# The Beaver Solution

## An Innovative Solution for Water Storage and Increased Late Summer Flows in the Columbia River Basin

Grant #G0900156

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## Abstract

Eastern Washington (WA) faces increasing water resource demands and a relatively fixed supply. The inability of our streams to store spring runoff has resulted in reduced flow in the Columbia River when peak water demand occurs in the summer and fall.

Water in beaver ponds, however, is slowly released through the inherently leaky nature of beaver dams and through groundwater seepage. The Lands Council undertook a year-long study to quantify the amount of water that could be stored by re-introducing beaver throughout Eastern WA. Research focused on two objectives: (1) to quantify the volume of water stored behind existing beaver dams throughout the study area and (2) to identify and quantify, in miles, stream segments with currently suitable habitat for beaver.

Our study of beaver dams in Eastern WA determined that the average surface water storage is 3.5 acre-feet. An additional five to 10 times more water is stored in the groundwater around the dams, meaning that each dam has the potential to store between 17.5 and 35 acre-feet of water. A habitat suitability analysis for beaver evaluated streams in Eastern WA based on slope, elevation, stream order, and transportation proximity. The results showed that 9,828 miles of stream met all criteria. An additional analysis to estimate vegetation availability found that approximately 70% of these stream miles have sufficient vegetation for beaver.

Final estimates reveal that beaver can potentially store between 2 and 4 million acre-feet of water in Eastern WA. Based on these findings, it is the belief of The Lands Council that natural storage reservoirs can be developed through beaver re-introduction on tributaries of the Columbia River as a cost-effective alternative to building large dams. It is hoped that these findings will be used to re-introduce beaver beginning in 2010 as part of the fulfillment of the water storage requirements of the Columbia River Basin Water Management Program (HB 2860).

# Introduction

In 2006, the Washington State Legislature directed the Department of Ecology (DOE) to "aggressively pursue development of water supplies to benefit both in-stream and out-of-stream uses" by enacting House Bill 2860, commonly referred to as the Columbia River Basin Water Management Program. The objective of this program is to provide an additional 3 million acre-feet of water storage that would benefit people, farms, and fish during the low flow periods of the year. Beginning in 2007, the DOE undertook an appraisal-level study for the potential development of dams and reservoirs in side channels of the Columbia River. A $30,000 grant from the DOE partially funded The Lands Council's initial research on using beaver activity as a viable water storage option. The purpose of this study was to (1) understand the potential of using beaver dams to store water and increase late-season flow in the upper Columbia River Basin and (2) to identify suitable habitat for beaver throughout 12 Eastern Washington counties: Pend Oreille, Stevens, Ferry, Okanogan, Chelan, Douglas, Kittitas, Grant, Lincoln, Spokane, Adams, and Whitman.

### *History of Problem*

*Changing hydrology.* Eastern Washington needs more options to manage its water due to increasing demands from downstream users, fish, and wildlife (Casola et al., 2006). Snowpack melts heavily and causes the highest volume of water to run downstream in the spring, when water demands are low, so most of the year's snowpack runoff cannot be used during the high-demand dry periods in summer and fall. The limited ability of our streams and rivers to store spring runoff results in reduced flow in the Columbia River when peak water demand occurs in the late summer and fall from farmers, cities, and salmon.

Climate change and increased demands for water in the Columbia Basin are urgent issues (Casola et al., 2006). In many areas, the demand for hydroelectric power, farm irrigation, salmon restoration, recreational activities, and municipal water supplies has left little water available to support healthy aquatic ecosystems. Potential changes in our water storage arrangements with Canada are an unknown variable that could further stress existing water supplies. A trend toward conversion of food cropland to energy crop production may also increase demand for water. For these reasons, all methods of retaining winter snowmelt and increasing water availability and storage in the Columbia Basin should be explored. While many studies focus on large engineered water storage projects, our study of natural water storage by beaver explores the potential and practicality of natural storage methods.

*History of beaver population and its reduction over time.* Since the last Ice Age nearly 15,000 years ago, beaver were the predominant managers of streams and wetlands throughout North America. Prior to the colonization of North America by European settlers, it is estimated that beaver numbered close to half a billion, with a range from the Arctic tundra south to the deserts of Mexico (Allen, 1983). They were present in every watershed and directly influenced the annual hydrograph through dam construction and water storage.

The history of beaver trapping in North America, and specifically the Columbia Basin, provides critical insight into the number of beaver that once inhabited this region and their role in maintaining healthy watersheds (Muller-Schwarze and Sun, 2003; Ott, 2003).

The Hudson's Bay Company (HBC) dominated fur trapping and trading throughout North America between the 17th and 19th centuries, when beaver pelt, which is waterproof and very insulating, was very valuable. As the United States began to emerge as a major power in the early 19th century, European trappers sought to eliminate the North American beaver population, believing this would devalue the land. After the Convention of 1818, the HBC established a "fur desert" policy within the Snake Country (the Snake River area of Idaho and its tributaries and eastern Oregon). Fearing the United States' control of the Pacific Northwest, the company decided to trap out all beaver from the United States in the early 1820s. They believed that the value of the land would be greatly depreciated without beaver (Ott, 2003).

In 1823, 4,500 beaver were trapped during the first Snake Country HBC Expedition. In the next expedition, trappers took out 18,000 beaver over 6 years from an area south of the Columbia River (Ott, 2003). As early as 1824, lead trapper Skene Ogden noted in his journal, "this part of the Country tho' once abounding in Beaver is entirely ruined" (Ott, 2003). By 1831, beaver trapping declined because the HBC did not know if the profits of the beaver pelts would justify the cost of sending out the trappers (Ott, 2003).

From the late 1820s through the early 1850s, the amount of beaver trapped in the Columbia District was steady, as shown by trapping records from the Snake Country and Fort Colville (not far from today's Colville, Washington). As a result of beaver trapping, the landscape began to change (Ott, 2003). Observations by trappers indicate that the extraction of beaver affected the level of the water table, caused erosion and sedimentation, increased evaporation rates, and impacted wildlife populations (Ott, 2003).

Many factors, including temperature increases and precipitation decreases in the 1820s and 1830s, trapping by Native Americans, fires, predation, and disease, contributed to the massive decline of beaver. However, the main drivers that led to their near-extinction by the mid- to late-1800s were political motivations and the value of beaver pelts. (Ott, 2003).

Beaver are slowly making a comeback in their historical watersheds, but human development has significantly altered the landscape. Many stream systems are no longer able to support the historic number of beaver that once flourished. Personal interviews with regional biologists of Washington Department of Fish and Wildlife reveal that beaver have rebounded to numbers in Eastern Washington around 50,000, a far lower number than their historical levels.

***Literature Findings on Water Storage***

Beaver function as ecosystem engineers, profoundly impacting stream hydrology, sediment transport, vegetation, water storage, and late season stream flows (Gurnell, 1998; Naiman, 1988; Rosell et al., 2005). Beaver construct dams to transform a shallow stream system into a wetland or lake area with sufficient depth to cover the entrance to their lodge. The water that covers the lodge entrance acts as a barrier for predators and allows beaver access to a winter food cache that they store under the water's surface (Allen, 1983; Collen and Gibson, 2001; WDFW, 2004).

To understand beavers' ability to store water, we conducted a review of relevant scientific literature. The literature supports the notion that beaver dams increase the water storage potential of small order streams (Gurnell, 1998; Neff, 1957; Rosell et al., 2005), through surface water stored behind dams and elevated water tables in areas near beaver dams (Lowry and Beschta, 1994; Westbrook, Cooper, and Baker, 2006; Woo and Waddington, 1990). There is evidence that beaver dams and groundwater reserves act as a buffer to the stream system, holding back

snowmelt and rain runoff and releasing it over time (Gurnell, 1998; Parker, 1986; as cited in Collen and Gibson, 2001).

*Storage of surface water and alteration of flow.* In the mid-1950s, DJ Neff studied the flow and amount of flooded area in the two headwaters of Chavez Creek, which held abandoned beaver colonies, and on Nutras Creek at a site where beaver colonies were active. Both streams were in glaciated, forested valleys in the Colorado Rockies. Results are shown in table 1.

TABLE 1. — WATER STORAGE CHARACTERISTICS, NUTRAS-CHAVEZ BEAVER-ABANDONMENT STUDY AREA, SAGUACHE COUNTY, COLORADO, 1954-55

| Characteristic | Nutras Creek | West Chavez | East Chavez |
|---|---|---|---|
| Stream flow at study area (second-feet) | 9.64 | 0.77 | 0.96 |
| Per cent of valley bottom area flooded[1] | 44.64 | 35.70 | 19.01 |
| Maximum potential water storage capacity[1] (acre-feet) | 23.78 | 16.63 | 9.63 |
| Actual water storage, Sept. 1955 (acre-feet) | 18.12 | 0.22 | nil. |

[1] If all recognizable ponds were full to capacity.

*Table 1.* From "Ecological effects of beaver habitat abandonment in the Colorado Rockies," by DJ Neff, 1957, *Journal of Wildlife Management, 21(1)*, p. 80–84.

Results from this study indicate that active beaver dams increase storage of water. Measurements taken in the fall (September 1955) show that stream flow is 10 times greater in a stream with beaver dams than in control streams without beaver (Neff, 1957).

In 1980, M. Allred published an article showing that stream flows were doubled a quarter mile downstream of beaver dams over flows directly below them, indicating elevated groundwater seepage. Although Allred's study is limited and not quantitative, his findings suggest that alteration of flow by beaver conserves water resources. (Allred 1980)

In 1990, Woo and Waddington focused on beaver impounded and un-impounded areas in coastal wetlands and streams in Ontario, providing empirical evidence that beaver ponds store water. The following water balance equation was used to characterize total inflow and outflow of a dammed vs. free-flowing water basin:

$$P + Qi + Gi = E + Qo + Go + ASd + ASp + ASg$$

"…where P is rainfall, Q and G are surface and groundwater flows, E is evaporation, ASd, ASp and ASg are depression, pond and groundwater storages, and i and o denote inflow and outflow" (Woo and Waddington, 1990). They concluded that "the dammed basin lost more water to evaporation, suppressed the outflow and increased the basin water storage." The figure below shows the inflow and outflow of both studied basins over 1.5 months. The bottom graph shows that inflow exceeds outflow in a beaver-dammed basin during heavy precipitation events, demonstrating water storage and flood attenuation. The data indicate that in a beaver-dominated stream, water is held back longer and released slower than in a stream without beaver dams.

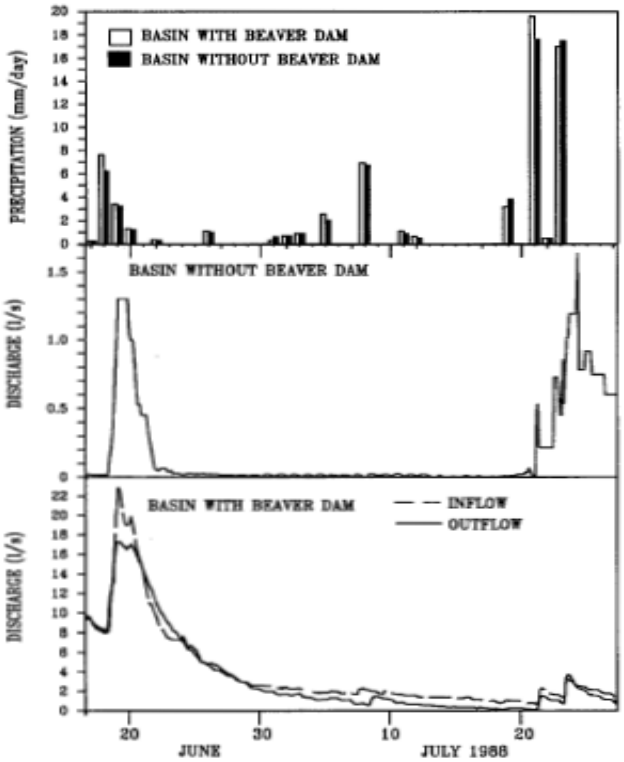


FIG. 8. Rainfall, evaporation and discharge for the basins without and with a beaver dam during the period 19 June to 28 July 1988.

*Figure 1*. From "Effects of Beaver Dams on Sub-Arctic Wetland Hydrology" by MK Woo and JM Waddington, 1990. *Arctic, 43*, p. 223–230.

Gurnell (1998) concluded that kinetic stream energy is dissipated at beaver dam sites, which forms steps in the streams. This causes ponds to form behind dam sites, which can also attenuate flooding by storing water during heavy precipitation events. Ponds subsequently sustain low flows by the slow release of stored water. Devito and Dillon's (1993) study found that when a beaver pond was full, water was discharged through overtopping, but when water was more than 5 cm below the dam crest, discharge was limited to dam seepage.

Collen and Gibson's (2001) review further examines the hydrological effects of beaver dams and shows that they significantly affect the downstream delivery of water. In one instance, beaver dam ponds effectively contained all the water from a storm event (51 mm) that occurred in previously dry conditions and provided some retention during large snowmelt events (Burns and McDonnell, 1998).

Both Gurnell's (1998) and Collen and Gibson's (2001) reviews concluded that beaver dams have water storage impacts during low and high flows.

Rosell et al. (2005) summarizes water storage capacity with the following statement:

> During dry periods, Duncan (1984) reported that up to 30% of the water in an Oregon catchment could be held in beaver ponds. By increasing storage capacity, it has been suggested that large numbers of beaver dams will lead to greater flows during late

summer (Parker 1986), which may result in continual flows in previously intermittent streams (Yeager & Hill, 1954; Rutherford, 1955).

Water spread over multiple channels is another aspect of water storage created by beaver dams. Rosell et al. (2005) finds in the Townsend (1953) and Woo and Waddington (1990) studies that stream channels may be divided into smaller, interconnected channels, which may become permanent routes of water flow. A study by Snodgrass (1997) shows that beaver dams also increase the amount of perennial streams in a watershed, a clear indication of an increase in above-ground water flow and storage.

*Groundwater storage*. Lowry and Beschta (1994) measured groundwater elevations and temperatures at beaver ponds in central Oregon. At their study sites, they observed that groundwater levels near the pond rose 0.3 m on average between August and November 1991. They also observed that the pond was "creating a large zone of groundwater storage with groundwater surface elevations that are relatively higher than in adjacent areas and which extend into the floodplain and slightly downstream of the dam." A well downstream of the dams and adjacent to the stream had a temperature lag time of about three months, which they interpreted to indicate impounded water is stored in the area for approximately three months.

Westbrook, Cooper, and Baker (2006) examined the effects of two beaver dams on surface inundation, groundwater levels, and flow patterns over three summers on the Colorado River in Rocky Mountain National Park. The results reveal that "beaver dams and ponds greatly enhanced the depth, extent, and duration of inundation associated with floods; they also elevate the water table during both high and low flows." The authors argue that beaver dams accomplish many of the same outcomes as overbank flooding, which has long been recognized as a key hydrological action (Workman and Serrano, 1999). These results provide empirical evidence to show that groundwater is stored in and around beaver ponds.

In summary, decades of peer-reviewed research have found that beaver dams store water above ground, in shallow adjacent sediments as groundwater, through wetland creation, and in multi-channel systems. Empirical evidence also shows that beaver dams can increase discharge during low flow and attenuate high-flow events.

### *Scope of Study*

Though it is clear that beaver, once abundant in the Northwest, are capable of storing water, evidence remains scarce as to how much water beaver can store and where suitable beaver habitat is available in Eastern Washington. This study examines whether (1) beaver are capable of meeting a large portion of Washington State's water storage needs (as defined in HB 2860) by providing a source of late summer water flow through natural water storage, and whether (2) there still exists a significant number of stream miles that contain suitable habitat for beaver to repopulate.

This paper examines the following:

1. The field methods used to measure the surface water storage in beaver dam complexes in 11 counties in Eastern Washington (dams were not measured in Kittitas County) are discussed. Water storage, groundwater storage, and field observations were measured for the dam complexes.

2. A habitat suitability index is proposed to show the available stream miles for beaver reintroduction in Eastern Washington based on four habitat characteristics. Analysis to estimate the proportion of stream miles with currently available vegetation follows.
3. Finally, the results from these two studies, as well as prior scientific literature, are used to estimate optimum beaver dam frequency per stream mile and to estimate the total water storage potential for beaver relocation in Eastern Washington. Results of each study and discussion follow. To address management concerns associated with beaver reintroduction, techniques to avoid beaver nuisances are also addressed.

## Methods

***Beaver Dam Water Storage Study***

To analyze a sample of beaver dams across the study area, The Lands Council measured at least one dam or a dam complex (dams all maintained by one family) in each of the 12 counties of the study area. Beaver dams were located with the help of natural resource and wildlife agencies. Dams were found in rural to urban locations, small- and medium-sized streams, agricultural and non-agricultural locations, public and private lands, and in both disturbed and non-disturbed areas. Initial measurements were taken June through August, while follow-up measurements at selected sites were taken in September and October, to observe dams at lower water levels. The Lands Council developed a methodology for measuring beaver dam complexes. The number of dams in a complex was recorded, though it was not considered necessary to measure all dams in a complex.

*Above-ground water storage.* Water storage of a beaver pond was considered to begin behind a given beaver dam and continue until another beaver dam or until a riffle in the stream. To determine the water storage capacity of each beaver pond, numerous depth points were recorded throughout the entire pond using a Trimble Geo XM handheld Global Positioning System (GPS*)* receiver (x-y accuracy to within 1 meter) and a standard 10-foot depth pole marked in ¼ foot increments. These measurements were made by wading or boating (where possible) into the beaver ponds to measure depths roughly 10 feet apart. This criteria method was altered where necessary to accommodate large vegetation mats and other inaccessible points in the wetland. Data points were taken closer together to capture pond bed topography when the pond bottom seemed to be changing dramatically. A thalweg was described where data permitted. Additionally, depth points were taken around the perimeter of the beaver pond and assigned a value of zero to define the perimeter of the beaver pond and for use in volume analysis. The length of the actual beaver dam, from vertex to vertex, was also recorded with the same GPS unit. When all depth and length points were taken, the data was imported from the GPS unit into ArcView 9.2 for analysis.

The pond depth measurements were clipped out of the master depth point data layer to create a depth point data layer for each individual pond. Each of these pond data layers was then processed through the Spline tool in ArcView 9.2 to develop a functional surface that approximated the bottom of the pond. Occasionally, the Spline tool created unexpected depth values outside of the pond perimeter and extra data points were added to force the Spline tool to stay within the recorded pond perimeter. Once the functional surface was developed, it was finally processed through the surface volume tool in ArcView to determine the volume present below the zero point (no depth) of the pond perimeter. This calculated the total surface water

volume of the individual ponds that were measured. Electronic formats of the resulting data can be found at www.landscouncil.org/beaversolution.

*Storage over time.* Following July measurements, the dam complexes in Whitman and Chelan Counties were re-measured in September and October to better quantify water storage patterns during the driest months. The depth of the thalweg in each pond was recorded and compared to July's data in ArcView. The change in depth between the thalweg in summer and fall was applied to the entire pond volume to show the change in water storage, using the Spline tool in ArcView 9.2.

