RETURN TO THE FLOODPLAIN: THE ROLE OF BEAVERS (CASTOR CANADENSIS) IN RESTORING CHANNEL COMPLEXITY AT WASSON CREEK

by

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A THESIS

Presented to the Department of Environmental Science and the
Robert D. Clark Honors College of the University of Oregon
in partial fulfillment of the requirements
for the degree of
Bachelor of Science

August 2004

An Abstract of the Thesis of

Sarah Marie Marshall for the degree of Bachelor of Science

in the Department of Environmental Science to be taken August 2004

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Approved: APPROVED: [redacted]

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During the study, Wasson Creek over-topped the banks of the main channel at the two stage- recording sites in response to a 6-10-year storm event. Following the event, the floodplain above the two largest beaver dams and around dams in a shallower, narrower secondary channel remained inundated for most of the study period. Despite minimal change in the path and sinuosity of the main channel over 65 years, beaver activity has altered water movement on the floodplain—particularly in areas where beaver dams cross the floodplain, beavers excavated channels on the floodplain, and flows were re-directed into a smaller, secondary drainage ditch. Given the high level of beaver activity on the floodplain (17 actively maintained dams) and suitable habitat, we can expect beavers to remain in the system—further creating a new complex of channels and wetlands on the Wasson Creek floodplain. Human intervention may be necessary to control reed canary grass (*Phalaris arundinacea*) and other invasive species.

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Janet Hodder

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ACKNOWLEDGEMENTS

So many wonderful people have entered my life as a result of this study. First, I am grateful to Jan Hodder, who introduced me to the South Slough NERR and the possibility of research on the southern Oregon Coast. Jan, who served as my primary advisor, provided feedback, support, and assistance from day one. Help from Craig Cornu, the stewardship coordinator at the South Slough, also made much of this study possible—including giving me the first tour of Wasson and Anderson Creek, listening to my ideas and providing feedback, sharing his knowledge about the South Slough, spending hours in the field setting up water level loggers with me, organizing the lower Wasson Creek elevation survey and reviewing drafts of this report.

Also at the South Slough, Sue Powell not only helped me acquire NOAA OIMB gauge data sets for the duration of this study, but was always there for support. In the final stretch of this project, Steve Rumrill's willingness to fill in as my secondary advisor literally saved my defense, and I cannot thank him enough.

In the field, assistance from Beth Tanner, Lea Goodrich, Alicia Omlid, and Brad Schallert was greatly appreciated—keeping me company on several rainy days and providing a helping hand. Special thanks to John Colby for meeting me on a November morning in the field to discuss the hydrology of the Wasson Creek basin, reviewing early parts of this study, and helping me obtain information and aerial photos for Deton Creek. I thank Bob Mahaffey and his wife for giving me a tour of their land at the Deton Creek site one very rainy day in November.

Last but not least, I wish to thank my support network at home. Both my parents and my friend Neil McCoy were especially helpful in reviewing the final drafts of this report. Also, on the U of O main campus, I thank Dennis Todd, my HC representative, for all of his cooperation and support in the final stretch of finishing my defense and final drafts.

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I. INTRODUCTION

Beavers have always fascinated me in their ability to rapidly transform the landscape—creating a diverse array of habitats and hydrologic conditions that we, as humans, could only hope to replicate in restoration projects. Using only what is available to them in the region immediately surrounding their home stream, beavers engineer incredibly durable structures often capable of withstanding high and variable water pressure, animal and human foot traffic, and weathering over time.

In this study, I have set out to document the relationship between beavers and stream hydrology at Wasson Creek, a degraded stream in the South Slough National Estuarine Research Reserve (SSNERR). Over the course of a year I observed conditions and changes to the channel and floodplain at Wasson with the hope of determining whether beaver activity alone can restore channel complexity at the site. With the restoration goal of returning Wasson Creek to a more sinuous, dynamic channel having greater interaction with the floodplain in mind, I evaluated beaver activity and hydrology using flooding frequency, the current floodplain layout, channel structure, and analysis of historical data for the region.

Ideally, my findings will help the South Slough NERR managers assess how much human intervention is necessary to achieve the goal of a more sinuous and dynamic channel that reflects the un-ditched state of Wasson Creek. Additionally, passive restoration at Wasson Creek, if successful, would provide a case study for landowners and land managers of other coastal watersheds like Wasson Creek. If beavers, which are present in many of these coastal stream systems, have the potential to catalyze the transition from a drainage ditch to a more structurally diverse meandering stream, then passive restoration could potentially be a more feasible, less costly option than active restoration measures in many coastal valleys.

Site History

The South Slough watershed, an 8,100 hectare (20,000 acre) sub-basin of the Coos watershed (Figure 1) has been altered by logging, agriculture, mining, and other human disturbances dating back to the early 20th century. Wasson Creek, which drains into the southernmost branch of the South Slough via the slough's main tidal channel, Winchester Creek (Figure 2), is one of many altered coastal streams that was historically straightened and dredged for agricultural purposes. Such channel simplification is one of a series of human activities in Oregon's coastal watersheds that have resulted in a reduction of riparian habitat and species diversity (Hudson and Heikkila, 1997; Reeves et al., 2002).

The earliest aerial photos on record for the region indicate that by 1939, Wasson Creek was re-routed into a series of linear drainage ditches along the margins of its former floodplain. Over time, Wasson Creek has cut further into its channel bed and steepened its banks through erosion. Since its initial alteration for agricultural purposes, the lower Wasson Creek floodplain has remained relatively undisturbed by human activity—including restoration work. If we compare aerial photos from 1939 and the present, there has been little change in the location of the main ditch and plant cover on the floodplain over the span of 65 years (Figure 3). As a result of such static conditions in what should be a relatively dynamic system, many of the habitats and processes that may have occurred on the floodplain prior to European settlement, such as a mosaic of wet meadow, wooded wetland, open water and shrub swamp habitats (Guard, 1995) and seasonal flooding, are now either fragmented or absent.

In 1974, the South Slough estuary became the first National Estuarine Research Reserve, which changed the focus of land management from natural resource extraction and farming to restoration, education, and research. Currently, land managers at the South Slough NERR are assessing what measures should be taken to restore Wasson Creek.

Restoring Wasson Creek

Restoration is often defined as the re-establishment of diverse ecosystem structure and function(s) in a disturbed or degraded landscape (Cairns, 1988; National Research Council, 1992; Williams et al., 1997). Ecosystem structure refers to components like stream channel shape, dams and other in-stream debris, and plant community composition corresponding with different habitat types on the floodplain. Ecosystem functions at Wasson Creek include processes like seasonal flooding, retention and filtration of water and sediments in floodplain wetlands, and successional changes in the biotic community.

Stream and wetlands restoration is a holistic approach to recovering a degraded system and must take into account ecosystem-wide processes and components rather than simply targeting isolated elements (NRC, 1992). Planning for a restoration project requires investigation of the natural processes, structures, and species that are currently present and would have historically occurred on a site (Ebersole et al., 1997). Though we cannot replicate or bring back the full range of historic processes and components once found at Wasson Creek, we can attempt to restore ecological processes necessary to the recovery of habitats and biological communities adapted to historic site conditions (Ebersole et al., 1997; Reeves et al., 2002).

Once a site's history and current status have been researched, a restoration plan can be developed. A restoration strategy for Wasson Creek could potentially involve an active, passive or a combined approach. Active restoration at Wasson would most likely entail using heavy equipment to fill in the incised ditch where necessary and then re-creating a meandering channel on the floodplain. Anderson Creek, adjacent to Wasson Creek, is an example of an active restoration project (Figure 4). At Anderson Creek, old drainage ditches were filled and stream flow was diverted into reconstructed complex stream channels. Large woody debris was then placed in the new channels and native trees, grasses, and shrubs were planted on the floodplain. Following initial active restoration work, land managers at the South Slough are letting nature take its course at Anderson and monitoring the progress.

A purely passive approach to restoring Wasson Creek would allow the system to recover on its own while being monitored, and would eliminate the need for substantial human intervention. Since the agricultural activity that led to Wasson's degraded state is no longer present, in-system components and processes (i.e. beavers and flooding) would be left to alter the current shape of the Wasson Creek ditch and return the stream to a more natural, sinuous state.

Mitsch and Gosselink (2000) suggest some general principles that may be adapted to help frame a restoration plan for Wasson Creek:

1. Plan for a system that can maintain itself in the long-run. This includes the use of existing ecosystem components (i.e. beavers, native plants, soil, and site hydrology) whenever possible.
2. Use existing processes and forces (such as a stream's potential energy and flooding) to accomplish restoration goals when possible.
3. Natural disturbances, as well as the hydrology and ecology of a site should be included in any restoration plan. Though the timing and scale of disturbances like floods cannot always be predicted, systems can generally recover and benefit from these "re-setting" events.
4. A restoration plan should have many goals, but a hierarchy consisting of one primary goal, followed by several secondary goals is useful.
5. Riparian and wetland habitats are ecotones, or interstitial habitats between a stream and an upland area, and this should be factored into the planning process.
6. A long-term time frame is essential. Recruitment and establishment of native species, development of soils, and stabilization of a stream channel are all processes that require time and patience.
7. Function should be prioritized over form. The success of a project will be, in part, determined by whether or not its main objectives, such as the reestablishment of critical processes like flooding, have been met.
8. Refuse the urge to over-engineer a system. Forms and structures should mimic and complement natural and historic systems.

According to this framework, a passive (or "hands-off") approach to restoration at Wasson Creek would leave beavers to develop the site over time, with the assumption that flooding, sediment impoundment in the ditch, excavation of new channels on the floodplain, and wetland creation resulting from their damming and other activities could lead to the accomplishment of several key goals. If the establishment of a new meandering channel and wetlands on the floodplain in place of the current ditch is a primary goal at Wasson, beaver dams may continue to 1) move water onto the floodplain and 2) create additional in-channel debris and sediment traps that will gradually fill in much of the existing ditch in the long-run. Secondary goals might include the restoration of habitat and species diversity on the floodplain and flooding out some of the non-native and invasive species like pasture grasses and reed canary grass (*Phalaris arundinacea*).

A combined active-passive restoration approach would involve many of the same goals and using site elements like beavers and seasonal flooding to restore Wasson Creek, but could include the addition of human intervention where necessary—particularly in areas where the channel is deeply incised and there is little beaver activity and where there is a high concentration of invasive species like reed canary grass and Himalayan blackberry (*Rubus discolor*). Some of the most incised portions of the stream channel, as observed in the lowest section of the floodplain, could be filled with sediments excavated to form a new channel on the floodplain, large woody debris could be added to the new channel (as seen at Anderson Creek), and disturbed areas could be replanted with species like alder (*Alnus rubra*), willow (*Salix spp.*), small-fruited bulrush (*Scirpus microcarpus*), and slough sedge (*Carex obnupta*).

Beavers as Restoration Engineers

Regardless of whether a more passive or active restoration approach is adopted at Wasson Creek, beavers will likely continue to be the predominant natural disturbance in this and other similar watersheds along the Oregon Coast. Of the estimated 70,000 beavers in Oregon, about half reside in Oregon's coastal watersheds, where they can successfully colonize lower order (1st-5th) streams (Naiman et al., 1986; Guthrie and Sedell, 1988; Suzuki and McComb, 1998).

Beavers are considered riparian obligates and a keystone species because of their active alteration of the surrounding biological and physical environment (Naiman et al., 1986; Jones et al., 1997; Hayes and Hagar, 2002). Jones et al. refer to beavers as "physical ecosystem engineers" in their ability to change aquatic landscapes such that overall structural and functional habitat diversity is enhanced (1994; 1997). Through dam construction and foraging, beavers significantly affect local surface and groundwater levels, stream channel form, retention of sediment and organic material, nutrient cycles, and the diversity and growth of streamside and wetland plants (Naiman et al., 1986).

In the absence of beavers, few natural disturbance agents are capable of transforming or restoring complexity in a stream channel over such a brief period of time. If we place their activity into a restoration context, beavers may be able to re-instate processes like stream channel adjustment, seasonal interaction between the stream and its floodplain, and the creation of diverse habitat types in a degraded system like the Wasson Creek watershed. In a sense, some of the positive impacts of beaver disturbances—including an increase in species richness in response to newly available habitats, extent and occurrence of processes like flooding and lateral migration of stream channels, and overall productivity on the Wasson Creek floodplain—may reverse some of the negative effects of previous human disturbance.

The key to understanding why and how beavers can dramatically alter aquatic landscapes like the Wasson Creek Valley is in basic beaver ecology. First of all, beavers are awkward on land, but anatomically well-adapted to the aquatic environment. On land, poor eyesight, body shape, and a large tail make beavers more vulnerable to predation (Hilfiker, 1991). In water, webbed hind feet, a dense, water-tight coat, adjustable metabolic rate, and high lung capacity all make locomotion and other submerged activities highly efficient (Warren, 1927; Hilfiker, 1991; Muller-Schwarze and Sun, 2003).

For beavers, damming and other earth-moving activities are often necessary to create a network of canals, pools, and other water passageways that facilitate safe movement and provide sufficient space and routes for food transport (Mills, 1913). By definition, a dam is used to collect water during higher flows and thus create a reservoir for periods of lower flow (Leopold, 1995). At Wasson Creek, beaver dams generally retain water during the winter months and then store it during the drier spring and summer months. Usually, dams buffer the surrounding stream system against abrupt changes in water level following storm events and increased base flow in a stream as water is slowly metered out (Leopold, 1995).

Depending on storage capacity and integrity, a human-made dam can potentially retain over 95% of sediment that reaches its upstream edge (Leopold, 1995). Beaver dams often function like human-engineered dams in retaining large quantities of sediment, but are far more dynamic in nature (Middleton, 1999). As observed at Wasson Creek, beaver dams are highly variable in their permanence and degree of maintenance. While some dams may persist for years and retain large volumes of sediment, others are washed out during periods of high winter flows and then reconstructed in the spring, summer, and fall. At times, dams may be abandoned altogether if a beaver colony relocates to another activity center or area where food and dam-building materials are more abundant.

In addition to introducing and retaining large woody debris in streams, beaver dams of all sizes and levels of maintenance trap coarse particulate organic matter (CPOM) like sticks and leaves along with sediment, which provides habitat for aquatic invertebrates and vertebrates (Gorshkov, 1999; personal observation). A single beaver's work in a coastal stream can result in the annual accumulation of several tons of woody debris (Maser and Sedell, 1994). At Wasson Creek, low stream flows during most of the year facilitate debris retention in the stream. Still, fine sediment in the channel bed, abrupt peaks in stream level in response to storm events, and the absence of large logs at Wasson Creek may restrict when and how much debris can be captured (Allan, 1995).

With a dense composition of woody debris and sediment, most of the dams at Wasson Creek are strong enough to support human and even elk traffic. To obtain such strength to withstand the force exerted by a large volume of water in pools upstream of their dams, beavers must begin with a strong foundation. Most dam work occurs at night, and construction activity tends to increase during seasons like spring and summer, when there are longer periods of dry weather (Strong, 1997; personal observation). For beavers on a small stream like Wasson Creek, a dam may only take a few nights to build (Long, 2000).

Initially, beavers lay branches on the channel bottom, parallel to the stream current (Long, 2000). When available on-site, rocks or larger pieces of logs may be used to anchor foundation material. Once a foundation is laid, sticks, branches, sod, root balls and other plant material are interwoven to add strength to the structure. Though strong branches and dense, cohesive sediments like the silty clays found at the Wasson site are preferable, beavers are opportunistic in their use of material and incorporate everything from sedges and salmonberry branches to old drainage pipe into dams. Sediment is then used to patch holes in the dam and secure all material (Long, 2000).

