THE GEOMORPHIC LEGACY OF SPLASH DAMS IN THE SOUTHERN OREGON COAST RANGE

by

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A THESIS

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Splash dams were in-stream structures that were used to facilitate log driving in the Oregon Coast Range (OCR) between 1880 and 1957. This study explores the potential legacy impacts of "splashing" on stream morphology in Camp Creek and the West Fork Millicoma in the Southern OCR. Field data on stream morphology, GIS analysis, and hydraulic modeling were used in a paired-reach and paired-basin approach to determine legacy impacts on stream widths, depths, cross-sectional shapes, wood accumulation and sediment size. The paired-reach approach did not demonstrate significant differences up- or downstream of past dam locations. The paired-basin approach indicates that "splashing" is associated with narrower streams and less fine sediment, although it is not clear whether this difference reflects legacy impacts of splash dams or other factors driving variations between basins. Splash dam releases significantly exceeded 100-yr flood magnitudes in headwater regions and were comparable to 100-yr flows in lower reaches.

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This work is dedicated to my family, Samuel Humphreys and Hayduke, who are always there for me.

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CHAPTER I

INTRODUCTION

Splash dams, temporary in-stream structures used to facilitate log transport in streams, were ubiquitous throughout the Oregon Coast Range (OCR) from the 1880s through the early 1900s, until they were outlawed in 1957. Despite their widespread use, only a few remnants remain today (Miller, 2010; Sedell, 1981) and their long-term impacts on stream morphology remain largely unknown. This research examines the potential legacy impacts of splash dams on fluvial systems in the Southern Oregon Coast Range. Specifically, I use a paired reach/paired basin approach coupled with field data on modern stream morphology, GIS analysis, and hydraulic modeling in splashed and un-splashed streams to determine splash dam effects on:

- Widths, depths, and width/depth ratios,
- The presence of large wood and complex log jams,
- Dominant channel bed material
- Discharge relative to natural flow regime

This research adds to the small body of literature on the environmental legacy of splash dams. Knowledge of the historical range of variability in stream conditions is crucial in determining viable restoration, logging and fisheries practices in impacted streams.

Background

Splash Dams

Splash dams were used to float timber from remote areas after harvesting. The dams were most common in mid-sized 3rd and 4th order streams (Sedell *et al*., 1991) and ranged in size from approximately two to 10m high with widths that spanned the channel

(Figure 1). Loggers skidded timber into the impoundments behind the dams, and then released the water, often during winter or spring freshets to increase the flow. The larger dams operated for multiple years and had spill gates that would open and close, allowing the rush of water and logs to spill out. Smaller dams were sometimes built without spill gates to transport one harvest and were dynamited to release the water and logs (Beckham, 1990).

Loggers prepared streams prior to splashing to facilitate log transport. Preparation included the removal of existing large wood, the dynamiting of large boulders and beaver dams, and the closure of all side channels and sloughs, all of which could obstruct logs as they flushed downstream (Sedell and Luchessa, 1981). This stream cleaning, often referred to as stream 'improvement,' occurred in large and mid-sized streams and, in this study, is considered to be part of the process of splashing and the subsequent legacy impacts. Splashing was dangerous work for the loggers and damaged properties downstream of the dams through flooding and bank erosion. Fish and fish habitat were also harmed (Wendler and Deschamps, 1955).

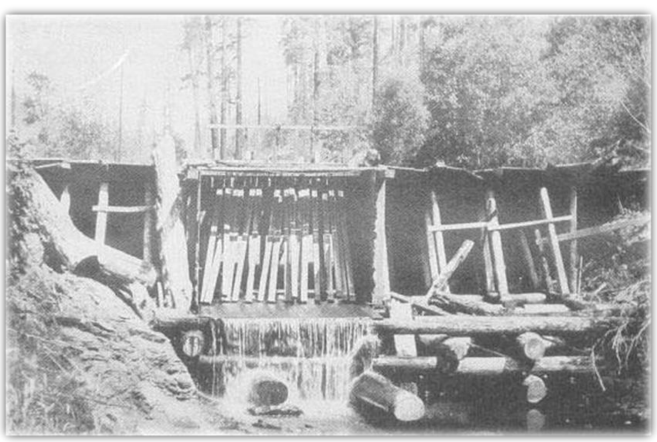


Figure 1: Splash Dam on Hamilton Creek, Oregon 1907
Source: Horner Museum, Oregon State University

The Log Boom Act of 1917 made the Public Utilities Commission (PUC) responsible for regulating splash damming (Montgomery, 2003). This act required boom companies to seek state franchises through the PUC to move timber they did not own, because river driving 'boom' companies often acted as independent contractors to drive logs for timber owners (Beckham, 1990). While opposition to splashing had been common, the 1917 act created a formal process for mediating complaints and imposing regulations. Riparian landowners often made objections to new splash dams, citing increased erosion, destruction of docks, and dangers to boat traffic in the streams. The Oregon State Fish Commission, which protected the interests of commercial fisheries and hatcheries, also voiced strong opposition to building of splash dams, citing the disastrous impacts that splashing had on salmon runs (Beckham, 1990). Despite the regulations, the decisions of the PUC were based mainly on their economic merit and generally favored the logging companies. A former logger describes this in his memoir *Swift Flows the River* (Beckham, 1990 p. 110-113):

> Although the federal government required that the river remain open to traffic and the state limited splashing to twice a week, we violated these rules and kept the river closed all through the winter months…If they had enforced the rules, splash dam logging would have been terminated.

Impacts of splashing were widely recognized, but there was tremendous demand for access to the large stands of virgin timber in the OCR and splashing was the most cost efficient means to transport the timber in many areas. Well-intentioned regulations went unenforced in the rush to extract the resources of the region. In 1957 the Oregon State Legislature banned the use of splash dams, although by this date railroads and logging roads were common and splash dams and log driving were essentially obsolete

(Montgomery, 2003). Many states instituted similar bans but some splashing and log driving continued in the United States throughout the 1960s. In 1971 Maine outlawed the practice and in 1971 the last large log drive occurred on the Clearwater River in Idaho, ending the splash dam era of logging (Beckham, 1990 pg. 144).

Previous Research on Splash Dam Impacts

Few studies have examined the effects of splash dams decades after cessation of splashing. Sedell and Luchessa (1981) initiated the study of splash dams in the Pacific Northwest in 1981 (p. 1), explaining that studies were necessary because:

> Until we understand the structure of undisturbed habitats that wild [fish] stocks develop within, and the sequence of changes that have occurred in those habitats, our present protection and enhancement efforts will lack both rational context and effective direction.

In the same report, Sedell and Luchessa discussed how the extensive use of splash dams in Oregon and Washington altered stream systems by simplifying the channel and reducing the interaction between the channel and floodplains. The report included a rough map of the splash dams of Western Oregon (Figure 2a) based on navigability reports written by Dr. James E. Farnell for the Oregon Department of State Lands (1976, 1979a,b,c; 1980a,b; 1981a,b,c,d). As splash dams were unregulated during much of their use, documentation of the location, size and use of the dams is limited.