Over the course of the summer through September 2009, a field researcher also visited the Liberty Lake dam complexes in Spokane County every other week to observe changes in pond levels and flow. Due to great variances in pond depths, those results were not analyzed in ArcView.

*Groundwater storage.* Wetland presence near and surrounding beaver dams and ponds was noted. Personal interviews and field observations were also used to estimate groundwater storage. Due to the complicated and expensive nature of other means of groundwater measurement, further methods were not employed. Storage values must be considered estimates.

*Field observations.* Dominant riparian species, defined as covering over 10% of the beaver pond and riparian area, were recorded at each site. Fish presence in the ponds behind beaver dams was also recorded. These and other field observations are included in Section 9.1, Appendix A.

***Habitat Suitability Index***

Geographic Information System (GIS) software was used to identify suitable beaver habitat in the study area. The proposed habitat suitability index utilizes slope, elevation, transportation proximity, and stream type. A fifth criteria, vegetation availability, used a separate method to determine suitability. These criteria are based on a literature search and are all key to long-term beaver habitat.

Key Habitat Characteristics

- elevation less than 6,000 ft
- low slope grade of 6% or less
- first through fourth order streams (WA Dept. Fish & Wildlife, 2004)
- presence of aspen, willow, or other desired riparian vegetation (Allen, 1983; Barnes and Mallik, 1996; Collen and Gibson, 2001; Gurnell, 1998; WA Dept Fish & Wildlife, 2004)
- proximity to major human transportation routes is considered so that habitat near roads is not utilized, decreasing potential flooding or other conflict with the built environment.

The data for the suitability index was generally available online from state agencies or other repositories of free GIS data. This data was downloaded and pre-processed to ensure a common data projection and coverage over the entire study area.

| Data Set Name | Availability |
|---|---|
| National Elevation Dataset (NED) @ 1 arc second | USGS Seamless Server |
| Transportation Network | Washington State Department of |

| | |
|---|---|
| | Transportation |
| Wahington State Watercourse Hydrography | Washington Deptartment of Natural Resources |
| Washington Orthoimagery (2006 NAIP) | Washington State Imagery Portal through Department of Ecology |

*Table 2.* Source of data for the suitability index.

The National Elevation Dataset (NED) data for elevation at 1 arc second available from the USGS seamless server was downloaded for the area of interest in 26 individual packets. These packets were then combined in ArcView 9.2 using the Mosaic function. Finally, the data was roughly clipped to cover the 12 counties of the study area. This dataset is additionally used as a starting point to develop the slope and elevation datasets below.

*Slope.* The raw NED elevation data was processed using the Slope function in ArcView to develop the slope layer in percent slope. This layer was then reclassified into areas with slope less than 6% and areas with slope greater than 6%. Areas with a preferred slope (below 6%) were given a value of 1 and areas above 6% were given a value of 2.

*Elevation.* The NED elevation data was reclassified into two categories based on beaver habitat preferences. Preferred areas (less than 6,000 feet above mean sea level) were given a value of 1 and areas over 6,000 feet were given a value of 2.

*Stream type.* The Washington State Watercourse Hydrography dataset was downloaded from the Department of Natural Resources website. This data was then clipped to the 12 counties of interest and included every potential water course in the study area. The data was examined and unsuitable water features were removed. These removed features included but are not limited to:

- Large rivers: Columbia, Snake, Spokane, Kettle, Pend Oreille, Wenatchee, and Yakima
    - The large rivers within the study area are too large for beaver to dam. However, some of the smaller rivers are occasionally dammed duirng extremely low water years.
- Coulees: Upper Grand Coulee and Moses Coulee
    - The coulees of the Columbia Plateau tend to be extremely dry except during the wettest years. This is not a habitat that is suitable for beaver or advantagous for water storage.
- Irrigation infrastructure: Frenchman Hills Wasteway, Bacon Siphons, etc.
    - Irrigation infrasturcture can provide suitable habitat for beaver, but the damage that can be caused when beaver plug an irrigation ditch may create conflicts with users.
- Unnamed streams: removed unnamed streams and side channels
    - The unnamed streams and side channels tend to be too steep for beaver. These extremely small channels also have water flow that occurs inconsistently. These unnamed streams also tend to have undefined stream channels on which beaver can construct dams.

- Lakes: Banks Lake, Moses Lake, Lake Chelan, etc.
    - While lakes do provide excellent habitat for beaver, there is no additional water storage benefit for beaver that build lodges on lake shores.
- Draws: Deadman Draw
    - Draws tend to be wet only during flash flood events. This is not a suitable habitat for the development of beaver dams because of the lack of a steady source of water.

The removal of these unsuitable water features reduced the dataset to smaller first through fourth order streams with a permanent to semipermanent flow. These potentially suitable water features were buffered to a distance of 150 feet (300 feet total). This buffer provided an estimate of the floodplain and an analog for the actual stream system. This data layer was then converted into a raster dataset with a resolution set to 1 arc second. Streams, being the preferred data in this dataset, received a value of 1, and areas without streams received a value of 2.

*Proximity to roadways.* The transportation network data was downloaded from the Washington Department of Transportation and clipped to the counties of the study area. The network data provided "road centerline arcs" for all roads in the study area. To address the width of roadways, the data was buffered to 100 feet on each side of the arc (200-foot total roadway width). This data was then converted to a raster dataset with a resolution of 1 arc second. In this dataset, waterways intersecting roads were given a value of 2 and waterways clear of roads were given a value of 1.

*Combined analysis.* The above four habitat suitablity data layers were used to determine the most suitable reaches of streams through a raster addition function. All data layers were added together and the resulting layer provided values based on the combined values of all the layers. Values in this layer ranged from 4 to 8, where all values of 4 provided optimal suitable habitat for beaver and values higher than 4 showed that one or more of the suitability criteria was violated. Only values of 4 were considered suitable habitat for further analysis. This layer was finally converted back into a polygon shape file and used to clip the original stream data layer to eliminate the unsuitable stream reaches and develop a stream data layer that contained only the stream reaches with suitable beaver habitat.

*Vegetation availability.* Methods used thus far to determine habitat suitability could not be applied to the final criteria of vegetation availability. We developed another method to find what proportion of the suitable beaver habitat, as defined by slope, elevation, stream type, and road proximity, currently supported desired vegetative communities. Without the ability to check all stream miles for suitable vegetation, we generated a statistically sound sample size using an online sample size calculator by Raosoft. We conservatively assumed that 50% of the population (i.e., stream miles) would have suitable vegetation. This number corresponds with the response distribution necessary for calculations. We chose a 90% confidence interval because the same is used in EPA aquatic resource monitoring. Raosoft's sample size calculator revealed the following:

> With approximately 9,500 miles[1] of available stream, at a 90% confidence interval, we accepted a 5.75% margin of error and assumed the response

[1] 9,500 is derived from results of the Habitat Suitability Index. For more information, see section 3.2

distribution is 50%. A sample size of 200 sites was necessary.

To conduct the analysis, 200 sites of the already determined suitable stream miles were randomly selected by the GIS software. These sites were then laid over July 2006 NAIP Orthoimagery for the study area. Each of these sites was then visually inspected to estimate presence of suitable vegetation for beaver.

***Final Water Storage Estimation***

Once analysis in the above area was complete, results were combined to estimate the optimal water storage potential following beaver reintroduction in suitable habitat throughout Eastern Washington. The following equation was used:

$$S \times D \times (A + (A \times G)) = W$$

Where

- *S* is the total available stream miles containing suitable habitat;
- *D* is the average number of beaver dams per mile in ideal conditions, determined by literature review;
- *A* is the average above-ground water storage capacity of a beaver dam, determined by the beaver dam water storage analysis;
- *G* is the groundwater storage estimate, proportionate to above-ground water storage and determined by personal interview and observation;
- then *W* is the total water storage estimate.

## Results

***Beaver Dam Water Storage Study***

We located dams in every county of the study area except Kittitas. One beaver dam complex thought to be in Ferry County is approximately 5 miles inside Okanogan County. We kept this as the dam site representative of Ferry County because of the size and complexity of the dam system, proximity to Ferry County, and location in a watershed that is predominantly in Ferry County. Figure 2 shows each dam location.

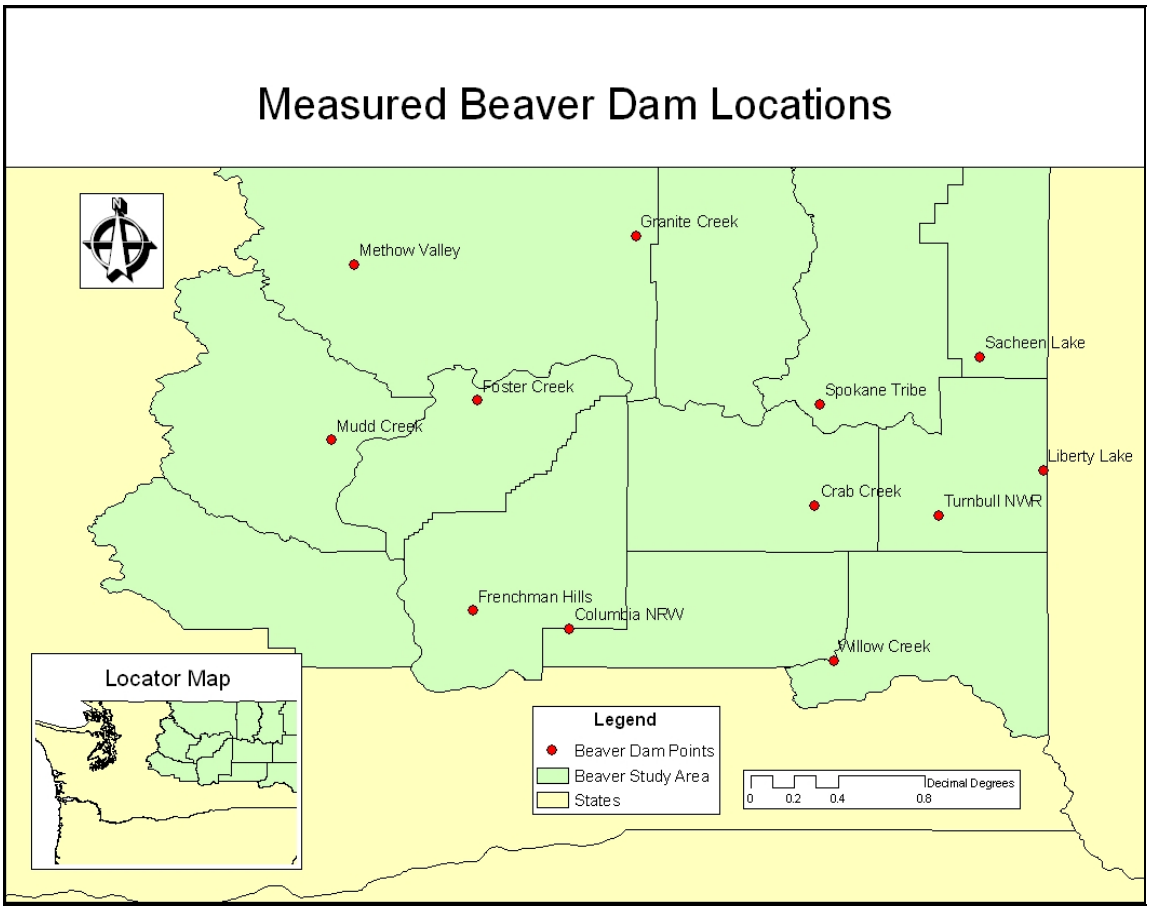


*Figure 2.* Location of measured beaver dams in study area.

Table 3 shows the date each complex was measured, whether or not beaver were actively maintaining the dams, the number of dams in each complex, and other observations.

| County | Active Vs. Inactive | Dams per Complex | Age of Complex | Fish Observed | Date Measured | Date Re-measured | Dominant Riparian spp. |
|---|---|---|---|---|---|---|---|
| Adams | active | 1 | 2 yrs | yes | 7/27/09 | N/A | N/A |
| Chelan | active | 3 | 10+ yrs | no | 7/27/09 | 10/7/09 | willow, aspen, sedges |
| Douglas | active | 5 | N/A | yes | 7/9/09 | N/A | willow, sedges |
| Ferry | active | 6 | 20+ yrs | yes | 6/12/09 | N/A | willow, birch, pine, grass |
| Grant | inactive | 1 | N/A | no | 7/10/09 | N/A | willow, grass |
| Lincoln | active | 3 | N/A | no | 7/10/09 | N/A | willow, |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | grass |
| Okanogan | active | 3 | 2 yrs | yes | 7/29/09 | N/A | maple, aspen, sedges |
| Pend Oreille | active | 3 | 20+ yrs | yes | 6/21/09 | N/A | willow, birch, aspen, pine |
| Spokane | active | 5 | 5+ yrs | yes | 5/14/09 | 9/12/09 | birch, cottonwood |
| Stevens | active | 1 | N/A | yes | 8/9/09 | N/A | willow, cottonwood |
| Whitman | active | 10 | 5+ yrs | yes | 4/15/09 | N/A | willow, sedges, grass |

*Table 3.* Dates of data measurement and field observations.

*Above-ground water storage.* The pond storage values for the day of measurement were determined for up to six dams per complex, with small dams storing as little as 1/8$^{th}$ of an acre foot to large dams storing nearly 50 acre feet. Results reveal an average storage capacity of 3.5 acre feet. Table 4 shows the surface area, cubic foot, acre foot storage values, and wetland presence for each pond.

| County | Dam Location | Dam | Surface Area (acres) | Cubic Feet | Acre Feet | Wetland |
|---|---|---|---|---|---|---|
| Adams | Columbia NWR | Dam 1 | 3.489 | 265,181 | 6.088 | Perimeter |
| Chelan | Mudd Creek | Dam 1 | 0.240 | 23,914 | 0.549 | Medium |
| Douglas | Foster Creek | Dam 1 | 0.052 | 2,353 | 0.054 | Not Present |
| Douglas | Foster Creek | Dam 2 | 0.032 | 1,508 | 0.035 | Not Present |
| Douglas | Foster Creek | Dam 3 | 0.034 | 1,625 | 0.037 | Perimeter |
| Grant | Frenchman Hills | Dam 1 | 0.010 | 562 | 0.013 | Perimeter |
| Lincoln | Crab Creek | Dam 1 | 0.031 | 1,098 | 0.025 | Not Present |
| Lincoln | Crab Creek | Dam 2 | 0.008 | 198 | 0.005 | Not Present |
| Okanogan | Granite Creek | Dam 1 | 2.762 | 520,074 | 11.939 | Not Present |
| Okanogan | Granite Creek | Dam 2 | 3.983 | 710,254 | 16.305 | Not Present |
| Okanogan | Granite Creek | Dam 3 | 1.020 | 57,614 | 1.323 | Large |
| Okanogan | Granite Creek | Dam 4 | 0.557 | 56,914 | 1.307 | Large |
| Okanogan | Granite Creek | Dam 5 | 0.229 | 20,449 | 0.469 | Large |
| Okanogan | Granite Creek | Dam 6 | 0.307 | 17,191 | 0.395 | Large |
| Okanogan | Methow Valley | Dam 1 | 0.290 | 38,110 | 0.875 | Large |
| Pend Oreille | Sacheen Lake | Dam 1 | 0.271 | 24,185 | 0.555 | Perimeter |
| Pend Oreille | Sacheen Lake | Dam 2 | 2.269 | 292,451 | 6.714 | Perimeter |
| Pend Oreille | Sacheen Lake | Dam 3 | 14.774 | 2,110,060 | 48.440 | Several Large |
| Spokane | Liberty Lake | Dam 1 | 1.985 | 110,795 | 2.544 | Medium |
| Spokane | Liberty Lake | Dam 2 | 0.229 | 15,391 | 0.353 | Medium |
| Spokane | Liberty Lake | Dam 3 | 0.156 | 8,727 | 0.200 | Perimeter |
| Spokane | Liberty Lake | Dam 4 | 0.392 | 26,720 | 0.613 | Not Present |
| Spokane | Liberty Lake | Dam 5 | 0.052 | 2,458 | 0.056 | Perimeter |
| Spokane | Liberty Lake | Dam 6 | 0.262 | 19,352 | 0.444 | Not Present |
| Spokane | Turnbull NWR | Dam 1 | 0.410 | 21,009 | 0.482 | Not Present |
| Stevens | Spokane Tribe | Dam 1 | 0.122 | 10,518 | 0.241 | Not Present |
| Whitman | Willow Creek | Dam 1 | 0.036 | 2,814 | 0.065 | Not Present |
| Whitman | Willow Creek | Dam 2 | 0.021 | 1,325 | 0.030 | Perimeter |
| Whitman | Willow Creek | Dam 3 | 0.017 | 986 | 0.023 | Perimeter |

*Table 4.* Surface area, cubic foot, acre foot storage values, and wetland presence for each pond.

*Storage over time.* In Whitman County, all dams in the complex were still fully functioning in the fall. Pond perimeters were visibly reduced, becoming 1–2.5 feet narrower on either side. However, thalweg depths remained the same in the fall as in the summer, making water storage analysis infeasible. The beaver dam in Chelan County was still deep enough that researchers were unable to measure the greatest thalweg depth. Instead, a 1.5-foot drop was noted based on water marks left on vegetation and mud at the pond's perimeter. After processing this through ArcView, the volume analysis showed that the 1.5-foot drop in depth equaled a loss of 0.31 acre feet of water, or 13,642 cubic feet. This 1/3 acre foot of water was slowly released downstream over the 2.5 months between the spring and fall measurements. The rate at which this water was released from the pond was averaged over the period between measurements as follows:

13,642 cubic feet / (86,400 seconds/day x 72 days) = 0.0022 cfs

In the spring, when dams are full and flows are high, the total inflow to a beaver pond is relatively equal to the total outflow. Over summer and fall, outflow becomes greater than inflow: upstream water flow declines, stored pond water is released, and pond levels decline. The 0.31 acre feet of water lost essentially increased flow past the beaver dam by 0.0022 cfs over the flow into the pond from August to October. This extra flow does not include any water that is released from groundwater into or out of the pond.

At the Liberty Lake dam complex in Spokane County, pond elevations remained unchanged and water continued to flow into and out of the ponds during most of the summer of 2009. In mid to late September, the largest pond began to drop in volume as upstream dams were enlarged and expanded. This period of construction eventually eliminated water flow to the largest pond and diverted the water flow into the central wetland complex. The new depth of the ponds and the remote location didn't allow for a re-measuring of the dams following this construction period, but we estimate that overall stored water volumes remained essentially unchanged due to the increased area of storage.