Any additions of sticks and other debris are made from the upstream side of the dam. When the water level of an upstream pond increases, beavers respond by adding new layers at the dam surface (Long, 2000). If water overtops a stream's banks and flows around the dam, beavers will extend the dam outward from the initial structure. At Wasson Creek, one dam (BD7) was extended for a total of 60 meters out across the floodplain (Figure 2).

Often, secondary dams built downstream of main beaver dams help to minimize the difference in water pressure on the upstream and downstream sides of a large dam (Strong, 1997; Long, 2000). Though this may seem like clever engineering, it is more likely a reflection of a healthy beaver colony, which through the availability of a large pond and abundant food resources has more builders available and a greater need to increase the number of safe water transit passages (Long, 2000). Where beavers are left undisturbed by human activities and excessive predation, habitat and food availability are the most determinate factors in beaver population size (Muller-Schwarze and Sun, 2003).

Beaver Activity at Wasson Creek

Currently, one or more beaver colonies occupy the Wasson Creek floodplain. As primary biological disturbance agents on the site, beavers have begun to significantly alter the stream channel as well as the surrounding floodplain by constructing a series of dams and creating ponds throughout the Wasson Creek ditch. The resulting sediment accumulation in pools behind the dams, in concert with the beavers' continual maintenance of dams, access channels, and plunge holes (tunnels that allow an escape route from foraging areas on the floodplain to the main channel; Figure 5), has led to a number of transformations in the shape and path of the ditch—particularly where dams extend out across the floodplain.

In these areas, a significant portion of the stream flow above the dams is redirected onto the floodplain over which it once meandered, especially during the winter months when stream flow is the highest. Downstream of a large beaver dam, altered stream flow patterns often lead to bank erosion and lowering of the channel bed (Leopold, 1995). As a result of downstream channel degradation and upstream aggradation of sediments, a stream's overall competence, or ability to transport sediment, is reduced around a dam (Leopold, 1995).

Through dynamic channel bed aggradation and degradation at Wasson Creek, beaver activity may be sufficient to, over time, help restore diversity and complexity to the entire degraded stream channel and floodplain. As anecdotal evidence, we can look at landscape alteration resulting from approximately 30 years of beaver activity at Deton Creek (Figure 6), another Coos Watershed tributary with a floodplain of comparable size to that of Wasson Creek (Mahaffey, personal correspondence).

Since the time when the landowner stopped using the creek's floodplain for cattle pasture, beavers have created extensive networks of dams, plunge holes, and canals that have transformed the entire floodplain into a terraced marsh filled with small islands and willow thickets. Deton Creek courses through the marsh, constantly recharging the water supply, with its main flow located in a wide, shallow channel along the valley edge. In addition to beavers, the overall structural diversity at Deton Creek provides a patchwork of habitats suitable for a number of marsh birds, salmon, amphibians, elk, and deer.

The beavers at Wasson Creek have been working to transform the floodplain since at least 1986. When Stone conducted an inventory of Wasson Creek (which he named "Theodore John Creek") between June 1 and September 20, 1986, he documented 15 beaver dams between the Wasson Creek/Winchester Creek confluence and where Wasson Creek crosses the floodplain (Figure 2) and 33 dams in the entire Wasson Creek drainage (Stone, 1987). Stone noted that from around 600' (~183m) upstream of Winchester Creek, he encountered a large freshwater marsh with grasses up to 6' (1.83m) in height—consistent with current conditions on the lower Wasson floodplain, where reed canary grass (*Phalaris arundinacea*) is the dominant plant cover (Stone, 1987). From that point on, he remarked that "beaver dam after beaver dam after beaver dam, water was not moving" and that beavers occupied such a large portion of the Wasson Creek valley that it was best left as it was (Stone, 1987).

Since Stone's report was published, one of the dams obstructing the northernmost culvert at the mouth of the Wasson floodplain was removed in spring, 1991 (Mike Graybill, personal communication; Figure 2; Appendix A). This practice is not uncommon, as beavers are notorious for using water control devices as a foundation for dams (Middleton, 1999). During this study, the old road and culvert were obliterated, but the beavers have yet to return. With the exception of dams 0 and 0.1, which are around 120m and 140m upstream of the former road, and were built in spring, 2004, there is still minimal beaver activity here.

II. STUDY AREA AND METHODS

The study was conducted in the Wasson Creek watershed (43°16'N, 124°19'W) of the South Slough National Estuarine Research Reserve, Coos County, Oregon between fall 2003 and summer 2004 (Figure 1). Elevation at the site ranges from sea level to 12m on the lower floodplain and to 171m at the highest point in the Wasson drainage. Wasson Creek, a 2.15km long tributary of Winchester Creek, is a precipitation-fed, third order stream in the Coast Ranges physiographic province (Franklin and Dyrness, 1988). Average annual precipitation for the Coos County region is 163.9cm, with 71.9% of rainfall occurring between November and March (Oregon Climate Service, 2004). Extreme fluctuations in temperature are rare in this coastal climate, with average annual mean high temperatures of 15.5°C and annual mean low temperatures of 7.5°C (Oregon Climate Service, 2004).

Soils on the Wasson Creek floodplain are primarily in the Nestucca silt loam group, characterized by a surface layer of silt loam overlying layers of silty clay, and respond to precipitation with relatively slow water permeability and runoff, and frequent winter flooding—all of which can be observed at Wasson Creek (USDA Soil Conservation Service, 1989). When used for hay or grazing livestock, as this site was historically used, the surface layer of these soils is subject to conditions like summer drought, winter flooding, wetness, and overall compaction—resulting in limited root growth for plants and overall compromised soil productivity (USDA Soil Conservation Service, 1989).

Seasonal soil saturation and standing water on the floodplain limit flora to primarily wetland plants. Vegetation on the floodplain is dominated by grasses, sedges, Creek, just before it crosses a former road, we can observe conditions with minimal current beaver influence.

To measure current conditions and predict future outcomes, I focused the majority of my field work on the lower and middle, transitory section of Wasson Creek. The three major objectives in the field component of this study were to: 1) Determine the location and frequency of over-bank flow in the Wasson Creek floodplain relative to a range of precipitation events; 2) Map and record stream channel patterns and the fate of over-bank flow on the floodplain; and 3) Describe and quantify how and the degree to which the original agricultural ditch has changed through time.

Determining Location and Frequency of Flooding with Respect to Precipitation

Recording Stream Stage

Between the autumn and spring seasons, watersheds in the Oregon Coast Range receive the majority of their hydrological input via precipitation. At the scale of Wasson Creek, rainfall events should roughly correlate with increases in both discharge (volume of water/ unit of time) and stream depth. By having a eight-month record of stream level during this study, I could link the current water year with the corresponding precipitation record and channel form in order to understand a) how beaver-dammed channel reaches react to precipitation events and b) what quantity and duration of precipitation are necessary for water to leave the Wasson Creek channel and spread out onto the floodplain.

Stage, or relative stream depth, was recorded at two points along Wasson Creek using data from two Global Water Instrumentation© WL15 water level loggers. The first logger (W.L.L.1) was located midway up the Wasson Creek floodplain between two of the largest dams in this study area (~40m upstream of BD5 and ~20m downstream of BD6—see Figure 2; Appendix A for dam and sensor locations) in an area with intensive beaver activity and water levels not exceeding bank full in the first six weeks of the 2003-2004 water year (October 1-November 11). The second logger (W.L.L.2), downstream, was located ~70m above BD1 and ~100m below BD2, and on the inside of a slight bend in the stream channel.

Each logger, or gauge, comprised an in-stream pressure transducer (converts pressure exerted by a given volume of water into relative stream depth) connected to a data logger above the water by a cable (Figure 7). Gauges were housed inside PVC schedule 40 pipes with 90 degree electrical conduit sweeps protecting the sensors at their base. Fence posts, tied to each pipe with wire, anchored the equipment 0.5-1m deep in the channel sediments. Both setups were secured to the stream bank using several bent rebar staples. A survey was conducted to establish elevations of water level logger placement and elevations required to exceed bank full at each recording point.

W.L.L.1 recorded stream level at 30-minute intervals from November 14, 2003 to July 2, 2004. W.L.L.2 recorded stream level from January 9, 2004 to July 2, 2004 at 30-minute intervals. Data were periodically downloaded from the loggers in the field and then analyzed using Global Logger and Microsoft Excel software.

Precipitation Data

The majority of hydrologic input into the Wasson Creek watershed comes from rainfall, which often leads to soil saturation, overland flow, and peaks in stream flow and level that drive many important geomorphic processes in the watershed (including chemical and physical weathering, initiation of mass movements, sediment transport, erosion and flooding). The precipitation record is a useful tool in understanding how these hydrologic processes are manifested on a beaver-impounded floodplain. Knowing what sort of precipitation event will potentially cause water to top the banks in a) areas of heavy beaver activity and b) areas of lower beaver activity can help us to understand how the beavers at Wasson Creek are influencing their immediate floodplain surroundings and the potential for diversion of water from the ditched base channel.

In order to relate stream stage data from this seven-month study to concurrent and past precipitation trends and predict the frequency of precipitation events that cause bank-topping flows on various sections of the Wasson Creek floodplain, I used real-time continuous precipitation data from the NOAA atmospheric monitoring station on the Oregon Institute of Marine Biology (OIMB) campus for analysis. The NOAA station is located approximately 8 kilometers from the Wasson Creek site.

In order to estimate the frequency of the large rainfall events that resulted in over-bank flow during this study, I analyzed the longer precipitation record from the North Bend airport (dating back to January 1, 1931), since these events should show up in comparable magnitude on a regional scale while smaller precipitation events are often variable across this landscape due to factors like topography. From all of these comparisons, I attempted to place the events at Wasson Creek during this six-month study into a historical (and future) context.

Measuring Stream Channel Patterns and Over-bank Flow

Lower Wasson Creek Survey

Understanding the morphology of the Wasson Creek channel and its associated floodplain is critical in both recording current conditions and predicting possible future responses to peak flow events and other disturbances. By constructing longitudinal and cross-sectional profiles of the lower Wasson Creek study area (from the former road to where the main Wasson Creek channel has crossed the floodplain since 1939, Appendices A, B and C), I attempted to quantify where, how, and to what extent beaver activity and other stream processes are leading to dynamic channel aggradation, erosion and initiation as well as place all other observations and measurements within the larger site context.

The elevation survey component combined data from a topographic survey conducted by a contracted professional surveyor in early May, 2004 with my own floodplain and channel bed measurements using a staff gauge, meter tape and compass. The surveyor provided assumed coordinates, based upon north-south and west-east axes, and corresponding elevations for points along fifty-six cross-floodplain transects taken at approximately 40' (12.2m) intervals. In addition to the cross-sections, I created three longitudinal transects from where the former road crosses Wasson Creek up to where the creek crosses the floodplain. Overall, the survey data, supplemented with my field measurements, provided a thorough elevation profile for the area covered in this study.

In-channel measurements at each cross-section allowed me to calculate bank-full width, bank-full depth at the thalweg (deepest part of the channel bed), and channel gradient using a combination of the surveyor's coordinates and graphs of the cross-sections in MS Excel. Bank-full height was calculated with respect to the left and occasionally the right bank of the main ditch and the right bank of the smaller channel located along the north end of the floodplain. Channel gradient was calculated across areas of high and low beaver activity, and for the entire length of the study area in both the main and secondary channel. Low beaver activity areas included the first ~410m of the main channel (survey cross sections 0+00-12+00) and the first ~230m of the secondary channel upstream from the Wasson Mouth (survey cross sections 0+00-7+60; Appendices A and B). High beaver activity (average dam density>2 dams/100m) areas extended up from the end points of low activity areas by ~304m in the main channel (survey x-sec. 12+00-21+50) and ~361m in the secondary channel (survey x-sec. 7+60-18+00).

Degree of channel incision at each cross section was calculated using bank-full width-to-depth ratios in the channel and entrenchment ratios. Since Wasson Creek courses a relatively narrow floodplain, entrenchment ratios were found using the floodplain width/bank-full channel width ratio. These calculations helped me assess where Wasson Creek is more or less capable of frequently topping its banks, combined with other factors like beaver activity. Calculations were field-checked through visual inspection of sediment deposition and matted or altered vegetation resulting from over-bank flow during the study period. Areas where the channel is deeply incised (and where Wasson Creek is limited in its ability to reach the floodplain) should have low width-to-depth and high entrenchment ratios and thus have a lesser likelihood of flooding.

Measuring Change in the Agricultural Ditch

Mapping

Beaver activity and erosion are two main forces that alter the shape of Wasson Creek. One goal of this research was to construct a map of the main ditches and channels that are in existence or currently forming on the floodplain to establish a baseline from which future change can be measured. Using this map, subsequent research can record changes in the extent of beaver activity, alterations in channel form, and the water level/ extent of water retention across the floodplain in response to a range of precipitation events.

In order to record the current path of the main channel and smaller channels forming on the floodplain (including those created by beavers), I used a topographic map created by a surveyor contracted by the SSNERR as a base map to trace water movement. Next, I transferred this information onto my own Wasson map and then supplemented finer-scale details such as the location of beaver dams, micro-channels and beaver plunge holes using cross-sections that I generated in Adobe Illustrator, using recent air photos, a meter tape and a compass. Using the map I generated and the surveyor's coordinates I also estimated the current sinuosity (S, where S=channel length/straight-line valley length, Knighton, 1998) and length of the main channels on the Wasson floodplain.

For the two widest dams in the study area, BD7 and BDH, I recorded depth profiles 1m upstream of the dams at 2m intervals along their entire span. BD7 was measured on November 10, 2003, starting on the south edge of the floodplain (Figure 8a), and BDH was measured on March 27, 2004, starting from the north edge of the floodplain (Figure 8b).

To analyze change in channel form and location of beaver dams and activity through time at Wasson Creek, I used aerial photos, taken by the USDA, BLM, Coos County, Oregon State Forestry, and USGS from 1939, 1955, 1962, 1991, 1999 and 2003, with the 1939 BLM set being the earliest photos on record for the Coos County region. The photos allowed me estimate sinuosity where channels were visible and unobstructed by extensive riparian vegetation, map any lateral migration of channels through time, and establish a timeline for beaver transformation of the floodplains where applicable.

Final maps included a main "plan view" map, overlays for stream change through time, three separate longitudinal cross-sections for the thalweg in the main ditch, the thalweg in the ditch along the north end of the floodplain, and the approximate center of the floodplain, and a series of fifty-six valley-wide cross-sections extending up the Wasson Creek floodplain to illustrate relative channel forms. Beaver dams and other prominent features were included on all maps as a reference.

Beaver Activity Monitoring

Beavers are primarily nocturnal in their feeding and construction and maintenance of dams; thus observation of animals in the act of dam maintenance at Wasson Creek is difficult during daylight hours (Muller-Schwarze and Sun, 2003). For the purpose of this study, monitoring where and approximately when beavers were actively maintaining dams and excavating channels was sufficient. All visible beaver activity was catalogued with photographs, measurements of dam dimensions where possible, and field notes, but study dams were limited to those that crossed the stream and presented a significant barrier to the downstream movement of water, evidenced by a hydraulic drop, or change in water level upstream and downstream of each dam.

