Lower North Fork Nooksack River:
Reach Assessment and Restoration Recommendations

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EXECUTIVE SUMMARY

In this study we used a combination of historical aerial photographs, digital terrain models, field habitat surveys, chinook salmon spawning surveys, redd scour monitors, and hydrologic data to show habitat change in the lower North Fork Nooksack River (RM 36.6 to 57.6) and its likely effect on North Fork/Middle Fork spring chinook. Landscape-scale changes due to timber harvest and floodplain encroachment have resulted in a dearth of large trees that can be recruited to the channel during floods, and therefore fewer logjams, more transient river bars, and smaller suitable areas for vegetation to become established. Combined with higher flood frequencies and intensities it appears that channel bars and islands are being destroyed at a greater rate than they are being created, and the active channel is widening at the expense of the floodplain and floodplain islands. The disappearance of channel islands implies a reduction in the protected back channels that provide the best rearing habitat for juvenile salmonids, and in the case of larger back channels, the best spawning habitat as well. Since the population of returning chinook adults can be closely related to the flood intensity during the incubation and rearing phases of their life cycle, we expect that a shift in habitat towards more protected back channels will have a demonstrable, positive effect on population productivity and abundance.

A summary of peer-reviewed articles from scientific journals that are relevant to the processes at work in the North Fork is presented at the beginning of the report, followed by summaries of “gray literature” reports that apply directly to the North Fork. Following the literature review, the Ecological Underpinnings of the Restoration Strategy are presented in a classical scientific format, where the site description and methods are followed by a brief discussion of the results, the data for which are presented primarily in tables and graphs. (The ecological findings and their significance were summarized in the preceding paragraph.) Following the ecological findings is a summary hypothesis of how the natural processes in the North Fork have been interrupted, how they differ from those in more pristine river systems, and how these habitat changes appear to be affecting the North Fork early chinook population. Following the hypothesis is an overview of current habitat in the North Fork study area, and how it varies from upstream to downstream. That chapter on Longitudinal Variation in Existing Habitat also compares the North Fork to basins where much of the research on large wood has been conducted, to better substantiate the North Fork findings and provide a relevant context for the North Fork among other rivers. Descriptions of each of the fourteen study reaches follow, providing details on how the reach has varied over time, the current habitat composition, the gradient, width, sinuosity, and constrictions in the reach, the potential for connection with floodplain channels, and the opportunities for restoration, particularly those that address the longevity of channel island and side channel function. The final chapter on Project Ranking lists specific objectives for restoration in the lower North Fork mainstem (the study area) and strategies for implementing each objective. A list of potential projects extracted from the detailed reach descriptions provides a starting point for watershed practitioners looking for restoration opportunities in the North Fork. Finally, each project on the list is ranked and prioritized according to objective and measurable criteria to evaluate areas where restoration has the greatest potential for success.

INTRODUCTION

The North Fork Reach Assessment was originally intended as a data collection and assimilation effort, with no plans for a final written report. The initial proposal was to collect and interpret data to support prioritization, design, and implementation of acquisition and restoration projects, without presenting a complete catalogue of all the historic conditions or current data that might pertain to North Fork habitat. Past work had already established that channel instability and habitat diversity were limiting the population of North Fork Nooksack spring chinook, and that more off-channel areas attractive to chinook for spawning would help recover this threatened species. The intention was to use a combination of GIS mapping and field surveys to document current habitat conditions, spawner concentration, bank hardening, back channels, historic channel migration areas, and disconnected floodplain habitat in the lower 21 miles of the North Fork. Existing data on riparian conditions, sediment supply, stream temperatures, and land uses provided a watershed context to site-specific restoration proposals. This information was to be used, in concert with watershed restoration partners and subject to public involvement, to identify the most promising sites for restoration or protection, and to choose at least one site for detailed analysis and project design. Projects at other sites were to be pursued either concurrently or in subsequent years. The objective was to generate a list of the most promising North Fork restoration sites for a construction project in summer 2006.

After the initial field mapping results and restoration options had been presented it was apparent that a written report on the findings would be useful in disseminating the results and progressing to project implementation. This report was thus compiled to document the data collection, assimilation, and analysis that led to the restoration project list. It is not intended as a comprehensive discussion of all the data available for the North Fork, although many local reports relevant to the North Fork have been included in the literature review. The primary intention of this report is a focused discussion of the ecological workings of the physical habitat in the lower North Fork (RM 36.6 to 57.6) as it pertains to chinook spawning and rearing, a detailed discussion of each of the 14 reaches in the lower North Fork, and the recommended restoration options in each.

BACKGROUND AND LITERATURE REVIEW

The North Fork Nooksack generally behaves as other rivers in the Pacific Northwest, according to the same ecological principles governing river morphology and ecology, although in several important ways it diverges from the pristine rivers where most of that research was conducted. This section discusses the emerging research on river form and its effect on fish habitat, as an introduction to the data on the North Fork presented in this report. Following the review of peer-reviewed literature is a summary of local reports pertaining directly to the North Fork.

1) Bar and channel form, channel typing

At large spatial scales (i.e., $10^1 – 10^3$ km^2) changes in the supply of large wood can trigger changes in both river-reach morphology and the interaction between a river and its floodplain (Montgomery et al. 2003). Large rivers generally have scattered large debris in the high water zone on the banks, and large accumulations of debris collecting on obstructions in the channel and on the outside of river bends. In these situations organic debris has little influence on a channel except at high flow (Keller and Swanson 1979). Where midchannel bars form on the downstream side of debris jams they often grow into islands if they become vegetated and are protected from erosion (Kellerhals et al. 1976). Even in arid areas with few trees, channel islands still form, but primarily in response to the coarser fractions of the bed load which locally cannot be transported (Leopold and Wolman 1957). The bar grows in height and downstream by continued deposition on its surface, forcing the water into flanking channels, which, to carry the flow, deepen and cut laterally into the original banks (Leopold and Wolman 1957). Braided channels build islands and bars to near the elevation of floodplains (Wolman and Leopold 1957). In primary channels with meandering or braided morphology, logjams promote sediment deposition and trap floating propagules (Latterell et al. 2006), initiating the process of vegetated island and floodplain formation. Development of midchannel bars due to diversion of water around debris dams and resulting deposition is often important in development of short island-braided reaches in otherwise meandering stream channels (Keller and Swanson 1979).

Kellerhalls et al. (1976) pointed out that the difficulty in classifying channel islands is that at higher flows islands and bars are submerged under a continuous sheet of water, and that a continuum of island concentration spans a range from infrequent islands separated by several channel widths, to braiding with multiple overlapping islands (Kellerhals and Church 1989). Channel islands are defined as well-vegetated surfaces reaching to at least floodplain elevation. Lower, unvegetated or lightly vegetated surfaces are channel bars (Kellerhals and Church 1989). Individual braids may not persist for long, but anastomosed systems, particularly if the banks are heavily protected by persistent woody vegetation, may remain consistently braided for long periods of time (Kellerhals and Church 1989). Channel bars probably contain more information on channel processes and bedload sediment transport than any other river feature (Kellerhals et al. 1976). Local scour at natural outcroppings is one of the most reliable indicators of potential scour in a reach (Kellerhals et al. 1976).

Lateral migration of a stream across its floodplain can take place with almost no change in channel width. The volume of material deposited tends to be about equal to the volume eroded (Wolman and Leopold 1957).

The island-braided channel type combines characteristics of anabranching and braided channels. Anabranching is the division of a river by islands whose width is greater than three times the water width at average discharge (Brice et al 1978, cited in Schumm 1985). Successive division and rejoining with accompanying islands is the characteristic denoted by synonymous terms, braided or anastomosing stream (Leopold and Wolman

1957). The term “anastomosis” is defined as the rejoining of different branches which have arisen from a common trunk, so as to form a network. Anastomosing channels are distinct from anabranched channels, as they are multiple channel systems having major secondary channels that separate and rejoin the main channel to form a network (Schumm 1985).

Rivers that are situated close to the meandering-braided threshold should have a history characterized by transitions in morphology from braided to meandering and vice versa (Schumm 1985)

Channels with a low ratio of bed load to wash load tend to be narrow, deep, and sinuous, whereas when the ratio is high the channels are relatively wide, shallow, and straight (Schumm 1985).

Channel pattern effectively stratifies the dynamics of rivers in the forested areas of the Pacific Northwest, with braided channels the most dynamic, meandering channels the least dynamic, and island braided channels intermediate between the two (Beechie et al 2006). Ecological theory suggests that biological diversity should be highest in island-braided channels where the intermediate disturbance theory would predict a high diversity of habitat.

Stable, incised channel reaches in rivers with small sediment loads will not be able to reduce their width quickly by sedimentation, whereas channels with high sediment loads may adjust to new obstructions in just one or more floods (Kellerhals and Church 1989). Since the river may have some lateral freedom to adjust its channel slope by varying its sinuosity, channel slope is neither fully imposed nor fully self-formed (Kellerhals and Church 1989). If the imbalance of sediment load relative to stream power is sufficiently great, the river will perform frequent avulsions within a broad channel zone, thereby taking up a braided habit through the material (Church 1992). Constrained valleys naturally have less room for off-channel habitats, and valley landforms have a direct effect ($r^2 = 0.74$) on the abundance of avulsion channels, braids, and side channels (Rot et al. 1998).

Strictly speaking, anastomosing channels are similar to those of low energy, anabranching delta and delta-fan systems. They require low gradients and stable banks, and are usually found in areas of cohesive soils. True anastomosing channels frequently show remarkable stability over time (Harwood and Brown 1993). Unlike single thread rivers, braided rivers tend to demonstrate (within the general range of base flows) relatively little change in usable habitat area with decreasing discharge, since loss of habitat in braids is offset by gains in the mainstem (Glova and Duncan 1985).

Floodplain forest clearing is unlikely to have major effects on the channel dimensions of a large river, but tends to lead to accelerated rates of channel migration (Kellerhals and Church 1989). In rivers greater than 20-30m bankfull width riparian effects do not dominate the channel, although laterally unstable channels in forests may recruit large volumes of wood debris which accumulate locally to influence bar and channel developments (Church 1992).

In forested regions, the formation of stable logjams promotes formation of an anastomosing channel morphology (Harwood and Brown 1993, Collins and Montgomery 2002, Montgomery et al. 2003, O'Connor et al. 2003).

2) LWD accumulations, LWD distribution across floodplains, channel migration, avulsion and island creation, side channel genesis and stability

By far the largest abundance of LWD was found on pioneer (recent) channel bars, followed by developing floodplains and the wetted and high flow channels. Of all the LWD found within the active channel and floodplain, 53 percent was in the channel and the remainder was on the floodplain. Patches of old-growth floodplain forest were commonly located immediately downstream of where buried logs and logjams were exposed in the banks of the river (Montgomery and Abbe 2006).

The wetted and high-flow channels had the highest bank erosion rates, as the channel shifted frequently within them. Established floodplains and terraces had substantially lower rates of channel erosion and shifting, indicating that once mature vegetation was established it tended to remain, whereas the patches without established vegetation shifted and eroded rapidly (Latterell et al. 2006).

In addition, local deposition catalyzed by logjams can form alluvial surfaces up to several meters higher than the active floodplain (Brummer et al. 2006). Thus the process of floodplain and terrace formation may be due to intrinsic and autonomous channel dynamics, rather than the changes in climate, hydrology, or wood supply as assumed by conventional ecological models (Montgomery and Abbe 2006).

In a braided, cobble-bedded river emanating from the Italian Alps, Gurnell et al. (2000) found that established channel islands collected and stored an average of 80 metric tons per hectare of large wood, whereas incipient (pioneer) channel islands collected almost an order of magnitude more wood than that.