*Groundwater storage.* Although not quantified, wetlands between beaver dams in Okanogan County's Methow Valley clearly store a large amount of groundwater. While trying to find a measureable perimeter of one beaver pond, our field researcher encountered a wetland measuring approximately 3 acres between the end of one beaver pond and the start of another. The soil moisture content was extremely high throughout this wetland, with many small overland flows and saturated soils. In a personal interview, Kent Woodruff, a wildlife biologist with the US Forest Service in Washington's Upper Methow Valley, estimated that groundwater storage is up to 10 times greater than surface water storage. This type of wetland creation is observed at other beaver dams (see Table 4).

*Field Observations.* Willow species were part of the dominant riparian vegetation in 8 of the 11 sites measured. Species were not noted at the Adams County site. Fish were observed in 8 of the 11 sites. Results are included in Table 4, and in further detail in Section 9.1, Appendix A.

***Habitat Suitability Index***

As noted above, the criteria for habitat suitability are

- elevation less than 6,000 ft
- low slope grade of 6% or less
- first through fourth order streams
- low risk of conflicts due to proximity to human transportation ways
- presence of aspen, willow, or other desired riparian vegetation.

Within the 12-county study area, there are approximately 77,000 miles of water courses. The results of the habitat suitability analysis reduced the total number of potentially suitable streams to 9,828 stream miles. After considering vegetation, we estimate with a 90% confidence interval that 70% of the these stream miles in the total study area currently have suitable vegetation. Figure 3 shows the final suitable stream habitat before vegetative analysis.

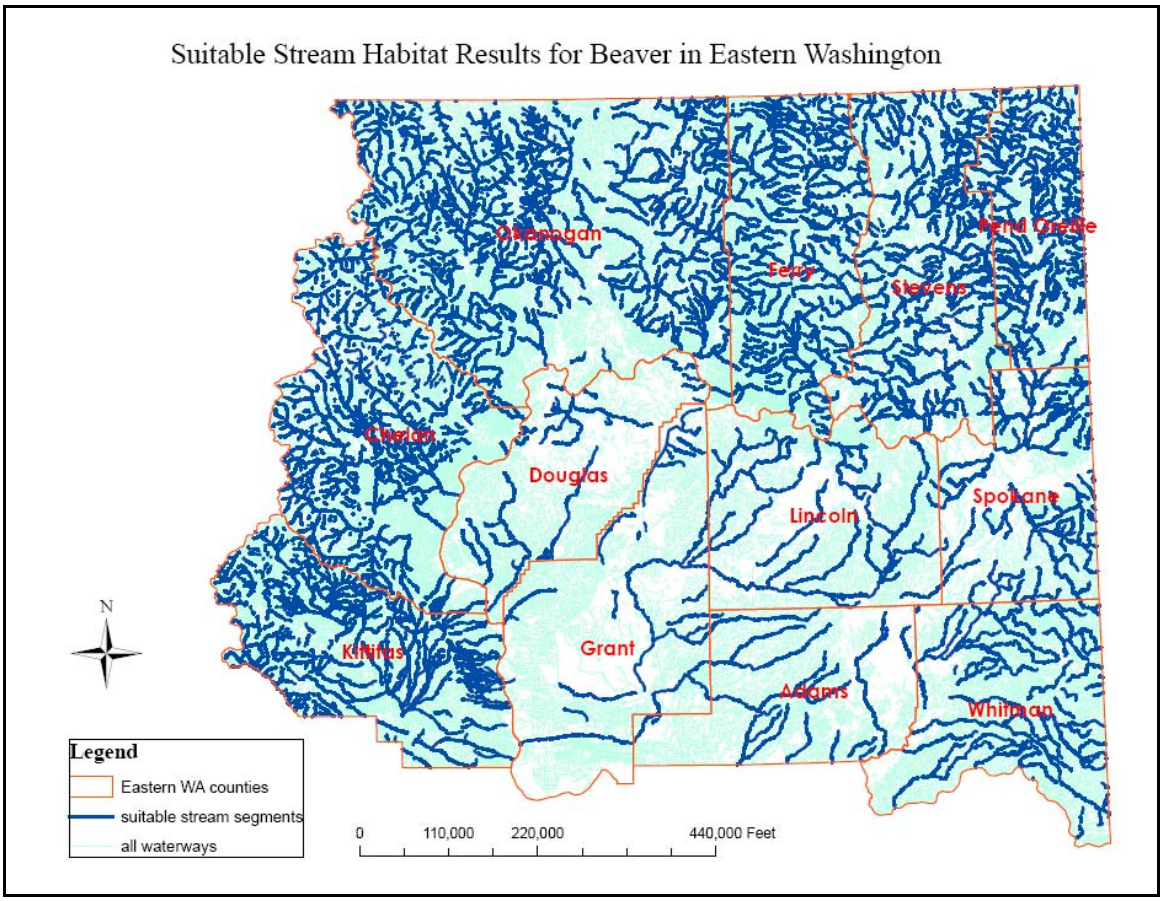


*Figure 3.* Suitable stream segments in the Eastern Washington study area are shown in dark blue. Results are derived from slope, elevation, stream order, and transporation proximity criteria.

Potential habitat is spread almost evenly over both public and private lands. However, the spatial distribution of potential habitat is not as evenly spread within the study area. The highest concentrations of potential habitat are located along the Eastern slope of the Cascade Range and in the forests of North Eastern Washington. There is a notable lack of potential habitat throughout the entire Columbia Plateau region. This lack of potentially suitable habitat is primarily due to the high desert ecosystem and agricultural lands that make up most of this region.

Table 5 shows the amount of suitable stream habitat by county while Tables 6 and 7 provide a breakdown of the relative amount of suitable stream habitat in each of the given categories of landowners. The GIS Data that was used for this section can be found online at http://www.landscouncil.org/beaversolution in electronic format for use in further studies.

| County | Stream Miles | Percentage |
|---|---|---|
| Okanogan | 2,070 | 21% |
| Kittitas | 1,070 | 11% |
| Stevens | 1,036 | 11% |
| Chelan | 1,129 | 11% |
| Ferry | 960 | 10% |
| Pend Oreille | 747 | 8% |
| Whitman | 707 | 7% |
| Spokane | 607 | 6% |
| Lincoln | 497 | 5% |
| Grant | 344 | 4% |
| Douglas | 252 | 3% |
| Adams | 340 | 3% |

*Table 5.* Suitable stream habitat miles by county.

| Land Type | Stream Miles | Percentage |
|---|---|---|
| Public Lands | 5,080 | 52% |
| Private Lands | 4,748 | 48% |

*Table 6.* Suitable stream habitat by ownership.

| Land Manager | Stream Miles | Percentage |
|---|---|---|
| US Forest Service | 3,246 | 33.1% |
| Tribal (Spokane, Colville, Kalispel, Yakima) | 871 | 8.9% |
| Washington Dept. of Fish & Wildlife | 277 | 2.8% |
| US Bureau of Land Management | 148 | 1.5% |
| US Bureau of Reclamation | 118 | 1.2% |
| National Park Service | 78 | 0.8% |
| US Fish & Wildlife | 72 | 0.7% |

*Table 7*. Suitable stream habitat by management agency.

The above values of stream miles represent suitable habitat before vegetation analysis because the vegetation analysis applies to the entire study area and is not broken down by county.

***Final Water Storage Estimation***

Using the results from our beaver dam water storage analysis and the stream habitat suitability index, it was possible to estimate the potential for water storage in both surface water and groundwater. The habitat suitability analysis determined *S* to be 9,828 stream miles. A review of articles reveals that the average number of dams per mile, or *D*, across North America is 11 (Naiman et al., 1988). Average surface-water storage in Eastern Washington, or *A*, is 3.5 acre feet. Personal interviews suggest that groundwater storage, or *G*, is 5 to 10 times the volume of surface-water storage, depending on the porosity of the local soil. We conservatively estimated

groundwater was 5 times as much as above-ground water in each dam. The following calculation gives the final water storage estimation.

9,828 x 11 x (3.5 + (3.5 x 5)) = 2,270,268 total acre feet of water storage

The reintroduction of beaver to the 9,828 miles of potentially suitable habitat could cause an increase of nearly 378,400 acre feet of surface water storage throughout the 12 counties of the study. When groundwater storage is considered, more than 2 million acre feet of water can be stored through the use of beaver dams.

## Discussion

Study results support the hypothesis that beaver are capable of providing a large portion of the state's water storage needs. The Columbia River Basin Water Management Program intends to create an additional 3 million acre feet of water stored in the Columbia River watershed. After studying the amount of water active beaver dams store above ground and in groundwater and estimating beaver repopulation potential based on the identification of suitable habitat throughout Eastern Washington, results show that over 2 million acre feet of water could be stored. This is a conservative estimate; if groundwater storage were 10 times more than above-ground water (the upper limit of storage capacity estimates), as opposed to 5 times (the lower limit of estimates), then over 4 million acre feet of water could be stored. Results from the literature review support the hypothesis that this stored water would augment late summer flow.

Results of the habitat suitability analysis indicate there is a significant amount of available habitat for beaver in Eastern Washington. Based on four relatively static habitat characteristics—slope, elevation, stream order, and proximity to transportation ways—there are almost 10,000 miles of streams with suitable habitat. Vegetation availability is a critical component of suitable habitat as well but harder to confirm. After analysis, approximately 70% of the almost 10,000 stream miles appear to have healthy riparian vegetation. This means that even without vegetative restoration, almost 7,000 stream miles are ready for beaver reintroduction. Suitable habitat without adequate vegetation could be restored over time to expand habitat availability. However, even with the high quality orthoimagery used to analyze vegetation, it was not possible to confirm whether riparian species were willow and/or aspen, two favored tree species of beaver. Individual site checking would be required prior to reintroduction to assure that proper vegetation is available.

When visiting beaver dams across Washington State, field researchers often were not equipped with a kayak or small boat to aid in measuring depths of larger beaver dams. As a result, researchers measuring on foot were often forced to measure beaver dams with depths no greater than approximately 6 feet; meaning ponds with smaller water volumes were measured. This may skew the dataset toward a low estimate of available water.

The final water storage value gives a conservative estimate of basin-wide water storage potential at optimal conditions. Fall re-measurements show that some of the water stored over summer is released over time and that water output is greater than input between July and October, indicating beaver dams augment late-season flow. Prior literature supports this as well. Results from a study by Lowry and Beschta (1994) indicate that water stored in and around beaver ponds is stored for approximately three months. This storage period would vary greatly depending on local topography, but it does indicate that water flow from spring runoff would be stored in beaver ponds for a period of time and would augment flow later in the year.

If large-scale beaver relocations were to take place, water storage and late-season flow augmentation would increase across watershed basins, even if individual dams were washed out or unproductive one year. Repopulating the 9,828 miles of stream habitat at 11 dams per mile would require significant numbers of beaver. Study results show that a beaver family maintains an average of 3 dams, and literature indicates that families consist of 6 beaver on average. This means that nearly 220,000 beaver would need to be relocated, although natural beaver reproduction would reduce this amount. Such a large-scale beaver reintroduction has not been attempted. Results of this study support the hypothesis that Eastern Washington can support a larger population of beaver and that their dams will increase water storage and late-season flow, making beaver restoration a viable and relatively inexpensive means of fulfilling HB 2860 requirements. In addition to water storage, further benefits of beaver reintroduction can be found in Section 9.2, Appendix B.

## Beaver Management

The Lands Council recognizes the challenges of co-existing with beaver. Beaver can flood roadways, plug culverts, flood farm fields, and take down desirable trees. This section addresses those challenges and provides recommendations to prevent damage to roads and property while allowing beaver to do what they do best—build dams. Human intervention can enhance dam construction and longevity by providing off-site materials for beaver dams as well as planting new trees and food sources for beaver.

### *Flooding of Roadways and Property*

The tendency for transportation networks to follow flat, low-gradient paths inevitably leads to roads being built very close to streams, which has meant that beaver dams and ponds can be found extremely close to roadways and culverts. For the initial suitability index, the Department of Ecology, Washington Department of Fish and Wildlife, and the Washington Department of Transportation recommended a buffer of 200 feet from roadways to suitable beaver habitat. Based on our field observations, where some of the largest beaver dams were located within 100 feet of a roadway, we proposed that the distance between roads and beaver dams be reduced to 100 feet from the center line. A large dam complex on Granite Creek near Republic, Washington was less than 15 linear feet from the edge of the roadway (Highway 20), and a portion of the road bed actually acted as part of the dam. Historic orthoimagery shows that this dam complex has been in place for at least the last 15 years. Typically, road dimensions in rural Eastern Washington are 12 feet from centerline to fog line, with an additional 10 feet of constructed shoulder outside of the fog line in two-lane roadways, providing a 78-foot buffer between the dams and the edge of the roadway.

*Figure 4.* In this photo, the roadway is directly adjacent to a beaver dam complex on Granite Creek near Republic, Washington. The distance from fog line to the edge of the water measures approximately 15 horizontal feet, and the distance from dam crest to the top of the roadway measures approximately 6 vertical feet. Photo by Brian Walker.

If managed correctly, beaver dams and roadways can be compatible. Beaver dams naturally slow down floodwaters by reactivating floodplains and reducing the erosive forces of streams that could undermine the integrity of roadways that are built alongside stream channels. Pond leveling devices can be used to prevent beaver ponds from flooding roads (see description below).

***Water Rights***

The Beaver Solution was developed out of the need to find water storage options in the Columbia Basin. The Columbia Basin Initiative seeks to find new water storage options to fulfill existing water rights and to address the need for additional water rights for new users. This water can also be available to meet demands for fish restoration flows and power generation at dams on the Columbia River. The issue of assigning water rights to beaver dams is complex beyond the scope of this study. Water storage in the basin can be examined in terms of many beaver dams cumulatively increasing summer flows. An analogy might be how spring snowpack and snow moisture assessments help water managers plan for summer operations.

Water right holders immediately downstream of beaver dams may be impacted for short periods of time while beaver are constructing or maintaining their dams. However, beaver dams are

inherently leaky, allowing water to flow over and through the dam during and after dam construction. Water that is lost in the pond due to evapotranspiration is generally less than 1% (Woo and Waddington, 1990).

***Plugged Culverts***

Small diameter culverts are used to convey water under roadways, and beaver may utilize them as a constriction point to build their dams. This makes the roadbed an integral part of the dam, which can lead to large amounts of water being stored on one side of a roadway, causing hydraulic pressure to build up and potentially weaken the roadbed. When beaver move into areas where culvert plugging or irrigation ditch plugging is a concern, Beaver Deceivers™ can provide a way to ensure that culverts remain open. Beaver Deceivers™ are installed on both the upstream and downstream sides of culverts. These devices limit the ability of beaver to pull materials into culverts while allowing water a larger surface area through which to flow. These devices, engineered by Skip Lyle, have been installed throughout the country where beaver activity is high. They require minimal maintenance and hold up for many years.

***Damaged/Lost Trees***

Beaver chew on trees and can damage or fall large trees. The loss of old trees or orchard trees can be of particular concern to landowners. If beaver are detected early, protective fencing can reduce or eliminate the damage that beaver can cause. If only a few trees need to be protected, fencing can be used to block beaver from approaching the trunk. The fence should be at least 3 feet tall and 1 foot away from the trunk of the tree. If a large number of trees need to be protected, it is best to construct an exclosure from fencing panels or rolls that enclose all of the trees and exclude beaver.

***Flooding***

For homes or other structures close to a stream channel, flooding is a major concern. Beaver create large ponds behind their dams that could impact homes that have been built on historic floodplains. A localized dam complex could reactivate the floodplain and threaten structures built in these areas. A pond leveling device can be used to reduce and maintain a lower water level in these dam complexes. Leveling devices typically consist of a thick-walled PVC pipe installed through the bottom of a beaver dam with a 90 degree elbow placed on the pipe on the upstream side of the dam. A second piece of pipe is placed on the elbow with a height that will lower the pond elevation to the desired level. Pond leveling devices can also be used to reduce flooding of agricultural lands.

***Plugged Irrigation Ditches***

Farmers throughout the Columbia Basin, Palouse, and other agricultural areas of Eastern Washington are concerned about beaver moving out of streams and into water conveyance infrastructure for agriculture. However, most agriculture water infrastructure has had trees and shrubs removed from the watercourse to help move water quickly from one location to another, and much irrigation infrastructure is lined with concrete and does not provide a suitable base for beaver to construct a dam complex. If an irrigation ditch does become a target for beaver dam construction activities, one of the previously discussed remedies can help manage the beaver activity.

***Disease***

There are concerns that beaver spread both Giardia and Tularemia in their feces. Several studies have shown that only a small fraction of beaver actually harbor these organisms. A report from

SL Erlandsen et al. (1990) showed that only 13% of beaver carried the Giardia parasite, while more than 95% of muskrats carried it. Smaller rodents, migrating ducks and domesticated animals (dogs, cattle, etc.) can also carry these parasites. Domestic water supplies are treated to eliminate the parasites.

***Mosquitoes***

Wetlands can provide the optimal habitat to breed mosquitoes. With the West Nile Virus recently confirmed in Washington, there is a major concern that wetlands associated with beaver dams could be a haven for mosquitoes that spread the virus. Beaver dams tend to have a properly-functioning wetland ecosystem where other aquatic organisms, such as dragonfly larvae, keep mosquito larvae numbers in check. In contrast, stagnant water in discarded buckets, old tires, backyard pools, and similar manmade containers provide a major source of habitats for mosquitoes. If mosquitoes continue to be a problem, several commercial insecticides are available to help control mosquito populations.

## Conclusions

There are 9,828 miles of stream in the 12 Eastern Washington counties of the study with potential for beaver reintroduction. Over half of these miles are on public lands. Through a preliminary analysis, estimates show that currently 70% of available stream miles have suitable vegetation. With an average of 3.5 acre feet of surface water and five times that in groundwater storage per beaver dam in Eastern WA, reintroduction of beaver to these streams can potentially store enough water to meet the goals the Department of Ecology has identified for water users.

This study can provide a reference point for future projects and studies on the water storage capacity created by beaver dams. The average storage capacity of 3.5 acre feet that was developed by this study can act as a benchmark for monitoring the overall effectiveness of beaver reintroduction to increase water storage. Groundwater measurements and modeling could further refine estimates of available water storage. Topical research questions of particular interest for future studies are

- Does the average volume of water in beaver dams increase or decrease as populations of beaver increase?
- Does water storage in dam complexes increase with the age of beaver dams?
- How is water storage impacted by the restoration effects that beaver dams have on degraded stream systems?

## Next Steps

The Lands Council's Beaver Solution project will reintroduce beaver into suitable watersheds in Eastern Washington to store spring runoff for late-summer use. The long-term vision of the Beaver Solution is that beaver will re-populate thousands of streams and store millions of acre-feet of water. Beaver ponds and groundwater will also restore damaged watersheds, improve fish and wildlife habitat, and provide a conservation incentive for property owners. The Lands Council hopes that the Beaver Solution will become a model for watershed restoration anywhere that beaver historically occurred, as it is much less expensive than artificial stream restoration.