To determine which dams were being actively maintained during this study, I staked pieces of 5mm diameter white nylon cord ranging from 0.75 to 2m in length (depending on how much cord was necessary to keep the downstream ends visible) at the points corresponding with where the main flow of the stream passed over Dams I-VII in the main Wasson channel. The first set of cords, installed in the fall, 2003, proved effective in indicating where beavers were adding new material to dams, but many were washed out with other material on the top layers of the dams during high winter flow events. On April 23-24, 2004, I installed new cords to monitor beaver dam maintenance through the remainder of this study on the dams in the main Wasson Channel and also on a large dam constructed on the opposite side of the floodplain in early spring, 2004 (BDH, Figure 2).

Cords were secured at the leading edge of each dam (where new additions of material are made) and then allowed to trail off the downstream side for visibility in case of coverage by sediment and plant material. When taking dam measurements or visiting the Wasson site, I noted changes in cord cover and then at the end of my study, recorded the total depth of material added to the surface of dams either by passive entrapment or by beavers. Placement of material by beavers, as opposed to passive input of leaves and other detritus, is generally apparent due to clues like streaked paw marks in sediment, piles of sediment (and often visible holes in the upstream channel where they have been excavated) or well-secured plant material with angled, gnawed ends.

In addition to documenting dam activity using cords and notes, I set up photo points at each dam in the lower Wasson Creek drainage at approximately the same compass reading. Photos were useful in constructing a supplemental visual record of dam change through the study period, and were taken approximately once every month.

III. RESULTS

Location and Frequency of Flooding with Respect to Precipitation

Stream Stage

Between November 14, 2003 and July 2, 2004, stream level exceeded bank level once at the water level logger sites. To overtop the banks at the W.L.L.1 station, stream level had to reach 1.1m (110cm) with respect to the logger's placement. From 10:11 on December 13 to 01:41 on December 14, 2003, W.L.L.1 recorded stream stage >1.10m (110cm), reaching a maximum of 1.33m (133cm) at 19:11 on December 13 (Figure 9). Total continuous precipitation in the 36 hours between 12:00 December 12 and 24:00 December 13 was 13.54cm at the OIMB gauge. During this period, there was a positive correlation between hourly precipitation and stream stage data, a strong relationship between daily rainfall and stream level (Table 1a) and a ~7-hour lag time between the highest hourly precipitation (14.48mm/hr) and stream level values in the study period (133cm).

At the W.L.L.2 station, stream level relative to the logger had to reach a predicted threshold of ~1.3m to overtop the stream bank and reach the floodplain. Though W.L.L.2 was not yet installed when the high flows occurred on December 13-14, sediment deposits, debris, and matted vegetation on the floodplain adjacent to the eventual W.L.L.2 station were evidence that flooding occurred around the site (Figure 10).

Between the launch of W.L.L.2 on January 9, 2004 and March 10, 2004 (11), there was a strong positive correlation between stream stage data sets (Table 1a). Within this time frame, W.L.L.1 stage was > 60.0cm 72.7% of the time (Figure 12a) and

W.L.L.2 stream level was < 30.0cm 87.9% of the time (Figure 12b). From 4:00 March 8, 2004 to 4:15 March 18, 2004, water level at W.L.L.2 dropped from 8.2cm to a minimum of 3.7cm at 5:00 March 11, 2004 and then rose to 27.8cm (Figure 12b). During this same period, W.L.L.1 stream stage declined from 55.5cm to 47.0cm and the OIMB precipitation gauge recorded no rainfall.

On April 7, 2004, the battery in W.L.L.1 had to be replaced—leading to a loss of ~6 days worth of stream stage data. Once both loggers were online again, there was a positive correlation between logger data sets (Table 1a) for the remainder of the study. From April 7, 2004 through July 2, 2004, W.L.L.1 recorded stream levels < 60.0cm 99.5% of the time and W.L.L.2 recorded stage >30.0cm 100% of the time (Figure 12). Precipitation at the OIMB gauge during the same period totaled 20.2cm—13.5% of the November, 2003- June 2004 total.

Overall, there was a positive correlation between daily OIMB gauge precipitation totals and peak stream levels at W.L.L.1 from November 15, 2003-July 1, 2004, and a stronger correlation from November 15, 2004 to March 10, 2004 (Table 1a; Figure 12a). Generally, the rise and fall of stream stage at both loggers was affected by the quantity and consistency of rainfall (Figure 12). When rainfall increased quickly and in high magnitude, or gradually built up to a peak event over the course of several days, stream level reached its highest peaks. Following a peak in stream stage, if there was little or no rainfall, the descending slope of the hydrograph was most extreme. Conversely, if rainfall continued in progressively smaller amounts, the slope of the hydrograph was more moderate (Figure 11).

When dams were impounding water downstream of the water level loggers, peaks and drops in stream level were generally smaller in magnitude and slope. During the times of peak stream flow in December, BD1 and BD3 were washed downstream—leaving only fragments of their foundation material behind. Prior to the reconstruction of BD1, between January 9 and March 11, 2004, W.L.L.2 recorded stream level changes between peaks and low points that were approximately double those recorded at W.L.L.1 (Figure 11).

Precipitation

Precipitation recorded at the OIMB gauge between November 1, 2003 and June 30, 2004 totaled 149.35cm (Figure 12). Of the rainfall recorded during the study, 86.48% fell between November 1, 2003 and March 31, 2004. When I compared precipitation data between the OIMB and North Bend FAA weather stations, there was a strong positive correlation between monthly data sets (Table 1b). Given the strong correlation between data sets, I calculated the recurrence interval (RI), or predicted frequency of occurrence through time, for yearly peak precipitation events, based upon the North Bend FAA station's data for the 1932-2003 water years. Events were ranked and then the total number of water years in the data set was divided by each rank number to calculate RI.

Using the equation for the best fit line of the precipitation vs. RI graph (Figure 13), a 9.7cm precipitation event should occur at a frequency of approximately every 5 years. A 6-year rainfall event equates to 10.2cm, a 10-year rainfall event is around 11.6cm, a 20-year event around 13.6cm, and a 50-year event around 16.1cm.

On December 13, 2003, when Wasson Creek overtopped its banks, the OIMB gauge recorded total daily precipitation at 11.63cm (~10-year event at the NB FAA gauge), with a peak hourly precipitation value of 14.48mm between 11:00 and 12:00 (Figure 9). Cumulative precipitation on the same day at the North Bend FAA gauge was 10.30cm (~6-year event)—1.33cm less than the OIMB gauge. Between December 12 and 14, 2003, there was only a 0.15cm difference in total precipitation at each station (14.45cm at NB FAA and 14.60cm at OIMB). From these figures, we can estimate that the storm event that caused flooding at both loggers (and most likely the ruin of BD1 and BD3) occurs approximately every 6-10 years.

Lower Wasson Creek Channel Patterns

Of the 56 cross sections taken by the surveyor, 37 provided sufficient data to estimate bank full width and depth in the main channel (C1) and 40 for the secondary channel (C2) on the north end of the floodplain (Figure 14; See Appendix B for cross sections). Elevation at the deepest point in the channel (thalweg) was recorded at every cross-section for the main channel and at 43 of the 46 cross sections where the secondary channel was present. Some of the surveyor's work may have been limited by heavy vegetation cover, extensive beaver plunge holes and unpredictable terrain south of the main channel. Several thickets of Himalayan blackberry (*Rubus discolor*) that have overgrown the channel on the north side of the floodplain may have provided a similar obstacle.

Across the total reach of the main channel, the slope of the deepest part of the channel bed was less than the gradient of the adjacent floodplain (Table 2a). Channel bed slope in the main ditch was the greatest in the high beaver activity area and the least in the low beaver activity section (Table 2a). In the secondary channel, channel bed slope was similar across all levels of beaver activity (Table 2a). Though there is some local variation in slope due to the presence of beaver dams (Appendix C), lower Wasson Creek is a very low-gradient stream.

Overall, mean bank full width was greater in the main channel (C1) than the secondary channel (C2) and in sections of both channels where there was higher beaver activity—particularly in C1 (Table 2b). C1 mean bank full depth was more than double that of C2 (Table 2b). Areas of low beaver activity were associated with slightly higher mean floodplain widths than areas of higher beaver activity (Table 2b).

Mean channel width/depth (W/D) and entrenchment ratios (ER) were greater in C2 than in C1 for all sections (Table 2b). Overall, C1 is more deeply incised, but C2 is a narrower channel with respect to the width of the floodplain. In areas of intense beaver activity in both C1 and C2, W/D ratios were slightly higher and ER lower (Table 2b)—indicating that where there was extensive beaver activity, the potential of Wasson Creek to flood and channel extent across the floodplain were greater. In comparing entrenchment ratios against bank full width/depth ratios, there was a rapid rate of increase in entrenchment ratio as bank full W/D ratio decreased (Figure 15).

Change in the Agricultural Ditch

Floodplain Transformation

Between 1939 and the present, there has been little change in the overall shape of the main Wasson Creek channel (Figure 16)—such that historical sinuosity is essentially equal to that of current conditions. The most significant difference between aerial photos is in the management/human activity visible on the floodplain and throughout the Wasson watershed. In 1939, the lower floodplain was divided into ~3 main zones for agriculture

(Figure 3), with the lowest section ending just below the current bridge and path (Figure 2). Downed trees and bare land in the upper watershed indicate logging activity.

From 1955 to 1962, there was a slight difference in vegetation patterns on the floodplain. In the 1955 air photo, vegetation is uniform across the floodplain (Figure 17). The 1962 photo, however, shows mottled vegetation color on the lower floodplain and darker vegetation areas in adjacent to the secondary channel—indicating where seasonal flooding may have occurred (Figure 17). Such vegetation patterns in the 2003 air photos are often associated with sedges and other wetland plants (vs. pasture grasses, which appear lighter and more uniform in color).

By 1991, beaver activity was evident on site—especially on the floodplain above where the Wasson Main channel switches to the north side (Figure 17). Diversity in plant cover and visible ponds suggest that dams were present, and the Stone report (1986) confirms that beavers were active throughout the watershed by this time. From this point on, air photos suggest a gradual increase in the diversity of sedges, rushes, and other grasses across the lower floodplain—which may be the result of the water table being locally altered by beaver activity. The removal of agricultural activity on the floodplain also probably contributed to an increase in plant diversity on the floodplain.

Currently, beaver activity has led to the development of a number of small channels on the floodplain outside of the relatively straight main and secondary channels—especially upstream and downstream of BD7 (Figure 16). In the depth profiles taken 1m upstream of BD7 and BDH, I could observe where the deepest points were with respect to the dams (Figure 8). At BD7, the profile taken in November, 2003 shows where the main channel would form after the dam was partially breached in December, 2003 (Figure 8a).

Where beavers created the largest dams, as seen at BD7, water and sediment were impounded both upstream and sometimes downstream of the dam. When the flow of the water became concentrated enough to breach a dam where the upstream pond was the deepest, the pond's bed upstream of the dam was further scoured by the concentrated flow of water and a number of meandering channels were slowly cut out onto the floodplain below the dam (Figure 16). Initially, much of the water was moving as overland flow, and these channels likely developed in places where there was the least resistance to erosion, such as some of the ground that had been saturated for more than a year (personal observation, Spring, 2003).

Eventually, much of the flow coming through the dam was either concentrated into a primary channel that moved water along a sinuous path toward the right side of the floodplain or drained off the floodplain through a beaver plunge hole with its outlet immediately above W.L.L.1. Sediments in the new channel were scoured and deposited downstream—leaving a more rigid clay layer exposed.

From the topo map generated by the surveyor, my own observations, and cross sections, I estimated the total length of the entire channel network formed on the floodplain in the BD7/BDH section, excluding the main or secondary channel, at >550m. In the deepest of the channels forming on the floodplain (Figure 16), sinuosity was greater than in any other main or secondary channel section in the study area (S=1.3, where total channel length=146m and straight line valley length=114m).

Using the map I generated and the surveyor's data points, I found an overall current sinuosity of 1.08 for the main channel in the study area and 1.12 for the secondary channel (Table 2a). Across high and low beaver activity areas, there was little difference in sinuosity.

Beaver Activity

Of the seven beaver dams included in the study area at the beginning of fall, 2003, all were actively impounding water and sediment as of November this year. Two washed downstream in December, 2003, when stream flow was at a maximum. Beginning in early spring, 2004, one washed-out dam (BD1) was replaced, followed by the second dam (BD3) in later months. Also, eight new dams were constructed in the secondary channel (Figure 2). All dams were measured and documented either at the beginning of the study (BD1-7) or as they were built (Table 3).

Overall, cords were useful in determining where beavers were actively maintaining dams in the study area. On November 11, 2003, ~5 days after the first set of cords was installed on dams, beavers had already added new vegetation and sediment over the cords on BD2 and BD6. In December, 2003, most of the cords were washed downstream—along with BD1, BD3, and much of the surface material on all of the dams. Had the cords been secured to a piece of rebar or other more substantial stake in the dams, they may have remained intact. By January 9, 2004, when W.L.L.2 was installed, most of the dam surfaces had been well-scoured by four peak flow events exceeding 80.0cm at the W.L.L.1 station and approximately six other peaks resulting in >70.0cm stage at W.L.L.1.

Until February-March, 2004, when some of the highest peak flows subsided in Wasson Creek, there was a lag in dam maintenance by beavers. By March 22, however, much of the floodplain extension of BD7 had been reconstructed, and eight new dams had been built in the secondary channel on the north side of the floodplain (Craig Cornu, personal communication). Where the secondary channel previously had little flow and no beaver activity, there were now large ponds of standing water and small streams of water flowing around dams onto the floodplain (Figure 16).

When I visited Wasson Creek to photo-document and measure the new dams on March 26 (Table 3), BD1 (located ~70m downstream of W.L.L.2) had also been mostly reconstructed—with its composition dominated by large branches, small logs, grasses and sedge (Figure 18). Overall, there was a substantial volume of water flowing over and around all of the dams in the study area. When dams were checked again on April 2, new grasses and twigs had been added to BD1, and most of the dam's upper surface was dry. Upstream, at the BD3 site, the only hint of a new dam was a large chunk of sediment and part of a log left over from the previous dam that were trapping some grasses and other material floating by.

On April 23, 2004, new cords were installed on Dams 1-6, BD0 (discovered on this date) and BDH (Figure 2). At this point in time, BD1 had already begun to back up more sediment and had additional material added to its surface since April 2 (Figure 18). BD2 had a new large log atop its surface, and additional material added to BD3 had created a slight drop between upstream and downstream water levels. Much of the sediment that had been trapped upstream of BD6, some of which was probably deposited by all of the flooding and erosion of the floodplain extension of BD7, was now exposed, and water flowing over the dam had been reduced to a trickle.

When dams were checked on May 14, 2004, BD3 showed the greatest change in added material, with ~30cm of sticks, grasses, and sediment on top of the cord. Below BD3, BD0 had no new beaver additions and BD2 had ~6cm of new material. I could not locate the cord on BD1 (as with BD5), but new material—evidenced by a comparison with the April 23, 2004 photo and recently cut plant debris—had been placed on the dam (Figure 18). With BD4 and BD6, new material was added upstream of, but not atop the cords, and beaver tracks were visible in the sediment on BD6. At BDH, both cords were still visible and had not been covered by any new material.

On June 9, 2004, two new dams were discovered. BD0.1, beneath a large sitka spruce (*Picea sitchensis*) was composed primarily of conifer branches. BD7.1, composed of silty clay sediment, small-fruited bulrush (*Scirpus microcarpus*), salmonberry (*Rubus spectabilis*), and other branches, was constructed where the main flow had breached the floodplain-wide extension of BD7 and created a new channel on the floodplain during the winter. BD0 had ~10cm of new material. The cord on BD1 was found, and showed that ~20cm of material had been added since its placement. All other dams showed some degree of activity in the presence of beaver-clipped green plant material and newly packed sediment. By this point, several of the dams, including BD2, BD4, BD5, and BD6 were heavily overgrown with reed canary grass (*Phalaris arundinacea*).

