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WATERSHED EVALUATION AND HABITAT RESPONSE TO RECENT STORMS

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WATERSHED EVALUATION AND HABITAT RESPONSE TO RECENT STORMS

Annual Report for 1999

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ABSTRACT

Large and powerful storm systems moved through the Pacific Northwest during the wet season of 1995-96, triggering flooding, mass erosion, and, alteration of salmon habitats in affected watersheds. This project study was initiated to assess whether watershed conditions are causing damage, triggered by storm events, to salmon habitat on public lands in the Snake River basin. The storms and flooding in 1995-96 provide a prime opportunity to examine whether habitat conditions are improving, because the effects of land management activities on streams and salmon habitat are often not fully expressed until triggered by storms and floods (Platts et al. 1989; Reid and Dunne, 1997).

To address these issues, we are studying the recent storm responses of watersheds and salmon habitat in systematically selected subbasins and watersheds within the Snake River system. The study watersheds include several in the Wenaha and Tucannon subbasins in Washington and Oregon, and the watersheds of Squaw Creek (roaded) and Weir Creek (unroaded) in the Lochsa River subbasin, Idaho. The study was designed to examine possible differences in the effects of the storms in broadly comparable watersheds with differing magnitudes or types of disturbance. Watershed response is examined by comparing storm response mechanisms, such as rates of mass failure, among watersheds with similar attributes, but different levels of land management. The response of salmon habitat conditions is being examined by comparing habitat conditions before and after the storms in a stream and among streams in watersheds with similar attributes but different levels of land management. If appropriate to the results, the study will identify priority measures for reducing the severity of storm responses in watersheds within the Snake River Basin with habitat for at-risk salmon.

This annual report describes the attributes of the study watersheds and the criteria and methods used to select them. The report also describes the watershed and fish habitat attributes evaluated and the methods used to evaluate them. Watershed responses and attributes evaluated include mass failures, historic soil loss, the integration of roads with the drainage network, estimated flood recurrence intervals, and headwater channel morphology. Habitat attributes evaluated include large woody debris, pool frequency and depth, substrate conditions, and bank stability.

Multiple analyses of habitat data in the Tucannon and Wenaha subbasins remain to be completed due to difficulties stemming from data characteristics that indicated that some of the pre-existing data may have be of questionable accuracy. Diagnostic attributes of the questionable data included a change in monitoring protocols during the pre- to post-flood analysis period, physically implausible temporal trends in some habitat attributes at some sites, and conflicting results for the same attribute at the same locations from different data sources. Since unreliable data can lead to spurious results, criteria were developed to screen the data for analysis, as described in this report. It is anticipated that while the data screening will prevent spurious results, it will also truncate some of the planned analysis in the Tucannon and Wenaha systems.

In the Tucannon and Wenaha subbasins, preliminary results indicate that headwater channels with roaded catchments were more unstable post-flood than channels with unroaded watershed areas. Monitored channel reaches draining roaded areas had a higher percent length of unstable banks, percent length of unstable slopes adjacent to the scourline, and frequency of nickpoints than monitored reaches in channels in the unroaded strata. These differences between the strata were statistically significant ($p < 0.10$) and indicate that bank erosion was probably greater in channels draining roaded and logged areas than in channels draining unroaded areas.

Measurement of soil pedestals on plots in the Tucannon subbasin indicates that livestock grazing has elevated soil erosion, contributing to increased storm runoff by reducing infiltration rates and available water storage in the soil profile. Mean soil loss in non-forested areas during the life of the plants on the pedestals is estimated at 3.5 cm per unit area, which equates to a loss of about 14,000 m^3/km of available water storage in the soil profile. Due to the lack of ungrazed areas in the watershed that could serve as controls, it was not possible to isolate the magnitude of the effect of livestock grazing from the effects of grazing by wild ungulates on soil erosion.

A total of 35 mass failures were triggered in the roaded watershed of Squaw Creek while no mass failures were triggered by the storms in the unroaded Weir Creek watershed. Nineteen of the failures were associated with roads, 15 were associated with timber harvest, and one initiated in a natural setting. Mass failures associated with roads also had the highest mean volume (1,091 m^3) of failures by land use category.

A significant amount (8-60%) of the road network surveyed in the Tucannon subbasin and the Squaw watershed were directly connected hydrologically to the channel network. The mean percentage of the road length contributing to streams or tributary channels increased in a downslope direction, with valley bottom roads having the highest percent length draining into streams or tributary channels. A significant amount of the road network also contributes to the formation of gullies >10 m in length in the Tucannon River subbasin.

In the Lochsa study watersheds, substrate conditions in Squaw Creek, a roaded and logged watershed, responded to the flood events in a significantly different manner than Weir Creek (unroaded watershed). Cobble embeddedness and surface fine sediment levels increased in Squaw Creek from pre- to post-flood in a statistically significant manner ($p <0.05$), indicating that watershed response to the events reversed pre-storm recovery in substrate conditions. In Weir Creek, cobble embeddedness and surface fine sediment levels exhibited no statistically significant change from pre-to post-flood, indicating that the flood events had little effect on substrate conditions.

Residual pool depths in Squaw Creek decreased from pre-to post-flood; the magnitude of the decrease varied among reaches. Pool frequency and percent pool habitat in Squaw Creek exhibited high inter-annual variability at all monitored reaches after the floods, indicating that pools are transient features, which is probably due to high sediment loads and bed instability triggered by watershed response to the storms.

The difference in substrate response between Weir and Squaw Creeks and the post-storm pool responses in Squaw Creek are probably due to the high levels of sediment introduced into Squaw Creek in response to the storm events. Increases in sediment delivery, and fine sediment, in particular, lead to increased levels of fine sediment in channel substrate, pool in-filling, and bed instability, as repeatedly documented in the field and laboratory settings. Besides the large quantity of sediment delivered to Squaw Creek by mass failures, additional fine sediment was also delivered from the road system to the stream, because a significant fraction of the roads act as extensions of the channel network.

The recurrence interval for the Nov. 1995 event in the study watersheds in the Upper Lochsa is estimated to be about 9.1 years based peak discharge data at a downstream gaging station on the Lochsa River. The recurrence interval for the Feb. 1996 event in the Tucannon River is estimated to be about 13.8 years based on peak discharge data at a downstream gaging station on the Tucannon River. However, the recurrence interval estimated from the downstream gaging station on the Tucannon River has a high potential for error as a estimator of recurrence intervals in the Tucannon River study watersheds, due to differences in land use, land forms, vegetation, rates of change in land use, and elevation between the watershed areas. The magnitudes of some of the peak discharge events, including the 1996 event, were estimated, rather than measured, at the Tucannon gaging station, increasing the potential for error in the estimated recurrence intervals.

INTRODUCTION

Large and powerful storm systems moved through the Pacific Northwest during the wet season of 1995-96, triggering widespread flooding, mass erosion, and, possibly altering salmon habitats in affected watersheds. This project study was initiated to assess whether watershed conditions are causing damage, triggered by storm events, to salmon habitat on public lands in the Snake River basin. This question is important because improvement in salmon habitat conditions is a goal of several plans for the recovery of salmon populations in the Columbia River Basin (e.g., CRITFC, 1995). The storms and flooding in 1995-96 provide a prime opportunity to examine whether habitat conditions are improving, because the effects of land management activities on streams and salmon habitat are often not fully expressed until triggered by storms and floods (Platts et al. 1989; Reid and Dunne, 1997).

To address these issues, we are studying the recent storm responses of watersheds and salmon habitat in systematically selected subbasins and watersheds within the Snake River system. Our study was designed to examine possible differences in the effects recent storms had in broadly comparable watersheds with differing magnitudes or types of disturbance. Watershed response is examined by comparing storm response mechanisms, such as rates of mass failure, among watersheds with similar attributes, but different levels of land management. The response of salmon habitat conditions is being examined by comparing habitat conditions before and after the storms in a stream and among streams in watersheds with similar attributes but different levels of land management. If appropriate to the results, the study will identify priority measures for reducing the severity of storm responses in watersheds within the Snake River Basin that are inhabited by at-risk salmon.

DESCRIPTION OF PROJECT AREAS

The primary study areas are eight watersheds and multiple segments of mainstem rivers within the upper portions of three subbasins tributary to the Snake River. These subbasins include the Tucannon in southeast Washington, the Wenaha in southeast Washington and northeast Oregon, and the Lochsa in north-central Idaho. Each of the three subbasins included in our study has a predominantly dendritic drainage pattern and runoff strongly influenced by snowmelt. Study areas within each subbasin contain habitat used by spring chinook salmon (Oncorhynchus tshawytscha), summer steelhead (O. mykiss), and bull trout (Salvelinus confluentus). The Lochsa River also supports a strong population of westslope cutthroat trout (O. clarki lewisi). The general location of these river subbasins and some of the watersheds selected for study are shown in Figure 1.

Tucannon and Wenaha Subbasins

Specific areas of study within the Wenaha and Tucannon River subbasins include mainstem segments of the Tucannon, S.F. Wenaha, and Wenaha Rivers, and the following watersheds within the Tucannon Subbasin: Panjab, Meadow, and Cummings Creeks and the Little Tucannon and Upper Tucannon Rivers. These watersheds are located in the Blue Mountains and most of the watershed areas are within the boundaries of the Umatilla National Forest (UNF). All six watersheds have volcanic (basalt) parent material. Table 1 outlines the general characteristics of the study watersheds.

Rounded ridgetops and canyons typify landforms in the study watersheds. Lower canyon slopes and north aspects are vegetated with mixed stands of grand fir, Douglas fir, Englemann spruce, lodgepole pine, or western larch. Vegetation is generally sparser on south-facing slopes, and often includes open stands of ponderosa pine. The first and second-order channels tend to be steep with strong lateral constraint. Higher order channels tend to have low to moderate gradients and variable constraint. Habitat use by spring chinook and summer steelhead is largely restricted to the higher order channels. One conspicuous feature of these channels is localized stream braiding, which is common in some stream settings.

Most of the Wenaha subbasin and the upper reaches of several streams in the Tucannon subbasin are within the Wenaha-Tucannon Wilderness Area. Natural disturbance regimes driven by wildfires, insects, and climatic extremes continue as a primary influence on ecological conditions within the wilderness. However, portions of the wilderness have been subjected to livestock grazing (primarily sheep), with the greatest grazing pressure generally occurring in the late 1800s and early 1900s. Outside the wilderness area, land use activities, combined with natural disturbances, have influenced watershed and salmon habitat conditions in the study areas.

Human uses of watersheds in the upper Tucannon subbasin have varied over time. These uses have included the subsistence activities of Native Americans, sheep and cattle grazing, mining, road construction, and logging. The most downstream publicly owned segments of the mainstem Tucannon River were channelized after flooding in the mid-1960s (USFS, 1994). Grazing in upper portions of the subbasin has declined since the early 1900s and livestock are now excluded from some areas (D. Grote, Fish. Bio., UNF, pers. comm.). Mining occurred in the Upper Tucannon and Cummings watersheds, with most operations abandoned in the 1920s (USFS, 1994). The first large timber sales on public lands in the subbasin occurred in the Cummings Creek watershed in the late 1950s. Since then an annual average of about 2-3 km^2 have been logged using various logging methods (USFS, 1994). Roads constructed in association with logging have been correlated with higher quantities of fine sediment in streambeds, although cobble embeddedness values remain relatively low in most riffles monitored by the Forest Service (USFS 1994). The watersheds of Cummings Creek, Meadow Creek, and the Little Tucannon River have been significantly logged and roaded, while the watersheds of the Upper Tucannon River and Panjab Creek have been logged and roaded to a lesser degree.

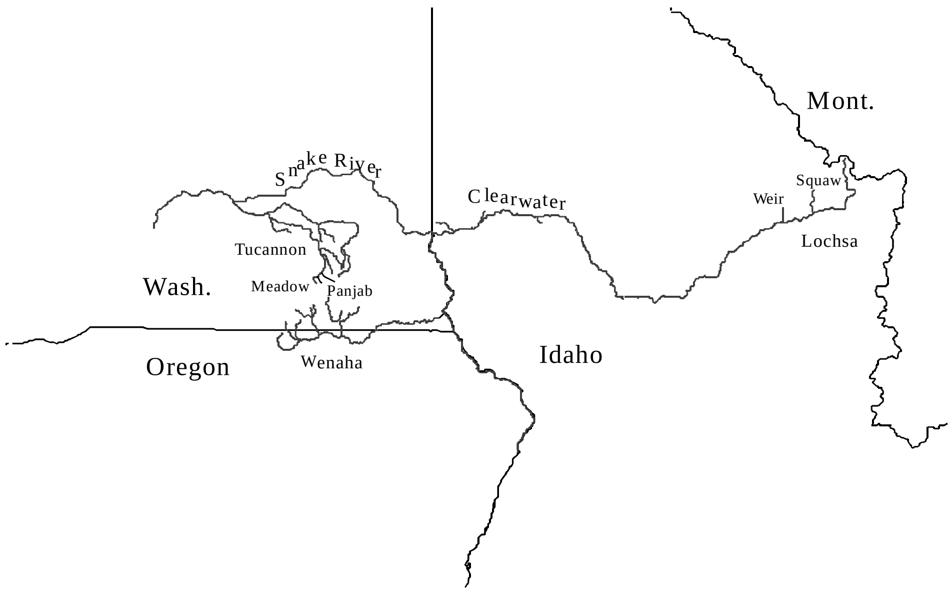


Figure 1. Generalized location map of the study areas within the Snake River basin.

Table 1. Selected characteristics of study watersheds in the three subbasins of the Snake River Basin.

	Tucannon Subbasin				Wenaha Subbasin	Lochsa Subbasin	
Watershed(s)	Upper Tucannon	Panjab and Meadow	Little Tucannon	Cummings	S.F. Wenaha	Squaw	Weir
Area (km^2)	101	66	21	51	140	44	34
Level of Development	wilderness to low	wilderness to high	high	high	wilderness	high	unroaded
Primary parent material	basaltics	basaltics	basaltics	basaltics	basaltics	granite, gneiss, glacial deposits	granite, gneiss, glacial deposits
Landtypes	canyons, rounded ridgetops	canyons, rounded ridgetops	canyons, rounded ridgetops	canyons, rounded ridgetops	canyons, rounded ridgetops	breaklands, slopelands	breaklands, slopelands
Aspect	north-west	north	north-east	north-west	north-east	south	south
Elevation range (m)	908-1948	908-1948	869-1597	628-1695	853-1847	948-2048	856-2030
Stream order	fourth	fourth	third	third	fourth	fourth	fourth

Lochsa River Subbasin

Areas of study within the upper Lochsa subbasin include mainstem segments of the Lochsa River and Crooked Fork, and a pair of watersheds with similar settings but dissimilar land-use histories: Weir Creek and Squaw Creek. These two watersheds in the Lochsa subbasin have comparable landforms and parent materials (Table 1). The primary difference between these two watersheds, both of which are within the Clearwater National Forest (CNF), is that Weir Creek is roadless, while the Squaw Creek watershed has been significantly roaded and logged.

