HISTORICAL CHANGES IN RIPARIAN VEGETATION AND CHANNEL MORPHOLOGY ALONG THE LOWER ENTIAT RIVER VALLEY, WASHINGTON: IMPLICATIONS FOR STREAM RESTORATION AND SALMON RECOVERY

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by

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ABSTRACT

HISTORICAL CHANGES IN RIPARIAN VEGETATION AND CHANNEL MORPHOLOGY ALONG THE LOWER ENTIAT RIVER VALLEY, WASHINGTON: IMPLICATIONS FOR STREAM RESTORATION AND SALMON RECOVERY

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The lower Entiat River Valley has been influenced by a variety of natural events and anthropogenic activities over the past century: these include floods, fires, dams, logging, and flood control works. These changes have all had a cumulative impact on the Entiat River and its riparian zone. This research sought to identify changes in riparian vegetation and channel morphology along the lower Entiat River while assessing causal factors and the implications of landscape change on aquatic habitat. The evidence suggests that historical land uses dating prior to 1945 account for most human-induced alteration along the lower river. Results illustrate that few cumulative changes in riparian vegetation or channel morphology occurred between 1945-1998, although spatial variations were present. Further, despite widespread speculation by resource managers, the U.S. Army Corps of Engineers did not dramatically alter the Entiat and is only responsible for a handful of flood control structures and stream works. Management recommendations benefit from this new understanding of disturbance history and offer realistic implementation possibilities.

ACKNOWLEDGEMENTS

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Finally, I would like to thank my famiiy. Mom, thank you for always believing in me and allowing me the freedom to dream big. To my wife Danielle, thank you for everything.

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CHAPTER I

INTRODUCTION

Problem Statement

The lower Entiat River Watershed has been shaped by a variety of natural and human-induced changes since Euro-American settlement began in the late 1880s. Floods, flood control activities, removal of riparian vegetation, placement of roads and other infrastructure, agricultural expansion, dams, grazing and logging have all had a cumulative impact on the Entiat River, its riparian zone and its aquatic species. Although all of the above actions have resulted in aquatic and riparian habitat alteration, resource managers have long assumed that flood control activities initiated by the U.S. Army Corps of Engineers (USACE) after the flood of record in 1948 resulted in the most significant changes to the river corridor.

In June 1948, the combination of intense thunderstorms, warm weather and a dense snowpack resulted in a catastrophic flood along the lower Entiat River Valley from the small town of Ardenvoir to its mouth, a distance of nearly ten miles. The flood destroyed homes, buildings, bridges, crops, roads, irrigation infrastructure and farmland. Flood control efforts were initiated by the USACE and may have included widening, deepening and straightening some portions of the river, along with the removal of large woody debris (LWD) and construction of levees and other protective bank features. Together, these channelization efforts could represent significant modifications to the lower Entiat River and may partially explain its lack of suitable aquatic and riparian habitat capable of sustaining salmon and steelhead. According to the Chelan County

Conservation District (CCCD)(2002), “The scope of this channelization and woody debris removal probably resulted in more fish habitat degradation than any other land use activity in the past century” (3-4). Despite this statement, there has been no comprehensive study of USACE involvement on the lower Entiat River or on the degree of morphological change to the river since the USACE conducted its work. Clearly, there is a need to research and document the broad scope of historical changes prior to, and after, the flood of 1948 in the lower Entiat River.

Purpose

The primary goal of this research was to map and document the spatial and temporal extent of historical change in the lower Entiat River and associated riparian zone from its confluence with the Mad River near Ardenvoir to its mouth. Emphasis was placed on the years following the flood of 1948 and on any related USACE activity, especially channelization. A more holistic investigation of stream change occurring prior to 1945 was also an integral part of this research.

The specific objectives of this research were to:

1) identify, document and map changes in riparian vegetation and channel morphology from ~1890-1998 along the lower Entiat River and assess causal factors including USACE involvement;
2) examine the implications of channel morphology and riparian vegetation on ecosystem function with particular emphasis on salmon and steelhead habitat;
3) make recommendations concerning management decisions and stream restoration efforts.

Significance

This research is significant for several reasons. The identification of the spatial and temporal patterns of stream alteration will help determine changes in river morphology and riparian zone characteristics along the lower Entiat River over the past century. According to Sparks (1990), understanding the normal behavior and natural character of a river and floodplain can help to better understand disturbance and environmental recovery. This research is also significant because it will help to identify linkages between stream alteration and habitat degradation. Lastly, this research will aid in the formation of feasible restoration projects that will benefit from an understanding of past stream conditions and the historical disturbance regime. Understanding the nature and causes of past channel change is necessary in order to design successful and sustainable restoration projects (Kondolf and Larson 1995). Historical analysis can uncover causes of channel change, document prior conditions and determine if patterns exist, all of which can help form realistic management and restoration objectives (Kondolf and Larson 1995). The restoration component is especially crucial for the Entiat River because the watershed is the focus of a variety of restoration and management scenarios currently being considered and implemented. Additionally, the research supports the recent emphasis placed on salmon recovery at the federal, state, county and local (watershed) level and provides critical baseline data for the Entiat. Ideally, this endeavor will help form a basis for restoration work in the watershed and help to determine what condition to “restore” the Entiat River based on observable historic form and function.

CHAPTER II

STUDY AREA

Location

The Entiat Watershed is located approximately 16 miles north of Wenatchee, west of Highway 97, in Chelan County (figure 1). The 53-mile long watershed consists of about 268,000 acres and is bounded on the northeast by the Chelan Mountains and on the southwest by the Entiat Mountains. Elevation varies from 700 feet at the mouth of the Entiat River to over 9,000 feet in the northwestern extreme. The watershed is primarily mountainous and mostly steep and rugged. The Entiat River Valley occupies a prominent location through the heart of the watershed and ranges in width from less than a mile to several miles across. Access to the watershed and valley is most easily accomplished by traveling north on Highway 97 ALT and turning west on the Entiat River Road just south of the town of Entiat. The specific study site is situated in the lower Entiat River Valley from the confluence of the Entiat and Mad Rivers near Ardenvoir to the mouth of the river (figure 2). The Entiat River enters the Columbia River at Lake Entiat, the reservoir located behind Rocky Reach Dam, which was completed in 1961.

Geology and Geomorphology

The Entiat River Watershed is comprised primarily of crystalline bedrock that is covered by alluvial and glacial deposits that range considerably in depth along its main valley (Kirk, Kerr, and Riddle 1995). Common crystalline rocks include schist and gneiss, granodiorite and quartz diorite (U.S. Forest Service (USFS) 1979). The bedrock

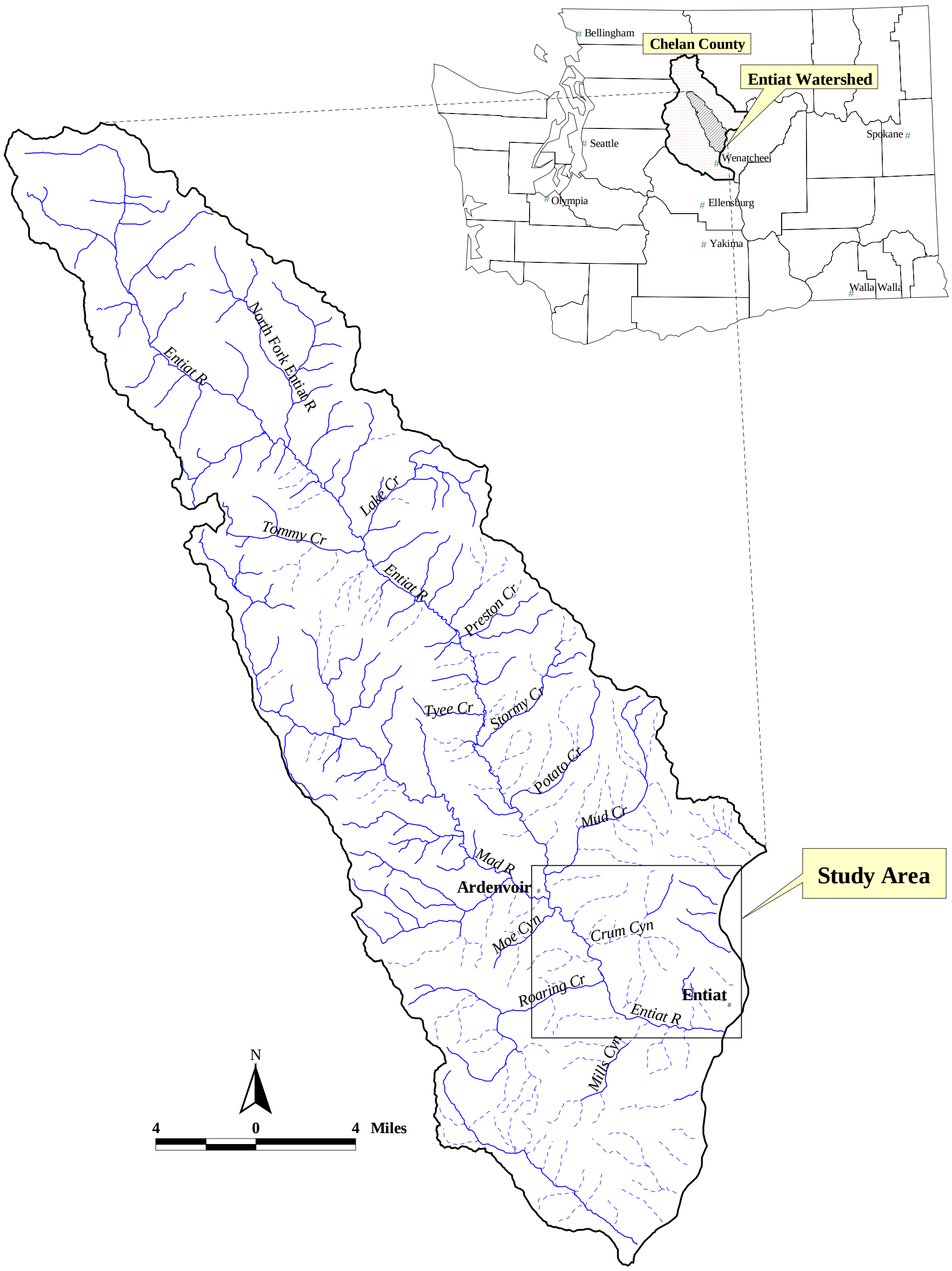


Figure 1. Small-scale map of Chelan County, the Entiat Watershed and the study area.

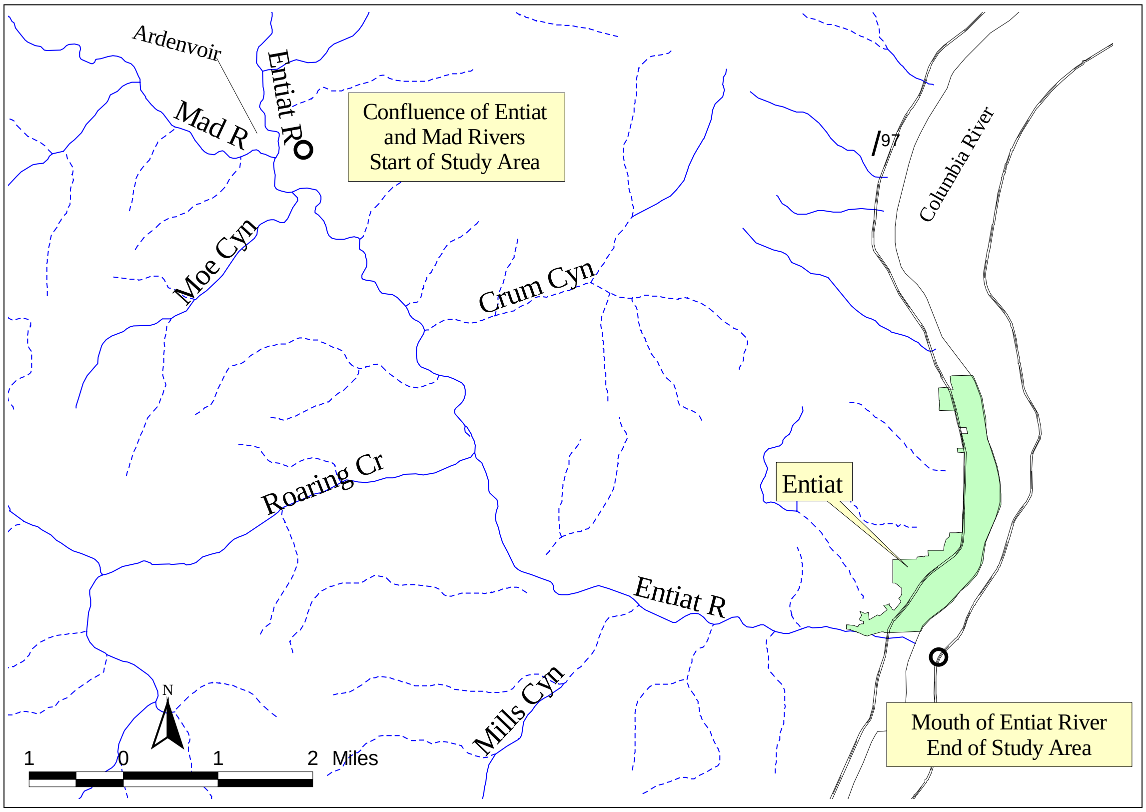


Figure 2. Large-scale map of the lower Entiat River Valley and the study area.

of the region is between 13 and 100 feet thick and is covered with gravel, sand and fine-grained material that serve as the main aquifer in the valley (Kirk, Kerr and Riddle 1995). The Entiat and Chelan Mountains, which form the border of the watershed, are typified by hard, angular rocks consisting of quartz diorite and granodiorite with smaller amounts of schist and gneiss (USFS 1979). Glacier Peak is located 15 miles west of the northern watershed boundary and has covered the area with tephra around a dozen times over the last 14,000 years, although it is now considered inactive (USFS 1979).

The lower Entiat Watershed is an area of non-glaciated mountain slopes shaped by stream downcutting and other slope processes (Andonaegui 1999). Debris flows and streams deposited sediment along the floodplain and as alluvial fans during flood events and a natural cycle of fill and scour occurs within the stream (Andonaegui 1999). Eroding sediments formed alluvial fans at the mouths of the canyons joining the Entiat River (USFS 1979). The majority of the study area consists of alluvial fans and alluvial terraces, many of which mark prime agricultural areas that are still farmed today. The soils in the lower valley are mostly fine sand and sandy loam in texture (Kocher 1922).

Glaciation was a dominant process in the upper valley and extended as far south as Potato Creek, five miles north of Ardenvoir. The large valley glacier was nearly 25 miles long and receded around 10,000 years ago, leaving a low-relief terminal moraine (USFS 1996; Andonaegui 1999). Above the moraine the valley is U-shaped and covered with till and outwash, while a V-shaped valley and alluvial river channel characterizes the region below the moraine (USFS 1979). Soils in the upper valley are more gravelly and coarse than those in the lower valley and are ill-suited for cultivation. According to the National Marine Fisheries Service (NMFS)(1998), numerous river characteristics including gradient, sinuosity, and entrenchment change below the moraine. Generally speaking, below the moraine the Entiat River is less sinuous, more entrenched and has a steeper gradient than the reaches above.

Weather and Climate

Weather and climate in the Entiat River Watershed is highly variable as a result of the dramatic elevation changes and overall situation of the watershed east of the Cascades. The upper portion of the watershed borders the Cascade Crest and the entire area is directly influenced by the orographic effects of the Cascade Mountains. As a result, the upper watershed is wetter and cooler than the lower portions of the watershed. Precipitation totals vary considerably, ranging from under 10 inches near Entiat to over 90 inches in the watershed's headwaters. Likewise, temperatures fluctuate widely in the watershed with highs in excess of 90° F common during the summer in the lower watershed and winter temperatures usually around 30° F (figure 3). Most winter precipitation occurs as snow, with annual snowfall totaling 50 inches near the mouth to over 400 inches in the headwaters (USFS 1996). The study area occupies a fairly dry portion of the watershed that is characterized by hot summer temperatures and moderate winter snowfall. Much of the annual precipitation in the watershed falls as snow, providing the main source of stream flow and groundwater in the watershed (CCCD 2002). The varied climate supports a mix of forestland, shrub-steppe, and cropland with an average growing season of around 150 days on the valley floor. Summer thunderstorms caused by intense convective lifting are common and can result in flash flood conditions in narrow side canyons and larger stream systems (USFS 1996).

Hydrology

The two main tributaries to the Entiat (a fourth order stream) include the Mad River and North Fork Entiat River. According to the U.S. Geological Survey (USGS) (2002), mean annual runoff of the Entiat is around 268,000 acre-feet at Ardenvoir and more than 350,000 acre-feet at the mouth. The Entiat River's peak flow typically occurs in June and July. High flows in the Entiat River are typically related to rapid spring snowmelt, convective storm events, or prolonged rains following wildfires (CCCD 2002). The USGS streamgage at Ardenvoir (figure 4) has records from 1958 to present, while a

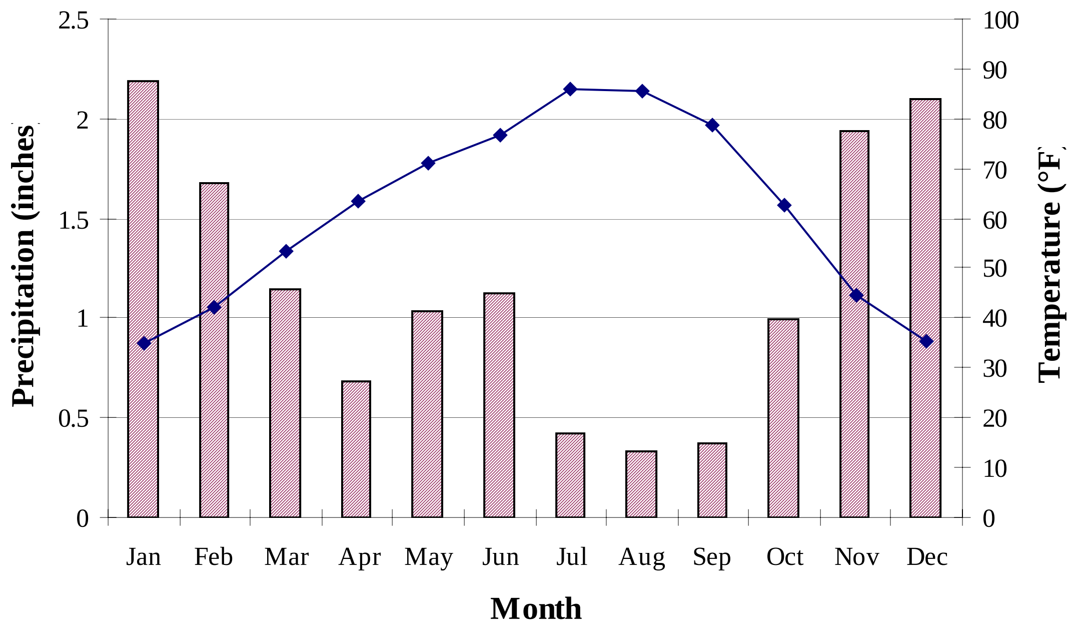


Figure 3. Climograph for the lower Entiat River Watershed near Roaring Creek and the Entiat Fish Hatchery, 1971-2000 (Western Regional Climate Center 2002).

gage near Entiat was operational at sporadic intervals between 1911-1958. A new streamgage was installed near Entiat in 1996. Because the majority of sediments found within the Entiat River aquifer are coarse, fairly unrestricted interaction between the aquifer and the Entiat River likely occurs (Kirk, Kerr and Riddle 1995). The Entiat River aquifer most likely empties into the Entiat River, the Columbia River aquifer, or both (Kirk, Kerr, and Riddle 1995).

