AN ABSTRACT OF THE THESIS OF

Stephanie L. Morét for the degree of Master of Science in Geology presented on November 4, 1997. Title: An Assessment of a Stream Reach Inventory and Channel Stability Evaluation: Predicting and Detecting Flood-Induced Change in Channel Stability.

Redacted for Privacy

Abstract approved: ______________________________
Charles L. Rosenfeld

Pre-flood (1995), and post-flood (1996) channel stability surveys were conducted on 22 reaches along Oak Creek, Benton County, Oregon in an effort to note if the flood of February 1996 altered the channel and if the channel stability survey that was being used accurately predicted the channels resistance to change resulting from a flood. The channel stability survey that was used was the method described in the 'Channel Stability Evaluation and Stream Reach Inventory' designed by the USDA Forest Service, Northern Region, in Colorado (Pfankuch, 1978).

This was a non-parametric study, based on an opportunity to reoccupy survey locations from a previous study. A model was proposed to describe the 1995 ratings as predictions for change should a flood event occur. This predicted change was compared to the actual change that occurred as a result of the 1996 flood in order to test the surveys ability to accurately predict change. Changes in the survey totals, the 15 channel stability

indicator items that compose the survey, and the sediment distribution were evaluated within and between years at the reach, station and stream scale.

An increase in the percentage of fine gravel occurred at all scales when post-flood and pre-flood sediment distribution was compared. Except for an increase in fine gravel, the stream remained similar to its pre-flood state.

In 1995, the stream's channel stability was rated as 'fair', indicating that a moderate amount of change should take place if a flood occurred. The 1995 predictions for change did not match the actual change observed after the February 1996 flood at the three scales when defined by the survey totals. When independently evaluating the fifteen individual channel stability indicator items, a considerable amount of change was detected at the reach level. Although change occurred in the indicator items at each reach, the stream average for each of the independent indicator items was similar between the two years. This may indicate that, although change occurred at the reach level, the stream maintained its physical diversity after the flood.

The survey method was unable to accurately predict changes to Oak Creek incurred by the February 1996 flood when viewed at the entire stream level, yet it may be more applicable at the reach level when viewing specific changes to channel stability indicator items. In general, the Stream Reach Inventory and Channel Stability Evaluation is designed for observational efficiency but does not have sufficient scientific basis or measurement precision to accurately predict the extent or type of channel change.

An Assessment of a Stream Reach Inventory and Channel Stability Evaluation:

Predicting and Detecting Flood-Induced Change in Channel Stability

by

Stephanie L. Morét

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Stephanie L. Morét, Author

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DEDICATION

In memory of

my father, Rick Fliger

who nurtured my passion for rivers and rocks

my grandmother, Estelle Johnson

born Stefania Stefanski, in Warsaw, Poland

my friend, Tracy Tingle, Ph.D.

Director of the Center for Big Science

(currently, Director of the Center for Even Bigger Science),

who pulled me into rivers

and

Amanda Prewitt

for her goodness and her love of geology

AN ASSESSMENT OF A STREAM REACH INVENTORY AND CHANNEL STABILITY EVALUATION: PREDICTING AND DETECTING FLOOD-INDUCED CHANGE IN CHANNEL STABILITY

Chapter 1

INTRODUCTION

"If you would be a real seeker after truth, you must at least once in your life doubt, as far as possible, all things."

-Descartes, Discourse on Method

1.1 The Importance of Channel Stability Studies

Many components of the river landscape are being altered at an alarming rate. Historical land use practices related to agriculture, forestry and urban expansion all contribute to modifying the morphology of the stream channel and cause channel instability. Channel stability is the ability of the channel to adjust to and recover from potential changes in flow or increases in sediment production (Pfankuch, 1978). Channel instability yields massive erosion and destruction of riparian and aquatic habitat. Erosion yields sediment, a non-point source of pollution.

Excess sediment or the wrong size sediment contributes to the decline of salmon by causing bed degradation (e.g. siltation) and decreasing water quality (Williamson et al., 1995). Channel erosion also undermines bridge supports and exposes pipelines or other structures buried within the river bed (Collins and Dunne, 1990). Channel instability results in increasing the intensity and frequency of mass wasting, particularly during floods, resulting in large scale disasters such as those that have repeatedly destroyed many homes and lives in Oregon and California in the past decade.

1.2 The Stream Reach Inventory and Channel Stability Evaluation

One method used to evaluate channel stability is the Stream Reach Inventory and Channel Stability Evaluation (SRICSE) designed by the USDA Forest Service in Colorado (Pfankuch, 1978). This method is used in 60% of our National Forests (Myers and Swanson, 1996).

The purpose of the SRICSE is to "provide information about the capacity of streams to adjust to and recover from potential changes in flow and/or increases in sediment production" (Pfankuch, 1978 p. 1). This information can be used at a 'point' such as a bridge site or it can be used for complete channel analyses for planning and management of watershed activities.

1.3 Research Questions

In the Spring of 1995, 22 reaches on Oak Creek were surveyed for channel stability using the SRICSE method of surveying channel stability (Figure 1). In February 1996, a rain-on-snow event occurred, causing a large flood (estimated to be an 80 year event; personal communication from K. J. Williamson, June 12, 1997) on Oak Creek. The

STREAM REACH INVENTORY AND CHANNEL STABILITY EVALUATION

Stream________________________	Velocity____________mps/fps	Exposed Bedrock__________%	Sml Cobble > 8cm__________%
Date__________________________	Discharge____________cms/fps	Lge Boulders > 1m__________%	Lge Gravel >3cm__________%
Location______________________	Gradient____________%	Sml Boulders >30cm__________%	Fine Gravel >1mm__________%
Width__________________m/ft	Stream Order________	Lge Cobble > 15cm__________%	Sand, Silt, Muck__________%
Depth__________________m/ft	Bed Composition__________________________		

	Item Rated	Excellent		Good		Fair		Poor	
	Upper Bank								
1	Landform Slope	Bank slope gradient <30%	2	Bank slope gradient 30-40%	4	Bank slope gradient 40-60%	6	Bank slope gradient >60%	8
2	Mass Wasting or Failure	No evidence of past or any potential for future mass wasting	3	Infrequent/very small. Mostly healed over, lo future potential	6	Moderate frequency and size. Raw spots eroded at high flow	9	Frequent or large causing sediment yearlong or potential	12
3	Debris Jam Potential	Essentially absent from immediate channel area	2	Present but mostly small twigs and limbs	4	Present, volume and size are both increasing	6	Moderate to heavy amounts, predominantly larger sizes	8
4	Vegetative Bank Potential	>90% plant density Vigor & variety =deep, dense, soil binding root mass	3	70-90% density. Fewer plant spp. lower vigor=<root mass	6	50-70% density. Lower vigor and still fewer species.	9	<50% density plus fewer species & less vigor	12
	Lower Bank								
5	Channel Capacity	Ample for present plus some inc. Peak flows contained. W/D ratio<7	1	Adequate. Overbank flows rare. W/D ratio 8 to 12	2	Barely contains present peaks. Occ overbank flood W/D 15: 25	3	Inadequate. Overbank flows common. W/D ratio > 25	4
6	Bank Rock Content	65% with large, angular boulders 12"+ numerous	2	40 - 65%, mostly small boulders to cobbles 6-12"	4	20 to 40%, with most in the 3-6" diameter class	6	<20% rock fragments of gravel sizes, 1-3" or less	8
7	Obstructions, Flow Deflectors, Sediment Traps	Rocks and old logs firmly embedded. Flow pattern without cutting or dep. Stable pools/riffles	2	Some present, causing erosive cross currents and minor pool filling. new/less firm Obs./Def	4	Moderately frequent, moderately unstable obst's & deflect'rs move w/ high water= bank cut/pool fill	5	Frequent obstr. and deflt'rs cause bank erosion yearlong. Sed. traps full, ch. migration	8
8	Cutting	Little or none evident. Infrequent raw banks less than 6" high	4	Some new increase in bar fm, mostly from large gravel	8	Mod deposition of new gravel & coarse sand on old/new bars	12	Almost continuous cuts, some over 24" hi. Failure/overhangs	16
9	Deposition	Little or no ch/point bar enlargement	4	some new inc./ mostly lg gravel	8	Mod dep'n on old & new bars	12	Lots deps'n. Accelerated bar dev	16
	Channel Bottom								
10	Rock Angularity	Sharp edges/corners, rough surfaces	1	Round edg/cor smooth surfaces	2	Well-rounded in 2-D	3	Well rounded in 3-D	4
11	Consolidation or Particle Packing	Assorted sizes tightly packed and/or overlapping	2	Moderately packed with some overlapping	4	Mostly a loose assortment with no apparent overlap	6	No packing evident. Loose assortment, easily moved.	8
12	Bottom Size Dist & % Stable Mat'l	No change in sizes evident. Stable materials 80-100%	4	Distribution shift slight. Stable materials 50-80%	8	Moderate change in sizes. Stable materials 20-50%	12	Marked distribution change. Stable 0-20%	18
13	Scouring and Deposition	Less than 5% of the bottom affected by scouring and deposition	6	5-30% affect'd. Scour at constrictions & where grades steepen. Some dep'n in pools	12	30-50% affected. Deposits & scour at obstrctins, constrictions, and bends. Some pool filling	18	More than 50% of the bottom in a state of flux or change nearly yearlong	24
14	Microbedforms	Frequent obs clasts, rocks, unfilled accum	4	Frequent obs casts loose rocks. accum not packed	6	Occ. obs clasts, no accum.	8	No obs. clasts on surfaces	10
15	Macrobedforms	Lateral bar/veg point bar w/o chute	2	Transverse longitudinal bar	4	Bank attachment. Diagonal bars	6	Act. point bars with chutes	8
		Rating Totals: Excellent:		Good:		Fair:		Poor:	
		Total Reach Score (Sum of Rating Totals):________							

Figure 1. The Stream Reach Inventory and Channel Stability Evaluation
(modified after Pfankuch, 1978)

stream was resurveyed after the flood to determine if the SRICSE was able to accurately predict the channels resistance to change during a flood.

This provided the opportunity to investigate two related questions: 1) How well does the channel stability evaluation predict the channels resistance to change in a flood? and 2) How much did the flood change the channel? This thesis seeks to answer these questions and in the course of the investigation note what factors are responsible for the observed changes.

1.4 Hypothesis

In order to evaluate how well the Stream Reach Inventory and Channel Stability Evaluation predicts change in the channel, the hypothesis is: The Stream Reach Inventory and Channel Stability Evaluation was unable to accurately predict the channel's adjustment to and recovery from changes in flow and/or increases in sediment delivery.

This hypothesis is contextual and makes no statistical claims. The study is statistically limited because there was no sampling design, of too few sampling points and because analysis of variance is not applicable in a single river, non-random context where the sample points are clustered into 5 groups. 'Change' will be defined by differences in scores between the two survey years and is described in Section 4.4.2. Channel stability will be defined according to the USDA Channel Stability Evaluation methods described in Chapter 4; Methodology.

1.5 Research Structure

The research structure is a case study (1 stream, 1 flood) with an observational design. It is a pilot study in the context that its intent is to assess a survey method for use in a larger project. Channel Stability Surveys were conducted on 22 stream reaches on Oak Creek, Benton County, Oregon (for location, see Figure 2) in Spring 1995. These same reaches were resurveyed in Spring 1996, following a large flood event (it has been suggested (K.J. Williamson, personal communication, 1997) that the flood on Oak Creek in February 1996 was an 80-year event).

The results of these surveys were evaluated at three different spatial scales. The reach scale is the smallest component, representing a short length on the channel exhibiting similar characteristics. The information gleaned at the reach scale is useful for 'on site' applications such as evaluating the placement of a forest road crossing a river. Several reaches in the same region can be used as 'replicates' for gleaning information about change at a larger spatial scale. In the case of this study, these larger regions, composed of 3 to 6 reaches each, are called 'stations'. There are five stations which represent locations in the watershed (Figure 2) and positions on the stream profile (Figure 3). This information is useful for assessing changes in the river relative to the distance from the head. The third scale is the stream scale. All of the data for the reaches are averaged to give information on the stream as a unit. The pre-flood and post-flood surveys were evaluated at these three spatial scales, differences in the data between the two surveys and changes to the stream after the flood were noted, and the results discussed.

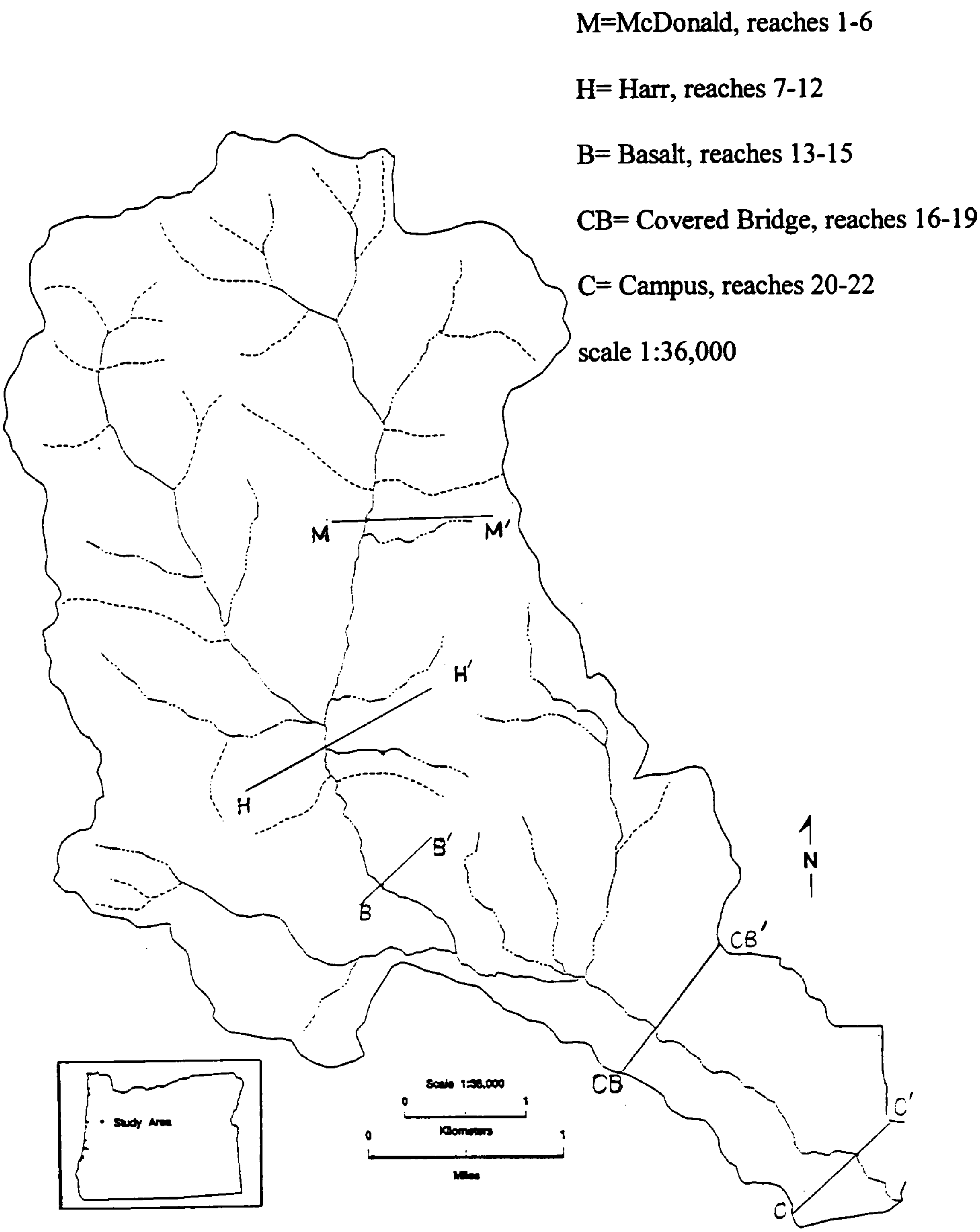
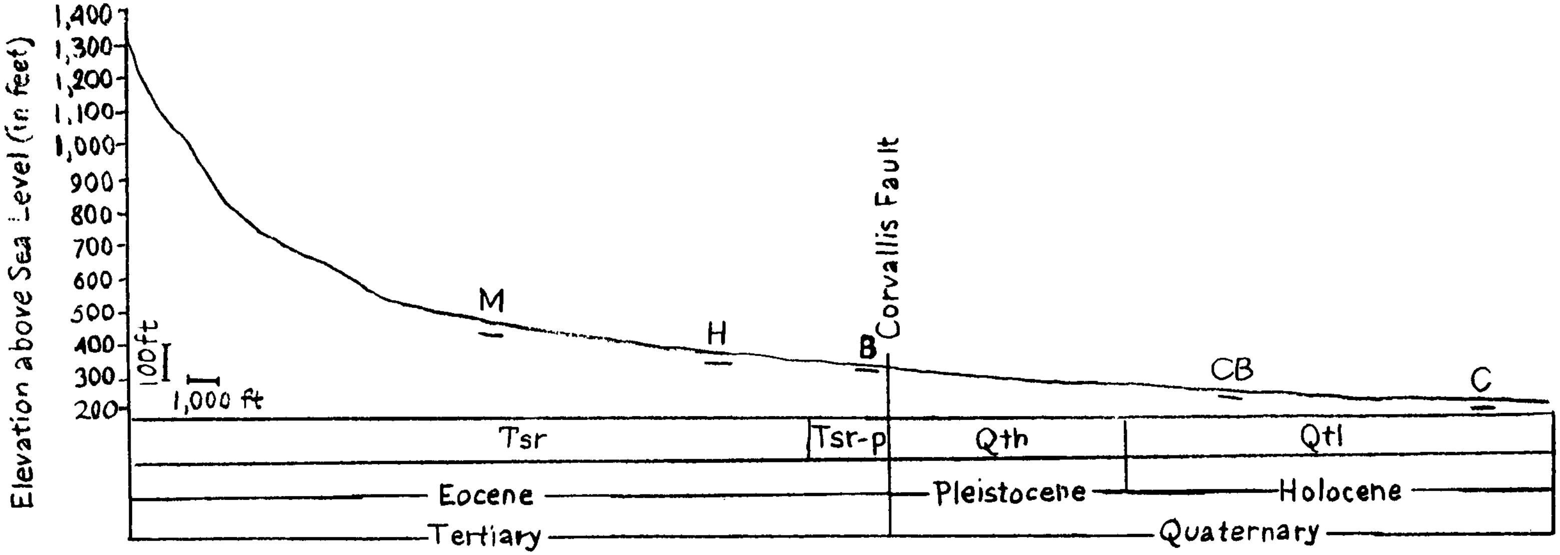


Figure 2. Oak Creek Watershed and Stream Reach Locations
(The mouth of Oak Creek is located approximately 44° 33' 30"lat., 123 ° 16' 30"long.)
(USGS, 1986; G.I.S. Cartography by Buckley, 1994)



Plan Distance from Head of Oak Creek to Mouth

Units: Tsr = Eocene volcanic rock
Tsr-p = Volcanic pediment
Qth = Quaternary higher terrace deposits
Qtl = Quaternary lower terrace deposits
Vertical Exaggeration = 10x

Stations: C = Campus
H = Harr
B = Basalt
CB = Covered Bridge
C = Campus

Figure 3. Longitudinal Profile of Oak Creek
(source: USGS, 1986)

As noted previously, the surveys in 1995 did not have a sampling design as they were conducted for another purpose. The result of this is that statistical inferences and the conclusions that can be drawn from this thesis are statistically limited. Other assessments, such as trends and descriptions of changes, however, can provide useful information for understanding more about using this method of surveying on this channel and how a flood influences the survey. It is a rare opportunity to have a large flood event occur so soon after using a survey which predicts how a flood might affect the channel stability of a stream.

Chapter 2

THE STUDY SITE AND FLOOD SETTING

"Now Suzanne takes your hand
And she leads you to the river"
-Leonard Cohen, Suzanne

2.1 Location and Descriptions of Research Area

2.1.1 Location of Oak Creek

Oak Creek is located in Benton County, Oregon, U.S.A., approximately 35 miles east of the Pacific Ocean. Oak Creek is a SSE trending watershed which begins in the east-central Coast Range and drains southeasterly into the west side of the Willamette Valley. The watershed is approximately 12.64 square miles, and it empties into the Marys River, shortly before the Mary's River joins the Willamette River. The head of the creek is in the McDonald Forest and the mouth of the creek is in Corvallis, Oregon. A map of the location of the research area within the state of Oregon and the Oak Creek Watershed is displayed in Figure 2.

2.1.2 The Five Research Areas and The Stream Reaches Inventoried

Five separate areas on Oak Creek were selected during a class project in 1995 (Moret, Jacek, and Allen, 1995) based on a) their location along the stream profile, b) their land use and c) their accessibility. The five areas, referred to as stations, are called in order from upstream to downstream, McDonald (M), Harr (H), Basalt (B), Covered Bridge (CB) and Campus (C). Their locations are noted in Figure 2.

REACH	STATION	RIVER MILE from river head	LAND USE	GEOLOGY
1M	McDonald	2.15	Forested	Volcanic Tsr
2M	McDonald	2.17	Forested	Volcanic Tsr
3M	McDonald	2.20	Forested	Volcanic Tsr
4M	McDonald	2.23	Forested	Volcanic Tsr
5M	McDonald	2.25	Forested	Volcanic Tsr
6M	McDonald	2.27	Forested	Volcanic Tsr
7H	Harr	3.20	Agricultural	Volcanic Tsr
8H	Harr	3.26	Agricultural	Volcanic Tsr
9H	Harr	3.32	Agricultural	Volcanic Tsr
10H	Harr	3.37	Rural-urban	Volcanic Tsr
11H	Harr	3.40	Rural-urban	Volcanic Tsr
12H	Harr	3.43	Rural-urban	Volcanic Tsr
13B	Basalt	4.04	Rural-urban	Volcanic Tsr-p
14B	Basalt	4.08	Rural-urban	Volcanic Tsr-p
15B	Basalt	5.14	Rural-urban	Volcanic Tsr-p
16CB	Covered Bridge	5.80	Agricultural	L. Terrace Dep Qtl
17CB	Covered Bridge	5.84	Agricultural	L. Terrace Dep Qtl
18CB	Covered Bridge	5.89	Agricultural	L. Terrace Dep Qtl
19CB	Covered Bridge	5.93	Agricultural	L. Terrace Dep Qtl
20C	Campus	7.08	Urban	L. Terrace Dep Qtl
21C	Campus	7.14	Urban	L. Terrace Dep Qtl
22C	Campus	7.20	Urban	L. Terrace Dep Qtl

Table 1. Stream Reaches with Associated Station, River Mile, Land Use and Surficial Geology

These five stations were then divided into reaches. There are a different number of reaches in each station (no statistical design) and some reach lengths were dictated by the homogeneity of the reach and others by lengths (which differ). For example, a long stretch of pool and riffles would constitute a single reach; the next reach might be a single stretch of slow moving water, unbroken by pools and riffles. Each reach is numbered in order from upstream to downstream and is followed by the letter representing the station where the reach was located (Table 1). For example, 1M represents the reach that is most upstream and is located in the McDonald Forest Station, 20C is the 20^{th} reach downstream, and it is located in the Campus Station.

2.1.3 Station Descriptions

The reaches were grouped into stations that were spaced at various locations along the stream (Figures 2, Table 1). The stream is approximately 7.3 miles long. The station descriptions are arranged from the top of the watershed to the mouth:

McDonald (M): The highest station in the watershed, closest to the head of the stream (river mile zero), is the McDonald Station which stretches from river mile 2.15 to river mile 2.27 and contains the first six reaches. The McDonald Station is in the McDonald-Dunn Forest which is carefully managed and researched by Oregon State University (OSU). It is located at about the one quarter point on the longitudinal profile. The station is similar to what one would expect in a mountain stream. It has a narrow valley floor and its sinuosity is relatively constrained. Oak Creek is connected to its floodplain in most areas in the McDonald Station. There appears to be a diversity of pools, riffles and bars and areas with large wood and without. The riparian tree population is primarily alder, indicating previous disturbance. Blackberry, salmonberry and poison oak were noted. Upland vegetation is primarily Douglas fir. Cut banks in the area have exposed layers of rocks from former channel beds, indicating that the channel has migrated in the past.

Harr (H): The next station downstream in the profile is the Harr Station which is located from river mile 3.20 to river mile 3.43. This station is located in the second quarter of the profile on a slope that is steadily dropping into the valley. The Harr Station contains reaches 7 through 12 and is divided by a road culvert between stations 9 and 10. This station is entrenched relative to its original floodplain, but has a fairly well developed bar system. Pools and riffles are found along the station. In some areas, the stream connects with its floodplain and, in others, the banks are nearly vertical. Woody debris is a common sight. Alder, salmonberry, poison oak and blackberry are included in the riparian vegetation.

Basalt (B): Below the Harr Station is the Basalt Station which is positioned approximately half way through the profile. The Basalt Station contains reaches 13, 14 and 15 and lies between 4.04 and 5.14 miles from the head of the stream on a slope similar to the Harr Station. This deeply entrenched station has nearly vertical ivy-covered banks with conifers and blackberries on the left bank and hedges at the top of the other bank. The reach is relatively straight compared to the McDonald and Harr Stations. There are no notable pools or riffles in this region; it appears to be one very long pool. There was relatively little wood in this station. The reaches were determined by length. The Corvallis Fault creates a basalt knickpoint immediately downstream from the station, giving the station its name.

Covered Bridge (CB): As the stream begins to level out into the Willamette Valley, the Covered Bridge Station is situated at about three quarters of the way down the profile. The Covered Bridge Station includes river miles 5.8 to 5.93 and contains reaches 16 through 19. It is a fairly complex station containing vegetated mid-channel bars and point-bars and has a well developed floodplain below its original floodplain. Overstory vegetation is primarily alder. Trails line the river right bank and a culverted road designed to be overwashed lies immediately downstream of Covered Bridge Reach 19.

Campus (C): The last station on Oak Creek before it joins the Marys River is the Campus Station which is at river mile 7.08 to 7.20. Reaches 20, 21 and 22 occupy this station. The stream gradient is relatively flat at this point as it nears its terminus a tenth of a mile downstream. The banks are nearly vertical and the channel bottom is made up of fine sediment and bedrock. An occasional bar is stabilized by human debris, such as an old washing machine.

2.1.4 Land Use on Stream Reaches

The land use categories are Forest, Agriculture, Rural-Urban and Urban. These land uses were determined by first looking on a land use map and then driving around the region to personally review the land use. The land use categories descriptions are:

Forest (F): Forested land use category represents forested areas which comprise the upper half of the watershed. All of the reaches in the McDonald Station are Forested. The conifer forest is mixed and the primary species are Douglas Fir, Western Hemlock, and Western Red Cedar. Oregon State University manages much of the forest in this region and, while it has been logged historically, there has been little logging recently. Logging, and logging roads, are widely known for their association with mass wasting events and causing sedimentation in the streams. Splash damming, a historical practice related to logging, scours the stream bed causing stream incision.

