A Spatial and Temporal Analysis of Riparian Vegetation along Satus Creek on the Yakama Indian Reservation

Kathryn Gellenbeck
Central Washington University

A SPATIAL AND TEMPORAL ANALYSIS OF RIPARIAN VEGETATION

ALONG SATUS CREEK

ON THE YAKAMA INDIAN RESERVATION

A Thesis

Presented to

The Graduate Faculty

Central Washington University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

Resource Management

---

by

Kathryn Gellenbeck

May, 1999

CENTRAL WASHINGTON UNIVERSITY

Graduate Studies

We hereby approve the thesis of

Kathryn Anne Gellenbeck

Candidate for the degree of Master of Science

APPROVED FOR THE GRADUATE FACULTY

5-25-99 — Morris Uebelacker, Committee Chair

5/25/99 — Lisa Ely

5/25/99 — Douglas N. Reynolds

6/14/99 — Raymond Z. Riznyk
Associate Dean of Graduate Studies

ABSTRACT

A SPATIAL AND TEMPORAL ANALYSIS OF RIPARIAN VEGETATION ALONG SATUS CREEK ON THE YAKAMA INDIAN RESERVATION

by

Kathryn Anne Gellenbeck

May, 1999

Satus Creek provides critical habitat for the Yakima River Basin steelhead. A diverse community of riparian vegetation is important for healthy fish habitat; vegetation changes can affect shade, cover, channel structure, water quality, and food availability. The purpose of this thesis is to analyze and illustrate riparian vegetation change, both temporally and spatially, along three separate reaches of Satus Creek. A Geographic Information Systems approach was applied to assess the vegetation change by comparing plant species composition and density on 1949 and 1995 aerial photographs. The GIS approach allowed patterns and trends in the vegetation to be identified. In less than fifty years, a significant shift from woody to herbaceous species has occurred. Black cottonwood (*Populus trichocarpa*) population size has decreased and white alder (*Alnus rhombifolia*) population size has increased. This thesis links these and other vegetation patterns occurring along Satus Creek to land use practices in the watershed.

ACKNOWLEDGEMENTS

Throughout this endeavor, many people have encouraged, supported and believed in my ability to accomplish this goal. I would like to acknowledge and thank those who have helped me along the way. First and foremost, I would like to thank the Yakama Indian Nation who granted me permission to perform this research. I would also like to thank the Satus Creek Restoration Team without whom this project would have never been developed. In particular, I want to thank Dave Lind. He has gone over and above his call of duty and without his unyielding support, expertise, advise, and friendship, I may never have gotten to this point.

I wish to express my appreciation to each of member of my committee for their contribution to this research. Dr. Morris Uebelacker has been a positive influence throughout my graduate schooling and was invaluable as my committee chair. His constant belief in my research and my ability to complete this thesis was a motivating factor for me. I am indebted to Dr. Uebelacker for his support and assistance. I also owe a debt of gratitude to Dr. Doug Reynolds and Dr. Lisa Ely. They provided me with the technical expertise needed for this thesis and were always willing to assist me with any problems I encountered.

The support, encouragement and humor from my friends and family helped me face the challenges of completing this thesis. My brother, Dr. Edward Gellenbeck has assisted me in so many ways that I will always be grateful to him. His steady and dependable nature has been a reassuring influence during these three years. Lisa Anderson was also a great support and always reminded me of what I would

accomplish when my motivation wavered. Lastly, I would like to dedicate this thesis to my beloved sister, Diane Gellenbeck who always supported and believed in my abilities even before I recognized them.

TABLE OF CONTENTS

LIST OF TABLES

TABLES **PAGE**

LIST OF ILLUSTRATIONS

FIGURE **PAGE**

CHAPTER I

INTRODUCTION

Since time immemorial, Yakama Indians and salmon have co-existed in the Columbia River Basin. The continued survival of salmon is essential to the Yakama Indians because salmon represent a part of their spiritual and cultural identity (Nez Perce Tribe et al. 1996, 2-4). Yakama oral literature records how Coyote freed the salmon from the five sisters and brought the salmon up the Columbia River and into the Yakima River Basin. The legend even speaks of Satus Creek and that "There the women treated him right, and he gave them plenty of salmon. Thus, salmon go up that stream." (John 1917, 125). Satus Creek and the salmon that reside there are the impetus for this thesis. This thesis focuses on changes in riparian vegetation along Satus Creek, a significant habitat area for salmon, on the Yakama Indian Reservation.

The Satus Creek watershed is the most important production area for the wild population of Yakima River summer steelhead (*Oncorhynchus mykiss*), a threatened salmon species (Satus Creek Watershed Restoration Team 1998, unnumbered). Satus Creek is a tributary of the Yakima River, which flows into the Columbia River. In recent years, Satus Creek summer steelhead has accounted for nearly half of the entire Yakima River Basin steelhead population while the Satus Creek watershed accounts for less than ten percent of the Basin area. These fish, though once prolific throughout the Yakima River Basin, are now limited to a few streams.

The riparian zone or riparian ecosystem is the transitional area between aquatic and terrestrial ecosystems. A riparian ecosystem is identifiable by soil characteristics, vegetation composition, and the presence of free or unbound surface waters (Hansen et al. 1995, 644). Typically, riparian ecosystems are a mosaic of plant communities with an unusually high level of biodiversity (Naiman, Decamps, and Pollack 1993, 209). The hydrology, climate, and substrate of a watershed influence the structure and function of the riparian ecosystem because these physical factors determine the composition of the vegetation (Swanson et al. 1982, 268).

Since Clements' concept (1916) of plant succession was first published, the study of vegetation change has interested plant ecologists. While the dynamics of vegetation change are complex and still not well understood, it continues to be a primary focus of research by plant ecologists. Riparian ecosystems provide many research opportunities to study vegetation changes that may result from environmental gradients, disturbance, and/or competition.

Studying vegetation change provides insights about the dominant processes and linkages controlling and influencing ecosystem structure and dynamics (Montgomery, Grant and Sullivan 1995, 375). In riparian ecosystems, disturbance regimes strongly influence riparian vegetation structure and function. In turn, riparian vegetation influences the structure and function of the stream channel. The disturbance regime of Satus Creek watershed has been and is being influenced by a complex interplay of human-induced and natural forces. The interconnection between these dynamic systems and the influence of disturbance on the patterns of riparian vegetation is central to this thesis because of their implications for Satus Creek steelhead. By analyzing changes in the vegetation structure, trends and patterns emerge that will assist in restoration decisions.

The ability to study landscape-level vegetation change both spatially and temporally has become more sophisticated with the advent of Geographical Information Systems (GIS). GIS is a computer-based system capable of storing, analyzing, and displaying spatial information. It allows the user to capture and process remotely sensed data for large areas, a complex task prior to its advent. The user is then able to analyze and display spatial and temporal data to determine patterns within the landscape (Haines-Young. Green, and Cousins 1993, 4). GIS has been a useful tool in the analysis of Satus Creek riparian vegetation.

PROBLEM STATEMENT

Wild steelhead in the Yakima Basin are at a small fraction of historic population levels, with some sources stating that the majority of Yakima Basin steelhead are now being produced in the Satus Creek watershed (National Marine Fisheries Service (NMFS) and National Oceanic and Atmospheric Administration (NOAA) 1999, 14525). The Satus Creek watershed steelhead population is designated as part of the Middle Columbia River Evolutionarily Significant Unit (ESU) and in March 1998 this ESU was proposed for listing as a threatened species under the Endangered Species Act (ESA) (NMFS and NOAA 1998, 11797). The NMFS took further action in March 1999 and listed the Middle Columbia River ESU as threatened under the ESA (NMFS and NOAA 1999, 14517). The vulnerable condition of the Satus Creek steelhead population is the ultimate problem of this thesis. To help address this problem, this thesis researches the past and present condition of riparian vegetation along Satus Creek that will assist in restoration of fish habitat.

Research Justification

The Yakama Indian Nation (YIN) is currently undertaking a restoration project for the Satus Creek watershed that is being funded by the Bonneville Power Administration (BPA). The project goal is to restore productive salmonid spawning and rearing habitat to its historical extent in the Satus Creek watershed. One part of the restoration plan is to assess the historical and current conditions of riparian vegetation along Satus Creek. An understanding of historic riparian vegetation conditions is useful when making restoration management decisions; however, no such data were available for Satus Creek prior to the completion of this thesis. Without such data, spatial and temporal patterns of riparian vegetation change cannot be identified or monitored.

The present condition of the riparian vegetation and the general stream channel for Satus Creek appears to be in a degraded state. According to Elmore and Beschta (1987, 261-262), a degrading riparian area has limited vegetation to protect the stream banks and provide shade. Summer streamflows are low and warm making fish habitat poor during these months. The diversity of wildlife habitat is also limited and forage production is low. Lastly, subsurface storage of water is reduced.

Riparian vegetation plays an important role in fish habitat and the condition of the stream channel. If the productivity of riparian vegetation decreases and species composition simplifies, then stream channels can become wider and shallower, stream banks can become unstable, and water temperature can increase (Platts 1983, 184). These stream changes adversely affect fish species by reducing fish habitat and food production.

PURPOSE OF THE STUDY

The purpose of this thesis is to illustrate and analyze riparian vegetation change, both temporally and spatially, along three separate reaches of Satus Creek. The vegetation analysis performed for this thesis determines the distribution and density of riparian vegetation utilizing aerial photographs and GIS. Although individual plant species are of interest, this thesis is based on mapping changes in plant associations. The production of baseline data is a significant contribution of this thesis because the YIN will be able to use it to conduct future research on the vegetation dynamics of Satus Creek.

Linking land use activities to the patterns and trends in riparian vegetation change is a daunting task; however, it is another objective for this thesis. Some human and natural disturbances that have contributed to the riparian vegetation and stream morphology changes include logging, road construction, diking, fires and the suppression of fires, livestock and feral horse grazing, and flooding.

A quantitative analysis of depositional bars for years 1949, 1964, 1979, 1995, and 1997 is also presented in this thesis. This analysis will provide a better understanding of the influence of Satus Creek on the riparian vegetational patterns and trends. It will also reveal trends in stream channel morphology and its impact on steelhead habitat.

METHODS OF ORGANIZATION AND RESEARCH

Aerial photographs provided the historical and current conditions of riparian vegetation and depositional bars along three separate reaches of Satus Creek. Aerial photographs also allowed the temporal data to be linked spatially through the construction of a GIS database. Once the spatial and temporal database had been established, quantitative analysis and spatial modeling was conducted utilizing ARC/INFO, a GIS developed by Environmental Systems Research Institute (ESRI).

A literature review of the role of disturbance regimes in riparian systems and the role of riparian vegetation in fish habitat is presented in Chapter II. These topics of research are important because they help the investigator to understand the dynamics occurring within riparian zones. They also assist in understanding how shifts in the vegetation dynamics can affect steelhead habitat.

Two dominant trees, white alder (*Alnus rhombifolia*) and black cottonwood (*Populus trichocarpa*), are present along Satus Creek. These two species are of interest because a shift in their density appears to be occurring. The autecology of these two species, also presented in Chapter II, provides insights into the meaning of the vegetation shifts occurring along Satus Creek.

Chapter III describes the physical geography of the Satus Creek watershed, land use practices, and the characteristics of the three stream reaches examined. In Chapter IV, the methods and techniques utilized to produce the GIS database, including data classification, capture, and processing, are explained. Chapter V presents the results for the three stream reaches studied including quantification of ground cover and depositional bars, vegetation age structure, and overstory and understory composition.

Chapter VI discusses the observed vegetational patterns and trends occurring along Satus Creek. Plausible linkages between riparian vegetation change and natural and human-induced disturbances are presented in this discussion, as well as recommendations on how to better understand the riparian vegetation change, and improve the existing conditions. The last chapter, Chapter VII, summarizes the research findings on the past and current conditions of Satus Creek riparian zone.

CHAPTER II

REVIEW OF LITERATURE

In this chapter, the literature reviewed is separated into two sections. First, the role of disturbance regimes in riparian ecosystems is discussed to assist the reader with understanding the dynamics of riparian vegetation. This information will be helpful when discussing the riparian vegetation patterns observed along Satus Creek. The second part of this chapter reviews the role of riparian vegetation in fish habitat in order to make clear the importance of healthy riparian vegetation in restoration of fish populations.

THE ROLE OF DISTURBANCE REGIMES IN RIPARIAN ECOSYSTEMS

Disturbance events play a significant role in defining the spatial and temporal properties of a riparian system and are important in the maintenance of both species and processes (Gregory et al. 1991, 540; Reice 1994, 48-49; Scott, Friedman and Auble 1996, 327; White and Pickett 1985, 7). Natural disturbances, such as floods, beaver activity and fires, have affected the riparian vegetation of Satus Creek; some human influences affecting the riparian vegetation have included logging, road construction, and livestock grazing. The following section defines a disturbance so that the reader will understand how it is being used in this thesis. Next, the types of disturbance events in riparian ecosystems and how they influence riparian community structure are presented. Lastly, the function of disturbances in plant colonization is explained.

Definition of a Disturbance

A disturbance is defined as "any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment." (White and Pickett 1985, 7). Continuing with this definition, a natural disturbance was classically believed to be an exogenous factor that acts at a single point in time, creates abrupt patches within the system and changes landscape patterns. Furthermore, a disturbance is the "mechanism which limits the plant biomass by causing its partial or total destruction." (Grime 1979, 39).

In theory, a system returns to the physical and biological parameters before the disturbance through autogenesis and the disturbance has functioned to "reset" the successional clock of the ecosystem. However due to natural restrictions, this may not occur. In these cases, the disturbance has merely introduced stochastic influences on community composition and reduced the predictability of the system's response (White and Pickett 1985, 7-9).

Types of Riparian Disturbance Events

Typically, there are two types of riparian disturbance events, chronic and episodic, each having different roles. Chronic events, such as annual flooding, are important for creating freshly disturbed environments for plant colonization. Episodic events, such as debris flows or high intensity floods, are most notable for shaping the floodplain components, particularly the stream channel and riparian vegetation (Franklin 1992, 28). Both types of disturbance events can create depositional bars that are important germination sites for black cottonwood and white alder.

The frequency and intensity of the disturbance events are important factors to understand when making management decisions because they can restructure the whole ecosystem. From this knowledge, inferences to the current condition can be made (Montgomery, Grant, and Sullivan 1995, 375). A frequent and intense disturbance regime may reduce or eliminate the dominant plant competitors, therefore allowing colonizing species to become dominant. This shift in species composition may result in reduced species richness. An intermediate disturbance regime leads to maximum species richness because some dominant species persist in the system along with colonizing species (Reice 1994, 428). Ultimately, the distribution of riparian vegetation is determined by its ability to tolerate geomorphic processes (disturbance regimes) at the severe end of the stress-equilibrium gradient (Hupp and Osterkamp 1996, 277-78).

Plant Colonization

In riparian communities, plants tend to grow rapidly following a disturbance. The first plant species to become established are at an advantage because they benefit from the greater availability of resources. Species arriving early and those species with faster growth rates restrict the success rate of certain seedlings by competing for sunlight, water, and nutrients. For example, woody riparian species are restricted to a relatively brief establishment period following a disturbance. This gives herbaceous species a competitive advantage because of their early arrival time and large reproductive effort (Canham and Marks 1985, 199). Seedling germination and forest regeneration may also be stimulated or arrested depending on the duration of the flood event. These complex reproductive requirements contribute to the dynamic nature of riparian ecosystems.

Black cottonwood and white alder are two dominant pioneer species occurring along Satus Creek whose germination is dependent on disturbance events. Black cottonwoods are a dioecious species that colonize germination sites by wind and water-dispersed seeds released from May to June. The seeds remain viable for one to two weeks but must have bare moist soil for 24 hours and abundant sunlight if they are to germinate. Cottonwoods reach sexual maturity after eight to ten years and typically live from 100 to 200 years (Braatne, Rood, and Heilman 1996, 58, 62, 64).

The short time frame of seed viability is a limiting factor in the life cycle of black cottonwoods. The possibility of germination is increased by the fact that seed dispersal typically coincides with declining stream flows following springtime snowmelt and storm flows (Braatne, Rood, and Heilman 1996, 65). Because cottonwoods are prolific seed producers, germinating seeds and seedlings are typically found in large numbers on stream bars that have freshly deposited alluvium. Abundance of sunlight and soil moisture are closely correlated with the growth and development of seedlings (Rood and Mahoney 1990, 456). Extensive mortality of seedlings results from flood events, however, cottonwoods are tolerant of burial and able to sprout from stems and roots. Cottonwoods will not germinate under existing stands due to the lack of sunlight and abundance of plant litter. They also are poor competitors in vegetated sites. These requirements for seed germination usually result in even-aged stands (Scott, Friedman, and Auble 1996, 328).

Information pertaining to autecology of white alder is limited. Red alder (*Alnus rubra*) is considered sympatric with white alder and can therefore be used for general information on life history. Alders are short-lived, nitrogen-fixing species that exhibit rapid juvenile growth. These aggressive, early seral species are monoecious, reaching sexual maturity between three and eight years of age. While seed production varies among trees, they are generally believed to be a prolific and consistent producer of seeds. The requirements for seed germination tend to be similar to cottonwoods, except that alder require less sunlight (Harrington, Zasada, and Allen 1994, 12).

Studies have found that white alders are restricted to perennial watercourses and are tolerant of severe floods, but do not recover swiftly from fire (Bendix 1994, 146; Dains 1988, 375). In the canyons of the Snake, Salmon and Clearwater rivers of

Idaho, Miller (1976) found that disturbance events ensure that white alder will be a component of the flora. White alder requires both a stable substrate and shallow rooting depth to year-round moisture. These requirements allow them to establish along low-flow margins even though they are continuously inundated during the wet season. By growing along the low-flow margins, they stabilize the stream banks by adding root strength and reducing shear stress (Lisle 1989, 13). White alders proximate to Satus Creek are typically in multi-trunk stands, but older trees removed from the active channel occur singly.

Environmental factors such as flooding, disease, shade, herbivory, root competition, and occasional droughts all limit the success of germination and survival of riparian plant species. When the germination of a certain species is prevented, the mosaic of plant communities becomes altered. The result of this shift in community structure may be less biodiversity within the riparian zone because species richness and evenness is adversely affected (Reice 1994, 49).

THE ROLE OF RIPARIAN VEGETATION IN FISH HABITAT

The structure and function of stream ecosystems are largely influenced by their interactions with riparian ecosystems (Williams, Wood, and Dombeck 1997, 6). The close connection between these systems is important to remember when considering healthy fish habitat. Riparian vegetation improves fish habitat by increasing channel complexity, hiding cover, stream bank stability, and nutrient input, while decreasing stream sedimentation and water temperature (Budd, Cohen, and

Saunders 1987, 588; Platts 1983, 184). The following section reviews literature on the functions of riparian vegetation in fish habitat and includes Satus Creek data where available.

