FLUVIAL WOOD PRESENCE AND DYNAMICS OVER A THIRTY YEAR INVERVAL IN FORESTED WATERSHEDS

by

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DISSERTATION ABSTRACT

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It has long been known that the presence of wood in rivers plays a vital biological and functional role and that a reciprocal relationship exists between woody material and the geomorphology of rivers. Fluvial wood studies, however, are rarely ongoing through time in order to ascertain long-term wood patterns within complete drainage networks. This dissertation addresses the temporal lag in fluvial wood patterns throughout four watersheds in the Oregon Coast Range by recreating a field dataset first collected in 1979 and then again in 1998. Statistical and spatial analysis of stream morphometric data at designated transects throughout the watersheds in addition to analysis of log step and log jam inventories provide insight into significant changes that have occurred over a thirty year interval at a multi-basin scale. These watersheds are located in areas that have been impacted by years of timber harvesting in the mid-twentieth century, however, clearcutting has been on the decline since the early 1980s. This research investigates the impacts that the legacy of clearcutting and subsequent afforestation has had on the abundance and volume of fluvial wood in the stream networks of these four watersheds. I digitized historical aerial imagery to determine the amounts of clearcutting in the basins over time. I integrated this variable with channel morphometric variables to assess predictors of wood abundance and volume through multiple regression analysis. Results show that the stream that has been the most affected by clearcutting has lower volumes of wood than measured in 1979 or 1998. Residence times of wood are short in these watersheds and wood abundance and volume was highly impacted by the debris flows that occurred during the Storm of 1996, prior to the 1998 data collection. There are statistically significant changes that have occurred in the stream morphology among the four watersheds. This dissertation also tests a method of detecting fluvial wood through airborne lidar analysis. This method provides an alternative to field surveys in areas of even the most extreme tree canopy cover.

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CHAPTER I

INTRODUCTION

Biophysical interactions and feedbacks between large wood and fluvial processes enhance complexity in mountain river environments and provide aquatic habitat where it may not otherwise be present (Gregory et al., 2003; Gurnell et al., 2002). In the Oregon Coast Range (OCR), fluvial wood is a primary driver of geomorphic change through its control of stream channel form, channel evolution, and sediment transport making it integral to anadromous salmonids (Murphy and Hall, 1981; Swanson et al., 1976). Fluvial wood promotes localized deposition and erosion of sediment, increases flow to the hyporheic zone, and traps additional large woody debris into log jams that reduce stream velocity and create associated pools and riffles (Abbe and Montgomery, 1996; Naiman et al., 1992). The fluvial wood community of researchers has grown substantially through recent decades with the continued recognition of the important role that large wood has in rivers world-wide. Physical models are able to simulate fluvial wood dynamics through time (e.g. Bocchiola, 2011), however, assessing the complexities of basin-scale wood dynamics through time in a field study requires a different approach.

This project examines the fluvial wood dynamics within four coastal watersheds of the Oregon Coast Range over a thirty year interval. In the summers of 1978 and 1979 Richard Marston visited thirteen coastal watersheds and established transects throughout the stream networks where he collected stream morphometric data and measured all fluvial wood spanning the width of the channel whether it is in the form of a log step or log jam. In the summers of 1996 and 1997 a Masters student of Marston, Jonathan Ferree, surveyed log steps and log jams in eight of the same watersheds while collecting stream data in the same transect locations. And most recently, in the summers of 2010 and 2012 I revisited four of these watersheds and collected data at the same transect locations in addition to surveying the fluvial wood in the form of log steps and log jams. The resulting field datasets are the foundation for analyzing the fluvial wood and stream morphology changes that have occurred within these OCR basins. In this dissertation, I investigate temporal changes in input, storage, and transport of fluvial wood over the last thirty years in order to extrapolate patterns and trends. I address key questions determining these changes by answering the following: (1) How have the volume, size, and type of fluvial wood changed in Oregon Coast Range watersheds between 1979 and 2012? (2) What stream channel morphology changes have occurred due to fluvial wood in these watersheds since 1979? (3) How have the effects of afforestation changed the landscape of fluvial wood since 1979? Additionally, I conduct a methodological evaluation to determine the presence of fluvial wood through remotely sensed data to answer the following question: (4) Can fluvial wood be detected through airborne lidar data analysis coupled with ground-reference data, and how can these techniques be used to better monitor fluvial wood changes and better test fluvial theory? The results of this research are based on a unique opportunity to analyze a reversal in human impacts through the afforestation that has occurred in the study area from the cessation of clear-cut logging in the watersheds. The Oregon Coast Range is a part of the multi-use Siuslaw Forest that has a long legacy of timber harvesting. In the early 1980s after Marston (1980) conducted the original stream surveys, Northwest Forest Plan regulations instigated a termination of clearcut logging in many parts of the OCR in order to preserve Northern Spotted Owl habitat. While logging did occur into the 1990s in the watersheds, it happened less frequently, and now has ceased entirely.

Chapter II addresses research question 1 by spatially and statistically comparing the three field datasets. I compare the cumulative distributions of wood in the form of log steps and log jams within the four creeks among the three years to assess the longitudinal distribution changes that have occurred through time. Proportional symbol maps show the spatial distributions among the three datasets providing visualization of the location and volume of wood throughout the basins and the changes that have occurred. I also utilize nonparametric tests to assess statistically significant changes in wood abundance and volume that have occurred among the three datasets for each of the four basins. This chapter addresses research question 3 by first delineating areas of clearcut harvesting through scanned historical aerial imagery that has been geo-referenced for selected years since the first dataset was conducted. I use spatial analysis to extrapolate parameters for multiple linear regression models predicting log step abundance, log jam abundance, and total volume for all four watersheds. For example, after subwatersheds are derived above each transect within the basins in GIS, the area within each subwatershed that has been clearcut is used as an independent variable. The results confirm that wood is dynamic and residence times are short in these basins. While the statistical analyses relating to afforestation do not indicate a land-use change signal in wood abundance and volume; spatial analyses show decreases in wood abundance and volume where harvesting has the strongest legacy.

Chapter III addresses research question 2 by comparing the stream morphometric data collected for the three field datasets. To assess the changes that have occurred in the stream morphology I investigate the hypothesis that creeks with reduced wood volumes will exhibit a stronger downstream hydraulic geometry (DHG). I assess the spatial variability of stream power residuals of a downstream hydraulic geometry derived stream power with the observed stream power throughout the basins for the three years. This comparison allows for speculation on land-use changes that have occurred through time. I utilize nonparametric tests to assess statistically significant changes in parameters such as bankfull width, bankfull depth, and median sediment sizes. And lastly, multiple linear regression analysis reveals predictors of change in bankfull width, bankfull depth, and the percent of pools found in the three years. The results from this chapter underscore the complexity and heterogeneity among the basins and within the three datasets. Some streams exhibit stronger downstream hydraulic geometry relationship than others, and results indicate that there is a trend towards stronger DHG in areas with less wood in the 2012 dataset. This supports the hypothesis that afforestation contributes to a higher DHG signal within these watersheds.

Chapter IV addresses research question 4 by investigating methods for visually interpreting fluvial wood within a lidar dataset of the study basins. I use 2009 high resolution point cloud data to detect wood within these forested watersheds. This first requires removing the forest canopy within the point cloud to unveil the stream channel. With saturation and intensity adjustments it is possible to see the distinct shape of large wood in the stream channels. I determine if the wood is part of a jam and compare it to the surveyed data. I map the wood to discern patterns; however, the data does not extend throughout the study basins limiting data analysis. The use of lidar data to determine the presence of fluvial wood in forested watersheds provides an innovative long-awaited methodology for fluvial wood detection for large spatial scales in regions of dense tree cover.

This research provides insight into the dynamics and complexities of fluvial wood in these forested watersheds. It investigates the influences that afforestation has on fluvial wood abundance and distributions throughout the basins and offers avenues of thought for overarching patterns and theories regarding a continually changing environment: both from stochastic processes and land-use change. This becomes critical for the incorporation of geomorphic processes into river management. The analysis of fluvial wood is a key component to monitoring stream health that is essential to the aquatic species found in the Oregon Coast Range.

CHAPTER II

INVESTIGATION OF FLUVIAL WOOD PRESENCE AND DYNAMICS OVER A THIRTY YEAR INTERVAL IN WATERSHEDS OF THE OREGON COAST RANGE WITH A LEGACY OF AFFORESTATION

1. Introduction

Fluvial wood, in the form of dead, singular logs greater than 10 cm in diameter, increases the complexity of river environments by creating complex channel hydraulics and morphology and associated providing aquatic habitat. Researchers have long known of the relationship between woody material and the geomorphology of rivers, and a large number of empirical and experimental studies have sought to quantify the nature of river-wood interactions. Field studies of wood in rivers, however, are rarely long enough to capture key temporal trends, lags, and uncertainties; those that do often lack the spatial scales necessary to describe fluvial wood interactions as processes acting across entire basins. This study reveals the complex dynamics of fluvial wood through both space and time, by repeat survey of a unique multi-basin database assessing the presence and significance of fluvial wood in the Oregon Coast Range. The survey was first conducted in 1978(Marston, 1982). Another researcher (Ferree, 1999) revisited a number of these same watersheds in 1998, and then they were visited lastly by this researcher in 2012.

The Oregon Coast Range is rich with forested watersheds where large wood is abundant in the channels, dynamic, improves aquatic habitat, and is the primary modifier of fluvial hydraulics and geomorphology. Additionally, the research basins in the OCR have a legacy of commercial timber harvesting during the mid-twentieth century that altered the forests significantly leading to questions relating past forest management to the size and abundance of wood in the streams of the basins most affected by clearcutting. Based on the three field datasets in tandem with historical aerial imagery, it is possible to assess the effects that clearcutting may have on the size and abundance of fluvial wood present within the creeks as well as the basin-scale dynamics and patterns of the fluvial wood. This study addresses two primary questions: 1) how have the volume, size, and type of fluvial wood changed in Oregon Coast Range watersheds between 1979 and 2012? And 2) how have the effects of afforestation changed the landscape of fluvial wood since 1979? One hypothesis is that the amount and volume of fluvial wood has decreased since 1979 due to the reduction of timber slash and landslides associated with timber roads. An alternative hypothesis is that there is an increase in the amount and volume of fluvial wood because there is greater wood supply through afforestation.

1.1. Background

The importance of large woody debris on stream ecology emerged in the late 1970s with a larger number of publications appearing in the early 1980s. A review of Marston’s (1980) list of references from his dissertation, which examines the geomorphic significance of log steps in Oregon coastal watersheds, reveals that only two published research sources specifically address large organic debris on streams. One is from the proceedings of a conference at Oregon State University (Froehlich, 1975; Hall and Baker, 1975), and the other resides in government reports (Swanson et al., 1976). Although there are some benchmark studies addressing the significance of large woody debris from across the United States (e.g. Angermeier and Karr, 1984; Bilby and Likens, 1980); the majority of early (1970s) research on the topic takes place in the Pacific Northwest.

During the 1970s and early 1980s forest managers regularly removed large wood and debris jams from channels for a multitude of reasons. In the Pacific Northwest wood in coastal drainage basins was removed to maintain clearance in the channel to mitigate flooding and to facilitate fish migration (Beschta, 1979)Diez et al., 2001; Piégay and Gurnell, 1997; Piégay et al., 1999). Deforestation and subsequent clearing of large dead wood along riparian corridors was widespread in North America for at least the last 150 years (Diez et al., 2001).

Several studies questioned the impacts of large wood removal from streams because the practice was so widespread during the mid-twentieth century. Research examining the ecological significance of large wood accelerated during the 1970s. Bilby and Likens (1980) analyzed the results of organic debris dams removed from an experimental forest in New Hampshire. The researchers measured a dramatic increase in the export of organic carbon from the ecosystem after retention mechanisms in the form of large wood were disturbed flushing out coarse, particulate, organic matter, or leaf litter. Without the large wood retention mechanisms, the stream acts more as a pipe, with inputs being rapidly transported, thus greatly impacting the aquatic ecosystem (Bilby and Likens, 1980).

Large stable debris in streams is critical for providing diverse habitats for fish and other organisms. This is particularly so in the Pacific Northwest of North America where woody debris loading is typically higher. Beschta (1979) analyzed the effects of the removal of large wood in a channel on sediment loads and found that large volumes of sediment were eroded by fluvial action after the removal. With an increase of localized sediment scouring pools began to fill and turbidity adversely affecting available aquatic habitat. Fish habitat is also sensitive to the removal of woody debris. In addition to creating pools for salmon to rest as well as shallower gravel beds necessary for fish spawning, experiments in removal by Angermeier and Karr (1984) determined that the wood cover also protects fish from predators and that fish were more likely to stay in shallow water if woody debris was present. They recommended, therefore, that removal of wood to be selective in order to minimize the disruption of biological properties.

Two additional, comprehensive, geomorphic studies were completed during this timeframe on the importance of woody debris in old growth forests. One of the studies, Marston’s (1982) work in coastal watersheds in Oregon, revealed comprehensive results on the geomorphic significance of log steps on a watershed scale. As part of the analysis, he measured the amount of sediment stored behind each log step. By comparing the total sediment storage behind log steps with an estimated mean annual sediment discharge derived by a morphometric index of mean annual sediment yield (Maxwell and Marston, 1980) he determined that the volume of sediment stored behind log steps in all third, fourth, and fifth order streams contain 123% of the mean annual sediment discharge throughout the watersheds. Keller and Tally (1982) discuss the role of large organic debris on channel form, fluvial processes, and development and maintenance of anadromous fish habitat in old-growth redwood forests. This chapter is part of a volume entitled *Adjustments of the Fluvial System,* which again shows the perceived importance of large woody debris research in the field of geomorphology.

Ultimately, this early period in large wood research culminated in a chapter of the streamside management book dedicated to large woody debris in forested streams within the Pacific Northwest (Bisson et al., 1987). The conclusions made in the chapter are (1) large woody debris enhances fish habitat in all stream sizes, (2) removal of trees in the riparian areas has altered the sources, transport, and re-distribution of debris in fluvial channels, altering fish population and biodiversity, and (3) there is an urgent need for long-term studies focusing on the protection of existing large woody debris and the recruitment of new debris from surrounding forests (Bisson et al., 1987).

Simultaneously during the mid-1980s, forest conservation and management increased due to several lawsuits and subsequent injunctions over the National Environmental Protection Act (NEPA) concerning the cumulative effects of timber harvesting in landslide prone areas of Siuslaw National Forest (Craig, 1987).The implementation of Northwest Forest Plan regulations including the federal designation of the forest as Northern Spotted Owl habitat increased pressure to cease timber sales in the watersheds into the 1990s (Thomas and Raphael, 1993). This regional implementation brought about changes to Pacific Northwest forests, including the cessation of clear cut logging practices in many areas, although corresponding research examining the role of riparian zones in aquatic habitat had a possible impact on management as well. The watersheds analyzed in this study all have a legacy of clearcutting ranging from 6% to up to 40% of watershed area in 1979. Since that time much of the clearcutting has ceased leading to the process of afforestation in much of the study area. Afforestation has subsequently initiated hypotheses regarding the changes that may have occurred throughout the 30 years since the original dataset was first collected. The termination of clearcutting and accompanying road-building that increases erosion and has been shown to increase the rates of sediment and large wood supply to streams (Swanston and Swanson, 1976) leads to the hypothesis that there will be a decrease in the amount of fluvial wood. There will be less wood entering the channel through landslides and debris torrents associated with roads as well as less slash entering the channels. A second hypothesis is that after a plot is clearcut tree species known to thrive in disturbed riparian areas, such as the hardwood red alder (*Alnusrubra*), will become established. This changes the size and volume of log steps and log jams as these hardwoods are significantly smaller than their larger conifer counterparts (Figure 2.1). The alternative hypothesis is that there will be an increase in the amount of fluvial wood due to an increase in wood supply through afforestation. A third hypothesis is that there should remain a greater abundance of wood found in the upper reaches of the stream networks as was found in Marston’s (1982) dataset. Despite the timber impacts, the stream networks will still support a greater amount of log steps and log jams in lower-order reaches because they are able to more effectively stabilize channel-spanning wood without being breached by storm flows.

Figure 2.1. Left photo is a red alder as a log jam in Cape Creek (Lane County). Right photo is a log jam consisting of conifers in Cape Creek (Lane County).

2. Study area

In order to answer the research questions I selected four forested watersheds previously surveyed by Marston (1980) and Ferree (1999) along the central Oregon Coastal Range (Figure 2.2). I chose these four watersheds because have been previously surveyed, they are still navigable despite increased growth, and there was no indication of illegal substance cultivation with associated hazards for the fieldwork crew. The watersheds are all located within the Siuslaw National Forest and provide a range of physiographic characteristics and impacts from years of forest management. This provides enough of a range to compare the effects that afforestation have had within and among the basins, however, it is still appropriate to make statistical determinations regarding the data for all four watersheds when combined into one uniform dataset. The basins are Cape Creek in Lincoln Co., Cummins Creek, Big Creek, and Cape Creek in Lane County (Table 2.1). Elevations range from sea level to 767 meters at Cummins Peak. The dominant geologic unit of the area is Yachats Basalt, an upper Eocene unit consisting of volcaniclastic breccias and basaltic lava flows. There are marine terrace deposits near the outlets of Cummins Creek and Cape Creek (Lane Co.). Additionally, the upper portion of Big Creek is underlain by Flournay Formation; sandstones with interbeds of siltstones (Loy et al., 2001). The mainstem channels are oriented along the fault lineaments and the thin residual soils are situated at or near the maximum angle of repose on steep convex-up slopes (Marston, 1982).

Table 2.1. Watershed Characteristics.

	Cape Creek (Lincoln Co.)	Cummins Creek	Big Creek	Cape Creek (Lane Co.)
Drainage Area (km^2)	4.82	24.66	39.37	31.86
Channel Slope Range (m/m)	0.01-0.59	0.01-0.42	0.00-0.37	0.00-0.46
Channel Elevation Range (m)	0-340	0-436	0-350	0-400

Of the four basins Cummins Creek has been least impacted by land-use practices. Cape Creek (Lincoln Co.) is the smallest of the four and has had some alterations towards the outlet of the creek for trails and bridges. Big Creek has a road that extends the majority of the creek and private property aligning some of its banks in addition to portions on the upper hillslopes. Cape Creek (Lane Co.) previously had logging roads extending along the main-stem channel, however, the roads have since been abandoned and the bridges have been taken down leaving behind remnants of concrete infrastructure. There have been restoration projects in Cape Creek (Lane Co.) evidenced by two immobile engineered log steps located in the lower portion of the outlet.

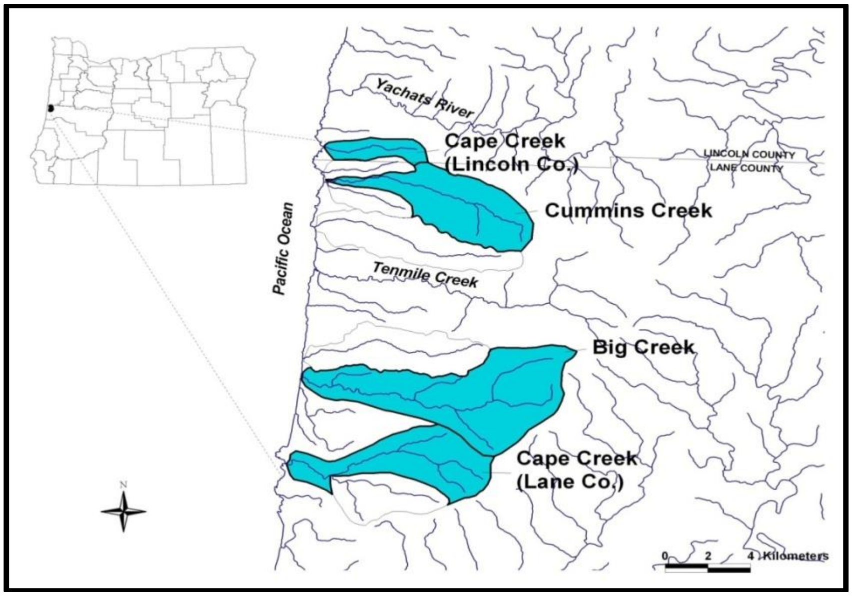


Figure 2.2. Oregon Coast Range Study Area Basins.

Longitudinal profiles illustrate the elevations of each of the four basins including the surveyed tributaries (Figures 2.3.-2.6.).

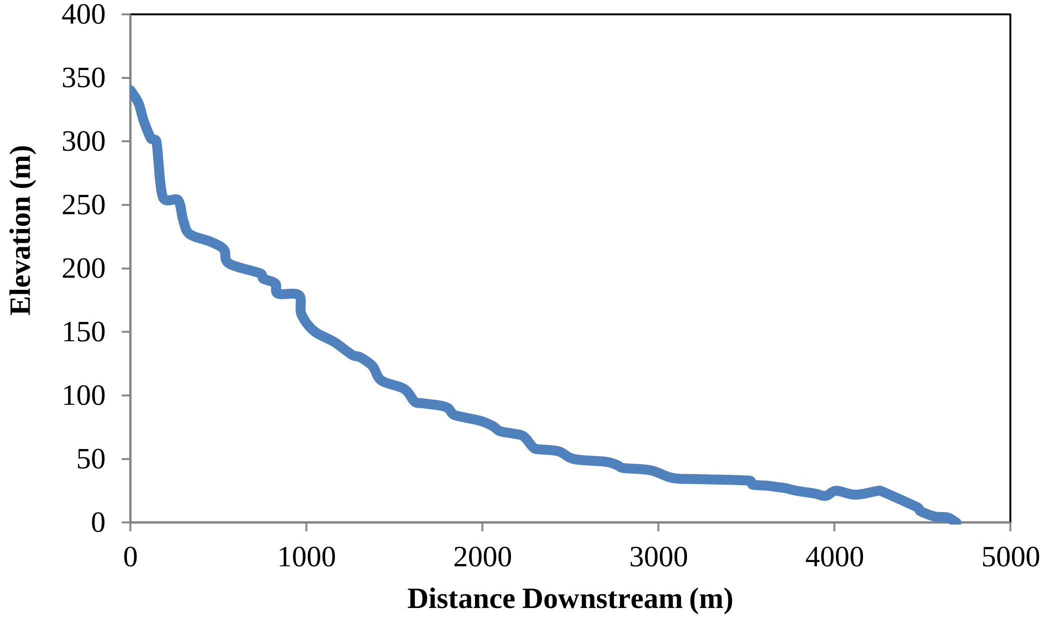


Figure 2.3. Longitudinal profile of Cape Creek (Lincoln County). Vertical scale exaggerated 10 times.

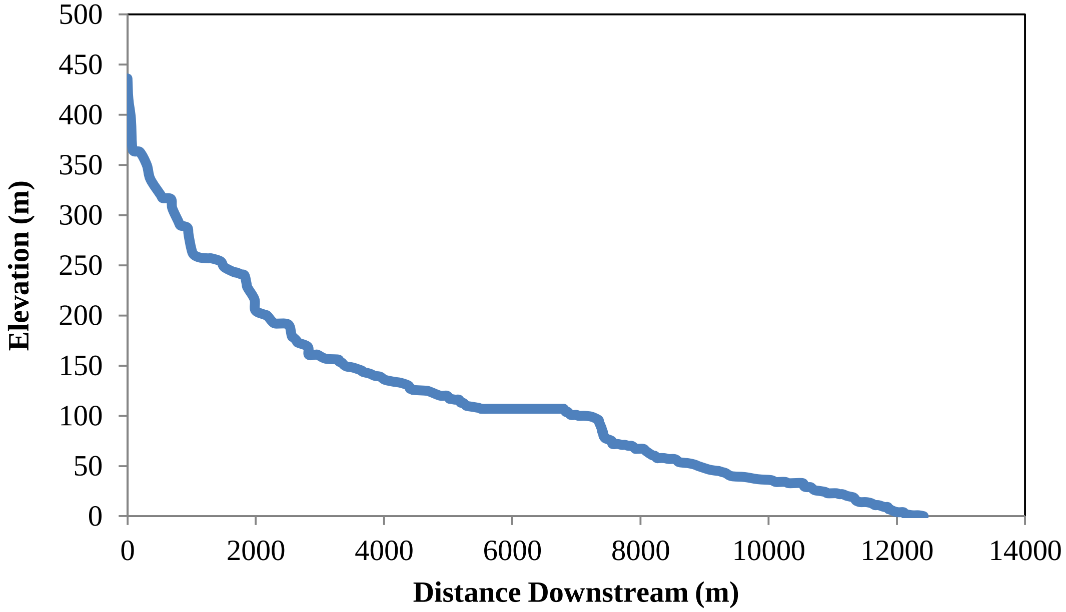


Figure 2.4. Longitudinal profile of Cummins Creek. Vertical scale exaggerated 40 times.

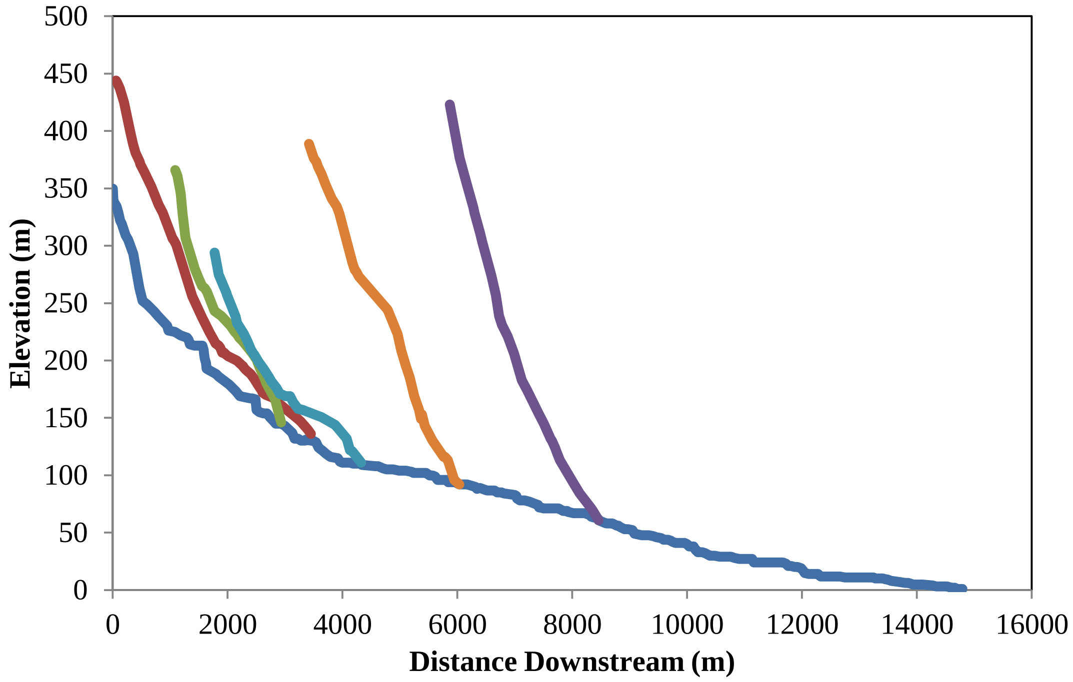


Figure 2.5. Longitudinal profile of Big Creek and tributaries surveyed. Vertical scale exaggerated 40 times.

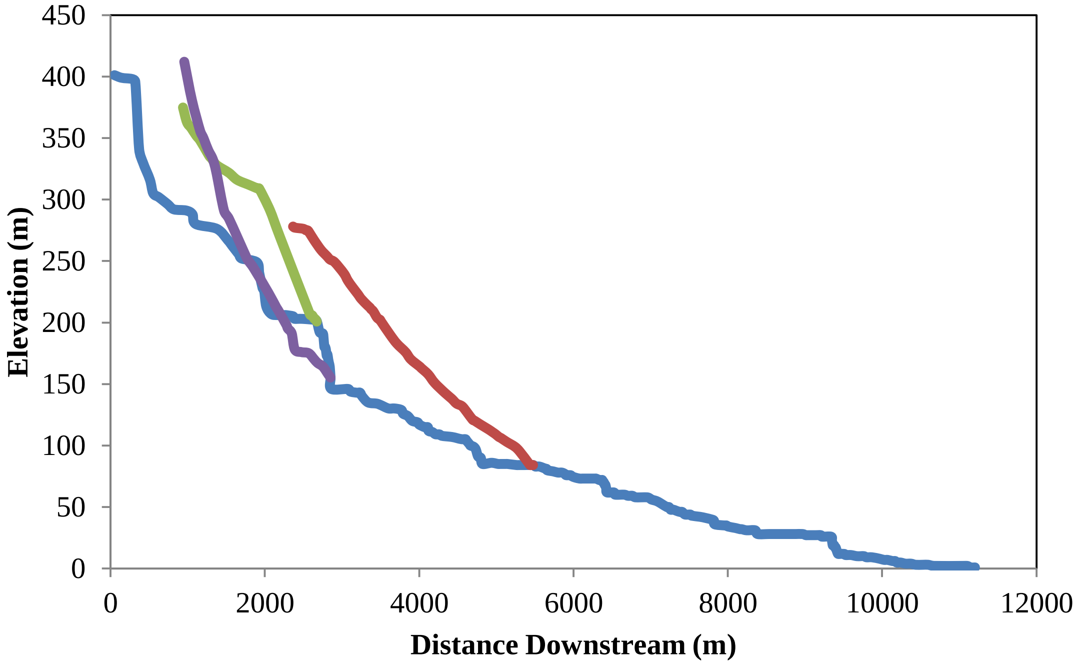


Figure 2.6. Longitudinal profile of Cape Creek (Lane Co.) and tributaries surveyed. Vertical scale exaggerated 40 times.

2.1. Geology and geomorphology of the Oregon Coast Range

The Oregon Coast Range is characterized by geomorphic features formed through non-linear interactions among the tectonics, lithology, and climate-driven hillslope processes of the region. From the hillslopes to the valley floors, the geomorphic features of the Oregon Coast Range (OCR) are linked by the geology of the region as it is still strongly influenced by active orogens (Personius, 1995; Whipple, 2004). Kelsey et al. (1994) hypothesize that the average topography of the OCR varies with latitude as a function of the age and plate density of the Cascadia subduction zone from north to south. The overarching topography, however, is characterized by steep soil and debris-mantled mountainous terrain largely composed of Eocene sedimentary rocks that overlie a volcanic base accreted to the North American plate in the early Paleocene (Dietrich and Dunne, 1978b; Orr et al., 1992). Uplift of the Oregon Coast Range commenced in the Miocene and continues today as evidenced by the abandoned wave-cut platforms along the coast (Kelsey et al., 1996).

Valley morphology in the highest portions of the Oregon Coast Range and lack of glacial forms indicate that it was not glaciated in the late Pleistocene, resulting in a relatively uniform bedrock lithology (Personius et al., 1993). Feedbacks exist between tectonics and geomorphological surface processes. With increasing rates of rock uplift and erosion, mass wasting processes promote sediment fluxes on steep slopes that may limit further topographic development. Hillslope processes such as landsliding exert a primary control on planform development and incision history in the Oregon Coast Range. Hillslopes achieve a threshold gradient and subsequently respond rapidly to fluvial network incision (Korup et al., 2010).

2.2. Vegetation and precipitation

Vegetation in the area is the large conifer western hemlock (*Tsugaheterophylla*). The large conifer Douglas fir (*Pseudotrugamenziesii*) predominates in the drier areas while the western red cedar (*Thujaplicata*) tends to occupy the moist regions of the hemlock zone. The large Sitka spruce (*Piceasitchensis*) is found near the coast intermixing with the western red cedar predominantly in swampy areas (Loy et al., 2001). Lastly, the hardwood red alder (*Alnusrubra*) inhabits the riparian zones of the study areas (Marston, 1980).The annual total rainfall can exceed 2,540 mm in the headwaters and 2,030 mm along the coast (Loy et al., 2001). The coastal streams experience high flow regimes during the winter months and experience low flow during the summers with most of the precipitation occurring as rain; snowfall is insignificant at less than a few inches per year (Loy et al., 2001). The winter two years prior to Ferree's 1998 data collection experienced a storm of record event that induced floods of record in the study area watersheds (Swanson, 1998). The Alsea Fish Hatchery located 40 km north of the study area provides precipitation data for the region near the study watersheds (Figure 2.7). In one month parts of this region received over 850 mm of rainfall with an annual total of 3550 mm. This storm undoubtedly caused major geomorphic shifts to occur within the channels. Numerous debris torrents occurred in Western Oregon during the 1996 storm events leading to widespread damage (Kelly, 1998). In the OCR the storms also triggered thousands of shallow landslides (Roering et al., 2003). The study area has had significant storms since then occurring in 2010 where in the month of December it received 496 mm of precipitation with an annual total of 2610 mm.

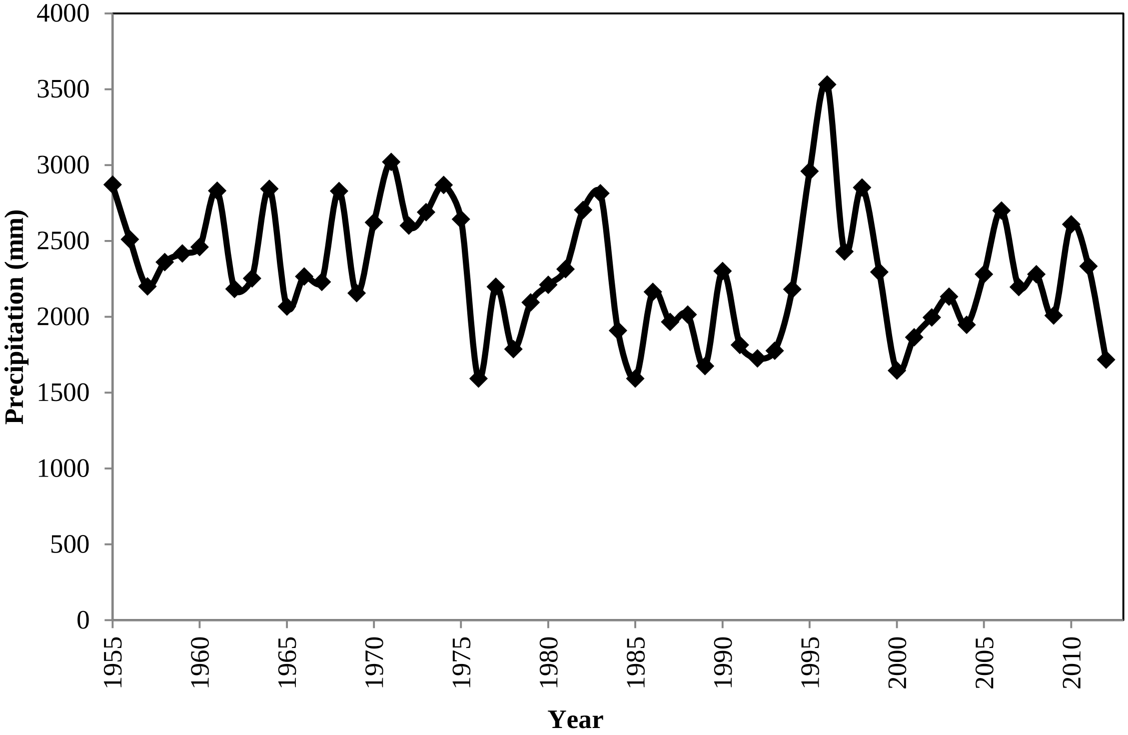


Figure 2.7. Precipitation for Period of Record at Alsea Fish Hatchery, Oregon Coast Range.

3. Methods

3.1. Field data collection

I mapped and measured the accumulations of fluvial wood in the form of log steps and jams continuously along the channel lengths within each watershed as it was surveyed. A log step is defined as an accumulation of wood that spans the entire width of the stream channel, trapping sediment in a plain or plug behind it. The stream flows over the sediment plain and over the anchoring wood mass creating an actual drop or fall within the active channel. Log jams, on the other hand, are accumulations of wood that do not store sediment and do not create a localized drop or fall within the channel (Figure 2.8) (Marston, 1980). I used a stadia rod, measuring tapes, and a laser range finder to measure the width, depth, and height of each wood accumulation to determine the volume of each log step and jam present. In order to obtain a more accurate volume similar to the methods of Marston (1980), each accumulation is viewed as a solid block of wood and then reduced by estimating the percent air or the difference between the visualized block and the actual deposit. I also took GPS coordinates with 2m spatial accuracy and photographs of each log step and jam to record locations and visual interpretation of the porosity of the jams.

Figure 2.8. The photo on the left is a log step and the photo on the right is a log jam.

The stream surveying methodology for this research and the research conducted by Ferree (1999)is modeled after Marston (1980) to accurately record change from the original transect data surveyed in 1978-1979. I began at the coastal outlet of each watershed and moved progressively upstream to a final endpoint originally determined by Marston (1980) and/or Ferree (1999) or until the stream was no longer passable. I established transects measuring 10 meters long parallel to the stream channel approximately every 0.4 kilometers (Table 2.2). I referenced U.S.G.S. 15-minute topographic quadrangle maps originally used in 1978 that contain the original transect locations to establish waypoints of their locations and imported them into a GPS. I established new transects in these same locations with the aid of GPS and visual determination at a local scale of river reaches without bends deemed to be the most likely place that data was collected previously. The spatial error of the new transects and those collected previously is likely 3-5 meters in most locations. In the lower-order portions of the stream networks, however, the spatial error may be greater. This is due to narrower stream channels with steeper slopes and the abundance of vegetation found in the upper reaches of the stream.

Table 2.2. Stream survey data collection for each watershed.

	Cape Creek (Lincoln Co.)	Cummins Creek	Big Creek	Cape Creek (Lane Co.)
Channel Length Surveyed (km)	5.0	11.3	18.8	12.7
Number of Transects	4	12	23	18

I measured bankfull width at the end points and at one-third and two-thirds distance from either end within each transect. Additionally, I measured bankfull depth once at the midpoint. The bankfull depth is defined as the depth of the channel or water surface elevation at this maximum height. Bankfull width is defined as the distance between channel banks when the water surface elevation is at the maximum height within the channel without flooding into the overbanks. I estimated channel slope with one person holding a laser range finder that provides slope in degrees at the upstream end of the transect and another person holding the stadia rod at the downstream end with their hand at eye height.

I conducted Wolman random pebble counts to determine a representative sampling of the size in millimeters of the sediment within each transect. Fifty random pebbles were selected by zigzagging the transect from downstream to upstream, selecting a pebble with each step until the intermediate or B-axis of 50 pebbles was measured and the entire length of the transect was covered.

To determine the amount of sediment stored behind the measured log steps, I measured the length, width, and depth of the sediment plain behind each step. The sediment depth was measured as the distance between the sediment and the top of log step subtracted by the height of the log step. I then obtained a volume and divided the product by two to account for the deposit’s wedge shape (Marston, 1980). This data duplicates the fluvial wood and sediment characteristics from the 1978 and 1998 datasets allowing for direct comparison among the three years.

3.2. Spatial and statistical analysis

In order to develop the variables to assess potential effects on wood abundance and volume within the watersheds (Table 2.3) I first imported the locations and associated volume characteristics of each log step and log jam from the three field datasets into shapefiles in GIS. The data were overlaid onto the National Hydrography Dataset stream networks. I created bins upstream of each transect location and determined the number of log steps and number of log jams within the bin, as well as total wood volumes, to associate wood abundance and volume in the 0.4km length of stream above a given transect. I also used the transect locations as pour points overlaid on a 10 meter DEM (National Elevation Dataset) within GIS to derive subwatersheds and associated upstream drainage areas.

To assess the role of the physical landscape in determining where wood may be located in the basins I created power law slope-area plots for the four basins. I used slope and drainage area data derived from Netmap (Benda et al., 2007) and logged them to determine a topographic signature in the landscape between channels that are primarily eroded by debris flows and channels that are primarily eroded by fluvial processes (Stock and Dietrich, 2003). For basaltic lithology the transition occurs around slopes of 0.05 and therefore this is the threshold used to delineate the zones for the study basins. The plots also include all transect locations in addition to those locations that have total wood amounts greater than ten pieces. Categorizing the transects in this way highlights the areas within the networks that have the most abundant wood and whether or not they fall in areas of debris flow scour or fluvial scour.

Next, I measured the distances downstream of the fluvial wood data to analyze longitudinal distributions of fluvial wood throughout the basins and potential variables influencing where the wood is located. The farthest distance upstream was determined by National Hydrography Dataset (NHD) stream coverage for each watershed. The resulting data allow for mapping of cumulative distributions of wood throughout the watersheds in addition to mapping proportional symbol maps depicting wood volumes within the drainage networks.

To determine the potential effects of harvesting on the local abundance of wood within the watersheds (Table 2.4), I scanned and georeferenced within GIS historical aerial imagery from the years 1979, 1984, 1994, 2000, 2005, and 2011. With this base data I created polygons delineating areas of freshly harvested areas for each of the years when present (Figure 2.9). The minimum mapping unit of the imagery is less than five meters and substantially smaller than the delineated areas of clearcutting. The delineations were made based on changes in image texture and tone from the areas of forest to fresh clearcuts and excluded any overhanging canopy into the polygons. I then overlaid these shapefiles onto the delineated subwatersheds of each transect in the basins to determine the percentage of clearcut area above each transect. This percentage was next used as a variable to incorporate into the multiple regression analysis discussed below.

Additionally, to analyze local riparian effects of clearcutting on the spatial distributions of log steps and jams, I created a 100m buffer along the stream networks (50 m on each side of the stream) to again determine the percentage of harvesting that has occurred adjacent to the stream channels. I also created a variable based on the number of years that have passed since each subwatershed has been harvested. For example, in the field data conducted in 2010-2012, if a subwatershed did not have any fresh clearcuts since 1979, it is given a value of 30. If the subwatershed had fresh clearcuts in 2000 it is given a value of 5. Lastly, I included dummy variables to identify which creek the transect is located in to account for potential significance based on different overall basin characteristics.

Table 2.3. Variables used in analyses.

Variable (units)	**Characteristics**
Step Count SC	Continuous; no. of steps/0.4km reach
Jam Count JC	Continuous; no. of jams/0.4km reach
Tot Wood Volume (m^3) V	Continuous; derived from field datasets
Slope residual$S$	Continuous; derived from field datasets
Drainage AreaDA (km^2)	Continuous; derived from ArcGIS Spatial Analyst
Bankfull width residual$w$	Continuous; derived from field datasetsat each transect
Bankfull depth residual$d$	Continuous; derived from field datasets at each transect
Percent clearcut PC	Continuous; derived from ArcGIS modelbuilder
Percent riparian clearcut RC	Continuous; derived from ArcGIS with 100m buffer in modelbuilder
Years growth YG	Continuous; derived from percent clearcut data
Creek	Binary; creek of transect location

Residuals are used for some variables to eliminate correlations between drainage area and other morphometric variables.

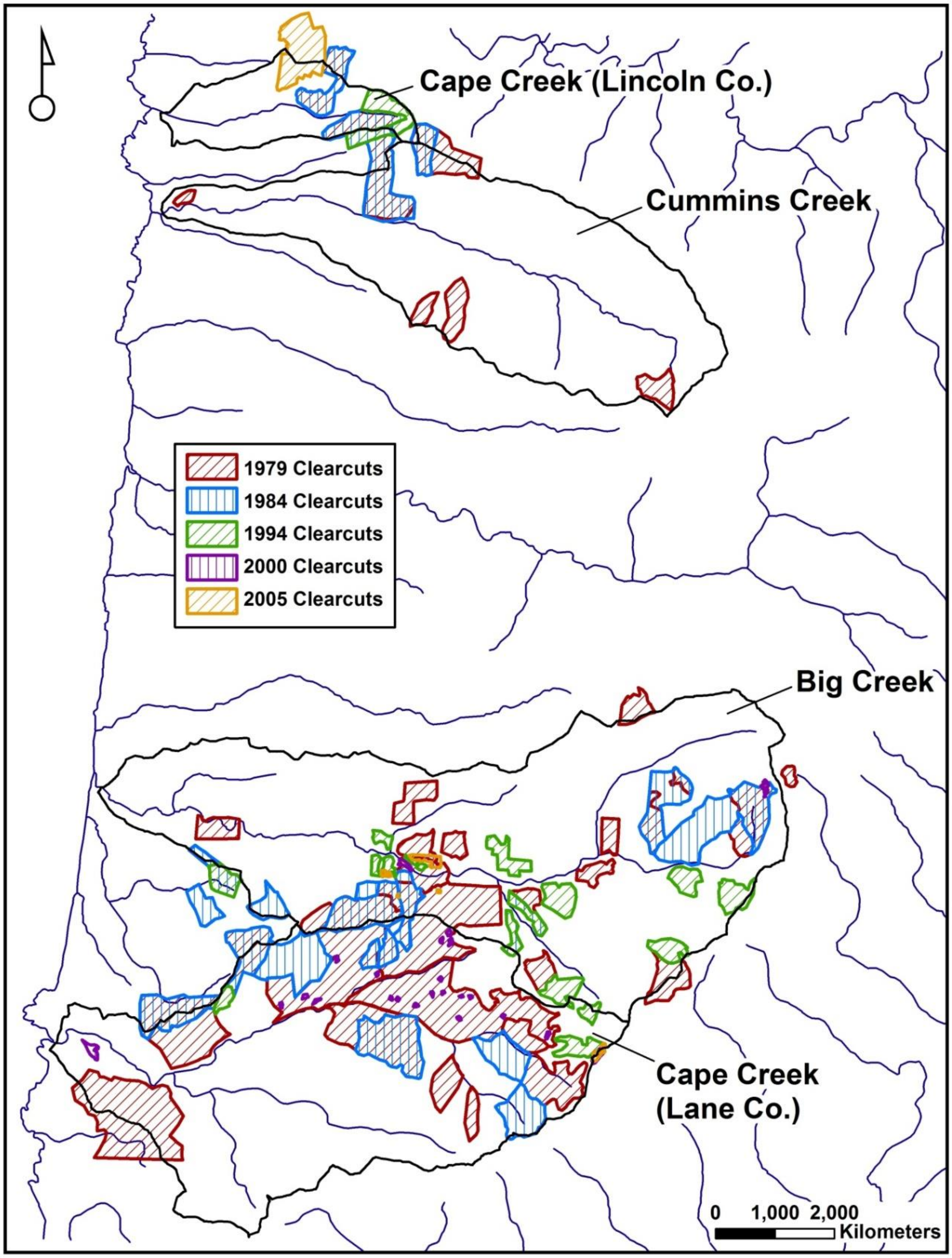


Figure 2.9. Historical fresh clearcut areas within the four basins.