Groundwater supplies the majority of stream flow in the Entiat from late summer through the winter (Kirk, Kerr, and Riddle 1995). Snowmelt is the principal surface and groundwater input source for the Entiat River and the majority of annual runoff occurs during the spring when snowmelt reaches its peak in the higher elevations (CCCD 2002). Annual stream flow can vary considerably along the Entiat due to a lack of water

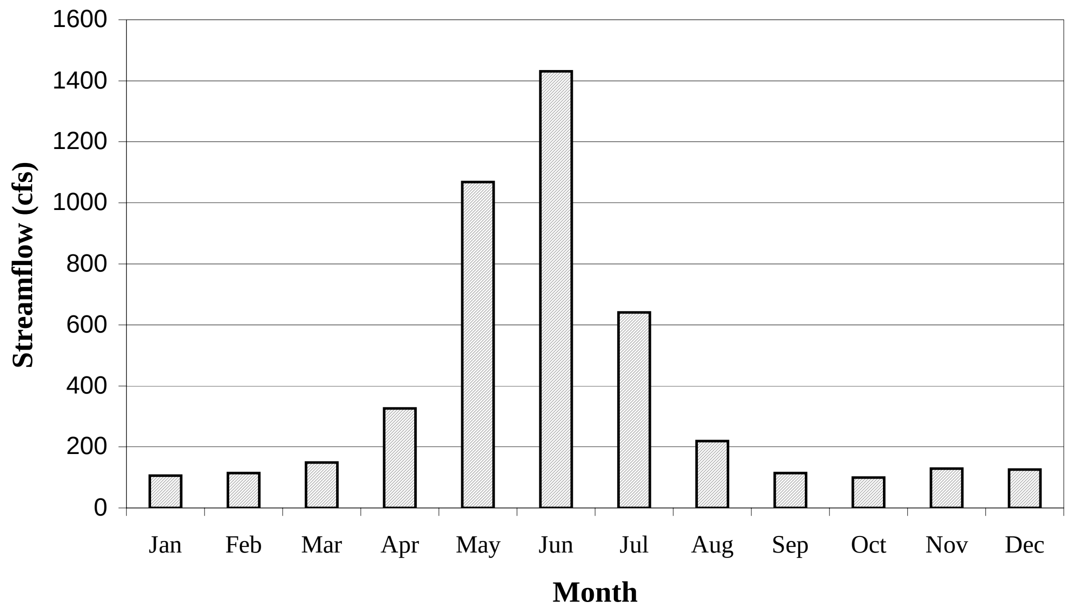


Figure 4. Mean monthly flow for the Entiat River near Ardenvoir 1957-2000 (Data from USGS 2002).

retention, natural watershed characteristics, irrigation withdrawals and human modification (NMFS 1998). River flows are below recommended levels to support fishery resources most of the year; however, there is a general lack of hydrologic data for much of the Entiat. Like many smaller watersheds, the stream flow record for the Entiat River is quite limited. Surprisingly though, irrigation withdrawal for agricultural purposes does not appear to significantly impact annual flow rates in the mainstem of the Entiat (Erickson and Lillquist 2002).

Vegetation

The Entiat Watershed supports a wide variety of vegetation because of its unique topographical position. Higher, and often wetter and cooler, portions of the watershed support alpine and subalpine species including subalpine fir, lodgepole pine, Engleman spruce, whitebark pine and subalpine larch, along with numerous forbs and shrubs (USFS 1996). Dryer and warmer locations support Douglas fir, ponderosa pine and to a lesser extent, grand fir (USFS 1996). The lower half of the Entiat Watershed contains bitterbrush and sagebrush and several types of grasses with scattered ponderosa pine and Douglas fir (USFS 1996). Common riparian species in the watershed include cottonwood, red-osier dogwood, willow, alder, river birch, broadleaf sedge and mixed conifer (Natural Resource Conservation Service (NRCS) 1998; CCCD 2002; Erickson and Lillquist 2002). Throughout the lower Entiat River, cottonwood is the dominant species, with red-osier dogwood and white alder as co-dominants (CCCD 2002). Cottonwoods play a crucial role in bank stability, although the issue of cottonwoods is a contentious one in the valley as the trees can harbor a pest known to damage pear trees and are sometimes removed by agriculturalists (NMFS 1998). Generally speaking, smaller age-class trees (8.0”-20.9”diameter at breast height) are most common in the lower ten miles, where large trees were removed to facilitate orchard plantings and to guard against pest infestation in agricultural fields (NRCS 1998).

Land Use

The first inhabitants of the Entiat Valley were Native Americans who hunted, fished and gathered in the region. The Entiats were a small, but distinct group that closely associated with the Wenatchees, Methows and Columbias (Hackenmiller 1995). The Entiats were related to the Wenatchee Salish or Middle Columbia Salish, shared a common dialect and often intermarried (Hackenmiller 1995). The Entiats occupied several small villages including a permanent one near the mouth of the Entiat and subsisted in part on the Entiat fishery (Smith 1983). The Yakama Nation retains hunting and gathering rights in the watershed under their 1855 Treaty and are an active participant in the resource management discussions and actions currently taking place in the watershed (CCCD 2002).

The first white settlers entered the Entiat River Valley around 1887 and came via foot, horseback, or steamboat before the establishment of rail in the region (Hull 1929). Early General Land Office (GLO) survey notes from 1883 mention the presence of several local ranchers and grazing herds, although organized and permanent settlement of the lower valley bottom appears to have occurred several years later. Prior to the orchard industry taking off financially, grazing, mining and logging were the most prevalent economic activities.

Sheep grazing in the Entiat River Valley started around 1880 and was one of the earliest uses of the watershed. Upwards of 60,000 sheep grazed near the headwaters of the Mad River and other tributaries in the early 1900s (Plummer 1902). As many as 13,000 sheep consistently grazed in the lower valley in the late 1800s and early 1900s and many of the sheep bands rotated between the Wenatchee, Chelan, and Entiat drainages (USFS 1996). Grazing on Forest Service land was drastically cut in the 1940s because of poor range conditions. Today, around 2,000 sheep graze in the watershed and only for a period of two or three months each year (USFS 1996). To protect riparian areas and limit erosion, no grazing is allowed on public land in the lower valley or directly along the Entiat River (USFS 1996). Grazing by cattle and horses has also declined significantly in recent years and current estimates place the number of cattle now grazing in the watershed at less than 300 each year (CCCD 2002).

Unlike many nearby watersheds and rivers, mineral extraction was not an especially popular or productive activity in the Entiat Watershed. Mining activity was quite limited in the lower and upper valley, and virtually non-existent in the Entiat River proper. Between 1885 and 1910, gold and other minerals were mined in the watershed and most efforts were focused in the Crum Canyon Region (Long 2001; CCCD 2002). After the early 1900s, mining activity tailed off dramatically as lumbering and agricultural activity held more financial promise.

According to legend, the first fruit trees in the Entiat Valley were planted from peach seeds in the late 1860s (Long 2001). White settlers focused early agricultural pursuits on prunes, apricots and peaches, starting commercial production in the late 1890s (Hull 1929; Long 2001). Prunes, apricots and peaches were quickly replaced with apple and pear orchards by the early 1900s (Hull 1929). Hay and other forage crops were also grown for domestic animals including horses, cattle and sheep. The Entiat Watershed attracted settlers from all over the country who came for the promise of cheap land, good soil and a growing agricultural market (Long 2001). The first irrigation canal was built in 1894, to support and expand the significant agricultural lands that were already being cultivated in the valley (USFS 1996). While no clear number exists, it is probably realistic to assume that upwards of 1,200 acres of land were planted in orchards at the heyday of fruit production in the valley judging by old aerial and ground photographs.

Today, less than a thousand acres are under orchard production and recent trends suggest a continued decline in production as lands devoted to irrigated agriculture are increasingly converted to residential purposes or simply left vacant (Erickson and Lillquist 2002). While orchard activities have historically been the economic backbone of the valley, this trend is changing as the orchard landscape is slowly transforming into a more intensive residential setting, including many second homes and recreational lots (CCCD 2002). The majority of orchard lands are located between the mouth of the Entiat and just north of Ardenvoir within the narrow river valley. Increased residential development unrelated to agricultural activities is rampant along the Entiat, particularly above Ardenvoir (CCCD 2002). Over half of the valley's 300 septic systems have been installed in the last five years (CCCD 2002).

Land ownership in the basin is predominantly public, with more than 86% of land falling under the management of the Wenatchee National Forest (WNF) and more specifically, the Entiat Ranger District. While total acreage in the basin is around 268,000 acres, approximately 224,000 acres are in public ownership. The vast majority of private, non-timber company land is located in the valley bottom, directly adjacent to the Entiat River along its floodplain and alluvial terraces. Private land use in the lower valley is dominated by irrigated orchards (apple and pear), irrigated pasture, and residences (USFS 1996).

Stream Morphology

The fluvial geomorphology of the Entiat River is an important consideration when one investigates changes over time, human impacts, and stream restoration alternatives. Increasingly, stream classification systems employ reach-level stream characteristics such as entrenchment, width/depth ratio, sinuosity, slope, and channel material (cobble, gravel, clay, etc.). By classifying stream segments or reaches, generalizations can be made regarding channel bed form and function that can facilitate and guide resource management decisions. The evolution and/or abundance of stream classification systems can be seen in a variety of literature (Leopold and Wolman 1957; Kellerhals, Church, and Bray 1976; Schumm 1977; Rosgen 1994; Montgomery and Buffington 1998).

The Entiat River has been thoroughly classified using the system developed by Rosgen (1994) (USFS 1996; NRCS 1998; CCCD 2002). The upper Entiat headwaters are classified as a Type A channel and are typified by steep slopes, high energy, significant entrenchment and a cascading/step-pool stream system. The rest of the Entiat River consists of a combination of Rosgen Type B, C, and F channels (figure 5). Essentially, below the terminal moraine (river mile 15), the Entiat River is a Rosgen Type F stream, moderate to low gradient, moderately entrenched, meandering alluvial riffle/pool channel stream with a high width-to-depth ratio. Upstream of the moraine, the Entiat River actually has a lower gradient, meandering riffle/pool channel, and entrenched Type F system. The Entiat River can also be thought of in terms of sediment zones, with the headwaters as the source, and the transport and depositional zones occurring successively downstream. The lower 20 miles are considered in the deposition zone, while the transport zone occupies the ten miles between the source and depositional regions (USFS 1996).

Like all “natural” streams, the Entiat River is a dynamic system capable of altering its morphology in response to a variety of natural and human-induced changes. Land-use managers and researchers believe that the lower Entiat River is less sinuous than its early historical morphological stream type because of flood control, road building and other anthropogenic influences (NRCS 1998). The lower Entiat consists mostly of boulder/cobble riffle, possibly a result of channelization and riprap activities constructed

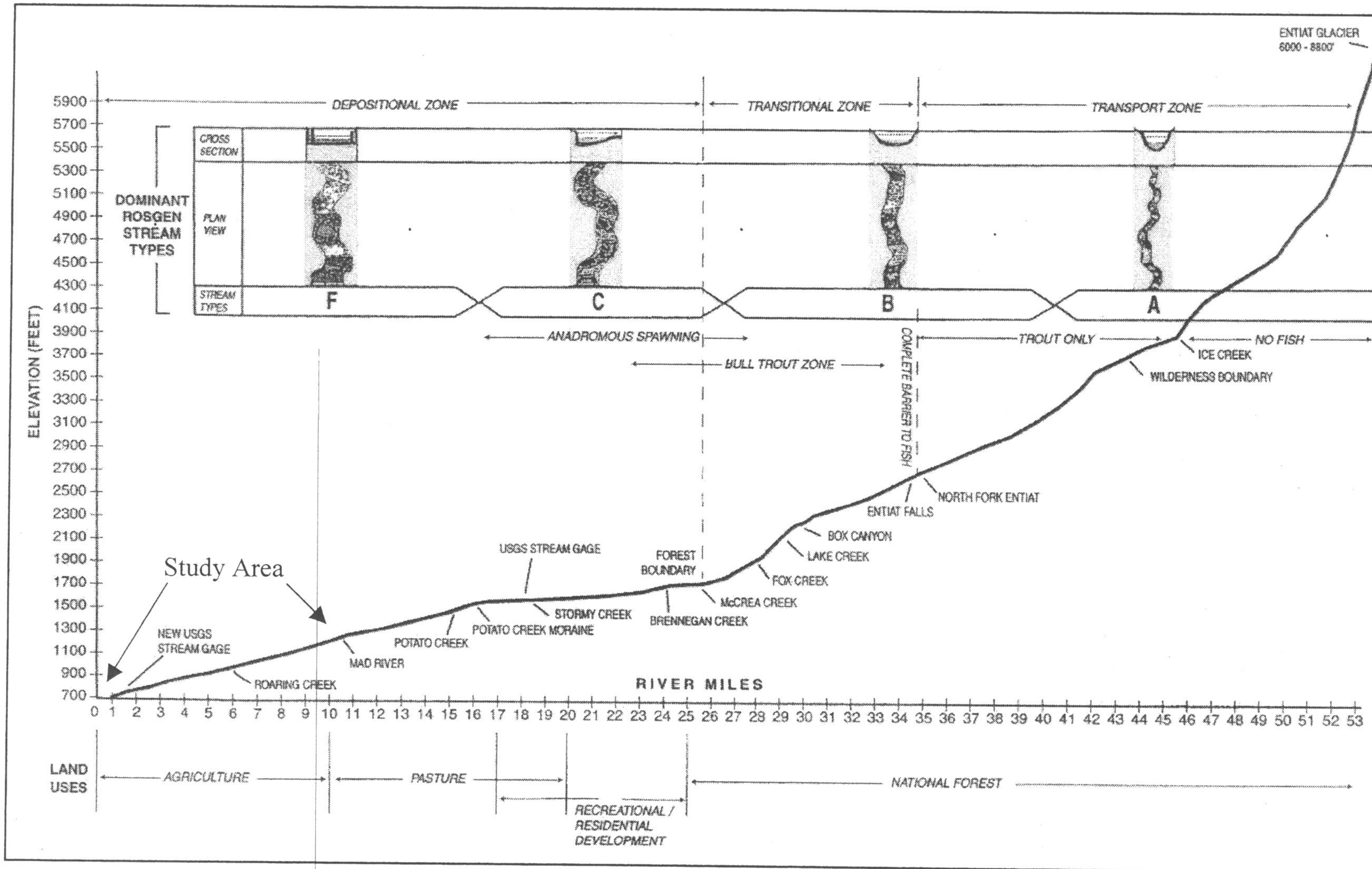


Figure 5. Rosgen stream classification for the Entiat River (modified from USFS 1996).

to protect against floods and lacks the large pools common in healthy stream systems (NMFS 1998; NRCS 1998). Historically, the lower Entiat likely had a lower width-to-depth ratio (narrower and deeper at bankfull discharge) along with more LWD and many other habitat features than present (NRCS 1998). The lower 25 miles of the Entiat River has a high width-to-depth ratio that is a result of natural and human-influenced conditions (CCCD 2002). Interestingly, stream bank erosion is not a significant problem along the Entiat and only contributes slightly to the overall problem of excessive sediment delivery to spawning gravels (NMFS 1998).

Aquatic Resources

Despite a noted loss in aquatic habitat features over the last 100 plus years, the Entiat River still supports economically and culturally important fish species including anadromous runs of Chinook salmon and steelhead, with a recreational fishery for rainbow and brook trout (CCCD 2002). Coho salmon were once present in the watershed, but are now considered extinct (Mullan et al. 1992). No sport fishing is allowed for salmon, steelhead, or bull trout. Chinook salmon and summer steelhead are both listed as endangered, and bull trout are listed as a threatened species under the Endangered Species Act. The relatively unhealthy status of salmon and steelhead in the Entiat is somewhat perplexing since many indicators of stream health are positive. Generally speaking, water quality in the Entiat River is good, although on occasion, certain segments do exceed temperature and pH parameters established by state and federal agencies (Kirk, Kerr, and Riddle 1995). Furthermore, despite wildfire and other range management issues, all current monitoring suggests little in the way of excessive suspended or fine sediment (Mullan et al. 1992; USFS 1996). One aspect of substantial concern centers on stream flow, which is far below recommended flow levels for spawning and rearing fish. Coupled with the already discussed concerns regarding the lack of habitat features (e.g., pools, LWD, riparian vegetation), there is clearly room for important management steps that could improve aquatic resource survival rates in the Entiat. Another important management issue centers around the fact that salmon and steelhead have to navigate through eight large hydroelectric dams on the mainstem of the Columbia River to enter the watershed to spawn and to embark upon their journey to the sea as juvenile fish. Until the broad regional issue of dams is better addressed, local habitat improvements may be limited in their success.

CHAPTER III

LITERATURE REVIEW

The following literature review represents the theoretical basis and establishes the validity of this research. An examination of flood events and their impacts to streams begins this chapter and sets the stage for the remaining discussion. The literature review concludes by examining the topic of stream restoration.

Impacts of Floods on Rivers

Floods and high flows are an essential component of fluvial systems. Not only are high flows instrumental in routing sediment and creating and maintaining habitat, they can also be responsible for a significant amount of the geomorphic work that takes place within a stream system (Wolman and Miller 1960). There are basically two types of high flow and flood events: frequent and infrequent. Frequent high flows have a recurrence interval of every one or two years and are basically analogous to bankfull discharge or the mean annual flood. Bankfull discharge refers to a cross section of a stream channel that is filled with water to the top of the bank (Williams 1978). These frequent events often do not involve any actual flooding, as the water is typically within the limits of the bank. Bed and bank erosion, sediment transportation and channel form appears to be associated more with bankfull discharge than large flood events because they are more frequent (Wolman and Miller 1960).

Large and rare floods such as the 100-year or 50-year flood event do not occur at a frequency sufficient enough to account for most channel processes. Therefore, frequent high flow events, not large and infrequent floods are responsible for the majority of sediment transport and channel work (Wolman and Miller 1960). This said, however, large floods are important in stream systems that have a high variability in flow and a relatively small drainage basin (Wolman and Miller 1960). Overall, arid regions with skewed flood magnitude and frequency statistics appear to be more inclined to catastrophic response (Baker 1977). After a large flow event, streams seem to return to a more steady state of low to medium flows, otherwise rare and infrequent events will become the dominant stream shaping force (Gupta and Fox 1974). Acknowledging that many flood features that look impressive immediately after a large flood event are often short-lived phenomena, Baker (1977) asserts that watersheds characterized by a combination of intense precipitation, high overland flow and small drainage size appear to be the most susceptible to catastrophic infrequent events. High magnitude floods also play an important role in the development of alluvial fans and terraces (Baker 1977). Macroturbulence is a key process that facilitates the movement of large boulders and other debris that do not get transported by more frequent events (Baker 1977). Large floods can severely erode riverbanks, alter the course/position of a channel, cause the migration of bends and meander cutoffs, transport large debris such as trees and boulders and remove adjacent riparian vegetation (Wolman and Miller 1960). Floods can, of course, also damage roads, bridges and homes, erode valuable farmland and, on occasion, threaten human life. It is for these reasons that flood control and channelization efforts are so common in many stream systems.