Primary landforms in the Weir and Squaw Creek watersheds are stream breaklands (both dissected and non-dissected) and rounded mountain slopelands (Wilson et al. 1983). The breaklands occur near stream channels and are over-steepened with straight to concave slopes, while the rounded mountain slopelands are found at all elevations and have slopes ranging from straight to convex-concave (Wilson et al. 1983). First and second-order streams in the Weir and Squaw Creek watersheds are generally steep with strong lateral constraint. Third and fourth-order channels within these watersheds tend to have lower stream gradients and more variable constraint. Anadromous fish in the watersheds are dependent primarily on habitats in third and fourth-order channels, with very limited steelhead use of a few short segments of second order streams immediately upstream of confluence with larger order channels (C. Huntington, unpublished data).

Forest vegetation in the upper Lochsa subbasin includes western red cedar, subalpine fir, Englemann spruce, lodgepole pine, white pine, grand fir, Douglas fir, mountain hemlock, ponderosa pine, and western larch. Deciduous species common found in riparian areas include alder and red osier dogwood.

Natural disturbances in the upper Lochsa subbasin are similar to those in the Tucannon and Wenaha subbasins, and include wildfires, insects, and climatic extremes. Human activities within the Squaw Creek drainage have expanded considerably since road construction in the area began in the 1950s. Logging and road construction intensified in the Squaw watershed from the 1950s through the 1970s, then diminished during the 1980s and 1990s (Espinosa et al., 1997). During the 1950s through 1970s, jammers and tractor skidding were the primary logging systems employed (CNF, 1998). These methods required the construction of an extensive system of low-standard roads on steep hillslopes. In the 1980s and 1990s, a shift to skyline and helicopter logging systems reduced the need for extensive construction of new harvest-related roads (Pipp et al. 1997). Currently, about 11% of the watershed area is estimated to be in a condition equivalent to a clearcut, according to the CNF's methods for estimating Equivalent Clearcut Area (CNF, 1998). The density of active roads in the watershed is estimated to be about 2.1 km/km^2, with another 2.0 km/km^2 of inactive roads that are not maintained (CNF, 1998). Prior to the 1995-96 events, in-channel habitat restoration work occurred in Squaw Creek, as part of efforts to mitigate previous damage to anadromous fish habitat in the watershed (Espinosa and Lee, 1991; Espinosa et al. 1997)

METHODS AND MATERIALS

Selection of Study Watersheds

We identified an initial pool of Snake River subbasins with watersheds containing spring chinook salmon habitat that could serve as candidates for project study, based on the following criteria: 1) they were affected by one or more of the 1995-96 major storms; 2) the subbasins have embedded watersheds with broadly comparable attributes, but differing levels of management disturbance, including largely undeveloped watersheds that could serve as controls in the study; 3) embedded watersheds have pre-storm or other data relevant to our study; 4) locations and other attributes of watersheds do not present major logistical obstacles; and, 5) ownership of candidate watersheds is primarily public, to facilitate access to sites and data. Based on a review of maps, existing publications, and interviews with resource specialists and scientists, five river subbasins were initially identified as potentially meeting the criteria, including the Lochsa (Idaho), South Fork Salmon (Idaho), Little Salmon (Idaho), Tucannon (Washington), and Wenaha (Oregon). Each of these basins include areas within the transient snow zone which were affected by the storms and all but the Wenaha include potential subsets of comparable watersheds with differing levels of land management disturbance.

Watersheds within each of these five river subbasins were examined for how well they met study criteria, based on available information. On the basis of this initial assessment, a list of watersheds within the subbasins that potentially met the study criteria was developed for more detailed examination. Table A in Appendix 1 contains a list of the candidate watersheds, and their attributes related to the study criteria, that were examined as potential study sites. Candidate watersheds within the Little Salmon River and the Tucannon River subbasins were evaluated on the ground to examine physical watershed attributes and stream characteristics. In June 1998, all of the candidate watersheds shown in Table A in Appendix 1, except those in Lochsa River subbasin, were examined by air for land use patterns, comparability of physical attributes, and stream characteristics. Based on the aerial and ground reconnaissance and review of available information summarized in Table A, the study team made the final selection of the watersheds within river subbasins for study under the project.

The watersheds nested within the Tucannon, Wenaha, and Lochsa River subbasins were selected for project monitoring. The Tucannon subbasin was selected because the embedded watersheds have different levels of logged areas and roads, allowing comparison of storm response across a gradient of land disturbance, in broadly comparable watersheds. Due to the availability of pre-storm data on the Tucannon River mainstem above Marengo, sections of this river were also selected for in-channel habitat monitoring. The South Fork of the Wenaha River is entirely within wilderness and was selected as a comparison for the Tucannon mainstem. All of the Tucannon and Wenaha watersheds have been subjected to grazing. Ungrazed watersheds are rare in the Columbia River basin (Rhodes et al., 1994). Based on evidence from the aerial survey, it was not possible to select an ungrazed watershed for use as an untreated control in basaltic river systems in the Snake River basin.

In the Lochsa, Squaw Creek and Weir Creek were selected for study because the watersheds have comparable natural attributes, but dissimilar levels of land management. Additionally, of all of the candidate watersheds, Squaw Creek had some of the most comprehensive pre-existing aquatic habitat data relevant to the study.

The South Fork Salmon River subbasin was rejected because the location would have exponentially increased project logistics and it did not contain watersheds that both met study criteria and included significant amounts of salmon habitat. In the Little Salmon River subbasin, habitat conditions in Boulder Creek (roaded) and Rapid River (unroaded) were intensively monitored prior to the storm events (Overton et al., 1993). However, these watershed candidates were rejected because aerial and ground evaluation indicated that Boulder Creek and Rapid River have dissimilar watershed and stream attributes.

Aquatic Habitat Conditions in the Tucannon and Wenaha River Subbasins

After selecting watersheds for study, we identified gaps in post-storm data on the condition of salmon habitat that needed to be filled to make comparisons of stream conditions before and after the storms. To increase accuracy and precision in the comparisons of conditions, we used the same methods to monitor post-storm habitat conditions as were used to gather pre-storm data on habitat conditions. Because the methods of collecting pre-storm data on habitat conditions varied among the streams in our study, the methods for monitoring post-storm habitat conditions also varied among these subbasins, watersheds, and streams.

Most pre-storm data on streams in the upper Tucannon and Wenaha subbasins were collected by the UNF, using modified Hankin and Reeves (1988) survey methods. Pre-storm data on the mainstem Tucannon River were also available from: 1) compilations of historic Bureau of Commercial Fisheries habitat surveys and subsequent re-surveys (McIntosh et al. 1993); 2) varied studies conducted or commissioned by the Soil Conservation Service (e.g., Hecht et al. 1982; D.W. Kelly & Associates, 1982); and, 3) other unpublished sources and aerial photos. Pre-storm data on these streams were acquired to provide a baseline for making multiple pre- versus post-storm comparisons within individual streams and across watersheds (Table 2). Post-storm data needed to evaluate changes in streams were collected by us in 1998, or were acquired from the UNF, Washington Department of Fish and Wildlife, or Natural Resource Conservation Service, or are being interpreted from air photos.

Data on anadromous fish habitat in study areas within the upper Tucannon and Wenaha subbasins are still being screened for data accuracy and analyzed to identify changes or differences in condition associated with storm response. The storm responses of individual stream reaches will be related to conditions in surrounding watersheds and compared across watersheds with differing types or patterns of land-use. These results will be summarized in the forthcoming final report.

Aquatic Habitat Conditions in the Lochsa River Subbasin

Pre-storm data on study streams in the upper portions of this subbasin included aerial photos and a variety of aquatic inventory and monitoring data, most of which were collected by Clearwater BioStudies, Inc. (CBS) over the past decade under contract to the CNF. The majority of these data were collected using transect-based methods described by CBS (1996a), CBS (1996b), Espinosa (1988), or Platts et al. (1983). These data provide a baseline for assessing pre- versus post-storm changes in stream conditions (Table 3). CBS has conducted some monitoring of stream conditions in selected areas of the Squaw watershed and in the mainstem Lochsa River since the 1995-96 event, also under contract to the Forest Service. These data were made available to our study in exchange for post-storm data we collected in 1998 at additional locations within the Weir and Squaw watersheds, as well as in lower mainstem Crooked Fork.

Data on anadromous fish habitat in stream reaches within the Weir and Squaw watersheds will be analyzed to identify pre- versus post-storm differences in pool abundance and distribution, residual pool depths, abundance and distribution of coarse woody debris, substrate conditions, bank stability, and channel form. The storm responses in individual reaches will be related to conditions in surrounding watersheds and compared across watersheds. Analyses of storm responses in the mainstem Lochsa River and Crooked Fork will include assessments of pre- versus post-storm differences in residual pool depths and channel form. The results will be reported in the forthcoming final report.

Table 2. Pre- and post-storm data on selected streams within the upper Tucannon and Wenaha River subbasins used to assess the storm response of watersheds and salmon habitat.

	Stream(s)	Location(s)	Pre-storm data on aquatic habitat	Post-storm data
<u>Tucannon Subbasin</u>				
Mainstem Tucannon R.	Tucannon R.	km 71.9-80.7	1935 BOF surveys[1] 1992 USFS surveys[2]	1997 USFS surveys[3] 1997 USFS surveys[3]
		km 80.7-89.9	1935 BOF surveys[1] 1992 USFS surveys[2]	1997 USFS surveys[3] 1997 USFS surveys[3]
		Multiple reaches	extent of channel braiding[4] 1937/1978 SCS river maps[5]	new (1998) surveys post-storm air photos
Upper Tucannon watershed	Tucannon R.	km 89.9-97.3 km 97.3-103.3	1992 USFS surveys[2] 1992 USFS surveys[2]	1997 USFS surveys[3] 1997 USFS surveys[3]
Meadow & Panjab watersheds	Panjab Cr.	km 0.0-3.1	1935 BOF surveys[1] 1992 USFS surveys[2]	new (1998) surveys new (1998) surveys
		km 3.1-4.8	1935 BOF surveys[1] 1992 USFS surveys[2]	new (1998) surveys new (1998) surveys
	Meadow Cr.	km 0.0-2.1	1992 USFS surveys[2]	new (1998) surveys
Little Tucannon watershed	Little Tucannon R.	km 0.0-1.9	1992 USFS surveys[2]	1996 USFS surveys[3]
Cummings watershed	Cummings Cr.	km 0.0-5.6	1935 BOF surveys[1] 1992 USFS surveys[2]	new (1998) surveys 1998 USFS surveys[3]
		km 5.6-10.0	1935 BOF surveys[1] 1992 USFS surveys[2]	new (1998) surveys new (1998) surveys
multiple watersheds	multiple streams	Multiple sites	multi-year substrate data[5] pre-storm air photos	new (1998) data post-storm air photos
<u>Wenaha Subbasin</u>				
Mainstem Wenaha R.	Wenaha R.	km 23.0-34.6	1994 USFS surveys[2]	1998 USFS surveys
S.F. Wenaha watershed	S.F. Wenaha R.	km 4.0-7.1	1994 USFS surveys[2]	new (1998) surveys

[1] McIntosh et al. (1993).

[2] Hankin and Reeves (1988) surveys, as modified by USFS, Region 6 protocols. Minor changes in these protocols over the years made it necessary to collect supplemental data for comparisons of data on some stream characteristics collected during pre- and post-storm years.

[3] Hankin and Reeves (1988) surveys as modified by USFS, Region 6 protocols. Changes in Region 6 protocols for large woody debris and substrate conditions required partial re-survey to allow us to attempt comparisons between pre- and post-storm data.

[4] D.W. Kelly & Associates (1982).

[5] Hecht et al. (1982).

Table 3. Pre- and post-storm data on selected streams within the upper Lochsa River subbasin used to assess the storm response of watersheds and salmon habitat.

	Stream(s)	Location(s)	Pre-storm data on aquatic habitat	Post-storm data
mainstem Lochsa River	Lochsa R.	55 specific pools	residual depths in 1994[a]	Depths in 1998[b]
		5 sets of riffles	pebble counts in 1994[a]	1996 and 1998 counts[b]
Mainstem Crooked Fork.	Crooked Fork	10 specific pools	residual depths in 1994[a]	Depths in 1998[b]
Squaw watershed	Squaw Cr.	km 0.00-0.83	1995 transect surveys[a]	1996, 1998 surveys[b]
		km 0.83-1.23	1995 transect surveys[a]	1996, 1997, 1998 surveys[b]
		km 4.53-5.10	1995 transect surveys[a]	1998 surveys[b]
		km 5.52-6.00	1995 transect surveys[a]	1996, 1998 surveys[b]
		km 6.00-6.81	1994 transect surveys[a]	1998 surveys[b]
		km 6.81-7.83	1995 transect surveys[a]	1996, 1997, 1998 surveys[b]
		4 monitoring sta.	1988-92 sediment data[a]	1996 and 1998 data[b]
		multiple sites	1995 pebble count data	USFS multi-year counts
	W.Fk. Squaw Cr.	km 0.00-0.76	1991 transect surveys[a]	1996, 1997, 1998 surveys[b]
		1 monitoring sta.	1988-92 sediment data[a]	1996 and 1998 data[b]
		monitoring site	1995 pebble count data	USFS multi-year counts
Weir watershed	Weir Cr.	km 0.64-1.33	1991 transect surveys[a]	1998 surveys[b]
		km 1.33-3.09	1991 transect surveys[a]	1998 surveys[b]
		km 3.09-5.13	1991 transect surveys[a]	1998 surveys[b]
		5 monitoring sta.	1988-92 sediment data[a]	1996 and 1998 data[b]
	W.Fk. Weir Cr.	km 0.00-2.42	1991 transect surveys[a]	1998 surveys[b]
Multiple watersheds	multiple streams	multiple sites	pre-storm air photos	Post-storm air photos

[a] Data collected by CBS under contract to the Forest Service.

[b] Data collected by CBS under contract to the Forest Service (all 1996 and 1997 data, plus a sizable portion of the 1998 data) or to the Columbia River Intertribal Fish Commission (the remainder of the 1998 data).

Mass Failure Surveys and Mapping

In two days in July 1998, the watersheds of the Wenaha and Tucannon River were surveyed by helicopter to identify mass failures and their locations for subsequent field investigation. While information indicated that aerial surveys had also been conducted by the UNF in the watersheds of the Tucannon River (UNF, 1997; Fitzgerald and Clifton, 1997), we were unable to determine if the surveys included global positioning system (gps) locations for all failures so that they could be subsequently surveyed on the ground. The Tucannon surveys also only enumerated failures with volumes estimated to be greater than about 76 m^3 (UNF, 1997; Fitzgerald and Clifton, 1997). Aerial survey was unnecessary in the watersheds of Weir and Squaw Creeks, because such surveys had already been completed. The CNF provided us with mass failure data, including the latitude and longitude for all inventoried sites in the Squaw and Weir Creek watersheds, as well as additional information on failure attributes.