Table 2.4. Total freshly clearcut areas within each watershed determined by historical aerial imagery.

Area Clearcut (km^2)	Cape Creek (Lincoln Co.)	Cummins Creek	Big Creek	Cape Creek (Lane Co.)
1979	0.7	1.7	5.2	10.8
1984	0.7	0.7	3.6	3.6
1994	0	0.7	1.8	0.4
2000	0	0	0.1	0.1
2005	0.3	0	0.1	0
Total	1.7	3.1	10.8	14.9

An initial covariance analysis explored the morphometric variables of each transect within the three datasets including drainage area, bankfull width, bankfull depth, and slope. The results showed that in some instances the variables significantly correlate (Table 2.5). To remove these effects of multicollinearity I derived residuals from power law equations of each variable with drainage area to use as the input data for the subsequent analysis. With the independent variables from Table 2.3, I analyzed the potential controls on the abundance of log steps, log jams, and total wood volumes. I did a stepwise multiple linear regression analysis (SPSS, 2009) for each of the three dependent variables (step count, jam count, and total wood volume) for each year (1979, 1998, and 2012). Stepwise regression builds a model by successively adding or removing independent variables based on the t-statistic of their estimated coefficients. I chose stepwise regression because of the large number of independent variables tested and its ability to systematically sort through and select the variables most useful in predicting each dependent variable.

Table 2.5. Correlation matrix for the 1979, 1998, and 2010 datasets.

1979	*DA*	Bankfull width	Bankfull depth	Slope
DA	1			
Bankfull width	**-.526*** **.000**	1		
Bankfull depth	-.381 .003	.235 .078	1	
Slope	**-.709*** **.000**	**-.466*** **.000**	.195 .146	1
1998	*DA*	Bankfull width	Bankfull depth	Slope
DA	1			
Bankfull width	**-.790*** **.000**	1		
Bankfull depth	**-.408*** **.002**	**.469*** **.000**	1	
Slope	**-.423*** **.001**	**-.440*** **.001**	**-.327** **.013**	1
2012	*DA*	Bankfull width	Bankfull depth	Slope
DA	1			
Bankfull width	**.783*** **.000**	1		
Bankfull depth	**.326** **.013**	**.442*** **.001**	1	
Slope	**-.453*** **.000**	**-.505*** **.000**	-.261 .050	1

The top number is the Pearson Correlation coefficient and the bottom number is the significance (2-tailed). N is 57 for each of the three years. Numbers in bold are significant at the ≥ 0.05 level.
* Correlation is significant at the 0.01 level (2-tailed).

Non-parametric statistical tests allow for comparison of the three datasets for each individual basin. I used the Wilcoxon signed rank test for paired data (SPSS, 2009) to compare the changes in the abundance of log steps and jams as well as changes in the volume of fluvial wood between each pair of watersheds.

4. Results

Across the four study watersheds, the most wood was present in 1998, an intermediate amount was present in 2012, and the smallest amount was present in 1979 (Table 2.6). The 1998 wood volume is also the largest by far, but volume was greater in 1978 than in 2012. Ferree (1999) measured a log step that contained a volume of

80,268 m^3. The researcher noted a zone of much debris including whole trees creating an extensive zone deposition.

Table 2.6. Wood step and jam abundance characteristics for the three datasets.

		1979		1998		2012	
		Log Steps	Log Jams	Log Steps	Log Jams	Log Steps	Log Jams
Cape Creek (Lincoln Co.)	Wood Count	8	12	25	16	15	16
	Average Wood Volume (m^3)	30.8	208.9	113.4	79.1	4.0	45.5
Cummins Creek	Wood Count	26	26	8	68	17	46
	Average Wood Volume (m^3)	77.0	130.3	3431.5	537.7	1.1	150.4
Big Creek	Wood Count	34	43	60	95	25	88
	Average Wood Volume (m^3)	57.6	58.0	55.3	211.1	6.7	194.6
Cape Creek (Lane Co.)	Wood Count	44	42	69	98	60	84
	Average Wood Volume (m^3)	274.0	307.9	38.1	99.2	1.1	35.5
Total	Wood count	112	123	162	277	117	234
	Wood volume	439.4	705.1	3638.3	927.1	12.9	426

The average wood volume of all of the log steps and log jams within each watershed is provided.

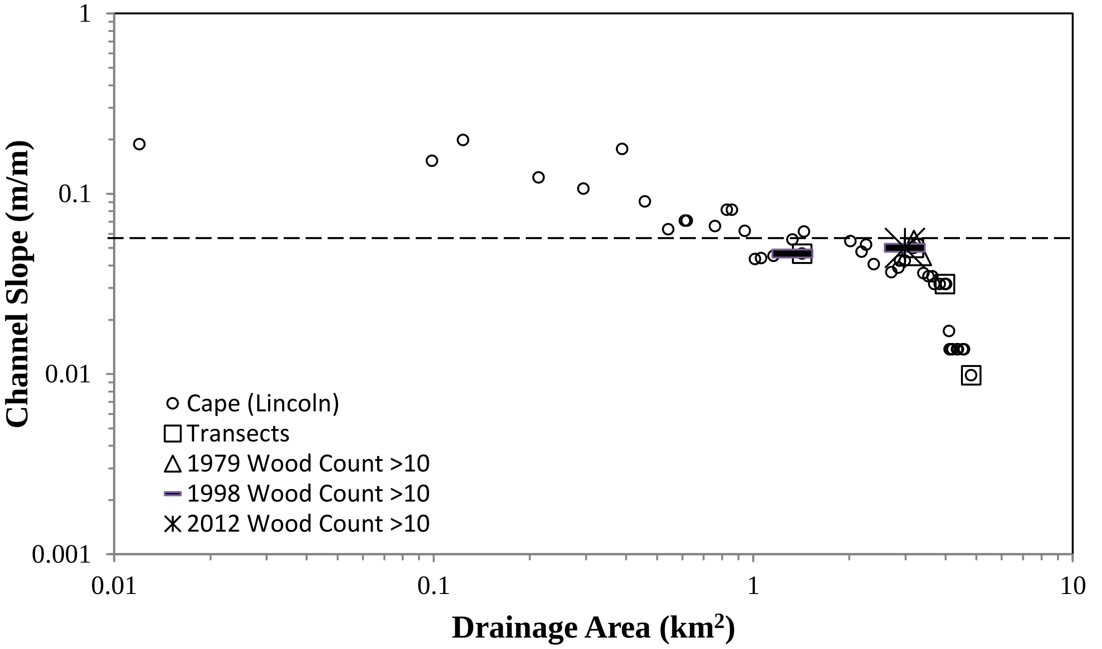
Slope-area plots for the four basins reveal the non-linear nature of debris flow scoured valleys in the basins and topographic shifts that occur during the transition to fluvial scoured valleys in the larger drainage areas (Figure 2.10). The plots show that the debris flow scoured areas are more variable indicating that debris flows may not be as efficient in eroding basalts resulting in more irregular slopes in the upper reaches. The majority of the field data were collected below the transition to debris flow scoured valleys. The transects with the most wood present for all three years in the creeks, with the exception of Cummins Creek, are situated right below the transition zone.

Cumulative distributions of the number of log steps and number of jog jams among the three datasets illustrate the locations of the wood within the basins and eliminate complexities of channel network confluences (Figure 2.11). The cumulative distributions show that in all four basins the number of log steps decreases in the downstream direction. Additionally, in 1979 there were fewer log jams downstream than in 1998 and 2012, in all four basins. Big Creek and Cape Creek in Lane County have more fluvial wood in their upper reaches than the other two watersheds. This may be attributed to the lower-order tributaries having been surveyed within these two basins (but not in the other two basins) and also the wider overall basin shapes of these two southern-most creeks.

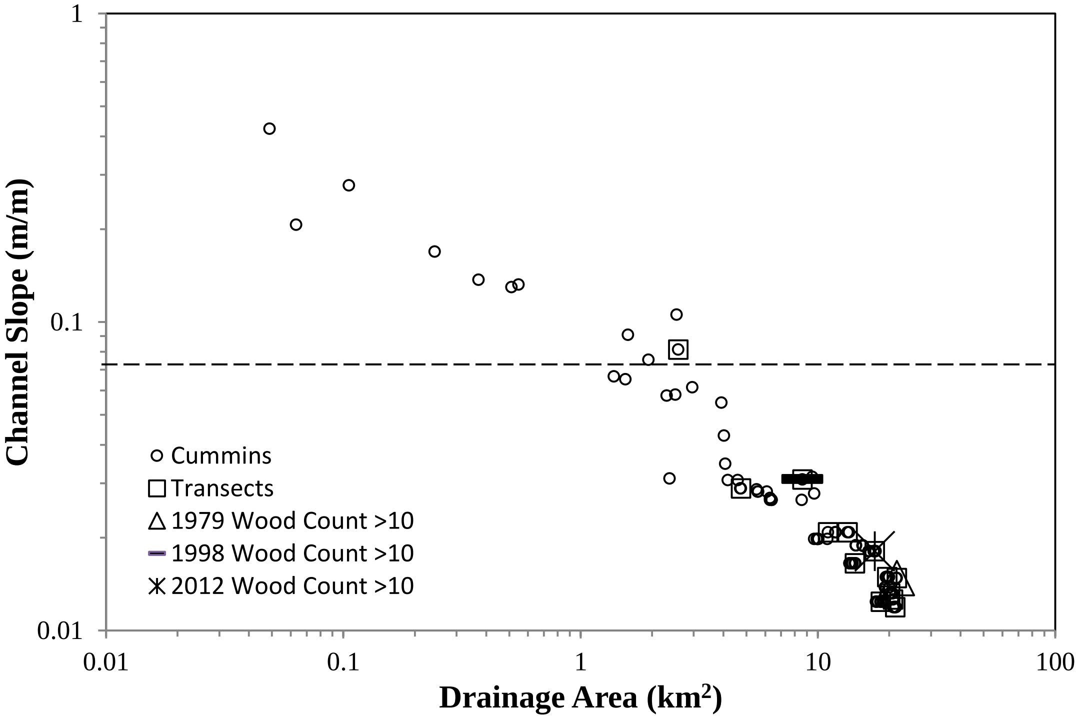
The spatial distributions of the wood volumes in the basins are shown by proportional symbol maps (Figure 2.12). It is important to note the scaling difference in wood volumes in Cummins Creek for 1998 compared to the other creeks and years. Some of the volume measurements were much greater in magnitude creating the need for additional data categories to illustrate the full range of wood volumes.

The results of The Wilcoxon signed rank test was used to test for differences in the number and volume of wood features over time in each watershed (Table 2.6). The significant differences that occur among the datasets are found with the 1998 dataset. There are no statistically significant differences between the 1979 and 2012 datasets. Wood volume was significantly larger in 1998 than in 1979 in Big Creek and Cape Creek (Lane County). In Cape Creek (Lane County), wood volume and number of jams were significantly greater in 1998 than 2012 In Cummins Creek wood volume the abundance of log steps, and the abundance of log jams were all significantly greater in 1998 than in 1979 and 2012.

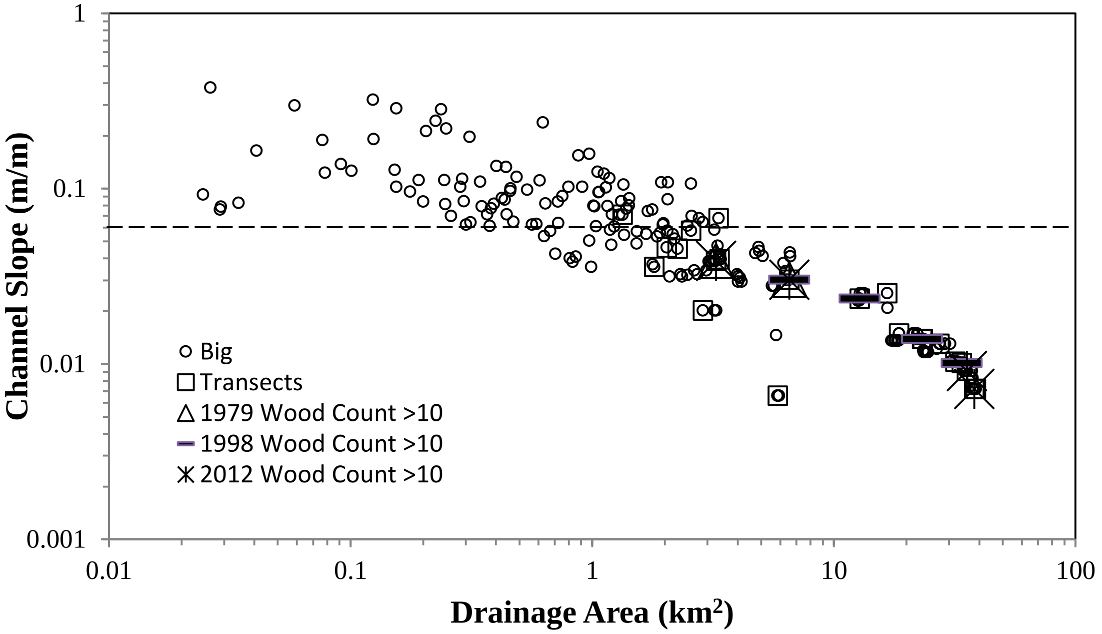
Figure 2.10 (next two pages). Slope-area plots for each of the four basins (a-d). The transect locations with total wood counts greater than 10 are also indicated. The dashed line represents the 0.05 slope threshold transitioning between debris-flow dominated erosion and fluvially dominated erosion.



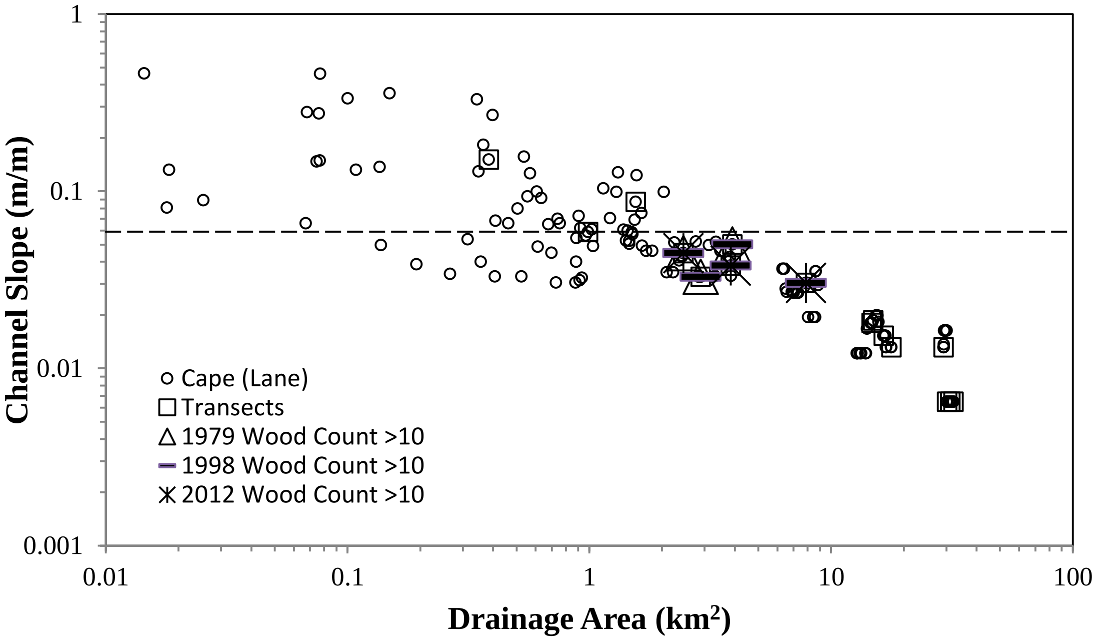
(a) Cape Creek (Lincoln Co.)



(b) Cummins Creek

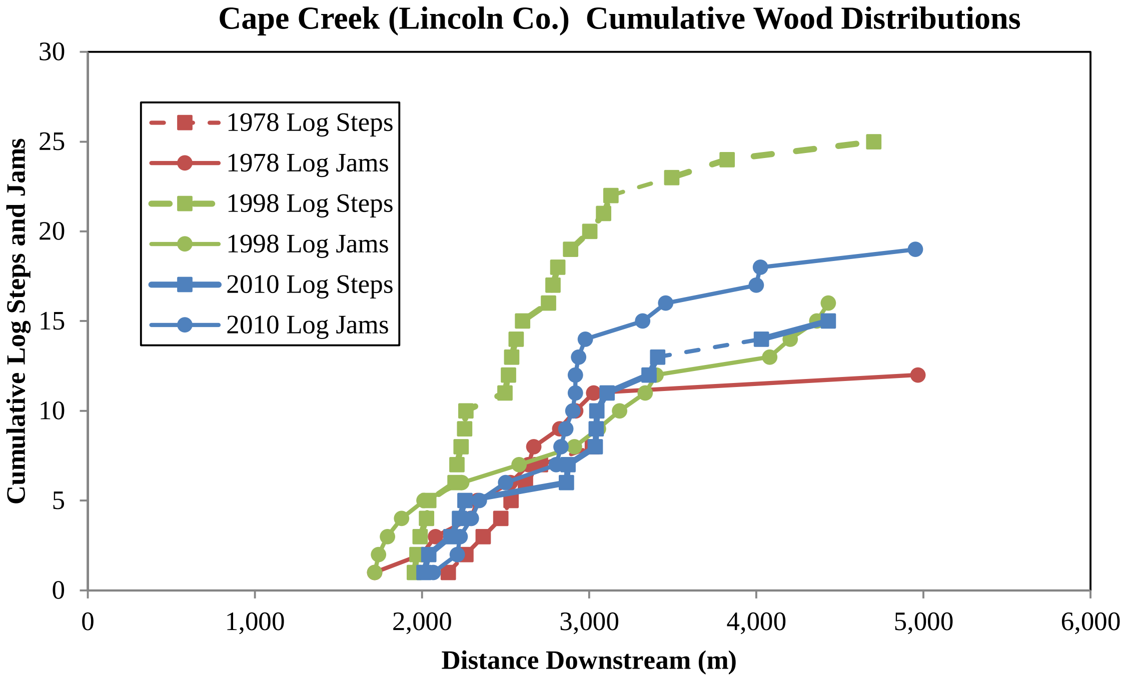


(c) Big Creek

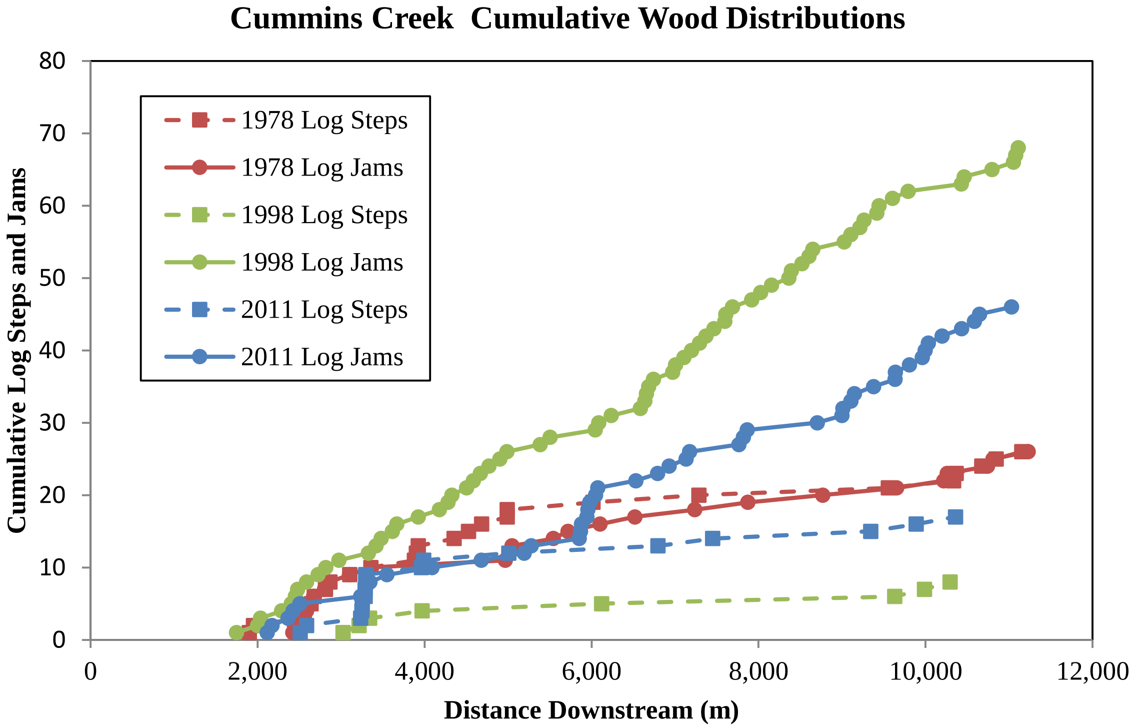


(d) Cape Creek (Lane Co.)

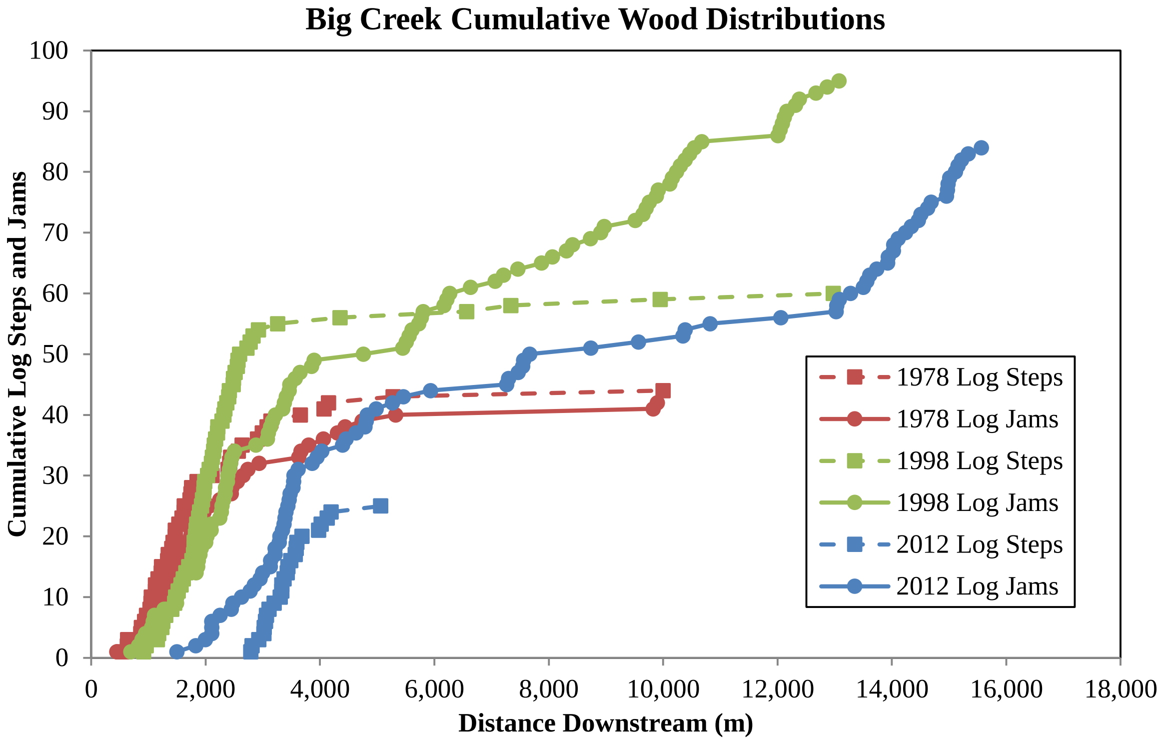
Figure 2.11 (next two pages). Cumulative distributions of log steps and log jams within the four basins (a-d). The watershed outlets are at the downstream end of the plots.



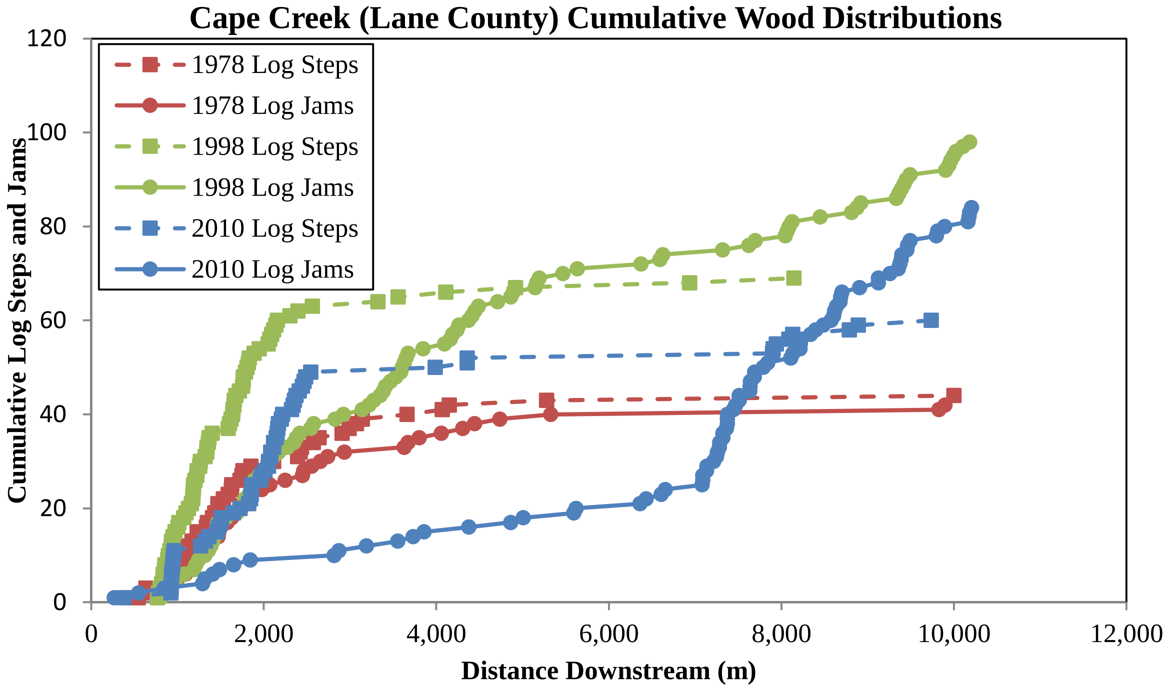
(a)



(b)


Big Creek Cumulative Wood Distributions
Cumulative Log Steps and Jams
0
10
20
30
40
50
60
70
80
90
100
0
2,000
4,000
6,000
8,000
10,000
12,000
14,000
16,000
18,000
Distance Downstream (m)
1978 Log Steps
1978 Log Jams
1998 Log Steps
1998 Log Jams
2012 Log Steps
2012 Log Jams

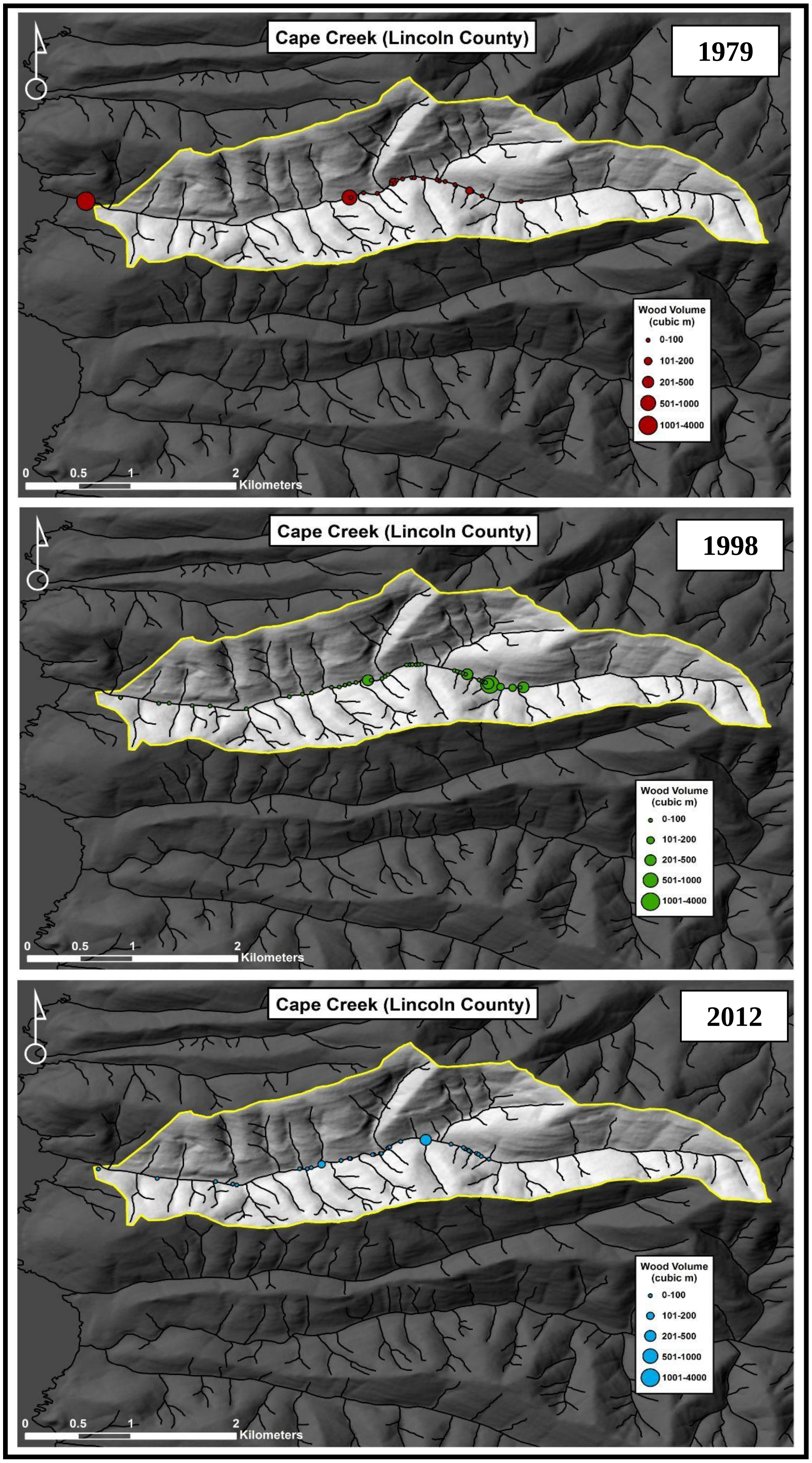
(c)


Cape Creek (Lane County) Cumulative Wood Distributions
Cumulative Log Steps and Jams
0
20
40
60
80
100
120
0
2,000
4,000
6,000
8,000
10,000
12,000
Distance Downstream (m)
1978 Log Steps
1978 Log Jams
1998 Log Steps
1998 Log Jams
2010 Log Steps
2010 Log Jams

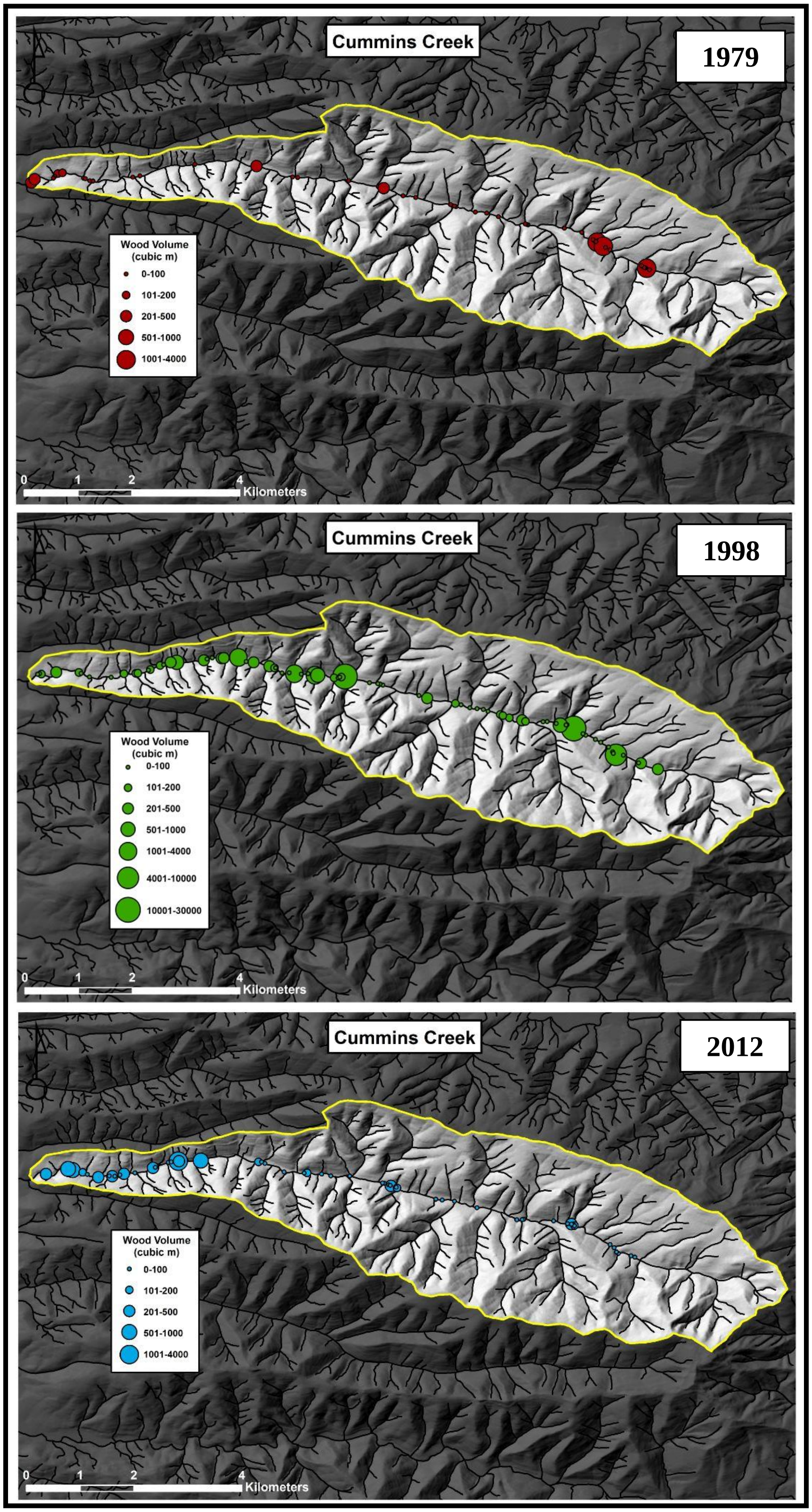
(d)

Figure 2.12 (next four pages). Proportional symbol maps showing wood volume in the four basins for each year (a-d).

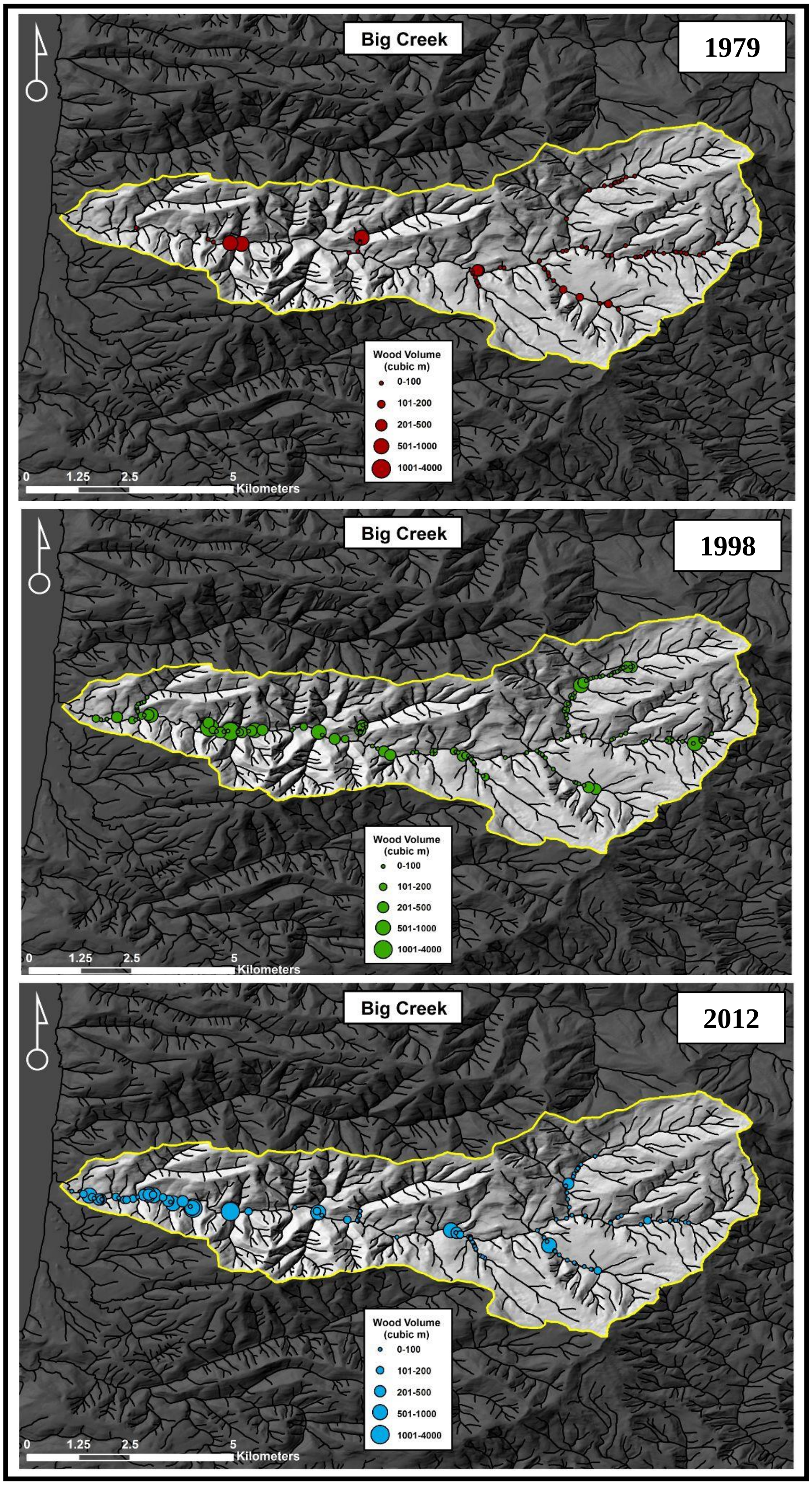
(a)



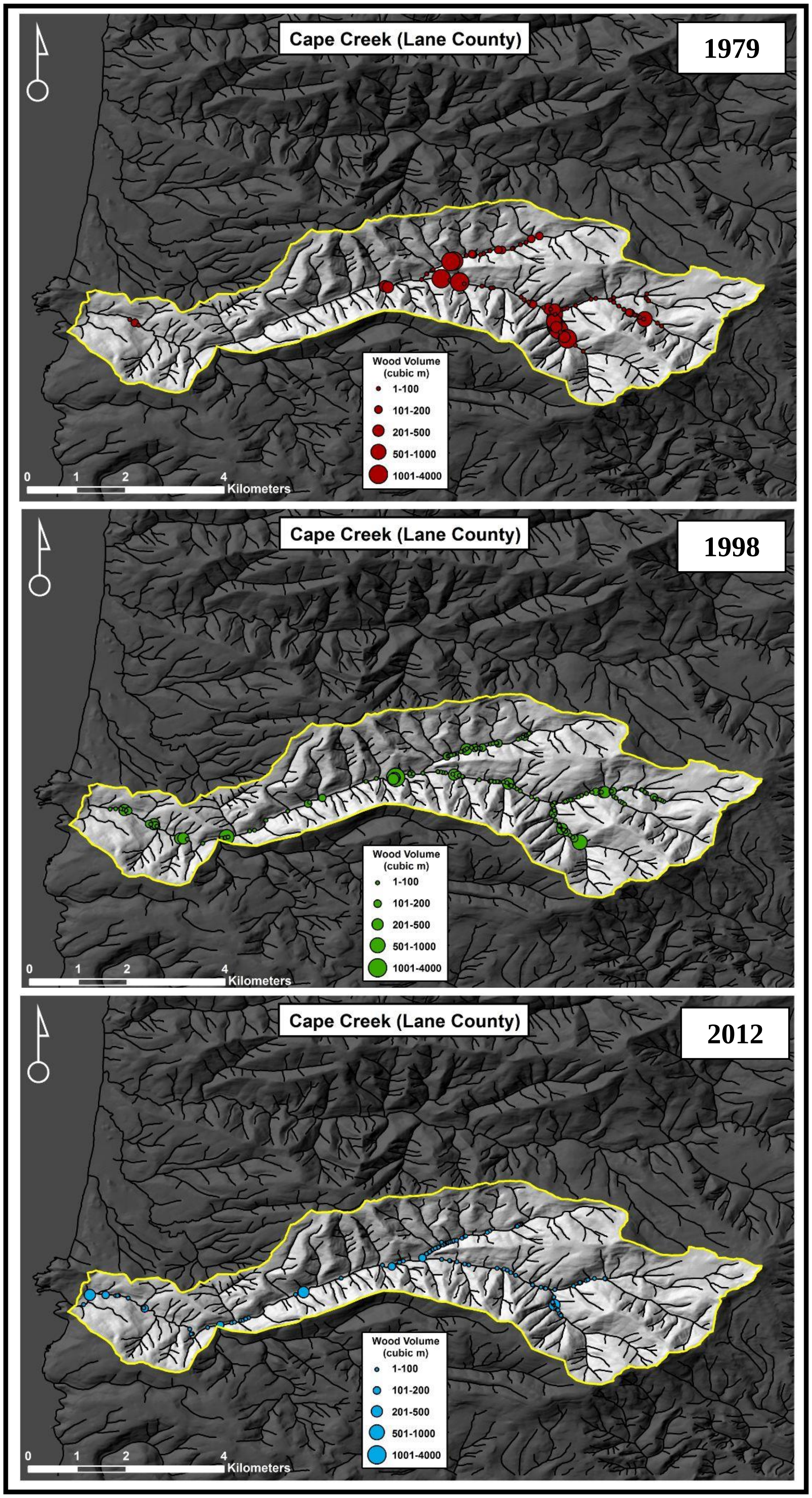
(b)


Cummins Creek
1979
Wood Volume (cubic m)
0-100
101-200
201-500
501-1000
1001-4000
0
1
2
4
Kilometers
Cummins Creek
1998
Wood Volume (cubic m)
0-100
101-200
201-500
501-1000
1001-4000
4001-10000
10001-30000
0
1
2
4
Kilometers
Cummins Creek
2012
Wood Volume (cubic m)
0-100
101-200
201-500
501-1000
1001-4000
0
1
2
4
Kilometers

(c)


Big Creek
1979
Wood Volume (cubic m)
0-100
101-200
201-500
501-1000
1001-4000
0
1.25
2.5
5
Kilometers
Big Creek
1998
Wood Volume (cubic m)
0-100
101-200
201-500
501-1000
1001-4000
0
1.25
2.5
5
Kilometers
Big Creek
2012
Wood Volume (cubic m)
0-100
101-200
201-500
501-1000
1001-4000
0
1.25
2.5
5
Kilometers

(d)


Cape Creek (Lane County)
1979
Wood Volume (cubic m)
1-100
101-200
201-500
501-1000
1001-4000
0
1
2
4
Kilometers
Cape Creek (Lane County)
1998
Wood Volume (cubic m)
1-100
101-200
201-500
501-1000
1001-4000
0
1
2
4
Kilometers
Cape Creek (Lane County)
2012
Wood Volume (cubic m)
1-100
101-200
201-500
501-1000
1001-4000
0
1
2
4
Kilometers

The multiple regression analysis combined the data collected for four watersheds for each of the datasets. The combined number of transects, and therefore n, for each of the regressions is 58 (Tables 2.7, 2.8, and 2.9). The multiple regression analysis to predict the number of log steps, log jams, and total volume of wood present within the channels resulted in low r-squared values (less than .20) for the three datasets in all but one case (Table 2.10). The exception is Cape Creek in Lane County in 1998, where predicted total wood volume had an r-squared value of 0.48. Otherwise, for the 1979 dataset no variable was statistically significant in predicting total wood volumes and for the 2012 dataset drainage area is the sole variable predicting total wood volumes. Drainage area was the sole significant variable for number of log steps in 1998 and 2012. For the 1979 dataset the drainage area combined with percent clearcut had predictive power.

