AN ABSTRACT OF THE THESIS OF

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Abstract approved:

Stephen H. Schoenholtz

Few studies have examined both long-term and fine-scale spatial variations in water quality of small streams in the Pacific Northwest. As such, a case study was conducted to determine if current physical and chemical properties of water in three streams located in the Oregon Coast Range differed from historically measured conditions, taking differences in past management regimes into account. In addition, this research provides an assessment of spatial and temporal variability in nitrate-nitrogen (N) concentrations and summer stream temperatures within each catchment.

The three research catchments were part of the Alsea Watershed Study (1959-1973), where effects of forest management practices were examined using a paired-watershed study design. One catchment, Needle Branch, was clear-cut with no protection provided to the stream. Harvesting in Needle Branch was followed by an intense broadcast burn to remove logging slash. Another catchment, Deer Creek, was patch-cut in three small units resulting in a 25% harvest of the total catchment area, but buffers were retained along fish-bearing streams. The third catchment, Flynn Creek, was used as a control.

In this revisit to the Alsea Watersheds, measurements were conducted continuously (discharge, turbidity), intermittently (suspended sediments), and at regular intervals (nitrate-N) for one year between October 2005 and September 2006. Summertime stream temperature was also measured every half-hour from mid-June to mid-September.

Comparisons of recent data with historic data show no detectable changes over time for streamflow characteristics (annual runoff volume, peak flow discharges, and number of low-flow days), annual sediment yield, or summer maximum stream temperatures. Current nitrate-N export was similar to historically measured values for Flynn Creek and Deer Creek; however, export at Needle Branch was increased over past levels. This observation may be caused by dense colonization of the riparian area with red alder (*Alnus rubra*), a N-fixing species, following the 1966 harvest. Patterns of nitrate-N concentration varied throughout each catchment and are likely influenced by the current distribution of red alder stands. Synoptically measured stream temperatures were variable along each stream's longitudinal profile. The ability to meet Oregon's water quality standard for temperature was dependent on measurement location and method of analysis. Evaluating individual sampling points as discrete records resulted in each stream exceeding the standard for at least one measurement location, whereas evaluating the criteria based on the mean of all data collected within the mainstem stream excluded Flynn Creek and Needle Branch from violation. These results highlight the physical and chemical variability of stream water draining Oregon Coast Range headwater catchments and provide insight as to where future work should be focused to gain a more thorough understanding of these dynamic systems.

A Physical and Chemical Characterization of Stream Water Draining Three Oregon Coast Range Catchments

by
V. Cody Hale

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APPROVED:

Major Professor, representing Forest Engineering

Head of the Department of Forest Engineering

Dean of the Graduate School

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

V. Cody Hale, Author

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CONTRIBUTION OF AUTHORS

Stephen Schoenholtz assisted in research development and served as the primary editor. George Ice provided technical advice imperative to the successful implementation of the research plan. John Stednick also contributed technical advice and provided supporting data.

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1 Introduction

1.1 INTRODUCTION

As responsible stewards of the land, forest managers are continually striving to improve their techniques for protecting the resources provided by forests. As such, effects of forest management on physical, chemical, and biological components of stream water have been studied extensively over the past half-century. The primary method for conducting such investigations has been the paired-watershed approach, first used in the U.S. nearly 150 years ago (Stednick, 1996). A paired-watershed experiment typically consists of at least two catchments located in close proximity to each other and having similar physical attributes (Clausen and Spooner, 1993). One watershed is designated a control and the other receives a treatment. Prior to treatment, data are collected during a “calibration” period. The treatment is then applied and data are collected in the subsequent post-treatment period. Treatment effects are discerned by comparing pre-treatment and post-treatment statistical relationships for the treatment and control watersheds.

During the 1950’s, over 150 paired-watershed studies were active across the U.S. (Holschen, 1967). However, many of these studies were terminated just a few years following treatment, prior to evaluating relatively long-term hydrologic recovery (Ziemer, 2000). As working forests enter their second and third rotations, it is necessary to assess effects of contemporary forest management practices in the wake of historical management. This is important for considering the potential for cumulative effects of multiple rotations and past harvesting practices on the landscape

(Boyle et al., 1997; Reid, 1993). In order to make such assessments, historic paired-watershed studies having long-term data records must be revisited.

Across the U.S., paired-watershed studies conducted by the U.S. Department of Agriculture (USDA) Forest Service at the Hubbard Brook, Coweeta, Fernow, Fraser, H.J. Andrews, and other experimental forests have been the primary source of long-term data records (Ziemer, 2000). At their inception, these studies tested forest management activities that were used on both industrial and federal forest lands. Over the past two decades, however, federal forest management strategies have diverged significantly from those used in the industrial sector. Therefore, while ongoing research at these federal sites is still important, contemporary industrial forest management issues are often not addressed.

Without the major long-term federal watershed studies addressing contemporary industrial forest management practices, the burden for conducting research that assesses the environmental impacts of alternative forest management options is limited to a few watershed studies. Even fewer studies are able to compare the impacts of past and current forest management activities, and to look at long-term recovery from management disturbance. In the Pacific Northwest, the Caspar Creek study conducted by the USDA Forest Service on northern California's Jackson State Demonstration Forest, the Carnation Creek study conducted by the University of British Columbia on Vancouver Island, British Columbia, Canada, and the Alsea Watershed Study (AWS) conducted by Oregon State University and the Oregon Department of Fish and Wildlife on both private and federal land in the Oregon Coast

Range represent the only studies that provide such a scenario (Ziemer, 1998; Hetherington, 1987; Moring and Lantz, 1975). While all are located in the Pacific Northwest, each of these studies is geographically unique with respect to climate, topography, geology, and forest type making their results regionally specific.

In the Oregon Coast Range, the AWS, conducted from 1959-1973, provided ground-breaking results that led to the development of the Oregon Forest Practice Rules aimed to protect water quality and aquatic habitat (Ice, 1991). These rules were the first of their kind in the U.S. The study concluded seven years following forest harvest and before several of the measured effects recovered to pre-treatment levels (Harris, 1977). In 1989, the New Alsea Watershed Study was initiated to evaluate long-term hydrologic recovery in the treatment catchments (Stednick and Kern, 1992). The results showed that 25 years after treatment the completely clear-cut watershed (Needle Branch) had not reached hydrologic recovery with respect to annual water yield and had significantly more low-flow days than observed during the pre-treatment period of the AWS (Stednick and Kern, 1992; Belt 1997). In addition, Belt (1997) predicted that annual yield in this catchment would not fully recover until 2026.

Just over 40-years after the AWS clear-cut treatment, the industrially managed Needle Branch catchment has been slated for its second-rotation harvest beginning in 2008. This provides a rare chance to evaluate contemporary forest practices in a basin that has been studied previously. To take advantage of this opportunity, the Alsea Watershed Study Revisited (AWSR) commenced in 2006 with the goal of replicating the original AWS in the Needle Branch catchment using modern forest management techniques.

In addition to assessing the effects of current forest practices, data collected in the AWSR pre-treatment calibration period allows a reevaluation of the New Alsea Watershed Study findings and an investigation into the recovery of other physical and chemical stream water parameters approximately 40 years after treatment. This thesis summarizes such an effort based on data collected during the 2006 water year.

1.2 RESEARCH OBJECTIVES

This research was conducted to determine if selected physical and chemical characteristics of stream water observed in the 2006 water year differed from those measured between 1959 and 1965, prior to historical forest harvesting. This objective was developed specifically with respect to

a. volume of annual runoff,
b. magnitude of peak flow,
c. number of low-flow days,
d. annual sediment yield,
e. annual nitrate-nitrogen (N) flux, and
f. summer maximum stream temperatures.

These parameters were measured primarily at the outlet of each catchment and therefore provide no information on variability within the stream network itself. A second objective was aimed at overcoming this limitation by documenting the spatial variability in nitrate-N concentrations and summer stream temperatures throughout the mainstem streams and tributaries within each catchment. Results from this work will also contribute to plans for future research on the effectiveness of current forest practice rules in these catchments.

1.3 NOTES ABOUT CHAPTER 2 AND APPENDICES

Peer review of research results is an important part of the scientific process, particularly for potentially controversial findings. Oregon State University encourages students to publish their results in peer-reviewed journals and allows graduate theses to be developed based on these manuscripts. Chapter 2 which follows is a draft manuscript describing the study design and findings from this research that will be submitted to an appropriate peer-reviewed journal.

Four appendices are contained in this document. Appendix A, *Field SOP*, is a step-by-step guide to the implementation of field activities associated with the data collection process for this study. Directions to site-specific research locations, detailed methods, and safety considerations are all addressed in this appendix. Appendix B, *Data Acquisition Procedures*, provides instructions for requesting data presented in this thesis. Appendix C, *Stage-discharge relationships for the 2006 Water Year*, supplies the rating information used to estimate discharge based on stage measurements collected throughout the year. Appendix D, *Procedures for Developing Turbidity-Suspended Sediment Concentration Relationships*, describes the methods used to estimate suspended sediment concentrations from the turbidity record.

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2 A Physical and Chemical Characterization of Stream Water Draining Three Oregon Coast Range Catchments

V. Cody Hale
Stephen H. Schoenholtz
George G. Ice
John D. Stednick

2.1 INTRODUCTION

Streams in the Oregon Coast Range provide critical habitat for aquatic biota as well as valuable human benefits (Brown and Krygier, 1970). Coho salmon (*Oncorhynchus kisutch*) and coastal cutthroat trout (*Salmo clarki clarki*) use many of these small streams as spawning and rearing areas (Brown and Krygier, 1970; Brown and Krygier, 1971; Moring and Lantz, 1975). Human uses include drinking water, irrigation, and recreation.

The highly productive forests of the Oregon Coast Range are an important resource for commercial timber production. Since the onset of intensive forest management in the mid-20th century, the composition of Coast Range forests has changed (Kennedy and Spies, 2004; Ripple et al., 2000). A landscape once dominated by older age-class coniferous forests has shifted to younger, even-aged conifer stands. Current rotation lengths in the Coast Range have been reduced to less than 50 years on most private timberland, meaning that the process of harvesting and re-growing timber stocks has increased the frequency of landscape disturbance to more than four times that of the natural fire regime, which is estimated to average 230 +/- 30 yrs (Ripple et al., 2000).

The hydrologic cycle and coupled processes are strongly influenced by such changes in the adjacent landscape (Binkley and Brown, 1993; Cairns and Lajtha, 2005; Harr, 1976; Hicks et al., 1991; Moore et al., 2004). Additionally, potential for cumulative effects from management activities, over space and time, may play a role in the response of a catchment to future perturbations (MacDonald, 2000; Reid, 1993).

As many of the second- rotation industrial forests in the Coast Range become ready for harvest, the need to identify persisting impacts from a legacy of unregulated harvesting becomes paramount (Boyle et al., 1997).

Assessing cumulative effects can be complicated by a lack of information regarding natural variation (Reid, 1993). Therefore, documenting temporal and spatial variability in the physical and chemical characteristics of water draining Oregon Coast Range headwater catchments is an essential step towards understanding the implications of continued intensive forest management for water resources.

Current regulations in Oregon mandate forest practices aimed at protecting water quality. These include equipment exclusion zones, limited harvesting in riparian areas, stream-crossing rules, and size constraints for clear-cuts, amongst others. The size of forest clearings created through harvesting is now generally limited to 48.5 ha (Oregon Administrative Rule (OAR) 629-105-0100). In the Oregon Coast Range, harvest units of this size typically occur as portions of small headwater catchments, owing to the high drainage densities found in this well-developed landscape (Forest Ecosystem Management Team, 1993). As a result, water quality regulations are now being applied to forest management activities at a relatively fine scale. However, these dynamic headwater systems are known to be highly variable in regard to regulated water quality parameters, such as nitrogen (N) inputs and temperature increases (Feller, 2005; Binkley et al., 2004; Ice, 1999; Poole et al., 2001). Therefore developing standards that account for such variability is critical to efficiently enforcing water quality regulations (Ice et al., 2007; Ice et al., 2004; Ice and Binkley, 2003).

Current water quality standards may not always be achievable in natural settings. Brief breaches of water quality criteria in unimpaired systems may detract resources from truly impaired waters under the current regulatory system (Ice et al., 2007). This problem could be avoided by implementing regulations that more adequately account for the range of natural variation (Ice et al., 2004). A comprehensive understanding of variability over time, space, and management regimes is necessary prior to successfully developing such criteria.

An ideal setting for obtaining this type of information is in areas that have a historic data record. In the Oregon Coast Range, the catchments used in the Alsea Watershed Study provide this opportunity.

2.1.1 The Alsea Watershed Study: A Legacy of Research

The Alsea Watershed Study (AWS), conducted from 1959 to 1973 in three small Oregon Coast Range catchments, was one of the first studies to evaluate impacts of historic forest harvesting methods on the aquatic environment (Moring and Lantz, 1975). Data were collected during a seven-year calibration period leading up to application of treatments, followed by seven years of post-treatment data collection. One catchment was clear-cut harvested to the streambanks, followed by a broadcast burn of the logging debris in a very hot fire. A second catchment was harvested in three small patch-cut units resulting in 25% of the area being cleared of trees; vegetated buffer strips were left along the streams and one of the three harvest units was broadcast burned with a low-intensity fire. A third catchment served as a control and was not actively managed.

The AWS found that clear-cut logging with no protection given to the stream adversely impacted water quality. Stream temperature increases caused by shade removal and decreases in dissolved oxygen, attributable to increased temperature and decomposition of fine organic matter left in the stream following the harvesting operation, were the primary water quality impacts (Harris, 1977; Moring and Lantz, 1975). Changes in the hydrologic regime and increases in sedimentation were also observed with varying degrees of magnitude in the clear-cut and patch-cut harvests (Harris, 1977; Moring and Lantz, 1975).

Since the AWS, the existing infrastructure has been utilized for a number of research endeavors. Stream gauging was reinitiated in 1989 as part of the New Alsea Watershed Study (NAWS), which aimed to assess long-term hydrologic recovery at the two harvested catchments (Stednick and Kern, 1992; Belt, 1997). Annual runoff in the clear-cut catchment was still greater than the AWS pre-treatment predictions for the period from 1990 to 1995. Belt (1997) estimated that this catchment would not reach full recovery with respect to water yield until 2026. The average number of low-flow days occurring annually from 1990 through 1995 in the clear-cut catchment was also found to be greater than predicted. This contrasts with observations of a decrease in the number of low-flow days in this catchment immediately following the AWS harvest (Harr and Krygier, 1972).

The clear-cut catchment is currently nearing the end of its second rotation. The Alsea Watershed Study Revisited (AWSR), a contemporary version of the AWS, commenced in 2006 to study effects of modern forest practices on the physical, chemical, and biological properties of these streams. The catchment which was initially clear-cut with no regard for stream protection will be harvested following guidelines of the current Oregon Forest Practices Rules (OAR, Chapter 629). Using the original AWS results, effects of current management practices will be measured against the unregulated harvesting practices of the past. In addition, the AWS dataset provides the ability to assess temporal changes in streamflow metrics, both physical and chemical, in reference and managed catchments over a relatively large timescale.

2.1.2 Objectives and Hypotheses

There were two primary objectives for this study. One was to take advantage of the AWS data record to aid in determining if treatment effects on physical and chemical stream water properties were still detectable. Streamflow characteristics, annual sediment yield, inorganic N flux, and summer maximum stream temperatures measured in the 2006 water year were compared to those measured prior to the AWS harvest. It was hypothesized that the past 40 years represented an adequate recovery period and that no significant departure from historically measured values would be observed due to either (1) legacy impacts of forest harvesting activities which included road building, logging, and burning of logging debris across the site or (2) natural changes. In the case of Deer Creek, which was recently thinned in several small units, it was hypothesized that these operations would not produce a detectable signal in the selected hydrologic metrics.

The second objective of this study was to characterize spatial and temporal variability in nitrate-N concentrations and stream temperature throughout each catchment in order to improve the science-base for assessing these water quality parameters in small headwater streams of the Oregon Coast Range. As an initial hypothesis, we postulate that headwater streams will demonstrate a relatively high degree of spatial and temporal variability in water quality.

2.1 METHODS

2.1.1 Site Description

The research catchments are located 16 km south of Toledo in Lincoln County, Oregon (Figure 1). This area lies within the Mid-Coastal Sedimentary Region of the Oregon Coast Range (Thorson et al., 2003). The Mid-Coastal Sedimentary Region is characterized as a moderately sloping, dissected mountainous region with medium- to high-gradient streams. The Slickrock and Bohannon soil series are present on >80% of the study area (Brown et al., 1973). In general, these soils are loams and gravelly loams on the hillslopes and valley bottoms and clay loams on the divides. The average soil depth ranges from 0.6 to 1.5 m. All series present are well-drained (Corliss, 1973). The underlying geology is the Tyee sandstone formation.

The Pacific Northwest has a Mediterranean-like climate with dry summers and wet winters. Precipitation primarily occurs from October to April in “long-duration, low-to-moderate intensity frontal storms" (Harr, 1976). Mean annual precipitation for the AWS pre-treatment period, 1959-1965, was 2,440 mm (Moring and Lantz, 1975). Rainfall has not been consistently measured on-site since the AWS, but long-term records from nearby gauges with similar elevation and relief provide mean annual precipitation amounts within 150 mm of the AWS pre-treatment mean (National Weather Service station ID 358481 at Tidewater, OR = 2,300 mm and station ID 350145 at the Alsea Fish Hatchery near Alsea, OR = 2,340 mm). Snow, while occurring occasionally, does not usually accumulate and is therefore a negligible portion of the precipitation record (Moring and Lantz, 1975).

The Flynn Creek study area is a 202 ha catchment (Harris and Williams, 1971). It served as the control catchment for the AWS and has since been preserved by the USDA Forest Service as a "Research Natural Area". Predominant vegetation at the time of the original study was 30-70 yr-old red alder (*Alnus rubra*) along with a mix of 30-50 yr-old and 70-110 yr-old Douglas-fir (*Pseudotsuga menziesii*) (Moring and Lantz, 1975). Brown et al. (1973) estimated the red alder component to be 68% of the forest cover. In a 1992 assessment, the catchment was comprised of 70% hardwood species (Table 1; Belt, 1997). In the Coast Range, red alder is the predominant hardwood species within 40 km of the coast (Compton et al., 2003). Current stand observations indicate that the red alder is senescing and being replaced by a shrub understory, predominantly consisting of salmonberry (*Rubus spectabilis*). The study area of Flynn Creek contains four mapped tributaries in addition to the main-stem.

Flynn Creek is a 2nd-order stream (Strahler, 1957) at the research-defined outlet (stream gauge). Average stream gradient is 0.025 m m^{-1} (Moring and Lantz, 1975).

Needle Branch, a 70 ha catchment (Harris and Williams, 1971), received the most extreme treatment in the AWS. The catchment was clear-cut harvested to the stream bank in the spring of 1966 and the logging debris was burned over the entire site in the fall of the same year (as a site preparation method). Vegetation prior to harvesting consisted predominantly of 70-100 yr-old Douglas-fir. Currently, the catchment is composed of approximately 40 yr-old Douglas-fir on the hillslopes with red alder of the same age-class inhabiting the riparian areas. Both the AWS pre-harvest and 1992 stand assessments categorized the Needle Branch catchment as being comprised of 80% conifer (Table 1; Brown et al., 1973; Belt, 1997). The understory is dominated by sword fern (*Polystichum munitum*), skunk cabbage (*Lysichitum americanum*), and salmonberry. The catchment was entered once in 1981 for a mid-rotation pre-commercial thinning (Stednick and Kern, 1992). Needle Branch is a 2nd-order stream at the outlet with two small tributaries. The average stream gradient is 0.014 m m^{-1} (Moring and Lantz, 1975).