Channelization

The term, “channelization” is associated with the widening, deepening and straightening of river channels and is synonymous with channel realignment, relocation and regulation (Brookes 1987). Channelization has been used to control flooding, drain wetlands for farming and other development, improve navigation, control stream bank erosion and align streams to better facilitate bridge crossings (Keller 1976; Brookes 1988). The process of channelization often involves the construction of levees, removal of riparian vegetation and placement of road embankments and riprap. The USACE and Soil Conservation Service (SCS), now the NRCS, have been responsible for the vast majority of federally-assisted channel modification efforts in the United States (Keller 1976). Essentially, flood control is accomplished by cutting off meanders along with widening, deepening and shortening of channels to allow for the efficient and rapid flow of water (Shankman and Samson 1991).

Channelized streams stand in stark contrast to more natural meandering streams that consist of sinuous stretches marked with an abundance of pools, riffles and other important factors that lead to favorable fish rearing conditions (Keller 1976; U.S. Department of Agriculture (USDA) 2001). Channelized streams have few pools or riffles and may have lost the natural sorting of streambed material, resulting in habitat degradation and a disruption of a variety of natural channel processes (Keller 1976). Nearly all rivers are meandering or sinuous to some degree as a result of similar physical processes and in no known case does a curved form naturally straighten for any considerable distance (Leopold 1997). Of course, one of the major exceptions to the aforementioned rule occurs in stream channels that have been channelized.

Channelization Impacts on Fish and Riparian Habitat

Adverse environmental impacts of channelization include damage to the stream channel and floodplain, fish, wildlife and aesthetics as well as other downstream effects including flooding (Keller 1976; Brookes 1988; USFS 2001). Indeed, the biological capabilities of many streams have been decimated to such an extent by channel modification that many experts believe channelization creates conditions that severely limit the production of stream dependent species (Keller 1976; Hicks et al. 1991; McIntosh et al. 1994). Channelization can have drastic consequences on stream fisheries. River modification alters the natural pool-riffle sequence which provides fish with cover during low and high flow conditions as well as a steady supply of organisms to feed on (Brookes 1987). Channelization also typically changes the width and depth ratio of a stream, usually resulting in shallow and unnatural flow levels that present even more obstacles to fish (Brookes 1987). Increasing the width of a channel or its downvalley slope through straightening is likely to disrupt the delicate balance between running water, sediment flow and physical channel characteristics, causing much of the environmental damage associated with channelization (Keller 1978). Channelized streams have little or no rearing habitat or protective cover features and available spawning habitat is usually of poor quality (Washington State Department of Fish and Wildlife (WDFW) 1996). Indeed, any activity that removes vegetation, disturbs sediment, increases the sediment content, alters stream temperature, or changes the flow patterns and velocity of a stream will affect fish (Keller 1976; Brookes 1988).

Channelization of streams to facilitate irrigation and/or plant crops can also result in lowered water tables, riparian vegetation destruction, altered stream flow regimes and increased water temperatures (WDFW 1996). Riparian habitat is extremely vulnerable to land use impacts because of its narrow width, proximity to streams and reliance on a natural balance of aggradation and degradation processes (WDFW 1996). By supporting high diversity, riparian habitat provides vital functions to fish, wildlife and the broader ecosystem (WDFW 1996). As noted by the (WDFW 1996), "In a relatively small area, riparian habitat supports a disproportionately high diversity and abundance of fish and wildlife" (14). High water velocities through a confined channel are more erosive than flows in a meandering system with adjacent riparian vegetation and can lead to channel instability and lost riparian vegetation (WDFW 1996). Furthermore, channelized streams seldom deposit the flood sediments that are essential for the establishment of cottonwood, willows and other riparian vegetation capable of providing important habitat (Scott, Friedman, and Auble 1996). Rivers that are channelized lack vegetated riparian zones and floodplains capable of buffering rivers and streams from runoff from heavily fertilized land, which can overload a stream system with nutrients (Sparks 1995). Besides the readily visible damage to fisheries, riparian vegetation and the overall "look" of the landscape, channelization also impacts more intricate environmental processes, affecting species diversity and biological productivity. Unfortunately, the biological implications of channelization can last decades after the initial work and perhaps much longer (Brookes 1988).

Impacts on Genetic Diversity and Biological Productivity

Humans generally modify streams to prevent flood damage and limit the effects of natural disturbances. Interestingly, the very reason why people feel the need to control natural river systems is why they are so productive, providing ideal conditions for a diverse biotic community. Reice (1994) notes, “It is the process of recovery that produces the high diversity we find in disturbed systems” (434). This is because disturbance creates patches (i.e., the environmental mosaic) that ultimately generate biodiversity. This is also why human efforts to stabilize ecosystems usually result in a loss of biodiversity (Reice 1994).

Estimates concerning the time required for biological recovery vary greatly. A study conducted on the Luxapalila River in Mississippi and Alabama (Arner et al. 1976) found that biological productivity in channelized sections of the river was significantly lower than in non-channelized sections, even though more than 52 years had passed. Another study focusing on the St. Regis River of Montana (Schaplow 1976) offered similar results and found that trout populations where significantly lower in altered and non-restored/mitigated portions of the river. While channelized streams will eventually form pools and riffles following modification, they are usually inferior to those formed pre-channelization as they are poorly developed, unstable and spaced at unnatural intervals (Keller 1975). A study of historical changes in fish habitat for select river basins in eastern Oregon and Washington concluded that the response of fish habitat to natural and human-induced disturbance varies considerably, although most research suggests that human modification degrades and simplifies habitat (McIntosh et al. 1994).

Implications on the Broader Ecological System

The influence of rivers is not limited to the channel and associated floodplain and riparian zone. The influence of rivers extends laterally and vertically across the landscape, impacting the hyporheic zone and groundwater. The hyporheic zone is the subterranean zone where groundwater and surface (river) water interact in a variety of complex and still undiscovered ways. It is believed that processes within the hyporheic zone influence species diversity, productivity and energy transfer of materials (Stanford and Ward 1993). In many river valleys human encroachment has occurred in floodplains and within river channels to the extent where connectivity between ecosystems has likely been severed entirely (Stanford and Ward 1993). This may be the case along channelized portions of the Entiat.

The spatial extent of the hyporheic zone is still poorly understood, although it appears the zone is crucial to the overall biotic productivity in the channel via nutrient discharge (Stanford and Ward 1988; Triska, Duff, and Avanzino 1990). This "nutrient discharge" is influenced by complex biotic processes within the channel and in the hyporheic zone (Triska, Duff, and Avanzino 1990). Although, ecological connectivity has not been clearly demonstrated everywhere, it is thought to occur in nearly all lotic (water based) ecosystems (Stanford and Ward 1993). Many riverine organisms display a remarkable amount of diversity and may traverse ecosystem boundaries (channel-riparian, channel-hyporheic) during their life cycle, thus demonstrating connectivity (Stanford and Ward 1993).

Impacts of Other Human Activities

While impacts caused by channelization represent the main focus of this research, other stream changes are caused by processes not directly related to channelization. The Pacific Northwest has a long history of development in most watersheds including log drives and logging, agricultural expansion, grazing, riparian vegetation, LWD removal, and various impoundments typically associated with mill, power and irrigation dams, all of which can influence stream morphology (Beschta 2000). Log drives were a common component of many northwest streams before the advent of rail and logging trucks. While the drives themselves may have resulted in little direct stream damage, they did result in the removal of LWD to allow free passage for timber headed downstream. Woody debris was also removed to lessen flooding impacts and under the guise of fish habitat improvement (Bisson et al. 1987; Bilby and Ward 1989). Logs were usually driven to a log mill dam, which decreased downstream flow, altered sediment transport rates and often blocked fish passage. Power generation dams were another common feature of many Northwest watersheds including the Entiat, where water was diverted in pipes and funneled into turbines leaving a large section of stream completely void or severely depleted of water.

Logging of riparian vegetation is particularly detrimental because it reduces shade, increases bank erosion and limits LWD input into streams. Woody debris plays a significant role in river systems by controlling energy dissipation and sediment transport, balancing the storage of organic and inorganic material, generally providing diverse habitat features that are created by hydrologic variability (Sullivan et al. 1987; Bilby and Ward 1989; Keller and MacDonald 1995; Bilby and Bisson 1998). Removal of LWD disrupts the delicate ecological balance that forms critical stream habitat features including pools, gravel bars, riffles and impacts the rate of erosion, channel migration and the health of the biological community (Bilby and Ward 1989). Unfortunately, streams do not recover quickly from debris clearing as most require old-growth trees of a sufficient diameter and age to sustain LWD on a long-term basis (Bisson et al. 1987; Rot, Naiman, and Bilby 2000).

To perhaps a lesser extent, grazing, urbanization and agricultural expansion have also taken their toll on stream resources. Grazing by cattle and sheep removes streamside vegetation, increases erosion rates and provides an excellent avenue for the expansion of invasive and exotic plant species. Urbanization impacts river systems by decreasing the permeability of surfaces, altering the hydrograph and reducing groundwater recharge (Patten 1998). Agricultural expansion removes important riparian trees, impacting recharge, infiltration and runoff rates, and causing the direct loss of wildlife habitat (Patten 1998).

Stream Restoration

The emerging evidence suggesting high connectivity between rivers and a much broader ecosystem and the implications of channelization and other land use impacts on these connections leads to one inevitable question: how can connectivity, floodplain function, and ecosystem health be restored? Efforts to restore large-scale sinuosity to channelized streams are isolated and mainly limited to portions of Europe, most notably Denmark and Germany (Brookes 1987; Kondolf 1996). For a variety of reasons including land ownership issues, hydrologic complexities, and cost effectiveness, large-scale meander restoration efforts have not been conducted in the United States (Brookes 1987; Kondolf 1996). With this in mind, clearly the goals of most river restoration efforts are to reclaim some functionality that partially resembles natural conditions since completely restructuring stream morphology over a moderate distance is unlikely.

It has been argued that the principal goal of river restoration should be to minimize/mitigate human constraints, allowing river systems to express themselves freely (Stanford et al. 1996). It is in this regard that studying, mapping, and understanding past river conditions gains validity and proves a useful restoration tool. Understanding past river conditions is critical to the planning, design and evaluation of restoration efforts (Kondolf and Larson 1995). There is a general lack of knowledge regarding the historical condition of the Entiat River and an absence of detailed river restoration efforts and historical records/mapping.

CHAPTER IV

METHODS

To recap, the intent of this research was to accurately determine and document the spatial and temporal extent of historical channel change in the lower Entiat River. Emphasis was placed on identifying changes in riparian vegetation composition and channel sinuosity that would serve as indicators of natural and human-induced modification. The procedural and analytical steps involved in setting up and conducting the research are addressed below.

Study Site Selection

The specific study area was selected for several reasons. First, the vast majority of river modification and historical development has occurred downstream of Ardenvoir, in the lower ten miles of the Entiat. The lower Entiat River is also considered the least likely stream reach to hold healthy ecological conditions capable of sustaining aquatic resources and high biological productivity (CCCD 2002). While there certainly may be other stream reaches needing study and restoration, the problem is most critical in the lower portion of the Entiat. Because of this, the lower Entiat is in need of additional research that informs management agencies of historical changes. While it might prove beneficial to investigate channel change further upstream and/or compare those results with the lower reach, the river changes dramatically from an alluvial system to one affected by glaciation and other fluvial/geomorphic processes that make direct comparisons challenging. Lastly, and most important, the lower Entiat is a focus of stream restoration efforts and is almost entirely in private ownership.

Identifying Changes in the Lower Entiat River Valley

The focus of this research was on identifying and quantifying, where possible, changes in riparian vegetation and channel morphology along the lower Entiat River. Together, these two variables represent important factors influencing the current and historical state of the Entiat River and serve as indicators of habitat loss and cumulative human influence. A variety of sources including historical aerial and ground photographs, topographic maps, documents and newspaper articles, along with digital data sets, aided in the analysis of temporal and spatial change within the study area. Digital data sets, tables and maps were created to summarize and explain the research results. Fieldwork was also used to verify findings and investigate present-day evidence of historical land uses and potential stream impacts. Historical analyses can assist with stream restoration efforts by providing an understanding of the underlying problem(s), helping set realistic restoration goals and selecting strategies to achieve goals and set objectives (Kondolf and Larson 1995).

As stated prior, one of the main research objectives was the identification, documentation and mapping of changes in riparian vegetation and channel morphology between 1890-1998 along the lower Entiat River. The methods employed in the course of this research varied depending upon the subsection of years in question; thus the research was stratified into two distinct categories based on available data and sources. The earliest available aerial photographs for the study area were taken in 1945. Thus, the methods and subsequent results have been stratified accordingly (pre/post-1945) to account for differences in primary source material and research techniques.

Pre-1945 Change Detection

Historical changes occurring prior to 1945 were evaluated in a qualitative manner by assessing and evaluating existing published and unpublished literature, and assembling a variety of rare historical photographs and documents. In addition to traditional library and journal research, resource management agencies, historical societies and museums were consulted and their archives searched. Some of the most important information was obtained through archival research at the USACE District Office in Seattle, the Washington State Historical Society in Tacoma, and the Wenatchee Valley Museum and Cultural Center. An entire day was spent at the USACE office, which proved invaluable and led to the uncovering of several pivotal findings mostly related to USACE activity following the 1948 flood. The latter two sources provided multiple old, rare photographs, some of which have never been published. These sources supplied critical spatial and temporal information that added much needed context and support to the quantifiable results that follow. A pre-1945 flood record was also created by researching the archives of the *Wenatchee Daily World* and the *Wenatchee World* newspapers for pertinent flood coverage. Repeat photography was utilized in an attempt to make direct temporal comparisons, although this technique was only marginal successful due to private land access issues and difficulties in locating the exact locations of the original photographs. The historical materials uncovered led to the formation of summary statements, generalizations and site-specific information regarding the state of the Entiat prior to 1945. The goal was to establish a temporal and spatial pattern of landscape condition and disturbance that would provide valuable information on alteration in the lower Entiat prior to 1945 and compliment the post-1945 aerial photograph analysis.

Post-1945 Change Detection

Historical changes occurring after 1945 were assessed in a much more quantitative manner, primarily through the utilization of aerial photographs and digital imagery. However, many of the same sources previously mentioned were also used to assist in post-1945 change detection and confirm the findings herein. The techniques employed to quantify changes in riparian vegetation and stream sinuosity after 1945 relied primarily on Geographic Information Systems (GIS) and other computer-aided cartographic techniques and procedures and followed the protocol outlined below:

1) Data acquisition
2) Image processing
3) Analysis of change

Data Acquisition

Three series of aerial photographs allowed for the creation of the temporal and spatial data sets crucial to this research. Hard copy Department of Defense aerial photographs from 1945 at a scale of 1:23,000 were obtained from the National Archives in Washington D.C. USGS black and white digital orthophoto quadrangles (DOQs) from 1998 were used as the map base within the GIS. Hard copy USFS aerial photographs from 1992 at a scale of 1:15,000 were also obtained to assist with the analysis and delineation of features from the black and white 1998 digital images. As Congalton and

Green (1995) note, aerial photography is a necessary component of any project designed to investigate changes over time and provides excellent overall accuracy and detail.

Image Processing

The 1945 hard copy aerial photographs were incorporated digitally into the GIS through scanning, orthorectification, georeferencing and resampling, so that accurate measures of spatial change along the Entiat River could be calculated. The 1945 aerial photographs were scanned using a large-format, tabletop scanner at a resolution of 600 dots per inch (dpi) to ensure that one-meter resolution (one pixel represents one meter) was achieved. The orthorectification process removed geometric distortion caused by camera orientation and topographic relief displacement and projects the data on a map projection system (Ehlers 1997). Referencing the photographs involved assigning map coordinates to the image data. The USGS digital orthophotos were used in conjunction with the scanned aerials from 1945 to establish control points that were used to resample (i.e., assigning and interpolation of new gray values for each pixel) the output pixel sizes and register the aerial photographs to the base dataset and associated coordinates. Approximately 30 control points were used to rectify and resample each image and the calculated root-mean square error (RMSE) hovered around one meter. Difficulties arose with finding suitable control points from which to register the photographs because of the lack of watershed development in terms of structures and other anthropogenic features from which to correlate the two data sets. Although the calculated error level was low, with a RMSE of less than one meter, the actual on-the-ground discrepancies appeared to exceed this in places. The computer program ERDAS Imagine was used to conduct this phase of the image processing, although ESRI ArcView GIS was the primary software used once the images were georeferenced and resampled. Because the 1998 imagery was already in digital form, additional image processing was not necessary for this imagery set.

Analysis of Change

A GIS was used to create features (vector layers) for each time series from which comparisons in riparian vegetation and sinuosity were made. The combination of intense agricultural activity abutting the stream and the narrow valley bottom helped to highlight the presence of riparian vegetation and ease its delineation. Having both the black and white 1998 digital imagery and the color aerials from 1992 allowed for conclusive identification of riparian zones. Avery and Berlin (1992) note that most simple vegetation classification methods differentiate between vegetated and non-vegetated areas or provide basic ecological divisions (i.e., forest, desert, grassland, etc.). For this study, riparian zones were readily discerned by their proximity to the Entiat River and their relative confinement between agricultural land, other development and the stream. For the most part, riparian zones stood in stark contrast to much of the surrounding environment and were rarely located more than 75 feet from the Entiat River. The 1945 aerial imagery was harder to discern overall, but the fact that hard copy and digital imagery was available aided tremendously. The benefit of the digital images was that one could easily zoom in on areas within the GIS at a scale greater than could be achieved with a magnifying glass and hard copy images. However, the hard copy images still provided better clarity, albeit at a reduced scale.

Channel morphology was analyzed by examining changes in channel sinuosity and this analysis required accurately defining the length and boundaries of the Entiat River. Unlike the easily discernable riparian vegetation units described above, the Entiat River was more challenging to discern as dense undergrowth, tree cover, and poor image quality exacerbated the inherent difficulties involved with defining the location and confines of a smaller stream. The edge of the riverbank was defined by adjacent vegetated boundaries and channel length was ascertained by measuring the thalweg (Gurnell, 1997; Downs and Priestnall, 1999). Sinuosity was calculated using the standard equation of channel length divided by valley length (Knighton 1984). Changes in channel type or sinuosity in sequential aerial photographs may indicate alteration in sediment supply and transport capacity, riparian vegetation, and LWD supply (Montgomery and MacDonald 2002). Valley length is simply the straight-line distance of two endpoints in the same reach. To simplify the process and ensure consistency, reach sections were made analogous to river mile segments, which allowed for more analytical capabilities and will hopefully provide more information to resource managers.

While this research is unique to the Entiat, others have used similar techniques to measure the impacts of channelization on streams. Gurnell (1997) used aerial photographs from six time series to compare information on channel form and integrate and analyze the data within a GIS. Sexton (1998) used aerial photographs and a GIS to compare changes in channel sinuosity, length and width on a portion of the Cache La Poudre River in Colorado. Both studies demonstrate the validity and importance of historical change analysis and the benefits of using various GIS software and techniques coupled with historical records and traditional sources (e.g., books, aerial photographs, reports, surveys, maps, etc.). The studies also raised important questions concerning the specific accuracy of digital imagery based research.