The Beaver Solution project is unique. While there are other efforts taking place to restore beaver, The Lands Council is the first to connect beaver restoration with the creation of water storage. The Lands Council believes that once success is demonstrated in pilot watersheds,

funding can be obtained from agricultural interests, municipalities, downstream hydropower utilities, and salmon recovery agencies.

The Lands Council has developed a two-year strategic plan for the Beaver Solution project, which started in January 2009 with the study of beaver dam complexes to develop water storage estimates and the identification suitable beaver habitat throughout 12 counties in Eastern Washington. The next phase started in October 2009 with the selection of specific beaver reintroduction sites with agency and landowner approval. In 2010, those sites, addressed more thoroughly in Section 9.3, Appendix C, will be re-assessed and prepared, required permits will be obtained from the Washington Department of Fish and Wildlife, available beaver will be identified, and relocation to pilot reintroduction sites will ensue. Monitoring the success (or failure) of these pilot projects will provide information to build support for additional reintroductions in 2011 and subsequent years. In the mid-term, the project will grow to reach more and more watersheds, since dozens would be needed to create any significant water storage. As pilot projects are monitored and as funding becomes available, efforts can be scaled appropriately and optimal watersheds for beaver relocation can be prioritized using site assessments and social contacts with landowners and land managers. For example, The Lands Council hopes to concentrate beaver reintroduction activities in the Hangman Creek drainage in order to characterize and quantify changes in surface and groundwater storage, stream discharge, and water quality as a result of beaver dam activity on a watershed scale.

There are numerous partners on this project, including the Washington Department of Fish and Wildlife, the US Forest Service, and county Conservation Districts throughout Eastern Washington. The Bureau of Land Management, Washington Department of Natural Resources, and wildlife agencies may need to be consulted in the creation or revision of beaver management and recovery plans. In addition, The Lands Council has recruited dozens of volunteers to plant trees and take part in river restoration projects.

The Lands Council's study on beaver dam complexes has provided important baseline information to guide beaver reintroduction. Beaver reintroduction plans will be created in 2010 for the five sites, and implementation will begin. The sites will be monitored prior to reintroduction and at appropriate intervals after reintroduction. Transmitters will be put on some beaver to monitor their movement. Success or failure that occurs in each watershed will be specifically monitored by measuring survival of beaver, number and size of beaver dams, changes in riparian size and vegetation, and changes in stream flow. Storm and flood events that could breach or destroy beaver restoration areas will be noted and monitored.

Measuring the changes in groundwater, and therefore storage and flow potential, is a metric that The Lands Council would like to include in its monitoring. Using piezometers at one or several sites could provide information that would be invaluable as the project expands to include multiple watersheds.

Interactions with landowners and the public are critical to the project's success and future expansion in more watersheds. The Lands Council will outreach to and garner support from the public, including agencies and those most affected by the project. Success will be measured by partnerships with landowners engaged in beaver reintroduction.

# Annotated Bibliography

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Results on a study to determine any preference in beavers' choice of woody plants in building their dams. Article specific to the Ontario region.

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Muller-Schwarze D, Sun L. 2003.The Beaver: Natural history of a wetlands engineer. Ithaca, NY. Comstock Publishing Associates. 190 p.

A comprehensive source, including trapping history and beaver behavior. The book also discusses beaver populations including reproduction, development, and life expectancy, as well as population densities and dynamics. The text includes ecology of beaver such as where they live and why, the landscapes they make, and their predators. The authors go in depth in addressing issues of reintroduction of beaver, how the Hudson's Bay Company influenced beaver depletion, and why beaver are needed as ecosystem engineers.

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vegetative patches on the landscape. Researchers see a complex pattern that involves formation of marshes, bogs, and forested wetlands.

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Beaver have a relationship with the surrounding physical environment. Results show active beaver areas and beaver-abandoned areas have a significant effect on portions of the flood plain.

Ott J. 2003. "Ruining" the rivers in the Snake Country: The Hudson Bay Company's fur desert policy. Oregon Historical Quarterly. 104(2): 166-195.

Author describes how the decimation of beaver throughout the Snake Country was a political attempt to keep explorers from settling in the West. The article describes how the fur desert policy came about, key trappers in carrying out this policy, and the amount of beaver that were killed during specific time frames. She also explains how the lack of beaver has impacted the environment.

Rossell F, Bozser O, Collen P, Parker H. 2005. Ecological impact of beavers *Castor fiber* and *Castor Canadensis* and their ability to modify ecosystems. Mammal Rev., 35: 248-276.

Good overview of beaver ecosystem benefits. The study concludes that beaver foraging has a considerable impact on the course of ecological succession, species composition, and structure of plant communities.

Snodgrass JW. 1997. Temporal and spatial dynamics of beaver-created patches as influenced by management practices in a south-eastern North American landscape. Journal of Applied Ecology. 34: 1043-1056.

Beaver increase patch-creation in local landscapes over time. Results also indicate that beaver activity increases the proportion of perennial streams in watersheds.

Washington Department of Fish and Wildlife. 2004. Stream Habitat Restoration Guidelines: Beaver Re-introduction. http://wdfw.wa.gov/hab/ahg/shrg/13-shrg_beaver_reintroduction.pdf. Accessed March 2009.

A thorough guide outlining techniques for relocating beaver along with other important information such as aging and sexing beaver, risks to property, associated costs, and more. Included as Appendix 9.4

Westbrook CJ, Cooper DJ, Baker BW. 2006. Beaver dams and overbank floods influence groundwater-surface water interaction of a Rocky Mountain riparian area. Water Resources Research, 42: W06404.

Examines the influence of two in-channel beaver dams and a 10-year flood event on surface inundation, groundwater levels, and flow patterns in a broad alluvial valley. The beaver dams and ponds greatly enhanced the depth, extent, and duration of inundation associated with floods; they also elevated the water table during both high and low flows.

Woo MK, Waddington JM. 1990. Effects of Beaver Dams on Subarctic Wetland Hydrology. Arctic, 43: 223-230.

Researchers use a water balance equation to compare the water balance at outlets of basins with and without beaver dams. The dammed basin suppressed the outflow and increased the basin water storage, although it lost more water to evaporation.

Workman SR, Serrano SE. 1999. Recharge to alluvial valley aquifers from overbank flow and excess infiltration. J. American Water Resources Assoc. 35: 425-432.

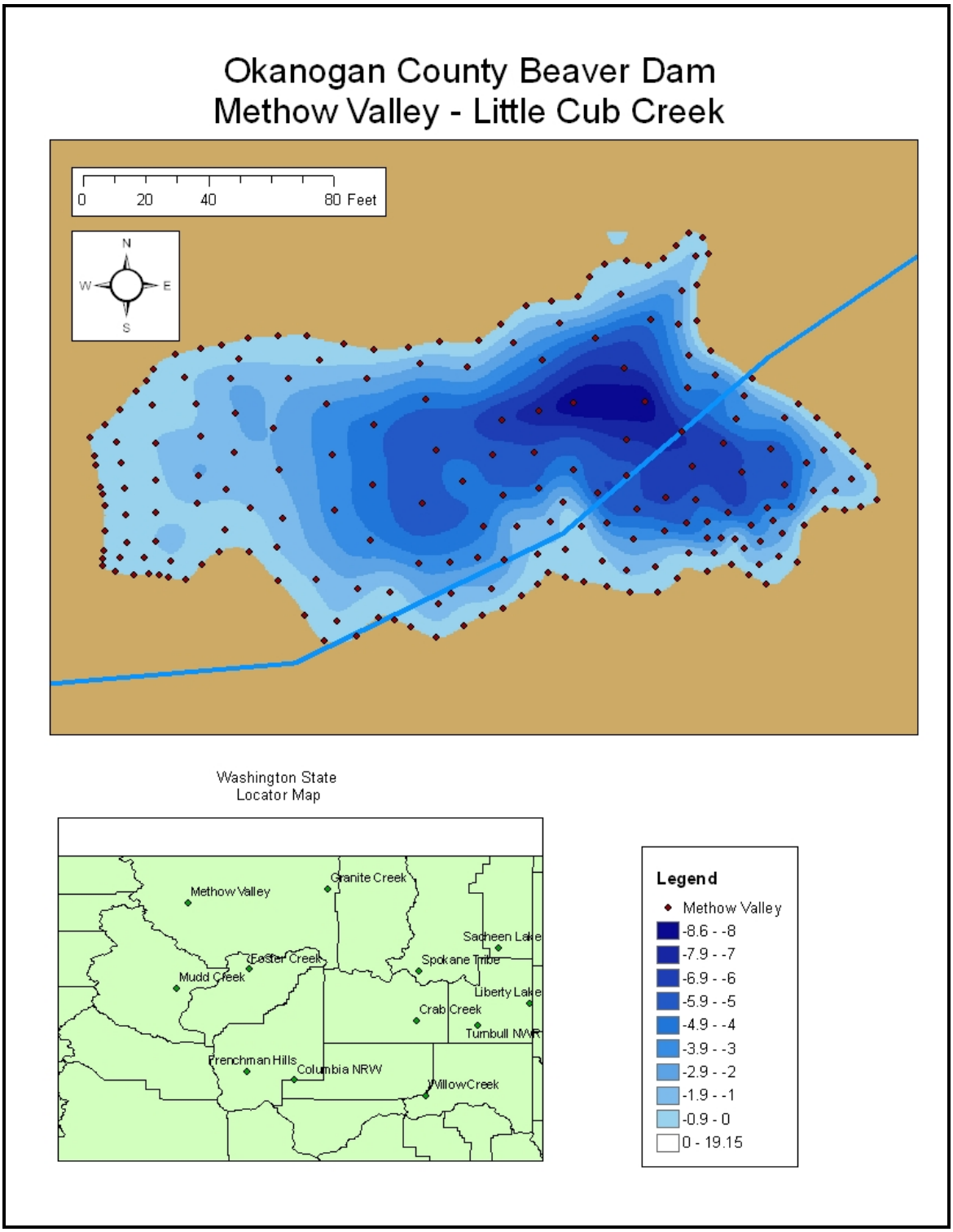
Aquifer recharge is an important hydrological process that is not easily quantified in natural systems. This study shows that in river systems, overbank flooding accounts for 65% of the total aquifer recharge, making overbank flooding an important and dominant force in hydrologic regimes.

# Appendices

## *Appendix A: Individual Dam Descriptions and Field Notes for Eastern Washington Beaver Dam Study*

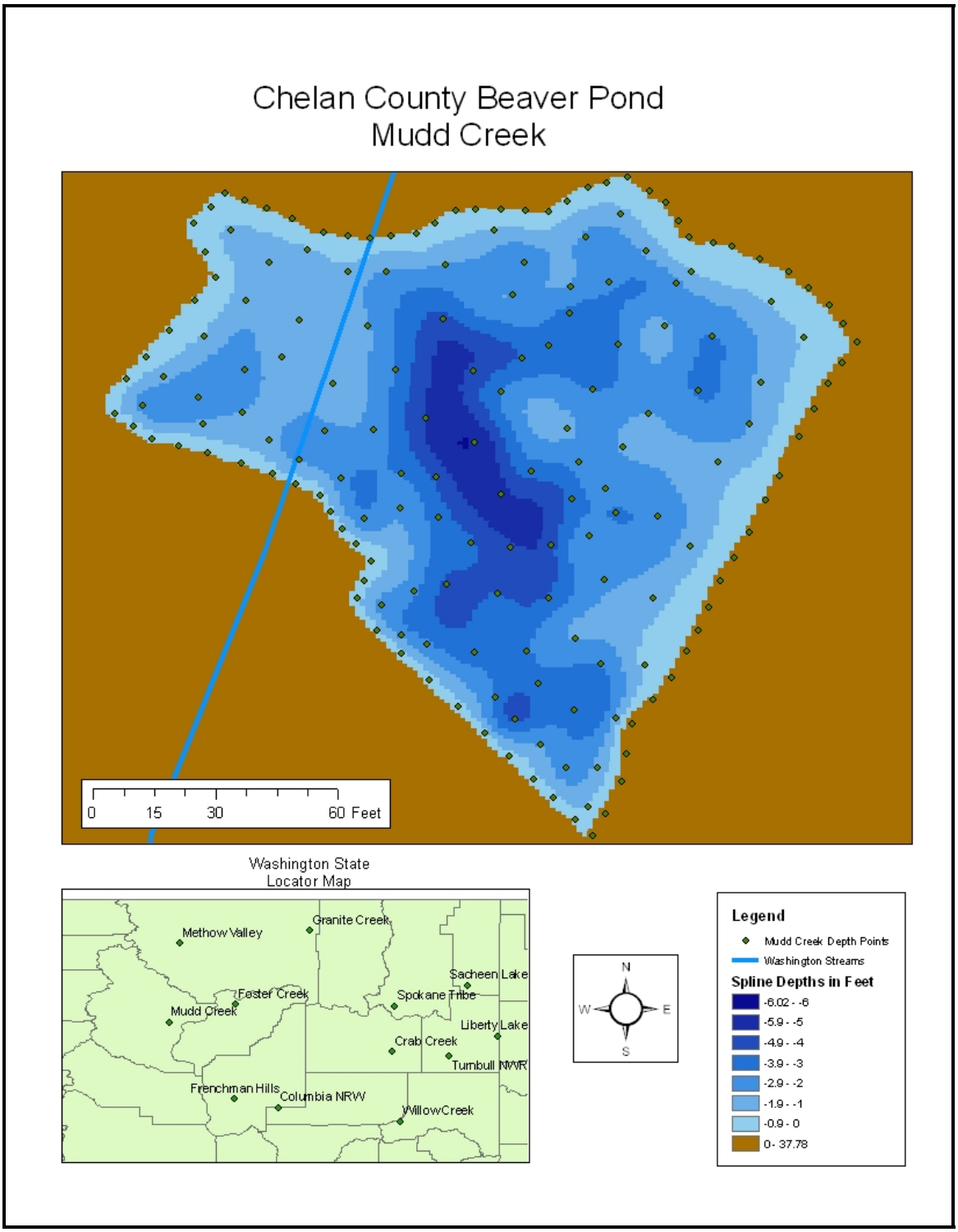
**County: Okanogan**
**Stream: Cub Creek**
**Date Measured: 07/29/09**

The three dams in this complex have been maintained for 2 years. One pond was measured behind the first beaver dam, where the thalweg was too deep to measure accurately. Based on the height of the dam and the surrounding pond depths, the deepest point was estimated at 8.5 feet. A wetland between 2 and 3 acres separated the first dam from the next. Riparian vegetation included willow and maple spp. and was extremely dense. These dams were created after a successful beaver relocation by the Methow Valley Ranger District, US Forest Service. The data on water storage from this beaver dam complex is of particular importance because it provides an example of beaver dams and ponds following human-induced relocation. The pond stored 0.87 acre feet of above-ground water in July.


Okanogan County Beaver Dam
Methow Valley - Little Cub Creek
0
20
40
80 Feet
N
W
E
S
Washington State
Locator Map
Methow Valley
Granite Creek
Sacheen Lake
Easter Creek
Spokane Tribe
Mudd Creek
Liberty Lake
Crab Creek
Turnbull NWR
Frenchman Hills
Columbia NRW
Willow Creek
Legend
Methow Valley
-8.6 - -8
-7.9 - -7
-6.9 - -6
-5.9 - -5
-4.9 - -4
-3.9 - -3
-2.9 - -2
-1.9 - -1
-0.9 - 0
0 - 19.15

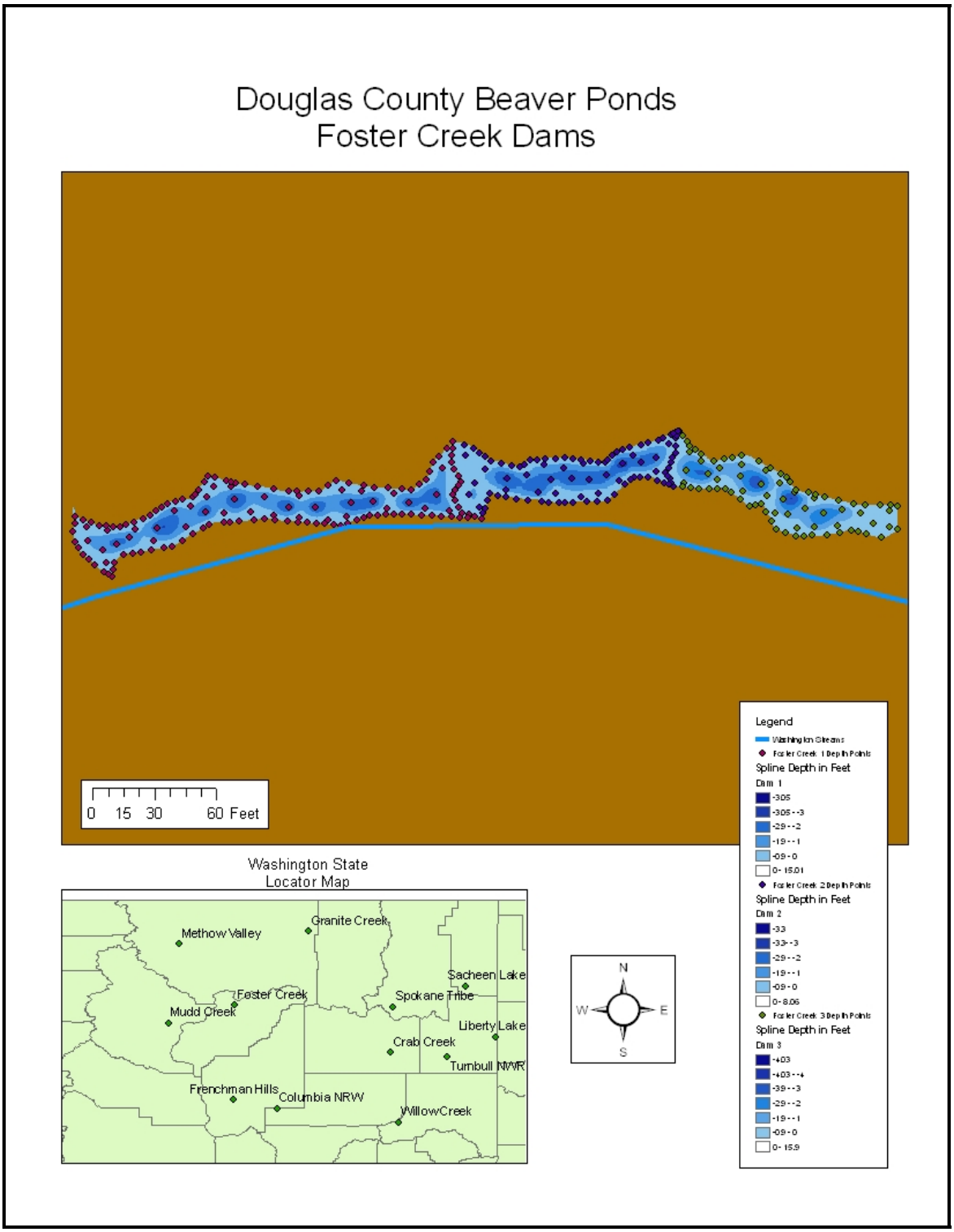
**County: Chelan**
**Stream: Mud Creek**
**Date Measured: 07/27/09**
**Date Re-measured: 10/7/09**

The three dams in this complex have been maintained for over 10 years. One pond was measured behind the first beaver dam, where the thalweg was too deep to measure accurately. Based on the height of the dams and the surrounding pond depths, the deepest point was estimated at 6 feet. Riparian vegetation included quaking aspen, willow spp., and sedges. Many of the aspen, however, are dead due to flooding. The location of the dam is important due to its proximity to the Columbia River. The site is approximately one mile upstream from where Mud Creek joins with the Entiat River, which flows into the Columbia River approximately 10 stream miles later. During fall re-measurements, the deepest point of the thalweg was still too deep to measure. Other depths were, on average, 1 foot less than prior measurements, so a 1-foot decrease in overall depth was applied throughout the pond. The pond stored 0.55 acre feet of above-ground water in July.