Fish Cover

Overhanging woody vegetation hides juvenile fish from predators and provides resting habitat. These calm, shaded areas are also important for adult salmon that need to conserve energy for spawning. Research on the effects of in-stream habitat development that included overhanging stream bank shelter found that wild brook trout (*Salvenlinus fontinalis*) populations increased substantially during the six-year period after installation of the structures (Hunt 1976, 361). Specifically, Hunt found that mean annual biomass of trout, mean annual number of trout over 15cm, and overall mean production all increased with the maximum numbers occurring in the sixth year.

A study conducted by Wesche, Goertler, and Frye (1987, 151-153) also found that overhead bank cover was the most significant factor in determining variation in trout population size among several small streams. They believed that overhanging vegetation, logjams and undercut banks created niches that increased the trout carrying capacity in their study.

Riparian trees are also the source of in-channel large woody debris (LWD) that serves as important fish cover. LWD creates pools and riffles while dissipating energy and reducing stream flow velocity. These deep, low velocity pools offer protection for rearing and over-wintering juveniles, and holding areas for adult fish prior to spawning. Complex habitat created by LWD provides "velocity shadows" that allow fish to conserve energy, with faster water nearby providing feeding opportunity.

In the Satus Creek watershed and elsewhere on the Yakama Indian Reservation, spawning ground surveys have shown an association between steelhead redds and overhanging shrubs along the stream banks (Lind 1999, personal communication). Another trend present on Satus Creek that relates to fish cover is that LWD appears to be deficient over long reaches. To compensate for the perceived lack of natural LWD, a restoration project was carried out that placed mature ponderosa pine (*Pinus ponderosa)* with massive root wads in Satus Creek during the summer of 1997. Importantly, this occurred in stream reach 1, one of the study reaches for this thesis and a significant spawning area for steelhead.

Stream Bank Stability

Riparian vegetation stabilizes stream banks by dissipating erosive energy, trapping fine sediment, and by protecting banks from ice flows, debris flows, and animal trampling. A dense network of roots can remain even when undercut by stream flow. Often fish are adapted to this habitat edge because stable, well-vegetated stream banks control water velocity and temperature, provide cover, and contribute terrestrial food. The stream bank condition influences the water depth and velocities that are important criteria for fish habitat (Platts 1983, 186).

A diverse riparian zone with different root types is best for protecting banks and increasing bank stability. The larger woody roots of trees and shrubs provide physical protection of the stream banks from strong hydraulic forces because they are deep growing. The smaller fibrous roots of herbaceous vegetation help to bind fine particles together. It is this combination of root types that is important in forming and protecting the interface of terrestrial and aquatic habitat (Platts 1983, 185).

Large woody debris is one of the most dominant elements in the physical structure of streams. LWD not only creates fish habitat directly, as discussed above, but it is important in determining stream reach characteristics. It is believed that LWD affects stream geometry by directing stream processes toward achievement of dynamic equilibrium (Heede 1985, 54). Stream equilibrium occurs when aggradation and degradation are in balance. In small streams, LWD creates a stair-stepped profile that levels the overall stream gradient and assists in obtaining stream equilibrium. The streambed becomes a series of long, low gradient sections separated by short, steep falls (Naiman et al. 1992,160). As water flows over these log steps energy is dissipated, resulting in lower flow velocities and less erosion of the stream bed and stream banks (Heede 1985, 56).

Stream Sedimentation

High concentrations of fine sediments in stream channels can negatively affect fish and other aquatic life. Rearing pools and spawning areas become blanketed with sediment which decreases the flow of oxygen-bearing water through gravel substrates and eventually suffocates eggs and developing fry. Fish may suffer from gill abrasion and fin rot when suspended sediments exceed 200 mg/L for several days. Food sources such as algae and macroinvertebrates can also be eliminated (Hooper 1994, 27). Salmonids may avoid these waters and even cease or delay migration (Knutson and Naef 1997, 23).

The YIN has determined that excessive levels of fine sediment are present in steelhead spawning areas in Satus Creek. A 1993 study found that five of the eight spawning riffles analyzed in Satus Creek contained more than 17% fine particles (Lind 1996, 2). Levels greater than 17% are considered "poor" according to Washington watershed analysis criteria because they interfere with spawning and egg incubation (Washington Forest Practice Board 1995, F-23).

While maintaining bank stability, riparian vegetation also reduces suspended sediment in the water. Riparian vegetation acts as a physical filter that captures suspended sediment by providing hydraulic roughness along channel margins and floodplains. The vegetation also physically reduces stream flow velocity that causes the suspended sediment to drop. Multi-stemmed plants, such as willows, are especially beneficial when it comes to impeding flow velocity and filtering sediments because of their large surface area (Debano and Hansen 1989,146). LWD also catches sediments by functioning as an in-channel barrier (Platts 1983, 184). By trapping suspended sediment and reducing stream flow velocity, vegetation actually helps to build and protect channel banks that produce healthy fish habitat.

Riparian vegetation also creates buffer strips that inhibit surface flow sediments from entering the stream. Plant litter and humus intercepts overland flow and allows the water to infiltrate the ground and eventually be returned to the stream (Knutson and Naef 1997, 23). Heede (1990) determined that 61 times more sediment was delivered when ponderosa pine buffer strips were missing. The width of buffer strips should be based on the slope gradient because areas with steep slopes will need larger buffers (Heede 1990, 4).

Water Temperature and Dissolved Oxygen

Water temperature is a critical characteristic of fish habitat and influences almost all aspects of salmonid life history. Findings show that steelhead respond negatively to water temperature increases. The following can occur: decreases in individual and population growth rates, cessation of downstream migration, increases in disease organisms and algae, and increases in fish mortality (US Army Corps of Engineers 1990, 11.4).

Preliminary evidence for Satus Creek suggests that water temperature is the most critical water quality parameter (Satus Creek Watershed Restoration Team 1998, unnumbered). Much of Satus Creek becomes too warm during summer to rear steelhead (Lind 1999, personal communication). From comparing aerial photographs, it is apparent that the stream channel has become wider with water depths probably shallower since 1949. This trend, combined with the removal of streamside vegetation, may be the principal reason why water temperatures are above critical thresholds today.

Streamside vegetation, especially tree canopy, helps to moderate stream temperatures. During summer, streamside vegetation shades the stream channel and reduces stream temperatures by intercepting solar radiation. During the winter, streamside vegetation prevents rapid cooling and freezing of the stream. Freezing water can produce anchor ice that increases fish mortality. Anchor ice can also reduce water interchange in the substrate, restricting oxygen uptake by fish eggs incubating during the winter (Knutson and Naef 1997, 22; Platts 1983, 187).

An adequate concentration of dissolved oxygen is necessary for fish and other aquatic organisms to survive. Water temperatures and dissolved oxygen are inversely related: as stream temperature increases, the concentration of dissolved oxygen decreases (Platts 1983, 186). Rising water temperatures increase metabolic demands in all cold-blooded organisms while less oxygen is available to fuel accelerated metabolic processes. The shade created by riparian vegetation moderates water temperature thus allowing more dissolved oxygen to be present. Riparian vegetation also influences turbulence, photosynthetic activity, and decomposition, all of which affect the concentration of dissolved oxygen. In 1979, Fretwell determined that dissolved concentrations of oxygen in Logy and upper Satus Creeks were adequate for healthy fish life. Current data do not indicate that dissolved oxygen levels are a limiting factor in the Satus Creek watershed (Adams 1999, personal communication).

Nutrient Input and Macroinvertebrates

Another important function of riparian vegetation is its contribution to the food web. Approximately fifty percent of the stream's nutrient and energy supply comes from the organic material of riparian vegetation (Cummins 1974, 640). This organic material provides nutrients to macroinvertebrates, the primary food source for steelhead (Cummins 1974, 637). The roots, foliage, and deciduous litter associated with riparian vegetation also provide habitat for macroinvertebrates. Lowered density of riparian vegetation affects the diet of salmonids by reducing the amount of macroinvertebrates present in the stream (Chapman and Demory 1963, 144).

CHAPTER III

DESCRIPTION OF THE STUDY AREA

Riparian ecosystems are adjacent to both aquatic and upland ecosystems which therefore influence riparian structure and function. This chapter describes the physical characteristics of the Satus Creek watershed in order to provide the reader with an idea of the landscape surrounding the three stream reaches analyzed for this thesis. Stream and vegetation characteristics for the three study reaches are also described separately. General information on current and historic land use practices of the watershed affecting riparian ecosystems is also presented within this chapter.

SATUS CREEK WATERSHED

Location

The Satus Creek watershed is completely contained within the Yakama Indian Reservation located in the south central part of Washington State (Figure 1). This 1,489 square km (575 square

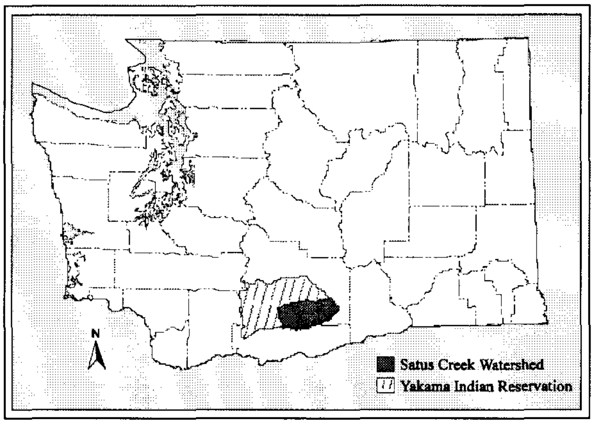


Figure 1: Satus Creek Watershed Location

mile) watershed comprises almost ten percent of the Yakima River Basin. Geographically, the watershed is found in the southeastern portion of the Reservation and is bounded by Toppenish Ridge to the north and Horse Heaven Hills to the south. The Yakima River is the eastern boundary for the watershed and the Simcoe Mountains form the western limit (Mundorff, Mac Nish, and Cline 1977, 2).

Physical Geography and Generalized Geology

The Satus Creek watershed is within the Yakima fold belt and is characterized by anticlinal ridges with intervening synclinal valleys. The majority of the watershed is rectangular in shape except for the portion that connects to the Yakima River (Figure 2). Figure 2 is a shaded relief map of the watershed that shows the prominent topographic features and the location of the three stream reaches examined by this thesis. The watershed is approximately 64 km (40 mi) in the east-west direction and 32 km (20 mi) in the north-south direction. Elevation ranges from approximately 1,768 m (5,800 ft) in the Simcoe Mountains to 198 m (650 ft) at the confluence of Satus Creek and the Yakima River.

The geology of the Satus Creek watershed consists of thick sequences of lava flows that comprise the Miocene-age Columbia River Basalt Group. The Yakima River Basalt is the uppermost formation of the Group and probably exceeds 1,500 m in thickness. It is also is the oldest rock found at the surface in the watershed. Geologists believe the source of these lava flows were fissures in the extreme southeastern corner of Washington and northeastern Oregon (Campbell 1984, 3, 10).

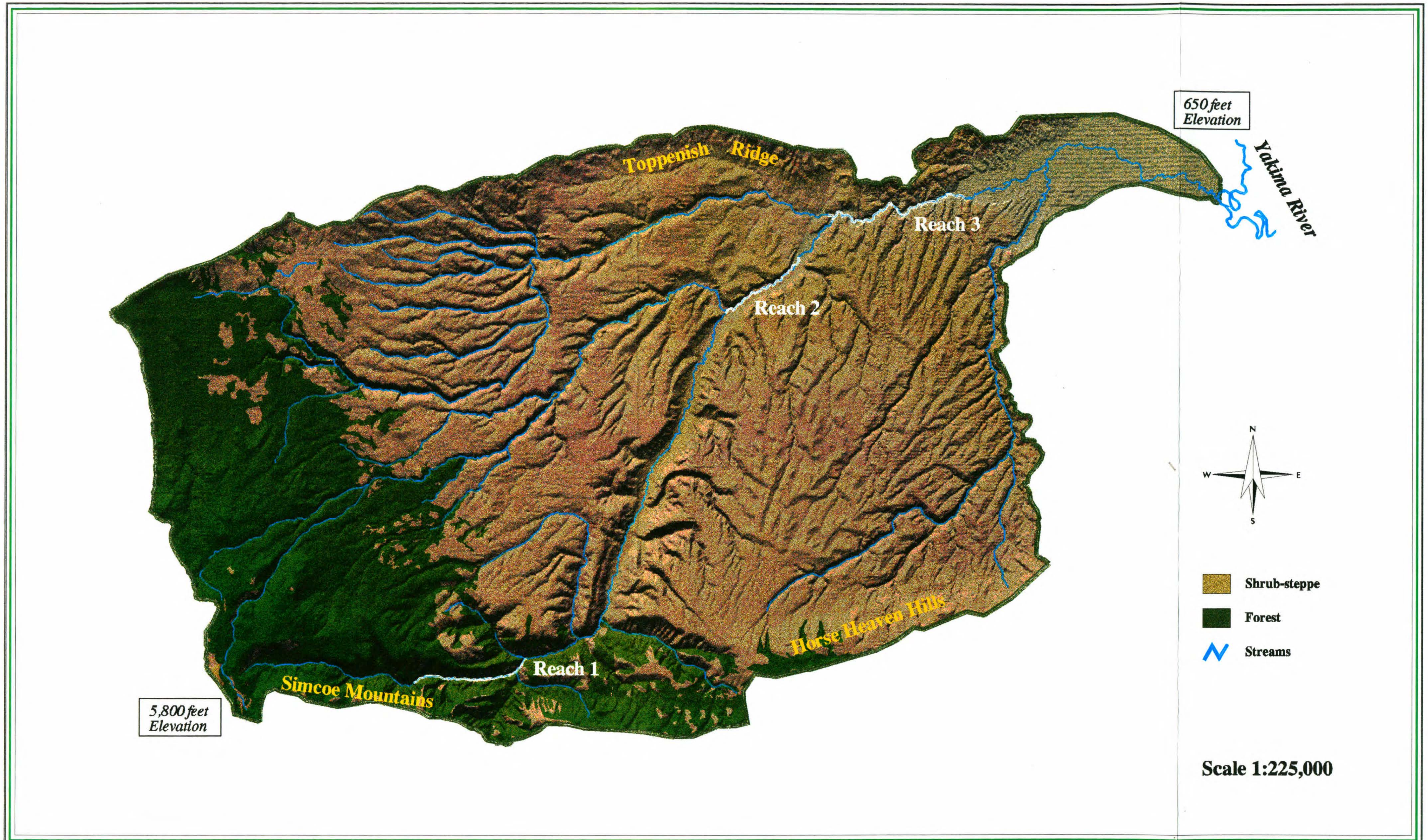


Figure 2: Topography of Satus Creek watershed with study reaches shown in white.

The geological processes that shaped the Satus Creek Watershed are subsidence, folding, and faulting of the Columbia River Basalt formations. The resulting anticlines, Toppenish Ridge and the Horse Heaven Hills, are the prominent topographic features and the divides for the drainage basin. Plateaus deeply incised by canyons characterize the watershed (Uebelacker 1984, 38). In the upland region, streams have eroded deep gorges in the basalt slope from the west to the east. Folds, faults, and joints control the stream courses in some areas (Mundorff, Mac Nish, and Cline 1977, 15).

Between lava flows, alluvial deposits were distributed from the north and west, producing what is called the Ellensburg Formation. The layers of gravel, sand, silt and clay were deposited on the uppermost basalt layers, as well as between the layers. In the late Pleistocene, outburst floods from Glacial Lake Missoula deposited a thick layer of fine-grained material referred to as the Touchet Beds. This layer of deposition is considered the most important disturbance event to have occurred in the lower Satus basin in the last 12,000 years (Mundorff, Mac Nish, and Cline 1977, 14).

Drainage Pattern

Satus Creek is the major drainage of the watershed and is approximately 71 km (44 mi) in length with an overall gradient of 1.9%. It begins at an elevation of 1,524 m (5,500 ft) on the northern slopes of the Simcoe Mountains and flows east from its headwaters for approximately nine miles while dropping 914 m (3,000 ft) in elevation through a deeply incised basalt canyon. The creek then changes direction by flowing northeast but continues to flow through basalt canyons as it loses another 305 m (1,000 ft) in elevation (Uebelacker 1984, 39). Although some of the lower portions of the creek are bordered by basalt cliffs, the valley bottom is up to one-half mile wide in some areas allowing the stream to meander, thus becoming wider and slower. Satus Creek eventually joins the Yakima River at river mile 69.6.

There are three main tributaries of Satus Creek: Dry, Logy, and Mule-Dry Creeks, each having unique stream flow patterns (Figure 3). Dry and Logy Creeks drain the northwestern part of the watershed. The Dry Creek subwatershed represents 409 square km (158 square mi) and the Logy Creek subwatershed represents 282 square km (109 square mi). Mule-Dry Creek drains approximately 259 square km (100 square mi) of the southeastern portion of the Satus Creek watershed. Both Dry and Mule-Dry Creeks have intermittent flows by late spring or early summer. Mule-Dry Creek flows into Satus Creek at river mile 8.5 and Dry Creek at river mile 18.5. Logy Creek is a unique tributary because it maintains year-round flow and enters Satus Creek farther upstream at river mile 23.6. The explanation for the continual stream flow of Logy Creek is the highly porous substrate of the portion of the Simcoe Mountains forming the Logy Creek headwaters (Mundorff, Mac Nish, and Cline 1977, 26).

