucannon River watershed which had frequent debris flows in small tributaries.

Findings and Recommendations:

- expect culverts to plug with debris during large floods and design to allow for overtopping;
- design crossings to accommodate bedload carried by high flows;
- assess upslope conditions to determine landslide and debris flow potential as well as unit discharge;
- use catchment basins at inlets to capture sediment and debris; and,
- evaluate the benefits of decommissioning damaged sites relative to repair costs, access needs, and downstream values.

SUMMARY

Flooding which occurred in November, 1995 and February, 1996 offers a unique opportunity to observe and document the effects of high flows on watershed function in the northern Blue Mountains. This assessment found that antecedent conditions (saturated soils, snow accumulation in mid and low elevations, and freezing temperatures) followed by a series of warm subtropical storm systems controlled the magnitude and extent of flooding, and that land uses can influence the type and severity of storm-related damage.

Watershed response included shallow rapid landslides and debris torrents on hillsides and in small tributaries, with higher frequencies in loam-clay-ash soils on moderate to steep slopes. Mass movement is also related to elevation, aspect, and land use activities. These features can have major impacts on human safety and management investments; future inventories will focus on the risk of debris flow and/or slide occurrence using the results from this initial assessment.

Using gaged stream data, flood magnitude was estimated for National Forest streams to be on the order of a "100 year" event, or flood with a 1 percent chance of occurring in any one year, on several National Forest rivers. Streams were subjected to rapid importation of sediment and debris from side tributaries and upstream channel erosion which caused downstream aggradation and lateral migration. Understanding and predicting channel response to extreme flood events will help reduce flood damage in the future.

Forest investments such as roads, hiking trails, campgrounds, and instream habitat structures were damaged during flooding as a result of mass wasting, erosion, and channel migration. In addition, land uses accelerated flood damage in some areas by decreasing slope and channel stability and potentially increasing flood magnitude. Flood assessment results include recommendations for instream habitat structure design and road-stream crossing maintenance and repair. Future assessments will focus on the frequency and rate of mass wasting at the subwatershed scale, monitor the rate of riparian vegetation recovery and channel response, and make recommendations to help reduce future flood damage.

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