Chelan County Beaver Pond
Mudd Creek
0 15 30 60 Feet
Washington State
Locator Map
Methow Valley
Granite Creek
Sacheen Lake
Foster Creek
Spokane Tribe
Mudd Creek
Liberty Lake
Crab Creek
Turnbull NWR
Frenchman Hills
Columbia NRW
Willow Creek
N
W
E
S
Legend
Mudd Creek Depth Points
Washington Streams
Spline Depths in Feet
-6.02 - -6
-5.9 - -5
-4.9 - -4
-3.9 - -3
-2.9 - -2
-1.9 - -1
-0.9 - 0
0 - 37.78

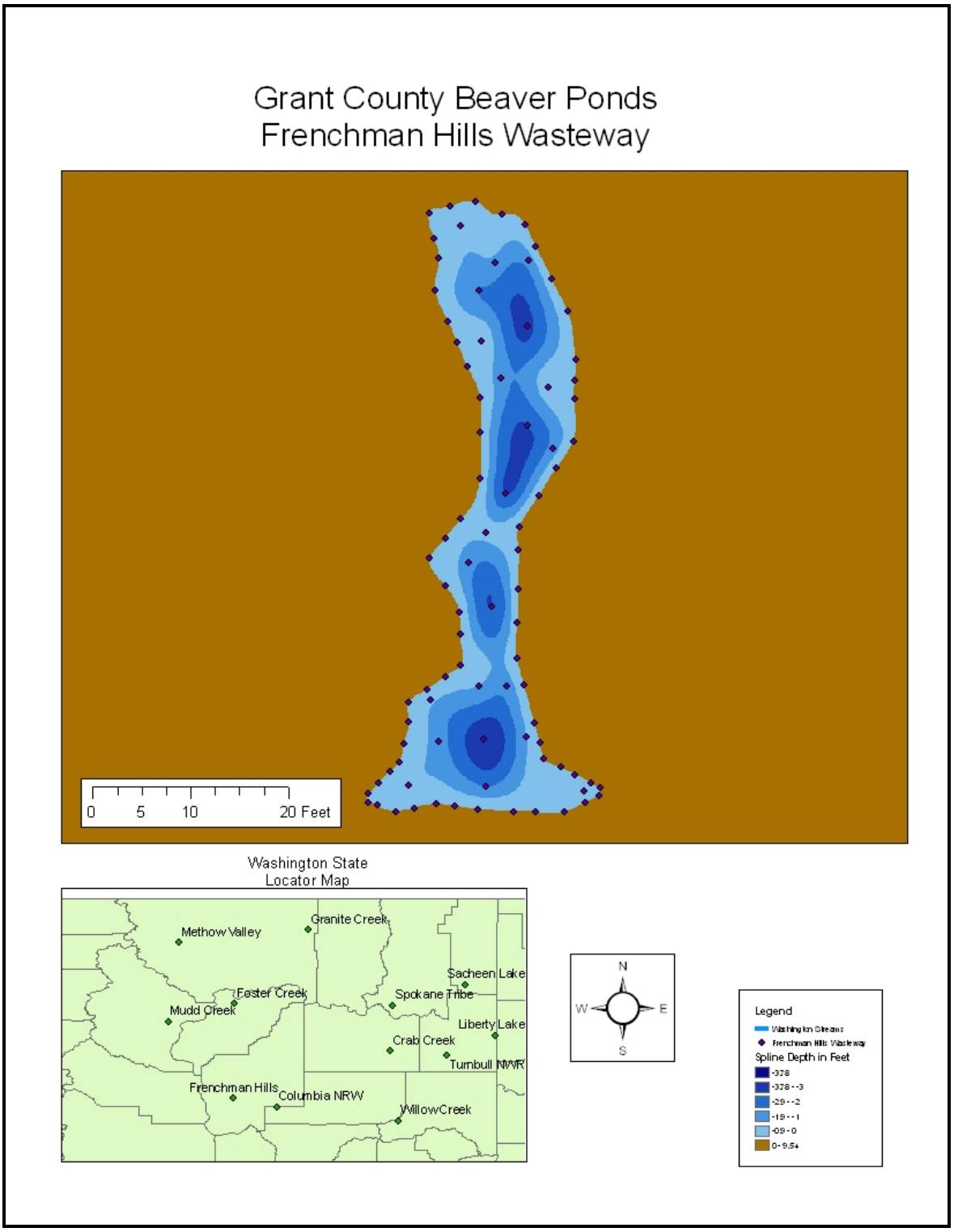
**County: Douglas**
**Stream: Unnamed**
**Date Measured: 07/09/09**

The five dams in this complex have been maintained for over 1 year, though the exact age is unknown. Three ponds were measured. The deepest point of the thalweg in these three ponds was 2.75, 3.25, and 3.5 feet. The dominant riparian vegetation was willow, sedge, and grass spp. Juvenile fish were observed in two of the three ponds. The unique feature of this complex is that it is "intermittent water," according to the *DeLorme Washington Atlas & Gazetter.* Water was flowing during summer measurements, but the pond was not re-measured in the fall to observe how much flowed out throughout the summer. Individual dams hold less than 0.1 acre feet, though the entire complex probably holds 0.5–1 acre feet of water, similar to the dam complex in Whitman County.


Douglas County Beaver Ponds
Foster Creek Dams
0 15 30 60 Feet
Legend
Washington Streams
Foster Creek 1 Depth Points
Spline Depth in Feet
Dam 1
-30.5
-30.5 - -3
-29 - -2
-19 - -1
-09 - 0
0 - 15.01
Foster Creek 2 Depth Points
Spline Depth in Feet
Dam 2
-33
-33 - -3
-29 - -2
-19 - -1
-09 - 0
0 - 8.06
Foster Creek 3 Depth Points
Spline Depth in Feet
Dam 3
-40.3
-40.3 - -4
-39 - -3
-29 - -2
-19 - -1
-09 - 0
0 - 15.9
Washington State
Locator Map
Methow Valley
Granite Creek
Foster Creek
Mudd Creek
Sacheen Lake
Spokane Tribe
Liberty Lake
Crab Creek
Turnbull NWR
Frenchman Hills
Columbia NRW
Willow Creek
N
W
E
S

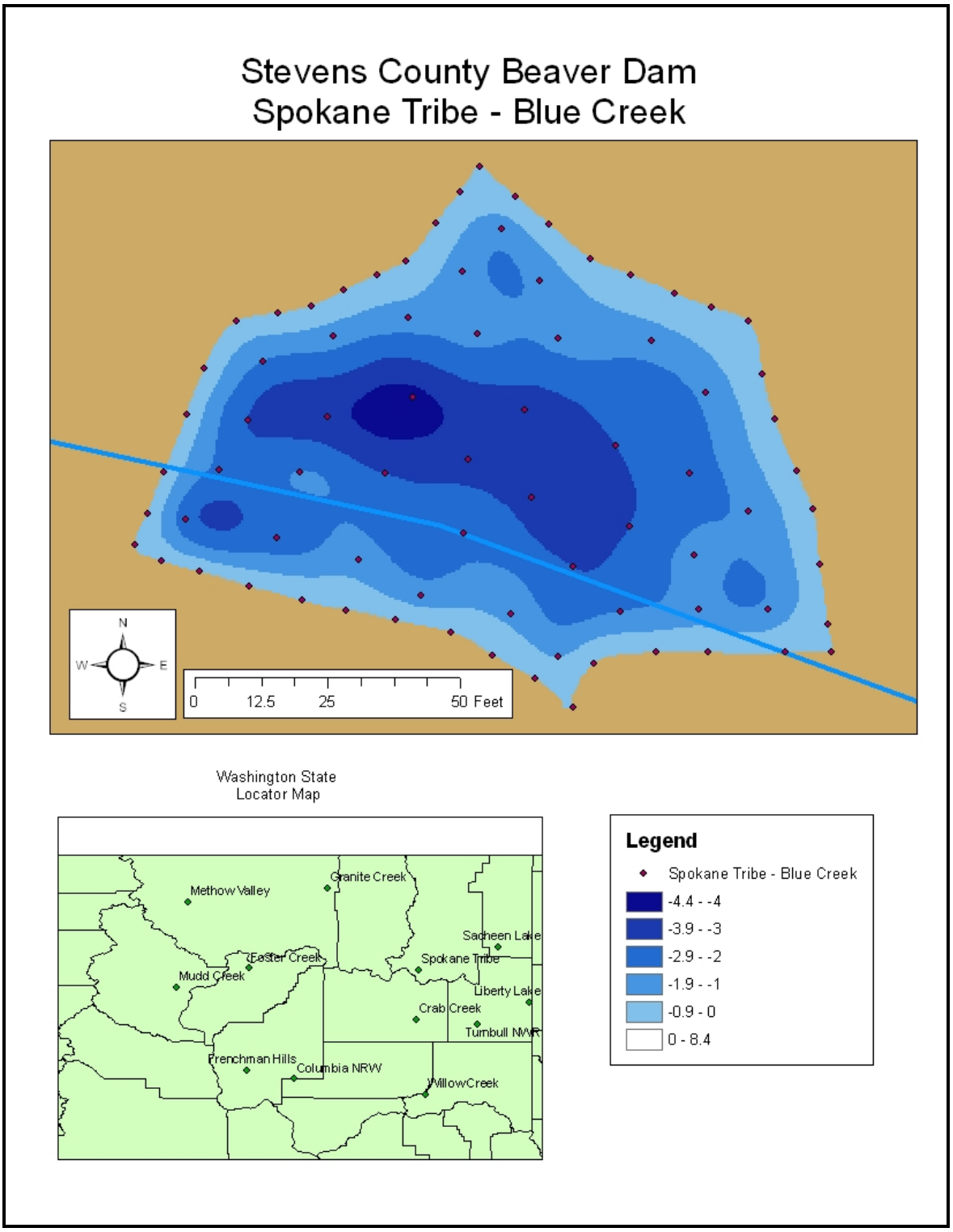
**County: Grant**
**Stream: Frenchman Hills Wasteway**
**Date Measured: 07/10/09**

The one dam found in an irrigation culvert in the Frenchman Hills Wasteway is the only inactive dam measured. The deepest point of the thalweg was 3.75 feet. When estimating available suitable habitat for beaver in Eastern Washington, we conservatively removed the Frenchman Hills Wasteway, irrigation canals, and other irrigation infrastructure, assuming that these areas were not ideal. This dam provides a prime example of beavers' ability to build in these systems. Riparian vegetation was not recorded at this site. This was the smallest dam surveyed, storing only 0.01 acre feet of above-ground water.


Grant County Beaver Ponds
Frenchman Hills Wasteway
0 5 10 20 Feet
Washington State
Locator Map
Methow Valley
Granite Creek
Sacheen Lake
Foster Creek
Spokane Tribe
Mudd Creek
Liberty Lake
Crab Creek
Turnbull NWR
Frenchman Hills
Columbia NRW
Willow Creek
N
W
E
S
Legend
Spline Depth in Feet

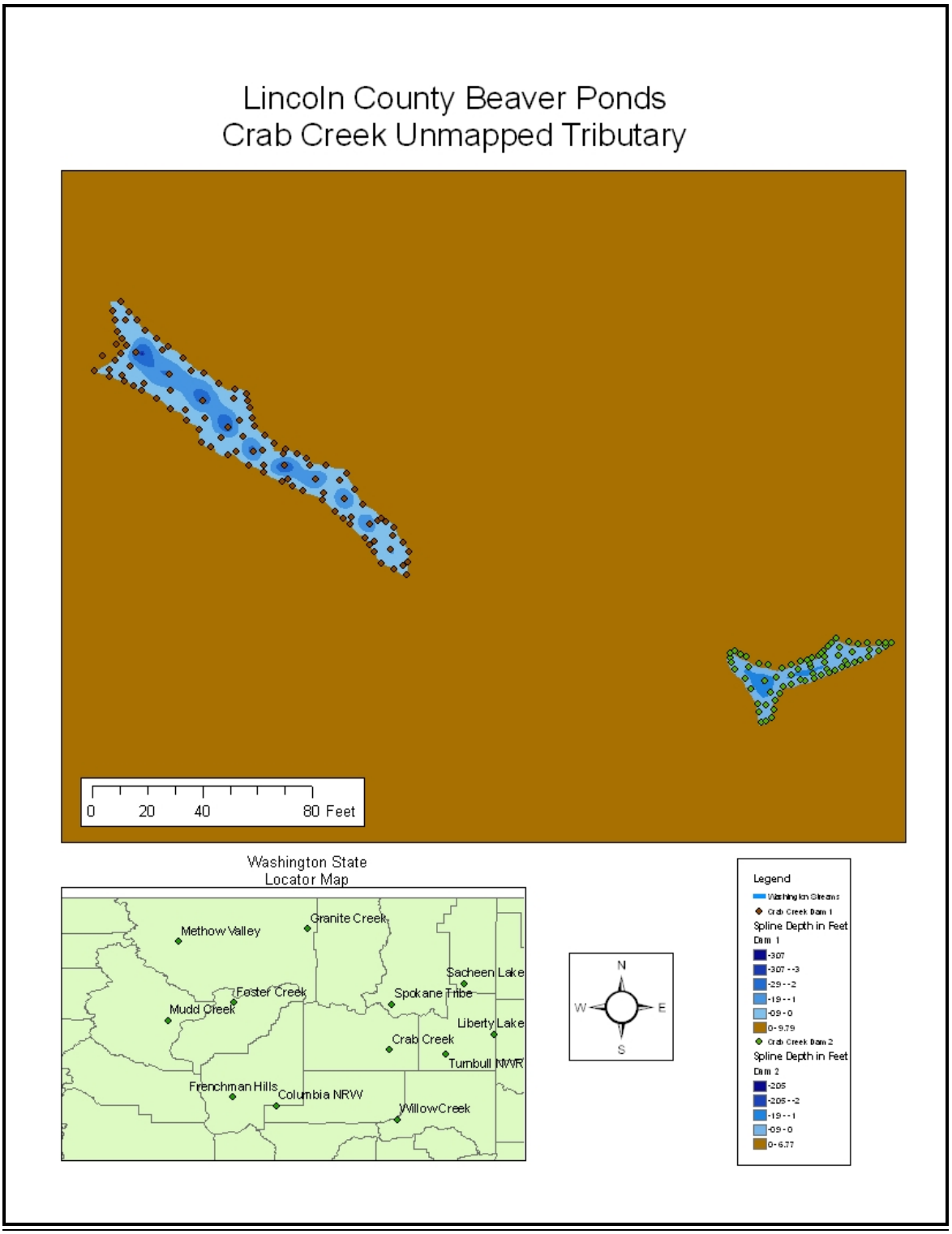
**County: Stevens**
**Stream: Blue Creek**
**Date Measured: 08/09/09**

There is one dam in this complex that has been maintained for over 2 years, though exact age is unknown. At the deepest point, the thalweg measured 4.25 feet deep. Dominant riparian vegetation included willow spp. and sedges. Juvenile fish were observed in the pond. The location of the dam is important: approximately 5 stream miles below the dam, Blue Creek reaches the Columbia River. The dam stores over 0.25 acre feet of above-ground water.


Stevens County Beaver Dam
Spokane Tribe - Blue Creek
N
W
E
S
0
12.5
25
50 Feet
Washington State
Locator Map
Granite Creek
Methow Valley
Sacheen Lake
Easter Creek
Spokane Tribe
Mudd Creek
Liberty Lake
Crab Creek
Turnbull NWR
Frenchman Hills
Columbia NRW
Willow Creek
Legend
Spokane Tribe - Blue Creek
-4.4 - -4
-3.9 - -3
-2.9 - -2
-1.9 - -1
-0.9 - 0
0 - 8.4

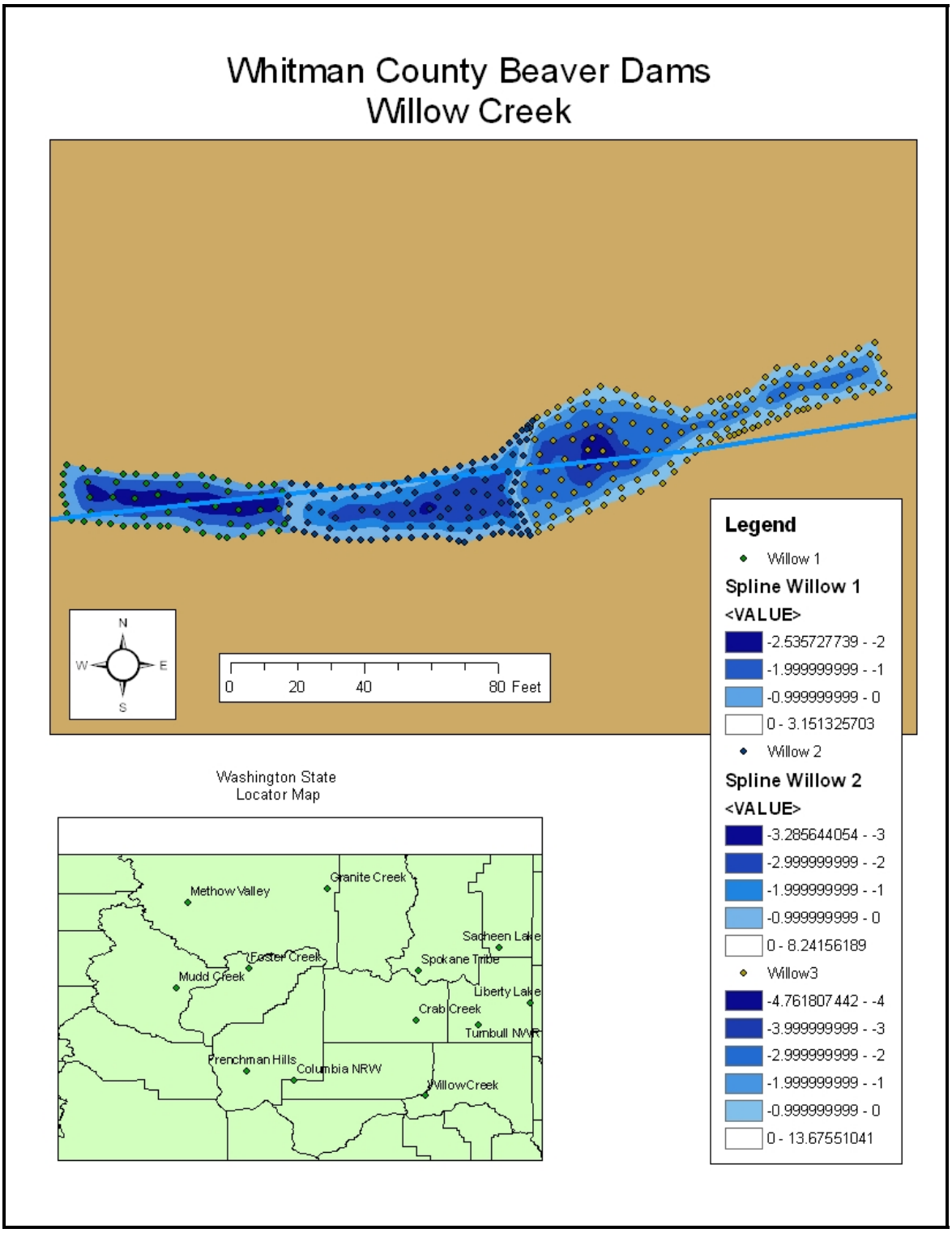
**County: Lincoln**
**Stream: Crab Creek**
**Date Measured: 07/10/09**

The three dams in this complex have been maintained for at least 2 years. Two out of the three ponds were measured for depths. The thalweg depths were 2.5 and 2 feet. The ponds were separated by riffles of water. Dominant riparian species were willow and grass spp., though active farmland is just a short distance from the stream. Juvenile fish were observed in both of the ponds. The site is designated by the *DeLorme Washington Atlas & Gazetter* as "intermittent water." In total, the ponds store approximately 0.5 acre feet of above-ground water.