As channels migrate they often coincide and are deflected off of stable logjams, causing avulsions, flow splits, channel islands, and side channels (Collins and Montgomery 2002, Brummer et al. 2006). In meandering streams formation of debris jams often results in a backwater effect upstream that may in favorable situations facilitate development of a meander cutoff (Keller and Swanson 1979). An aerial photo analysis on the Nisqually River in southern Puget Sound showed that flow splits often form when the river intersects an abandoned main channel, diverting flow. Jams then tend to form at the flow split, stabilizing it (Collins and Montgomery 2002). Just as often wood accumulations would block or meter flow into abandoned channels, preventing the mainstem from avulsing into its former channel. The resulting switching back and forth in state from abandoned channel/floodplain slough to main channel was considerably more common in the Nisqually River than the more typical avulsion process that is associated with channel migration and meander cutoff (Collins and Montgomery 2002). In addition to the geomorphic effects, as LWD diversifies flows it reduces and deflects stream energy and creates pockets of relatively stable spawning gravels better protected from the scouring effects of high flows (Naiman et al. 1992).

On the west slope of the Olympic mountains, where record-sized trees and channels enlarged by heavy rainfall dominate the landscape, large logjams promote bar growth, avulsions, and meander cutoffs, resulting in wide, mobile active channels (O'Connor et al. 2003). Regardless of local channel migration rates, log jams appear to be areas of conifer germination and growth that eventually form floodplain areas resistant to channel migration (Fetherston et al. 1995, O'Connor et al. 2003). Channel migration is critical to the maintenance of high levels of wood storage in the mainstem. This process enhances wood retention, replenishes floodplain wood reservoirs, and may help to dampen fluctuations in instream wood storage as the channels periodically recapture abandoned logs (Latterell et al. 2006). Buried logs can last for hundreds or sometimes thousands of years, although the majority of LWD pieces in the active channel were recruited in the most recent one or two decades (Hyatt and Naiman 2001). As the channel migrates, switches or incises, large wood is abandoned, where it either decays or becomes buried until the channel returns to reclaim it (Latterell 2005). Collins and Montgomery (2002) showed that wood jams were integral to maintaining a multiple channel pattern and a dynamic channel-floodplain connection.

Channel islands that originate from LWD jams can achieve heights of several meters above the wetted channel after an avulsion, incision, or active channel shift (O'Connor et al. 2003, Brummer et al. 2006, Montgomery and Abbe 2006). These floodplain surfaces are typically much flatter than the main channel itself (Montgomery and Abbe 2006), but can have substantial topographic variation over short distances. Logjam complexes can locally elevate the channel bed and deposition within that bed, so that even moderate floods can cause surface deposition and avulsion up to and exceeding 2 m above the adjacent floodplain (Montgomery et al. 2003, Brummer 2006, Montgomery and Abbe 2006). As the height above the floodplain to which bedload aggraded reaches up to several times the diameter of key-member logs, channels flowing through old-growth forests are likely to move up and down by at least a few meters over the time scale of tree senescence (Montgomery and Abbe 2006).

3) mosaics and patches, source distances

In pristine river systems the shifting mosaic of active channel and forested terrace “patch types” may shift frequently and drastically within certain reaches, but taken over a large river corridor a dynamic equilibrium exists where the relative composition of different patches remains largely unchanged (Latterell et al, 2006, Kollmann ___). Latterell (2005) showed how lateral channel migration on the Queets River resulted in a shifting mosaic of cobble and vegetation patches in which the distribution, arrangement, and longevity of the patches varies in time and space, but that relative abundance remains relatively constant at the valley scale.

Half the key pieces originated within 107 m of the 1939 channel, but nearly one-fourth (22%) were from greater than 200 m away (Latterell 2005). Wood delivery was concentrated in key recruitment hotspots, and channel erosion (rather than wind throw or other causes) was responsible for 82 percent of key LWD piece recruitment.

Latterell (2005) showed that channel meandering is the dominant LWD input mechanism, contributing 82 percent of the total number of logs. Half the key pieces originated within 107 m of the 1939 channel margin (the earliest aerial photo date in the study), and nearly one-fourth (22%) were captured from greater than 200 m away (Latterell 2005). On average, 47 percent of the overall volume and 19 percent of all the logs were contributed by lateral channel erosion (Latterell 2005).

4) forest growth, positive feedback, buried jams

A basic tenet of the theory of vegetational succession is that organisms themselves modify and gain control of their physical environment (Odum 1969). Fritts and Swetnam (1989) used tree ring records to demonstrate control of the moisture variable by forest stands. On the west slope of the Olympic mountains forest succession on cobble bars typically begins with a homogenous young stand of *Alnus rubra* and *Salix scouleriana,* developing into a mixed stand of *Picea sitchensis, Acer macrophyllum,* and *Populus trichocarpa*, which matures into a floodplain of *Picea sitchensis* and *Tsuga heterophylla,* which ultimately becomes a climax community dominated by *Tsuga heterophylla* (Fonda 1974, Franklin and Dyrness 1988). Each of these seres is accompanied by changes in soil type, soil moisture, and soil temperature (Fonda 1974). All soils reach full saturation over the winter, but the more developed (mature) soil profiles tend to hold moisture further into the summer drought (Fonda 1974), thus the older a floodplain patch is the more suitable it is for growing trees. In later seres the fallen logs themselves are the preferred seedbed for hemlock and spruce, due mostly to the competition with herbs and mosses on the forest floor (Harmon and Franklin 1989). In old growth valleys the increasing modification and control of the physical environment by successively more mature forest stages is clearly seen in the correlation between zonal patterns of vegetation, changes in soil horizons, and lateral and elevational distance from the channel (Fonda 1974, Rot et al. 1998, Latterell et al. 2006).

Montgomery and Abbe (2006) documented the persistence of island “hard points” in the Queets river floodplain, and demonstrated that these immovable islands were founded on buried logjams. Logjams were found on the upstream end of 98% (all but one) of the sampled islands. Average key-piece diameter was 1.8 m, which they estimated would take an average of 300 to 400 years to grow. Mature trees growing on islands over the buried LWD achieved estimated ages of 500 years. Montgomery and Abbe hypothesize that these stable hard points are indirectly responsible for the growth of large trees, which in turn are recruited to the river to form logjams, which indirectly begat more trees in a positive feedback loop. After island formation the floodplain surfaces tend to build up with succeeding floods, and can alter local river gradients and lateral topography, giving a heterogeneous form to what might otherwise be featureless cobble braids. It appears that the primary requirement to maintain the system, once established, is a supply of trees large enough to form key-member logs (Montgomery and Abbe 2006). The absence of large diameter trees can therefore result in the loss of islands and side channels, and simplify the topographic complexity of the valley bottom (Montgomery and Abbe 2006).

Nevertheless, depletion of floodplain wood reservoirs might have lasting consequences for the ecology of riparian areas (Latterell et al. 2006). The destruction of floodplain patches by the river provides a vital, continued supply of relatively small wood that, when trapped by key pieces, amasses into large jams which sculpt complex aquatic habitat beneficial to stream organisms (Latterell et al. 2006). In natural river networks low gradient river segments have abundant LWD distributed in large accumulations forming depositional areas that provide sites for future floodplain vegetation to colonize (Sedell et al. 1988). LWD accumulations are sites of initial plant colonization within the developing forested floodplain (Fetherston et al. 1995). Once floodplains get established the LWD provides nurse logs and elevated seeding substrate that is not as subject to flooding as the surrounding area, which favors plants intolerant of saturated soil conditions and tends to increase the botanical biodiversity of a site (Pollock et al. 1998).

5) habitat benefits of side channels, spawning and rearing preferences

The center of the main channel can be a hostile environment for aquatic organisms, where high sediment transport maintains a relatively sterile substrate, and high velocities extract large energy tolls from fish and aquatic macroinvertebrates (Church 1992). The channel margin and secondary channels are often more favorable, both hydraulically and from the aspect of food availability, and side channels frequently provide the best habitats (Kellerhals and Church 1989, Church 1992). Of the three main types of off-channel habitat—floodplain channels, abandoned mainstems, and terrace tributaries—abandoned mainstems are typically larger, younger, and tend to retain hydrologic continuity with the mainstem better than other channel types (Coe 2001).

Although the characteristics of preferred spawning habitat vary widely among sites and among stocks (largely dependent on the habitat available) spring chinook, like fall and summer chinook, generally prefer to spawn in areas with depths between 24 and 100 cm and velocities between 30 and 100 cm/s (Bjornn and Reiser 1991, Spence et al. 1996, WDFW & WDOE 2000). Vronskiy (1972) observed chinook spawning in 2-3 m wide tributaries of the Kamchatka River in Russia, where he described large numbers of chinook redds in the side channels of an island braided reach. Geist et al. (2002) examined chum and chinook spawning in a side channel of the Columbia River and demonstrated a preference among chinook for upwelling areas. Other research has shown a chinook preference for downwelling (Burger et al. 1985, Bjornn and Reiser 1991). Brunke and Gonser (1997) suggested that the more complex the channel pattern the more prevalent are the upwelling and downwelling zones. On the Kenai River in Alaska nearly all the chinook that spawned in the mainstem did so in the reach with a predominance of channel islands, in the gravels at the upstream tip of the islands where downwelling current was likely (Burger et al. 1985). Beechie et al. (2006) quantified chinook spawning areas throughout the Skagit River system and found as much as 8% of the available spawning area in large channels was in the side channels, particularly in island-braided reaches. In the Suiattle River, a tributary of the Skagit that is in many ways similar to the North Fork Nooksack (in basin size, gradient, and glacial runoff), Beechie et al. (2006) assumed *no* mainstem spawning during summer, and that essentially all chinook spawning occurred in the side channels.

While off-channel areas have frequently been shown to provide superior habitat for overwintering coho juveniles (Bustard and Narver 1975, Brown and Hartman 1988, Beechie et al 1994), fewer studies have documented such off-channel use by chinook (Swales et al. 1986, Murphy et al. 1989, Beechie et al. 2005). In winter, due to their low metabolism in cold water, food availability is a low priority for chinook juveniles, which feed very little, and then usually at night (photonegativity) (Cunjak 1996). Preferred cover is rubble-boulder substrate where rock diameters are proportional to the size of the fish (Cunjak 1996). The fish often exit the substrate to feed at night in the water column. In interior basins where rivers commonly freeze in the winter, chinook juveniles either burrow into riverbed substrate or migrate downstream (Chapman and Bjornn 1969, Swales et al. 1986, Hillman et al. 1987). In freezing rivers overwintering chinook juveniles have a strong affinity for unembedded cobble if it is available, but in its absence will gravitate to shallow areas with submerged sedges, overhanging banks, and velocities < 12 cm/s (Hillman et al. 1987). In summer, chinook juveniles tend to use habitats with water velocities < 20 cm/s, depths of 20-80 cm, and close association with cover (Hillman et al. 1987). In the heavily glaciated Taku River in Southeast Alaska, Murphy et al. (1989) showed that chinook juveniles were more likely that other salmonids to be found in the moderately swift waters at the mainstem channel margins and sloughs, but that chinook were also predominant (at 5-8 fish per 100m^2) in off-channel terrace tributaries and tributary mouths. Beechie et al. (2005) showed higher densities of juvenile in the backwaters and channel edges of the Skagit River, compared to lower densities around mainstem cobble bars. Chinook juveniles were frequently found in Fraser River tributaries where there was no chinook spawning the previous season, indicating that the absence of spawners does not necessarily mean an absence of appropriate habitat, and that juveniles can migrate widely to access the habitat most appropriate for rearing (Murray and Rosenau 1989). In the braided Rakaia River in New Zealand, Glova and Duncan (1985) noted that chinook juveniles were generally found in marginal areas of shallow, slow-moving water with ample vegetative or wood cover. Larger juveniles (>55mm FL) preferred backwaters and side pools adjacent to major channels (Glova and Duncan 1985).

6) Temperature effects

Stream temperatures can fluctuate more among individual habitats in the lower alluvial reaches of large rivers than they do longitudinally along the entire river corridor, primarily due to the elevated temperatures in backwaters and isolated pools (Arscott et al. 2001). In higher reaches the temperature differences among instream habitats is relatively minor. In summer the off channel habitats could be either warmer or cooler than the mainstem, depending on the connection with hyporheic and phreatophytic waters, and thermal response time of off-channel habitats depended on the proximity to the main channel. Average daily temperature is controlled primarily by elevation, which is a direct predictor of air temperature variation, whereas the best predictors of daily (diel) temperature fluctuation were azimuth and slope (Arscott et al. 2001). The more the reach azimuth deflected from due south, the less the diel variation. The influence of slope was likely due to heat exchange via turbulence. Longitudinal patterns of average daily, minimum, and maximum temperature were influenced primarily by elevation, and secondarily by azimuth, except where these patters were interrupted by groundwater influences. There is potential across a single floodplain for a multitude of thermal regimes depending on structural complexity.