The Deer Creek study area is a 303 ha catchment (Harris and Williams, 1971). The AWS treatment was comprised of three small patch-cuts with retention of stream buffers. The USDA Forest Service has intermittently clear-cut harvested and thinned small units within the catchment in intervening years since the initial AWS treatment. Prior to the AWS, the Deer Creek catchment was comprised of 68% red alder (Brown et al., 1973). Current vegetation consists of Douglas-fir stands of various age-classes.

Red alder is present in the riparian areas and on some hillsides and, as of 1992, represents only 36% of the forest composition (Table 1). The understory vegetation consists primarily of sword fern and salmonberry. Deer Creek is a 2nd-order stream and contains five mapped tributaries in addition to the main-stem. The average stream gradient is 0.018 m m^{-1} (Moring and Lantz, 1975).

2.2.2 Data Collection and Analysis

2.2.2.1 Precipitation: Precipitation measurements were obtained using a network of four tipping-bucket rain gauges (Figure 1). The gauges were outfitted with Hobo Event Loggers (Onset Computer Corporation, Bourne, MA) for data collection. A single gauge was located adjacent to each catchment. An additional gauge, “Meadow”, was located in an open meadow central to all catchments.

The 2006 precipitation record was compiled as the mean precipitation measured from the Needle Branch, Deer Creek and Meadow rain gauges. The Flynn Creek gauge was plagued with technical problems; therefore its record was not included in the analysis. Data gaps in the 2006 record resulted from rain gauge installation not occurring until October 23, 2005 and data loss from June 19, 2006 to September 30, 2006. Precipitation measured at the Newport, OR Airport (National Weather Service station ID 356032; approximately 14 km NW of the study area) and the Alsea Fish Hatchery (approximately 25 km SE of the sites) was averaged to estimate daily rainfall for these two periods.

2.2.2.2 Streamflow Characteristics: Stream stage measurements were recorded on ten-minute intervals with a Druck pressure transducer (Druck

Incorporated, New Fairfield, CT) and a Campbell Scientific CR-10X datalogger (Campbell Scientific, Incorporated, Logan, UT). The pressure transducer was mounted in the stilling well below the existing gauge house. Transducer accuracy was confirmed with a staff plate reading during each field visit (for a more detailed explanation, reference the *Field SOP*, Appendix A). Broad-crested v-notch weirs installed by the U.S. Geological Survey during the AWS were utilized for determining discharge.

Historic stage-discharge relationships were verified by occasional instantaneous measurements using the velocity-area method (Rantz et al., 1982). Stream depth and velocity were measured on equal intervals across the width of flow at a cross-section immediately upstream of the weir. Velocity was measured to the nearest 0.03 m s^{-1} using a Global Water FP101 flow probe (Global Water Instrumentation, Incorporated, Gold River, CA). Discharge measurements were made intermittently throughout the study period and across a range of flows.

Historic AWS streamflow records were used to create pre-treatment regression relationships between the harvested (Needle Branch and Deer Creek) and control (Flynn Creek) catchments, similar to the relationships reported by Harris and Williams (1971). Each catchment's annual runoff volume, peak flows, and number of low-flow days for the 2006 water year were compared to the historical relationships.
Annual runoff volume was calculated from the mean daily flow record for each stream. Peak flow events were specified by a mean daily discharge $\geq$5.47 l sec^{-1} ha^{-1} at Flynn Creek, following Harris and Williams (1971) and subsequently Stednick and

Kern (1992). Low-flow days were designated by a mean daily discharge <0.11 l sec^{-1} ha^{-1} (or 1 cubic foot per second per square mile: Needle Branch = 7.65 l sec^{-1}; Flynn Creek = 22.1 l sec^{-1}; Deer Creek = 33.1 l sec^{-1}), as described by Harr and Krygier (1972).

2.2.2.3 Suspended Sediment: Samples were collected for suspended sediment concentration analysis using the Turbidity Threshold Sampling (TTS) strategy (Lewis and Eads, 2001). Turbidity is recognized as the single best surrogate for estimating suspended sediment concentration in stream water (Beschta, 1980; Gomi et al., 2005). The TTS method utilizes real-time turbidity and stage data to trigger automated sample collection so that multiple samples are collected across the range of turbidities for a given storm (Lewis and Eads, 2001). Additionally, this strategy allows for collection of samples based on turbidity increases not associated with storms, such as bank failures or land slides.

An OBS-3 turbidity probe (D&A Instrument Company, Port Townsend, WA) and an ISCO Model 3700 Portable Sampler intake (Teledyne ISCO, Incorporated, Lincoln, NE) were mounted on an instrument boom submerged at the channel thalweg to approximately six-tenths of the total stream depth. The intake was oriented in a downstream direction to reduce clogging and produce the best conditions for collecting representative samples for suspended sediment concentration analysis (Thomas, 1985). A counter-weight mounted on the back of the boom allowed for vertical positioning to adjust with changing flow depth. The boom was cabled across the stream so that it could be positioned at any point on the cross-section, allowing adjustment for a migrating channel. The *Turbidity Threshold Sampling Field Manual* (http://www.fs.fed.us/psw/topics/water/tts/manuals/tts_4_general_field_manual.doc) contains details on auto-sampler settings along with other specifications.

Suspended sediment samples were analyzed at Oregon State University. Samples were processed using conventional vacuum filtration techniques (1.5 µm glass microfibre filter) for suspended sediment concentration analysis (Eaton et al., 1995). Laboratory turbidities were measured on a Hach 2100P portable turbidimeter prior to analysis (Hach Company, Loveland, CO) to confirm field measurements.

Similar to the streamflow analysis, annual sediment yield relationships for the AWS pre-treatment period were recreated from data provided in Harris and Williams (1971). Water year 2006 annual sediment yield was estimated by developing a suspended sediment concentration (SSC)-turbidity rating curve and then predicting SSC based on the corrected turbidity record. Field turbidity probes are subject to fouling from a number of sources, such as organic debris, biofilms, and atmospheric exposure. Erroneous turbidity data were adjusted or removed from the record by assessing field notes, laboratory samples (turbidity fouling often causes discrepant samples to be collected), turbidity trends prior to and following the apparent fouling period, and discharge data. Turbidity data were not available for the first 10 days of October 2005 and from July 10 through September 30, 2006. These were periods of generally very low turbidity and suspended sediment loads. No storms were observed during these periods and therefore turbidity was extrapolated using the mean value for the three adjacent days of record. Annual suspended sediment yield was compared to the AWS pre-treatment relationships to assess the current status of these streamflow characteristics in relation to historical observations.

2.2.2.4 Dissolved Nitrogen: A synoptic sampling network was developed to collect stream water samples from critical points within each basin for dissolved inorganic-N analysis (Figure 2). In addition to inorganic-N, total Keldjahl-N was determined in water samples collected from catchment outlets and at the site of a future upstream gauging station within Needle Branch. Synoptic sampling points were located to capture variability along the mainstem stream and within its contributing sources (tributaries and seeps). Thirteen locations were sampled within the Flynn Creek catchment (seven on the main stem and six in tributaries). Seven locations were sampled within the Needle Branch catchment (five on the main stem and two in tributaries). In May 2006, an additional sampling location was established at the upstream extent of fish habitation on the main stem of Needle Branch. Fisheries biologists identified the upstream extent of fish habitation by surveying each reach with electro-fishing gear. Thirteen locations were sampled within the Deer Creek catchment (seven on the main stem, four in tributaries, and two in seeps). Because of resource constraints, the upstream reaches of Deer Creek and Flynn Creek were not sampled in detail. Grab samples from each designated point in the synoptic network were collected on a monthly basis following the guidelines outlined in the *Field SOP*, beginning in November 2005 with the exception of samples collected from the gauging locations which began in October 2005. Samples were collected in acidwashed, polyethylene bottles and subsequently stored on ice while in the field and in transit to the analytical laboratory. Samples were analyzed for nitrate+nitrite-N on an ALPKEM 3000 Flow Injection Analyzer (O.I. Analytical, College Station, TX) by the National Council for Air and Stream Improvement, Inc. (NCASI) laboratory in Corvallis using EPA method 353.2 (National Council for Air and Stream Improvement's Quality Assurance Project Plan, http://www.ncasi.org/programs/areas/forestry/alsea/AlseaQAPP1-17-06.doc). Because nitrite-N is immediately oxidized to nitrate-N under aerobic conditions, the nitrate+nitrite-N value is considered nitrate-N only (Stednick, 1991). Ammonia-N was analyzed using EPA method 350.1. Total Keldjahl N (TKN) was analyzed using EPA method 351.2. The NCASI laboratory's minimum detection limit is 0.01 mg l^{-1} for the nitrate+nitrite-N and ammonia-N analysis and 0.02 mg l^{-1} for the TKN analysis (Diana Cook, pers. comm., March 13, 2007).

Monthly and annual nitrate-N fluxes were calculated for each stream based on monthly grab sample results and mean monthly discharge. Total inorganic nitrogen (TIN) and total organic nitrogen (TON) were calculated using the following equations:

$$TIN = (NO_3 + NO_2) + NH_3 \qquad \textit{Equation 1}$$

$$TON = TKN - NH_3 \qquad \textit{Equation 2}$$

Descriptive statistics and graphical methods were used to provide spatial and temporal characterization for the dynamics of nitrate-N concentration within each stream network.

2.2.2.5 Stream Temperature: Summer stream temperature measurements were collected using Hobo Water Temperature Pro temperature loggers (Onset Computer Corporation, Bourne, MA). Loggers were deployed at all synoptic sampling locations and at the upstream extent of fish habitation in Flynn Creek and Needle Branch (Figure 2). Temperature data were collected with 0.2˚ C precision on half-hour intervals from June through September 2006. The loggers require no calibration, however a calibration check was performed using a laboratory thermometer (precision 0.1˚ C) prior to deployment and upon retrieval to verify accuracy.

Although temperature data were collected throughout each stream network, only data from loggers deployed in the mainstem stream and primary tributaries were used in the analysis. The small tributaries and seeps all were dry before the end of the sampling period and because the loggers associated with these locations were mostly found buried in substrate it was difficult to discern true surface water temperature data from that collected from the subsurface. In each catchment, these sources were minimal contributions relative to the flow volume of the mainstem stream; therefore their removal from the record was considered negligible. It should be noted that Needle Branch mainstem temperature loggers were deployed in locations that retained water for the course of the summer, although many channel segments were dry. Because any area with water present represented potential habitat for aquatic biota, data from all mainstem Needle Branch sampling sites were used in the analysis.

Temperature records were analyzed at both individual-logger and study-reach scales. Study-reach means were calculated to account for spatial variability of stream temperature along the longitudinal profile. Instantaneous measurements were averaged across the network of mainstem loggers to obtain a single record of “average mainstem” temperatures at 30-minute intervals for each stream. From this record, daily mean, mean mainstem maximum, and mean mainstem minimum temperatures were computed. Regressions of monthly maximum stream temperatures from the AWS pre-treatment were recreated from data provided in Moring and Lantz (1975). Mean mainstem maximum temperatures from the five peak stream temperature days measured in 2006 were plotted against the regression results to assess changes from historic conditions. Additionally, descriptive statistics were used to illustrate spatial and temporal variability in the summer stream temperature regime.

Estimates of stream shade were obtained by measuring canopy closure with a spherical densiometer along the length of each stream and tributary. Sampling points were located every 25 m along the longitudinal profile of the stream. An average of four measurements, one in each cardinal direction, was used to determine mean percent shade for each sampling point following Lemmon (1956). Stream shade data were reduced to mean shade for each mainstem study reach.

2.3 RESULTS

2.3.1 Precipitation

Annual precipitation for the study area was approximately 2,250 mm for the 2006 water year, 190 mm less than the annual average measured during the course of the AWS pre-treatment period (2,440 mm). Daily precipitation exceeded 40 mm on nine days (Figure 3). Ten storm events had an average precipitation rate exceeding 30 mm per day over the course of the storm. The largest event of the 2006 water year measured 217 mm over the 6-day period from December 26 to 31, 2005.

2.3.2 Streamflow Characteristics

The 2006 annual hydrograph was typical for the Pacific Northwest climate pattern (Figure 3). The water year began with low flows and discharge increased with the onset of fall rains. Peak flows occurred during late December and early January, coincident with the largest storms of the year. With the exception of two small precipitation events, the recession to baseflow began in mid-March and continued throughout the summer. Flynn Creek and Deer Creek remained perennial throughout the summer. Periodic spikes in the Deer Creek and Flynn Creek record during late July and August, which do not coincide with any measured precipitation, are suspected to be instrument error. Discontinuous flow was noted in Needle Branch as early as mid-July and continued until the end of the water year. However, water was present at the gauge throughout the year. This was likely due to the concrete weir forcing hyporheic flow to surface. By late September, surface water extended no more than 25 m upstream of the weir and only small isolated pools and short reaches of flowing water existed throughout the Needle Branch system.

Flynn Creek annual runoff totaled 2,015 mm for the 2006 water year. Based on 22 years of record at Flynn Creek, 2006 was in the 74th percentile of annual flows. Needle Branch yielded 1,994 mm; 71 mm greater than predicted by the AWS pre-treatment model. Deer Creek generated 2,032 mm of annual runoff, exceeding the AWS pre-treatment prediction by 83 mm. The values for both Needle Branch and Deer Creek, when compared to Flynn Creek, were within the 95% prediction intervals of the AWS pre-treatment relationships (Figure 4).

Two 2006 stormflow events observed at Flynn Creek were >5.47 l sec^{-1} ha^{-1}, the peak-flow criterion (equivalent to 1,105 l sec^{-1}). A mean daily discharge of 5.72 l sec^{-1} ha^{-1} was measured on December 31, 2005. Concurrent values at Needle Branch and Deer Creek were 6.11 and 5.30 l sec^{-1} ha^{-1}, respectively. A January 10, 2006 storm produced a peak flow of 6.61 l sec^{-1} ha^{-1} at Flynn Creek. This event, which was the largest of the 2006 water year, had a 2.1-yr recurrence interval (based on 18 years of peak annual flows). Needle Branch and Deer Creek measured 6.83 and 6.63 l sec^{-1} ha^{-1}, respectively, for the same event. Peak flow values from both events were within the 95% prediction intervals of the AWS pre-treatment relationships (Figure 5).

Low-flow days, designated as a mean daily flow <0.11 l sec^{-1} ha^{-1}, were computed for each stream. The criterion is equivalent to a mean daily flow of 22.2, 7.7, and 33.3 l sec^{-1} at Flynn Creek, Needle Branch, and Deer Creek, respectively. Flynn Creek met the criterion on 115 days during the 2006 water year. Needle Branch had a total of 148 low-flow days, 22 more than predicted by the AWS pre-treatment relationships. Deer Creek was one day less than the AWS pre-treatment prediction with 115 low-flow days in 2006. Both Needle Branch and Deer Creek were within the 95% prediction intervals of the AWS pre-treatment relationships (Figure 6).

2.3.3 Suspended Sediment

Significant suspended sediment transport was measured in eight storms over the course of the 2006 water year. Transport largely occurred on the rising limb of the storm hydrographs. The largest volume of suspended sediment was discharged during the peak of the wet season when the larger storms occurred. Approximately 87%, 83%, and 89% of the annual suspended sediment load for Flynn Creek, Needle Branch, and Deer Creek, respectively, was transported during five storms which occurred from December 21, 2005 to February 2, 2006, a 43-day period. Maximum measured suspended sediment concentrations were 446, 235, and 379 mg l^{-1} for Flynn Creek, Needle Branch, and Deer Creek, respectively (Table 2). These values were relatively low compared to the maximum concentrations measured in the AWS pre-treatment period.

The 2006 annual suspended sediment yield for Flynn Creek was 416 kg ha^{-1}. Needle Branch exported 249 kg ha^{-1}. This was 145 kg ha^{-1} less than the AWS pre-treatment prediction. Deer Creek was 137 kg ha^{-1} less than the prediction, with an estimated annual export of 345 kg ha^{-1}. Annual suspended sediment yields for both Needle Branch and Deer Creek, when compared to Flynn Creek, were within the 95% prediction intervals of the pre-treatment relationships (Figure 7).

2.3.4 Dissolved Nitrogen

Monthly and annual nitrate-N fluxes were determined for each stream. Monthly flux followed the seasonal pattern of stream discharge (Figure 8). Nitrate-N export increased as a function of increasing discharge in the fall months, peaked during the winter high-flow period, and then decreased in unison with the annual baseflow recession.

Annual nitrate-N export for the 2006 water year was 30, 18, and 31 kg ha^{-1} at Flynn Creek, Needle Branch, and Deer Creek, respectively (Figure 9). These values are comparable to the export rates measured in 1965 and 1967 for Flynn Creek and Deer Creek. However, the 2006 flux measured in Needle Branch was the largest on record.

Total organic N (TON) represented a relatively small fraction of the total N measured in each stream, never exceeding 10% of the total measured N (Table 3). Total organic N values were generally higher in the summer and fall than they were in winter and spring, with the exception of the winter measurement of TON at the weir in Needle Branch.

Nitrate-N concentrations were also measured throughout each catchment on a monthly basis. Figure 10 shows seasonal concentrations for the upstream and downstream extent of sampling on the mainstem stream and for the primary tributaries in each catchment. Spatial and seasonal variations in nitrate-N concentrations were observed. Variation was greatest among tributaries for Flynn Creek and Deer Creek, whereas the mainstem concentrations were fairly similar. The annual average absolute difference in nitrate-N concentrations measured at the upstream and downstream extents of the mainstem stream were 0.12 and 0.08 mg l^{-1} for Flynn Creek and Deer Creek, respectively, whereas the annual average absolute difference in the selected tributaries was 0.67 and 0.70, respectively. Concentrations throughout these catchments varied the least during the summer months. Upstream Needle Branch concentrations were consistently higher than those measured downstream and in tributaries, indicating a dilution effect in the lower stream reaches (annual average absolute difference measured at the upstream and downstream extents of the mainstem stream was 0.69 mg l^{-1}, whereas the difference in tributaries was 0.09 mg l^{-1}). This pattern was muted but still apparent during the summer. Catchment-wide concentrations were highest during the November 2005 sampling period for each stream network, contrary to the timing of the peak in nitrate-N export. The maximum observed concentration for 2006, 3.16 mg l^{-1}, was measured in FC-t-25, the most downstream tributary in the Flynn Creek catchment. The maximum concentration at Needle Branch was 1.66 mg l^{-1}, measured at NB-m-865. The Deer Creek maximum, 2.21 mg l^{-1}, was measured at DC-t-1475. Catchment-wide concentrations systematically decreased following the November peak with the lowest measured values occurring in September 2006.

2.3.5 Summer Stream Temperature

Instantaneous stream temperatures ranged from 9.1 to 17.5 °C in Flynn Creek, 9.1 to 16.9 °C in Needle Branch, and 8.7 to 19.0 °C in Deer Creek for the 2006 summer temperature monitoring period. Figure 11 shows the mean mainstem daily maximum stream temperatures along with the magnitude of diel temperature fluctuations for each stream. Deer Creek was consistently the warmest stream and was also the least shaded (Table 4). Needle Branch was the coolest and shaded the most. Overall, stream shade was high in each catchment: 93% for Flynn Creek, 96% for Needle Branch, and 87% for Deer Creek. Deer Creek also had the largest diel range, followed by Flynn Creek and then Needle Branch (Figure 11). Deer Creek produced diel fluctuations >4.0 °C on 11 days throughout the summer. In contrast, diel fluctuations in Needle Branch only exceeded 2.0 °C on six days during the same time period. It should be noted that Deer Creek is the largest of the three streams and has an upstream reach which traverses a naturally occurring open meadow. This section at least partially accounts for the lower level of shading at Deer Creek.