Indeed, the accuracy of historical change research and GIS, particularly on smaller streams such as the Entiat, needs to be addressed. It is common for channel change data to fall within the error range inherent in the rectification of the photographs (Gurnell 1997). Further, aerial photographs themselves have inaccuracies caused from distortion and displacement, although these problems can be partially corrected using modern computer software (Congalton and Green 1995). However, aerial photographs do contain inherent positional inaccuracies including tilt (perspective distortion) and terrain distortion (elevation variation) that cannot entirely be removed (Bolstad and Smith 1995). In this study, care was exercised to ensure that the findings represent legitimate geomorphic change rather than errors accumulated in the handling of the data as suggested by Gurnell (1997).

Despite the concerns mentioned above, the challenges and associated difficulties of this study were overcome to the greatest extent feasible by using newer and more capable technology and by utilizing a standard protocol for all data entry procedures. Errors were reduced by using imagery of roughly the same scale, ensuring that one handler/operator entered all data, using standard control points to measure comparisons, and by employing a standard definition of riverbank location. The overall accuracy of the GIS process depends on the data layer with the lowest accuracy/resolution (Lee and Lunetta 1995). Despite the difficulties and inherent error of the data, the overall research results were significant and provide an intriguing look at historical changes to the Entiat River. After all, the exact location of the Entiat River, or a patch of riparian vegetation, is not nearly as important as the overriding study area characteristics that explain the evolutionary pattern of the watershed. Thus, the overall quality and significance of the research findings is consistent with the expressed goals and objectives of this study.

Since stream channels naturally change over time, an important consideration of this research involved differentiating between human induced and natural changes along the Entiat River. Changes in stream channel position can be caused by erosion of banks, deposition of bars within the channel and sometimes by chute flow or avulsion (Hooke 1995). As suggested by Montgomery and Buffington (1993), all evidence for channel change was evaluated against potential "causal mechanisms" for the watershed. Of course, natural flooding and erosion can also be accelerated by human influences such as removal of riparian vegetation and overgrazing, further complicating the search for a causal mechanism. During this research, the evaluation and differentiation of human versus natural changes in the Entiat was achieved by using a variety of historical sources described above, to pinpoint areas of intense activity and verifiable change.

Implications of Environmental Change and Management Recommendations

To clarify the methodology for the remaining research objectives, the following discussion is warranted. Changes in riparian vegetation composition and stream morphology were examined to evaluate their general impact on ecosystem function and salmon and steelhead habitat. This was done by closely comparing changes along the lower Entiat River, while taking into account the spatial and temporal patterns. Reports, studies and management documents were reviewed in an attempt to establish links between any changes and aquatic habitat decline.

The management recommendations produced are based primarily on the research results and specifically address a variety of restoration steps thought to be beneficial to the health of the Entiat Watershed. Existing and proposed management and restoration scenarios were taken into consideration along with the overriding regulatory framework. While some recommendations are original, others reinforce, clarify or expand upon pre-existing management options. The intended focus is on realistic recommendations that have a good chance at successful implementation.

CHAPTER V

RESULTS AND DISCUSSION

The results of this research are grouped into two main subsets: those changes to the lower Entiat River and associated riparian zone that occurred prior to 1945 (date of earliest aerial photographs) and those that happened from 1945-1998. Because the pre-1945 analysis lacks a before-and-after analytical component, the format of this section is not analogous to the post-1945 component. Instead, human impacts and the study area conditions are discussed simultaneously for the most part in the pre-1945 section.

State of the Lower Entiat River Pre-1945

Pre-1945 Flood Chronology

The two largest flood events in the Entiat Watershed occurred in 1894 and 1948. There is relatively little data or historical information regarding the effects of the 1894 flood on the Entiat River Valley. The 1894 flood was a regional event that impacted the entire Columbia River Basin and it was probably similar in size to the 1948 flood event in terms of discharge and land inundation along the Entiat Valley. Dense snowpack, higher than average temperatures and heavy rains were the main forces behind the 1894 event. The year 1924 saw localized flooding along Goman, Byrd and Ribbon Cliff Canyons as a result of intense thunderstorms (*Wenatchee Daily World*, 16 August 1924; USFS 1996). All three of the canyons are located north of the study area and drain directly into the Columbia River. While it may be logical to assume that the Entiat also flooded during the 1924 event, convective storms can be very localized and there is not written evidence of widespread flooding. Table 1 provides a summary of the main flood events in the

Table 1. Entiat River Watershed flood chronology

Flood Year	Details
1894	Large regional flood, but population in the Entiat is sparse
1924	Localized flooding in Goman, Byrd and Ribbon Cliff Canyons
1948	Worst flooding in recorded history along the Entiat River
1956	Flash flooding covers Highway 97 with mud and debris
1972	Flooding and bank erosion along much of the Entiat Valley
1974	Flooding and bank erosion throughout the Entiat Valley
1977	Extensive flooding in Crum Canyon and Ringstead Canyon
1989	Flooding in Roaring Creek and Dinkelman Canyon
1997	Flood flood/debris flow in Potato Creek and Stormy Creek

Note: Adapted from USFS 1996.

lower Entiat River Valley. Further discussion of the 1948 flood and other post-1945 flood events occurs later in this chapter.

Settlement of the Entiat River Valley

The lower Entiat River has an intriguing settlement and land use pattern analogous to many other smaller watersheds on the eastern slopes of the Cascade Mountains. During its initial settlement in the late 1880s until the mid-1940s the lower Entiat was the focus of two main land uses: logging and agriculture. Grazing and mining activities were also pursued in the watershed, but were short-lived and mostly occurred out of the lower river valley. Agricultural and logging activities started to dominate the lower Entiat River landscape soon after initial Euro-American settlement. Historical photographs (figures 6-7) taken in 1914 help to convey the intensity of agriculture in the lower valley and provide some intriguing glimpses into the Entiat of old. Farming and the construction of irrigation facilities initially focused on the lower four miles of the

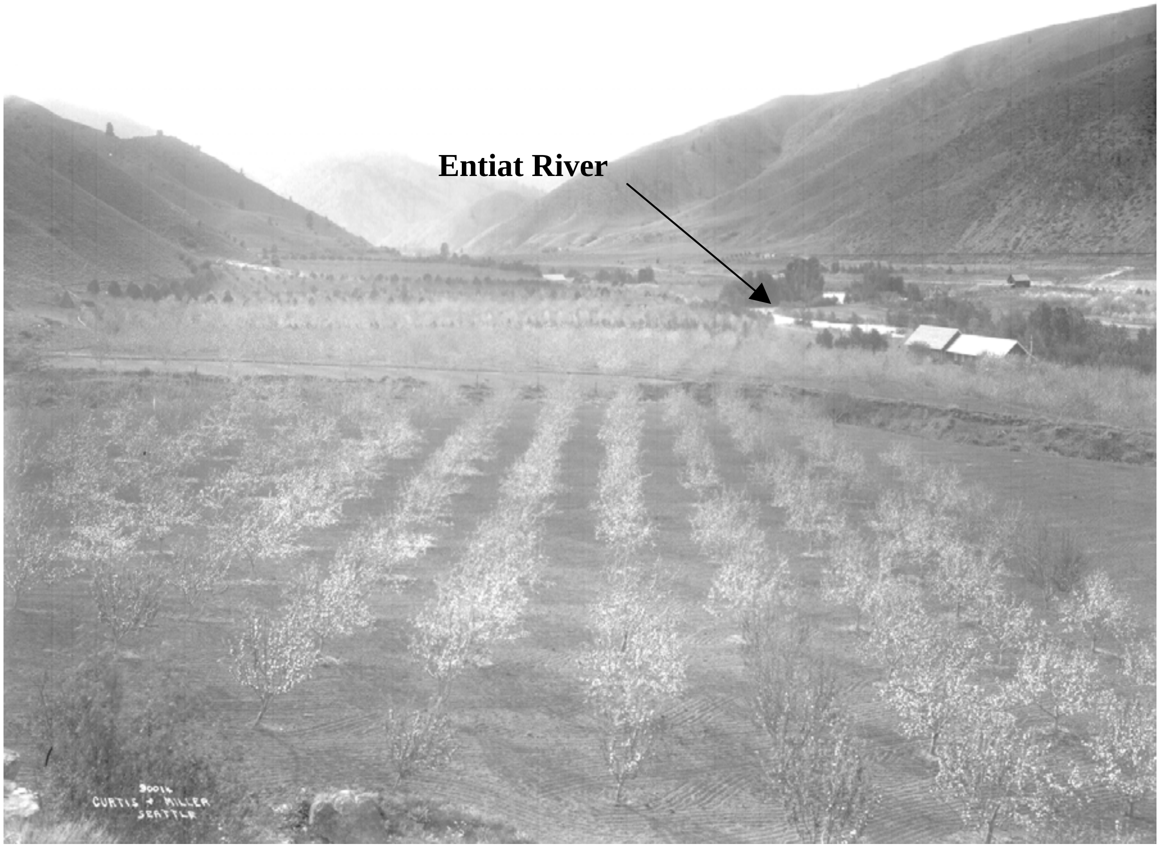


Figure 6. Upvalley view near Keystone Canyon, 1914. Notice the lack of a cover crop between orchard trees and absence of riparian vegetation along the Entiat River. The adjacent slopes are also devoid of trees (Photograph courtesy of the Washington State Historical Society, Asahel Curtis Collection, #30014).

Entiat Valley. By 1902, there was already more than 500 acres in cultivation with over 1,000 acres accessible to irrigation ditches (Plummer 1902). The evolution and growth of agricultural production in the lower Entiat is challenging to chronicle because of its dispersed nature, rapid expansion and lack of early records. Figure 6 clearly illustrates a valley and upland landscape mostly absent of riparian vegetation and forestland, which had been replaced to make room for orchards. The Entiat River corridor is visible in the photograph near the structures and appears to be mostly cleared of riparian vegetation.

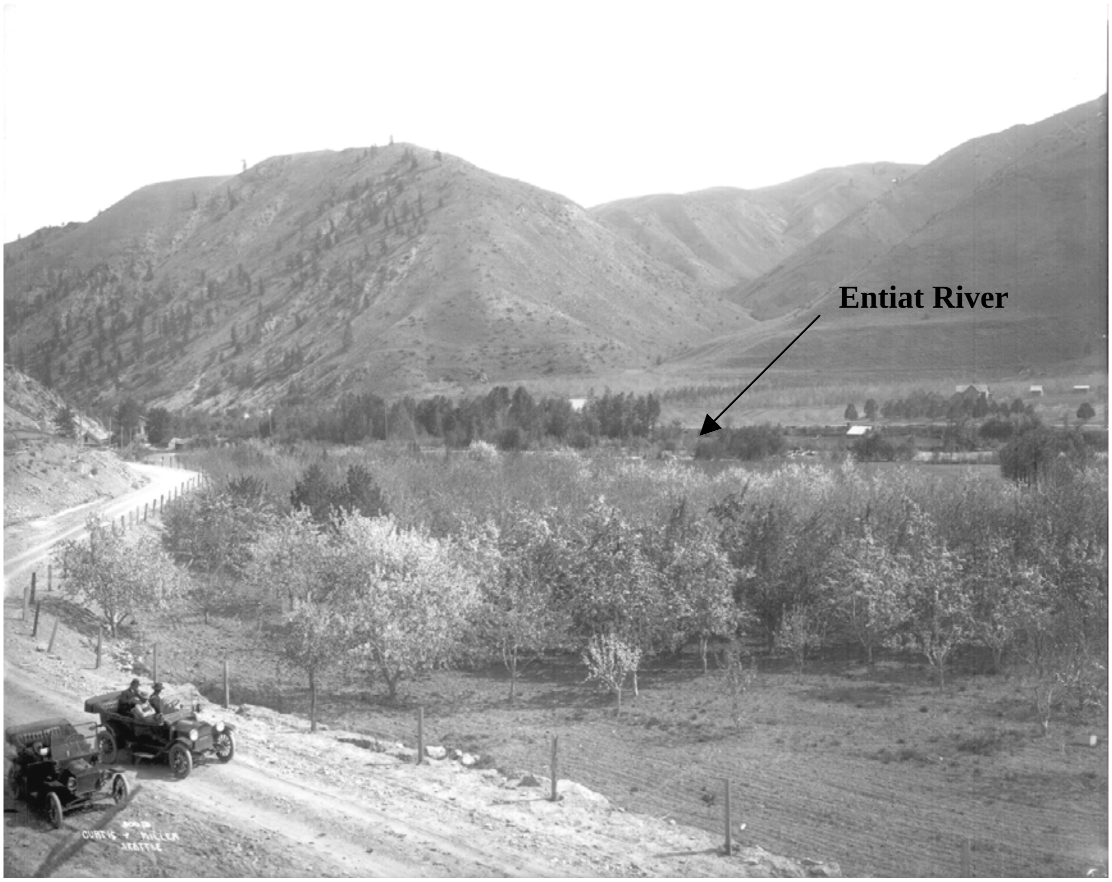
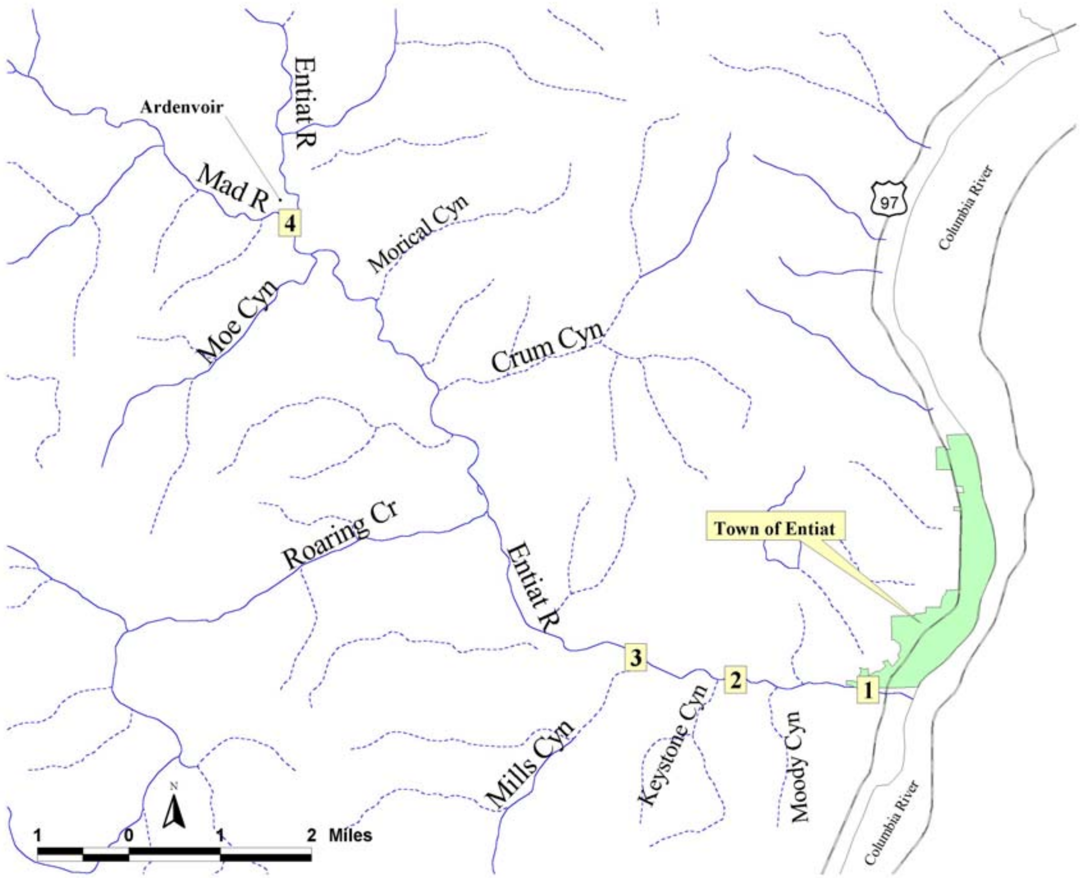


Figure 7. Downvalley view of the lower Entiat River near Keystone Canyon, 1914. A dense band of riparian vegetation is clearly evident in the middle of the photograph adjacent to the Entiat River (Photograph courtesy of the Washington State Historical Society, Asahel Curtis Collection, #30013).

Timber harvest and processing affected the lower Entiat in numerous ways including streamside removal of trees for timber and for agricultural expansion, along with the construction of dams and associated sawmills adjacent to the river. An early forest survey conducted in the Cascades by the USGS (Plummer 1902), noted that the vast majority of tree cutting took place on the riverbanks or on the immediately adjacent slopes. Logging in the watershed also impacted the Entiat through increased erosion and peak flows along with a less predictable, “flashier” hydrological regime and changes in sediment budgets. The first sawmill and dam along the lower Entiat (figure 8) was constructed near the mouth of the river in 1888 (Long 2001). The mill, commonly known as “Gray’s Mill,” harnessed stream power to manufacture wood products including boxes for the burgeoning apple crop (figure 9). Quite high in stature, the dam was used to impound logs that were driven down the river and to generate electrical power. The dam blocked fish passage almost completely, although an ineffective fish ladder was apparently constructed at some time (U.S. Bureau of Fisheries 1937). The mill was bought, sold and rebuilt through the years, before finally closing in 1917 (Long 2001). Three other dam and/or mill features have been built along the lower Entiat and are summarized below in chronological (and upstream) order.

The Power Dam

In 1909, a dam and power plant were built along the Entiat to serve the surrounding population, which was growing substantially in the early 1900s (Long 2001). The power plant was located over a mile upstream of the river mouth, while the water intake and actual dam were located more than a mile upstream of the power plant (figure 10). The dam was around three feet high and formed a barrier to fish passage during low flows when nearly all of the stream water was diverted to the power plant, leaving the river of stream between the dam and the power plant virtually dry (U.S. Bureau of Fisheries 1937; Bryant and Parkhurst 1950). The power plant and diversion works were completed by the Entiat Light and Power Company and eventually came to be operated by the Wenatchee Valley Gas and Electric Co., Puget Sound Power and Light Company and finally by the Chelan County Public Utility District (Parker and Lee 1922; Hull 1929;



Map ID#	Common Name	Approximate Years of Operation
1	Gray's Mill	1888-1917 (non-continuous)
2	The Power Dam	1909-1960s (exact time of dam removal unknown)
3	Kellogg Mill	1913-1932 (mill closed in 1917)
4	Harris Mill	1930-1948 (dam washed out in the flood of 1948)

Figure 8. Principal locations of passage barriers and damming activity in the lower Entiat River Valley.

Figure 9. Early postcard depicting the dam at "Gray's Mill" near the mouth of the Entiat River, ca. 1916. This particular dam is likely the last incarnation of the dam and mill activity that began in 1888 at this location (photographer unknown).

Long 2001). Power production was abandoned at the site in 1938 and the dam and canal were used to funnel irrigation water for some time, although a fish ladder was installed at the dam in 1939 (Bryant and Parkhurst 1950). The exact time of dam removal is not known. It was visible in the 1945 aerial photographs. The power plant was demolished sometime in the 1960s (Long 2001).

The Kellogg Mill

The Kellogg Mill and dam were built in 1913 near Mills Canyon just above river mile three. The dam was eight feet high and served as a complete barrier to fish except during peak flows (Bryant and Parkhurst 1950). The dam spanned the entire width of the

Figure 10. Power plant built by the Entiat Light and Power Company near river mile one, ca. 1910. The large pipe in the photograph funneled water impounded by a three-foot high dam located more than a mile upstream (Photograph courtesy of the Wenatchee Valley Museum and Cultural Center, Chamber Collection, #86-24-90).