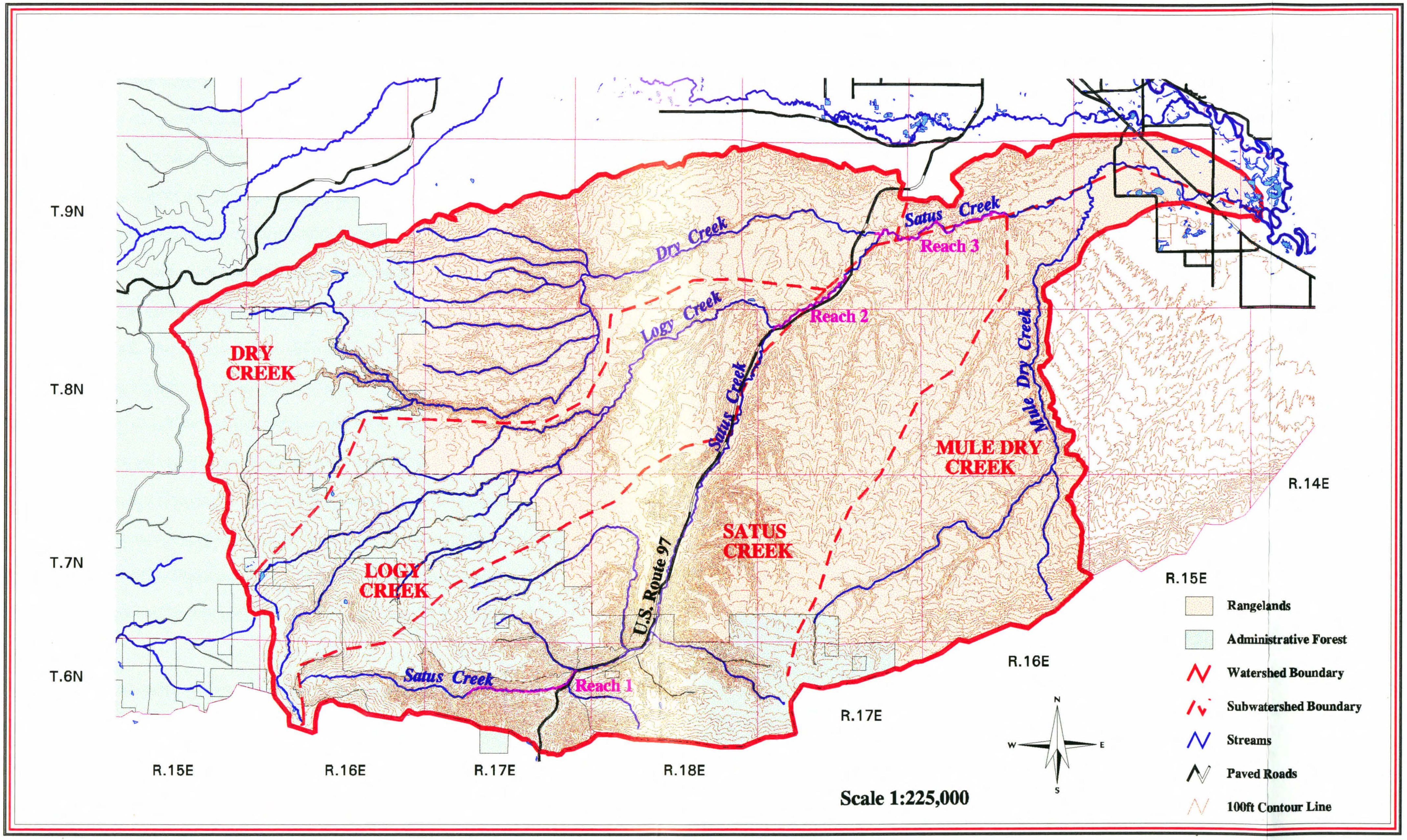


Figure 3: Subwatersheds, perennial streams and intermittent streams within the Satus Creek watershed. Study reaches are shown in magenta.

Climate

The Satus Creek watershed is located in the rain shadow of the Cascade Mountains causing precipitation to decrease eastwardly. In the southwestern region of the watershed, precipitation is approximately 89 cm (35 in), while the northeastern region receives less than 25 cm (10 in) (Mundorff, Mac Nish, and Cline 1977, 7). Precipitation is mostly in the form of snowfall with considerable amounts at higher elevations. By spring, snowpack typically begins to melt providing increased streamflow; however, some snowpack remains at the highest elevations until May or early June (Mundorff, Mac Nish, and Cline 1977, 8).

Rain-on-snow events, common from late fall to early spring at the mid-elevation range, are part of the disturbance regime for Satus Creek watershed and can result in major flood events. The floods in November 1995, February 1996, and New Year's day 1997 were all the result of rain-on-snow events. Historic flood data are limited on the Yakama Indian Reservation but other major floods are believed to have occurred in 1933 or 1934, 1964, and 1974. Summer thunderstorms are another disturbance event that has significantly affected the morphology of the stream channels.

Cool to cold winters and hot, dry summers are normal for the Satus Creek watershed. In lower elevations of the valley basin, mean monthly air temperature is –1.0° C for January and 22.3° C for July. Daily temperatures can be extreme in the summer ranging from 4.5° C to 40.5° C. The winter daily temperature extremes can also be dramatic, ranging from -25° C to 10° C (Hubble 1992, 9). For elevations above 1,219 m (4,000 ft), summer temperatures rarely exceed 35° C and frost may appear throughout the year (YIN 1931, 9).

Vegetation

Most of the watershed, approximately 1,114 square km (430 square mi), is representative of shrub-steppe vegetation, with the remainder in coniferous forest and irrigated agriculture. The forested regions range from high elevation montane to dry forest types. Only a small portion of the watershed is covered with high elevation forests with small riparian meadows dispersed throughout this region. Forest overstory species here include mountain hemlock (*Tsuga heterophylla*), subalpine fir (*Abies lasiocarpa*), western white pine (*Pinus monticola*), Englemann spruce (*Picea engelmanii*), and lodgepole pine (*Pinus contorta*). Common understory species are big huckleberry (*Vaccinium membranaceum*), myrtle blueberry (*Vaccinium myrtillus*), common snowberry (*Symphoricarpus albus*), elk sedge (*Carex geyeri*) and pinegrass (*Calamagrostis rubescens*) (Satus Creek Watershed Restoration Team 1998, unnumbered).

Montane forests located in the mid-elevation region of the watershed have climate that is more moderate with precipitation between 50 to76 cm (20 to 30 in) per year. The plant communities of this region are diverse and productive. Some of the more common species include grand fir (*Abies grandis*), Douglas-fir (*Pseudotsuga menziesii*), western larch (*Larix occidentalis*), ponderosa pine (*Ponderosa pinus*), and small stands of quaking aspen (*Populus tremuloides*). The understory is a diverse mixture of shrub and grass species (Satus Creek Watershed Restoration Team 1998, unnumbered).

The dry forest plant community serves as an intermediate zone between the montane forest and the shrub-steppe. Ponderosa pine or Oregon oak (*Quercus garryana*) are the dominant overstory species within this zone and may occur together but not necessarily. The Oregon oak plant communities are found in the steeper draws of the shrub-steppe. Understory plant species are a mixture of shrub steppe and montane forest species (Satus Creek Watershed Restoration Team 1998, unnumbered).

The shrub-steppe rangeland covers approximately seventy-five percent of the watershed and is separated into two zones. In the higher elevations, the predominant plant species for the shrub-steppe are bluebunch wheatgrass (*Agropyron spicatum*), Idaho fescue (*Festuca idahoensis*), big sagebrush (*Artemisia tridentata*), and bitterbrush (*Purshia tridentata*). In the lower elevations, plant species such as Sandberg bluegrass (*Poa sandbergii*) and stiff sagebrush (*Artemisia rigida*) are present (Satus Creek Watershed Restoration Team 1998, unnumbered).

Riparian corridors transect the shrub-steppe creating lush green strips of vegetation in the otherwise arid plant communities. These riparian ribbons are highly diverse and significant regardless of where they are located in the watershed. Riparian plant species vary in composition according to elevation and distance from the stream channel. In higher elevations, such as stream reach 1, the riparian zones are narrow corridors confined to small streams with a coniferous overstory. The lower elevation riparian corridors, that include stream reaches 2 and 3, typically are wider and contain a multitude of deciduous species. The most prominent riparian overstory species in the lower elevation is black cottonwood (*Populus trichocarpa*). Further information on vegetation along the stream reaches examined for this thesis is presented later in this chapter.

Soils

The parent material for most of the soils in the upper watershed is basalt and for the valley bottom it is alluvium. The semi-arid climate has limited soil development in the watershed; soils are thus often shallow and rocky on the ridges and hill slopes. Loess and volcanic ash are also components of the soil. Loess was blown from the southwest making it thickest on the northeastern sides of the ridges. The gullies and vegetation have also trapped loess, which has created rich soils in the valley bottom that can be agriculturally productive when irrigated (Campbell 1984, 22).

Land Use

Historically, the Satus Creek watershed was a significant winter village area for the Yakama Indians. During the harsh winters, they occupied base camps that were located on canyon bottoms, alluvial fans, alluvial flats and terraces. Typically, base camps along Satus Creek consisted of ten to twenty houses while along the tributaries there were usually less than ten houses (Uebelacker 1984, 183). The high canyon walls along the middle portion of Satus Creek protected many winter villages from the harsh northwesterly winds. The construction of houses, daily life activities, and grazing herds of horses and cattle must have caused alterations to the surrounding riparian habitat but the impacts are not known.

Intensive livestock grazing has seriously affected the condition of the Yakima Basin. Yakama Chief Kamiakin was the first person to bring cattle into the Yakima Basin in 1840. Soon after, many of the Yakamas were raising small herds of cattle and beef had become a staple food source. Cattle grazing began to intensify after white settlers began to settle in the valley in the 1860s. Cattle herds expanded to 150,000 head by the 1880s but steadily decreased over the next fifty years. Sheep were also introduced to the Yakima Basin in 1873 and flocks totaled many thousand by 1878. (YIN 1931, 44-45).

Sheep, cattle, and horse grazing have all impacted the vegetation of Satus Creek watershed. As far back as 1860, 2,000 cattle were reported grazing at the mouth of Satus Creek. These numbers continued to grow because of a ready and highly profitable market (YIN 1931, 44). From the 1930s to the 1950s, livestock associations began to be formed to better manage the grazing resources and a system of fenced pastures and range units was developed (Satus Creek Watershed Restoration Team 1998, unnumbered). The total number of cattle permits peaked in the mid-1970s for the watershed (Figure 4). By 1998, only eight individuals have cattle grazing rights totaling 7,774 Animal Unit Months (AUM) (Satus Creek

Watershed Restoration Team 1998, unnumbered). Sheep are no longer being permitted to graze in the watershed.

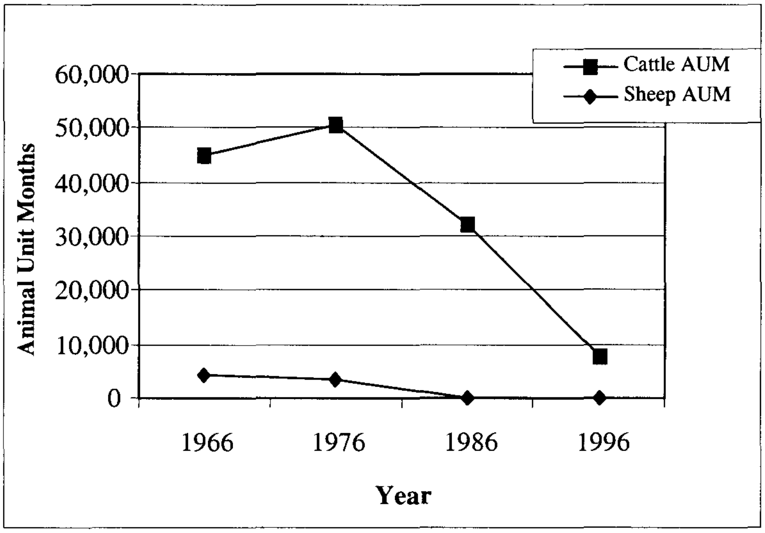


Figure 4: Permitted AUMs for Satus Creek Watershed.

Horses have been a part of the landscape for over two centuries and reached their peak of 18,000 by 1880 (Satus Creek Watershed Restoration Team 1998, unnumbered). Wild horses continue to roam the hills of the watershed. The results of overgrazing and trampling of stream banks by livestock and wild horses have led to "wide, shallow, warm and sediment-laden streams" (Lind 1996, 2).

Fire suppression has been part of land management for Eastern Washington since European settlers arrived and timber became a commodity. Prior to white settlers arriving and as recently as seventy years ago, Native Americans utilized fire to encourage and create food source areas and forage for game (Uebelacker 1984, 158). In the 1920s, fire protection became a concern for the Yakama Indian Nation because of the commercial value of timber. A system of protection that included lookout stations manned with a forest guard was created along with telephone lines, roads, and trails. These safety measures are managed by the Branch of Forestry and continue today (Williams and Babcock 1983, 119-128).

Large-scale timber harvesting did not begin in the watershed until 1948–1949 with the Satus Creek Logging Unit (Williams and Babcock 1983, 165). Prior to this sale, small sawmills were in operation that provided lumber to agency programs and tribal members. A pine beetle epidemic throughout the watershed caused an alarm and created an urgency to sell the timber. Delays occurred but eventually two separate sales were made that were called the Satus Creek Unit and the Dry-Logy Unit. These two units encompassed 137,282 acres with a total of 419,073,150 board feet being cut between the 1950s and 1970s (Williams and Babcock 1983, 181, 184). A summary of logging in the watershed is depicted in Figure 5. It appears that logging peaked around 1973. Data for this graph was compiled by the Satus Creek Watershed Restoration Team from *The Yakima Indian Nation Forest Heritage* by Williams and Babcock, 1983.

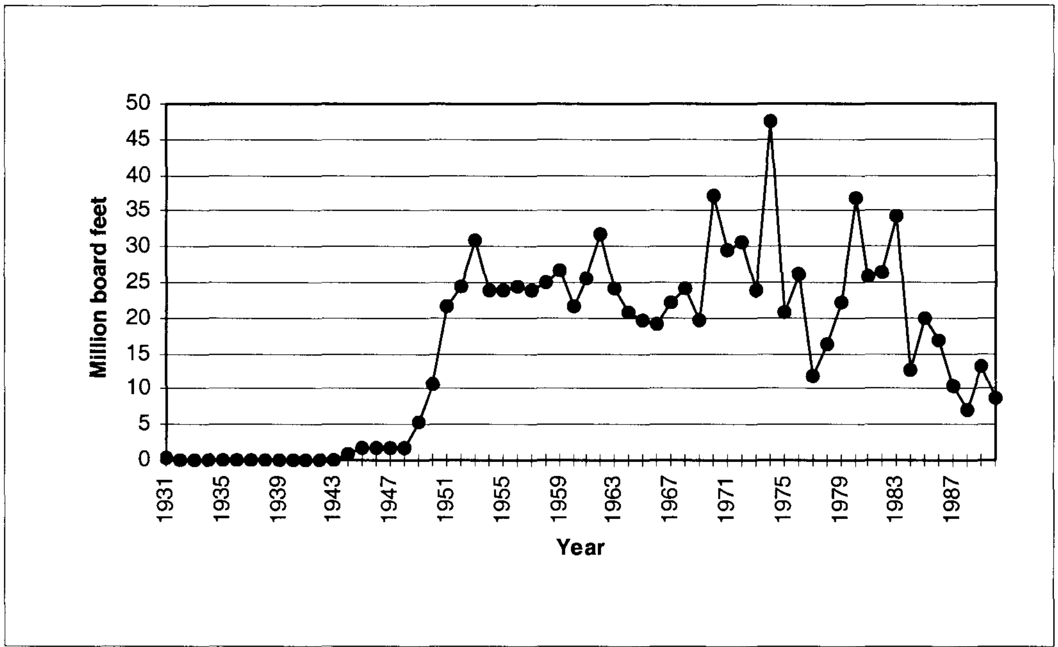


Figure 5: Total timber harvested from Satus Creek watershed.

Road construction intensified in the watershed when access to timber became a major concern. U.S. Route 97 was in place when logging started in 1949 making transport easier. This highway crosses the stream channel in five places and restricts the floodplain in some locations. Riprap has been installed to inhibit channel margins scouring. Numerous gravel roads have also been constructed to facilitate logging and range access. These roads are located throughout the watershed on steep slopes, alluvial valleys, and riparian meadows. Some direct effects of logging roads have been diking and constriction of the stream channel, loss of floodplain, and destruction of riparian vegetation.

SITE CHARACTERISTICS

Three separate stream reaches are examined in this thesis. The physical differences in size and stream length are summarized in Table 1. Although all stream reaches are along Satus Creek, each has a unique geomorphology and vegetational composition. To address the unique characteristics of each stream reach, the following section describes them separately. Comparisons of patterns and trends will be discussed in Chapter 5.

Table 1: Summary of characteristics for each stream reach.

	Reach 1	Reach 2	Reach 3
Total Area (hectares)			
1949	50	140	198
1995	42	140	196
Stream Length (kilometers)			
	7.7	6.4	10.3

Stream Reach 1

Stream reach 1 flows for approximately 7.7 km (4.8 river miles) through a narrow basalt canyon with cliffs as high as 213 m (700 ft) (Figure 2). The canyon floor is only about 24 m (79 ft) wide in the upper end and widens to about 120 m (393 ft) downstream. This reach begins at an elevation of 841 m (2,760 ft) and ends at 658 m (2,160 ft) creating a gradient of two percent. The narrowness of the canyon and the gradient causes stream reach 1 to be fast-flowing with little meandering. It is a series of riffles and pools with areas of downcutting. The stream bars within this stream reach are mostly large basalt cobbles with little interstitial sediment.

Stream reach 1 is located in the montane forest region with the dominant overstory species being ponderosa pine. Douglas-fir, grand fir, and black cottonwood are also overstory species in the canyon. Understory species include Sitka alder *(Alnus sinuata)*, common snowberry (*Symphoricarpus albus*), red-osier dogwood *(Cornus stolonifera)*, mock-orange (*Philadelphus lewisii*), wild rose (*Rosa spp.*), and grasses. Sitka alder is the most dominant riparian shrub species along the stream banks.

Stream Reach 2

Stream reach 2 begins at the confluence with Logy Creek and flows approximately 6.4 km (4.0 river miles). The stream is bordered to the north by steep basalt talus slopes, 91 m (300 ft high), and by U.S. Route 97 to the south. The valley bottom for this reach is the widest of all the reaches with an average width of 432 m

(1,417 ft), however U.S. Route 97 bisects the valley bottom and reduces the floodplain area. The elevation for this stream reach is approximately about 335 m (1,100 ft). The reach loses approximately 33 m (110 ft) in elevation, creating a gradient of 0.5 percent.

The morphology of stream reach 2 varies depending on location. Some sections are fast-moving with overhanging riparian vegetation shading the stream channel while other sections are wide, deep pools or wide, shallow riffles. The portions where the stream channel is wide and shallow are also incised and contain large stream bars. The substrates of the stream bars are medium-sized cobble with fine sediment interspersed.

The vegetation for Stream Reach 2 consists of a black cottonwood or white alder (*Alnus rhombifolia*) overstory. Riparian understory woody species may include white alder, red-osier dogwood (*Cornus stolonifera*), choke cherry (*Prunus virginiana*), wild rose (*Rosa spp.*), birch (*Betula spp.*), hawthorn (*Crataegus douglasii*) and willows (*Salix spp.*). Much of the area is vegetated with weedy annuals with some patches of noxious weeds. A few riparian meadows containing sedges and cattails can be found along old side channels dammed by past beaver activity. Extensive stands of white alder line the stream channel.

Stream Reach 3

Stream reach 3 begins at the confluence with Dry Creek and flows for approximately 10.3 km (6.4 river miles) making it the longest stream reach examined.

The elevation for this reach ranges from 292 m (960 ft) to 250 m (820 ft) with a stream gradient of 0.4 percent. The stream reach flows through a valley bottom that ranges in width from 408 m (1,338 ft) to 144 m (472 ft). The valley slopes are mostly basalt talus with cliffs as high as 67 m (220 ft). The middle portion of this stream reach is inaccessible by automobile. Stream reach 3 ends where the canyon widens into the valley bottom and the lands have been converted to agricultural uses (Figure 2).

The current condition of the stream channel is wide, incised, and with slow flow in summer. This reach has been referred to as a moonscape because of the large depositional bars present. The substrate of these stream bars is composed of small to medium cobble with considerable amounts of fine sediments.

The riparian plant species along stream reach 3 are similar to those of stream reach 2. However, the vegetation is more disturbed and decadent. The dominant overstory species is black cottonwood with understory species such as red-osier dogwood, choke cherry, hawthorn and wild rose. A few areas still contain a nearly impenetrable understory of mixed riparian shrub species. White alder stands line the channel margins. Noxious weeds are a serious problem throughout the lower parts of Satus Creek and especially in stream reach 3.