Agriculture (Ag): The agricultural areas are typically livestock pasture or arable land being used for growing crops. Harr Reaches 7, 8 and 9 are adjacent to the OSU Sheep Farm and all of the Covered Bridge border the OSU Agricultural Research Farms. Agricultural land often exists on former wetlands that have been drained for the purpose of agriculture, thus restricting the channels lateral movement.

Rural-Urban (R-U): Rural-urban areas are those areas that have rural residential development. Often one house sits on at least one-half acre of land and the owners may have horses or large gardens. Such houses are found along reaches 10, 11 and 12 of the Harr Station and along the entire Basalt Station. Rural-urban landowners often modify the stream landscape by landscaping the riparian zone, altering the drainage with land fill and water diversions, and removing natural large woody debris from the banks and stream. Constraining the lateral movement of the stream and removing the woody debris that traps sediment and diverts flow, both contribute to channelizing the stream. The basalt station, reaches 13 through 15, is completely landscaped on both sides of the Oak Creek and there is a concrete walkway along the top of the river right bank on Reach 13 at the basalt station and water drainage pipes draining directly into the stream. Some of the landscaping, such as ivy, appear to be stabilizing the steep channel banks.

Urban (U): As Oak Creek drops into the Willamette Valley, it passes through Corvallis near the streams confluence with the Marys River. This area has urban land use and covers reaches 20, 21 and 22 and river mile 7.08 through 7.20 (Campus Station). These reaches are deeply entrenched and have pavement at the top of the banks on both sides and multiple family housing on the river right bank. The restriction of lateral movement has contributed to the incision in the stream. The stream appears to be disconnected from its floodplain, but during the flood, one back patio area of a housing unit built against the stream was covered with water. The channel bottom has a lot of exposed bedrock and urban debris such as pieces of metal, concrete, bricks, porcelain, many sizes of appliances and many mystery items. There is relatively little wood (unless it is an abandoned human structure) in the channel despite the oak trees on the upper bank region.

2.1.5 Geology on Stream Reaches

The surficial geologic units under the main stem of Oak Creek are Tertiary Siletz River volcanics (Tsr), Tertiary Siletz River volcanics covered by a thin pediment of alluvium and colluvium (Tsr-p), and Quaternary lower terrace deposits of alluvium (Qtl) (Bela, 1979). Each of these units are described in Section 2.3.2. As a rule, the basalt unit (Tsr) should be more resistant than the weathered basalt pediment (Tsr-p) which is more resistant than the alluvium (Qtl). Generally, more resistant rock units, such as basalt, are found in the uplands where they constrain the stream with their resistant valley walls. Alluvium is reworked stream deposits in this area and is much less consolidated and less resistant to the forces of the stream. Alluvium is often associated with a broad floodplain.

One half of all of the reaches sit upon Tsr, a basalt unit. These reaches, 1 through 12, comprise the McDonald and Harr Stations. Tsr-p is the unit found in reaches 13, 14 and 15, all of which fall in the Basalt Station. The remaining 7 reaches, 16 through 22, all lie within the Quaternary lower terrace deposits of alluvium. This area covers both the Covered Bridge and the Campus stations.

2.2 History of Oak Creek

2.2.1 Cultural History

Before the 1840's, the main anthropomorphic impacts on Oak Creek were fires set by the Calapooi (Kalapuyah) Indians to create a prairie-savanna habitat used to concentrate game (Towle, 1982; Yamaguchi, 1992). Original cadastral survey notes from the 1850's describe the Willamette Valley vegetation as prairie and open woodland with oak and fir in the foothills. The Coast Range was composed of dense forests of Douglas fir, maple, cedar, and hemlock. Along the creeks were "...gallery forests, or wooded strips of varying width and continuity" (Yamaguchi, 1992).

Explorers and fur trappers were the first Europeans to come to the Willamette Valley during the 1810's and 1820's when "fur brigades" of the Hudson's Bay Company arrived (Yamaguchi, 1992). Settlers first appeared in the north Willamette Valley in the 1830's. Corvallis (originally Marysville) was first settled by Joseph Conant Avery in 1845 (Read, 1984-1986). The pioneering era in the Corvallis area lasted from approximately 1846 to 1860 following the establishment in 1846 of the Applegate Trail which split near Corvallis and had two spurs going through the Soap Creek and Fairmount Precincts.

Historical records show that most early settlement occurred in the Soap Creek basin. There is little mention of activity in the Oak Creek basin until the Oak Creek School was opened in 1860 (Read, 1984 to 1986). Early settlers avoided settling on low, swampy floodplains due to fears of flood and disease which may explain why records show the first settlements on Oak Creek (1845 - 1885) to have been near the McDonald Forest, away from the heavily braided lower creek system. Settlement was expanded by the passage of the Oregon Donation Land Act in 1850 which allowed U.S. citizens who had lived and worked on a given piece of land for four consecutive years to receive 320 to 640 acres of land depending on marital status (Read, 1984-1986).

Grazing was the first form of agriculture to dominate the Corvallis area due to the lack of available farming supplies and equipment (Read, 1984 to 1986). The advent of both steamboat traffic on the Willamette River in 1853 and the market provided by the California Gold Rush encouraged settlers to switch to wheat farming as their main agricultural product. Today, agricultural land along Oak Creek, with the exception of the Oregon State University dairy farm, is largely used for non-irrigated pasture and hay. Much of the agricultural land today sits on drained wetlands. The effects of over 100 years of agriculture in this area include filling of side channels, rip-rapping, removing gallery forest, and channelizing tributaries.

Commercial logging initially occurred in the Oak Creek basin from the 1880's to the 1930's, with the busiest period occurring during the 1900's (Yamaguchi, 1992). Impacts to the creek during this period include road building within the historic floodplain, splash damming, removal of riparian vegetation and large organic debris, increased landslide activity, and water removal for powering small sawmills. A flume was constructed sometime after 1915 to divert water from the west fork of Oak Creek to the current Brand S Plywood Mill on Reservoir Road (Yamaguchi, 1992). Timber harvest levels declined in the Oak Creek headwaters following the establishment of the McDonald Forest in 1930.

Historical channel stabilization efforts can be noted in all of the research stations. At the McDonald Station, rip-rap has been placed at the top of Reach 5M to stabilize the bank from road encroachment. Between Harr reaches 9H and 10H, rip-rap is used to stabilize the culvert. The Basalt station has rip-rap at the outlet of the culvert above 13B and stabilizing ivy is planted all along the south banks (right bank, looking downstream) and part of the north banks of reaches 13B and 14B. The top of the upper bank (former floodplain) also has bushes and a concrete walkway on the river right bank of reaches 13B and 14B. The Covered Bridge station has rip-rap at various locations in reaches 16CB and 17CB and below 19CB, rip-rap is used to stabilize a culverted river crossing. At the Campus station, concrete is the primary lateral stabilization technique, where both sides of the former floodplain are covered in concrete, and both concrete and buildings are on the river right banks. On the channel bottom, large appliances and furniture such as abandoned washers and bed frames help to stabilize channel bars. Some rip-rap is also present along all of the reaches in this station.

There are other land use effects on Oak Creek in addition to the rip-rap, planted vegetation, and concrete used to stabilize the stream. Existing impacts to the creek include sedimentation from forest roads, sedimentation from periodic slope failures in ephemeral draws, historical decline in the beaver population, removal of woody debris from the stream, drainage and constraint, culverts, and some degree of impact from recreational use (i.e. trails, cut banks). There is evidence that the river has dropped relative to its former position. Remnant side channels are higher than 1m above the current bank full height.

2.2.2 Aerial Photographic History

A review of long-term changes in riparian areas was conducted by Rogers for a watershed analysis performed on Oak Creek in 1994 (Augerot et al., 1994). Natural color photographs at 1:24,000 scale flown in 1993 were purchased from Western Aerial Contractors of Eugene, Oregon. For the historical assessment, copies of black and white photographs from 1944, at a scale of ~1:15,000 were used. An additional collection of black and white photographs from 1936, housed in the map library at Oregon State University, was also used.

I also reviewed these large scale (~1:10,000), large format photos. They showed many details in the lower half of the drainage. Coverage was not available for the upper half of the watershed. The lower portion of the Oak Creek watershed, dominated by agricultural and residential land uses, has had the most notable changes over the years. The most notable change in aerial photos has been simplification and incision of the channel. For example, the lower portion of the watershed was braided in 1936 and is a single sinuous channel today (Figure 4). Field reconnaissance conducted in this region lends further evidence of former braids; blackberries thrive in the former channels.

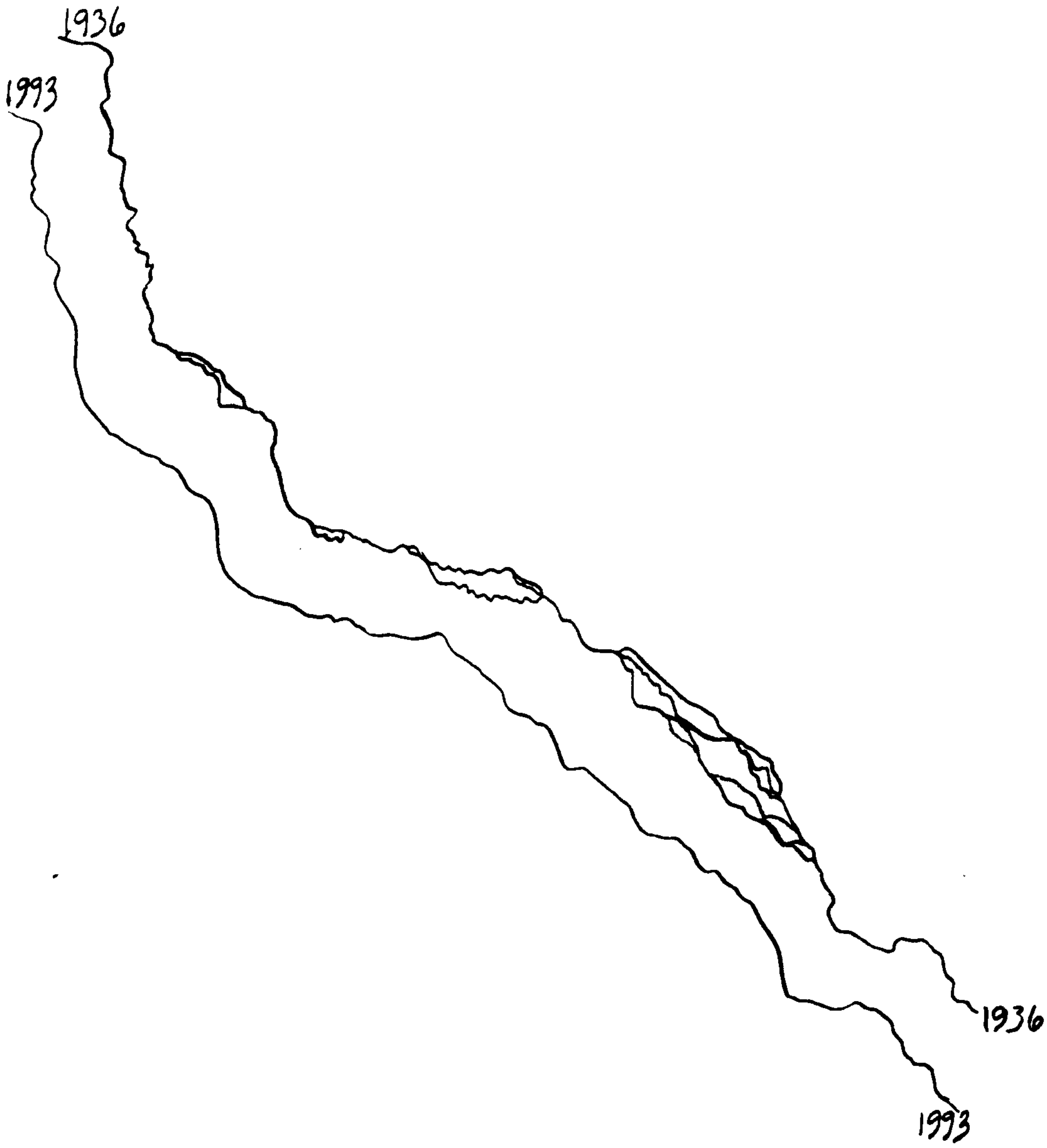


Figure 4. Oak Creek: Lower Mainstem: Channel Comparison, 1936 and 1993 (modified from Augerot et al., 1994)

2.3 Geologic Setting

2.3.1 Regional Geologic History

The Coast Range, Willamette Valley and Cascades of West Central Oregon are associated with the subduction of the Farallon and Juan de Fuca Plates beneath North America. Volcanics of the Cascade mountains form where the leading edge of the subducting plate is hot enough to release fluids. Where the plate is shallow and cold, sediments and crust are scraped off and piled up, forming the Coast Range. Two parallel mountain ranges are thus formed: the Coast Range is underlain by an accretionary wedge and the volcanic Cascades are a magmatic arc. The depression in between is the Willamette Valley forearc basin.

The principal bed rock units found in the Oak Creek area is basalt of the Siletz River Volcanics. This volcanic material formed as pillow basalts at a mid-ocean ridge during the Lower Eocene epoch, about 50-60 million years ago (Ma), and it traveled upon the oceanic plate (Farallon) until the plate descended beneath the continental crust of the North American plate during the early Eocene about 50 Ma. Some of the pillow basalt on the subducting slab was scraped off onto the continental margin and was accreted onto the western margin of North America. The spreading ridge that developed the Siletz River Volcanic basalts on the oceanic plate also developed volcanic island archipelagos. These 'seamounts' were too big to be scraped off or subducted and they joined the North American landmass by colliding with the continental margin toward the end of the early Eocene. In all, a 50 to 100 mile width of landmass was added to the continental margin;

these oceanic basalts form the backbone of the present day Oregon and Washington Coast Range system (Duncan and Kulm, 1989).

During the middle to late Eocene, the Juan de Fuca plate began subducting beneath the continental margin. The accreted material that is the present day Coast Range was, at that time, a forearc basin. The sedimentary rocks that comprise the Tyee, Spencer, and Flournoy Formations were deposited on the Siletz River Volcanics (McWilliams, 1973; Orr, Orr and Baldwin, 1992) adding more material to the continental margin. During the latter part of the Miocene (and continuing today), the material that is presently the Coast Range began to uplift.

During uplift, the Coast Range has developed a series of synclines and anticlines paralleling the Pacific Coast. The uplift and folding is accompanied by a series of fractures and faults caused by crustal extension and compression. Most of the faults are nearly vertical and dip to the west or east (Orr, Orr and Baldwin, 1992). The most notable fault in the study region is the Corvallis fault (Figure 5) which strikes northeast and defines the boundary between the Willamette Valley and the Coast Range in the study area. This fault is about 50 kilometers long and has been recently been interpreted as "a low-angle thrust, with the early Eocene Siletz River Volcanics thrust southeastward over late Eocene Tyee and Spencer sandstones" (Goldfinger, 1991). Prior to that, it was interpreted as a high angle reverse fault that dipped to the northwest (Allison, 1953; Vokes et. al., 1954) The fault was most active during the late Eocene, and there was probably some minor intermittent activity in the late Quaternary (Goldfinger, 1991). The Corvallis fault cuts across Oak Creek about 100 feet downstream from the Basalt station (Reach B15) creating a slight (about 2 foot) knickpoint. This is the location, not coincidentally, where

[hatched box]	= Mass Movement	Tsr	= Siletz River Volcanics
• • •	= Concealed Fault	Tsr-p	= Siletz River Volcanics Pediment
▬ ▬	= Inferred Fault	Tf	= Middle Eocene Sandstone
——	= Approximate Contact	Qtl	=Quaternary Lower Terrace Deposits

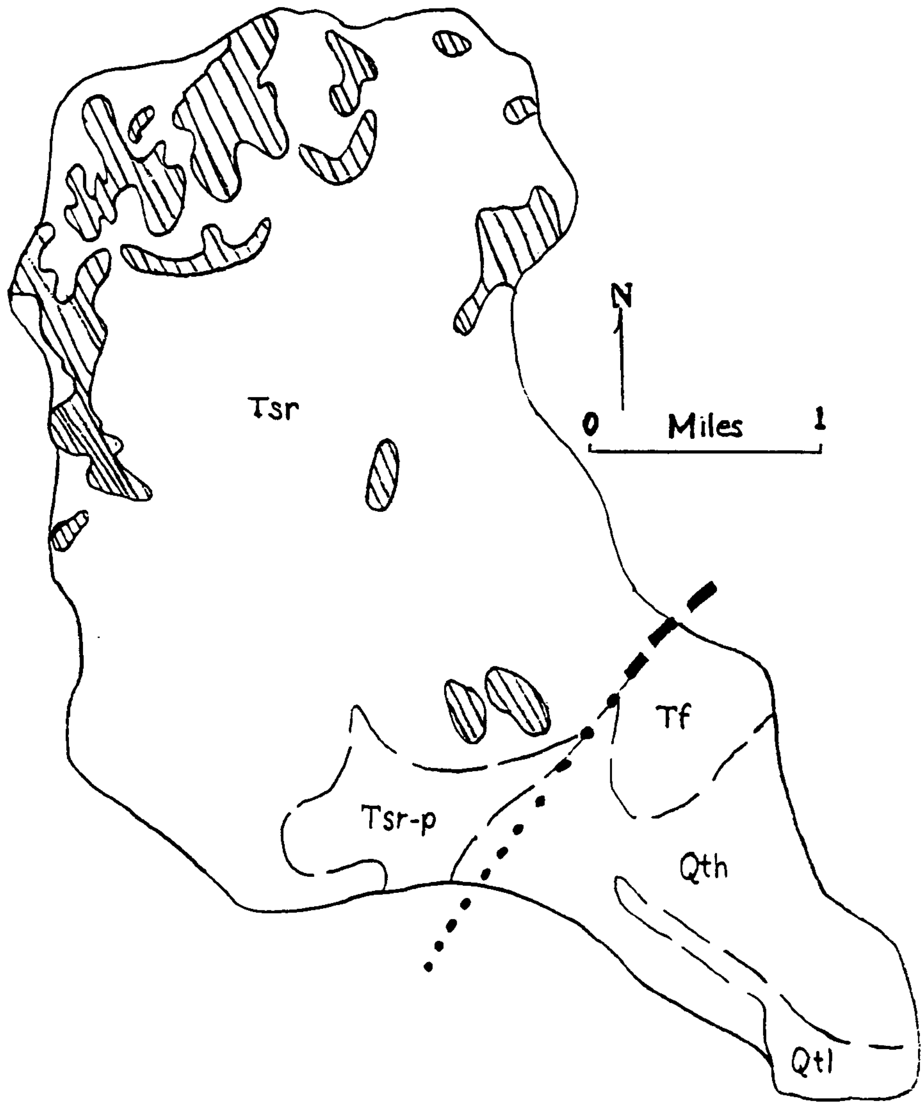


Figure 5. Geology and Geologic Hazards Map of the Oak Creek Region
(The mouth of Oak Creek is located approximately 44° 33' 30"lat., 123 ° 16' 30"long.)
(modified from Bela, 1979)

the Siletz River Volcanics contacts the Quaternary alluvium. In other places within the watershed, the volcanics are nonconformably overlain by Tertiary turbidite sandstones of the Tyee (middle Eocene) and Spencer (late Eocene) Formations.

The Siletz River Volcanic Series are an accumulation of basaltic pillow lavas and breccias with interbedded marine tuffaceous sedimentary rocks (Snavely, Wagner and MacLeod, 1965). These fractured pillow basalts have been uplifted and exposed to a humid, temperate climate and abundant vegetation. Because of this, the exposed Siletz River Volcanics are highly weathered and prone to clay in thick weathered zones on lower hillslopes.

Basalt is fine-grained and contains various percentages of the minerals pyroxene (augite), calcium plagioclase, olivine, and glass. Secondary minerals include magnetite, hematite, ilmenite, and quartz (Prinz, Harlow and Mottana, 1978), although magnetite and ilmentite can be primary minerals as well. Mafic minerals weather and break down to form smectitic clays. Much of the channel bottom and bank material on Oak Creek includes clays and insoluble iron oxides (hematite, goethite, limonite) derived from the Siletz River Volcanics.

The Corvallis Fault separates the Siletz River Volcanics from the younger sediments of the Willamette Valley (Figure 5). During the late Eocene through Oligocene, the Willamette Valley was a shallow water, broad, continental ocean shelf overlying a foundation of accreted Siletz River volcanics. During the Eocene, the Tyee and Spencer formations were deposited in the Corvallis area; these gently dipping strata form the rolling, hills near Corvallis (Lovell, 1969; Orr, Orr and Baldwin, 1992).

Large scale Pleistocene floods from Lake Missoula, Montana scoured out the Columbia River Gorge and backed up into the Willamette Valley, leaving boulders and temporary lakes. During the Pleistocene and Holocene, alluvium from glacial events in the High Cascades was deposited as fans in the eastern Willamette Valley (Howell, 1968). The Willamette River has reworked this glacial alluvium, the lacustrine deposits (blue diatom rich clays) and the fluvial alluvium from the Coast Range (Graven, 1991).

2.3.2 Location and Description of Rock Units in the Oak Creek Watershed

The Oak Creek watershed is primarily composed of Eocene basalt and Willamette River terrace deposits (presumably of glacio-fluvial origin) from the Pleistocene and Holocene (Figure 5). The basalts (Tsr & Tsr-p) comprise the upper half of the watershed, and the stream terrace deposits (Qth & Qtl) make up the lower half of the Oak Creek Watershed Profile. The river sediment within the basalt region is primarily basalt with an occasional zeolite cobble. Below the inactive Corvallis fault zone, Oak Creek flows through the less resistant river deposits and some tributaries drain material from Tertiary sedimentary deposits into the mainstem of Oak Creek.

Except where the channel hits bedrock, the channel bottom is dominated by rounded to sub-angular gravel beds with some cobble and sand, silt and clay that are of varying bed thickness. The stream banks contain layers of gravel, with varying degree of particle angularity, at different bank heights, suggesting a pattern of channel migration and gravel bar formation alternating with burial by fine sediments.

The descriptions of the following lithologic units (Figure 5) are from the Department of Geology and Mineral Industries-State of Oregon map showing geology and geologic hazards of Eastern Benton County Oregon, 1979 (Bela, 1979):

Tsr: Eocene volcanic rock: Siletz River Volcanics; 3,000 to 9,000 feet of marine deposited dark greenish-gray to black, vesicular to amygdaloidal pillow lava and basalt flows, with minor interbedded and overlying tufaceous claystone, siltstone, and basaltic sandstone; flow breccia and coarse pyroclastics rare; often 20-50 feet deep-weathered zones light rusty-brown silt and clay soils (1-4 ft thick; with shrink/swell cracks). Hazards include local mass movement in colluvium on steep slopes. Perched water zones related to fracture, adequate for domestic use.

Tsr-p: Volcanic pediment: Gently inclined, planar erosion surface cut into Tsr and generally veneered with thin deposits of unconsolidated material in transport; shallow, intermittent drainages; dark-brown to reddish-brown silt and clay soil 1-10 feet thick with shrink/swell cracks; creep processes active on slopes and near drainages; incised streams flow on bed rock; limited mass movement near breaks in slope.

Qth: Quaternary higher terrace deposits: Semiconsolidated gravel, sand, silt, and clay of variable thickness (10-200 feet) on higher terraces near foothills; surficial material generally 10-30 feet light-brown silty clay and fine sand; transitional with pediments and thinner near bedrock foothills (several tens of ft or less);100 ft at OSU; small to moderate ground water yields, limited by storage where thin over bedrock; poorly to well drained silt-loam soils.

Qtl: Quaternary lower terrace deposits: Semiconsolidated cobbles, gravel, sand, silt, clay, and organic matter of variable thickness on lowland terraces and along usually entrenched tributary rivers and streams; surficial material generally 10-30 ft light-brown silty clay and fine sand; characterized by low, undulating, fluvial surface with meander scrolls and oxbow lakes; subject to major and local flooding, ponding and high ground water; moderate to good ground water potential if deposits are thick and interbedded sand and gravel occur beneath water table; poorly to well-drained silt and clay soils.

2.3.3 Geologic Hazards

Although the Corvallis fault crosses Oak Creek 100 feet downstream from Reach B15 (Figure 5), the fault is presently inactive. The fault was active during the late Eocene, and may have had minor intermittent activity in the late Quaternary (Goldfinger, 1991). As indicated on the geology and geologic hazards map (Figure 5), mass wasting composes the majority of the geologic hazards in this region. Mass wasting produces sediment which, if deliverable to the river, may notably impact channel stability. The map explanation in Bulletin 98- Geologic Hazards of Eastern Benton County, Oregon, (Bela, 1979) describes 2 types of geologic hazards associated with mass movement as follows:

> Mass Movement: Earthflow and slump topography are shown for areas greater than 5 - 10 acres. These areas represent moderately sloping terrain with irregularities of slope, drainage, or soil distribution. They are detected in aerial photographs and supplemented by field checks, where recent movement is recognized by tension cracks, headwall scarps, hummocky terrain, bowed trees, and/or active soil creep. Mass movement is widespread in Tsr volcanic units; particularly in areas of stream-bank erosion or active headward erosion in hillside drainages. Among possible hazards are continued movements, low cutbank stability, and poor and irregular drainage. Where features are unmapable due to dense forest cover or photo scale, slide regions may go undetected.
>
> Steep-slope mass movement: General areas of high slide potential were identified primarily by whether the average regional slope is greater than 50%. These areas are subject to localized rockfall, rockslide, debris avalanche, debris flow, earthflow, and slump and may include a few areas of deep failure involving bed rock in addition to soil and regolith. Steep slope mass movement is widespread in steeply sloping Tsr terrain. Specific occurrences are controlled by faults, joints, contacts with intrusive rocks, soil water, soil thickness, vegetative cover, and land use. Thick accumulations of colluvium often occur at or near the bases of steep slopes.

Much of the mass wasting in the forested regions of this watershed goes undetected due to canopy cover. The majority of these small events are debris flows and debris avalanches which start as rotational slumps (Shively, 1989). Although forest practices in this watershed have contributed to mass wasting, the current vegetation is much more coniferous since the advent of white settlers, and this vegetation, brought about by fire suppression, helps to stabilize the slopes.

Sediment from mass wasting adds to the diversity of the river landscape. Deliverable sediment from mass wasting can adversely affect channel stability if it occurs, *en masse*, as a debris flow or sediment pulse (e.g. post-logging). However, mass wasting is also a natural part of the watershed, supplying sediment for transient storage which helps stabilize the channel and creates habitat diversity.

2.4 Geomorphic Setting

2.4.1 Altitude and Relief

Oak Creek watershed has a 1,940 feet of relief within its 12.64 square mile area. Its highest point is McCulloch Peak at 2,155 feet above sea level. The mouth of the stream is at 215 feet elevation where it joins the Marys River in Corvallis, Oregon. The total relief of the Oak Creek Watershed is 1,940 feet.

2.4.2 Longitudinal Profile

The longitudinal stream profile of Oak Creek depicts a stream that has reached relative equilibrium in terms of sediment erosion, delivery and deposition, in relation to climate and lithology, on a large temporal (10^3 to 10^4 years) and spatial (watershed) scale. As displayed by the Oak Creek stream profile (Figure 3), an equilibrium profile is "concave upward with a short, steep gradient near the head of the watershed, an intermediate length and slope reach in the middle, and a long, shallow gradient channel in the lower reach" (Mount, 1995).