Napolitano (1998) evaluated splash dam impacts in Northern California by comparing his field data on historical disturbance due to splash dams, log driving and wood removal in the second growth forest along North Fork Caspar Creek to data collected by Keller and Tally (1979) and Tally (1980) on a similar steep, gravel bedded 2nd order, old growth stream. He found that the old growth stream had five times as much sediment and 20 times as much unfilled storage capacity, which is space created by large wood where sediment can potentially be deposited and stored. The variation between splashed and un-splashed streams occurred because of differences between the size, complexity and stability of large wood and debris jams between the second growth basin and the old growth basin. Naplitano (1988, p. 7) summarized the results of his work by stating:

> The channel has not recovered its previous morphology because jams in the channel are now less stable, stepping is less pronounced with smaller diameter trunks, and the resistance to bank erosion afforded by second-growth trees on the valley fills limits lateral migration. These factors have caused the stream to remain entrenched, and to have a narrower width to depth ratio than the reach above the splash dam…It is unlikely that North Fork Caspar Creek will recover its former morphology, until the former relationship between the size of woody debris and flow magnitude is reestablished.

More recently and concurrent with this study, Miller (2010) created a comprehensive GIS database and map of splash dams in Western Oregon using splash dam locations from Sedell and Luchessa's 1981 publication coupled with historical documentation analysis, interviews, aerial photo analysis and field verification (Figure 2b). Coupling these locations with regional data sets on channel widths, depths, sediment class, habitat units and slope (ODFW, 2010), Miller found 15% more bedrock channel area, fewer deep pools and fewer key pieces of large wood in splashed channels, suggesting that legacy effects exist 50 to 130 years after splashing (Miller, 2010).

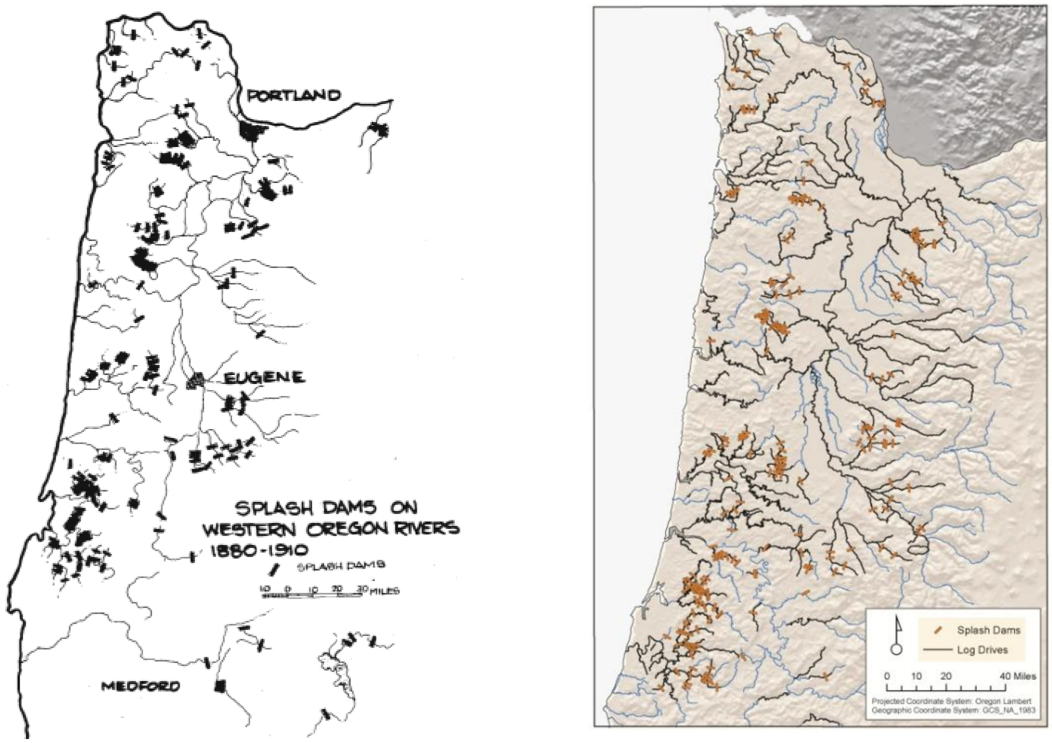


Figure 2: Splash Dam Maps a) Splash dam distribution in Western Oregon based on reports by James Farnell for the Oregon Department of State Lands (Sedell and Luchessa, 1982). B) Map of splash dam locations from Miller (2010) based on Sedell and Luchessa's 1982 map, historical documentation analysis, interviews, aerial photo analysis and field verification.

Elsewhere, a study on the Vindelälven River in Sweden reconstructed alterations made over a century of log driving (Tornlund and Oslund, 2002). Ellen Wohl (2000, 2001) found that splash dams and log driving have decreased channel complexity and led to channel widening. Schmal and Wesche (1989) examined the impacts of railroad tie drives in the Rocky Mountains and concluded that splashed streams in lower gradient reaches were 1.2 to 3.6 times wider.

The limited amount of previous research suggests that splash dams and log driving have a lasting impact on mountain stream systems. The results of these works attest to the importance of evaluating the historic conditions of modern systems. My research attempts to quantitatively document impacts of splashing and log driving in the

Oregon Coast Range and understand the legacy of these practices by comparing splashed and un-splashed systems. Due to increased frequency of high magnitude floods, high stream gradients, and the removal of key wood and boulders, I hypothesize that splashed streams will have downcut their channels and flushed out finer sediments. If this hypothesis is correct, the legacy of splashing should be relatively entrenched channels, fewer key pieces of large wood and less small sediment than un-splashed streams.

Study Area

Southern Oregon Coast Range

This study focuses on two basins, Camp Creek and the West Fork (W.F.) Millicoma River, which are located in the southern OCR (Figure 3). The maps of splash dam locations by Sedell and Luchessa (1981) and Miller (2010) (Figure 2) show that the Southern OCR experienced the highest density and longest duration of splashing in the region.

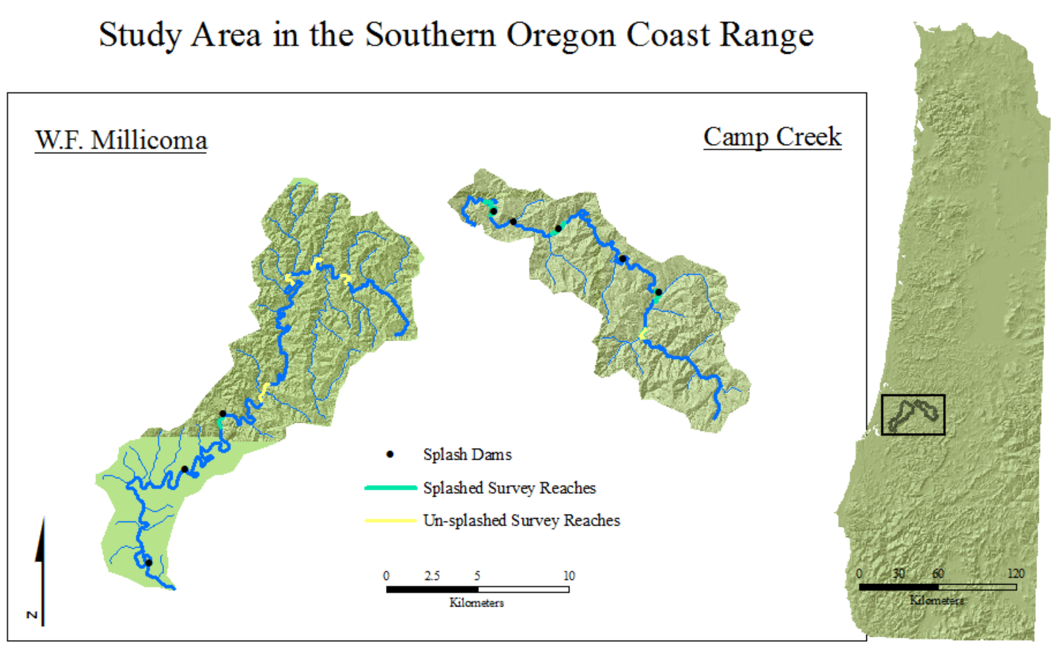


Figure 3: Study Area

The OCR of western Oregon ranges from sea level to 1,250 m in elevation. Consisting predominantly of bedded marine sandstones, siltstones and areas of intrusive volcanics (Baldwin, 1964), the OCR is highly dissected by rivers. Average annual precipitation ranges from 165 cm to 220 cm and falls mainly during the winter months (Surfleet, 1997). Between November and April, flows are flashy as individual storms drop large amounts of moisture on the range. Base flows sustain summer and fall flows in larger basins, but many first and second order stream dry up during that period. Snowfall is relatively rare and does not usually contribute significantly to peak flows. The region supports 5 species of salmonid: steelhead, coastal cutthroat trout, coho, chinook and chum (Burnett *et al*., 2007).