CHAPTER IV

DEVELOPMENT OF METHODS AND TECHNIQUES

This chapter outlines the methodologies used to create the data analyzed in this thesis. Development of data was a major focus of this thesis and understanding the process involved will be useful for future reference. First, background information relating to this project is presented to inform the reader of the previous work performed. Next, details are presented on how the aerial photographs were interpreted and how the classification system was defined. The creation of GIS coverages from aerial photographs is also described. Lastly, the chapter concludes with a summary of how the data were analyzed.

BACKGROUND INFORMATION

I started this thesis as an employee of the YIN. In this way, I inherited the delineation of riparian vegetation and GIS coverages for stream reaches 2 and 3. In the summer of 1997, I initiated ground-truthing the vegetation delineation and attributions. I spent several weeks gaining familiarity with individual riparian species and general plant composition. I concluded that the attribution of the vegetation was inaccurate. I based this conclusion on the fact that the previous work did not reflect on-the-ground patterning. I therefore created a new set of attributes and reassigned all the polygons. I determined all the riparian vegetation data used for this thesis and made additions or modifications to polygons established by others when necessary.

Besides inaccuracies with riparian vegetation attributions, the inherited GIS vegetation coverages contained significant errors. Due the unreliability of certain coverages, I was unable to use particular stream reach data. This accounts for the large distance between stream reaches 1 and 2.

OVERVIEW

Three segments of Satus Creek were selected for spatial and temporal analysis of riparian vegetation and depositional bars. Aerial photographs served as the primary source for data collection, while GIS was used for spatial analysis. The ability of GIS to convert various map scales to a single scale simplified working with multiple aerial photograph data sets. In addition to stereoscopic and GIS analysis, field observations were made to assess the current condition of the vegetation and stream channel.

Data Sources

The availability of multiple sets of aerial photographs from different years was a deciding factor for choosing this type of remote sensing. There were a total of five different sets of aerial photographs used for this analysis. Table 2 summarizes the characteristics of each photo set and whether vegetation and/or flood bars were delineated.

Table 2: Satus Creek Aerial Photographic Information

						Number of Photographs		
Year	**Date Taken**	**Scale**	**Color**	**Vegetation**	**Flood Bars**	**Section 1**	**Section 2**	**Section 3**
1949	June 30	1:20,000	No	Yes	Yes	2	2	4
1964	August 5	1:15,840	No	No	Yes	3	3	4
1978-79	May 30 or June2	1:12,000	Yes	No	Yes	5	4	7
1995	September 22	1:12,000	Yes	Yes	Yes	5	2	5
1997	May 12	1:12,000	Yes	No	Yes	7	3	5

Data Extraction

Interpretation of aerial photographs is a subjective and time-consuming endeavor. Delineation of aerial photographs was done using a mirror stereoscope with 8-power magnification. Vegetation and flood bar polygons were delineated onto clear Mylar overlays using a Rapidograph Koh-I-Noor 0.25 mm pen for the aerial photographs for each year. The consistency of the vegetation stand determined the polygon delineation and the valley bottom was used as the defining border for delineation of vegetation. The delineated areas typically included the floodplain and alluvial terraces. In certain areas where the valley bottom became very wide and the terraces did not contain riparian vegetation in 1949 or 1995, the edge of the riparian vegetation was the defining border. Due to time constraints, only 1949 and 1995 aerial photographs were interpreted for studying vegetation change. The intermediate years, 1964 and 1978-79, were used to determine any trends in sediment deposition; therefore only depositional bars were delineated. In addition, the 1997 aerial photographs were used only for depositional bar delineation.

Difficulties arose with photographic interpretation because the small-scale aerial photographs (1:20,000) were black and white. However, verification of 1949 and 1964 aerial photographs was aided by comparing them with later photographs that are in a larger scale and in color. Differences in quality of aerial photographs also proved to be challenge throughout the interpretation process, particularly for 1995 stream reach 1 photographs. Careful examinations and comparisons for all stream sections for each year improved accuracy of delineation.

Data Classification

The classification system developed for this project is a combination of six attributes that identify the overstory and understory ground cover, their cover class, and age class for a delineated polygon. Each attribute consists of a single digit integer that is contained within the polygon attribute table (PAT). A PAT is the method used by GIS to identify what a polygon represents. The PAT categories (moving from right to left) include: *dominant species in the overstory* (DSO), *dominant species in the understory* (DSU), *dominant overstory cover class* (DCO), *dominant understory cover class* (DCU), *dominant overstory age class* (DAO), and *dominant understory age class* (DAU).

The vegetation classifications for 1949 and 1995 are slightly different because the ability to interpret vegetation species increased for 1995 (Table 3). Plant species chosen were those that are readily discernible from the aerial photographs or identified during ground truthing, and are significant in the plant dynamics occurring on Satus Creek.

Table 3: ARC/INFO Polygon Attribute Table for Vegetation Categories, DSO and DSU

Integer	1949	1995
0	Flood bar	Flood bar
1	Other/Unknown	Other/Unknown
2	Agricultural lands	Weedy Annuals/Noxious Weeds
3	Herbaceous vegetation	Basin Wildrye
4	Xeric Shrubs	Xeric Shrubs
5	Riparian Shrubs	Riparian Shrubs
6	Undetermined riparian tree	Quaking Aspen
7	Alder	Alder
8	Black Cottonwood	Black Cottonwood
9	Conifer	Conifer

Integer 6, for the 1949 DSO and DSU, represents an undetermined riparian tree. This tree category was typically located within a thickly vegetated area and is believed to be a black cottonwood or mature white alder. Actual determination was impossible because of the small photographic scale and lack of color. Integer 5 represents a mixture of riparian shrub species. For stream reach 1, the mixture of riparian shrubs mostly consists of snowberry, mock-orange, red-osier dogwood, sitka alder and wild rose. For stream reaches 2 and 3, the mixture mostly consists of black hawthorn, red-osier dogwood, birch spp., chokecherry, mock-orange, wild rose, smooth sumac and an occasional white alder. Integer 4 represents xeric shrub species that can include big sagebrush, rigid sagebrush, bitterbrush, fourwing saltbrush (*Atriplex canescens*), and rabbit-brush (*Chrysothamnus nauseosus*). Some of the more prevalent weedy annuals and noxious weeds, integer 3, are cheatgrass (*Bromus* *tectorum*), scotch thistle (*Onopordum acanthium*), and knapweed (*Centaurea spp.*). Integer 7 represents Sitka alder in stream reach 1, and white alder in stream reaches 2 and 3.

Vegetation codes were also created to represent certain plant cover types or land features. These codes (Table 4) were necessary because the inherited PAT was created to only allow for ten integers. Wet herbaceous vegetation cover was distinguished by its dark, smooth appearance that indicates the presence of water in black and white photographs. Agricultural lands typically represent pastures and associated structures. Water represents in-stream water due to the stream channel becoming wide and exposed.

Table 4: ARC/INFO Vegetation and Land Cover Codes

Code	
999999	Water
229900	Agriculture/Pastures
339999	Wet herbaceous vegetation
339900	Undetermined herbaceous vegetation
119988	Roads

The dominant overstory and understory species cover class, DCO and DCU represents the proportion of ground covered by a plant species and is measured by a percentage range. There are a total of seven percentage ranges that are based on the *Canopy Cover Classification* developed by Daubenmire in 1959 (Table 5). The last two integers are the relative age of the dominant overstory and understory species (Table 6).

Table 5: ARC/INFO Polygon Attribute Table for Percent Coverage, DCO and DCU

Integer	
0	undetermined
1	1 - 5%
2	6 - 25%
3	26 - 50%
4	51 - 75%
5	76 - 95%
6	95 - 100%
9	100%

Table 6: ARC/INFO Polygon Attribute Table for Stand Age, DAO and DAU

Integer	
0	undetermined
1	young
2	mature
3	decadent

Data Capture

Data capture refers to the process of transforming map data to a digital format for storage in the computer (Lo and Shipman 1990, 289). For this thesis, a Macintosh version of Adobe PhotoDeluxe was used to capture the image of the scanned Mylar. This image was then transferred into ARC/INFO and a multi-step process was performed using Arctools and ArcEdit to create the coverages.

After the polygons were edited, it was necessary to transform each aerial photograph coverage into real world coordinates. The transformation required a separate tic coverage to be digitized containing ground control points that could be accurately identified on both aerial photographs and topographic maps. This step produced errors in the inherited GIS coverages. Determining the same location on the topographic maps and the aerial photographs was difficult in some areas because the stream corridor is relatively undeveloped. Even when precise locations could be identified, certain areas remained skewed due to the distortion of the aerial photograph.

After each aerial photograph coverage was transformed into Universal Transverse Mercator (UTM) coordinates using four ground control points, the individual photo coverages were then appended to create one continuos stream section. Lastly, the PAT was created in INFO and the appropriate attributes were assigned to each polygon.

Data Analysis

The analysis performed for this thesis is a quantitative summary of vegetation cover in 1949 and 1995 and deposition bars for the years mentioned. Since the plant species were assigned a percent cover class, it was necessary to convert the percentage into actual on the ground area. The ARC/INFO frequency command was used to separate out each ground cover, its cover class, and age. Area was used as the summary item. Once the first frequency file was created, area_true was added to the file so the calculated actual area for each ground cover could be placed there. The appropriate midpoint for each percent cover class was used in the calculation that determined the actual ground area covered by a plant species. It was necessary to perform this sequence of commands for both the overstory and understory for each year. The statistics command was used to summarize the total area for each ground cover type. The final step was to convert the area into percentages of total area so that comparisons could be made.

Another part of the analysis was computing the area for overstory and understory composition. To perform this calculation, a frequency file was created using area as the summary item for the dominant species in the overstory and the dominant species in the understory. These results represent the total area for overstory and understory composition and do not indicate the individual percentage of cover by the overstory or the understory species.

CHAPTER V

RESULTS

In this chapter, results on the findings for vegetation change, vegetation age structure, and overstory and understory composition are reported for each stream reach. In addition, findings on the distribution of depositional bars for all the stream reaches are explained. Lastly, results on depositional bar frequency and sizes are presented for each stream reach.

STREAM REACH 1

Vegetation Change

The total area determined for ground cover in 1949 was 43.3 ha compared to 31.5 ha for 1995 (Table 7). The large difference in total areas resulted from the construction of Lakebeds Road that reduced the area of floodplain. Roads were not

Table 7: Total area in hectares for ground cover along stream reach 1 in 1949 and 1995. NA refers to not applicable.

	1949	1995
Stream Bars	0.0	0.4
Other/Unknown	0.0	0.2
Weedy Annuals/Noxious weeds	NA	0.4
Basin Wildrye	NA	0.0
Herbaceous Vegetation	3.2	0.5
Wet Herbaceous Vegetation	0.0	0.0
Xeric Shrubs	0.0	0.0
Mixed Riparian Shrubs	14.6	5.7
Aspen	NA	0.0
Undetermined Riparian Tree	2.0	NA
Alder	0.3	3.6
Cottonwood	5.9	4.0
Conifer	17.4	16.6
Agriculture/Pastures	0.0	0.0
Roads	0.0	0.1
Water	0.0	0.0
total	43.3	31.5

present in the floodplain in 1949 but are now influencing the stream channel and the vegetation structure.

The percentages of total area for the different ground covers are shown in Figure 6. Total area of herbaceous cover decreased by 71%. No wet herbaceous areas were visible in either year. Mixed riparian shrubs decreased by 61% between 1949 and 1995 while Sitka alder increased by 1100%. Combining all shrub species shows a decrease of 38%. Total tree species decreased by 18.5%, with cottonwoods decreasing by 32% and coniferous species increasing by 5%.

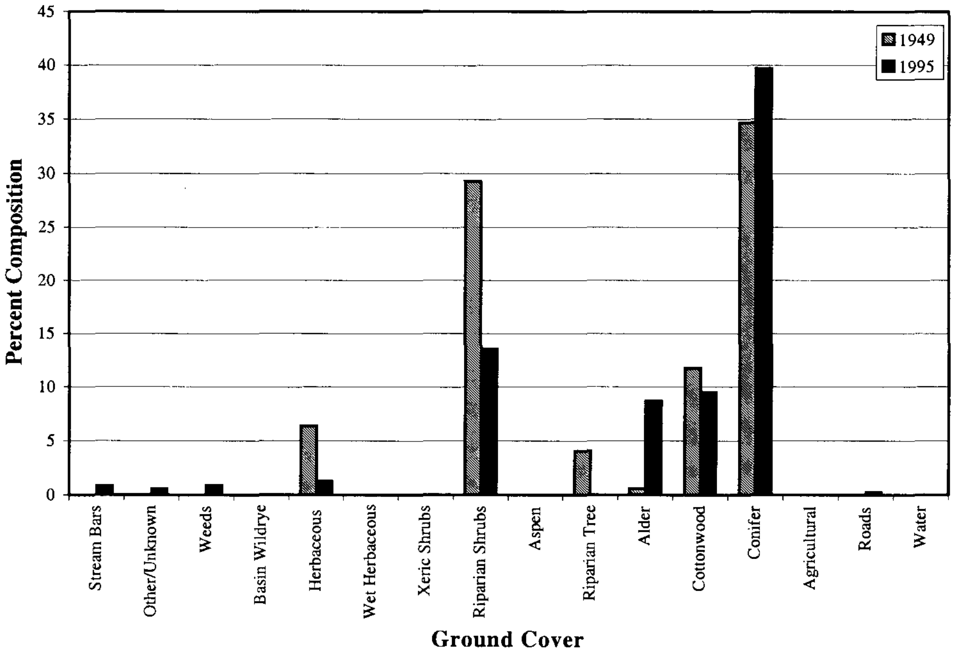


Figure 6: Percentages of ground cover for stream reach 1 in 1949 and 1995.

Vegetation Age Structure

Examination of the vegetation age classes for woody species along stream reach 1 reveals a shift in species structure (Table 8). The total area of mature mixed riparian shrub species decreased from 11.1 ha in 1949 to 3.9 ha in 1995. This 65% decrease in riparian shrubs had the most influence on the change in total area of mature riparian woody species present from 1949 to 1995. No discernible stands of mature alder were present in 1949 but by 1995 they represented 2.9 ha of the total vegetation. The total area of mature conifers remained about the same for both years but more diversity in age structure was present in 1949. The area of mature cottonwoods decreased by 49% from 1949 to 1995, and both young and decadent stands were present in 1995.

Table 8: Total area in hectares for age classes of woody riparian species along stream reach 1. NA refers to not applicable.

	Young		Mature		Decadent		Undetermined	
	1949	1995	1949	1995	1949	1995	1949	1995
Riparian Shrubs	0.1	1.1	11.1	3.9	0.0	0.0	3.2	0.7
Undet. Riparian Tree	0.1	na	1.9	na	0.0	na	0.1	na
Alder	0.3	0.2	0.0	2.9	0.0	0.0	0.0	0.5
Aspen	na	0.0	na	0.0	na	0.0	na	0.0
Cottonwood	0.0	0.7	5.9	3.0	0.0	0.2	0.0	0.0
Conifer	1.3	0.6	15.9	16.0	1.0	0.0	0.0	0.0
total	1.8	2.7	34.7	25.9	1.0	0.2	3.2	1.2

Overstory and Understory Composition

Changes in understory composition for black cottonwood is occurring along stream reach 1 (Table 9). In 1949, cottonwoods appeared to mostly occur with a mixed riparian shrub understory that may have included Sitka alder as well as other shrub species. The total area of black cottonwood overstory and mixed riparian shrub understory has decreased by 76% over time. Sitka alder as an understory was not present in 1949 but covered 2.2 ha in 1995. Black cottonwoods did not occur with a herbaceous understory in either year.

Table 9: Total area in hectares of understory composition for black cottonwoods along stream reach 1.

	Cottonwood & Alder	Cottonwood & Riparian Shrubs	Cottonwood & Herbaceous
Stream Reach 1			
1949	0.0	11.3	0.0
1995	2.2	2.7	0.0

The other dominant overstory species along stream reach 1 are coniferous trees. Table 10 represents the total area for the various understory ground cover associated with conifers. Conifers typically had a more open understory in 1949 as indicated by the increased area with a herbaceous understory. A noticeable difference in the total area is seen in a conifer overstory with a cottonwood understory. This combination of plant species increased by almost 367% between 1949 and 1995. Another noticeable change is the total area of conifer overstory with a riparian shrub understory. In 1949, the area was 14.4 ha while in 1995 it was 8.5 ha. This represents a decrease of 41%.

Table 10: Total area in hectares of understory composition for conifers along stream reach 1.

	Conifer & Conifer	Conifer & Cottonwood	Conifer & Alder	Conifer & Riparian Shrubs	Conifer & Herbaceous
Stream Reach 1					
1949	1.7	1.8	0.5	14.4	2.2
1995	0.7	8.4	0.4	8.5	0.8

STREAM REACH 2

Vegetation Change

Stream reach 2 has exhibited some major shifts in the species composition from 1949 to 1995. Table 11 shows the findings on the total area for each ground cover type and Figure 7 represents graphically the percentage of total area that it covers.

Table 11: Total area in hectares for ground cover along stream reach 2 in 1949 and 1995. NA refers to not applicable.

	1949	1995
Stream Bars	2.5	6.3
Other/Unknown	0.0	0.0
Weedy Annuals/Noxious weeds	NA	31.2
Basin Wildrye	NA	5.1
Herbaceous Vegetation	24.8	0.8
Wet Herbaceous Vegetation	19.3	0.0
Xeric Shrubs	1.5	12.2
Mixed Riparian Shrubs	54.1	18.6
Aspen	NA	0.1
Undetermined Riparian Tree	6.0	NA
Alder	2.9	28.1
Cottonwood	27.6	24.5
Conifer	0.0	0.0
Agriculture/Pastures	0.0	0.0
Roads	0.0	0.0
Water	0.8	4.6
total	139.7	131.45

The most dramatic ground cover change occurred in mixed riparian shrub species. In 1949, mixed riparian shrubs covered 54.1 ha comprising almost 39% of the total ground cover. By 1995, mixed riparian shrubs had decreased to only 14% of the total ground cover. The type of shrub species present also shifted over time. Pure alder stands comprised 21% of the total vegetation in 1995 while they only represented 2% in 1949. The total area for cottonwoods decreased by 11%, from 27.6 ha in 1949 to 24.5 ha in 1995. In addition, the total area for undetermined riparian trees was 6 ha in 1949. It is most likely that this species was black cottonwood. If this were the case then the percent decrease would more than doubled.