On August 13, 2004, a total of ~8cm of material had been added to BD0, 30cm to BD1, and ~40cm to BD2. I was unable to locate the other cords because they had either been buried in debris or the dams had been covered with a dense patch of reed canary grass and some small-fruited bulrush. BD7, and 7.1, which was then incorporated into a re-constructed floodplain-wide dam, had created a substantial body of standing water on the floodplain and active maintenance was apparent by the presence of newly cut small-fruited bulrush, slough sedge (*Carex obnupta*), and sediment.

IV. DISCUSSION

Flooding Dynamics

Of the processes I observed at Wasson, flooding resulting from beaver activity was one of the most influential factors in altering the shape, path of water, and movement and deposition of sediment on the floodplain. Though only one rain storm caused Wasson Creek to flood its main channel at both of the water level logger stations, this ~6-10-year event provided insight into how the main Wasson Creek channel responds to rapid peaks in stream level and discharge when there is a high level of beaver activity. With base stream flow in beaver-dammed reaches already high from previous rainfall (>60cm at W.L.L.2), this storm event was sufficient to cause flooding around most of the main channel. Stream flow during the event appears to have scoured many of the beaver dam surfaces, but resulted in the destruction of only one smaller beaver dam (BD3) in the high-beaver activity area. In the lower beaver activity area, where there is a ~170m gap between BD1 and BD2, stream energy was probably greater because of less resistance from beaver dams. BD1 was most likely destroyed at this time, but may have remained intact long enough to be a contributing factor in over-bank full flow upstream.

Upstream of W.L.L.1, the floodplain extension of BD7 was also probably breached when W.L.L.1 recorded an abrupt peak in stream stage on December 13, 2003. Though we were unable to observe the relationship between peak timing at both water level loggers during the event, W.L.L.1 data illustrate how a rapid peak in stream stage can occur even in the presence of two large beaver dams ~20m and ~60m upstream and a series of dams beginning with BD5 ~40m downstream. Matted reed canary grass on the downstream side of both BD6 and BD7, in addition to some observed overflow at the dams in November, 2003, and January, 2004, suggested that some water was probably flowing over the upstream dams, but another main contributor may have been water draining off the floodplain upstream of W.L.L.2.

Beaver Activity on the Floodplain

Between December, 2003 and April, 2004, flooding in the form of overland flow and the creation of small channels on the floodplain around BD6 and BD7 was at its maximum extent. During this period, beaver-created features shaped many of the flow patterns observed on the floodplain—including drainage of a substantial volume of water through a beaver plunge hole at the downstream-most extent of overland flow adjacent to the main channel.

What was initially constructed as a beaver escape tunnel between the floodplain and the main channel turned into a drain for much of the overland flow caused by flooding of the channel above BD6 and BD7 (Figure 5; Figure 19). By early May, when surveyors constructed an elevation profile of the site, the plunge hole had developed into a hollow that declined 0.30m from the surrounding floodplain and had a maximum diameter of ~8m. Other plunge holes are abundant around BD6 and BD7, but none were observed to drain significant volumes of water off the floodplain.

Beaver plunge holes and channels, which are excavated in the form of ditches extending out from a beaver pond, may play an important role in slowly re-shaping and adding channel complexity to the Wasson floodplain—especially when they are scoured by one or several seasonal floods. In the channel network surrounding BD7, for instance, nearly all channels above the dam's floodplain extension have been created by beavers (Figure 16). While these channels and plunge holes re-direct flow into the main channel at times, most of the channels I observed were built off large beaver ponds extending on the floodplain and many of the plunge holes I discovered were in areas where there was no substantial overland flow on the floodplain.

As a reference for the cumulative effects of beaver channels, plunge holes, and dams, we can look at the floodplain upstream of the area covered in this study. Upper Wasson Creek is laced with an elaborate network of channels and dams while the deep main channel on the north side of the floodplain remains (Figure 2; Figure 3). To give a rough estimate of depth in the main channel just above where Wasson Creek crosses the floodplain, I measured one dam that was over 1.5m in height from its uppermost surface to the channel bottom downstream! Large volumes of water remaining on the floodplain may be the result of a raised water table, low-permeability soil, and having the energy of the main stream flow dissipated by a winding path through channels and a series of dams (Hillman, 1998).

Yet another beaver activity—pond excavation above a dam—can alter main-channel shape and at times lead to increased channel complexity on the floodplain. The two depth profiles, recorded at BD7 and BDH, illustrate the formation of new channels and topography on the floodplain when beavers excavated sediment to use in dam construction. At BD7, where water from the main channel upstream was re-directed onto the floodplain, the depth profile taken before the dam was partially breached in December, 2003, shows where flow was the most concentrated and thus exerted the most force on the dam (Figure 8a). Since the floodplain extension of BD7 was composed primarily of sedges and sediment, it lacked much of the structural stability found in the portion of the dam built in the main ditch.

Following the mid-December, 2003 storm event, the floodplain in many areas was inundated such that lesser peak flow events caused extensive flooding in areas along the secondary channel (especially between BDA-C, BDD-H), above BD6, and all around BD7 (Figure 16). Where a substantial volume of sediment was deposited on the floodplain below the breached points along BD7, additional rainfall events provided water to re-work and organize the sediment into bars. Wherever water left the channel, sediment and organic material from the stream bed were deposited on the floodplain (Figure 10). In areas of low topographic relief, water collected in pools—many of which remained into the late spring/early summer.

Cross sections and other topographic data from this study provide a useful reference for determining where high and low points exist on the floodplain—creating surface convexity and concavity that help direct the movement of water. Concave land surfaces on a floodplain are typically less stable than convex surfaces in the event of small disturbances (Knighton, 1998), and may suggest where a future channel could form on the floodplain if seasonal flooding and beaver activity persist. In addition to providing a footprint for the movement of water on the floodplain, topographic relief on the floodplain at Wasson also allows us to see where the historic main channel may have flowed (Figure 16).

Beaver Activity in the Main and Secondary Channels

Given that nearly all dams in both the main and secondary channels were actively maintained at some point during the eight months of this study, we can most likely expect a continued beaver presence in shaping the lower Wasson Creek valley. During the study, only one dam (BD5) was not confirmed as actively maintained. In addition, beavers at Wasson appear to exhibit some site fidelity in re-constructing BD1, BD3, and BD7 at the exact locations where they were destroyed by winter flows.

Dams at the Wasson site varied in size and composition—most often related to what materials were available close to the dam sites. All dams played some role in impounding water, sediment, and other materials in the channel bed or on the floodplain, but the most influential dams, in terms of altering the adjacent floodplain, were those that exceeded bank full channel height and had been extended out across the floodplain (particularly BD7 and BDH). These findings are consistent with a study by Naiman et al. (1986), where researchers found that the determining factor in a dam's retention capacity was not the bulk volume of the dam, but rather the surface area of meadows and ponds upstream of dams, with even small dams of 4-18m^3 in volume impounding between 2000 and 6500m^3 of sediment (Naiman et al., 1986).

Although beaver dams causing prolonged seasonal flooding across the floodplain are critical in large-scale sediment and water retention on a year-round basis, relatively small dams in the main channel still play an important role in buffering changes in stream flow upstream and downstream of the dam. Looking at the combined W.L.L.1/W.L.L.2 hydrograph, (Figure 11), the abrupt change in stream level at W.L.L.2 in mid-March, 2004 illustrates the effect of beaver dam construction on stream level upstream. Despite a lack of rainfall between March 8 and March 18, stream level rose and stabilized at W.L.L.2 following BD1 reconstruction ~70m downstream.

One of the most impressive beaver feats observed during this study was the construction of eight dams in less than two months in the secondary channel. This side channel, which was not initially a focus in this study, could potentially be a crucial component in the restoration of channel complexity at Wasson Creek. Since the smaller secondary channel is, on average, less than half the depth of the main channel, has higher channel width/depth ratios, and is far more diverse in channel form (Table 1; Appendix B), water can reach the floodplain twice as easily as from the main channel.

Originally, the secondary ditch was probably constructed as an overflow channel to keep the floodplain drained for agriculture. Most of the Wasson Creek flow was directed through the main ditch—leading to greater erosion and incision of the main channel bed through time. Since there is little evidence of previous beaver activity in the secondary channel, new construction probably spiked in response to the re-direction of the main Wasson flow beginning in December, 2003. While the main BD7 dam remained intact and kept sediment and water impounded upstream, holes in the floodplain extension of the dam acted like floodgates—releasing water into both the secondary channel and the main channel downstream of the dam.

As water continued to flow across the floodplain toward BDH between early January and early June, 2004, I saw the water impounded behind BD7 go from a pond spanning nearly the entire width of the floodplain to barely a trickle by mid-May (Figure 21). Meanwhile, water level in the secondary channel remained over bank full in most places. On June 9, water was again backed up behind the full extent of BD7, but the secondary channel was still flooded in many areas—particularly around BDG-H. Beavers had repaired the full extent of BD7, added onto BDH, further excavated ditches extending up the floodplain from the pond, and created a marsh. By July 2, despite little rainfall in the summer months, the pond was deeper and more expansive than it had been in the spring (Figure 21).

Predicting the Trajectory of Change for Wasson Creek

According to Johnston and Naiman (1990), the landscape alteration we see in the first ~30 years of beavers occupying and damming Wasson Creek will most likely have the greatest influence in directing the site's trajectory of change—consistent with the approximate time frame for beaver alteration at Deton Creek between 1976 and 2004 (Figure 6). From the Stone report (1986) and aerial photos, we know that beavers have been active in the Wasson Creek system since at least the mid-1980s. Still, the activity level and time span required for beavers to sufficiently fill in sections of the main channel in the future is unknown.

Though trapping or other means would be required to accurately estimate how many beaver colonies occupy the Wasson Creek watershed, we can predict beaver activity on the lower floodplain based on the number of large ponds. Johnston and Naiman (1990) found that a single colony of beavers created, on average, 2.2 substantial ponds and occupied around 10ha of land. At Wasson Creek, where the largest active pond (above BD7) covers at least 2000m² of the floodplain, and the remaining ponds are smaller and confined primarily to the main and secondary channels, we may be seeing the work of only one healthy colony below where Wasson Creek crosses the floodplain (Figure 2).

Though it is possible for 3 colonies to occupy 1km² of land (Voigt et al., 1976; Naiman et al., 1986), 0.4-0.8 colonies/km² in optimal habitat is a more commonly observed figure (Aleksiuk, 1968; Voigt et al., 1976, Bergerud and Miller, 1977; Naiman et al., 1986). Home ranges of colonies, which consist of the entire area used by the members of a group for foraging, may overlap, but territories (consisting of beaver ponds, lodges, dams, canals, trails, and food caches) are more exclusive and limited to kin groups (Muller-Schwarze and Sun, 2003).

A single beaver colony typically consists of about six individuals, but can range between one and ten animals (Muller-Schwarze and Sun, 2003). Within a colony, there are generally two each of adults, two-year-olds and one-year-olds (Muller-Schwarze and Sun, 2003). Average life expectancy for an adult beaver is around ten years, and females begin to reproduce around age two—reaching maximum fertility when they are about seven years old (Muller-Schwarze and Sun, 2003).

Beaver population growth in a given area is typically slow and primarily limited by the availability of optimal habitat, which can influence how many offspring are produced and their survival rate (Muller-Schwarze and Sun, 2003). Using the habitat classification model developed by Suzuki and McComb (1998), much of the lower Wasson Creek valley appears to fit within prime beaver habitat parameters—with stream gradient falling well below the ideal limit of 3% slope, average channel width in both the main (4.86m ± 0.90 SE) and secondary channels (3.46m ± 0.78 SE) within or close to the optimal range of 3-4m, and all valley floor widths > 25m (Suzuki and McComb, 1998). In addition, salmonberry (*Rubus spectabilis*) and red alder (*Alnus rubra*), which are a preferred food for beavers in the Oregon Coast range (Suzuki and McComb, 1998), are abundant in the immediate vicinity of the main and secondary channels—with slightly more alders on the north side of the floodplain.

Ecological Implications of a Continued Beaver Presence at Wasson

Given the suitable beaver habitat at Wasson Creek and the current level of beaver activity in the study area, beaver presence should continue in the watershed. As a result of their activities, we should expect the maintenance of an open-canopy zones on the floodplain due to beaver foraging and some vegetation killed by a raised water table (personal observation; Figure 22), further retention of debris, sediments, and water across the floodplain, a higher incidence of floodplain wetlands, and an increase in anaerobic conditions in some of the soil on the floodplain (Naiman et al., 1986). In the main Wasson channel, a pool-drop character (Hillman, 1998), which we can already begin to see in the current longitudinal profile (Appendix C), should continue to develop.

Fauna on site should continue to benefit from the creation of diverse habitat patches and the edges on the floodplain. Beaver ponds and standing water on the floodplain are already occupied by species such as rough-skinned newts (*Taricha granulosa*), red-legged frogs (*Rana aurora*), Pacific treefrogs (*Hyla regilla*), garter snakes (*Thamnophis spp.*), marsh wrens, song sparrows, and mallard ducks (personal observation). In addition, there is ample evidence of elk, raccoon, and deer at the site.

Vegetation patterns on site should continue to be altered along with changes in the water table, soils, and level of disturbance around the site. Given that beavers typically forage within 20m of pond edges, we can expect the vegetation along the margins of most of the lower Wasson Creek floodplain (average width= 71.8m ± 3.32SE) to be affected by their presence—especially since they now occupy both the main and secondary channels (Barnes and Mallik, 2001). In a study by Barnes and Mallik (2001), all alder stems that were cut by beaver were within 20m of pond edges. Beaver foraging may provide a setback for the establishment of additional trees and shrubs on the floodplain, but species like alder and willow (which is not currently present on the floodplain) are typically able to re-establish their initial densities after being cut back (Barnes and Mallik, 2001).

Since beaver populations and activity centers are dynamic, there is a possibility of beavers re-locating within and outside the watershed if resources such as preferred food plants are limited, or if some of their ponds fill with sediment over time—facilitated by dams impounding sediment and by the low gradient of the Wasson Creek valley. In addition, young beavers typically leave home at two years of age (or three years in the case of high population densities) to establish or join another colony (Muller-Schwarze and Sun, 2003). Such dispersal is typically accomplished by swimming downstream from a parent colony (Muller-Schwarze and Sun, 2003).

Once established, a beaver colony may remain in the same location for several years or more, unless it is forced to relocate by major floods or other disturbances (Muller-Schwarze and Sun, 2003). Though we cannot predict the location of beaver activity centers on the floodplain in the long run, ponds and meadows created by beavers may still persist for more than fifty years as they are altered and re-flooded by successive colonies of beaver (Johnston and Naiman, 1990).

Where beaver ponds are abandoned or water levels are drawn down, the plant community will most likely succeed to a grass and sedge community (Johnston and Naiman, 1990). At Wasson Creek, species like slough sedge (*Carex obnupta*) and small-fruited bulrush (*Scirpus microcarpus*), which are already present on site, are likely to colonize beaver meadows. Invasive reed canary grass (*Phalaris arundinacea*) must be monitored, as new shoots have already begun to colonize some of the disturbed patches on the floodplain dominated by native plants.