The terrain of the OCR tends to be steep, with large areas having 35-45 degree slopes (Dietrich and Dunne, 1978). Landslides, debris flows and other mass movements are common throughout the OCR, dictating topography in many areas (Benda, 1990). First and 2nd order streams are debris flow dominated systems, while higher order streams are fluvially dominated (Benda, 1990; May, 2003). The irregular supply of sediment from debris flows results in channel bed morphology that cycles between gravel and bedrock/boulder (Benda, 1990).

Land ownership in Camp Creek and the West Fork Millicoma is a mosaic of private, Bureau of Land Management (BLM), U.S. Forest Service (USFS), State of Oregon, Tribal and other public lands. Major industries in the region include timber and commercial fishing, both of which have declined significantly in recent decades.

In order to facilitate the paired basin analysis, two study basins were chosen that had known splash dam locations and similar geology, land use, basin area, and stream size (Table 1). Reconnaissance surveys identified streams that fit the above criteria and were both physically and legally accessible. Sites were chosen to minimize other impacts such as mining, small dams and water withdrawals.

Table 1: Basin Characteristics

	Basin Area of Upper Reach (km^2)	Basin Area of Lower Reach (km^2)	Total Basin Area (km^2)	Average Slope of Survey Reaches	Dominant Sediment Class	Geology**	Elevation (m) at highest/lowest survey reach	Annual Precipitation* (cm/year)	Average Snowfall* (cm/year)
Camp Creek	30.3	86.7	93.7	0.005	Bedrock	Sedimentary Sandstone/Siltstone	189 to 93	150 to 180	<164
W.F. Millicoma	26.5	98.4	141.2	0.008	Bedrock	Sedimentary Sandstone/Siltstone	297 to 126	180 to 200	<164

*Oregon Climate Service Data, (1971-2000) **Oregon Geospatial Data

Camp Creek

Camp Creek is part of the Umpqua River Basin and has a basin area of ~94 km^2 at its mouth (Figure 3). Three of the surveyed reaches were in the splashed portion of Camp Creek downstream of the confluence with Little Camp Creek. The single un-splashed survey site was just upstream of the confluence.

Camp Creek flows through the Tyee formation, a middle Eocene sandstone/siltstone dominated sequence of turbidite deposits, and the Yamhill formation, a middle Eocene siltstone/sandstone deposit (Snavely *et.al.*, 1964; Snavely *et.al.*, 1969). Field observations and aerial photo analysis indicated that a majority of lower Camp Creek, which is primarily managed by the BLM and private timber interests, was clear cut in the last 20 years, leaving very little mature riparian buffer. Portions of this area have been replanted, most recently in 2006, while many adjacent hillslopes remain bare. A paved logging road runs near and in some places directly adjacent to Camp Creek for the length of the stream. Numerous unpaved logging roads split off on either side of the creek. Hunting, fishing and off highway vehicles (OHVs) are common recreational activities in this area.

The West Fork Millicoma River

The W.F. Millicoma River is part of the Coos River basin, and has a basin area of ~136 km^2 (Figure 3). W.F. Millicoma was chosen for the study because it is similar to Camp Creek in terms of geology, topography, basin area, and climate, but the upper four survey reaches were not splashed, making it a good comparator to the splashed locations on Camp Creek. The lowest survey reach of the W.F. Millicoma was likely splashed, although the precise location of the dam is unknown.

The W.F. Millicoma, like Camp Creek, flows through the Tyee Formation. The upper W.F. Millicoma River included in this study sits in the Elliott State Forest, which is managed by the Oregon Department of Forestry (ODF) and owned by the Department of State Lands (DSL). The Elliott State Forest covers 93,000 acres and is habitat for four species of salmonids, and numerous amphibians and bird species including Coho salmon, Tailed frog and Northern Spotted owl (ODF, 2003). In 1956-1976 and prior to the restoration efforts, the Oregon Game Commission conducted ‘stream cleaning’ that removed large wood from the channel for the purpose of enhancing fish passage (ODF, 2003). In more recent times, the forest has been managed both for timber harvest and habitat conservation. In 1998 the Coos Watershed Association (CWA) placed large wood at 11 sites in the headwaters of the W.F. Millicoma to create and improve salmonid spawning habitat (Banks *et al.*, 2001; ODF, 2003). The wood placement projects occurred upstream of the reaches surveyed in this study, as well as on tributaries.

Hunters, anglers and OHVs commonly using the forest. Logging roads run throughout the basin and occasionally run adjacent to the stream, although much of the W.F. Millicoma is not easily accessible by roads.

CHAPTER II

METHODS

I used a paired basin/paired reach approach that compared splashed and non-splashed basins and reaches to document potential long-term effects of splash dams. Field data on stream morphology were collected using longitudinal surveys. Basin areas and slopes were extracted from DEMs and LiDAR in GIS. I used peak discharge and dam break models to evaluate effects of dams on peak flows and regression analysis to evaluate relative effects of dams, roads, basin area and slope on stream characteristics.

The Paired Basin/Paired Reach Approach

I used a paired basin/reach approach to analyze potential impacts of splash dams: a) up and downstream of individual dams (the paired reach approach), and b) at splashed and un-splashed sites of similar basin area in different basins (the paired basin approach). In the paired basin approach, up and downstream of dams were considered splashed because of the stacked nature of the dams. In the paired reach approach upstream was considered un-splashed and downstream splashed in order to determine any localized effects of the dams. The paired basin approach relied on the four un-splashed W.F. Millicoma sites that had similar basin areas to the splashed sites on Camp Creek. All sites were used for the statistical analysis of the effects of basin area, slope and splashing on channel characteristics. Dam sites used in this study were identifiable by dam remnants at the site to insure accuracy of location. Dam locations and attributes were derived from Miller (2010).

Field Methods

I surveyed morphology along four 1 km reaches on Camp Creek and five 1 km reaches on the W.F. Millicoma during the winter of 2009/10. Three of the survey reaches on Camp Creek were associated with dam sites and consisted of ten 50m sections above the dam location and ten below. The remaining survey reach was above all known dams and consisted of 20 50m sections, the same sampling layout was used on the W.F. Millicoma. Based on initial surveys, the 1 km reaches captured variability representative of the streams and were a practical distance to survey given logistical constraints. In each 1 km reach I collected data at 20 sections, each ~50 m long. Fifty meters is a distance that enabled a complete survey of the channel from one spot. Data collected at each 50 m section included width, depth, number of pieces of large wood, and dominant sediment class. In addition I took a GPS point, photos and sketched a cross section profile at each survey section.