Timing of daily extreme temperatures was unique for each catchment. Peak temperature at Flynn Creek typically occurred between 14:00 and 15:00, whereas daily minimum usually occurred between 08:00 and 10:00. At Needle Branch, daily maximum was reached slightly later, between 15:30 to 16:30, and minimum temperature was reached slightly earlier, between 06:00 and 08:30. Timing of daily maximum temperature in Deer Creek was not synchronous across the catchment. Maximum temperatures in the upstream reaches, with relatively less shade, occurred between 13:30 and 14:30. However, downstream reaches did not reach peak temperature until approximately 16:00 to18:00. Timing of daily minimum in Deer Creek was consistent throughout the stream and generally occurred between 06:00 and 09:00.

Within-catchment spatial variation was apparent in the range of temperatures measured for any single interval. Instantaneous measurements along the longitudinal profile differed by as much as 2.9 °C for Flynn Creek, 4.5 °C for Needle Branch, and 5.7 °C for Deer Creek. Stream temperature generally increased in a downstream direction, with the exception of Deer Creek, which increased to distance 700 m upstream of the weir and then slightly decreased downstream to 0 m at the weir.

Tributaries did not represent significant sources of heating or cooling in Flynn Creek or Needle Branch. The mainstem mean daily temperature at Flynn Creek was, on average, only 0.4 °C warmer than the coolest tributary and 0.2 °C cooler than the warmest tributary. Mainstem mean daily temperature in Needle Branch differed from the warmest tributary by an average of 0.2 °C. Tributary DC-t-480 was a cool water source for the mainstem stream. It averaged 1.3 °C cooler than the mainstem mean daily temperature. Volume of this source relative to the mainstem volume is unknown and therefore no inferences can be made to the magnitude of influence this tributary has on the mainstem stream based on a mixing model analysis, such as that described by Brown (1969).

The 7-day moving mean of the daily maximum (7DMMDM) temperature was determined using the mainstem mean for each stream to compare to Oregon Department of Environmental Quality's temperature standard (Figure 12). The three streams are considered "core cold water habitat" with a not-to-exceed standard of 16.0 °C for the 7DMMDM (OAR 340-041-0028). Deer Creek exceeded the standard on seven consecutive days (Table 5). Flynn Creek, while not exceeding the standard, came within 0.5 °C on four consecutive days. The maximum 7DMMDM temperature at Needle Branch was 14.3 °C. An analysis of the 7DMMDM temperatures at discrete measurement locations showed that Flynn Creek exceeded the standard at five of six locations for a maximum duration of six days (Table 5). Needle Branch exceeded the standard at one of seven locations for a maximum of three days. Deer Creek exceeded the standard at six of seven locations for a maximum of 13 days.

The five warmest mainstem mean stream temperatures for the 2006 water year were compared to the AWS pre-treatment relationships of maximum monthly stream temperatures for June, July, and August. All five Needle Branch maximum temperatures were below the predicted mean, but within the 95% prediction intervals of the pre-treatment relationships (Figure 13). The Deer Creek peaks were all greater than the predicted mean and all but one was within the 95% prediction intervals. The modeled relationships only modestly account for the variation within the data (R^2= 0.55 and 0.48 for Needle Branch versus Flynn Creek (Figure 13a) and Deer Creek versus Flynn Creek (Figure 13b), respectively) and should be viewed as a very coarse method of assessing differences from the historic peak temperature relationships.

2.4 DISCUSSION

2.4.1 Streamflow Characteristics

The streamflow characteristics chosen for analysis in this paper represent only a small number of potential analyses that could have been conducted to determine differences from the historically observed hydrologic regimes. Parameters assessed here reflect those that showed large changes following complete forest removal at Needle Branch: annual runoff volume, peak flows, and number of low-flow days. Hydrologic alterations caused by forest harvesting are expected to decrease over time as vegetation is reestablished (Hicks et al, 1991; Harr et al., 1979). However, initiation of a young forest stand supplants any possibility of expecting a static response over time (Beschta et al., 2000). This study represents an opportunity to document if return to pre-treatment conditions has occurred.

Annual runoff volume is expected to increase following forest removal because of a decrease in losses associated with interception and transpiration (Harr, 1976; Harr et al., 1979; Keppler and Ziemer, 1990; Rothacher, 1970; Stednick, 1996). Mean annual runoff volume for Needle Branch increased 26% following harvest (Harris, 1977). After seven years of monitoring following harvest, there was no indication that runoff was recovering to pre-harvest levels. In 1991 and 1992, a preliminary NAWS analysis found that Needle Branch exceeded the pre-treatment prediction by 149 and 313 mm, respectively (Stednick and Kern, 1992). Further analysis of an extended NAWS dataset (1989-1995) concluded that Needle Branch had not reached hydrologic recovery with respect to annual water yield (Belt, 1997). A regression line slope analysis estimated that Needle Branch would not reach full hydrologic recovery, with respect to annual runoff, until 2026 (Belt, 1997). Annual runoff at Deer Creek, where only 25% of the catchment area was harvested, increased only slightly following the treatment and was found to be within the expected range of AWS pre-treatment variation by both Stednick and Kern (1992) and Belt (1997).

Needle Branch exceeded the original pre-treatment prediction by only 71mm for the 2006 water year. Deer Creek exceeded the historic prediction by 83 mm. Although both watersheds with harvesting histories exceeded the pre-treatment predictions, they were within the 95% prediction limits of their respective regression equations. Two of the original AWS harvest units in Deer Creek were actively thinned during and just prior to the 2006 water year, indicating this level of disturbance is not detectable within the AWS pre-treatment regression capabilities.

Increases in peak flows following forest harvest are often attributable to reduction in infiltration capacity caused by soil compaction from equipment traffic, increase in hydrologic connection from road network installation, loss of canopy interception which acts to buffer storm intensities, and reduction in evapotranspiration resulting in greater antecedent soil moisture and less available storage to dampen a storm event (Keppler and Ziemer, 1990; Wright et al., 1990). To what extent peak flows are increased following forest harvest has been the source of much debate (Bowling et al., 2000; Jones and Grant, 1996; Thomas and Megahan, 1998; Beschta et al, 2000). Most agree that peaks resulting from smaller storms (5-year return intervals and less) are affected immediately following vegetation removal (Beschta et al., 2000, Harr, 1976; Thomas and Megahan, 1998; Wright et al., 1990). Although peak flows associated with forest harvesting continue to be an important issue, differences from AWS pre-treatment conditions were not expected to exist with regard to this hydrologic parameter. In fact, the 20% increase in peak flows at Needle Branch following harvest was found to be statistically insignificant based on the pre-treatment regression (Harris, 1977). Only a slight increase in peak flows was detected following the patch-cut at Deer Creek. Belt (1997) also did not detect any statistical differences in peak flows between the AWS pre-treatment period and the NAWS monitoring period, but he warned of a low sample size from the AWS pre-treatment period reducing the ability to detect changes. As expected, the 2006 values were within the pre-treatment prediction intervals.

Low flows are of interest because of their occurrence during stressful summer drought periods when water is in highest demand by plant communities and also critical for maintaining suitable fish habitat (Bond et al., 2002; Hicks et al., 1991). Summer low-flow volumes typically increase immediately following harvest, but have been found to decrease in the long-term (Harr and Krygier, 1972; Keppler and Ziemer, 1990; Hicks et al., 1991; Stednick and Kern, 1992; Belt, 1997). At Needle Branch, the number of low-flow days was decreased at a statistically significant level during each year of the AWS post-harvest period due to an increase in low-flow volumes (Harr and Krygier, 1972). Both the preliminary and extended NAWS analyses found that Needle Branch had significantly more low-flow days during the 1990-1995 monitoring period than predicted by the AWS pre-treatment relationships. This finding aligns with that of the Hicks et al. (1991) evaluation of long-term streamflow records at the H.J Andrews Experimental Forest situated on the west slope of the Cascades, near Blue River, OR. It was hypothesized that the conversion of riparian vegetation from a conifer- to a hardwood-dominated forest as the result of harvesting may play an important role in the increase of low-flow days because of an increase in evapotranspiration rate in the near-stream area, which is important to baseflow generation. Belt (1997) proposed the same hypothesis for Needle Branch. Recent research results from studies of tree physiology show that red alder of the age-class found in Needle Branch have a greater transpiration potential when compared to Douglas-fir of the same age (Moore et al., 2004), supporting the Hicks et al. (1991) and Belt (1997) arguments. The number of low-flow days at Deer Creek decreased in only two of the seven post-treatment years. However, the decrease did not occur immediately following harvest and no trend to recovery was observed during the ensuing years of record (Harr and Krygier, 1972; Harris, 1977).

2.4.2 Suspended Sediment

Accelerated sedimentation associated with forest management activities is most often linked to sediment-laden runoff from forest roads and landslides associated with harvesting and road building activities (Beschta, 1978; Brown and Krygier, 1971; Croke and Hairsine, 2006; Gomi et al., 2005; Lewis et al., 2001). Increased sediment inputs are believed to primarily impact the aquatic community through changes in habitat structure and availability, such as filling in pool habitat or covering spawning gravels (Beschta, 1978). Other possible adverse effects include: reduced visibility for feeding by fish, damage to fish sensitive gills and clogging of invertebrate collector nets, and shifts in primary productivity and invertebrate communities.

During the AWS post-treatment period, a 205% increase in suspended sediment yield was measured at Needle Branch. The increase was attributable to the hot burn, which exposed mineral soil and lack of a vegetative buffer strip for impeding sediment transport to the stream (Moring and Lantz, 1975). Pulling of debris from the channel and mechanical damage to the channel banks from yarding probably also contributed to the increased sediment load observed downstream. The extent to which established wood was pulled from the channel during the stream clean-up is not well documented (Moring and Lantz, 1975) but oral histories indicate some wood was removed. Beschta (1979) found that removal of wood debris to improve fish passage in coastal Oregon resulted in channel scour.

A 54% increase in suspended sediment yield was measured at Deer Creek following road construction. This increase was primarily attributable to road failure and resulting landslides. No significant changes in sediment yield were measured at Flynn Creek. Because of the nearly fully forested condition of each catchment and lack of human activities in the near-stream environment, current annual suspended sediment yields for the three catchments were not expected to be different than values measured during the AWS pre-treatment period. The 2006 estimates agreed with the AWS pre-treatment predictions.

Thomas (1990) discussed issues associated with changing measurement methods when comparing contemporary data to that collected historically. Although this point effectively relates to all of the data collected during the 2006 water year, techniques for determining suspended sediment yield, in particular, have changed since the AWS. Methods used during the AWS included rising-stage samplers, known to provide overestimates of sediment yield because sampling was restricted to the sediment-heavy rising limb of the hydrograph, and manual samples collected with a depth-integrated sampler. SSC-discharge rating curves were then developed to estimate sediment production. The SSC-discharge relationship is biased because of the hysteresis effect of sediment discharge over the course of a storm event (Thomas, 1990). Both methods vary greatly from the technology employed by the TTS method used in 2006 which estimates sediment concentration based on turbidity. However, the TTS method estimated yields were comparable to historic values. The largest peak flow event of 2006 had a return interval of approximately 2.1 years. Maximum suspended sediment concentrations measured in 2006 were relatively low compared to those measured in the AWS pre-treatment period (Table 2). It remains to be seen if these methods will remain comparable in years with larger sediment producing events.

2.4.3 Dissolved Nitrogen

Monthly nitrate-N export rates were generally proportional to discharge (Figure 8). This effect was expected because nitrate-N is not strongly sorbed to soil particles and is therefore easily flushed as water moves through the profile (Cairns and Lajtha, 2005; Miller, 1974). However, peak concentrations generally occurred in the fall, prior to peak discharge rates (Figure 10). The sampling protocol used in this study prohibited assessment of changes in nitrate-N concentrations both over a diel cycle and during the course of a storm, which may have provided further insight as to why peak concentrations preceded peak export. Scherer (1995) conducted a more detailed study at Flynn Creek and Deer Creek in which stream nutrients were measured over a diel cycle during the summer low-flow period and over the rising and falling limbs of three individual storms. His work concluded that no discernable changes in nitrate-N concentrations occurred across the diel cycle. The storm-based work showed that for the first storm of the season, summer baseflow nitrate-N concentrations were tripled by the time of the hydrograph peak (1.0 to 3.3 mg l^{-1} at Flynn Creek and 0.9 to 3.1 mg l^{-1} at Deer Creek). Peak concentrations decreased by approximately 36% during the hydrograph recession. Subsequent storms resulted in a dilution of nitrate-N concentrations. On average, pre-storm concentrations were reduced by 0.5 mg l^{-1} over the course of the event. Based on Scherer's (1995) findings, there is evidence that the first storm of the year, which occurred from October 31-November 3, 2005, may have flushed nitrate-N at levels that caused the highest measured concentrations for the year to occur during the November sampling event.

In the two years following the AWS harvest treatments, nitrate-N export at Needle Branch tripled from pre-treatment levels, while no change was detected at Deer Creek. Comparing annual export for 2006 to historical values indicates that Flynn Creek and Deer Creek were within previously measured ranges. Needle Branch, however, exported more nitrate-N in 2006 than in any year on record, including the two years immediately following harvesting. Stream nitrate-N in the Oregon Coast Range has been closely linked to the abundance of red alder, a N-fixing species, within the catchment (Compton et al., 2003; Wigington et al., 1998). It is likely that the increase in nitrate-N export at Needle Branch may be related to an increase in red alder along the once conifer-dominated riparian zone following harvest (Brown et al., 1973; Harr, 1976). Because a shift from conifer- to hardwood-dominated riparian areas has been documented elsewhere in the Oregon Coast Range over the past half-century (Kennedy and Spies, 2004), future research should focus on the possibility of increasing stream nitrate-N across the region with respect to local and downstream ecological implications.

Evaluation of the organic and inorganic components of total N revealed that TON was only a small proportion of total N in the stream water of all three research catchments. This finding is similar to the Compton et al. (2003) assessment that nitrate-N comprised up to 92% of the total N in Oregon Coast Range streams. This is contrasted by results from the Oregon Cascades which show that TON is the dominant or co-dominant form of stream N in those forested catchments (Cairns and Lajtha, 2005; Vanderbilt et al., 2003). Export rates in the Cascades are usually less than 1 kg ha^{-1} yr^{-1}, also much lower than Coast Range rates.

Nitrate-N concentrations varied considerably throughout each catchment (Figure 10). Wigington et al. (1998) also found that concentrations varied greatly across a larger sample size (n=45) and hypothesized that the primary control on variability was forest vegetation. Forest soils under red alder have been found to hold as much as 20,000 kg ha^{-1} of organic N (Miller, 1974). Binkley et al. (1994) documented annual N-loading under mixed conifer and alder stands ranging from 50-100 kg ha^{-1} and from 100-200 kg ha^{-1} for pure red alder stands. Red alder obviously plays an important role in the areal distribution of soil N across the Coast Range landscape. Deer Creek was the only catchment to undergo a substantial shift from hardwood to conifer since the AWS pre-treatment period. Percent hardwood in

Needle Branch did not change from the AWS pre-treatment period to 1992, but riparian vegetation in Needle Branch was converted to red alder immediately following harvest (Brown et al., 1973; Harr, 1976). Shifts in the abundance and location of red alder stands likely play a large role in the within-catchment variability of nitrate-N production.

2.4.4 Summer Stream Temperature

Variability of stream temperature was evident in timing of peak temperatures and differences in synoptically measured values along the longitudinal profile within a given day of measurement. Tributaries were not a major source of temperature variability. Diel peak temperature timing was likely a result of local conditions affecting the temperature logger, such as timing and duration of solar exposure along with groundwater contributions and hyporheic exchange (Johnson, 2003; Johnson 2004). These same factors can also help explain differences in measured temperatures along the stream reach. An energy budget is necessary to truly dissect the factors affecting the observed spatial and temporal variations (Johnson 2003).

Effect of spatial variations in stream temperature was exemplified in the application of the state temperature standard to both the mainstem mean maximum temperatures and maximum temperatures measured at the individual loggers along the mainstems. Applying the standard to the mainstem mean 7DMMDM temperatures resulted in seven consecutive days of exceedance for Deer Creek. Flynn Creek and Needle Branch mainstem mean 7DMMDMs did not exceed the standard. However, if the standard was applied to each measurement location, the results were much different. Four locations in Flynn Creek exceeded the standard; one for six days, one for four days, and two for two days (Table 5). A single location in Needle Branch exceeded the standard for three days. Five of the six mainstem temperature loggers in Deer Creek exceeded the standard. Given the high level of stream shading and the relatively undisturbed history of Flynn Creek, it is evident that the standard is not always achievable, even in undisturbed settings. Ice et al., (2007) explored the possibility of allowing for "small, brief excursions" beyond set criteria for multiple water quality metrics. Stream temperature data provided here indicated that this approach should be considered for the "core cold water" temperature standards for the mid-coastal region of the Oregon Coast Range.

The primary control on changes in stream temperature following timber harvesting is solar radiation (Brown, 1969). Catchments with fully forested riparian areas are expected to provide stream shade adequate to prevent excessive warming caused by solar inputs. Removal of streamside vegetation, as in the case of the Needle Branch AWS treatment, allows increased solar inputs resulting in dramatically increased stream temperatures (Brown and Krygier, 1970). Because each catchment is currently forested and average stream shade was greater than 85% for all three catchments, it was expected that maximum summer stream temperatures would not significantly differ from those measured historically. Needle Branch and Deer Creek were both within the 95% prediction intervals of the pre-treatment regressions (Figure 13), however all 2006 values were below the predicted mean for Needle Branch and above the pre-treatment mean for Deer Creek. Future attention should be given to understanding whether any subtle shifts in temperature patterns have occurred since the AWS or subsequent management activities within Deer Creek.

2.5 SUMMARY AND CONCLUSIONS

The findings presented in this paper assess the current and historic data record for three 2nd-order Oregon Coast Range streams to 1) determine if effects of past forest management activities and/or natural events have changed the hydrologic regime, including selected physical and chemical stream water properties, from historically observed conditions, and 2) document the variability of selected streamflow characteristics for catchments under varying management strategies. This research is observational and represents an initial effort to understand the current status of the three research streams coincident with the inception of the AWSR. The principle conclusions of this work are:

1) Measurements of annual runoff, peak flows, and number of low-flow days during the 2006 water year indicate that hydrologic recovery from disturbances associated with forest harvesting in the original AWS has occurred for both Needle Branch and Deer Creek;

2) Annual suspended sediment yield for the 2006 water year was within the pre-treatment prediction intervals for both Needle Branch and Deer Creek, despite a large disparity in the methods of sampling and data analysis; this is further evidence of hydrologic recovery in these two catchments;

3) Annual nitrate-N export at Needle Branch for 2006 increased over historically measured values, but Flynn Creek and Deer Creek were within past ranges. Although Needle Branch is exporting more nitrate-N than previously observed, Flynn Creek and Deer Creek continue to surpass Needle Branch in flux rate. Interannual variation is evident in all three streams;

4) Summer stream temperatures were variable along the longitudinal profile in the three streams and measurement locations may influence the likelihood of the stream meeting state water quality standards, even in a natural setting. Summer mainstem mean maximum stream temperatures measured in 2006 for both Needle Branch and Deer Creek indicate no prolonged, or in the case of Deer Creek, ongoing forest management effects on maximum summer temperatures.

It is anticipated that data collected as part of the AWSR will provide for more detailed and robust investigations into both the long-term changes and background variability in streamflow characteristics in these catchments. As datasets covering longer periods are compiled, more powerful statistical approaches will be possible for comparing current and historic data. Hydrologic investigations designed to obtain an integrated understanding of processes governing water movement across a range of catchment conditions will compliment the AWSR research objectives. Low flows are certainly an important issue, deserving greater attention in the future. Contemporary research techniques and instrumentation should be applied to provide a more process-based linkage of low flows and forest management activities. Extending future N investigations into the surrounding landscape will present the opportunity to discover soil N variability associated with forest cover types and potential changes over time. Coupling these terrestrial-based observations with detailed studies of catchment hydrology will offer insight as to the primary controls on solute transport within these systems. Also, a larger sample population across Coast Range waters will allow a better understanding of regional stream N patterns. Continued stream temperature monitoring will improve understanding of interannual variability in future research aimed at documenting temperature regimes in natural and managed settings.