In addition to sedges, rushes and grasses growing in beaver meadows, we may see an increase in the extent of trees and shrub cover along the margins of the floodplain. Barnes and Mallik (2001) found that after twelve years, there was an increase in the growth of conifers along the edges of abandoned beaver ponds. Typically, beavers avoid cutting conifers in favor of softwood trees like alders and aspens that are less than 10cm in diameter (Nolet, 1997). At Wasson Creek, we may see a response in the growth of species like Sitka spruce (*Picea sitchensis*) and Douglas-fir (*Pseudotsuga menziesii*). Also, as observed at Wasson Creek, red elderberry (*Sambucus racemosa*) will most likely continue to increase in number, as it is selectively avoided by beaver (Suzuki and McComb, 1998).

Recommendations for Human Intervention

Even if beavers remain the primary agents in restoring Wasson Creek, invasive species like reed canary grass and Himalayan blackberry are still a major concern on site—particularly in the lowest sections of the floodplain. Invasive species like reed canary grass may be removed through a combination of hand-pulling, repeated cut-backs, discing or plowing, and eventual seeding or plugging in of native plants to increase native diversity and competition (Lyons, 1998). Though herbicides are often effective in controlling reed canary grass, they should be avoided due to the close proximity of all areas on the Wasson floodplain to the stream and wetlands (Lyons, 1998).

Beavers may have a neutral effect on some of the invasive species at Wasson Creek, as their dams often provide bare sediment for invasive species to colonize, but also inundate large areas of soil, which can damage seed stocks of species like reed canary grass (Lyons, 1998). Still, many of the processes that have already been reinstated by beavers at Wasson Creek, like flooding and seasonal inundation of the floodplain, may favor some of the native grasses, rushes and sedges already on-site and help keep reed canary grass populations under control (Stromberg and Chew, 2002). In either case, the best strategy is to use natural forms of control rather than introduce more disturbances or chemicals into the Wasson Creek watershed.

Future Questions

In the future, a number of questions may provide further insight into a restoration strategy for Wasson Creek—especially if a passive restoration approach is considered. First of all, plant diversity on the floodplain should be addressed—particularly with respect to how much of the vegetative cover is native and how much is composed of invasive species like reed canary grass. From this type of analysis, managers can assess whether significant control of species like reed canary grass and Himalayan blackberry is necessary.

Secondly, sediment transport at Wasson Creek needs further investigation, and may help us understand how long it could take for the main Wasson ditch to naturally fill in with sediment assuming a continued high level of beaver activity and dam maintenance. Also, knowing how much sediment will be required to fill the ponds to the extent that water could be more permanently diverted onto the floodplain would be useful.

Another important component in assessing sediment transport, stream power, and what changes we can continue to expect in the main channel is stream discharge (typically expressed in cubic feet or meters per second). Though stream stage assisted in monitoring flooding, beaver activity, and how Wasson Creek responds to a range of precipitation events, knowing the discharge regime of a stream is useful in determining its overall capacity to alter the channel bed and floodplain over time.

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Figure 2. Wasson Creek Map. Shows study area, Winchester Creek, beaver dams, water level loggers, path, and other landmarks.

Figure 3. Change on the Wasson Creek Floodplain through time, as seen in the 1939 and 2003 Wasson Creek aerial photos.

Figure 4. Active Restoration at Anderson Creek. Shows large woody debris and new, sinuous channel in 2003, compared with the old, straightened channel in 1991.

Figure 5. Beaver plunge hole diagram. Illustrates how beavers excavate tunnels between their foraging areas and the main channel or pond.

Figure 6. Deton Creek aerial photo series. Shows how beavers have transformed the floodplain from pasture used for cattle grazing to a marsh.

Figure 7. Cross-section of a water level logger set-up in the stream channel.

Figure 8. 1m upstream depth profiles, looking upstream.
a. BD7: left side of graph is at the southern edge of the floodplain; original channel is to the far left, followed by the newer channel(s) forming on the floodplain heading out along the dam.
b. BDH: right side of the graph marks the northern edge of the floodplain. Shows how variable the depth profile can be upstream of a beaver dam, though the dam had only been in existence for ~1-2 months when measurements were taken.

Figure 9. OIMB Precipitation vs. Wasson Creek Stage at W.L.L.1, December 11-18, 2003 (storm event graph). Shows hourly rainfall at the OIMB gauge and the change in Wasson Creek stream level at W.L.L.1. Between 10:11 December 13 and 1:41 December 14, 2003, W.L.L.1 recorded stream stage above bank full level.

Figure 10. Flooding evidence at the W.L.L.2 site, January 9, 2004. Matted grass, sediment, and debris deposited during the December 13, 2003 flood event at the eventual W.L.L.2 site mark where flooding occurred.

Figure 11. Relative main channel stage vs. time. Graph of stream stage at both water level loggers, calibrated to W.L.L.1 to show relative change between loggers.

Figure 12. a. Precipitation (at the OIMB gauge) and stream level at W.L.L.1 vs. time between November 14, 2003 and July 2, 2004.

b. Precipitation (at the OIMB guage) and Stream level at W.L.L.2 between January 9, 2004 and July 2, 2004. Installation of W.L.L.2 was delayed by technical problems with the logger.

Figure 13. Precipitation vs. recurrence interval graph. Aids in predicting the frequency of a given rainfall event (n-year event). The event that led to extensive flooding at Wasson Creek was a 6-10 year event.

Figure 14. Cross-sections used to measure channel dimensions in the main and secondary channels, taken where sufficient data was available to estimate bank full width, bank full depth, and floodplain width.

Figure 15. Entrenchment ratio vs. width/depth ratio in the main and secondary channels. As width/depth ratios increase, entrenchment ratios rapidly decrease—making flooding of the stream channel during a high-rainfall event more likely.

Figure 16. Channel paths on the lower Wasson Creek floodplain, including the historic (1939) and current (2004) ditches and potential future channels. Darker lines indicate the primary channels; lighter blue lines show where new channels are already forming/may develop in the future. All lines based upon a topographic map of the site and field observations.

Figure 17. 1955-1991 Wasson Creek aerial photo series. Changes in floodplain vegetation highlighted in yellow, where mottled vegetation patterns indicate likely seasonally flooded sites.

Figure 18. BD1 photo series, beginning in November, 2003 and ending in August, 2004. Shows the original dam, the channel after the dam was blown out in December, 2003, and construction of the new dam.

Figure 19. Overland flow between BD6 and BD7, terminating in a beaver plunge hole. Water flowing through the plunge hole then entered the main channel immediately above W.L.L.1.

Figure 20. November 7, 2004 photo of a beaver-excavated channel on the upper Wasson Creek floodplain.

Figure 21. Changes on the floodplain upstream of BD7 during the study. Shows original dam in November, 2003, the main breach point in January, 2004, and the transformation between a drained floodplain (May, 2004) and a marsh (July, 2004).

Figure 22. Large woody debris in the upper Wasson Creek channel and in the study area, upstream of BDA. The trees, which are mostly alders, were probably killed by a raised water table.

Table 1a. Correlation between mean daily stream stage and OIMB daily precipitation.

Table 1b. Comparison (using two-tailed t tests) between North Bend FAA and OIMB precipitation gauge data sets.

Table 2a. Wasson Creek channel and floodplain patterns. Includes channel length, sinuosity calculations, channel slopes, and floodplain gradient.

Table 2b. Channel dimensions and calculations for the main and secondary Wasson Creek stream channels. Includes mean bank-full widths and depths, floodplain widths, channel width/depth ratios, and entrenchment ratios.

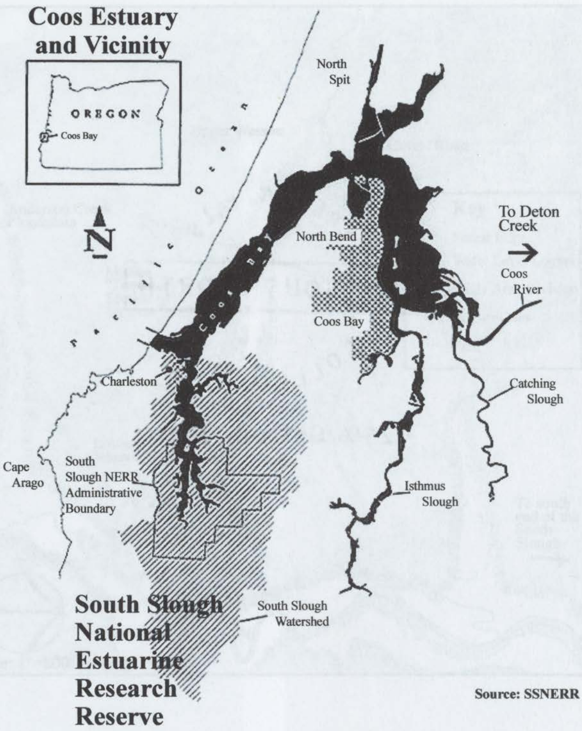
Table 3. Beaver dam measurements and composition notes. Covers all dams located in the Wasson Creek study area between November, 2003 and August, 2004.

Appendix A. Wasson Creek base map—includes beaver dams, survey transects, groundwater monitoring transects from a forthcoming study, W.L.L. locations, a 2003 air photo of the site, cross-section numbers, and longitudinal profiles for the main channel, secondary channel, and floodplain.

Appendix B. Cross-sections corresponding with transects marked on the base map. Cross sections are given at 5x vertical exaggeration to best illustrate subtle surface concavity and convexity across the floodplain.

Appendix C. Longitudinal profiles across the study area. Shows a vertically exaggerated profile of the deepest part of the main and secondary channels, in addition to the profile for the approximate center of the floodplain.

Figure 1. Regional Map



Source: SSNERR

Figure 2. Wasson Creek Map

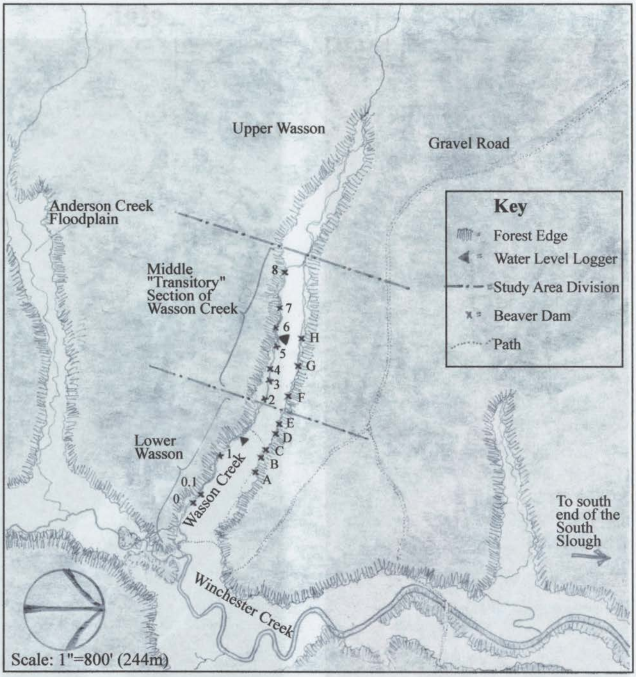
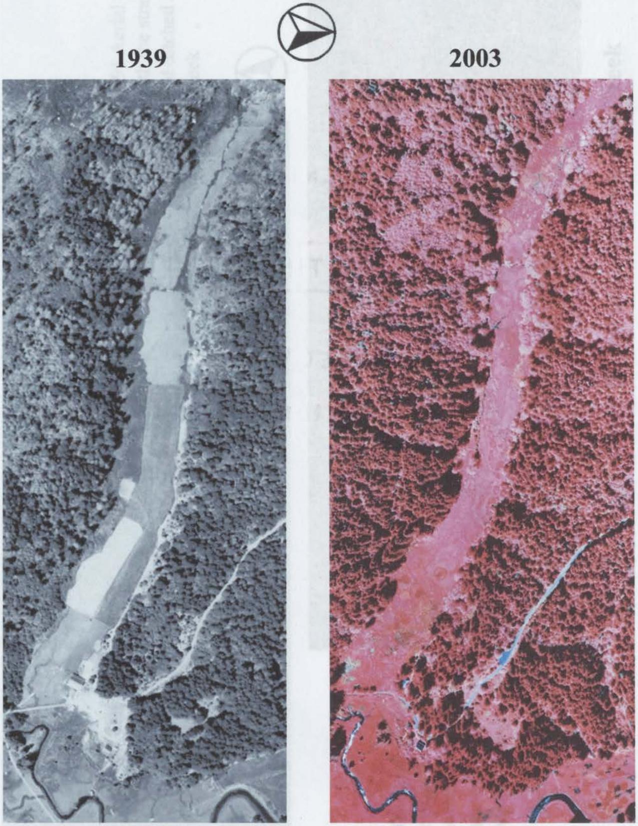
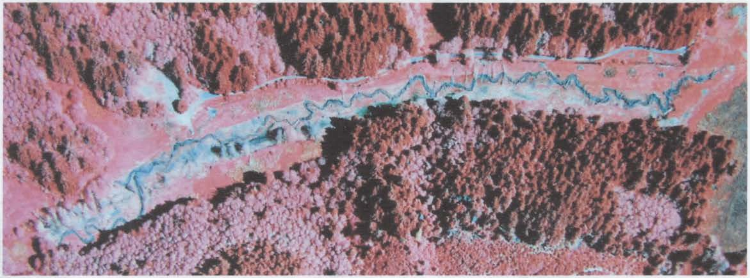


Figure 3. Change on the Wasson Creek floodplain through time.



1991 Aerial photo with the straigtened and ditched Anderson Creek



2003 Aerial photo showing the new, sinuous channel and large woody debris at Anderson Creek

Figure 4. Active Restoration at Anderson Creek

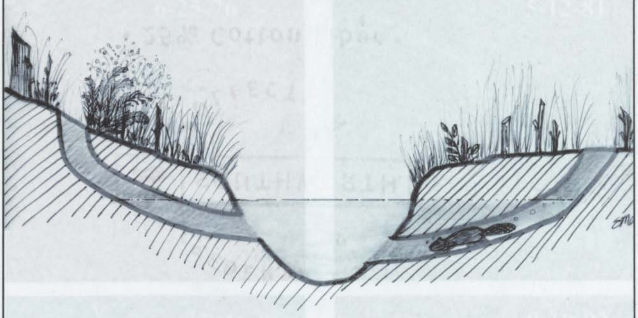


Figure 5. Plunge holes allow beavers to escape predators--providing safe underground routes between foraging sites on land and beaver ponds (above). In the case of the bank-dwelling beavers at Wasson Creek, similar passages are created between bank burrows and the stream channel (below).