At the upstream end of each 50 m section, I measured wetted channel width (defined as width of water surface), bankfull width, bankfull depth and maximum water depth with a survey grade laser range finder. Bankfull stage was identified based on changes in slope, bank shape, and high water marks or location of debris and sediment. I used the laser range finder to estimate water depth by shooting points at bankfull stage and at an estimated location for the channel bottom (Figure 4).

At each of the 20 survey sections in the 1 km reach I sketched a cross sectional profile, noting bank characteristics and the presence of roads. I also took photos looking upstream, downstream and across the stream at the center point of each 50 m section to document channel characteristics that were not captured by the measurements. High accuracy GPS (±0.5 m) points were taken to mark these locations.

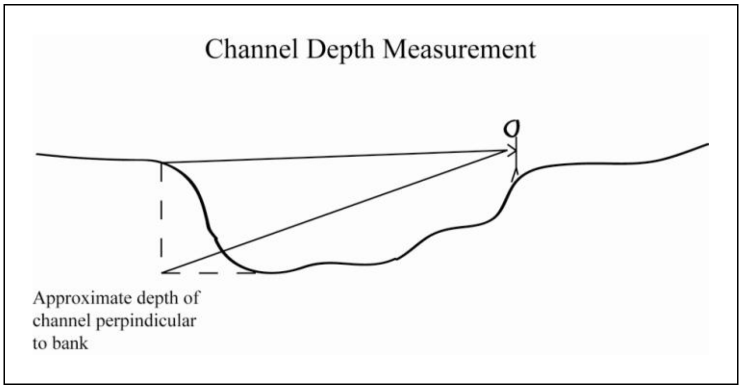


Figure 4: Diagram of depth measurement

In each 50 m-section I ranked the relative dominance of bedrock, sands/fines, gravel/cobble and boulders on the channel bed, based on visual estimates while walking the stream. Observations were made from the bank and by walking over sections that were not visible due to deeper water or shadows.

In each section I counted number of pieces of large wood. I defined large wood following May and Greswell (2003) as any wood that lay wholly or partially within the bankfull channel and was greater than 20 cm in diameter and 2 m long. Photos were taken of notable wood pieces and large jams. I performed all sediment and large wood surveys to insure consistency of visual estimates.

GIS Methods

One-meter resolution bare earth data LiDAR taken during the winter of 2008 were acquired for both Camp Creek and the W.F. Millicoma from the Oregon Department of Geology and Mineral Industries. GPS points from fieldwork were placed on top of the LiDAR data to extract a longitudinal profile for individual 1 km reaches and 50 m sections using the 3D analyst profile tool in ArcGIS. I exported the point data from GIS to Excel and used linear regression to define slope for each reach and section. I hand delineated basin boundaries LiDAR data and measured their areas using the area measurement tool in ArcMap.

Qualitative Analysis

Channel cross section sketches were randomly selected by survey number from both splashed and un-splashed datasets. I examined sketches and corresponding photos to determine if any distinct characteristics existed in channel shape between splashed and un-splashed reaches. I also used the sketches to determine whether individual cross sections were influenced by the presence of a road.

Hydrologic Modeling

I modeled natural flood flows and dam break peak discharges to estimate the discharge from splashing relative to the natural flow regime of both streams. To model natural flow regimes for the study basins I used the USGS National Streamflow Statistics Model (USGS, 2010). Input variables included basin area, maximum 24 hr 2 year precipitation, mean maximum January temperature, available water capacity and soil permeability and were obtained from NRCS web soil survey (Coos County, Oregon, 1989) and USGS program manual for NSS (Ries and Krouse, 2002). The outputs I selected were discharges for 2, 50, 100 and 500 year floods. Because these systems are un-gauged and there is no recorded discharge measurement associated with splashing, several assumptions were made to compare natural and splash discharges. For example the dam outburst equation assumes the complete failure of the dam whereas, in the case of splash dams that operated for several years, the release was likely more controlled.

Costa's (1988) dam break model provided estimates of peak dam-break discharge

$$Q_{max}=10.5h^{1.87} \quad (1)$$

Where h is the height of the water depth in meters just upstream of the dam and Q_{max} is the maximum discharge in m^3/s when the dam is released. The main variable in the dam outburst equation is the height of the water behind the dam, which is generally unknown. In this study, a range of heights were tested based on the known height of a few dams on Camp Creek (Miller, 2010).

Statistical Analysis

I used the R statistics program (R, 2010) to build linear regression models that describe the relationship between the control variables (basin area and slope) and the response variables that I measured in the field (width, depth and large wood). The classification of splashed and un-splashed, as well as the influence of roads, was introduced to the model as factor or ‘dummy variables’. The Akaike Information Criterion (AIC) was used for model selection (Akaike, 1974). The AIC number compares the goodness of fit of different models. I used AIC to help determine the relative improvement of a model when more control variables were added. The outputs of the models describe how useful each control variable is in explaining changes in the response variable.

CHAPTER III

RESULTS

The following sections summarize the results of the paired reach/ paired basin analysis. Basic statistics for width, depth, W:D ratio, large wood and sediment are presented for the paired reaches in Tables 2 and 3 and for the paired basins in Tables 4 and 5. The paired reach analysis compared reaches upstream and downstream of dams on Camp Creek, but not on the WF Millicoma due to the uncertain location of the dam on that river. Width, depth, W: D ratios, wood and sediment were compared for upstream and downstream reaches at each dam. The paired basin analysis compared the same variables as the paired reach analysis between survey reaches of similar basin areas on the W.F. Millicoma and Camp Creek.

Paired Reach Analysis

The paired reach analysis looked at morphology, large wood, and sediment up and downstream of dams with basin areas of 47 km^2 (dam 1), 74 km^2 (dam 2) and 87 km^2 (dam 3). At dams one and two the stream is wider downstream of the dams, but dam three shows no difference in width relative to dam location. Depths are comparable up and downstream of the dams. Overall the channel was slightly more wide and deep below all dams. W: D ratios are larger downstream of dams one and two but larger upstream of dam three (Table 2). In general, morphology varied among reaches without a strong relation to location up or downstream of dams.

Likewise, the number of pieces of large wood did not differ systematically above and below dams. The number of pieces of wood ranged from 0 to 50 per reach with the average above dams ranging from 1.25 to 12.3 pieces and below dams from 4.2 to 7.2

pieces. The dominant sediment class on the channel bed also did not show a strong relationship to dam location, although there are generally fewer fines below the dam sites (Table 3).

Table 2: Paired Reach Data
10 reaches above and 10 reaches below dam locations on Camp Creek

Basin Area (km^2)	Camp Creek Dam Sites		Bankfull Width (m)		Bankfull Depth (m)		Bankfull W:D		Wood (# of Pieces)	
			Above	Below	Above	Below	Above	Below	Above	Below
47.0	**Dam 1**	**Max**	23	31.8	2.8	3.58	9.4	12.8	50	30
		Mean	14.2	16.0	2.1	2.2	6.7	7.9	12.3	7.2
		Min	10.1	10.6	1.9	1.19	4.2	3.9	3	1
74.2	**Dam 2**	**Max**	18.4	20.6	2.4	2.7	10.1	13.8	12	10
		Mean	16.3	18.3	1.9	1.9	8.7	9.8	6.9	4.2
		Min	15.5	15.8	1.6	1.4	7.2	5.8	3	0
87.0	**Dam 3**	**Max**	28.1	33.8	2.7	2.7	19.5	15.4	3	12
		Mean	20.6	20.8	2.0	2.4	11.5	9.0	1.25	4.9
		Min	17.6	16.0	0.9	1.5	6.7	6.5	0	1

Table 3: Paired Reach Sediment Data:
Percent dominant sediment on channel bed above and below dams on Camp Creek