Each helicopter survey used two observers. In the Wenaha River, the entire watershed area above the confluence of the mainstem with Butte Creek was surveyed. In the Tucannon, the watershed area above Marengo was surveyed. In each survey, each major tributary was flown to the headwaters. Tributary watersheds flown in the Wenaha River watershed include: Butte, Rock, Slick Ear, Beaver, Shooly, Milk, Cougar, and Jaussaud Creeks, and the South and North Forks of the Wenaha River. Tributary watersheds flown in the Tucannon River watershed include: Tumulum, Cummings, Meadow, and Panjab Creeks, and the Little Tucannon River. The generalized flight paths of both flight surveys will be mapped and presented in the forthcoming final report. When a mass failure was spotted, the helicopter was maneuvered directly over the initiation point and the latitude and longitude from the gps was recorded along with general estimates of failure size, whether the failure directly entered the channel network, associated land use at the initiation point (e.g., natural, grazed, roads, recent logging), and failure type (e.g., scoured headwall, slump, etc.)

The gps locations and notes from the aerial surveys were used to direct the ground survey efforts in the Tucannon watershed. During the ground surveys, mass failures identified from the air were located and site characteristics were measured. For purposes of consistency, the site characteristics measured were based on the those previously measured in the CNF survey of failures in the Lochsa River subbasin (Pipp et al., 1997). These site characteristics include: associated land use (roads, natural, etc.), slope shape, lineal distance from watershed divide, slope gradient above and below the failure, failure dimensions, and other site attributes (Pipp et al., 1997).

Site characteristics of mass failures in the Wenaha subbasin will be derived from location information from the aerial overflight in conjunction with map analysis. Logistical obstacles, in combination with project budget constraints, precluded ground investigation of all mass failures in the Wenaha.

The results of the ground and aerial surveys will be cross-checked with maps to refine the latitude and longitude locations, which will be provided in the forthcoming final report. Failure dimensions and field notes will be used to estimate mass failure volumes in the Wenaha and Tucannon. The UNF has also supplied us with the data from its mass failure survey in the Tucannon. The results of the UNF survey will be used to cross-check and augment the project survey of mass failures. The CNF's mass failure data will be used for the Squaw and Weir watersheds in the Lochsa. The final report will include summary data for all inventoried mass failures in all surveyed watersheds, including location, associated land use, slope gradients, slope aspect, estimated failure volumes, and whether or not the failures directly entered the channel networks. Failures will be grouped by primary type of land use (e.g., roads, natural, etc) associated with the initiation point. These groupings will be analyzed to determine if there appears to be significant differences in attributes, such as slope gradient or aspect, at the initiation points of failures associated with different land use categories (e.g., logged areas, roads, natural, etc.). The number and mean and total volume of failures will be reported by watershed and primary type of land use at the initiation point.

Headwater Channel Conditions

In the Tucannon and Wenaha subbasins, we monitored conditions in smaller tributary channels in 19 roaded and 19 unroaded subwatersheds to investigate potential differences in headwater channel response to the storms within the two strata. Initial reconnaissance indicated that increased channel erosion might have been one of the major storm response mechanisms in the basaltic watersheds of the Tucannon and Wenaha, while available data indicated that mass failures were the dominant watershed storm response in the study watersheds in the Lochsa River subbasin. Initial landscape analysis indicated that it was not possible to stratify roaded and unroaded subwatersheds on the basis of similar aspect and area without creating significant logistical obstacles with respect to access. Therefore, subwatersheds in both strata were selected based on access considerations and land use criteria (roaded, unroaded), across a range of drainage area and aspects. The size of the subwatersheds monitored ranged from about 0.9 to 3.6 km^2. The channels were monitored for bank stability, height and number of nick points, channel width, thalweg depth, and channel gradient. Bank stability was determined via the methods of Bauer and Burton (1993) with minor modifications.

The final report will summarize results of analyses of our data from headwater channel monitoring, including monitoring locations, upstream subwatershed area, bank stability (%), number of nick points, channel width, thalweg depth, and channel gradient. The data for width, depth, and bank stability will be analyzed with subwatershed area factored into the analysis.

Survey of Channel Network Extension by Road Networks

A subsample of roads in the study watersheds in both the Lochsa and Tucannon River subbasins were surveyed to estimate the degree of hydrologic integration of the road network with the stream network. Roads can contribute to elevated peakflows by causing overland flow, intercepting subsurface flow, and accelerating delivery of runoff by extending of the channel network in managed basins (Wemple et al., 1996). The road survey used an approach patterned after a simplification of the methods of Wemple et al. (1996).

The roads were surveyed using a stratified-random sampling scheme. Roads on the UNF within the Tucannon subbasin and on the CNF in the Squaw watershed in the Lochsa were assigned to one of three strata based on hillslope position: 1) valley bottoms, which included the bottom third of slopes extending from the mainstem rivers (>3rd order) to drainage divide; 2) ridgetops, which included the upper third of the slopes extending from the mainstem rivers to drainage divide; and, 3) midslopes, which included the remainder of the slope area. These strata were delineated on USFS administrative maps. Total road lengths within the delineated strata areas were estimated from the maps, using scaled measurements of individual road segments. Road segments 1609 m in length were randomly selected so that the total length of surveyed segments was approximately 10% of the estimated total length of roads within the strata.

Based on field evidence, the surveyed road segments were divided into sections with drainage that terminated homogeneously in one of four categories: 1) to channel tributaries or tributary extensions with clear signs of active, contiguous flow to channels; 2) to slopes without any of evidence of downslope gullying or concentrated runoff; 3) to slopes with downslope gullying <10 m in length; and 4) to slopes with downslope gullying >10 m in length. In each of the sections, the length, width, average longitudinal road slope, and length of cut and fill slopes were measured. The road drainage in each section was also characterized by whether it exited the road via a ditch, a culvert, a waterbar, or via diffuse outsloped drainage. The average height of the contiguous cut and fill sections within road segments was also estimated. The length, width, and depth of gullies <10 m long were measured. The length of gullies that were > 10m long was not measured for logistical reasons; these length will be estimated from maps under the assumption that they terminate at the nearest downslope stream tributary.

The lengths of road sections within the drainage categories were summed for each road in each stratum, in each watershed sampling unit. These lengths were used to determine the average fraction of the road network within the slope categories that act as extensions of the channel network. A summary of the road survey data for each road and slope position stratum in each watershed will be included in the final report

Based on our field evaluations in the Tucannon and those of Pipp et al. (1996) in the Lochsa, road lengths derived from available administrative maps significantly underestimate the total length of roads in watersheds, because the maps omit some roads that are low standard, closed, or abandoned. To provide a correction factor for road lengths estimated from the maps, road lengths will be estimated from recent aerial photos in subsections of the watersheds and compared to road lengths estimated from the administrative maps over the same watershed area. This will be used to provide a more accurate estimate of the fraction of the actual road network sampled during the surveys and to estimate the amount of road in each stratum that act as channel extensions which can increase storm runoff.

Soil Loss on Non-forested Lands

Soil loss in historically and currently grazed non-forested lands was investigated in the Tucannon watersheds by measuring the height of soil pedestals (also termed "erosion mounds") beneath plants and lichen bands on exposed rocks. Soil pedestals are widespread on non-forested areas in the Tucannon River watersheds. The soil pedestals and rock bands can provide an indication of the amount of soil eroded from the area during the life of the plant on the pedestal (Reid and Dunne, 1996). Topsoil loss can influence storm runoff by reducing infiltration rates and soil moisture storage in the soil profile.

Five sites were randomly selected for monitoring of soil loss indicators from a pool of 10 non-forested and accessible sites on the UNF that were identified from a 1:150,000 scale topographic map. In each site, two plots with an area of 9 m^2, were randomly placed on each site. Within each plot, the following were determined and recorded: estimated plant cover, slope, aspect, plant type on pedestal, and the number of exposed rocks and soil pedestals within the plot. The height of subset of the pedestals and bands were measured and the basic soil texture of the pedestals was determined. A truncated pebble count based on the method of Wolman (1954) was used to provide a quantitative indication of the soil particles sizes at the soil surface outside of the pedestals. The soil pedestal data was analyzed to provide an indication of the amount of soil eroded from these sites during the life of the plants on the pedestals and effects on available water storage in the soil profile.

Flood Recurrence Intervals

Where possible, recurrence intervals for the flood events triggered by 1995-1996 storm events were estimated from hydrologic records from the U.S. Geological Survey stream gaging stations within the study river basins that have an adequate period of record (>20 years). The use of flow records that are less than 20 years in length to estimate flow recurrence intervals introduces a high degree of uncertainty and results are prone to error (Dunne and Leopold, 1978).

Peakflow records from the USGS station #13337000 on the Lochsa River near Lowell, Idaho were used for standard hydrologic analysis for recurrence intervals for the events in Squaw and Weir Creek. The station near Lowell is approximately 73 km downstream from the confluence of Weir Creek and the Lochsa River and about 94 km downstream from the Squaw Creek/Lochsa River confluence. Downstream gaging stations can be used to estimate peak discharge (by correcting for drainage area) and recurrence intervals in upstream ungaged sites. The most proximate stations are the most desirable for use, especially in mountainous terrain, where flows frequencies in upper elevations may differ from downstream frequencies (Dunne and Leopold, 1978). Other gaging stations within the Lochsa River system will also be evaluated for potential use in the analysis of recurrence intervals. However, all of the gaging stations in the upper Lochsa River identified thus far, have far less than 20 years of peak flow data.

Estimation of flow frequency in ungaged streams based on data from somewhat remote stations is may be of questionable accuracy where there is a significant difference in land use, climate, vegetation and/or geology, all of which may influence flow magnitudes and frequencies. Geology, land use, and vegetation do not dramatically shift from the study watersheds to the Lowell gaging site; however, climate, as influenced by altitude does significantly vary between the gaging site and the study watersheds. Although this may limit the accuracy of estimating the recurrence intervals of the events in the study watersheds based on the downstream gaging site data, there appears to be no data of adequate duration at other stations on the Lochsa River for alternative analysis.

Peakflow records for USGS gaging station # #13344500 on the Tucannon River above Starbuck were used to estimate the recurrence intervals for the events in the Tucannon River system. This gaging station is about 57 km downstream from the UNF boundary. The distance from the study areas to the UNF boundary varies. As previously discussed, when using a gaging site for estimation of recurrence intervals in an ungaged site, desirable attributes include a record > 20 years in duration and homogeneity in land use, geology, vegetation, and climate between the gaged and ungaged sites. While the Starbuck site meets the former criterion with 42 years of peak flow data, it does not meet the latter criteria. In comparison with the study sites, the watershed above Starbuck has significantly more area in tilled agriculture and far less forested area and is lower in elevation. (WDF et al., 1990). Further, although land use has changed over the past four decades in the roaded study watersheds in the Tucannon during the period of data record, it has undergone greater change in the watershed above Starbuck during the period of record (1915-1997). There has been a significant loss of riparian and floodplain woodland during and increased conversion of land to agriculture in the watershed above Starbuck (WDW et al., 1990), both of which can affect flows and recurrence intervals (Dunne and Leopold, 1978). Therefore, the results of the analysis of recurrence intervals for the upper Tucannon study areas based on the gaging site should be treated with caution.

The gaging station data were analyzed via a regression line fit to a lognormal distribution of peakflows to estimate recurrence interval (e.g., Dunne and Leopold, 1978) for the 1995-1996 flood events. Although other methods beside the lognormal distribution are often used to estimate recurrence intervals, there is typically little difference among the methods in the estimated recurrence intervals associated with a flow magnitudes when it is within the range of flow data (Dunne and Leopold, 1978). The results of alternative methods for estimating the recurrence intervals of the storms and flood flows in the watersheds of the Tucannon subbasin (Fitzgerald and Clifton, 1997) and Squaw Creek (Pipp et al., 1997) will also be compared to recurrence intervals estimated from stream gage records in the forthcoming final report.

RESULTS AND DISCUSSION

Aquatic Habitat Conditions in the Tucannon and Wenaha River Subbasins

During the analysis of pre- and post-flood data, it became apparent that there were some data reliability issues that presented obstacles to the planned analyses of the pre- and post-flood habitat condition data (summarized by type and source in Table 2). Identified data reliability issues include the following. First, there were conflicting results in data or observations from different sources for specific habitat conditions. Second, changes in Forest Service monitoring protocols/criteria over the pre-and post-flood period created inter-year or inter-stream differences in data that were possibly an artifice of changes in protocols/criteria rather than an indicator of difference in condition, rendering the results questionable. This problem persisted even though we collected supplemental data in an effort to make adjustments to data when protocols/criteria had changed. Three, some pre-existing data also exhibited highly anomalous patterns over time, rendering the data questionable. Approaches to resolving these difficulties, including criteria for screening potentially questionable data, were identified and will be used to complete an adjusted suite of analyses (Table 4) in the near future. Several pre- versus post-flood comparisons of conditions within individual stream reaches, and across multiple reaches, that were planned for the study will not be possible due to some of the problems identified in the available data.

However, we should be able to answer several important questions related to storm impacts on salmon habitat within the Tucannon River subbasin.

Results of analyses of aquatic habitat data from the Tucannon and Wenaha subbasins that have already been completed are reported here. Results of additional analyses of data from these subbasins will be provided in the forthcoming final report.

Post-flood Habitat Conditions in Study Reaches: Selected post-flood habitat characteristics for 11 study reaches in the Tucannon/Wenaha study area are summarized in Table 5. Large woody debris (LWD) abundance was more variable among reaches than most of the other habitat characteristics examined during this study. LWD levels were generally highest in the wilderness reaches of the mainstem Tucannon River (89.9 pieces/km) and Panjab Creek (68.1 pieces/km), and lowest in the surveyed reaches of the mainstem Tucannon River below Panjab Creek (5.8-14.2 pieces/km), Little Tucannon River (10.5 pieces/km), and lower Cummings Creek (7.2 pieces/km). Mean cobble embeddedness in riffles was relatively low in all 11 reaches (range = 10-25%), but was higher (range = 26-46%) within the pools in each reach. The most pronounced responses of many of these reaches to recent floods appeared in the field to have been raw banks (3-36% for reaches on which we have screened data), bedload movement, and braiding (0.0-3.8 braided channel segments per kilometer of stream). Detailed analyses of the relative condition of reaches with similar watersheds but dissimilar land use histories are on-going.