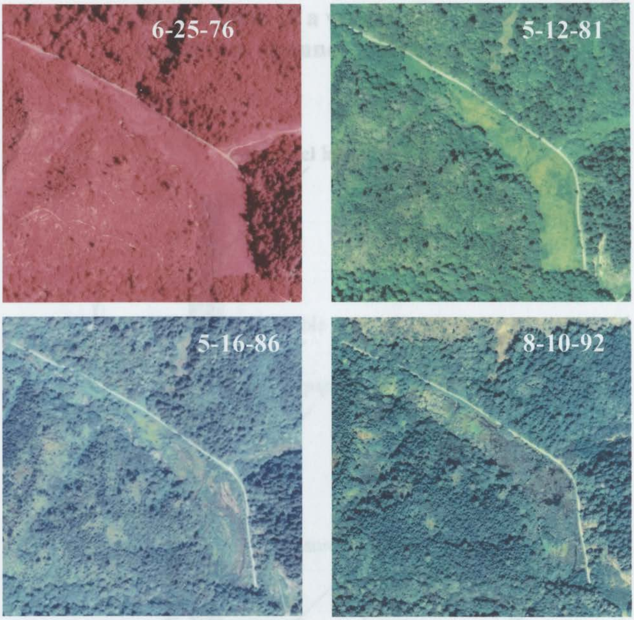
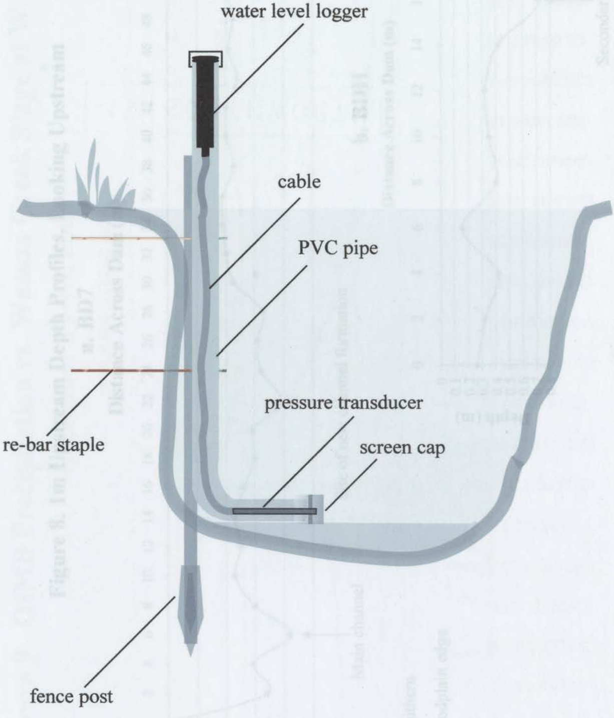


Figure 6. Deton Creek Aerial Photo Series

Scale: 1"~1300'
(Source: Bureau of Land Management)

Figure 7. Cross-section of a water level logger set-up in the stream channel (not to scale).



Sarah Marshall, 2004

Figure 8. 1m Upstream Depth Profiles, Looking Upstream

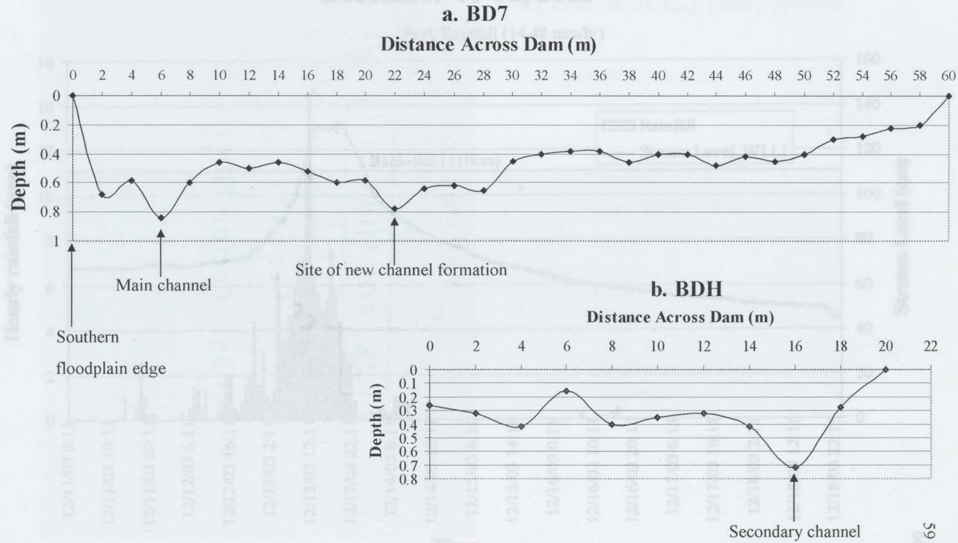


Figure 9. OIMB Precipitation vs. Wasson Creek Stage at W.L.L.1, December 11-18, 2003

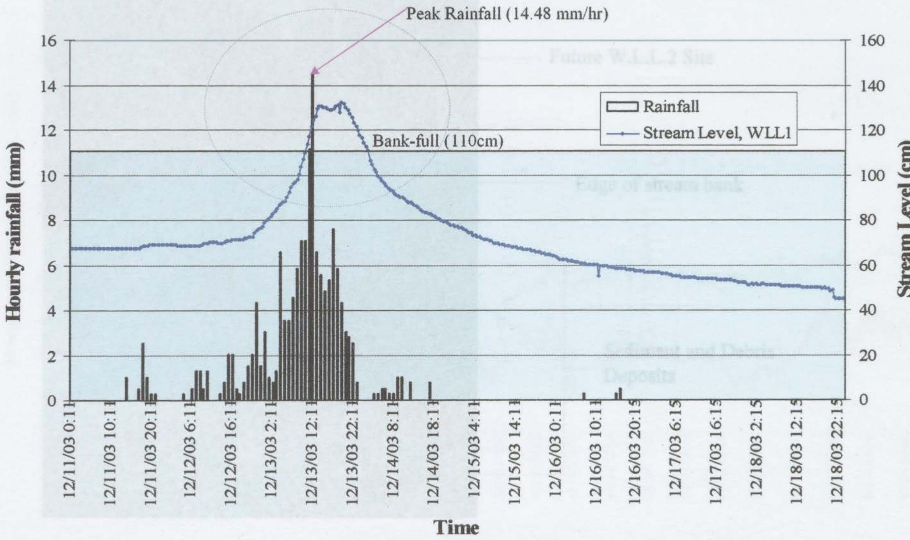


Figure 10. Flooding Evidence at the W.L.L.2 Site, 1/9/04

Future W.L.L.2 Site

Edge of stream bank

Sediment and Debris Deposits

Figure 11. Relative Main Channel Stage vs. Time

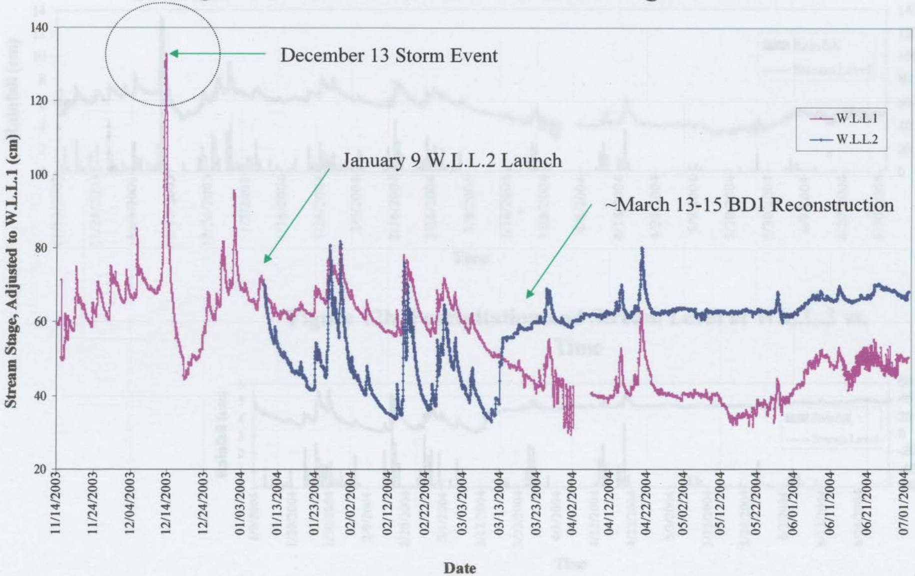


Figure 12a. Precipitation and Stream Level at W.L.L.1 vs. Time

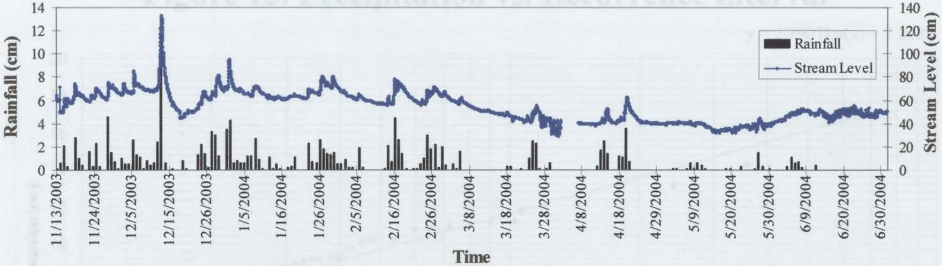


Figure 12b. Precipitation and Stream Level at W.L.L.2 vs. Time

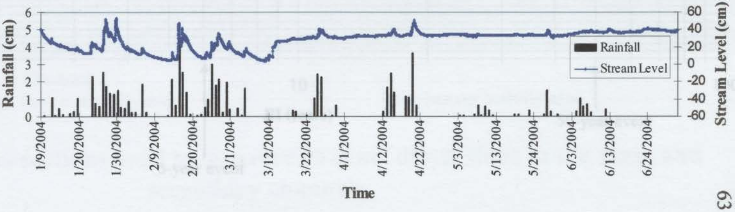
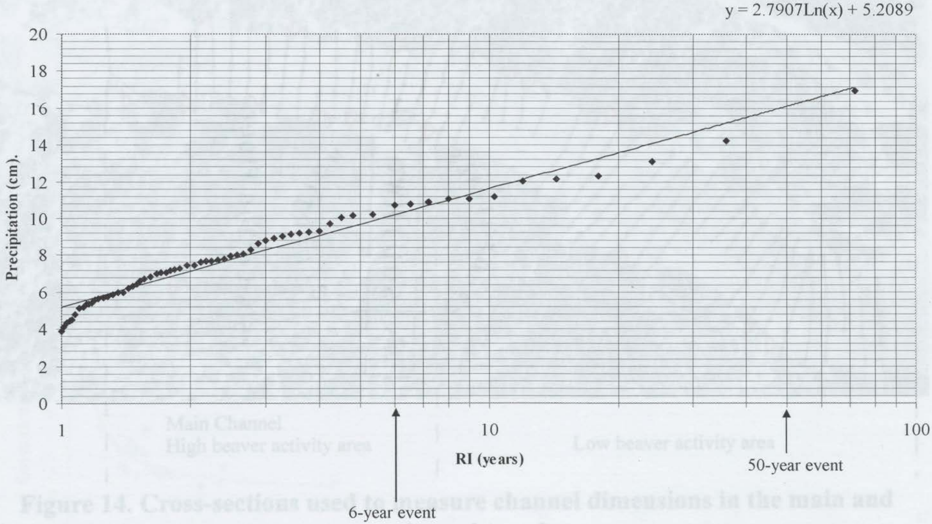


Figure 13. Precipitation vs. Recurrence Interval



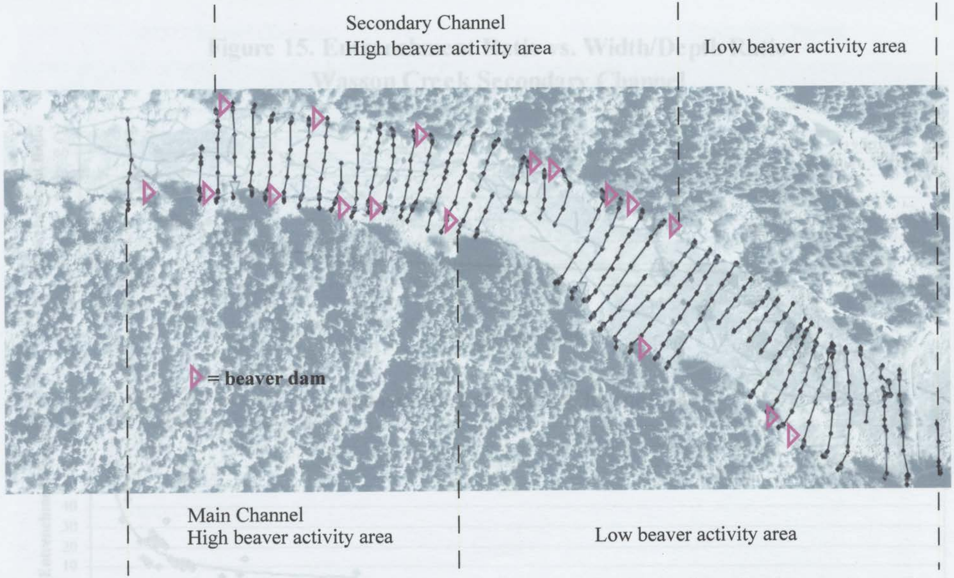
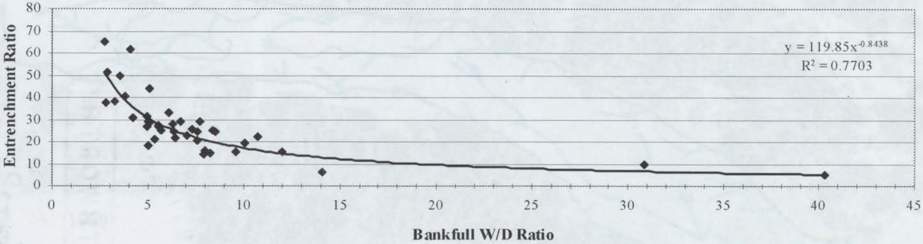


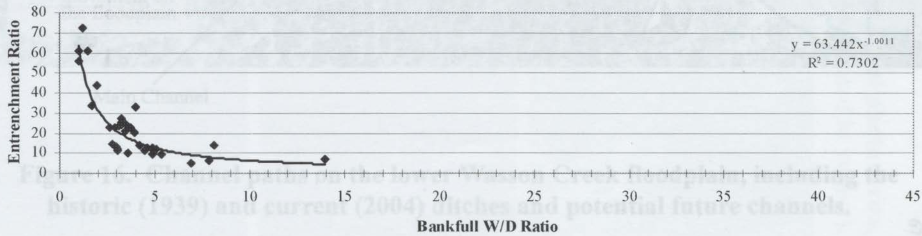
Figure 14. Cross-sections used to measure channel dimensions in the main and secondary channels.

Figure 15. Entrenchment Ratio vs. Width/Depth Ratio

Wasson Creek Secondary Channel



Wasson Creek Main Channel



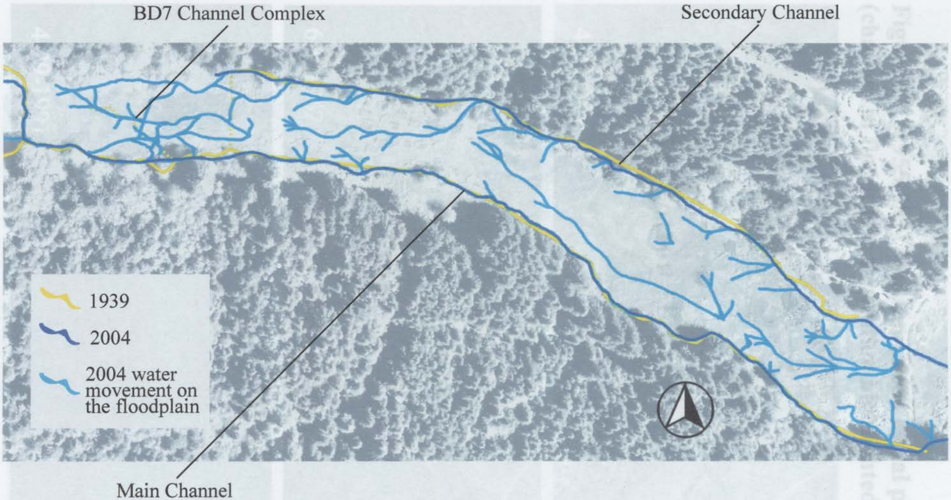
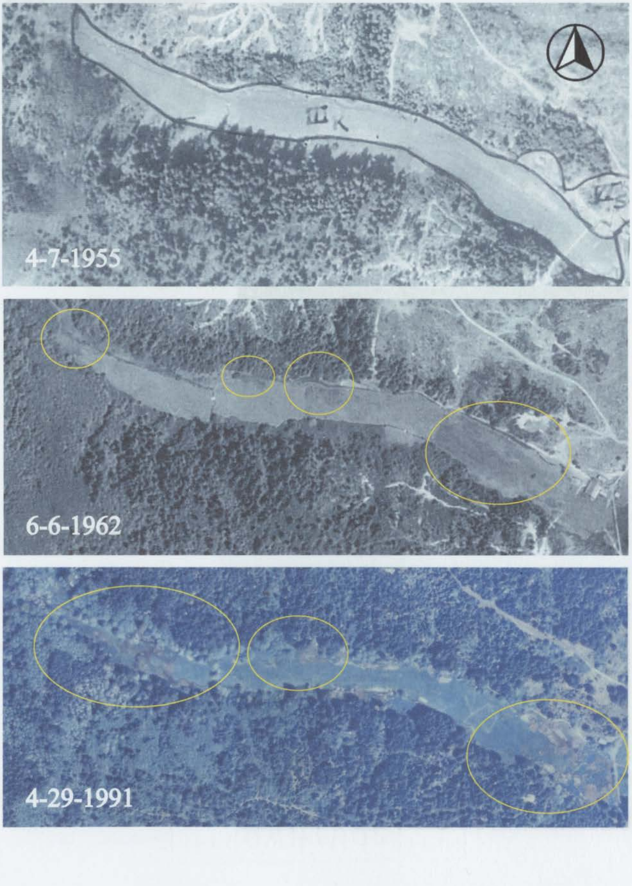


Figure 16. Channel paths on the lower Wasson Creek floodplain, including the historic (1939) and current (2004) ditches and potential future channels.