Dominant Sediment		Sands/Fines	Gravel/Cobbles	Bedrock	Boulders
Dam 1 47.0 km^2	Above	82.0	0.0	18.0	0.0
	Below	62.5	12.5	12.5	12.5
Dam 2 74.0 km^2	Above	40.0	0.0	60.0	0.0
	Below	30.0	10.0	50.0	20.0
Dam 3 87.0 km	Above	20.0	10.0	50.0	20.0
	Below	0.0	0.0	100.0	0.0

Paired Basin Analysis

In the paired basin analysis data above and below dams are merged into one dataset of 20 cross sections and compared by basin area. Field data at paired basin areas

(Table 4) showed that splashed reaches have slightly narrower channels than un-splashed reaches, although depths are comparable (Figure 5, Table 4). However, widths in the un-splashed portion of Camp Creek are also slightly narrower than the un-splashed sections of the WF Millicoma with a similar basin area, calling into question whether the width differences are related to splashing or other factors. Following the more narrow widths, the width/depth ratios are smaller for splashed reaches. For both width and W: D ratios the effect becomes less notable as basin area increases (Figures 5a,c).

Table 4: Paired Basin Data

Basin Areas (km^2)		Basic Statistics	**Width (m)**		**Depth (m)**		**W:D**		**Wood (# of Pieces)**	
C.C.	W.F.		C.C. Splashed	W.F. Un-splashed	C.C. Splashed	W.F. Un-splashed	C.C. Splashed	W.F. Un-splashed	C.C. Splashed	W.F. Un-splashed
31.5	28.0	**Max**	17.2*	18.4	3.5	1.9	13.5	19.4	15	16
		Mean	13.8*	14.5	2.3	1.3	6.5	11.9	6.8	5.8
		Min	9.2*	11.5	1.3	0.8	3.2	7.4	2	0
47.0	50.0	**Max**	31.8	26.7	3.7	1.8	12.8	23.4	50	15
		Mean	14.9	20.2	2.1	1.4	7.2	15.0	9.9	4.1
		Min	10.1	14.6	1.2	1.0	3.9	9.1	1	0
74.0	70.0	**Max**	20.6	26.6	2.7	2.4	13.8	20.5	12	30
		Mean	17.3	22.0	1.9	1.6	9.3	14.6	5.6	7.1
		Min	13.0	19.1	1.4	1.2	5.8	11.1	0	0
87.0	88.0	**Max**	33.8	36.0	3.0	3.8	19.5	18.5	12	35
		Mean	20.7	29.0	2.2	2.4	10.3	12.5	3.4	5.1
		Min	15.6	25.1	0.9	1.4	6.5	9.6	0	0

*Indicates un-splashed reaches of Camp Creek

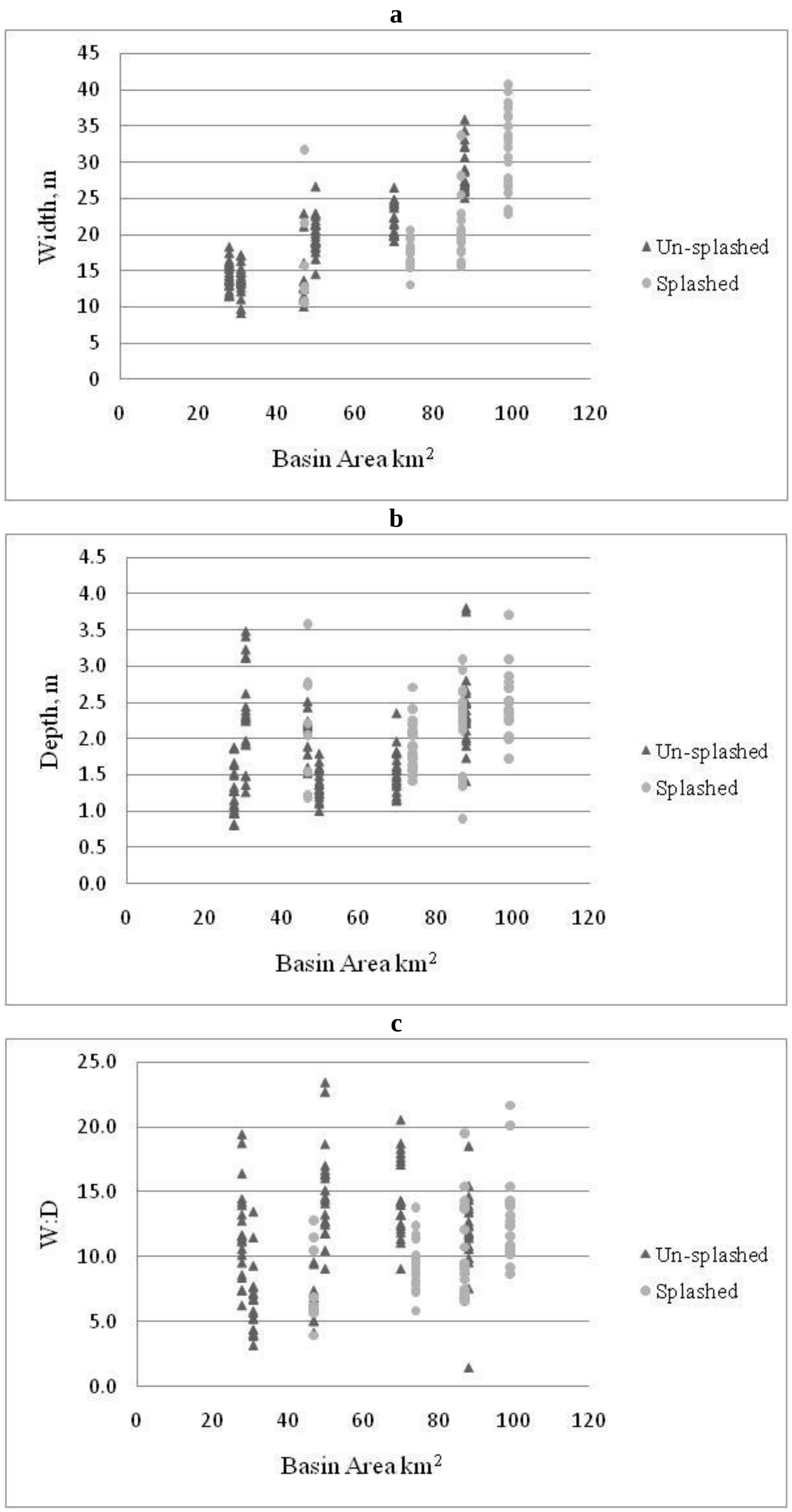


Figure 5: Morphological Variables **a)** width by basin area, splashed vs. un-splashed **b)** depth by basin area, splashed vs. un-splashed **c)** W:D ratio by basin area, splashed vs. un-splashed

The abundance of pieces of large wood showed no clear difference between splashed or un-splashed reaches. The splashed reaches have an average of 4.6 pieces of large wood per section while the un-splashed reaches averaged 6.2 pieces of large wood per cross-section. There are more large complex log jams in non-splashed reaches but the data set regarding outliers is too sparse to reach a firm conclusion (Figure 6). The majority of the large complex log jams were found at the uppermost basin site (drainage are 31 km^2) of Camp Creek, which was above all known splash dams. In this reach there were three large log jams composed of between 20 and 50+ individual pieces of large wood (Figure 7). Three log jams of similar size were found in the un-splashed reaches of the W.F. Millicoma, two in basin area 1 (28 km^2) and one in basin area 4 (88 km^2).