As expected, the more resistant rocks dominate the higher elevations and less resistant material is found in the lowlands. Where Oak Creek intercepts the Marys River, the gradient is very low, indicating the erosional base level for the Oak Creek watershed. The two shallow knickpoints that show up in the forested basalt region may be explained by recent uplift in the Coast Ranges, adjustment for mass wasting events or by photosurvey techniques being impaired by the large vegetation and/or clearcuts. Because the profile represents a river close to equilibrium, the expectation based on the 'change model' (Figure 11) infers that the channel stability should be 'excellent', yet it is rated as 'fair' in both the 1995 and 1996 channel stability evaluation surveys. The channel instability observed is probably indicative of smaller spatial and temporal scale phenomena, which may have more pronounced effects on the channel planform depending on the causal mechanism.

2.4.3 Planform

The stations (McDonald, Harr and Basalt) that are in the basalt units, Tsr and Tsr-p, are characterized by steep valley wall slopes. Generally, in basaltic, upland watersheds the river morphology is controlled by incision into the bedrock. In such a case, the resistant walls would restrict the river to a single channel. As the gradient decreases (see Figure 3) and discharge increases due to tributary input, the river has more energy to expend. Marie Morisawa (1968 p. 35-37) describes energy in a river as follows:

> Two primary types of energy occur on a river, potential energy and kinetic energy. Potential energy is expressed by multiplying the weight (W)of the water times the head (z) which is the difference in elevation between the points that the energy is being measured ($E_p = Wz$). Kinetic energy equals half of the mass of the water, times the square of the velocity at which the water is moving ($E_k = MV^2/2$). Total energy ($E_p + E_k$) is influenced primarily by velocity, which in term is a function of the gradient of the stream, the volume of the flowing water, the viscosity of the water and the characteristics of the channel cross section and bed. Two equations have attempted to describe velocity in a river, the Chézy formula and the Manning formula.
>
> The Chézy formula is expressed as $V = C\sqrt{RS}$, where R is hydraulic radius (the area divided by the wetted perimeter), S is slope and C is a constant which depends upon gravity and other factors contributing to the friction force, which in turn depends upon roughness and channel straightness and channel cross-section. The Manning Formula, $V = 1.49R^{2/3}S^{1/2}$, is an attempt to refine the Chézy formula in terms of the constant C.
>
> Energy in a river typically dissipates by heat (caused by friction from turbulence), transportation, and from eroding sediment from the river banks and beds which generally results in meandering.

Meandering would be expected to occur at the Harr and Basalt stations because the valley floor constraints have lessened and the gradient has decreased. However, these stations appear relatively confined and channelized.

When the Corvallis Fault Zone is crossed, Oak Creek flows through the lowland, Quaternary stream terrace deposits. The erodible banks, further gradient decrease, and discharge increase from tributaries should cause the river to meander or braid. This expected scenario is noted to a slight extent at the Covered Bridge station and not at all at the Campus station, which are dominated by agricultural and urban use, respectively. It is likely that land use is responsible for simplifying the channel. The stream does not meander or braid in 1993 as much as it did it 1936 (see Figure 4) and incision through natural banks, bed rock, and man-made fill is found throughout the lower stream system.

While local geology, climate and hydrology are commonly thought of as the dominant fluvial response variables affecting the channel pattern in regions with little human influence, the channel pattern in Oak Creek may be primarily influenced by other factors relating to land use. Although abandoned channels from the former braided Oak Creek are apparent in many areas along the creek, the channel has been constrained by land use, including draining wetlands and rip-rapping for agricultural and urban land use. Presently, Oak Creek is expending energy by incising down into the channel instead of meandering or braiding. This entrenchment is aggravated by the removal of woody debris and beaver dams in the stream which both hold sediment in transient storage. The historical and present removal of large wood and dams contribute to the entrenchment and simplification of the stream resulting in a lower sinuosity.

Sinuosity (S) is defined as channel length/straight line valley length. Because the stream reaches are short relative to the wavelength of their meanders, the sinuosity of the stations was calculated and the length used to calculate sinuosity was 2000 feet for each station. The sinuosity at present for each of the stations is: McDonald, 1.06; Harr, 1.22; Basalt, 1.10; Covered Bridge, 1.18; and Campus, 1.26. In general, sinuosity greater than 1.5 is referred to as meandering and below 1.5 is straight or sinuous (Leopold, 1992). The McDonald and Harr values are not too surprising as the McDonald station is in the forested upland regions and is constrained by steep valley walls. The stream becomes more sinuous when it drops into the Harr Station as expected. It is surprising that the sinuosity decreases in the Basalt, Covered Bridge and Campus stations. In theory, the sinuosity should increase as the gradient decreases and the valley floor is less constrained. Land use has contributed to simplifying the channel. This is most notable at the Basalt Station which is straight, entrenched, and lined with ivy on its nearly vertical upper banks. Houses line both sides of the channel in this region.

2.4.4 Topographic and Station Cross-Sections

Topographic cross-sections (Figure 6) and stream cross-sections (Figure 7) of each station were taken in order to assess the influence of local topography on (a) slope stability and sediment delivery and (b) lateral river constraint. Each topographic cross-section was selected to emphasize the highest point on the drainage divide surrounding the stream station. The length of each topographic cross section was determined by the highest point of elevation on either side of the creek. The vertical axis is exaggerated ten times in order to show the topography in the lowland, Covered Bridge and Campus stations. In the Spring of 1996, stream cross-sections were taken at the same position where the topographic cross-sections crossed the stream. At floodplain height, a stretched tape measure was leveled using a clinometer and depth measurements were taken every foot or in smaller increments to accommodate changes in channel bottom topography.

Volcanic stations: Reaches 1 through 6, located within the McDonald Forest, are represented by cross-section M to M'. This topographic cross-section represents the steepest valley slopes. Although basalt is a relatively resistant material, this area is subject to mass wasting, particularly where the slope exceeds 50%. Mass wasting is responsible for the delivery of soil and colluvial and alluvial material of boulder to mud size to Oak Creek. The V-shape that is present at the McDonald Station is characteristic of upper watershed channels which have not been glaciated. Typically, the material higher in the watershed is more resistant than valley material. Also, there is less water volume and discharge and denser vegetation higher in the watershed. Harr (H-H') and Basalt (B-B') stations are also in the more resistant basalt even though they are lower in the watershed. They are still moderately restricted by the valley floor, but not nearly to the extent of the McDonald Station and considerably less than the lowland stations. As noted in the stream cross-section, the channel is deeply entrenched and not connected to its original floodplain in most of the Harr and all of the Basalt reaches.

Stream terrace stations: The Covered Bridge (CB -CB') and Campus (C -C') stations are broad and flat, by topographic map standards, reflecting their relationship to their floodplain before entrenchment (Figure 6). The higher topography in the Covered Bridge cross-section is where the transect intercepts some neighboring sedimentary formations. The broad, flat topography represents a stream terrace deposited by the Willamette during the Holocene. This semi-consolidated deposit is easily erodible. The stream cross-section at the Covered Bridge, shows that, while Oak Creek is disconnected from its original floodplain above, a new floodplain has developed within the entrenched stream.

This could be for several reasons. The stream may have been constrained by land use and incised; there is evidence of rip-rapping in these reaches. As this area is on highly erodible material and has been grazed, it is possible that the channel banks were devegetated and trampled, widening the channel. For the past five years, agricultural

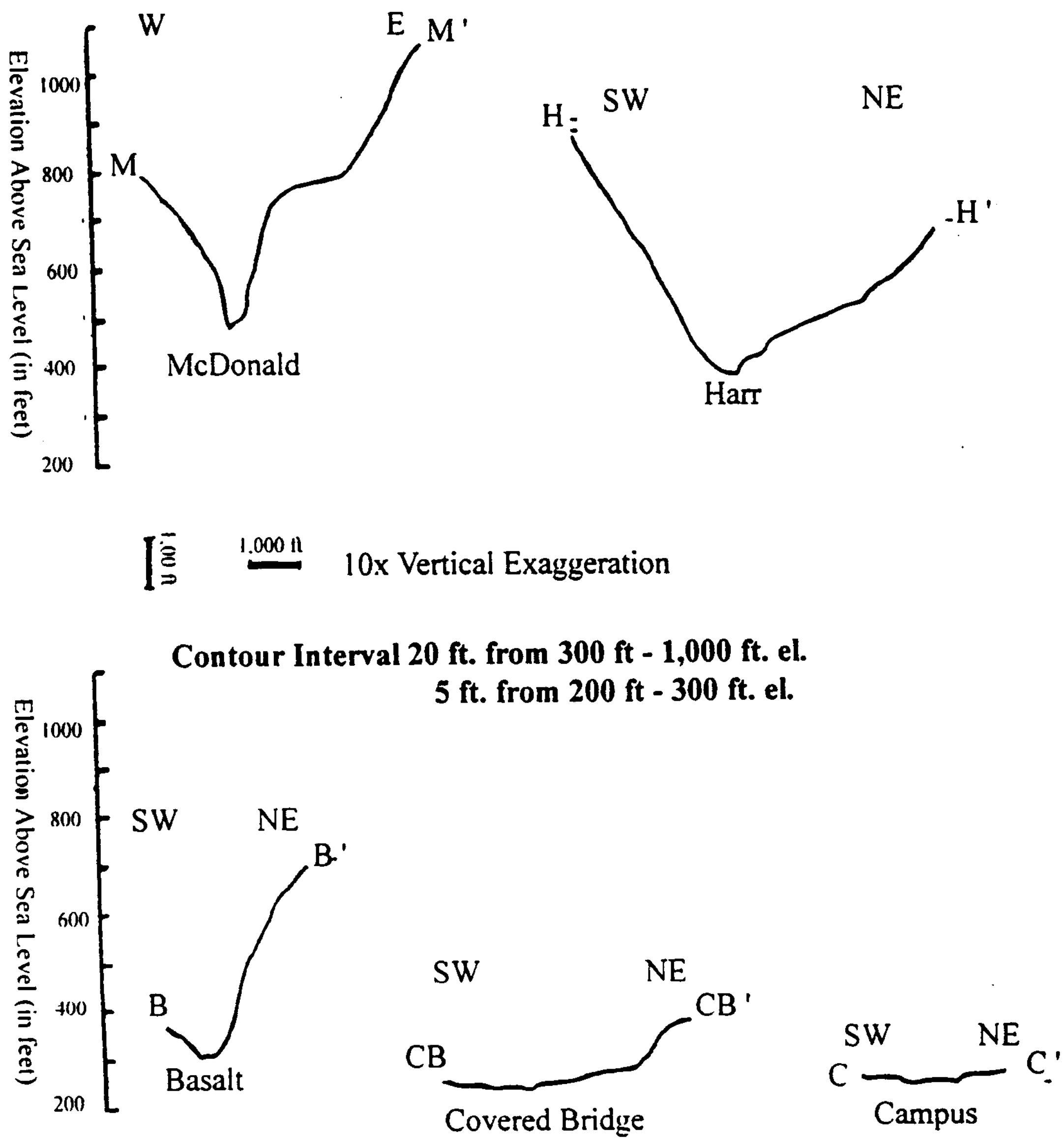


Figure 6. Topographic Cross-Sections on Oak Creek
(source: USGS, 1986)

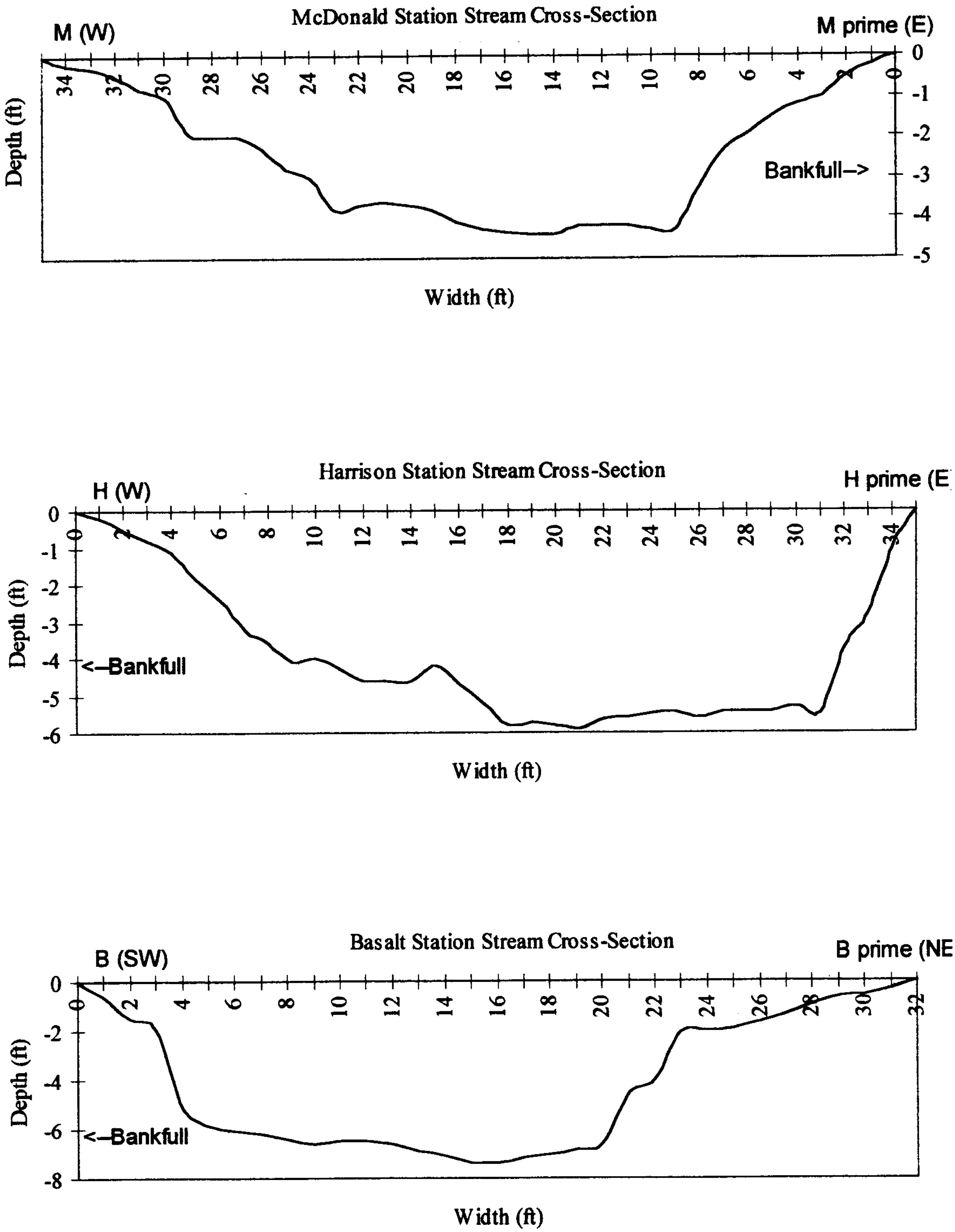
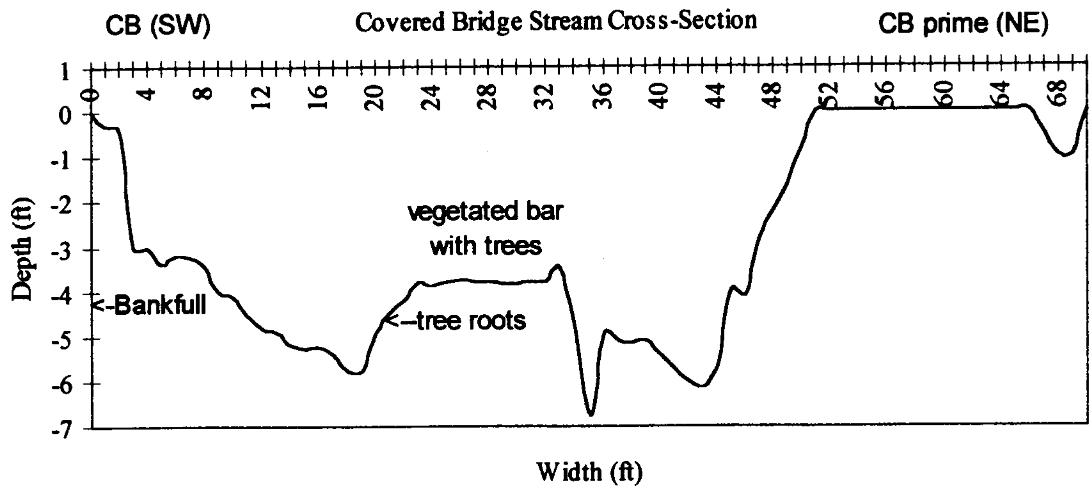


Figure 7a. Stream Cross-Sections on Oak Creek
(Spring 1996)



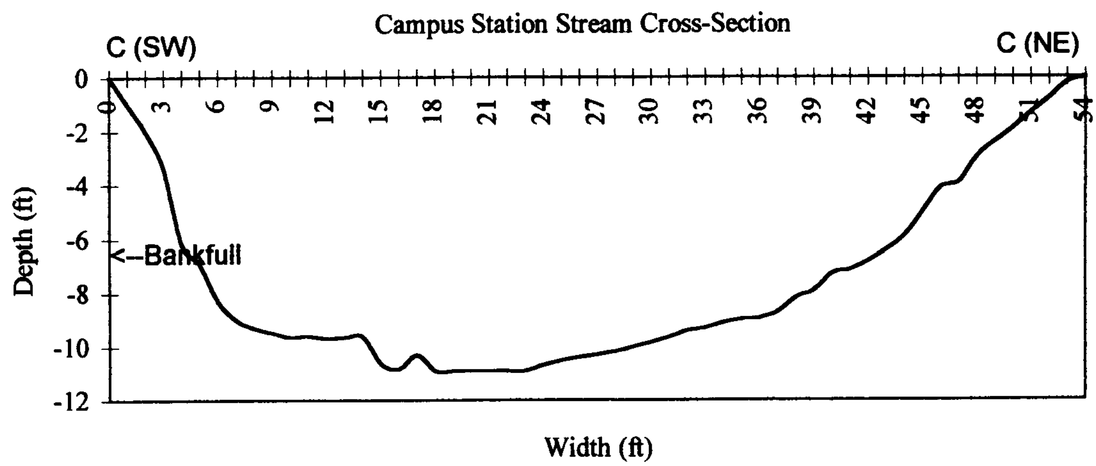


Figure 7b. Stream Cross-Sections on Oak Creek
(Spring 1996)

livestock has been kept out of the river, allowing vegetation to become reestablished, stabilizing the banks and bars. There is a road crossing with a culvert upstream from the covered bridge. The road dams water and water over-tops the road during large flood events. This back up may also cause aggradation of the present floodplain.

The topographic cross-section of the campus station reflects a broad, flat valley floor, devoid of lateral constraint on the valley floor. The stream cross-section however, reveals a deeply entrenched stream, which is no longer able to spill onto the floodplain during a flood; hence, it is removed, or disconnected from its floodplain. The floodplain on both sides of the stream is covered with asphalt and concrete.

It is notable that below the McDonald Forest research station, Oak Creek in general, does not connect to its original floodplain even in a flood as severe as the February 1996 flood. The stream is simplified and entrenched along most of its length.

2.4.5 Soil Units and Their Local Distribution

Soils are an important component of channel stability. Soil influences the type and density of vegetation. Permeability and compaction in soils influence subsurface flow, which effects the hydrology of the stream. Soils and geology also influence erosion and control the amount of sediment and the characteristics (e.g., size and shape) of the sediment that enters the stream. This effects the roughness of the channel and the sediment load in the stream; and mass wasting can also alter the channel course. The following soils are found in the Oak Creek watershed and the descriptions are from the Soil Survey of the Benton County Area (Knezevich, 1975).

Forested Lands; Uplands: The forested uplands of Oak Creek basin are dominated by the Price-Ritner Complex and Dixonville series. The Price Series (fine, mixed, mesic, Dystric Xerochrepts) consists of deep well-drained soils that formed in colluvium and residuum weathered from basic igneous rock. The Ritner series (clayey-skeletal, mixed, mesic Dystric Xerochrept) is characterized by moderately deep, well-drained soils which also formed from basic igneous rocks. Runoff and erosion hazard for these soils varies with slope. Where runoff is slow and the hazard of erosion is slight for the Price silty clay loam (3-12%), it increases substantially to rapid runoff and high erosion hazard for the Price-Ritner complex on 20 to 30% slopes. Other soils found in the headwaters of this basin include the Philomath, Jory, and Witzel Series. Runoff for these soils ranges from moderate to rapid, and erosion hazard is moderate to high.

Forested Lands; Channel Banks and Bottoms: Headwater stream bottoms consist mostly of the Witham and Waldo Series. Witham soils (fine, montmorillonitic, mesic, Vertic Haploxerolls) are deep, somewhat poorly drained soils that formed in alluvium. Runoff is slow to medium, and the hazard of erosion is slight. For the Waldo soils (fine, mixed, mesic Fluvaquentic Haplaquolls) runoff is slow, the hazard of erosion is slight, and permeability is slow. These soils consist of deep, poorly drained soils that formed in recent alluvium.

Lower Basin; Uplands: The foothills of the Oak Creek Basin are dominated by the Dixonville Series, while the lower slopes and terraces are comprised largely of Bashaw, Waldo, Amity, and Dayton Series. Well-drained, moderately deep soils that formed in colluvium compose the Dixonville Series (fine, mixed, mesic Pachic Ultic Argixerolls). This series has moderate runoff potential, and a slight to moderate erosion hazard. Moving down from the foothills, one encounters the deep, poorly drained soils of the Bashaw series (very fine, montmorillonitic, mesic Typic Pelloxererts). Runoff is very slow or ponded, the erosion hazard is slight, and permeability is slow. The Waldo (Fluvaquentic Haplaquolls), Amity (Argiaquic Xeric Agiabolls), and the Dayton (Typic Albaquualfs) series have similar characteristics except for slightly better drainage in the Amity soils.

Lower Basin; Channel Banks and Bottoms: Oak Creek's floodplain consists mostly of the Bashaw clay series, with some areas of Witham silty clay loam. The Bashaw clay (Typic Pelloxerert) is a deep, poorly drained soil that formed in recent alluvium. Runoff is very slow or ponded, the hazard of erosion is slight, and permeability is slow. The Witham series (Vertic Haploxeroll) is a deep, somewhat poorly drained alluvial soil with slow to medium runoff, slight erosion hazard, and slow permeability.

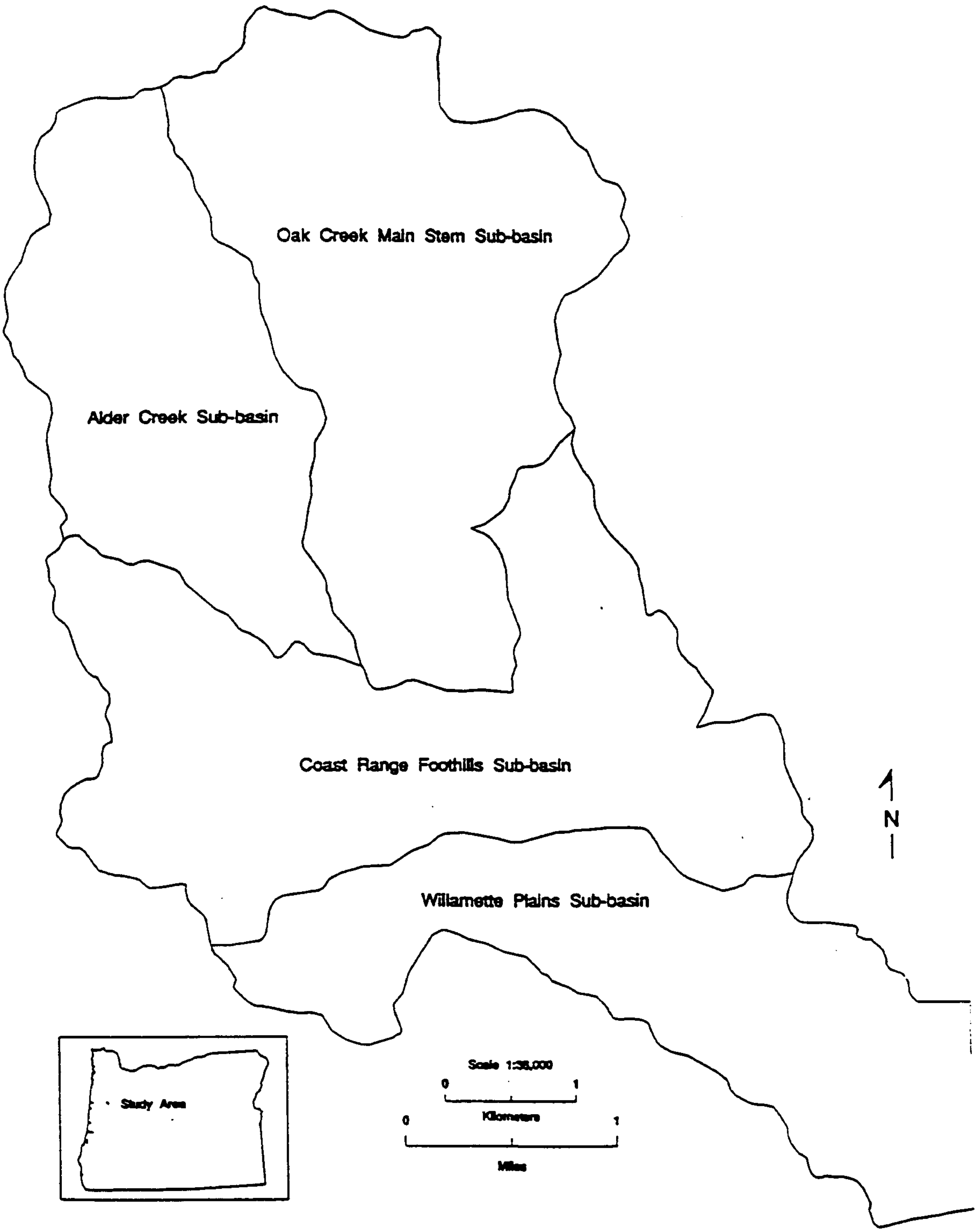


Figure 8. Sub-basins in the Oak Creek Watershed (Buckley, 1994)

2.5 Drainage Basin

2.5.1 Oak Creek Watershed and Sub-Basins

The Oak Creek watershed drains approximately 12.64 square miles of the eastern Coast Range and western Willamette Valley in and near Corvallis, Oregon. The watershed is a composite of four sub-basins (Figure 8). The Oak Creek main stem sub-basin drains the northeast upper elevations and the Alder Creek sub-basin drains the higher elevations in the Northwest portion of the watershed. Directly below these lie the Coast Range Foothills sub-basin and below that, in and around the mouth of the watershed, is the Willamette Plains sub-basin. Sub-basins are defined by drawing the drainage divides of the primary tributary for each sub-basin.