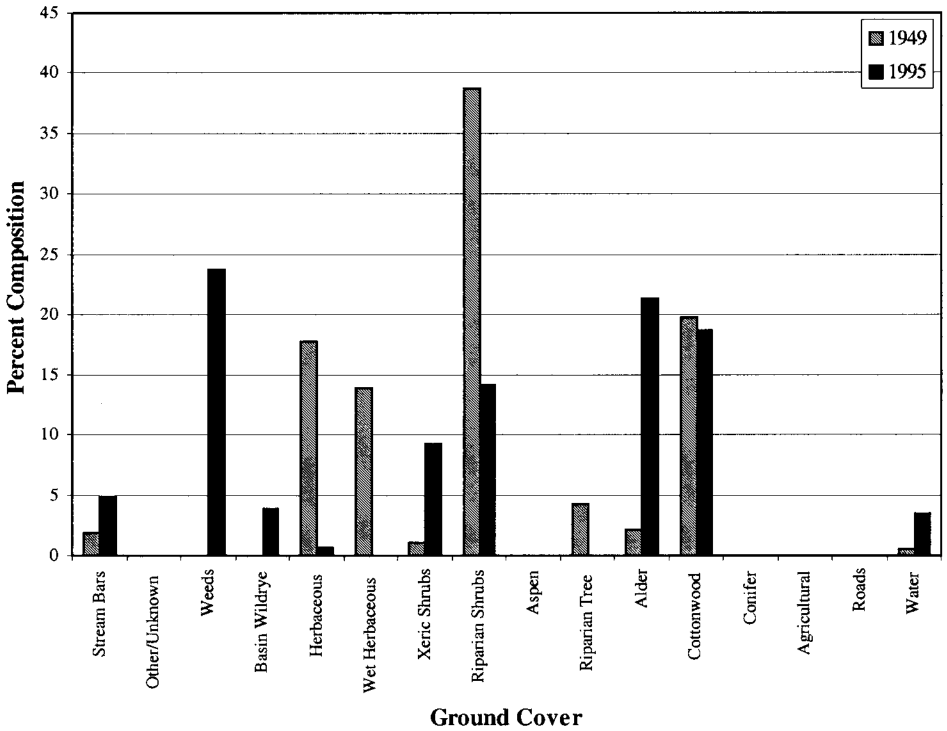


Figure 7: Percentages of ground cover for stream reach 2 in 1949 and 1995.

Herbaceous cover totaled 44.1 ha in 1949 and 37.1 ha in 1995. This included weedy annuals, noxious weeds, basin wildrye, herbaceous vegetation, and wet herbaceous vegetation. The change in total area represented a decrease of 15%.

When xeric shrubs are combined with the total area for herbaceous cover, the total areas are 45.6 ha in 1949 and 49.3 ha in 1995 resulting in a 8% increase. Xeric shrubs increased by 713% over time. The substantial increase in xeric shrubs for 1995 is partly due to the ability to ground-truth. No discernible wet herbaceous cover was present in 1995 but wet herbaceous areas covered almost 15% of the ground cover in 1949. The presence of wet herbaceous vegetation accounts for the higher area covered by herbaceous species in 1949, as well as the difficulty encountered when determining the cover class percent for herbaceous cover. Lastly, the total area for both stream bars and in-stream water increased from 1949 to 1995.

Vegetation Age Structure

Examination of the vegetation age classes for woody species along stream reach 2 reveals trends in age structure (Table 12). Both young and mature woody species decreased over time while decadent species increased over time. Black cottonwoods showed signs of aging in 1995 that was not present in 1949. In 1949, mature cottonwoods covered 27.6 ha and by 1995 they had decreased to 8.5 ha.

Mature alders changed from just 1.0 ha in 1949 to 17.8 ha in 1995 representing a 1680% increase. Conversely, more young alders were present in 1949 than in 1995. Another considerable change in age structure occurred in mixed riparian shrubs over time. The amount of both young and mature mixed riparian shrubs decreased from 1949 to 1995 in keeping with the overall decline of mixed riparian shrubs.

Table 12: Total area in hectares for age classes of woody riparian species along stream reach 2. NA refers to not applicable.

	Young		Mature		Decadent		Undetermined	
	1949	1995	1949	1995	1949	1995	1949	1995
Riparian Shrubs	17.3	0.1	33.0	18.5	0.0	0.0	3.8	0.0
Undet. Riparian Tree	0.0	na	6.0	na	0.0	na	0.0	na
Alder	2.0	10.3	1.0	17.8	0.0	0.0	0.0	0.0
Aspen	na	0.1	na	0.0	na	0.0	na	0.0
Cottonwood	0.0	0.0	27.6	8.5	0.0	16.0	0.0	0.0
Conifer	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
total	19.3	10.5	67.6	44.7	0.0	16.0	3.8	0.0

Overstory and Understory Composition

Black cottonwood is the dominant overstory species along stream reach 2. It can be found with three types of understory: white alder, mixed riparian shrubs, and herbaceous species (Table 13). The most obvious shift in overstory and understory composition is the presence of cottonwoods with herbaceous ground cover that includes weedy species. This combination was not noticeably present in 1949 but by 1995 it covered approximately 16 ha or 11% of the total area. The herbaceous understory in 1995 may have contained some decadent riparian shrub species but herbaceous species had become more dominant.

Another noticeable shift is toward the presence of white alder as a dominant understory species. In 1949, white alder may have been a component in the mixed riparian shrub composition. However, by 1995, pure white alder stands had become a common understory along stream reach 2. As results of this shift, areas with a mixed riparian shrub understory decreased by 28% over time.

Table 13: Total area in hectares of understory composition for cottonwoods along stream reach 2.

	Cottonwood & Alder	Cottonwood & Riparian Shrubs	Cottonwood & Herbaceous
Stream Reach 2			
1949	0.0	56.0	0.0
1995	9.6	40.1	16.1

STREAM REACH 3

Vegetation Change

Table 14: Total area in hectares for ground cover along stream reach 3 in 1949 and 1995. NA refers to not applicable.

	1949	1995
Stream Bars	3.0	14.4
Other/Unknown	0.0	0.7
Weedy Annuals/Noxious weeds	NA	36.4
Basin Wildrye	NA	2.8
Herbaceous Vegetation	21.4	11.6
Wet Herbaceous Vegetation	0.8	0.0
Xeric Shrubs	9.6	14.9
Mixed Riparian Shrubs	84.9	27.0
Aspen	NA	0.0
Undetermined Riparian Tree	3.1	NA
Alder	7.7	21.2
Cottonwood	32.3	23.3
Conifer	0.0	0.0
Agriculture/Pastures	22.5	0.0
Roads	0.0	0.0
Water	0.0	10.5
total	185.2	162.8

The ground cover along stream reach 3 has also changed substantially over time (Figure 8). The total area vegetated by ground cover decreased from 185.2 ha in 1949 to 162.8 ha in 1995 (Table 14). This discrepancy in total area is the result of less dense vegetation cover.

In 1949, pastures were a part of the landscape of stream reach 3 but by 1995 these areas have shifted to mostly weed patches with some scattered xeric shrubs. The total amount of land covered by pastures in 1949 was 22.5 ha and for all types of herbaceous cover it was 44.7 ha. Of the 44.7 ha, wet herbaceous vegetation consisted of 0.8 ha. By 1995, herbaceous vegetation, which includes weedy annuals, noxious weeds, and basin wildrye, covered a total of 50.8 ha. Herbaceous vegetation has shown almost a 14% increase over time. No discernable wet herbaceous vegetation was present in 1995.

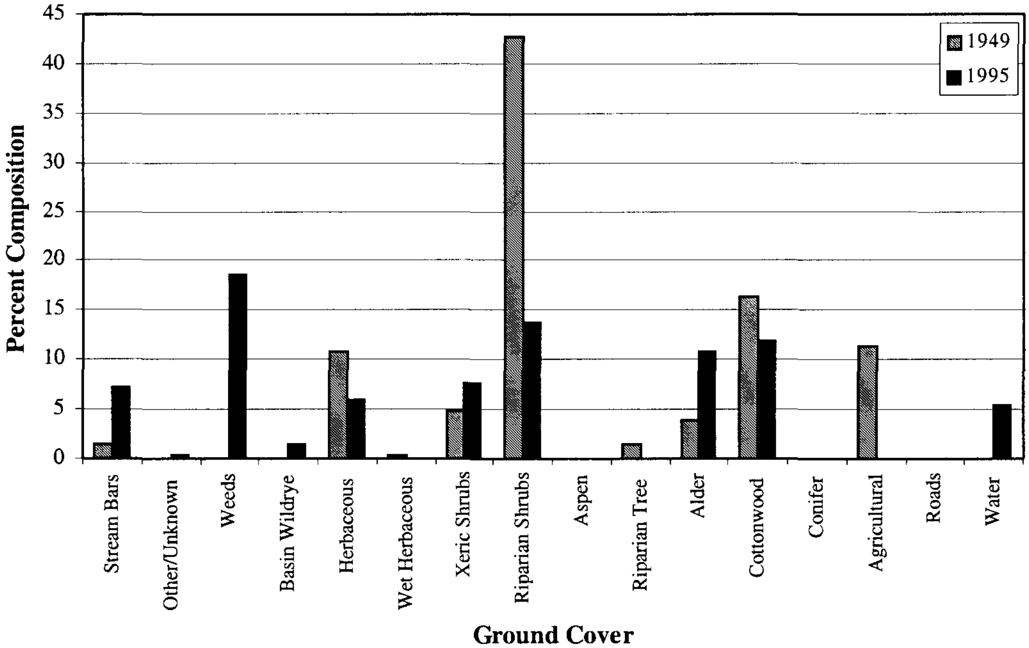


Figure 8: Percentages of ground cover for stream reach 3 in 1949 and 1995.

Vegetation shifts that are present along stream reach 2 are also present along stream reach 3. Mixed riparian shrubs have decreased by 68% while white alders have increased by 175%. The area of overstory tree species has also decreased over time. Black cottonwoods combined with undetermined riparian tree species decreased by 52%.

Increases in xeric shrubs, stream bars, and the amount of visible in-stream water all occurred between 1949 and 1995. Xeric shrubs increased by 55% and stream bars by 387%. Although some water was present in 1949, it was not large enough to delineate. By 1995, water represented approximately 5% of the total ground cover.

Vegetation Age Structure

A dramatic decrease in the total area covered by mature woody species took place between 1949 and 1995 (Table 15). Stream reach 3 had the greatest decrease in mature riparian shrubs of all the stream reaches. This ground cover decreased from 80.2 ha in 1949 to 22.9 ha in 1995. Black cottonwoods also exhibited a shift in age structure over time. The amount of mature cottonwoods decreased by 56% and decadent cottonwoods were not discernible in 1949 but had reached 9.3 ha by 1995. Of the young woody species, white alders exhibited the most change going from just 0.9 ha in 1949 to 11.7 ha in 1995.

Table 15: Total area in hectares for age classes of woody riparian species along stream reach 3. NA refers to not applicable.

	Young		Mature		Decadent		Undetermined	
	1949	**1995**	**1949**	**1995**	**1949**	**1995**	**1949**	**1995**
Riparian Shrubs	2.0	2.9	80.2	22.9	0.0	0.0	2.7	1.9
Undet. Riparian Tree	0.0	na	3.1	na	0.0	na	0.0	na
Alder	0.9	11.7	6.8	9.5	0.0	0.0	0.0	0.0
Aspen	na	0.0	na	0.0	na	0.0	na	0.0
Cottonwood	0.1	0.0	32.1	14.0	0.0	9.3	0.0	0.0
Conifer	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
total	3.1	14.5	122.2	46.4	0.0	9.3	2.7	1.9

Overstory and Understory Composition

From the results, a shift in the overstory and understory composition is apparent for stream reach 3 (Table 16). This stream reach shows the greatest decrease of all the reaches with respect to black cottonwood overstory with a mixed riparian shrub understory. It also shows the most increase in black cottonwood with a herbaceous understory. Area covered by black cottonwoods and mixed riparian shrubs decreased by almost 51% while black cottonwoods with a herbaceous understory increased by 889%. Similar to stream reach 2, black cottonwoods with a herbaceous understory may have contained remnant patches of riparian shrubs but increases in herbaceous species resulted in it becoming the dominant understory cover. In the 1995 aerial photographs, these patches of riparian shrubs could not be accounted for in the ground cover; this contributed to the discrepancy in total ground cover area for the two years.

Table 16: Total area in hectares of understory composition for black cottonwoods along stream reach 3.

	Cottonwood & Alder	Cottonwood & Riparian Shrubs	Cottonwood & Herbaceous
Stream Reach 3			
1949	6.3	73.2	4.6
1995	8.0	35.9	45.5

DEPOSITIONAL BAR DISTRIBUTION

For all stream reaches, the total area of depositional bars increased between 1949 and 1979 and decreased between 1979 and 1995 (Table 17 and Figure 9).

Table 17: Total area in hectares of depositional bars.

	1949	1964	1979	1995	1997
Stream Reach 1	0	0.7	3.9	0.4	1.7
Stream Reach 2	2.6	3.9	21.7	6.3	13.1
Stream Reach 3	3.0	5.9	22.4	14.4	32.9
total	5.6	10.5	48.0	21.1	47.7

Stream reaches 1 and 2 had the most area covered by depositional bars in 1979 while stream reach 3 had the highest in 1997. The total area of depositional bars for all the stream reaches was slightly higher in 1979 than in 1997.

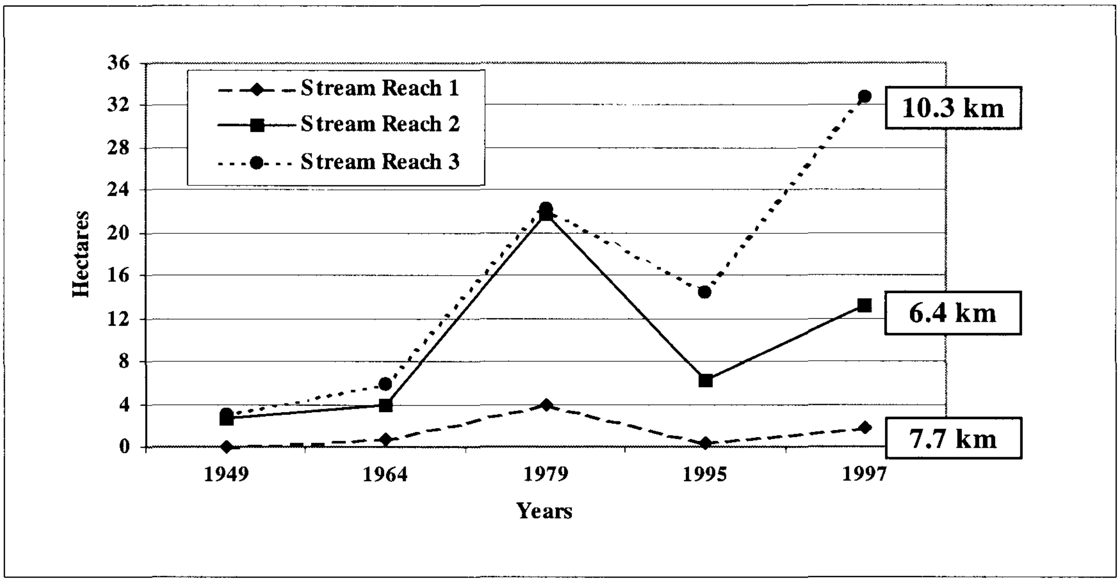


Figure 9: Total area in hectares of depositional bars for three reaches of Satus Creek and their length in kilometers.

Table 18: Percentage of total area of depositional bars.

	1949	1964	1979	1995	1997
Stream Reach 1	0.0	1.7	9.3	1.0	4.6
Stream Reach 2	1.6	2.4	13.1	3.8	7.9
Stream Reach 3	1.5	3.0	11.3	7.3	16.6

Table 18 represents the percentage of total area covered by depositional bars for all years. The total area used was the average of total area for 1949 and 1995 except in the case of stream reach 1. Since the total area was reduced for stream reach 1 by road construction, the total area for 1995 was used for the intervening years between 1949 and 1995. The pattern for total area shown in Figure 9 is similar to the pattern for percentage of total area, Figure 10. The 1979 and 1997 increases appear more dramatic for stream reach 1 because of equal scaling with the other reaches. Also, the percent total for stream reach 3 in 1997 is higher than in 1979. Lastly, stream reach 2 has a higher percent total than stream reach 3 for 1979 but less total area covered by depositional bars.

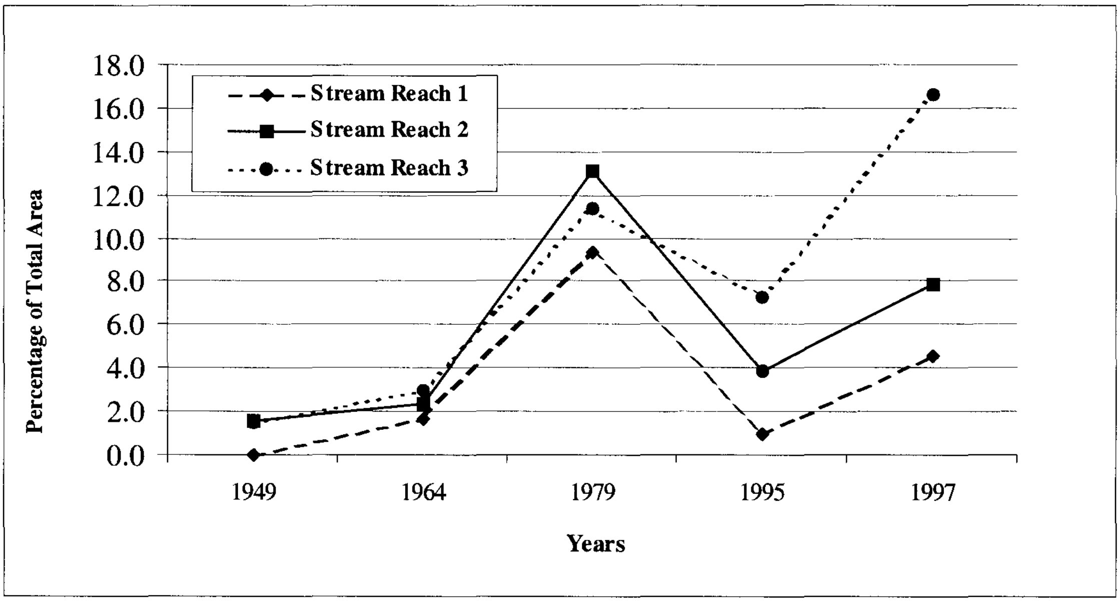


Figure 10: Percentage of total area for deposition bars for three reaches of Satus Creek.

DEPOSITIONAL BAR SIZE

Stream Reach 1

Table 19: Frequency and Size of depositional bars for Stream Reach 1. Units are in square meters.

Year	frequency	min size (sq. m)	mean size (sq. m)	max size (sq. m)
1949	0	0	0	0
1964	9	157	728	2,357
1979	51	151	763	3,207
1995	3	713	1,180	1,941
1997	42	16	623	6,374

Of all the years for stream reach 1, 1979 showed the highest frequency of depositional bars while 1995 had the least (Table 19). The low frequency in 1995 resulted from poor quality aerial photographs that made the ability to detect smaller depositional bars impossible. This limitation also accounts for the large minimum and mean depositional bar sizes in 1995. This discrepancy will be considered when determining trends of depositional bars for Satus Creek. The year 1997 showed a substantial increase in the maximum size of deposition bars.