Lincoln County Beaver Ponds
Crab Creek Unmapped Tributary
0 20 40 80 Feet
Washington State
Locator Map
Methow Valley
Granite Creek
Sacheen Lake
Foster Creek
Spokane Tribe
Mudd Creek
Liberty Lake
Crab Creek
Turnbull NWR
Frenchman Hills
Columbia NRW
Willow Creek
N
W
E
S
Legend
Spline Depth in Feet
Dam 1
-3.07
-3.07 - -3
-2.9 - -2
-1.9 - -1
-0.9 - 0
0 - 9.79
Crab Creek Dam 2
Spline Depth in Feet
Dam 2
-2.05
-2.05 - -2
-1.9 - -1
-0.9 - 0
0 - 6.77

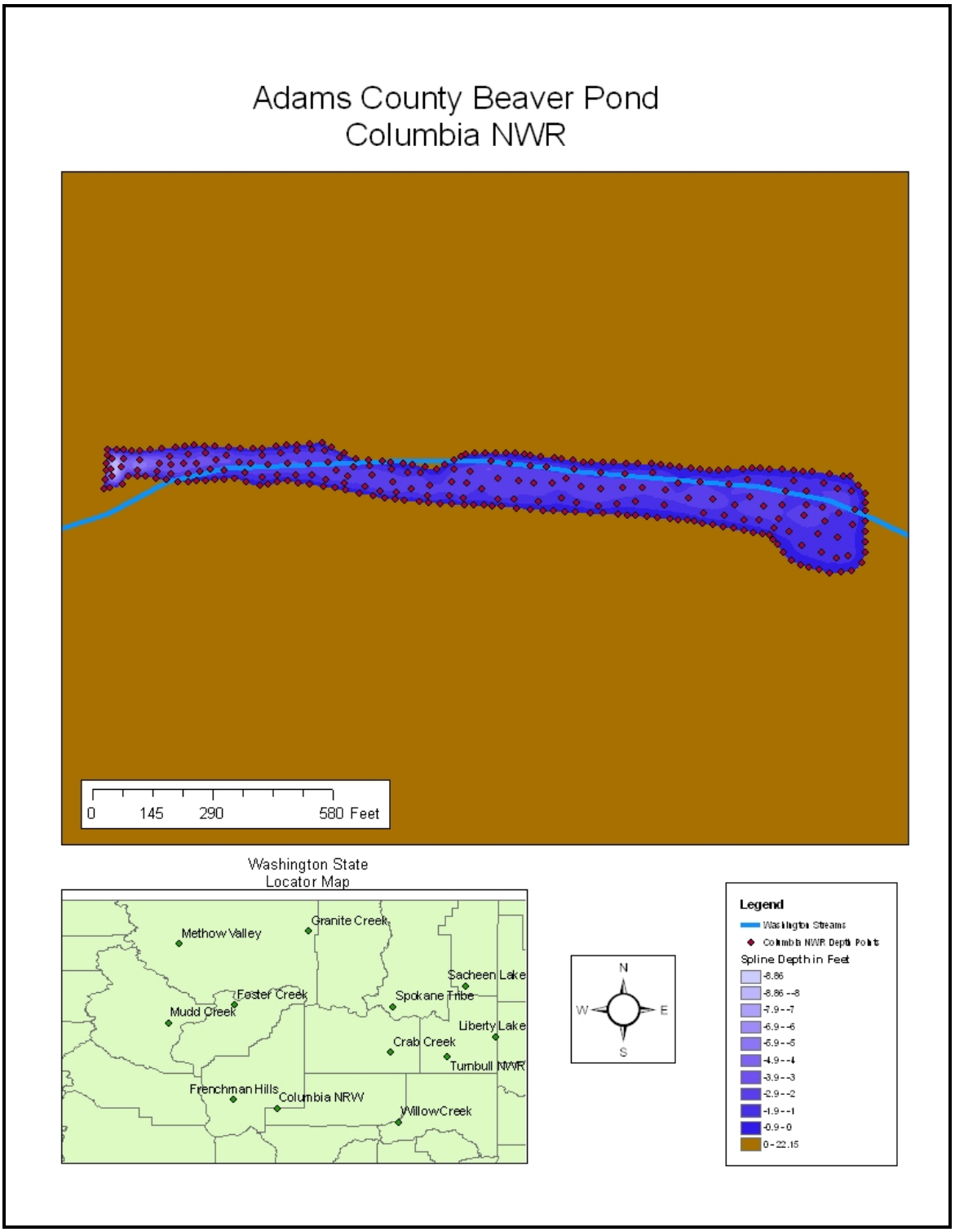
**County: Whitman**
**Stream: Willow Creek**
**Date Measured: 07/16/09**
**Date Re-measured: 10/07/09**

The 10 dams in this complex have existed for over 3 years. Three ponds were measured, revealing thalweg depths of 2.5, 3.25, and 4.75 feet. Dominant riparian vegetation includes willow, sedge, and grass spp. Juvenile fish were observed in all three ponds during July measurements. The ponds were re-measured in the fall, though due to shifting sediment throughout the pond bottoms, results were inconclusive regarding a difference in water storage over this time. Though individual dams stored less than 0.1 acre foot, the entire complex stored nearly 1 acre foot of above-ground water in July.


Whitman County Beaver Dams
Willow Creek
N
W
E
S
0
20
40
80 Feet
Legend
Willow 1
Spline Willow 1
<VALUE>
-2.535727739 - -2
-1.999999999 - -1
-0.999999999 - 0
0 - 3.151325703
Willow 2
Spline Willow 2
<VALUE>
-3.285644054 - -3
-2.999999999 - -2
-1.999999999 - -1
-0.999999999 - 0
0 - 8.24156189
Willow3
-4.761807442 - -4
-3.999999999 - -3
-2.999999999 - -2
-1.999999999 - -1
-0.999999999 - 0
0 - 13.67551041
Washington State
Locator Map
Methow Valley
Granite Creek
Sacheen Lake
Foster Creek
Spokane Tribe
Mudd Creek
Liberty Lake
Crab Creek
Turnbull NWR
Frenchman Hills
Columbia NRW
Willow Creek

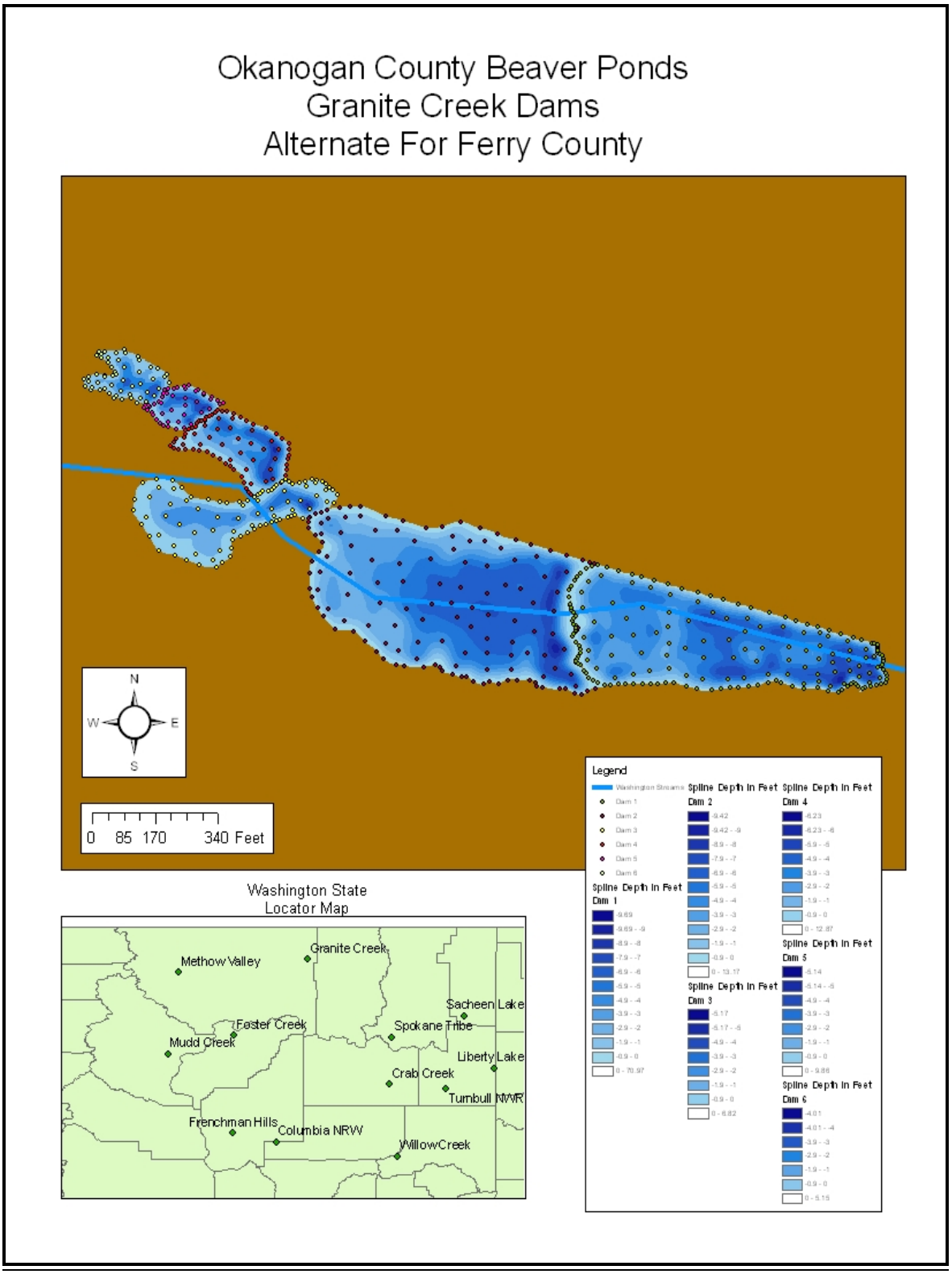
**County: Adams**
**Stream: Unknown**
**Date Measured: 07/27/09**

The one dam in this complex has existed for over 1 year. The deepest point of the thalweg, near the base of the dam, was too deep to measure and was estimated at 7 feet deep. This was one of the largest beaver ponds measured, extending back from the dam for hundreds of feet. Dominant riparian species were not recorded. Juvenile fish were observed throughout the pond. It is located within the Columbia National Wildlife Refuge. The pond stored a total of 6 acre feet of above-ground water.


Adams County Beaver Pond
Columbia NWR
0
145
290
580 Feet
Washington State
Locator Map
Granite Creek
Methow Valley
Sacheen Lake
Foster Creek
Spokane Tribe
Mudd Creek
Liberty Lake
Crab Creek
Turnbull NWR
Frenchman Hills
Columbia NRW
Willow Creek
N
W
E
S
Legend
Washington Streams
Columbia NWR Depth Points
Spline Depth in Feet
-8.86
-8.86 - -8
-7.9 - -7
-6.9 - -6
-5.9 - -5
-4.9 - -4
-3.9 - -3
-2.9 - -2
-1.9 - -1
-0.9 - 0
0 - 22.15

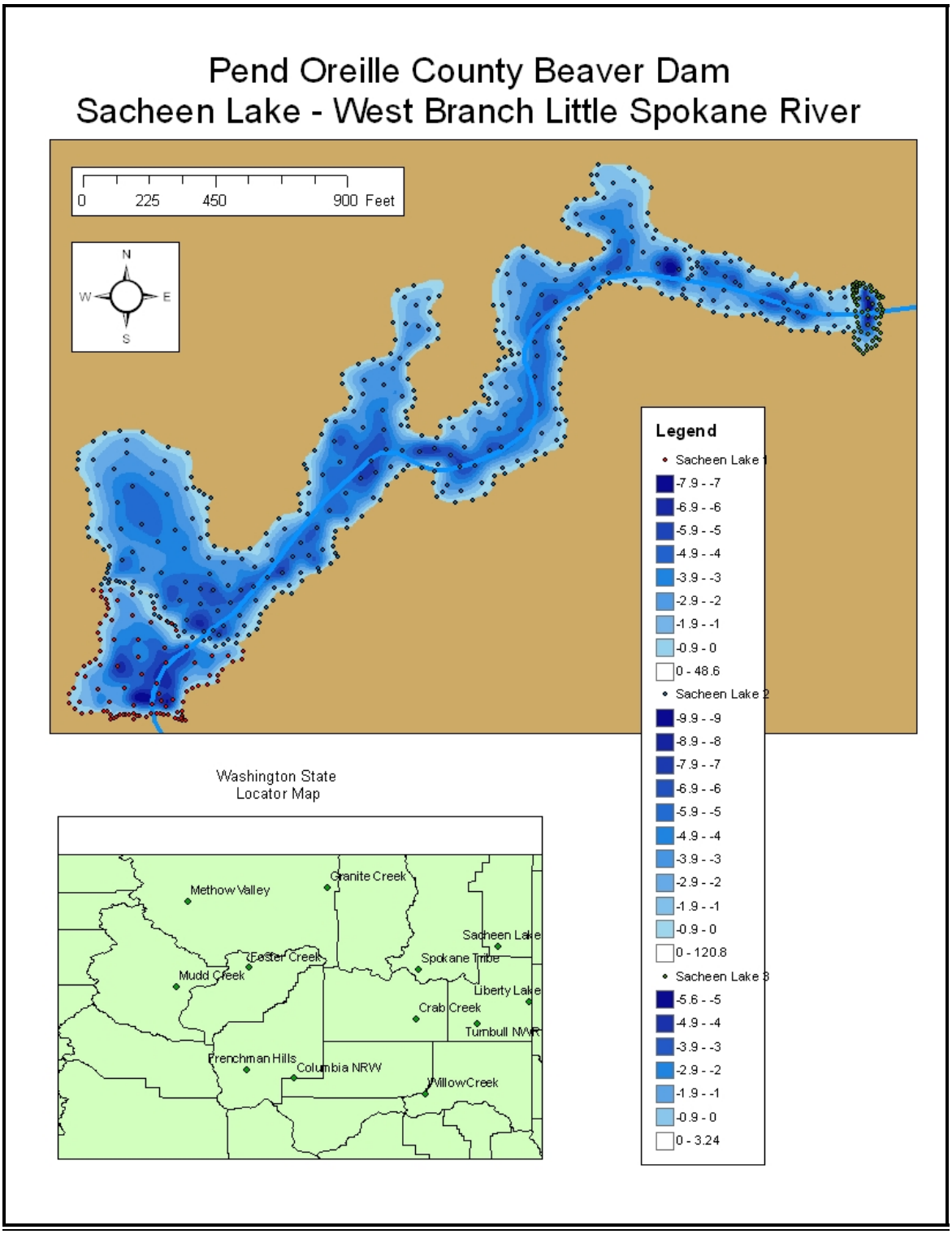
**County: Ferry**
**Stream: Granite Creek**
**Date Measured: 06/12/09**

The six dams of the Granite Creek complex comprised the oldest dam complex measured in the study with evidence dating back at least 20 years. This complex also held two of the longest dams in the study, each in excess of 300 feet. Mapping this dam was very useful due to the proximity of the roadway to the dams and the length of time the dams have been in place. Four of the beaver dams in this complex directly abut the road base; however, no dam is blocking the culvert running under the road at the bottom of the dam complex. The dominant tree species for this dam site included Ponderosa pine along one shoreline and 15 to 20 acres of alder, water birch, aspen, and cottonwood at the upstream end of the dam complex. Juvenile and adult fish were noted in all of the ponds. A raptor nest (possibly osprey) was also noted in a pine snag near the wetland edge. Total complex surface storage exceeded 30 acre feet.