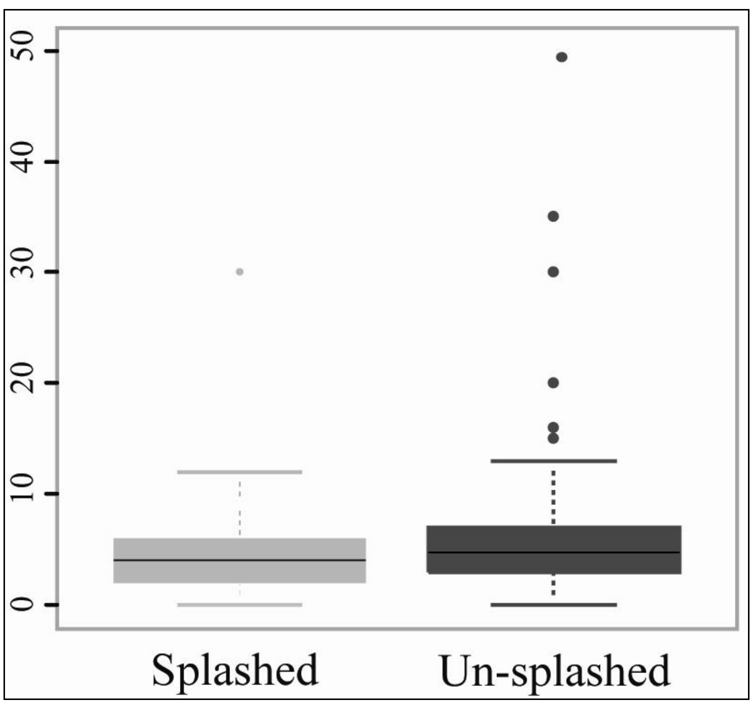


Figure 6: Large Wood
Pieces of large wood per
50m section. Outliers represent large log jams.

Figure 7: Photos of large log jams on the un-splashed reach of Camp Creek

The aggregated data indicate that bed material in the splashed reaches is more often dominated by bedrock than gravels/cobbles or sands/fines when compared to un-splashed reaches. Bedrock is the dominant sediment class in 55% of splashed reaches while un-splashed reaches are dominated by bedrock 31% of the time (Table 5, Figure 8).

Table 5: Paired Basin Sediment Data:
Percent dominant sediment on channel bed in paired basin areas on W.F. Millicoma and Camp Creek

Dominant Sediment		**Sands/Fines**	**Gravel/Cobbles**	**Bedrock**	**Boulders**
Basin Area 1 (31.5/28.0 km^2)	CC	10.0*	80.0*	10.0*	0.0*
	WF	40.0*	55.0*	5.0*	0.0*
Basin Area 2 (47.0/50.0 km^2)	CC	75.0	5.0	15.0	5.0
	WF	20.0*	25.0*	55.0*	0.0*
Basin Area 3 (74.0/70.0 km^2)	CC	35.0	5.0	60.0	0.0
	WF	20.0*	25.0*	55.0*	0.0*
Basin Area 4 (87.0/88.0 km^2)	CC	10.0	5.0	80.0	5.0
	WF	15.0*	40.0*	45.0*	0.0*

*Indicate un-splashed reaches

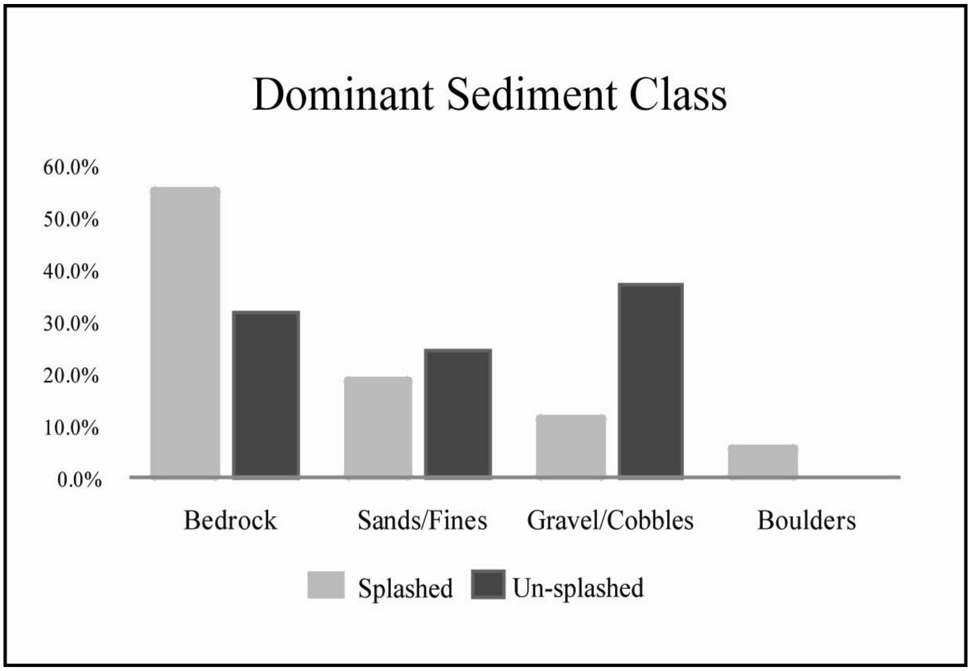


Figure 8: Percent dominant sediment class in splashed vs. un-splashed reaches

The multivariate analysis of response variables as a function of basin area, slope, roads and splashing indicates that basin area was the strongest indicator of width but was only loosely associated with depth and large wood (Table 6). Splashing showed a strong negative relationship with width, suggesting that it is associated with narrower widths. Slope exhibited a weaker, but still significant, positive relationship to width showing that steeper slopes are associated with wider channels. Roads were statistically related to width in the AIC analysis (p, 0.01), but did not change the AIC by two or more and did not alter the r^2 value, so are not included in the linear model shown in Table 6. Splashing, channel slope and roads were not significantly related to depth or large wood.

Table 6: Results of Linear Regression Models for Control and Response Variables (includes models where variable entry changed the AIC by 2 or more)													
Response Variable	Intercept	Control Variable	Coefficient	ΔAIC	Control Variable	Coefficient	ΔAIC	Control Variable	Coefficient	ΔAIC	R^2	ΔAIC
Width	7.02	Basin area	0.21	0	---	---	---	---	---	---	0.54	0
	5.41	Basin area	0.26	10	Splashed	-4.48	0	---	---	---	0.61	26
	4.88	Basin area	0.27	8	Splashed	-4.74	6	Slope	62.33	NA	0.61	8
Depth	1.4	Basin area	.01	NA	---	---	---	---	---	---	0.12	NA
Large Wood	9.01	Basin area	-.05	NA	---	---	---	---	---	NA	0.04	NA

Channel Cross Sections

Qualitative analysis of randomly selected cross section profiles indicated that variations in channel shape were probably the result of natural variability and were not related to splashing (Figure 9). The impact of roads, in addition to splashing, on channel morphology is presented in Figure 10 and shows that there is no clear relationship between the variables. Although it was my impression, based on sketches, that roads might be affecting channel shape by limiting its movement and causing it to be narrower with steeper banks, the regression analysis indicated that roads did not add to model explanation of width or depth.

Hydrology

Figure 11 compares natural flows calculated using the NSS model to dam burst flows calculated using the dam burst model. Results of the Costa (1988) dam burst equation indicate that the flows generated by splashing significantly exceeded 100-yr flood magnitudes in headwater regions and were comparable to 100-yr flows in lower reaches.