2.5.2 Channel Network

Oak Creek Watershed has a dendritic drainage pattern. Using the Strahler Order method of classification, Oak Creek is a fourth order stream on a 7.5 minute quadrangle topographic map, if ephemeral streams are drawn in by hand. The true bifurcation ratio (Rb) of the Oak Creek Watershed is 3.6 (Table 2).

Bifurcation ratios allow for rapid estimates of stream order relationships when using Horton Analysis. These relationships have been established by noting trends in the data of many rivers. While a river may not necessarily follow the general trend, an appreciable discrepancy may point out a relationship imbalance in the stream network that could be influencing the stability of the stream.

Horton's Law of Drainage Composition includes the Law of Stream Numbers which states $N_u = R_b^{s-u}$, where N_u is the number of streams of an order u, R_b is the bifurcation ratio, S is the highest order of the basin and u is the order number. In the case of Oak Creek, $N_u = 3.6^3$ which equals 47 streams, not the 39 that were counted; an error of 20.5%. This error may be that the Law of Stream Numbers is a 'principle' or 'generalization', not a 'law' and the stream naturally has 39 first order stream segments. Possibly, the aerial photogrammetry that the map was based on missed some topography under the dense canopy, thus eliminating streams on the topographic map. It is more probable that land use has eliminated some first order streams, particularly where there is a transition from the foothills to the valley floor. This is in the agricultural and rural-urban and urban regions where fill is added and waterways are diverted into culverts to drain property for development. If this is the case, the elimination of these streams could influence the natural stream hydrology and channel stability.

Stream Order (u)	Number of streams of order u (N_u)	Total length of steams of order u in miles (sigma L_u)	Mean stream length of order u in miles (L_u)	Bifurcation Ratio N_u / N_u + 1 (R_b)
1	39	20.00	0.51	4.3
2	9	6.55	0.73	4.5
3	2	3.68	1.84	2.0
4	1	4.12	4.12	
	Total stream miles:	34.35	True R_b:	3.6

Table 2. Bifurcation Ratio of the Oak Creek Watershed

2.5.3 Drainage Density

The stream frequency (Fs) in the Oak Creek Watershed is 4.04 stream segments per square mile (Table 5). The drainage density (D) in the watershed is 2.72 miles of stream per square mile of watershed. As seen on the map of the Oak Creek Watershed (Figure 2), the drainage density is higher toward the head of the watershed than near the mouth of the watershed. In the higher drainage density areas, there is a finely divided network of streams with short lengths and steep slopes. As the drainage density decreases, the stream lengths are longer, the valley sides are steeper and the streams are further apart, which is normal in most watersheds.

Total number of Streams (N)	Area (A) of drainage basin in square miles	Stream Frequency (Fs) number steams/area	Drainage density (D) stream miles/area
51.00	12.64	4.04	2.72

Table 3. Drainage Density of the Oak Creek Watershed

2.6 Vegetation and Climate

2.6.1 Vegetation

The vegetation in the Oak Creek Watershed varies between the upland regions of the watershed and the lowland regions (MSS Imagery, 1988). The upper half of the watershed is forested. The conifer forest is mixed and the primary species are Douglas Fir, Western Hemlock and Western Red Cedar. Along the disturbance zones of the channel, Red Leaf Alder dominates. Toward the center of the watershed, there are two distinct regions, a woodland of Oregon Oak and California Oak mixed with Douglas Fir and Ponderosa Pine in a pasture-like setting and a mixed evergreen and broadleaf deciduous forest. At the mouth of the watershed there is agricultural cropland and improved pastureland and urban vegetation.

2.6.2 Climate- General Temperature and Precipitation

Corvallis and the Oak Creek Watershed lie at the western edge of the Willamette Valley, which parallels the Pacific Coast which is approximately 40 miles to the west. Corvallis is influenced by the marine air but does not have the coastal fog and drenching rains found at the coast (Taylor 1993). The temperature and precipitation has an annual cycle where most of the precipitation occurs during the cooler months from November to March and the summers are fairly warm and dry (Taylor, 1994). The mean annual temperature in Corvallis between 1961 and 1990 was 51.9 °F (Taylor, 1994).

The volume of water entering the stream is directly controlled by the climate. The Oak Creek watershed has a humid-temperate climate. The annual mean rainfall in Corvallis is about 45 inches of rainfall on average per year (Taylor, 1994) where most of this falls during the wet winter months. Given that rainfall increases with elevation in the Willamette Valley, the rainfall in the forest at the head of the Oak Creek Watershed is considerably greater than at the stream's mouth in Corvallis achieving an annual average rainfall of 70 to 75 inches at its highest elevations (Taylor, 1994).

The high rainfall and temperate climate can encourage rock weathering and soil formation and can also saturate material on steep slopes which induces mass wasting. However, this climate is also well suited for encouraging dense vegetation which intercepts precipitation and overland flow and which can stabilize slopes and banks.

2.6.3 Temperature and Precipitation during the Flood of 1996

A wet winter, a surplus of snow and frost, an intense rain, and a warm temperature all combined to bring about the Flood of February 1996. "From October to January, most of Northwest Oregon received at least 125% of normal precipitation" (Taylor, 1997). The wet winter had saturated the soils and raised the stream. Beginning in mid-January, precipitation was above average. An intense cold spell hit the Willamette Valley during the week of January 29th. These two events caused the precipitation to be stored as snow and frost in the Oak Creek drainage basin. During the period of February 5-9, "a series of intense surges of subtropical moisture inundated western Oregon" (Taylor, 1997). George Taylor (1997) from the Oregon Climate Service wrote: "...on February 6th, a strong subtropical jet stream reached Oregon. This warm, very humid air mass, which originated near the Equator in the western Pacific (near the Date Line), brought record rainfall amounts to northern sections of the state. Although such subtropical storms are by no means rare, it is unusual for them to persist with such intensity for such a long period of time (3-4 days)". The precipitation, taken in combination with the snow and frost melted by the warm rain and the already saturated soils caused the Flood of 1996.

2.7 Hydrology and Flood Hydrology

2.7.1 Rain-dominated Hydrology

Oak Creek Watershed is typically influenced by rain-dominated hydrology rather than snow-dominated, rain-on-snow, or groundwater-dominated hydrology, which are commonplace elsewhere in Oregon. In rain-dominated hydrologic systems, the amount of rainfall over time is reflected in the creek's discharge over time with a relatively short time lag (hours and days as opposed to months, as in a snow-dominated system). For example, a large rainfall event would yield a corresponding peak discharge and as the rain dissipates, a relative decrease in discharge would soon follow. Peak flows resulting from rain-dominated hydrology account for the majority of the annual floods on Oak Creek.

2.7.2 The Flood of February 1996, A Rain-on-Snow Event

Although precipitation induced events cause most of the floods on Oak Creek, the Flood of 1996, was produced by a rare rain-on-snow event. The last such event occurred in 1964. As noted in Section 2.6.3, snow and frozen ground in the Oak Creek watershed were melted by an intense warm rain which started on February 6th, 1996. This warm rain combined with the snow and frost which both melted, adding additional water to the already saturated sub-surface flow. This combination resulted in flows which were so large that the gaging station malfunctioned before a hydrograph was completed. Currently, the Oak Creek gauging station records are unavailable. Because of these two factors, we are unable to quantify the flood event in terms of the percent chance that a flood of that magnitude would occur in any given year (e.g. 'the 100 year flood'). The 1964 flood has been referred to as a 100 year event, and the stream gauge did not break during that flood. Williamson (Personal Communication, 1997) has related that the flood on Oak Creek might be about an 80 year event.

Chapter 3

LITERATURE REVIEW

"God does not play dice with the universe."
-Albert Einstein, saying

3.1 Channel Erosion and Equilibrium

If rivers are the primary agent shaping the earth's surface, erosion is the tool with which this work is done. It is important to appreciate the fact that erosion, and the subsequent transport and deposition of the eroded sediment, is a natural river process. The basic function of a river is to erode, transport and deposit sediment in order to maintain equilibrium. Equilibrium in the longitudinal profile, also known as the graded profile, represents a morphology that is in balance with the forces that act through and upon a river over a temporal scale of 10^4 years (Mount, 1995). The key process variables controlling this are slope, depth, discharge, velocity, gradient, base level, and sediment load (Brookes, 1996; Mount, 1995). Catastrophic disturbances alter the stream-energy conditions enough to initiate channel response along the entire river; responses are typically rapid and dramatic (Simon, 1992). To maintain equilibrium, sediment must be eroded and deposited throughout the main trunk forming meanders, incision, pools, riffles and floodplains (Brookes, 1996; Mount, 1995). The state of maintaining equilibrium in a natural, unaltered stream is called dynamic equilibrium and quasi-equilibrium is the term used to describe when erosion in one area is offset by deposition in another area, usually due to human activity (Henderson, 1986).

Both natural and human modifications to the stream can cause an increase in the amount of erosion. Tectonic uplift creates knickpoints on the river and can cause meander bends to cut off, increasing the gradient along those reaches, which increases erosion and aggradation (Haible, 1980). The Corvallis Fault, which creates a knickpoint below Reach 15B on Oak Creek, was created by tectonic forces during the Eocene, about 55 Ma (Goldfinger, 1991; Orr, Orr and Baldwin, 1992). Knickpoints generally migrate upstream as the river erodes, transports and deposits sediment in an effort to smooth out the longitudinal profile (Gardner, 1984). Mary's River, which is the base level for Oak Creek has developed a convex bulge in the longitudinal profile which may be the result of current tectonic uplift (Rhea, 1993). Oak Creek, however, maintains more of a concave upward profile, representing a river that has reached equilibrium and is in a state of maintaining its dynamic equilibrium with the tectonic uplift. Such a condition is called dynamic metastable equilibrium (Mount, 1995).

3.2 Channel Erosion and Land Use

Equilibrium is maintained in order to reduce and distribute a rivers work and this maintenance will continue regardless of our intervention, often resulting in unforeseen problems (Mount, 1995). Land use modifies the river in a variety of ways. There is a process and pattern feedback relationship between man-made adjustments to the river and the river readjusting the land in response.

Man-made adjustments to the river ultimately result in altering a channel's morphology, sediment load and hydraulic characteristics, resulting in erosion (Brookes, A; Collins and Dunne, 1990; Dunne and Leopold, 1978; Mount, 1995, Scott, 1973; Simon and Robbins, 1982; Simon, 1995; Williamson et al., 1995). Adjustments to this disturbance can involve short time scales (days) and limited spatial extents or last up to hundreds of years (Simon, 1995). Referring to erosion associated with channelization, Dunne and Leopold (1978, p. 707) list the following potential costs or disadvantages of channel modification: "1) Channel instability or effects of channel readjustment to the imposed conditions; 2) Downstream effects especially increased bank erosion, bed degradation or aggradation; and 3) Esthetic degradation, especially the change in steam biota and the visual alteration of riparian vegetation, of stream banks and channel pattern or form."

Bank erosion is the primary source of stream sediment and thus causes the most changes to the river form (Knighton, 1992). This modification causes damage to private and agricultural land, aquatic habitat and human infrastructure (Collins and Dunne, 1990; Knighton, 1992; Mount, 1995; Scott, 1973, Williamson et al. , 1995) by encroaching upon land and adding sediment to the system. Channelization (which can be both a causal and a response variable), forest practices, agricultural use and urban development all contribute to modifying the stream.

When the banks are confined or a knickpoint is initiated, the channel incises down into the stream bed resulting in a channelized stream. Brookes (1996) notes that channelization, which involves manipulation of the dependent hydraulic variables of slope, depth, width and roughness, induces instability at the channelized reach and upstream and/or downstream from that reach. The channelization on Oak Creek is primarily a result of forest, agricultural and urban practices.

Forestry practices, such as logging, causes masses of sediment to enter the river, which causes the channel to erode laterally. This undermines steep slopes, causing landslides which add more sediment which exacerbates the instability (Dunne and Leopold, 1978). Forestry practices have been curtailed in recent history on Oak Creek.

Grazing, clearing and farming land also add sediment to the river and cause both aggradation and degradation. Sediment is added from soils that are eroded from grazed and farmed hillslopes. In-stream grazing causes banks to be devegetated and physically trampled resulting in lateral erosion and grazing can result in cutting off meander bends which increases the gradient, causing a knickpoint in the profile. Agricultural practices cause removal of vegetation from the riparian area which, on silty or clayey-silt banks, causes channel erosion, deepening and gullying (Dunne and Leopold, 1978). Draining land for agricultural purposes and stabilizing the river to 'protect' land resources result in confining the channel, causing it to incise. In a study of the 176 km^2 Almond catchment in Scotland, researchers noted that farming practices contributed 35 tons of sediment and urban housing excavations contributed 128 tons of sediment to the catchment during a major storm event during the winter of 1975-1976; this was 26% of the total sediment budget (Al-Jabbarri, Al-Ansaari and McManus, 1980).

Urbanization confines the channel, and paving and compacting the land surface deprives the subsurface of flow, which causes more runoff. The effect of urbanization is that it increases peak discharges and increases the duration of the high flows which result in quasi-equilibrium channel expansion or in catastrophic channel incision (Booth, 1990).

In quasi-equilibrium channel expansion, "the cross-sectional area increases in near-proportion to the discharge increases that initiated them" (Booth, 1990).

The land use practices imposed upon Oak Creek have resulted in channelizing and simplifying the stream. Forestry, agricultural, rural-urban and urban land use have each contributed to this decline. Erosion, transportation and deposition of sediment have been altered from their pre-land use state and will continue to function in a dynamic metastable state until equilibrium has been re-established.

3.3 Channel Failure

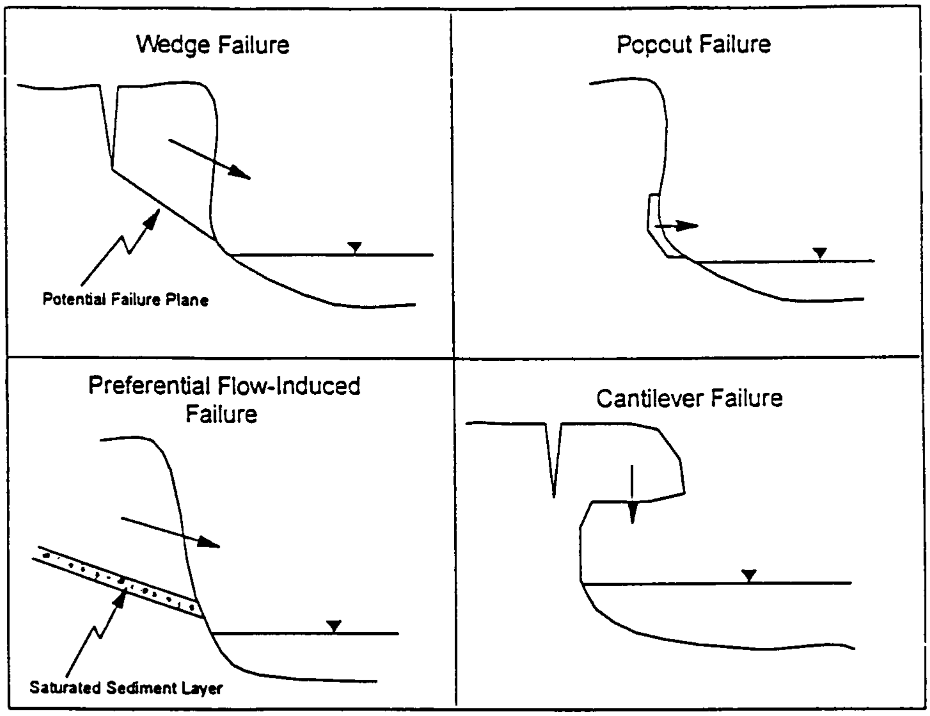
There are several processes responsible for the erosion of the channel and its subsequent failure. There are many classification schemes to describe this. Knighton (1992) notes that four main processes are responsible for stream erosion: the direct action of water, slumping, rotational slipping and frost action.

The mechanisms by which streambank failure occurs include: "1) erosive attack at the toe of the underwater slope, leading to failure of the overlying bank; 2) erosion of the soil along the banks, caused by currents; 3) sloughing of saturated cohesive banks incapable of free drainage; 4) flow slides (liquefaction) in saturated silty and sand soil; 5) erosion of soil by ground-water seepage out of the bank; 6) erosion of the upper bank or the river bottom due to wave action; 7) freeze-thaw action; 8) abrasion by ice and debris; and 9) shrinking a swelling of clays" (Henderson, 1986).

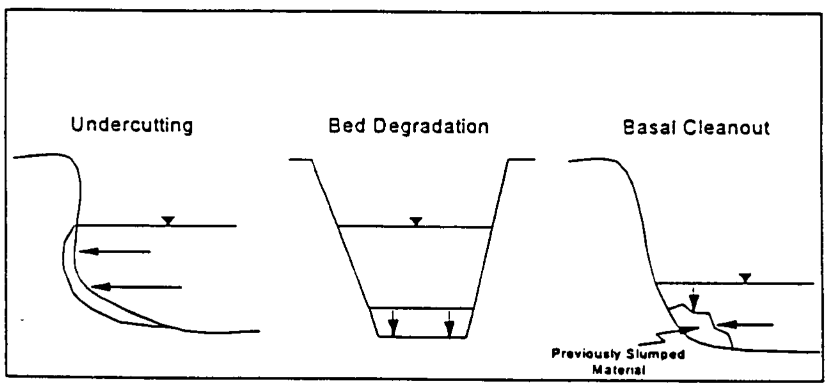
The classification scheme that is most suitable for the Stream Reach Inventory and Channel Stability Evaluation is by O'Neill and Kuhns (1994), both the 'evaluation' and the classification scheme are produced out of the same Rocky Mountain USDA Forest Service Station. The authors categorize stream bank erosion by which mechanism dominates the failure: gravitational or mechanical failure versus failure by tractive force (Table 4, Figure 9). Gravitational failure relates to material strength where soil moisture dominates the erosion process through decreases in material strength (pore pressure) and increases in material stress at the bank face. Irrigation and seasonal wetting and drying can accelerate bank erosion by gravitational failure (O'Niell and Kuhns, 1994). "Tractive erosion is dominated by fluid forces where erosion results from a change in the balance between fluid shear stress and material strength." Discharge can increase critical shear stress on a bank that has a constant material strength, so tractive erosion is more common at higher level flows (O'Niell and Kuhns, 1994).

Mechanism	Classification	Typical Flow Conditions	Sediment Characteristics	Bank Moisture	Descriptions
Wedge Failure	Gravitational	Low	Fine-grained Cohesive	Varies	Tension cracks formed behind bank.
Popout Failure	Gravitational	Low	Fine-grained Cohesive	Saturated	Small blocks forced out at base of channel bank due to pore pressure and overburden.
Preferential Flow-Induced Failure	Hydrologic/ Gravitational	Low	Interbedded Fine/Coarse	Saturated	Selective removal of coarse material due to preferential flow. Removal of support during rapid drop in stage.
Cantilever Failure	Gravitational	Low	Composite Fine/Coarse	Varies	Tension cracks form near base of cantilever. Linked to undercutting.
Undercutting	Tractive	High	Generally Non-Cohesive	N/A	Shear stress applied to the lower bank. Rate inc. w/ Q
Bed Degradation	Tractive	High	Relatively	N/A	Shear stress applied to the channel bed. Banks fail due to gravitational mechanisms.
Basal Cleanout	Tractive	Varies	N/A	N/A	Banks made unstable by removal of material at base. Residual strength of material determines requisite flow.

Table 4. Mechanisms Related to Gravitational Failure and Tractive Erosion (O'Niell and Kuhns, 1994)



Gravitational Failure Mechanisms.



Tractive Erosion Mechanisms.

Figure 9. Gravitational Failure Mechanisms and Tractive Erosion Mechanisms (O'Niell and Kuhns, 1994)

3.4 Channel Stability Studies

Fluvial erosion is a major geomorphic hazard (Gares, Sherman and Nordstrom, 1994). Despite the importance of fluvial erosion, relatively few studies have been conducted in this field (Gares, 1994; Knighton, 1992). Fluvial erosion looses attention because adjustments to cope with river bank erosion are often incorporated into flooding projects (Gares, Sherman and Nordstrom, 1994). A growing awareness of stream habitat and stream restoration issues may push more studies to be conducted in channel stability. Kondolf and Sale (1985) note that long term channel stability evaluation is an important component of instream flow assessments because "significant instability may invalidate the results of habitat simulation, especially when studying habitat variation over time."

Myers and Swanson (1996) researched the relationships between grazing management and aquatic habitat on three streams in a rangeland watershed in northwestern Nevada. They used the same Stream Reach Inventory and Channel Stability Evaluation rating system that was used in this thesis and an aquatic habitat survey for four years. They noted that the aquatic habitat improved as the riparian vegetation was reestablished due to improved livestock management. They declared that the "ocular stability variables tracked the quantitative habitat and morphologic variables well enough to recommend that ocular surveys be used to monitor changes with time between more intensive aquatic surveys (Myers and Swanson, 1996)."

Kondolf and Curry (1986) documented channel stability on the Carmel River by studying historic maps, photographs and channel cross-sections. When conducting a study in Monterey, California, they noted that the erosive power of high magnitude events and the resistive forces of bank vegetation both play a primary role in channel stability. The researchers found that the stability of the stream could be disrupted by both high and low magnitude events. A large erosive force in a high magnitude event created massive bank erosion, channel migration, and aggradation in 1911. However, in 1978 and 1980, the authors noted that low magnitude events were responsible for erosion on stream reaches where the bank vegetation was removed.

The relationships between bank vegetation and bank erosion was researched on stream banks in northern Mississippi by Grissinger and Bowie (1984). The study noted a cyclic relationship in that bank height and angle limit vegetation by controlling mass failure frequencies. This causes bank instability which in turn limits the vegetation which could stabilize the bank from recurring failure. Part of the reason that a critical bank height was ever-present was that the massive, dense silt unit had a well-developed polygonal structure that caused near-vertical bank angles. They were often stable without vegetation except where the channel entrenchment exposed weak toe materials, in which case, the bank was undercut leading to unstable banks. This study illustrated the usefulness of noting the soil and surficial geologic unit in the stream reaches.

Bank vegetation and steepness may not always play an important role in channel stability. On a channel stability study conducted in the Sierra Nevada during a high water year, bank vegetation was found to have little influence on incised streams (Zonge and Swanson, 1996). The researchers explained that this finding may be because the "streams were too far from a new dynamic equilibrium". The authors also noted that there was no relationship between the observed bank retreat and near-bank velocities or between the bank retreat and bank steepness.

Channel slope and geologic material were found to be the critical factors for identifying streams susceptible to incision in urbanized basins in King County, Washington (Booth, 1990). Increased slopes and weaker geologic material increase erosion so Booth (1990) suggested mapping these as a planning tool when planning urbanization. On the River Tay in Scotland, Gilvear (1993) suggested identifying areas of former braiding a planning tool for predicting erosion. The author noted that areas of former braiding were most likely to erode.

In a paper on fluvial hazards, Schumm (1994) noted that there are many misperceptions of fluvial hazards relating to channel stability. Three in particular are: "1) a perception of stability, which leads to the conclusion that any change is not natural, 2) a perception of instability, which leads to the conclusion that change will not cease, and 3) a perception of excessive response, which leads to the conclusion that changes will always be major." The author noted three types of geomorphic hazards spanning three different temporal scales: "1) an abrupt change that produces a catastrophic event (e.g. a landslide), 2) a progressive change that leads to an abrupt change (e.g. meander cutoff, channel avulsion), and 3) a progressive change that has slow, but progressive results (e.g. meander shift, channel incision)" (Schumm, 1994). This latter hazard (type 3) is likely to lead to expensive litigation because human actions, not compounded natural river response, are often blamed for channel instability.

3.5 Assessing Channel Change

It is sometimes difficult to distinguish between what is a natural amount of erosion and what is unnatural. Often, damage to ecosystems and human infrastructure alert us that a river may be experiencing unnatural rates and magnitudes of erosion. In order to assess the erosion and its geomorphic effects on the river it is necessary to quantitatively monitor change in the system. Several methods have been suggested to measure change in a river.

Kondolf and Larson (1995) note that historical analysis can reveal underlying causes of channel change. They suggest that planning, designing and evaluating restoration projects should be guided by understanding past changes and that planning should address the historical causes and patterns of channel degradation. The historical analysis should cover all of the areas of the catchment within the zone of influence (Kondolf and Larson, 1995).

Aerial photographs prove an invaluable tool to compare historic changes in channels and to note landslides, riparian changes and land use which may have impacted the channels (Kondolf and Sale, 1985; Kondolf and Larson, 1995). Kondolf and Sale (1985) consider this a first step in historical channel stability analysis. In addition to observing historical aerial photographs, they suggest looking at historic maps, ground photographs, historic survey data (such as bridge surveys), geomorphic evidence (flood deposits) and written and verbal narrative accounts to note major channel changes. If the channel has been stable no further analysis is needed.

Geoindicators are also used for river monitoring. Osterkamp and Schumm (1996) suggest using the following methods when monitoring erosion: erosion stakes, painted-rock lines, cliff-recession markers and mass movement pins. Hughes (1977) used profiles, cross-sections and peg measurements when studying the rates of erosion on meander arcs. He noted that "peg measurements record the surface loss at the upper part of the bank, and therefore only illustrate the end product of erosion and bank retreat over a period of time". This can be a problem because at the same time, the bank can be undermined and more sediment can be lost, but the peg measurement will not have an immediate effect (Hughes, 1977).

The ideal situation is to have a monitoring system in place before a destabilizing event occurs so that change can be measured in the channel. However, the need for such an arrangement is not always known in advance.

Chapter 4

METHODOLOGY

"You can only predict things after they've happened."
-Eugene Ionesco, Rhinoceros

This section describes the Stream Reach Inventory and Channel Stability Evaluation which was used in this study. The field methodology involved implementing this survey at each of the reaches noted in Table 1. In 1995, the results were obtained by comparing surveys on all reaches with Marganne Allen and Laura Jacek, graduate students in Forestry and Geosciences, respectively. In 1996, the upper six reaches of the watershed were surveyed with Miles Barkhurst who had over a decade of full time experience in various engineering capacities with the Forest Service and had completed Rosgen training on channel analysis. Both sets of 1996 surveys were consistently given the same scores, so the remaining surveys were completed independently.

In October 1997, a small, separate study was conducted to estimate the precision in the original studies' ocular estimates of sediment size distribution. Ocular surveys were conducted two days apart at the following reaches: McDonald 4, Harr 10 and Covered Bridge 19. For each measurement, the standard deviation of the difference in values between the two days was divided by its mean and multiplied by 100 percent to get a percent error (Appendix C). Only size distribution estimates whose values were greater than or equal to 10 percent were used. The average percent error of all of the estimates greater or equal to ten is 12%. This estimate of the error should be considered when evaluating the survey results.

In order to understand the study, discussion and results, the contents of the survey manual is presented here. Because of this, most of the information contained in chapter 4 are the thoughts, words and expressions of the authors who designed the survey (Pfankuch, 1978). The portions of this chapter that are quoted or paraphrased from the Stream Reach Inventory and Channel Stability Evaluation manual are either in quotations or indented and single spaced.

4.1 Stream Reach Inventory and Channel Stability Evaluation Overview

The stream reach inventory portion of the survey assesses basic stream inventory items such as sediment size distribution, width and depth (width times average depth equals area), discharge, gradient and stream order (Figure 1).