Entiat River and was constructed out of logs (figure 11). The mill was closed in 1917 after it burned, but the dam remained an obstacle to fish passage until 1932, when sportsman dynamited a hole partially through the dam to improve fish migration (U.S. Bureau of Fisheries 1937; Bryant and Parkhurst 1950). During its short existence, the mill processed and stored considerable volumes of timber as evident by its large millpond

Figure 11. The Kellogg sawmill near Mills Canyon, 1914. Clearly, the Entiat River was heavily modified in this section. The millpond/reservoir behind the dam held vast quantities of timber and was hundreds of feet long (Photograph courtesy of the Washington State Historical Society, Asahel Curtis Collection, #30019).

beyond the dam (figure 12). Logs were floated down the river to the millpond from logging sites far upstream and upvalley (Long 2001).

The Harris Mill

Constructed in 1930, the Harris Mill was located just over ten miles from the mouth of the Entiat at the junction of the Entiat and Mad Rivers near present-day Ardenvoir A dam and millpond were built along with a bridge just above the dam that

Figure 12. Downriver view near Mills Canyon in 1914. The large stacks of timber are ready for processing at the Kellogg Mill (Photograph courtesy of the Washington State Historical Society, Asahel Curtis Collection, #30017).

crossed near Cooper's Store (Long 2001). The dam spanned the entire width of the Entiat River, was over 13 feet high and had a crude and ineffective concrete fish ladder built into it (U.S. Bureau of Fisheries 1937). The U.S. Bureau of Fisheries Survey (1937) on the day of observation, noted that the Harris Mill Dam was "virtually an impassable barrier" and that only half of the river flow was discharging through the spillway (9). The dam, millpond, and bridge were all destroyed during the 1948 flood. The millpond and bridge were rebuilt shortly after (Long 2001). Overall, there is no indication that the dam was rebuilt, although it seems logical to assume that at least some type of smaller dam or dam-like structure was used in conjunction with the newly constructed millpond. The millpond was used for some time until equipment upgrades rendered them obsolete (Long 2001). The mill was closed in 1979, marking the end of a long-standing historical use in the Entiat River Valley.

Pre-1945 Cumulative Impacts

Taking into account the broad mix and intensity of the land uses described above, it is clear that the lower Entiat River was greatly impacted by flood and human activity long before the 1948 flood and any rehabilitation projects that followed. With the exception of the 1894 regional flood, the Entiat Watershed did not sustain extensive or widespread flooding prior to 1948. Therefore, from the time of initial settlement until 1948, the flood of 1894 marks the only large flood in the watershed and the study area. Unfortunately, a lack of written documentation, photographs and other records precludes a detailed or specific qualitative analysis of the impacts of the 1894 flood on channel morphology and riparian vegetation. Certainly the flood eroded land, uprooted at least some riparian vegetation and impacted instream habitat features such as woody debris and the distribution of sediment. Overall though, there is no compelling evidence suggesting that significant changes in channel morphology or riparian vegetation took place as a result of the flood. Photographs and other documentation primarily link the removal of riparian vegetation to agricultural, logging and other anthropogenic activities. The fact that the Entiat River is fairly entrenched, along with a lack of meander scars, further discredits the theory that large-scale lateral movement of the river or extensive bank erosion took place as a result of the flood.

A variety of historical documents provide insight into the health of the Entiat River in terms of its fishery. An 1894 U.S. Bureau of Fisheries report on Columbia River fisheries neglects the Entiat River entirely. An early historical account of the region (Hull 1929) stated that fish were so plentiful in the Entiat River during the 1890s that it "was an easy manner to catch them with pitchforks" (445). In the 1930s, surveys of all streams in the Columbia Basin were undertaken with the expressed goal of providing information "for a complete program for the maintenance and rehabilitation of the fisheries of the Columbia River" (Rich 1948, 1). The surveys measured many stream variables including fish numbers, obstructions, diversions, and spawning grounds.

Stream surveys conducted in the Entiat by the U.S. Bureau of Fisheries between 1934-1937 provide some startling insight into the condition of the Entiat fishery during this time. For instance, no Chinook salmon were counted and cutthroat and steelhead were listed as "scarce," while rainbow, eastern brook, and dolly varden trout were listed as "fair" (U.S. Bureau of Fisheries 1937). The survey also noted 19 diversions and several passage barriers (dams) along the lower Entiat. Of the 19 diversions, 18 were screened to block fish from entering by 1950 (Bryant and Parkhurst 1950). The screening of the diversions provided improved "productive capacity" of the Entiat, which ultimately made it eligible for transplant stocks of fish blocked by Grand Coulee Dam (Bryant and Parkhurst 1950). In fact, by the 1940s most of the former hazards impacting the migration of fish had been partially or completely removed. The Grand Coulee Fish-Maintenance Project was formally started in 1939 by the U.S. Fish and Wildlife Service and over 3,000 summer Chinook salmon were released in the Entiat from 1939-1940 (Fish and Hanavan 1948). In 1941, the Entiat Fish Hatchery was constructed seven miles from the mouth near Roaring Creek and is still in operation today.

Pre-1945 Summary

It is evident that flooding and the intensive operations at numerous mill sites along with logging, grazing and agricultural activity dramatically impacted the Entiat River pre-1945 in terms of riparian vegetation, sediment routing, stream flow dynamics, channel characteristics and aquatic habitat. Historical photographs illustrate that much of the lower Entiat River lacked riparian vegetation by the early 1900s. It was removed principally to open up agricultural fields and to provide timber to the mills. Three locations along the lower Entiat were utilized as sawmill sites complete with millponds and dams. Another dam was used in conjunction with a power plant to generate electricity for the region. Together, these four sites establish that clear passage for salmon and steelhead in the Entiat was blocked completely or partially from 1888 through at least 1948 and perhaps longer. Overall, there is little evidence to suggest that grazing and mining had much of a direct impact on the lower Entiat River. Indirectly, mining and grazing activity may have resulted in higher erosion and sedimentation and increased peak discharge, although the overall long-term impacts of these actions is probable very minimal.

Changes in the Lower Entiat River Valley 1945-1998

Post-1945 Flood Chronology

The flood history of the Entiat Watershed post-1945 consists of mostly small and/or isolated events, with the exception of the 1948 flood. The flood of 1948 was a regional event of epic proportion as the USGS (1949) report states: "The flood of May-June 1948 in the Columbia River Basin was the greatest in the basin since the flood of 1894 and the most disastrous in respect to monetary loss and overall impact in the history of the basin" (1). The flood was a result of above average temperatures and heavy rains in late May and early June that were preceded by below average temperatures that delayed snowmelt (USGS 1949; CCCD 2002). The problem was compounded by above average snow pack that season. Over 50 people were killed as a result of the three-week long flood and hundreds of million dollars in damage occurred (Bonneville Power Administration (BPA) 2003). The 1948 flood remains the largest single disaster in the Basin and is credited with accelerating the demand for multipurpose dams on the Columbia (BPA 2003). Over 582,000 acres were flooded and more than 5,000 homes destroyed, leaving over 30,000 people homeless (Pacific Northwest River Basins Commission 1971). Vanport, Oregon was hit especially hard as over 32 deaths occurred along with near total destruction of the town of 18,000 people (BPA 2003). Along with providing further impetus for dams on the Columbia, a rapid call for the "restoration of facilities damaged or destroyed by the flood" was also put into action by the federal government (USGS 1949, 1).

In the Entiat River Valley, the flood left at least 50 people homeless and caused hundreds of thousands of dollars in damage (figures 13-14). Ardenvoir, the Stanley

Figure 13. Flooding along the lower Entiat River Valley, 1948. (Photograph courtesy of the Wenatchee Valley Museum and Cultural Center, Gamble Collection, #83-28-9).

Figure 14. Flood damage to the Entiat River Road near the Stanley Grade, 1948. (Photograph courtesy of the Wenatchee Valley Museum and Cultural Center, Gamble Collection, #83-28-7).

Grade and Roaring Creek were hit particularly hard. At Ardenvoir, the main bridge was completely destroyed, as was the Harris sawmill and the associated dam and millponds. Thirteen families were stranded on the west side of the river near the fish hatchery when the main bridge at Roaring Creek was washed out. All told, at least eight bridges were completely destroyed and swept downstream. Damage to irrigation systems was severe as the flood left over 300 acres waterless for some time. The vast majority of damage occurred from Ardenvoir downstream (*Wenatchee Daily World*, 8 June 1948). The 1948 Entiat River flood had an estimated flow rate of 10,800 cubic feet per second (cfs), the highest peak discharge ever recorded on the Entiat (Pacific Northwest River Basins Commission 1971). According to a USACE summary (1948b), the flood of 1948 caused nearly continuous damage to flood control works and erosion from Ardenvoir to the mouth.

Post-1948 flooding in the Entiat Watershed is best characterized by smaller and more localized events with the principal floods occurring in 1972, 1974, 1977 and 1989. Flooding and streambank erosion occurred in June of 1972 was caused by record snowpack and heavy rains, with flows in excess of 6,000 cfs at Ardenvoir (USFS 1979). Damage was severe in the upper basin near Brief and Preston Creek (20 miles from the mouth), where four people were killed when a six foot high debris dam formed and burst and a flood torrent consumed three cabins near the river (*Wenatchee World*, 11 June 1972). In 1974, high spring runoff caused additional bank erosion, along much of the Entiat River (USFS 1979). The 1974 flood also damaged several flood control levees and was described as having a “racing current, tawny with sediment, and heavy with wave-tossed debris…” (*Wenatchee World*, 17 June 1974), although a subsequent article noted that floodwaters had dropped without significant damage in the Entiat (*Wenatchee World*, 19 June 1974). In 1977, the Entiat Watershed was impacted by localized flood events in June and July. In June, heavy rains and hail sent mudflows down Crum Canyon and Ringstead Canyon, destroying orchards, homes and roads in its path (*Wenatchee World*, 14 June 1977). Then in July, heavy thundershowers sent "rivers of mud" down McKinstry, Byrd and Crum Canyons, blocking present-day Highway-97 ALT and the Entiat River Road (*Wenatchee World*, 22 July 1977). Water 10 feet deep and 50 feet wide was reported pouring out of Crum Canyon (*Wenatchee World*, 22 July 1977). The flood and debris torrent created a large fan of mud and debris into the Entiat River, diverting it against the far bank (USACE 1977). Flash flooding, mudflows and debris torrents occurred in Dinkelman and Mills Canyon in August of 1989, following an intensive convective storm (*Wenatchee World*, 21 August 1989). Sediment in the lower Entiat below Dinkleman Canyon was so thick that nearly all of the fish in the reach were killed (*Wenatchee World*, 22 August 1989). Flood events often follow within a year or two of large wildfires, as was the case in 1972, 1977 and 1989.

Riparian Vegetation 1945-1998

The lower Entiat River corridor had, within its boundaries, approximately 167 acres of riparian vegetation in 1945 and 170 acres in 1998 (table 2). As represented in both time series, riparian vegetation was, and continues to be, scattered in small, sparsely populated clusters. These clusters are located for the most part, directly adjacent to the Entiat River. During both periods, large gaps in riparian foliage are common, as are narrow bands of vegetation that provide little to no shading or buffering capability.

Table 2. Changes in riparian vegetation coverage along the lower Entiat River Valley by river mile, 1945-1998

River Mile	Riparian Acreage 1945	Riparian Acreage 1998	Change in Acreage	Percent Change 1945-1998
0-1	14.52	26.04	11.52	79.31
1-2	13.72	16.99	3.27	23.82
2-3	4.85	11.19	6.34	130.75
3-4	32.49	17.10	-15.39	-47.37
4-5	16.99	14.05	-2.93	-17.27
5-6	14.19	15.02	0.83	5.86
6-7	22.22	19.81	-2.41	-10.85
7-8	6.64	10.60	3.96	59.66
8-9	19.07	16.80	-2.28	-11.94
9-10	11.93	12.53	0.60	5.05
10-Mad R.	9.91	10.30	0.39	3.97
Totals	166.53	170.43	3.90	2.21

Figure 15 provides a locator map for the series of maps that will be referenced in this section and the next. Riparian vegetation increased most dramatically from 1945 to 1998 in the lower three miles (figures 16-17) of the Entiat. Aerial photograph analysis illustrates a near doubling of total riparian acreage in the lower mile of the Entiat River from 1945 to 1998. Riparian vegetation increased more than 130% between river miles two and three, although the riparian corridor in this section is very narrow. The most significant decrease in riparian vegetation occurred between river miles three and four (figure 17). Above river mile four, overall riparian vegetation did not really change dramatically as depicted in figures 16-20, although the spatial distribution did shift. The one exception to this rule occurred between river miles seven and eight, which saw a 59% increase in riparian vegetation (figure 19).

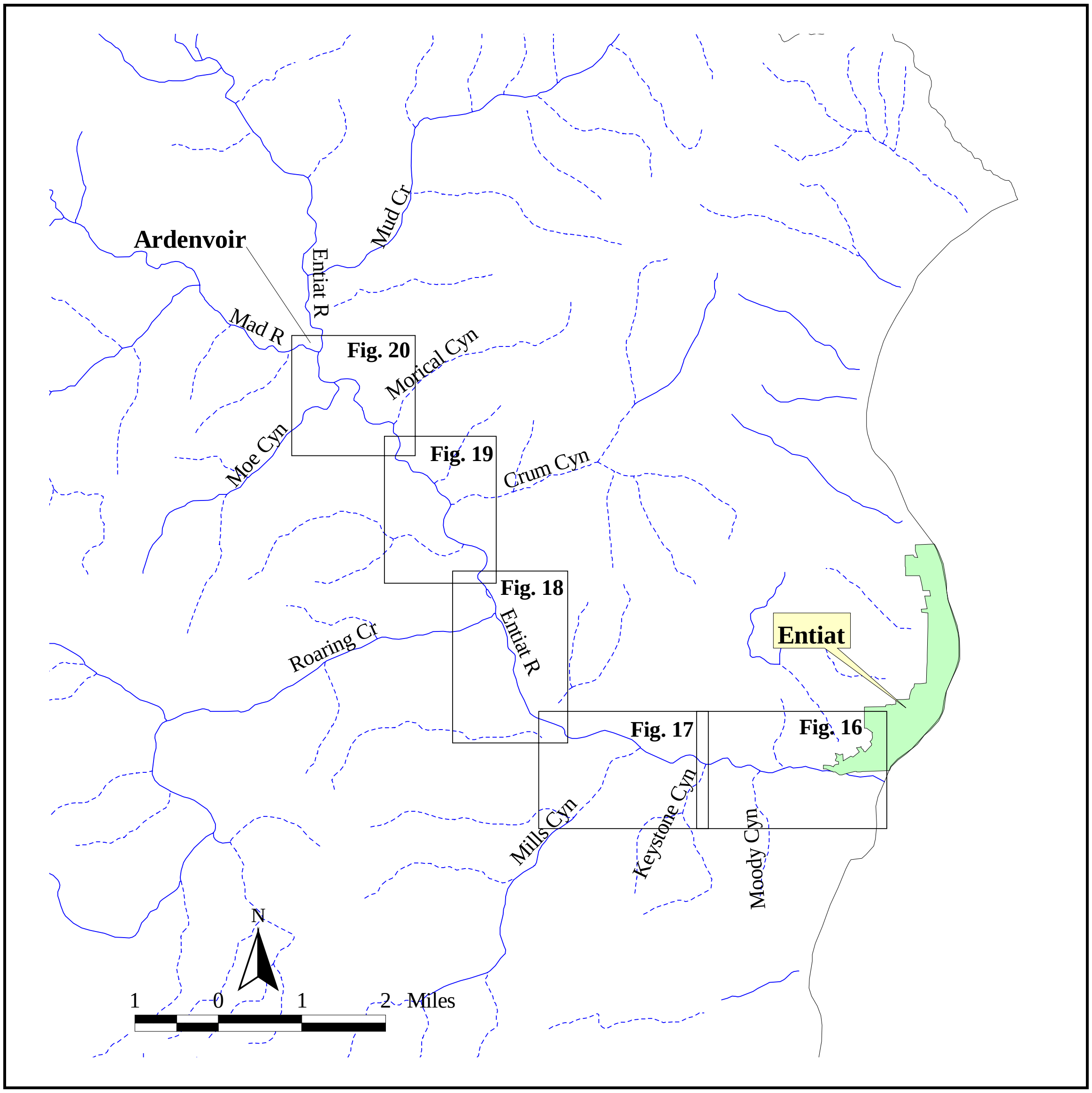


Figure 15. Locator map depicting map coverage for the study area.

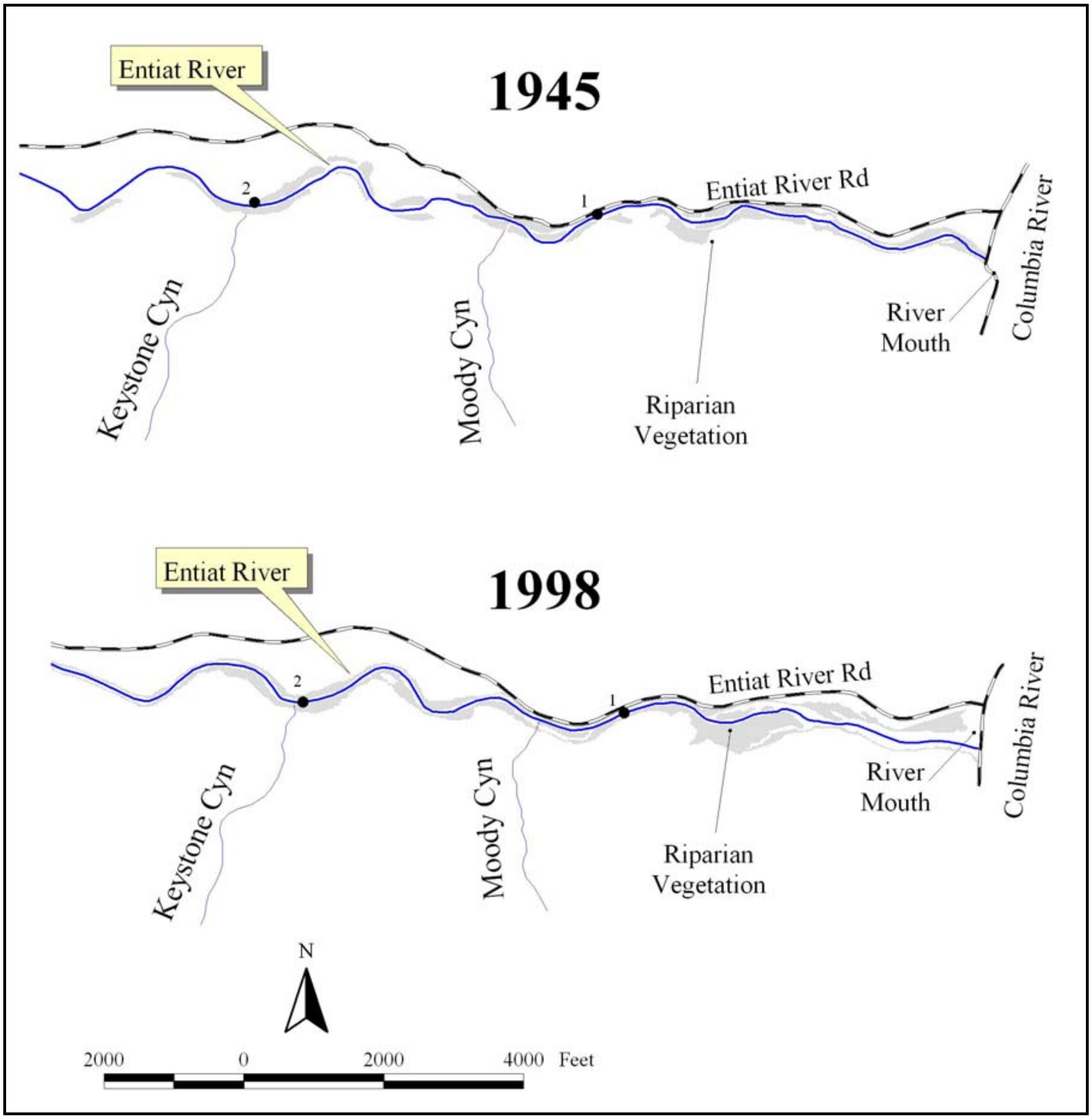


Figure 16. Riparian vegetation and channel sinuosity, river miles 0-2.5, lower Entiat River. Note the dramatic increase in riparian vegetation below river mile one as a result of sedimentation from Rocky Reach Dam.