Stream Reach 2

Table 20: Frequency and Size of depositional bars for Stream Reach 2. Units are in square meters.

Year	frequency	min size (sq. m)	mean size (sq. m)	max size (sq. m)
1949	16	240	1,621	14,698
1964	36	172	1,081	2,765
1979	46	414	5,056	17,435
1995	35	114	1,832	10,165
1997	39	44	3,367	20,188

The frequency of depositional bars along stream reach 2 is relatively consistent for the years 1964, 1995, and 1997 (Table 20). The year 1949 had the least amount of depositional bars and 1979 had the most following the same pattern seen in stream reach 1. In 1949, the maximum sized depositional bar appears to be the remnants of an old channel that contained alluvial deposits. When this old channel depositional area was left out of the results, the mean size for this year is 749 square meters, a difference of 872 square meters. The year 1979 had the largest mean size for depositional bar sizes and 1997 had the largest maximum size.

Stream Reach 3

Stream reach 3 findings on depositional bar sizes and frequencies are different than for other reaches. This is the only reach to have the highest frequency of depositional bars in 1995; the maximum occurred in 1979 for the other two stream reaches (Table 21).

Table 21: Frequency and Size of depositional bars for Stream Reach 3. Units are in square meters.

Year	frequency	min size (sq. m)	mean size (sq. m)	max size (sq. m)
1949	18	573	1,682	3,769
1964	42	311	1,399	5,050
1979	71	125	3,149	18,125
1995	105	156	1,382	8,125
1997	45	59	7,304	32,476

The relative mean size of depositional bars was approximately the same in 1949, 1964, and 1995, but increased in 1979 and increased substantially by 1997. The mean size in 1997 almost doubled that of 1979. Data on maximum depositional bar size for stream reach 3 shows the most interesting findings. Maximum size increased from 1949 to 1964 and more than tripled from 1964 to 1979; but then was reduced by more than half between the years 1979 and 1995, yet quadrupled again from 1995 to 1997. The year 1997 also had the smallest minimum size of depositional bars. Possible explanations for these patterns and trends are presented in the next chapter.

CHAPTER VI

DISCUSSION AND RECOMMENDATIONS

Throughout this chapter, connections are made between the changes in riparian vegetation, land use practices, disturbance events, Satus Creek, and the steelhead that reside there. The chapter is divided into four sections. The first section discusses general vegetation changes and, when possible, links land use practices to help explain them. Next, changes in vegetation age structure are presented. The third section examines the shifts in overstory and understory composition and the implications of these shifts. Lastly, patterns and trends in depositional bars are discussed and their effects on the riparian vegetation along Satus Creek.

PATTERNS AND TRENDS

Both human and natural events and processes influence riparian systems. The ability to make a clear connection between these factors and the condition of Satus Creek and steelhead is challenging and difficult. However, certain vegetation and depositional patterns and trends were identified along all three reaches and are as follows:

- The area covered by mixed riparian shrub species and the area covered by black cottonwoods has decreased, while the area covered by alder species has increased.
- The age structure of black cottonwoods has shifted: the number of mature black cottonwoods has decreased and the number of decadent black cottonwoods has increased.
- The area of black cottonwood with a mixed riparian shrub understory has decreased; the area of black cottonwood with a herbaceous understory has increased.
- The area and number of depositional bars has increased from 1949 to 1997.

Figures 11, 12 and 13 (located in the envelope affixed to the back cover) are maps that graphically depict some of the riparian vegetation patterns discovered from this analysis. They are an important component of this thesis and should be reviewed simultaneously when reading this discussion. For all of the maps, the dominant species may represent anywhere from 1 to 99 percent of the polygon area; therefore, the maps cannot depict certain vegetation changes. Also, with these maps when the understory is other/unknown, it usually means that the overstory was so thick that the understory was not visible.

VEGETATION CHANGE AND THE EFFECTS OF LAND USE

Stream Reach 1 (Figure 11)

Modern land use in the area of stream reach 1 mostly consists of road building, diking of the stream to protect roads from flood damage, logging, and livestock grazing. Lakebeds Road, built in the early 1970s, is now the northern boundary of the floodplain. Road enhancements, and dikes built to protect the road, constrict the stream channel during high flow periods. These structures have contributed to the destabilization and degradation of riparian habitat. The loss of floodplain due to Lakebeds Road has also impacted the stream channel. The total percentage of floodplain area loss is approximately 16% (Figure 11). Reduction in floodplain area can reduce base flows because less water is infiltrated and stored underground (Elmore and Beschta 1987, 261; Mount 1995,87). Lower base flows adversely affect steelhead by shrinking habitat area and decreasing water quality.

By constricting the stream channel, Lakebeds Road influences the stream flow dynamics of stream reach 1 by preventing the channel from meandering and dissipating energy. The result is increased stream flow velocities during high flow periods and increased overall stream gradient. These changes appear to have contributed to increased erosion, incised stream banks, winnowing of sediment stored in the bars, channels and floodplain, and destruction of riparian vegetation (Mount 1995, 50). Furthermore, increased stream flow velocities have caused undercutting of the stream banks and, since black cottonwoods typically grow along the stream channel, they have been directly affected by this process. Evidence of this undercutting process can be seen throughout all the stream channels and is a factor in the decreasing presence of black cottonwoods along Satus Creek.

The construction of Lakebeds Road in the mid-1970s was the primary cause for most of the vegetation change between 1949 and 1995. Many areas that were once covered with herbaceous vegetation and mixed riparian shrubs have been destroyed, along with overstory tree species (Figure 11). Since understory riparian vegetation aids in deposition of sediments during overbank flooding (Debano and Hansen 1989, 141; Knighton 1984, 81), this understory vegetation loss combined with the earthen road surface, embankments and cutslopes has increased the suspended sediments carried by stream flows. The increase in suspended sediment has resulted in poor water quality and spawning habitat for steelhead.

Large-scale timber harvesting in the Satus Creek watershed began in 1949 and has led to a loss of protective ground cover. Reductions in vegetational cover especially along skid trails and logging roads can result in increased overland flow and decreased infiltration (Debano and Hansen 1989, 141). This loss of vegetation is particularly significant where rain-on-snow events occur because a thinner forest canopy intercepts less snowfall, which causes more snow to accumulate on the ground. This increased snowpack results in increased snow melt (Strock et al. 1995, 2). When overland flow becomes excessive, the result is increased stream flows that will enlarge and incise the stream channel (Debano and Hansen 1989, 141). Overall, logging and road construction affect stream habitat and salmonids by altering stream channels and increasing sediments (Eaglin and Hubert 1993, 844). These processes appear to be occurring on Satus Creek.

Logging has also occurred within the riparian zone of stream reach 1. Many large conifers adjacent to the stream channel have been removed. Fish prefer a stable, well-vegetated stream bank because of the protected habitat it provides them. In 1949, the stream channel was barely visible in the aerial photographs but by 1995 it was clearly visible throughout the reach. Overall, tree species have decreased by approximately 18.5% along stream reach 1 exposing the stream channel. The combination of channel undercutting, logging, and construction of Lakebeds Road are the primary causes for the visible decrease in tree species. Removal of streamside trees has resulted in reduced bank stability and allowed for more severe erosion as stream flow velocities have increased due to other factors. This has contributed to the now present exposed, wide, and shallow stream channel.

In the 1980s and 1990s, logging has been restricted in the riparian zones on the Yakama Indian Reservation. Efforts are being made to reinstate logging to create a supposed healthier and more natural riparian zone. Logging the Satus Creek riparian zone would cause it to deviate further for the conditions present in 1949.

The many land use activities along stream reach 1 have allowed natural disturbances to more severely impact Satus Creek. As noted in Chapter 2, alders are a pioneer species adapted to disturbance events. Alders have increased significantly along this reach. Although the ability to identify alder increased in the 1995 aerial photographs due to ground truthing, this would not account for all of the increase observed. This influx of alder is also common throughout all the stream reaches. The percentage shift of alder is due to the combination of human-induced and natural disturbances and suggests that the riparian zone, as well as the stream channel, is undergoing adjustments to newly imposed forces in the watershed.

Stream Reaches 2 and 3 (Figures 12 and 13)

Similarities in vegetation change, stream channel characteristics, and land use activities between stream reaches 2 and 3 permit simultaneous discussion. While road construction has influenced both stream reaches, it has not been as dramatic as in stream reach 1. U.S. Route 97, paved in 1949, has influenced Satus Creek for over a century and crosses Satus Creek in five locations (Department of Interior 1894). In particular, it crosses just upstream of stream reach 2 as well as between stream reaches 2 and 3. It also crosses over Dry Creek less than a mile before its confluence with Satus Creek, the start of stream reach 3 (Figure 3). Construction of the highway required armoring and relocating of the stream channel, and directly influenced stream flow characteristics. Armoring of channels can have negative effects on the maintenance of spawning grounds for salmonids (Mount 1995, 50). In addition to the highway, dirt roads are also located on the floodplain and terraces along both reaches. These roads have compacted and eroded the soil. Their influence on the riparian zone and stream channel has been similar to Lakebeds Road but to a much lesser degree.

In the past, cattle grazing has been intensive in the lower elevations of the watershed, and stream reaches 2 and 3 are no exception. The remnants of a cattle ranch and subsequent dirt roads crossing the channel are present along the middle portion of stream reach 2. This ranch is referred to as the Beard Ranch and was present as long ago as 1894 (Department of Interior 1894). Stream reach 3 had 22.5 ha of pastures in 1949 and some remnant ranch buildings are still are found (Figure 13). Bank trampling, removal of forbs, shrubs and young trees, floodplain leveling, and channelization, all resulted from these livestock activities are easily observed.

Cattle grazing has had the most obvious impact on the riparian vegetation along both of these stream reaches. Cattle reduce vegetation by cropping back herbaceous cover, eliminating seedlings and saplings, stunting plants by eating young shoots, and destroying overhanging vegetation. Cattle also influence the understory species composition by deterring certain plant species. This selective herbivorous behavior can be a dominant factor in determining some plant communities. This is particularly relevant to cottonwoods because they respond differently to understory species composition (Merigliano 1996, 26).

Black cottonwoods appear to be declining along both stream reaches. The loss of black cottonwoods can not be compensated for by other tree species along Satus Creek. Research indicates that once cottonwoods die, so does the riparian forest ecosystem (Braatne, Rood, and Heilman 1996, 74). The death of the native riparian forest ecosystem will have serious implications to the survival of wild Satus Creek steelhead because habitat diversity and food sources will be reduced, while stream temperatures will be increased (Theurer, Lines and Nelson 1985, 64).

The decline in black cottonwood is detrimental to the health of the stream channel and steelhead habitat because shade, nutrients, and bank stability is lowered. Black cottonwood is also the primary source of LWD in the lower reaches. The incision of the channel has reduced the stream's ability to capture LWD as well as maintaining the LWD in the channel during high flows. Field observations indicate that most of the downed cottonwoods are on the banks of the incised channels making them useless as steelhead habitat. Attempts may be made at placing and securing some of this vital LWD into the stream channel.

While there are still some healthy stands of mature black cottonwoods along stream reach 2, most are spatially separated from the active stream channel. The black cottonwoods along stream reach 3 are not healthy and are far removed from the incised channel. Many factors have influenced the black cottonwood population including channel incision, livestock grazing, undercutting by the stream channel, competition from weeds, and beaver activity. It appears that the preferred food for Satus beavers is black cottonwood, however, some other riparian shrub species are eaten and used in their dams. White alder appears to be the least preferred food and rarely shows evidence of being eaten or used in beaver dams. To prevent the destruction of black cottonwoods by beaver, the trunks of mature healthy trees need to be protected particularly along stream reach 3. Satus Creek cannot afford to continue to lose these trees.

The patterns and trends seen in decreasing riparian shrubs, other than white alder, and in increasing noxious weeds (Figures 12 and 13) can mostly be attributed to improper livestock grazing. Cattle have degraded large understory stands of riparian vegetation along Satus Creek and allowed weeds to infiltrate through their trails. Mixed riparian shrubs have decreased by 65% for stream reach 2 and by 68% for stream reach 3. The 1949 riparian shrub stands were denser than the stands in 1995, however, some herbaceous patches are visible within the riparian shrub understory in the 1949 photographs. These patches were not always delineated because of the time required to make these additions to the original GIS coverages. To compensate, modifications were made to the understory cover classes. These 1949 herbaceous patches suggest that the effects of cattle grazing were already present.

While white alders have always been a component of the vegetation composition, a dynamic increase is now occurring along Satus Creek. Alders are beneficial because they fix nitrogen and provide bank stability along Satus Creek. As mentioned earlier, white alder are adapted to highly disturbed stream systems, however, they may be out-competing other riparian species. White alders have increased by 868 % along stream reach 2 and by 175% along stream reach 3. In 1949 white alders appeared to be lining the stream channel in some sections of stream reach 2 but due to the small polygon size needed to delineate these stands, they were not separated out from the surrounding riparian shrubs. By 1995 large distinct stands of white alder line the stream channel (Figures 12 and 13). The effect of this competition on black cottonwoods and other riparian shrub species along stream reaches 2 and 3 is an area for future research.

In addition to degrading riparian vegetation, overgrazing results in trampled stream banks, unstable stream channels, and poor fish habitat (Elmore and Beschta 1987, 261; Kauffman and Krueger 1984; Trimble and Mendel, 1995). In 1949, much of Satus Creek had overhanging vegetation covering the channel and the water was not visible. The stream channel appeared wide only along certain sections, particularly in areas near cattle ranches. However, due to the small aerial photographic scale used, these water polygons were not delineated. By 1995, the stream channel is clearly visible and water can be delineated as a component of the ground cover (Figures 12 and 13). Field observations confirm the widened and degraded condition of the Satus Creek.

Incision is common throughout stream reaches 2 and 3 along with widening of the stream channel. Incised channels are the result of decreased erosional resistance of the stream bed and increased erosional forces. Reduction of vegetation due to logging, roads, and overgrazing has decreased the erosional resistance of Satus Creek. In addition, decreased permeability and cohesion of soil also allows erosion to occur. Some of the increased erosional forces mentioned by Schumm, Harvey, and Watson (1984, 12) that occur in Satus Creek are channelization, constriction by roads, increased discharge and flood peaks, and steepening of the stream gradient. An incised channel lowers base flows for all of its tributaries further destabilizing the watershed (Shields, Knight, and Cooper 1995, 971).

This serious incision has created a new floodplain, and the resulting terraces no longer become flooded during overbank floods which limits riparian species recruitment. These terraces are vegetated with some riparian species such as black cottonwood, hawthorn, and birch but xeric shrubs, weedy annuals and noxious weeds such as cheat grass, scotch thistle and knapweed are now becoming the dominant ground cover. The declining condition of the riparian woody species could be the result of the lowered water table during the dry, hot summer months because water stress reduces plant productivity by causing stomatal closure and loss of carbon fixation (Groeneveld and Griepentrog 1985, 44).

The observed pattern of increased xeric shrubs and decreased wet herbaceous cover also could be the consequences of improper grazing practices and incision. If the water table was being lowered due to downcutting by the stream channel, then this would be more beneficial to xeric species than to mesic species. This could explain the trend that appears to be occurring along Satus Creek

Herbaceous species were not discernable in 1949; therefore the vegetation code 339900 was used for all herbaceous species. This code presented some problems when computing area. Through ground truthing, species and percent composition were better identified in 1995 and weed species were recognized as a large component of the present herbaceous vegetation (Figures 12 and 13). Noxious weeds are now a serious problem along both stream reaches but particularly along stream reach 3. In the Western U.S., noxious weeds are a problem throughout areas disturbed by cattle grazing. These aggressive species are adapted to many habitats and often out-compete native species.

The depositional bars along stream reaches 2 and 3 are heavily vegetated with weedy species, particularly knapweed, scotch thistle, and yellow sweetclover (*Melilotus officinalis).* Weed species evolved in habitats that are subjected to disturbance (Grime 1979, 42) and as mentioned, they have a competitive advantage because of their early arrival time and large reproductive effort. These fast growing species shade the stream bars, and their demand for nutrients could be adversely affecting germination of black cottonwoods. Although these weed species help to trap sediments and bind soil, their presence should be a management concern because they indicate poor stream health (Hansen et al. 1995, 2).

Several small riparian meadows were located during reconnaissance that were not visible on the aerial photographs. These meadows are important bank storage areas that retain water throughout the drier parts of the year and return cooler water to Satus Creek. Some of the riparian meadows were in a degraded condition despite efforts by the Satus Restoration Project to terminate grazing in the riparian zone; evidence of cattle activity was seen in the latter part of September 1998. Trampling and grazing of these meadows negatively affects their water holding functions. These meadows are also important for catching and binding sediments and provide some protection to the stream banks. These meadows should be mapped and surveyed to monitor future trends and provide insight into the condition of the riparian zone.

Along stream reach 2, a riparian meadow was located at the end of an old side channel that had been dammed by past beaver activity. The cool water present in this side channel indicates that it is fed by groundwater. These side channels are a significant source of cooler water within the floodplain, particularly if riparian vegetation shades them during the summer months. Steelhead are known to be attracted to inflows of cool in water in the summer so rehabilitating these side channels would improve the health of Satus Creek and provide rearing habitat for steelhead.

VEGETATION AGE STRUCTURE

The age classification used for this thesis is very general and can be misleading for some species. The ability to distinguish between young and mature age classes can be subjective, thus decreasing age classification for certain species. Ground truthing helped verify the vegetation age for 1995. Vegetation ages in the 1949 aerial photographs were difficult to determine, so less age class heterogeneity resulted.

Despite difficulties in discerning age classes, apparent patterns and trends are occurring with black cottonwood and white alder along Satus Creek. Although conifers exhibited some shifts in age class structure along stream reach 1, no clear patterns have emerged for these species. Mixed riparian species also exhibited shifts in age class structure with regard to mature species. This shift can be attributed to the overall decrease of this vegetation cover.

Black cottonwoods have shown the most change in age structure of the species studied. The ability to identify decadent black cottonwoods on aerial photographs is higher than for other woody species because of declining conditions in the tree canopy. However, the 1995 aerial photographs were taken in September when trees were beginning to lose their leaves. This factor may have influenced some of the age class delineation. All stream reaches contained fewer mature black cottonwoods in 1995 than in 1949 and decadent black cottonwoods were observed along all reaches. Some small patches of black cottonwood seedlings were found during ground truthing along stream reach 3 that were not presented in the results because they were not identifiable on the aerial photographs. This may be true for all the stream reaches.

Attempts at coring black cottonwood to determine age proved difficult. Black cottonwoods store large amounts of water in their trunks; this made reading the tree rings challenging. Better techniques at aging cottonwoods could help reveal information on the hydrological conditions that created the needed substrate for black cottonwood germination. It also will inform resource managers on the life history of Satus Creek black cottonwoods.

The declining health of black cottonwood stands should be a serious concern of the YIN because they are the foundation for the low elevation riparian forest ecosystem. The probable explanation for the age structure shift of black cottonwoods is overgrazing. Records of AUMs show that cattle numbers peaked in 1976. Repercussions of heavy grazing around that time are seen today by the decrease in young to mature trees.