The channel stability evaluation consists of 15 channel stability indicator (CSI) items which are each designed to answer 3 basic questions: "1) What are the magnitudes of the hydraulic forces at work to detach and transport the various organic and inorganic bank and channel components? 2) How resistant are these components to the recent stream flow forces exerted on them? and 3) What is the capacity of the stream to adjust and recover from potential changes in flow volume and/or increases in sediment production?" The CSI items are divided between three areas of the channel cross-section: the upper banks, the lower banks and the channel bottoms.

4.1.1 Definition of Channel Stability

Channel stability is defined by Pfankuch (1978) as the ability of the channel to "adjust and recover from changes in discharge or increases in sediment delivery". Changes in discharge generally refer to floods which produce a pulse increase in discharge or flow. A change in sediment delivery can be associated with logging, construction, road building and mining practices which can alter the sediment delivery to a river system. In such an event, atypical sediment pulses can occur. A river which can undergo changes in discharge or sediment delivery without a marked change in channel stability or sediment size distribution is said to have channel stability. Alternately, a channel which notably changes during a flood or pulse sediment event is said to have channel instability.

4.1.2 Purpose and Use

> The procedures were developed to systemize measurements and evaluations of the resistive capacity of mountain stream channels to the detachment of bed and bank materials and to provide information about the capacity of streams to adjust and recover from potential changes in flow and/or increases in sediment production.
>
> The information can be used at a 'point' for gleaning data at such places as bridge sites or campgrounds or it can be used for complete channel analyses for fisheries, timber management, water balance, multi-use inventories and planning. The river can also be stratified by categories such as geology or stream order for specific uses.

4.1.3 Design

The stream reach inventory portion of the survey is a list of often-inventoried items that most stream monitoring programs note. Notable items include the location, channel dimensions, gradient, velocity, discharge, stream order, bed composition and some water quality variables which were not monitored in this study. The bed composition is surveyed by visually assessing the reach for relative percentages of exposed bedrock, large boulders (>1m), small boulders (>30cm), large cobble (>15cm), small cobble (>8cm), large gravel (>3cm), fine gravel (>1mm), and sand, silt and muck. This ocular survey is accomplished by walking the reach several times until confidence in the assessment is established.

The channel evaluation portion of the inventory is often judgement-based. There are 15 CSI items and 4 ratings for each item: excellent, good, fair, and poor (Figure 1). Each rating has a description outlined in the Stream Reach Inventory and Channel Evaluation booklet. In a model channel, a description would be found to match each rating every time, but often a judgement call must be made. In the case of Oak Creek, the chosen rating reflects the 'closest match', but does not necessarily reflect each description exactly.

All CSI items and ratings are weighted differently (have varying rating scores) depending on the importance that the survey authors assigned to that item's influence. For example, as shown on the survey form (Figure 1), out of the six channel bottom CSI items, Scouring and Deposition is weighted more heavily than any of the other items. A rating of 'excellent' on Scouring and Deposition earns a score of 6 points where the same rating for Rock Angularity only earns 1 point. Thus, Scouring and Deposition influences the survey results more than Rock Angularity.

The 15 CSI items are divided into three areas of the channel: the upper bank, the lower bank and the channel bottom (Figure 10). The upper bank is "the portion of the topographic cross section from the break in general slope of the surrounding land to the normal high water line. Terrestrial plants and animals normally inhabit this area." The lower bank is "the intermittently submerged portion of the channel cross section from the normal high water line to the water's edge during the summer low flow period." The channel bottom is "the submerged portion of the channel cross section which is totally an aquatic environment."

After all of the variables have been assessed and assigned a value (Figure 1), the values are summed for each rating category (excellent, good, fair, poor). These rating totals are then added to achieve a total reach score, which can also be correlated to a rating of excellent, good, fair or poor. The reach scores are then added to get a total score for the river. The total score also corresponds to the ratings of excellent, good, fair and poor where excellent infers that the river is able to handle a sudden change in discharge or sediment delivery without much change and poor infers that such an event will cause a lot of changes in the channel. This design has the advantage of analyzing a single reach or region for stability or it can assess the entire river for channel stability. The regions of the channel cross-section can also be appraised for notable problems.

4.2 Channel Stability Indicator Items

The Channel Stability Indicator Items are categorized by the Upper Channel Banks, the Lower Channel Banks and the Channel Bottom (Figure 10). Each region of the channel is weighted as a total of the combined scores of the CSI items contained within that region.

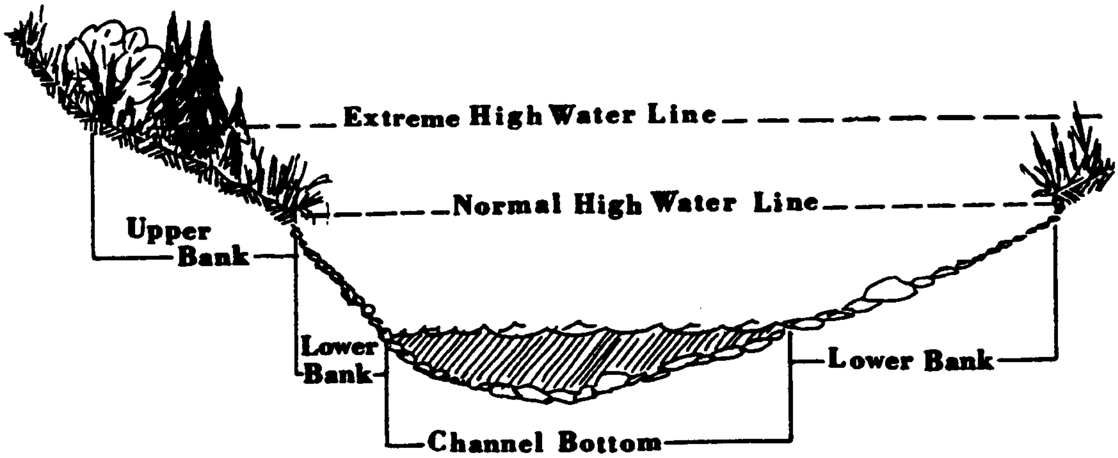


Figure 10. Channel Regions: Upper Bank, Lower Bank, Channel Bottom (by Pfankuch, 1978)

4.2.1 Upper Channel Banks

The land next to the stream is generally terrestrial. It can be a wide, flat alluvial flood plain or a steep slope coming off of a mountain. Intermittently, this dry land flood plain becomes a part of the water course. Forces of velocity and turbulence tear at the vegetation and land. These short lived hydrologic forces can produce on-site channel enlargement and downstream sedimentation. Resistance of the component elements on and in the banks are highly variable. This section has channel stability indicator items designed to aid in rating this relative resistance to detachment and transport by floods.

There are 4 CSI items in the Upper Channel Bank Region. These are landform slope, existing or potential mass wasting or failure, debris jam potential (floatable objects) and vegetative bank potential. The upper bank region has the lowest weighting of the three channel regions being surveyed (Table 5).

Landform Slope (LS) assesses the steepness of the land adjacent to the channel to determine the lateral extent to which banks can be eroded and the potential volume of slough which can enter the water. Basically the steeper the slope, the poorer the rating.

Mass Wasting (MW) involves existing or potential detachment from the soil mantle and downslope movement into waterways of relatively large pieces of ground. Mass movement of banks by slumping or sliding introduces large volumes of soil and debris into the channel suddenly, causing constrictions or complete damming followed by increased stream flow velocities, cutting power and sedimentation rates. Conditions deteriorate in this element with proximity, frequency and size of the mass wasting areas and with progressively poorer internal drainage and steeper terrain.

Debris Jam Potential (DJP) assesses floatable objects. These objects are usually deposited on stream banks naturally but sometimes by humans and generally consist of tree trunks, limbs, twigs and leaves. When they reach the channel they are obstructions, flow deflectors and sediment traps (see lower bank section). This category assesses the potential for placing these impediments into the flow, based on where they now lay (are they stuck or are they going to float away). It also includes the possibility of creating new debris jams under certain flow conditions.

Vegetative Bank Protection (VBP) notes that the soil in the bank is held in place largely by the plant roots. Riparian plants have almost unlimited water for both crown and root development. Their root mats generally increase in density with proximity to the open channel. Trees and shrubs generally have deeper root systems that grasses and forbs. Roots seldom extend far into the water table, however, and near the shore of streams they may be shallow rooted and subject to windthrow. In addition to the root mat stabilizing the banks, the stems help to reduce the velocity of flood flows. Turbulence is generated by streams in what may have been laminar flow. The greater the density of vegetation, the greater resistance to stream energy and therefore the better the rating.

4.2.2 Lower Channel Banks

The lower channel banks are located between the normal high water and low water line. This area has sparse vegetation that can be either terrestrial or aquatic. The lower channel banks define the present stream width. Channel bank stability is indicated under a given flow regime by minor and almost imperceptible changes in channel width from year to year. There is no encroachment of the water environment into the land environment.

When channel flow increases, the banks may weaken and both cutting (bank encroachment) and deposition (bank extension) begin, usually at bends and points of constriction. Cutting is evidenced by steepening of the lower banks. Eventually the banks are undercut, followed by cracking and slumping. Deposition behind rocks or bank protrusions increase in length and depth.

The lower bank region is weighted more heavily than the upper bank region, but less than the channel bottom (Table 5). There are five CSI items that evaluate the lower bank region. These are channel capacity; bank rock content; obstructions, flow defectors and sediment traps; cutting; and deposition.

	Channel Stability Indicator Item	Rating Score excellent	Rating Score good	Rating Score fair	Rating Score poor	Notable Change in Rating
	Upper Banks:					
1	Landform Slope	2	4	6	8	2
2	Mass Wasting	3	6	9	12	3
3	Debris Jam Potential	2	4	6	8	2
4	Vegetative Bank Potential	3	6	9	12	3
	Lower Banks:					
5	Channel Capacity	1	2	3	4	1
6	Bank Rock Content	2	4	6	8	2
7	Obstructions/Flow Deflectors/Sediment Traps	2	4	6	8	2
8	Cutting	4	8	12	16	4
9	Deposition	4	8	12	16	4
	Channel Bottom:					
10	Rock Angularity	1	2	3	4	1
11	Consolidation/ Particle Packing	2	4	6	8	2
12	Bottom Size Distribution & Percent Stable Materials	4	8	12	16	4
13	Scouring and Deposition	6	12	18	24	6
14	Micro Bedforms	4	6	8	10	2
15	Macro Bedforms	2	4	6	8	2
	Totals:					
	Upper Banks	10	11-20	21-30	31-40	10
	Lower Banks	13	14-26	27-39	40-52	13
	Channel Bottoms	21	22-36	37-53	54-70	17
	Survey Total	<44	45-82	83-122	123-162	40

Table 5. Channel Stability Evaluation Rating Table: Obtainable Scores (after Pfankuch, 1978)

Channel Capacity (CC) evaluates the ability of the cross-sectional area of the channel to accommodate normal peak flow volumes without bank deterioration. This category requires assessing the height of previous bank flows relative to the channel to see if the capacity has been exceeded and to determine the width to depth ratio. In an entrenched system such as Oak Creek, the width to depth ratio generally qualifies most reaches for an excellent rating. The higher the ratio the more likely the river will overrun its banks.

Bank Rock Content (BRC) examines the materials that make up the channel bank to test the relative resistance of this component to detachment by flow forces. This is done by observing the rock content of the surface rocks and exposed cut banks. As vegetation is generally lacking in this area, it is the volume, size and shape of the rock content which holds the bank together. This indicator item was often compromised because it has two qualifiers which often conflict. For example, a rating of excellent requires that rock must make up 65% or more of the volume of the banks. In addition (and), the most numerous rock size within this matrix is angular 12 inch boulders. Often, the rock content would not match up with the rock size.

Obstructions (O) and Flow Deflectors (FD) may produce adverse stability effects when they increase the velocity and deflect the flow into unstable and unprotected banks and across unstable bottom materials. Examples of these include large rocks, embedded logs and bridge pilings. If these cause a pattern of flow which erodes banks or shifts sediments continuously, it is undesirable. Sediment Traps (ST) are channel obstructions which dam the flow partly or wholly and form pools or slack water areas. These lower the gradient causing a loss in sediment transport power. Sediment build up is considered undesirable as the pools will fill up and then the channel will migrate. Beaver dams are considered an unstable sediment trap, capable of damage.

Cutting (CUT) and Deposition (DEP) are concomitant processes, although they are evaluated separately. They are classified apart because it is possible for each to be taking place in different reaches at the same time. They are the most heavily weighted items in the lower bank region. Cutting causes aquatic vegetation to be scoured or uprooted and is one of the first signs of channel degradation. In areas lacking vegetation, there is a steepening of the banks. It usually begins near the top and extends down to where, in extreme cases, the whole bank becomes a vertical wall. If plant roots or material composition bind the surface horizon of the adjacent upper bank, undercutting will follow until the weight of the overhang causes the overhang to crack and slump into the channel. Little evidence of cutting is excellent, nearly continuous bank cutting is poor.

Deposition of sand and gravel bars in places where they previously did not exist indicates upstream erosion. These bars tend to grow with continued watershed disturbance. Extensive deposits of fresh silts, sands and gravels are rated as poor. Some fresh deposits on bars and behind obstructions of gravel and larger size material is rated as good.

4.2.3 Channel Bottom

Water flows over the channel bottom nearly all of the time in perennial streams. It is, therefore, an almost totally aquatic environment, composed of inorganic rock. It is also a complex biological community of plants and the original version included two CSI items to account for this. In the Coast Range of Oregon, sun doesn't reach the watershed as much as other places and an abundance of plants is lacking so the two CSI items were replaced by my advisor, Professor Rosenfeld, with Micro Bedforms and Macro Bedforms, which better relate to Oregon Coast Range streams.

Inventory in this channel region needs to be accomplished during the low flow season and when the water is free of suspended or dissolved substances. This was difficult to do during the rainy Spring season of 1996. Within fifteen minutes of a light shower, the channel bottom would be obscured due to the quick reaction time of the small watershed. Sun initiated immediate action in order to complete the surveys.

The channel bottom region has the most influence on channel stability and is the most heavily weighted of the three regions (Table 5). The CSI items in this category are Rock Angularity, Consolidation or Particle Packing, Bottom Size Distribution and Percent Stable Materials, Scouring and Deposition, Micro Bedforms and Macro Bedforms.

Rock Angularity (RA) is important in maintaining channel bottom stability because angular rocks will lock into place with each other making a bed composed of angular rocks more resistant to detachment. They resist tumbling when detached and are more likely to be imbricated than rounder rocks. Rounded rocks pack poorly and are easily detached.

Consolidation or Particle Packing (C,PP) assesses how wedged or interlocked the rock and soil particles are. An imbricated bed has an excellent rating. Rocks in a loose array are not stable. This indicator item was often referred to as the 'kicking category' because, in addition to observations, the channel bed was kicked and then assessed to see how difficult it was to dislodge material.

Bottom Size Distribution (BSD) and Percent Stable Materials (%SM) reflect the array of sizes and the geologic source within the basin. In part this category is based on a 'sense' of an abnormal situation. Basically, upstream flow tends to wash away fines and leave larger rocks sizes behind whereas, in downstream reaches, where the gradient is lower and the flow is slower, sediment starts to drop out, and the fines collect. Two elements of bottom stability are assessed: the change or shift from the natural variation of component size classes and the percentage of all of the components which are judged to be stable materials. Bedrock is always a stable material.

Scouring and/or Deposition (S&D) is self defined. If 5% or less of the channel bed has scouring or deposition, the bed is not mobile year round and the rating is excellent. On the other hand, if over 50% of scouring and deposition is noted it indicates that the bottom is moving not only during high flow periods but at most seasons of the year, which earns a poor rating.

Micro Bedform (MiB) evaluates the groupings of rocks on the channel bottom. If the rocks are grouped and packed together in a 'clast' they are more stable. As clasts become infrequent and the rocks become looser, the rating degrades.

Macro Bedform (MaB) appraises the channel bars for stability. A lateral bar or vegetated point bar without a chute has an excellent rating. Transverse or longitudinal bars are good; bank attachment or diagonal bars are rated fair; and active point bars with chutes are rated poor.

4.3 Evaluating the Stream Surveys

4.3.1 Evaluation Categories

In order to appraise the flood induced channel changes between the Spring of 1995 and the Spring of 1996, the following categories were evaluated. The individual channel stability indicator (CSI) items and their groupings by channel region (upper bank, lower bank and channel bottom) were initially assessed for each reach (1 through 22); station (M,H,B,CB,C), land use type (F, Ag, R-U, U), surficial geologic unit (Tsr, Tsr-p, Qtl), and for the stream as a unit (Table 1). The trends within each of the years and between years were noted.

A total of 665 rating combinations were analyzed. Fifteen channel stability indicator item scores, a total score for each of 3 channel regions, and 1 total score are rated for each of 22 reaches and 1 stream as a whole. This combination creates 437 rating evaluations (19 x 23). The aforementioned variable scores are also assessed in relation to 5 stations, 4 land use types and 3 surficial geologic units, making 228 more ratings (19 x 12) which were evaluated. The relevant results from these evaluations are summarized in Chapter 5.

4.3.2 Evaluation Technique

All of the data was put into a Microsoft Excel worksheet. The columns and rows were set up as in the abbreviated example in Table 6 for the initial analysis. The evaluation category data were used as point source data. From this, comparative data such as means and standard deviations were extracted. Graphs were constructed in order to note trends and relationships.

Evaluation Categories: Survey Results	22 columns of reaches subdivided by stations, means, S.D.	3 columns of channel regions and 1 stream total followed by means, S.D.	5 columns of stations followed by means, S.D.	4 columns of land use followed by means, S.D.	3 columns of geologic units followed by means, S.D.
15 rows of '95 stability indicator items					
3 rows of channel region '95 totals					
'95 stream total					
13 rows of '95 stream reach inventory data					
The 4 sets of rows were repeated for 96, 96-95 & |96-95|					

Table 6. Initial Analysis Array

4.3.3 Confounding Variables Between Station, Land Use and Geology

The effects that land use and geology had on channel stability were unable to be determined due to confounding variables. There are confounding variables between land use and geology alone but when station, representing both river mile and position in the watershed and on the profile (Figures 2 and 3), is added, this problem is confounded even further. Even using 2 of the 3 variables, there is an incomplete factorial structure to the observed factors (Table 7).

Land Use / Geology	Forest	Agriculture	Rural-Urban	Urban
Tsr	X	X	X	
Tsr-p			X	
Qtl		X		X

Table 7. Land Use and Surficial Geology

Given only land use and geology, it is difficult to differentiate which variable contributes to a channel stability item or score for a given reach or station. For example, all of the reaches that have Tsr-p also have Rural-Urban land use (and all are in the Basalt Station which is a function of river mile and position on the profile). Similarly, an overall estimate of urban land use is unobtainable since the only time urban land use is in the study is when it is associated with the Quaternary alluvium.

Only 'simple effect' contrasts are possible- it is possible to observe the differences between forest, agricultural and rural-urban within Tsr, but there is no information to tell us whether those effects would be the same or different within Tsr-p or Qtl.

If a simple effect comparison was found statistically significant, it still would not be statistically meaningful due to the small data sets. For example, it is possible to distinguish a relationship between Tsr and Tsr-p within Rural-Urban land use (Table 7), but there are only three data points in each category, rendering any distinction meaningless.

Table 7 illustrates how, in observational studies, on one stream, one may get a limited range of possible combinations. Because of the problems with confounding variables, the effects of land use and geology were withdrawn from the study except to reference descriptions and discussions.

4.4 Evaluating the Survey Method and Channel Change

4.4.1 Evaluating the Survey Method

In 1995, the Channel Stability Evaluation predicted the channels resistance to change if a flood event would occur. In order to evaluate if the survey method worked, this prediction must be compared to the changes that occurred in the stream as a result of the flood. In a planned study, differences in cross-sections and measurements from mass wasting pegs and pebble counts would be used to monitor change. These items were not available in this study, however, the survey evaluated 15 CSI items which describe various physical components within the channel, many of which reference information found in a cross-section and data given by mass wasting pegs.

The items that give cross-section and mass wasting information are found in all three regions of the channel. For example, on the upper banks, the Mass Wasting and Landform Slope categories mimic those monitoring tools. On the lower banks, Cutting and Deposition both relate to the cross-section and mass wasting. On the channel bottom, Scouring and Deposition, and Consolidation and Particle Packing can represent changes in the cross-section. In addition, the Stream Reach Inventory has an ocular assessment of the sediment distribution for each reach for both years which can give information similar to a pebble count. The change in the 15 CSI items and the change in the sediment distribution between the pre-flood and post-flood surveys will be used to evaluate change in the channel.

4.4.2 Evaluating Change

The Channel Stability Evaluation operates with the assumption that there should be varying degrees of change in the channel for each rating. However, no measurable definition of change is given. In order to measure this change a model is presented. The model used to assess the ability of the Channel Stability Evaluation to accurately predict change is called the 'change model' (Figure 11). The change model compares the change that actually occurred between the two years surveyed to the change that was predicted to occur. The predicted change is based on two assumptions. The first assumption is that if the Channel Stability Evaluation survey score tabulated in 1995 corresponded to a rating of 'excellent', no change or very little change should have occurred in the survey area during the February 1996 flood. Similarly, if the rating was 'good', some change should have occurred, if 'fair' more change and if 'poor', even more change. The second assumption relates to how this change is measured. The unit used to measure the change is based on a difference in the rating score between two ratings. This difference is referred to as a 'notable' change in rating. For example, on Table 5, a notable change in rating for the Landform Slope category is 2, a notable change for the Upper Banks is 10, and a notable change for the survey total is 40.

Given the definition of a notable change, if the 1995 rating was good, the rating category could change (e.g. from good to fair) or not change, but the change in score must be at least ½ of a notable change in score (see Figure 11). For fair, a notable amount of change should have taken place. This is 40 points for the reach total score (Table 5). An even greater amount of change should be expected to occur in an area which was rated as 'poor' in 1995. This would be designated by having a 'notable' change of at least 1½ entire changes in rating.

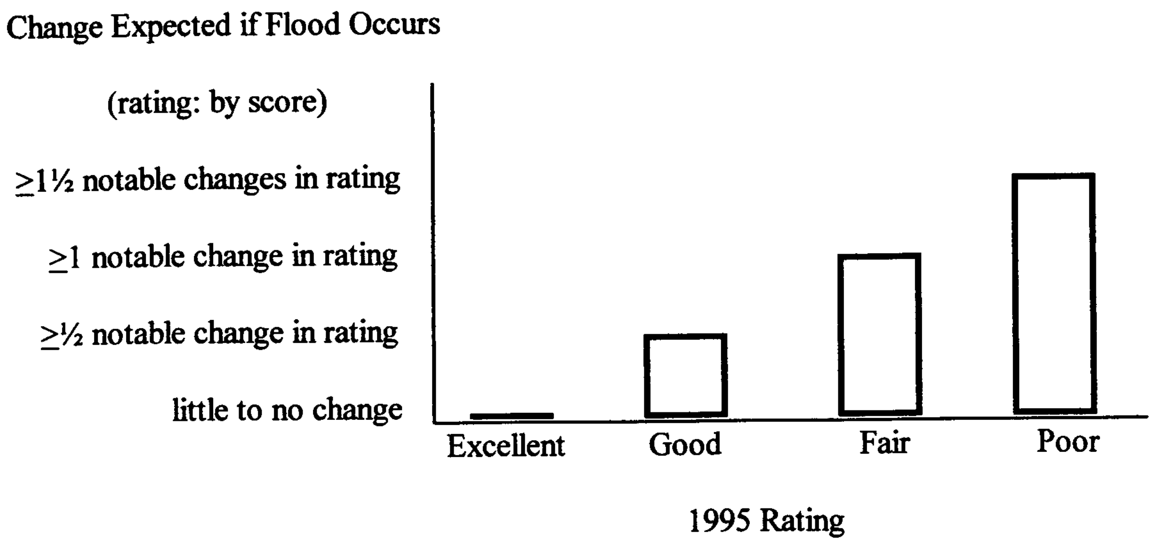


Figure 11. Expectation of Change for a Given Rating: The Change Model

Chapter 5

RESULTS

" 'Tis strange -but true; for truth is always strange; Stranger than fiction."
-Lord Byron, Don Juan

5.1 Predicted versus Actual Change in the Channel Stability Evaluation Totals

The 1995 and 1996 stream surveys were evaluated at 3 different spatial scales: reach, station and stream. The primary objective was to detect if the 1995 predicted change from the 1995 Channel Stability Evaluation (CSE) survey rating matched the actual change that occurred as a result of the flood. Using the change model, the predicted change is the expected change in score that should occur in the event of a flood for a given 1995 rating (Figure 11).

5.1.1 Change at the Reach Scale

In 1995, 16 of the reach predictions were rated 'fair', 4 were rated as 'good and 2 reaches were 'poor'. The predictions for each reach are shown in Figure 12. There were no reaches rated as 'excellent'.

Of the predictions made in 1995, only 1 reach, Reach 9, accurately predicted the change that occurred as the result of the flood. In 1995, Reach 9 was rated as 'good' which indicated that at least a ½ of a notable change should occur, which is 20 'points' for a reach total. A degradation in score of 25 points occurred, supporting the prediction.

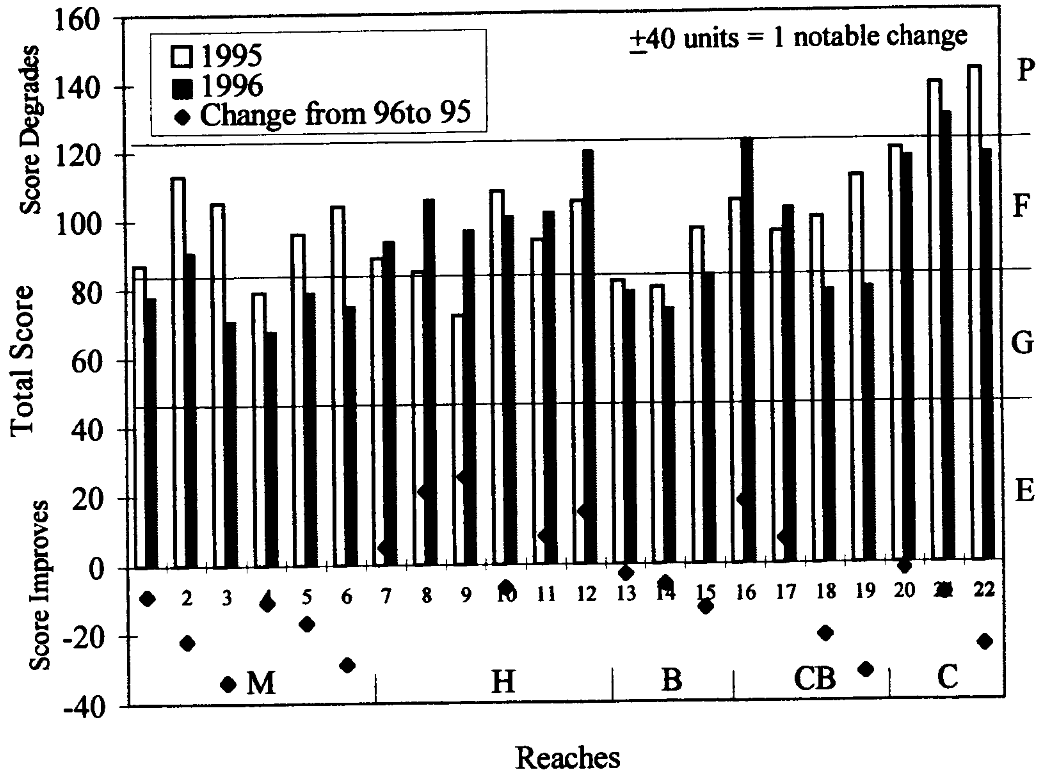


Figure 12. Change in Reach Total Scores

Another 9 reaches were off by ½ of a notable change in score. Reaches 2, 3, 4, 6, 8, 13, 14, 18 and 19 were all close to the predicted change. Reaches 2, 3, 6, 8, 18 and 19 were rated as 'fair' in 1995 which, given the change model, means that 1 notable change in score should occur if a flood hits. For these reaches at least ½ or more of a notable change in score occurred. Reach 8 had the only degradation in score between the 2 years. Reaches 4, 13 and 14 were rated as 'good' in 1995, which corresponds to a predicted change in total score of at least 20 points. The actual change was less than 20 points, which was off by ½ of a notable change in score. In all 3 reaches the rating improved after the flood.