Table 4. Summary of data reliability issues encountered with pre-existing data in the Tucannon and Wenaha systems, criteria for data screening, and analyses possible with screened data.

Difficulties Encountered

- UNF data on pool abundance in the study area were affected by a failure to identify all pools, especially during the pre-flood period. Larger and deeper pools were identified with a high degree of reliability, but smaller and shallower (but still primary) pools appear to have been overlooked at times. Pool identification criteria changed during the analysis period.
- Inconsistency in identification of pools creates likely bias in residual depth measurements, because smaller pools are overlooked.
- Definitions of large woody debris (LWD) that Region 6 of the Forest Service used prior to the flood changed after the 1995-96 flood. Pre-flood data for LWD included "leaners and spanners," which were not included in subsequent monitoring. This created apparent changes in LWD levels that are partially an artifice of changes in criteria, rather than LWD status, rendering temporal comparisons questionable. Monitoring efforts to account for this confounding effect proved unsuccessful.
- Some data on raw banks and other attributes were, in direct conflict with field observations and/or exhibited temporal variation that rendered the data questionable. The precise causes of the problem are unclear, but may include surveyor difficulty in measuring parameters, sub-sampling protocols that introduce high variance in estimates over short stream reaches, or changes in monitoring criteria and protocols.
- Data from different monitoring efforts show conflicting results for the same attribute in the same monitored area.

Data Screening Criteria

- Direct measurement data (e.g., annual data from cobble embeddedness stations, air photo interpretations, etc.) are considered valid.
- Data based on ocular estimates of measurable channel features will be used only if calibrated with direct measurements.
- Data will be rejected for analysis if there have been significant changes in parameter definition or field protocols over time.
- Data that include values that clearly conflict with field observations or data or observations made by other knowledgeable individuals, will not be used in comparative analyses.

Analyses Feasible with Screened Data

- Post-flood analyses of spatial variation in LWD at multiple stream reaches within the Tucannon R. subbasin and at a single reach on the S.Fk. Wenaha R.
- Post-flood analyses of spatial variation in pool frequency, residual pool depth, cobble embeddedness, braiding frequency, and percent raw bank in multiple stream reaches in the Tucannon R. subbasin and a single reach on the S.Fk. Wenaha R.
- Evaluation of historic changes in the abundance of large, deep pools in Tucannon R., Panjab Cr., and Cummings Cr.
- 1993-98 time series evaluations of cobble embeddedness measurements taken at established monitoring stations in the mainstem Tucannon River and multiple tributaries.
- Air photo analysis of historical and pre- to post-flood changes in riparian condition, channel widening, and braiding along the mainstem Tucannon R., with an emphasis on areas evaluated by others during the early 1980s

Table 5. Abbreviated summary of stream survey data for assessing variations in post-flood habitat conditions within the Tucannon/Wenaha study area.

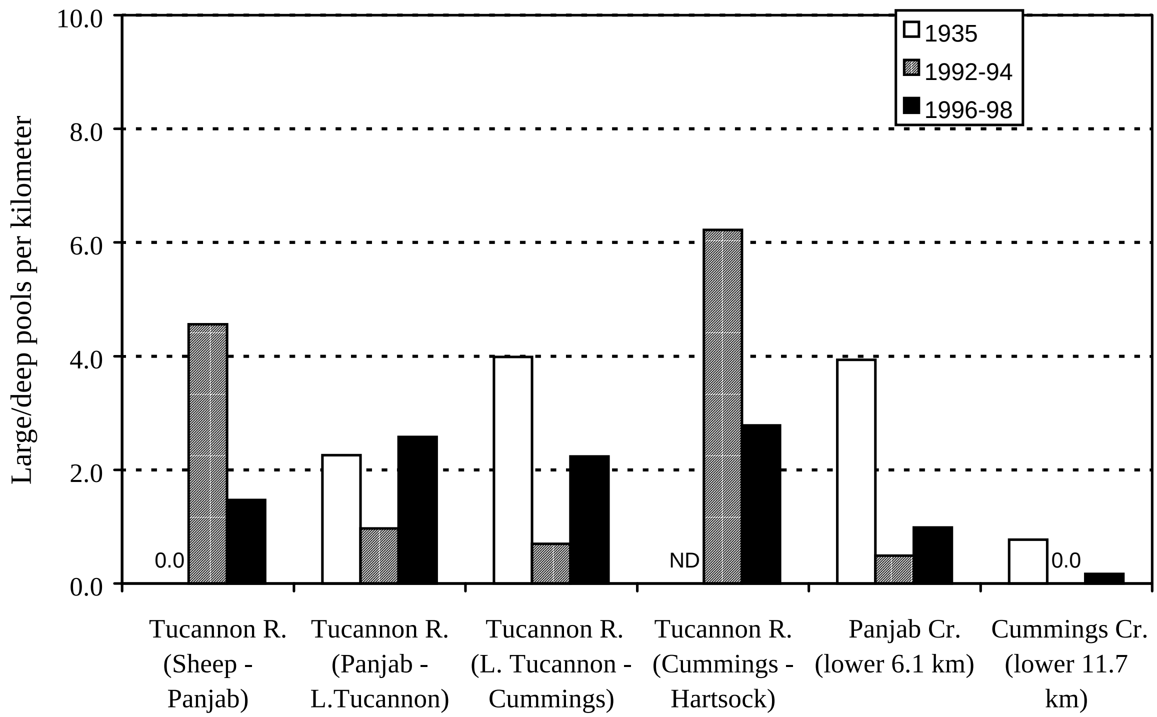
Stream	Reach	LWD/km	Pools/km	Residual pool depth (cm)	Mean cobble embeddedness		Braided segments/ km	Percent raw bank
					Riffles	Pools		
Tucannon R.	km 97.3 - 103.3	**89.8**	---	---	17	29	2.3	---
Tucannon R.	km 89.9 - 97.3	**28.7**	---	---	22	34	1.4	---
Tucannon R.	km 80.7 - 89.9	**5.8**	---	---	18	27	1.2	---
Tucannon R.	km 71.9 - 80.7	**14.2**	---	---	14	30	1.2	---
Panjab Cr.	km 3.1 - 4.8	**68.1**	28.4	27	25	38	1.8	---
Panjab Cr.	km 0.0 - 3.1	37.9	27.2	36	15	32	3.8	18
Meadow Cr.	km 0.0 - 2.1	55.1	27.8	35	19	46	3.6	9
L. Tucannon R.	km 0.0 - 1.9	**10.5**	---	---	21	30	2.3	---
Cummings Cr.	km 5.6 - 11.7	24.5	30.0	30	18	35	2.2	36
Cummings Cr.	km 0.0 - 5.6	**7.2**	---	---	16	32	0.0	---
S.Fk. Wenaha R.	km 4.0 - 7.1	23.2	8.1	48	10	26	2.2	3

Note: Values in bold are 1997 or 1998 data acquired from the Pomeroy RD, UNF. All other data were collected during 1998 as part of this study.

Large/Deep Pools: Numbers of large (area >20 m^2) and deep (>0.90 m) pools are low in much of the study area and appear to have followed at least two different trajectories since they were counted in 1935 by the Bureau of Commercial Fisheries (McIntosh, 1993). Large/deep pools in the mainstem Tucannon River between Panjab and Cummings creeks and in each of these two tributaries decreased from 1935 to the pre-flood period (McIntosh, 1993), and then, increased following the flood (Figure 2). In the Tucannon above Panjab Creek, and in the mainstem between Cummings Creek and Hartsock Grade, there has been a significant loss of large, deep pools after the flood (Figure 2).

Although important, increases in the numbers of large/deep pools in parts of the Tucannon River or its tributaries in response to the 1995-96 flood do not necessarily mean a net gain in pool habitat. The Washington Department of Fish and Wildlife (Viola 1997) noted a substantial flood-related reduction in total pool habitat in portions of the mainstem where available large/deep pool data suggest little change or actual gains.

Figure 2. Numbers of large pools (area > 20 m^2 and depth > 0.9 m) in the mainstem Tucannon R., Panjab Cr., and Cummings Cr., 1935-1998. Data sources: McIntosh et al. (1993), UNF, M. Schuller (NRCS, Spokane, WA), and CBS.



Cobble Embeddedness at Monitoring Stations: Mean cobble embeddedness was relatively low and variable among years between 1993 and 1998 at six monitoring stations on tributaries to the Tucannon River and at six additional stations on the mainstem (Figures 3 and 4). Eleven of the 12 stations exhibited a similar pattern in cobble embeddedness levels in response to the 1995-96 storm event. Cobble embeddedness levels at 5 of 6 tributary stations and at all 6 mainstem stations were higher in 1996 after the flood than prior to the event and had dropped somewhat by 1998 (Figures 3 and 4). This trend in cobble embeddedness is similar to the trend in surface fine sediments found by Clifton et al. (1999) at monitoring sites in the Tucannon mainstem, using the pebble count method.

Trends in cobble embeddedness in the Little Tucannon River differed from those in the other 11 study reaches. Cobble embeddedness at the Little Tucannon station decreased after the 1995-96 flood, followed by an increase in 1998 (Figure 3). The difference in substrate trends in the Little Tucannon River in comparison with sites in other streams is but one manifestation of how its response to the storm and flood differed from the other study streams in the Tucannon subbasin. In 1998, the structure of Little Tucannon River clearly exhibited the most pronounced storm response of any of the streams under study, including recently the created of flood levees comprised of unstable sediment, channel downcutting in some areas, and channel widening and braiding in others.

Figure 3. Measured cobble embeddedness 1993-1998 at monitoring stations in Tucannon River tributaries. Data sources: Pomeroy R.D., UNF and CBS.

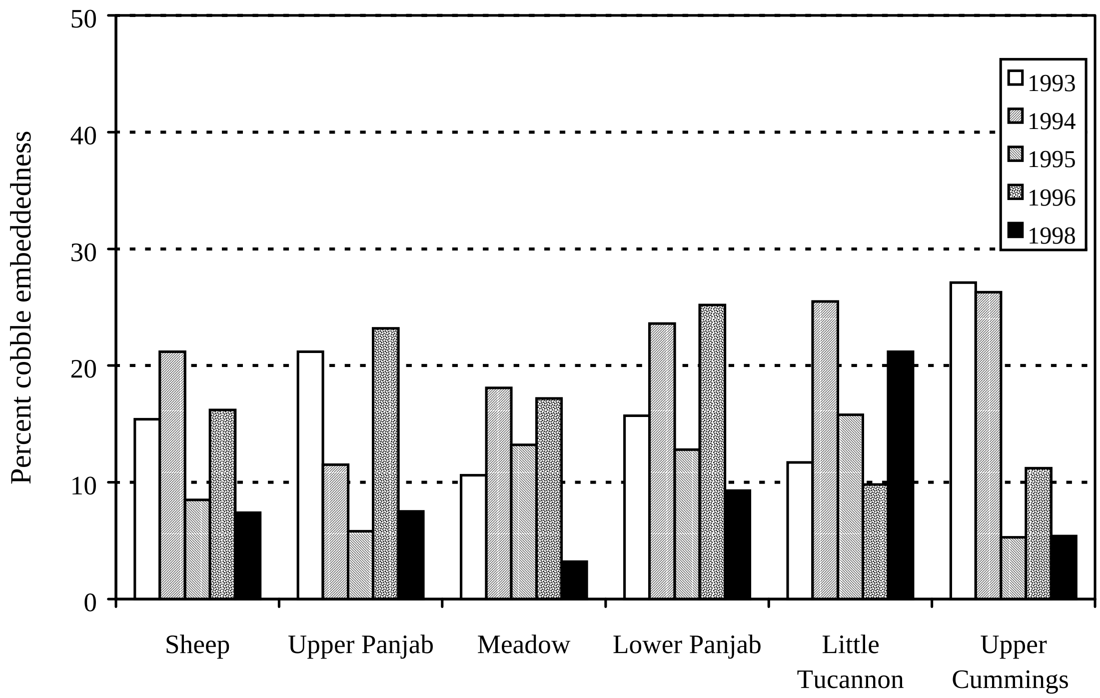
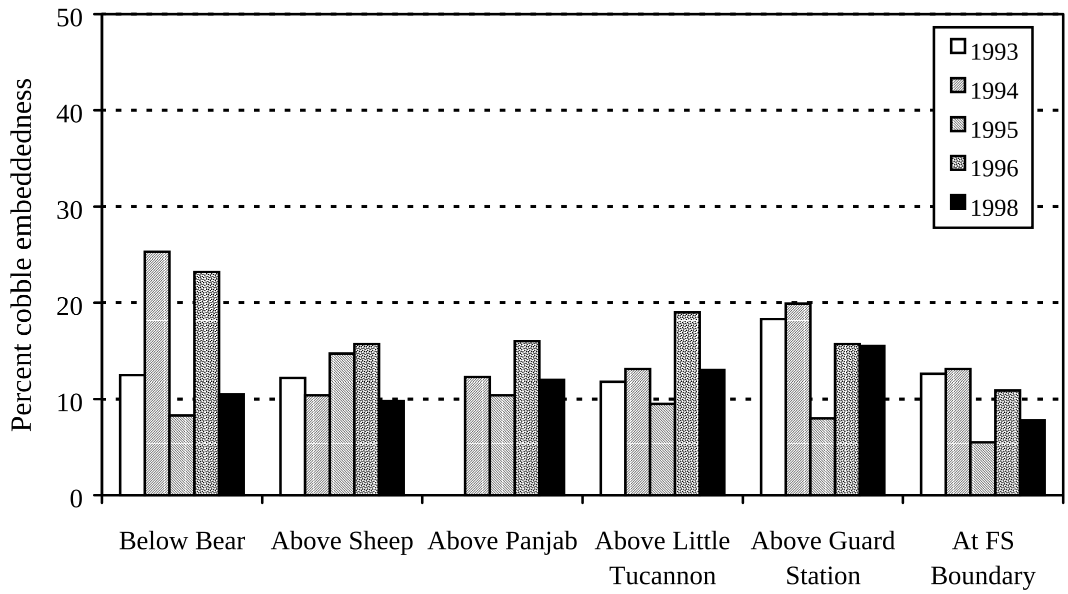


Figure 4. Measured cobble embeddedness 1993-1998 at monitoring stations in Tucannon River mainstem. Data sources: Pomeroy R.D., UNF and CBS.



Aquatic Habitat Conditions in the Lochsa River Subbasin

The types and sources of data collected or acquired on aquatic habitat conditions in the Lochsa subbasin are summarized in Table 3. Results of some of the completed analyses of these data are reported here. Additional analyses of data from the Lochsa subbasin are on-going and results will be provided in the forthcoming final report.