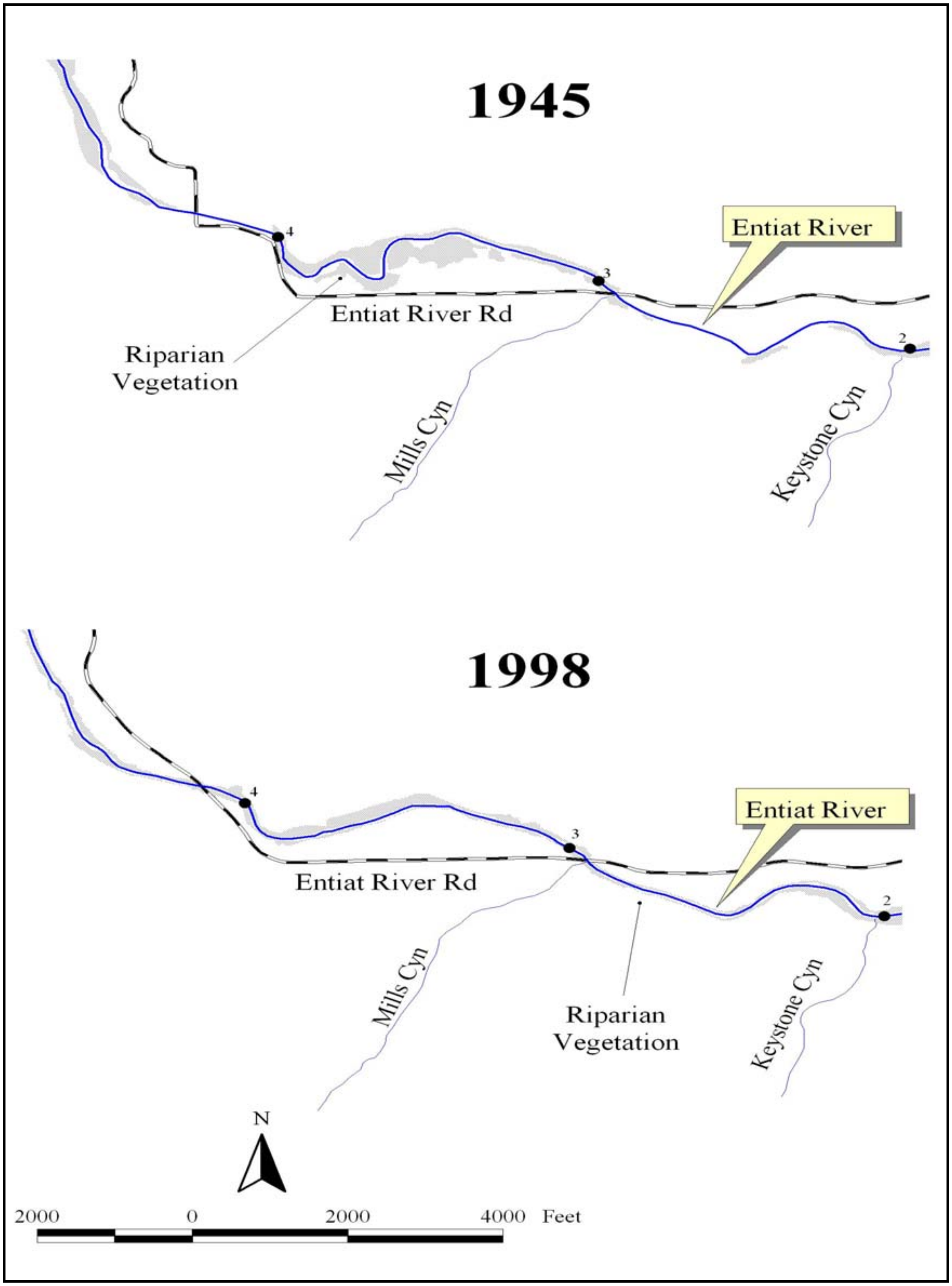


Figure 17. Riparian vegetation and channel sinuosity, river miles 2-4.5, lower Entiat River. Notice the dramatic loss in stream sinuosity between river miles 3-4, likely caused by a flood control project that channelized that section of stream.

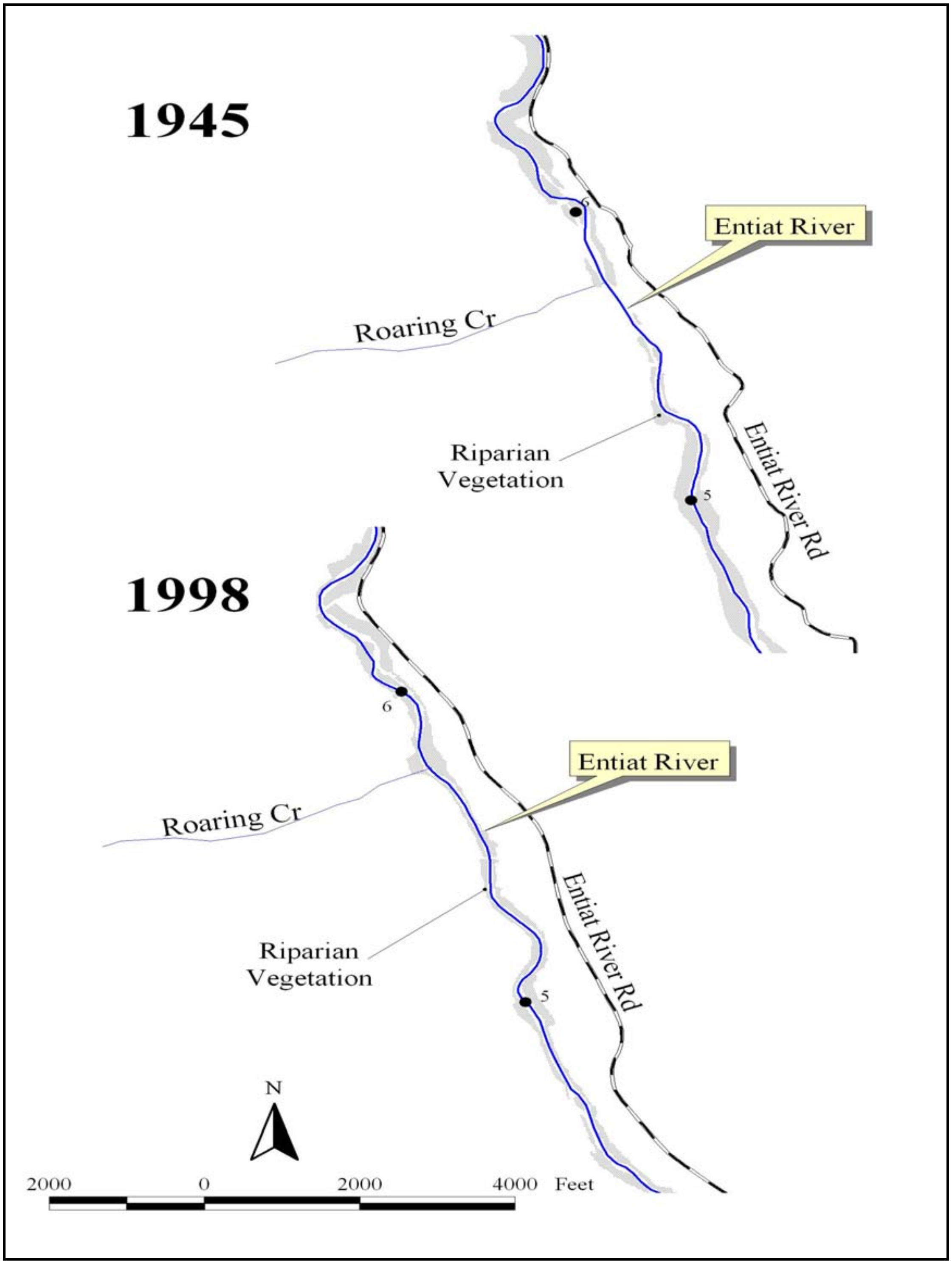


Figure 18. Riparian vegetation and channel sinuosity, river miles 4.5-6.5, lower Entiat River. Spatial distribution of riparian vegetation has clearly shifted throughout this reach. Minor stream changes and Entiat River Road alterations are also evident.

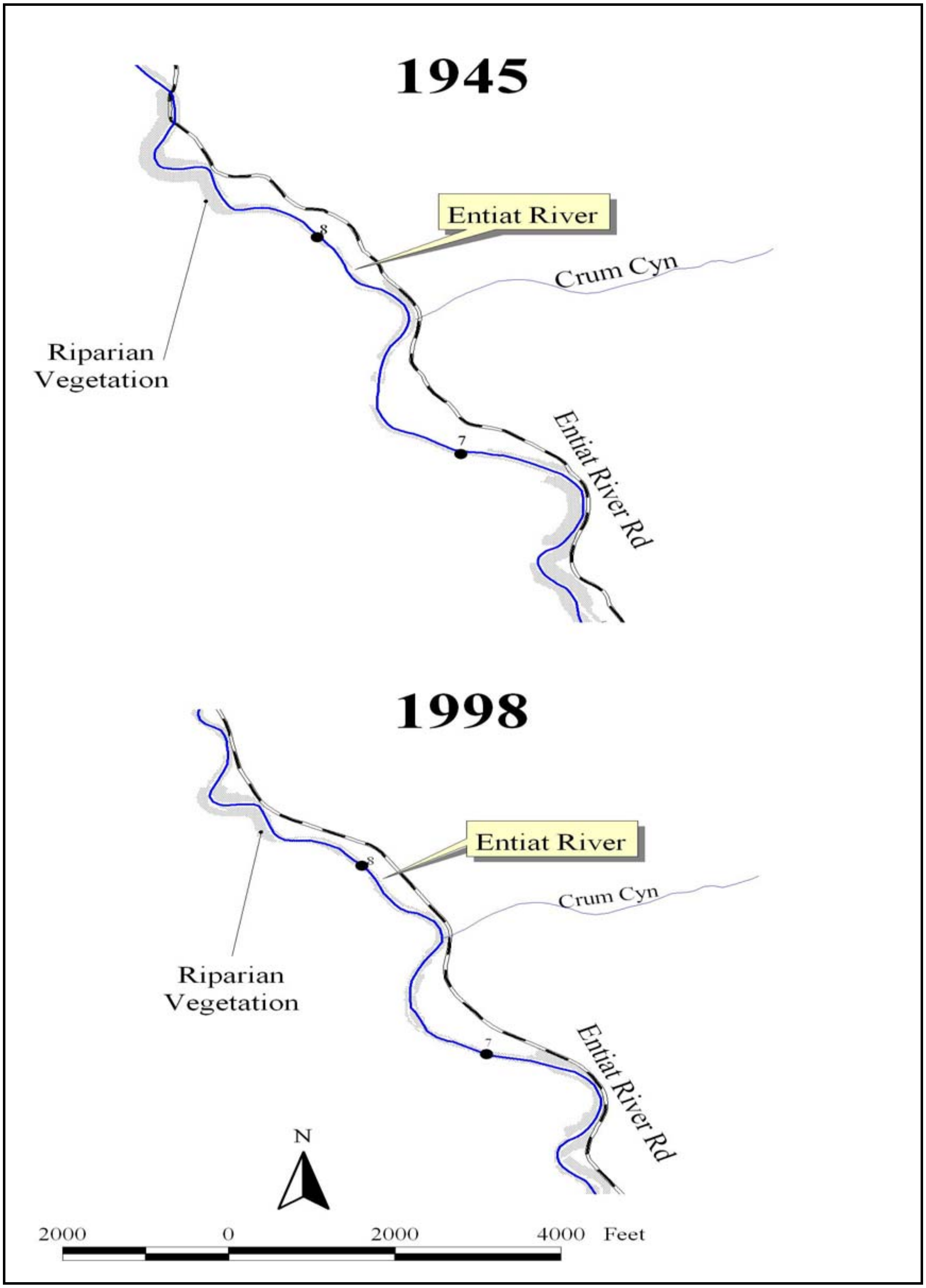


Figure 19. Riparian vegetation and channel sinuosity, river miles 6.5-8.5, lower Entiat River. Minor road and riparian changes are highlighted in this reach.

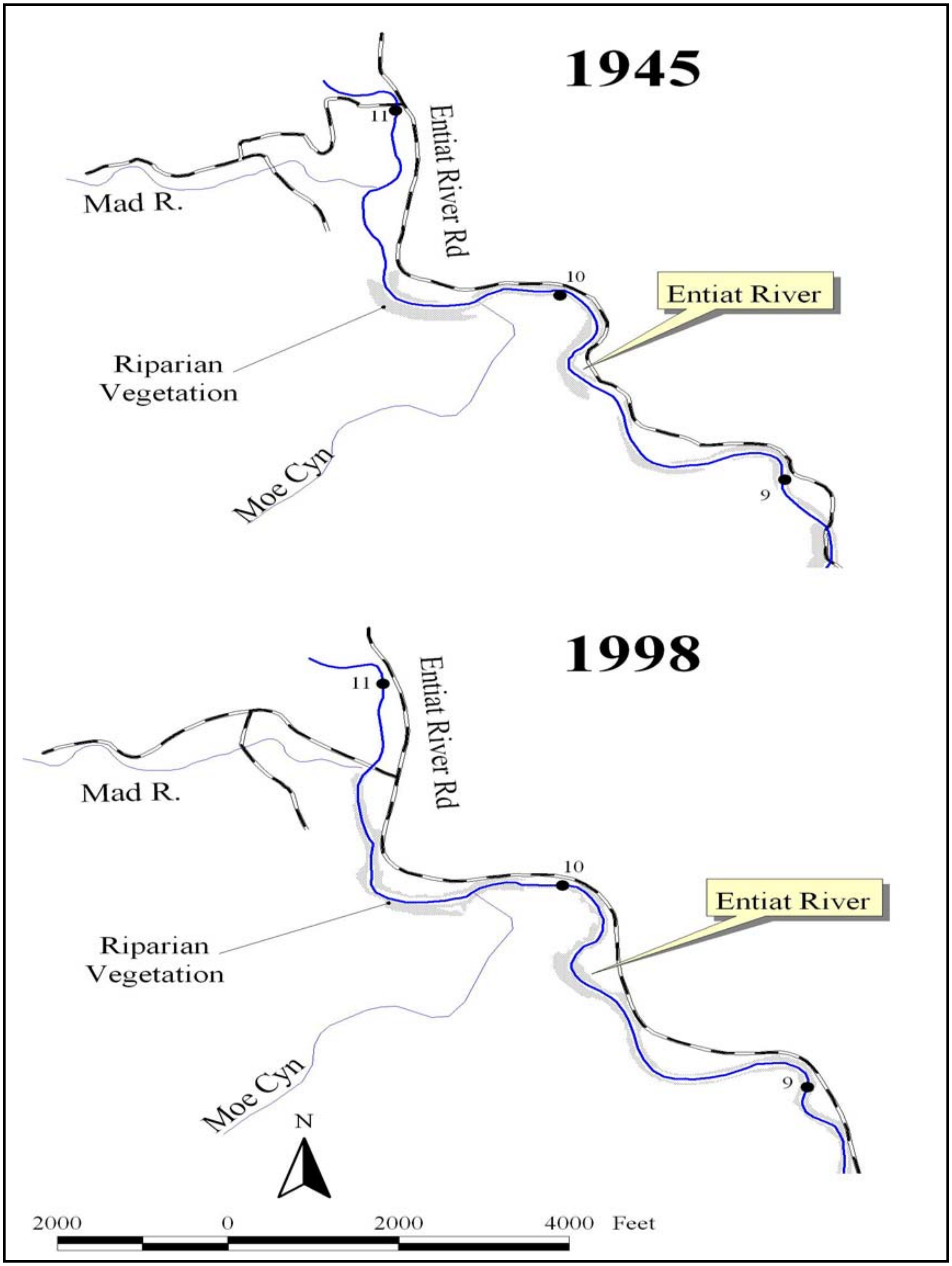


Figure 20. Riparian vegetation and channel sinuosity, river miles 9-11, lower Entiat River. Slight growth of riparian vegetation near Ardenvoir and the Harris mill and dam site are evident.

Surprisingly, cumulative riparian vegetation acreage was virtually unchanged between 1945 and 1998. This is not to say that the state of riparian vegetation habit at along the Entiat Valley is in a healthy or optimal condition or that riparian coverage did not change in specific reaches. As evident on every map (figures 16-20), portions of the Entiat River are devoid of riparian vegetation, or at best, have only thin strips of vegetation to filter runoff, provide shade and habitat and maintain bank stability. In many cases, orchard land and residential development extends to the bank of the Entiat River, with virtually no buffer of native vegetation.

The Wilcoxon signed rank statistical test (Wilcoxon T) was used to ascertain the significance of observed change. Table 3 illustrates the results of the Wilcoxon T and provides some other summary data. The null hypothesis states that no significant differences exist in the quantities of riparian vegetation between 1945 and 1998. Conversely, the alternative hypothesis asserts that significant change occurred between the two time series. A rejection level of .05 was utilized (two-tailed). The observed P-value was 0.56, which resulted in the null hypothesis being accepted; there is no significant difference in riparian vegetation between 1945 and 1998. The interquartile range provides a measure of spread and dispersion for each time series by listing the difference between the 75th (Q_3) and 25th (Q_1) percentile, eliminating the more extreme data on either end. Quartile deviation represents the average deviation of the quartiles from the median and is calculated by halving the difference of the quartiles (Q_3-Q_1/2). The results suggest that riparian vegetation varied more in 1945 and that the range of variation around the mean is less for the 1998 data (less deviation and dispersion). Clearly, riparian vegetation differed more greatly between the various river miles in 1945

Table 3. Riparian vegetation 1945 and 1998, statistical summary and Wilcoxon signed rank test

Statistical Value	1945 (acres)	1998 (acres)
Median	14.19	15.02
Interquartile Range (Q_3-Q_1)	9.16	5.91
Quartile Deviation	4.58	2.96
Wilcoxon Signed Rank P-value (two-tailed)	0.56	

than in 1998. This indicates that riparian vegetation was more uniformly distributed in 1998 than in 1945, which makes sense considering the various land uses and human impacts that occurred prior to 1945 as previously described.