Local reports on the North Fork and Tributaries

A report for the Washington Department of Transportation (WSDOT), the North Fork Nooksack River Corridor Analysis (GeoEngineers 2001), looked at the North Fork and identified sites where highway maintenance problems were frequent enough to qualify as “chronic environmental deficiencies” (CED) in need of permanent repair or road realignment. The river corridor was divided into 10 reaches and the hydrology, geomorphology, and erosion hazard potential was assessed (qualitatively) for each. Moving SR-542 was recommended for those sites where the highway is clearly within the erosion hazard zone, river-road interaction is common, and the highway is affecting the geomorphic processes of the river (GeoEngineers 2001). Those sites include major realignments of the road around the Warnick Bridge, on the floodplain between Maple and Boulder creeks, and downstream of the Coal Creek confluence. Considerations of bridge realignment at Boulder Creek were deferred to recommendations the prior Boulder Creek Flood Potential report (Gowan 1989).

The WSDOT report on Boulder Creek Flood Potential (Gowan 1989) looked at the causes and frequencies of debris flows in that basin and recommended that SR-542 be realigned to cross Boulder Creek further upstream, at the apex of the alluvial fan. Encouraging judicious upstream land use practices was the other management recommendation receiving emphasis (Gowan 1989). The report, written before the severe 1990 floods, emphasized that Boulder Creek and its tributaries are deeply incised and that the unconsolidated, over-steepened stream banks lack mature vegetation, and thus provide an immense supply of sediment for future debris flows. Between 1947 and 1969 the landslide area in the Boulder Creek drainage was not increasing, but multiplied by a factor of four between 1969 and 1989, when the report was written. An update to the Boulder Creek landslide inventory would indicate whether more restrictive forest practices have stemmed the increase in landslide areas, or if other factors are responsible for the frequent debris flows that affect the channel today.

The Glacier and Gallop creeks alluvial fan analysis (Raines et al. 1996) examined the hydrologic records, geomorphic conditions, forest practices history, and current flood potential in the Glacier and Gallop basins and identified the stream hazards for residents and infrastructure in and near the town of Glacier. Their analysis described different flood scenarios for the two different creeks, but with similar recommendations for reducing the flood hazards. Glacier Creek is highly subject to high flow and rain-on-snow events, but the largest floods probably result from short-term debris dams that form in the upper Glacier Creek gorge, releasing stored water and debris in amounts far exceeding (by a factor of 700 in 1989) the normal flood capacity of the system. Upper Gallop Creek and its tributaries are also subject to debris flows, but the debris is deposited at the bottom of the valley walls and does not translate directly downstream to the SR-542 bridge crossing (DaPaul 1994). The flood problems at the Gallop Creek bridge are due to high sediment load and a rapidly fluctuating stream bed at the bridge, rather than an over-abundance of water discharge. As with Gallop Creek, Glacier Creek is capable of accommodating a 50-year flood or greater, but the bed fluctuations from the high sediment load result in a volatile channel and frequent flooding and sedimentation problems at the SR-542 bridge and in the town of Glacier (Raines et al. 1996).

A master’s thesis by Indrebo (1998) divided the North Fork into geomorphic reaches and classified each according to methods described by Rosgen (1994, 1996). The reach breaks in some cases encompass several miles of river, and neglect to distinguish between important geomorphic influences such as major sediment-contributing tributaries (e.g. Boulder, Canyon, Cornell, and Glacier Creeks). Thus the reach-averaged widths, slopes, and substrate measurements disguise important fluctuations within each of several large reaches. The conclusions, which are mostly superficial, are often based on inconclusive data, and are of little value.

The Watershed Analysis for the North Fork Nooksack River (MBSNF 1995) compiled by the Mount Baker Ranger District of the Mt. Baker Snoqualmie National Forest concentrated on the North Fork above the town of Glacier, and included the area drained by Glacier Creek. The MBSNF watershed analysis is therefore upstream and geographically distinct from this North Fork assessment, although some of the MBSNF conclusions are relevant for the lower North Fork. The upper North Fork experienced four major fires over the detectable ecological history, in 1300, 1508, 1701, and 1856, with several smaller fires recorded during the 1900s. The MBSNF analysis points out that high transport rates of LWD in the upper reaches has left the channel devoid of structure and with little complexity. Off-channel areas with clear (i.e. non-glacial) runoff are noted as highly valuable to fish and low in abundance in the upper North Fork, similar to the conditions shown in this report to be repeated downstream. The MBSNF report cites

Schuett-Hames and Schuett-Hames (1984) in declaring that the primary fish habitat limitations on the upper North Fork are lack of channel stability, low pool/riffle ratios, a lack of stable instream large woody debris, and fine sediment deposition (MBSNF 1995).

The Lummi Natural Resources Department conducted extensive surveys of channel stability and fine sediment in spawning gravels during the summers of 1982 and 1983 (Schuett-Hames and Schuett-Hames 1984). For the channel stability ratings numerical values were applied to 15 physical characteristics of the stream banks and bed, according to the methods of Rickert et al (1978). The stream bank ratings should be interpreted with caution however, since the methods give lower stability ratings for streams with high concentrations of LWD, in contrast to more modern methods. The gravel and stability sampling was widespread, and most of the effort was expended on the lower ends of tributaries accessible to anadromous fish. One fine sediment sample was collected for each of the North and South fork mainstems, and no stability assessment was done for the North Fork mainstem. Channel stability ratings ranged from 56 points on Thompson Creek to 129 for Cornell Creek. The report concludes that stream instability was adversely affecting redd survival in many Nooksack spawning areas. The fine sediment data from Schuett-Hames and Schuett-Hames (1984) was incorporated into and reinterpreted in the redd scour and spawning gravel study produced by the Nooksack Natural Resources department almost twenty years later (Hyatt and Rabang 2003)

ECOLOGICAL UNDERPINNINGS OF THE RESTORATION STRATEGY

Site description

The North Fork of the Nooksack River originates on the glaciated flanks of Mount Baker near the Canadian border in Whatcom County, Washington (Figure 1). The North Fork meets the Middle and South Forks Upstream of the town of Deming (at a basin area of 750 km^2), then ultimately flows into Puget Sound near the city of Bellingham. At 1935 km^2 (786 mi^2) the Nooksack is the fourth largest watershed in Puget Sound, and is home to five Pacific salmon species: chinook (*Oncorhynchus tshawytscha)*, chum *(O. keta), pink (O. gorbuscha),* coho *(O. kisutch)*, and a riverine population of sockeye (*O. nerka)*. Chinook, steelhead (*O. mykiss),* and bull trout (*Salvelinus confluentus)* are listed as threatened under the Endangered Species Act. Average annual precipitation in the North Fork basin is 218 cm., with the highest average monthly discharges occurring in June (1500 cfs, measured at the USGS gauge #12205000), and average low flows in March (380 cfs). Flood peaks typically occur between October and February. The highest recorded flood out of a 37 year record (13,700 cfs at USGS gauge 12205000) was in October 2003. Terrain in the North Fork basin is generally mountainous, with elevations ranging from 88 m at the downstream end of the study reaches to the Mt Baker summit at 3285 meters above sea level. Vegetation in the area is classified in the *Tsuga heterophylla* zone (Franklin and Dyrness 1988) with an understory generally dominated by swordfern (*Polystichum munitum)* and salmonberry *(Rubus spectabilis)*. The forested floodplains have extensive stands of red alder (*Alnus rubra),* cottonwood *(Populus trichocarpa),* western hemlock *(Tsuga heterophylla),* Douglas fir *(Pseudotsuga menziesii)*, and western redcedar (*Thuja plicata)*, much of which has been through multiple harvests beginning in the late 1800s.

[fix map, add Mt Baker, Canadian border, SF and MF]

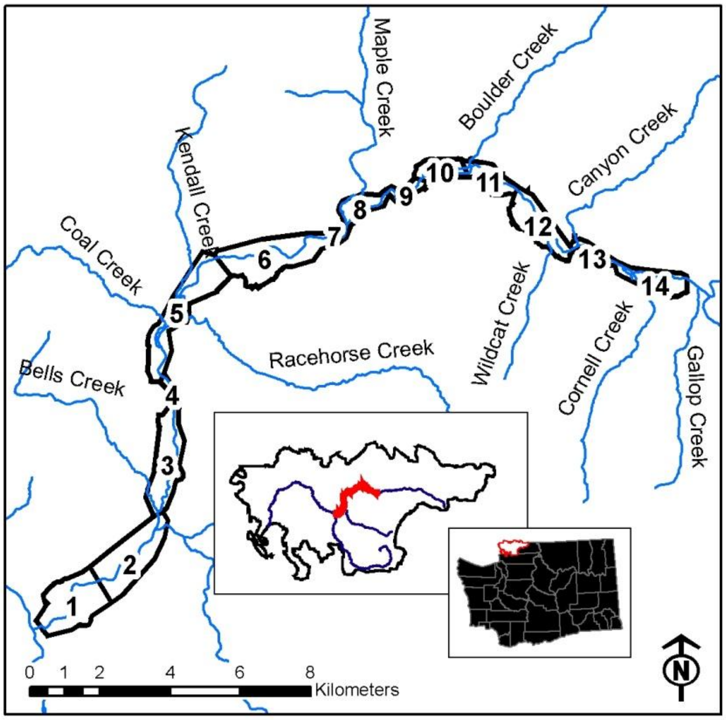

Figure 1. The North Fork Nooksack was divided into 14 reaches for analysis and comparison. Each reach was measured and compared on the basis of channel gradient, width, habitat composition, and other geomorphic and biologic variables. The study area extends from the confluence with the South Fork Nooksack, upstream to the town of Glacier, WA, on Gallop Creek and near the base of Mt Baker.

Methods

Historical and current river habitat

Aerial photographs dating back to 1933 and maps dating back to 1885 were scanned and georeferenced in a geographical information system (GIS) to allow stream outlines and features to be digitized and compared through time (Collins and Sheikh 2002, 2004). For each year the outlines of the wetted channel were digitized and attributed for one of four land cover types: low-flow wetted channel, bare or lightly vegetated high-flow channels, floodplain islands, and floodplains. The outline of the floodplain encompasses all four land forms for each photo year, such that total area is consistent over time. Fourteen channel reaches were established along the 40 river kilometers in the study area, dividing the river into self-similar units based primarily on gradient and confinement.

Aerial photos for historical habitat delineation were collected from several sources, primarily from the University of Washington River History Project, Whatcom County Planning Department, Washington Department of Natural Resources (DNR), and remote sensing flights contracted by NNR. The River History Project photos were redundant to products delivered to NNR (Collins and Sheikh 2003) and the Whatcom County River and Flood Engineering department (Collins and Sheikh 2004), but are referred to collectively as (Collins and Sheikh 2004). The River History photos that encompass the North Fork include photo years 1933 (partial coverage to below Boulder Creek), 1938, 1955, 1966-67, 1976, and 1986. Washington DNR digital ortho quadrangles (DOQs) were flown in 1998. The NNR (2002) aerial photos were flown by Walker and Associates on November 4, 2002. The Whatcom County planning department orthophotos were flown by Pictometry in late February and early March of 2004. Channel outlines subsequent to the Thanksgiving 2004 floods were interpreted from a TerraPoint LiDAR flight contracted by NNR and flown on March 27th 2005.

A channel occupation grid was created by compiling the channel outlines digitized from the historical aerial photos, and calculating a frequency of channel occupation for each cell in a 2m x 2m grid (Collins and Sheikh 2004). The grid shows the percentage of the record during which each 2-m cell was occupied by the active channel (i.e., the low flow and high flow channels) and floodplain sloughs. For example, if eight sets of aerial photos or maps cover a particular 2-m cell, and the active river or a floodplain slough occupied that cell six of the possible eight times, then the "percent occupancy" is 75 percent.