Over the course of the stream, the reaches within the stations show similar trends between the two years. All of the reaches within the McDonald, Basalt and Campus stations have improved. All but one of the reaches in the Harr station have degraded. The Covered Bridge station is divided, where the two upstream reaches have degraded and the 2 downstream reaches improved. Overall, there are 15 improvements and 7 degradations from 1995 to 1996.

5.1.2 Change at the Station Scale

The reach totals within each station were used as mean reach scores to get a station total. The pre-flood and post-flood station total scores were compared between the pre-flood survey from spring of 1995 and the post-flood survey executed in 1996 and the difference between the two years was noted (Figure 13).

In 1995, McDonald, Harr, Basalt and Covered Bridge Stations had a 'fair" rating and Campus Station was rated as 'poor'. A 'fair' rating corresponds to an expected change of at least 40 points for a total score and a 'poor' rating should have an 60 point change. None of the station scores had a match between the predicted change and the actual change. McDonald Station did, however, come within ½ of a notable change (20 points). McDonald Station changed by 20.3 points.

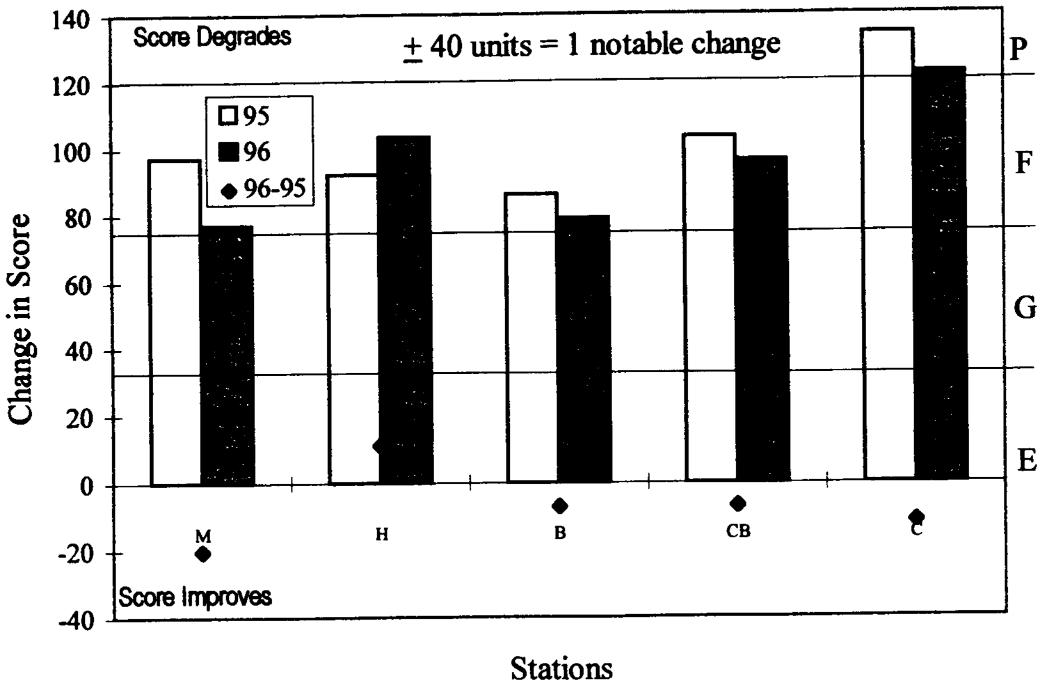


Figure 13. Change in Mean Total Scores for Stations

5.1.3 Change at the Stream Scale

In both 1995 and 1996 the rating for the entire stream was 'fair' (Figure 14). The predicted change was at least 1 notable change in score, or 40 points. The stream total improved by 6.36 points, which is 15.9% of the change that was expected to occur in the event of a flood.

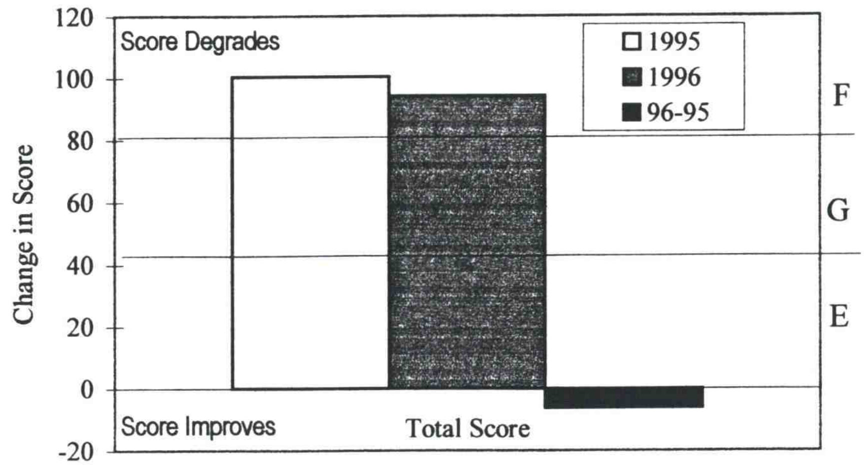


Figure 14. Change in Mean Total Scores for Stream

5.2 Change in the Sediment Distribution

The sediment size distribution displayed in Figures 15, 16, and 17 represents the changes between the pre-flood and post-flood Stream Reach Inventory (SRI) data for exposed bedrock (EB), large boulders (LB) >1 m, small boulders (SB) >30 cm, large cobble (LC) >15 cm, small cobble (SC) >8 cm, large gravel (LG) >3 cm, fine gravel (FG) >1 mm, and sand, silt and muck (SSM). Figure 15 represents the sediment distribution at the reach scale, Figure 16 is at the station scale and Figure 17 represents the stream scale. As the station and stream scales are functions of the reaches, the trends between the 3 figures are similar, but the range within a size category can vary considerably. As noted in the figures, the post-flood increase in fine material (<3 cm) and exposed bedrock was at the expense of material greater than 3 cm, particularly material in the small cobble (8 cm to 15 cm) size category.

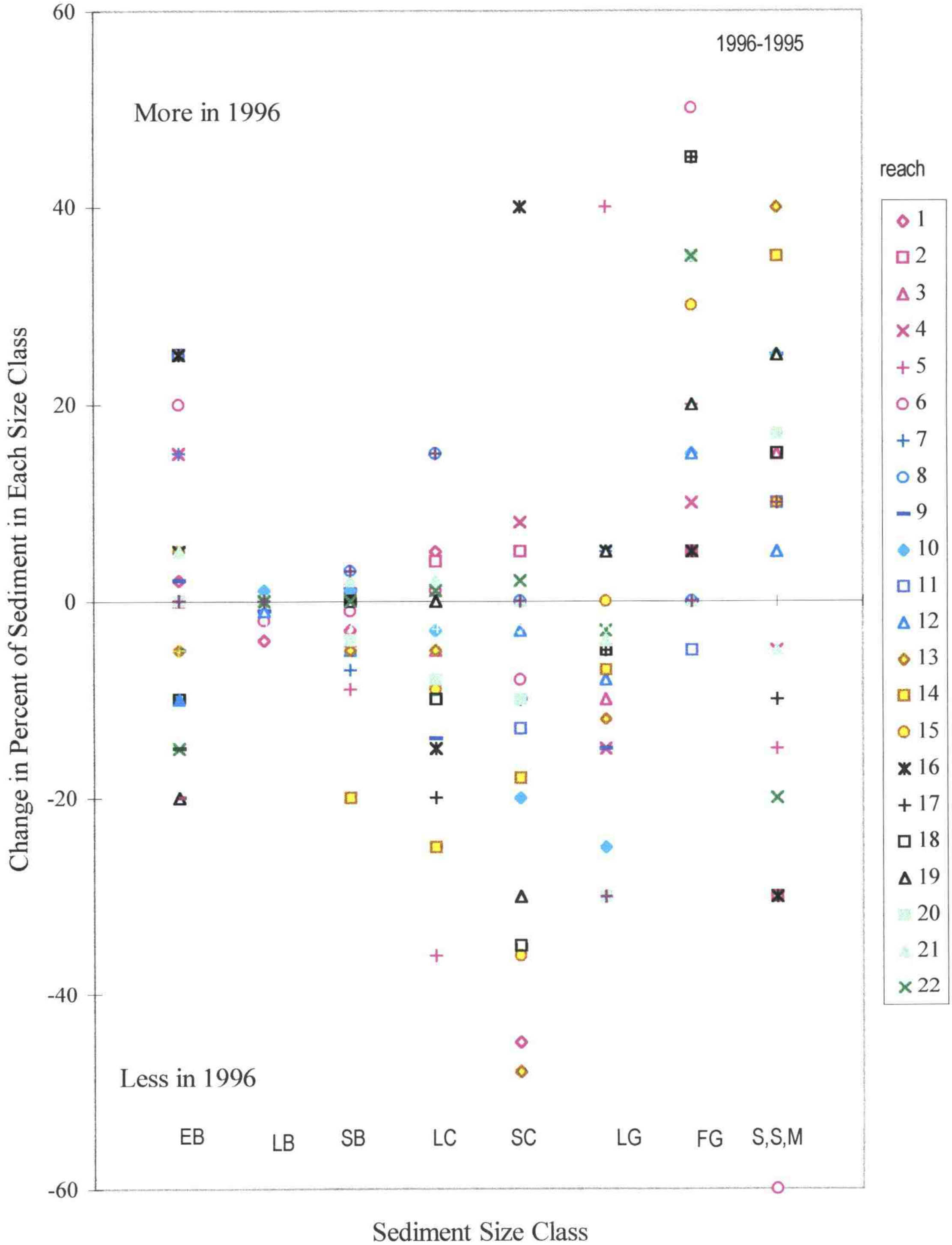


Figure 15. Change in Sediment Distribution for Reaches

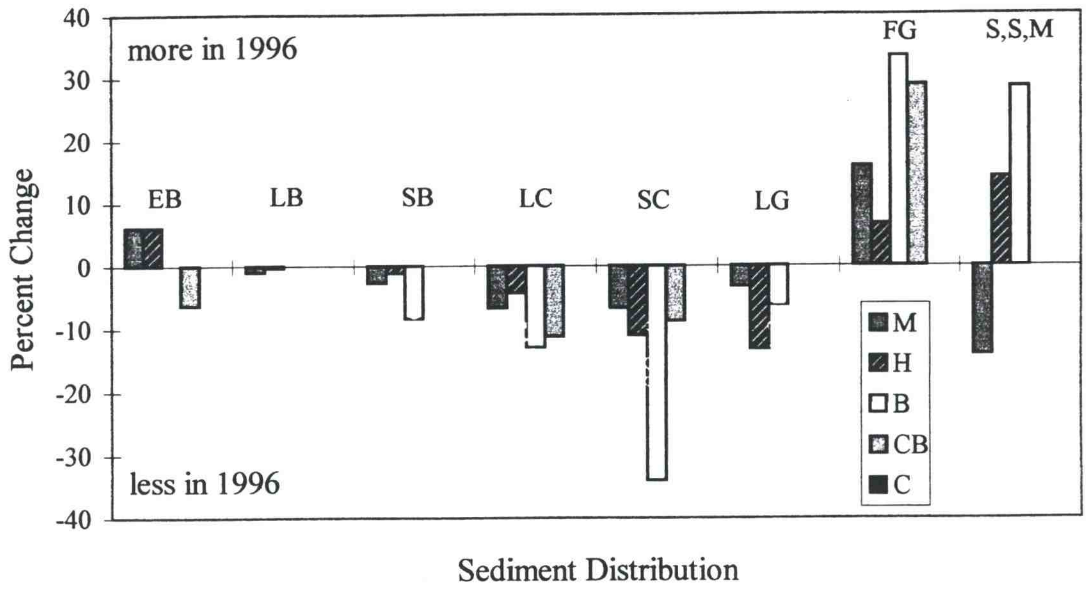


Figure 16. Change in Mean Sediment Size Distribution for all Reaches within Stations

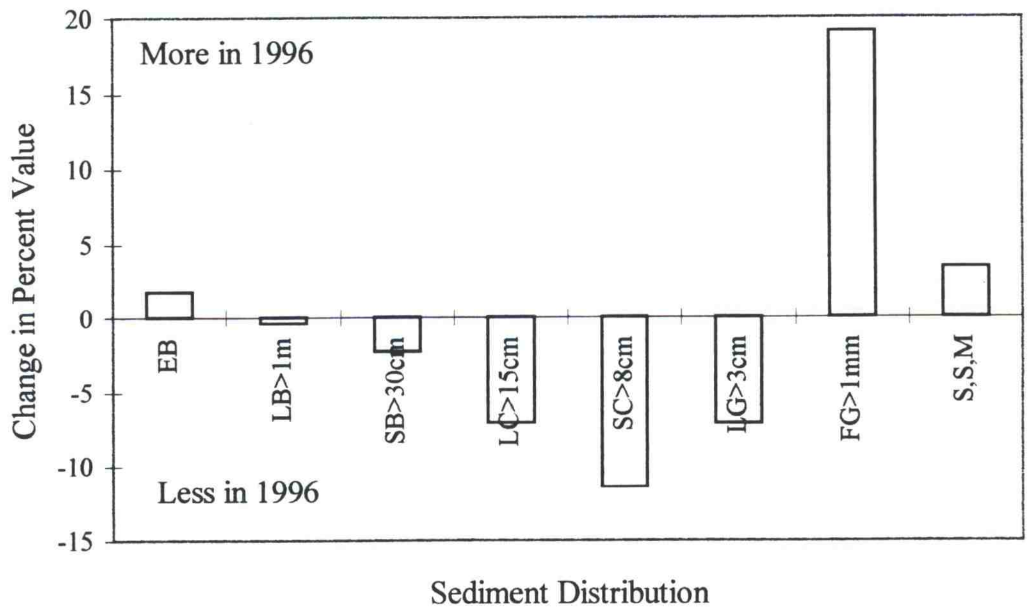


Figure 17. Change in Mean Sediment Distribution for all Reaches Averaged

5.2.1 Change at the Reach Scale

Changes in sediment distribution at the reach scale show a general trend of an increase in bedrock and sediment smaller than 3 cm, and an decrease in sediment greater than 3 cm (Figure 15). The range of change within each sediment size category varies greatly between reaches. This range of change is lowest for the large boulder category (1% gain to 4% loss) and greatest for the sand, silt and muck category (40% gain to 60% loss).

There is also a great diversity when following the path of a single reach. For example, reach 6 has a 50% increase in fine gravel (>1mm) and a 60% decrease in sand, silt and muck (<1mm), neighboring reaches within the same station do not have such a dramatic change between the two similar sediment sizes. Reach 21, on the other hand, stays very consistent between the two years within all of the sediment sizes, varying between -5 and 5% change.

The reaches are color coded by station to detect trends in similar reaches (Figure 15). Trends over all of the sediment sizes are difficult to detect although the general absence of a particular sediment size relates to a smaller distribution of change between the years. For example, there were few small boulders (>30cm) and fewer large boulders (>1m) in the surveyed regions of Oak Creek. These sediment sizes do not have much variation in change when compared to the other sizes. Trends within sediment sizes are much easier to detect.

In the exposed bedrock category, all of the reaches within the McDonald Station show an increase in bedrock exposure. Within the large boulder size only 5 reaches have any change. These reaches are in McDonald and Harrison stations. The small boulder and large cobble categories are similar in that all of the reaches in the Basalt and Covered Bridge stations have none to fewer of these sediment sizes in 1996 than they had before the flood in 1995. There is no change or less small cobble size material among the reaches in the Harr and Basalt stations. This category only had 4 reaches gain small cobble: 2M, 4M, 22C and 16CB, where 16CB appears to be an outlier. Only 3 reaches increased their large gravel content: 5M, 9H and 16CB, where 5M is an outlier. All of the other reaches showed no change or had less material in 1996. The fine grained sediment size category exhibited no change or an increase in 1996. Only reach 11H displayed a decrease in this size of sediment. The smallest size category, sand, silt and muck, had the largest diversity, and all of the reaches within the Basalt and Harr stations displayed an increase in this sediment size after the flood.

5.2.2 Change at the Station Scale

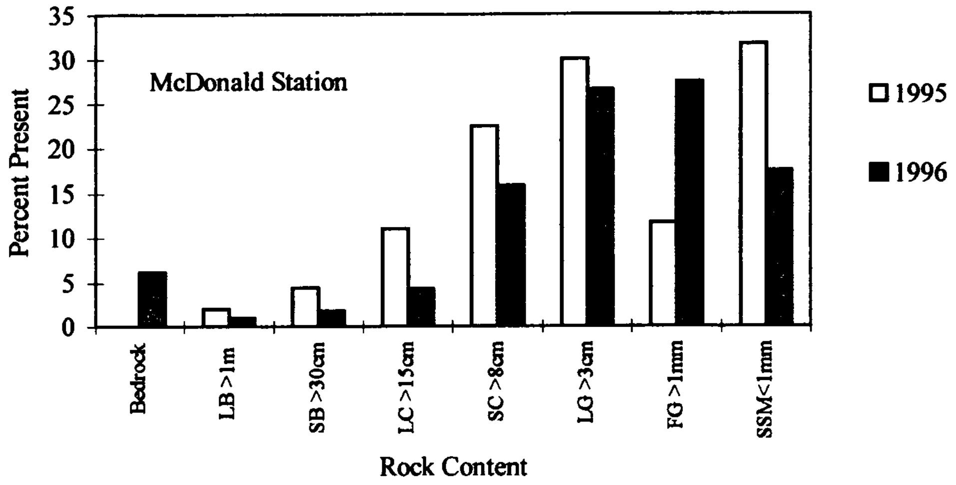
The changes at the station scale give information about sediment distribution which relates to the location in the watershed (Figure 2) and position on the river profile (Figure 3). The data represent the change in mean sediment distribution of 3 to 6 reaches within the stations. Most of the stations had a similar pattern of sediment distribution except for a few locations (Figure 16). The pattern is similar to the pattern exhibited in the reaches except that all of the sediment smaller than bedrock but greater than 3 cm either stayed the same or decreased after the flood, whereas the fine gravel (1 mm to 3 cm) increased. On average, the stations changed by the following amounts: McDonald, 7.1%; Harr, 7.2%; Basalt, 15.4%; Covered Bridge, 3.3%; and Campus, 5.8%.

The bedrock category is fairly evenly divided where the two stations upstream, McDonald and Harr, gained more bedrock (by 6.2% each). Basalt station displayed no change and the two downstream stations, Covered Bridge (6.3%) and Campus (3.3%), lost bedrock. There is little change in the large and small boulder categories due to the lack of presence of those sizes. The large boulders have a small decrease in the McDonald (1%) and Harr (0.33%) stations. The small boulder category also displays a small decreases in the McDonald (2.7%) and Harr (1.17%) stations and an 8.37% decrease in the Basalt station and a slight decrease in the Campus Station (0.67%). The large gravel decreases in all of the stations except Covered Bridge, which doesn't change. The changes by station are: McDonald, 3.3%; Harr, 13.3%; Basalt, 6.6%; and Campus, 12.3%. The trend of decrease changes to an increase in all of the stations in the fine gravel size category. Fine grained material at McDonald increased by 15.8%, Harr by 6.7%, Basalt by 33.3%, Covered Bridge by 28.3% and Campus by 23.3%. The last sediment size category, sand, silt and muck had both increases and decreases. The highest and lowest stations on the stream, McDonald (14.2%) and Campus (2.7%) both had less sand, silt and muck in 1996 than in 1995. There was no change in the Covered Bridge Station and there was an increase in sand, silt and muck in both the Harr (14.3%) and Basalt (2.7%) stations in the post-flood survey of 1996.

The trend of sediment distribution for each of the survey years and between survey years is represented in Figures 18a and 18b. These data represent change both within and between the stations. The stations are aligned in the figures from upstream to downstream.

The pattern within the stations shows that, in 1995, there is a bimodal distribution of sediment at the McDonald, Covered Bridge and Campus Stations, where the location of the first mode varies and the second mode is in the Sand, Silt and Muck category. In 1995, the initial mode of McDonald, Harr and Campus Stations peaks at the large gravel (>3 cm) sediment size and at the Basalt and Covered Bridge stations the mode peaks at the small cobble (>8 cm) category.

When viewing Figures 18a and 18b, there is an interesting trend between the two years. There is a trend between the initial mode of each of the stations in 1995 when compared to the 1996 peaks (disregard the bedrock for now), when viewed from upstream to downstream. The sediment distribution appears to shift toward the smaller sediment sizes from 1995 to 1996 for each of the stations. Overall, there appears to be a fining of material in the distribution of 1996 sediment from upstream to downstream as well. There is also more bedrock exposed at the two upstream stations and less bedrock exposed at the two downstream stations in the 1996 post-flood survey.



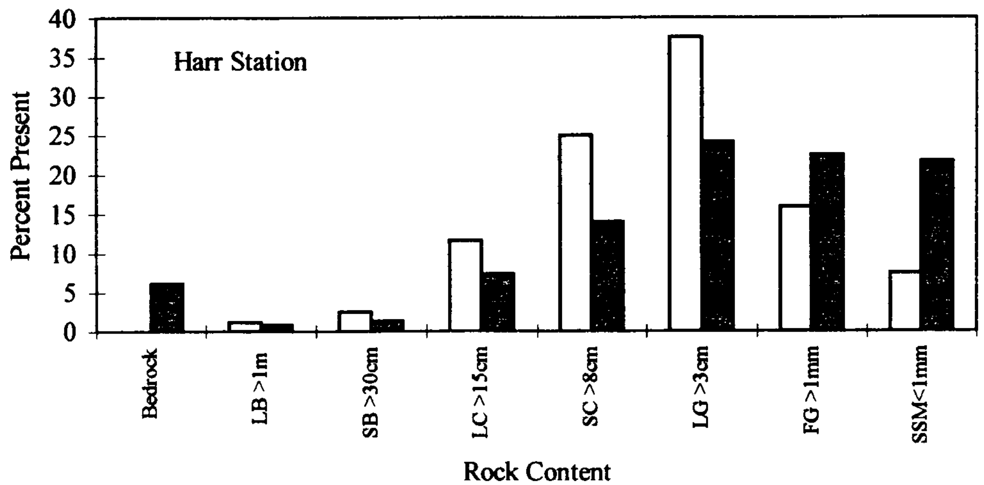


Figure 18a. Station Sediment Distribution

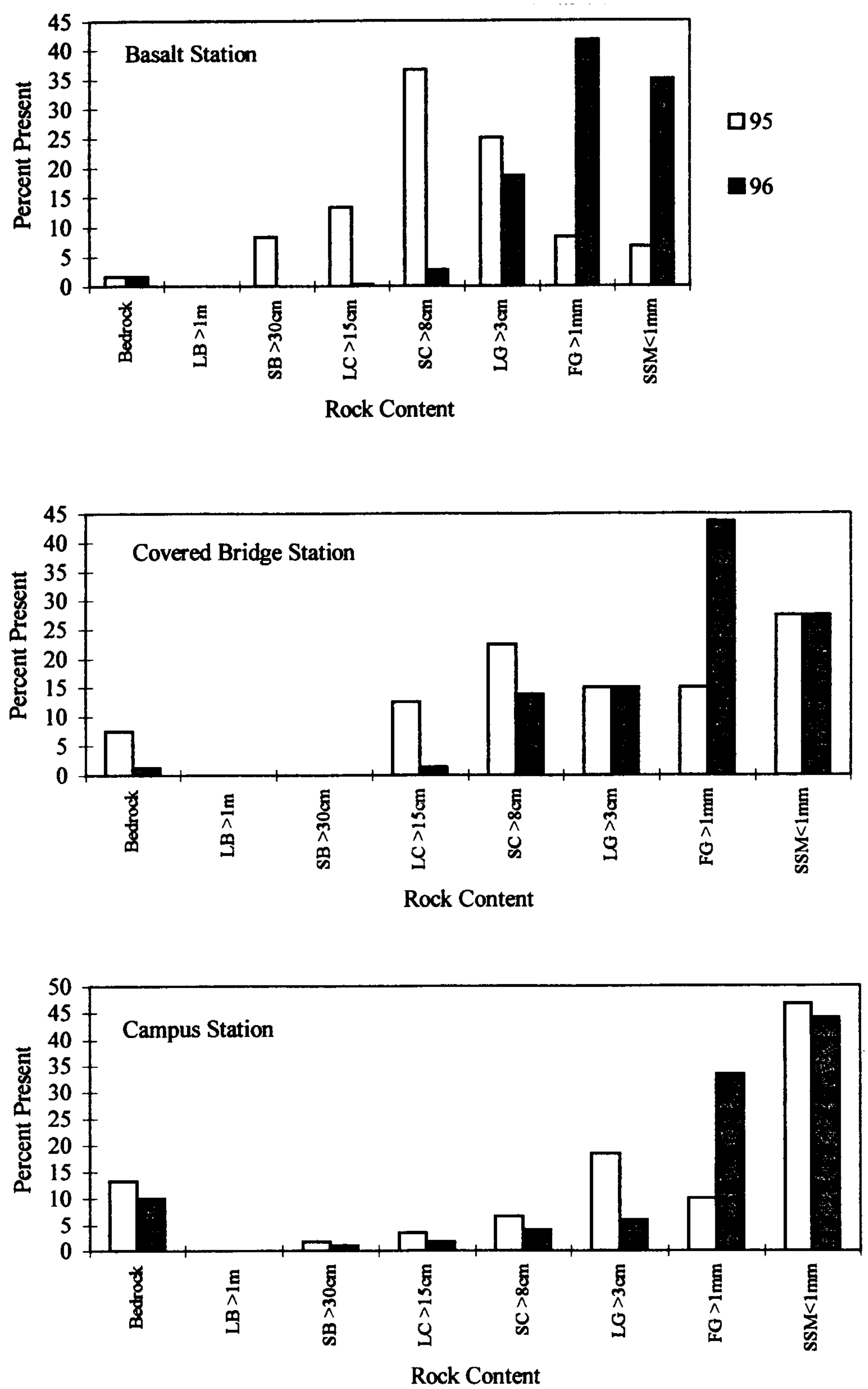


Figure 18b. Station Sediment Distribution

5.2.3 Change at the Stream Scale

The stream scale represents the averages of all of the reaches and is displayed in Figure 17. As noted, the trend reflects Figures 15 and 16. The mean change for the sediment sizes at the stream scale is as follows: large boulders decreased by 0.4%, small boulders by 2.3%, large cobbles by 7.1%, small cobbles by 11.4% and large gravel by 7.1%. Three sediment size categories displayed an increase after the February 1996 flood. Exposed bedrock increased by 1.7%, fine gravel by 19.1%, and sand, silt and muck increased by 3.5%.