Table 2.7. *p*-Values indicating statistical significance of the differences in total wood volume, number of log steps, and number of log jams among the 1979, 1998, and 2012 datasets.

	Total Wood Volume (m^3)	Log Steps	Log Jams
Cape Creek (Lincoln Co.)			
1979 vs. 1998	.273	**.03 (>1998)**	.465
1998 vs. 2012	.068	.285	1.00
1979 vs. 2012	.715	**.03 (>1998)**	.180
Cummins Creek			
1979 vs. 1998	**.015 (>1998)**	**.018 (>1979)**	**.016 (>1998)**
1998 vs. 2012	**.041 (>1998)**	**.027 (>2012)**	**.008 (>1998)**
1979 vs. 2012	**.028 (>1979)**	.236	.277
Big Creek			
1979 vs. 1998	**.001 (>1998)**	.878	**.035 (>1998)**
1998 vs. 2012	.089	.209	.834
1979 vs. 2012	**.014 (>2012)**	.316	.057
Cape Creek (Lane Co.)			
1979 vs. 1998	.407	.186	**.005 (>1998)**
1998 vs. 2012	**.006 (>1998)**	.218	**.040 (>1998)**
1979 vs. 2012	.080	.308	.129

(Values in bold are significant at the $p<0.05$ level)

The residuals of the step count regressions, plotted in Figure 2.13, reveal some significant under-predictions within the 1998 dataset and to a lesser degree the 2012 dataset. These under-predictions mean that there is more wood in actuality than is being predicted by the model. And lastly, for jam counts the 1979 the predicting variable is drainage area. The 1998 dataset had no significant variables to predict the number of jams, and the 2012 dataset had some predictability (r^2 of 0.106) with bankfull width residuals. Percent clearcut in the riparian buffer were not significant for any of the models.

Table 2.8. Data ranges for 1979 data used in multiple regression analysis.

1979 DATASET				
	Cape Creek (Lincoln Co.)	Cummins Creek	Big Creek	Cape Creek (Lane Co.)
Variables	n = 4	n = 13	n = 23	n = 18
Step Count	0-7	0-5	0-13	0-6
Jam Count	0-8	0-5	0-7	0-8
Tot Wood Volume (m3)	0-866	0-2171	0-1788	0-7044
Slope residual	-0.007--0.02	-0.003-0.004	-0.02-0.02	-0.02-0.01
Drainage Area (km2)	1.37-4.57	2.59-21.52	1.32-38.68	0.38-32.09
Bankfull width residual	-4.98--1.22	-5.28-3.37	-3.31-1.78	-8.67-3.79
Bankfull depth residual	-0.34-0.09	-0.01-0.64	-1.17-0.35	-1.68-0.42
Percent clearcut	15.39-38.07	2.45-10.46	1.87-38.18	20.18-100
Percent riparian clearcut	3.37-10.68	0.17-0.94	0-8.05	0-11.89
Years growth	n/a	n/a	n/a	n/a
Creek	0/1	0/1	0/1	0/1

Table 2.9. Data ranges for 1998 data used in multiple regression analysis.

1998 DATASET				
	Cape Creek (Lincoln Co.)	Cummins Creek	Big Creek	Cape Creek (Lane Co.)
Variables	n = 4	n = 13	n = 23	n = 18
Step Count	1-16	0-3	0-14	0-22
Jam Count	2-5	2-8	0-12	0-15
Tot Wood Volume (m^3)	19-2784	0-13837	0-2336	0-12351
Slope residual	-0.02-0.02	-0.03--0.004	-0.02-0.02	-0.09-0.31
Drainage Area (km^2)	1.37-4.57	2.59-21.52	1.32-38.68	0.38-32.09
Bankfull width residual	-1.55-0.99	-5.99-4.92	-10.55-2.08	-9.82-7.29
Bankfull depth residual	-0.34-0.12	-0.39-0.30	-0.48-0.25	-0.30-0.30
Percent clearcut	37.42-98.23	2.45-13.02	6.57-70.37	39.14-100
Percent riparian clearcut	7.56-24.09	0.17-0.94	0-13.80	0-11.89
Years growth	5	10-15	1-10	1-10
Creek	0/1	0/1	0/1	0/1

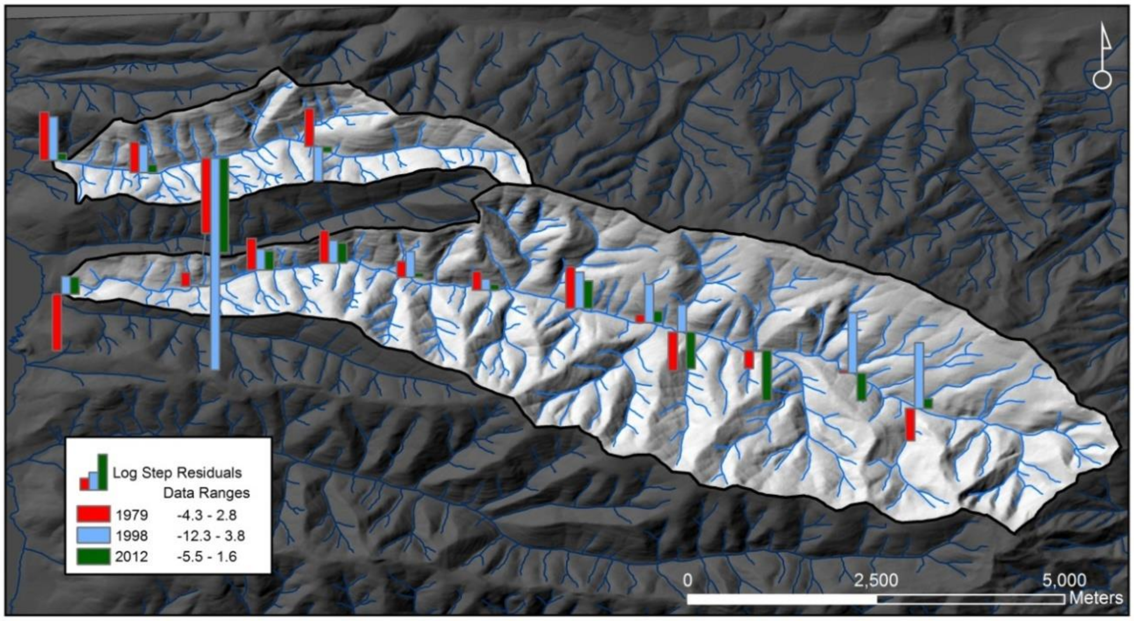
Table 2.10. Data ranges for 2012 data used in multiple regression analysis.

2012 DATASET				
	Cape Creek (Lincoln Co.)	Cummins Creek	Big Creek	Cape Creek (Lane Co.)
Variables	n = 4	n = 13	n = 23	n = 18
Step Count	2-8	0-5	0-7	0-8
Jam Count	1-8	0-9	0-12	0-9
Tot Wood Volume (m3)	3-16	0-1300	0-3290	0-391
Slope residual	-0.004-0.02	-0.05-0.01	-0.07-0.07	-0.04-0.09
Drainage Area (km2)	1.37-4.57	2.59-21.52	1.32-38.68	0.38-32.09
Bankfull width residual	-3.35-0.88	-12.14-2.16	9.39-4.81	-2.91-6.58
Bankfull depth residual	-1.49-0.07	-0.05--0.04	-0.31-0.17	-0.29-0.31
Percent clearcut	43.51-98.23	3.14-13.02	6.6-70.4	40.33-100
Percent riparian clearcut	7.56-24.09	0.18-0.94	0-13.8	0-11.91
Years growth	5-15	25-30	5-25	5-25
Creek	0/1	0/1	0/1	0/1

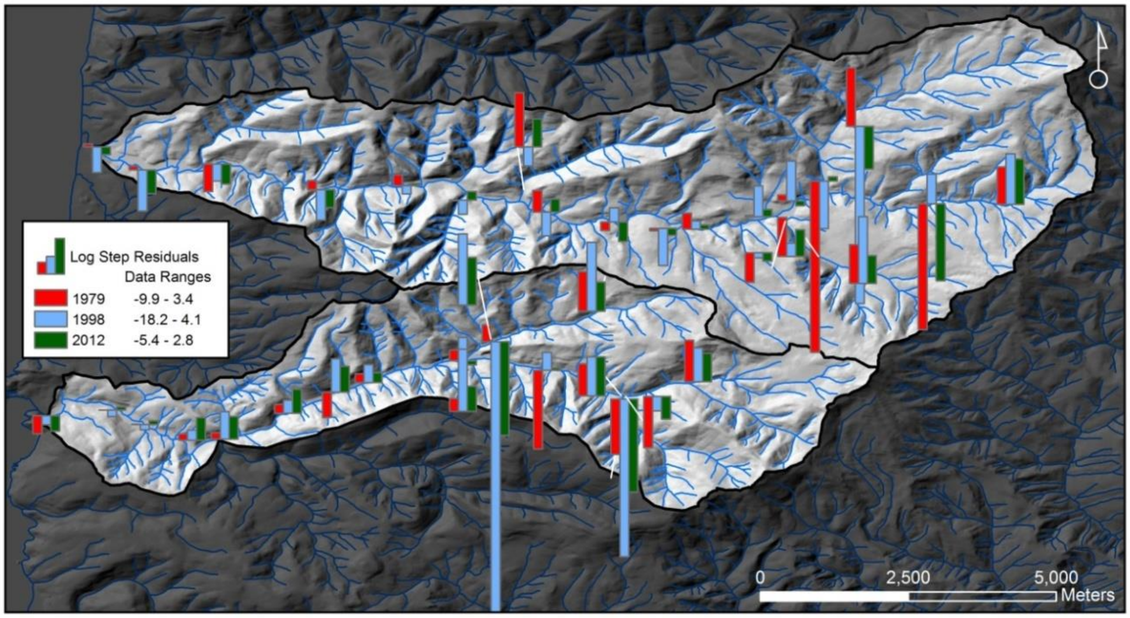
Table 2.11. Results of step-wise multiple regression analysis.

	Step Count			***Jam Count***			***Volume***		
	1979	**1998**	**2012**	**1979**	**1998**	**2012**	**1979**	**1998**	**2012**
Adjusted R^2	0.126	0.129	0.182	0.130	n/a	0.106	n/a	0.333	0.299
Predictor									
Drainage Area	$1^{(-.325, -2.562)}$	$1^{(-.381, -3.030)}$	$1^{(-0.444, -3.637)}$	$1^{(-.381, -3.057)}$				$2^{(0.352, 3.173)}$	$1^{(0.445, 3.651)}$
Cape (Lane)								$1^{(0.315, 2.384)}$	
Big Distance to debris flow								$3^{(-0.281, -2.111)}$	
Percent clearcut	$2^{(-0.290, -2.285)}$								
Bankfull width						$1^{(-.350, -2.743)}$			

Numbers 1 and 2 indicate the most to least amount of predictive power of each variable. For example, in 1979 drainage area has the highest t-statistic value and therefore is the first added variable in the regression. Percent clearcut has the next highest t-statistic value and the two together comprise the final model for step abundance in 1979. The superscript numbers are the standardized beta values and the *t*-values, respectively.



(a)



(b)

Figure 2.13. Maps of predicted log step location residuals. Bars above the line are over-predictions and bars below the lines are under-predictions. Cape Creek in Lincoln Co. and Cummins Creek (a). Big Creek and Cape Creek in Lane County (b).

5. Discussion

To assess the changes in the volume, size, and type of fluvial wood in these watersheds of the Oregon Coast Range, this study combines three field datasets spanning thirty years. The effects of afforestation on fluvial wood in the watersheds are evident through analysis of the field data in combination with aerial imagery. The results of the first research objective show that there are changes among the three years, yet causation is not clear. The results may be indicative of a group of watersheds in disequilibrium with time-dependent recruitment and transport of fluvial wood. However, trends do emerge that confirm processes from land-use change that influence the locations, and perhaps more importantly, the volumes of fluvial wood in the channels.

5.1. Field observations and limitations

During the 2012 data collection some sections in the upper reaches of the watersheds were impassable due to understory vegetation growth. An example is a tributary of Cape Creek in Lane County (Wapiti Creek) that was surveyed both in 1979 and 1998. Ferree (1999) noted that it had just been clearcut in 1998; yet, when I attempted to survey the creek in 2012 it was obstructed by growth and we were unable to access the creek. The same scenario occurred in some of the uppermost sections and lower order tributaries of the other three watersheds. While in many cases we were still able to traverse through growth to see the stream, it inhibited surveying. Development of thick brush along the channels as part of afforestation likely impedes the transport of wood in these networks. The increase in brush and vegetation growth may hinder the abundance of wood making its way into the headwater sections by providing a barrier to the stream.

5.2. Harvesting impacts

The delineation of clearcut areas within the basins shows significant decreases in the amount of clearcutting that has occurred beginning during the time that the 1979 dataset was collected, and continuing – albeit in decreasing amounts – as recently in 2005. It is clear from Figure 2.9 and Table 2.4 that Big Creek and Cape Creek (Lane Co.) have been significantly more impacted by harvesting than others. These differences lend themselves to a comparison between the least harvested of the four basins, Cummins Creek, and the three other basins that are more impacted by timber harvesting. As an aside, it is interesting to note that the only tract of clearcutting that extended to the riparian zone was conducted in 1984, after the initial surveys in Cape Creek (Lincoln Co.). Concurrent with this comparison I will discuss the three hypotheses within the individual creeks as well as collectively.

5.3. Cummins Creek

Cummins Creek in 1979 had an equal number of log steps and log jams in its channel and a relatively even dispersal of wood abundance and volume. Despite the dramatic increase in wood volume in 1998, by 2012 the volume of wood measured in jams decreased to a level close to the 1979 level. However, the volume of wood measured in log steps was markedly reduced in 2012. One reason for this may be that the streams have succeeded in undercutting the voluminous log steps enough to form a log bridge or have otherwise diverted around the log steps creating a new meander or secondary channel. I observed this at numerous during the 2012 data collection. This is the more likely scenario rather than the second hypothesis that it is a change in the tree species within the riparian areas. Clearcutting was minimal and a qualitative review of field data photographs does not support it as well. The largest volumes of wood recorded in 2012 are in the downstream reaches of the channel close to the outlet. When comparing the 1998 wood volumes in Figure 2.12b to the 2012 wood volumes, it is evident that the significant volumes have dispersed and migrated downstream within the last 14 years. These results do not support the hypothesis that a difference will be detected in the number of log steps and log jams due to the cessation of clearcutting. Because the wood abundance is similar in 1979 and 2012, it may be inferred that the significant wood abundance difference in 1998 is due in most part to the storm events of 1996, rather than to afforestation. The increases in volume from 1979 to 1998 are evident in all the watersheds but are greatest in Cummins Creek because it has more mature forest, creating greater volumes of nourishment during episodic events such as debris flows. The slope-area plot for Cummins Creek (Figure 2.10b) indicates that the greatest abundance of wood occur in fluvially-dominated reaches of the drainage network rather than debris flow dominated even in the 1998 dataset where debris flows triggered from the storm were present. The greater abundance of log steps and jams in the lower reaches of Cummins Creek are not in line with the third hypothesis suggested that the greatest abundance would remain in the upper reaches as documented in the 1979 dataset.

5.4. Cape Creek (Lincoln County)

Cape Creek in Lincoln County is less than a quarter the size of Cummins Creek, making it the smallest of all four basins. Despite having the lowest total area of clearcutting, this creek has had 35% of its watershed clearcut. The results of the non-parametric tests comparing the three datasets reveal no statistically significant changes in the abundance or volume of fluvial wood in this basin. It is evident from Table 2.5, however, that the volume of wood throughout the basin decreased from 1998 to 2012. However, this decrease does not occur to the extent that the first hypothesis that there will be a significant decrease in fluvial wood through time or the second hypothesis that there will be a significant decrease in wood volume may be supported. Interestingly, the fluvial wood in the channel is located primarily 2,000-3,500 meters downstream from the headwaters for all three years surveyed (Fig. 2.11a). No statistical significance was found in the multiple regression analysis for proximity to clearcut sites, and because there was no clearcutting in the basin during the 1979 survey, clearcutting is not an explanation for the concentrated location of fluvial wood. It is possible that local effects such as valley width or a change in elevation may be concentrating the wood in this particular stretch of the channel. The slope-area plot shows that the greatest wood concentrations occur right below the transition from debris flow dominant channels to fluvial dominant channels (Figure 2.10a). It is possible that in this basin the transition in the topography causes the wood to accumulate in these reaches. The regression model for the 1998 and 2012 datasets for Cape Creek in Lincoln County shows sizable under-estimations for log steps predicted upstream of the transect bin containing the large portion of the wood (Fig. 2.13). This indicates that controlling factors other than drainage area are influencing the number of log steps formed. Moreover, these results support the third hypothesis that there remains a greater abundance of fluvial wood in the upper reaches of the basin.

5.5. Big Creek

Big Creek is the largest of the four basins and has been harvested as recently as 2005. Its fluvial wood concentrations in both log step and jam form are the greatest in the upstream tributaries between 0-5,000 meters downstream and do not appear again until 8,000 meters downstream in the 1998 and 2012 datasets. The 1979 dataset does not record any log jams downstream of 10,000 meters and for all three datasets the amount of log steps diminishes rapidly below 5,000 meters downstream. The lower reaches of Big Creek begin at this point to widen out with numerous bars and secondary channels present – a departure from Cummins Creek and Cape Creek (Lincoln Co.) that remain more confined in narrower valleys. A similar number of large log jams were recorded in the 1998 and 2012 surveys with a heavy concentration occurring towards the outlet in 2012. The data showing these more recent jams reject the third hypothesis that wood will remain in greater amounts in the upper reaches. The slope-area plot (Figure 2.10c) indicates that the transects with the greatest abundance of wood are located near the transition between debris flow scour and fluvial scour. This may indicate that where there is a topographic shift in the channels wood can accumulate in large numbers. The volume of wood in the form of large log jams increases from 1979 to 1998 and then remains relatively unchanged from 1998 to 2012. This incongruence among the volume of jams in the datasets does not support the second hypothesis that wood volumes are smaller in basins affected by clearcutting, but becomes complicated by the much lower average volume of each log step found in 2012. The nonparametric tests show significant increases in the amounts of wood volume between the 1979 and the 1998 datasets in Big Creek. The wood volume significantly decreases from 1998 to 2012; however, the wood volume is significantly greater in 2012 than in 1979. There is a marked increase, however, in the number of log jams present in Big Creek in 2012 (Figure 2.11c) then in

1979 rejecting the first hypothesis that there is a decrease in the abundance of fluvial wood due to afforestation.

5.6. Cape Creek (Lane County)

Cape Creek in Lane County is by far the basin most heavily impacted by a legacy of clearcutting (greater than 40 percent clearcut in recent decades) in addition to stream restoration designs. The evidence seen during data collection are immobile artificial log steps present in downstream portions (approximately 8,000-10,000m in Figure 2.6d) of the channel. The nonparametric tests show the greatest volume of fluvial wood was present in 1979. There is a significant decrease in the amount of wood volume between the 1998 and the 2012 datasets as well as between the 1979 and 2012 datasets. Cape Creek (Lane Co.) also has significant increases in the number of log jams between the 1979 and the 1998 datasets as well as the 1998 and the 2012 datasets, but not between the 1979 and 2012 datasets. This does not support the first hypothesis that the abundance of log steps and jams has changed due to harvesting. The multiple regression results indicate that Cape Creek (Lane Co.) holds some predictive power with total wood volume. The residuals (Fig. 2.13) indicate the very large under-predictions of wood in Cape Creek (Lane Co.) as well. While the multiple regression model does not show that percentage clearcut in the riparian buffer is a significant predictor for abundance or volume of fluvial wood, the significance of its location within this creek a predictor of total wood volume stands out as an indirect response to its timber harvesting history. Figure 2.7d provides spatial evidence that the volumes of wood in the basin have decreased over time. This supports the second hypothesis that while the abundance remains steady or even increased the associated volume of the log steps and log jams has decreased. While the number of log steps has continued to be concentrated in the upper reaches of the network, the number of log jams has increased in the lower reaches in the 1998 and 2012 datasets rejecting the third hypothesis that the majority of the fluvial wood would remain in the upper reaches. And finally, like Big Creek and Cape Creek (Lincoln Co.), the slope-area plot (Figure 2.10d) indicates that the transects containing the greatest abundance of wood occur just below the transition between debris flow scoured channels and fluvially eroded channels indicating that a local shift in the topography may be a driver of fluvial wood accumulation.

5.7. Storm of 1996 impacts

A significant variable among the three datasets is the amount of precipitation that occurred prior to the field datasets being conducted. As revealed previously, there were not storms preceding data collection in 1979 and 2012 that produced numerous debris flows. However, the 1998 dataset was collected shortly after the period of record storms for the Oregon Coast Range in 1996. These events triggered and mobilized landslides and debris flows (May and Gresswell, 2004; Roering et al., 2003) and additions of fluvial wood into the systems effectively increasing the amount and volume of wood present in the OCR (Ferree, 1999). This is the predominant cause of the overall greater abundance of wood surveyed in 1998 compared to 1979 and 2012. This result offers insight into the residence time of the fluvial wood in these basins. A key example is the massive log step mentioned above that was measured in Cummins Creek in 1998. There was no evidence of this single log step or log jam at the same location during the 2012 survey. Therefore, it may be concluded that the wood successfully disseminated and migrated downstream with typical rainfall averages between those times. This reveals that the wood residence times in these watersheds are short. Substantial amounts and volumes of fluvial wood may transport through these watersheds in less than a decade. The effects of precipitation lead to a hypothesis that wood patterns at this temporal scale are not in equilibrium at shorter time scales.

6. Conclusions

The Oregon Coast Range is unique both in its physical character and land-use management. It is an active dynamic region that is abundant with vegetation due to its maritime climate. Because its watersheds are so heavily forested, there is complexity to its steep mountain streams from the abundance of fluvial wood that form steps. These forested watersheds have historically been areas of resource extraction in the form of timber harvesting. The four watersheds surveyed in the years 1979, 1998 and 2012 have similar geologic substrates and climate; however, they vary in size and each has its own history of harvesting and subsequent road-building and history of timber harvest.

The data show in large part that the wood in these channels is dynamic and residence times are brief. A storm event can trigger episodic pulses of sediment and debris into the channels overwhelming other land-use considerations such as clearcutting. The analysis of the three datasets has shown that while an increase in overall wood abundance may occur after a significant event such as the storm of 1996, over time the wood will transport through the channels and readjust to levels comparable to those prior to this storm of record. While the two hypotheses proposed relating to afforestation have, for the most part, been rejected by the data analysis the scenarios which they supported are compelling. This is particularly so in Cape Creek in Lane County where the overall volume of log steps and log jams has decreased considerably under timber harvest since

1979. Additionally, the third hypothesis that the majority of fluvial wood will continue to occur in the upper reaches of the watershed is only supported in Cape Creek in Lincoln County. Because of the abundance of non-forest vegetative growth it may be concluded that the upper reaches of these basins are no longer accessible to fluvial wood deposits – a certain effect of afforestation.

CHAPTER III

ASSESSING STREAM MORPHOLOGY CHANGES LINKED TO FLUVIAL WOOD DYNAMICS IN THE OREGON COAST RANGE OVER A THIRTY YEAR INTERVAL

1. Introduction

The production and entrainment of large wood and its dynamic interactions within riparian corridors increases complexity of river environments by providing aquatic habitat and creating associated complex channel hydraulics and morphology. In mountain streams, fluvial wood is often the primary facilitator of geomorphic change creating stepped longitudinal profiles, step-pools, and step-riffles where they may not otherwise be found (Montgomery and Buffington, 1997). Fluvial wood creates stable and persistent sediment storage sites in mountain streams and reduces mean travel distances of entrained particles (Beschta, 1979; Bilby, 1981; Marston, 1982; Montgomery et al., 1996; Nakamura and Swanson, 1993; Swanson et al., 1976). Clearcut timber harvesting of the hillslopes and riparian corridors of these riverscapes increases rates of landsliding (Montgomery, 2000; Sidle RC, 1985; Swanston and Swanson, 1976) and inhibits sediment storage capacity (Montgomery et al., 2003). However, far less is known about the longer-term legacies that timber harvesting has on instream wood and its morphological impacts on sediment storage, instream features such as step-pools, and energy dissipation. This study focuses on four coastal watersheds within the Oregon Coast Range that are occupied by a working forest that has long been affected by management, particularly timber harvest. Changes that have occurred in the stream morphology over thirty years are assessed by recreating in 2012 a field dataset documenting fluvial wood dynamics first created in 1979 by Richard Marston (Marston, 1980) and again by Jonathan Ferree in 1998 (Ferree, 1999) providing three total datasets documenting fluvial wood dynamics. The first objective is simply to assess the changes that have occurred in stream morphology among the three datasets over the thirty year interval. The second objective is to assess changes in downstream hydraulic geometry (DHG) among the years and basins to test the hypothesis that DHG will be stronger with less wood volume. The third objective is to analyze the spatial distribution of stream power across the four basins to discern patterns and trends associated with fluvial wood changes throughout the thirty year interval.

1.1. Background

Flow alteration from geomorphic processes influence the ecological response and disturbance regime in mountain streams (Montgomery, 1999; Poff et al., 2006). The study basins have all had hillslope clearcuts to varying extents within the last fifty years. In the last thirty years, however, the amount of timber harvesting in the watersheds has been reduced dramatically due initially to National Environmental Protection Act (NEPA) lawsuits concerning the cumulative effects of timber harvesting in landslide prone areas of Siuslaw National Forest (Craig, 1987). Afforestation has continued throughout the recent decades leading to questions regarding the effects of this growth on stream morphology, primarily through changes in wood abundance and volume in the channels. It has been hypothesized that the amount and volume of wood has decreased in these watersheds due to the reduction of timber slash and landslides associated with timber roads (Atha, 2013). While wood is often introduced into the channel by dead trees that fall in, bank undercutting, or blow-down, an important mechanism of wood input in the Oregon Coast Range is debris flow activity. Montgomery et al. (2003) investigated the extent to which debris flows influenced pool creation and how this influence has changed with logging practices. They found that debris flows become more important in harvested watersheds because of a lack of available key log pieces to form significant jams. Research addressing the changes in wood abundance and volume from the datasets in this project has shown a decreasing trend in the wood volumes stored in the watersheds, particularly in the watersheds that have the most extensive history of clearcutting (Atha, 2013).

In addition to instream wood and debris flows (Montgomery and Buffington, 1997), mountain rivers are also influenced by resistant rock and differential tectonic uplift throughout the basins which may affect how a river adjusts channel geometry with average annual flows (Wohl, 2000). The channel geometry of these watersheds is influenced by differential tectonic uplift, instream wood, the presence of debris flows in addition to timber harvesting. One proposed hypothesis is that the two watersheds, Big Creek and Cape Creek (Lane County) that have experienced greater harvesting impacts historically will have a more well-developed downstream hydraulic geometry than their less affected counterparts. Downstream hydraulic geometry (DHG) asserts that channel variables will vary as a power function of discharge in the downstream direction with drainage area often being substituted for discharge (Fonstad and Marcus, 2010). Without the influence of mature forest and resulting significant wood volumes in the streams, I hypothesize that the streams will have greater stream power and ability to adjust to changes in the magnitude and frequency of bankfull and greater discharges resulting in higher coefficients of determination (r^2) between response variables such as bankfull width or bankfull depth and drainage area.

Stream power, the rate of energy expenditure as water travels downstream in a channel, is a useful parameter for examining geographic variability in mountain streams (Fonstad, 2003). Stream power is used to describe particle entrainment (Graf, 1983) in mountain rivers and its spatial pattern has been found to influence erosion, sediment transport, and deposition (Lecce, 1997). In forested mountain streams geomorphically significant log steps may develop where individual logs spanning the width of the channel effectively trap sediment behind them. Consequently, the log steps reduce the amount of potential energy available for conversion to the kinetic energy of water flowing over the step consequently dissipating energy used for sediment routing (Marston, 1982). This paper tests the downstream hydraulic geometry concept and examines the spatial distribution of stream power across the four basins as part of the stream morphology change assessment.

2. Study area

The study area consists of four forested watersheds along the central Oregon Coastal Range (Figure 2.2). I chose these watersheds because they have been previously surveyed by Marston (1982) and Ferree (1999). The watersheds are all located within the

Siuslaw National Forest and provide a range of physiographic characteristics and impacts from years of forest management. The watersheds to be examined are Cape Creek in Lincoln Co., Cummins Creek, Big Creek, and Cape Creek in Lane County (Table 3.1). Elevations range from sea level to 767 meters at Cummins Peak. Clearcut areas delineated from historical aerial imagery beginning in the year that the first dataset was collected and ending in 2011 (Atha, 2013) show the variable amounts of timber harvesting over the last thirty years in the study basins (Table 3.1). The amount of clearcutting was heaviest in 1979 resulting in many bare slopes and timber slash in the basins at that time.

Table 3.1. Watershed Characteristics

	Cape Creek (Lincoln Co.)	Cummins Creek	Big Creek	Cape Creek (Lane Co.)
Drainage Area (km^2)	4.82	24.66	39.37	31.86
Channel Slope Range (m/m)	0.01-0.59	0.01-0.42	0.00-0.37	0.00-0.46
Channel Elevation Range (m)	0-340	0-436	0-350	0-400
Total area clearcut 1979-present (km^2)	1.7	3.1	10.8	14.9

.

The watersheds are composed predominantly of Yachats Basalt, an upper Eocene unit consisting of porphyritic basaltic lavas that are intruded by dikes of more resistant aphanitic basalt (Dietrich and Dunne, 1978). The hillslopes are convex with narrow ridgetops with thin gravely sandy loam situated at the angle of repose (Dietrich and Dunne, 1978; Marston, 1982). Douglas fir (*Pseudotsugamenziesii*) and western hemlock (*Tsugaheterophylla*) are the dominant tree species on the hillslopes of the basins. Western red cedar (*Thujaplicata*) occupies moist regions intermixing with large Sitka spruce

(*Piceasichensis*). Hardwood red alder (*Alnusrubra*) is found throughout the riparian zones of the watersheds (Marston, 1980). The temperate climate is wet with an average total annual rainfall of 2,540 mm in the headwaters and 2,030 mm along the coast. The Alsea Fish Hatchery located 40 km north of the study area provides precipitation data for the region near the study watersheds (Figure 2.7). These basins have a high flow regime in the winter months and a low flow regime in the summer months. The precipitation is largely rainfall with snowfall averaging less than a few inches per year (Dietrich, 1975). It is important to note that during the winter two years prior to Ferree's 1998 data collection, a major storm event induced the floods of record in the study area watersheds causing significant storm damage, debris flows, and shifts in stream morphology (Ferree, 1999). A significant storm since then occurred in December 2010 when it received 19.54 mm of precipitation with an annual total of 2610 mm, however, it did not exceed the typical precipitation averages for this study area.

3. Methods

3.1. Recreating a field dataset

In order to address the research objectives, the methods included collecting stream morphometric data within the four watersheds as well as surveying fluvial wood in the form of log steps and log jams spanning the width of the channel. This study provides the third repeat survey of the study area and the foundation to assess changes that have occurred in the stream morphology over the last thirty years.

Field data collection included moving progressively upstream from the coast of each watershed recording data at transects first established by (Marston, 1980). The survey ends in the headwater reaches at endpoints originally determined by Marston (1980) and/or Ferree (1999) or until the stream is no longer passable (Table 2.2). I utilized GPS and U.S.G.S. 15-minute topographic quadrangle maps originally used in 1979 to locate the transect locations spaced approximately 0.4 km apart throughout the channels. Each transect is 10 meters long parallel to the stream (Figures 3.1-3.4). I visually determined in the field river reaches without meander bends deemed to be the likely location of where data were collected previously. The spatial error of the new transects and those collected previously is likely 3-5 meters in most locations. In the lower-order portions of the stream networks, however, the spatial error may be greater. This is due to narrower stream channels with steeper slopes and the abundance of vegetation found in the upper reaches of the stream.

I measured bankfull width as the distance between channel banks where the water surface elevation is at the maximum height within the channel without flooding into the overbanks. This was done at four cross-sections evenly spaced throughout each transect. I measured bankfull depth as the distance between channel banks when water surface elevation is at the maximum height within the channel without flooding into the overbanks once at each cross-sectional midpoint. I estimated channel slope with one person holding a laser range finder that provides slope in degrees at the upstream end of the transect and another person holding the stadia rod at the downstream end with their hand at eye height. Slope was measured at the transects for all three datasets. Figures 3.5-3.8 highlight the variations in slope for the three years and also compare them to averaged slopes for the networks obtained from Netmap data (Benda et al., 2007). These variations in slope are important as the parameters are used to derive variables such as mean stream power. In order to determine the changes in channel unit types (Bisson et al., 2006) among the three datasets I recorded estimations in the channel area percentages during low flow conditions in riffles, pools, rapids, steps, and cascades found within each transect.

To compare changes in median grain sizes of the four watersheds as well as obtain the d_{84} parameter necessary to determine a ratio indicating a threshold for rivers having well or poorly developed DHG – discussed in further detail below – I conducted Woman pebble counts within each transect. I measured the B-axis of 50 random pebbles to determine size in millimeters. I selected a pebble with each step (when possible) while zigzagging the transect length.

In addition to the morphometric data collected at each transect, I measured and recorded the locations via GPS of all channel-spanning fluvial wood. Marston (1980) and Ferree (1999) mapped channel-spanning wood on 1:5000 scale maps providing accurate locations and measurements in the datasets from 1979 and 1998. This wood takes the form of log steps, defined as an accumulation of wood that traps sediment in a plain or plug behind it and the stream flows over it, and log jams that are porous and do not have a sediment plain or create a significant drop or fall within the active channel (Marston, 1980).

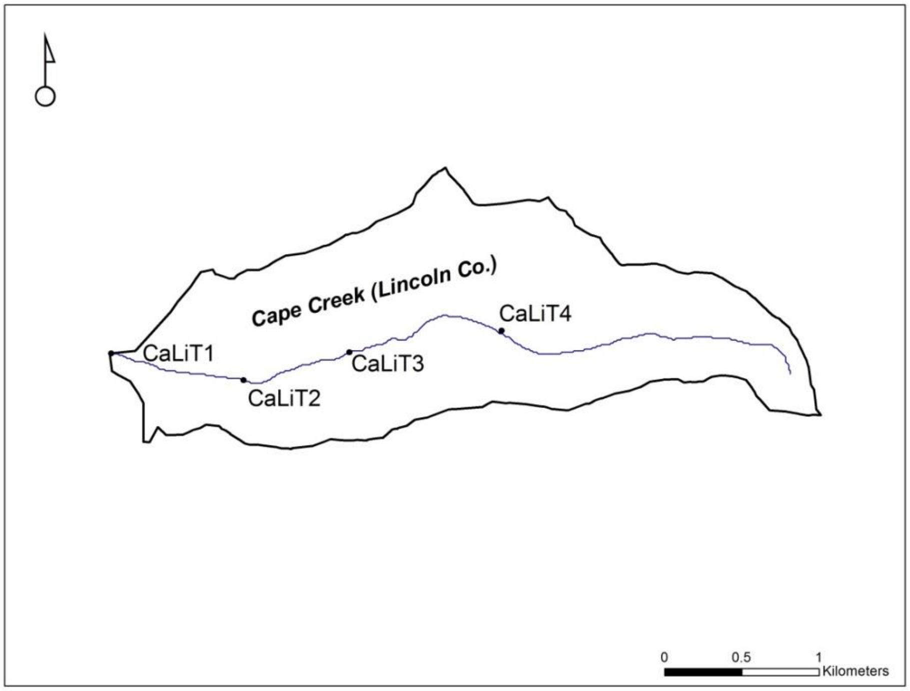


Figure 3.1. Transect locations for Cape Creek (Lincoln County).

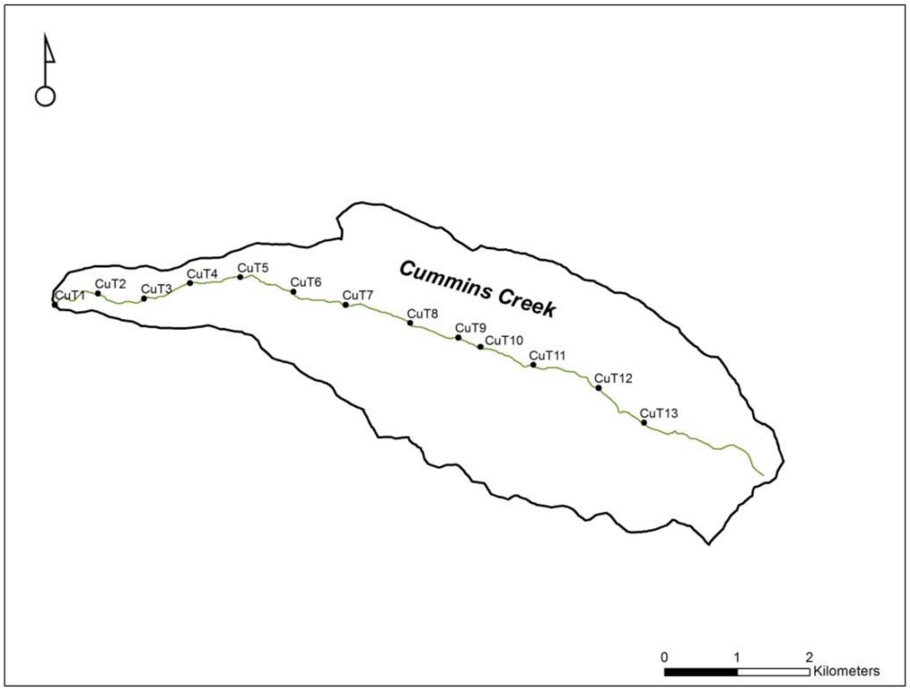


Figure 3.2. Transect locations for Cummins Creek.

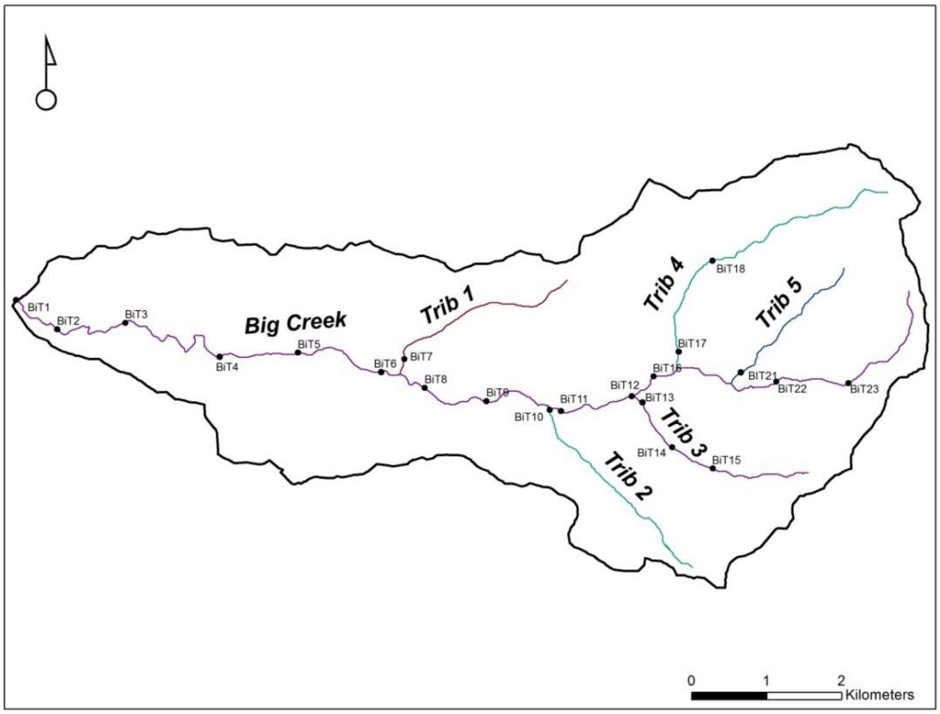


Figure 3.3. Transect locations for Big Creek.

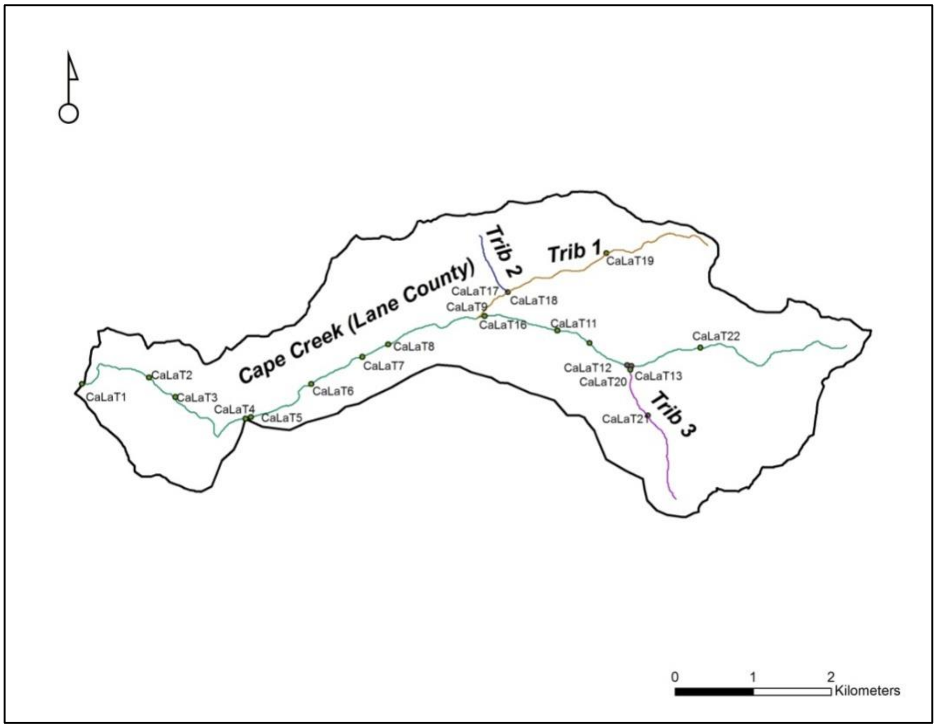


Figure 3.4. Transect locations for Cape Creek (Lane County).

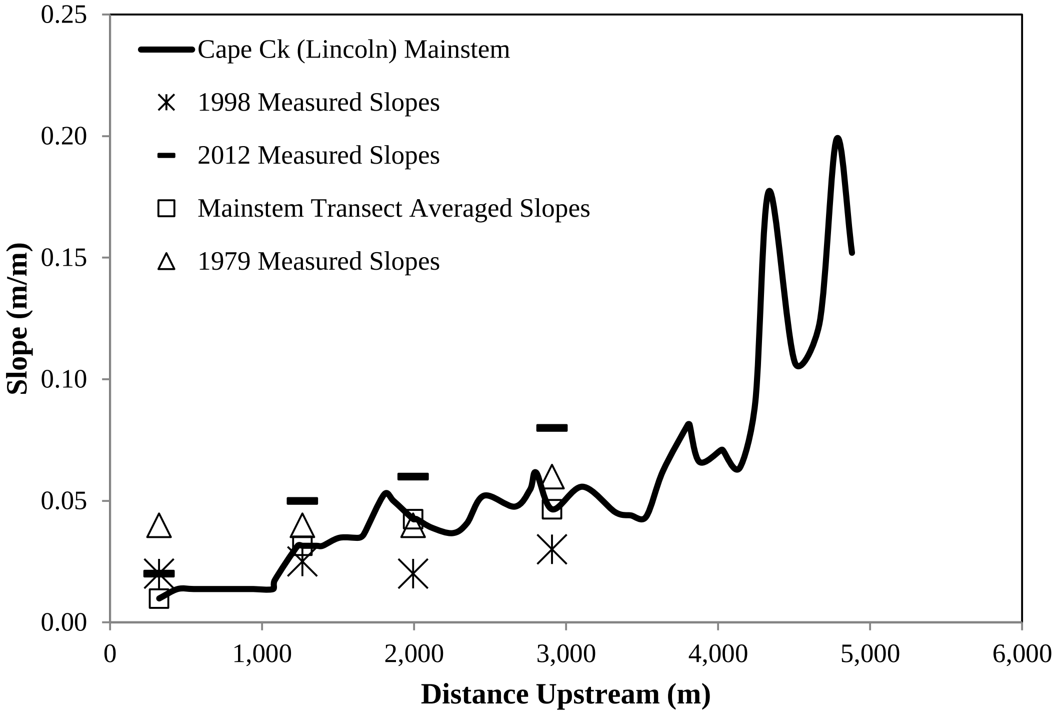


Figure 3.5. Cape Creek (Lincoln Co.) averaged slopes derived from Netmap data with transect locations. The field-based measured slopes are also shown for the 1979, 1998, and 2012 datasets.