2.6 AKNOWLEDGEMENTS

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Table 1. Percent coverage by forest vegetation type in catchments of the Alsea Watershed Study as of 1992 (Belt, 1997).

Catchment	Old-Growth Conifer	Regenerated Conifer	Hardwood
		(%)	
Flynn Creek	30	0	70
Needle Branch	0	80	20
Deer Creek	33	31	36

Table 2. Maximum suspended sediment concentrations for the Alsea Watershed Study pre-treatment period and 2006 water year.

Catchment	AWS pre-treatment (1959-1965)	2006
	(mg l^{-1})	
Flynn Creek	1,860	446
Needle Branch	969	235
Deer Creek	1,480	379

Table 3. Seasonal values of total organic nitrogen (TON) as a percent of total nitrogen for the 2006 water year at the Alsea Watershed Study.[1]

Season	FC-m-0	NB-m-0	NB-m-750	DC-m-0
	(%)			
Fall	3.8	8.8	6.1	4.6
Winter	1.4	6.6	1.7	0.7
Spring	1.7	1.7	0.9	0.8
Summer	3.4	9.1	4.9	6.3
Mean	*2.6*	*6.6*	*3.2*	*3.1*

[1]FC = Flynn Creek, NB = Needle Branch, DC = Deer Creek; “m” indicates mainstem sampling location; XX = distance (m) upstream from weir.

Table 4. Reach mean stream shade measured during summer 2006 at the Alsea Watershed Study.

Catchment	Stream Shade
	%
Flynn Creek	93
Needle Branch	96
Deer Creek	87

Table 5. Comparison of state temperature standard exceedance events based on location and data evaluation method (7DMMDM[1] > 16 °C) during the 2006 water year at the Alsea Watershed Study.

Catchment	Discrete locations with 7DMMDM exceeding 16 °C	Maximum number of days exceeded at a discrete location	Number of days mainstem average 7DMMDM exceeded 16 °C
Flynn Creek	4 of 7	6	0
Needle Branch	1 of 7	3	0
Deer Creek	5 of 6	13	7

[1]7DMMDM: 7-day moving mean of the daily maximum temperature.

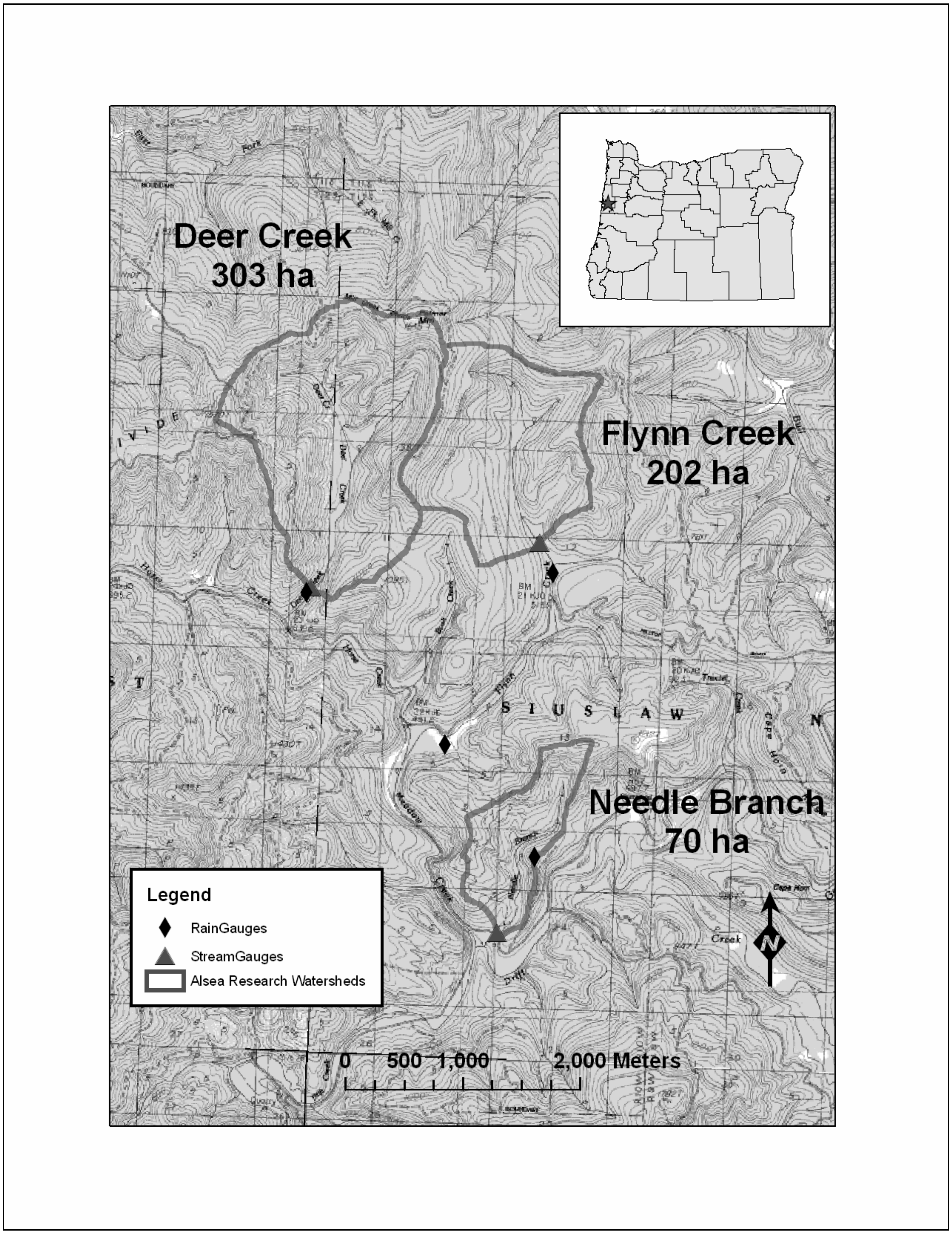

Figure 1. Research catchments, stream gauges, and rain gauges for the Alsea Watershed Study, Oregon.

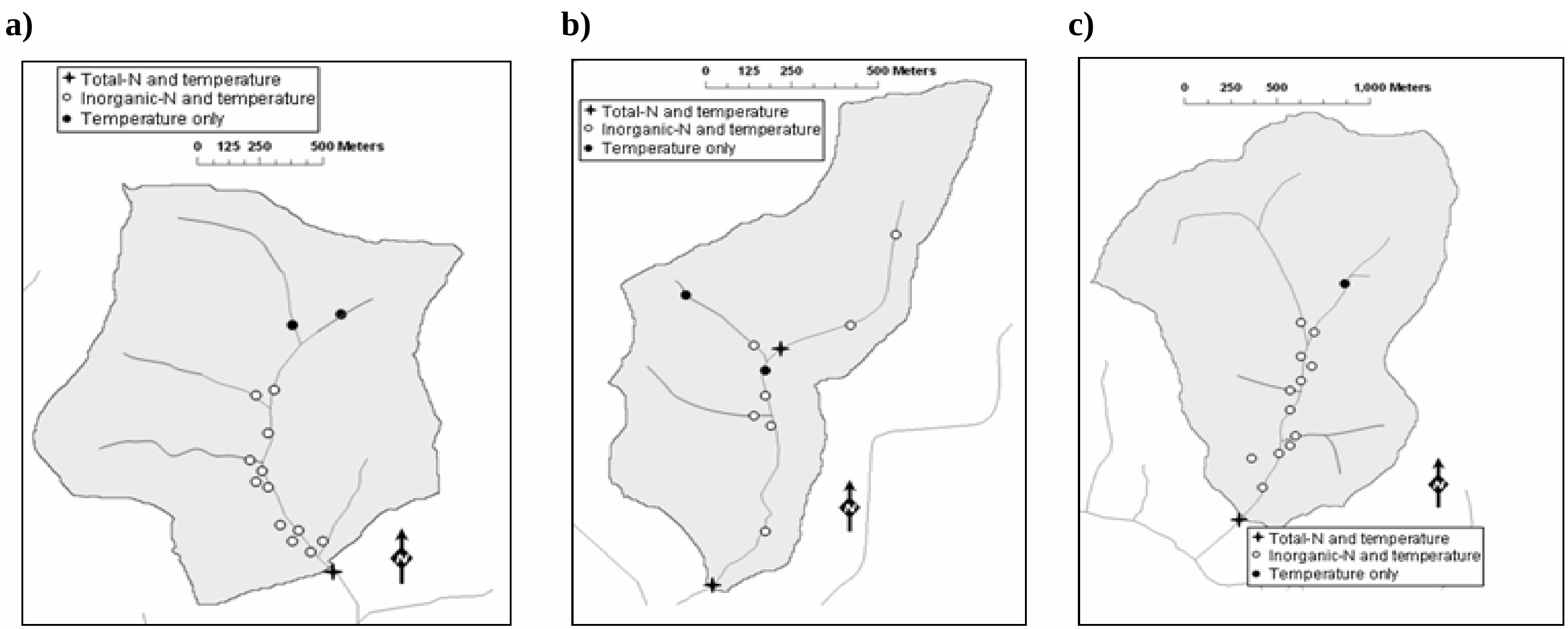

Figure 2. Stream nitrogen and temperature monitoring locations for Flynn Creek (a), Needle Branch (b), and Deer Creek (c) (note change in scale) within the Alsea Watershed Study, Oregon.

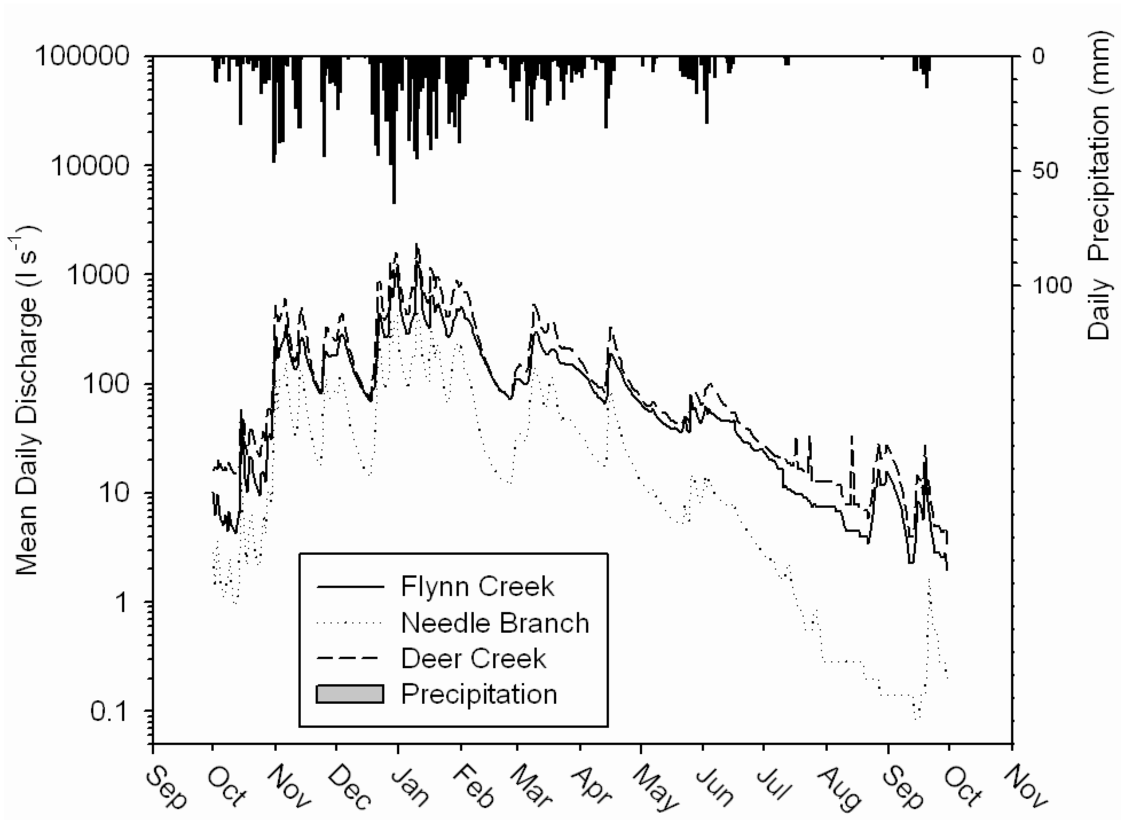

Figure 3. Flynn Creek, Needle Branch, and Deer Creek annual hydrographs for the 2006 water year plotted with daily precipitation at the Alsea Watershed Study.

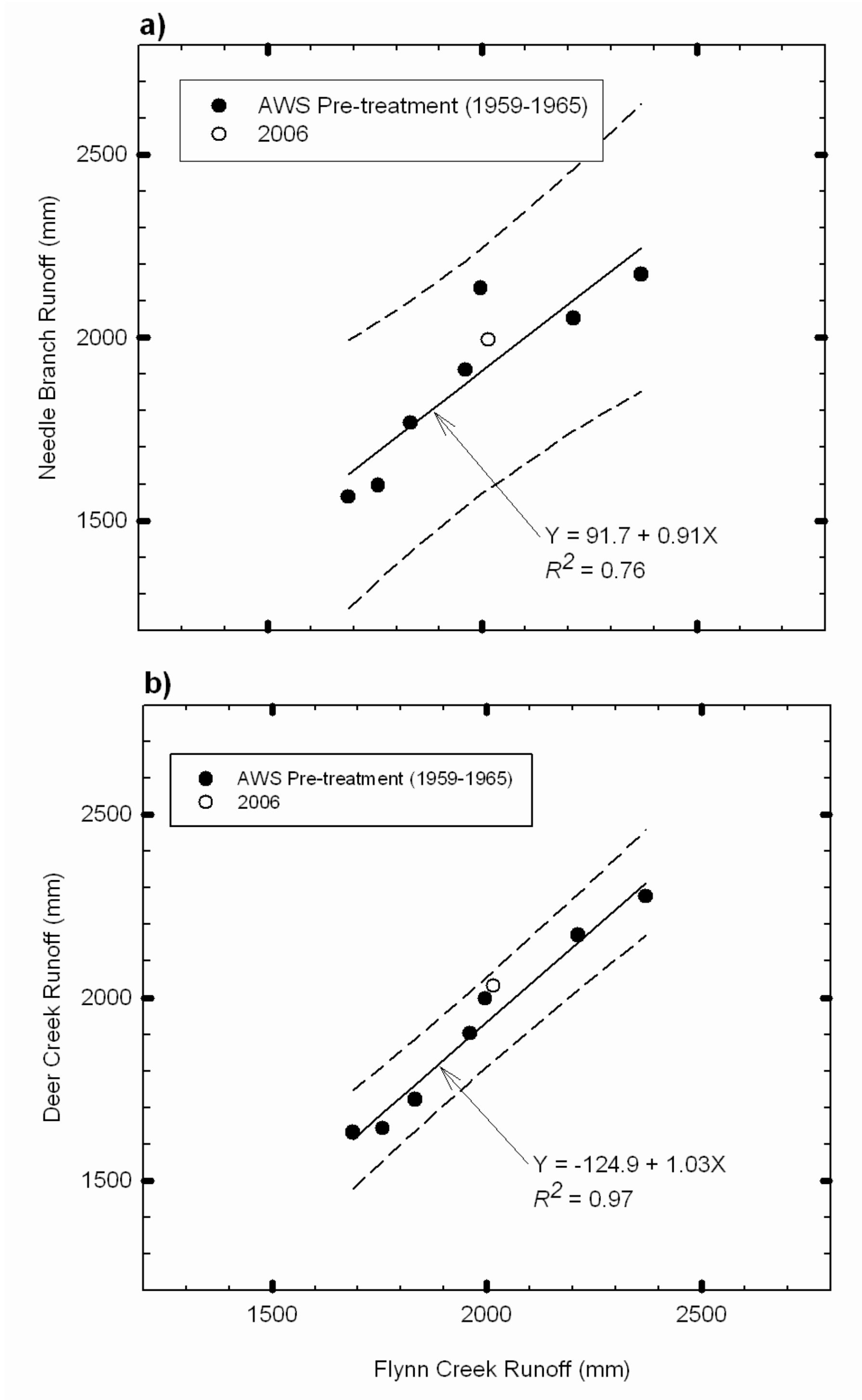

Figure 4. Alsea Watershed Study pre-treatment relationships for annual runoff volumes of Needle Branch (a) and Deer Creek (b) versus Flynn Creek with the 2006 values indicated.

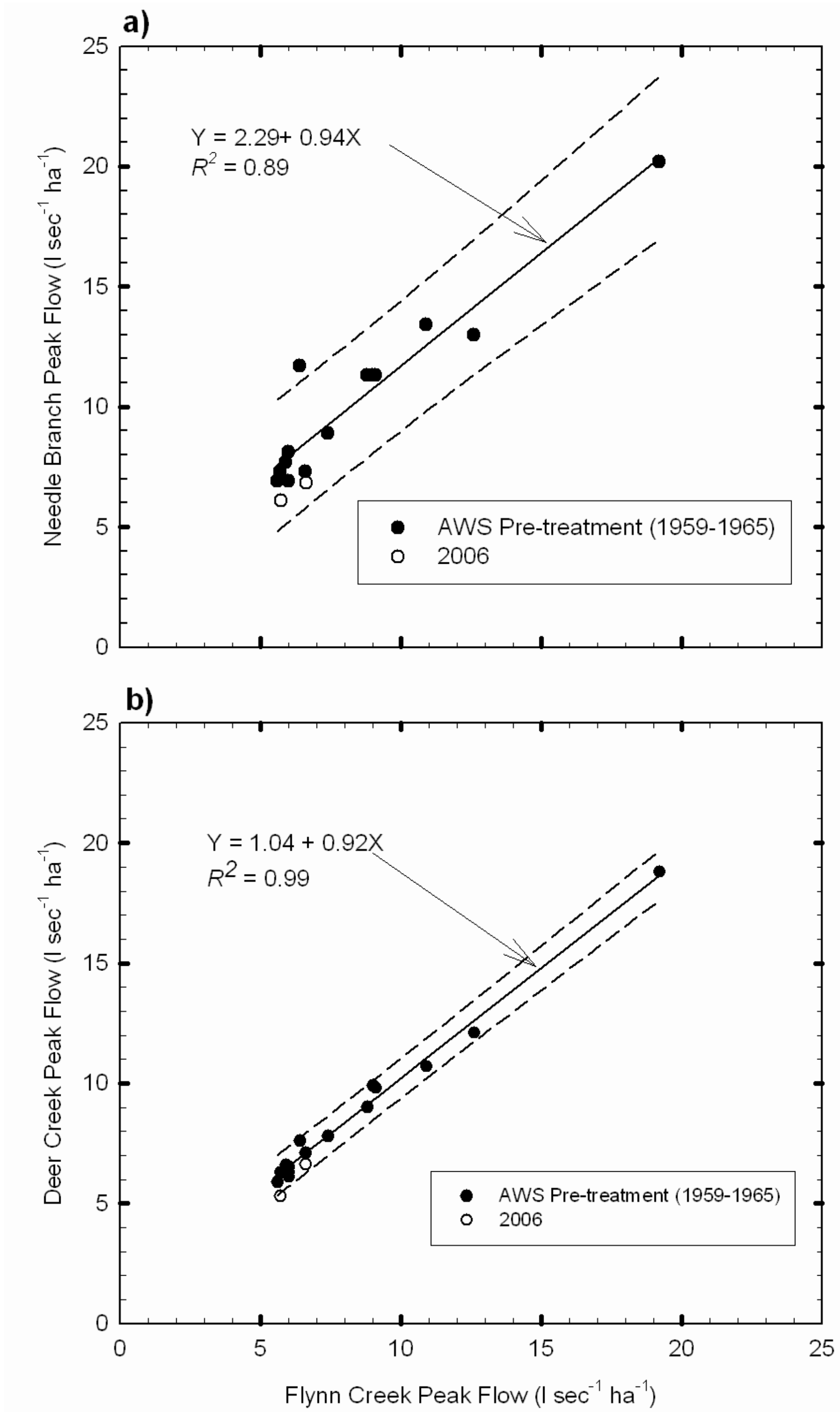

Figure 5. Alsea Watershed Study pre-treatment relationships for peak flows (mean daily flows >5.47 l sec^{-1} ha^{-1}) of Needle Branch (a) and Deer Creek (b) versus Flynn Creek with the 2006 values indicated.