The 2005 habitat and channel maps were based on the LiDAR digital terrain model, annotated from field surveys, and attributed for the same land types used for the historical analysis (high flow, low flow, channel island, and floodplain). Habitat surveys were conducted by foot on the North Fork in late spring and summer 2005, drawing habitat units on 1:6000 scale LiDAR base maps. Observations from the foot surveys included classifying all wetted areas into mainstem, braid, back channel, tributary, or slough units. Mainstem units were further divided into pools, riffles, glides, or cascades. The habitat classification reduces ambiguity by breaking all habitats into mutually-exclusive categories. Mainstems carry the predominance of discharge, but were occasionally split into two or possibly three channels if each carried more than 25 percent of the flow through the reach. Braids are separated from the mainstem by sparsely vegetated cobble bars and carry no more than 25 percent of the flow in that reach. Back channels were separated from braids and mainstems by a mid-channel island or bar with persistent woody vegetation greater than 7-10 years in age. Back channels were connected to the mainstem at both the upstream and downstream ends. Sloughs were hydraulically connected to the mainstem at the downstream end at low flow, but disconnected at the upstream end except at high flow. Both back channels and sloughs in some cases received tributary, hyporheic, or groundwater flow. In those cases the decision on whether a habitat was back channel or tributary rested on whether the dominant substrate was delivered by the mainstem or the tributary. Other habitat units appear in the survey maps where conditions prevented clear categorization into one of the above categories (e.g.: beaver ponds in back channels, isolated ponds with juvenile fish on cobble bars). The final call on habitat types often depended on depth and velocity of flow as well as hydrologic source area.

Riparian forests

The difference between the first-return and last-return from a given LiDAR pulse was used to construct bare-earth and with-vegetation digital terrain models (DTMs), from which the height of vegetation was measured (Means et al. 2000, Lefsky et al. 2002). A subtraction of the bare earth elevation model from the all-return model resulted in a 2m x 2m GIS grid of vegetation heights, primarily in the floodplain but extending up the valley walls where the LiDAR coverage allowed. Under favorable conditions many tree species achieve record-setting sizes in the Pacific Northwest (Waring & Franklin 1979), but average heights after 100 years for Sitka spruce (*Picea sitchensis*), Douglas-fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), and black cottonwood (*Populus trichocarpa*) generally exceed 40 meters (USDA 1990). Vegetation height pixels > 40 meters were extracted from the grid and coded with the distance from the pixel to the edge of the (2005) active channel. Vegetation heights and distances to the channel were summarized by reach and for the study area as a whole.

Large woody debris surveys

Large woody debris surveys were conducted by Lummi Natural Resources on the North Fork in 2004, wherein locations of single LWD pieces greater than 9 m^3 and logjam accumulations were mapped on the floodplain. Wood meeting the size and functional classification were located with a geographic positioning system and attributed for channel interaction, species category, and other details. The 9 m^3 threshold is consistent with the threshold for key piece size (10.7 m^3) for channels greater than 50 m bankfull width recommended by Fox et al. (2003). Ocular estimates of jam and key piece size were used after an initial period of measuring each log and each jam.

During the 2005 NNR habitat surveys accumulations of LWD were noted on the habitat maps where those accumulations either significantly affected the channel in ways that would influence the creation or maintenance of a channel island, or were simply large enough to be useful in a restoration project, either for augmentation or preservation.

Hydrology and flood intensity

To examine time trends in flood peaks, flood records for the North Fork Nooksack were obtained from the U.S. Geological Survey stream gauge 12205000, (North Fork Nooksack above Glacier Washington). Both daily average and instantaneous peak flow were examined from 1937 to 2005 using relational databases and statistical software (StatSoft 2005). While instantaneous flood peaks determine flood inundation extent and strongly influence flood damage, average daily discharge (the annual maximum series) integrates flow over 24-hour time spans. This “effective flow” which often transports the greatest quantity of sediment over time (Wolman & Miller 1960) corresponds to the flow at or above bankfull stage, and may be a better indicator of channel change than instantaneous peak flows recorded over much shorter (15-minute) periods.

Channel migration zones

Channel migration zones were delineated based on 2004 photogrammetry data, aerial photographs, hydraulic models, and field observations. The historic migration zone (HMZ) was based primarily on Collins and Sheikh (2004) data, by merging the outer boundaries of North Fork channels from aerial photographs over all years, and expanding those for more recent erosion. The HMZ delineation also includes georeferenced USGS maps from 1918 and General Land Office maps from the 1880s. The avulsion hazard zone (AHZ) was drawn using channel features and floodplain depressions carved by the river-- those that were outside the HMZ-- and then using a HEC-RAS hydraulic model with photogrammetric terrain data to determine which of those depressions would likely be inundated in a 10-year flood (eliminating those that were elevated above the flood level). The erosion hazard zone (Pittman 2005) was estimated based on average erosion rates for each reach (Collins and Sheikh 2004), taking into account areas of non-erodible bedrock and boulder-dominated landslide deposits. The average annual erosion rate was multiplied by 100, for a 100-year planning horizon, and applied to the outermost boundary of the HMZ (Rapp and Abbe 2003). The final CMZ combined the outermost limits of the AHZ or the EHZ, which in virtually all reaches was the EHZ.

Geomorphic analysis

Sinuosity was calculated by placing reach breaks along the mainstem channel centerline (in the GIS) and calculating stream length between the breaks, then comparing that to the straight-line reach length. Reach breaks were placed primarily at bridges, canyons, and landslide fans where the river flows through a controlled, confined channel (pinch points). Euclidean distance between reach breaks was calculated using the Pythagorean theorem.

Longitudinal channel and floodplain profiles for each reach were digitized in the GIS and elevation data were extracted from the 2005 LiDAR digital terrain model. Profiles of the mainstem channel centerline were then compared to floodplain and side-channel profiles for indications of avulsion hazard and potential re-connection of side channels. Extracted data were imported into the Statistica software package (StatSoft 2004) for graphing and analysis.

Comparison data for other rivers was drawn from the SSHIAP database (NWIFC 2007). Elevation and watershed area were extracted from a USGS 10m DEM for points denoting gradient breaks along each watercourse. Average precipitation was calculated from

Channel widths were calculated by delineating the active channel area for each of 14 reaches and then dividing that area by the reach length. Aerial photo coverage, and hence digitized channel margins, was available for the entire North Fork study areas in seven photo years: 1938, 1955, 1966, 1976, 1986, 1998 (Collins and Sheikh 2004), and 2005. The active channels include channel islands in addition to high-flow and low-flow channels.

Changes in channel elevation, and therefore shifts in aggradation and degradation, were evaluated using digital terrain models. Channel widening is typically associated with sediment aggradation, so it was important to document whether, or the extent to which, changes in the sediment supply were contributing to changes in the active channel over time. To detect elevation changes in the active channel and floodplain a digital terrain model (DTM) constructed from the 2005 LiDAR was compared to a DTM constructed from 1994 photogrammetry. Subtraction grids (the elevation of a 2m x 2m cell in 1994 subtracted from the same cell in 2005) were used to reveal patterns of scour and fill where the active channel had shifted in the intervening years, but these grids were difficult to summarize analytically. The GIS was therefore used to extract elevation data at a 2 m interval along each of 148 transects spaced every 200 m over the 40 km study area (Figure 2). Each of the 45,000 sampling points was attributed for transect number, station along the transect, reach number, elevation in 2005 and 1994, and habitat type in 2005 and 1994. The resulting geodatabase allowed for queries in bed elevation changes at several spatial scales and over the decadal time span.

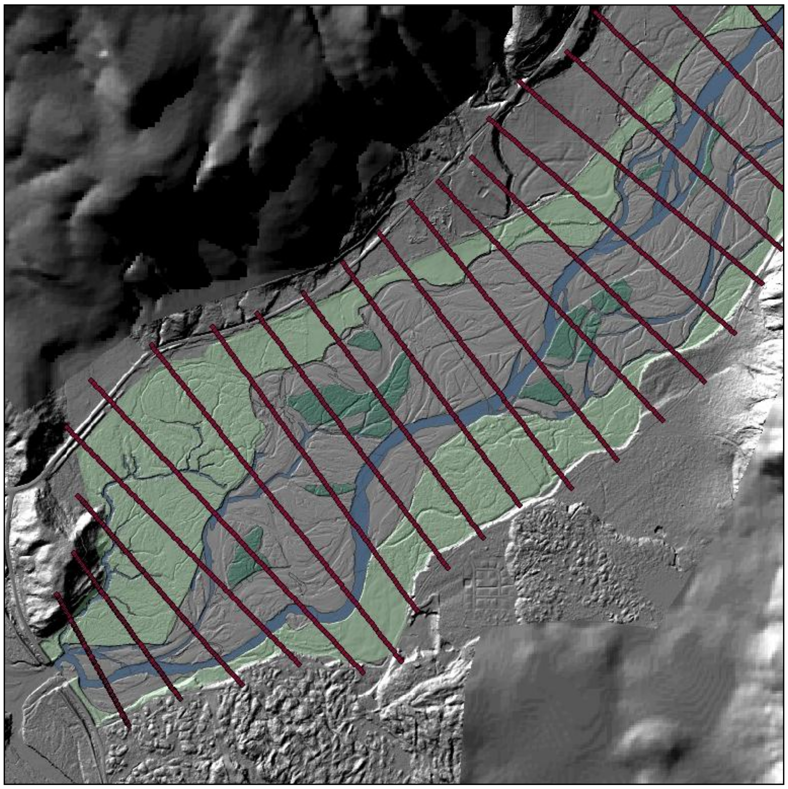

Figure 2. LiDAR base map of the lowest reach of the North Fork near the intersection of SR-542 and SR-9 (in the northwest corner), showing the transect points used to extract elevation data from 2005 and 1994 DTMs. Transects are spaced every 200 meters and points along the transects are spaced every 2 meters.

The 2005 LiDAR digital terrain model was used to calculate and display the elevations of the active channel and floodplain relative to the stream centerline. The “flat channel” grid removes the gradient along the longitudinal profile of the river and shows the floodplain channels relative to the mainstem water surface elevation, and is useful in detecting side channels (both connected and unconnected) that are at the same elevation as or lower than the mainstem (Sofield and Reinhart 2006). Conversely, the average height of channel islands and other features above the mainstem can be extracted from the grid and evaluated for likelihood of flood inundation or flood risk. The FlatChan grid was created by establishing transects in the GIS, orthogonal to mainstem flow, at a 200 m interval up the channel over the entire study area. The value of the lowest elevation on each transect was applied as the elevation of the entire transect, and a TIN (triangulated irregular network) was built from the 148 transects and a bounding polygon. The elevation of the TIN was subtracted from the elevation of each 2m grid cell in the bare earth DTM, resulting in the FlatChan grid in which the river slope has been removed and all elevations are relative to the mainstem elevation (or, in some cases, lower side channels).

Redd scour monitoring

Redd scour and fine sediment intrusion were measured in 2001 and 2002 at various chinook spawning sites in the North and South forks (Hyatt and Rabang 2002). Redd scour monitors constructed of stainless steel cable and practice golf balls were inserted into the stream bed and monitored over the incubation season to measure the streambed scour after floods. Seventy-nine monitors were installed for the 2001-02 flood season, and 159 monitors were installed the following year. Incubation season scour depths were calculated for each monitor and compared within and among sites. Scour in excess of 20 cm or burial in excess of 50 cm from the original bed elevation was considered a “redd failure” for that incubation season.

Off-channel spawning

Chinook spawner surveys on the North Fork are conducted annually by the Washington Department of Fish and Wildlife and tribal natural resources staffs. Repeated redd and carcass surveys at index sites throughout the spawning season record spawning activity, and are extrapolated each year to estimate total salmonid escapement. Due to glacial silt in the North Fork mainstem during spawning season, observer bias in detecting off-channel spawning is likely, with relatively fewer redds detected in the mainstem. Known (observed) North Fork chinook redd locations for 2005 were located in the GIS using digital ortho-photographs and LiDAR for reference. Of the 158 known redd locations in the North Fork for 2005, 75 are in the study area. These redd locations were overlaid with the 2005 habitat maps to examine patterns and proportions of mainstem vs. off-channel spawning.