Significant improvements in restricting livestock grazing within the Satus Creek watershed have been made by the Satus Restoration Project Team and these restrictions should allow revegetation of black cottonwood to occur. Forced germination or planting of black cottonwoods is a viable restoration project for the Satus Creek Restoration Team. Rooted cuttings or nursery-grown seedlings can easily be established on the moist, alluvial soils of eastern Washington in the spring (Braatne 1999, personal communication). Cottonwood seedlings grow rapidly and are effective stabilizers of alluvial deposits. Swenson (1988) provides detailed guidelines on revegetating sites with black cottonwood cuttings to help increase survival rates.

White alder is the other species that has exhibited a shift in age structure. All stream reaches increased in mature alders with stream reach 2 showing the most increase. Stream reaches 2 and 3 have also increased substantially in young white alders. This increase in white alder suggests that disturbance events have increased and become more severe along Satus Creek because this species is tolerant of increases in severe disturbances.

White alders are fast growing and appear to reach maturity in eight years. Most of the white alder stands lining the stream channel are approximately twenty-five years of age because they were barely present in 1979 photographs. The flood event of 1974 most likely established the present-day stands. Truly mature white alder that are at least fifty years in age are occasionally found in various locations in the riparian zone. They can be within a dense understory, next to the active channel, or far removed from the active channel. Their spatial variation is very different from what we see today among the younger alder.

Overstory and Understory Composition

Of all the patterns measured, the changes in the overstory and understory composition seem the most significant. A substantial shift has occurred in the understory associated with black cottonwood. All stream reaches show that areas with a mixed riparian shrub understory are decreasing while areas with an alder understory are increasing. Stream reaches 2 and 3 are also increasing in areas with an herbaceous understory. These shifts indicate that the plant communities along Satus Creek are undergoing a succession of some kind, possibly related to increasing frequency or intensity of natural disturbance events or the impacts of overgrazing.

Stream reaches 2 and 3 presently contain a limited number of undisturbed stands of black cottonwoods with a diverse, dense shrub understory but, as measured on the 1949 aerial photographs, these plant communities once dominated the floodplain. The loss of this plant community is affecting the stream bank stability, fish cover, and debris recruitment (Hansen et al. 1995, 248). Woody species increase bank stability due to surface roughness a subsurface root matrix along the stream banks. They also provide much-needed shade in the hot dry summer months. Lastly, the decrease in riparian buffer width has likely contributed to increasing sedimentation of Satus Creek. This overall decrease in woody species impacts the quality of steelhead habitat and argues for restoration efforts.

It appears that herbaceous species are replacing most of the riparian shrub understory of black cottonwood along stream reaches 2 and 3. Heavy grazing and incision have been identified as primary factors for this shift. A healthy riparian shrub understory can affect the soil moisture stress required for herbaceous species, thus preventing their ability to become the dominant understory (Merigiliano 1996, 34). However, once grasses and weedy annuals become established they deplete soil moisture that can negatively affect cottonwoods and other riparian woody species (McQueen and Miller 1972, E27).

According to Hall and Hansen (1997), once a shift from woody to herbaceous vegetation occurs, it becomes very difficult to return to the former woody community. While it may be possible to recreate these woody plant communities, it can be very costly. Consequently, it is best to maintain the shrub-dominated understory before it becomes too degraded (Hall and Hansen 1997, 142).

Alders are replacing the mixed riparian understory along all three stream reaches. At the present, stream reach 2 contains the most black cottonwoods along with a white alder understory. However, over time, white alder may eliminate the black cottonwoods through competition as a result of the natural successional process following increased disturbance events along Satus Creek. The potential effects of a dramatic increase in white alder on plant succession patterns are still not yet clear. Miller (1976, 70) found that white alder stands had little or no understory where stream channels were unstable and disturbance was high. Monitoring of plant succession in stream reach 2 would help in understanding the plant dynamics along Satus Creek and answer important questions regarding white alder competition and the effects on existing black cottonwoods.

Stream reach 1 is exhibiting a shift in understory species association with conifers. Areas with an understory of mixed riparian shrubs, herbaceous cover, or conifers have all decreased over time while areas with black cottonwoods as an understory increased over time. Conifer canopy cover in 1995 appears denser and has limited understory visibility. Poor quality aerial photographs taken in 1995 have also hampered determination of understory. The combination of land use activities addressed in the previous section and suppression of fire may have contributed to the shift in understory in stream reach 1.

While this thesis shows overall trends and patterns in plant communities along Satus Creek, detail on the diversity of plant species is an area for future study. To completely understand the dynamics of the riparian plant communities along Satus Creek, a field-based riparian plant classification system should be performed before these remnant communities are destroyed. This classification will assist with restoration and management decisions along Satus Creek.

DEPOSITIONAL BAR PATTERNS AND TRENDS

Disturbance events create areas of exposed sediment known as depositional bars in riparian systems by removing vegetation and depositing sediments. Since fluvial systems are dynamic, these processes fluctuate in intensity and frequency. The findings of this thesis clearly show fluctuations in depositional bar size and total area for all three stream reaches. Further analysis of depositional bar findings could constitute a thesis on its own; this thesis focuses on the relationship of depositional bars to the patterns and trends in riparian vegetation along Satus Creek.

The pattern for depositional area for all three stream reaches show a gradual increase from 1949 to 1964 and then a dramatic jump from 1964 to 1979. The depositional area for all stream reaches then decreased from 1979 to 1995. Even with this decrease, stream reaches 2 and 3 still had more depositional area in 1995 than 1964, however stream reach 1 did not. The poor quality of aerial photographs already mentioned and its heavier forest canopy cover may be the reasons that stream reach 1 does not follow this trend. By 1997, all stream reaches had more depositional area than in 1995. Stream reach 3 is the only reach to have more area covered by depositional bars in 1997 than in 1979. This trend may be due to the low position of stream reach 3 in the watershed and its low gradient, therefore making it more likely to accumulate sediment.

The patterns and trends in deposition bars along Satus Creek appear to be correlated to major flood events that occurred in 1933 or 1934, 1964, 1974, late 1995 (after aerial photographs), 1996, and 1997. The 1964 flood may have caused the increase in depositional area between 1949 and 1964. This increase in depositional bars does not appear to have altered the riparian plant structure. By the middle of the 1970s, grazing and logging activity peaked for the watershed (Figures 4 and 5). These intensive land use practices combined with a major event occurring in 1974 are most likely the cause for this dramatic increase in total depositional area and depositional bar size. Depositional bar areas decreased by 1995 but the riparian zone still showed serious signs of degradation and the impacts of the 1974 flood can still be seen.

The depositional bars present in 1979 had become vegetated by white alder along the stream margins by 1995. The remaining depositional area appears to be sparsely vegetated by willows and probably weeds. The floods of 1995, 1996 and 1997 removed many of these large stands of white alder seen in 1995, thus further setting back the clock of plant species succession. The removal of white alder has further exposed and widened the stream channel decreasing the quality of steelhead habitat.

The major floods of 1995, 1996 and 1997 have increased the maximum size of depositional bars. Larger depositional bars suggest that more sediments are being moved through the watershed during major flood events and being deposited within the riparian zone. The cumulative effects of land use activities may also be contributing to the substantial size increase of depositional bars by removing upland vegetation and disturbing the soil.

An interesting finding is the decreased frequency of depositional bars along stream reach 3 in 1997 compared to 1995 despite the fact that 1997 had more total area covered by deposits. The maximum size of depositional bars quadrupled within just two years. It appears that individual depositional bars have combined to form a large depositional area. The effect of this substantial increase in depositional bar size on the overall amount of riparian vegetation for stream reach 3 has been more dramatic than the results found for 1995.

Patches of deposited alluvium are important germination sites for riparian species. However, these large areas of deposits were created at the expense of considerable amounts of riparian vegetation. The destruction of this vegetation has contributed to the degraded condition of Satus Creek and its steelhead habitat by reducing bank stability, subsurface storage of water, and stream flows, while increasing water temperature and stream sedimentation (Elmore and Beschta 1985, 261).

CHAPTER VII

CONCLUSION

This thesis investigates patterns and trends in riparian vegetation along three stream reaches of Satus Creek and identifies sensitive or critical areas of the landscape. The data presented in this thesis provides the YIN with insights on the riparian vegetation changes occurring along Satus Creek and assists in their restoration of steelhead habitat.

Several patterns and trends were identified through this thesis that were suspected but not validated. Obviously, Satus Creek is in a degraded condition and steelhead habitat is poor but the condition of Satus Creek fifty years ago had not been previously documented. Through this analysis, the condition of riparian vegetation along Satus Creek fifty years ago was determined to be relatively intact. Signs of declining conditions were not detected prior to the 1979 aerial photographs. Within approximately the last twenty years, diversity and vigor of riparian vegetation has been identified as declining, as well as the overall riparian vegetation cover.

Of all the findings, the most significant should be the shift of understory species from riparian shrubs to herbaceous cover. Black cottonwoods are the overstory species for these plant associations but are in a state of decline. The loss of this woody plant association will likely have a serious impact on the future condition of Satus Creek. Another major finding is the dramatic influx of alder within the riparian zone. Although alder is a natural component of the system, its increase is a result of increased intense disturbance events in Satus Creek. The influence of alder on the plant dynamics of Satus Creek was not determined in this thesis but could be monitored in the future to gain a valuable understanding of this riparian system.

GIS is a useful tool for displaying and analyzing temporal and spatial data and a vital component of this thesis. The dynamic nature of riparian systems makes them highly complex and challenging to study. Mapping riparian vegetation dynamics has been a problem in the past due to temporal fluctuations over the same area. Even when mapped, limitations continue to exist in showing all vegetational aspects. In this thesis, GIS allowed multiple vegetational aspects to be linked spatially and then quickly quantified.

Certain limitations were present with the classification system used in this thesis but they were inherited, and therefore difficult and time consuming to change in GIS. A suggestion for future vegetation mapping projects would be to design a classification that does not limit the number of species that can be used. In addition, consistency of cover classes is important because of their effects on interpretation. Lastly, delineation of vegetation polygons should be done first, and attributes assigned later. This would help to lessen subjectivity of the interpretation. It would also allow the interpreter to first become familiar with the vegetation composition and then design a more accurate and consistent classification system.

The symbiotic relationship between a stream and its riparian vegetation is influenced by a wide variety of environmental and cultural factors. Often it is difficult to determine the specific influences that have altered the systems because combinations of factors have usually contributed to the change. This study has shown the linkages between certain patterns of vegetation change and land use activities, but the complexity of Satus Creek vegetation dynamics requires more research and monitoring.

To fully understand the distribution and dynamics of riparian vegetation, disturbance maps are essential. The impacts of these disturbance events along Satus Creek have been significant loss in woody riparian vegetation, increase in erosion and deposition along the stream margins, as well as widening of the stream channel. The analysis of depositional bars has helped to explain the patterns and trends of the riparian vegetation along Satus Creek. It is clear that managing the disturbance flow regimes lies at the center of all restoration efforts.

Patterns and trends in riparian vegetation are the result of watershed level activities. It is hard to ignore the degraded condition of the Satus Creek riparian ecosystem when attempting to restore steelhead habitat. Healthy riparian vegetation is vital for the recovery of steelhead. However, if restoration efforts are to work then they must address the full scope of watershed activities that are degrading the system. It was not possible to describe fully the vegetation dynamics occurring along Satus Creek, but it is hoped that this thesis provides the framework for future restoration efforts and will be useful to future YIN resource managers.

REFERENCES

Adams, S. 1999. Personal Communication. Wildlife and Fisheries Biologist at the Yakama Indian Nation.

Bendix, J. 1994. Among-site variation in riparian vegetation of the southern California transverse ranges. *American Midland Naturalist* 132(1): 136-151.

Braatne, J.H. 1999. Personal conversation. Professor at University of Washington.

Braatne, J.H., Rood S.B. and P.E. Heilman. 1996. Life history, ecology, and conservation of riparian cottonwoods in North America. In B*iology of Populus and its implications for management and conservation*, ed. R.F. Stettler, H.D Bradshaw, Jr. P.E. Heilman and T.M. Hinckley, 57-85. Ottawa: NRC Research Press.

Budd, W.W., P.L.Cohen, and P.R. Saunders. 1987. Stream corridor management in the Pacific Northwest: I. Determination of stream-corridor widths. *Environmental Management* 11(5); 587-597.

Campbell, N.P. 1984. *Geology of the Yakima Area.* Yakima: Yakima Valley College.

Canham, C.D. and P.L. Marks. 1985. The response of woody plants to disturbance: patterns of establishment and growth. In *The ecology of natural disturbance and patch dynamics,* ed. S.T. Pickett and P.S. White, 197-216. Orlando: Academic Press, INC.

Chapman, D.W. and R.L. Demory. 1963. Seasonal change in the food ingested by aquatic larvae and nymphs in two Oregon streams. *Ecology* 44: 140-146.

Clements, F.E. 1916. *Plant Succession: an analysis of the development of vegetation.* Washington: Carnegie Institution of Washington.

Cummins, K.W. 1974. Structure and function of stream ecosystems. *Biological Science* 24 (11): 631-641.

Dains, V.I. 1988. Water relations of white alder. Paper presented at the *Proceedings of the California riparian systems conference: protection, management, and restoration for the 1990s; September 22-24;* Davis, CA. Gen. Tech. Rep. PSW-110, Berkley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture. 375-380.

Daubenmire, R.D. 1959. A canopy coverage method of vegetation analysis. *Northwest Science* 33: 43-46.

Debano, L. and W. Hansen. 1989. Rehabilitating depleted riparian areas using channel structures. In *Practical Approaches to Riparian Resource Management an Educational Workshop*, ed. R. Gresswell, B. Barton, and J. Kershner. Billings: U.S. Bureau of Land Management.

Eaglin, G.S. and W.A. Hubert. 1993. Effects of logging and roads on substrate and trout in streams of the Medicine Bow National Forest, Wyoming. *North American Journal of Fisheries Management* 13: 844-846.

Elmore W. 1992. Riparian responses to grazing practices. In *Watershed Management balancing sustainability and environmental change*, ed. Robert J. Naiman. New York: Springer-Verlag New York, Inc.

Elmore, W. and R.L. Beschta. 1987. Riparian areas: perceptions in management. *Rangelands* 9: 260-265.

Franklin, J. 1992. Scientific basis for new perspectives in forests and streams. In *Watershed Management balancing sustainability and environmental change*, ed. Robert J. Naiman. New York: Springer-Verlag New York, Inc.

Fretwell, M.O. 1979. *Quality of surface and ground waters, Yakima Indian Reservation, Washington, 1973-74.* Open-file report 77-128. Tacoma: U.S. Dept. of the Interior, Geological Survey.

Gregory, S.V., F.J. Swanson, W.A. McKee, and K.W. Cummins. 1991. An ecosystem perspective of riparian zones: focus on links between land and water. *Bioscience* 41(8): 540-551.

Grime, J.P. 1979. *Plant Strategies and Vegetation Processes.* Chichester: John Wiley & Sons.

Groeneveld, D.P. and T.E. Griepentrog. 1985. Interdependence of groundwater, riparian vegetation, and streambank stability: A case study. Paper presented at the *Symposium, Riparian Ecosystems and their Management: reconciling Conflicting Uses*, April 16-18, Tucson: 54-58.

Haines-Young, R., D.R. Green, and S. Cousins. 1993. Landscape ecology and geographical information systems. In *Landscape ecology and GIS*, ed. R. Haines-Young, D.R. Green, and S. Cousins, 3-8. London: Taylor & Francis Ltd.

Hall, J.B. and P.L. Hansen. 1997. *A preliminary riparian habitat type classification system for the Bureau of Land Management Districts in Southern and Eastern Idaho*. Technical Bulletin No. 97-11. Idaho Bureau of Land Management. July.

Hansen, P.L., R.D. Pfister, K. Boggs, B.J. Cook, J. Joy, and D.K. Hinckley. 1995.*Classification and Management of Montana's Riparian and Wetland Sites*. Missoula: The University of Montana.

Harrington, C.A., J.C. Zasada and E.A. Allen. 1994. Biology of red alder (*Alnus rubra* Bong.). In *The biology and management of red alder*, ed. D.E. Hibbs, D.S. DeBell and R.F. Tarrant, 3-22. Corvallis: Oregon State University Press.

Heede, B. 1985. Interaction between streamside vegetation and stream dynamics. Paper presented at the *Symposium, Riparian Ecosystems and their Management: reconciling Conflicting Uses*, April 16-18, Tucson: 54-58.

Heede, B. 1990. *Vegetation strips control erosion in watersheds*. USDA Forest Service: Rocky Mountain Forest and Range Station. Research Note RM-499.

Hooper, W.C. 1994. Riparian zone considerations for management of fish, fish habitat, and sport fishing in New Brunswick. In *Proceedings of the Symposium on Riparian Zone Management.* R&D Report No.9, Cooperation Agreement on Forest Development. January 17 –19, New Brunswick: 23–31.

Hubble, J.D. 1992. A study of the summer steelhead, *Oncorhynchus mykiss* in several intermittent tributaries of the Satus Creek Basin, Washington. M.S. thesis, Central Washington University.

Hunt, R. L. 1976. A long-term evaluation of trout habitat development and its relation to improving management-related research. *Transaction of the American Fisheries Society.* 105(3): 361-365.

Hupp, C. and W. Osterkamp. 1996. Riparian vegetation and fluvial geomorphic processes. *Geomorphology* 14: 277-295.

John, S. 1917. Coyote, his son, and the salmon. In *Ghost Voices, Yakima Indian myths, legends, huor, and hunting stories,* ed. D. Hines, 121-6. Issaquah: Great Eagle Publishing, Inc.

Kauffman, J.B. and W.C. Krueger. 1984. Livestock impacts on riparian ecosytems and streamside management implications: a review. *Journal of Range Management* 37:430-438.

Knighton, D. 1984. *Fluvial forms and processes.* London: Edward Arnold.

Knutson, K.L, and V.L. Naef. 1997. *Management Recommendations for Washington's Priority Habitat: RIPARIAN.* Olympia: Washington Department of Fish and Wildlife.

Lind, David. 1996. *Early Implementation Project Satus Watershed Restoration: Contract NO. 96FC96064.*

Lind, David. 1999. Personal Communication. Fisheries Biologist at the Yakama Indian Nation. Toppenish, WA.

Lisle, T.E. 1989. Channel-dynamics control on the establishment of riparian trees after large floods in northwestern California. Paper presented at the *Proceedings of the California riparian systems conference: protection, management, and restoration for the 1990s; September 22-24;* Davis, CA. Gen. Tech. Rep. PSW-110, Berkley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture. 9-13.

Lo, C.P. and R.L. Shipman. 1990. A GIS approach to land-use change dynamics detection. *Photogrammetric Engineering & Remote Sensing* 56(11): 1483-1491.

McQueen, I.S. and R.F. Miller. 1972. Soil moisture and energy relationships associated with riparian vegetation near San Carlos, Arizona: Gila river phreatophyte project. Geological Survey Phreatophyte Project. U.S. Gov. Printing Office: Washington.