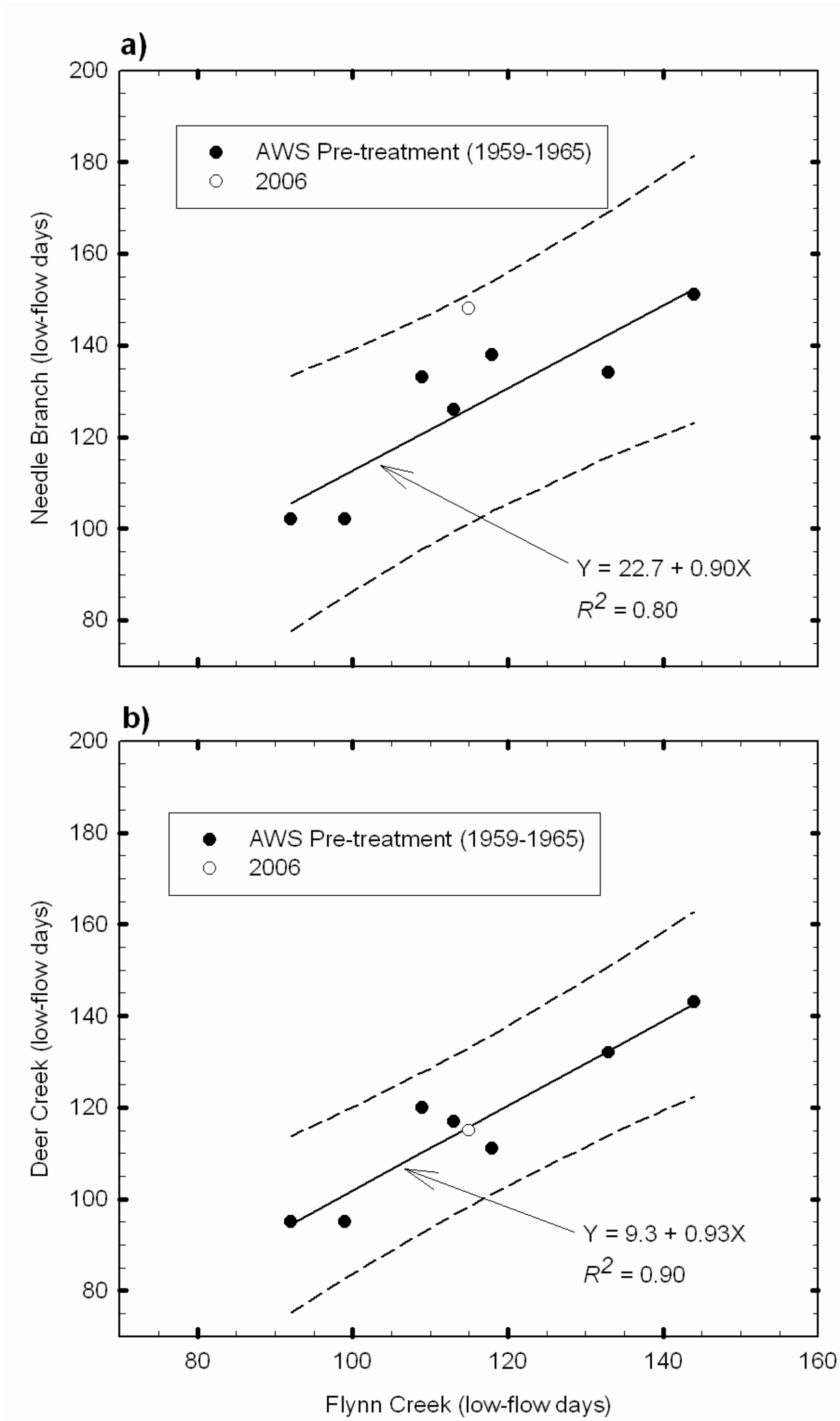

Figure 6. Alsea Watershed Study pre-treatment relationships for number of low-flow days (mean daily flow < 0.11 l s^{-1} ha^{-1}) for Needle Branch (a) and Deer Creek (b) versus Flynn Creek with the 2006 values indicated.

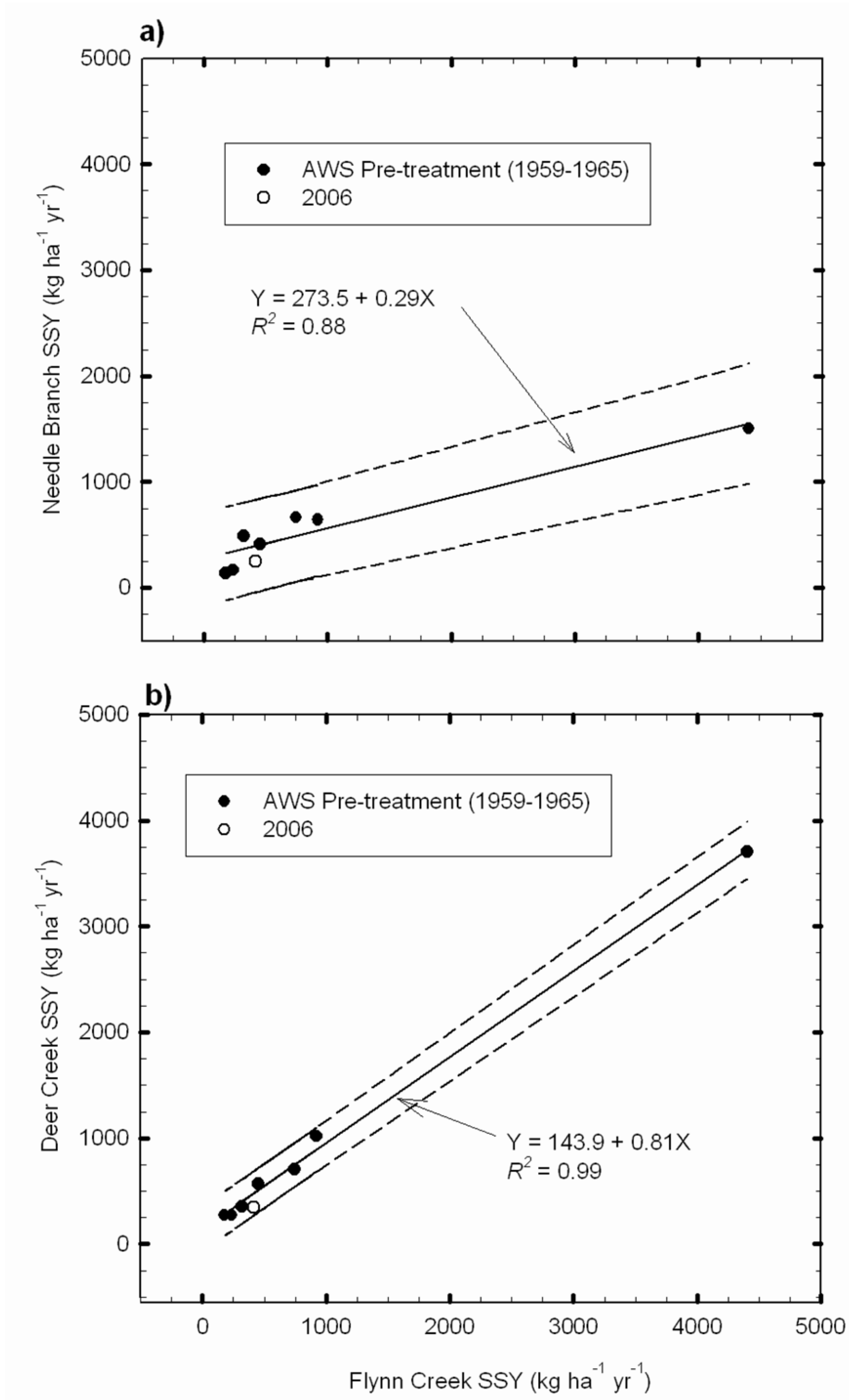

Figure 7. Alsea Watershed Study annual suspended sediment yield (SSY) pre-treatment relationships for Needle Branch (a) and Deer Creek (b) versus Flynn Creek with the 2006 values indicated.

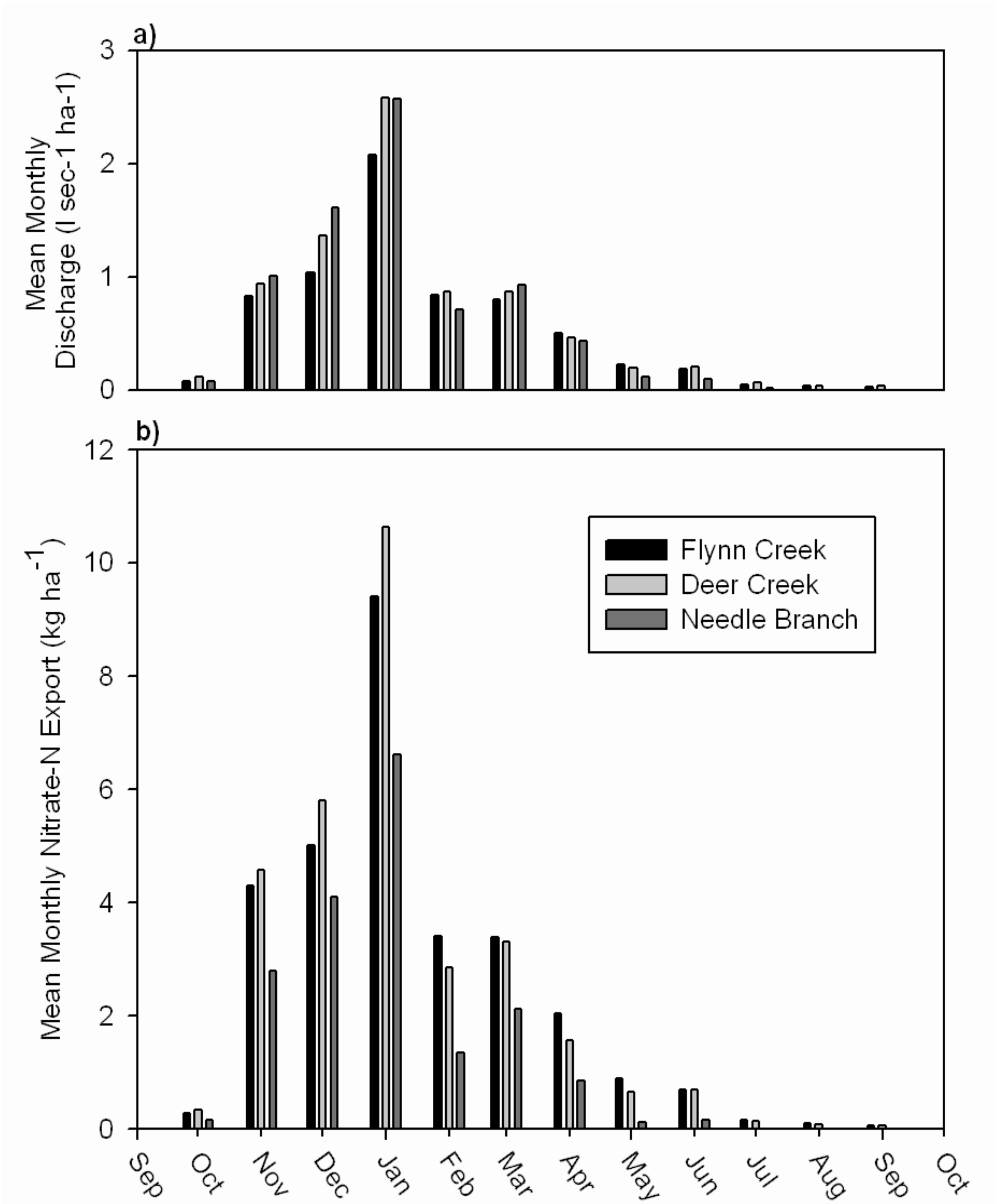

Figure 8. Mean monthly discharge (a) and mean monthly nitrate-N export (b) for Flynn Creek, Needle Branch, and Deer Creek during the 2006 water year at the Alsea Watershed Study.

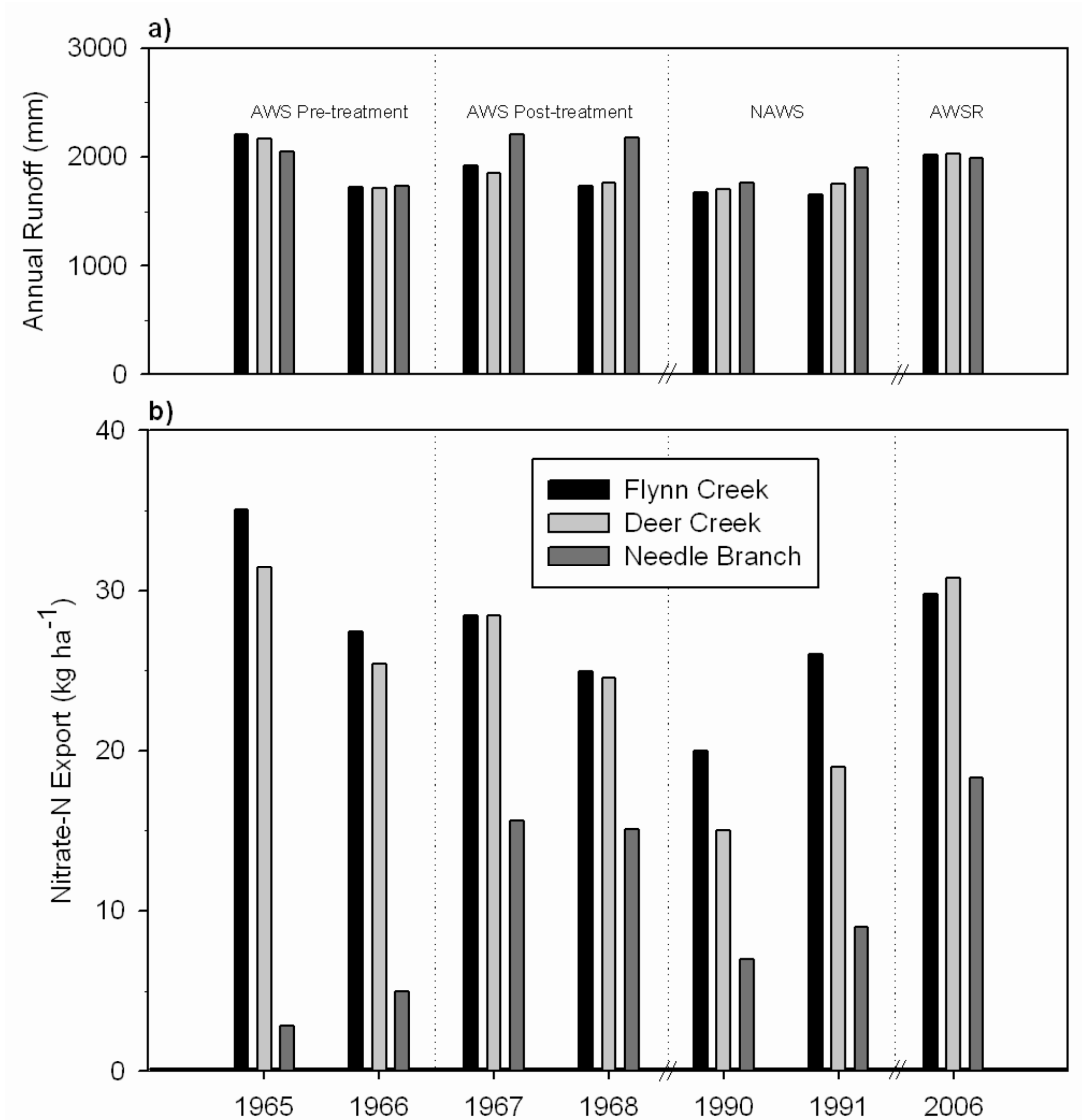

Figure 9. Annual runoff (a) and annual nitrate-N export (b) measured at Flynn Creek, Needle Branch, and Deer Creek during the Alsea Watershed Study (AWS; 1965-1967), New Alsea Watershed Study (NAWS; 1990-91), and the Alsea Watershed Study Revisited (AWSR; 2006).

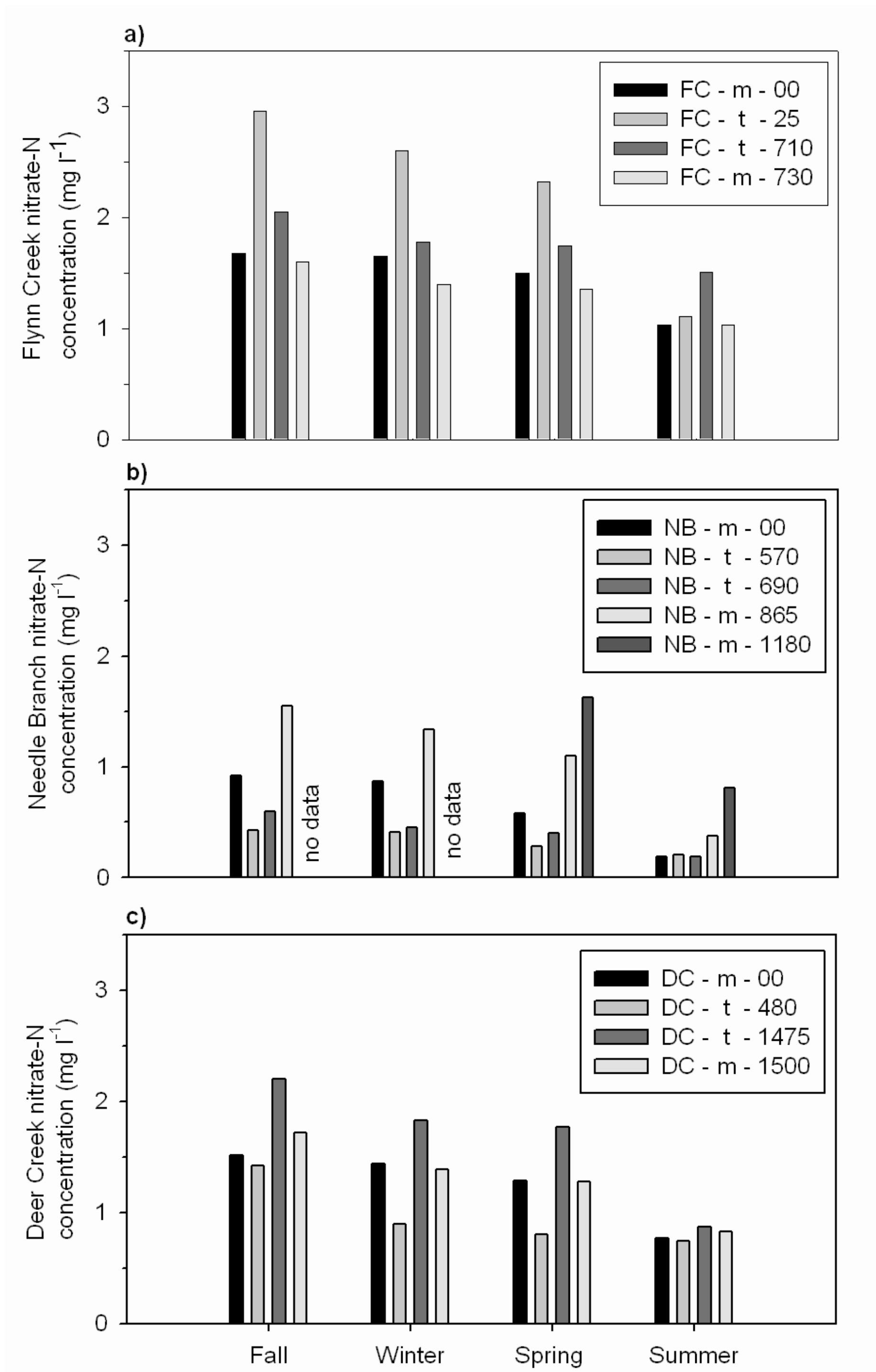

Figure 10. Nitrate-N concentrations measured throughout the Flynn Creek (a), Needle Branch (b), and Deer Creek (c) stream networks at the Alsea Watershed Study (Fall: October through December, Winter: January through March, Spring: April through June, Summer: July through September; m = mainstem and t = tributary sampling locations; XX = the distance (m) upstream of weir).