Recruit/spawner ratio and flood intensity

The number of adult fish returning from a given brood year, divided by the number of adult fish that spawned that year, is known as the recruit/spawner ratio, and indicates the productivity of a population integrated over the entire salmonid life cycle. Most chinook salmon return as four-year-olds, but some return as early as age two, and some not until their sixth year. Dividing the sum of all subsequent returning offspring for a given brood year by the number of spawning adult fish in that brood year results in the recruit/spawner ratio. A recruit/spawner ratio of less than unity indicates that the population is not self-perpetuating. Recruit/spawner ratios are determined by WDFW personnel as part of an ongoing effort to regulate the fishery. The recruit/spawner ratios for North Fork spring chinook were regressed against (daily average) peak incubation season floods at the North Fork gauge (USGS 12205000), to demonstrate the relationship between flood intensity and fish productivity.

Results

Historical habitat

The aggregate area of channel islands in the North Fork has been decreasing dramatically since the mid-1990s, for which the floodplain areas have not compensated (Figure 3). When channel land types are summed over the entire study area it is apparent that the relative abundance of different land types has been changing over time. Aggregate area of unvegetated active channel (i.e. high flow channel) has risen appreciably, most noticeably since the early 1980s when flood intensity increased. Channel islands are forested areas within the active channel with flowing low-flow channels on all sides, and mature (~20 m) vegetation established, frequently with a mix of young conifers and mature hardwoods. The aerial photo record shows that channel islands area was greatest, particularly in the lower reaches of the North Fork, between 1938 and about 1994. During this period channel island area for the North Fork below Glacier varied between 50 and 85 hectares. By 1998 the island area had dropped to about 42 ha, and by 2005 it had dropped further to 25 ha. The 2005 island area is about 38 percent of the historical average up to that time (66 ha), and represents a significant decrease (Z= -1.64, p<0.0001) in channel proportion that had remained relatively constant until 1994.

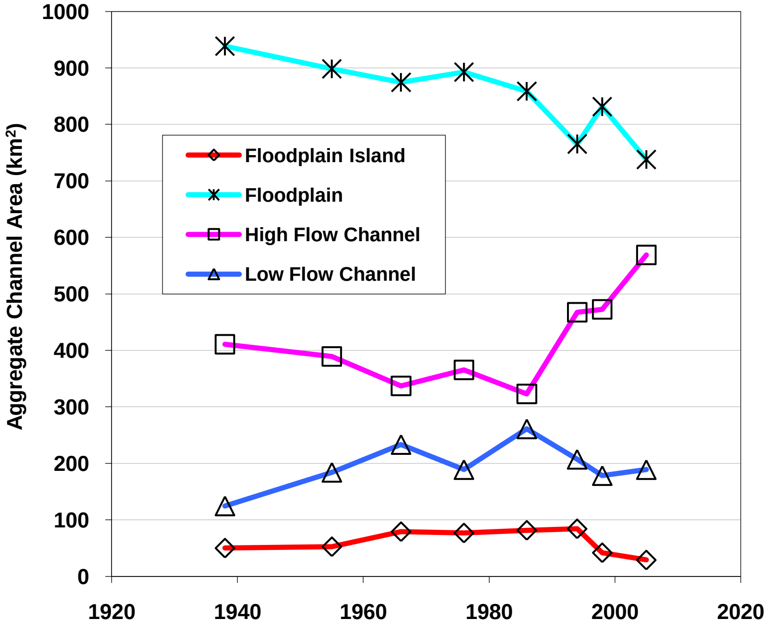

Figure 3. North Fork floodplain land type changes over time. The aggregate channel island area dropped suddenly between 1994 and 1998, and currently is 38 percent of the historical average. Floodplain areas have also declined, and active channel "high flow" areas have increased substantially since the early 1980s, which correlates with a shift in increasing flood flows.

Because of the way both floodplains and channel islands form from incipient channel bars, often the distinction between island and floodplain is only the condition of the channel that separates them. However, on the North Fork the islands and floodplain areas have been decreasing together (Figure 3), so loss of one is not being offset by gain in the other.

As with channel islands, floodplains in the North Fork study area receded as high-flow areas expanded. For all aerial photo years represented in the analysis (1938-2005), a consistent outer boundary of the floodplain was used so that the total area in the analysis remained constant for all years regardless of the channel migration. Although the low-flow channel areas fluctuated according to river discharge, the high flow channels expanded, and the floodplain areas show a clear and relatively consistent decline over time.

The average annual gain in high-flow areas between 1938 and 2005 is approximately 2.5 ha/year. However, the high flow area gradually decreased from 1938 until 1986, and then nearly doubled from 1986 to 2005 at a rate of 13 ha/yr.

Bed elevation changes

Changes in channel bed elevations between 1994 and 2005 varied widely across transects and between reaches, with some reaches rising and others falling (Table 1). When limited to 2005 high-flow and low-flow sampling points (i.e. current active channel) the average bed elevation change for the entire study area was –0.20 m, indicating that the bed was not aggrading, and was likely incising. When the calculations were broadened to include the high flow and low flow points from both 1994 and 2005 the average bed elevation change was –0.18 m, indicating a "backfilling" effect on abandoned channels over time. Reaches with positive (aggrading) changes or the least negative changes were downstream of the major sediment-contributing tributaries of Boulder Creek and Canyon Creek. Confined reaches with little potential for sediment storage (Big Rock Canyon, Maple Canyon, Mahaffey Canyon) showed significant changes, possibly due to small floodplain areas and the disappearance of single bars.

Reach Num	*ReachName*	*River Mile*	*Length*	*Width*	*Gradient*	*Maximum Gradient*	*Sinuosity*	*Elevation Change*
01	Pipeline	36.7 - 38.3	2587	443	0.0038	0.0075	1.24	-0.43
02	Rutsatz	38.3 - 40.6	2827	470	0.0044	0.0120	1.08	-0.18
03	Kenny/Bell	40.6 - 42.9	3416	283	0.0043	0.0102	1.08	-0.11
04	Big Rock Canyon	42.9 - 43.7	936	58	0.0034	0.0062	1.08	-0.07
05	Hatchery	43.7 - 46.7	4537	224	0.0050	0.0093	1.17	-0.21
06	Farmhouse	46.7 - 49.4	3803	278	0.0061	0.0145	1.11	-0.19
07	Maple Canyon	49.4 - 49.8	510	39	0.0048	0.0083	1.10	-0.55
08	Maple Creek	49.8 - 50.6	1807	183	0.0064	0.0180	1.25	-0.27
09	Mahaffey Canyon	50.6 - 51.4	1515	85	0.0059	0.0128	1.42	0.12
10	Below Boulder	51.4 - 52.3	1549	166	0.0066	0.0164	1.21	0.19
11	Lone Tree	52.3 - 53.3	1696	275	0.0078	0.0147	1.12	-0.45
12	Wildcat	53.3 - 54.8	2677	174	0.0091	0.0209	1.15	0.01
13	Canyon	54.8 - 55.8	1743	141	0.0084	0.0175	1.35	-0.19
14	Cornell	55.8 - 57.3	2360	163	0.0094	0.0205	1.12	-0.11

Table 1. Reach location and geomorphic characteristics. Measurements are based on the 2005 LiDAR, with units in meters. Gradient is averaged over entire reach, whereas maximum gradient measures the steepest 100 meter segment within each reach. Elevation change is a subtraction of the exposed channel bed elevation in 1994 from the elevation in 2005, as described above.

LWD size and wood availability

Distribution of LWD in the North Fork was uneven, and key pieces were not spatially correlated with logjams. Reference conditions for western Washington rivers greater than 100 km^2 of watershed area indicate that in unmanaged basins the total volume of all LWD is approximately 200 m^3 per 100 m of channel (Fox et al. 2003). In the North Fork Nooksack the volume of key pieces is never more than 5.25 m^3 per 100 m of channel in any reach, and the average for all reaches combined is 1.2 m^3 per 100 m (Table 2).
[get key pieces/100m from Fox and Bolton 2007, instead of volume/100m stated above]

Reach Name	Key LWD count	LWD jam count	#Key pieces/ 100m	%Area Mature Timber	Floodplain Area (ha)
01 Pipeline	7	14	0.11	2.90	220
02 Rutsatz	2	4	0.03	0.98	187
03 Bell/Kenny	4	2	0.05	0.30	158
04 Big Rock Canyon	0	0	0.00	0.06	8
05 Hatchery	5	5	0.05	1.33	209
06 Farmhouse	3	15	0.03	0.83	230
07 Maple Canyon	0	0	0.00	1.90	3
08 Maple Creek	12	1	0.31	0.54	65
09 Mahaffey Canyon	0	3	0.00	2.03	24
10 Below Boulder	9	2	0.24	0.67	65
11 Lone Tree	26	5	0.58	3.14	78
12 Wildcat	8	6	0.13	1.34	129
13 Canyon	2	0	0.06	0.68	24
14 Cornell	19	3	0.35	0.49	95

Table 2. Key LWD and floodplain timber statistics by river reach. Key LWD pieces were > 9m^3, and LWD jams were large enough to affect the channel at high flows. Percent area mature timber is the area of the floodplain in trees > 40m height.

On the Nooksack floodplain trees exceeding 40 meters in height are rare. Table 2 shows the total floodplain area for each of the 14 North Fork reaches, and the proportion of each reach occupied by mature timber. Only one reach on the North Fork registered above three percent in timber greater than 40 meters in height, and only 1.3 percent of the floodplain as a whole has the mature timber that can contribute LWD similar to what was historically present. Median distance from the edge of the active channel to vegetation > 40 m in height was 137 meters, indicating that unfettered channel migration will be required to recruit existing mature trees to the river.

Hydrology

Average daily discharges show a distinct pattern of higher frequency and intensity in the most recent two decades of the 67-year flood record (Figure 4). Of the ten highest daily discharges since 1937, eight occurred in the most recent 20 years. Average daily discharge did not exceed 200 m^3/s (~7000 cfs) until 1984, but has done so six times since then. Instantaneous peak floods show a less distinct pattern, occurring in a more random distribution across the period of record, but it is the average daily peak flows which integrate bedload movement over time and are responsible for the bulk of sediment transport. Wolman and Miller (1960) argued that the channel-forming flow is roughly equivalent to bankfull stage, and has a recurrence interval of 1.5 years.

Over the period of record (1937 – 2003) the 1.5 year flow for the North Fork at Glacier was 4860 cfs (137 m^3/s), and has been exceeded eight times prior to October 1980 and 23 times since. In the first half of the flood record (1937-1969) the 1.5 year flow was 4690 cfs and in the second half (1970-2003) it increased to 5350 cfs.

It is impossible to attribute these flood increases unequivocally to systematic changes in precipitation associated with global warming, however similar increases in the variability of cool season precipitation have been documented across the region since about 1973 (Hamlet and Lettenmaier 2006).