Large Woody Debris (LWD): The abundance of instream LWD in anadromous fish habitat in study reaches of Squaw Creek decreased after the 1995-96 flood (Figure 5). Losses of LWD were greatest in Squaw Creek above km 6.00, where LWD abundance was highest before and after the flood. However, LWD levels also decreased from pre- to post-flood in downstream reaches where LWD levels were relatively low prior to the flood. LWD abundance in Squaw Creek below about km 5.10 increased in the post-flood period, but this is partially due to incompletely documented Forest Service placement of approximately 200 pieces of LWD into the stream channel, rather than stream recovery. There has been some partial recovery of LWD levels above km 6.81, but the levels of LWD in 1998 were only about half of pre-flood levels.

LWD levels also decreased during the pre- to post-flood period in unroaded Weir Creek, but to a smaller degree than in Squaw Creek (Figure 5). Because there is LWD data for only one post-flood year on Weir Creek (1998), it is not known how LWD levels varied during the post-flood period. Field observations in 1996 indicate that lateral channel adjustments may have annexed a few riparian conifers into the stream.

Figure 5. LWD in reaches of Squaw Creek before and after the 1995-96 flood. Pre-flood conditions in Squaw Creek above km 6.00 surveyed in 1994 and below km 6.00 surveyed in 1995. Data source: CBS.

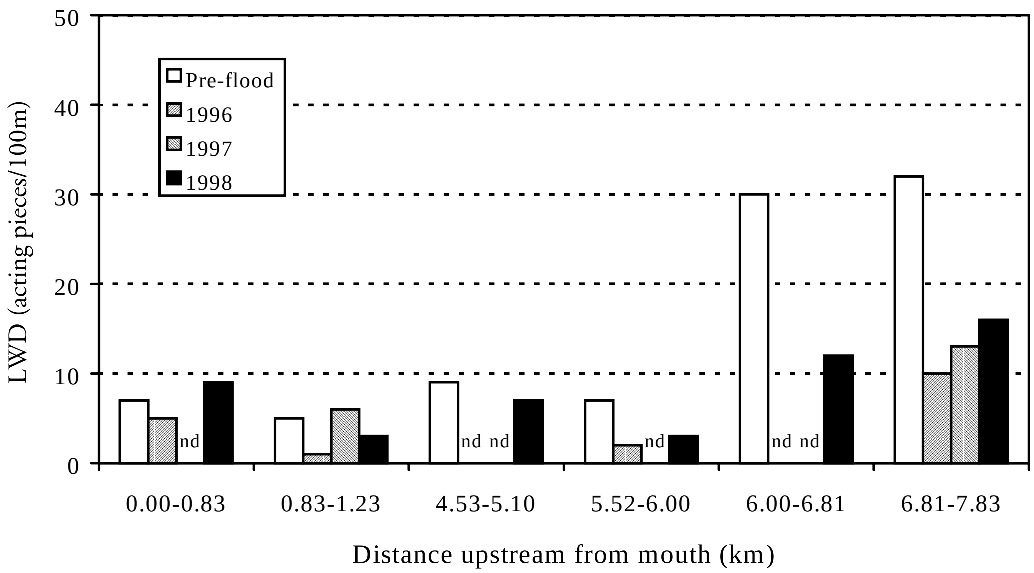
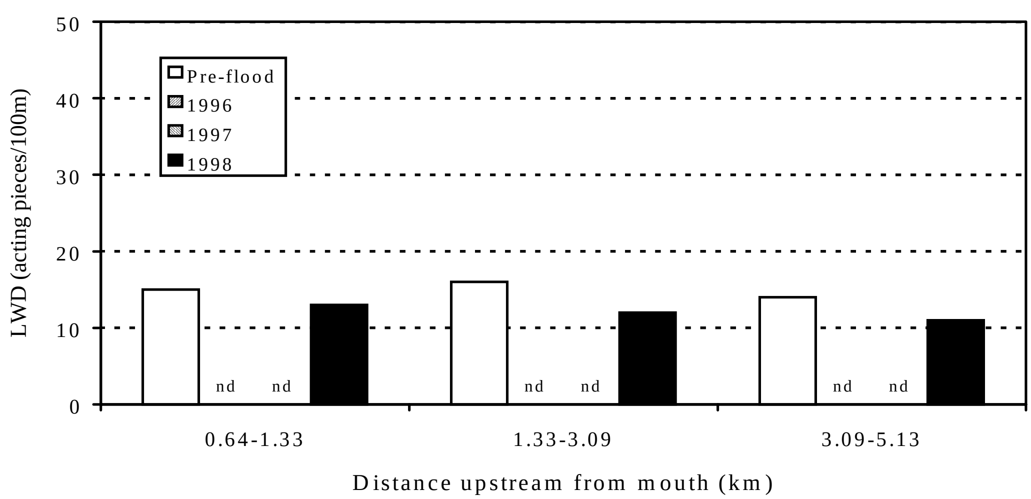


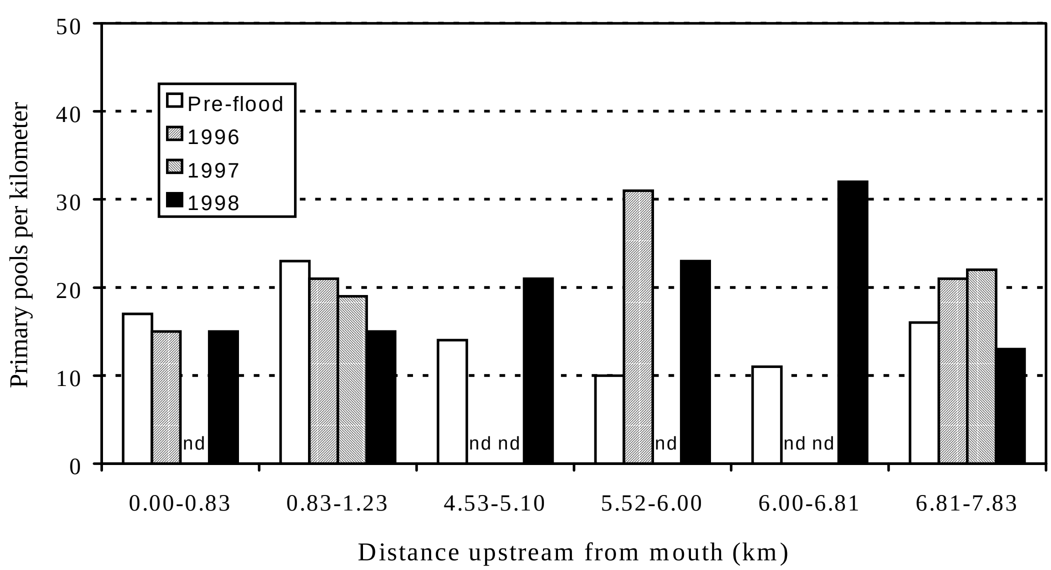
Figure 6. LWD in reaches of Weir Creek before and after the 1995-96 flood. Pre-flood conditions in Weir Creek were surveyed in 1991. Data source: CBS.



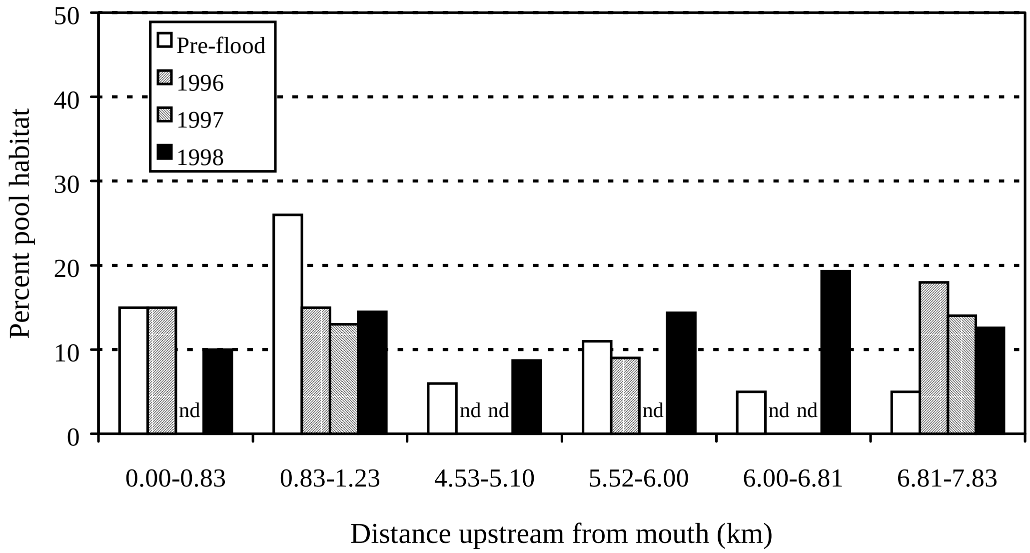
Pool Abundance: Pool frequency (#/km) trends from pre- to post-flood in study reaches of Squaw Creek exhibited considerable spatial variation (Figure 7). Pool frequencies (#/km) in study reaches of Squaw Creek above km 4.53 initially increased from the pre- to post-flood period. However, these reaches also exhibited pronounced inter-annual variation since the flood events (Figure 7), indicating that pools are transient and that pool conditions in these reaches are highly unstable, probably due to high sediment loads coupled with bed instability. In contrast to the pool responses in the upstream reaches, reaches in lower Squaw Creek (below km 1.23) decreased in pool frequency from pre- to post-flood; since the flood, numbers of pools in these reaches have either held steady or continued to decline following the initial flood-induced decrease. In multiple instances, pool frequencies in study reaches of Squaw Creek increased at the same time that LWD abundance decreased. Examination of data showed that this pattern was associated with increases in the abundance of pools created by boulders or bedrock, presumably as a consequence of major channel change.

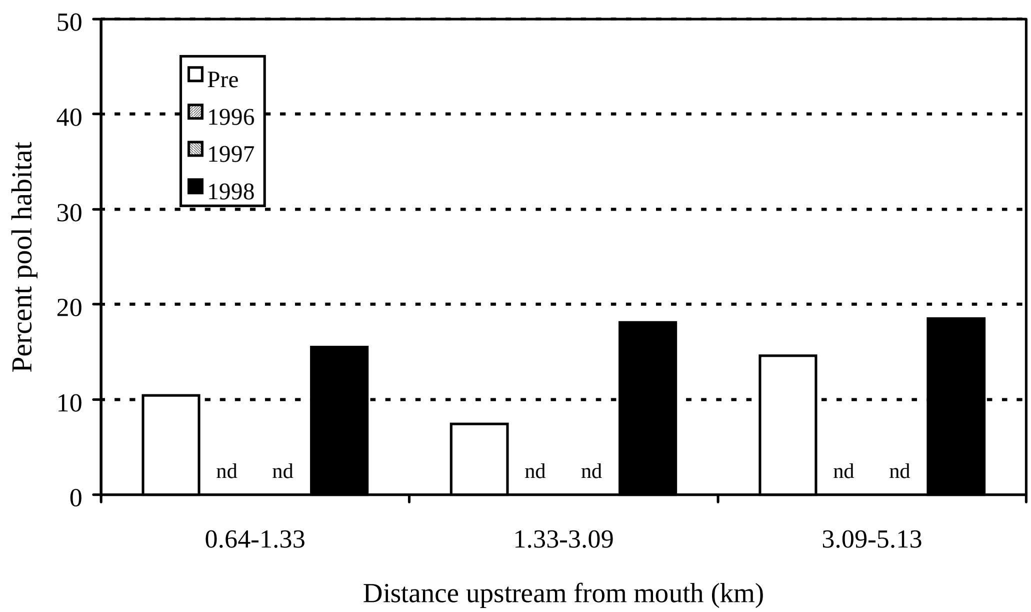
Pool frequency (#/km) data were not collected on Weir Creek during the pre-flood period, so comparisons of differential flood-related changes in pool abundance between Weir and Squaw creeks are based on analysis of the areal extent of pools (percent pool habitat). The percent pool habitat data for Squaw Creek (Figure 8) follow the same general patterns as trends in change in pool frequency (Figure 7). Percent pool habitat increased in all study reaches in Weir Creek (Figure 9) from pre-flood (1991) to post- flood (1998).

Figure 7. Pool frequency in study reaches of Squaw Creek before and after the 1995-96 flood. Pre-flood conditions in Squaw Creek above km 6.00 were surveyed in 1994 and below km 6.00 were surveyed in 1995. Data source: CBS.



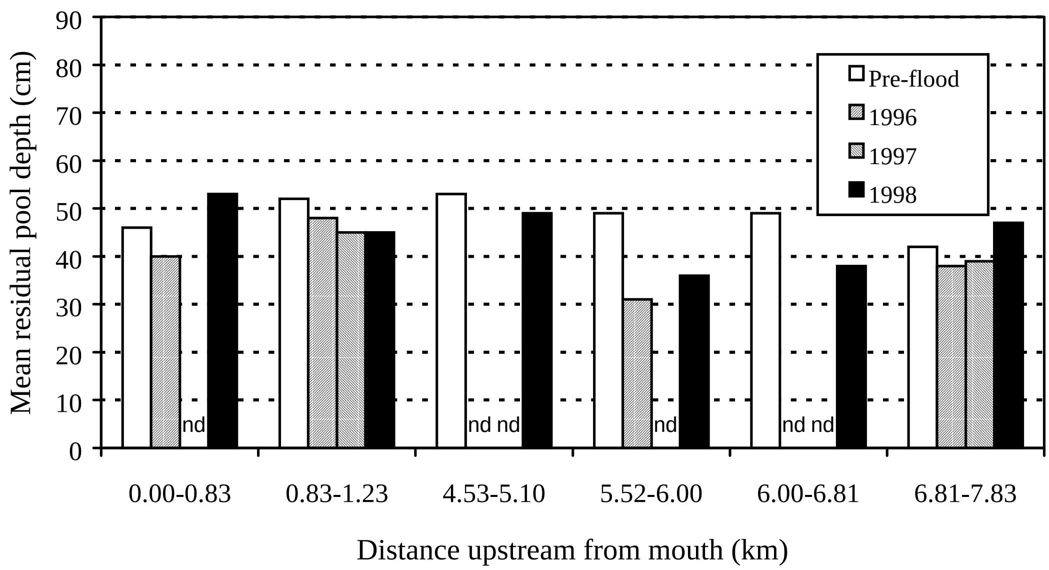
Figures 8 and 9. Percent pools in Squaw Creek (Fig. 8) and unroaded Weir Creek (Fig. 9) before and after the 1995-96 flood. Pre-flood conditions in Squaw Creek above km 6.00 surveyed in 1994 and below km 6.00 surveyed in 1995. Pre-flood conditions in Weir Creek surveyed in 1991. Data source: CBS.





Residual Pool Depths: The 1995-96 flood reduced mean residual depths of pools in the study reaches of Squaw Creek (Figure 10). The magnitude of the reduction and subsequent changes in residual pool depths during the post-storm period, varied among the individual reaches. Pre-flood data on residual pool depths in Weir Creek do not exist, so the flood effects on residual pool depths in Weir Creek cannot be analyzed.