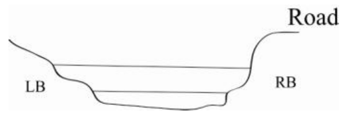
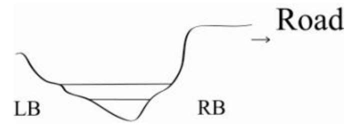
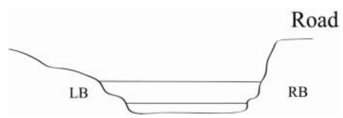
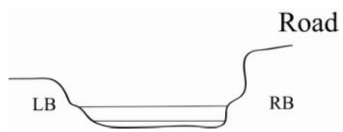
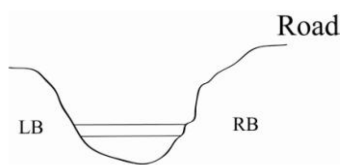
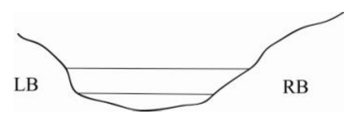
Splashed		**Un-splashed**	
			
XS004 on Camp Creek		XS055 on Camp Creek	
			
XS005 on Camp Creek		XS117 on W.F. Millicoma	
			
XS041 on Camp Creek		XS150 on W.F. Millicoma	
			
XS045 on Camp Creek		XS166 on W. F. Millicoma	

Figure 9: Cross section sketches and corresponding photos randomly selected from splashed and un-splashed reaches

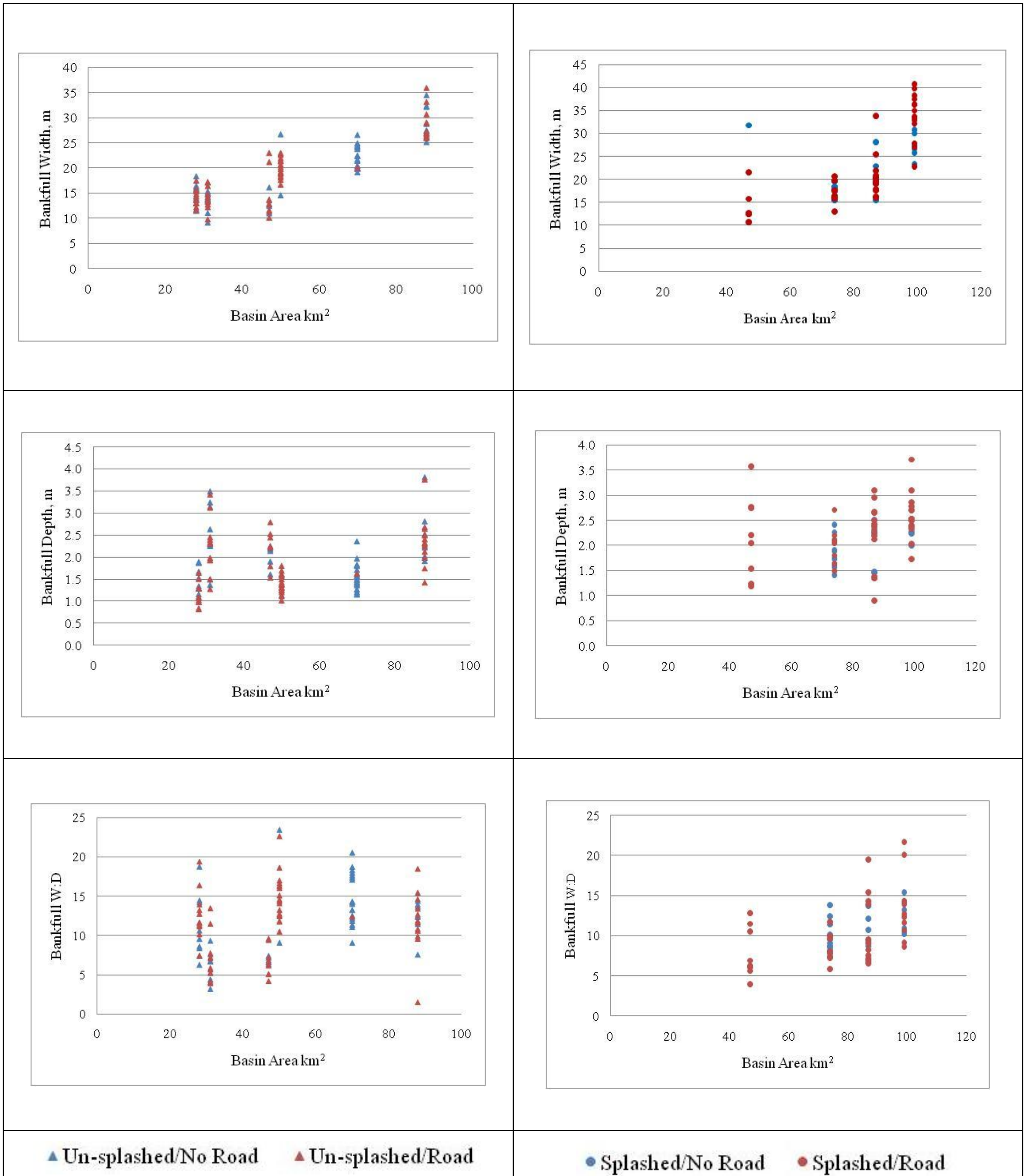


Figure 10: Influence of Roads on Morphological Variables

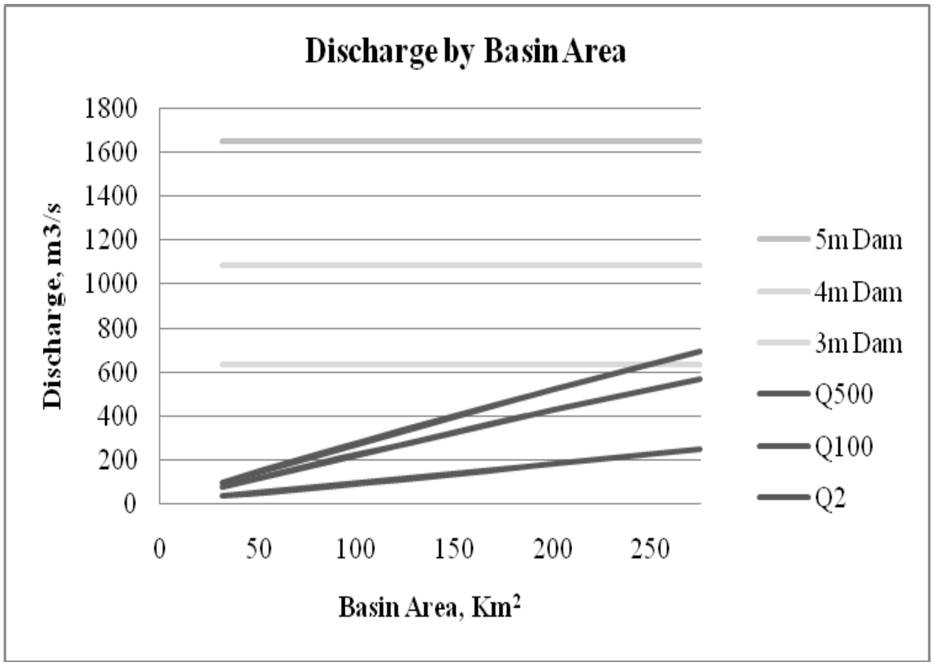


Figure 11: Modeled Natural Discharges vs. Dam Outburst Discharges

CHAPTER IV

DISCUSSION

The purpose of this study was to provide preliminary analysis of the geomorphic variables that were considered likely to display the legacy of splashing. It is apparent from these data that some variables display a relationship that is consistent with a legacy of splashing while others do not.