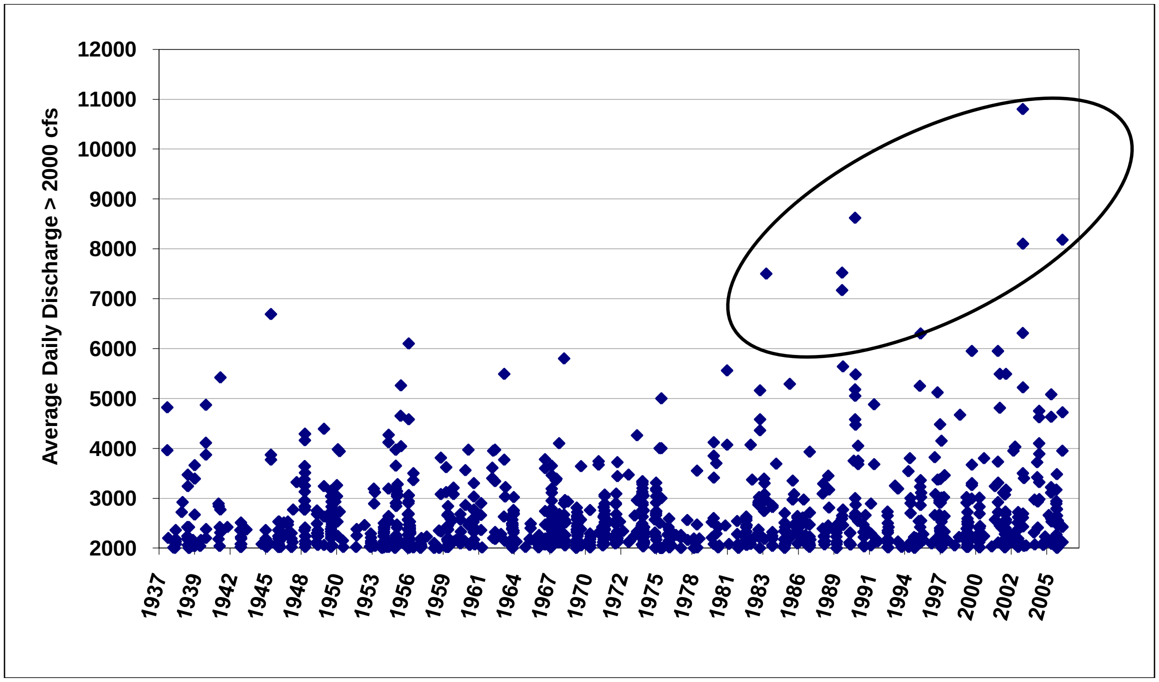

Figure 4. Average daily discharges greater than 2000 cfs for the North Fork Nooksack (USGS gauge 12205000). Out of 73 years of record, 9 out of 11 average daily flows greater than 6000 cfs occurred in the most recent 20 years. Floods are not only getting more frequent, they are getting higher. No average daily flows greater than 7000 cfs occurred before 1980, yet there have been six such events since then. The largest flood on record was in October 2003. Instantaneous peak discharges show a similar but less distinct pattern, with high peak flows throughout the flood record.

Redd scour

Redd scour showed clear and statistically significant relationships with habitat type, whether measured by average depth of scour or redd failure rate (Figure 5). Higher redd failure rates were measured in the more intense 2001-02 flood year than in 2002-03. Redd failure rates were nearly twice as high in mainstems than in braids, back channels, and sloughs. Scour depths were likewise deeper in mainstems and braids than in off-channel habitats. Redd failure showed only weak predictive relationships with local geomorphic variables such as flood depth and substrate size.

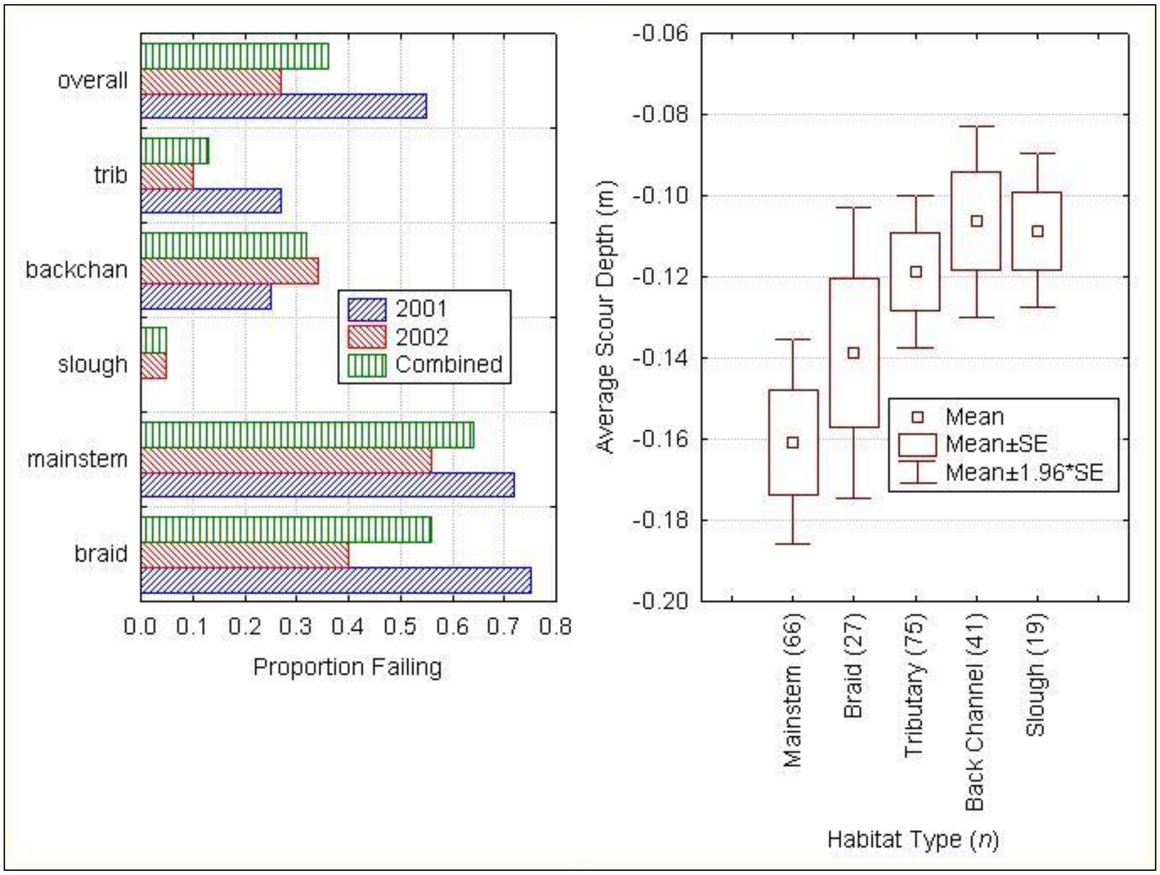

Figure 5. Redd failure rate (left) and redd scour depth (right) categorized by habitat type in the North and South forks. Redd failure combines the effect of redd scour to 20 cm depth or burial greater than 30 cm deeper than initial conditions. Failure rate is higher in years of more intense flooding, but is also significantly higher in mainstems and braids than in off-channel areas such as back channels and sloughs. Scour depth is significantly deeper in mainstems and braids than in off-channel habitats such as back channels and sloughs. Data from Hyatt and Rabang 2003.

Chinook spawning

Table 3 shows known chinook redd locations grouped by habitat type, as determined from habitat surveys in summer 2005. In the study area almost half of the known chinook redds (36/75) were in off-channel habitats, despite those habitats comprising only 17% of the available wetted area. The number of natural-origin spawners in the North and Middle Forks in 2005 was estimated at 210 fish. Due to the turbid glacial river conditions detection of mainstem redds is more difficult than in the shallower off-channel areas, but the survey data demonstrate that off-channel areas, if available, are frequently used by chinook for spawning.

	REDDS (n)		*AREA (ha)*	
Habitat Type	off-channel	mainstem	off-channel	mainstem
back channel	21		17.89	
braid		16		22.04
glide		2		51.49
pool		8		4.83
riffle		13		72.82
slough	8		11.26	
tributary	7		2.78	
TOTALS	36	39	31.93	151.18
	48%		17%	

Table 3. Proportions of 2005 spring chinook redds relative to wetted habitat areas. Almost half (36/75) of the redds in the study reaches were in off-channel habitat areas, even though those areas only made up 17% of the wetted habitat. Redd detection in the mainstem is imperfect due to turbid glacial flows, but chinook use of North Fork off channel habitats for spawning is clearly documented.

Recruit/Spawner ratios

Peak (daily average) flood discharge during the incubation season explains more than 82 percent of the variation in Nooksack natural-origin recruit/spawner ratios (Figure 5), despite the many and varied influences on salmonid survival throughout their life cycle. Some of the flood peaks occurred while eggs were still in the gravel, and other peaks occurred after fry had likely emerged from their redds, indicating that both spawning and early rearing habitat are less than optimum for North Fork chinook. A similar relationship has been documented in the Skagit River to the south, where same-year out migrant fry show an inverse linear relationship with flood peaks, although that relationship does not consolidate effects over the entire life cycle.

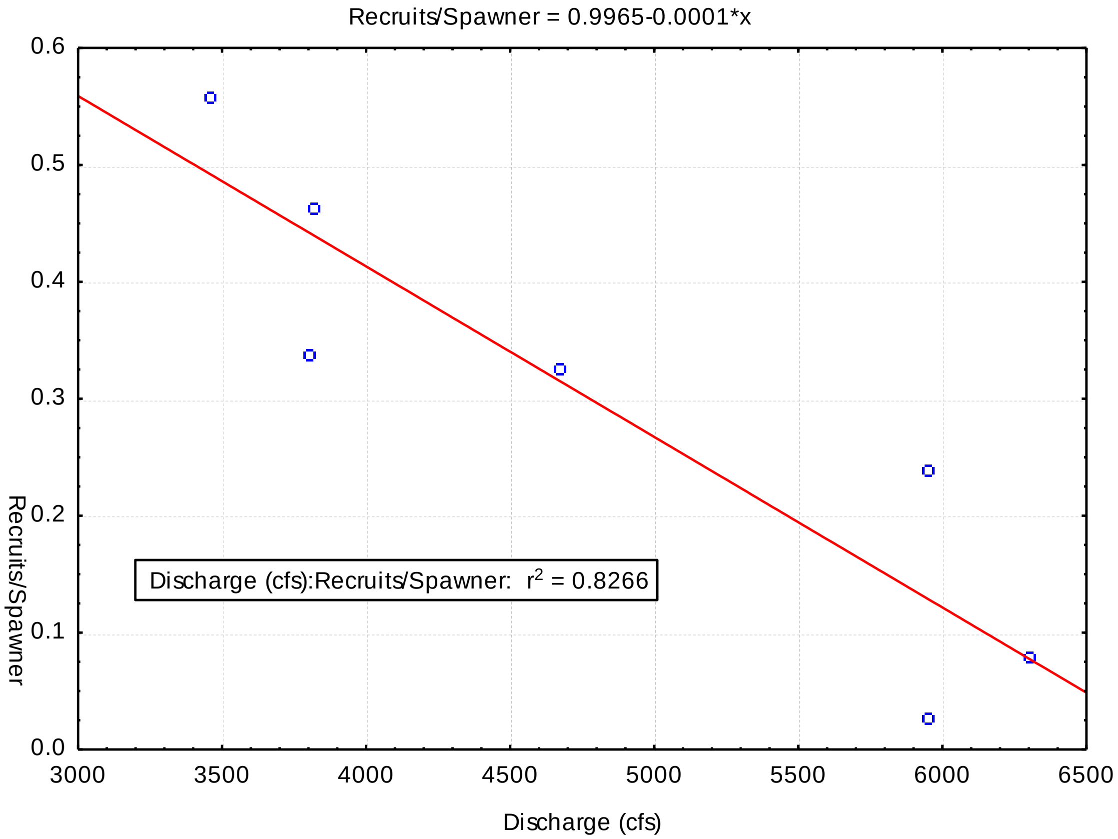

Figure 6. Recruit/spawner ratio regressed against discharge in incubation year. The recruit/spawner ratio is the number of natural-origin adult fish returning as two-to-six-year-olds from a specific brood year, thus encapsulating survival over the entire salmonid life cycle. Note that the recruit/spawner values are < 1, indicating that the chinook population is not reproducing at a sustainable level. Over 82 percent of the variation in recruit/spawner ratios is explained by the flood intensity during the incubation year. Redd scour and availability of flood refugia are commonly cited as having a significant effect on chinook population viability.

Habitat hypothesis

Given the changes in channel island area over time, and drawing from data presented here and in supporting research, we propose the following hypothesis to relate the habitat changes we've observed in the North Fork to the decline of the spring chinook populations. Channel islands tend to form around and behind logjams of very large wood (Abbe and Montgomery 1996, Collins and Montgomery 2002, Montgomery and Abbe 2006). Logjams of a size sufficient to maintain stability during floods are now rare in the Nooksack River below Glacier (Table 2). Floodplains were logged extensively over the past 100 years, so that trees of a size sufficient to initiate and stabilize a large logjam are likewise rare on the North Fork floodplain (Table 2). After logging, ample reservoirs of LWD remained embedded in the channel and floodplain for decades, but that wood has since decayed and is now smaller and in most cases has likely been exported from the channel (Hyatt and Naiman 2001, Latterell et al. 2006). As floods have become more intense and more frequent (Figure 4) the natural process of channel island and floodplain destruction has accelerated (Figure 3), while the lack of LWD has interrupted the process of channel island and side channel formation (Collins and Montgomery 2002, O’Conner et al. 2003). The decrease in off-channel habitats has coincided with a decrease not only in incubation survival (Figure 5), but evidently in rearing survival as well, since floods are implicated as the largest driver in overall population productivity (Figure 6). Channel volatility and disappearance of channel islands and back channels seems primarily determined by increased flooding and lack of stable “hard points” in the channel (Abbe and Montgomery 1996, Collins and Montgomery 2002), since the channel appears to be incising and channel aggradation therefore must play a relatively minor role (Table 2).