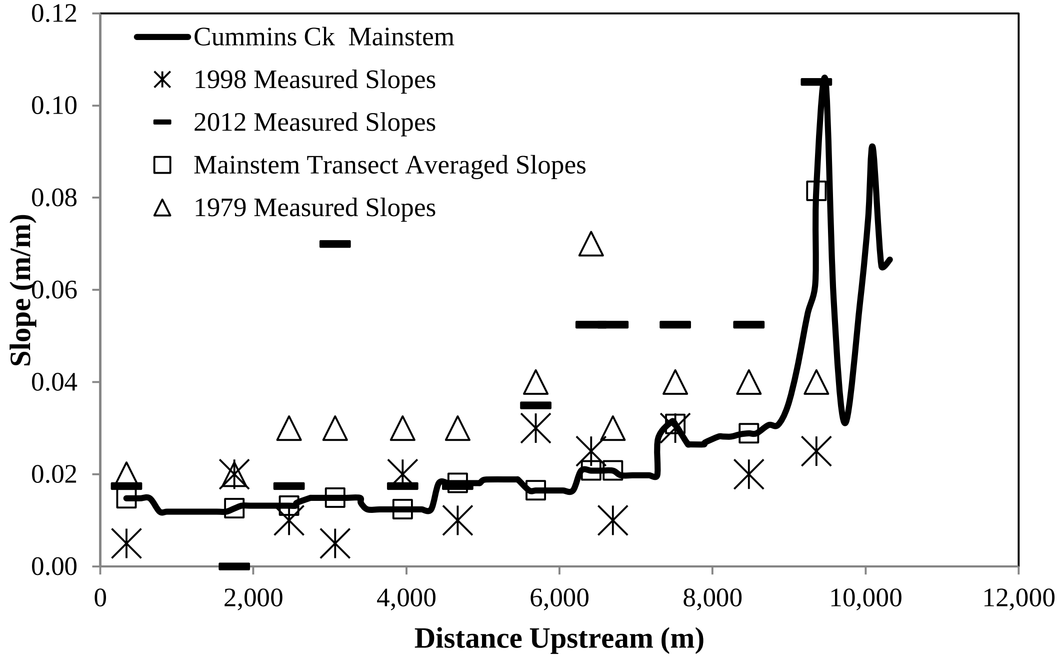
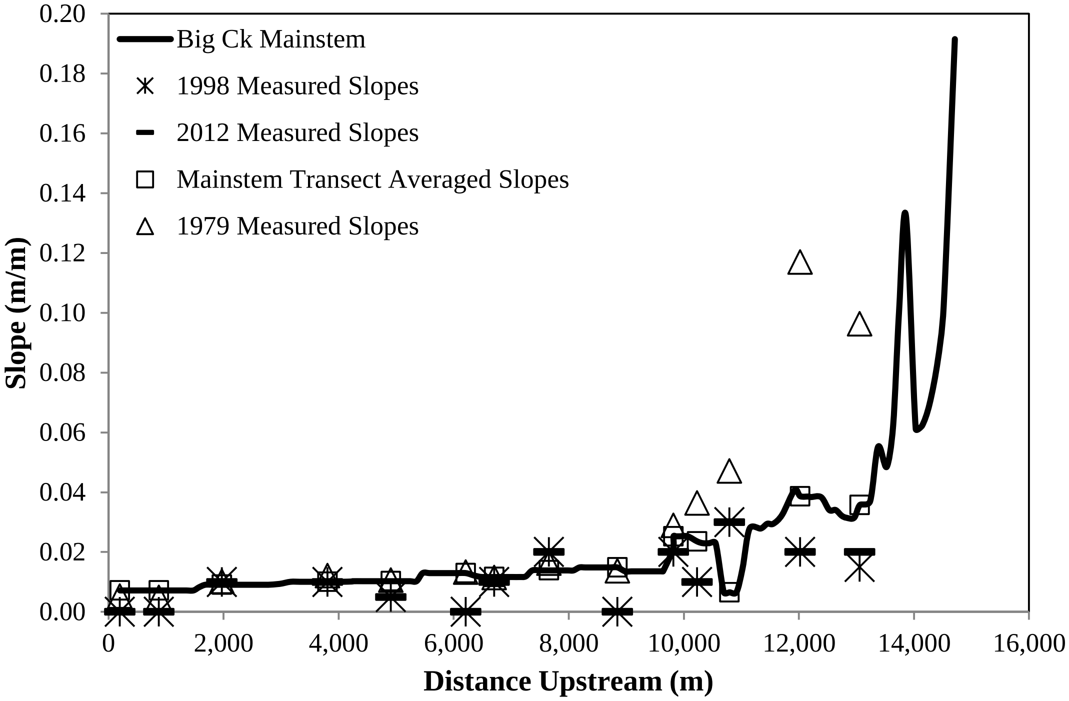
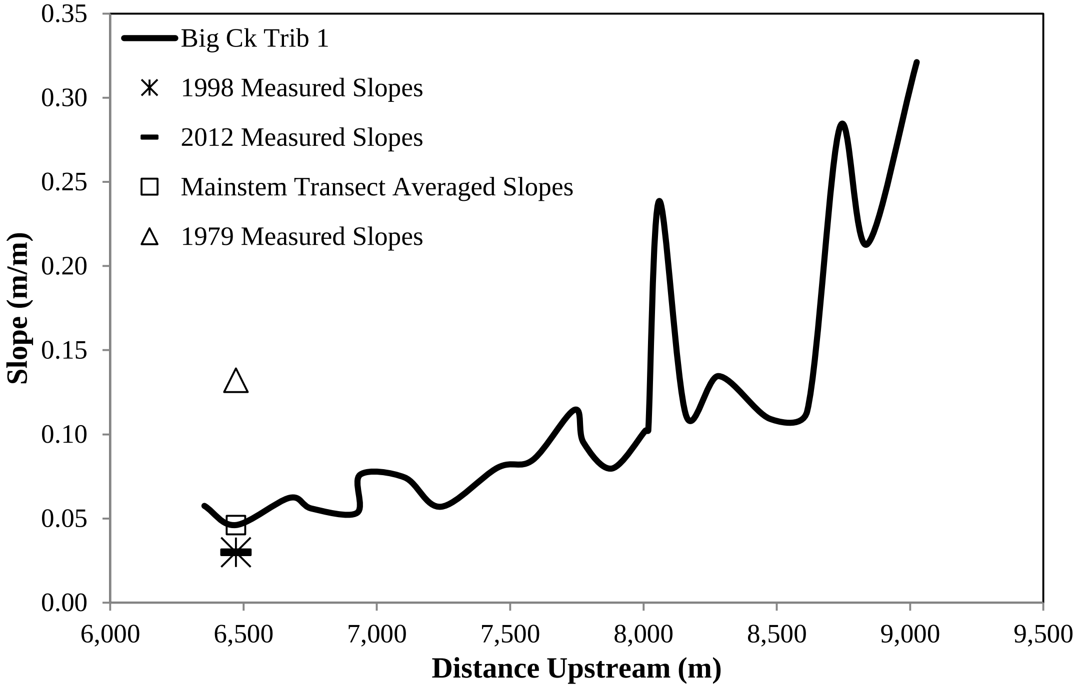


Figure 3.6. Cummins Creek averaged slopes derived from Netmap data with transect locations. The field-based measured slopes are also shown for the 1979, 1998, and 2012 datasets.

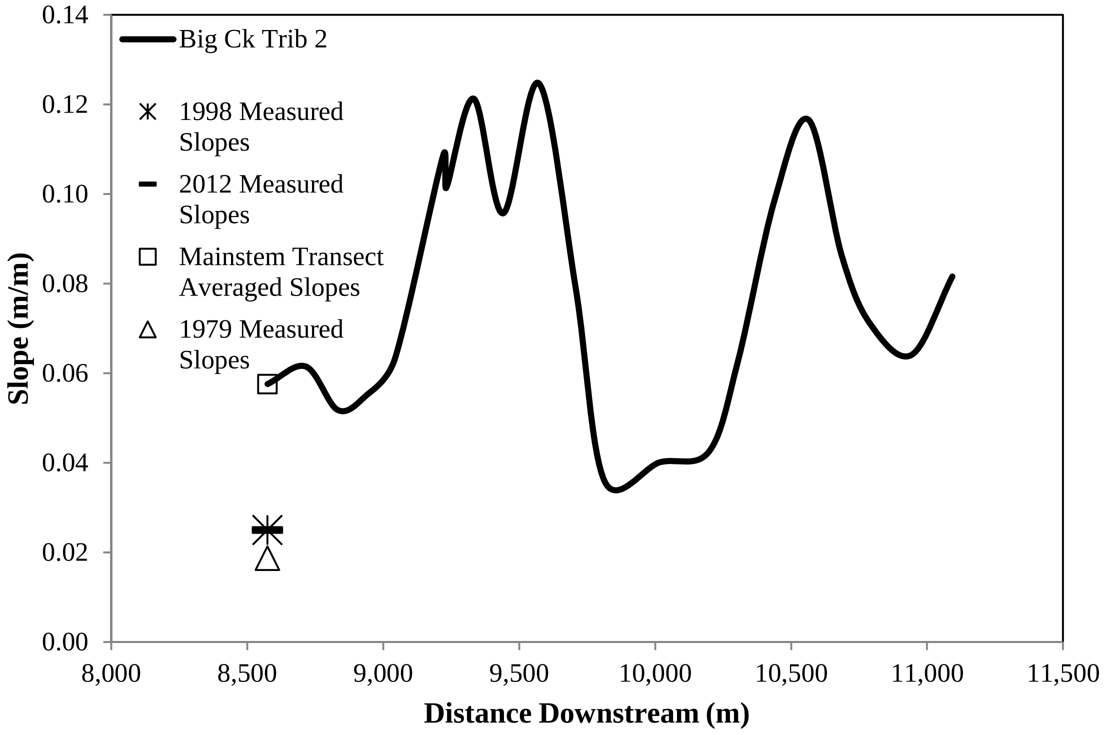
Figure 3.7 (next 3 pages)**.** Big Creek mainstem and tributaries averaged slopes derived from Netmap data with transect locations (a-f). The field-based measured slopes are also shown for the 1979, 1998, and 2012 datasets. The tributary names correspond with Figure 3.3.



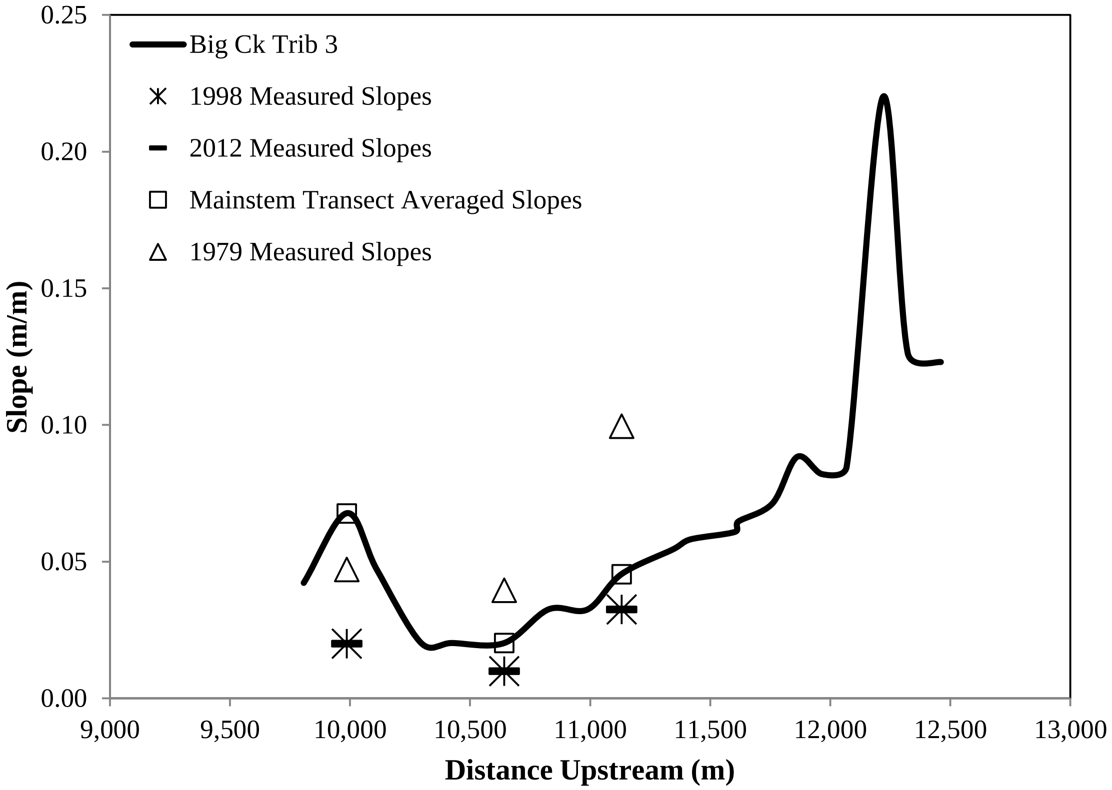
(a)



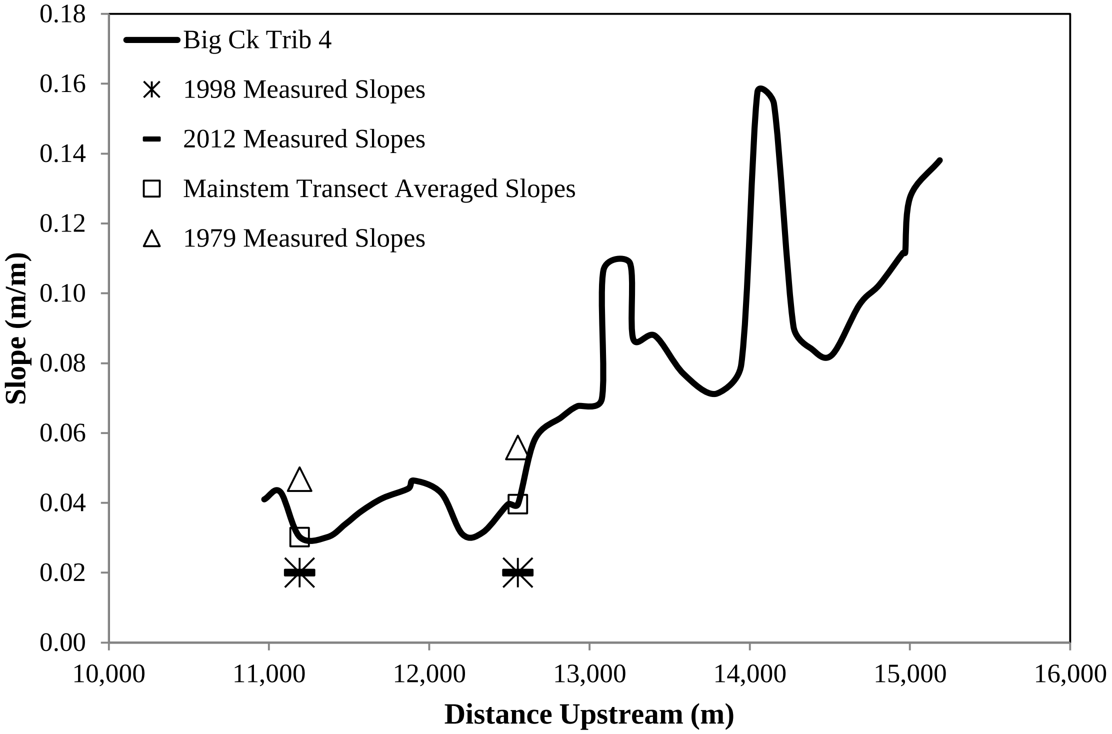
(b)


Big Ck Trib 2
1998 Measured Slopes
2012 Measured Slopes
Mainstem Transect Averaged Slopes
1979 Measured Slopes
Slope (m/m)
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
8,000
8,500
9,000
9,500
10,000
10,500
11,000
11,500
Distance Downstream (m)

(c)

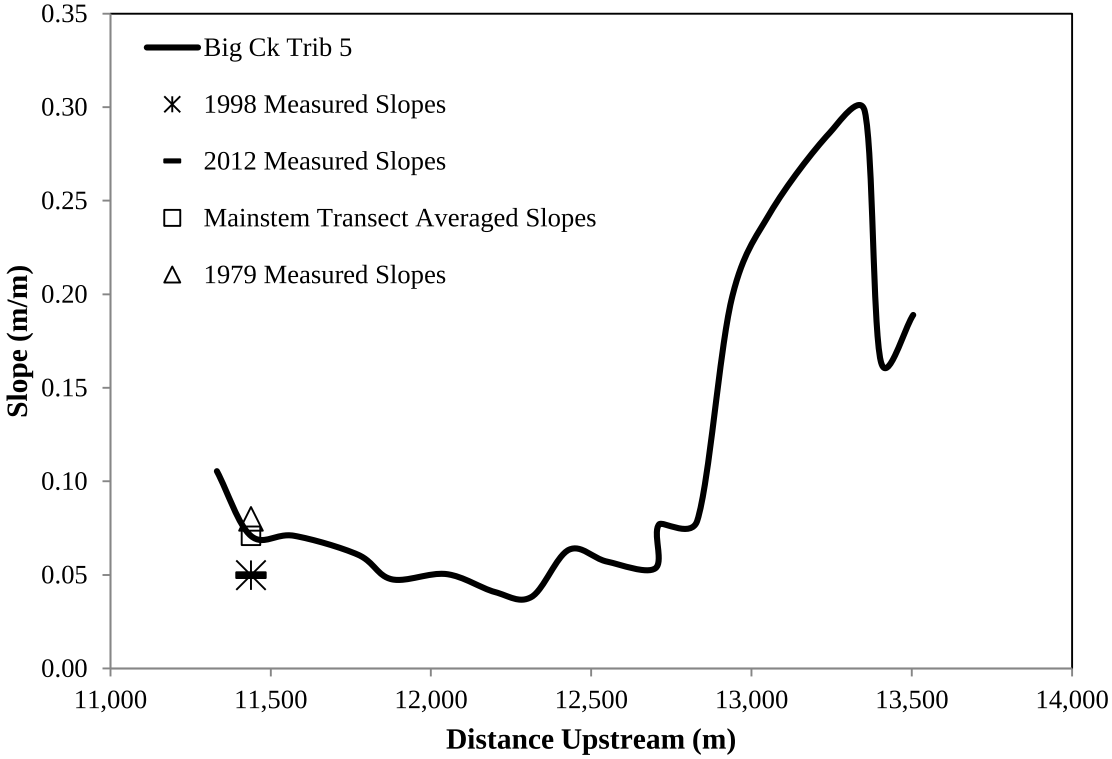

Big Ck Trib 3
1998 Measured Slopes
2012 Measured Slopes
Mainstem Transect Averaged Slopes
1979 Measured Slopes
Slope (m/m)
0.00
0.05
0.10
0.15
0.20
0.25
9,000
9,500
10,000
10,500
11,000
11,500
12,000
12,500
13,000
Distance Upstream (m)

(d)



0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Slope (m/m)
10,000
11,000
12,000
13,000
14,000
15,000
16,000
Distance Upstream (m)
Big Ck Trib 4
1998 Measured Slopes
2012 Measured Slopes
Mainstem Transect Averaged Slopes
1979 Measured Slopes

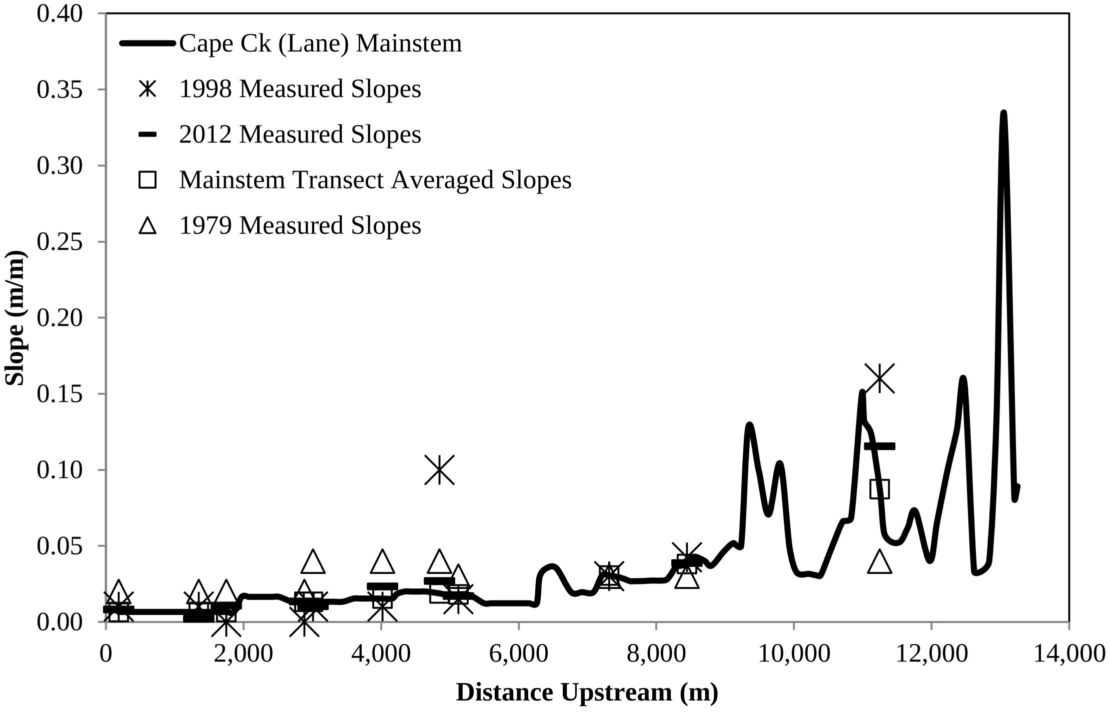
(e)



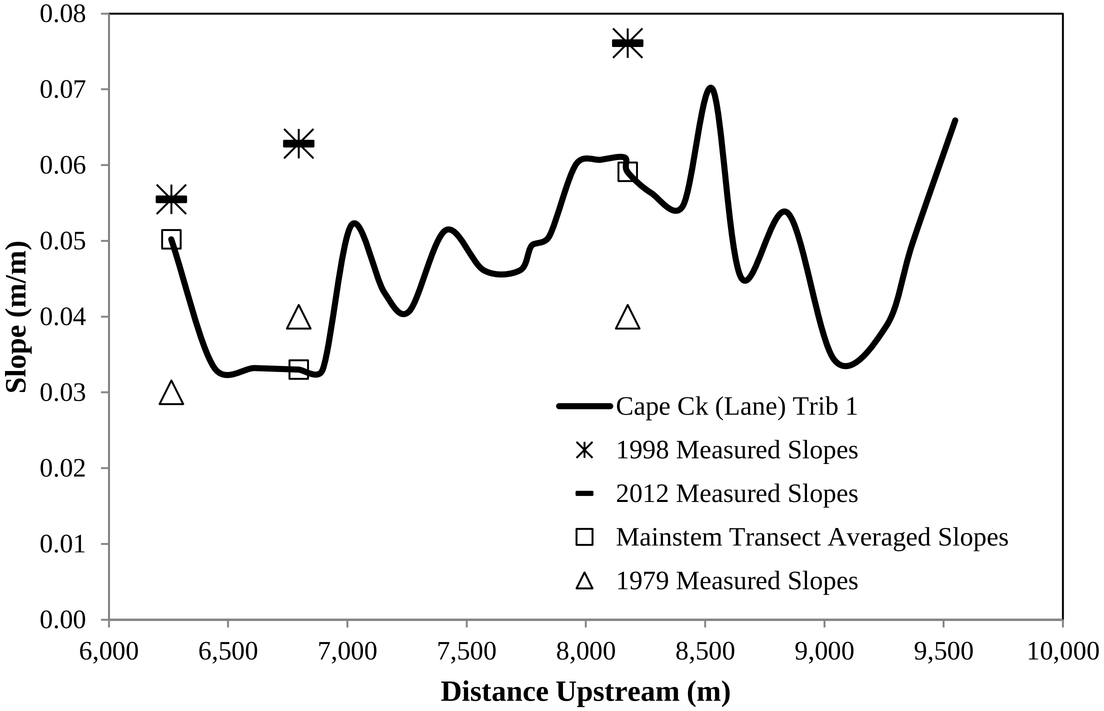
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Slope (m/m)
11,000
11,500
12,000
12,500
13,000
13,500
14,000
Distance Upstream (m)
Big Ck Trib 5
1998 Measured Slopes
2012 Measured Slopes
Mainstem Transect Averaged Slopes
1979 Measured Slopes

(f)

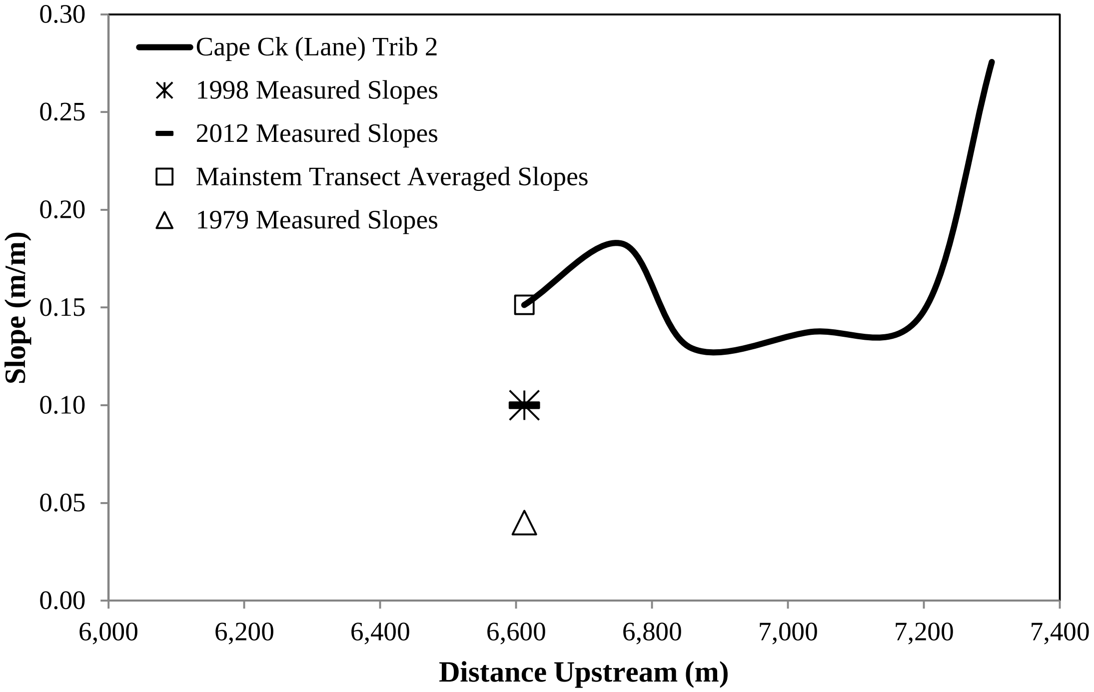
Figure 3.8 Cape Creek (Lane Co.) (next 2 pages). mainstem and tributaries averaged slopes derived from Netmap data with transect locations (a-d). The field-based measured slopes are also shown for the 1979, 1998, and 2012 datasets. The tributary names correspond with Figure 3.4.



(a)

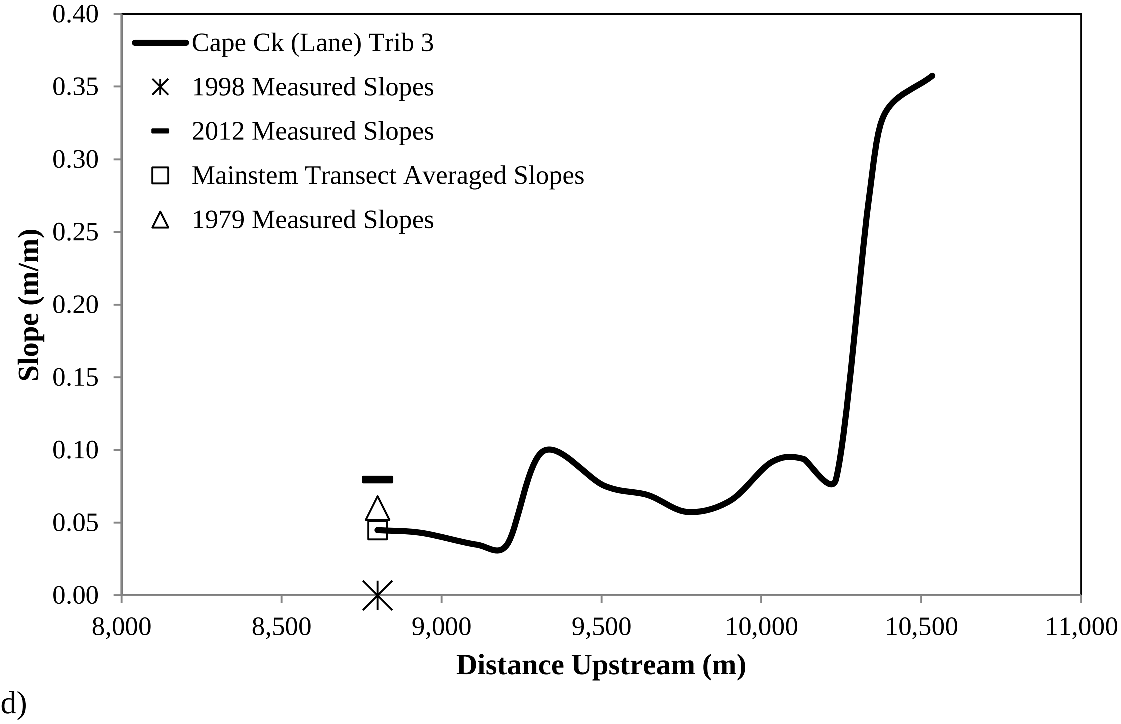


(b)



0.30
0.25
0.20
0.15
0.10
0.05
0.00
Slope (m/m)
6,000
6,200
6,400
6,600
6,800
7,000
7,200
7,400
Distance Upstream (m)
Cape Ck (Lane) Trib 2
1998 Measured Slopes
2012 Measured Slopes
Mainstem Transect Averaged Slopes
1979 Measured Slopes

(c)



0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Slope (m/m)
8,000
8,500
9,000
9,500
10,000
10,500
11,000
Distance Upstream (m)
Cape Ck (Lane) Trib 3
1998 Measured Slopes
2012 Measured Slopes
Mainstem Transect Averaged Slopes
1979 Measured Slopes

(d)

I measured the length, width, and depth of the sediment plain behind each log step to determine the amount of sediment stored behind the surveyed log steps of the channels. I then obtained a volume and divided the product by two to account for the deposit’s wedge shape (Marston, 1980). These data duplicate the fluvial wood and sediment characteristics from the 1979 and 1998 datasets allowing for direct comparison among the three years. To determine the volume of wood in the channels I used a stadia rod, measuring tapes, and a laser range finder to measure the width, depth, and height of each wood accumulation. I estimated the percent air for each log jam to account for porosity.

3.2. Derived data collection

With the morphometric variables collected in the field it is possible to derive an approximation of mean stream power, the rate of energy expenditure per unit area of the channel bed, for the three dataset from 1979, 1998, and 2012. I first used the transect locations as pour points overlaid on a 10 meter DEM within GIS to derive subwatersheds and associated upstream drainage areas. I then derived mean stream power (sometimes called unit stream power) at bankfull stage for each transect in the watersheds for each of the three years based on the equation (Fonstad 2003)

$$\omega = \rho g R S_e V \qquad (1)$$

in watts per square meter (W/m^2) where ρ is the density of the water and sediment mixture and g is the acceleration due to gravity. R is the hydraulic radius of the channel, equal to A/P where A is the cross-sectional area of the stream flow and P is the length of the wetted perimeter. S_e is the water surface elevation slope (approximated by bed slope measured at each transect during low-flow conditions) and V is the mean-averaged depth flow velocity in m/s. I obtained an estimate of V through the Manning equation, using Jarrett's (1984) equation for hydraulic roughness. Jarrett's equation has been shown to be the most accurate for mountain streams (Marcus et al., 1992). Sensitivity analysis reveals that the estimated error in field measurements is not significant relative to estimations of stream power and the changes in the variable among the years. The estimated percent error for slope is determined to be 15%, the percent error for bankfull width and bankfull depth are both estimated to be 5%. Using these estimates, the one standard deviation of error for mean stream power is 20 W/m^2 for 1979, 9 W/m^{2}for 1998, and 9 W/m^{2}for 2012. The average differences in stream power among the datasets is greater than 100 W/m^2, therefore, the error associated with field measurements is less than changes seen in derived stream power.

Comparing a regional DHG mean stream power to field-based mean stream power for each of the basins provides a method for assessing the geographic variations of prediction for the three datasets (Fonstad, 2003). Under this concept downstream increase in discharge is a power function of drainage area. For example, if

$$Q = k\mathrm{DA}^{m} \tag{2}$$

where Q is the discharge of a particular return interval and DA is the upstream drainage area in square kilometers (km^2). Therefore, the DHG stream power used in this study is the power expected if DHG was absolute. The power functions of the form

$$W = a\mathrm{DA}^{b} \tag{3}$$

where the coefficients a and b are determined from empirical regression analysis of basin channel measurements are used to derive DHG variables used to calculate a mean power estimate (Fonstad, 2003).

With the 2012 dataset I first derived the power law equations for hydraulic radius and velocity with drainage area (Table 3.2). These equations were then used to calculate expected DHG hydraulic radius and velocity for each transect. To determine a DHG slope value for each transect, I utilized an exponential equation with drainage area (Table 3.2). It may be argued that there is stronger exponential profile in streams than a power profile rendering the exponential relationship with drainage area more potent (Fonstad, 2003). Next, I input these DHG variables into equation 1 to derive DHG stream power for the 2012 dataset to serve as a regional proxy for expected channel adjustments. I chose the most recent dataset based on stable weather conditions at the time of the survey, fewest numbers of debris flow deposits in the channel, and fewest fresh clearcuts, compared to 1979 and 1998. The final step was simply subtracting the observed stream power from the DHG stream power for each transect in each year to obtain a stream power residual. This allows for direct spatial inter-comparison of basins.

Table 3.2. Power equations used to derive regional DHG mean stream power.

Variable	2012
Hydraulic Radius (R)	$R=0.2255(DA)^{0.1518}$
Velocity (V)	$V=1.1223(DA)^{0.0005}$
Slope (S)	$S=0.0573e^{-0.059(DA)}$

Debris flows are mass movements of sediment and large wood that scour channels and leave large deposits of material. To evaluate the influence that debris flow deposits may have on stream dynamics for the 3 datasets, I measured the distance upstream for each recorded debris flow in the watersheds in GIS. Marston (1980) and Ferree (1999) estimated debris flow locations for their datasets by examining aerial photos of the watersheds. I digitized these data within GIS and added the debris flows detected since 1999 and visible in the years my field research (Figures 3.9-3.10).

3.3. Statistical analysis

In order to address the hypothesis of a strengthening DHG relationship through time as a consequence of reduced wood volumes, I assessed the power relationships of drainage area with control variables largely dictated by drainage area for each watershed. I included the data from all transects to create two-variable plots examining drainage area as an independent variable with control variables.

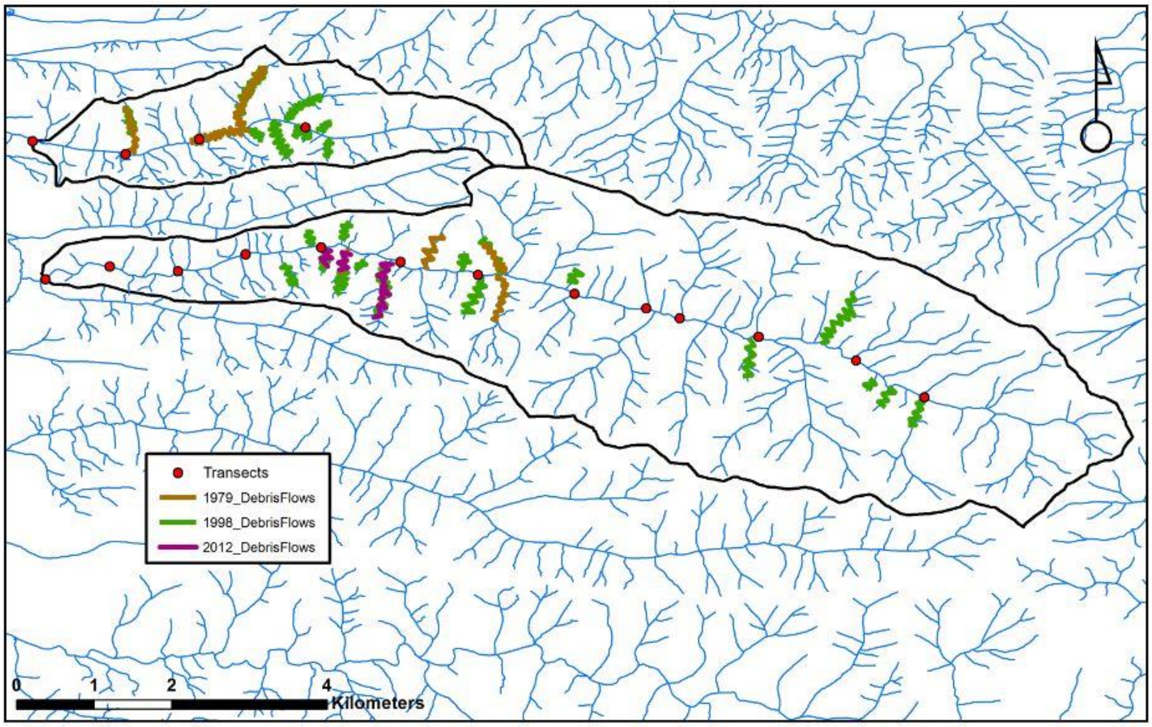


Figure 3.9. Locations of debris flows detected in the years of field data collection in Cape Creek in Lincoln Co. (north) and Cummins Creek (south).

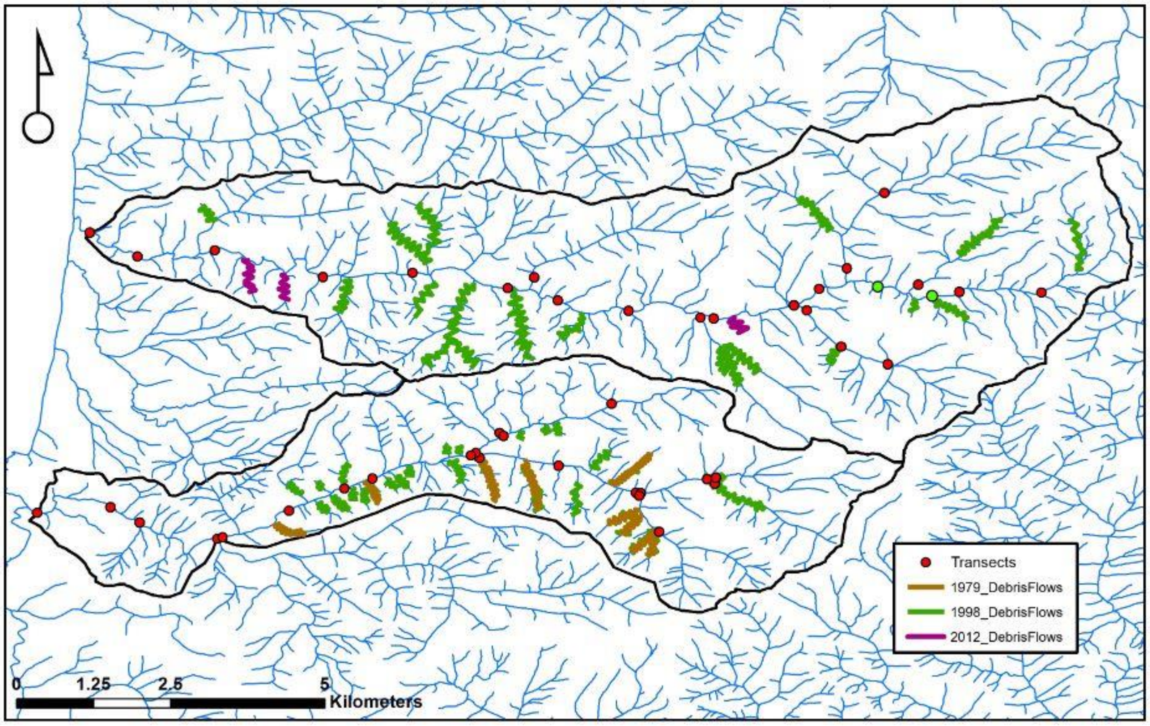


Figure 3.10. Locations of debris flows detected in the years of field data collection in Big Creek (north) and Cape Creek in Lane County (south).

If the relationship is strong (high r^2) between the two variables tested, then the DHG relationship is stronger. Plots of drainage area with bankfull width as the dependent variable were first developed for each watershed among the datasets as often these variables are the most highly correlated (Figures 3.11-3.14). Additional control variables tested are bankfull depth, observed velocity, bankfull depth, and wood abundance. A significant percentage of stream morphology parameters measured in this study can be predicted by drainage area alone. It is the goal of this analysis, however, to predict beyond drainage area to gain a more nuanced explanation of the drivers of geomorphic change in these streams. In order to remove the effect of drainage area on bankfull width, bankfull depth, and slope I plotted each variable with drainage area and fit a power law equation to each. With these equations I then calculated a predicted variable and subtracted the observed values to obtain residuals for bankfull width, depth, and slope. These residuals are used for subsequent statistical analyses assessing correlations that may still exist in the data without the effects of drainage area. I developed bivariate correlation matrices for the datasets to examine statistically significant correlations for all of the parameters considered in the study. This is a measure for acknowledging all of the significant relationships and the nature of them, whether it is an inverse relationship or not, for example.

For the analysis exploring predictions of stream morphology changes among the watersheds using the multiple collected and derived parameters I used step-wise multiple regression (SPSS, 2009). I chose this test because it allows for independent variables to be added or removed based on their t-statistic to create the most robust model for the dependent variables tested. This is appropriate given the number of variables tested and the exploratory nature of the analysis. The dependent variables tested are bankfull width residuals, bankfull depth residuals, and percent pools for the three datasets using the list of independent variables below (Table 3.4). The data from all four watersheds was combined to increase robustness. I used the nonparametric Wilcoxon signed rank test to directly compare significant changes that have occurred within each stream for the three years. I chose key variables reflective of morphologic change measured in the field.

Table 3.3. Variables used in analyses.

Variable (units)	**Characteristics**
Bankfull width residual$w$ (m)	Continuous; derived from field datasets at each transect
Bankfull depth residual$d$ (m)	Continuous; derived from field datasets at each transect
Slope residual$S$ (m/m)	Continuous; derived from field datasets
Drainage AreaDA (km^2)	Continuous; derived from ArcGIS Spatial Analyst
Stream Power Residual ω Res (W/m^2)	Continuous; derived from field datasets
Velocity v (m/s)	Continuous; derived from field datasets
d_{16}(mm)	Continuous; derived from field datasets
d_{50}(mm)	Continuous; derived from field datasets
d_{84}(mm)	Continuous; derived from field datasets
$\%\ Pools$(percent)	Continuous; derived from field datasets
Sediment Storage $SedStor$ (m^3)	Continuous; derived from field datasets
Step Count SC (count)	Continuous; no. of pieces/transect subwatershed
Jam Count JC (count)	Continuous; no. of pieces/transect subwatershed
Tot Wood Volume V(m^3)	Continuous; derived from field datasets
Distance to debris flows (*Dist DF*)	Continuous; derived from aerial photo interpretation and ArcGIS

4. Results

With the exception of Cape Creek (Lane Co.) the bankfull widths have widened throughout the last thirty years (Table 3.4). A dramatic widening between the 1979 and 1998 datasets has occurred in Cummins Creek, although the trend does not continue with a comparatively small widening between 1998 and 2012. The bankfull depths become deeper in Cummins Creek while becoming shallower in the others.