Figure 17. 1955-1991 Wasson Creek aerial photo series, (changes in floodplain vegetation highlighted in yellow).



November 10, 2003

Figure 18. BD1 Photo Series

January 30, 2004

March 26, 2004

June 2, 2004

Figure 19.
Overland flow between BD6 and BD7 (left), terminating in a beaver plunge hole (below).

January 9, 2004

Figure 20.
Beaver-excavated channel, upper Wasson Creek floodplain.

November 7, 2003

Figure 21. Changes on the floodplain upstream of BD7 during the study.

BD7 and upstream pond,
November 10, 2003

Breach in BD7,
January 9, 2004

By May 14, 2004, the pond upstream of BD7 was mostly drained, with only several of the beaver-excavated channels still holding water (above). Following the reconstruction of the entire floodplain reach of the dam, however, the pond was again filled with water by July 2, 2004.

Figure 22. Large woody debris in the upper Wasson Creek channel (above; March 26, 2004 photo) and in the study area, upstream of BDA (below; April 23, 2004 photo). Trees in beaver-influenced systems are often felled by beavers or killed by raised water tables. Regardless of how they enter a stream, logs often increase habitat and structural diversity in the channel and on the floodplain as they dissipate a stream's energy, create shelter for aquatic species, add nutrients to the system, and provide surfaces for plant growth.

Table 1a. Correlation between Mean Daily Stream Stage and OIMB Daily Precipitation

	df	Correlation Coefficient (r)	*P*
W.L.L.1 and W.L.L.2			
January 9, 2004 to July 2, 2004	8124	-0.459	< 0.001
January 9, 2004 to March 10, 2004	2947	0.919	0.000
March 15, 2004 to July 2, 2004	4985	0.537	0.000
W.L.L.1 and OIMB Precipitation			
November 15, 2003 to July 1, 2004	225	0.522	< 0.001
November 15, 2003 to March 10, 2004	116	0.581	< 0.001
March 15, 2004 to July 1, 2004	104	0.201	< 0.001
W.L.L.2 and OIMB Precipitation			
January 10, 2004 to July 1, 2004	173	-0.022	< 0.001
January 10, 2004 to March 10, 2004	60	0.427	< 0.001
March 15, 2004 to July 1, 2004	108	0.185	< 0.001
Storm Event Bracket (December 11-18, 2003)			
Daily OIMB precipitation and W.L.L.1 stage	7	0.839	0.001
Hourly OIMB precipitation and W.L.L.1 stage	190	0.673	< 0.001
13:00 December 12 to 23:00 Dec. 13, 2003	34	0.586	<0.001

Table 1b. Comparison (using two-tailed *t* tests) between North Bend FAA and OIMB precipitation gauge data sets.

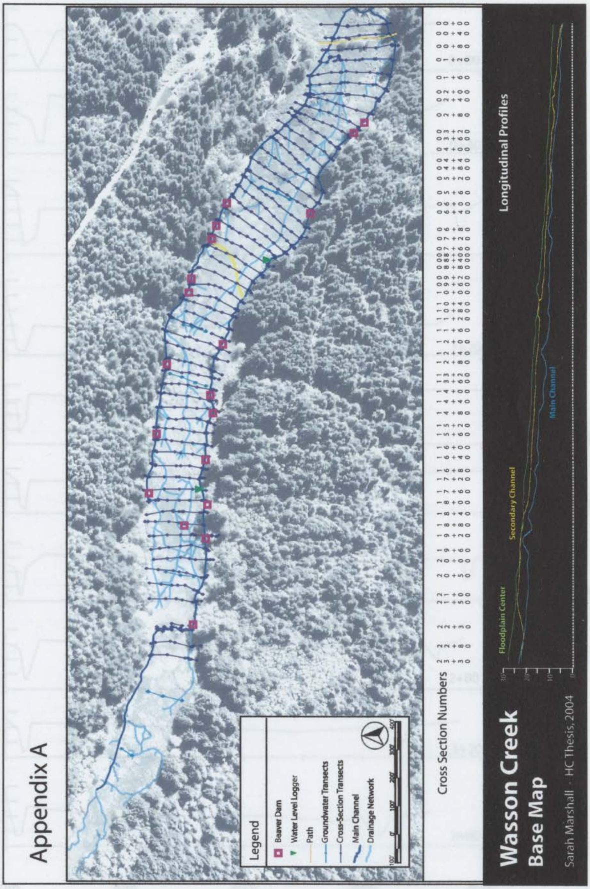
Month	North Bend FAA Gauge		OIMB Gauge						
	Mean	SE	Mean	SE	df	Correlation	*t* Stat	*t* Critical	*P*(T<=*t*)
November-03	0.83	0.37	0.80	0.32	29	0.961	-0.328	2.045	0.745
December-03	1.34	0.62	1.31	0.69	30	0.985	-0.208	2.042	0.836
January-04	0.91	0.30	0.93	0.31	30	0.939	-1.177	2.042	0.248
February-04	0.87	0.34	0.90	0.36	28	0.936	-1.020	2.048	0.316
March-04	0.31	0.19	0.32	0.20	30	0.983	-2.507	2.042	0.018
April-04	0.40	0.33	0.41	0.27	29	0.945	-0.895	2.045	0.378
May-04	0.17	0.09	0.15	0.09	30	0.867	-0.867	2.042	0.393
June-04	0.15	0.11	0.11	0.08	29	0.568	-0.174	2.045	0.863
Nov.-June	0.62	0.35	0.61	0.36	242	0.962	-2.048	1.970	0.042

Table 2a. Wasson Creek Channel and Floodplain Patterns

	Straight Line Channel Length	Total Channel Length	Sinuosity	Channel Slope (%)	Adjacent Floodplain Slope (%)
Main Channel					
Total Channel	660.33	714.76	1.08	0.69	0.76
Low Beaver Activity (0+00-12+00)	385.13	410.66	1.07	0.57	0.64
High Beaver Activity (12+00-21+50)	285.89	304.10	1.06	0.86	0.92
Secondary Channel					
Total Channel	651.10	728.31	1.12	0.80	0.74
Low Beaver Act. (0+00-7+60)	217.39	229.38	1.06	0.81	0.53
High Beaver Act. (7+60-18+00)	345.20	361.17	1.05	0.80	0.89

Table 2b. Channel Dimensions and Calculations in the Wasson Creek Main and Secondary Channels

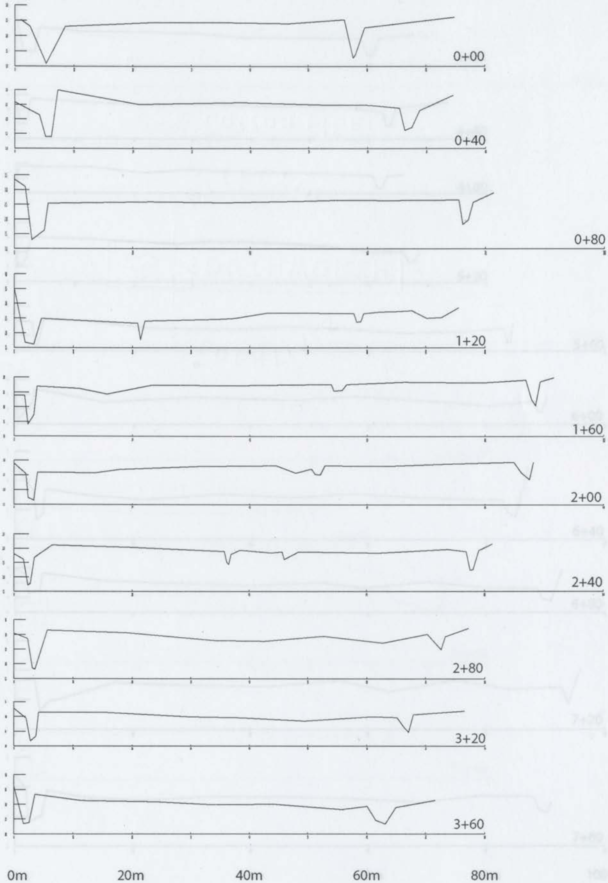
	Main Channel			Secondary Channel		
	Mean	SE	N	Mean	SE	N
Bank Full Width						
Total Set	4.65	0.88	37	3.46	0.78	40
Low Beaver Activity	4.06	0.85	20	3.11	0.51	17
High Beaver Activity	5.34	0.88	17	3.71	0.93	23
Bank Full Depth						
Total Set	1.17	0.09	37	0.47	0.05	40
Low Beaver Activity	1.09	0.06	20	0.53	0.05	17
High Beaver Activity	1.26	0.09	17	0.43	0.04	23
Floodplain Width						
Total Set	73.25	3.72	37	73.46	3.19	40
Low Beaver Activity	79.67	3.14	20	80.18	3.01	17
High Beaver Activity	63.45	1.67	17	68.48	2.30	23
Channel W/D Ratio						
Total Set	4.02	0.76	37	7.94	2.20	40
Low Beaver Activity	3.77	0.83	20	6.72	2.05	17
High Beaver Activity	4.32	0.65	17	8.85	2.31	23
Entrenchment Ratio						
Total Set	22.39	5.21	37	27.56	4.17	40
Low Beaver Activity	26.60	5.16	20	32.01	4.97	17
High Beaver Activity	17.42	4.97	17	24.28	3.20	23



Appendix A
Legend
Beaver Dam
Water Level Logger
Path
Groundwater Transects
Cross-Section Transects
Main Channel
Drainage Network
Cross Section Numbers
Wasson Creek
Base Map
Sarah Marshall · HC Thesis, 2004
Longitudinal Profiles
Floodplain Center
Secondary Channel
Main Channel