LONGITUDINAL VARIATION IN EXISTING HABITAT

Instream habitat conditions change markedly from the downstream confluence with the South Fork to the upstream extent of the study area at Glacier Creek. The downstream reaches are longer and wider, with fewer tributary junctions and fewer bedrock outcrops than the upstream reaches. Not only are the reaches larger, but the size of individual habitat units tend to be larger as well. As one progresses upstream the streambed gradients increase (Figure 7), discharge decreases, average widths and depths decrease, and substrate size increases.

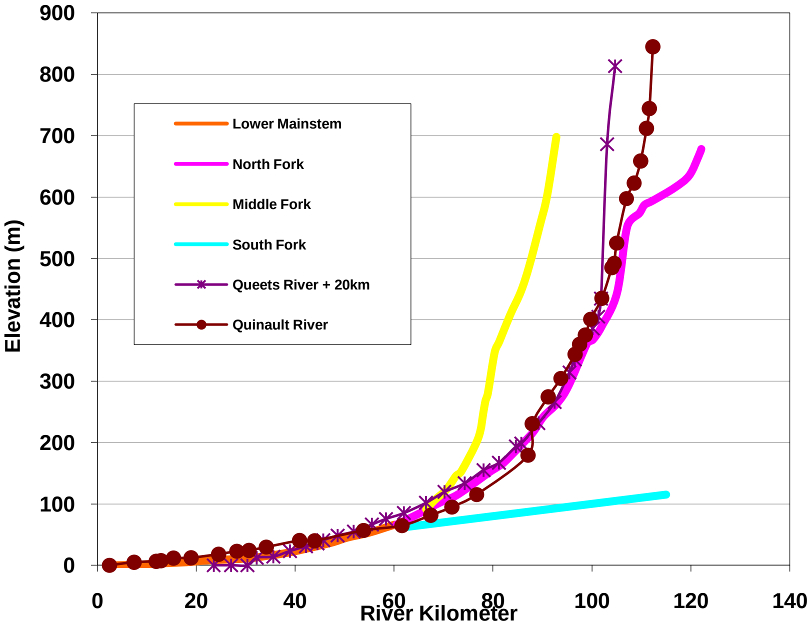

Figure 7. Longitudinal profiles of the lower mainstem and three forks of the Nooksack River. The South Fork is substantially lower gradient than the North Fork, and the Middle Fork is steeper. The Queets and Quinault rivers exhibit remarkably similar profiles to the North Fork (but note that 20 kilometers were added as downstream length on the Queets). Comparisons to rivers on the west slope of the Olympics are relevant since much of the research on LWD in large rivers is from that area.

All of the North Fork study reaches fall within prescribed thresholds for the island-braided channel type (Leopold and Wolman 1957, Church 1992, Beechie et al 2006), and compare favorably in terms of discharge and gradient to river reaches where channel islands are prevalent (Figure 8). Beechie et al. (2006) stratified western Washington rivers by channel type and delineated upper and lower thresholds for island-braided channels. All of the North Fork study reaches fall between the upper threshold (which distinguishes island braided from braided reaches), and the lower threshold (which distinguished island braided from meandering reaches). Island-braided channels are distinguished from braided channels by their degree of stability (Schumm 1985). In braided reaches the bars and thalweg shift within the unstable channel, and sediment load and caliber are large, as are the gradient and discharge. Island braided reaches are distinguished by multiple channels separated mainly by vegetated islands. Stability is higher and disturbance frequency is lower, and the proportion of suspended sediment to bedload is lower in island braided than in braided channels. Braided channels are typically found high in the channel network of gravel bedded rivers, island braided in the middle, and meandering channels downstream (Leopold and Wolman 1957, Beechie et al. 2006). Island braided reaches, by virtue of their wide variety of channel forms, variation in depths and velocities, abundant cover, and a high ratio of bank to total channel length (i.e. edge habitat), provide some of the most productive habitats for salmonids (Church 2002).

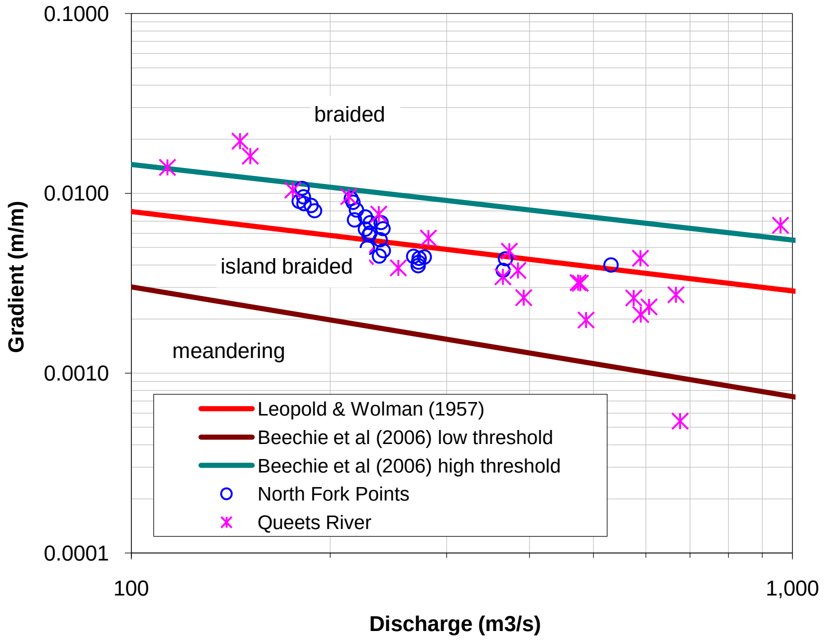

Figure 8. Discharge vs. Gradient (SQ plot) for North Fork Nooksack points, compared to Queets River points and geomorphic thresholds. River reaches with higher gradients for a given discharge would plot above the island braided threshold and in the region for braided reaches. Points below the lower island-braided threshold would be expected to exhibit a meandering river planform. Several of the braided reaches on the North Fork plot within the island-braided bounds, indicating a tendency toward the island-braided form if returned to more natural riparian and wood loading conditions.

All alluvial/braided reaches in the North Fork had sinuosity values tightly grouped around 1.1, while confined reaches through canyons and around landslide outcrops had sinuosity values in the 1.3 to 1.4 range. Bedrock outcrops trained the channel into a sinuous planform, rather than sinuosity resulting from a meandering channel type. Sinuosity ranged from a nearly arrow-straight 1.02-1.03 in the braided reaches just upstream of Boulder Creek and downstream of Racehorse Creek, to a fairly contorted 1.28-1.49 in the landslide dominated reaches below Slide Mountain. The highest sinuosity (1.49) was in Mahaffey Canyon, at about river mile 50.8, in the vicinity of a large ancient slide off Slide Mountain.

Wetted habitat in the lower reaches of the North Fork is predominantly glides, shifting to a predominance of riffles in the upstream reaches. Riffles and glides can be interchangeable depending on discharge, but the clear trend is for larger and more frequent glide units in the downstream-most reaches and a lower proportion of glides in the upstream reaches (Figure 9). Conversely, cascades are found predominantly in the upstream reaches and in lower proportions in the downstream reaches. The abundance of cascades is dependent on the gradient and bedrock outcrops mentioned earlier, and are found mostly in the canyon-like reaches and in the steepest reaches just below Glacier Creek. Braided habitats are most abundant in the Farmhouse reach immediately upstream of the Kendall hatchery, and in the Lone Tree reach just above the Boulder Creek confluence. Pools contribute little in habitat area in the North Fork, and are found in consistently low proportions throughout the study area. Comparing the North Fork to the South Fork Nooksack below Acme, the South Fork had approximately 10 percent of the habitat area in pools (Soicher et al. 2005), whereas the North Fork had only about 3 percent.

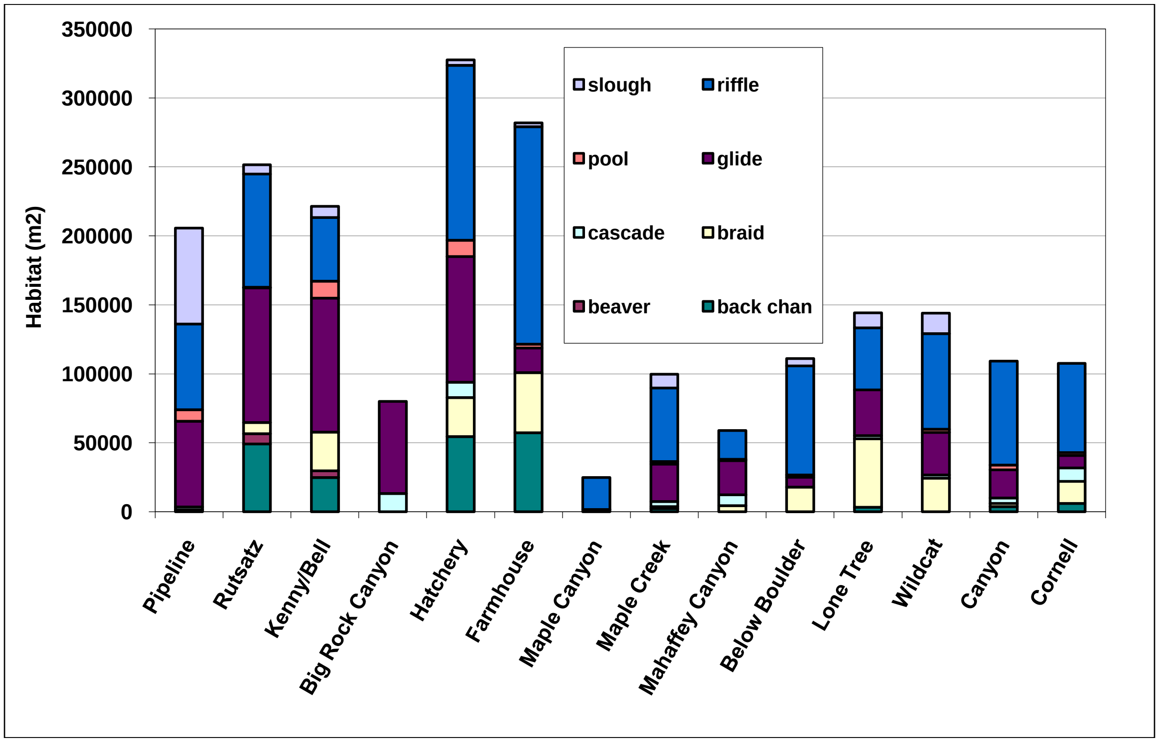

Figure 9. Wetted habitat composition in the North Fork study reaches, showing a decreasing relative abundance of glides, and increasing riffles and cascades, with a declining absolute wetted habitat in the upstream direction (left to right).

Off-channel habitats include back channels, sloughs, and beaver sloughs. The greatest area and the greatest proportion (by reach) of off-channel areas were in the lowest part of the river below the Middle Fork confluence. The Jim Creek slough on the right bank and the Rutsatz slough on the left bank provide immense off-channel rearing areas in years when those habitats are accessible, and the extensive network of back channels near the Rutsatz slough provide, in good water years, ample areas for summer and fall spawning.

Upstream of the Mosquito Lake Bridge, on the right bank around the Bell Creek confluence, is a notable area of ample rearing habitat that is often devoid of juveniles. Although fish sampling was not conducted as part of this study, their presence or absence was noted during field surveys. The two adjacent Farmhouse and Hatchery reaches contained most of the flowing back channel habitat, not only due to the extensive Bear Creek back channel but to smaller back channels on the right bank as well.