Okanogan County Beaver Ponds
Granite Creek Dams
Alternate For Ferry County
N
W
E
S
0 85 170 340 Feet
Washington State
Locator Map
Methow Valley
Granite Creek
Sacheen Lake
Foster Creek
Spokane Tribe
Mudd Creek
Liberty Lake
Crab Creek
Turnbull NWR
Frenchman Hills
Columbia NRW
Willow Creek
Legend
Washington Streams
Dam 1
Dam 2
Dam 3
Dam 4
Dam 5
Dam 6
Spline Depth in Feet
Dam 1
Spline Depth in Feet
Dam 2
Spline Depth in Feet
Dam 3
Spline Depth in Feet
Dam 4
Spline Depth in Feet
Dam 5
Spline Depth in Feet
Dam 6

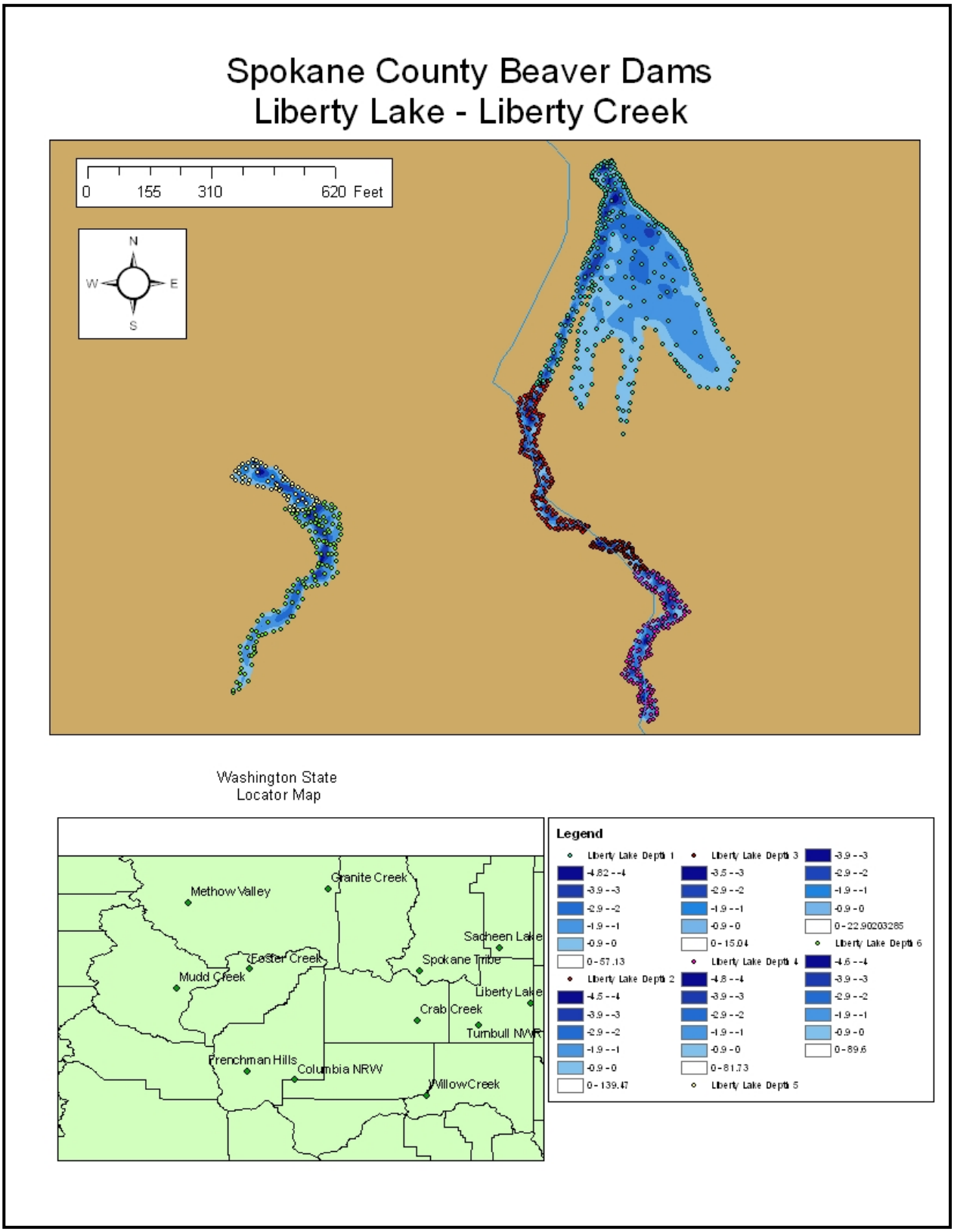
**County: Pend Oreille**
**Stream: West Branch Little Spokane River**
**Date Measured: 06/21/09**

The four beaver dams of this complex have an extremely well documented history and are believed to cause flooding in an upstream lake, Sacheen Lake. The two downstream dams are well defined and appear to be active dams with a lodge present behind each dam. The two upstream dams appear to be inactive. They have been breached with incorrectly installed beaver tubes (similar to Beaver Deceivers™, a system using tubes to divert water out of beaver ponds), and water flows freely through the tubes and several breaches. However, water is still held between the upper two dams and the upper dam acts as a hydraulic constriction for water flowing out of Sacheen Lake 1 mile upstream. Riparian vegetation for the complex is primarily Ponderosa pine with interspersed pockets of aspen, willow, alder, and cottonwood close to the shoreline. The waterway is heavily clogged with an unknown species of water lily and common cattail. The waterway is also heavily congested with a submerged aquatic plant resembling milfoil. Total surface storage for the three dams was in excess of 55 acre feet.


Pend Oreille County Beaver Dam
Sacheen Lake - West Branch Little Spokane River
0 225 450 900 Feet
N
W
E
S
Legend
Sacheen Lake 1
-7.9 - -7
-6.9 - -6
-5.9 - -5
-4.9 - -4
-3.9 - -3
-2.9 - -2
-1.9 - -1
-0.9 - 0
0 - 48.6
Sacheen Lake 2
-9.9 - -9
-8.9 - -8
-7.9 - -7
-6.9 - -6
-5.9 - -5
-4.9 - -4
-3.9 - -3
-2.9 - -2
-1.9 - -1
-0.9 - 0
0 - 120.8
Sacheen Lake 3
-5.6 - -5
-4.9 - -4
-3.9 - -3
-2.9 - -2
-1.9 - -1
-0.9 - 0
0 - 3.24
Washington State
Locator Map
Methow Valley
Granite Creek
Sacheen Lake
Spokane Tribe
Easter Creek
Mudd Creek
Liberty Lake
Crab Creek
Turnbull NWR
Prenchman Hills
Columbia NRW
Willow Creek

**County: Spokane**
**Stream: Liberty Creek/Liberty Lake**
**Date Measured: 5/14/09**

The beaver dams at Liberty Lake are on two branches of a bifurcated stream system, Liberty Creek. Historically, it was a single stream system, but it was split in two in the late 1800s to move it out of a marsh delta to allow haying of the wetland grasses. There are five dams on the eastern branch and two dams on the western branch. The dams are located within a highly used county park with several developed trails, one of which had to be moved to a higher location following flooding by one of the dams. The dams have completely blocked both streams and now re-direct the flow back into the delta instead of along man-made canals along the edges of the delta. Establishment of the beaver dams has resulted in several dozen Ponderosa pines dying in the flooded areas, but initial willow and aspen recruitment was noticed at the high water mark for the newly created wetlands. Other noted species included large cottonwoods, water birch, and alder. The delta primarily consisted of reed canary grass with small pockets of common cattail and hard stem bulrush. A large number of frogs was noted in the emergent vegetation in the ponds. Smaller fish (2 to 3 inches) were noted in the lower dams and larger fish (4 to 8 inches) were noted in the upstream dams. Total surface water storage capacity for these dams was around 4 acre feet. Larger amounts of groundwater storage were evident in the wetland delta.


Spokane County Beaver Dams
Liberty Lake - Liberty Creek
0 155 310 620 Feet
N
W
E
S
Washington State
Locator Map
Methow Valley
Granite Creek
Sacheen Lake
Easter Creek
Spokane Tribe
Mudd Creek
Liberty Lake
Crab Creek
Turnbull NWR
Frenchman Hills
Columbia NRW
Willow Creek
Legend
Liberty Lake Depth 1
-4.82 - -4
-3.9 - -3
-2.9 - -2
-1.9 - -1
-0.9 - 0
0 - 57.13
Liberty Lake Depth 2
-4.5 - -4
-3.9 - -3
-2.9 - -2
-1.9 - -1
-0.9 - 0
0 - 139.47
Liberty Lake Depth 3
-3.5 - -3
-2.9 - -2
-1.9 - -1
-0.9 - 0
0 - 15.04
Liberty Lake Depth 4
-4.8 - -4
-3.9 - -3
-2.9 - -2
-1.9 - -1
-0.9 - 0
0 - 81.73
Liberty Lake Depth 5
-3.9 - -3
-2.9 - -2
-1.9 - -1
-0.9 - 0
0 - 22.90203285
Liberty Lake Depth 6
-4.6 - -4
-3.9 - -3
-2.9 - -2
-1.9 - -1
-0.9 - 0
0 - 89.6

### *Appendix B: Additional Ecosystem Services*

Beaver provide a variety of ecosystem services beyond water storage. Valuation of these services ranges from wetlands credits to mitigating the cost of erosion to the economic benefits of sediment storage. This section describes the suite of ecosystem services that beaver provide and, where feasible, suggestions for how economic value might be measured. When considering the scope of possibilities for beaver reintroduction, it is useful to remember that virtually every first through fourth order stream in North America supported beaver in the past (Clark, 1998; Collen and Gibson, 2001) and that wetlands have been reduced by 195,000–260,000 km² since 1834 (Naiman, 1988).

Beaver build dams and construct natural wetland reservoirs that store and slowly release spring runoff and mitigate downstream flood damage. The stored water seeps out throughout the year and increases late season flows, providing downstream water quantity benefits (Gurnell, 1998; Collen and Gibson, 2001). The value of each acre-foot of available water storage—or each additional cubic foot per second of flow that results from the shifted hydrograph—depends on when and where the water is available. Valuation should consider other options, such as developing large scale storage projects to store spring runoff for late season flows, conservation programs to ensure water availability in the late summer, and purchasing water rights to ensure adequate water supply for various uses.

Beaver dams raise water tables so that additional water is stored in local groundwater reserves. Water can infiltrate stream banks and percolate downward to the aquifer (Allred, 1980). Aquifer recharge from beaver dams exceeds water loss by evapotranspiration (Woo and Waddington, 1990; Clark, 1998). Beaver dams spread groundwater into a wider area above and below the dam impoundment, assisting in subsurface irrigation of crops and plants. Raised groundwater tables also bring water within reach of pump irrigation infrastructure.

Beaver can grow and restore wetlands. The Ecosystem Services Office at the US Forest Service is currently considering wetland credit trading. Wetland credits have traded from as little as $4,000 to as much as $125,000 per acre. Wetlands foster natural biogeochemical processes that sequester phosphorus and convert nitrogen to nitrate. Wetlands reduce flow velocity enough to allow phosphorus and other suspended solids to settle out of the water column, bind to bottom sediments, and improve water quality. Natural wetlands typically remove 40–50% of the phosphorus that flows into them while promoting vegetative growth that utilizes and binds phosphorus to the wetland. The monetary value of the removal of phosphorus in a natural wetland system or beaver pond can be compared to the costs of construction of wastewater reclamation facilities that remove phosphorus, agricultural practices that reduce phosphorus runoff during rain events and flooding, and the purchase of phosphorus waste-load allocations for compliance with government regulations. In other biogeochemical processes, nitrogen is converted to nitrate and ammonium in the anaerobic conditions of pond sediments. When the pond drains and aerobic conditions return, the nitrogen-rich soils build productive meadows. Beaver ponds are proven to alter biogeochemical processes in similar ways (Naiman et al., 1994).

Beaver enhance native fisheries by creating nursery habitat upstream (e.g., ponds and braiding) and spawning habitat (e.g., clean water) downstream. Seep water is colder below beaver dams and helps cool streams, which is beneficial for fish. Beaver provide numerous benefits for listed steelhead, salmon, and other native species. Fish habitat is created when beaver form pools and

help to increase stream complexity necessary for predator evasion, spawning, and rearing. Beaver increase water quantity in late summer by increasing groundwater inputs from dammed areas and recharging aquifers. Water quality is also improved when sediment is removed from streams and when beaver-created riparian vegetation shades and cools water. According to Pollock, et al. (2004), loss of beaver dams resulted in a 68–94% reduction in coho smolt production potential in the coast range. The value of these benefits can be compared to human-engineered restoration projects aimed at restoring stream complexity, water quantity and quality, and riparian habitat to benefit salmon and steelhead populations. While reputable numbers on the effects of these restoration projects on fish survival and productivity are difficult to find, project costs are available.

Beaver-created wetlands have a positive impact on bird habitat and bird populations. A survey of land managers throughout Wyoming found that 2,819 km of first to third order streams exhibit enhanced waterfowl habitat with beaver present. A beaver reintroduction project in Wyoming produced a 20% increase in bird species richness and resulted in mallards and marsh hawks nesting inside study areas within only two years (McKinstry, Caffrey, and Anderson, 2001).

Beaver can help repair incised streams and provide stream bank erosion control. Beaver build dams that capture sediment while allowing water to leak through the dams. This sediment raises incised channel beds closer to their floodplain, which restores and increases frequency of overbank flooding, providing for aquifer recharge and reducing flood erosion. Sediment also strengthens dams, allowing some to continue to function at least partially after beaver abandonment or extirpation. The role of beaver dams in sediment control can be compared to the following human measures: in-stream structures to raise channel beds of incised streams, sediment removal from drinking or municipal water sources, and in-stream structures to curb erosion (e.g., large woody debris, rip rap, engineering meanders, etc.).

Capturing spring runoff will assist in climate mitigation. Additionally, beaver increase carbon storage. Naiman (1988) showed that carbon stored in a riffle lasted 24 years compared to 161 years in a pond. Similarly, the ratio of standing carbon stock in a pond compared to a riffle was 12,000 to 4,400.

Lastly, beaver increase human amenities and aesthetics. Anglers and hunters purchase fishing, hunting, and trapping permits and may save money on food expenditures. Recreationists spend money to watch wildlife. An example of the valuation of amenities is found in “Wildlife Watching in the US: The Impacts of National and State Economies in 2006,” by Jerry Leonard (2008).

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***Appendix C: Sites Identified for Beaver Introduction and Outreach Efforts***

The Lands Council's habitat suitability analysis has identified approximately 10,000 miles of potentially suitable habitat for beaver on various named streams throughout Eastern Washington. Specific stream drainages have been identified for pilot reintroductions in 2010 on both public and private lands. These drainages were chosen because they fall within the geographic area of The Lands Council's water and forest programs, provide suitable beaver habitat, and are a source of water for the Columbia River.

The Lands Council has enlisted the support of agencies with land or management jurisdiction in these drainages to identify pilot beaver relocation sites on public land and potentially willing private landowners. A number of private landowners were contacted in the fall of 2009 to seek their support and involvement in this project to set the stage for relocation activities in 2010. Specific outreach activities for the selected drainages are described below. Stream segments were chosen based on the habitat suitability analysis, input from the Forest Service and local Conservation Districts, locations of willing landowners, and on-the-ground habitat surveys.

The Lands Council developed a brochure on the Beaver Solution to use for outreach to landowners, land managers, and the general public. In addition, the Beaver Solution section of The Lands Council's website, www.landsouncil.org/beaversolution, contains facts on beaver, summaries of scientific papers, links to websites, and other pertinent resources.

***Sites Identified for Beaver Relocation***

*Spokane County: Hangman Creek Drainage and Little Spokane River.* With the help of the Spokane County Conservation District, specific stream segments were identified to field check for potential beaver reintroduction. The District has an inventory of occupied and formerly occupied beaver sites incorporated into the Spokane County Proper Functioning Condition Stream Inventory & Assessment. Based on input from the Conservation District and field surveys, a section of California Creek has been selected for potential beaver reintroduction, and the landowner is being contacted to seek his support of this project. Cottonwood Creek and the Little Spokane River will also be considered for future beaver relocation activities, and an ongoing survey by Lewis and Clark High School students is identifying new sites.

*Ferry and Stevens County*. The Lands Council has identified several drainages on or near the Colville National Forest with neighboring private lands and private in-holdings that contain suitable beaver habitat. The US Forest Service has a database of existing and potential beaver sites. Two sites have been selected: Bacon Creek (with the support of a private land owner) and South Fork Chewelah Creek/Wilson Creek (US Forest Service land). Other potential drainages include: Pierre Creek, Mill Creek, Deadman Creek, East Deer Creek, Little Boulder Creek, and the Little Pend Oreille River. The Little Pend Oreille National Wildlife Refuge manager is very interested in beaver reintroduction and has located a site for pilot reintroduction in 2010. This is an area of high potential for wetland restoration because the refuge excludes cattle, and the National Wildlife Refuge system's mission is to protect and restore wetlands and wildlife habitat.

*Lincoln County: Crab Creek Drainage*. This is an area of great interest for potential beaver reintroduction due to the amount of potential habitat in this drainage. The Lands Council will be contacting the Lincoln County Conservation District and the Bureau of Land Management (BLM) to identify possible locations and willing landowners within the Crab Creek drainage.

***Public Outreach***

In an effort to build broad support for the Beaver Solution, we have identified specific government committees and organizations to meet with during the winter of 2010 to present the results of the Beaver Solution study, seek input and feedback, and solicit support for this project. These organizations include the Columbia River Policy Advisory Group (PAG), Eastern Washington Farm Bureau, and Eastern Washington Council of Governments. In addition, presentations are being scheduled with planning and implementation groups in Water Resource Inventory Areas (WRIAs) that include potential beaver relocation sites. WRIA groups include WRIA 53 (Lower Lake Roosevelt), WRIA 43 (Upper Crab-Wilson), WRIA 55/57 (Little Spokane/Middle Spokane), and WRIA 56 (Hangman).

A presentation will be prepared that explains the purpose and goals of the project, information on the benefits of beaver, the scope of our research, methodology and results, and specific issues addressed in the report (e.g., surface and groundwater storage, late season flow, management issues, challenges for land owners, and ecosystem services).

Over 70 participants from around the West gathered to share their knowledge of beaver at the first annual Working Beaver Forum held on March 31–April 1, 2009. The Forum was organized by The Lands Council, Oregon Natural Desert Association, Grand Canyon Trust, and the National Forest Foundation. The Working Beaver Forum was designed for local, state, and federal agencies; tribal agencies; and non-profit organizations interested in beaver management. The goal of the forum was to convene a group of interested parties to discuss issues related to beaver and their benefit to watersheds.

To engage the general public in the project, The Lands Council held a very successful public event in September 2009 at Liberty Lake County Park, “Picnic with the Beavers,” which was attended by over 100 people. Participants learned about the Beaver Solution, the role that beaver play in the Liberty Lake watershed, and the importance of beaver to the Coeur d’Alene Tribe.

*Appendix D: Washington Department of Fish and Wildlife Re-introduction Guidelines*

# BEAVER RE-INTRODUCTION

## 1. DESCRIPTION OF TECHNIQUE

Beaver can be important regulators of aquatic and terrestrial ecosystems, with effects far beyond their food and space requirements[1]. Beaver have the potential to modify stream morphology and hydrology by cutting significant amounts of wood and building dams. This in turn influences a variety of biological responses within and adjacent to stream channels. Historically, beaver have been key agents of riparian succession and ecology throughout North America. They can naturally transform pioneer woody vegetation into physical features that result in the expansion of floodplains, riparian community structure, diversity, and productivity[2].

The predominance of beaver in the Pacific Northwest drew many early trappers and explorers to this part of the country. By 1900, unregulated exploitation left beaver almost extinct. Their removal, by extensive trapping, resulted in incised channels, loss of riparian and wetland areas, and loss of channel complexity critical to fish and invertebrate production. The beaver population in the U.S. has been reduced from a pre-European estimate of 60–400 million to a current level of 6–12 million[1].