Table 3.4. The average bankfull widths and bankfull depths at transect locations for the three datasets.

	Bankfull width			Bankfull depth		
Stream	**1979**	**1998**	**2012**	**1979**	**1998**	**2012**
Cape Creek (Lincoln Co.)	31.9	19.9	26.5	4.6	3.2	3.7
Cummins Creek	65.9	107.1	117.6	5.9	8.8	10.4
Big Creek	126.2	203.3	218.8	20.3	17.3	14.7
Cape Creek (Lane Co.)	20.3	17.3	14.7	22.2	12.8	9.5

Sediment sizes have trended downward, getting much smaller in the 1998 and 2012 datasets, with the greatest size decreases occurring in Big Creek and Cape Creek (Lane Co.). The average d_{84} value in Cape Creek (Lane Co.) was 365mm in 1979, 117mm in 1998, and 107mm in 2012. Likewise, average d_{84} in Big Creek was 246mm in 1979, 120mm in 1998, and 90mm in 2012. Similar trends occur for the average d_{50}; however, d_{16} is more variable among the datasets.

4.1. Downstream hydraulic geometry

The downstream hydraulic geometry relationship between bankfull width and drainage area is strongest in Big Creek with r^2 values ranging from 0.77-0.83 among the datasets. The other basins show more scatter (Figures 3.11 - 3.14). It is important to note that in Cape Creek (Lane Co.) the DHG relationship strengthens in the more recent datasets. Additional results testing bankfull depth and velocity with drainage area also show dissimilar results (Table 3.5.). Cape Creek (Lincoln Co.) maintains a strong relationship with bankfull depth; however, the data is insufficient to make any determination with confidence. The DHG relationship with bankfull depth in Cummins

Creek is stronger in 1979, and then takes a downward turn in 1998, increasing again in the 2012 dataset. Derived velocity measurements in Cummins Creek correlate somewhat with drainage area in 1979), however in 1998 and 2012 the relationship dwindles to very low r-squared values. While Big Creek has the strongest DHG with bankfull width, r-squared values among the datasets is low when comparing both bankfull depth and velocity to drainage area. Lastly, Cape Creek (Lane Co.) had very low correlations with bankfull depth and velocity in 1979 (0.001 and 0.01) and in 1998 (0.15 and 0.04). In 2012 the relationship strengthened with bankfull depth (0.33) but not for velocity (0.01).

Table 3.5. Resulting r-squared values of two-variable plots comparing drainage area with bankfull depth and velocity.

	Bankfull depth and Drainage area (r^2)			**Velocity and Drainage Area (r^2)**		
Stream	**1979**	**1998**	**2012**	**1979**	**1998**	**2012**
Cape Creek (Lincoln Co.)	1.0	0.96	0.77	1.0	0.99	0.91
Cummins Creek	0.42	0.16	0.33	0.45	0.04	0.07
Big Creek	0.17	0.39	0.60	0.21	0.20	0.31
Cape Creek (Lane Co.)	0.01	0.15	0.33	0.02	0.04	0.01

Cape Creek (Lincoln Co.) is considered to have a well-developed downstream hydraulic geometry for all three datasets according to criteria put forth by Wohl (2004) that at least two of the three response variables (w, d, v) have r-squared values >.50 for mountain streams. Big Creek in 2012 also meets the criteria of having well-developed DHG, however no other stream in any other year meets these criteria. Additionally, a ratio, mean stream power per unit area relative to the coarse-grain-size fraction (Ω/d_{84}), has been shown to be an effective discriminator of DHG with a threshold of 10,000 kg/s^3

distinguishing between streams exhibiting strong and poor DHG (Wohl, 2004). This ratio was tested among the datasets revealing that for all three years and all four watersheds the DHG is poorly developed.

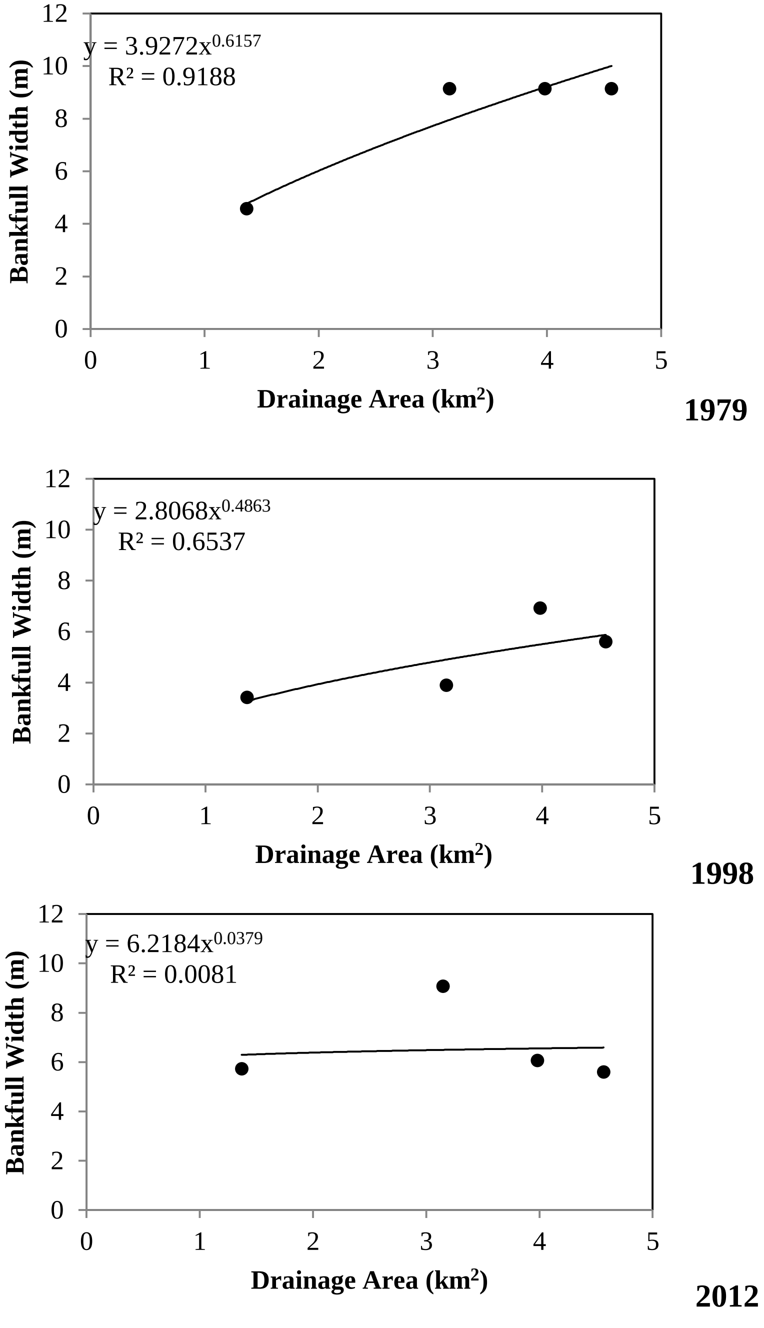
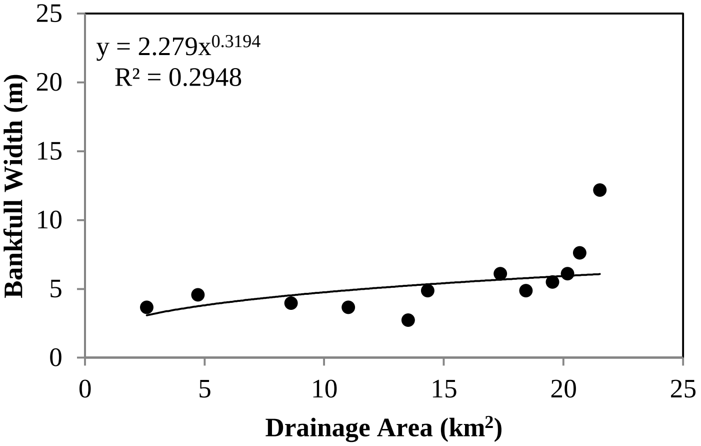
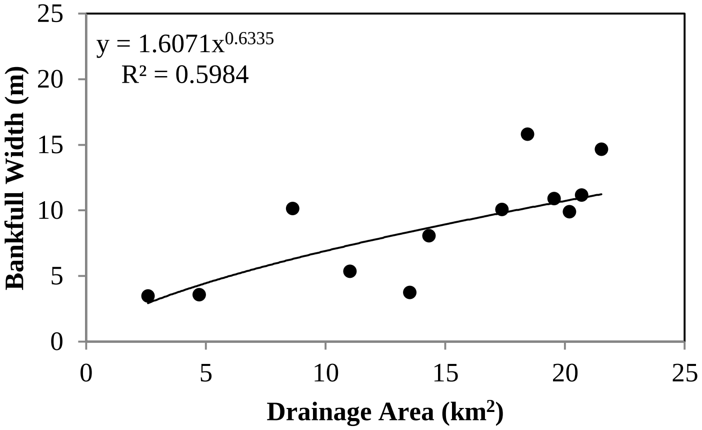


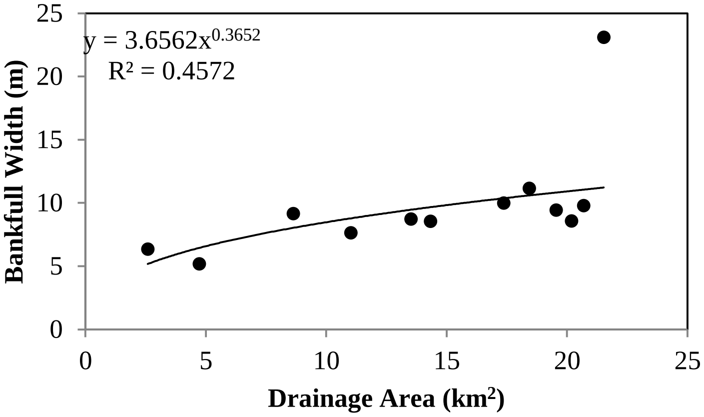
Figure 3.11. Cape Creek (Lincoln County) average bankfull widths in relation to drainage area.



1979

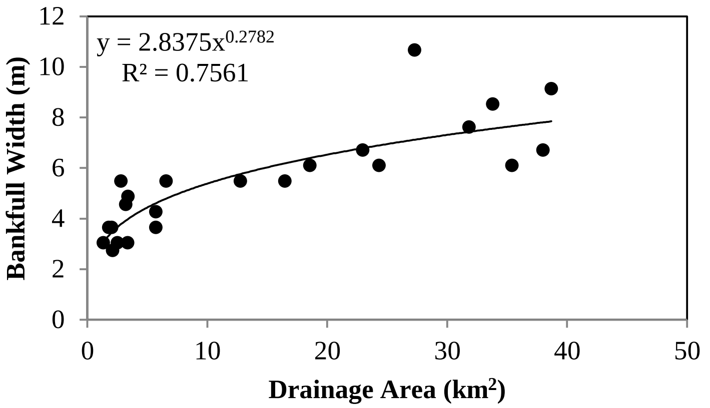


1998

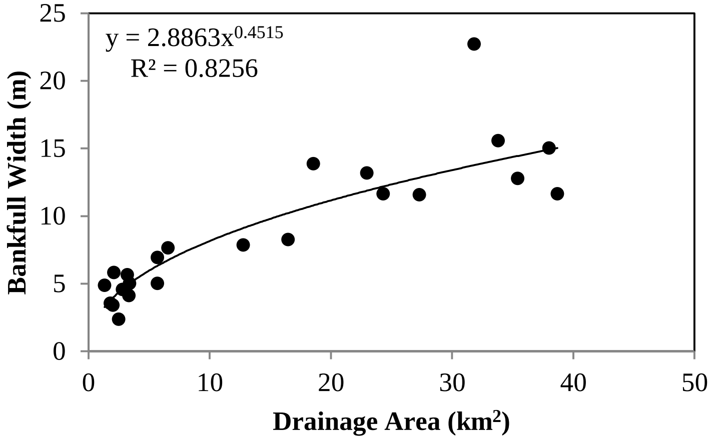


2012

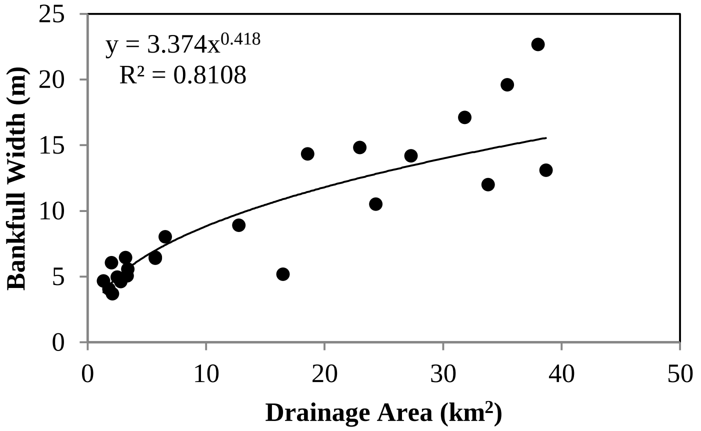
Figure 3.12. Cummins Creek average bankfull widths in relation to drainage area.



1979

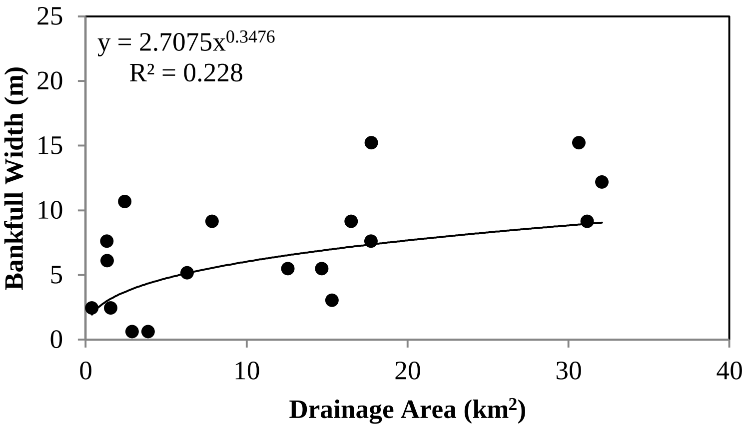


1998

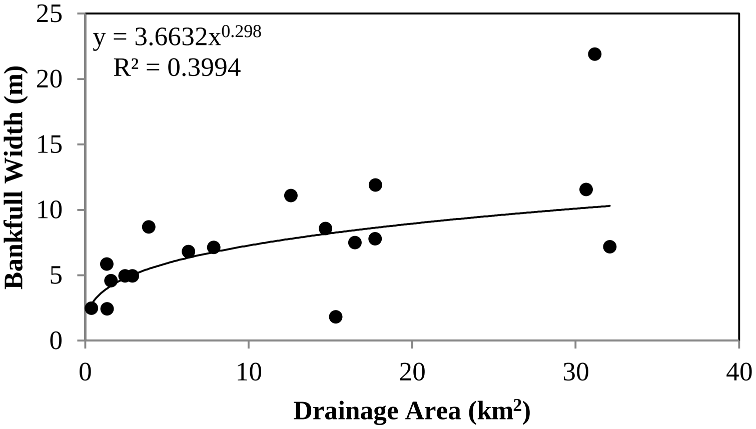


2012

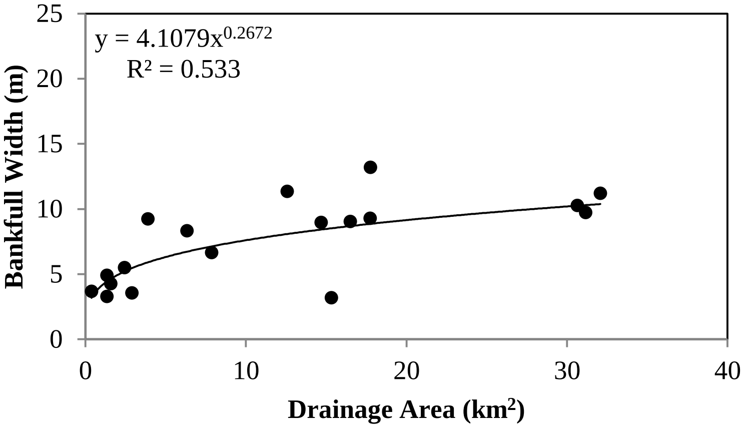
Figure 3.13. Big Creek average bankfull widths in relation to drainage area.



1979



1998



2012

Figure 3.14.Cape Creek (Lane County) average bankfull widths in relation to drainage area.

4.2. Correlations

Many of the variables measured in the field and derived from field or GIS data have been shown to correlate in fluvial studies. The same is true for the three datasets; however, using the bankfull width, bankfull depth, and slope residuals has effectively removed the multicollinearity potential from drainage area. The results (Tables 3.6 – 3.8) show significant inverse correlations among the four datasets with drainage area and wood abundance. This indicates that the larger the drainage area, the less wood is present in the streams. This relationship has relevance when considering the inverse relationship with log steps and drainage area as mechanisms for storage retention in the upper reaches of the watersheds. The correlations also confirm the assumed relationships among the variables regarding sediment storage and stream power as they have a significant inverse relationship. Inverse correlations also exist between slope and d_{84} as well as sediment storage.

4.3. Regression

For the three datasets the above variables were used to predict bankfull width residuals, bankfull depth residuals, and the percentage of pools for the four watersheds using step-wise multiple regression analysis. Residuals, as described above, are used as the dependent variables to avoid collinearity among the datasets. The resulting model shows the variables best explain the data distribution. Table 3.9 shows the order of significance that each independent variable has in the model for each year. The Beta values provided are the standardized coefficients for each variable, the value which the variable's data should be multiplied by in the final linear equation to predict the dependent variable.

Table 3.6. Correlation matrix for the 1979 dataset.

	DA	SC	JC	V	ω Res	$d16$	$d50$	$d84$	% $Pools$	Sed $Stor$	$Dist$ DF	w	d	S
DA	1	**-.276** **.038**	**-.381** **.003**	-.167 .214	.097 .472	-.223 .095	-.304 .021	**-.429** **.001***	**.386** **.003***	-.193 .150	-.118 .380	-.063 .640	.033 .809	.075 .581
SC	**-.276** **.038**	1	.484 .000	.051 .705	-.108 .422	-.116 .390	.052 .702	.225 .093	-.095 .480	.251 .060	.252 .059	-.110 .415	.056 .676	-.113 .403
JC	**-.381** **.003***	**.484** **.000***	1	**.535** **.000**	-.070 .606	-.003 .984	.191 .154	**.267** **.045**	-.030 .822	**.447** **.000***	**.355** **.007***	-.117 .387	-.038 .778	-.086 .524
V	-.167 .214	.051 .705	**.535** **.000***	1	.008 .952	-.053 .694	.029 .832	.156 .247	.003 .980	**.436** **.001***	.061 .650	.043 .753	-.070 .603	-.094 .489
ω Res	.097 .472	-.108 .422	-.070 .606	.008 .952	1	-.089 .512	-.173 .198	-.236 .077	.154 .252	**-.483** **.000***	-.140 .300	**.600** **.000***	**.666** **.000***	**.378** **.004***
$d16$	-.223 .095	-.116 .390	-.003 .984	-.053 .694	-.089 .512	1	**.673** **.000***	**.663** **.000***	-.233 .081	-.079 .558	.202 .131	.116 .390	-.074 .585	-.089 .511
$d50$	**-.304** **.021**	.052 .702	.191 .154	.029 .832	-.173 .198	**.673** **.000***	1	**.802** **.000***	-.175 .192	.186 .166	-.102 .452	.072 .595	-.052 .702	-.212 .113
$d84$	**-.429** **.001***	.225 .093	**.267** **.045**	.156 .247	-.236 .077	**.663** **.000***	**.802** **.000***	1	-.202 .133	**.292** **.028**	.106 .430	.168 .210	-.070 .604	**-.370** **.005***
% $Pools$	**.386** **.003***	-.095 .480	-.030 .822	.003 .980	.176 .191	-.233 .081	-.175 .192	-.202 .133	1	-.135 .317	-.190 .157	.207 .123	-.008 .951	.126 .349
Sed $Stor$	-.193 .150	.251 .060	**.447** **.000***	**.436** **.001***	**-.485** **.000***	-.079 .558	.186 .166	**.292** **.028**	-.135 .317	1	-.003 .981	**-.261** **.050**	-.150 .265	**-.268** **.044**
$Dist$ DF	-.118 .380	.252 .059	**.355** **.007***	.061 .650	-.139 .301	.202 .131	-.102 .452	.106 .430	-.190 .157	-.003 .981	1	-.214 .111	-.070 .605	-.037 .782
w	-.063 .640	-.110 .415	-.117 .387	.043 .753	**.606** **.000***	.116 .390	.072 .595	.168 .210	.207 .123	**-.261** **.050**	-.214 .111	1	**.409** **.002***	-.049 .717
d	.033 .809	.056 .676	-.038 .778	-.070 .603	**.666** **.000***	-.074 .585	-.052 .702	-.070 .604	-.008 .951	-.150 .265	-.070 .605	**.409** **.002***	1	-.055 .683
S	.075 .581	-.133 .403	-.086 .524	-.094 .489	**.378** **.004***	-.089 .511	-.212 .113	**-.370** **.005***	.126 .349	**-.268** **.044**	-.037 .782	-.049 .717	-.055 .683	1

The top number is the Pearson Correlation coefficient and the bottom number is the significance (2-tailed). N is 57. Numbers in bold are significant at the ≥ 0.05 level.

*. Correlation is significant at the 0.01 level (2-tailed)

Table 3.7. Correlation Matrix for the 1998 dataset.

	DA	SC	JC	V	ω Res	$d16$	$d50$	$d84$	% $Pools$	Sed $Stor$	$Dist$ DF	w	d	S
DA	1	**-.388** **.003***	.171 .204	**.334** **.011**	-.022 .872	-.021 .877	**-.392** **.003***	**-.342** **.009***	**.447** **.000***	-.058 .668	-.140 .298	-.220 .100	-.028 .838	-.135 .317
SC	**-.388** **.003***	1	**.265** **.047**	-.141 .297	.206 .125	-.148 .271	-.053 .696	-.031 .819	-.190 .157	-049 .717	-.010 .940	.065 .631	-.094 .487	.021 .875
JC	.171 .204	**.265** **.047**	1	.149 .268	.035 .798	.106 .431	-.138 .305	-.193 .149	-.145 .282	.096 .479	-.064 .636	-.145 .281	.001 .993	-.122 .367
V	**.334** **.011**	.141 .297	.149 .268	1	.068 .613	.024 .860	-.253 .058	-.264 .047	.134 .321	-.079 .558	-.066 .626	.079 .561	.229 .087	-.103 .446
ω Res	-.022 .872	.206 .125	.035 .798	.068 .613	1	-.009 .948	-.234 .079	**-.317** **.016**	-.002 .989	-.184 .171	**-.710** **.000***	.035 .799	.188 .162	.148 .273
$d16$	-.021 .877	-.148 .271	.106 .431	.024 .860	-.009 .948	1	**.578** **.000***	**.318** **.016**	-.220 .099	-.104 .439	.064 .635	**-.363** **.006***	-.130 .334	-.164 .224
$d50$	**-.392** **.003***	-.053 .696	-.138 .305	-.253 .058	**-.234** **.079**	**.578** **.000***	1	**.871** **.000***	**-.489** **.000***	.018 .893	.170 .207	-.127 .348	.023 .865	-.043 .754
$d84$	**-.342** **.009***	-.031 .819	-.193 .149	**-.264** **.047**	**-.317** **.016**	**.318** **.016**	**.871** **.000***	1	**-.371** **.005***	-.014 .920	**.310** **.019**	.029 .833	.154 .251	-.003 .984
% $Pools$	**.447** **.000***	-.190 .157	-.145 .282	.134 .321	-.002 .989	-.220 .099	**-.489** **.000***	**-.371** **.005***	1	-.073 .587	-.019 .891	.105 .437	**-.305** **.021**	.002 .989
Sed $Stor$	-.058 .668	.049 .717	.096 .479	-.079 .558	-.184 .171	-.104 .439	.018 .893	-.014 .920	-.073 .587	1	-.019 .886	**-.113** **.404**	-.221 .099	-.060 .657
$Dist$ DF	-.140 .298	-.010 .940	-.064 .636	-.066 .626	**-.710** **.000***	.064 .635	.170 .207	**.310** **.019**	-.019 .891	-.019 .886	1	-.106 .907	.031 .817	**-.308** **.020**
w	-.220 .100	.065 .631	-.145 .281	.079 .561	.035 .799	**-.363** **.006***	-.127 .348	.029 .833	.105 .437	-.113 .404	-.016 .907	1	.240 .072	-.082 .543
d	-.028 .838	-.094 .487	.001 .993	.229 .087	.188 .162	-.130 .334	.023 .865	.154 .251	-.305 .021	-.221 .099	.031 .817	.240 .072	1	-.026 .850
S	-.135 .317	.021 .875	-.122 .367	-.103 .446	.148 .273	-.164 .224	-.043 .754	-.003 .984	.002 .989	-.060 .657	**-.308** **.020**	-.082 .543	-.026 .850	1

The top number is the Pearson Correlation coefficient and the bottom number is the significance (2-tailed). N is 57. Numbers in bold are significant at the ≥ 0.05 level.

*. Correlation is significant at the 0.01 level (2-tailed).

Table 3.8. Correlation Matrix for the 2012 dataset.

	DA	SC	JC	V	ω Res	$d16$	$d50$	$d84$	% $Pools$	Sed $Stor$	$Dist$ DF	w	d	S
DA	1	**-.444** **.001***	.227 .089	**.446** **.001***	.104 .441	.026 .850	-.009 .947	-.082 .546	**.398** **.002***	**-.271** **.042**	**.414** **.001**	-.252 .061	.094 .491	-.151 .262
SC	**-.444** **.001***	1	**.366** **.005**	-.057 .672	-.084 .537	.122 .366	.155 .248	.022 .872	-.169 .209	**.407** **.002***	-.079 .557	-.078 .567	-.027 .841	-.029 .833
JC	.227 .089	**.366** **.005***	1	**.369** **.005***	-.046 .732	-.044 .748	-.080 .553	-.074 .586	.212 .113	.154 .254	.445 .001	**-.350** **.008***	-.131 .336	-.082 .545
V	**.446** **.001***	-.057 .672	**.369** **.005***	1	-.071 .599	-.052 .702	-.094 .485	.012 .927	.270 .042	-.074 .584	**.749** **.000***	**-.285** **.033**	-.162 .234	-.020 .880
ω Res	.104 .441	-.084 .537	-.046 .732	-.071 .599	1	-.011 .934	.026 .850	.013 .924	-.018 .893	.007 .958	-.073 .591	.185 .173	**.710** **.000***	006 .966
$d16$	.026 .850	.122 .366	-.044 .748	-.052 .702	-.011 .934	1	**.902** **.000***	**.695** **.000***	-.296 .025	.084 .534	-.260 .051	.213 .116	-.018 .896	-.089 .509
$d50$	-.009 .947	.155 .248	-.080 .553	-.094 .485	.026 .850	**.902** **.000***	1	**.866** **.000***	-.254 .056	.051 .705	-.335 .011	.178 .190	.045 .742	-.113 .401
$d84$	.082 .546	.022 .872	-.074 .586	.012 .927	.013 .924	**.695** **.000***	**.866** **.000***	1	-.230 .085	.087 .522	-.237 .076	.151 .268	.098 .470	-.098 .467
% $Pools$	**.398** **.002***	-.169 .209	.212 .113	**.270** **.042**	-.018 .893	**-.296** **.025**	**-.254** **.056**	-.230 .085	1	-.070 .607	**.283** **.033**	-.235 .082	-.253 .060	.003 .980
Sed $Stor$	**-.271** **.042**	**.407** **.002***	.154 .254	-.074 .584	.007 .958	.084 .534	.051 .705	.087 .522	-.070 .607	1	-.062 .647	-.025 .854	-.044 .747	.235 .079
$Dist$ DF	**.414** **.001***	-.079 .557	**.445** **.001***	**.749** **.000***	-.073 .591	-.260 .051	**-.335** **.011**	-.237 .076	**.283** **.033**	-.062 .647	1	**-.400** **.002***	-.142 .295	**-.007** **.957**
w	-.252 .061	-.078 .567	**-.350** **.008***	-.285 .033	.185 .173	.213 .116	.178 .190	.151 .268	-.235 .082	-.025 .854	**-.400** **.002***	1	**.309** **.021**	-.072 .599
d	.094 .491	-.027 .841	-.131 .336	-.162 .234	**.710** **.000***	-.018 .089	.045 .742	.098 .470	-.253 .060	-.044 .747	-.142 .295	**.309** **.021**	1	-.137 .315
S	-.151 .262	-.029 .833	-.082 .545	-.020 .880	.006 .966	-.089 .509	-.113 .401	-.098 .467	.003 .980	.235 .079	-.007 .957	-.072 .599	-.137 .315	1

The top number is the Pearson Correlation coefficient and the bottom number is the significance (2-tailed). N is 57. Numbers in bold are significant at the ≥ 0.05 level.

*. Correlation is significant at the 0.01 level (2-tailed).

Table 3.9. Results of step-wise multiple regression analysis with bankfull width, bankfull depth, and % pools as dependent variables.

	W residual			***D residual***			***% Pools***		
	1979	**1998**	**2012**	**1979**	**1998**	**2012**	**1979**	**1998**	**2012**
Adjusted r^2	0.487	0.116	0.195	0.537	0.189	0.547	0.134	0.421	0.299
Variable									
ω*Res*	$1^{(0.758, 7.290)}$			$1^{(0.802, 8.167)}$		$1^{(0.707, 7.781)}$			
d (residual)			$2^{(0.268, 2.15)}$					$2^{(-0.287, -2.82)}$	$3^{(-0.299, -2.635)}$
DA							$1^{(0.386, 3.103)}$	$3^{(0.331, 2.971)}$	$1^{(0.434, 3.821)}$
Dist DF			$1^{(-0.315, -2.743)}$						
% Pools					$1^{(-0.367, -3.007)}$	$2^{(-0.242, -2.67)}$			
d_{16}		$1^{(-.363, -2.889)}$							$2^{(-0.31, -2.74)}$
d_{50}								$1^{(-0.388, -3.501)}$	
d_{84}	$2^{(0.258, 2.494)}$								
JC									
S (residual)	$3^{(-0.240, -2.205)}$			$2^{(-0.358, -3.648)}$				$4^{(-0.255, -2.463)}$	
V					$3^{(0.257, 2.115)}$				
w					$2^{(0.258, 2.128)}$				

Numbers 1-4 represent the most to least amount of predictive power of each variable. For example, in 1979 when predicting bankfull width, residual stream power has the highest t-statistic value and therefore is added first to the regression. D_{84} has the second highest t-statistic and slope has the third highest t-statistic. All three variables make up the final model predicting residual bankfull width in 1979. The variables SC and SedStor were excluded from all of the regression models for all of the years and are therefore not included in the table. The superscript numbers are the beta values and the *t*-values, respectively.

Predictions of bankfull width for the three years are drawn from entirely different variables with $d_{84}$from 1979 andd_{16} in 1998 being the closest in similarity. When predicting bankfull depth, in both 1979 and 2012, stream power residuals have the most predictive power and, in combination with S and $\%Pools$ respectively, account for over fifty percent of prediction. The available variables have the lowest predictive power for $\%Pools$, though drainage area is a significant variable for all three years. Interestingly, there are inverse relationships between bankfull depth and the percentage of pools in 1998 and 2012.

4.4. Nonparametric statistics

The results of the Wilcoxon signed rank test show statistically significant differences at least once for every stream morphometric category (Table 3.11). Cape Creek in Lincoln County did not have any significant changes in stream morphology among the three datasets. Cummins Creek and Big Creek have significant increases in d_{84} among all three datasets with Big Creek also having significant increases among all three years for d_{50} as well. Overall, Big Creek has seen the biggest changes in its morphology. In addition to clast size differences, it has statistically significant changes occurring among all three datasets in the amount of sediment storage, the percentage in pools, and slope. Cummins Creek has seen the second highest amount of change with significant changes occurring in bankfull width and depth, as well as slope. Cape Creek in Lane County has significant changes among the three datasets in bankfull depth as well as velocity. There are also statistically significant changes occurring in median sediment size in Cape Creek (Lane Co.

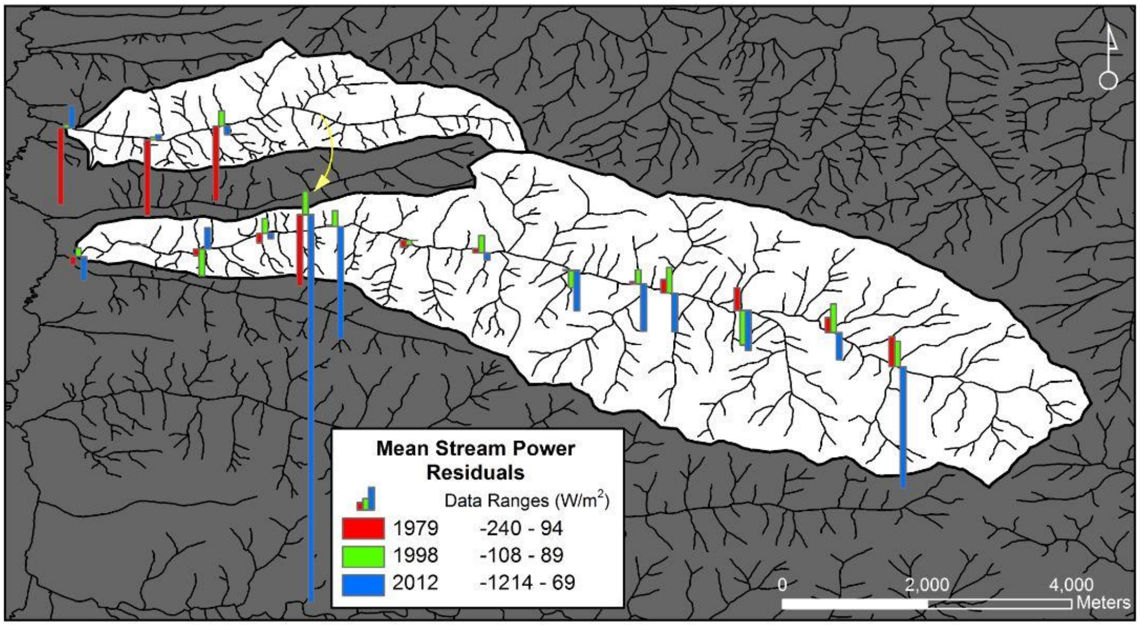
Table 3.10. p-Values indicating statistical significance of the stream morphometric variables among the 1979, 1998, and 2012 datasets. The year with increased values are in parentheses for significant changes. (Values in bold are significant at the $p<0.05$ level).

	d_{16}	d_{50}	d_{84}	Sed Storage (m^3)	%Pools	BF Width (m)	BF Depth (m)	Slope	Velocity
Cape Creek (Lincoln Co.)									
1979 vs. 1998	.137	.072	**.034 (>1978)**	**.034 (>1998)**	.392	**.034 (>1978)**	**.033 (>1978)**	**.033 (>1978)**	**.034 (>1978)**
1998 vs. 2012	**.034 (>2012)**	**.034 (>2012)**	0.50	**.034 (>1998)**	.179	.233	.357	.072	.357
1979 vs. 2012	0.50	.072	**.034 (>1978)**	.232	.179	.137	.357	.357	.072
Cummins Creek									
1979 vs. 1998	.530	**.003 (>1979)**	**.003 (>1979)**	.214	**.007 (>1979)**	**.005 (>1998)**	**.006 (>1998)**	**.003 (>1979)**	.060 **(>1979)**
1998 vs. 2012	**.005 (>2012)**	.937	**.002 (>1998)**	.263	.514	.433	**.050 (>2012)**	**.012 (>2012)**	**.041 (>2012)**
1979 vs. 2012	**.015 (>1979)**	**.003 (>1979)**	**.002 (>1979)**	**.008 (>1979)**	**.006 (>1979)**	**.002 (>2012)**	**.002 (>2012)**	.937	**.002 (>2012)**
Big Creek									
1979 vs. 1998	.465	**.002 (>1979)**	**.000 (>1979)**	**.014 (>1998)**	**.000 (>1979)**	**.000 (>1998)**	.201	**.003 (>1979)**	**.001 (>1979)**
1998 vs. 2012	.274	**.019 (>1998)**	**.002 (>1998)**	**.001 (>1998)**	**.023 (>2012)**	.186	**.046 (>1998)**	**.000 (>2012)**	.101
1979 vs. 2012	.648	**.000 (>1979)**	**.000 (>1979)**	**.001 (>1979)**	**.012 (>1979)**	**.000 (>2012)**	**.018 (>1979)**	**.002 (>2012)**	**.000 (>1979)**
Cape Creek (Lane Co.)									
1979 vs. 1998	**.003 (>1979)**	**.000 (>1979)**	**.000 (>1979)**	.507	.326	.948	**.001 (>1979)**	.378	**.007 (>1979)**
1998 vs. 2012	**.000 (>2012)**	.528	.215	.061	.071	.199	**.000 (>1979)**	**.079 (>2012)**	**.000 (>1979)**
1979 vs. 2012	.085	**.001 (>1979)**	**.000 (>1979)**	.182	**.008 (>1979)**	.616	**.000 (>2012)**	.309	**.001 (>1979)**

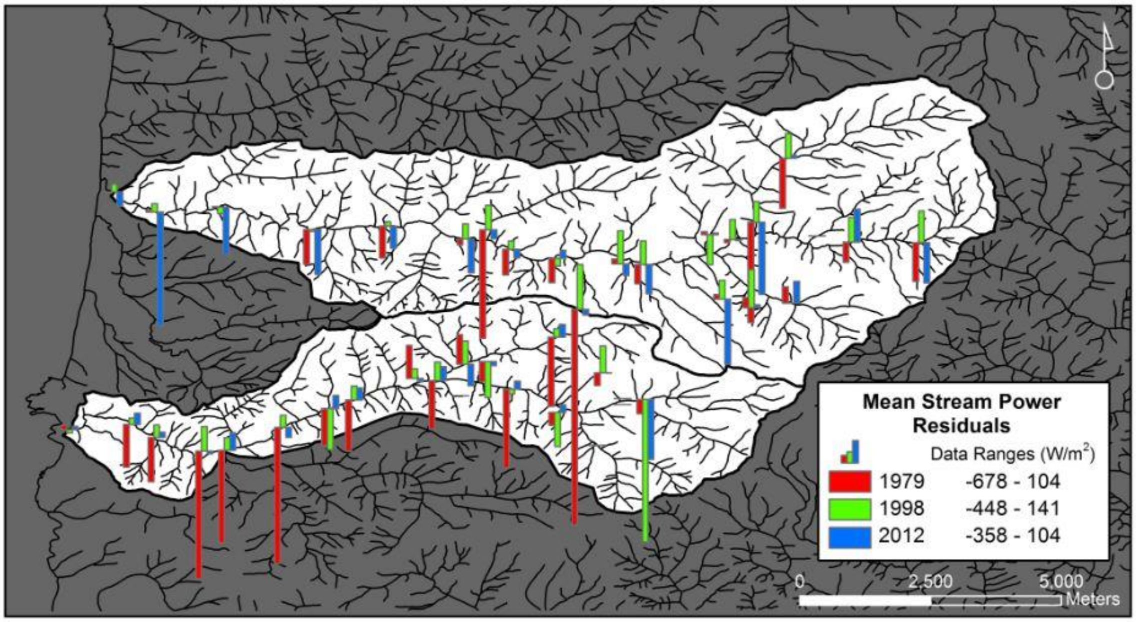
4.5. Stream power trends

The spatial distributions of stream power residuals illuminate areas of under (field based prediction is less than DHG prediction) and over-prediction for the three datasets (Figure 3.15). The results are heterogeneous and show a lot of variation among the three years. The under-predictions are greatest in 1979 and 2012 with the most extreme under-estimations in Cape Creek (Lincoln County) in 2012 and in Cape Creek (Lane Co.) in 1979.

Figure 3.15 (next two pages)**.** Watersheds maps depicting the geographic variations in stream power deviations (a-b). The bars below the line depict under-estimations and the bars above the line depict over-estimations for the three years.



(a)



(b)

5. Discussion

The study basins have all experienced significant changes in stream morphology over the last thirty years. Despite the four basins being coastal basins with similar basaltic lithology and mixed alluvial-bedrock channels, becoming predominantly alluvial channels towards the outlets at the coast, the changes among them have been diverse and have shown to be predicted by different parameters. The temporal component among these datasets provides snapshots of the stream dynamics during which unique events contribute to the morphology of the channels. The 1979 dataset was collected while the basins were still being heavily clearcut leading to bare slopes and heavy instream wood loads in some cases (Atha, 2013). The 1998 dataset was conducted very recently after the 1996 flood of record for the Oregon Coast Range. These floods triggered a large number of debris flows, a large volume of instream wood to be deposited in the channels, and other widespread storm damage (Ferree, 1999). The 2012 dataset was conducted during the afforestation process with thick heavy growth in the riparian zones, often ensconcing the channel completely with vegetation. None of the watersheds in this study meet the criteria of having a well-developed DHG based on the ratio (Ω/d_{84}) put forth by Wohl (2004) to describe the threshold between the two categories, however, some exhibit a stronger DHG relationship than others, providing unique insights into land-use impacts on channel morphology.

5.1. Cape Creek (Lincoln County)

Cape Creek (Lincoln Co.) has seen the least amount of change as evidenced by the results of the Wilcoxon test directly comparing the data among the three years. Despite a low r^2 value in 2012 when comparing bankfull width with drainage area, the basin fits the criteria in all three years as having well-developed downstream hydraulic geometry. This positive fit may have much to do with its relatively small size and number of transects; however, it has enough data to support the general theory. As one of the two watersheds considered to be less influenced by clearcutting, it fits the hypothesis that DHG is not increasing in time due to decreases in wood volume, but rather has maintained a strong DHG signal.

5.2. Cummins Creek

Cummins Creek has undergone significant changes in channel geometry. Although it has remained relatively stable in its DHG when compared to the other watersheds, and continues to widen and deepen through time within the datasets (Table 3.5), there are clearly other controls acting on the channel keeping it from adjusting to regular flood events as evidenced through the fluctuations in stream morphometric variables with drainage area. Cummins Creek has been the least affected by clearcut harvesting. It has abundant mature forest. Wood was mobilized to form log steps in the floods preceding the 1998 survey. This likely contributed to the significant changes in bankfull depth among the datasets as well as the r^2 values between bankfull depth and drainage area. The 2012 dataset has a lower r^2 value than in 1998; however both are much higher than the 1979 r^2 supporting the hypothesis that DHG relationships are increasing over time, but not linearly.

5.3. Big Creek

Big Creek has become increasingly wider and shallower in the last thirty years. It has a strong well-defined relationship between bankfull width and drainage area for the three datasets, and the relationship between drainage area and bankfull depth becomes more defined over time. It has seen the most significant changes in sediment size, sediment storage, and % pools among the three datasets. The amount of sediment storage increased from a total of 714 m^3 in 1979 to 3841 m^3 in 1998 and has since decreased to 80 m^3 in 2012 (Appendix A). The sediment storage of the post-flood 1998 dataset has likely been transported out from behind the log steps and re-positioned by 2012, making the bankfull depths shallower. Big Creek has experienced significant clearcut harvesting (27% of its basin); however, it has had an increase in the amount of wood volume among the datasets as well. Despite this, it has trended toward a well-developed DHG in bankfull depth and has maintained a stable r^2 value from 1998 to 2012 in its relationship between bankfull width and drainage area. This does not support the hypothesis that the DHG will get stronger with less wood volumes, but rather, it has with an increase in overall wood volume.

5.4. Cape Creek (Lane County)

Cape Creek (Lane Co.) has a continuing decrease in % pools and sediment storage. The reduction in sediment storage is directly connected to the decrease in the amount of significantly sized log steps in the basin (Atha, 2013). This likely links with the decrease in pools as well. The hypothesis put forth that we would expect to see an increase in a DHG signal with a decrease in the amount of wood volume is supported by the relationship between bankfull width and drainage area for Cape Creek (Lane Co.), which has gotten progressively stronger from 1979 to 1998 to 2012. Like Big Creek, Cape Creek (Lane Co.) has gotten shallower, however, unlike Big Creek it has also gotten narrower. The increasing strength of DHG in both bankfull width and depth appears to link a trend towards channel adjustment with afforestation and associated decreases in wood volume and sediment storage.