Despite the fact that overall acreages of riparian vegetation remained virtually the same, some shifts in the spatial distribution of riparian vegetation did occur and are worth discussing in more detail. First, there is the possibility that the flood of 1948 or subsequent flooding altered the distribution of riparian vegetation between the two time series. Flooding can remove riparian vegetation principally through bank and bar erosion. Conversely, the redistribution of sediments coupled with overbank flood deposition can encourage new riparian growth and nourish existing stands. Overall, it is not believed that any of the post-1945 floods resulted in significant removal or redistribution of riparian vegetation. This argument is supported by the fact that documented human activity can be specifically linked to most areas experiencing significant changes in riparian vegetation composition.

The increased riparian vegetation near the mouth of the Entiat River can be explained by the rise in base level experienced by the lower river in response to Rocky Reach Dam, which was completed in 1961 creating Lake Entiat (figure 16). The dam elevated the mouth of the Entiat River by as much as 20 to 40 feet judging by USGS topographical maps. Before Rocky Reach Dam was built, stream sediments were deposited into the Columbia River and its associated floodplain. Following dam construction, sediments were deposited in large quantity along the lower Entiat River, causing a delta and several bars to form (Chelan County Public Utility District 2000). The addition of fresh, fine sediment to stream systems provides ideal conditions for the establishment of cottonwood trees and other riparian species (Scott, Friedman, and Auble 1996). The increase in riparian vegetation between river miles one and three may also be partially linked to increased sedimentation and the rise in base level of the lower river. Another, perhaps more plausible explanation, can also be found in the historical record as it pertains to mill and dam activity. As noted previously, two dams and a power plant were located between river miles one and three. Removal of the associated infrastructure and the end of intense logging, milling and other activity from the riparian corridor in these areas, most certainly opened up new lands for riparian growth and colonization (figures 16-17).

Decreases in riparian vegetation between river miles three and four correspond well with locations where agencies and/or landowners built levees and realigned the stream, as will be subsequently discussed in more detail (figure 17). The end result of the channelization work was a less sinuous stream that provided ideal conditions for the expansion of agricultural crops and residential development at the expense of riparian vegetation. The 1945 aerial photographs clearly show this portion of the Entiat as a diverse floodplain with a very sinuous channel and dense riparian growth.

The remaining stream sections are generally characterized by only slight changes in riparian composition. Figure 17 illustrates adjustments in riparian vegetation as agricultural activities have expanded near the edge of the river, resulting in a net loss of vegetation. The area surrounding Crum Canyon, between river mile seven and eight, saw more than a 50% increase in riparian vegetation between 1945 and 1998, although the overall quantity and width of vegetation remains quite small (figure 19). This increase is best explained by growth in the overall width of riparian zones directly adjacent to the Entiat River rather than one specific causal mechanism. Increased riparian growth from 1945 to 1998 was also seen below the Mad River confluence along the site of the Harris Mill, where the closure of the mill and removal of the dam most certainly allowed for riparian expansion and new growth.

Channel Morphology 1945-1998

Like the results of the riparian vegetation study, the overall sinuosity of the lower Entiat was virtually unchanged between 1945 and 1998 (table 4). Considering the processes involved and associated measurement error levels inherent with aerial photograph and digital analysis, it becomes clear that no discernable difference exists in the sinuosity of the Entiat River between 1945 and 1998. There are some spatial differences between the two time series, but the differences are so minute, they hardly deserve mention. Despite several flood events and debris torrents/fan deposits in some of the side canyon mouths, only minute changes in channel morphology were detected. The

Table 4. Lower Entiat River 1945 and 1998, sinuosity measurements by river mile

River Mile	Sinuosity 1945	Sinuosity 1998	Change in Sinuosity	Percent Change 1945-1998
0-1	1.07	1.04	-0.03	-2.80
1-2	1.17	1.15	-0.02	-1.71
2-3	1.13	1.13	0.00	0.00
3-4	1.31	1.12	-0.19	-14.50
4-5	1.12	1.10	-0.02	-1.79
5-6	1.10	1.09	-0.01	-0.91
6-7	1.33	1.33	0.00	0.00
7-8	1.20	1.22	0.02	1.67
8-9	1.25	1.28	0.03	2.40
9-10	1.35	1.32	-0.03	-2.22
10-Mad R.	1.58	1.50	-0.08	-5.06
Median	1.20	1.15	-.02	-.02

only two stream segments that displayed significant changes occurred between river mile three and four, where stream sinuosity was decreased by 14% and between river miles ten and the confluence of the Mad River, which saw a 5% decrease in stream sinuosity. Readers are directed to the previously displayed maps (figures 16-20) for reach-specific information.

Regarding statistical tests, the Wilcoxon T could not be used to determine if a significant difference in stream sinuosity exists between the two periods because of the high number of tied ranks (six) that were present. As a result, the test assumptions were not met since well over 25% of the values were tied and any calculated P-value would have been meaningless. The interquartile range was calculated at 0.21 and 0.22 for 1945 and 1998 respectively, and the quartile deviation was 0.11 for both series. These statistics lend further support to the notion that very little change in stream sinuosity was observed between 1945 and 1998.

As previously mentioned, the changes seen between river miles three and four (figure 18) are best explained by flood control and bank stabilization projects in the area that rerouted several hundred feet of the Entiat River. In the process, the stream was channelized and several meanders were removed. While the exact year of the project is difficult to pinpoint, it does appear to have occurred sometime between 1945 and the late 1950s. Interestingly, no specific mention of the project was ever located in the USACE archives and it is unclear exactly who spearheaded the project. Changes in sinuosity between river mile ten and the Mad River confluence were likely caused by the Harris Mill, which operated before and after the 1948 flood. The mill included a sizable dam and pond system, and the Entiat River was modified accordingly to accommodate the intensive operations at the site. While the mill was in operation prior the 1945, morphological changes near the site between 1945 and 1998 can be explained by the changing scale and intensity of operations at the mill. The mill and ponds also had to be reconstructed after the 1948 flood, further linking human-induced channel change to this site. The results of the sinuosity measurements further confirm that widespread and dramatic changes did not occur in the lower Entiat River corridor due to the 1948 flood or the channelization and flood control efforts that followed.

Now that it has been conclusively demonstrated that neither cumulative riparian vegetation nor channel sinuosity changed significantly between 1945 and 1998, one inescapable question follows: what about all the supposed flood control and channelization projects started by the USACE following the 1948 flood? After all, it only stands to reason that USACE activities should have resulted in reduced riparian vegetation and channel sinuosity. A concise discussion of USACE involvement in the lower Entiat River appears below and is followed by a summary of the research results relevant to the post-1945 data.

USACE Investigations

Although active in the Columbia River Basin much earlier, the USACE were not involved in flood control efforts in the Entiat River Valley until after the 1948 flood (USACE 1953). The fact that many years had passed since the last significant flood, along with increased development and floodplain encroachment, made the 1948 flood particularly disastrous (USACE 1953). A survey conducted soon after the flood noted 28 flood control works along the Entiat, all of which were located downstream of Ardenvoir (USACE 1948a). This amounted to nearly 14,000 feet (or 2.6 miles) of protective structures that were installed prior to the 1948 flood. Assuming the study area includes around 10.5 miles of the Entiat River, there are 21 total miles (i.e., both sides of the river: 10.5 miles x 2) that have the potential for flood control activity. Thus, flood control features have been built on approximately 12% of the lower Entiat River. It is unclear when the majority of the structures were erected, as severe flooding had not occurred in the Entiat Valley since 1894. Some of the structures may have been emergency flood control works placed in haste as floodwaters rose in the spring of 1948. More than likely though, the majority of them had probably been placed adjacent to the Entiat River to protect against annual flooding. If this were the case, most of the flood control works were likely in place by the early 1900s as the agricultural boom took hold.

In a survey conducted soon after the flood, the USACE (1948b) concluded that 21 flood control structures were damaged by the event. The existing flood protective works consisted of low gravel levees and bank protective works utilizing riprap (USACE 1953). The low gravel levees were utilized to block the rising floodwaters, essentially raising the bankfull discharge level of the Entiat River, while the riprap was used to shore up erosive banks. The distinction between levees and bank protection is not always clear as both processes were/are often used simultaneously. Along with restoration of destroyed flood control works, the report (USACE 1948b) also touted the benefits of instream debris clearing and the need for flood storage higher in the valley. Early cost estimates to restore levee and bank protective works on the Entiat was estimated at around $84,000 (USACE 1948b). Funding was not sufficient to repair all damaged flood control works in the Entiat, although at least six major projects were in the works shortly after the 1948 flood (USACE Entiat Watershed files) (figure 21). It is unclear exactly when, or even if, each individual project was completed, however detailed plans and drawings were formulated (figure 22). Projects A-D were completed in February and November of 1949 at a cost of $77,530 (USACE 1953). Project D is in the vicinity of the portion of the Entiat where significant losses in riparian vegetation and sinuosity occurred between 1945 and 1998. However, USACE documentation (USACE Entiat Watershed files) suggests that in addition to a small USACE project in the area, the property owner(s) also constructed significant flood control works including a 700 foot long levee containing 4,000 yards of material in 1949. There is no conclusive evidence suggesting that Projects E-F were ever completed by the USACE, although they certainly may have been done by private landowners, the USACE, or other agencies/entities. The flood control projects

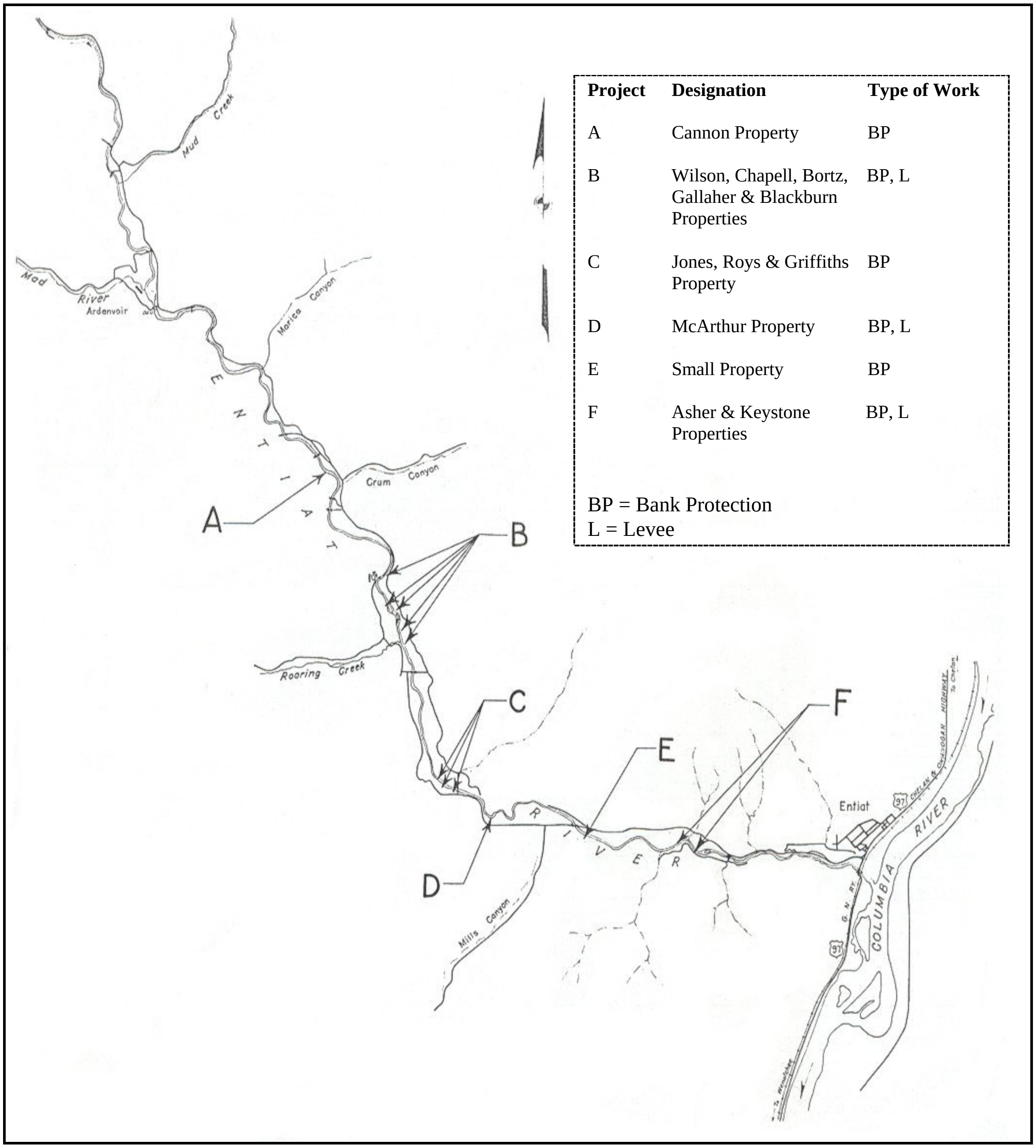


Figure 21. USACE 1949 map detailing the location of priority rehabilitation efforts and flood control projects (adapted from USACE Entiat Watershed Files).

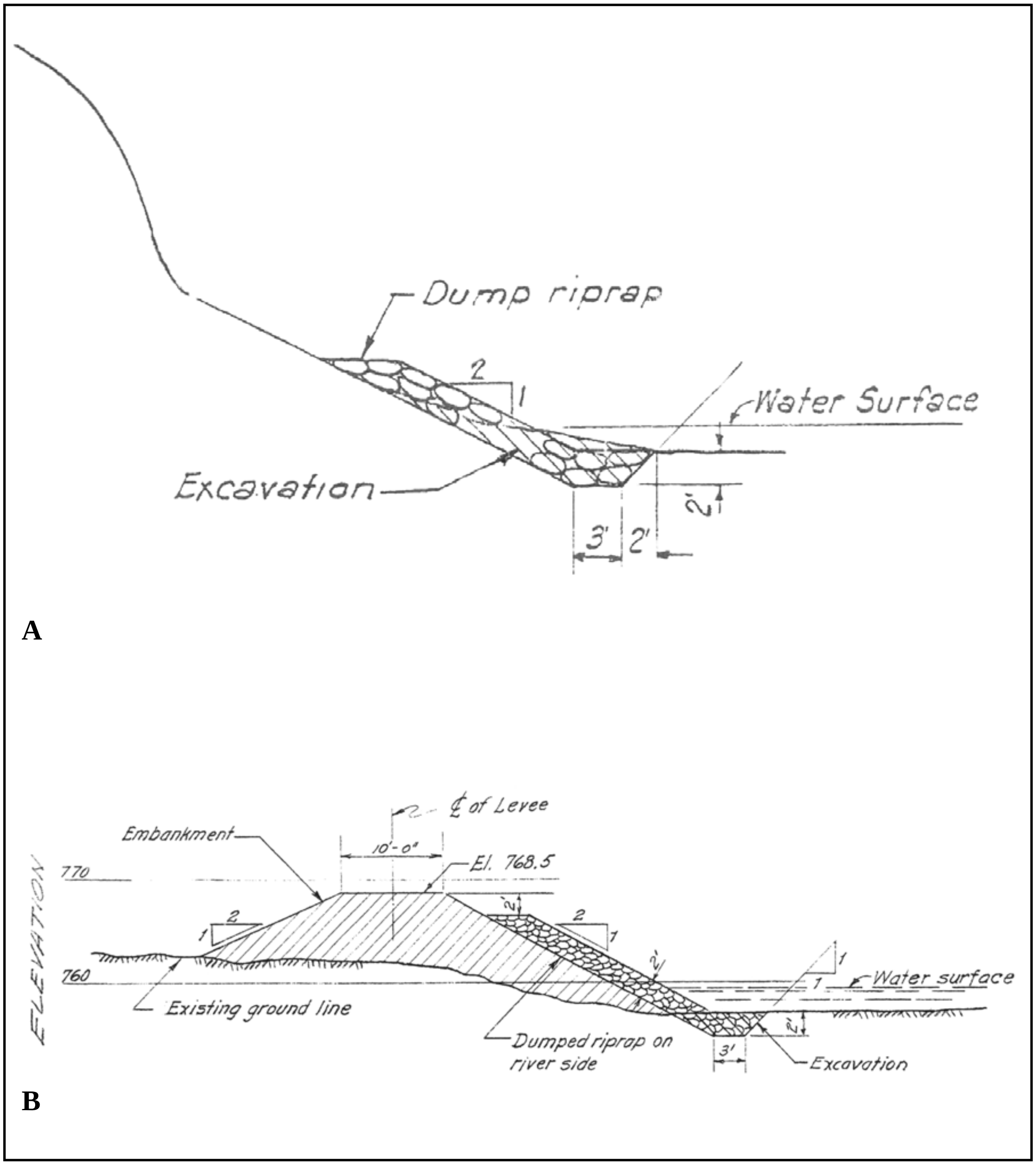


Figure 22. Drawings of USACE flood control projects in the lower Entiat River Valley. The diagram on top (A) illustrates a simple bank protection structure utilizing riprap, while the bottom drawing (B) displays a common levee design (USACE Entiat Watershed files).

constructed by the USACE appear to have used a combination of levees and bank protection/riprap in their design. A typical levee was fairly small, perhaps ten feet or less in height and had riprap incorporated into it, especially at the ends to stabilize the feature and prevent it from being washed away. Bank protection and riprap were used without levees in some segments to prevent erosion and the undercutting of stream banks. In nearly all cases, the flood control works were constructed at the outside bend of stream meanders where erosive energy would be most intense. There is no evidence of meander removal or stream reshaping by the USACE in any of the written documentation or technical drawings analyzed for this research.

Overall, the USACE was not very active in the lower Entiat River Valley. While there were over two cumulative miles of protective flood works in the lower Entiat at the time of the 1948 flood, it appears as though private landowners constructed nearly all of them. Documentary evidence suggests that the USACE only had limited involvement in the Entiat, consisting primarily of a handful of reconstruction projects. Most of the flood control works in the lower Entiat Valley consist of small levees and banks lined with riprap that are difficult to discern from other land features in the field, are not visible on aerial photographs and pre-date the 1948 flood (figures 23-24). It should be noted that the USACE was also active in the lower Entiat after flood events in 1974 and 1977, including a stabilization project near the confluence of the Entiat River with Crum Canyon (USACE Entiat Watershed files). A clearing and snagging operation was also conducted by the USACE in 1971, which removed ten miles of debris from the Entiat above river mile 16 (USACE Entiat Watershed files).

Figure 23. Pre-existing rock riprap bank protective structure located above river mile four during the 1948 flood (Photograph courtesy of the Wenatchee Valley Museum & Cultural Center, Gamble Collection, #83-28-10).

Figure 24. Present-day view of an old levee feature located downstream of the Roaring Creek Bridge. Most of the levee and bank protection features are difficult to discern from the landscape because of their inconspicuous size and the fact that many are now covered by dense vegetation.