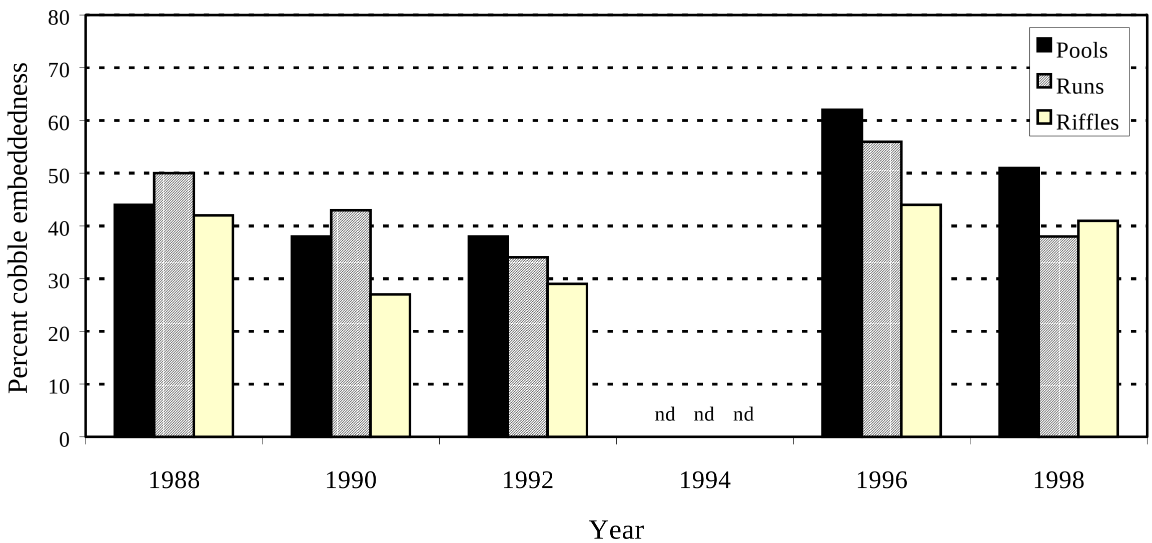
Figure 10. Mean residual depths of primary pools in Squaw Creek before and after the 1995-96 floods. Pre-flood conditions above km 6.00 surveyed in 1994 and below km 6.00 surveyed in 1995. Data source: CBS.

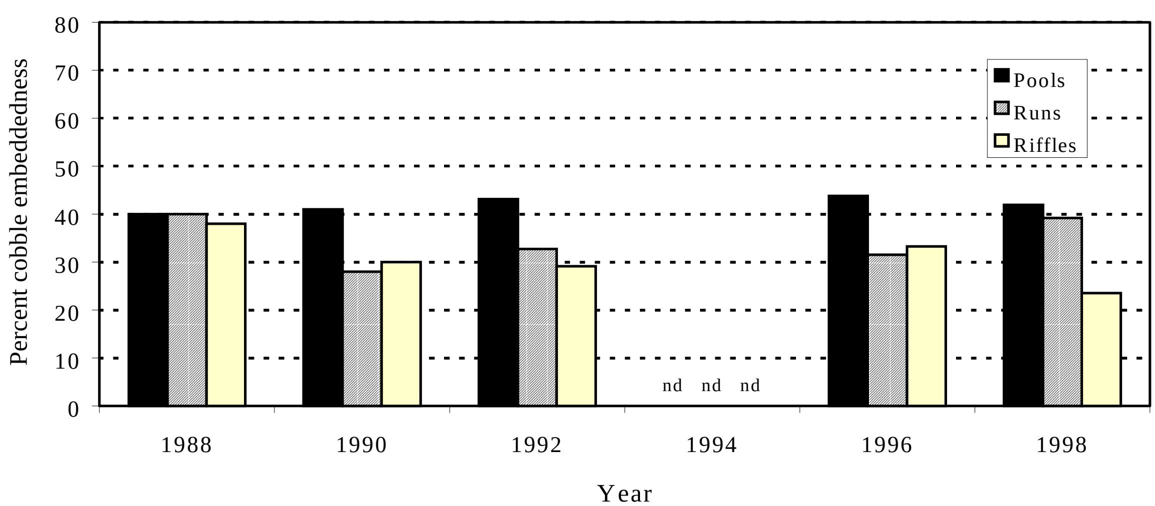


Mean Cobble Embeddedness at Monitoring Stations: Mean cobble embeddedness measured at monitored pool, run, and riffle stations (five each) on Squaw and Weir Creeks indicate that that response of stream substrate to the flood events differed between the two streams (Figures 11 and 12). In Squaw Creek, embeddedness levels elevated by past watershed disturbance generally exhibited a declining trend prior to the storm. The 1995-96 flood effects increased cobble embeddedness in Squaw Creek to levels substantially outside the range of values measured prior to the flood. The increase in cobble embeddedness from the pre-flood (1992) to post-flood period in Squaw Creek (1996 and 1998) were statistically significant at $p < 0.01$. By 1998, mean cobble embeddedness at run and riffle stations in Squaw Creek remained higher than in the last year of pre-flood measurement (1992) (Figure 11), at levels similar to those measured in 1988. Although mean cobble embeddedness at monitored pool stations was lower in 1998 than in 1996, the difference was not statistically significant ($p > 0.05$). Cobble embeddedness levels in 1998 in Squaw Creek remained higher than before the floods (Figure 11).

The increases in mean cobble embeddedness at monitored pool, run, and riffle stations on Weir Creek in response to the flood were significantly less than the increases measured at stations on Squaw Creek. Post-flood embeddedness levels measured at Weir Creek stations in 1996 and 1998 were generally similar to the range of values measured at the same stations in 1988, 1990, and 1992 (Figure 12). The differences in cobble embeddedness levels in Weir Creek between the pre-storm period (1992) and post-storm period (1996 and 1998) were not statistically significant ($p \gg 0.05$).

Figures 11 and 12. Mean cobble embeddedness 1988-1998 at pool, riffle, and run stations (five each) in Squaw Creek (Fig. 11) and unroaded Weir Creek (Fig. 12). Data source: CBS.





Surface Fines at Monitoring Stations: Percent surface fines (<6 mm) in pool, riffle, and run stations in Squaw Creek underwent significantly greater increases in response to the flood similar stations in Weir Creek (Figures 13 and 14). Fine sediment levels increased substantially at the Squaw Creek stations between pre- (1992) and post-flood periods (1996 to 1998); these increases were statistically significant ($p < 0.05$). Although there was a slight decrease in surface fines in pools and runs between 1996 and 1998 in Squaw Creek (Figure 13), it was not statistically significant ($p > 0.05$).

Surface fine sediments at the pool, run, and riffle monitoring stations on Weir Creek showed little change between 1992 and 1996, then underwent insignificant increases at pool and run stations between 1996 and 1998, as a possible lagged effect of the flood (Figure 14). However, in contrast to the increases in surface fine sediment levels in Squaw Creek, the changes in surface fine sediments in Weir Creek from pre- to post-flood were not statistically significant ($p > 0.05$).

Figure 13. Percent surface fines (<6mm) at monitored pool, riffle, and run stations (five each) on Squaw Creek. Data source: CBS

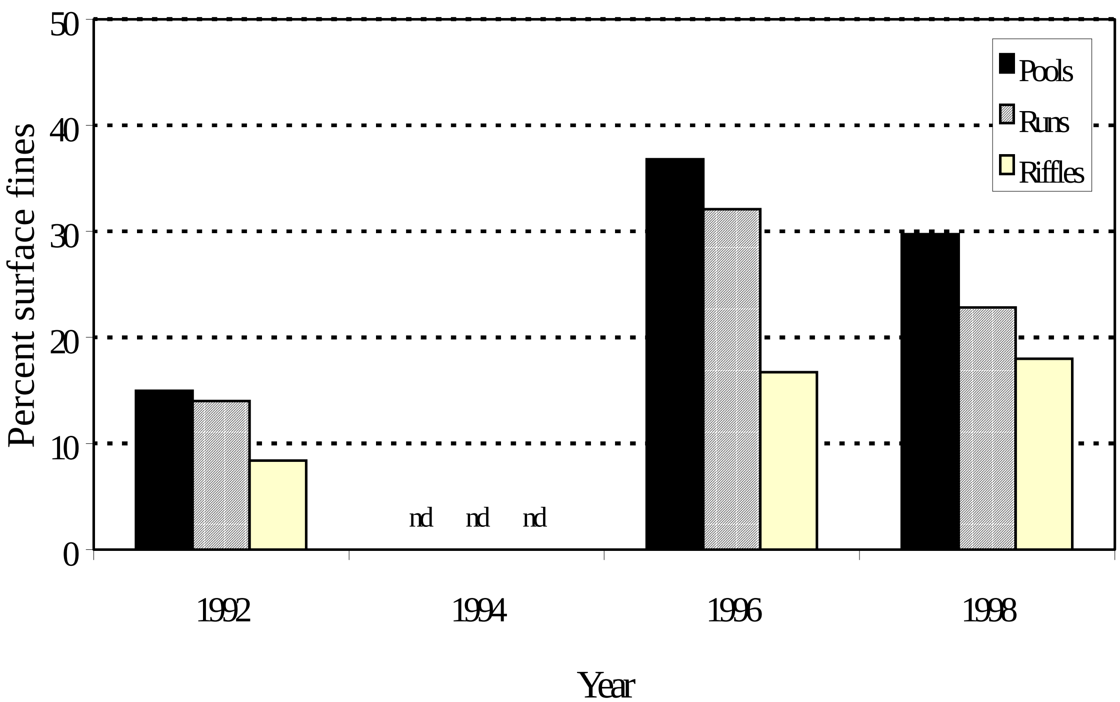
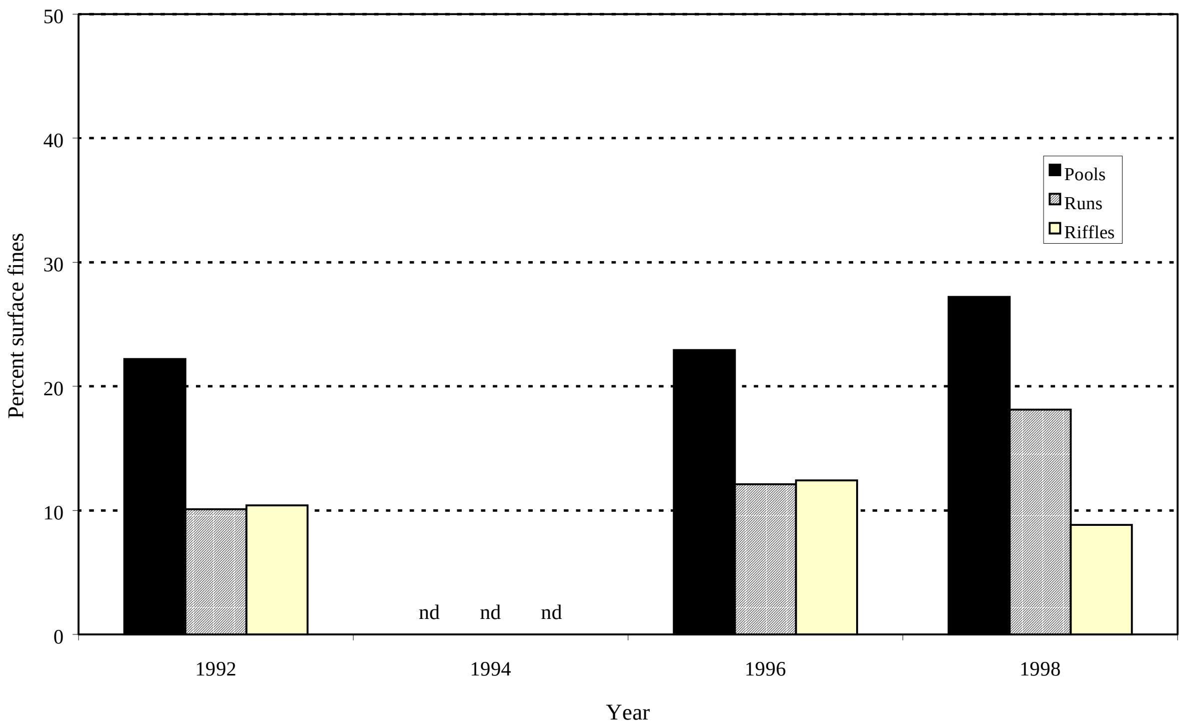


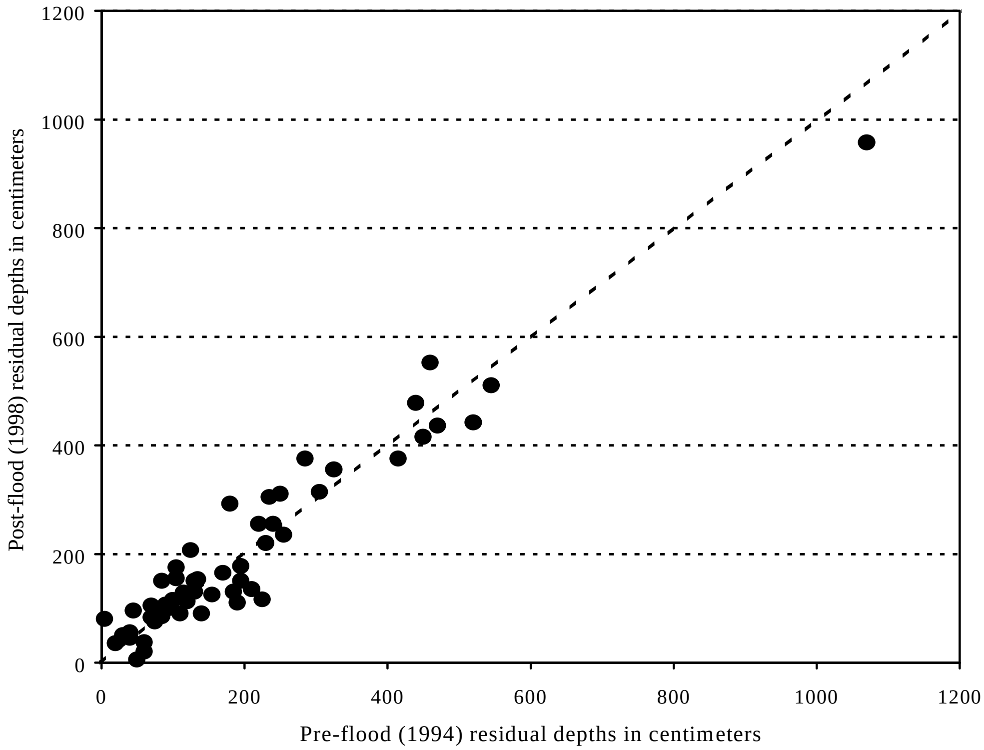
Figure 14. Percent surface fines (<6mm) at monitored pool, riffle, and run stations (five each) in unroaded Weir Creek. Data source: CBS



Residual Depths of Lochsa River Pools: Taken as a whole, changes in the residual depths of 55 pools in the mainstem Lochsa river were small (Figure 15), although potential patterns of change related to varying levels of disturbance or storm response in the surrounding watershed remain to be examined. The mean residual depth of the pools after the flood (203 cm in 1998) was nearly identical to that measured for the same pools prior to the flood (199 cm in 1994); the difference was not statistically significant ($p > 0.05$)

Residual Depths of Crooked Fork Pools: Residual pool depths decreased in lower Crooked Fork (below Brushy Fork Creek) from pre- to post- flood. A random sample of 10 pools measured in both 1994 and 1998 indicated a 40% reduction in mean residual depth (133 cm to 80 cm) over this period. This reduction is statistically significant using a paired T-test ($p<0.05$).