5.5. Regression

The results of the multiple regression analysis investigating predictors of bankfull width, bankfull depth, and % pools for the three datasets show that the predictors are not consistent across years. Using bankfull width and depth residuals as the dependent variable allows for exploration of other variables as predictors of channel geometry changes. Drainage area is the only dependent variable that has predictive power for the % pools. As drainage area increases, slope typically decreases allowing for increased pool formation. Its predictive power on the % pools for the three datasets underscores the power of drainage area as a variable explaining fluvial process. In addition to drainage area, bankfull depth inversely correlates with % pools in 1998 and 2012. This first appears counter-intuitive, however, in the upper reaches of the watersheds with smaller channel geometry, wood jams and boulders create an increased abundance of channel unit types and associated pools. Mean stream power residuals are also included as the key predictor of bankfull width in 1979 and bankfull depth in both 1979 and 2012. This seems appropriate given the ability of stream power to move bedload.

5.6. Stream power trends

There is striking higher-than-predicted stream power throughout the basins for the 1979 and 2012 datasets. Stream power has the most under-predictions in 2012 in Cummins Creek and Big Creek, while in 1979 the greatest under-predictions are occurring in Cape Creek (Lincoln Co.) and Cape Creek (Lane Co.). The measured slopes for these two datasets are comparatively higher than for the 1998 dataset which may partially explain the higher-than-predicted stream power found in the upper reaches of the basins in those years. Mass-wasting deposits or log steps may create knickpoints, which are not predicted from the exponential equation for slope. These knickpoints produce local high slope values (Fonstad, 2003).

A key reason for the under-prediction of stream power in the 1979 is likely due to the amount of bare hillslopes and riparian zones from clearcutting for much of the southern-most watersheds. Less vegetation on hillslopes would cause the watersheds to have a flashier discharge during precipitation events even with the associated increases of instream wood. This theory is supported by the more accurately predicted stream power occurring in Cummins Creek in 1979 where clearcutting was consistently minimal. There does not appear to be a strong association with the location of active debris flows in the channel at the time of survey to strong under or over-predictions of stream power furthering the hypothesis that the under-estimations are due to localized high slopes and land-use effects.

5.7. Geomorphic equilibrium

These results lead to speculation on whether the river systems are displaying forms and processes of (a) dynamic equilibrium, in which the system is receiving and outputting a similar amount of material, (b) disequilibrium, in which the river systems were previously in a state of equilibrium, but are currently not in equilibrium and are moving towards a future state of equilibrium, or (c) nonequilibrium, in which the river systems do not ever achieve equilibrium. The data from this study suggest for Cummins Creek and to a lesser extent Cape Creek in Lincoln County the river systems are in a state of dynamic equilibrium. They regularly experience debris flows and geomorphic threshold events that introduce mass influxes of large wood and sediment. However, they are also able to adjust and output material such as heavy wood loadings within a short amount of time (Atha, 2013). The statistical changes reflected in the analysis for Cummins Creek are primarily a result of the storm events of 1996, as the amount of sediment storage is not statistically different in the consecutive years and the increases in wood from 19789 to 1998 have returned to volumes similar to those in 1979. Cape Creek in Lincoln County has not had any statistically significant change in the stream morphology parameters. There have been significant changes within Cummins Creek, Big Creek, and Cape Creek (Lane Co.) in the sediment size distributions among the three datasets and the parameters predicting the amount of change in channel geometry are heterogeneous among the three years. Yet, the overall amount of change in sediment storage and the abundance of wood (Atha, 2013)is not as statistically significant in Cape Creek (Lincoln County) as it is in the other three watersheds. However, the variations between drainage area and bankfull width, depth, and velocity indicate that there are factors present inhibiting DHG. Big Creek and Cape Creek (Lane County) have statistically significant differences among almost all of the stream parameters across the three years. This provides evidence that they are still in a state of disequilibrium since 1979 due to the amount of clearcutting within the basin. However, Big Creek maintains a strong DHG and Cape Creek (Lane County) is trending towards a stronger DHG since 1979 indicating that it is moving towards a new equilibrium.

6. Conclusions

The primary research question driving this paper simply asks what stream morphology changes have occurred among three datasets surveyed in 1979, 1998, and 2012. The hypothesis put forth is that the downstream hydraulic geometry relationship in the two watersheds, Big and Cape Creek (Lane Co.) will have a stronger DHG in the more recent datasets because of a decrease in overall wood volume, particularly in the 2012 dataset. The results have shown that the hypothesis may be upheld and the DHG relationship is becoming stronger in these two watersheds. Analyses of the changes that have occurred in the channel morphology show that there have been statistically significant changes over time among many of the variables. Multiple regressions reveal that the parameters predicting bankfull width, bankfull depth, and percent pools are varied throughout the three years. This supports the conclusion that stream power varies nonlinearly throughout the basins in the downstream direction. The predicted stream power significantly over-estimated stream power particularly in the 1979 dataset also supporting the hypothesis that land-use change in the form of clearcut harvesting greatly altered stream power. Overall, the stream morphology in these watersheds is highly heterogeneous and dynamic. The stochastic nature of the Oregon Coast Range in addition to land-use alterations continues to intrigue.

CHAPTER IV

DETECTING FLUVIAL WOOD IN FORESTED WATERSHEDS USING LIDAR DATA: A METHODOLOGICAL ASSESSMENT

INTRODUCTION

In-stream large wood influences channel form and ecological complexity of forested watersheds. The importance of wood, defined here as pieces greater than 10cm in diameter and at least 1m long, to in-channel geomorphic processes (e.g. Faustini and Jones, 2003; Keller and Swanson, 1979; Keller and Tally, 1982) and channel pattern (e.g. Montgomery and Abbe, 2006; Nakamura and Swanson, 1993) is well understood. However, research recording the abundance and distribution of fluvial wood typically requires extensive fieldwork over time, or otherwise is constrained to small spatial scales. More recently, however, with the use of remote sensing, it has become easier to conduct studies on a larger spatial scale in some instances. Marcus et al. (2002), for example, attempted to map distributions of fluvial wood in Yellowstone National Park using one meter per pixel 4-band airborne multispectral imagery. Classification of woody debris was poor, primarily because of spectral confusion between gravel and wood in mixed pixels when the size of the woody debris was smaller than the pixels. They concluded that imagery with finer spatial resolution would be needed. A second attempt by Marcus et al. (2003) found that with hyperspectral 128-bandimagery with one-meter spatial resolution, large woody debris could be detected within the same study area. Google Earth, on the other hand, was used successfully to visually identify large woody debris in open rivers with broad open floodplains such as the Queets River in the Olympic Peninsula Region of Washington (Atha, 2013b).

Complications arise with even the greatest spatial resolution, however, in areas of dense tree cover. Where there is fluvial wood, there is most often thick riparian tree cover that partially or completely obscures the channel in remotely sensed images. Vehmas et al. (2009) evaluated the use of airborne lidar to bypass tree canopy and extrapolate downed deadwood through measurements in the gap between the lower vegetation and the upper canopy of forest landscapes in eastern Finland. This approach assigned classes to the point data based on height and texture. Three classes were assigned based on a field inventory: downed deadwood (DDW), saplings and lesser vegetation (VEGE), and no downed deadwood or small vegetation present (CLEAR). With these classifications Vehmas et al. (2009) determined the different gap distances from the tree canopy to the differently classed forest cover resulting in a method for downed deadwood detection in forests. To date, the success of fluvial wood identification with remotely sensed imagery has been promising, but with continued advancement in airborne laser imagery, a more successful methodology may emerge. This paper seeks to (i) identify and map fluvial wood in densely forested watersheds utilizing high-resolution airborne lidar data and (ii) assess the patterns and abundance of single log pieces compared with log jams using mapped wood data derived from lidar datasets.

Background

Light detection and ranging (lidar) is an active family of remote sensors in that they provide their own source of energy and are therefore independent of solar illumination. More importantly, they can compare the characteristics of this transmitted and returned energy to assess not only the brightness of the backscatter, but also the angular position, changes in frequency, and timing of reflected pulses (Campbell and Wynne, 2011). Laser technology was invented in the late 1950s; however, it is only relatively recently that lidar can be considered remote sensing instruments. By the late 1980s several technologies matured to lay a foundation for the development of precision lidar systems that are now used to acquire topographic data and other environmental applications. These technologies include inertial measurement units (IMUs) that enable precise control and recording of orientation of aircraft, global positioning systems (GPS) to provide accurate geographic locations of aircraft as they collect data, and highly accurate clocks for timing lidar pulses (Campbell and Wynne, 2011).

Lidar instruments measure the round-trip time for a pulse of laser energy to travel between the sensor and a target (Dubayah and Drake, 2000). Near-infrared wavelengths of the incident energy pulses are most often used in vegetation studies where the energy pulse reflects off the branches and leaves of forest canopy as well as ground surfaces. The energy pulse returns back to the instrument where it is then collected by a telescope. The travel time of the pulse, from its initiation to its return to the sensor, provides a distance or range between the two (Dubayah and Drake, 2000). The measurement of this time delay from pulse emission to its return provides coordinates of points where the reflections take place (Estornell et al., 2011). The combination of the sensor’s computer, IMUs, and a differential GPS allows each point to be georeferenced with a vertical and horizontal accuracy of a few centimeters (Suárez et al., 2005). The resulting data consists of x,y,z coordinates known as point cloud data.`

With this vertical and horizontal accuracy it is possible to precisely filter the point cloud data in order to focus on particular elevations in the landscape. This study addresses the following research questions. Can fluvial wood be detected through airborne lidar data analysis, and how can these techniques be used to better test fluvial theory? The frequency of single wood pieces and log jams is assessed to test the hypothesis that log jams are more frequent than single log pieces in the lower reaches of river basins. This hypothesis is based on the conceptual model that the transport capacity of the streams in lower reaches will effectively provide wood supply to create jams; however, the transport capacity is not so great that it will transport the wood before jam formation is possible.

STUDY AREA

The study area in the central Oregon Coastal Range consists of approximately the furthest downstream kilometer before the creeks flow into the Pacific Ocean, in four forested watersheds. The study basins vary in size, but are in close proximity to one another (Figure 2.2). The watersheds are all located within the Siuslaw National Forest and have a range of physiographic characteristics and impacts from years of forest management. The climate of the Oregon Coast Range is ideal for year-round forest growth. The total annual rainfall can exceed 2,540mm and snowfall is minimal (Dietrich, 1975; Loy et al., 2001). For a study assessing the use of lidar to detect fluvial wood, this environment provides extreme conditions in the form of a dense tree canopy. The basins to be examined are Cape Creek in Lincoln Co. (4.82 km^2), Cummins Creek (24.66 km^2), Big Creek (39.37 km^2), and Cape Creek in Lane County (31.86 km^2). Elevations range from sea level to 767 meters at Cummins Peak. In the early 1980s clearcut timber harvesting ceased in the area due to Northwest Forest Plan regulations designating the area as Northern Spotted Owl habitat (Thomas and Raphael, 1993). As a result, the study basins have been undergoing the process of afforestation to varying degrees within the last thirty years. Today vegetation covers the channels in most places, with some reaches having the entire channel thickly covered making them impassable (Atha, 2013a). This vegetation consists of woody vines and shrubs such as Himalayan blackberry (*Rubusarmeniacus*). The large conifer western hemlock (*Tsugaheterophylla*) is the dominant woody tree species providing canopy cover of the creeksin the study basins. Douglas fir (*Pseudotsugamenziesii*) is prominent in the drier areas while western red cedar (*Thujaplicata*) and Sitka spruce (*Piceasichensis*) are found in the moist areas. Within the riparian zones of the study watersheds, the hardwood red alder (*Alnusrubra*) dominates. High resolution satellite-based imagery of the study area reveals the forest density of these coastal watersheds (Figure 4.1).

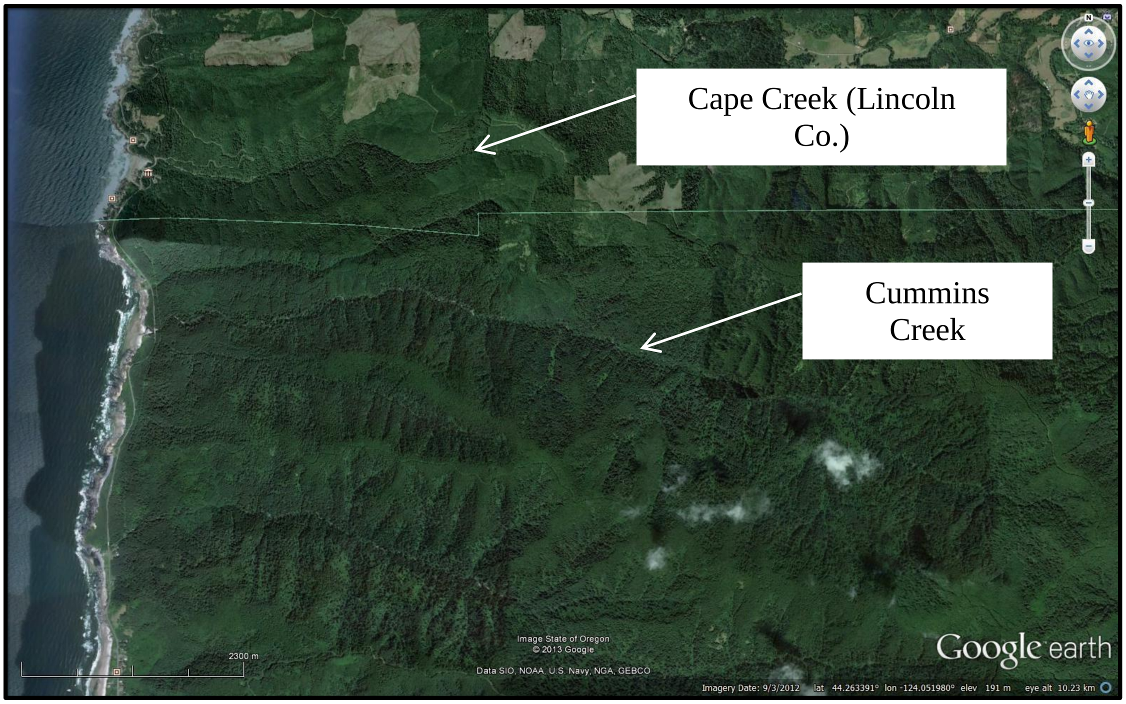


Figure 4.1. Google Earth image showing the amount of vegetative cover in two of the study basins: Cape Creek (Lincoln Co.) and Cummins Creek.

The watersheds are composed predominantly of Yachats Basalt, an upper Eocene unit consisting of volcaniclastic breccias and basaltic lava flows (ref.). The mainstream channels are oriented along fault lineaments. The thin residual soils situated at or near the maximum angle of repose cover the steep convex-up slopes (Marston, 1982). Marine wave-cut terraces made up of silts, sands, gravels, and organic materials, exist to varying degrees throughout the coastal regions of the study area (Marston, 1982).

This study area was chosen in part because of the high-resolution lidar data that is available for the coastal sections of the watersheds. The Oregon Department of Geology and Mineral Industries (DOGAMI) contracted the collection of lidar data in 2009 for Oregon North Coast for 4,022 square kilometers (Figure 4.2). I surveyed the study basins for fluvial wood in the summers beginning in 2010 and ending in 2012. Results of this previous research have shown that residence times of fluvial wood in these basins are short (Atha, 2013a), therefore, ground-reference data collected from years outside of when the lidar was flown are not accurate enough for direct comparison. However, because of my recent experience and knowledge of the watersheds (Atha, 2013a), the large wood that is typically found within them, and the amount of additional vegetation present, the study area is ideal for this qualitative methodological assessment.

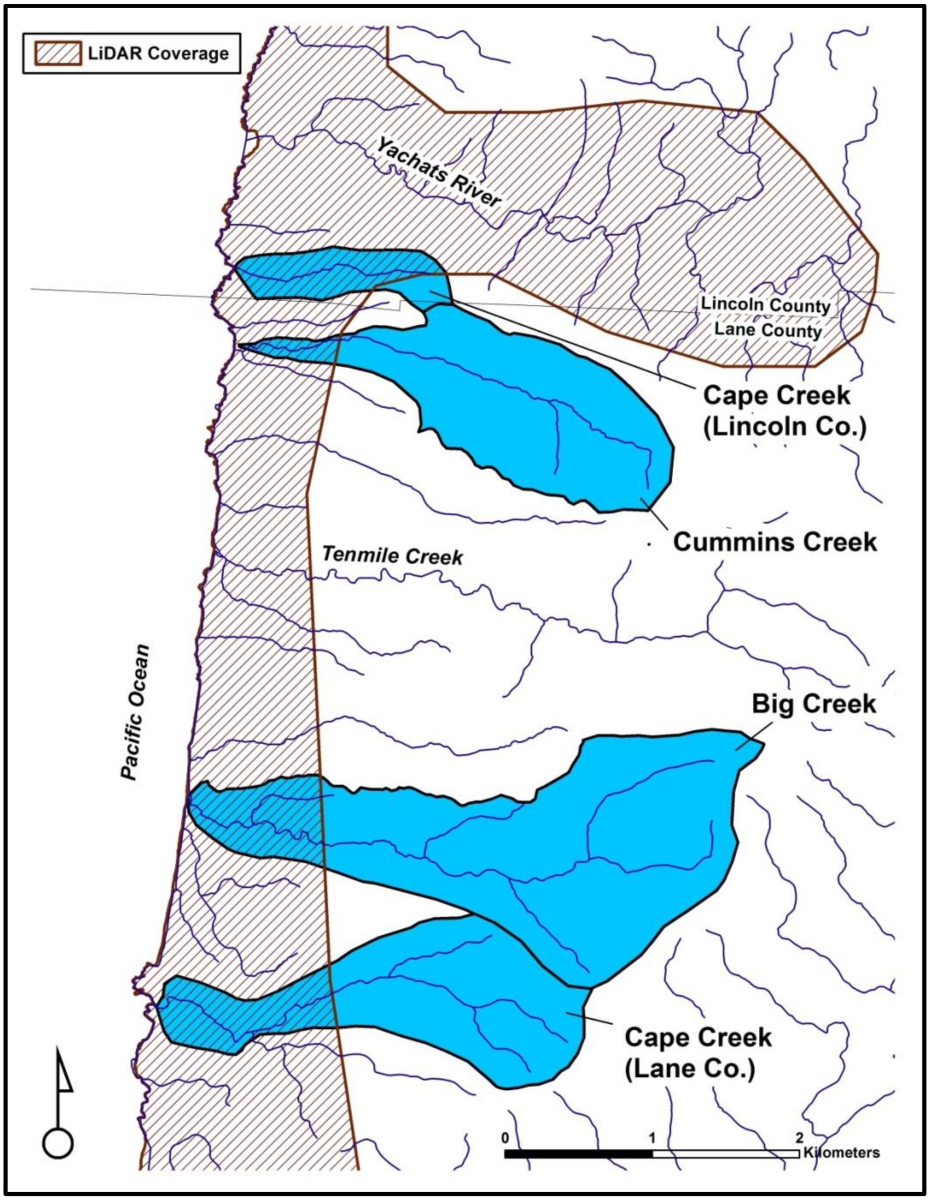


Figure 4.2. Lidar coverage for the study basins. The areas of lidar coverage overlapping the watersheds are the areas investigated for fluvial wood detection.

METHODS

Detecting Fluvial Wood

The accuracy of the average point spacing of the DOGAMI lidar data used for this study is less than one meter on average. While some types of surfaces may return fewer pulses than the laser originally emitted, resulting in the delivered density less than the native density, the minimum mapping area unit (unit density returns) is smaller than the fluvial wood to be detected. It is important to note that the methodology is based on a visual and interpretive approach. I began by importing the point cloud data into Cloud Compare, a freeware software program (Girardeau-Montaut, 2013), and exported the coordinates to scalar x,y,z fields to view all of the returns. Afterward each watershed was divided into multiple sections to assess individually in order to customize the display settings to the varying slopes and vegetation heights within the datasets. This allows for more precise analysis of each section. Next, a point within the channel was selected to determine the z coordinate to then filter the data to contain only the range of new z values close to and along the mainstem channel. The display parameters of the scalar field provide options such as saturation display ranges to create color contrasts in the elevations of the data. It is through this process of toggling the saturation that objects within the channel become apparent. Often the differences in elevation allow fluvial wood to be identified within the channel. Within the software it is possible to rotate the display in three dimensions around chosen center points allowing a shift in perspective and for possible wood to be inspected from all angles (Figure 4.3).

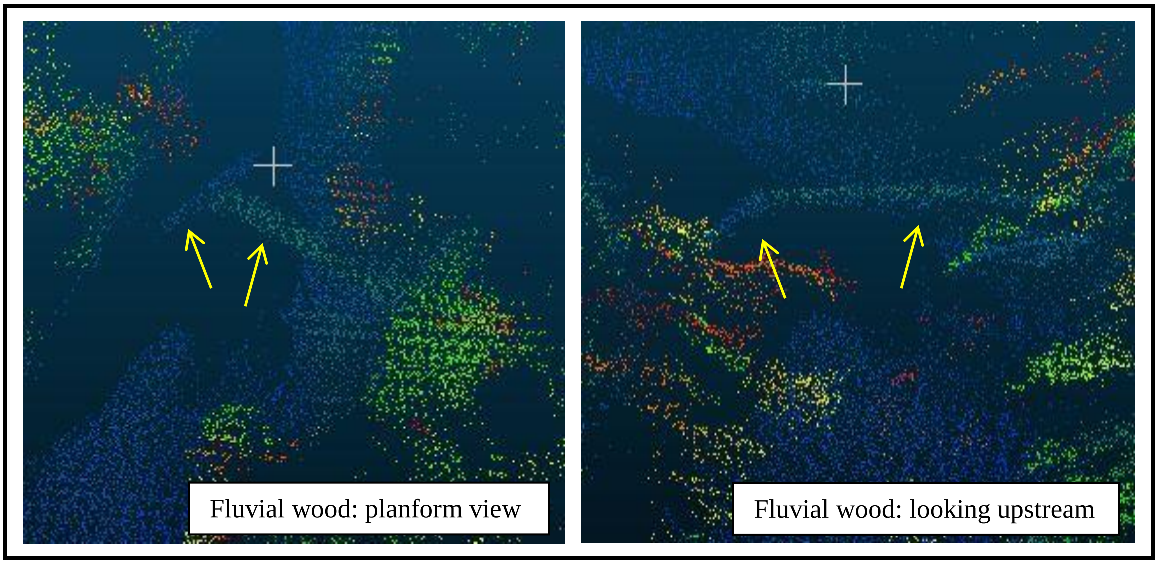


Figure 4.3. Fluvial wood detected in lidar.

When the fluvial wood has been located, I next put a marker on the center of the wood. This records the coordinates of the wood. Concurrently, a spreadsheet was updated with the x,y,z coordinates, the point number as recorded in Cloud Cover, and whether or not it is part of a log jam. Determining log jams from single logs in the channel is a subjective practice. In some instances it is apparent that the logs are part of a jam, and other times it requires application of criteria. As an example, the planform view of fluvial wood in Figure 4.3 shows what appears to be a single log wedged against another single log. While some may consider this a jam based on the two logs present, others may perceive the log as being singular in the sense that there are not porous multiple logs spanning the channel width. Therefore, it is important to set criteria and perhaps have a sole identifier of wood types for the analysis. In this study, Figure 4.3 is considered a single log and not part of a jam.

Some log jams present within the channels are more apparent in the point cloud than others. For example, in Big Creek which has multiple channels, jams may be difficult to discern in secondary channels. Additionally, islands and significant bars add complexity to the channel making the distinction between wood in the channel and island vegetation at times challenging (Figure 4.4).

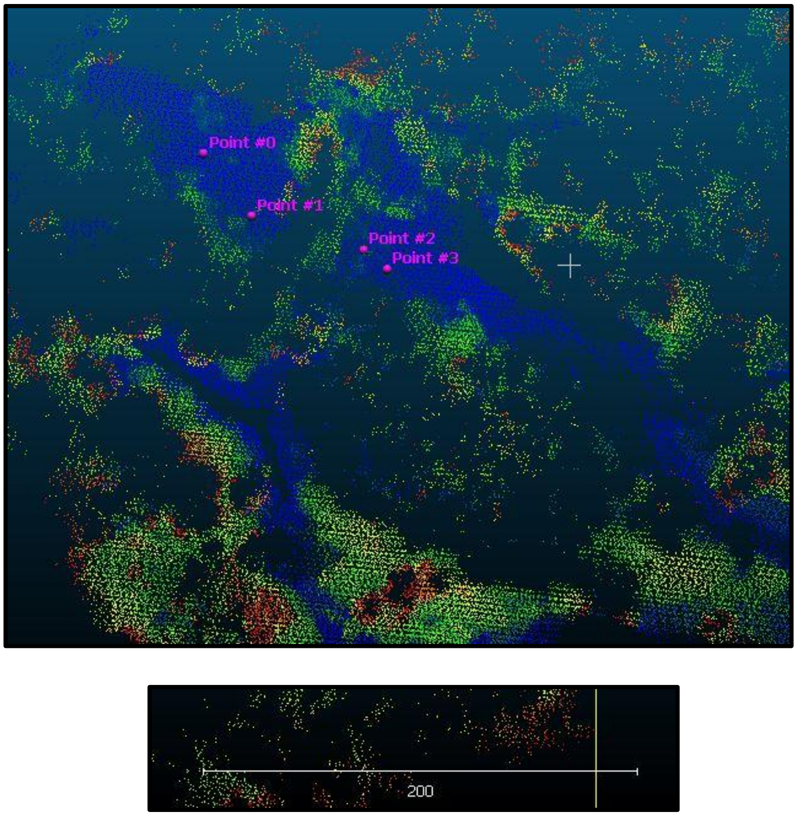


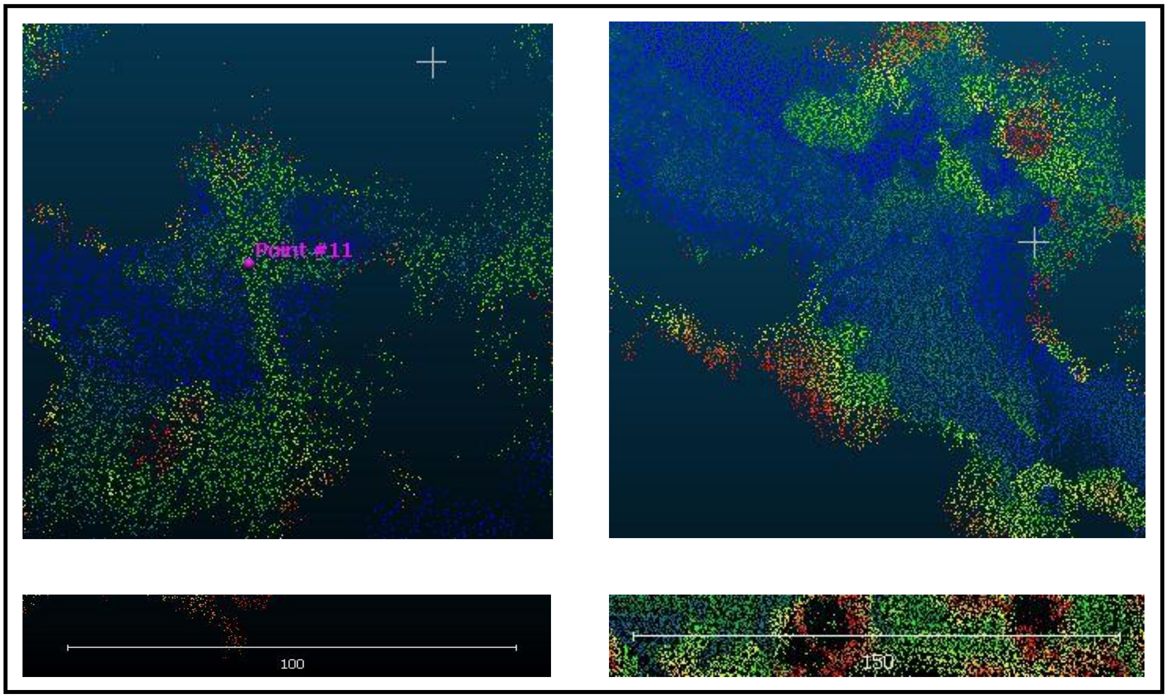
Figure 4.4. Fluvial wood located in Big Creek in areas with islands. The scale unit is feet.

Data Analysis

To test the hypothesis that log jams are more frequent than single log pieces in lower reaches of these smaller mountain river basins I mapped the wood locations in ArcGIS and identified the point locations of wood as being either a single log or a log jam. Additionally, cumulative distribution plots of both the single logs and log jams for each creek were created to compare the locations in terms of distance downstream.

RESULTS AND DISCUSSION

It is possible to detect fluvial wood using high-resolution lidar point cloud data in these densely forested watersheds using the earlier described approach. I documented in-stream wood in the main channels of all four basins, determined if each wood was a single log piece or a log jam, and recorded its spatial coordinates. In areas within Cummins Creek, for example, complex log jams spanning significant spatial areas were identified (Figure 4.5). It is useful to expose the planform view of these complex log jams beneath the tree canopy to gain greater understanding of the clustering and shape of the wood. This perspective is absent when surveying wood of this volume in the field rendering this methodology potentially useful for a multitude of research objectives.



(a) (b)

Figure 4.5. Lidar point cloud data showing the planform view of a) a log jam in Cummins Creek and b) a complex large log jam in Cummins Creek. The scale unit is feet.

However, there are clear limitations in this methodology, particularly in assessing areas outside of the main channel. Smaller lower-order creeks, for the most part, contain low vegetation canopy height to channel width ratios impeding wood detection beneath the growth. An example of questionable log jams in Cape Creek (Lane County) shows an area where fluvial wood is likely present, but is not clear (Figure 4.6a). Another example, located in the upstream portion of Cape Creek (Lincoln County) shows another ambiguous log jam (Figure 4.6b). There is some striping in the data for Big Creek which may lead to error in interpretation. While it impeded analysis somewhat, wood was still identifiable. Big Creek is the most open of the watersheds with the widest valley and floodplain with a thinner canopy than the narrower channels assessed. At first appearance it seems that wood in the channel would be more apparent, however, as mentioned above, careful attention needs to be paid in areas with secondary channels and significant islands. Without previously visiting the watersheds it is not certain that differentiating the riparian zone and island vegetation from wood in the channel can be achieved with confidence. Overall, experience surveying these streams prior to lidar analysis aided the ability to make determinations regarding wood. Using this methodology in an area that does not have ground-truth data, photos of the wood in the channels, or other previous data in addition to an understanding or sense of place would likely limit the ability to make educated estimations of the abundance of wood in streams with this amount of vegetative cover. For this reason, more empirical tests comparing lidar-based wood surveys with field-based wood surveys are needed. Similarly, the development of advanced large wood extraction algorithms from lidar analysis will further the potential of remotely sensed surveys of wood.

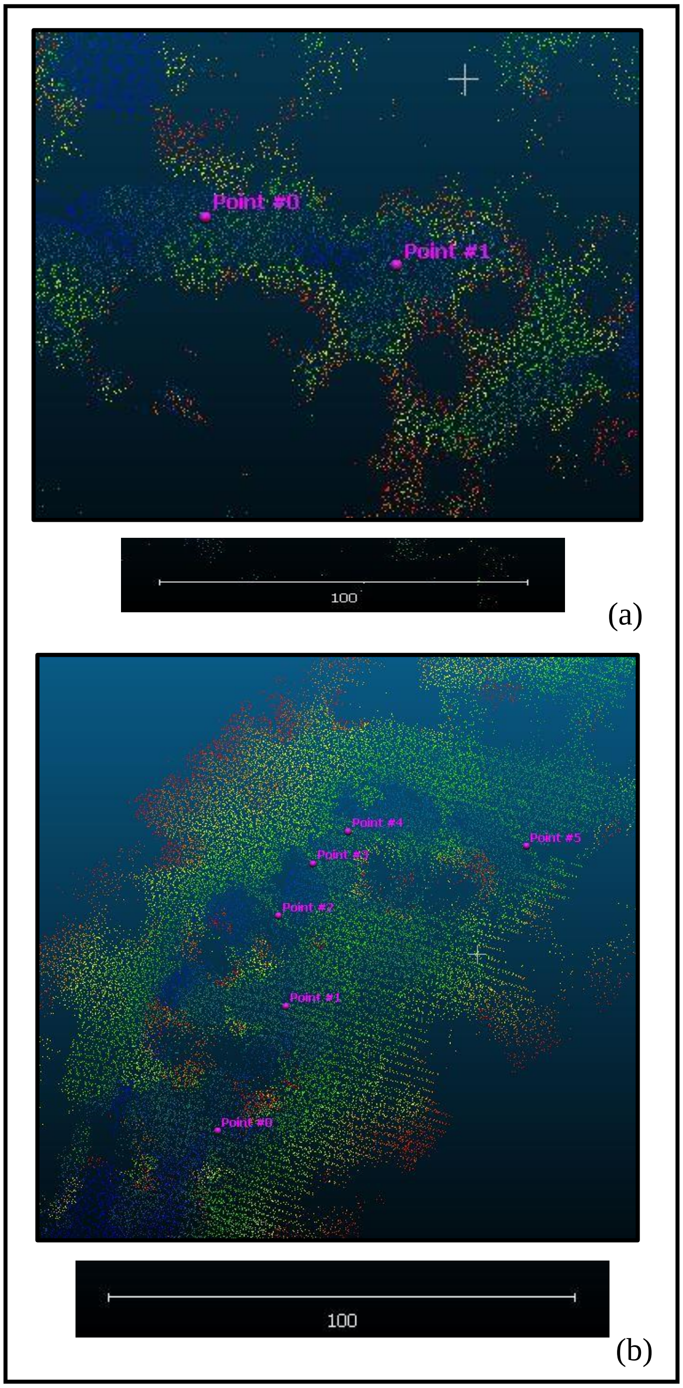


Figure 4.6. Lidar images in planform view of a) less apparent log jams in Cape Creek Lane County and b) log jams in Cape Creek in Lincoln County. The scale unit is feet.

Mapped Fluvial Wood

The spatial distributions of the wood detected using lidar reveal clusters of single logs and log jams identified within the basins (Figure 4.7). It is apparent that wood even in the lower reaches of these basins with the greatest amount of stream transport capacity remains abundant. For both Cummins Creek and Big Creek, the number of log jams is greater than the number of single log pieces, while Cape Creek (Lincoln County) has the same number of each and Cape Creek (Lane County) has fewer log jams than single pieces (Table 4.1).

Table 4.1. In-stream wood detected using lidar within the four study basins.

	Single Logs	**Log Jams**	**Total Wood**
Cape Creek (Lincoln County)	15	15	30
Cummins Creek	38	50	88
Big Creek	15	20	35
Cape Creek (Lane County)	26	17	43

Cumulative Wood Distributions

Cumulative distributions show the locations of the single log pieces and log jams within each creek (Figure 4.8). The distance downstream refers to the location in meters downstream from the headwater channels as defined by the National Hydrography Dataset. Therefore, the cumulative distribution graphs show different distances where the wood begins based on the varying channel lengths upstream of where the lidar coverage beginsfor each creek. Likewise, the farthest distances downstream towards the outlets of the creeks vary as well based on channel length differences.

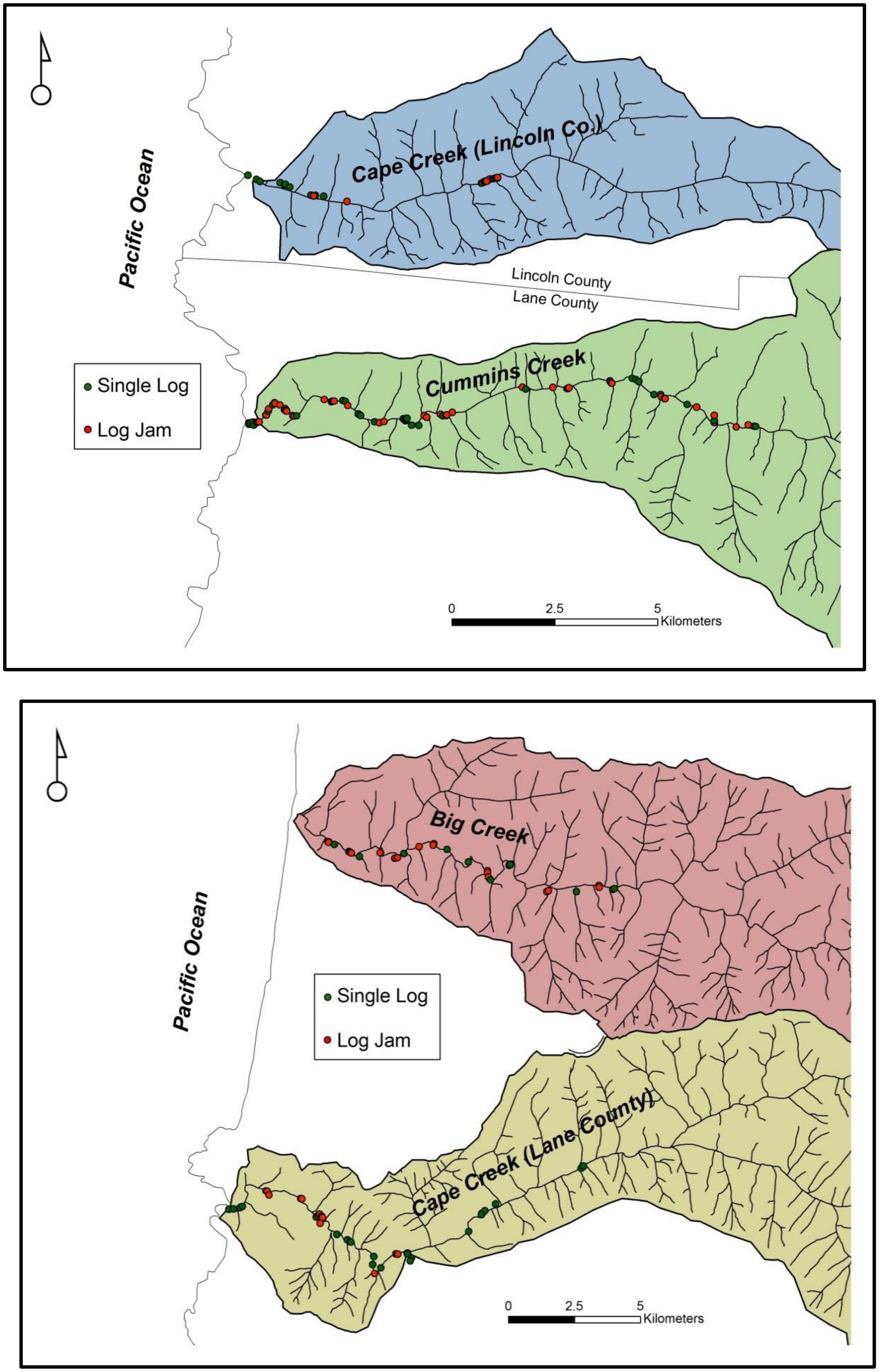


Figure 4.7. Fluvial wood locations detected through lidar.

When viewing the distributions of all four creeks together, the abundance of log jams and single pieces is much greater in Cummins Creek than in the other three creeks, and there are a significantly higher number of jams within the lower reach. The number of single logs in Cape Creek (Lane County) is much higher than the number of log jams; these single pieces begin farther upstream and continue farther than log jams downstream towards the outlet. This is in line with previous findings that more wood in greater volumes are found in Cummins Creek, a watershed that has been less affected by clearcut harvesting and has steeper slopes than Cape Creek in Lane County (Atha, 2013a). These characteristics lead to increased mobility of wood throughout the Cummins Creek basin through debris flow activity, greater transport capacity, and a greater abundance of voluminous wood in the channel. Cape Creek in Lane County has, on the other hand, experienced clearcutting of up to 40% of the drainage area, and is currently undergoing the process of afforestation. This process has resulted in lower volumes of wood that do not have the stability to form significant log jams.

Individual plots of each creek with varying x-axes reflecting the basin size of each creeks how in greater detail the locations of single pieces and log jams (Figure 4.9). The following data show that in Cummins Creek and Big Creek the hypothesis that there will be an increase in the number of log jams compared to single log pieces may be upheld. In Cape Creek (Lincoln County) the number of each is the same and in Cape Creek (Lane County) the hypothesis is not supported. Previous studies put forth conceptual models for the longitudinal distributions of wood in forested mountain rivers. Wohl and Jaeger (2009) found a threshold of the proportion of wood pieces in jams in relation to channel slope. In channels steeper than 0.11 wood in jams is substantially lower because of limited transport. Low gradient areas well below 0.11 – such as where the wood detected in this study is located (0.0001-0.02) – may have a low proportion of wood in jams because the stream is supply limited. The supply of wood in the channel is limited because the transport capacity is high enough to carry wood downstream and on through the outlet to the coast. This hypothesis is supported by the interpretation of results from Marcus et al. (2002) and Abbe and Montgomery (2003). In these basins, I hypothesize that the number of jams will be greater than single pieces because of the relatively small size of the drainage areas. The supply will be sufficient enough to create jams because the transport capacity is not to the extent that wood is unable to collect in jams. Abbe and Montgomery (2003) noticed decreases in log jams in drainages >300km. The largest drainage area within our study area is Big Creek at <40km. The channel slopes in the study area vary from 0.002-0.07 m/m providing variability in stream power. These streams situate in the middle between wood supply limited reaches and transport limited reaches yielding a greater abundance of jams. I attribute the greater abundance of single log pieces relative to log jams in Cape Creek (Lane County) to low wood volumes found in the creek due to its history of forest management as discussed above. Field surveys in this creek found a large proportion of the fluvial wood consists of the small tree red alder (*Alnusrubra*). This species does not provide stable ramped instream wood (wood that is angled into the channel from the bank) pieces necessary to initiate substantial log jam formation.