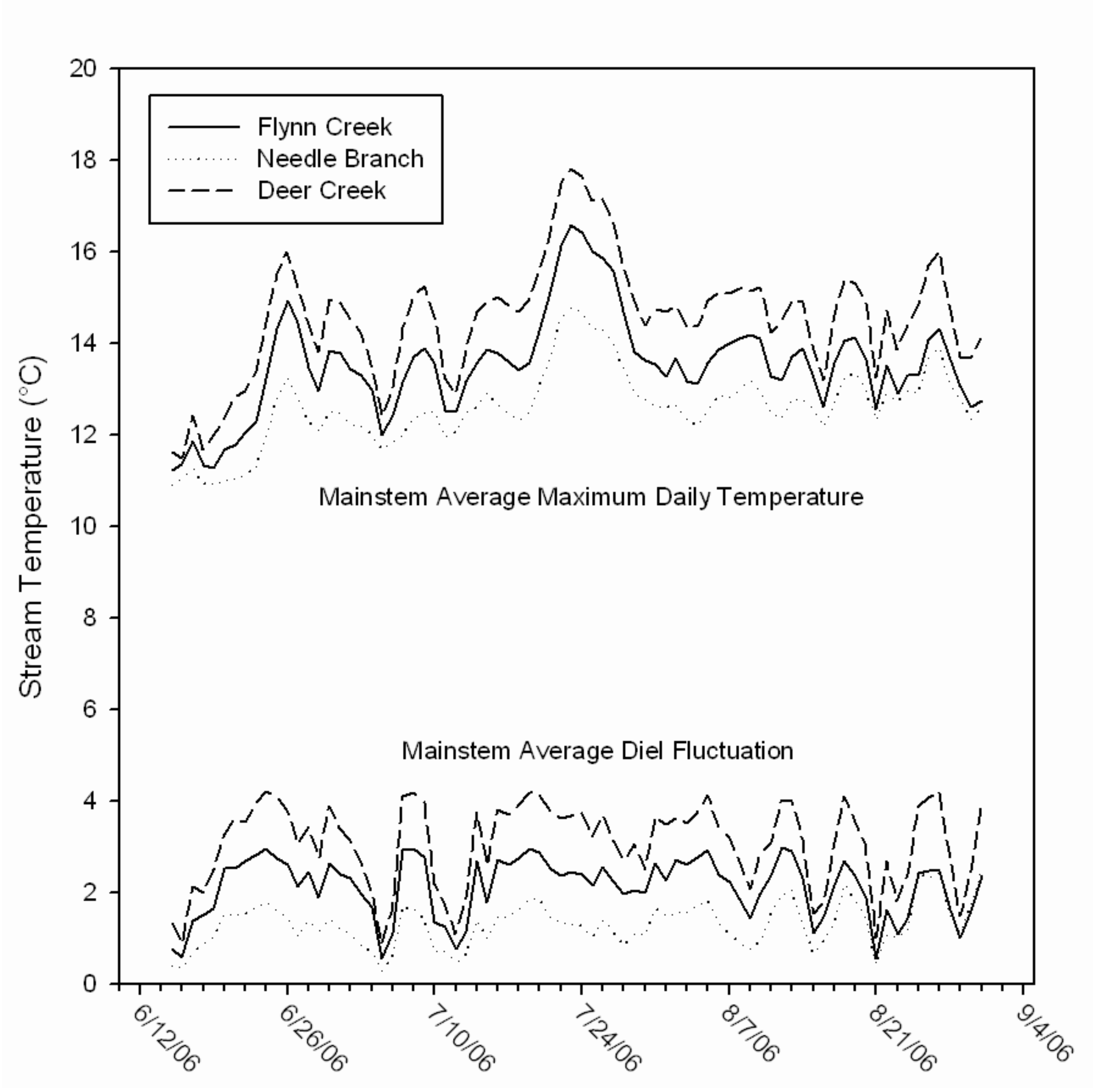

Figure 11. Maximum daily stream temperatures and diel fluctuations averaged across all mainstem temperature measurements for Flynn Creek, Needle Branch, and Deer Creek during summer 2006 at the Alsea Watershed Study.

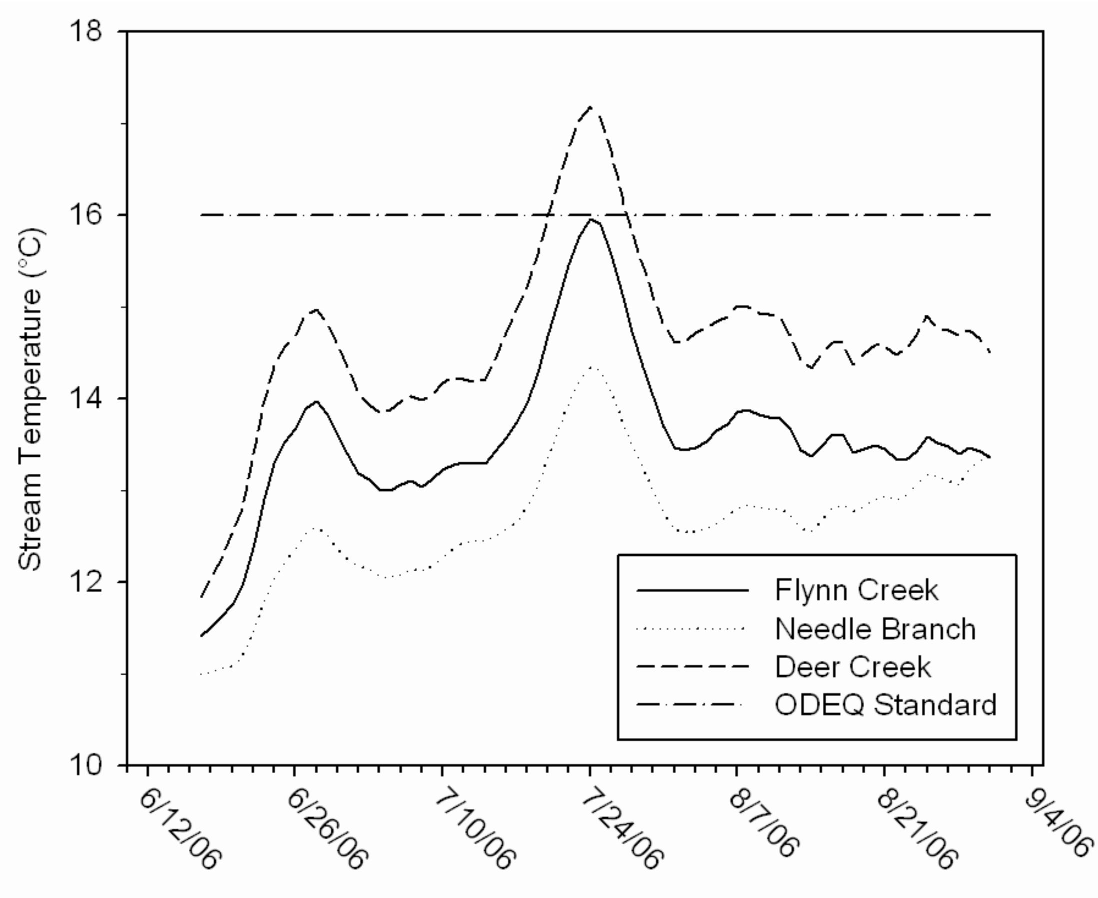

Figure 12. Seven-day moving means of the daily maximum (7DMMDM) mainstem mean stream temperature during summer 2006 for Flynn Creek, Needle Branch, and Deer Creek plotted with the state temperature standard for these streams (7DMMDM not-to-exceed 16 °C).

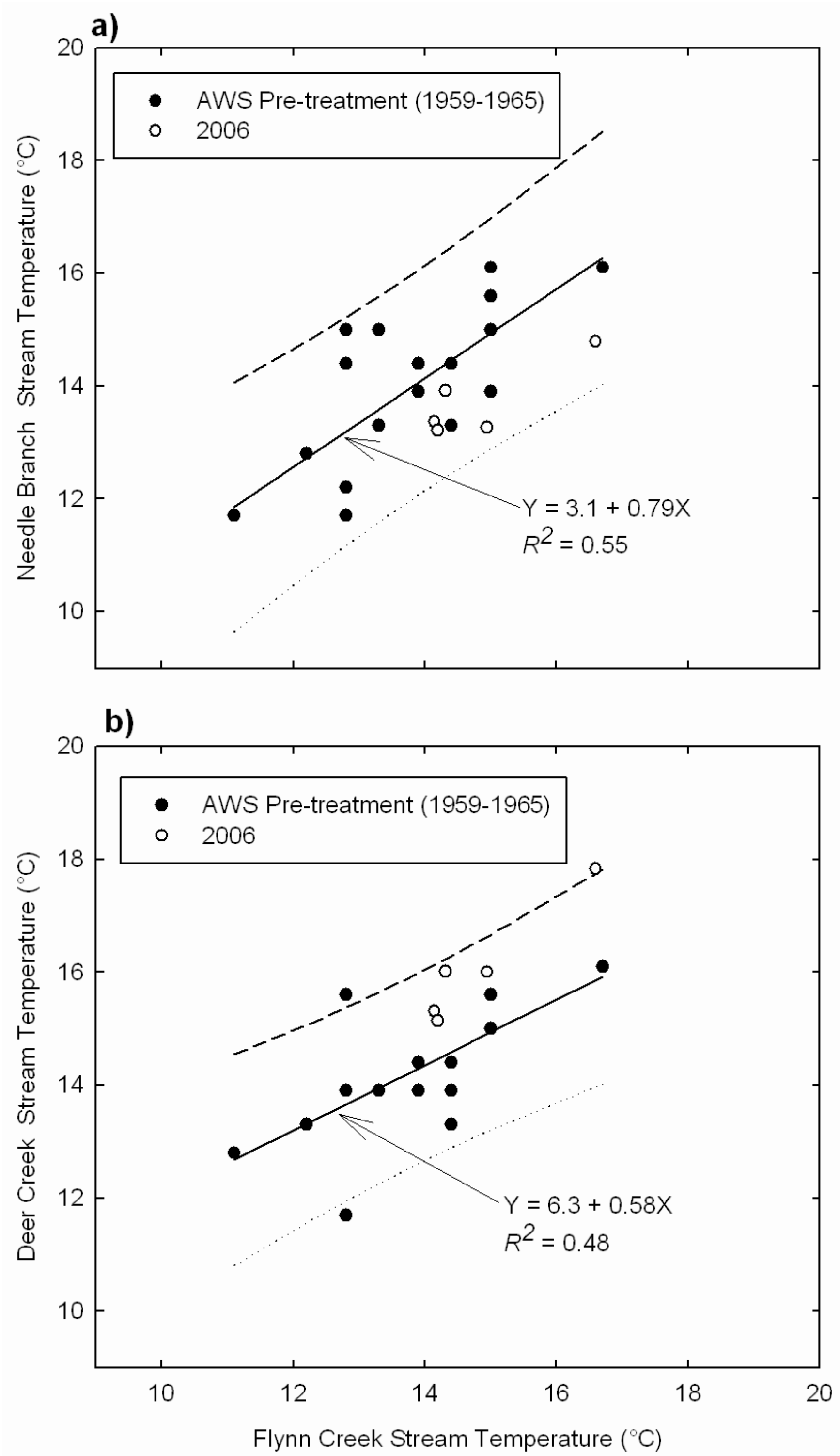

Figure 13. Alsea Watershed Study monthly maximum temperature pre-treatment relationships for Needle Branch (a) and Deer Creek (b) versus Flynn Creek with the peak temperatures for 2006 indicated.

3 Conclusions

3.1 SUMMARY OF FINDINGS

The findings presented in this thesis are the results of research undertaken to understand and document temporal and spatial variability of stream water in three 2nd-order Oregon Coast Range streams. Specifically, current and historic data were compared to determine if the hydrologic regime, including selected physical and chemical stream water properties, had returned to the pre-management conditions over the past forty years. In addition, spatial and temporal variability of stream nitrate-N and temperature was assessed.

Long-term change was determined by comparing current relationships between the control (Flynn Creek) and treatment (Needle Branch and Flynn Creek) catchments of the AWS to the relationships derived from data collected prior to treatment in the AWS. Results indicated that both the Flynn Creek-Needle Branch and Flynn Creek-Deer Creek relationships for annual runoff volume, peak flow magnitude, number of low-flow days, annual sediment yield, and summer maximum temperatures for 2006 were not different than those defined by the AWS pre-treatment period (within 95% confidence limits based on the historic data). Nitrate-N export at Needle Branch for 2006 was greater than historically measured values, but still less than the annual fluxes measured at Flynn Creek and Deer Creek. Both Flynn Creek and Deer Creek were within previously measured ranges.

Spatial variability was evaluated by comparing nitrate-N and stream temperature data synoptically collected throughout each catchment. Nitrate-N concentrations were heterogeneous throughout each stream network indicating nonuniform inputs from the surrounding landscape. The observed variability was hypothesized to be related to location and abundance of red alder present within the catchment. Stream temperatures were variable along the longitudinal profile. Choice of measurement locations influenced frequency with which each stream met state water quality standards, even in the control catchment.

3.2 FUTURE RESEARCH

The AWSR presents an excellent opportunity to assess impacts of current forest practices on aquatic resources, as well as to investigate, in detail, various facets which comprise the study as a whole to obtain a more thorough understanding of Oregon Coast Range streams. Based on findings of this preliminary study, there are several research areas that deserve future attention. Emphasis should be placed on both annual runoff and low-flow assessments at Needle Branch. An extended dataset will provide further evidence to help identify any prominent trends in either of these parameters. The TTS technique provides a new method of investigating suspended sediment transport relative to those used historically in the Oregon Coast Range. Again, as more data are compiled, increasingly detailed investigations will be possible. The long-term changes in nitrate-N export observed at Needle Branch deserve further attention. A more comprehensive biogeochemical assay should focus on determining the dynamics and mechanisms controlling nitrate-N input to the stream. Continued documentation of temperature variability in streams draining natural and managed basins will aid in determining acceptable temperature ranges for this region. It is also suggested that future temperature and nitrogen investigations incorporate additional streams into the study plan so as to capture a broader range of variability across the Coast Range landscape.

APPENDICES

APPENDIX A

Field SOP:

Standard Operation Procedures for Servicing Gauging Stations, Rain Gauges, and Water Quality Sampling,

The Alsea Watershed Study Revisited

Prepared by Cody Hale

May 2006 (updated March 2007)

Introduction

These standard operating procedures (SOPs) have been developed to provide guidance to field personnel responsible for servicing and maintaining the gauging stations and rain gauges associated with the Alsea Watershed Study Revisited. This document is intended to be used in conjunction with the National Council for Air and Stream Improvement Quality Assurance Project Plan (hereafter referred to as NCASI and QAPP, respectively). The QAPP can be accessed at:

http://www.ncasi.org/programs/areas/forestry/alsea/AlseaQAPP1-17-06.doc.

There are currently three gauging sites that were initially installed by the United States Geological Survey as part of the original Alsea Watershed Study, one each at Flynn Creek, Needle Branch, and Deer Creek. A fourth gauging site was added in the Needle Branch catchment in fall 2006. Water quality and quantity data are collected at each station. Specifically, stage (the depth of water at the gauge), turbidity, temperature, and conductivity are measured *in situ*. Samples to be analyzed for suspended sediment concentration are collected using an auto-sampler. Grab samples are collected for nutrient analysis.

Data are obtained from Leopold-Stevens, Model A-35 stage recorders (Leopold-Stevens Company, Beaverton, OR) and instrumentation associated with the Turbidity

Threshold Sampling (TTS) protocol developed by the US Forest Service's Redwood Sciences Laboratory. TTS involves the use of turbidity thresholds in conjunction with stage data to trigger the collection of suspended sediment samples via an automated sampler. The TTS equipment includes a Campbell Scientific CR-10X datalogger (Campbell Scientific, Incorporated, Logan, UT), a D&A Instruments OBS-3 turbidity probe (D&A Instrument Company, Port Townsend, WA), a Druck pressure transducer (Druck Incorporated, New Fairfield, CT), a temperature and conductivity probe, and an ISCO 3700 Automated Sampler (Teledyne ISCO, Incorporated, Lincoln, NE). Four tipping bucket rain gauges outfitted with HOBO event loggers (Onset Computer Corporation, Bourne, MA) are located in the study vicinity.

Field Equipment

Necessary equipment will vary depending on the task/s to be completed in the field. A checklist for typical equipment required when servicing the gauging stations and rain gauges is contained in Attachment A. Before leaving for the field, stamp the field book with rubber stamp containing necessary headings for data to be collected and print out field forms for gauge houses (Attachment A). Also, make sure a contact person knows your expected destinations and return time.

Directions

The Alsea Watershed Study Revisited research catchments are located in the Coast Range of Oregon, Lincoln County (Figure A.1). The sites are usually accessed from Corvallis or Toledo.

From Corvallis:

- Take Hwy 20 west to Burnt Woods (approximately 22 miles)
- Take left on Burnt Woods-Harlan Rd (there's a turn lane and a country store on the left)
- Follow Burnt Woods Rd to Harlan (approximately 8 miles)

- In Harlan, Burnt Woods-Harlan Rd more or less dead ends into Harlan Rd- Take a Right
- Follow Harlan Rd for approximately 1.5 miles, take left on Grants Creek Rd
- This road immediately crosses Big Elk Creek, veer right onto FS road 31 after bridge (tune CB to 17)

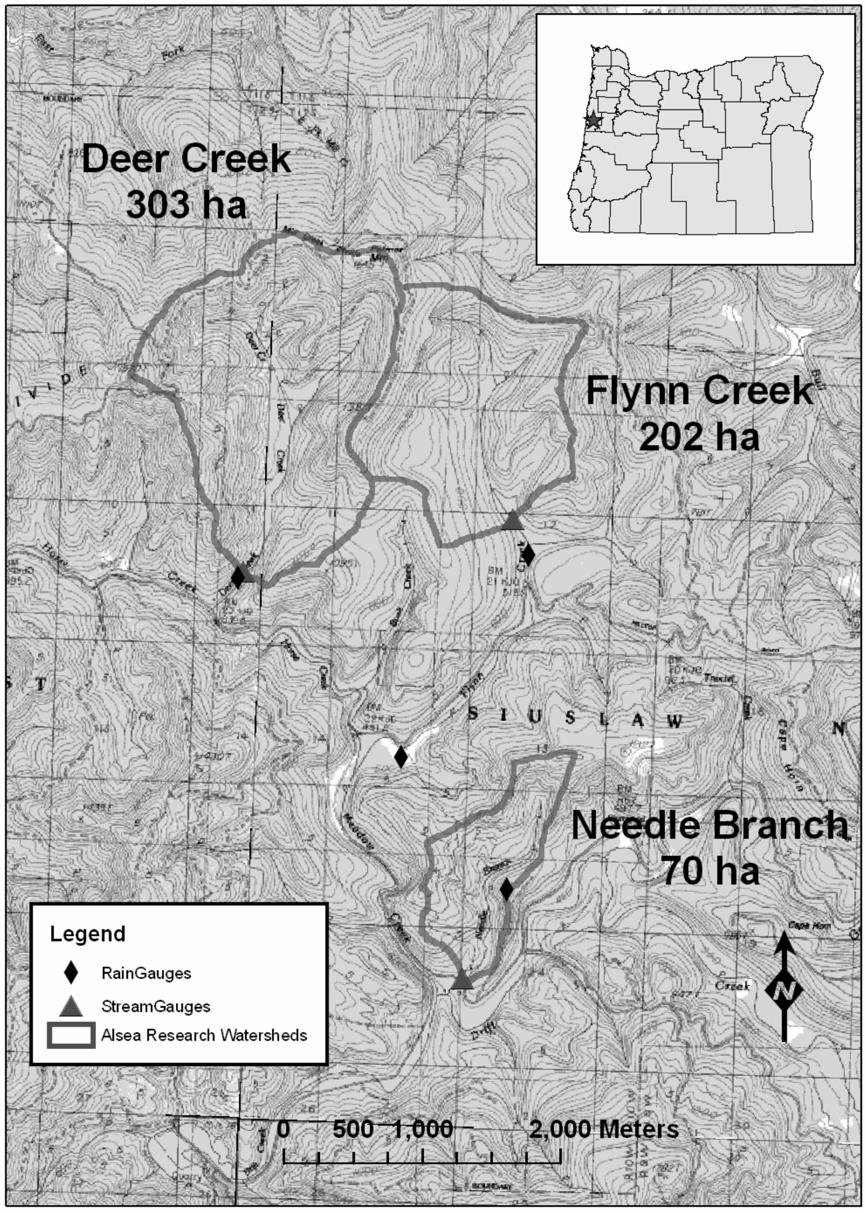

Figure A.1. Map identifying research catchments, stream gauges, and rain gauges for the Alsea Watershed Study, Oregon.