Figure 15. Pre- vs. post-flood residual depths for 55 pools in the mainstem Lochsa River, Idaho. Pools falling on the dashed line had identical residual depths in 1994 and 1998.



Mass Failure Surveys and Analysis

The data from the ground and aerial surveys in the Wenaha and Tucannon River watersheds are being cross-verified with topographic maps. Analysis will ensue once cross-verification is complete. Based on our ground surveys in the Tucannon system, it is clear that there were some mass failures and road failures at culverts that could not be properly inventoried on the ground or identified from the air due to post-storm reconstruction of roads prisms, culverts, and cut and fill slopes. Fitzgerald and Clifton (1997) reported that 95% of surveyed culverts in the Tucannon River watershed failed. Our fieldwork indicated that most of these culvert failures had been reconstructed by the beginning of our surveys in July 1998. Therefore, the UNF's mass failure survey data will be used to augment our data and analyses of mass failure characteristics.

Analysis of mass failure data from the CNF for Squaw and Weir Creeks is on-going and all results are preliminary. Table 6 summarizes some of the preliminary results of the analysis of mass failures triggered by the 1995-96 storms, as inventoried by the CNF in Squaw and Weir Creeks. In Squaw Creek, there were a total of 35 mass failures inventoried. As previously reported by the CNF (Pipp et al., 1997; CNF, 1998), nineteen of the failures were associated with roads, 15 were associated with timber harvest, and one initiated in a natural setting. By land use category, failures associated with roads accounted for the greatest percentage of the number of failures (54%). Our preliminary analysis indicates that mass failures associated with roads also had the highest mean volume (1,091 m^3) of failures by land use category (Table 6). In the unroaded and unlogged watershed of Weir Creek, there were no mass failures triggered by the 1995-96 storm events. Other analyses of failure frequency and volume associated with site characteristics are on-going.

Headwater Channel Conditions

The preliminary results of the monitoring of headwater channels are summarized in Table 7. It should be noted that these preliminary data have not been normalized to account for the effect of catchment area on the attributes. Therefore, the results in Table 7 should be treated with caution, since catchment area typically exerts a profound influence on channel dimensions, such as width and depth, and may also influence attributes such as bank stability.

The preliminary results indicate that channels draining roaded and logged subwatersheds had lower bank stability, more nickpoints, and higher levels of slope instability above the scour line than channels in unroaded and unlogged subwatersheds; all these differences between strata were statistically significant at $p < 0.10$ (Table 7). These differences between the two strata indicate that channels in the roaded strata were more unstable vertically and laterally post-storm than channels in unroaded areas. Nickpoints are diagnostic of vertical bed instability (Richards, 1982; Heede, 1991) and can occur in response to increased discharge. Although nickpoints typically form in response to increases in the ratio of streamflow to bedload transport, nickpoints often cause downstream sedimentation as they migrate upstream (Richards, 1982). Reduced bank stability may be due to the loss of stabilizing bank vegetation, increased discharge, or a combination of the two factors. All attributes related to channel instability were greater in the roaded strata, on average, than in the unroaded strata, except for the height of instability above the scour line (which included both depositional features, such as flood levees, and depositional features, such as destabilized slopes caused by undercutting). The minor difference in the mean height of unstable slopes above the scour line was not statistically significant.

The results in Table 7 also indicate that attributes in channels in the roaded strata generally exhibited higher inter-channel variability than in channels in the unroaded strata; mean height of unstable slopes above the scour line was the only exception to this pattern. Although this pattern could be due to greater variability in upstream catchment area, it may also be due to greater longitudinal variation in attribute condition due to sequences of scour and fill in response to higher flows and bedload transport. Field notes and observations repeatedly noted that channels in the roaded strata exhibited scour and fill sequences with wide variations in width and depth. Channels in the roaded strata also exhibited higher intra-channel variability in channel width than did channels in the unroaded strata, consistent with field observations on scour and fill sequences.

Table 6. Number and volume of mass failures triggered by the 1995-1996 storm events in Squaw and Weir Creek watersheds by associated land use at the initiation point. The density of mass failures is expressed in the number mass failures per unit watershed area (n/km^2). Mass failure volume is expressed in terms of the volume eroded by the mass failure. A dash (-) indicates that the category is not applicable.

	Total--All settings				Roads				Harvested Areas				Natural Settings			
Watershed	n	(n/km^2)	Vol. ($1000\ m^3$)		n	(n/km^2)	Vol. ($1000\ m^3$)		n	(n/km^2)	Vol. ($1000\ m^3$)		n	(n/km^2)	Vol. ($1000\ m^3$)	
			Total	Mean			Total	Mean			Total	Mean			Total	Mean
Squaw Cr.	35	0.8	31.9	0.91	19	0.43	20.7	1.09	15	0.34	11.0	0.73	1	0.02	0.15	-
Weir Cr.	0	0	0	0	-	-	-	-	-	-	-	-	0	0	0	0

Table 7. Summary of preliminary results of monitoring in headwater channels in Tucannon and Wenaha subbasins. CI = magnitude of confidence interval at $p = 0.10$; attributes marked with asterisk (*) indicate that the difference between mean values for the unroaded and roaded strata are statistically significant at $p < 0.10$. See text for additional details and discussion.

Strata	n	Mean width at scour line				Mean depth at scour line				Mean depth * mean width at scour line				Mean bank stability			Unstable slopes above scour line						Nickpoints		
		range (m)	Mean (m)	Std. dev.	CI	range (m)	Mean (m)	Std. dev.	CI	range (m^2)	Mean (m^2)	Std. dev.	CI	Mean length stable* (%)	Std. dev.	CI	Mean length unstable* (%)	Std. dev.	CI	Mean height (m)	Std. dev.	CI	Mean freq. * (#/ stream)	Std. dev.	CI
Unroaded	19	0.51-5.7	1.98	0.48	0.18	0.5-1.00	0.37	0.12	0.05	0.05-4.39	0.78	0.40	0.15	81.10	20.83	7.86	1.65	2.72	1.03	2.16	1.20	0.44	0.37	0.68	0.26
Roaded/ Logged	19	0.46-6.50	2.22	0.95	0.36	0.06-1.50	0.40	0.21	0.08	0.04-7.65	1.02	0.99	0.37	53.90	23.21	8.76	5.57	6.30	2.37	1.89	0.83	0.31	0.95	0.97	0.37

Survey of Channel Network Extension by Road Networks

The preliminary results of the road drainage survey are summarized in Table 8. Based on these results, a significant amount of the surveyed road network in all slope position strata, in both watersheds, acts as extensions of the channel network, with road drainage routed to tributary channels or gullies >10 m in length. In both watersheds surveyed, the mean percentage of the road length contributing to streams or tributary channels increased in a downslope direction by slope position stratum, with valley bottom roads having the highest percent length draining into streams or tributary channels. A significant amount of the road network also contributes to the formation of gullies >10 m in length (Table 8). In both watersheds, roads in the valley bottom stratum had the lowest mean percent length contributing to gullies >10 m. This may be due to the relatively close proximity of the roads to streams or the generally less steep slopes in the valley bottom stratum. Wemple et al. (1996) found that gullies from road drainage generally occurred on steeper slopes.

Notably, the methods used to select sampled road segments may underestimate the amount of channel extension by road networks. The selection method was based on mapped roads, which typically have higher standard construction. Lower standard roads may have been underrepresented due to the selection method, possibly resulting in underestimates of channel extension by roads.

Table 8. Channel network extension by roads in the watersheds of the Tucannon River subbasin and in the Squaw Creek watershed. The categories of mean percent road length routed to streams and gullies >10 m length are not exclusive; some road lengths with drainage routed directly to tributary channels via gullies >10 m in length are included in both categories.

Watershed	Road segments surveyed (n)	Slope position category of roads	Mean percent road length with drainage routed to streams or tributary channels	Mean percent road length routed to gullies >10 m in length
Tucannon	13	Ridgetop	18	6.2
Tucannon	2	Midslope	28	24
Tucannon	3	Valley bottom	52	7.1
Squaw	4	Ridgetop	7.5	6.3
Squaw	4	Midslope	18	3.6
Squaw	1	Valley bottom	59	0

Soil Loss on Non-forested Lands

The preliminary results of monitoring of soil pedestals are summarized in Table 9. The soil loss estimates were made using the pedestal height data to estimate soil loss per unit area, correcting for the estimated amount of soil remaining under the pedestals. The amount of water storage lost in the soil column was determined from the soil loss estimates with an assumed soil porosity of 0.4, which is within the range of porosity typically found in topsoil.

Other data collected during the measurement of soil pedestals also indicates that significant loss of topsoil has occurred in non-forested areas within the watershed. The truncated pebble counts of surface particles outside of the pedestals yielded mean particle diameters ranging from 6 - 64.3 mm with a mean of 36.5 mm over the 10 plots on the five sites. In contrast, analysis of texture by feel of soils under the pedestals consistently indicated that the soil texture was sandy loam, which has a mean particle diameter that is considerably less than 1 mm. This indicates that surface soil outside of the pedestals was considerably coarser than soil under the pedestals, which is an indication of accelerated topsoil loss. Pedestals heights under small trees adjacent to the plots were also higher than under shrubs, forbs and grasses within the monitored plots. Since trees are likely older than shrubs, grasses, and forbs within the plots, this observation also corroborates the results of measured pedestal data.

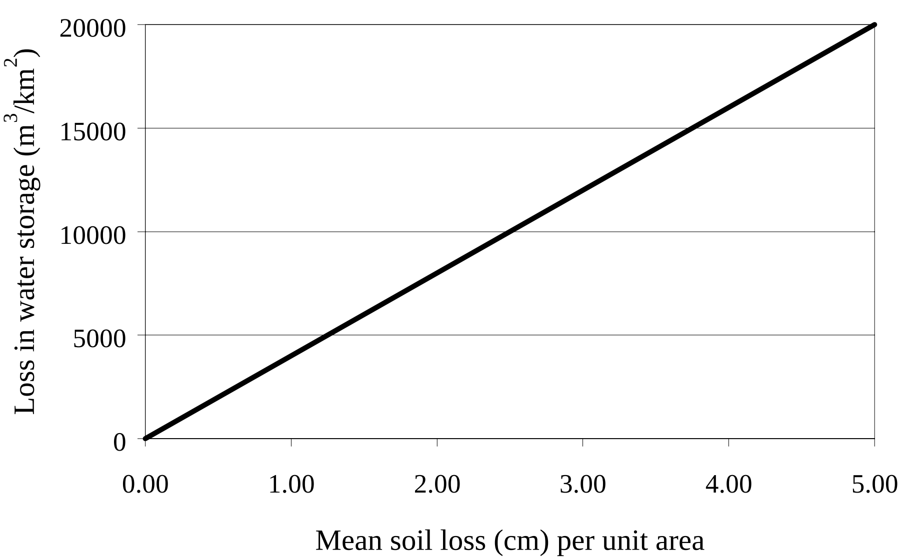
The results in Table 9 indicate that soil loss is likely to have contributed to increased runoff during storm events via two mechanisms. First, water storage in soils has been reduced via erosion, as estimated in Table 9. Much of the overland flow generated in mountainous environments is generated via flow over saturated areas (Dunne and Leopold, 1978). The estimated loss in water storage in the soil profile caused by accelerated soil loss is significant (Table 9). Figure 16 illustrates the relationship between the loss of water storage per unit area and soil loss where the lost soil has a porosity of 0.4. Second, the uppermost layers of topsoil typically have the highest infiltration rate in a soil profile (Hillel, 1971). Therefore, loss of the uppermost topsoil has likely reduced infiltration rates, increase the frequency and magnitude of overland flow during rain and snowmelt events. These effects of grazing on runoff are likely compounded by soil compaction caused by grazing, which has been documented to be significant (J. B. Kauffman, Assoc. Prof., Dept of Fish. and Wildlife, Oregon State Univ., pers. comm.) Soil compaction also increases runoff by reducing infiltration rates and available water storage in the soil profile (Hillel, 1971; Dunne and Leopold, 1978)

The results of the pedestal monitoring indicate that soil loss caused by grazing in non-forested areas has contributed to accelerated soil loss and increased runoff. However, the implications of results are limited by several factors. First, although livestock pressure is greater in non-forested areas than forested areas due to both ease of access and forage palatability, wild ungulate grazing typically follows a similar pattern for similar reasons. Although we found that soils pedestals seldom occurred within forested areas, this condition together with patterns of grazing use by both wild ungulates and livestock confounds efforts to isolate the relative effects of livestock on soil loss. Second, there are no accessible non-forested areas within the watersheds that have not been grazed by livestock, which could serve as comparable control sites to aid in isolating the effects of livestock versus wild ungulates on soil loss. For these two reasons, it is difficult to isolate the degree of the effect of livestock on soil loss in comparison to wild ungulates. Third, the age of grasses and shrubs on the pedestals are not known, so the rate of accelerated soil loss is not known with great precision. Despite these limitations, our data indicate that livestock grazing has contributed to elevated erosion and runoff during storms and snowmelt.

Table 9. Summary of preliminary results of soil pedestal monitoring on plots (n =10). Mean soil loss estimated from pedestal data; loss in water storage calculated from soil loss estimates assuming porosity = 0.40. CI = confidence interval at p = 0.10.

Attribute	Range (cm)	Mean (cm)	Std. Dev.	CI	Loss in water storage (m^3/km^2)
Mean pedestal height	1.54 - 5.31	3.76	1.24	0.65	--
Mean soil loss	1.52 - 5.00	3.53	1.1	0.40	14,124.6

Figure 16. Relationship of depth of soil loss to loss in water storage per unit area in a soil profile with uniform soil loss and porosity of lost soil = 0.4.