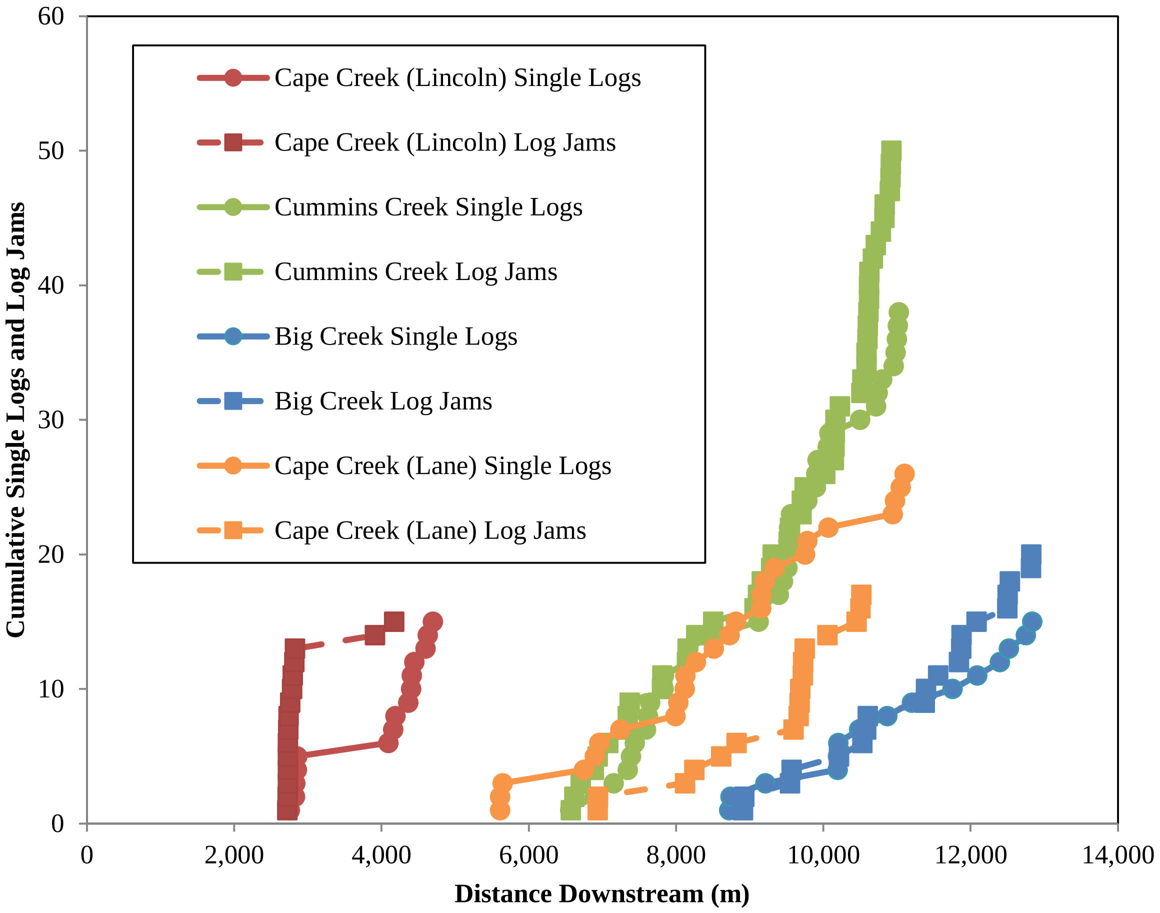
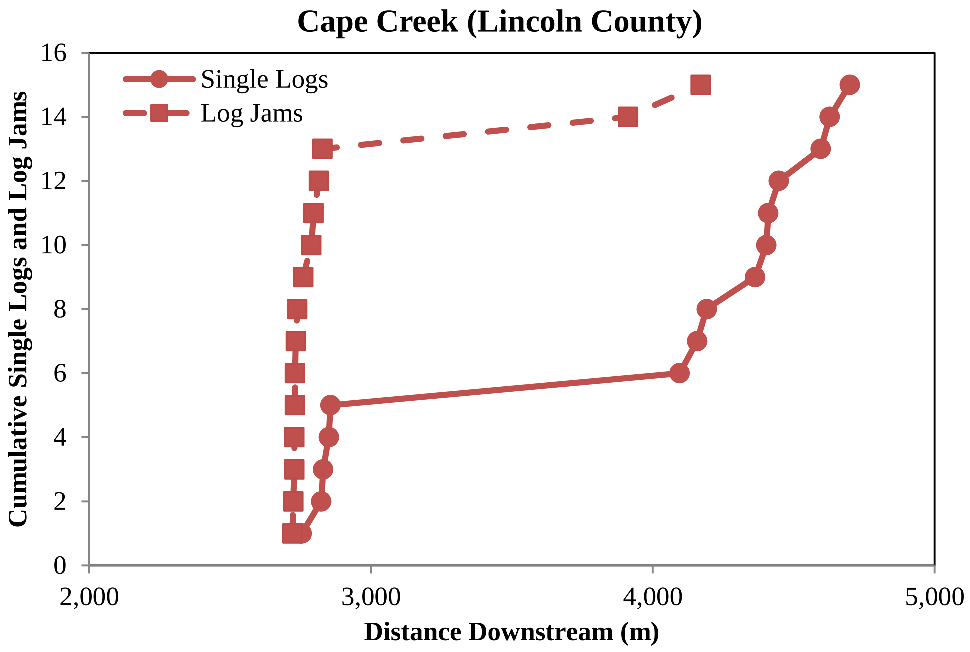
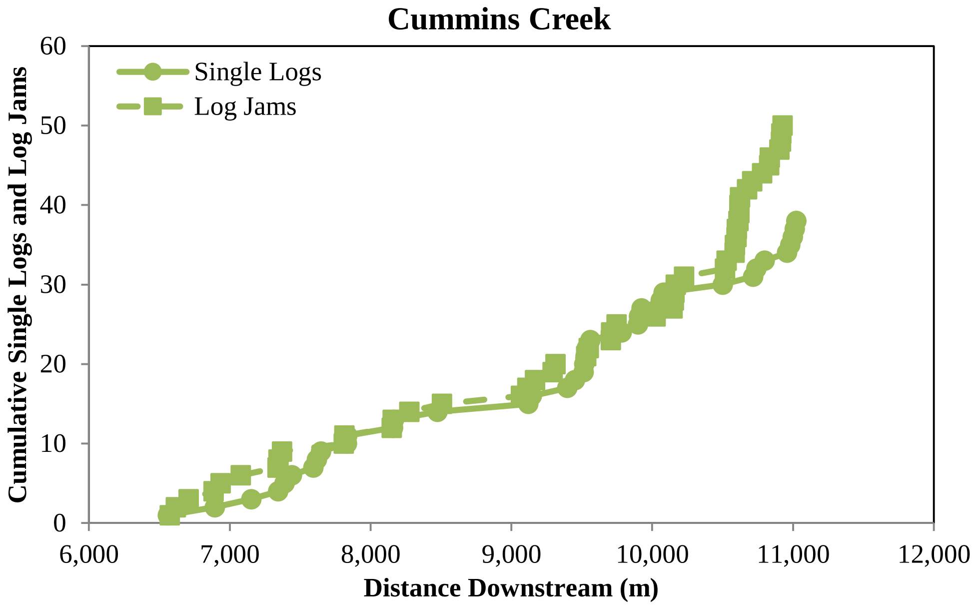


Figure 4.8. Cumulative distributions of single logs and log jams located within the four basins. The x-axis shows the distance in meters moving downstream from left to right. The varying basin sizes illustrate the differences among the upstream distance starting points in the data.

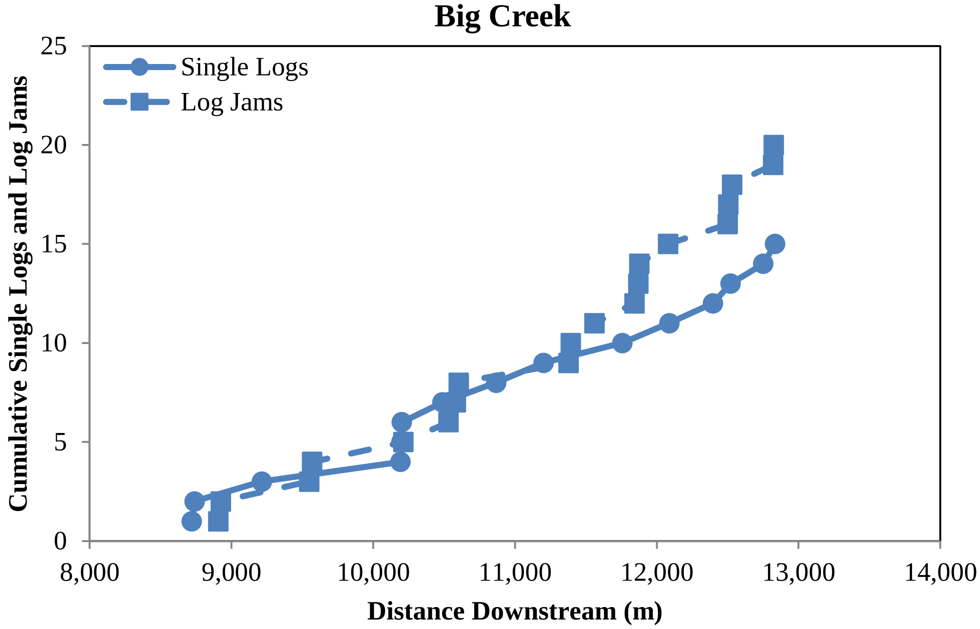
Figure 4.9 (next three pages). Cumulative distributions of single log pieces and log jams in a) Cape Creek (Lincoln County), b) Cummins Creek, c) Big Creek, and d) Cape Creek (Lane County).



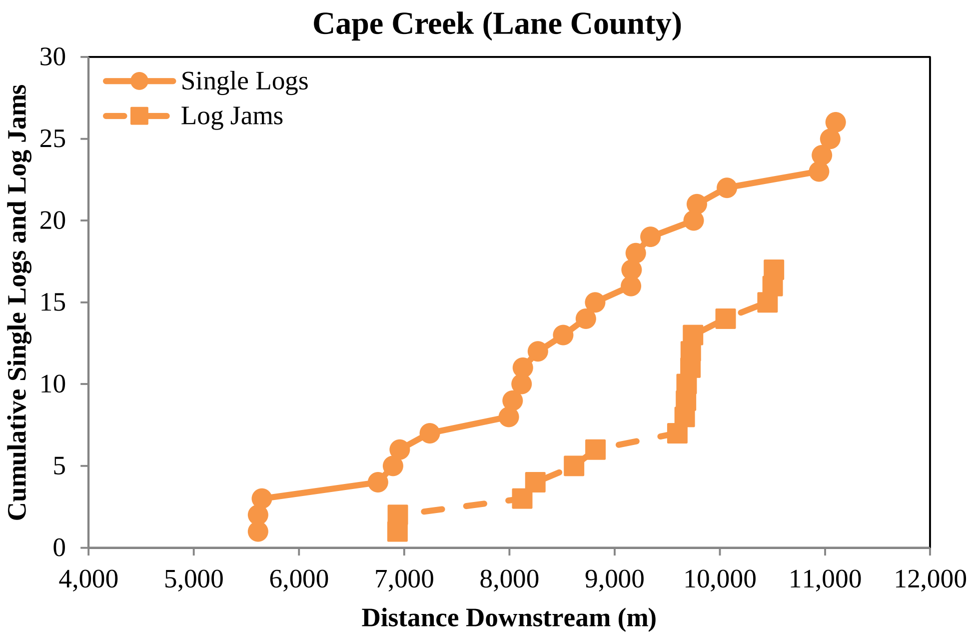
(a)


Cummins Creek
Cumulative Single Logs and Log Jams
Distance Downstream (m)
Single Logs
Log Jams
0
10
20
30
40
50
60
6,000
7,000
8,000
9,000
10,000
11,000
12,000

(b)


Big Creek
Cumulative Single Logs and Log Jams
Distance Downstream (m)
Single Logs
Log Jams
0
5
10
15
20
25
8,000
9,000
10,000
11,000
12,000
13,000
14,000

(c)



(d)

CONCLUSIONS

I successfully detected fluvial wood through high-resolution airborne lidar data in four densely forested mountain watersheds in the Oregon Coast Range. This methodology has the potential to decrease the amount of difficult fieldwork typically necessary to survey large wood on a basin-scale. Because the method was successful in this environment with dense tree canopy, it has the potential to be more successful in areas with less vegetation cover. With lidar data, the complexity of log jams may be viewed from a planform perspective, allowing for analysis of wood clustering and shape. The ability to detect fluvial wood through lidar decreases in lower-order creeks due to narrow channels with vegetation cover. Islands and secondary channels within the channel are an additional challenge in fluvial wood detection using lidar data; it is difficult to distinguish island and riparian vegetation from wood pieces in the channel. Large wood is not stationary; therefore, analysis of changes in wood patterns through time with lidar has the potential to provide rapid development of a robust dataset with minimal fieldwork. It is the hope of this researcher that lidar becomes available for more of this study area and is flown with regularity to record change in this dynamic forest and stream environment.

Although the lidar data does not cover the study watersheds in their entirety, rather just the most downstream reaches; I applied the resulting data to assess a conceptual model regarding the presence of jams in areas of mountainous watersheds with large drainage areas. I hypothesized that the number of jams in these study reaches would be greater than the number of single pieces of wood detected in the lidar. The data supported this hypothesis firmly in Cummins Creek and Big Creek, however, it was not supported in Cape Creek (Lane County). Cape Creek (Lincoln County) has the same number of single logs as log jams. Cape Creek (Lane County) may have fewer log jams because of its history of being clearcut and the subsequent afforestation process that has caused an increase in smaller broad-leaf tree species such as the red alder in disturbed areas consequently reducing the volume of fluvial wood.

CHAPTER V

SUMMARY

In this dissertation, I explore the fluvial wood dynamics over a thirty year interval in four watersheds of the Oregon Coast Range. This research assesses the impacts that afforestation has had on these basins by recreating field datasets first conducted in the late 1970s by Richard Marston and then in 1998 by Jonathan Ferree. The basins in this dissertation have all historically experienced clearcutting in varying degrees. However, due to forest regulations enacted in the early 1980s, timber harvesting in the study area declined steadily since the first dataset was collected and has ceased entirely thirty years later. The research questions of this dissertation largely concern the changes that have taken place in the abundance, volume, and subsequent sediment storage of fluvial wood in theses basins in addition to the changes that have occurred in the stream morphology of these basins due to land-use practices. This dissertation also provides a method of fluvial wood detection using lidar technology.

In chapter II changes in the volume, size, and type of fluvial wood among the 1979, 1998, and 2012 datasets are evaluated. This chapter also addresses the effects of afforestation since 1979 on the landscape of fluvial wood since 1979. This is accomplished by first surveying four study basins: Cape Creek (Lincoln Co.), Cummins Creek, Big Creek, and Cape Creek (Lane Co.). In each watershed, I surveyed all channel-spanning wood in the form of log steps and log jams for the entire network. This field data in conjunction with data derived from historical aerial imagery of the basins delineating clearcut areas allow for spatial and statistical analyses to test the possible controls on fluvial wood abundance and volume. Results from this chapter show that residence times of large wood are short in these basins and significant storm events such as those experienced prior to the 1998 dataset collection can greatly increase the amounts of wood found in the channels. Cape Creek (Lane Co.) has had up to 40% of its hillslopes clearcut and is still seeing the effects from this management today. Afforestation in the basin has led to a significant decrease the large wood volumes in this creek due to changes in the forest composition.

Chapter III addresses the changes that have occurred in the stream morphology of the four study basins. The first objective of this study focuses on the changes in downstream hydraulic geometry (DHG) of the basins among the field datasets to test the hypothesis that DHG will strengthen with less wood volume. The second objective in this chapter is to analyze the spatial distribution of stream power across the four basins and among the three datasets to extrapolate patterns and trends associated with changes in the abundance and volume of fluvial wood throughout the thirty year interval. I collected stream morphometric data in the same locations as the two previous researchers in the field providing the data parameters to analyze DHG as well as calculate a predicted stream power for each transect location. The DHG of Big Creek and Cape Creek (Lane Co.) is becoming increasingly well-developed in more recent years, supporting the hypothesis. The predicted stream power significantly over-estimated observed stream power, particularly in 1979, supporting the hypothesis that land-use change – particularly clearcutting – greatly altered stream power at that time. Statistical analysis reveals significant changes occurring among many of the variables collected in the field among the three years. However, the significant changes detected through nonparametric tests and significant variables emerging from multiple regression analyses are disparate among the four watersheds for the three datasets. This indicates that each stream has local variables acting on it that transcend lithology and climate.

Chapter IV is a methodological evaluation assessing the possibility of detecting fluvial wood from high resolution airborne lidar in these densely forested watersheds. This chapter explores a new method of surveying wood in forested watersheds on larger spatial scales beyond traditional long-term field studies. By removing the tree canopy from lidar point cloud data I successfully detected fluvial wood in the lower reaches of the main channels of all four creeks. I was able to discern single log pieces and log jams within the data and map their locations. Limitations occur when deciphering wood in the lower-order tributaries and in areas with vegetated islands and low-lying vegetation in dense riparian areas that obscure the wood present in the channel. The method allows for the complexity of jams to be seen from a planform perspective which is often absent from field data collection and may be useful for a number of future research objectives. The wood detected from the lidar also revealed that there are a greater amount of log jams compared with single log pieces in these basins supporting the hypothesis that more jams would be present at the larger drainage areas near the outlets of these basins.

The basins analyzed in this dissertation are highly dynamic and heterogeneous in the context of fluvial wood. This dissertation highlights the implicit effects that longer term land-use has had on the abundance and volume of the wood that is vital to stream complexity and aquatic habitat. Statistically significant changes have occurred in all of the basins among the three datasets, however, each basin has a unique physiography and history of forest and stream management lending to disparate controls on morphology. In the future, I hope that continued efforts to survey the fluvial wood in these streams through field surveys or lidar technology take place in order to monitor the next phase of change. Recent efforts to incorporate geomorphic processes into river management should ideally include the analysis of fluvial wood to monitor stream health. There is also an urgent need for research in watershed-scale river restoration efforts globally. Researchers worldwide might very well embrace the key component of restoration which this work renders: quantifying stream health through inventory of river complexity.

APPENDIX A

WOOD DATA FROM THE 1979, 1998, AND 2012 DATASETS

Year	Creek	Type	Distance Downstream (m)	Volume (m3)
1979	Big	Step	2163	2.00
1979	Big	Step	10543	8.00
1979	Big	Step	10097	896.00
1979	Big	Step	7782	36.00
1979	Big	Step	2083	11.00
1979	Big	Step	2176	27.00
1979	Big	Step	2442	31.00
1979	Big	Step	2502	4.00
1979	Big	Step	5343	224.00
1979	Big	Step	4827	17.00
1979	Big	Step	4123	48.00
1979	Big	Step	2169	28.00
1979	Big	Step	2141	84.00
1979	Big	Step	1546	168.00
1979	Big	Step	1187	106.00
1979	Big	Step	778	2.00
1979	Big	Step	3569	21.00
1979	Big	Step	3204	6.00
1979	Big	Step	2096	16.00
1979	Big	Step	2397	22.00
1979	Big	Step	2677	20.00
1979	Big	Step	3122	2.00
1979	Big	Step	2109	9.00
1979	Big	Step	1907	20.00
1979	Big	Step	1278	0.00
1979	Big	Step	1472	25.00
1979	Big	Step	1385	3.00
1979	Big	Step	1835	5.00
1979	Big	Step	1731	2.00
1979	Big	Step	1559	3.00
1979	Big	Step	1984	7.00
1979	Big	Step	1735	90.00
1979	Big	Step	1821	10.00
1979	Big	Step	1875	4.00
1979	Big	Jam	12258	1.70
1979	Big	Jam	10434	8.50
1979	Big	Jam	9886	891.98

1979	Big	Jam	7775	37.38
1979	Big	Jam	2242	4.76
1979	Big	Jam	2023	24.47
1979	Big	Jam	1990	45.31
1979	Big	Jam	1894	566.34
1979	Big	Jam	2315	5.61
1979	Big	Jam	2216	29.73
1979	Big	Jam	2123	27.18
1979	Big	Jam	2038	10.62
1979	Big	Jam	5130	226.53
1979	Big	Jam	4709	16.99
1979	Big	Jam	2049	28.32
1979	Big	Jam	1970	84.95
1979	Big	Jam	1825	16.99
1979	Big	Jam	624	107.04
1979	Big	Jam	393	2.04
1979	Big	Jam	3926	47.57
1979	Big	Jam	3321	21.41
1979	Big	Jam	1110	6.12
1979	Big	Jam	2398	22.65
1979	Big	Jam	1886	15.86
1979	Big	Jam	1858	6.80
1979	Big	Jam	1782	10.19
1979	Big	Jam	1636	9.97
1979	Big	Jam	1609	91.75
1979	Big	Jam	3012	2.04
1979	Big	Jam	2447	20.39
1979	Big	Jam	2396	6.80
1979	Big	Jam	1199	6.37
1979	Big	Jam	2233	9.34
1979	Big	Jam	2170	19.82
1979	Big	Jam	2008	5.10
1979	Big	Jam	1504	2.04
1979	Big	Jam	1439	5.10
1979	Big	Jam	1337	24.78
1979	Big	Jam	1289	3.40
1979	Big	Jam	1289	0.34
1979	Big	Jam	1050	3.40
1979	Big	Jam	954	4.59
1979	Big	Jam	588	12.74
1998	Big	Step	12973	1.74
1998	Big	Step	9950	70.35
1998	Big	Step	7337	29.15

1998	Big	Step	6563	7.41
1998	Big	Step	2405	34.89
1998	Big	Step	2371	3.12
1998	Big	Step	2337	4.20
1998	Big	Step	2152	6.54
1998	Big	Step	2318	18.98
1998	Big	Step	1975	13.16
1998	Big	Step	4351	0.36
1998	Big	Step	2207	6.31
1998	Big	Step	2175	39.86
1998	Big	Step	2099	83.62
1998	Big	Step	1786	1.07
1998	Big	Step	1233	23.02
1998	Big	Step	1180	2.82
1998	Big	Step	960	221.73
1998	Big	Step	3258	113.19
1998	Big	Step	2923	12.59
1998	Big	Step	2829	31.58
1998	Big	Step	2778	5.89
1998	Big	Step	2486	258.75
1998	Big	Step	2564	619.07
1998	Big	Step	2216	57.36
1998	Big	Step	2142	92.83
1998	Big	Step	1984	7.53
1998	Big	Step	1946	0.65
1998	Big	Step	1842	7.33
1998	Big	Step	1823	11.59
1998	Big	Step	1799	6.45
1998	Big	Step	1763	7.99
1998	Big	Step	1706	30.84
1998	Big	Step	1653	2.27
1998	Big	Step	1608	5.44
1998	Big	Step	1569	221.71
1998	Big	Step	1519	24.57
1998	Big	Step	1475	25.89
1998	Big	Step	1156	3.68
1998	Big	Step	1254	1.45
1998	Big	Step	1407	0.88
1998	Big	Step	1459	0.88
1998	Big	Step	1897	7.64
1998	Big	Step	1835	5.76
1998	Big	Step	1305	1.97
1998	Big	Step	917	190.00

1998	Big	Step	2116	27.34
1998	Big	Step	2061	9.45
1998	Big	Step	2037	11.79
1998	Big	Step	1970	194.86
1998	Big	Step	1930	165.10
1998	Big	Step	1879	443.89
1998	Big	Step	1802	26.84
1998	Big	Step	2721	48.16
1998	Big	Step	2596	0.85
1998	Big	Step	2557	4.91
1998	Big	Step	2513	34.02
1998	Big	Step	2482	10.33
1998	Big	Step	2417	11.29
1998	Big	Step	2285	4.78
1998	Big	Jam	13075	149.12
1998	Big	Jam	12868	70.62
1998	Big	Jam	12382	182.43
1998	Big	Jam	12673	311.16
1998	Big	Jam	12313	14.10
1998	Big	Jam	12164	136.72
1998	Big	Jam	12120	44.93
1998	Big	Jam	12084	6112.77
1998	Big	Jam	12049	433.35
1998	Big	Jam	12007	515.76
1998	Big	Jam	10674	265.75
1998	Big	Jam	10547	1090.08
1998	Big	Jam	8973	12.26
1998	Big	Jam	8908	67.34
1998	Big	Jam	9510	238.41
1998	Big	Jam	9644	698.53
1998	Big	Jam	9705	359.18
1998	Big	Jam	9757	14.16
1998	Big	Jam	9916	134.65
1998	Big	Jam	9879	302.78
1998	Big	Jam	10117	1198.01
1998	Big	Jam	10161	68.41
1998	Big	Jam	10236	64.66
1998	Big	Jam	10302	496.93
1998	Big	Jam	10464	194.94
1998	Big	Jam	10384	10.38
1998	Big	Jam	8730	167.44
1998	Big	Jam	8416	570.09
1998	Big	Jam	8309	61.89

1998	Big	Jam	8063	253.93
1998	Big	Jam	7876	146.57
1998	Big	Jam	7060	220.59
1998	Big	Jam	7210	496.42
1998	Big	Jam	7458	50.87
1998	Big	Jam	3459	87.95
1998	Big	Jam	3569	47.94
1998	Big	Jam	6632	42.08
1998	Big	Jam	6271	53.34
1998	Big	Jam	6221	115.72
1998	Big	Jam	6170	38.65
1998	Big	Jam	5806	122.70
1998	Big	Jam	5770	72.66
1998	Big	Jam	5725	41.28
1998	Big	Jam	5611	358.32
1998	Big	Jam	5561	133.42
1998	Big	Jam	5508	47.56
1998	Big	Jam	5446	78.86
1998	Big	Jam	1924	125.66
1998	Big	Jam	2503	17.18
1998	Big	Jam	2458	15.16
1998	Big	Jam	2435	77.99
1998	Big	Jam	4760	90.85
1998	Big	Jam	2340	17.48
1998	Big	Jam	2288	65.36
1998	Big	Jam	2249	49.40
1998	Big	Jam	1274	94.26
1998	Big	Jam	1057	28.60
1998	Big	Jam	828	227.41
1998	Big	Jam	3898	5.03
1998	Big	Jam	3413	56.48
1998	Big	Jam	3850	19.13
1998	Big	Jam	3653	32.66
1998	Big	Jam	3470	46.36
1998	Big	Jam	3379	35.86
1998	Big	Jam	3350	58.85
1998	Big	Jam	3221	55.17
1998	Big	Jam	3098	142.36
1998	Big	Jam	3082	85.62
1998	Big	Jam	2882	102.00
1998	Big	Jam	2379	84.99
1998	Big	Jam	2414	39.08
1998	Big	Jam	2315	62.78

1998	Big	Jam	2275	67.32
1998	Big	Jam	2096	64.71
1998	Big	Jam	1902	35.60
1998	Big	Jam	1872	81.03
1998	Big	Jam	1497	277.82
1998	Big	Jam	3168	95.31
1998	Big	Jam	3139	42.30
1998	Big	Jam	1597	45.24
1998	Big	Jam	1557	102.57
1998	Big	Jam	1528	192.48
1998	Big	Jam	1492	50.23
1998	Big	Jam	1107	36.61
1998	Big	Jam	1083	514.21
1998	Big	Jam	950	19.03
1998	Big	Jam	889	46.82
1998	Big	Jam	690	19.23
1998	Big	Jam	2097	10.56
1998	Big	Jam	2022	19.56
1998	Big	Jam	2001	213.03
1998	Big	Jam	1859	6.09
1998	Big	Jam	1835	30.82
1998	Big	Jam	2387	25.63
1998	Big	Jam	2346	29.49
2012	Big	Step	2788	0.20
2012	Big	Step	3027	0.31
2012	Big	Step	3045	1.76
2012	Big	Step	3686	1.71
2012	Big	Step	3200	0.04
2012	Big	Step	4194	2.30
2012	Big	Step	4125	26.19
2012	Big	Step	4019	3.11
2012	Big	Step	3973	1.52
2012	Big	Step	5063	8.40
2012	Big	Step	3332	1.03
2012	Big	Step	2932	0.58
2012	Big	Step	2814	84.24
2012	Big	Step	3595	2.00
2012	Big	Step	3586	0.66
2012	Big	Step	3491	0.77
2012	Big	Step	3369	1.37
2012	Big	Step	3304	0.78
2012	Big	Step	3109	9.09
2012	Big	Step	3065	0.28

2012	Big	Step	3018	16.59
2012	Big	Step	3566	1.58
2012	Big	Step	3426	1.51
2012	Big	Step	3331	0.24
2012	Big	Step	3438	0.19
2012	Big	Jam	2780	15.12
2012	Big	Jam	2849	26.22
2012	Big	Jam	2995	36.86
2012	Big	Jam	3130	7.15
2012	Big	Jam	3299	2.18
2012	Big	Jam	3530	143.44
2012	Big	Jam	3406	11.16
2012	Big	Jam	3374	28.84
2012	Big	Jam	3216	16.74
2012	Big	Jam	3134	0.30
2012	Big	Jam	4984	54.12
2012	Big	Jam	4786	59.35
2012	Big	Jam	4630	3.53
2012	Big	Jam	4457	11.99
2012	Big	Jam	4394	297.00
2012	Big	Jam	4029	8.87
2012	Big	Jam	3949	71.25
2012	Big	Jam	3862	58.80
2012	Big	Jam	3538	56.00
2012	Big	Jam	4826	19.43
2012	Big	Jam	4811	48.60
2012	Big	Jam	5270	36.86
2012	Big	Jam	5457	3.22
2012	Big	Jam	5932	28.01
2012	Big	Jam	3216	78.00
2012	Big	Jam	2954	4.23
2012	Big	Jam	2625	84.80
2012	Big	Jam	2478	30.28
2012	Big	Jam	2450	50.05
2012	Big	Jam	2255	52.08
2012	Big	Jam	2108	56.27
2012	Big	Jam	2107	3.39
2012	Big	Jam	2105	4.99
2012	Big	Jam	1993	108.68
2012	Big	Jam	7262	21.52
2012	Big	Jam	3618	1.97
2012	Big	Jam	3543	9.45
2012	Big	Jam	3441	31.82

2012	Big	Jam	3390	17.32
2012	Big	Jam	3343	1.90
2012	Big	Jam	3289	6.08
2012	Big	Jam	7300	88.80
2012	Big	Jam	7465	195.30
2012	Big	Jam	7544	414.96
2012	Big	Jam	7559	42.12
2012	Big	Jam	7669	549.23
2012	Big	Jam	8733	80.60
2012	Big	Jam	1829	134.40
2012	Big	Jam	9567	4.75
2012	Big	Jam	3475	8.03
2012	Big	Jam	3460	13.60
2012	Big	Jam	15567	83.49
2012	Big	Jam	15337	116.85
2012	Big	Jam	15220	675.96
2012	Big	Jam	15154	177.84
2012	Big	Jam	15111	68.60
2012	Big	Jam	14981	120.77
2012	Big	Jam	15008	215.22
2012	Big	Jam	14974	341.25
2012	Big	Jam	14956	73.46
2012	Big	Jam	14685	138.04
2012	Big	Jam	14624	64.24
2012	Big	Jam	14505	109.35
2012	Big	Jam	14463	107.10
2012	Big	Jam	14340	195.20
2012	Big	Jam	14239	34.91
2012	Big	Jam	14110	386.46
2012	Big	Jam	14025	205.72
2012	Big	Jam	14034	628.43
2012	Big	Jam	13937	132.00
2012	Big	Jam	13923	906.25
2012	Big	Jam	13738	148.94
2012	Big	Jam	13611	302.64
2012	Big	Jam	13561	52.22
2012	Big	Jam	13503	913.75
2012	Big	Jam	13277	307.58
2012	Big	Jam	13081	72.38
2012	Big	Jam	13038	784.00
2012	Big	Jam	13023	2494.08
2012	Big	Jam	12055	2343.60
2012	Big	Jam	1499	122.88

2012	Big	Jam	10821	82.67
2012	Big	Jam	3304	736.00
2012	Big	Jam	10383	103.72
2012	Big	Jam	10347	736.00
1979	Cape (Lane)	Step	2907	179.00
1979	Cape (Lane)	Step	2640	12.00
1979	Cape (Lane)	Step	1745	8.00
1979	Cape (Lane)	Step	1588	588.00
1979	Cape (Lane)	Step	1531	616.00
1979	Cape (Lane)	Step	1046	50.00
1979	Cape (Lane)	Step	1346	53.00
1979	Cape (Lane)	Step	1406	2408.00
1979	Cape (Lane)	Step	1467	308.00
1979	Cape (Lane)	Step	2437	59.00
1979	Cape (Lane)	Step	1726	22.00
1979	Cape (Lane)	Step	1432	28.00
1979	Cape (Lane)	Step	1225	50.00
1979	Cape (Lane)	Step	1122	134.00
1979	Cape (Lane)	Step	1026	8.00
1979	Cape (Lane)	Step	932	16.00
1979	Cape (Lane)	Step	866	1.00
1979	Cape (Lane)	Step	9999	27.00
1979	Cape (Lane)	Step	5280	336.00
1979	Cape (Lane)	Step	2420	3.00
1979	Cape (Lane)	Step	1849	8.00
1979	Cape (Lane)	Step	2113	3360.00
1979	Cape (Lane)	Step	1757	120.00
1979	Cape (Lane)	Step	1335	101.00
1979	Cape (Lane)	Step	635	185.00
1979	Cape (Lane)	Step	1124	17.00
1979	Cape (Lane)	Step	968	27.00
1979	Cape (Lane)	Step	1468	27.00
1979	Cape (Lane)	Step	1629	13.00
1979	Cape (Lane)	Step	4151	1064.00
1979	Cape (Lane)	Step	4070	15.00
1979	Cape (Lane)	Step	3141	11.00
1979	Cape (Lane)	Step	3073	22.00
1979	Cape (Lane)	Step	2990	17.00
1979	Cape (Lane)	Step	2574	266.00
1979	Cape (Lane)	Step	1168	1344.00
1979	Cape (Lane)	Step	1227	364.00
1979	Cape (Lane)	Step	877	11.00
1979	Cape (Lane)	Step	2391	62.00

1979	Cape (Lane)	Step	1624	22.00
1979	Cape (Lane)	Step	1053	7.00
1979	Cape (Lane)	Step	633	18.00
1979	Cape (Lane)	Step	546	22.00
1979	Cape (Lane)	Step	3660	67.00
1979	Cape (Lane)	Jam	9827	27.18
1979	Cape (Lane)	Jam	9898	152.91
1979	Cape (Lane)	Jam	5326	339.80
1979	Cape (Lane)	Jam	2554	59.47
1979	Cape (Lane)	Jam	2447	3.40
1979	Cape (Lane)	Jam	4735	0.00
1979	Cape (Lane)	Jam	2069	3398.02
1979	Cape (Lane)	Jam	1856	8.50
1979	Cape (Lane)	Jam	1739	122.33
1979	Cape (Lane)	Jam	1576	13.59
1979	Cape (Lane)	Jam	1471	27.18
1979	Cape (Lane)	Jam	1279	101.94
1979	Cape (Lane)	Jam	768	186.89
1979	Cape (Lane)	Jam	1102	16.99
1979	Cape (Lane)	Jam	874	27.18
1979	Cape (Lane)	Jam	4059	67.96
1979	Cape (Lane)	Jam	4307	15.29
1979	Cape (Lane)	Jam	4442	1087.37
1979	Cape (Lane)	Jam	2740	11.89
1979	Cape (Lane)	Jam	2935	181.23
1979	Cape (Lane)	Jam	3670	22.65
1979	Cape (Lane)	Jam	3629	16.57
1979	Cape (Lane)	Jam	3800	11.33
1979	Cape (Lane)	Jam	1819	8.50
1979	Cape (Lane)	Jam	1745	594.65
1979	Cape (Lane)	Jam	1626	297.33
1979	Cape (Lane)	Jam	1662	611.64
1979	Cape (Lane)	Jam	1481	2446.58
1979	Cape (Lane)	Jam	1373	54.37
1979	Cape (Lane)	Jam	1168	1347.88
1979	Cape (Lane)	Jam	1283	356.79
1979	Cape (Lane)	Jam	2461	59.47
1979	Cape (Lane)	Jam	2246	61.16
1979	Cape (Lane)	Jam	1975	22.65
1979	Cape (Lane)	Jam	1502	28.32
1979	Cape (Lane)	Jam	1114	6.80
1979	Cape (Lane)	Jam	444	22.65
1979	Cape (Lane)	Jam	850	679.60

1979	Cape (Lane)	Jam	1094	135.92
1979	Cape (Lane)	Jam	999	7.65
1979	Cape (Lane)	Jam	1323	50.97
1979	Cape (Lane)	Jam	2655	237.86
1998	Cape (Lane)	Step	8147	50.15
1998	Cape (Lane)	Step	6937	1.12
1998	Cape (Lane)	Step	4918	0.64
1998	Cape (Lane)	Step	3559	50.19
1998	Cape (Lane)	Step	4109	1.91
1998	Cape (Lane)	Step	3324	1.30
1998	Cape (Lane)	Step	1819	13.26
1998	Cape (Lane)	Step	1789	1.17
1998	Cape (Lane)	Step	1762	1.45
1998	Cape (Lane)	Step	1717	0.76
1998	Cape (Lane)	Step	1677	0.36
1998	Cape (Lane)	Step	1644	150.11
1998	Cape (Lane)	Step	1603	142.50
1998	Cape (Lane)	Step	1015	22.01
1998	Cape (Lane)	Step	1072	30.06
1998	Cape (Lane)	Step	1160	127.63
1998	Cape (Lane)	Step	1185	5.50
1998	Cape (Lane)	Step	1184	5.62
1998	Cape (Lane)	Step	1227	1.74
1998	Cape (Lane)	Step	1256	203.74
1998	Cape (Lane)	Step	1338	4.36
1998	Cape (Lane)	Step	1365	9.68
1998	Cape (Lane)	Step	2303	8.03
1998	Cape (Lane)	Step	2395	2.68
1998	Cape (Lane)	Step	1755	208.07
1998	Cape (Lane)	Step	1806	16.88
1998	Cape (Lane)	Step	1179	1.07
1998	Cape (Lane)	Step	1223	6.46
1998	Cape (Lane)	Step	1264	50.20
1998	Cape (Lane)	Step	1357	4.33
1998	Cape (Lane)	Step	1400	7.83
1998	Cape (Lane)	Step	1657	30.34
1998	Cape (Lane)	Step	1639	153.97
1998	Cape (Lane)	Step	779	2.64
1998	Cape (Lane)	Step	815	1.47
1998	Cape (Lane)	Step	914	58.01
1998	Cape (Lane)	Step	829	5.58
1998	Cape (Lane)	Step	853	0.28
1998	Cape (Lane)	Step	886	36.87

1998	Cape (Lane)	Step	951	107.85
1998	Cape (Lane)	Step	930	0.30
1998	Cape (Lane)	Step	1096	39.80
1998	Cape (Lane)	Step	1200	17.38
1998	Cape (Lane)	Step	1176	19.95
1998	Cape (Lane)	Step	1125	5.12
1998	Cape (Lane)	Step	768	1.44
1998	Cape (Lane)	Step	796	1.00
1998	Cape (Lane)	Step	850	25.41
1998	Cape (Lane)	Step	832	30.21
1998	Cape (Lane)	Step	892	129.49
1998	Cape (Lane)	Step	926	72.07
1998	Cape (Lane)	Step	970	32.06
1998	Cape (Lane)	Step	1006	9.21
1998	Cape (Lane)	Step	1321	132.32
1998	Cape (Lane)	Step	1342	67.21
1998	Cape (Lane)	Step	1588	111.91
1998	Cape (Lane)	Step	1621	79.29
1998	Cape (Lane)	Step	1652	51.85
1998	Cape (Lane)	Step	1760	20.75
1998	Cape (Lane)	Step	1831	2.44
1998	Cape (Lane)	Step	1889	42.95
1998	Cape (Lane)	Step	1948	14.55
1998	Cape (Lane)	Step	2157	134.62
1998	Cape (Lane)	Step	2139	14.05
1998	Cape (Lane)	Step	2114	13.73
1998	Cape (Lane)	Step	2091	5.04
1998	Cape (Lane)	Step	2069	12.29
1998	Cape (Lane)	Step	2050	9.63
1998	Cape (Lane)	Step	2563	3.91
1998	Cape (Lane)	Jam	10183	37.79
1998	Cape (Lane)	Jam	10103	18.42
1998	Cape (Lane)	Jam	10027	16.72
1998	Cape (Lane)	Jam	9361	51.96
1998	Cape (Lane)	Jam	9391	160.57
1998	Cape (Lane)	Jam	9421	392.54
1998	Cape (Lane)	Jam	9446	64.56
1998	Cape (Lane)	Jam	9492	157.12
1998	Cape (Lane)	Jam	9993	36.29
1998	Cape (Lane)	Jam	9964	201.28
1998	Cape (Lane)	Jam	9940	73.26
1998	Cape (Lane)	Jam	9903	138.56
1998	Cape (Lane)	Jam	9333	67.98

1998	Cape (Lane)	Jam	8812	16.09
1998	Cape (Lane)	Jam	8875	259.15
1998	Cape (Lane)	Jam	8921	310.98
1998	Cape (Lane)	Jam	7695	44.75
1998	Cape (Lane)	Jam	8123	74.09
1998	Cape (Lane)	Jam	8091	39.70
1998	Cape (Lane)	Jam	8067	994.07
1998	Cape (Lane)	Jam	8046	26.29
1998	Cape (Lane)	Jam	7624	86.06
1998	Cape (Lane)	Jam	7320	52.00
1998	Cape (Lane)	Jam	6626	190.26
1998	Cape (Lane)	Jam	6591	92.74
1998	Cape (Lane)	Jam	6372	121.46
1998	Cape (Lane)	Jam	5633	28.78
1998	Cape (Lane)	Jam	5467	24.81
1998	Cape (Lane)	Jam	5193	217.13
1998	Cape (Lane)	Jam	5163	435.44
1998	Cape (Lane)	Jam	5144	1027.10
1998	Cape (Lane)	Jam	4862	43.14
1998	Cape (Lane)	Jam	4894	114.08
1998	Cape (Lane)	Jam	4711	66.55
1998	Cape (Lane)	Jam	3469	33.22
1998	Cape (Lane)	Jam	3532	79.41
1998	Cape (Lane)	Jam	3586	66.78
1998	Cape (Lane)	Jam	3606	29.95
1998	Cape (Lane)	Jam	3629	40.55
1998	Cape (Lane)	Jam	3650	23.34
1998	Cape (Lane)	Jam	3670	45.91
1998	Cape (Lane)	Jam	3847	35.43
1998	Cape (Lane)	Jam	4094	57.51
1998	Cape (Lane)	Jam	4162	9.34
1998	Cape (Lane)	Jam	4188	136.83
1998	Cape (Lane)	Jam	4239	241.95
1998	Cape (Lane)	Jam	4260	60.77
1998	Cape (Lane)	Jam	4371	60.16
1998	Cape (Lane)	Jam	4414	30.95
1998	Cape (Lane)	Jam	4447	15.45
1998	Cape (Lane)	Jam	4490	9.23
1998	Cape (Lane)	Jam	3413	68.59
1998	Cape (Lane)	Jam	3385	210.67
1998	Cape (Lane)	Jam	3347	41.94
1998	Cape (Lane)	Jam	3275	12.62
1998	Cape (Lane)	Jam	3220	23.93

1998	Cape (Lane)	Jam	3142	60.11
1998	Cape (Lane)	Jam	2921	53.02
1998	Cape (Lane)	Jam	2826	29.65
1998	Cape (Lane)	Jam	2577	26.03
1998	Cape (Lane)	Jam	1770	67.04
1998	Cape (Lane)	Jam	1564	18.69
1998	Cape (Lane)	Jam	871	534.50
1998	Cape (Lane)	Jam	986	101.36
1998	Cape (Lane)	Jam	1080	10.29
1998	Cape (Lane)	Jam	1213	38.36
1998	Cape (Lane)	Jam	1241	3.15
1998	Cape (Lane)	Jam	1316	24.27
1998	Cape (Lane)	Jam	1466	18.69
1998	Cape (Lane)	Jam	2278	16.43
1998	Cape (Lane)	Jam	2348	24.49
1998	Cape (Lane)	Jam	2377	48.33
1998	Cape (Lane)	Jam	2420	25.36
1998	Cape (Lane)	Jam	2172	11.10
1998	Cape (Lane)	Jam	1948	79.18
1998	Cape (Lane)	Jam	2032	60.67
1998	Cape (Lane)	Jam	2112	86.55
1998	Cape (Lane)	Jam	1781	234.70
1998	Cape (Lane)	Jam	1827	47.94
1998	Cape (Lane)	Jam	1888	179.36
1998	Cape (Lane)	Jam	1188	11.67
1998	Cape (Lane)	Jam	1456	17.46
1998	Cape (Lane)	Jam	1433	15.75
1998	Cape (Lane)	Jam	809	41.46
1998	Cape (Lane)	Jam	826	10.76
1998	Cape (Lane)	Jam	862	36.51
1998	Cape (Lane)	Jam	1357	14.94
1998	Cape (Lane)	Jam	1385	50.86
1998	Cape (Lane)	Jam	1410	33.14
1998	Cape (Lane)	Jam	1450	38.93
1998	Cape (Lane)	Jam	1689	34.86
1998	Cape (Lane)	Jam	1708	104.50
1998	Cape (Lane)	Jam	1849	284.95
1998	Cape (Lane)	Jam	1873	34.41
1998	Cape (Lane)	Jam	2050	36.81
1998	Cape (Lane)	Jam	2020	39.68
1998	Cape (Lane)	Jam	2545	22.24
1998	Cape (Lane)	Jam	8451	79.04
2012	Cape (Lane)	Step	921	4.70

2012	Cape (Lane)	Step	1501	0.60
2012	Cape (Lane)	Step	2080	1.20
2012	Cape (Lane)	Step	1972	0.40
2012	Cape (Lane)	Step	1957	1.80
2012	Cape (Lane)	Step	1853	0.90
2012	Cape (Lane)	Step	1858	0.20
2012	Cape (Lane)	Step	1825	3.30
2012	Cape (Lane)	Step	1726	1.50
2012	Cape (Lane)	Step	2219	8.00
2012	Cape (Lane)	Step	2356	0.50
2012	Cape (Lane)	Step	2342	0.10
2012	Cape (Lane)	Step	2321	0.10
2012	Cape (Lane)	Step	2467	0.20
2012	Cape (Lane)	Step	2448	0.80
2012	Cape (Lane)	Step	931	1.40
2012	Cape (Lane)	Step	931	0.05
2012	Cape (Lane)	Step	925	0.40
2012	Cape (Lane)	Step	939	0.10
2012	Cape (Lane)	Step	951	0.05
2012	Cape (Lane)	Step	944	1.30
2012	Cape (Lane)	Step	950	0.10
2012	Cape (Lane)	Step	960	0.10
2012	Cape (Lane)	Step	928	0.80
2012	Cape (Lane)	Step	2484	0.30
2012	Cape (Lane)	Step	2412	0.10
2012	Cape (Lane)	Step	2374	0.20
2012	Cape (Lane)	Step	1645	0.60
2012	Cape (Lane)	Step	1508	1.60
2012	Cape (Lane)	Step	1475	1.30
2012	Cape (Lane)	Step	1460	0.20
2012	Cape (Lane)	Step	1363	1.40
2012	Cape (Lane)	Step	1322	0.20
2012	Cape (Lane)	Step	1270	1.20
2012	Cape (Lane)	Step	9735	1.00
2012	Cape (Lane)	Step	8890	0.20
2012	Cape (Lane)	Step	8789	2.70
2012	Cape (Lane)	Step	8131	5.40
2012	Cape (Lane)	Step	8087	3.40
2012	Cape (Lane)	Step	7943	1.20
2012	Cape (Lane)	Step	7905	2.90
2012	Cape (Lane)	Step	7897	2.90
2012	Cape (Lane)	Step	4358	0.20
2012	Cape (Lane)	Step	4358	0.20