Gauging Stations

For Flynn Creek (Figure A.2):

Follow FS 31 and continue past the end of asphalt. At this point the road begins to descend. At the bottom of the descent there is a hairpin turn which crosses a creek (culvert, not bridge), this is Flynn Creek (also an open wet meadow on the left side of the road which Flynn Creek meanders through). Parking is best on the right side of the road. Be sure to clear the vehicle of the road to allow for log trucks and other traffic to pass. On foot, cross over the earthen mound and follow the trail to the gauge house.

For Needle Branch- lower gauge (Figure A.3):

Continue past Flynn Creek on FS 31 and take a left at the dead end into FS 59 (also known as 1000 Line Rd) and tune CB to 4. Follow 59 for ~1.7 miles. Needle Branch gauging station is located on the left side of the road immediate across from the ranch. Remember that you are on private property so be respectful and make sure to park appropriately so that log trucks can pass.

For Needle Branch- upper gauge (Figure A.3):

From Flynn Creek, follow FS 31 approximately 0.9 miles heading towards FS 59. Take a left on Plum Creek 1005 (PC 1005). At the first junction, take a right turn and continue until the next intersection. Park at this intersection and follow the logging road that bears left off the main road (the road with a ditch to discourage traffic is the correct road). Continue down this road until it dead ends at an old logging deck. Pick up flagged trail and descend to gauging station.

For Deer Creek (Figure A.2):

Either take a right on FS 59 (from 31) or turn around from Needle Branch. Follow FS 59 for approximately 1.2 miles from FS 31 (2.9 miles from Needle

Branch). Take a right into opening and park near the far end. On foot, walk through cut in the tree and follow trail to Deer Creek gauge house.

From Toledo:

- Follow Hwy 20 Business to SE Butler Bridge Rd, take left or right depending on direction of approach
- Veer right onto South Bay Rd after first bridge crossing
- Continue on South Bay and cross two bridges, turn left onto 1000 Line Rd
- Deer Creek turnout is on the left at approximately mile 6.8
- Needle Branch is located on the left near mile 10
- FS 31 to Flynn Creek is on the left near mile 8, follow for 1.1 miles park on left at hairpin curve

Rain Gauges

Flynn Creek rain gauge (Figure A.2):

Follow the trail to Flynn Creek Gauging station, rain gauge is on the right just before the trail turns to the left. A marked trail should be maintained from the main trail as the currently cleared road begins to re-vegetate.

Needle Branch rain gauge (Figure A.3):

Continue past Needle Branch gauging station on FS 59 (1000 Line Rd) and take the first left (approximately 75 m). Follow forest road and take a left at the first split. Rain gauge is located at the far end of the old loading dock, immediately opposite of the road.

Deer Creek 59 rain gauge (Figure A.2):
Follow Deer Creek trail and drop down to the creek (not marked to avoid vandalism) just before the gauge house. Follow creek downstream through riffle section and rain gauge is located on the left bank shelf.

Meadow rain gauge (Figure A.2):
From Flynn Creek, follow FS 31 approximately 0.9 miles heading towards FS 59. Take a left on PC 1005. Park after crossing the steel bridge. Rain gauge is located in the meadow on the right side of the road. Follow the opening in the *Rubus* and continue nearly parallel to PC 1005.

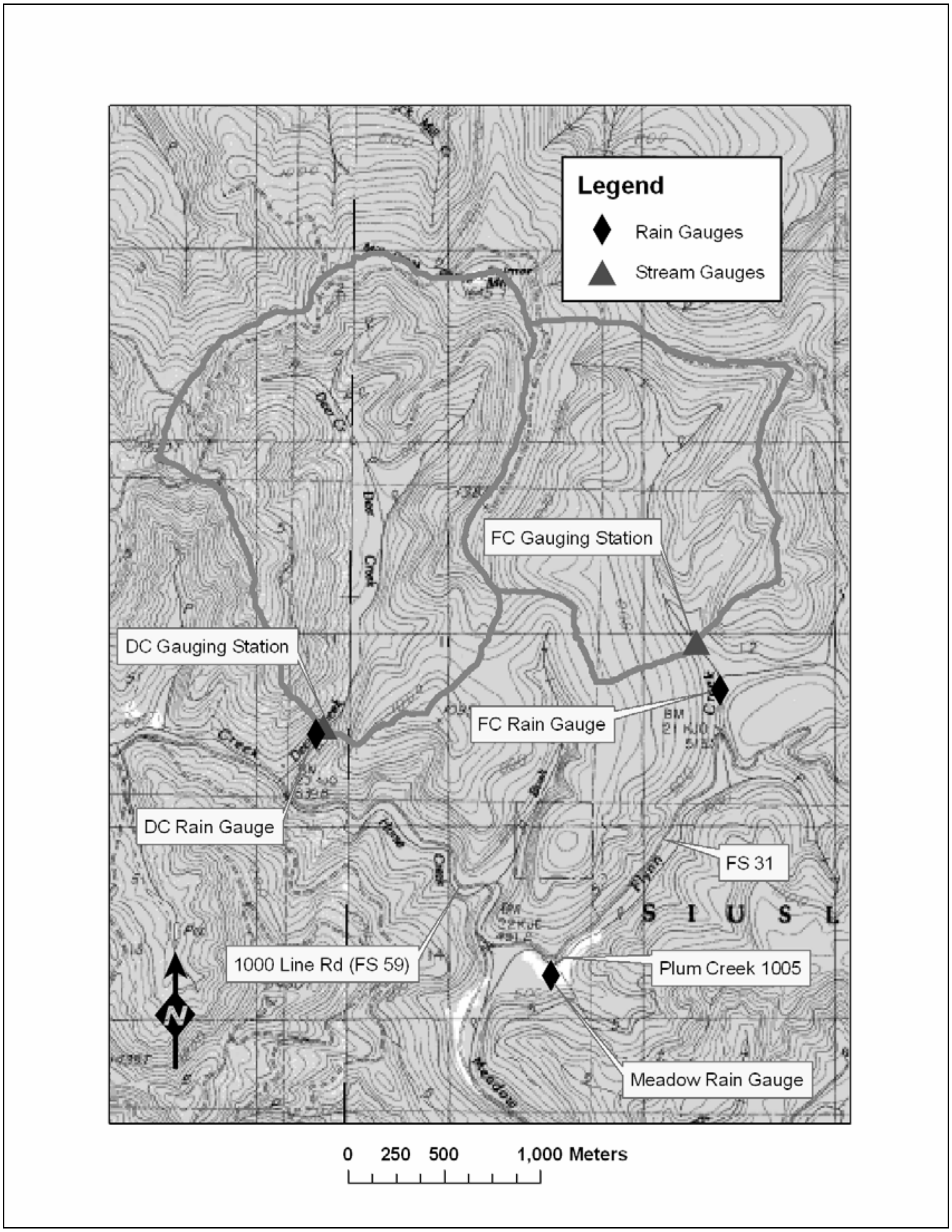

Figure A.2. Map identifying gauging stations (Flynn Creek and Deer Creek), rain gauges, and associated roads for the Alsea Watershed Study, Oregon.

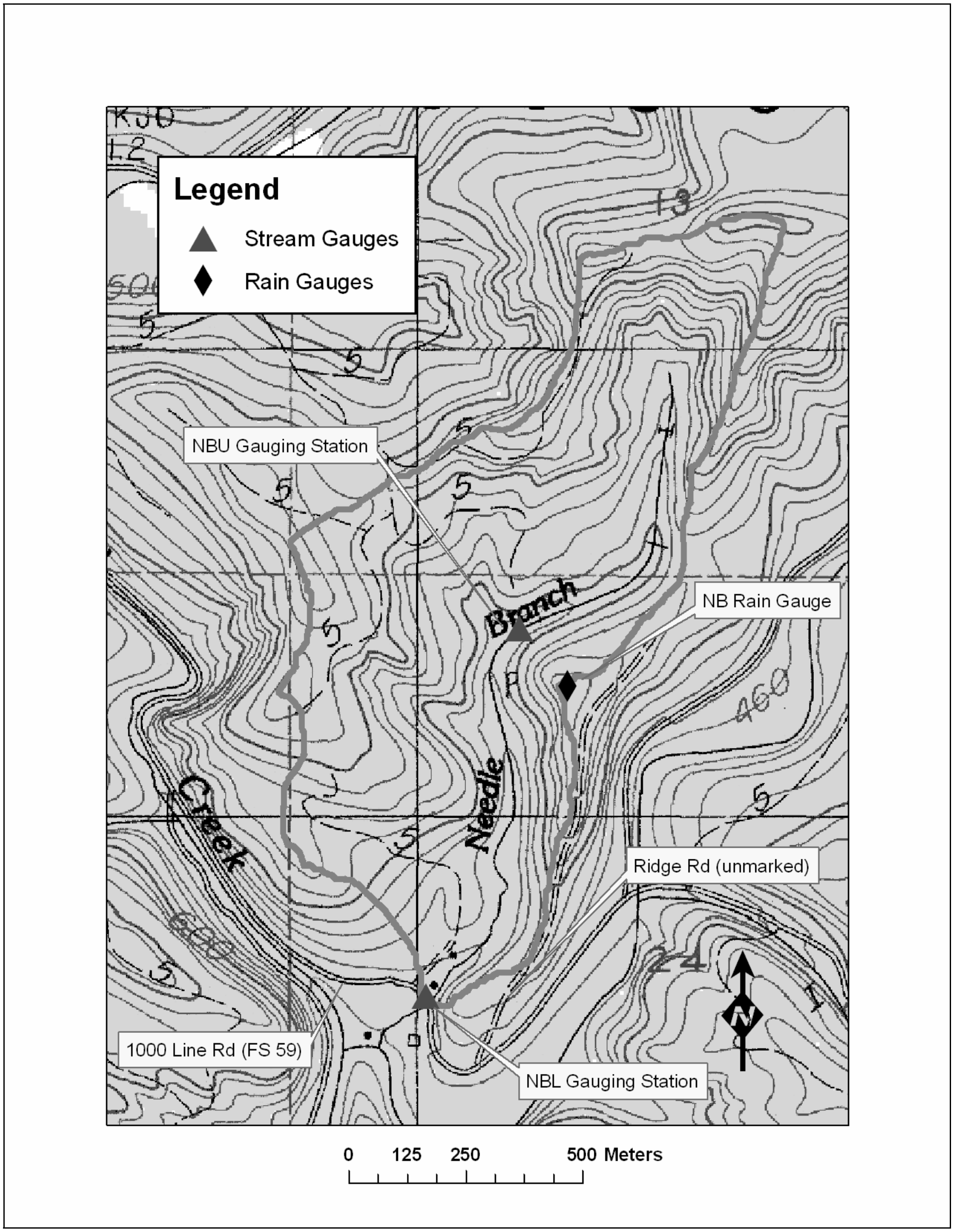

Figure A.3. Map identifying Needle Branch gauging stations, rain gauge, and associated roads for the Alsea Watershed Study, Oregon.

Servicing and Retrieving Data from Stream Gauges

Servicing intervals for the stream gauges vary by season and by the current climate patterns. It is recommended that the gauges be serviced at least weekly during the wet season. Attempts should be made to service the gauges immediately prior to an expected storm system whenever possible. This allows for correction of any fouling that may occur during a recession period (especially common early in the wet season with leaf fall) and ensures the highest quality data. Gauges should again be serviced as soon as possible, following a storm. Batteries should be changed on a monthly basis, or when voltage nears 12.0 volts.

Field personnel should plan to visit the gauging stations during several of the storm events throughout the year to observe and document conditions and collect a depth integrated sample using a DH-48 integrated sampler. Flow measurements should also be made at this time. This is accomplished by:

- Stretching a tape across the channel (use rebar and heavy duty clips to secure tape above water's surface)
- Use a flow velocity meter to make measurements at equal intervals across the channel (every foot or half foot depending on channel width and flow characteristics)
- Measure and log depth and distance from left or right edge of water at the same intervals

During the dry season, gauges can be serviced on a bi-weekly basis. At this time, turbidity probes and ISCO's will be removed from the system and brought to the lab for any necessary maintenance and then storage. The turbidity probe's calibration should be checked with a calibration standard prior to storage. This check should be conducted again prior to deployment, calibrate if necessary (see OBS-3 Instruction Manual and TTS Manual).

The following outline provides a step-by-step guide for field personnel servicing the stream gauges (*italics provide an explanation for each step)*:

1) Visually assess weir and TTS boom for any obvious interference and note in field book and on field forms. Typical interferences include, but are not limited to, debris caught in the weir or on the instrumentation, sediment covering the stilling well intake, and/or beaver activity causing backwater effect in the vicinity of the gauge (*quality control step to ensure data accuracy*).
    a. If there is an obvious problem, continue to step 2 without fixing it and then repeat steps 3 and 4 after fixing it, noting specifically changes in stage and/or turbidity that occurred as a result of the maintenance.
    b. If there is no problem, note and continue to step 2.
2) Enter the gauge house and connect laptop to the Campbell Scientific datalogger via the 9-pin connector cable (*provides opportunity to immediately assess datalogger real-time display for potential problems and determine the next "awakening" time for measurement; awakenings occur on ten minute intervals and are indicated by the illumination of the OBS button in the "Ports and Flags" window*)
    a. Open LoggerNet software
    b. Connect to the correct datalogger (from list)
    c. Open "Numeric Window" and "Ports and Flags" window
3) Log the following information in field notebook and on gauge house data sheet (*data collection*)
    a. Field visit records
        i. Date and Time
        ii. Field personnel present
        iii. Current weather conditions

b. Data retrieval and manual verification measurements

(*Steps i-ix provide data necessary for quality control used when compiling, correcting, and analyzing data at a later date*)

i. Stage

1. TTS (from numeric window)
2. Reference stage (*verifies accuracy of instrumentation*) - Measure the outside reference "tape-down" with the staff plate located in each gauge house. Tape-down is located…
    a. Flynn Creek- on the upstream side of the weir, right of the notch, top of bolt- Subtract measured value from 3.27 to get reference stage in feet.
    b. Needle Branch- on the left bank, weir approach wall, top of lowest bolt- Subtract measured value from 2.89 to get reference stage in feet.
    c. Deer Creek- on the upstream side of the weir, right of the notch, top of bolt- Subtract measured value from 2.78 to get reference stage in feet.
3. Stevens stage measurement (*back up for datalogger*)- at time of reading, mark on scroll: the current position (by rotating the pulley gently), the date, time, initials, and reference stage
    a. Complete section of field form associated with Stevens recorder
    b. Reset time or stage, if necessary
    c. Wind clock, if necessary

ii. TTS system battery voltage (new and old battery in the case of a battery change)
iii. Median turbidity
iv. Dump #
v. Next Bottle #
vi. If probe was wiped or boom was cleared
vii. If fouling was evident
viii. Samples attempted and retrieved (from ISCO)
    1. note if correct volume was collected
    2. note that ISCO was reset after collection, if applicable
ix. Other information pertinent to specific visit

4) If TTS samples have been collected since the previous visit, perform a data dump.
    a. Fill out bottle labels for each sample collected. Provide:
        i. Dump #
        ii. Location ID
        iii. Bottle number (from ISCO carousel)
        iv. Date of retrieval
        v. Total number of bottles retrieved for this visit
        vi. Initials

See TTS Field Manual for explicit instructions for the following steps:

    b. If collecting a depth integrated sample (*collected intermittently during wet season, especially during storm events, to verify the performance of the auto-sampler against a USGS accepted method for suspended sediment concentration sample acquisition*)
        i. Click and highlight the “DI” button in the “Ports and Flags” window
        ii. Wait for ISCO sample to be triggered at next “awakening” (*awakening is when OBS-3 turbidity probe and other sensors*

are activated to take a measurement, every 10 minutes under current settings and indicated by the illumination of the OBS button in the "Ports and Flags" window)

iii. Collect depth integrated sample with DH-48
    1. Place bottle in sampler
    2. Beginning on one side of the flow, submerge sampler slowly through the water column and move to the opposite bank perpendicular to flow while continuing to lift and submerge the sampler
    3. The goal is to completely fill the bottle with one pass across the channel

c. Immediately following an "awakening", click and highlight the "Dump" button in the "Ports and Flags" window (*performed to download data from datalogger and collect samples from ISCO*)
d. In LoggerNet window, choose "Custom Collection"
e. Depending on data needs, choose "Collect All" (this datalogger with current settings only holds approximately one month's worth of data, so don't expect to access the entire record with this setting) or "Collect All Since Last Collection". Name the file with station initials and dump date (i.e. FCG060125) and save in "newdata" folder.
f. While file is downloading, Stop ISCO program (press stop), access and cap bottles, remove and label (in sequential order)
g. Replace retrieved bottles with clean ones and replace cover
h. Reset ISCO by pressing "Start" then "Enter"
i. Check downloaded data by using the TTS RawPlot software
    i. Launch program
    ii. Select file number to view
    iii. Plot Stage-Turbidity and look for any obvious problems that may need addressing in the field

j. If battery change is required, after dump (*batteries should be changed when voltage reaches 12 volts or lower*):
    i. Power off ISCO and disconnect computer from datalogger
    ii. Quickly switch battery leads
    iii. Power on ISCO and reconnect to computer
    iv. Reset any settings in the numeric window, if necessary (minimum stage, turbidity offset, stage offset, etc.)
    v. Check to make sure "Dump" number and "Next bottle" have been changed to appropriate values (usually current dump number plus one for "Dump" and one for "Next bottle"), manually change, if necessary

k. Upon return to office, immediately create back up file to be saved on another server

Downloading Rain Gauge Data

Rain gauges should be downloaded bi-weekly during the wet season. The dataloggers have the capacity to collect data over longer time periods, but this interval will allow the field personnel to detect any problems with the instrumentation (electrical or mechanical) without losing a critical amount of data. The following steps should be taken upon arrival at the rain gauge:

1) Note rain gauge name, date, time of visit, and initials in field book.
2) Note any necessary observations that may affect the rain gauge performance (clogging or evidence of tampering, mainly)
3) Remove cover by twisting clockwise
4) Use Hobo Shuttle to download data
    a. Connect to data logger
    b. Press button on shuttle
    c. Toggle through the options (see Shuttle directions)

   d. Make sure “Relaunch” is successful

5) Replace cover
6) Upon return to the office, immediately download Shuttle data to laptop computer and create a backup file on another server

Collecting Water Quality Samples

Water quality samples are to be collected at each gauging location (Figures 1 and 2) on a monthly interval. Physical samples will be accompanied by *in situ* water quality measurements made with a Hydrolab Quanta (Hach Company, Loveland, CO). Dissolved oxygen (in milligrams per liter and percent saturation), temperature (C˚), pH (standard units), and specific conductivity (µS/cm) will be recorded. Turbidity will be measured using a Hach 2100P Turbidimeter either in the field or in the lab using a re-suspended sub-sample of the nutrient sample collected in the field. Appendix A contains the field equipment checklist for water quality sampling. Laboratory analytical methods and Quality Assurance/Quality Control procedures are outlined in the QAPP.