Morphology

The paired reach approach did not reveal any consistent variations in morphology, wood, or sediment up or downstream of dams. While dams one and two were ~2m wider downstream of the dams, dam three showed the opposite relationship. Site-specific impacts may have been obscured by the stacked nature of the dams. For example, all sites up and downstream of dam three are also downstream of dams one and two and therefore impacted by splashing. Width, depth, wood and sediment are also all susceptible to local factors, including valley confinement, landslides and depth to bedrock, which may have obscured legacy impacts from splashing.

The results of the paired basin analysis for morphological variables show that splashed reaches tend to be narrower than un-splashed at mid sized drainage areas (Figure 5a). This relationship between splashing and channel width is counterintuitive to what would be expected in a system where frequency and magnitude of large flows had been increased. Schmal and Weshe (1989) and Wohl (2000, 2001), for example showed significant widening of the channel in relation to splashing in the Rocky Mountains. However, Napolitano's 1998 study in the Northern California Coast Range showed entrenchment, which is consistent with the lower width/depth ratios in my study area.

Likewise, Miller's 2010 study in the Oregon Coast Range found evidence for a legacy of entrenchment based on larger terrace heights associated with splashed basins. In my study area, the association of splashing with narrower widths decreased as basin area increased (Figure 5a), which would be consistent with the capacity of larger channels to better absorb large flows without being altered.

The narrowing of channels, which is the primary factor driving the lower width-depth ratios, is difficult to explain as a result of splashing. It is possible that downcutting into sediments followed by bank collapse and stabilization by vegetation could lead to channel narrowing. If this were the case, the difference between Coast Range and Rocky Mountain streams could be due to the higher density of vegetation and presence of fine sediment in the Coast Range. The fine sediment allowed for incision, while the dense vegetation may have stabilized the banks preventing excessive widening and the. Alternatively, the difference in width found in this study might be a function of variables not measured in this study such as valley confinement. However, several obvious variables that might control width such as slope and proximity to road were discounted by the multivariate analysis. A more extensive study will be needed to confirm if narrowing and entrenchment in the Coast Range are definitely associated with splashing.

Depths at paired basin areas were comparable and did not show a consistent relationship to splashing (Figure 5b, Table 4). This could indicate that depth of sediment over bedrock was a limiting factor to incision from splashing. During fieldwork high terraces were noted (but not measured) on Camp Creek, indicating that the stream may have cut down through a significant amount of sediment. Similar terraces were not seen on the W.F. Millicoma. It is also possible that error in depth measurements obscured underlying patterns.

While width/depth ratios are generally larger in un-splashed basin areas it is unclear whether this relationship is a legacy of splashing due to uncertainty regarding the cause of differences in channel width. However, width/depth ratios display a similar relationship with basin area as width, indicating that if legacy impacts are present they are most apparent in mid-size basins. This is further supported by the hydraulic analysis (Figure 11), which indicates that dam burst flows exceeded natural flows by a much greater magnitude in smaller basin areas than larger basin areas.

Wood

The amount of large wood showed no correlation with splashed or un-splashed reaches in the paired reach or paired basin analyses. It is notable that large complex log jams exist only in the un-splashed reaches of Camp Creek and the W.F. Millicoma (Figure 6). These data are difficult to interpret in the context of splash dams because logging, stream cleaning, restoration and debris flows all alter the amount and structure of wood in streams. Historically, logging companies cleared logs and debris from streams below splash dams to prevent timber from hanging up on obstructions. Subsequent logging operations dumped slash into streams, blocking fish passage and resulting in a large-scale campaign of 'stream cleaning' by state and federal agencies. Eventually, restoration projects were undertaken to restore in-stream wood. This complicated relationship between humans and in-stream wood over the past century makes it difficult to draw direct correlations between one historic impact and current conditions. Splashing may have reduced the amount of large complex log jams in mid-size basin areas, but the small number of log jams makes this difficult to determine.

Sediment

At individual dams sites there appeared to be a smaller percentage of fines below the dams, but the relationship was inconsistent, indicating that local factors not related to splashing might have generated the variability. Channel bed composition of splashed reaches on Camp Creek was dominated by bedrock, but this changed dramatically in the uppermost un-splashed reach. There were significant deposits of sediment ranging from sands to gravel/cobbles that were anywhere from a 0.05 to .5m deep (Figure 12). This sediment was associated with large log jams, suggesting that both removal of large wood below the dams and the increase in flow caused by the splashing may have depleted the sediment that would otherwise be found in mid sized basin areas in Coast Range streams. The sediment data for the W.F. Millicoma did not display such obvious trends, with many of the un-splashed reaches dominated by bedrock, although large deposits of sands and gravels were once again often associated with large wood. These findings, coupled with the results of the Miller (2010) who found a greater occurrence of bedrock in splashed reaches, show that splashing is a likely contributor to the dominance of bedrock in channels in the Oregon Coast Range that are surrounded by steep, soil-mantled hillslopes.

Figure 12: Photos of sediment in the un-splashed reach of Camp Creek

Hydrology

The dam outburst equation yielded flows many times that of typical natural flows predicted by the NSS model. Prediction error of between 30% and 60% is common in the NSS model with the greatest error occurring when the model is used for streams in the western United States (Cooper, 2005). Both Camp Creek and the W.F. Millicoma are un-gauged systems that are in areas susceptible to local variations in climate and soil that are not well accounted for in the regionalization portion of the NSS model (Cooper, 2005). However, it is important to consider the flows generated by splashing in comparison to natural flows because failure of both natural and constructed dams can cause floods that are unprecedented in the stream system and affect significant change in channel morphology (Costa, 1988). These large flows, over the course of many years, may have exceeded a disturbance threshold that the streams have yet to recover from. This disturbance from splashing was most apparent in mid size basin areas suggesting that the degree to which natural flow was exceeded is correlated to the level of legacy impact found and, potentially, the rate of recovery. Although there is significant error associated with both models it is apparent that splashing generated larger than natural flows at a higher frequency than would occur in a natural system.

Future Research and Management Implications

The W.F. Millicoma and Camp Creek have histories of logging, road building, stream cleaning and small-scale restoration, all of which contributed to the current geomorphic condition of the channels. These impacts occurred on multiple spatial and temporal scales making it extremely difficult to determine a direct causal relationship between a past impact and the current geomorphic condition of the stream channels. In order to fully address the influence of splash dams a more extensive study in more basins would be needed. Future projects should focus on mid-size basins and basin scale data as these were shown to display the strongest relationship to splashing.

The discussion of historic conditions of streams is relevant to our understanding of current conditions. However, reconstructing past environments should not be the goal of modern restoration. Classifying healthy vs. unhealthy ecosystems by our knowledge of historic conditions undermines the inherently dynamic nature of stream systems (Reeves and Duncan 2009). The valuable part of identifying our legacy impacts on streams is separating our perceptions of a healthy stream from the reality of a dynamic stream system.

Conclusion

The era of splashing in the Oregon Coast Range was an economically and culturally important part of Oregon's history. Knowledge of the time of splash dams and log drives has been fading away for over half a century but the evidence of splashing still remains. This study shows that widespread splashing in the Oregon Coast Range from the 1880s to 1957 altered the natural flow regime, may have caused streams to be entrenched, and decreased the amount of small sediment by increasing flows and removing large wood. These legacies represent the lasting impacts of human alterations in streams and inform us that our current actions and management of stream systems have consequences that will long out last this generation.

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