2012	Cape (Lane)	Step	2546	1.40
2012	Cape (Lane)	Step	2204	0.10
2012	Cape (Lane)	Step	383	0.05
2012	Cape (Lane)	Step	2168	3.70
2012	Cape (Lane)	Step	2162	0.20
2012	Cape (Lane)	Step	2155	1.20
2012	Cape (Lane)	Step	2143	0.10
2012	Cape (Lane)	Step	2112	0.30
2012	Cape (Lane)	Step	2112	0.20
2012	Cape (Lane)	Step	2082	0.10
2012	Cape (Lane)	Step	2056	1.50
2012	Cape (Lane)	Step	2053	0.20
2012	Cape (Lane)	Step	2013	2.50
2012	Cape (Lane)	Step	1858	0.10
2012	Cape (Lane)	Step	1845	0.10
2012	Cape (Lane)	Step	3986	0.30
2012	Cape (Lane)	Jam	266	86.39
2012	Cape (Lane)	Jam	549	983.58
2012	Cape (Lane)	Jam	844	626.59
2012	Cape (Lane)	Jam	1288	193.82
2012	Cape (Lane)	Jam	1317	55.22
2012	Cape (Lane)	Jam	1408	94.61
2012	Cape (Lane)	Jam	1488	101.02
2012	Cape (Lane)	Jam	1648	61.33
2012	Cape (Lane)	Jam	1842	401.31
2012	Cape (Lane)	Jam	2815	566.91
2012	Cape (Lane)	Jam	2869	14.46
2012	Cape (Lane)	Jam	3190	176.09
2012	Cape (Lane)	Jam	3553	335.24
2012	Cape (Lane)	Jam	3733	35.88
2012	Cape (Lane)	Jam	3856	90.13
2012	Cape (Lane)	Jam	4378	312.48
2012	Cape (Lane)	Jam	4862	81.10
2012	Cape (Lane)	Jam	5007	970.92
2012	Cape (Lane)	Jam	5619	64.55
2012	Cape (Lane)	Jam	6363	92.87
2012	Cape (Lane)	Jam	6433	399.52
2012	Cape (Lane)	Jam	6605	90.95
2012	Cape (Lane)	Jam	6652	7.31
2012	Cape (Lane)	Jam	7082	337.82
2012	Cape (Lane)	Jam	7214	70.15
2012	Cape (Lane)	Jam	7373	289.88
2012	Cape (Lane)	Jam	7087	3.25

2012	Cape (Lane)	Jam	7087	41.40
2012	Cape (Lane)	Jam	7137	5.66
2012	Cape (Lane)	Jam	7133	4.28
2012	Cape (Lane)	Jam	7259	12.42
2012	Cape (Lane)	Jam	7286	15.69
2012	Cape (Lane)	Jam	7280	35.73
2012	Cape (Lane)	Jam	7248	33.97
2012	Cape (Lane)	Jam	7320	4.49
2012	Cape (Lane)	Jam	7323	0.36
2012	Cape (Lane)	Jam	7363	0.60
2012	Cape (Lane)	Jam	7375	0.17
2012	Cape (Lane)	Jam	7375	58.05
2012	Cape (Lane)	Jam	7443	9.22
2012	Cape (Lane)	Jam	7513	29.30
2012	Cape (Lane)	Jam	7632	210.12
2012	Cape (Lane)	Jam	7640	3.89
2012	Cape (Lane)	Jam	7685	40.56
2012	Cape (Lane)	Jam	7788	21.51
2012	Cape (Lane)	Jam	7842	32.76
2012	Cape (Lane)	Jam	7472	32.69
2012	Cape (Lane)	Jam	7511	158.46
2012	Cape (Lane)	Jam	7637	22.33
2012	Cape (Lane)	Jam	7690	118.49
2012	Cape (Lane)	Jam	8134	5.52
2012	Cape (Lane)	Jam	8217	59.11
2012	Cape (Lane)	Jam	8338	55.57
2012	Cape (Lane)	Jam	8397	3.11
2012	Cape (Lane)	Jam	8485	0.45
2012	Cape (Lane)	Jam	8576	26.42
2012	Cape (Lane)	Jam	8906	13.34
2012	Cape (Lane)	Jam	9126	26.31
2012	Cape (Lane)	Jam	8703	10.00
2012	Cape (Lane)	Jam	8686	20.56
2012	Cape (Lane)	Jam	8639	12.61
2012	Cape (Lane)	Jam	8618	23.23
2012	Cape (Lane)	Jam	8604	1.44
2012	Cape (Lane)	Jam	8219	44.70
2012	Cape (Lane)	Jam	8226	78.30
2012	Cape (Lane)	Jam	9811	80.36
2012	Cape (Lane)	Jam	9893	55.75
2012	Cape (Lane)	Jam	10162	4.00
2012	Cape (Lane)	Jam	10175	24.14
2012	Cape (Lane)	Jam	10183	29.92

2012	Cape (Lane)	Jam	10204	20.23
2012	Cape (Lane)	Jam	9396	0.76
2012	Cape (Lane)	Jam	9456	20.94
2012	Cape (Lane)	Jam	9125	84.74
2012	Cape (Lane)	Jam	9260	4.35
2012	Cape (Lane)	Jam	9355	3.15
2012	Cape (Lane)	Jam	9375	72.07
2012	Cape (Lane)	Jam	9390	94.83
2012	Cape (Lane)	Jam	9461	925.30
2012	Cape (Lane)	Jam	9491	182.99
2012	Cape (Lane)	Jam	9794	8.18
1979	Cape (Lincoln)	Step	3019	6.00
1979	Cape (Lincoln)	Step	2708	2.00
1979	Cape (Lincoln)	Step	2532	2.00
1979	Cape (Lincoln)	Step	2472	5.00
1979	Cape (Lincoln)	Step	2367	14.00
1979	Cape (Lincoln)	Step	2262	39.00
1979	Cape (Lincoln)	Step	2157	168.00
1979	Cape (Lincoln)	Step	2618	10.00
1979	Cape (Lincoln)	Jam	2668	169.90
1979	Cape (Lincoln)	Jam	2637	40.77
1979	Cape (Lincoln)	Jam	2529	14.15
1979	Cape (Lincoln)	Jam	2332	5.09
1979	Cape (Lincoln)	Jam	2292	1.69
1979	Cape (Lincoln)	Jam	1998	6.12
1979	Cape (Lincoln)	Jam	2080	1.87
1979	Cape (Lincoln)	Jam	1717	14.16
1979	Cape (Lincoln)	Jam	3027	849.51
1979	Cape (Lincoln)	Jam	2823	33.98
1979	Cape (Lincoln)	Jam	2919	10.19
1979	Cape (Lincoln)	Jam	4967	1359.21
1998	Cape (Lincoln)	Step	4704	19.09
1998	Cape (Lincoln)	Step	3825	21.45
1998	Cape (Lincoln)	Step	3494	24.02
1998	Cape (Lincoln)	Step	3130	46.69
1998	Cape (Lincoln)	Step	3087	28.30
1998	Cape (Lincoln)	Step	2889	7.90
1998	Cape (Lincoln)	Step	2812	62.11
1998	Cape (Lincoln)	Step	2783	82.22
1998	Cape (Lincoln)	Step	2757	32.28
1998	Cape (Lincoln)	Step	2601	6.30
1998	Cape (Lincoln)	Step	2563	51.42
1998	Cape (Lincoln)	Step	2536	98.31

1998	Cape (Lincoln)	Step	2516	21.78
1998	Cape (Lincoln)	Step	2496	13.57
1998	Cape (Lincoln)	Step	2262	23.19
1998	Cape (Lincoln)	Step	2254	44.84
1998	Cape (Lincoln)	Step	2235	51.05
1998	Cape (Lincoln)	Step	2209	59.43
1998	Cape (Lincoln)	Step	2198	210.17
1998	Cape (Lincoln)	Step	2041	1.75
1998	Cape (Lincoln)	Step	2027	39.82
1998	Cape (Lincoln)	Step	1989	1.97
1998	Cape (Lincoln)	Step	1969	488.00
1998	Cape (Lincoln)	Step	1954	1378.64
1998	Cape (Lincoln)	Step	3005	21.67
1998	Cape (Lincoln)	Jam	4432	30.86
1998	Cape (Lincoln)	Jam	4079	7.13
1998	Cape (Lincoln)	Jam	4202	1.91
1998	Cape (Lincoln)	Jam	4361	2.11
1998	Cape (Lincoln)	Jam	3401	80.04
1998	Cape (Lincoln)	Jam	3336	9.47
1998	Cape (Lincoln)	Jam	3183	21.09
1998	Cape (Lincoln)	Jam	2911	298.89
1998	Cape (Lincoln)	Jam	2580	83.72
1998	Cape (Lincoln)	Jam	2238	54.88
1998	Cape (Lincoln)	Jam	2012	85.47
1998	Cape (Lincoln)	Jam	1877	131.79
1998	Cape (Lincoln)	Jam	1792	127.26
1998	Cape (Lincoln)	Jam	1740	42.24
1998	Cape (Lincoln)	Jam	1717	276.61
1998	Cape (Lincoln)	Jam	3055	11.95
2012	Cape (Lincoln)	Step	4431	20.00
2012	Cape (Lincoln)	Step	4031	0.60
2012	Cape (Lincoln)	Step	3409	2.50
2012	Cape (Lincoln)	Step	3358	3.20
2012	Cape (Lincoln)	Step	2864	3.40
2012	Cape (Lincoln)	Step	2873	1.50
2012	Cape (Lincoln)	Step	2258	0.10
2012	Cape (Lincoln)	Step	2172	3.50
2012	Cape (Lincoln)	Step	2041	3.60
2012	Cape (Lincoln)	Step	2011	11.10
2012	Cape (Lincoln)	Step	3106	2.40
2012	Cape (Lincoln)	Step	3046	0.70
2012	Cape (Lincoln)	Step	3037	3.40
2012	Cape (Lincoln)	Step	3043	0.40

2012	Cape (Lincoln)	Step	2224	2.90
2012	Cape (Lincoln)	Jam	241	5.23
2012	Cape (Lincoln)	Jam	1168	3.71
2012	Cape (Lincoln)	Jam	1193	3.33
2012	Cape (Lincoln)	Jam	1734	14.42
2012	Cape (Lincoln)	Jam	1872	45.30
2012	Cape (Lincoln)	Jam	2215	0.80
2012	Cape (Lincoln)	Jam	2256	1.94
2012	Cape (Lincoln)	Jam	2274	2.36
2012	Cape (Lincoln)	Jam	2275	23.94
2012	Cape (Lincoln)	Jam	2290	40.09
2012	Cape (Lincoln)	Jam	2333	12.57
2012	Cape (Lincoln)	Jam	2361	8.06
2012	Cape (Lincoln)	Jam	2389	1.16
2012	Cape (Lincoln)	Jam	2693	86.41
2012	Cape (Lincoln)	Jam	2850	11.89
2012	Cape (Lincoln)	Jam	2896	1.01
2012	Cape (Lincoln)	Jam	2964	14.40
2012	Cape (Lincoln)	Jam	2980	2.22
2012	Cape (Lincoln)	Jam	3125	13.15
1979	Cummins	Step	11151	224.00
1979	Cummins	Step	10845	22.00
1979	Cummins	Step	10672	101.00
1979	Cummins	Step	10365	45.00
1979	Cummins	Step	10336	4.00
1979	Cummins	Step	9553	42.00
1979	Cummins	Step	6016	252.00
1979	Cummins	Step	4989	9.00
1979	Cummins	Step	4989	9.00
1979	Cummins	Step	4684	4.00
1979	Cummins	Step	4526	25.00
1979	Cummins	Step	4355	11.00
1979	Cummins	Step	3925	7.00
1979	Cummins	Step	3879	19.00
1979	Cummins	Step	3902	10.00
1979	Cummins	Step	3359	1.00
1979	Cummins	Step	3104	36.00
1979	Cummins	Step	2869	25.00
1979	Cummins	Step	2812	2.00
1979	Cummins	Step	2679	1064.00
1979	Cummins	Step	2643	4.00
1979	Cummins	Step	2560	0.00
1979	Cummins	Step	2510	8.00

1979	Cummins	Step	1952	13.00
1979	Cummins	Step	1903	4.00
1979	Cummins	Step	7286	62.00
1979	Cummins	Jam	11228	226.53
1979	Cummins	Jam	10809	22.65
1979	Cummins	Jam	10742	101.31
1979	Cummins	Jam	10260	45.31
1979	Cummins	Jam	10218	4.25
1979	Cummins	Jam	9654	42.48
1979	Cummins	Jam	8770	63.43
1979	Cummins	Jam	7873	254.85
1979	Cummins	Jam	7235	9.06
1979	Cummins	Jam	6518	4.25
1979	Cummins	Jam	6101	25.48
1979	Cummins	Jam	5717	11.33
1979	Cummins	Jam	5543	6.79
1979	Cummins	Jam	5046	10.19
1979	Cummins	Jam	5017	19.11
1979	Cummins	Jam	4965	0.67
1979	Cummins	Jam	2498	12.75
1979	Cummins	Jam	2443	4.25
1979	Cummins	Jam	2423	1359.21
1979	Cummins	Jam	2586	8.49
1979	Cummins	Jam	2623	0.34
1979	Cummins	Jam	2672	4.25
1979	Cummins	Jam	2802	1087.37
1979	Cummins	Jam	2857	1.69
1979	Cummins	Jam	3102	25.48
1979	Cummins	Jam	3365	35.39
1998	Cummins	Step	10292	6.67
1998	Cummins	Step	9987	13.12
1998	Cummins	Step	9630	181.05
1998	Cummins	Step	6119	12.98
1998	Cummins	Step	3972	206.06
1998	Cummins	Step	3342	66.25
1998	Cummins	Step	3215	24805.11
1998	Cummins	Step	3023	0.72
1998	Cummins	Jam	11111	83.17
1998	Cummins	Jam	11081	83.97
1998	Cummins	Jam	11051	150.87
1998	Cummins	Jam	10461	231.66
1998	Cummins	Jam	10427	199.10
1998	Cummins	Jam	10796	73.36

1998	Cummins	Jam	9792	177.46
1998	Cummins	Jam	9602	157.84
1998	Cummins	Jam	9445	89.70
1998	Cummins	Jam	9417	25.47
1998	Cummins	Jam	9263	182.18
1998	Cummins	Jam	9214	13428.65
1998	Cummins	Jam	9107	28.42
1998	Cummins	Jam	9025	20.90
1998	Cummins	Jam	8651	128.47
1998	Cummins	Jam	8604	109.40
1998	Cummins	Jam	8520	17.00
1998	Cummins	Jam	8394	240.84
1998	Cummins	Jam	8363	535.30
1998	Cummins	Jam	8155	284.29
1998	Cummins	Jam	8025	28.71
1998	Cummins	Jam	7918	31.11
1998	Cummins	Jam	7688	306.06
1998	Cummins	Jam	7609	235.88
1998	Cummins	Jam	7595	2293.12
1998	Cummins	Jam	7464	69.15
1998	Cummins	Jam	6585	236.77
1998	Cummins	Jam	6638	251.68
1998	Cummins	Jam	6656	163.72
1998	Cummins	Jam	6685	19.57
1998	Cummins	Jam	6741	77.18
1998	Cummins	Jam	7007	86.78
1998	Cummins	Jam	6970	1045.97
1998	Cummins	Jam	7107	38.27
1998	Cummins	Jam	7369	28.31
1998	Cummins	Jam	7292	2498.95
1998	Cummins	Jam	7198	611.17
1998	Cummins	Jam	6237	110.56
1998	Cummins	Jam	6088	73.64
1998	Cummins	Jam	4179	98.31
1998	Cummins	Jam	4283	44.61
1998	Cummins	Jam	4326	336.13
1998	Cummins	Jam	4503	115.20
1998	Cummins	Jam	4583	30.84
1998	Cummins	Jam	4773	69.00
1998	Cummins	Jam	4670	54.21
1998	Cummins	Jam	4904	20.07
1998	Cummins	Jam	4985	28.94
1998	Cummins	Jam	5385	115.03

1998	Cummins	Jam	5505	100.71
1998	Cummins	Jam	6044	145.34
1998	Cummins	Jam	3924	115.25
1998	Cummins	Jam	3670	82.73
1998	Cummins	Jam	3616	36.63
1998	Cummins	Jam	3328	47.59
1998	Cummins	Jam	3418	672.74
1998	Cummins	Jam	3481	66.71
1998	Cummins	Jam	2973	59.89
1998	Cummins	Jam	2817	16.23
1998	Cummins	Jam	2725	6.08
1998	Cummins	Jam	2587	36.75
1998	Cummins	Jam	2480	74.78
1998	Cummins	Jam	2452	16.29
1998	Cummins	Jam	2403	9181.12
1998	Cummins	Jam	2289	17.10
1998	Cummins	Jam	2035	12.29
1998	Cummins	Jam	2003	210.64
1998	Cummins	Jam	1747	290.87
2012	Cummins	Step	10358	11.27
2012	Cummins	Step	9887	0.43
2012	Cummins	Step	9344	1.40
2012	Cummins	Step	7451	0.71
2012	Cummins	Step	6795	0.10
2012	Cummins	Step	5010	0.18
2012	Cummins	Step	3964	1.63
2012	Cummins	Step	3990	0.10
2012	Cummins	Step	3295	1.37
2012	Cummins	Step	3295	0.23
2012	Cummins	Step	3290	0.06
2012	Cummins	Step	3290	0.22
2012	Cummins	Step	3237	0.21
2012	Cummins	Step	3251	0.26
2012	Cummins	Step	3255	0.31
2012	Cummins	Step	2587	0.14
2012	Cummins	Step	2510	0.28
2012	Cummins	Jam	2116	43.44
2012	Cummins	Jam	2175	19.58
2012	Cummins	Jam	2366	88.94
2012	Cummins	Jam	2426	62.93
2012	Cummins	Jam	2509	9.09
2012	Cummins	Jam	3235	142.80
2012	Cummins	Jam	3289	326.98

2012	Cummins	Jam	3348	47.84
2012	Cummins	Jam	3549	16.74
2012	Cummins	Jam	4088	7.51
2012	Cummins	Jam	4681	14.69
2012	Cummins	Jam	5193	59.63
2012	Cummins	Jam	5279	39.36
2012	Cummins	Jam	5851	36.36
2012	Cummins	Jam	5867	105.30
2012	Cummins	Jam	5879	44.61
2012	Cummins	Jam	5945	206.34
2012	Cummins	Jam	5957	44.06
2012	Cummins	Jam	5979	80.52
2012	Cummins	Jam	6049	34.83
2012	Cummins	Jam	6073	2.81
2012	Cummins	Jam	6530	13.80
2012	Cummins	Jam	6792	26.83
2012	Cummins	Jam	6931	7.06
2012	Cummins	Jam	7130	105.98
2012	Cummins	Jam	7174	77.61
2012	Cummins	Jam	7766	56.70
2012	Cummins	Jam	7818	11.34
2012	Cummins	Jam	7863	173.76
2012	Cummins	Jam	8702	517.44
2012	Cummins	Jam	9000	214.72
2012	Cummins	Jam	9012	1075.00
2012	Cummins	Jam	9108	10.40
2012	Cummins	Jam	9148	81.53
2012	Cummins	Jam	9376	241.61
2012	Cummins	Jam	9635	78.42
2012	Cummins	Jam	9639	30.44
2012	Cummins	Jam	9807	261.94
2012	Cummins	Jam	9961	79.49
2012	Cummins	Jam	9995	482.14
2012	Cummins	Jam	10035	51.35
2012	Cummins	Jam	10196	208.66
2012	Cummins	Jam	10431	137.70
2012	Cummins	Jam	10583	682.27
2012	Cummins	Jam	10646	629.24
2012	Cummins	Jam	11029	226.55

APPENDIX B

TRANSECT DATA FROM THE 1979, 1998, AND 2012 DATASETS

1979 Transect Data

Transect	DA (km^2)	Step Count	Jam Count	Bankfull W (m)	Bankfull D (m)	Slope	Observed Stream Power (W/m^2)	2012 DHG Stream Power (W/m^2)	Stream Power Residual (W/m2)	d_{16}	d_{50}	d_{84}	%Pools	SedStor (m3)
Cape Linc 1	4.57	0	0	3.77	1.71	0.04	376.73	136.80	-239.9333	89.4	147.0	223.0	10	0.0
Cape Linc 2	3.98	1	3	3.77	1.75	0.04	376.73	138.67	-238.0577	32.0	256.0	147.0	30	0.0
Cape Linc 3	3.15	7	8	3.77	1.82	0.04	376.73	140.55	-236.1823	137.0	73.5	388.0	10	78.0
Cape Linc 4	1.37	0	0	3.60	2.02	0.06	360.41	137.52	-222.8939	22.6	119.0	194.0	20	168.0
Cummins 1	21.52	5	5	0.89	1.01	0.02	88.72	63.70	-25.0183	13.0	169.0	274.0	70	28.0
Cummins 3	20.69	1	1	0.87	1.04	0.02	87.16	66.51	-20.6586	27.9	147.0	239.0	70	5.0
Cummins 4	20.18	0	1	0.99	1.05	0.03	98.70	68.28	-30.4199	24.3	104.0	169.0	50	0.0
Cummins 5	19.55	0	1	0.65	1.07	0.03	65.20	70.53	5.3316	16.0	181.0	338.0	50	0.0
Cummins 6	18.43	1	1	0.97	1.10	0.03	97.13	74.66	-22.4672	29.9	147.0	223.0	50	51.0
Cummins 7	17.36	1	2	0.65	1.14	0.03	65.45	78.81	13.3557	52.0	147.0	315.0	50	255.0
Cummins 8	14.32	0	2	0.89	1.24	0.04	89.50	91.56	2.0620	29.9	181.0	274.0	50	0.0
Cummins 9	13.51	2	3	0.87	1.27	0.07	87.45	95.19	7.7406	10.6	147.0	274.0	50	56.0
Cummins 10	11.01	5	0	0.64	1.37	0.03	63.58	106.93	43.3532	48.5	128.0	294.0	50	76.0
Cummins 11	8.62	4	2	0.48	1.48	0.04	47.58	118.64	71.0597	12.1	147.0	274.0	50	109.0
Cummins 12	4.73	3	5	0.89	1.70	0.04	89.18	136.23	47.0489	8.0	68.6	256.0	30	226.0
Cummins 13	2.59	5	3	0.47	1.87	0.04	47.44	141.00	93.5579	22.6	104.0	338.0	30	104.0
Big Lane 1	38.68	0	0	0.29	0.64	0.01	29.31	25.31	-3.9935	1.9	6.1	27.9	70	0.0
Big Lane 2	38.00	0	1	0.19	0.65	0.01	19.18	26.27	7.0945	2.3	24.3	64.0	70	8.0
Big Lane 3	35.41	2	2	0.29	0.70	0.01	28.84	30.29	1.4563	2.0	4.3	32.0	70	34.0
Big Lane 4	33.79	0	2	1.43	0.73	0.02	143.21	33.08	-110.1300	21.1	147.0	223.0	70	99.0
Big Lane 5	31.81	0	0	1.37	0.77	0.03	137.27	36.85	-100.4176	16.0	147.0	256.0	70	0.0
Big Lane 6	27.29	1	2	0.66	0.87	0.03	66.20	46.99	-19.2061	26.0	90.5	208.0	70	15.0
Big Lane 7	2.02	0	3	4.81	1.94	0.04	481.40	140.39	-341.0020	32.0	73.5	137.0	70	0.0

Big Lane 8	24.31	0	0	1.35	0.94	0.03	135.10	55.05	-80.0523	111.0	256.0	388.0	70	0.0
Big Lane 9	22.97	2	3	1.36	0.97	0.03	136.14	59.08	-77.0506	119.0	223.0	315.0	70	11.0
Big Lane 10	2.49	3	4	1.26	1.88	0.04	125.51	140.99	15.4790	111.0	274.0	478.0	70	172.0
Big Lane 11	18.56	1	1	1.35	1.10	0.03	135.10	74.19	-60.9065	18.4	119.0	223.0	70	20.0
Big Lane 12	16.47	2	1	0.73	1.17	0.01	73.36	82.40	9.0421	5.7	147.0	223.0	70	17.0
Big Lane 13	3.34	5	3	1.26	1.80	0.02	125.95	140.21	14.2645	5.7	59.7	194.0	30	136.0
Big Lane 14	2.80	1	0	1.09	1.85	0.02	108.74	140.92	32.1809	18.4	90.5	194.0	30	40.0
Big Lane 15	2.09	1	2	0.89	1.93	0.03	88.75	140.55	51.7955	21.1	111.0	274.0	30	6.0
Big Lane 16	12.76	2	2	1.09	1.30	0.02	108.74	98.65	-10.0899	39.4	158.0	274.0	70	25.0
Big Lane 17	6.55	13	2	4.45	1.59	0.05	444.93	128.56	-316.3666	52.0	294.0	549.0	30	6.0
Big Lane 18	3.38	0	5	2.98	1.80	0.05	297.61	140.15	-157.4596	19.7	104.0	338.0	30	44.0
Big Lane 19	5.70	6	2	0.96	1.64	0.03	95.83	132.36	36.5276	4.0	104.0	223.0	50	7.0
Big Lane 20	5.70	0	2	0.60	1.64	0.02	59.64	132.36	72.7211	4.3	84.4	256.0	50	21.0
Big Lane 21	1.32	0	1	1.47	2.03	0.03	147.36	137.18	-10.1877	22.6	73.5	256.0	50	0.0
Big Lane 22	3.20	10	7	2.03	1.82	0.03	203.47	140.47	-63.0013	6.1	68.6	239.0	50	53.0
Big Lane 23	1.79	0	1	2.61	1.96	0.04	261.36	139.73	-121.6337	55.7	181.0	294.0	50	0.0
Cape Lane 1	32.09	1	0	0.22	0.76	0.02	22.23	36.30	14.0706	1.9	27.9	55.7	0	3.0
Cape Lane 2	31.16	0	2	1.73	0.78	0.02	173.33	38.16	-135.1717	26.0	84.4	119.0	20	0.0
Cape Lane 3	30.65	0	0	1.79	0.79	0.02	179.08	39.24	-139.8436	42.2	84.4	128.0	10	0.0
Cape Lane 4	17.76	0	0	4.80	1.12	0.02	479.68	77.25	-402.4294	19.7	73.5	208.0	90	0.0
Cape Lane 5	17.74	0	0	3.69	1.13	0.04	368.69	77.33	-291.3618	64.0	194.0	388.0	10	0.0
Cape Lane 6	16.50	0	0	5.10	1.17	0.04	509.89	82.26	-427.6249	90.5	194.0	416.0	50	0.0
Cape Lane 7	15.32	2	0	2.03	1.21	0.04	203.39	87.21	-116.1722	158.0	445.0	676.0	30	0.0
Cape Lane 8	14.68	0	1	2.51	1.23	0.03	251.08	89.97	-161.1169	97.0	294.0	512.0	0	119.0
Cape Lane 9	12.57	0	5	2.51	1.31	0.03	251.08	99.52	-151.5667	104.0	338.0	549.0	80	374.0
Cape Lane 11	7.86	6	5	3.69	1.52	0.03	369.44	122.33	-247.1108	27.9	137.0	338.0	20	493.0
Cape Lane 12	6.31	0	1	1.70	1.60	0.03	169.70	129.65	-40.0477	97.0	223.0	338.0	20	0.0
Cape Lane 13	1.32	4	8	1.78	2.03	0.03	177.63	137.18	-40.4536	48.5	549.0	388.0	30	139.0
Cape Lane 16	3.88	0	2	0.35	1.76	0.03	35.21	138.96	103.7471	73.5	194.0	294.0	20	0.0
Cape Lane 17	0.38	0	0	1.83	2.29	0.04	183.43	119.94	-63.4884	119.0	274.0	388.0	10	0.0
Cape Lane 18	2.89	0	8	0.47	1.84	0.04	47.40	140.86	93.4564	64.0	194.0	416.0	50	414.0
Cape Lane 19	1.34	0	1	3.55	2.03	0.04	354.91	137.31	-217.6025	29.9	104.0	208.0	20	0.0
Cape Lane 20	2.44	6	7	8.19	1.89	0.06	819.31	140.96	-678.3480	11.0	294.0	512.0	20	2388.0
Cape Lane 22	1.57	0	2	1.83	1.99	0.04	183.43	138.75	-44.6735	388.0	512.0	630.0	20	6.0

1998 Transect Data

Transect	DA (km^2)	Step Count	Jam Count	Bankfull W (m)	Bankfull D (m)	Slope	Observed Stream Power (W/m^2)	2012 DHG Stream Power (W/m^2)	Stream Power Residual (W/m^2)	d_{16}	d_{50}	d_{84}	%Pools	SedStor (m^3)
Cape Linc 1	4.57	1	4	5.61	1.01	0.02	125.48	136.80	11.32	35.3	61.9	111.0	40	17.2
Cape Linc 2	3.98	2	2	6.92	0.85	0.03	130.43	138.67	8.24	42.2	87.6	139.0	0	54.4
Cape Linc 3	3.15	16	5	3.90	0.85	0.02	93.17	140.55	47.38	28.6	82.2	178.0	10	520.0
Cape Linc 4	1.37	6	5	3.42	0.46	0.03	63.17	137.52	74.35	21.4	49.4	100.0	10	683.7
Cummins 1	21.52	0	4	14.68	1.19	0.01	36.31	63.70	27.40	22.6	50.8	100.0	60	22.7
Cummins 3	20.69	1	6	11.19	1.09	0.02	150.77	66.51	-84.26	33.8	76.1	147.0	10	0.0
Cummins 4	20.18	0	5	9.91	0.49	0.01	20.99	68.28	47.28	41.2	90.5	177.0	0	0.0
Cummins 5	19.55	0	7	10.91	0.82	0.01	20.97	70.53	49.56	38.1	80.6	138.0	30	0.0
Cummins 6	18.43	0	7	15.81	0.76	0.02	89.13	74.66	-14.48	21.1	68.6	124.0	0	0.0
Cummins 7	17.36	1	8	10.09	0.55	0.01	25.01	78.81	53.80	37.1	78.8	155.0	0	23.6
Cummins 8	14.32	0	2	8.09	0.79	0.03	145.75	91.56	-54.19	38.4	95.3	198.0	70	0.0
Cummins 9	13.51	0	2	3.77	0.46	0.03	51.33	95.19	43.86	11.3	79.5	176.0	40	0.0
Cummins 10	11.01	1	7	5.38	0.58	0.01	26.45	106.93	80.48	16.0	64.0	128.0	30	104.4
Cummins 11	8.62	3	7	10.15	1.06	0.03	226.68	118.64	-108.04	19.5	70.7	124.0	10	12598.9
Cummins 12	4.73	0	8	3.59	0.52	0.02	47.41	136.23	88.81	36.8	77.6	161.0	0	0.0
Cummins 13	2.59	0	2	3.50	0.52	0.03	60.69	141.00	80.31	13.4	58.7	135.0	20	0.0
Big Lane 1	38.68	0	1	11.65	0.73	0.00	0.00	25.31	25.31	1.6	5.8	64.0	90	0.0
Big Lane 2	38.00	1	7	15.04	1.19	0.00	0.00	26.27	26.27	20.6	50.8	97.0	60	67.0
Big Lane 3	35.41	0	6	12.78	0.89	0.01	51.58	30.29	-21.29	23.2	42.9	74.0	90	0.0
Big Lane 4	33.79	1	10	15.59	0.73	0.01	38.62	33.08	-5.54	32.0	51.3	97.0	0	1245.6
Big Lane 5	31.81	0	6	22.72	0.85	0.01	22.38	36.85	14.47	41.5	77.7	124.0	0	0.0
Big Lane 6	27.29	1	3	11.59	1.10	0.00	0.00	46.99	46.99	37.0	68.8	128.0	15	84.8
Big Lane 7	2.02	5	4	3.42	0.46	0.03	63.17	140.39	77.23	32.0	69.6	111.0	20	346.0
Big Lane 8	24.31	2	3	11.65	0.61	0.01	29.45	55.05	25.59	18.4	77.6	165.0	5	279.2
Big Lane 9	22.97	0	11	13.18	0.73	0.02	83.72	59.08	-24.64	39.6	79.2	125.0	0	0.0
Big Lane 10	2.49	6	3	2.38	0.37	0.03	36.54	140.99	104.45	22.6	73.0	128.0	0	78.5
Big Lane 11	18.56	1	1	13.88	1.22	0.00	0.00	74.19	74.19	32.0	70.3	120.0	35	71.9
Big Lane 12	16.47	0	3	8.27	1.25	0.02	177.27	82.40	-94.87	36.3	78.6	122.0	50	0.0
Big Lane 13	3.34	4	0	4.12	0.76	0.02	81.56	140.21	58.65	39.4	82.7	128.0	0	210.5
Big Lane 14	2.80	3	2	4.58	0.49	0.01	20.68	140.92	120.25	35.5	64.0	115.0	0	54.0
Big Lane 15	2.09	0	0	5.83	0.73	0.03	139.05	140.55	1.50	32.0	70.7	124.0	20	0.0

Big Lane 16	12.76	0	7	7.87	0.70	0.01	35.66	98.65	62.99	27.9	69.8	114.0	10	1.8
Big Lane 17	6.55	6	12	7.66	0.61	0.02	63.34	128.56	65.22	11.9	64.0	119.0	15	582.5
Big Lane 18	3.38	14	4	5.03	0.61	0.02	61.84	140.15	78.31	32.0	68.2	116.0	0	492.6
Big Lane 19	5.70	2	0	5.03	0.73	0.03	125.23	132.36	7.14	16.0	74.1	147.0	20	0.0
Big Lane 20	5.70	0	0	6.95	0.58	0.03	75.27	132.36	57.10	32.0	85.4	155.0	0	104.1
Big Lane 21	1.32	2	0	4.88	0.73	0.05	221.10	137.18	-83.92	20.2	89.3	161.0	0	64.8
Big Lane 22	3.20	2	6	5.67	0.61	0.02	62.39	140.47	78.08	33.9	74.7	116.0	10	56.9
Big Lane 23	1.79	1	3	3.57	0.58	0.02	40.22	139.73	99.51	33.2	61.7	109.0	50	101.3
Cape Lane 1	32.09	0	7	7.17	0.85	0.01	46.88	36.30	-10.58	1.3	2.6	32.0	50	0.0
Cape Lane 2	31.16	0	4	21.90	0.55	0.01	18.39	38.16	19.77	34.4	64.0	115.0	20	0.0
Cape Lane 3	30.65	0	6	11.56	0.92	0.00	0.00	39.24	39.24	33.2	61.7	111.0	80	0.0
Cape Lane 4	17.76	1	0	11.90	0.98	0.00	0.00	77.25	77.25	34.1	58.2	104.0	90	27.1
Cape Lane 5	17.74	0	7	7.78	0.73	0.01	37.88	77.33	39.45	29.6	48.3	88.0	20	0.0
Cape Lane 6	16.50	1	2	7.50	0.82	0.01	44.69	82.26	37.58	25.4	76.1	124.0	20	10.6
Cape Lane 7	15.32	0	1	1.83	0.46	0.10	216.52	87.21	-129.31	16.0	72.6	124.0	0	0.0
Cape Lane 8	14.68	1	7	8.57	0.61	0.02	46.07	89.97	43.90	35.6	78.8	155.0	0	13.7
Cape Lane 9	12.57	1	11	11.10	0.76	0.01	40.72	99.52	58.79	32.0	66.0	113.0	20	134.0
Cape Lane 11	7.86	2	15	7.14	0.76	0.03	136.72	122.33	-14.39	39.0	68.4	120.0	0	0.0
Cape Lane 12	6.31	1	1	6.80	0.82	0.01	44.36	129.65	85.29	14.3	64.0	123.0	10	46.9
Cape Lane 13	1.32	5	12	5.86	0.88	0.04	243.81	137.18	-106.63	32.0	74.9	128.0	15	152.4
Cape Lane 16	3.88	0	0	8.69	0.64	0.03	107.49	138.96	31.47	33.3	66.0	110.0	10	27.1
Cape Lane 17	0.38	0	0	2.47	0.46	0.10	232.58	119.94	-112.64	14.3	80.6	167.0	10	0.0
Cape Lane 18	2.89	22	13	4.94	0.82	0.02	67.38	140.86	73.48	10.1	49.4	100.0	20	357.6
Cape Lane 19	1.34	0	0	2.44	0.58	0.04	111.64	137.31	25.67	10.1	52.5	103.0	20	6.7
Cape Lane 20	2.44	13	6	4.94	0.58	0.00	0.00	140.96	140.96	21.1	48.9	96.0	20	784.4
Cape Lane 22	1.57	2	3	4.58	0.58	0.16	586.43	138.75	-447.68	32.0	88.4	194.0	20	76.5

2012 Transect Data

Transect	DA (km^2)	Step Count	Jam Count	Bankfull W (m)	Bankfull D (m)	Slope	Observed Stream Power (W/m^2)	DHG Stream Power (W/m^2)	Stream Power Residual (W/m^2)	d_{16}	d_{50}	d_{84}	%Pools	SedStor (m^3)
Cape Linc 1	4.57	2	1	5.60	0.70	0.02	67.50	136.80	69.30	76.2	102.9	155.2	20	6.3
Cape Linc 2	3.98	2	3	6.06	0.50	0.05	123.87	138.67	14.81	68.4	91.4	131.2	10	0.6
Cape Linc 3	3.15	8	8	9.08	0.50	0.06	167.92	140.55	-27.37	82.6	110.5	138.6	30	65.2
Cape Linc 4	1.37	3	4	5.73	1.98	0.08	1351.81	137.52	-1214.29	44.9	63.5	104.5	50	25.7
Cummins 1	21.52	0	3	23.10	1.13	0.02	138.70	63.70	-75.00	31.8	55.5	83.5	50	6.4
Cummins 3	20.69	1	6	9.78	1.35	0.00	0.00	66.51	66.51	40.8	71.5	101.5	85	0.7
Cummins 4	20.18	0	3	8.58	0.83	0.02	85.56	68.28	-17.28	73.2	90.0	130.0	0	0.0
Cummins 5	19.55	0	3	9.43	0.85	0.07	421.08	70.53	-350.55	64.8	90.5	125.0	0	0.0
Cummins 6	18.43	1	4	11.15	0.75	0.02	74.54	74.66	0.12	48.8	70.0	105.3	0	0.5
Cummins 7	17.36	1	9	9.98	0.93	0.02	101.67	78.81	-22.86	33.0	52.0	70.6	80	0.0
Cummins 8	14.32	0	2	8.55	0.93	0.03	219.06	91.56	-127.50	34.4	58.0	83.3	0	0.0
Cummins 9	13.51	1	0	8.73	0.73	0.05	243.44	95.19	-148.26	55.7	92.0	131.0	0	0.9
Cummins 10	11.01	4	2	7.63	0.70	0.05	227.65	106.93	-120.72	47.8	70.5	99.2	0	2.5
Cummins 11	8.62	5	4	9.15	0.73	0.05	243.89	118.64	-125.25	41.8	60.5	92.0	0	6.6
Cummins 12	4.73	4	5	5.18	0.70	0.05	221.36	136.23	-85.13	45.8	76.5	110.2	0	1.4
Cummins 13	2.59	2	0	6.33	0.73	0.11	521.19	141.00	-380.19	32.8	60.0	89.2	0	0.0
Big Lane 1	38.68	0	5	13.10	0.79	0.02	70.01	25.31	-44.70	32.0	45.5	62.8	100	0.0
Big Lane 2	38.00	1	11	22.68	0.98	0.05	384.39	26.27	-358.12	3.8	22.5	49.8	30	0.0
Big Lane 3	35.41	1	12	19.61	1.09	0.02	180.49	30.29	-150.20	18.8	32.0	74.2	70	0.0
Big Lane 4	33.79	1	2	12.02	0.89	0.03	174.11	33.08	-141.03	46.8	80.0	137.2	70	0.0
Big Lane 5	31.81	0	4	17.12	0.78	0.02	106.84	36.85	-69.99	31.7	51.5	69.2	100	0.0
Big Lane 6	27.29	0	4	14.20	0.65	0.04	154.04	46.99	-107.05	40.9	84.0	187.1	20	6.1
Big Lane 7	2.02	1	0	6.08	0.66	0.04	168.23	140.39	-27.84	11.8	39.5	72.2	10	0.4
Big Lane 8	24.31	0	1	10.53	0.59	0.03	82.25	55.05	-27.21	31.2	80.0	157.6	75	0.0
Big Lane 9	22.97	2	7	14.84	0.82	0.01	34.12	59.08	24.97	33.1	59.5	99.1	20	2.1
Big Lane 10	2.49	3	5	4.98	0.48	0.07	178.12	140.99	-37.13	20.5	50.0	81.4	10	30.2
Big Lane 11	18.56	1	0	14.35	0.64	0.04	166.05	74.19	-91.86	39.6	72.0	118.8	20	0.0

Big Lane 12	16.47	1	1	5.20	0.52	0.03	77.68	82.40	4.71	39.8	67.0	85.3	30	0.0
Big Lane 13	3.34	3	3	5.08	0.49	0.12	345.12	140.21	-204.90	31.7	57.0	91.1	40	2.3
Big Lane 14	2.80	1	7	4.63	0.49	0.05	132.28	140.92	8.65	19.0	47.0	88.9	30	0.0
Big Lane 15	2.09	1	1	3.70	0.50	0.03	71.55	140.55	69.00	28.0	59.0	83.1	50	0.0
Big Lane 16	12.76	2	5	8.93	0.53	0.04	101.25	98.65	-2.60	12.5	32.0	66.0	75	10.6
Big Lane 17	6.55	2	9	8.04	0.64	0.09	355.47	128.56	-226.91	42.8	81.5	140.0	20	21.4
Big Lane 18	3.38	5	1	5.58	0.46	0.06	130.65	140.15	9.50	30.8	80.0	110.8	30	0.0
Big Lane 19	5.70	1	2	6.48	0.56	0.07	238.26	132.36	-105.90	19.8	39.0	70.5	30	0.0
Big Lane 20	5.70	1	0	6.40	0.61	0.05	165.96	132.36	-33.59	24.5	49.0	77.5	30	1.6
Big Lane 21	1.32	0	2	4.69	0.49	0.02	38.64	137.18	98.53	20.0	44.0	84.8	20	0.0
Big Lane 22	3.20	7	6	6.45	0.47	0.02	36.90	140.47	103.58	17.8	29.5	40.0	10	5.2
Big Lane 23	1.79	0	0	4.08	0.54	0.09	266.83	139.73	-127.11	20.8	30.0	41.5	30	0.0
Cape Lane 1	32.09	1	8	11.20	0.65	0.01	26.28	36.30	10.02	76.5	94.0	130.0	0	0.0
Cape Lane 2	31.16	0	2	9.73	0.46	0.00	3.51	38.16	34.65	41.8	65.5	97.1	30	0.0
Cape Lane 3	30.65	0	1	10.25	0.50	0.01	23.73	39.24	15.51	42.7	63.5	107.2	0	6.7
Cape Lane 4	17.76	0	1	13.18	1.00	0.01	85.37	77.25	-8.11	45.4	75.0	104.4	70	0.0
Cape Lane 5	17.74	0	2	9.28	0.50	0.01	22.71	77.33	54.62	52.8	79.0	124.5	10	1.6
Cape Lane 6	16.50	0	2	9.03	0.80	0.02	113.17	82.26	-30.90	45.8	69.5	105.3	5	0.0
Cape Lane 7	15.32	0	0	3.19	0.40	0.03	45.63	87.21	41.59	26.8	42.0	106.8	10	0.0
Cape Lane 8	14.68	1	5	8.95	0.60	0.02	51.99	89.97	37.98	32.8	57.5	102.4	10	0.0
Cape Lane 9	12.57	2	5	11.35	0.40	0.03	55.96	99.52	43.55	39.7	80.0	120.6	0	7.0
Cape Lane 11	7.86	2	7	6.64	0.60	0.03	96.79	122.33	25.54	51.7	80.5	125.3	10	0.7
Cape Lane 12	6.31	0	0	8.32	0.60	0.04	130.21	129.65	-0.55	53.2	73.0	100.0	0	0.0
Cape Lane 13	1.32	4	4	4.91	0.40	0.06	112.78	137.18	24.39	41.8	63.0	108.3	20	228.4
Cape Lane 16	3.88	1	9	9.23	0.50	0.06	148.88	138.96	-9.92	39.0	63.0	90.2	30	4.0
Cape Lane 17	0.38	0	0	3.68	0.30	0.10	132.42	119.94	-12.48	29.8	45.5	82.5	10	50.8
Cape Lane 18	2.89	8	9	3.55	0.60	0.06	209.26	140.86	-68.40	38.8	66.0	110.6	10	94.9
Cape Lane 19	1.34	1	0	3.28	0.30	0.08	97.03	137.31	40.27	36.4	69.0	112.0	5	0.0
Cape Lane 20	2.44	8	7	5.50	0.40	0.08	158.73	140.96	-17.77	44.8	77.0	105.3	20	13.5
Cape Lane 22	1.57	1	0	4.27	0.50	0.12	328.05	138.75	-189.30	44.7	60.0	86.6	0	0.0

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