The following steps should be followed when collecting samples:

- Prior to leaving for the field
    - Make arrangements with NCASI laboratory for sample delivery date and request bottles and labels
    - The HydroLab should be calibrated according to its instruction manual
    - The Turbidimeter should be calibrated according to its instruction manual
    - Bottles and labels should be picked up from NCASI laboratory
    - Buy ice
- Upon arriving at sample location
    - Submerge Hydrolab Quanta in channel thalweg and allow to equilibrate
    - Measure reference stage as described in Servicing Stream Gauges outline (3.iv.2) and note in field book
    - Put on nitrile gloves (new pair at each site)
    - Label bottle with necessary information, including Site ID, Date, Time, and Initials
    - Collect sample from mid-depth in channel thalweg

- Record Site ID, Date, Time, Dissolved oxygen (in milligrams per liter and percent saturation), temperature (C˚), pH (standard units), and specific conductivity (μS/cm) in field book
- Either
  - Measure and record turbidity in the field using cuvette, or
  - Sub-sample each sample in the lab using nitrile gloves and the cuvette in the Turbidimeter case to measure turbidity
- Fill out chain of custody form (Appendix A)
- Deliver samples to NCASI laboratory within 24 hours of collection

720 SW 4th Street
Corvallis, Oregon 97333

Safety Plan

Safety is first priority when working in the field. The following list is not intended to be exhaustive but should be used as starting point for conducting safe field research:

- A contact person should always know your intended destinations and return time.
- Follow all field safety requirements stipulated by the landowner
- All safety gear listed in the field checklist should be carried.
- Wear clothing and footwear adequately suited to the climate and field conditions
- Always drive with lights on.
- Tune radio to 17 when traveling FS 31 and 4 when traveling FS 59 and announce mile number, direction, and vehicle type at every posted mile
- Have safety numbers easily accessible
  - Samaritan Toledo Health Clinic- 541-336-5181
  - George Ice/NCASI -541-752-8801
  - Jeff Light/ Plum Creek- 541-336-6227

- Report any unsafe conditions to NCASI and/or supervisor immediately upon return

Directions to Samaritan Toledo Health Clinic, (541-336-5181; Figure A.4):

- From Alsea research watersheds, take FS 59 (1000 Line Rd) north towards Toledo
- Dead end into South Bay Rd, take right
- Veer left onto Elk City Rd (turns into Butler Bridge Rd)
- Take slight right onto S Main St
- Take left onto US Hwy 20 Bus.
- Go to 1744 NW Hwy 20 Bus, Toledo, OR 97391

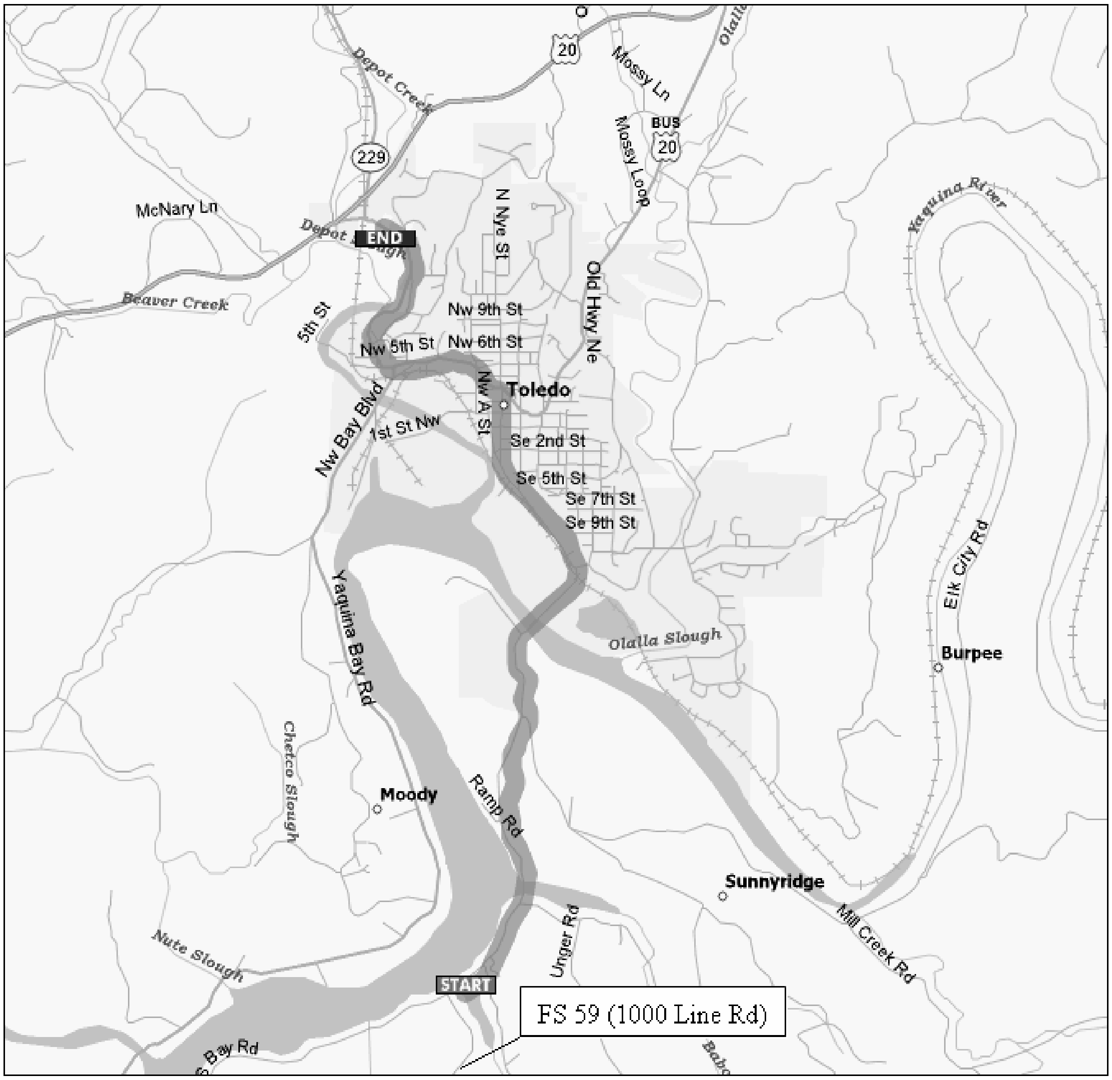

Figure A.4. Map showing route from FS 59 (1000 Line Rd) to Samaritan Health Clinic.

Attachment

Field Forms

Field Equipment Checklist for Servicing Gauging Stations and Rain Gauges			
First Aid Kit*		Laptop Computer	
CB radio*		Campbell Scientific Interrogation Cable (9-pin connector)	
Hard Hat*		Toolbox	
Hand Saw*		Bottle Labels (SSC)	
Pulaski*		24 ISCO Bottles per station	
Waders/High Boots*		Bottle Caps	
Orange Field Vest*		Rain Gauge Interrogation Cable	
Safety Numbers*		Hobo Shuttle for Rain Gauge	
Whistle*		5, 3v Lithium Battery (CR2032) for rain Gauges (if needed)	
Let contact person know plans*		Charged 12v Batteries (if needed)	
Field Book and field forms		DH-48 Integrated Sampler	
Write in the Rain Pen, Pencils, & Sharpie		DH-48 bottles (1 per station)	
Backpack		Instruction Manual (ISCO)	
Camera		TTS Field Manual	

* indicates necessary field safety equipment

Field Equipment Checklist for Water Quality Sampling			
First Aid Kit*		Laptop Computer	
CB radio*		Campbell Scientific Interrogation Cable (9-pin connector)	
Hard Hat*		Toolbox	
Hand Saw*		Bottle Labels (nutrients)	
Pulaski*		Sample Bottles	
Waders/High Boots*		Nitrile gloves	
Orange Field Vest*		Quanta Hydrolab (calibrated)	
Safety Numbers*		Hach 2100P Turbidimeter (calibrated)	
Whistle*		Flagging	
Let contact person know plans*		Cooler	
Field Book and field forms		Ice	
Write in the Rain Pen, Pencils, & Sharpie		Machete	
Backpack		Miscellaneous	
Camera			

*indicates necessary field safety equipment

APPENDIX B

Data Acquisition Procedures

Alsea Watershed Study Revisited Data

Data presented in this thesis were collected as part of the Alsea Watershed Study Revisited, funded primarily by the National Council for Air and Stream Improvement. A limited access database has been developed to allow information sharing in a controlled environment. A data request form is available at:

http://www.ncasi.org/programs/areas/forestry/alsea/current_study.aspx.

Alternatively, contact Terry Bousquet or George Ice to obtain procedures for acquiring data:

Terry Bousquet, Database Manager
tbousquet@wcrc-ncasi.org

Dr. George Ice, Principal Investigator
GIce@wcrc-ncasi.org

National Council for Air and Stream Improvement
PO Box 458
Corvallis, OR 97339
Phone: 541-752-8801
Fax: 541-752-8806

Historic Alsea Watershed Study Data

Historic data was obtained from Alsea Watershed Study publications cited in this thesis and through the U.S. Geologic Survey's Nation Water Information System. The direct link to pages containing streamflow records for the Alsea Watershed Study period is http://waterdata.usgs.gov/or/nwis/. Table B.1 provides the "Site Number" for accessing each stream's record.

Table B.1. USGS Site Numbers for the Alsea Watershed Study streams.

Stream	*USGS Site Number*
Flynn Creek	14306800
Needle Branch	14306700
Deer Creek	14306810

APPENDIX C

Stage-Discharge Relationships for the 2006 Water Year

Stream discharge at the Alsea Watersheds Study streams has historically been estimated using stage-discharge relationships, or ratings, developed by the U.S. Geological Survey for the broad-crested v-notch weirs installed during the original study. Adjustments to the ratings were occasionally made to account for shifts in the relationships, usually caused by sediment changing the channel and stilling pool configuration. Dr. John Stednick continued with adjustments as he re-instrumented the gauges for the New Alsea Watershed Study. He provided the Alsea Watershed Study Revisited the most recent results of his adjustments for determining discharge in the 2006 water year. Manual discharge methods were made throughout the year using the velocity-area method to check for any short-term shifts and also to validate the provided ratings. The manual measurements confirmed that the Needle Branch and Deer ratings were accurate. However, there was a discrepancy in measured versus estimated discharge for the lower range of stages at Flynn Creek. This was corrected by using the results of the manual measurements to model a new relationship for this lower range of stages. The resulting rating for Flynn Creek consists of an equation for stages 1.80 to 3.29 feet (Equation 1) and a lookup table for stages of 3.30 to 4.80 feet (Table C.1). Table C.2 provides the lookup table for the Needle Branch stage-discharge relationships. Equations 2 and 3 represent the relationships for Deer Creek at stages of 0.80 to 1.29 feet and 1.30 to 4.40 feet, respectively.

For Flynn Creek stages (ht) of 1.80 to 3.29 feet:

$$\textit{Discharge } (cf\ s^{-1}) = 6.765*ht^{2}-23.831*ht+21.017 \quad \textit{Equation 1.}$$

For Deer Creek stages (ht) of 0.80 to 1.29 feet:

$$\textit{Discharge } (cf\ s^{-1}) = 0.8027*ht^{4.2104} \quad \textit{Equation 2.}$$

For Deer Creek stages (ht) of 1.30 to 4.40 feet:

$$\textit{Discharge } (cf\ s^{-1}) = 0.7739*ht^{3.8241} \quad \textit{Equation 3.}$$

Table C.1. Lookup table for Flynn Creek discharge based on stages (ht) 3.30 to 4.80 feet.

Stage (ft)	Discharge ($cf\ s^{-1}$)
3.30	16.40
3.40	19.80
3.50	23.80
3.60	28.60
3.70	34.00
3.80	40.00
3.90	46.50
4.00	54.00
4.10	62.00
4.20	71.00
4.30	81.00
4.40	92.00
4.50	105.00
4.60	119.00
4.70	134.00
4.80	150.00

Table C.2. Lookup table for Needle Branch discharge based on stage.

Stage (ft)	Discharge ($cf\ s^{-1}$)	Stage (ft)	Discharge ($cf\ s^{-1}$)	Stage (ft)	Discharge ($cf\ s^{-1}$)
1.00	0.02	1.35	0.47	1.70	2.02
1.01	0.02	1.36	0.49	1.71	2.09
1.02	0.02	1.37	0.52	1.72	2.16
1.03	0.03	1.38	0.54	1.73	2.23
1.04	0.03	1.39	0.57	1.74	2.30
1.05	0.04	1.40	0.60	1.75	2.37
1.06	0.04	1.41	0.63	1.76	2.44
1.07	0.05	1.42	0.65	1.77	2.51
1.08	0.06	1.43	0.68	1.78	2.59
1.09	0.07	1.44	0.71	1.79	2.67
1.10	0.08	1.45	0.74	1.80	2.75
1.11	0.08	1.46	0.78	1.81	2.84
1.12	0.09	1.47	0.81	1.82	2.93
1.13	0.10	1.48	0.84	1.83	3.02
1.14	0.12	1.49	0.88	1.84	3.11
1.15	0.13	1.50	0.92	1.85	3.20
1.16	0.14	1.51	0.96	1.86	3.30
1.17	0.16	1.52	1.01	1.87	3.40
1.18	0.17	1.53	1.06	1.88	3.50
1.19	0.19	1.54	1.11	1.89	3.60
1.20	0.20	1.55	1.16	1.90	3.70
1.21	0.21	1.56	1.21	2.00	5.00
1.22	0.22	1.57	1.26	2.10	6.70
1.23	0.24	1.58	1.31	2.20	9.00
1.24	0.26	1.59	1.36	2.30	12.00
1.25	0.27	1.60	1.41	2.40	15.00
1.26	0.29	1.61	1.47	2.50	18.50
1.27	0.31	1.62	1.53	2.60	22.00
1.28	0.32	1.63	1.59	2.70	26.00
1.29	0.34	1.64	1.65	2.80	30.00
1.30	0.36	1.65	1.71	2.90	34.50
1.31	0.38	1.66	1.77	3.00	39.00
1.32	0.40	1.67	1.83	3.10	44.00
1.33	0.42	1.68	1.89	3.20	49.00
1.34	0.44	1.69	1.95		

APPENDIX D

Procedures for Developing Turbidity-Suspended Sediment Concentration Relationships

Introduction

Annual suspended sediment yield (SSY) was estimated by developing a suspended sediment concentration (SSC)-turbidity relationship. The relationship, or rating, was modeled based on the results of SSC samples collected during the course of the year. SSC samples were triggered by changes in turbidity, which is the best known surrogate for SSC. Instantaneous SSC was then estimated based on *in situ* turbidity values measured at ten-minute intervals. The instantaneous SSC values were combined with the associated instantaneous discharge estimates to provide an estimate of instantaneous SSY. The instantaneous SSY values were then extrapolated across the ten-minute intervals to provide a continuous record of SSY at each gauge location. Annual SSY was calculated as the sum of the continuous SSY for the entire year. The remainder of this appendix provides step-by-step details for this procedure.

Methods

Data Reduction: The turbidity and stage records, in conjunction with laboratory SSC results, were used to estimate the annual SSY at each gauging location. The turbidity probe uses an optical sensor, which is subject to fouling from debris, aquatic insects, biofilms, and basically any other non-turbidity related influence that obscures its "field of vision" from a representative view of stream water. Fouling results in the collection of erroneous data which must be either culled

or adjusted within the dataset. A software package, TTSAdjuster, was designed to facilitate this process. It is available at http://www.fs.fed.us/psw/topics/water/tts/adjuster/AdjusterInstall.htm.
The TTSAdjuster User's Manual presents the procedures used to develop a corrected turbidity record and is available at:
http://www.fs.fed.us/psw/topics/water/tts/adjuster/AdjusterManual.html.
Stream stage, measured at ten-minute intervals, was used to estimate discharge by applying the stage-discharge relationships presented in Appendix C.

Model Development: Laboratory suspended sediment concentration values were paired with the "adjusted" turbidities corresponding to the times at which the samples were collected. Linear regression was used to model SSC (mg l^{-1}) based on turbidity (Formazin Backscatter Units- FBU). Several transformations were applied to the data during the model development process in order to achieve the best possible fit (determined by highest R^2 value) while meeting the constant variance and normality assumptions of the regression procedures. The attempted transformations included logging, square rooting, and squaring either the independent (turbidity) or dependent (SSC) variables, or both. This process, applied to the data record as a whole, yielded unsatisfactory results. A second effort to find a best-fit model while also meeting the model assumptions involved separating the data into turbidity ranges that had similar slopes in the SSC-turbidity scatterplot. Each range of turbidities and associated SSC values was subsequently modeled. Again, transformations were also applied. Several combinations of turbidity ranges were attempted. All resulting models with acceptable fits and which met the constant variance and normality assumptions were then compared.

Model Comparison: To compare the models, annual SSY was estimated with each model. As previously mentioned, annual SSY was determined by estimating an instantaneous SSC with each turbidity-SSC model. The instantaneous SSC (mg l^{-1}) was converted to instantaneous SSY (mg s^{-1}) by multiplication with the instantaneous discharge (l s^{-1}) for that measurement point. The instantaneous SSY was then extrapolated across the ten-minute period over which that point represented to provide a continuous measure of SSY. The annual SSY was then estimated by summing the continuous SSY values over the annual record.

The models which had the best fit and which best met the linear regression assumptions were given first priority in the comparison. However, transformations introduce a certain amount of bias into the model results. Therefore, in the case of multiple models with similar fit and similar results, the simpler model was chosen (simpler = fewest transformations and fewest parameters).

Results

The procedures described above resulted in a two-phased model for estimating SSC at Flynn Creek. For turbidities (t) less than or equal to 20 FBUs:

$$SSC\ (mg\ l^{-1}) = -11.643 + 1.5088*t \qquad \textit{Equation 1.}$$

For turbidities (t) greater than 20 FBUs:

$$SSC\ (mg\ l^{-1}) = -37.806 + 3.1683*t \qquad \textit{Equation 2.}$$

A two-phased model was also chosen for Needle Branch. For turbidities (t) less than or equal to 19 FBUs:

$SSC\ (mg\ l^{-1}) = -17.037 + 1.9309*t$ *Equation 3.*

For turbidities (t) greater than 19 FBUs:

$SSC\ (mg\ l^{-1}) = -39.39 + 3.031*t$ *Equation 4.*

A three-phased model was chosen for Deer Creek. For turbidities (t) less than or equal to 27 FBUs:

$SSC\ (mg\ l^{-1}) = -26.219 + 1.6119*t$ *Equation 5.*

For turbidities (t) greater than 27 and less than or equal to 50 FBUs:

$SSC\ (mg\ l^{-1}) = -106.29 + 3.9755*t$ *Equation 6.*

For turbidities (t) greater than 50 FBUs:

$SSC\ (mg\ l^{-1}) = -31.877 + 2.1576*t$ *Equation 7.*