As the role of beaver in managing and maintaining stream and riparian ecosystems has gained recognition, interest in the potential for reintroducing beaver to recover stream and riparian function in degraded ecosystems has grown. Beaver have been successfully transplanted into many watersheds throughout the United States during the past 50 years. This practice was very common during the 1950s after biologists realized the loss of ecological function resulting from over-trapping of beaver by fur traders before the turn of the century. Reintroduction has restored the beaver populations in some areas, but many areas are still devoid of beaver. For example, a Wyoming survey found that beaver had been extirpated from 25% of all 1$^{st}$- to 3$^{rd}$-order streams originally occupied by them. Furthermore, many areas that still held beaver were not ecologically functional because their numbers were so low that they did not mean much to the system. Much unoccupied habitat or potential habitat still remains, especially in the shrub-steppe ecosystem, hard hit by trapping and over-exploitation. In forested areas, where good beaver habitat already exists, reintroduction has been used to restore some areas[3]. In rangelands, where loss of riparian functional value has been most dramatic, the potential role of beaver in restoring degraded streams is most appreciated but least understood[3].

Transplanting beaver may create the conditions needed to both establish and maintain riparian shrubs or trees. In the case of newly restored habitat or areas far from existing populations, reintroduction of beaver without further habitat improvement might be warranted[3]. Transplanting success rates can be high, but this depends on the site, the condition of the predator community, the time of year they are moved, and the age class of animals transplanted[2, 4].

## 2. PHYSICAL AND BIOLOGICAL EFFECTS

Successful reintroduction of beaver has demonstrated: 1) an elevated water table upstream of the dam, which in turn improves vegetation condition, reduces water velocities, reduces bank erosion, and improves fish habitat (increased water depth, better food production, higher

dissolved oxygen, and various water temperatures), 2) reduced sedimentation downstream of the dam, 3) increased water storage, 4) improved water quality, and 5) more waterfowl nesting and brooding areas[5]. These effects, at the landscape level, influence the population dynamics, food supply, and predation of most riparian[1] and aquatic species. Beaver dams on coastal streams increase landscape-scale habitat diversity by creating a unique wetland type for that area[6].

Beaver ponds can alter water chemistry by changing adsorption rates for nitrogen and phosphorus, by trapping coliform bacteria[5], and by increasing the retention and availability of nitrogen, phosphorus and carbon[1]. Beaver-altered streams also cause taxonomic and functional changes in the benthic macroinvertebrate community due to the effects of impoundment and subsequent alteration of water temperature, water chemistry and plant growth[7].

Beaver can also influence the flow regime within a watershed. Beaver ponds can improve infiltration and ground water storage by increasing the area where soil and water meet. Headwaters can retain more water from spring runoff and major storm events and release it more slowly, resulting in a higher water table and extended summer flows. This increase in water availability, both surface and subsurface, usually increases the width of the riparian zone and, consequently, favors wildlife communities that depend on that vegetation. The richness, diversity, and abundance of riparian-dependent birds, fish, herptiles, and mammals can increase as a result. Beaver ponds are important waterfowl production areas and can also be used during migration. In some high-elevation areas of the Rocky Mountains, these ponds are solely responsible for the majority of local duck production[5]. In addition, species of high interest, such as trumpeter swans, sandhill cranes, moose, mink, and river otters, use beaver ponds for nesting or feeding areas[3]. Beaver ponds also provide very important salmon habitat in western Washington and Oregon. Juvenile coho and cutthroat are known to over-winter in beaver ponds and the loss of beaver pond habitat has resulted in the loss of salmon production potential[8].

By introducing beaver into the lower watersheds of first-, second-, and sometimes third-order drainages, or below areas of erosion, beaver activity and stream sediment transport can re-elevate the bed level of incised channels; reactivate floodplains; increase stream bank water storage and aquifer recharge; and increase sediment deposition and storage, creating favorable micro-site conditions for maximizing natural vegetative stabilization of the drainage[2]. Once viable beaver complexes become established and are self-sustaining (3 to 4 years), the complexes themselves will begin to form natural gully plugs of a quarter- to a half-mile in length, accelerating sediment deposition and riparian recovery further upstream. By facilitating the establishment of beaver dam complexes at intervals throughout a watershed, this process can create a leapfrog effect, helping to accumulate or stabilize sediment throughout the system[2].

Beaver can be used to initiate or accelerate the natural restoration of degraded or lost riparian systems. Identifying limiting factors and providing supplemental management techniques to compensate for these factors are important. When physical site conditions can be improved for initiating natural riparian establishment, the system can develop to a self-sustaining level in as little as 3 to 4 years. By transplanting beaver to degraded sites, providing supplemental dam material during initial construction (to reduce dam washout prospects), and maximizing vegetative re-growth and establishment, riparian recovery and succession can be accelerated[2].

## 3. Application of Technique

Beaver can be reintroduced to any watershed where they have been extirpated within the following parameters:

- The channel is less than 3% slope to minimize dam blow-outs.
- The water supply is perennial or beaver are released on ephemeral streams during a period with sufficient water to create a dam and lodge.
- The stream geomorphology is such that beaver activities will be supported. For example beaver do not seem to colonize as well in volcanic stream systems due to the instability of the channel.
- Beaver will not cause unacceptable damage to public or private property or facilities (See McKinstry and Anderson[9], for problem areas to avoid as well as benefits that landowners feel they receive from beaver.)
- There is an adequate food source (at least 18 acres of willow or 6 acres of *Populus* species within 100 feet of the stream)[10] and dam building materials.
- Their activities will not conflict with other management prescriptions, such as endangered species management or instream flow issues.
- The valley is at least 60' wide (150' or more is best)[10].
- The site is below 6,000' elevation. The short growing season and heavy snowfall above this elevation may be limiting factors for beaver[10].

## 4. Risk and Uncertainty

### *4.1 Uncertainty of Technique*

Perhaps the most difficult aspect of this technique is trapping beaver. The process can be time-consuming and requires dedication. However once they are captured, they are easy to handle and transport[11]. Transplanting beaver is not an exact science. On average only 15–20% of relocated beaver stay in their new stream systems[4]. Translocated beavers in Wyoming lived an average of 86 days post-release and predation and emigration accounted for 30% and 51% of the losses, respectively[4]. Beavers in the 2.5 year-old age class were the most likely to survive and modify habitat, although older beavers had similar survival rates. All beavers < 1-year old died within 60 days of release. Other researchers have found that the average distance from the release site to the area of establishment is eight miles, and many move further[12].

Reintroduction into degraded riparian areas within the shrub-steppe zone is controversial. Conventional wisdom holds that a yearlong food supply must be present before reintroducing beaver. In colder climates, this means plants with edible bark, such as willow, aspen, or cottonwood must be present to provide a winter food supply. But often these species are the goal of restoration. In some cases, willow or other species can be successfully planted as described in the *Riparian Restoration and Management Technique*. In other areas, conditions needed to sustain planted cuttings, such as high water table and minimal competition with other vegetation, might preclude successful establishment. Transplanting beaver before willows are established might create the conditions needed to both establish and maintain riparian trees and shrubs. In these cases, supplemental food should be provided at or near the reintroduction site[13].

With the dramatic drop in beaver trapping that has occurred since Initiative 713 in Washington, the population is expected to increase, making available vacant beaver habitat increasingly

scarce. Being territorial, their numbers are self-limiting, but they will continue to increase stream occupancy in the streams of Washington if left untrapped.

### *4.2 Risk to Infrastructure and Property*

Moving beavers during spring and summer can result in them emigrating and becoming a nuisance downstream. However, transplants in spring have been used in Wyoming to effectively colonize ephemeral streams that might otherwise be dry by late summer[4]. Potential conflicts with other stream restoration or management activities should always be considered in transplant operations[2]. Common problems include cutting or eating desirable vegetation, flooding roads or irrigation ditches by plugging culverts, and increasing erosion by burrowing into the banks of streams, reservoirs, or dikes[9]. In addition, beaver carry Giardia pathogens, which can infect drinking water supplies and cause human health problems. In these areas, it is important to work in cooperation with adjacent landowners[3].

### *4.3 Risk to Habitat*

Beavers can disrupt the habitat of other wildlife species. Negative impacts include loss of spawning habitat, increase in water temperatures beyond optimal levels for some fish species, alteration of riparian vegetation and habitat, barriers to migration for some fish species, and habitat conversion from lentic to lotic systems. Therefore, caution should be used in introducing beaver into areas where they were not endemic[3].

## 5. METHODS AND DESIGN

### *5.1 Data Collection and Assessment*

In any stream where beaver restoration is being considered, first evaluate whether the habitat is suitable and if beavers once used the area. Eight variables are helpful in this evaluation: (the following information is adapted from Vore 1993[10])

1. Previous beaver activity—indications of previous beaver occupancy include old dams and lodges, beaver cuttings, collapsed bank dens, and old beaver runways. If there has been no beaver activity for many decades evidence may be overgrown and appear as humps or small ridges. Interviews with people who have long lived in the area and/or trappers can also be useful in this assessment.
2. Water—a relatively stable, perennial water source is important. After damming, the water depth should be sufficient to accommodate lodges or bank dens and winter food caches.
3. Stream gradient—this is one of the most important factors. Beaver favor streams with low gradient. Less than 3% is ideal, although they will use higher gradient streams.
4. Valley width—beaver prefer valleys that are a minimum of 60’ and preferably greater than 150’ wide to provide sufficient quantities of their preferred food sources.
5. Food—winter food is often a limiting factor. There should be at least 18 acres of willow or 6 acres of *Populus* species within 100’ of the stream per beaver colony.
6. Dam building material—The same species used for winter food are used to build dams. Heavy conifer cover is not thought to be good beaver habitat.
7. Stream substrate—beaver do not seem to colonize as well in volcanic stream systems due to the instability of the channel

8. Elevation—the short growing season and heavy snowfall above 6,000' elevation may be limiting factors.

Additional considerations for managing beaver include watershed erosion rates and volumes, dam and pond cycling frequencies, carrying capacity, population dynamics and their management, and site-specific factors, such as bank stability, soil type, stream order and size[1]. Note the presence of culverts, irrigation structures, or other structures the beaver may plug and infrastructure that may be flooded. A contingency plan should be developed if that occurs (see section 10 *Maintenance*). Determine the level of cooperation or concern from the neighboring landowners.

### *5.2 General Design Information*

- Transplant beaver during their principal dam building period, August–October. This will allow for time to gather a food cache, but limit their time to emigrate prior to constructing a dam, lodge, and food cache for the coming winter.
- Transplant at least 4 beavers (2 of each sex) to a site, preferably from the same colony[10]. See section 5.5 *Aging and Sexing*, on sexing beaver.
- Target trapping to dam- and lodge-building beaver (as opposed to river-dwelling beaver) since that is the habitat type you are trying to restore.
- Target trapping to 2.5 year old beaver as much as possible since they are the most likely to survive and modify habitat[4]. See section 5.5 *Aging and Sexing,* on aging beaver.
- Expect beaver to cut and use a large number of trees for dam construction during the first year or two after transplant.
- It may be helpful to provide beaver with additional building materials to use near the reintroduction site. This can encourage beaver to stay near the site and strengthen dams built of sagebrush or other shrubs[13]. The primary criteria for placing wood to encourage beaver use are:
  - the height of the structure above the water (< 0.2 m)
  - the proximity of a structure to a bank den (< 70 m)
  - the proximity to a deep pool (< 70 m)
  - and an unconfined stream channel[14].
- Do not allow harvest of beaver in newly established colonies for at least three years. If the project is on private property, "No Trapping" signs should be posted to identify the area off limits to trapping. If the project is on public property, the Washington Department of Fish and Wildlife will need to develop trapping closures for that area.
- Grazing may need to be delayed or deferred for several seasons, depending on riparian condition. When resumed, use a grazing system beneficial to riparian systems, especially one that benefits willow and *Populus* communities.
- To be successful, there must be cooperation between adjacent landowners and local wildlife officials. A cooperative evaluation of existing habitat quality and potential adverse beaver activity is very important[2, 3].
- When evaluating sites for potential beaver releases, gradient should be less than 3%, and the site should have adequate food supply.

### *5.3 Trapping*

Snares and suitcase-style traps are the best methods for trapping beaver[15], however, snares are illegal for use in Washington State. For Bailey live traps, select small channels and make sure the beaver frequent the shore for feeding. The water should be at least 10 to 12 inches deep. Hancock live-traps can be used in any area that beaver frequent including dry land. Most commonly they are set on lodges and dams.

Both Bailey and Hancock live traps are shaped and operate like a large suitcase. The Bailey's trap must be set in an open position, entirely under water with the trip pan 8 inches below the water surface. Some shoveling may be required to properly position the trap for optimal trapping conditions. The trigger should also be adjusted to about 4 inches under the water. This will ensure that muskrats swimming over it will not spring the trap. Remember, it is very important that you do not disturb the surroundings more than absolutely necessary when setting the beaver trap. Freshly cut willow branches, or poplar (aspen or cottonwood) less than 1¼-inch diameter can be used as bait, and placed on the shoreline where the beaver visit. If there is a chance that the beaver will not pass over the center of the trap while moving towards the bait, long sticks or small logs should be placed in the mud out from the shore, leading to the trap at an angle to form an open "V" on the lake side. The opening generated by the logs should be about 14 to 16 inches wide over the center of the trap. The open "V" forces the beaver to swim over the trip pan of the trap and through the opening to reach the willow bait on the shore at the rear of the trap. As the beaver swims over the trap, its body hits the trip pan and springs the trap. Before leaving the set trap, splash water over everything that was handled, including the area that was walked over. Wait until the water clears and look the trap over very carefully. Make sure that none of the mesh strands are over the end of the trigger arms at the hinges, and that the safety hooks are released. Once sprung, the trap is positioned about one-half of the way out of the water, capturing the beaver unharmed and able to breathe.

Hancock traps are similar to Baileys, however, water depth is not an issue and they can be set on dry ground as well. For Hancock traps, select an area where beaver are frequenting and anchor the trap so that when it is closed it is not under water. Since the back portion of the trap is out of the water you can use fresh cut willow or aspen as bait and even artificial scent mounds with commercial beaver lure can be used to attract them to the trap.

All traps need to be checked on a daily basis, preferably in the early morning since prolonged exposure may cause death to the trapped beaver. Both Bailey and Hancock traps may be used to transport captured beavers, although it may be preferable to store them in a caged area prior to transplanting to wait while other beavers are captured.

### *5.4 Handling*

It is often necessary to keep beavers in captivity while other adult beavers of the appropriate sex are caught. Rasmussen and West, as quoted in Vore[10], discuss holding captive beaver for as long as 10 days as follows:

> "Holding live beavers to obtain pairs and numbers for transplanting should be done in specially designed holding pens and crates to insure success. Beavers held for transplanting should have access to water to enable them to partly submerge at all times as a necessity in performing certain bodily functions.

> Care must be taken in preventing the beavers from becoming chilled or overheated while being transported to new sites. Kits are particularly susceptible to extremes in temperature and all ages are sensitive to excessive exposure to heat and sunlight.
>
> A temporary collapsible holding pen was constructed which measured 6' by 4' by 4'. The top was left open, or shaded with shrubbery when in use. All four sides were made of 20-gage sheet metal, and were held together at the corners by means of iron rods pushed through a series of hasps and eyes. The bottom consisted of an angle iron frame covered with netting, and was made to fit in flanges formed by turning in the bottom of the four sides. The bottom screen must be very heavy, comparable to material used in screening gravel. This pen was placed in a stream or pond in such a way that several inches of water was present along one side or in the corner while the remainder of the pen remained dry."

If it is necessary to sedate beavers for any reason (to determine sex, for example) during handling, transport, or confinement, ketamine HCL combined with acepromazine has been used successfully[16]. Ketamine is a fast-acting non-barbiturate, general anesthetic that is an uncontrolled substance and therefore obtainable from a veterinarian. Animal sedation should only be performed by a qualified and experienced biologist.

### 5.5 Aging and Sexing

Sexing beaver is difficult since they do not have external sex organs and they have a cloaca, which makes identification extra difficult. Palpating for the baculum is the most common methods of sexing beaver. Teats are evident in females only while they are nursing. Beaver can be easily handled with a commercial catchpole and these allow you to handle the beaver for sexing, ear-tagging, or attaching radio transmitters.

There is no way to positively age live beaver. However, beaver can be placed into one of four age classes (kit: 0-1 year, juvenile: 1-2 years, subadult: 2-3 years, adult: 3 years or more) based on weight, total length, and tail width. Use at least two criteria to determine age[10].

| Age of Beaver | Weight | Total Length | Tail Length | Tail Width |
|---|---|---|---|---|
| Adult | ≥43 lbs | ≥42" | ≥11.5" | ≥6.5" |
| Subadult | 30-43 lbs | 38-42" | 10.2-11.3" | 5.0-6.2" |
| Juvenile | 10-29 lbs | 27.5-37.7" | 7.1-10" | 3.1-5.0" |

## 6. Permitting

A Permit is required from the Washington Department of Fish and Wildlife to live trap and move beaver. Washington Administrative Code 232-12-271 (http://www.wa.gov/wdfw/wlm/game/trapping/index.htm) covers the Criteria for Planting Aquatic Plants and Releasing Wildlife. Check with a representative of the Washington Department of Fish and Wildlife.

## 7. Construction Considerations

If you are not an experienced beaver trapper, it is recommended that you hire someone who is. Contact the Washington Trappers Association for information at: Washington State Trappers Association, Box 2245, Olympia, WA 98507.

## 8. Cost Estimation

Live traps are approximately $350 each.

## 9. Monitoring

Transplanted beaver can be radio tracked by using tail-mounted transmitters. See Rothmeyer et al.[17] for details on this technique. Radio tracking may be desirable to determine how many of the transplanted beaver stay in the area and where they go if they emigrate. Based on the objectives of the transplant, you may also want to monitor water quality, temperature, fish presence/absence, and riparian vegetation. Infrastructure and land use constraints may require additional monitoring, including water level recording and visual inspection of culverts, irrigation structures, or other structures that may become plugged, flooded, or otherwise compromised by beaver activity. See the *Monitoring Considerations Appendix*.

## 10. Maintenance

In cases where beaver live in close proximity to humans or features important to humans, they may need to be removed or their damage controlled. Control of nuisance beaver usually involves removing the problem animals directly or modifying their habitat. Beaver can be live-trapped (Bailey or Hancock traps) and relocated to a more acceptable location or killed by trapping (e.g., Conibear #330) or shooting[18]. In cases where the water level in a dam must be controlled to prevent flooding, a pipe can be placed through the dam with the upstream side perforated to allow water flow. This will allow the dam to be retained while controlling the water level of the pond. See Finnigan and Marshall[19] for more information on ways to manage beaver impacts.

Grazing may need to be withdrawn for several seasons, depending upon riparian condition. When resumed, use a grazing system beneficial to riparian areas.

## 11. Examples

North Fork Nooksack River:
http://www.n-sea.org/fishtale/fall2001/BeaverRelocationProject.shtml
Fox Creek, Oregon:
http://www.freedom-here-and-now.com/foxcreek/beaver.html

## 12. References

### *12.1 Related Literature*

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