Merigliano, M.F. 1996. *Ecology and Management of the South Fork Snake River cottonwood forest.* Idaho BLM, Technical Bulletin 96-9.

Miller, T.B. 1976. Ecology of riparian communities dominated by white alder in western lands. M.S. thesis, University of Idaho.

Montgomery, D. R., G. E. Grant, and K. Sullivan. 1995. Watershed analysis as a framework for implementing ecosystem management. *Water Resources Bulletin.* 31: 369 –386.

Mount, J.F. 1995. *California Rivers and Streams – The conflict between fluvial process and land use.* Berkeley: University of California Press.

Mundorff, M.J., R.D. Mac Nish, and D.R. Cline. 1977. Water Resources of the Satus Creek Basin, *Yakima Indian Reservation, Washington.* Open-file report 76-685. Tacoma: U.S. Dept. of the Interior, Geological Survey.

Naiman, R.J., T. Beechie, L. Benda, D. Berg, P. Bisson, L. MacDonald, M. O'Connor, P. Olson, and E. Steel, eds. 1992. Fundamental elements of ecologically healthy watersheds in Pacific Northwest Coastal Ecoregion. In *Watershed Management balancing sustainability and environmental change*, ed. R.J. Naiman. New York: Springer-Verlag New York, Inc.

Naiman, R.J., H. Decamps, and M. Pollack. 1993. The role of riparian corridors in maintaining regional biodiversity. *Ecological Applications* 3(2): 209-212.

National Marine Fisheries Service and National Oceanic and Atmospheric Administration. 1998. Endangered Species: proposed threatened status for two ESUs of steelhead in Washington and Oregon. *Federal Register* vol. 63: 46. 11797 – 11809.

National Marine Fisheries Service and National Oceanic and Atmospheric Administration. 1999. Endangered and Threatened Species: Threatened status for two ESUs of steelhead in Washington and Oregon. *Federal Register* vol. 64: 57. 14517 – 14529.

Nez Perce Tribe, Confederated Tribes of the Umatilla Indian Reservation, Confederated Tribes of the Warm Springs Reservation of Oregon, Confederated Tribes and Bands of the Yakama Indian Nation, Columbia River Inter-Tribal Fish Commission. 1996. *Wy-kan-ush-mi-wa-kish-wit: The Columbia River anadromous fish plan of the Nez Perce, Umatilla, Warm Springs and Yakama Tribes.*

Platts, W.S. 1983. Vegetation requirements for fisheries habitats. *Managing intermountain rangelands – improvements of range and wildlife habitats.* General Technical Report INT-157, Intermountain Forest and Range Experiment Station, U.S. Department of Agriculture Forest Service, Ogden, UT.

Reice, S.R. 1994. Nonequilibrium determinants of biological community structure. *American Scientist* 82(5): 424-435.

Rood, S.B., and J.M. Mahoney. 1990. Collapse of riparian poplar forests downstream from dams in western prairies: probable causes and prospects for mitigation. *Environmental Management* 14: 451-464.

Satus Creek Watershed Restoration Team. 1998. *Satus Creek Watershed Analysis.*

Schumm, S.A., M.D. Harvey, and C.C. Watson. 1984. *Incised channels: morphology, dynamics and control.* Littleton: Water Resources Publications.

Scott, M.L., J.M. Friedman, and G.T. Auble. 1996. Fluvial process and the establishment of bottomland trees. *Geomorphology* 14: 327-339.

Shields Jr., F.D., S.S. Knight, and C.M. Cooper. 1995. Rehabilitation of watersheds with incising channels. *Water Resources Bulletin* 31: 971-982.

Storck, P., D.P. Lettenmaier, B.A. Connelly, and T.W. Cundy. 1995. *Implication of forest practices on downstream flooding: Phase II final report.* Timber, Fish & Wildlife, TFW-SH20-96-001.

Swanson, F.J., S.V. Gregory, J.R. Sedell, and A.G. Campbell. 1982. Land-water interactions: the riparian zone. In *Analysis of coniferous forest ecosystems in the western United States*, ed. R.L. Edmonds, 267-291. Stroudsburg: Hutchinson Ross Publishing Company.

Swenson, E.A. 1988. Progress in the understanding of how to reestablish native riparian plants in New Mexico. In *Restoration, creation, and management of wetland and riparian ecosystems in the American West.* A symposium of the Rocky Mountain Chapter of the Society of Wetland Scientists. K.M. Mutz, D.J. Cooper, M.L. Scott, and L.K. Miller, technical coordinators. Denver, CO, November 14-16. 239pp.

Theurer, F.D., I. Lines, and T. Nelson. 1985. Interaction between riparian vegetation, water temperature, and salmonid habitat in the Tucannon River. *Water Resources Bulletin* 21: 53-64.

Trimble, S.W. and A.C. Mendel. 1995. The cow as geomorphic agent – a critical review. *Geomorphology* 13: 233-253.

Uebelacker, M.L. 1984. *Time Ball: A Story of the Yakima People and the Land.* Yakima: The Yakima Nation.

United States Army Corps of Engineers. 1990. *Fisheries Handbook of Engineering Requirements and Biological Criteria by Fish Passage Development and Evaluation Program.* North Pacific Division. Oregon: Portland. 11.1 - 11.3.

United States Department of Interior. 1894. Survey Maps for Township 9N, Range 19E, Willamette Meridian. Produced by G.C. Mills. Olympia: Surveyor Generals' Office.

Washington Forest Practices Board. 1995. *Board manual: standard methodology for conducting watershed analysis – version 3.0.* Under Chapter 222-22 WAC. November.

Wesche, T A., Goertler, C.M., and C.B. Frye. 1987. Contributions of riparian vegetation to trout cover in small streams. *North American Journal of Fisheries Management* vol. 7: 151–153.

White, P.S. and. S.T. Pickett. 1985. Natural disturbance and patch dynamics: An introduction. In *The ecology of natural disturbance and patch dynamics*, ed. S.T. Pickett and P.S., 3-13. White Orlando: Academic Press, Inc.

Williams, G.D. and W.A. Babcock. 1983. *The Yakima Indian Nation Forest Heritage: a history of forest management on the Yakima Indian Reservation, Washington.* Missoula: Heritage Research Center.

Williams, J.E., C.A. Wood, and M.P. Dombeck. 1997. Understanding watershed-scale restoration. In *Watershed restoration: principles and practices*, ed. J.E Williams, C.A. Wood, and M.P. Dombeck. Bethesda: American Fisheries Society.

Yakama Indian Nation. 1931. *Working plan report of the grazing resources and activities of the Yakima Indian Reservation.* January.

Stream Reach 1

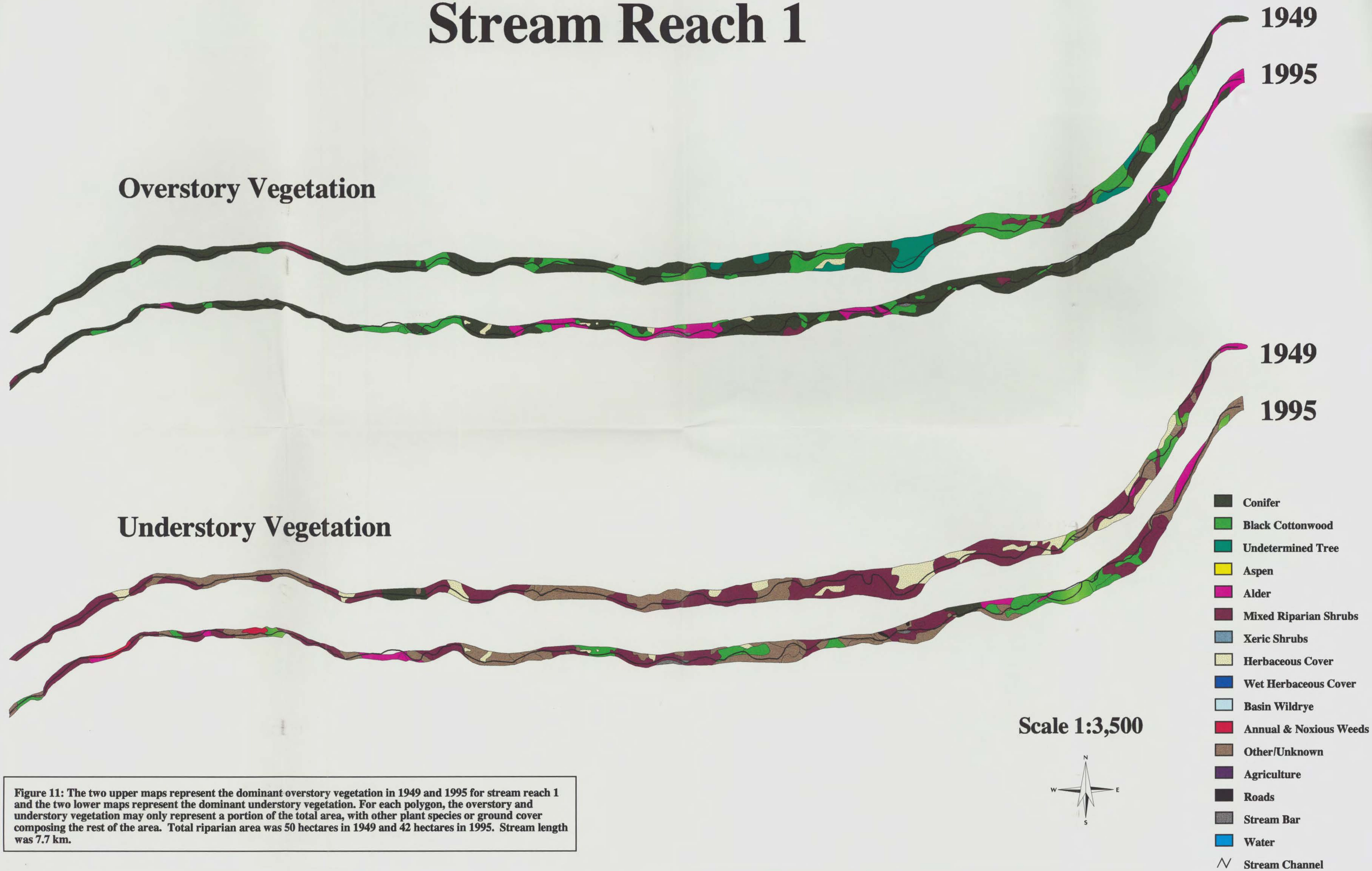
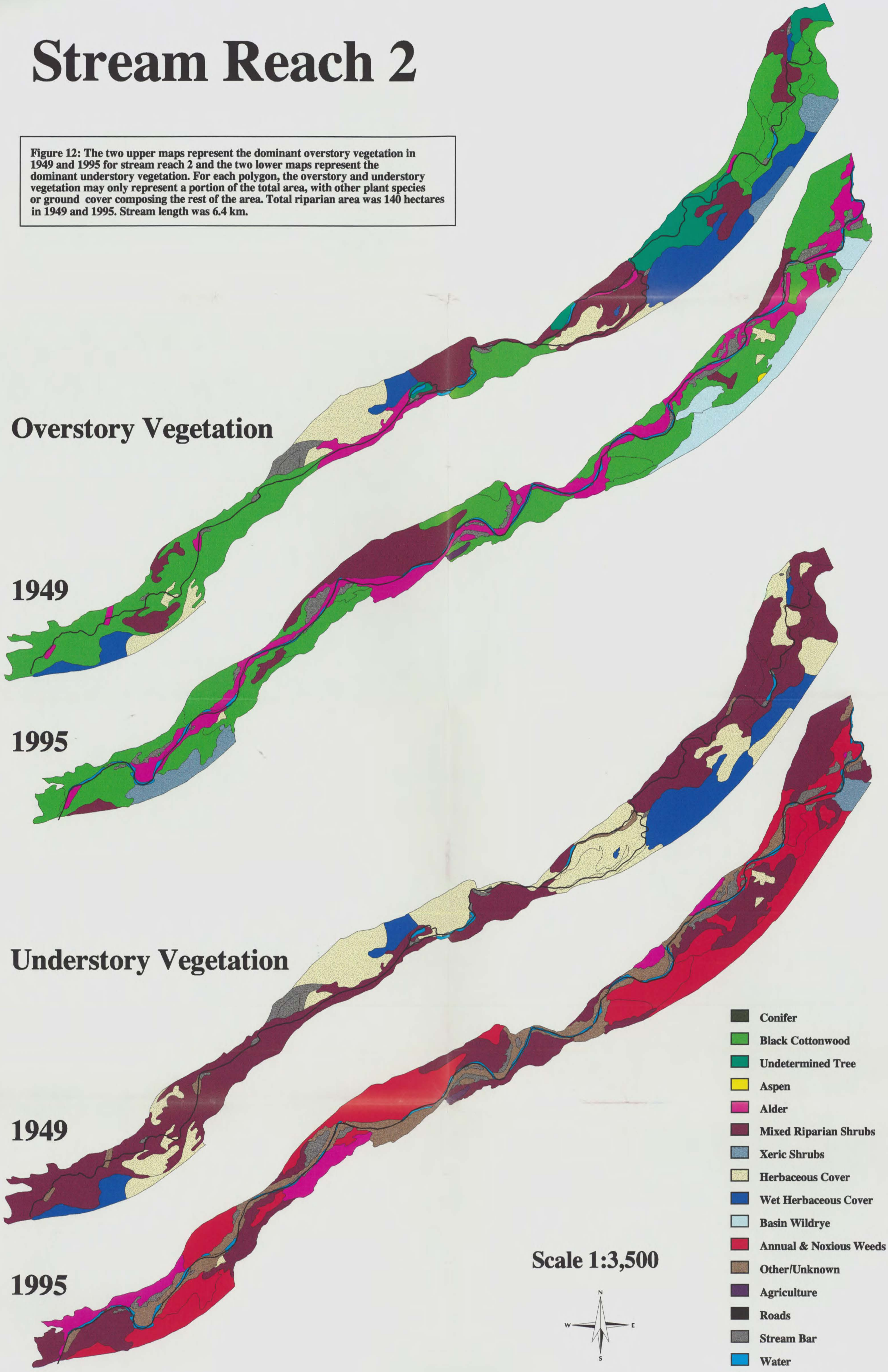


Figure 11: The two upper maps represent the dominant overstory vegetation in 1949 and 1995 for stream reach 1 and the two lower maps represent the dominant understory vegetation. For each polygon, the overstory and understory vegetation may only represent a portion of the total area, with other plant species or ground cover composing the rest of the area. Total riparian area was 50 hectares in 1949 and 42 hectares in 1995. Stream length was 7.7 km.

Stream Reach 2

Figure 12: The two upper maps represent the dominant overstory vegetation in 1949 and 1995 for stream reach 2 and the two lower maps represent the dominant understory vegetation. For each polygon, the overstory and understory vegetation may only represent a portion of the total area, with other plant species or ground cover composing the rest of the area. Total riparian area was 140 hectares in 1949 and 1995. Stream length was 6.4 km.



Stream Reach 3

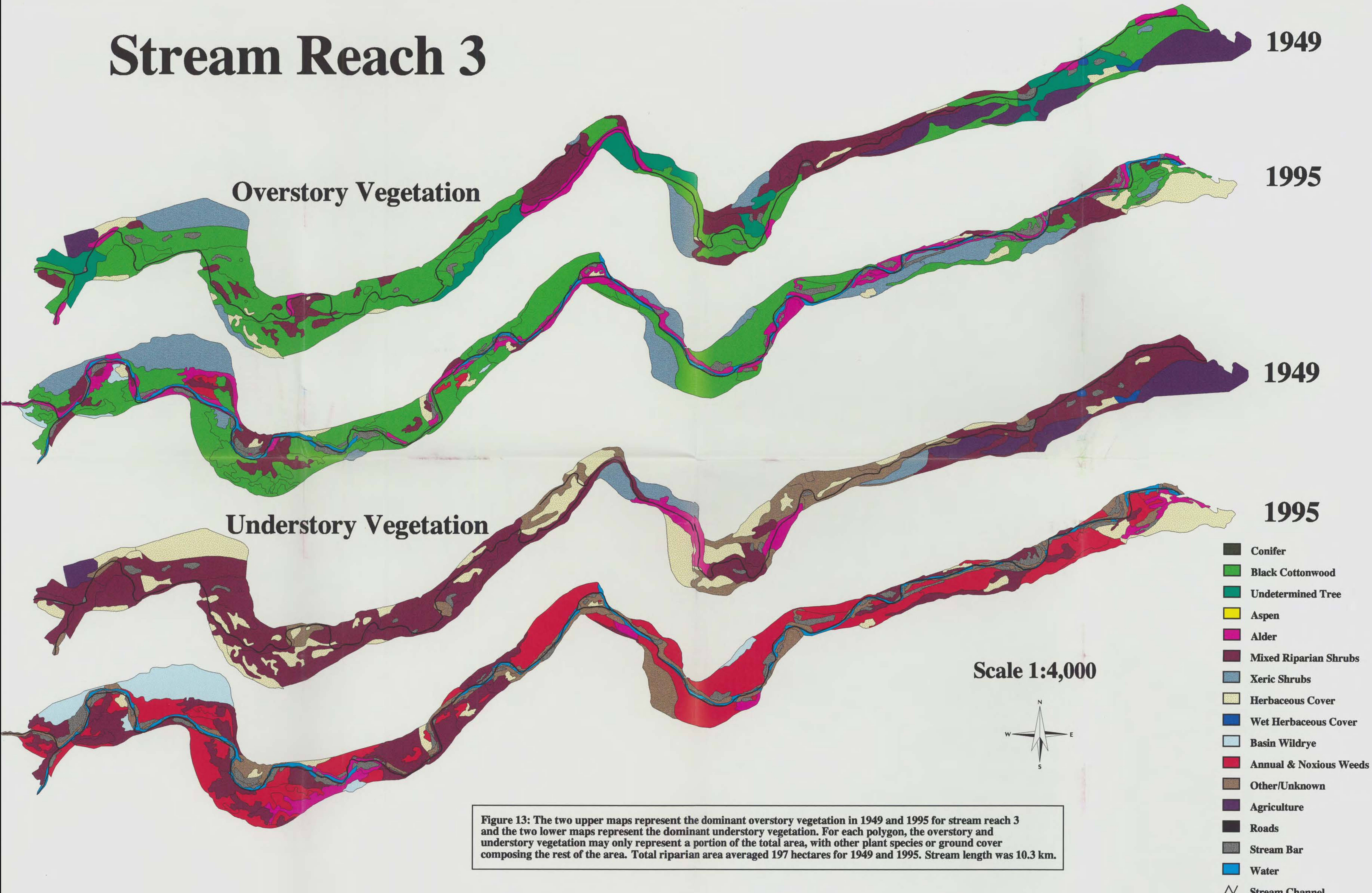


Figure 13: The two upper maps represent the dominant overstory vegetation in 1949 and 1995 for stream reach 3 and the two lower maps represent the dominant understory vegetation. For each polygon, the overstory and understory vegetation may only represent a portion of the total area, with other plant species or ground cover composing the rest of the area. Total riparian area averaged 197 hectares for 1949 and 1995. Stream length was 10.3 km.