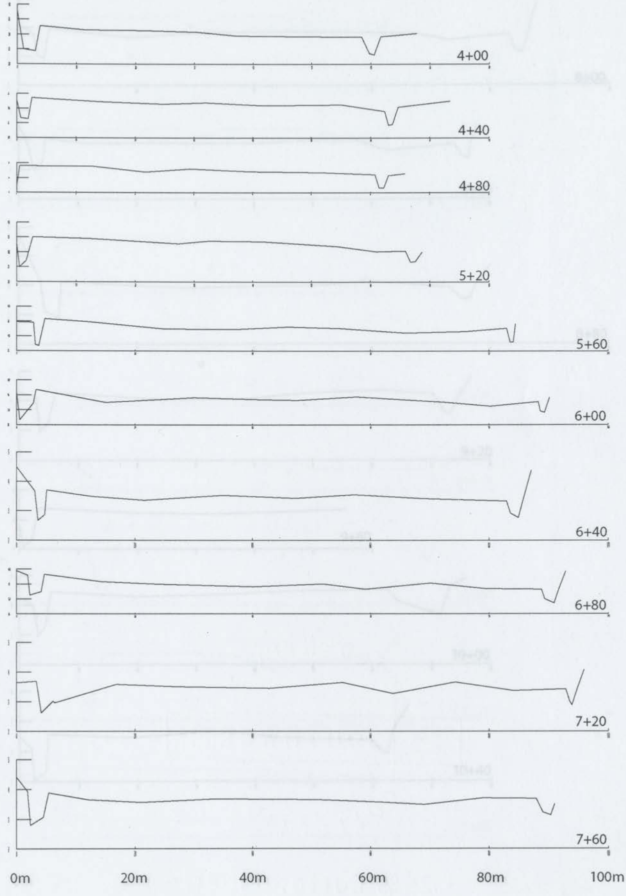
Appendix B

Wasson Creek Cross-sections 0+00-3+60, 5x Vertical Exaggeration



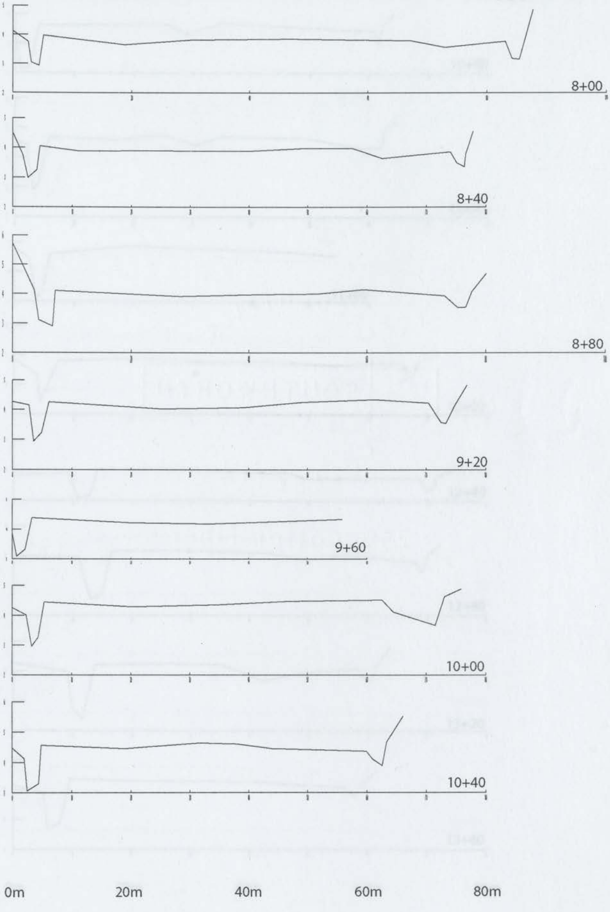
Appendix B

Wasson Creek Cross-sections 4+00-7+60, 5x Vertical Exaggeration



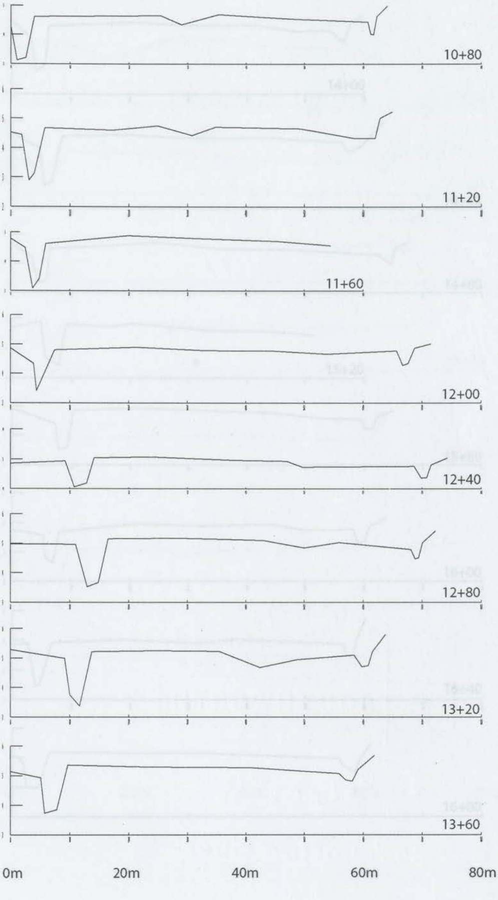
Appendix B

Wasson Creek Cross-sections 8+00-10+40, 5x Vertical Exaggeration



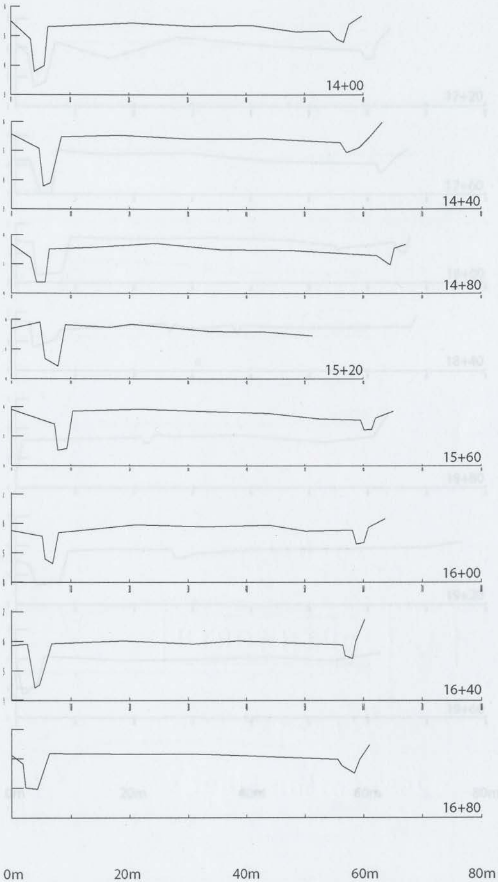
Appendix B

Wasson Creek Cross-sections 10+80-13+60, 5x Vertical Exaggeration



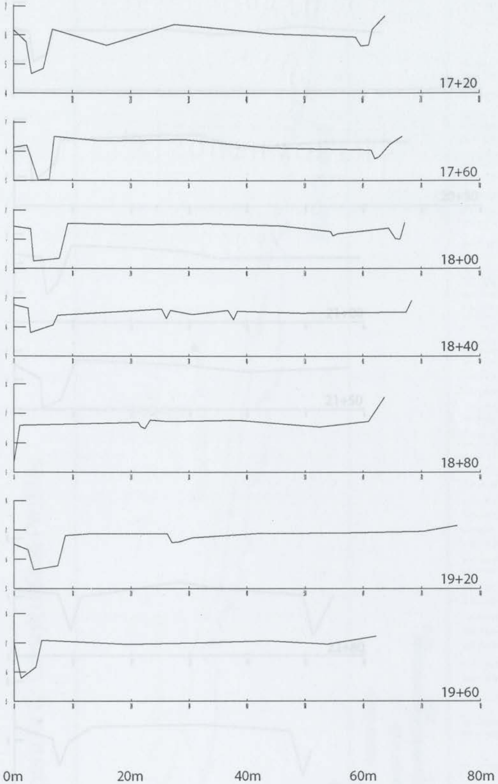
Appendix B

Wasson Creek Cross-sections 14+00-16+80, 5x Vertical Exaggeration



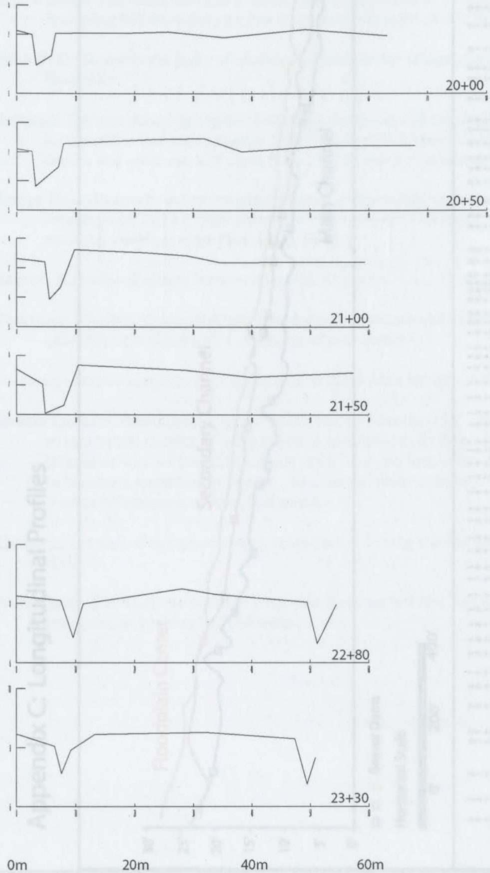
Appendix B

Wasson Creek Cross-sections 17+20-19+60, 5x Vertical Exaggeration

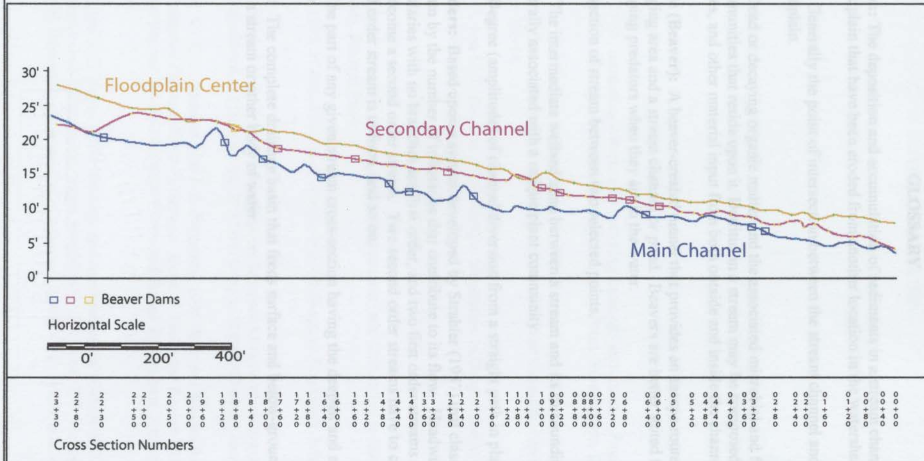


Appendix B

Wasson Creek Cross-sections 20+00-23+30, 5x Vertical Exaggeration



Appendix C: Longitudinal Profiles



GLOSSARY

Aggradation: The deposition and accumulation of sediments in a stream channel or on a floodplain that have been eroded from another location in the watershed.

Bank Full: Generally the point of intersection between the stream channel and the floodplain.

Detritus: Dead or decaying organic matter and the associated microbial and fungal communities that reside upon it. Detritus in a stream may be composed of sticks, leaves, and other material input from both outside and inside the channel.

Plunge Hole (Beaver): A beaver-created tunnel that provides an escape route between a foraging area and a stream channel or pond. Beavers are better suited for escaping predators when they are in the water.

Reach: A section of stream between two selected points.

Riparian: The intermediate wetland zone between a stream and its surrounding uplands, generally associated with a unique plant community.

Sinuosity: Degree (amplitude) of channel diversion from a straight path in plan-view.

Stream Orders: Based upon a system developed by Strahler (1957) that classifies a stream by the number of tributaries that contribute to its flow. Headwater tributaries with no branches are first order, and two first order streams must merge to become a second order stream. Two second order streams have to combine if a third order stream is to form, and so on.

Thalweg: The part of any given stream cross-section having the deepest and strongest flow.

Watershed: The complete drainage basin that feeds surface and below-ground water into a stream or other body of water.

LITERATURE CITED

Aleksiuk, M. 1968. Scent-mound communication, territoriality, and population regulation in beaver (*Castor canadensis* Kuhl). Journal of Mammalogy **49**:759-762.

Allan, J. D. 1995. Stream Ecology: Structure and function of running waters. Chapman & Hall, New York.

Barnes, D. M., and A. U. Mallik. 2001. Effects of beaver, *Castor canadensis*, herbivory on streamside vegetation in a northern Ontario watershed. Canadian Field-Naturalist **115**:9-21.

Bergerud, A. T., and D. R. Miller. 1977. Population dynamics of Newfoundland beaver. Canadian Journal of Zoology **55**:1480-1492.

Cairns, J. J. 1988. Increasing diversity by restoring damaged ecosystems. Pages 333-343 *in* E. O. Wilson, editor. Biodiversity. National Academy Press, Washington, DC.

Ebersole, J. L., W. J. Liss, and C. A. Frissell. 1997. Restoration of Stream Habitats in the Western United States: Restoration as Reexpression of Habitat Capacity. Environmental Management **2**:1-14.

Franklin, J. F., and C. T. Dyrness. 1988. Natural Vegetation of Oregon and Washington. Oregon State University Press, Corvallis.

Gorshkov, Y. A., A. L. Easter-Pilcher, B. K. Pilcher, and D. Gorshkov. 1999. Ecological restoration by harnessing the work of beavers. Page 69 *in* P. E. Busher and R. M. Dziecidowski, editors. Beaver Protection, Management, and Utilization in Europe and North America. Plenum Press.

Guard, B. J. 1995. Wetland Plants of Oregon and Washington. Lone Pine Publishing, Renton, WA.

Guthrie, D., and J. Sedell. 1988. Primeval beaver stumped Oregon coast trappers. News & Views, Department of Fisheries and Wildlife, Oregon State University **June**: 14-16.

Harrelson, C. C., C. L. Rawlins, and J. P. Potyondy. 1994. Stream Channel Reference Sites: An Illustrated Guide to Field Technique. General Technical Report RM-245. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Hayes, J. P., and J. C. Hagar. 2002. Ecology and management of wildlife and their habitats in the Oregon Coast Range. Pages 99-134 *in* S. D. Hobbs, J. P. Hayes, R. L. Johnson, G. H. Reeves, T. A. Spies, J. C. Tappeiner II, and G. E. Wells, editors. Forest and Stream Management in the Oregon Coast Range. Oregon State University Press, Corvallis, OR.

Hilfiker, E. L. 1991. Beavers: water, wildlife and history. Windswept Press, Interlaken.

Hillman, G. R. 1998. Flood wave attenuation by a wetland following a beaver dam failure on a second order boreal steam. Wetlands **18**:21-34.

Hudson, W. F., and P. A. Heikkila. 1997. Integrating public and private restoration strategies: Coquille River of Oregon. Pages 235-252 *in* J. E. Williams, C. A. Wood, and M. P. Dombeck, editors. Watershed Restoration: Principles and Practices. American Fisheries Society, Bethesda, MD.

Johnston, C. A., and R. J. Naiman. 1990. Aquatic patch creation in relation to beaver population trends. Ecology **71**:1617-1621.

Jones, C. G., J. H. Lawton, and M. Shachak. 1994. Organisms as ecosystem engineers. Oikos **69**:373-386.

Jones, C. G., J. H. Lawton, and M. Shachak. 1997. Positive and negative effects of organisms as physical ecosystem engineers. Ecology **78**:1946-1957.

Knighton, D. 1998. Fluvial forms and processes : a new perspective, Rev. and updated ed edition. Arnold, London ; New York.

Leopold, L. B. 1995. Fluvial Processes in Geomorphology. Dover Publications, New York.

Long, K. 2000. Beavers: A Wildlife Handbook. Johnson Books, Boulder, CO.

Lyons, K.E. 1998. Element Stewardship Abstract for *Phalaris arundinacea* L. Reed Canary Grass. The Nature Conservancy, Arlington, VA.

Maser, C., and J. R. Sedell. 1994. From the Forest to the Sea: The Ecology of Wood in Streams, Rivers, Estuaries, and Oceans. St. Lucie Press, Delray Beach, FL.

Middleton, B. 1999. Wetland Restoration: Flood Pulsing and Disturbance Dynamics. John Wiley & Sons, New York.

Mills, E. A. 1913. In Beaver World. Houghton Mifflin, Boston.

Mitsch, W. J., and J. G. Gosselink. 2000. Wetlands, Third edition. John Wiley & Sons, New York.

Muller-Schwarze, D., and L. Sun. 2003. The Beaver: Natural History of a Wetlands Engineer. Cornell University Press, Ithaca.

Naiman, R. J., J. M. Melillo, and J. E. Hobbie. 1986. Ecosystem alteration of boreal forest streams by beaver (*Castor canadensis*). Ecology **67**:1254-1269.

National Research Council (N.R.C.). 1992. Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy. National Academy Press, Washington, DC.

NOAA. 2004. Local Climatological Data, Charleston, Oregon.

Nolet, B. 1997. Management of the beaver (*Castor fiber*): towards restoration of its former distribution and ecological function in Europe. Nature and Environment **86.**

Oregon Climate Service (O.C.S.). 2004. Climate Summary for North Bend, Oregon.

Reeves, G. H., K. M. Burnett, and S. V. Gregory. 2002. Fish and aquatic ecosystems of the Oregon Coast Range. Pages 68-98 *in* S. D. Hobbs, J. P. Hayes, R. L. Johnson, G. H. Reeves, T. A. Spies, J. C. Tappeiner II, and G. E. Wells, editors. Forest and Stream Management in the Oregon Coast Range. Oregon State University Press, Corvallis.

Stone, L. S., P. F. E. Corp, O. D. o. S. Lands, and U. S. O. o. O. a. C. R. M. S. P. Division. 1987. A physical and biological inventory of streams in the South Slough estuarine system. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of Ocean and Coastal Resource Management, Sanctuary Programs Division, Washington, D. C.

Strahler, A. N. 1957. Quantitative analysis of watershed geomorphology. American Geophysical Union EOS Transactions **38**:913-920.

Stromberg, J. C., and M. K. Chew. 2002. Flood pulses and restoration of riparian vegetation in the American Southwest. Pages 11-49 *in* B. Middleton, editor. Flood Pulsing in Wetlands: Restoring the Natural Hydrological Balance. John Wiley and Sons, New York.

Strong, P. 1997. Beavers: Where Waters Run. Northword Press, Minnetonka, MN.

Suzuki, N., and W. C. McComb. 1998. Habitat classification models for beaver (*Castor canadensis*) in the streams of the central Oregon Coast Range. Northwest Science **72**:102-110.

USDA Soil Conservation Service (S.C.S.). 1989. Soil Survey of Coos County, Oregon. National Cooperative Soil Service, Washington, DC.

Voigt, D. R., G. B. Kolenosky, and D. H. Pimlott. 1976. Changes in summer foods of wolves in central Ontario. Journal of Wildlife Management **40**:663-668.

Warren, E. R. 1927. The Beaver: Its Works and Ways. Williams and Wilkins, Baltimore.

Williams, J. E., C. A. Wood, and M. P. Dombeck. 1997. Understanding watershed-scale restoration. Pages 1-13 *in* J. E. Williams, C. A. Wood, and M. P. Dombeck, editors. Watershed Restoration : Principles and Practices. American Fisheries Society, Bethesda, MD.