Flood Recurrence Intervals

The analysis of flood recurrence intervals for the floods in Weir and Squaw Creek in the Lochsa subbasin were estimated from data at the USGS stream gaging site #313337000 on the Lochsa River near Lowell. The gaging site clearly meets study criteria because it includes 72 years of peakflow data. While the data from the site at Lowell may not be completely representative of flow recurrence intervals in the study basins due to differing hydrologic processes operating at differing rates due to the influence of altitude and other factors (Dunne and Leopold, 1978), the length of record at the site makes it a compelling choice. The peak discharge measured at Lowell after the Nov. 1995 rain-on-snow event in the Lochsa was the 9th highest event on record at the site. Using a lognormal distribution and a line derived from regression ($R^2 = 0.95$) based on flow records for annual peak discharges (Dunne and Leopold, 1978), the Nov. 1995 event has an expected recurrence interval of about 9.1 years, with an exceedance probability of about 11.0% for any given year. The Feb. 1996 was not the peak event for the year, but using the same methods as for the Nov. 95 event, the Feb. 1996 event in the Lochsa has a recurrence interval of about 1.2 years with a probability of exceedance of about 82.6% for any given year.

Other methods and gaging station records are being evaluated for use in estimating the recurrence intervals of the flood. We will also undertake analysis to examine how representative the Lowell gaging site on the Lochsa may be for the upper Lochsa study sites.

Data from the USGS gage site #13344500 on the Tucannon River above the town of Starbuck were used to estimate the recurrence interval of the flood events in the Tucannon River system. Using a lognormal distribution and a line derived from regression ($R^2 = 0.99$), the recurrence interval of the Feb. 1996 event is estimated to be about 13.8 years, with a probability of exceedance of about 7.2% for any given year. The Nov. 1995 event was not the peak event of the year, but using the same methods as for the Feb. 1996 event, the Nov. 1995 event has a recurrence interval of about 1.18 years with a probability of exceedance of about 84.7% for any given year. However, as discussed in the methods section, the data from the site above Starbuck may not be representative of the recurrence intervals in the upper basin due to significant differences in watershed attributes affecting peak discharge. Further, the magnitude of some peakflow events in the data record were estimated, rather than measured, including the Feb. 1996 event. For these multiple reasons, it is likely that the recurrence intervals estimated for the study watersheds in the Tucannon subbasin based on the Starbuck gaging site are not accurate.

Clifton et al. (1999) used the stage-area method to estimate peak discharges from the flood events in the Tucannon River at several locations, together with regional flood equations (Fitzgerald and Clifton, 1997), to estimate the recurrence interval of the estimated peak discharges. Based on these results, Clifton et al. estimated that the recurrence intervals of peak flow magnitudes estimated in the Tucannon were less than 25 years at all stations on the Tucannon River on the UNF where flows were estimated.

In the Wenaha subbasin, the ability to estimate recurrence intervals for the storm and flood events severely limited by the lack of a stream gage. Clifton et al. (1999) used the same methods in the Tucannon and Wenaha Rivers to estimate peak discharges and recurrence intervals from the flood events in the Wenaha River. Based on these results, it was estimated that the recurrence intervals for the flow magnitudes estimated in the Wenaha River ranged from 50 to five years depending on the location of measurements.

SUMMARY AND CONCLUSIONS

Some aspects of the data analysis are still in progress. Therefore, it is too early to summarize the complete project conclusions, but preliminary results include the following. Some of the pre- and post- storm habitat data for the Tucannon and Wenaha subbasins are of questionable reliability due to monitoring protocols which changed over time and other factors. These data will be screened for reliability to prevent spurious results from pre- and post-event data comparisons. It is anticipated that the data screening will truncate some of the planned analyses of change in habitat conditions triggered by the storms.

In the Tucannon and Wenaha subbasins, preliminary results indicate that headwater channels with roaded catchments were more unstable, vertically and laterally, after the flood events than similar channels with unroaded watershed areas. Monitored reaches in headwater channels in the roaded sampling strata had higher percent length of unstable banks, percent length of unstable slopes adjacent to the scourline, and frequency of nickpoints than in monitored reaches in channels in the unroaded strata. These differences between the two strata were statistically significant for all three channel attributes. These differences also indicate that bank erosion was probably greater in channels draining roaded and logged areas than channels draining unroaded areas.

Measurement of soil pedestals on plots in the Tucannon subbasin indicates that livestock grazing has elevated soil erosion. Mean soil loss in non-forested areas during the life of the plants on the pedestals is estimated at 3.5 cm per unit area. The elevated soil erosion has contributed to increased storm runoff by reducing infiltration rates and available water storage in the soil profile. Due to the lack of ungrazed areas in the watershed that could serve as controls, it was not possible to isolate the magnitude of the effect of livestock grazing from the effects of grazing by wild ungulates on soil erosion.

In the Lochsa study watersheds, substrate conditions in Squaw Creek, a roaded and logged watershed, responded to the flood events in a significantly different manner than Weir Creek (unroaded watershed). Cobble embeddedness and surface fine sediment levels increased in Squaw Creek from pre- to post-flood in a statistically significant manner, indicating that watershed response to the events reversed pre-storm recovery in substrate conditions. In Weir Creek, cobble embeddedness and surface fine sediment levels exhibited no statistically significant change from pre-to post-flood, indicating that the flood events had little effect on substrate conditions.

Residual pool depths in Squaw Creek decreased from pre-to post-flood; the magnitude of the decrease varied among reaches. Pool frequency and percent pool habitat in Squaw Creek exhibited high inter-annual variability at all monitored reaches after the floods, indicating that pools are transient features, which is probably due to high sediment loads and bed instability triggered by watershed response to the storms. Due to a paucity of post-storm data on pools in unroaded Weir Creek, the post-storm inter-annual variability of pool habitat is undocumented.

The difference in substrate response between Weir and Squaw Creeks and the post-storm pool responses in Squaw Creek are probably due to the high levels of sediment introduced into Squaw Creek in response to the storm events. Thirty-five mass failures in Squaw Creek were triggered by the storm event, adding a large amount of sediment to the creek; additional sediment was also delivered from the road system via overland flow, since a significant fraction of the road network is directly integrated into the stream system (Table 8). Although mass failures can deliver a mix of sediment sizes, 65% of the mass failure volume eroded was associated with roads. Fine sediment fractions usually comprise the majority of sediment delivered from roads. Overland flow from roads primarily delivers fine sediment fractions. In the unroaded watershed of Weir Creek, there were no mass failures or integration of roads into the channel network. Increases in sediment delivery and fine sediment in particular lead to increased levels of fine sediment in channel substrate, pool in-filling, and bed instability, as repeatedly documented in the field and laboratory settings (Rhodes et al., 1994).

A significant amount of the road network in study watersheds in the Tucannon and Lochsa subbasins was hydrologically integrated into the channel network, effectively increasing drainage density. In both subbasins, the percent of the road network integrated with the channel network increased in a downslope direction. Integration of the road network has contributed to increased runoff by efficiently delivering overland flow and, possibly, via interception of groundwater.

The recurrence interval for the Nov. 1995 event in the study watersheds in the Upper Lochsa is estimated to be about 9.1 years based on 72 years of peak discharge data at a downstream gaging station on the Lochsa River. The recurrence interval for the Feb. 1996 event in the Tucannon River is estimated to be 13.8 years, based on 42 years of peak discharge data at a downstream gaging station on the Tucannon River. Due to differences in land use, land forms, vegetation, rates of change in land use, and elevation between the watershed area of the Tucannon River gaging station and the study watersheds, the recurrence interval estimated from the downstream gaging station has a high potential for error as a estimator of recurrence intervals in the Tucannon River study watersheds. The magnitudes of some of the peak discharge events, including the 1996 event, were estimated, rather than measured, at the Tucannon gaging station, increasing the potential for error in the estimated recurrence intervals.

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SUMMARY OF PROJECT EXPENDITURES

There were no major purchases of property under the project during the year. Table 10 summarizes project expenditures for the year.

Table 10. Summary of project expenditures in 1999 by major category of expenditure.

Category	Total Expenditures from 1/1/99 to 12/31/99
Salaries and Fringe	$10,362.54
Travel	$15.98
Supplies	0
Oper. & Maint.	0
Subcontracts	$32,140.66
Indirect	$3,923.10
Total	$46,442.28

Appendix A: Table 1. Preliminary assessment of general attributes (related to study criteria) of candidate watersheds considered for study

Subbasins	Lochsa	Lochsa	Lochsa	Lochsa	Lochsa	S.Fk. Salmon	S.Fk. Salmon	S.Fk. Salmon	S.Fk. Salmon
Nested watersheds	**Papoose**	**Squaw**	**Beaver**	**Weir**	**Mainstem**	**Blackmare**	**Buckhorn**	**Fitsum**	**Mainstem**
Ownership	pred. public	public	mixed	public	pred. public	public	public	public	public
Level of development	heavy	heavy	intermed.	none	light	none	developed	light	intermed.
Natural disturbances	***	fires	***	fires	fires	fires	fires	fires	fires
Potential control(s)	Weir	Weir	Weir	control	none	control	Blackmare	Blackmare	none
Extent of salmon habitat	several km	several km	several km	a few km	181 km	2-3 km	2-3 km	2-3 km	extensive
Primary geology/parent material	granitic	granitic	granitic	granitic	granitic	granitic	granitic	granitic	granitic
Landtypes	breaklands/ slopelands	breaklands/ slopelands	breaklands/ slopelands	breaklands/ slopelands	breaklands	breaklands/ slopelands	breaklands/ slopelands	breaklands/ slopelands	breaklands/ slopelands
Aspect	south	south	west	south	west	east	east	east	north
Elevation (m above MSL)	1006-2115	948-2048	1091-2112	856-2030	466-2688	1276-2658	1183-2761	1139-2761	640-2740
Runoff pattern	snowmelt	snowmelt	snowmelt	snowmelt	snowmelt	snowmelt	snowmelt	snowmelt	snowmelt
Drainage pattern	dendritic	dendritic	dendritic	dendritic	dendritic	dendritic	dendritic	dendritic	dendritic
Drainage area (sq km)	54	44	28	34	3045	47	65	80	3290
Channel types	B, A	B, A	B, A	B, A	B,A	B,A	B,A	B,A	C,B
Stream order	4	4	4	4	7	3	4	4	5
Streamflow gage(s)	no	yes	no	no	yes	no	no	no	yes
Watershed analyses	yes	yes	no	no	no	no	no	no	partial
Specialized GIS layers	yes	yes	yes	yes	yes	yes	yes	yes	yes
Landslide inventories	yes	yes	yes	yes	yes	no	no	no	no
Pre-storm air photos	yes	yes	yes	yes	yes	yes	yes	yes	yes*
Post-storm air photos	yes	yes	yes	yes	yes	no	no	no	yes
Historic channel surveys	no	no	no	no	yes	no	no	no	no
Pre-storm habitat surveys	yes	yes	yes	yes	yes	no	yes	no	no
Post-storm habitat surveys	yes	yes	yes	yes	no	no	no	no	no
Pre-storm sediment data	yes	yes	no	no	yes	yes	yes	yes	yes
Post-storm sediment data	yes	yes	no	yes	yes	yes	yes	yes	yes
Pre-storm channel data	yes	yes	no	no	no	no	no	no	yes*
Post-storm channel data	yes	yes	no	no	no	no	no	no	yes*

* high resolution videography

*** Unknown/uncertain

Appendix A: Table 1 (continued). Preliminary assessment of general attributes (related to study criteria) of candidate watersheds considered for study

Subbasins	L. Salmon	L. Salmon	L. Salmon	L. Salmon	Tucannon	Tucannon	Tucannon	Tucannon	Tucannon	Tucannon	S.F. Wenaha
Nested watersheds	**Boulder**	**Rapid**	**Mainstem**	**Whitebird**	**U. Tucannon**	**Panjab/ Meadow**	**Bear**	**L. Tucannon**	**Cummings**	**Mainstem**	**S.F. Wenaha**
Ownership	95% public	public	mixed	pred. public	public	public	public	public	pred. public	mixed	public
Level of development	developed	none-light	developed	mod	light-mod	light/mod	light	high	high	heavy	wilderness
Natural disturbances	***	fires	***	***	***	***	***	***	***	***	fires
Potential control(s)	Rapid	control	none	Rapid	S.F. Wenaha	control/ treatment	control?	Panjab?	upper Tucannon?	S.F. Wenaha	control
Extent of salmon habitat	Several km	several km	extensive	several km	extensive	limited	limited	limited	limited	extensive	extensive
Primary geology/parent material	border/ volcanic	volcanic/ border	mixed	volcanic/ granitic	basaltic	basaltic	basaltic	basaltic	basaltic	basaltic	basaltic
Landtypes	Slopelands/ breaklands	breaklands	variable	breaklands	canyons/ ridgetops	canyons/ ridgetops	canyons/ ridgetops	canyons/ ridgetops	canyons/ ridgetops	bottomland	canyons/ ridgetops
Aspect	north-east	north-east	north	west	north	north	north	north-east	north-west	north	northeast
Elevation (m above MSL)	920-2012	597-2438	539-2862	475-1783	908-1948	908-1948	1247-1945	869-1597	628-1695	497-1948	853-1847
Runoff pattern	snowmelt	snowmelt	snowmelt	snowmelt	snowmelt	snowmelt	snowmelt	snowmelt	snowmelt	snowmelt	snowmelt
Drainage pattern	dendritic	dendritic	dendritic	dendritic	dendritic	dendritic	dendritic	dendritic	dendritic	dendritic	dendritic
Drainage area (sq km)	101	142	1491	277	101	66	18	21	51	419	140
Channel types	B,A	B,A	C,B	B,A	B,A	B,A	A,B	A,B	A,B	B,C	B
Stream order	4	5	7	4	4	4	3	3	3	4	4
Streamflow gage(s)	no	no	no	no	no	no	no	no	no	yes	no
Watershed analyses	yes	yes	yes	no	yes	yes	yes	yes	yes	yes	no
Specialized GIS layers	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Landslide inventories	no	no	no	no	yes	yes	yes	yes	yes	yes	no
Pre-storm air photos	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Post-storm air photos	no	no	no	yes	yes	yes	yes	yes	yes	yes	yes
Historic channel surveys	no	yes	no	no	no	yes	no	no	yes	yes	yes
Pre-storm habitat surveys	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Post-storm habitat surveys	no	no	no	no	yes	no	no	no	no	yes	yes
Pre-storm sediment data	yes	yes	no	yes	yes	yes	yes	yes	yes	yes	yes
Post-storm sediment data	no	no	no	no	yes	yes	no	no	no	yes	no
Pre-storm channel data	no	no	no	yes	no	no	no	no	no	yes	no
Post-storm channel data	no	no	no	no	yes	yes	no	no	no	yes	no

*** Unknown/uncertain