Implications of Cumulative Changes to Aquatic Habitat

It is clear that all of the expressed research questions have been answered and explained in detail with one exception: the implications of floods and human modification in the Entiat to aquatic habitat and the general health of the ecosystem. Suffice to say, it does not appear that floods or one particular type of human alteration can be conclusively linked to salmon habitat degradation in the Entiat. Instead, the evidence suggests that the lower Entiat River ecosystem is the cumulative product of a few principal activities including logging, dam and sawmill construction, farming and flood control efforts along with flooding. The potential impacts of floods have been discussed in detail in previous sections and will not be repeated here. Because the majority of changes and impacts appear to have been initiated or occurred entirely prior to 1945, the focus of this section has been adjusted accordingly. Historical photographs and records provide little insight into the historic morphology of the Entiat River channel and associated riparian vegetation. Clearly, many activities including logging, farming, along with the construction of sawmills, millponds and other infrastructure potentially could have reduced the sinuosity, habitat complexity and riparian composition of the lower Entiat River. However, it is difficult to believe that intensive channelization could have occurred, as stream modification requires a considerable amount of manpower, technical expertise and financial resources. Without large floods and the active involvement of the USACE in the watershed, there was no impetus for large-scale channelization of the lower watershed prior to 1945 and the post-1945 aerial photograph analysis does not support major changes. The USACE records do illustrate, however, that a large portion of the lower Entiat River contained flood control features such as levees and riprap revetments, although most of them appear to be relatively small structures. Localized levee construction, bank stabilization efforts and road building restricted movement of the Entiat to at least some degree. The narrow river valley, which is really “canyon-like” in some segments, coupled with few meander scars, oxbows or other geomorphic features, lend little credence to the assertion that the Entiat River migrated laterally in historic time over much distance.

Certainly, log drives, dams, logging and agricultural expansion impacted riparian vegetation densities and stream health in numerous ways, even if widespread channelization did not occur. The early log drives choked the river with debris and hampered fish migration. Dams and diversions along the Entiat altered the sediment dynamics of the stream, impacted the pool-riffle sequence and prevented the migration of salmon and steelhead. The removal of riparian vegetation resulted in increased stream temperatures, decreased LWD input into the stream and made the riverbank more susceptible to erosion. With approximately 12% of total bank length impacted to some degree by bank protection and road embankment structures, surely some consequences exist to aquatic resources and overall stream health. Levees and other bank protection features such as riprap and road embankments can cut off rivers from their floodplains laterally, reducing the survival rates of riparian vegetation.

The shortage of deep holding/resting/rearing pools in the lower Entiat is considered the major limiting factor to the survival of aquatic species in the Entiat. This shortage results in longer incubation periods, higher mortality rates, increased predation and the formation of anchor ice that can damage eggs and fry (USFS 1996; CCCD 2002). Elimination of beaver, human-induced riparian modification, changes in upslope vegetation and hydrologic regime, fire suppression, flood control, grazing and timber harvest may all play key roles in this change (USFS 1996). Salmon and steelhead require cool and clean water, adequate flows, resting areas when they return to spawn, including deep pools, vegetative cover and instream features such as LWD to protect them from predators and for resting (Andonaegui 1999). Major pools declined significantly in the lower Entiat River between the stream surveys of the 1930s (U.S. Bureau of Fisheries 1937) and the NRCS survey conducted in 1995 (NRCS 1998). The two sets of data are difficult to directly compare, because different sized stream reaches were utilized. As such, measurements such as width and depth are not useful to contrast; however, the surveys do provide an interesting contrast regarding the number of large pools present in the lower Entiat. According to the U.S. Bureau of Fisheries (1937), approximately 51 resting pools existed in the lower 12 miles of the Entiat (table 5). By 1995, pools in the lower 11 miles totaled only around five (NRCS 1998). Unfortunately, the survey data from the 1930s does not contain information pertaining to riparian vegetation or LWD so no comparisons can be made.

With all of this said, there is debate on whether the historical abundance of salmon and steelhead in the Entiat River differed markedly from now (Mullan et al. 1992). Besides a handful of eyewitness accounts and historical documents, there are no historical fish count records or surveys that predates the U.S. Bureau of Fisheries surveys of the 1930s, further complicating the resource management dilemma and making it impossible to link specific habitat losses with fish declines in the Entiat. As discussed earlier, dams near the mouth of the Entiat in the late 1800s and early 1900s completely blocked access to migrating fish, most certainly decimating native stocks.

Table 5. Stream characteristics by station, lower Entiat River 1930s

Station	River Mile	Width (feet)	Depth (feet)	Pools (per mile)
1	0	71	2.5	n/a
2	1.3	57	1.5	3
3	2.8	62	1.3	1
4	4.1	63	1.3	7
5	5.8	123	2.0	16
6	8.2	64	1.5	6
7	12.2	70	1.5	1

Note: Adapted from U.S. Bureau of Fisheries 1937.

Simultaneously, agricultural expansion and logging activities resulted in the removal of riparian vegetation and channel modification, stressing the fishery and hampering any chance of restoring fish runs. Regional development of the Columbia Basin and numerous dams along the mainstem Columbia further limited the reestablishment of the fishery even after clear passage had been obtained up the Entiat.

Despite differing opinions on the historical abundance of salmon and steelhead in the Entiat Watershed, the quantity and quality of instream and riparian habitat has clearly declined over the last 100 years. While specific quantitative data is relatively scarce, it is clear that resting pools, LWD and riparian vegetation have all declined significantly. Steam morphological variables including width, depth, substrate and sinuosity have perhaps changed comparatively less over the years. Taking into account the broad scope of historical changes in the lower Entiat River Valley and the new push for stream restoration and salmon recovery, the overall potential for steam rehabilitation deserves some mention. After all, what is the potential abundance of riparian vegetation in the lower Entiat? What about stream sinuosity, pool abundance and LWD? The answers to those questions do not come easily, as the lower Entiat is a diverse landscape that varies greatly in terms of valley and channel width, bankfull elevation, riparian zones and similar terrain elements.

In general terms, the variability of a Type F stream is not high, simply because of its high entrenchment and moderately high width-to-depth ratio. Using the Rosgen (1994) classification system, a basic range can be established. Essentially, a Type F stream has little room to vary with the exception of slope and channel material. Some researchers contend (NRCS 1998) that the historical pattern of the lower Entiat is more analogous to a Type B and/or Type C stream. Type B and Type C streams are less entrenched and have a higher sinuosity and pool system compared to Type F streams. What this means in terms of actual numbers is difficult to determine. The NRCS (1998) calculated what a natural/preferred stream system might look like as far as pool features and found that the lower Entiat should have around 100 large pools that would be created and maintained mostly by the presence of LWD. In terms of riparian vegetation, if we accept the highest quantity by river mile regardless of year, a total of around 193 acres is achieved, which is the equivalent of a 75-foot wide average riparian buffer along each side of the lower Entiat. Because of its relatively steep profile and narrow valley width, the lower Entiat may not have differed greatly in terms of sinuosity. In fact, many present-day reaches of the lower Entiat would be classified using the Rosgen (1994) system as having moderate to high sinuosity. High entrenchment rates, the steep gradient and the narrow valley may also weaken the theory that a broad riparian floodplain lower extended very far laterally across the valley. In terms of LWD, it is probable that the

Entiat would have been influenced greatly by woody debris, which would have also created and maintained a variety of pool and instream habitat features. The massive decline in pool abundance between the 1930s and the 1990s is at least partially explained by decreases in LWD (NRCS 1998).

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Before discussing the resource management implications of this research, it is important to recap the key results as follows:

Conclusions

- Older photographs and documents dating prior to 1945 illustrate localized, but intense alteration to parts of the Entiat River including removal of riparian vegetation, logging, floodplain encroachment, streamside development and impoundments (dams).

While these events certainly shaped the Entiat, such changes are difficult to quantify. However, since the lower Entiat appears to have changed little from 1945-1998, most changes to the lower Entiat must have occurred prior to 1945. Realistically, it would be difficult to imagine that any large-scale anthropogenic stream changes (e.g., meander removal, dredging, intensive channelization, etc.) took place pre-1945 simply because of the enormous monetary expense to non-federal agencies, lack of technical support and the absence of historical documentation or on-the-ground evidence. Although certainly the cumulative impact of logging, damming, agricultural expansion and other land uses probably resulted in significant change along the lower Entiat.

- Historical land use prior to 1945, especially lumbering and its associated infrastructure such as dams, likely caused the most severe damage to the lower

Entiat River in the form of direct channel change along with alteration to flow and sediment dynamics.

Most of the intensive and highly damaging logging practices including dams and the log drives ceased by the 1930s and certainly by 1945, although lasting ramifications likely linger to this day in the form of altered sediment dynamics, stream morphology and lack of large woody debris.

- The lower Entiat River was impacted by major flood events in 1894 and 1948. Smaller flood events in the Entiat River along with more localized flooding in tributary streams and normally dry canyons have resulted in periodic damage to property and infrastructure in the watershed.

Flood events can increase sediment loading, alter the movement and distribution of spawning gravels and LWD, and influence local channel configuration in terms of width, depth, shape and bed composition. Despite these realities, it is unlikely that flooding has occurred at a frequency or scale sufficient to cause noticeable changes in riparian vegetation or channel morphology in the lower watershed. Large flood events can dramatically impact instream habitat features and spawning and rearing conditions, severely limiting the viability of aquatic populations, but few long-term ramifications usually result.

- The USACE did not play a large role in the construction of new flood control works in the lower Entiat River Valley.

It appears that all USACE construction activities were repairs to pre-existing features built by individual landowners and perhaps aided (financially and technically) by the SCS. These pre-existing flood control works amounted to over two miles of levees and bank protection. Specific details regarding the time of construction and other characteristics such as height, length and material is generally lacking. Given the fact that agricultural activity dominated the lower Entiat Valley starting in the early 1900s and the area suffered a major flood event in 1894, it is probably fair to assume that much of the lower Entiat contained flood control works long before the flood of 1948. In fact, annual flooding was probably the impetus for most flood control work, not the rare and infrequent large flood events.

- The lower Entiat River was not dramatically altered between 1945 and 1998 in terms of riparian vegetation and channel morphology.

Riparian vegetation and stream sinuosity are virtually identical between the two time series, with only minor spatial differences. Aerial photographs, ground photographs and documentation from the USACE and other agencies do not support the theory that large-scale flood control projects were undertaken by the USACE or any other entity post-1945. Clearly some human alteration in the form of LWD removal, road construction, agricultural activity, logging and the construction of Rocky Reach Dam has impacted the study area since 1945.

- The overall restoration potential of the lower Entiat River may be relatively low because of its high gradient (entrenched) form and the fact that sinuosity and riparian vegetation may not have differed greatly from current numbers.

However, scientific documentation notes a dramatic loss in stream pools and a drastic decline in salmon and steelhead numbers over the last century. Despite this, there is still the potential to reestablish a more nature pool-riffle sequence and to place LWD within the stream to help form and maintain pool and other habitat. Riparian vegetation can also be increased to at least some degree along the lower Entiat.

- Concern for the state of the Entiat River fishery extends as far back as the early 1900s as evidenced by fish ladders constructed in many dams and the activeness of local sportsman's groups.

Greater emphasis began in the 1930s as fish surveys were completed and sportsman began to call for more protection and stream restoration. Recent restoration initiatives and the new focus on salmon and steelhead recovery at the local, state and federal level has resulted in important research, additional funding and a receptive public. Landowners and the general public also appear to be generally supportive of habitat recovery efforts.

- A major obstacle to the recovery of Entiat River salmon and steelhead is the fact that returning fish have to traverse eight large hydroelectric dams on the mainstem Columbia River before they enter the watershed.

Until the broad regional issue of dams and their impact to aquatic resources is adequately addressed, most habitat improvements in the Entiat will not be sufficient to bring back salmon and steelhead populations to sustainable levels. A sustainable population means that their long-term survival is no longer threatened by extinction and may possibly be marked by resumption in the cultural and/or recreational harvest of the species. Local habitat improvement efforts will, however, improve conditions for resident fish and other aquatic/terrestrial species and should still be pursued wherever possible.

- This research clearly supports the notion that historical preservation is an important component for managing resources and every effort should be made to protect the historical record of yesterday for the people and natural resource issues of tomorrow.

The historical record includes such items as photographs, written documentation, reports, personal interviews, maps, surveys, scientific samples and historic structures. Local libraries, historical societies, governmental agencies and museums are the ideal lead entities in this pursuit and should make their collections accessible to the general public.

- Similarly, it is also obvious that many impacts to the Entiat River predate most historical records.

At best, only a handful of photographs, personal accounts and other records typically remain to explain an important segment of the region's history. This is especially true in smaller watersheds such as the Entiat where cycles of boom and bust and low population totals hampered the retainment of accurate historical records.

Management Recommendations

The following management recommendations are an important final component of this study. This is where the results meet reality, hopefully leading to well-informed and practical management recommendations that have a realistic chance of successful implementation. The following recommendations benefit from the research contained herein and lend support to the natural resource decision-making process by specifically addressing management scenarios and restoration steps. The following recommendations will ultimately benefit all of the Entiat River Watershed's inhabitants if implemented properly:

- Limit streamside development along the Entiat River.

This recommendation is twofold. First, restricting development allows riparian vegetation and stream channel processes the freedom to operate in a more natural manner. Second, limiting development in flood-prone areas is simply good public policy that limits private, local, state, and federal fiscal and emergency responsibility during catastrophic flood events. Property owners maintain a vested right to build on their land and/or continue their current use, but land use regulations and zoning should promote larger parcels and lighter density along the Entiat River and its floodplain. Stream buffers and setbacks, along with large parcel zoning (low density) will go a long way towards allowing natural channel processes to operate freely.

- Encourage landowners to plant native riparian vegetation along the Entiat River. Over 75% of the riparian habitat available to salmon along the lower mainstem of the Entiat is privately owned (NMFS 1998).

Riparian plantings will increase shade along the Entiat River and eventually supply LWD to the stream. Several riparian restoration projects have already taken place along the Entiat, with initial efforts focused in the prime spawning habitat grounds, outside of the study area (CCCD 2002). To encourage plantings, technical advice and tree plantings should be made available free or at low cost to landowners. The logical lead agencies in this effort would be the CCCD and the NRCS. The Washington State University Cooperative Extension Service also has a long-standing tradition of assisting agriculturalists in the region, mostly through technical expertise and educational services. Each of these entities has an established relationship with area farmers and landowners and do not carry the stigma that other more heavy-handed state and federal regulatory agencies may have.

- Along with planting native riparian buffers, landowners should be encouraged to implement Best Management Practices (BMPs) through a farm management plan to limit surface runoff, soil erosion and water pollution.

Examples of BMPs include the planting of cover crops in agricultural fields, maintaining or creating vegetated buffers between streams and residential/agricultural uses, fencing livestock out of wetlands and riparian zones and using measures to contain erosion and limit additional stream sedimentation and bank erosion. BMPs are low cost, relatively simple measures that cumulatively can play an important role in restoring the watershed. All applicable management agencies should already have lists and pamphlets regarding BMPs that can be easily distributed to landowners. Local workshops held by regulatory agencies would help get the word out and provide technical advice.

- The private sector is encouraged to continue its impressive work in the Entiat Watershed, which has included the promotion of conservation practices and environmental protection.

Specifically, the Chelan-Douglas Land Trust has been very active in the Entiat Watershed and has received large grants from the Washington State Salmon Recovery Funding Board to purchase and restore land along the Entiat. Over 300 acres of critical habitat, containing more than three miles of riverfront property along the middle Entiat, has been protected thus far. While direct purchase of land is an important component of conservation objectives, conservation easements and other less expensive options may be capable of protecting more habitat long-term and providing just as many benefits to salmon rehabilitation/stream restoration efforts. Conservation easements adjacent to the Entiat River provide an excellent opportunity to establish riparian buffer corridors, replant native vegetation and allow the Entiat River to migrate more freely.

- Land trusts and conservation groups are encouraged to purchase land and/or easements in the lower Entiat River.

To date, most focus has been in the “Stillwaters Reach” of the Entiat, which starts approximately six miles above Ardenvoir near river mile 16 and contains prime spawning grounds. Although the spawning grounds are critically important and should be protected, focusing entirely on them makes it easy to lose sight of other pressing conservation needs. Salmon and steelhead require sufficient habitat conditions in the lower Entiat in order to ascend to the Stillwaters Reach in the first place. Further, young salmonids spend the majority of their rearing time in the lower Entiat and require suitable habitat conditions including LWD, deep pools and shade, all of which are sorely lacking in the lower river. Protecting the Stillwaters Reach of the Entiat River is of critical importance, but focusing only on this reach will not, in and of itself, adequately restore aquatic resources. A holistic long-term management and land acquisition plan must include the direct purchase of land and/or obtainment of conservation easements in the lower Entiat River, otherwise the goals of stream restoration and salmon recovery may never be fully realized. There may be limited opportunity for easements in the lower Entiat River as much of the land is used for commercial agriculture. On the other hand, many single-ownership large parcels are still present and have the potential for conservation easements.

- Revisions in the Chelan County Code, Comprehensive Plan, and Critical Areas Ordinances may be necessary to ensure that new growth is consistent with current natural resource values.

While current agricultural activity would likely be “grandfathered,” new residences and farmsteads should be required to comply with adequate protective buffers and setbacks that are based on the best available science. Agriculturalists and landowners should be made fully aware of existing Chelan County tax programs such as the Open

Space Tax Program and the Public Benefit Rating System that provide incentives for property owners to conserve and restore land. Agricultural activity should be highly encouraged by current regulations so that large expanses of land remain intact and under single ownership.

- Continue the process of providing instream habitat features such as LWD and rock weirs, which create pool habitat and resting/rearing areas.

These types of habitat structures are relatively inexpensive to build and can have a dramatic impact on survival rates for rearing and migrating salmon and steelhead, along with resident fish such as trout. Rock weirs and LWD have been placed in the Entiat in several locations, with initial efforts starting in 1997 (CCCD 2002). It is unlikely that any of the completed restoration efforts impacted the results of this research, simply because the size and scope of the projects have been quite small and for the most part, occurred out of the study area. Stream complexity can be at least partially restored by introducing LWD back into the stream or by constructing artificial structures that serve as surrogate to natural stream obstructions (Sullivan et al. 1987). It will be decades until large woody debris and other instream features such as pools and riffles start to form naturally, so these artificial structures can play a key role in the interim.

- Large-scale restoration efforts in the form of restoring side channel habitat, establishing artificial meanders, purchasing large tracts of land, propagation of hatchery fish, or other evasive, lengthy and/or expensive stream restoration measures may not be needed in the Entiat.

Instead, intensive small-scale and localized initiatives to restore and maintain LWD, pools and riparian vegetation should be the preferred restoration and management option. Economists use the term "diminishing returns" to describe the point at which the return on an investment is disproportionately low when compared to the expenditure involved (e.g., time, money, effort). Similarly, stream restoration can be thought of in terms of a "return on investment," keeping in mind cost-effectiveness, efficiency and long-term expenditures. Using this approach in the Entiat to evaluate and implement restoration projects will help to ensure that resource managers get the most for their money over the long run. Expensive management options may not be the most beneficial long-term solution, compared to many of the more simplistic and inexpensive stream and riparian zone improvements discussed above.

- Finally, acknowledge that past human-induced impacts especially flood control efforts, logging/sawmill activity and dams, along with agricultural activities, have affected the Entiat River in ways that can never fully be mitigated.

Humans are a part of the environment and it is unrealistic and infeasible to assume that the Entiat River will ever return to a "pre-contact" ecological state. The historical land use and development pattern of the Entiat Watershed should be understood, embraced and remembered. Logging, grazing, dams, agricultural development, and flood control have all helped shape the people and landscapes of the Entiat. Stream restoration and management efforts must recognize these historical patterns and work to reach a balance between today's values and yesterday's dreams. The complete historical land use history of the Entiat, or the countless ways in which humans have and continue to alter the watershed, will never be completely understood. This, however, is not to say that restoration efforts should not be pursued or that they are hopeless. Those who manage, work and live in the Entiat must strive to create and maintain a system that takes into account human impacts to natural resources, mitigates them whenever possible and seeks to correct past wrongs that have been compounded through time, ignorance and mismanagement.

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