5.3 Change in the Channel Stability Indicator Items

Change in the channel stability indicator items was also investigated at the reach, station and stream scales. Change was evaluated by distinguishing 'notable' changes (a complete change by one rating, either positive or negative).

5.3.1 Change at the Reach Scale

The channel stability indicator items experienced a diversity of change when viewed individually at the reach level. Table 8 displays the notable changes that occurred between 1995 and 1996. All of the reaches experienced some positive and some negative change for various CSI items. The magnitude of change varied from a degradation of 3 notable changes in score (Table 5) to an improvement of 3 notable changes. The changes by channel region are as follows:

	UPPER BANK				LOWER BANK					CHANNEL BOTTOM									
ITEM Station reach	LS	MW	DJP	VBP	CC	BRC	O, FD, ST	CUT	DEP	RA	C, PP	BSD %SM	S&D	MiB	MaB	number of improvements	number of degradations	items affected per reach (of 15)	Percent of items affected
M 1	+	-			-	+	+ +			+		+	-	-	+	6	4	10	67
2	+	-			-	+	+	+	-	+	+ +	+ +	+			8	3	11	73
3	+	+		+	-					+			+++			5	1	6	40
4		+			+			-			+	+	+ +	+	-	6	2	9	53
5					-		+	+	+				+	+	- -	5	2	7	47
6	+		+ +		+		+ +				- -	+	+ +	-	+	7	2	9	60
H 7	- -	-			-	+	+		-		+					3	4	7	47
8	-				-		+				+		-		- -	2	4	6	40
9	- - -		-		-			-	+		- -	+			- -	2	6	8	53
10	- -		+		-		+++		-		-			+	+ +	4	4	8	53
11	- - -		+ +		-				+		-		-			2	4	6	40
12	- -	-	-		- -			- -					+	-	- -	1	7	8	53
B 13		-	+ +		- -			-			- -		+	+	+ +	4	4	8	53
14			+ +		-		+				+		+		- -	4	2	6	40
15		+					+					+	+		-	4	1	5	33
CB 16	- -	- -			- -		- -	- -	-				+	+		2	6	8	53
17	- -	-			-			+				+		+	-	3	4	7	47
18	-	+			-		+ +	+	+ +			+	+ +	+	-	7	3	10	67
19	-				-		+		+ +			+ +	+ +	+		5	2	7	47
C 20			+		-	-			- -				+	-	+	3	4	7	47
21		-	-	+						+	+	+	+	-		5	3	8	53
22		-	+	+	-		+ +			+	+ +		+ +			6	2	8	53
# reaches improved	4	4	7	3	2	3	12	4	5	5	7	10	15	8	5				
# reaches degraded	10	9	3	0	18	1	1	5	5	0	5	0	3	5	9				
# reaches affected (of 22)	14	13	10	3	20	4	13	9	10	5	12	10	18	13	14				
percent reaches affected	64	59	46	14	91	18	59	41	46	23	55	46	82	59	64				

Table 8. Number of Notable Changes in CSI Items by Reach
(where + is one notable positive rating change, and - is one notable degradation in rating)

Upper Bank: The landform slope category had 4 improvements and 10 degradations. All of the improvements were in reaches in the McDonald station. All of the reaches in the Harr and Covered Bridge stations decreased by 1 to 3 notable changes. No changes in landform slope occurred in any of the reaches in the Basalt and Campus stations. Thirteen of the 22 reaches were affected by mass wasting. The mass wasting had improvements in reaches 3, 4, 15 and 18 and degradations in reaches 1, 2 7, 12, 13, 16, 17, 21 and 22. The debris jam potential category had 10 reaches improve and 3 reaches degrade. Reaches 6, 11, 13, and 14 had improvements by two notable changes and reaches 10, 20 and 22 improved by 1 notable change. Reaches 9, 12, and 21 had a negative change. Vegetative bank potential had the fewest changes of all of the CSI items. There were improvements on reaches 3, 21 and 22.

Lower Banks: The channel capacity had the most reaches affected of the CSI items. Improvements occurred on 2 of the reaches and 2 reaches experienced no change. a degradation in rating occurred on 18 reaches. This may be because flood debris was evident in 1996 and not in 1995, and the assessment was biased by this debris. The bank rock content category had improvements on reaches 1, 2, and 7 and a degradation on reach 20. Obstructions, flow deflectors and sediment traps improved on 12 reaches where reach 10 had 3 notable changes; reaches 1, 6, 18 and 22 had 2 notable improvements and reaches 2, 5, 7, 8, 14, 15, and 19 had 1 notable improvement. Reach 16 experience 2 notable degradations. The cutting and deposition categories had a fairly even division of improvements and degradations in score. The improvements to cutting were in reaches 2, 5, 17, and 18 and the degradations were in reaches 4, 9, 12, 13, and 16, where reaches 12 and 16 had 2 notable degradations. The improvements to deposition were in reaches 5, 9, 11, 18 and 19 and the degradations were in 2, 7, 11, 16, and 20, where reaches 18, 19, and 20 had 2 notable changes.

Channel Bottom: Rock Angularity improved in 5 reaches, reaches 1, 2 and 3 in the McDonald station and Reaches 21 and 22 in the Campus station. Consolidation and particle packing improved by two notable changes in reaches 2 and 22 and by one in reaches 4, 7, 8, 14 and 22. This category degraded by two notable changes in reaches 6, 9 and 13 and by one change in reaches 10 and 11. The bottom size distribution and percent stable material had improvements on almost half of the stream reaches. Reaches 2 and 19 had two notable changes and reaches 1, 4, 6, 9, 15, 17, 18 and 21 had one notable change. Scouring and deposition had change occur on 18 of the reaches where only reaches 1, 8 and 11 were negative. Reach 3 had three notable changes, reaches 4, 6, 18, 19, and 22 had two notable changes and reaches 2, 5, 12, 13, 14, 15, 16, 20 and 21 had one change. The microbedforms category degraded in reaches 1, 6, 12, 20 and 21 and improved in reaches 4, 5, 10, 13, 16, 17, 18, 19. The macrobedforms category degraded by two notable changes in reaches 5, 8, 9, 12, and 14 and by one change on reaches 4, 15, 17 and 18. Improvements were noted on reaches 1, 6, 10 and 13, where reaches 10 and 13 had two notable changes.

5.3.2 Change at the Station Scale

The changes in CSI items at the station scale did not have as many notable changes as at the reach scale (Table 9). Because the stream scale represents the average of 3 to 6 reaches and represents a particular position on the main channel, the notable changes will be described in detail. Notable changes are represented by bold numbers in Table 9 and ½ of a notable change is underlined.

	1996-1995 Channel Stability Indicator Item	Notable Change in Rating	McDonald	Harr	Basalt	Covered Bridge	Campus	Stream Total
	Upper Banks:							
1	Landform Slope	2	1.5	**-4.3**	0	**-3.3**	0	-1.4
2	Mass Wasting	3	-0. 7	-0.8	-0.3	-1	-2	-0.9
3	Debris Jam Potential	2	0.8	0.2	**2.7**	0.3	0. 7	0.8
4	Vegetative Bank Potential	3	0.5	0	0	-0.3	2	0.5
	Lower Banks:							
5	Channel Capacity	1	0.3	**1.2**	**1**	**1.3**	0. 7	-0.9
6	Bank Rock Content	2	0.8	0.3	0	0	-0.7	0.2
7	Obstructions/Flow Deflectors/Sediment Traps	2	**2.2**	1.5	1.3	0.8	2	0.5
8	Cutting	4	1	-2.3	-2	**-4**	1	-1.2
9	Deposition	4	0.8	-1.3	0	3	-2.7	0.1
	Channel Bottom:							
10	Rock Angularity	1	0.5	0	0	0	0.7	0.2
11	Consolidation/ Particle Packing	2	0.5	**-2.2**	-2	-0.3	**2**	-0.5
12	Bottom Size Distribution & % Stable Materials	4	**4.5**	1.7	2.7	**4.5**	2	3.1
13	Scouring and Deposition	6	**8.3**	-1.7	**6**	**7.5**	**8**	5.1
14	Micro Bedforms	2	0.2	0.5	0.7	**2**	-1.3	0.7
15	Macro Bedforms	2	-0.3	-1.5	-0.7	-1	0.7	0.7
	Totals:							
	Upper Banks	10	2.2	-5	2.3	-4.3	0.7	-1.1
	Lower Banks	13	4.5	-3	-1.7	-1.5	-1	-0.2
	Channel Bottoms	17	13.7	-3.2	0	12.8	12	7.7
	Survey Total	40	20.3	-11.2	7.3	7	11.7	6.4

Table 9. Change in CSI Items at the Station and Stream Scales
(bold indicates ≥1 notable change, underline indicates ≥1/2 of a notable change in rating)

McDonald: There were 3 notable changes at the McDonald station. Obstructions, flow deflectors and sediment traps went from between 'fair' and 'good' to being between 'excellent' and 'fair'. In 1995, the score indicated that the channel had moderately frequent obstructions with noticeable bank and bottom erosion and sediment accumulated behind obstructions. In 1996 there were fewer obstructions to the flow and less sediment traps, where some of the obstructions became embedded and no longer diverted flow into an erosional pattern. In particular, the 1995 score was lower because there were several small debris jams composed of beaver sticks (identified by teeth marks). The presence of these dams lower the score because they potentially increase damage when they break up. These dams were blown out in the February 1996 flood and so were not present in 1996.

In 1995, the bottom size distribution and percent stable materials category was rated as 'fair' and in 1996 it improved to 'good'. In 1995, the stable materials were thought to be 20 to 50% based on evidence of the stable material that was in the channel and the amount of change from the natural variation expected at that position in the watershed. In particular, there was a lot of sand, silt and muck, which is usually found lower in the watershed. In 1996, the stable materials increased to 50 to 80%.

The scouring and deposition went from fair in 1995 to good in 1996. In 1995, 30 to 50% of the bottom was in a state of flux and cutting took place below obstructions and at constrictions, the pool deposits of sand, silt and muck were filling the pools. In 1996, much of the obstructions and the sand, silt and muck was washed away. Cutting was only taking place only at constrictions and deposition occurred in the backwater areas. Five to 30% of the bottom was in a state of flux after the flood. In looking at the reaches within the station, all of the reaches improved except reach 1, which may be influenced by the sediment sampler. Reach 3 went from poor to excellent.

The total survey score improved from 1995 to 1996 from 'fair' to 'good' by ½ of a notable rating. The upper banks had a degradation within the good category by ½ of a notable change and the lower banks improved from fair to good by 34.6% of a complete rating change. The channel bottom improved by 80% of a notable rating from 'fair' to 'good'.

Harr: Landform slope degraded from 'excellent/good' to 'fair/poor' between the two surveys. In 1995, the slopes went from being about 30% to being about 60%. In looking at the reach data, all of the Harr reaches showed change, but the 3 reaches below the culvert, 10, 11 and 12 showed more change than the reaches above the culvert. In addition, the two reaches above the culvert and the 2 reaches below the culvert went to poor in 1996, indicating that the culvert might be influencing the slope during a flood.

The channel capacity was 'excellent' in 1995 and 'good' in 1996. In 1995, the channel was assessed as being able to contain the present peak volumes plus additional flow if needed. In 1996, the channel was thought to be able to contain most flows. The 1996 rating was based on citing flood debris outside the channel area, which was unavailable in 1995.

Consolidation and particle packing went from excellent to good. In 1995, it was difficult to dislodge the particles that compose the surface layer of the channel bed. In 1996, the material had been loosened by the flood and so was easier to dislodge.

The total score decreased within the 'fair' rating by about 28% of a rating change. The upper banks went from 'good' to 'fair' and had ½ of a notable rating change. the lower banks degraded within the 'fair' category by 23% of a complete rating change and the channel bottoms also remained in the 'fair' category and decreased by 17.6% of a notable change.

Basalt: four notable changes occurred at the Basalt station. The debris jam potential went from 'fair' to between 'excellent' and 'good'. In 1995, there was a noticeable accumulation of woody debris small enough for the river to float away in a flood. This debris was not present in 1996 because the flood washed it away, resulting in an improvement in the rating.

The channel capacity went from 'excellent' in 1995 to 'good' in 1996. Again, in 1995, the river was assessed as being able to contain most flows and then some, and in 1996, the evidence from the flood suggested that the channel couldn't contain the flood.

The consolidation and particle packing improved in the Basalt station from 'good/fair' to 'excellent/good'. Like Harr, the channel bed was more imbricated before the flood and then the flood disturbed the substrate, loosening the rocks.

The scouring and deposition went from 'good/fair' before the flood to 'excellent/good' after the flood. The affected length of scour and deposition as described for the McDonald station went from 30% of the channel to about 5% of the channel.

The total score improved from 'fair' to 'good' in category, but only by 18% of a rating change. The upper banks went from 'fair' to 'good' but 23% of a rating, the lower banks degraded within the 'good' category by 13% of a rating step and the channel bottom showed no change within the 'good' category.

Covered Bridge: There were 6 notable changes in rating at the Covered Bridge station, 1 on the upper banks, 2 on the lower banks and 3 on the channel bottom. The landslide slope category went from 'good/fair' to 'fair/poor'. In 1995, the side slopes were about 50% on 1 or both banks and, in 1996, the side slopes were about 60%. The cutting category indicates that the slopes may have been undercut in the flood causing steeper banks. The cutting went from 'good/fair' to 'fair/poor'. In 1995 there was intermittent to significant bank cutting at the reaches surveyed in this station which were approximately a foot high. After the flood, the 1996 surveys showed that there was considerably more cutting evident. The channel capacity went from 'excellent' to 'good/fair' for the same reasons listed in the Harr and Basalt stations.

The bottom size distribution and percent stable material went from 'fair/poor' to 'good/fair'. In 1995, a moderate to a pronounced shift in sized distribution was expected if a flood occurred where the stable materials were only about 20%. In 1996, a slight to moderate shift in sizes with about 50% stable material was expected likely due to the increase in fine gravel.

The scouring and deposition improved from 'fair/poor' in 1995 to 'good' in 1996. In 1995, moderate to common changes occurred on the channel bottom with about a 40% shift in materials. In 1996, the affected length was about 5 to 30%, there were fewer obstructions and cutting was only occurring at constrictions and deposition in backwater areas.

Microbedforms went from 'fair' to good' where in 1995 there were occasional groups of clasts, but not really an accumulation of clasts. In 1996, however, there were frequent groupings of clasts or loose rocks that had accumulated, but they were not packed tightly together.

The scores for the upper banks, lower banks, channel bottom and total score for the Covered Bridge station all stayed within the 'fair' category between 1995 and 1996. The total score had an improvement of 17.5% of a notable change, the upper banks degraded by 42.5%, the lower banks degraded by 11.5%, and the channel bottom improved by 75% of a notable change in rating.

Campus: This station had 3 notable changes between the pre-flood and post-flood surveys. Obstructions, flow deflectors and sediment traps went from 'fair' in 1995 to 'good' in 1996. Prior to the flood, there was moderately frequent, often unstable obstructions causing noticeable erosion in the channel with sediment accumulating behind obstructions. Most of these were washed out by the flood, leaving newer obstructions which are more likely to float off during high flow. There was also some sediment trapped in pools in 1996.

The consolidation and particle packing category improved from 'fair/poor' in 1995 to 'good/fair' in 1996. In 1995, the rocks on the channel bottom were loose without overlapping. In 1996, it was determined that these were slightly more packed. There were few rocks left greater that 3 cm in this region after the flood to use to assess this category.

Scouring and deposition also changed at the Campus station. The rating went from 'poor' to 'good/fair'. In 1995, both cutting a deposition were common on the channel bottom and it was noted that 50% of the bottom was moving during the year. In 1996, the bedrock increased and the sand, silt and muck decreased, raising the rating.

The campus station had the poorest overall score in both 1995 and 1996. In 1995, the rating was 'poor' and in 1996 the rating slightly improved to 'poor/fair' by 29.4% of a notable change in rating. The upper banks remained fair with an improvement of 6.7% of a notable rating change. The lower banks degraded by 7.7% and the channel bottoms improved by 70.6% of a notable rating change. This change was largely due to improvements in consolidation and particle packing and scouring and deposition.

5.3.3 Change at the Stream Scale

There was little change in channel stability item scores between the 1995 pre-flood survey and the 1996 post-flood survey when the reaches were averaged to get data at the stream scale (Table 9). There were no notable changes in CSI items. Figure 19 shows the mean CSI item scores for 1995 versus 1996. As displayed, there is a positive correlation between the pre-flood survey totals and the post-flood survey totals. The variables within the channel regions also averaged one another out over the course of the stream (Figure 20).

On the upper banks, the landform slope and the mass wasting categories degraded and the debris jam potential and the vegetative bank potential improved. The CSI items averaged each other out to some degree, and the change in score degraded by 11.4%.

The lower banks had the channel capacity and the cutting categories decrease and the bank rock content and the obstructions, flow deflectors and sediment traps categories increase. Deposition also increased, but only slightly. Although all 5 categories underwent change, the net result of all of this was a degradation in the lower bank score by 0.18% of a notable change in rating.

There was more change in the channel bottom and this change had a strong influence on the stream total score. The consolidation and particle packing and the macrobedforms categories degraded slightly between the years and the rock angularity and microbedforms slightly improved. The bottom size distribution and percent stable material and the scouring and deposition categories improved by 25% and 84.8% of a notable rating category change. Given these strong changes in rating and the fact that these categories are the most heavily weighted out of all of the variables, the channel bottom improved overall by 45.5% between 1995 and 1996. The channel bottom has the most weight of all of the three channel regions and therefore has the most influence of the stream total. The total stream rating improved by 15.9% but stayed within the 'fair' category for both years.

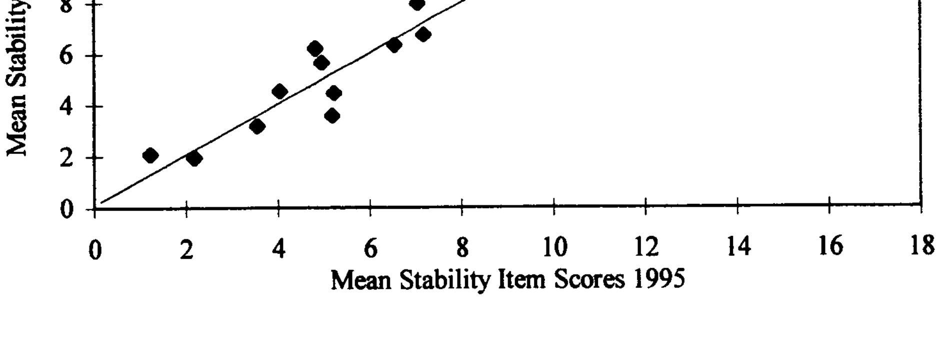
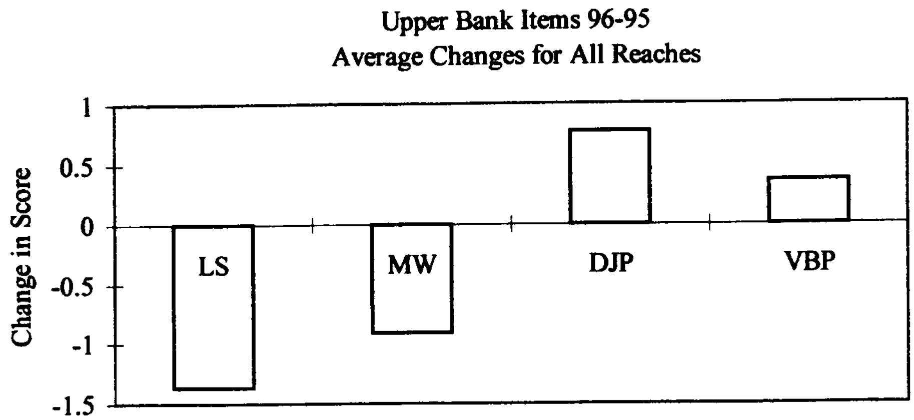
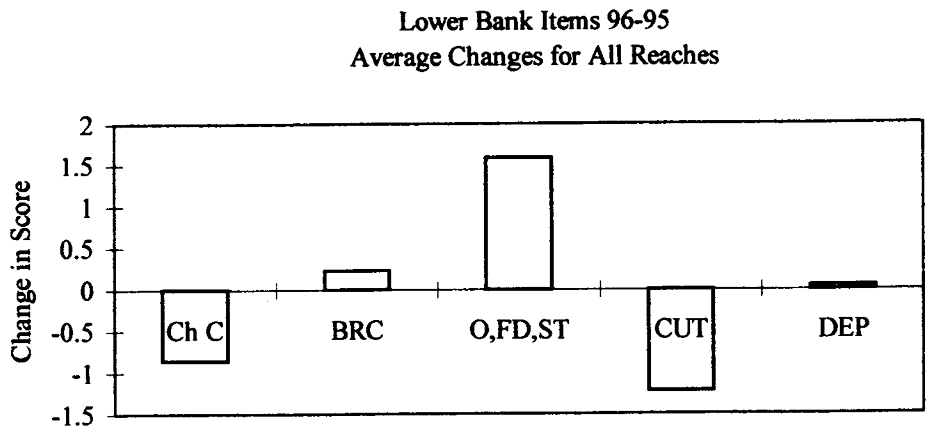


Figure 19. Change in Mean Channel Stability Indicator Item Scores on Oak Creek





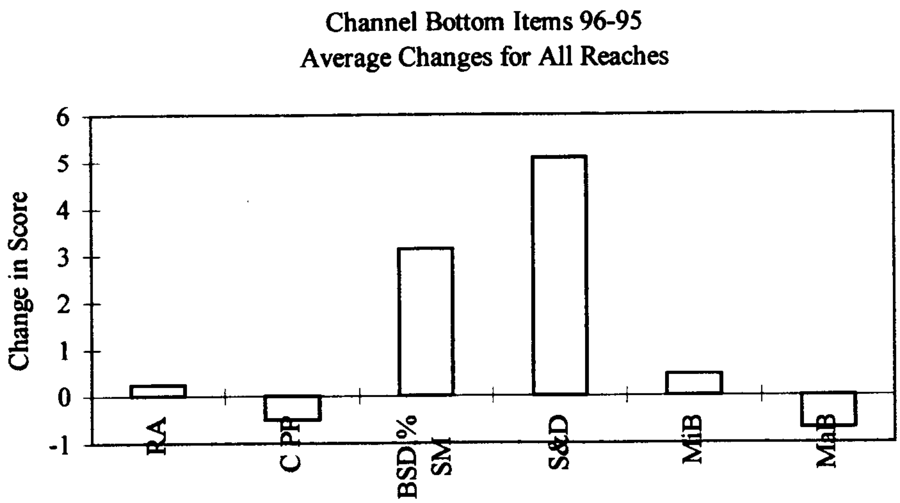


Figure 20. Change in Mean CSI Item Scores Within Channel Regions

Chapter 6

DISCUSSION

"Then she gets you on her wavelength
And she lets the river answer"
-Leonard Cohen, Suzanne

6.1 Evaluation of Change

In order to answer the question "Did the Stream Reach Inventory and Channel Stability Evaluation accurately predict the channel resistance to change in a flood on Oak Creek?", the question "Did the flood change the channel?" must first be addressed. This is addressed by noting the predicted versus actual change in the CSE survey totals, by noting the changes in sediment distribution, and by noting the changes to the channel stability indicator items before and after the flood. These changes are observed at the reach, station and stream scales to note, if change occurred, where and to what extent in each spatial scale it occurred.

6.1.1 Change in the Channel Stability Evaluation Survey Totals

The 'change model' (Figure 11), assumes that a better rating should have less change than a poor rating. Given this model, the pre-flood survey predictions should show up in the post-flood survey as corresponding changes in stream reach totals.

On the reach scale, 1 of 22 reaches (4.5%) accurately predicted the change that would occur. Another 8 reaches came within 1 rating category and therefore were off by

½ of a notable score. At the station scale, there were no stations that had a match between predicted change and actual change that occurred when using the model. There was one station that fell into a neighboring rating category. At the stream scale, the predicted change was not close to the actual change. The actual change was 15.9 % of the change that was predicted to occur in the event of a flood. While the predicted versus actual changes worked slightly better as the spatial scale decreased, overall the Channel Stability Evaluation was not able to accurately predict changes in the channels ability to resist detachment to bed and bank material when this resistance is evaluated as changes in the CSE survey totals.

There may be several reasons that the total scores did not accurately predict change on Oak Creek. The first reason is that the survey was made for mountain streams and 73% of the reaches in this study are in the lowlands. The second is that sometimes there are two variables to consider in one channel stability item category and sometimes these variables are not compatible. For example, in the Bottom Size Distribution and Percent Stable Materials category (see Figure 1), the rating selection has two variables, one based on the change of size of the bed material and one is a percentage of the stable materials. On Oak Creek, the individual variables did not always fall into the same rating category. Since there was only one combination available per rating, a compromise had to be made.

Another reason the survey method was found to be unreliable in this study may be based on the model used to predict change and on the subjectivity of the survey method. Subjective reasoning is behind the assumption that there would be a notable change in the channel given a 'fair' rating. There is nowhere in the actual survey manual that gives an 'expectation' for a given rating. The survey is an ocular survey and interpreting the data that goes into the survey is also subjective.

It is possible that the survey may be sensitive on this watershed is because of the geology. Oak Creek is clay-rich along the length of the surveyed reaches. The survey does not mention clay in any of the CSI items assessed. It is possible that the clay has an influence on the channel stability that is not accounted for in the survey. Clay is carried by water as small particles. It acts like an adhesive and rocks and twigs stick to it and in it. A bedrock of granite or sandstone will interact with the stream differently from a weathered basalt (clay) bedrock. Also, it is possible that what sometimes appears to be a homogenous bedrock unit may be an accumulation of clay sized sediment transported from upstream.

6.1.2 Change in the Sediment Distribution

The trends between the reach, station and stream scales were similar but the different scales gave different types of information. The reach scale gave information on the magnitude and diversity of change. For example, the change in large boulder ranges are similar in both the reach (1% to -4%), station (0 to 1%) and the stream (-0.36%) sediment distribution data. However, the Sand, Silt and Muck category has a reach range which depicts a change in percent value from 40% to -60%, yet has a stream average of 3.5%. It is difficult to judge the diversity of change throughout the stream by looking at the stream totals, yet it is useful to know the mean change in sediment distribution in order to evaluate the impact of the flood over the stream. The station data are useful to evaluate trends at a local level and over the stream.

In general, particularly at the station and stream level, there was an increase in fine material (<3 cm) and exposed bedrock in the 1996 post-flood survey when compared to the 1995 pre-flood survey. Sediment greater than 3 cm, particularly small cobble (8 cm to 15 cm), decreased. There was also more bedrock exposed at the two upstream stations and less bedrock exposed at the two downstream stations, indicating scour at the upstream end. Overall, there was a fining of material at each of the stations, although McDonald and Campus lost some sand, silt and muck. Sediment size also decreased from the head to the mouth. The most notable change was an increase in fine gravel. Only one reach experienced a decrease in fine gravel.

The increase in fine gravel may be a result of the armour layer being disturbed during the storm and exposing the finer material beneath; the sand, silt and muck would likely have been flushed out in the suspended load during such high flows. It is a well known phenomena that an armour layer can be scoured during a flood, the sand and gravel removed, and the bed will rearmour on the falling limb of the hydrograph.

Fine gravel may also have been contributed from the upper bank region. In every station, the 1995 Mass Wasting scores predicted that the upper banks would deliver sediment to the system if a flood event occurred. As a general rule, sediment is moved in pulses during floods from areas higher in the watershed to areas lower in the watershed. The increase in fine grained material may reflect a natural deposition of sediment delivered from lower order streams in the basin.

6.1.3 Change in the Channel Stability Indicator Items

Diversity of change in the channel stability indicator items was highest at the reach scale and lowest at the stream scale. Each reach had from 5 to 11 of the channel stability items incur a notable change. Often these changes were greater than one notable change (see Table 8). The stations had between 2 to 6 of the CSI items change notably. The average was 3.2 notable changes per station out of 15 possible, or 21.3%, which is less than half of the changes that took place at the reach scale. At the stream scale, no notable changes took place.

The variability and diversity of change of the individual channel stability indicator items at the reach versus stream scale provide some insight into how the flood impacted the stream. While there were local changes, overall, these changes balanced each other out over the course of the stream and the channel did not change its general character. The channel maintained a diversity among the CSI items before and after the flood, over the course of the stream. As the physical characteristics of the stream influence the stream habitat, maintaining diversity is important to resource managers.

A common way to measure change to the channel is to measure change in a cross-section. The cross-section can be mimicked by the CSI items: landform slope and mass wasting (upper bank), cutting and deposition (lower bank), and scouring and deposition and by observing change in the sediment size distribution (channel bottom). In looking at these components which mimic the stream cross-section, little change occurred to the banks, yet the channel bottom underwent change.

Chapter 7

SUMMARY AND CONCLUSIONS

"A dreamer is one who can only find his way by moonlight, and his punishment is that he sees the dawn before the rest of the world."

-Oscar Wilde, The Critic as Artist

7.1 Summary and Conclusions

Pre-flood (1995), and post-flood (1996) channel stability surveys were conducted on 22 reaches on Oak Creek, Benton County, Oregon, to determine if the flood of February 1996 altered the channel and if the channel stability survey accurately predicted the channels resistance to change in a flood in this region when 'put to the test' in an actual flood event. This was a non-parametric study based on the opportunity to reoccupy survey locations following a major transport event. The channel stability survey that was used was the method described in the "Channel Stability Evaluation and Stream Reach Inventory" designed by the USDA Forest Service, Region 10 in Colorado.

In order to assess change in the channel, a model was proposed that assigned a 'predicted change' to each rating that was given in the pre-flood survey. The predicted change was the change that was expected to occur if a major transport event occurred. The predicted change was compared to the actual change to see if the survey accurately predicted change. The difference in survey scores between the two years was used to assess change. The change in survey scores, sediment size distribution and change in the channel stability indicator items were evaluated. All evaluations of change were conducted at the reach, station, and stream scales.

The descriptive statistics used indicate that, while the Channel Stability Evaluation had little predictive ability, the overall scores remain similar to the total values originally examined. At any given reach, specific inventory items varied in their significance, but the overall scores remained remarkably consistent. The individual channel stability indicator items varied substantially at the reach scale, yet they cancelled one another out in the survey totals, at all scales when change between the years was compared. On average, 51% of the individual channel stability indicator items in each of the reaches were affected by a change of at least one rating scale on the survey. Given the view that these reaches are spread over the stream, a fair amount of change occurred on the stream. However, the sum of these changes evened out when viewed as a mean channel stability resistance score showing that relatively little change occurred to the resistance of the channel to the detachment of bed and bank material. Overall, there was a fining of sediment after the flood and, in particular, an increase in fine gravel.

The hypothesis for this study is "The Stream Reach Inventory and Channel Stability Evaluation was unable to accurately predict the channel's adjustment to and recovery from changes in flow and/or increases in sediment delivery." In 1995, the channel was rated as 'fair', indicating that a fair amount of change should take place if a flood occurred. A fair amount of change did take place when looking at individual physical components at each reach, yet the sum of those changes was similar in both years at the reach level and at the stream level, indicating that the stream maintained its physical diversity and did not change overall. Given that, the hypothesis is correct when viewed over the stream level, yet may not be correct at the reach level when viewing specific changes.

The fact that the stream has maintained its physical diversity is interesting in the context of aquatic habitat and aquatic ecosystem recovery from hydrologic disturbance. Diversity of aquatic habitat has a positive relationship to species diversity. Disturbance provides habitat diversity which aids in maintaining community structure where community structure is controlled by the interaction between disturbance and patchiness (Anderson, 1992; Reice, 1994).

Patchiness is essential to ecosystem recovery from hydrologic disturbance at many spatial scales. At the reach scale, refugia might include woody debris or pools, whereas at the watershed scale, aquatic biota recovery is partially dependent on the juxtaposition of unimpacted reaches (Sedell et al., 1990). As noted earlier, the reaches in this study underwent a great deal of change that varied between reaches. Even if refugia could not be found within some of the reaches, it is likely that it could be found elsewhere on the stream. Overall, the diversity was maintained, indicating that species richness should be maintained following the hydrologic disturbance on Oak Creek.

While this study has interesting implications, the results presented only apply to Oak Creek in relation to the February 1996 flood event. The Stream Reach Inventory and Channel Stability Evaluation was designed for observational efficiency and may not have sufficient scientific basis in this region or measurement precision to accurately predict the type or extent of channel change. Further, the evaluation may be sensitive to lowland watersheds as it was designed for mountain streams and it may be sensitive to the high clay content in the stream.

7.2 Significance of Results

The Channel Stability Evaluation and Stream Reach Inventory is used in 60% of all National Forests (Myers and Swanson, 1996) and in other studies. It is one of the few surveys that looks specifically at estimating channel stability and may seldom be questioned. Given the results of this study, users of this survey should run a pilot study in their region before committing to the survey for long term studies or before using the survey as a basis in management decisions. Both the survey and the interpretation of the survey are subjective and the results can be altered by the surveyors and by the location of the surveys. Cross-sections, mass-wasting pegs, and photo-documentation should be taken as soon as possible in order to quantitatively show change to the channel if a flood occurs.

7.3 Recommendations for Future Research

Future research should be directed at designing a channel stability evaluation that is more universally adaptable to different types of rivers in differing areas. Such a Universal Channel Stability Survey could take years to develop and it would be difficult to test because large flood events are, theoretically, infrequent.

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APPENDICES

Appendix A

Channel Stability and Sediment Distribution Data, 1995

Item Rated	Reach:	1M/95	2M/95	3M/95	4M/95	5M/95	6M/95
Landform Slope 95		4.	4.	6.	2.	3.	4.
Mass Wasting or Failure 95		3.	6.	9.	3.	6.	6.
Debris Jam Potential (floatable objects) 95		4.	6.	4.	6.	4.	6.
Vegetative Bank Potential 95		3.	3.	6.	3.	3.	3.
Channel Capacity 95		1.	1.	1.	3.	1.	2.
Bank Rock Content 95		8.	8.	4.	6.	8.	8.
Obstructions, Flow Deflectors, Sed Traps 95		8.	4.	4.	4.	5.	6.
Cutting 95		12.	16.	6.	6.	12.	6.
Deposition 95		8.	8.	8.	4.	12.	8.
Rock Angularity 95		2.	3.	3.	2.	2.	2.
Consolidation or Particle Packing 95		4.	6.	6.	4.	4.	2.
Bottom Size Distribution and % Stable Materials 95		12.	12.	12.	8.	8.	16.
Scouring and Deposition 95		6.	24.	24.	18.	18.	24.
Micro Bedforms 95		4.	10.	6.	8.	8.	5.
Macro Bedforms (bars) 95		8.	2.	6.	2.	2.	6.
Total Score 95		87.	113.	105.	79.	96.	104.
Upper Banks 95		14.	19.	25.	14.	16.	19.
Lower Banks 95		37.	37.	23.	23.	38.	30.
Channel Bottom 95		36.	57.	57.	42.	42.	55.
Exposed Bedrock (%) 95		0.	0.	0.	0.	0.	0.
Large Boulders >1m (%) 95		5.	0.	5.	0.	0.	2.
Small Boulders >30cm (%) 95		5.	0.	5.	5.	10.	2.
Large Cobbles >15cm (%) 95		5.	0.	10.	10.	40.	1.
Small Cobbles >8cm (%) 95		65.	5.	35.	10.	10.	10.
Large Gravel >3cm (%) 95		65.	25.	30.	40.	10.	10.
Fine Gravel >1mm (%) 95		5.	20.	10.	15.	10.	10.
Sand, silt, muck (%) 95		10.	70.	5.	20.	20.	65.

Item Rated	7H/95	8H/95	9H/95	10H/95	11H/95	12H/95
Reach:						
Landform Slope 95	2.	6.	2.	4.	2.	2.
Mass Wasting or Failure 95	9.	3.	8.	12.	9.	6.
Debris Jam Potential (floatable objects) 95	5.	4.	4.	4.	8.	6.
Vegetative Bank Potential 95	3.	3.	3.	3.	3.	3.
Channel Capacity 95	1.	1.	1.	1.	1.	1.
Bank Rock Content 95	4.	8.	6.	6.	8.	5.
Obstructions, Flow Deflectors, Sed Traps 95	6.	6.	4.	8.	3.	8.
Cutting 95	12.	4.	4.	16.	12.	6.
Deposition 95	8.	12.	4.	8.	12.	12.
Rock Angularity 95	2.	2.	2.	2.	2.	2.
Consolidation or Particle Packing 95	2.	2.	2.	2.	2.	4.
Bottom Size Distribution and % Stable Materials 95	12.	12.	12.	8.	8.	12.
Scouring and Deposition 95	12.	12.	12.	18.	12.	24.
Micro Bedforms 95	6.	6.	6.	8.	7.	10.
Macro Bedforms (bars) 95	5.	4.	2.	8.	5.	4.
Total Score 95	89.	85.	72.	108.	94.	105.
Upper Banks 95	19.	16.	17.	23.	22.	17.
Lower Banks 95	31.	31.	19.	39.	36.	32.
Bottom 95	39.	38.	36.	46.	36.	56.
Exposed Bedrock (%) 95	0.	0.	0.	0.	0.	0.
Large Boulders >1m (%) 95	3.	2.	1.	0.	0.	1.
Small Boulders >30cm (%) 95	10.	0.	0.	0.	0.	5.
Large Cobbles >15cm (%) 95	25.	5.	15.	5.	10.	10.
Small Cobbles >8cm (%) 95	40.	20.	15.	25.	20.	30.
Large Gravel >3cm (%) 95	15.	50.	30.	50.	45.	35.
Fine Gravel >1mm (%) 95	5.	20.	30.	10.	20.	10.
Sand, silt, muck (%) 95	5.	5.	10.	10.	5.	10.

Item Rated	13B/95	14B/95	15B/95
Reach:			
Landform Slope 95	8.	8.	8.
Mass Wasting or Failure (existing or potential) 95	6.	6.	6.
Debris Jam Potential (floatable objects) 95	6.	6.	6.
Vegetative Bank Potential 95	3.	3.	3.
Channel Capacity 95	1.	1.	1.
Bank Rock Content 95	6.	4.	7.
Obstructions, Flow Deflectors, Sediment Traps 95	2.	4.	6.
Cutting 95	6.	6.	6.
Deposition 95	4.	8.	8.
Rock Angularity 95	2.	2.	2.
Consolidation or Particle Packing 95	4.	2.	4.
Bottom Size Distribution and % Stable Materials 95	10.	10.	12.
Scouring and Deposition 95	12.	12.	18.
Micro Bedforms 95	6.	6.	6.
Macro Bedforms (bars) 95	6.	2.	4.
Total Score 95	82.	80.	97.
Upper Banks 95	23.	23.	23.
Lower Banks 95	19.	23.	28.
Bottom 95	40.	34.	46.
Exposed Bedrock (%) 95	5.	0.	0.
Large Boulders >1m (%) 95	0.	0.	0.
Small Boulders >30cm (%) 95	5.	20.	0.
Large Cobbles >15cm (%) 95	5.	25.	10.
Small Cobbles >8cm (%) 95	50.	20.	40.
Large Gravel >3cm (%) 95	25.	20.	30.
Fine Gravel >1mm (%) 95	5.	10.	10.
Sand, silt, muck (%) 95	5.	5.	10.

Item Rated	16CB/95	17CB/95	18CB/95	19CB/95
Reach:				
Landform Slope 95	3.	4.	4.	6.
Mass Wasting or Failure (existing or potential) 95	6.	6.	9.	9.
Debris Jam Potential (floatable objects) 95	8.	6.	4.	4.
Vegetative Bank Potential 95	3.	3.	3.	3.
Channel Capacity 95	1.	1.	1.	1.
Bank Rock Content 95	6.	6.	6.	8.
Obstructions, Flow Deflectors, Sediment Traps 95	2.	6.	6.	4.
Cutting 95	8.	8.	8.	12.
Deposition 95	8.	8.	12.	12.
Rock Angularity 95	2.	2.	2.	2.
Consolidation or Particle Packing 95	6.	4.	3.	4.
Bottom Size Distribution and % Stable Materials 95	14.	12.	12.	16.
Scouring and Deposition 95	24.	18.	18.	18.
Micro Bedforms 95	8.	8.	8.	8.
Macro Bedforms (bars) 95	6.	4.	4.	5.
Total Score 95	105.	96.	1.	112.
Upper Banks 95	20.	19.	20.	22.
Lower Banks 95	25.	29.	33.	37.
Bottom 95	60.	48.	47.	53.
Exposed Bedrock (%) 95	0.	0.	10.	20.
Large Boulders >1m (%) 95	0.	0.	0.	0.
Small Boulders >30cm (%) 95	0.	0.	0.	0.
Large Cobbles >15cm (%) 95	20.	20.	10.	0.
Small Cobbles >8cm (%) 95	10.	10.	35.	35.
Large Gravel >3cm (%) 95	15.	15.	15.	15.
Fine Gravel >1mm (%) 95	15.	15.	15.	15.
Sand, silt, muck (%) 95	40.	40.	15.	15.

Item Rated Reach:	20C/95	21C/95	22C/95
Landform Slope 95	8.	8.	8.
Mass Wasting or Failure (existing or potential) 95	9.	9.	9.
Debris Jam Potential (floatable objects) 95	6.	4.	4.
Vegetative Bank Potential 95	6.	6.	6.
Channel Capacity 95	1.	3.	1.
Bank Rock Content 95	6.	8.	8.
Obstructions, Flow Deflectors, Sediment Traps 95	6.	6.	6.
Cutting 95	16.	12.	16.
Deposition 95	4.	16.	16.
Rock Angularity 95	2.	3.	3.
Consolidation or Particle Packing 95	6.	8.	8.
Bottom Size Distribution and % Stable Materials 95	12.	16.	16.
Scouring and Deposition 95	24.	24.	24.
Micro Bedforms 95	6.	8.	10.
Macro Bedforms (bars) 95	8.	8.	8.
Total Score 95	120.	139.	143.
Upper Banks 95	29.	27.	27.
Lower Banks 95	33.	45.	47.
Bottom 95	58.	67.	69.
Exposed Bedrock (%) 95	5.	15.	20.
Large Boulders >1m (%) 95	0.	0.	0.
Small Boulders >30cm (%) 95	5.	0.	0.
Large Cobbles >15cm (%) 95	10.	0.	0.
Small Cobbles >8cm (%) 95	15.	5.	0.
Large Gravel >3cm (%) 95	40.	10.	5.
Fine Gravel >1mm (%) 95	15.	10.	5.
Sand, silt, muck (%) 95	10.	60.	70.

Appendix B

Channel Stability and Sediment Distribution Data, 1996

Item Rated	1M/96	2M/96	3M/96	4M/96	5M/96	6M/96
Reach:						
Landform Slope 96	2.	2.	4.	2.	2.	2.
Mass Wasting or Failure 96	6.	9.	6.	6.	6.	4.
Debris Jam Potential (floatable objects) 96	3.	6.	5.	6.	3.	2.
Vegetative Bank Potential 96	3.	3.	3.	3.	3.	3.
Channel Capacity 96	2.	2.	2.	2.	2.	1.
Bank Rock Content 96	5.	6.	4.	6.	8.	8.
Obstructions, Flow Deflectors, Sed Traps 96	4.	2.	4.	3.	3.	2.
Cutting 96	10.	12.	6.	12.	6.	6.
Deposition 96	5.	12.	8.	4.	8.	6.
Rock Angularity 96	1.	2.	2.	2.	2.	2.
Consolidation or Particle Packing 96	4.	2.	5.	2.	4.	6.
Bottom Size Distribution and % Stable Materials 96	8.	4.	5.	4.	10.	10.
Scouring and Deposition 96	12.	18.	6.	6.	10.	12.
Micro Bedforms 96	7.	8.	6.	6.	6.	7.
Macro Bedforms (bars) 96	6.	3.	5.	4.	6.	4.
Total Score 96	78.	91.	71.	68.	79.	75.
Upper Banks 96	14.	20.	18.	17.	14.	11.
Lower Banks 96	26.	34.	24.	27.	27.	23.
Channel Bottom 96	38.	37.	29.	24.	38.	41.
Exposed Bedrock (%) 96	2	0	0	15	0	20
Large Boulders >1m (%) 96	1	0	5	0	0	0
Small Boulders >30cm (%) 96	2	1	5	1	1	1
Large Cobbles >15cm (%) 96	10	4	5	1	4	2
Small Cobbles >8cm (%) 96	20	10	35	18	10	2
Large Gravel >3cm (%) 96	35	20	20	25	50	10
Fine Gravel >1mm (%) 96	10	25	15	25	30	60
Sand, silt, muck (%) 96	20	40	20	15	5	5

Item Rated	7H/96	8H/96	9H/96	10H/96	11H/96	12H/96
Reach:						
Landform Slope 96	6.	8.	8.	8.	8.	6.
Mass Wasting or Failure 96	9.	6.	9.	10.	9.	9.
Debris Jam Potential (floatable objects) 96	6.	5.	6.	2.	3.	8.
Vegetative Bank Potential 96	3.	3.	3.	3.	3.	3.
Channel Capacity 96	2.	2.	2.	2.	2.	3.
Bank Rock Content 96	2.	8.	6.	6.	8.	5.
Obstructions, Flow Deflectors, Sed Traps 96	4.	4.	4.	2.	4.	8.
Cutting 96	12.	6.	8.	14.	12.	16.
Deposition 96	12.	14.	8.	12.	8.	10.
Rock Angularity 96	2.	2.	2.	2.	2.	2.
Consolidation or Particle Packing 96	4.	4.	6.	4.	5.	4.
Bottom Size Distribution and % Stable Materials 96	8.	12.	6.	8.	8.	12.
Scouring and Deposition 96	12.	18.	16.	18.	18.	18.
Micro Bedforms 96	6.	6.	7.	6.	7.	8.
Macro Bedforms (bars) 96	6.	8.	6.	4.	5.	8.
Total Score 96	94.	106.	97.	101.	102.	120.
Upper Banks 96	24.	22.	26.	23.	23.	26.
Lower Banks 96	32.	34.	28.	36.	34.	42.
Bottom 96	38.	50.	43.	42.	45.	52.
Exposed Bedrock (%) 96	0.	0.	2.	5.	25.	5.
Large Boulders >1m (%) 96	2.	2.	0.	1.	0.	0.
Small Boulders >30cm (%) 96	3.	3.	1.	1.	0.	0.
Large Cobbles >15cm (%) 96	20.	20.	1.	2.	0.	1.
Small Cobbles >8cm (%) 96	20.	20.	5.	5.	7.	27.
Large Gravel >3cm (%) 96	20.	20.	15.	25.	38.	27.
Fine Gravel >1mm (%) 96	20.	20.	30.	25.	15.	25.
Sand, silt, muck (%) 96	15.	15.	35.	35.	15.	15.

Item Rated	Reach: 13B/96	14B/96	15B/96
Landform Slope 96	8.	8.	8.
Mass Wasting or Failure (existing or potential) 96	9.	7.	3.
Debris Jam Potential (floatable objects) 96	2.	2.	6.
Vegetative Bank Potential 96	3.	3.	3.
Channel Capacity 96	3.	2.	1.
Bank Rock Content 96	6.	4.	7.
Obstructions, Flow Deflectors, Sediment Traps 96	2.	2.	4.
Cutting 96	12.	6.	6.
Deposition 96	4.	8.	8.
Rock Angularity 96	2.	2.	2.
Consolidation or Particle Packing 96	8.	4.	4.
Bottom Size Distribution and % Stable Materials 96	8.	8.	8.
Scouring and Deposition 96	6.	6.	12.
Micro Bedforms 96	4.	6.	6.
Macro Bedforms (bars) 96	2.	6.	6.
Total Score 96	79.	74.	84.
Upper Banks 96	22.	20.	20.
Lower Banks 96	27.	22.	26.
Bottom 96	30.	32.	38.
Exposed Bedrock (%) 96	0.	0.	5.
Large Boulders >1m (%) 96	0.	0.	0.
Small Boulders >30cm (%) 96	0.	0.	0.
Large Cobbles >15cm (%) 96	0.	0.	1.
Small Cobbles >8cm (%) 96	2.	2.	4.
Large Gravel >3cm (%) 96	13.	13.	30.
Fine Gravel >1mm (%) 96	40.	45.	40.
Sand, silt, muck (%) 96	45.	40.	20.

Item Rated	16CB/96	17CB/96	18CB/96	19CB/96
Reach:				
Landform Slope 96	6.	8.	8.	8.
Mass Wasting or Failure (existing or potential) 96	12.	9.	6.	7.
Debris Jam Potential (floatable objects) 96	8.	5.	4.	4.
Vegetative Bank Potential 96	3.	4.	3.	3.
Channel Capacity 96	3.	2.	2.	2.
Bank Rock Content 96	6.	6.	6.	8.
Obstructions, Flow Deflectors, Sediment Traps 96	6.	5.	2.	2.
Cutting 96	16.	12.	12.	12.
Deposition 96	12.	8.	4.	4.
Rock Angularity 96	2.	2.	2.	2.
Consolidation or Particle Packing 96	6.	4.	4.	4.
Bottom Size Distribution and % Stable Materials 96	12.	8.	8.	8.
Scouring and Deposition 96	18.	18.	6.	6.
Micro Bedforms 96	6.	6.	6.	6.
Macro Bedforms (bars) 96	7.	6.	6.	4.
Total Score 96	123.	103.	79.	80.
Upper Banks 96	29.	26.	21.	22.
Lower Banks 96	43.	33.	26.	28.
Bottom 96	51.	44.	32.	30.
Exposed Bedrock (%) 96	5.	0.	0.	0.
Large Boulders >1m (%) 96	0.	0.	0.	0.
Small Boulders >30cm (%) 96	0.	0.	0.	0.
Large Cobbles >15cm (%) 96	5.	0.	0.	0.
Small Cobbles >8cm (%) 96	50.	0.	0.	5.
Large Gravel >3cm (%) 96	20.	10.	10.	20.
Fine Gravel >1mm (%) 96	20.	60.	60.	35.
Sand, silt, muck (%) 96	10.	30.	30.	40.

Item Rated	Reach:	20C/96	21C/96	22C/96
Landform Slope 96		8.	8.	8.
Mass Wasting or Failure (existing or potential) 96		9.	6.	12.
Debris Jam Potential (floatable objects) 96		4.	3.	2.
Vegetative Bank Potential 96		6.	2.	3.
Channel Capacity 96		2.	8.	2.
Bank Rock Content 96		8.	8.	8.
Obstructions, Flow Deflectors, Sediment Traps 96		4.	6.	2.
Cutting 96		13.	12.	16.
Deposition 96		12.	16.	16.
Rock Angularity 96		2.	2.	2.
Consolidation or Particle Packing 96		6.	6.	4.
Bottom Size Distribution and % Stable Materials 96		12.	12.	14.
Scouring and Deposition 96		18.	18.	12.
Micro Bedforms 96		8.	40.	10.
Macro Bedforms (bars) 96		6.	8.	8.
Total Score 96		118.	155.	119.
Upper Banks 96		27.	19.	25.
Lower Banks 96		39.	50.	44.
Bottom 96		52.	86.	50.
Exposed Bedrock (%) 96		5.	20.	5.
Large Boulders >1m (%) 96		0.	0.	0.
Small Boulders >30cm (%) 96		1.	2.	0.
Large Cobbles >15cm (%) 96		2.	2.	1.
Small Cobbles >8cm (%) 96		5.	5.	2.
Large Gravel >3cm (%) 96		10.	6.	2.
Fine Gravel >1mm (%) 96		50.	10.	40.
Sand, silt, muck (%) 96		27.	55.	50.

Appendix C

Error Estimates for Ocular Measurements, 1997

Error estimates for repeated ocular measurements
October 14th (a) & 16th (b), 1997

Errors by size class and reach

Sediment Distribution	Reach M4a	M4b	SD/avg	% error	Reach H10a	H10b	SD/avg	% error	Reach CB19a	CB19b	SD/avg	% error	Errors across all 3 reaches: Avg %error for estimates >= 10	Std Dev
Exposed Bedrock (%)	0	0	0	0	0	0	0	0	0	0	0	0		
Large Boulders >1m (%)	2	2	0	0	0	0	0	0	0	0	0	0		
Small Boulders >30cm (%)	2	2	0	0	2	2	0	0	0	0	0	0		
Large Cobbles >15cm (%)	3	3	0	0	2	3	0.28	28	0	0	0	0		
Small Cobbles >8cm (%)	3	6	0.47	47	11	15	0.22	22	0	0	0	0		
Large Gravels >3cm (%)	15	22	0.27	27	40	40	0.00	0	15	10	0.28	28	18	16
Fine Gravels >1mm (%)	35	30	0.11	11	25	25	0.00	0	55	60	0.06	6	6	5
Sand, silt, muck (%)	40	35	0.09	9	20	15	0.20	20	30	30	0.00	0	10	10
Errors within each reach														
reach avg for estimates >= 10			0.16	16			0.10	10			0.11	11		
std dev for estimates >= 10			0.10	10			0.12	12			0.15	15		

Errors across all size classes and all 3 reaches	
Avg % error of all estimates >= 10	12
Std Dev % error of all estimates >= 10	11