Channel islands are so heavily weighted towards the lower North Fork that the lowest reach (below the Middle Fork confluence) has three times more forested island habitat (~20 hectares) than the 11 remaining reaches combined. The lowest two reaches (of the combined North Fork and Middle Fork) are by far the largest reaches. The lowest two reaches contain 29 percent of the entire study area (including floodplains) and have 73 percent of the floodplain island area. The next largest area of floodplain islands is immediately upstream, above the Mosquito Lake Bridge (~4.5 ha). None of the other reaches contain more than 1 ha of channel islands. The land between the mainstem and the Bear Creek back channel was considered floodplain, not island; otherwise the Kendall and Farmhouse reaches would have the largest forested island concentration. Although floodplain islands are disappearing from the system, often it is the younger, incipient floodplains and islands, rather than the already established islands, that provide the best opportunity for restoration and enhancement.

Channel widths generally decrease in the upstream direction (Figure 10) stream gradients increase, and sinuosity depends primarily on interaction with bedrock and landslide outcrops. Average channel widths (across the active channel, including islands) range from a maximum 450 meters in the largest, most downstream reach to a minimum 22 meters in the bedrock confined reaches downstream of Maple Creek. With the exception of the bedrock and landslide controlled reaches the general trend is for the width to narrow with decreasing discharge upstream.

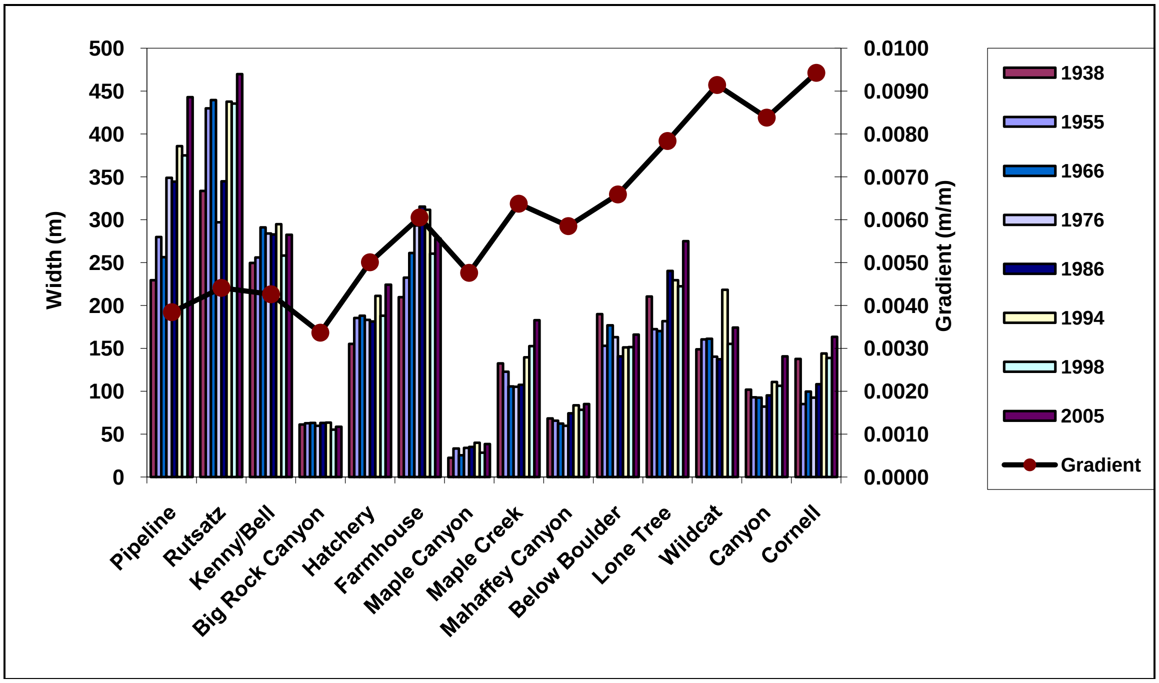

Figure 10. Active channel width and gradient in the 14 study reaches. Widths vary longitudinally according to discharge and valley width. Downstream reaches are to the left of the graph. A slight widening is evident from the sediment and discharge contributions of Canyon Creek, which first appear in the Wildcat Reach. Reaches below Maple Canyon were subject to early Holocene glaciation and discharge from the Fraser River, widening the valley. Upstream of Maple Canyon are several landslide deposits from Slide Mountain, constraining the river in a narrower valley.

CHANNEL DESCRIPTIONS BY REACH

The North Fork Nooksack was divided into 14 reaches for comparison and analysis (Figure 1), and in the section that follows each of those reaches is discussed in the context of restoration. Reach boundaries typically include geomorphic changes between sediment transport and storage, so confined canyon-like (pinch-point) reaches are segregated from unconfined reaches with braids, bars, multiple channels, and active channel migration. Some reaches were divided based on junctions with larger tributaries. For each reach the physical habitat composition, channel gradient, and propensity of migration and avulsion is discussed along with potential projects consistent with the ecological findings already presented. Proposed restoration projects are often grouped into several activities in a localized area, some reaches having more than one such group and some having none.

Reach 1: Pipeline

The Pipeline Reach extends from the State Route (SR) 9 bridge near the confluence with the South Fork (RM 36.7) to a point (at RM 38.3) about halfway upstream to the Mosquito Lake Bridge and the confluence with the Middle Fork (Figure 11). The upstream boundary falls where an extensive network of left bank side channels enters the mainstem. The mainstem in this reach is wide and heavily braided, with extensive channel islands and back channel complexes shifting with frequent flood disturbances. The right bank floodplain in the vicinity of the pipelines and Jim Creek is densely carved with former river meanders and side channels. Three natural gas pipelines (in a single corridor) cross under the river just upstream of the SR 9 bridge, and extensive bank hardening lies along the lower 760 meters of the left bank, but otherwise the banks are not heavily developed. The reach is accessible from several points, being bounded by SR 542 to the north, SR 9 to the west, and Rutsatz Road to the south. Land ownership is mostly private holdings, with Williams Pipeline owning and leasing a corridor across the floodplain, and the Whatcom Land Trust holding a large parcel on the left (south) bank.

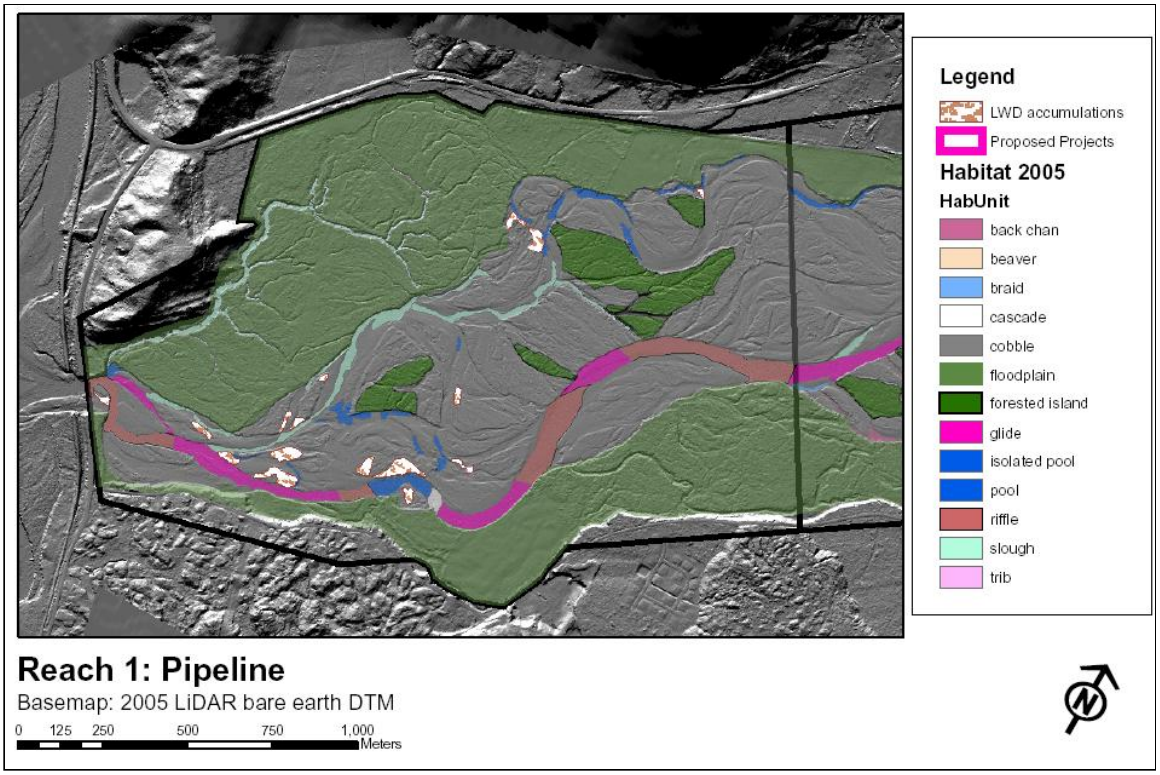

Figure 11. Reach 1 site map. The intersection of SR-9 and SR-542 is evident in the northeast corner of the map. An extensive network of sloughs drains the north floodplain and surrounding hillsides. Large landslide deposits constrain the channel from the south. Large wood deposits now occupy the active channel downstream of Whatcom Land Trust property into which the channel migrated during the 2003 floods.

Wetted habitat in the Pipeline reach is split almost evenly among riffle (30%), glide (30%), and slough (34%). Appendix A lists wetted habitat areas and proportions for each reach. The high proportion of slough habitat, both in the floodplain and out in the active channel, gives the Pipeline reach the highest proportion of off-channel habitat (34%) of the 14 reaches in the North Fork study area. The active channel sloughs, disconnected from the mainstem at the upstream end but hydraulically connected at the downstream end, are extensive former mainstem channels where channel avulsions have shifted the mainstem elsewhere. Many of the former mainstems are located on the floodplain and flow among mature cottonwood-dominated riparian forests. Several of these side channels are regularly inundated at flood flows, and the lower end of the Jim Creek slough complex is backwatered from the mainstem at all but low flows. In addition to the sloughs the Pipeline reach also has the largest area of isolated pools, which are connected at high flow (and likely by hyporheic flows), but are disconnected from the mainstem at low flows. Juvenile fish were noted in several of the isolated pools during habitat surveys. The single cascade habitat unit in mid-reach is due to the mainstem channel migrating into and over a bank stabilization project, and the remnant large rip rap now at the bottom of the channel forms a cascade-like hydraulic drop. The channel avulsion that occurred in October 2003 eroded into 17 acres of left bank floodplain owned by the Whatcom Land Trust, much of which was in mature coniferous timber. Wood loading in the reach is consequently high (third) relative to the other North Fork reaches, with 0.27 key pieces and 2.4 m^3 per 100 linear meters of channel. Mature floodplain timber is likewise relatively high (second), with 2.9% of the floodplain covered with trees more than 40 meters in height.

Geomorphically the Pipeline reach and the next reach upstream, the Rutsatz reach, are distinct from the rest of the North Fork, in that they lie below the confluence with the Middle Fork and exhibit different channel patterns from the rest of the river. The Pipeline and Rutsatz reaches were initially classified as one reach, but were split because the size of the unified reach skewed comparisons with the reaches upstream. Large increases in the flows of sediment and water from the Middle Fork, as well as a history of volcanic lahars, have resulted in a wider and more active channel with a higher proportion of channel islands. Channel island area in the lowest two reaches is five times greater than the channel island area in the 12 upstream reaches combined.

The Pipeline reach is the second widest (443 m) and second flattest (0.0038 m/m) of the 14 reaches in the North Fork study area, and has one of the most actively shifting channels in the river. Channel width in the Pipeline reach has consistently increased over time, from 230 m in 1938 to 440 m in 2005. The historical average width is 317 meters and the river is now 40% wider than that. Average water surface slope for the reach as a whole is 0.0038, and no 100 m segment along the mainstem is greater than 0.01 m/m. Propensity for a channel avulsion is high, due to the many abandoned channel meanders and flood scars on the floodplain, and the similarity in right bank floodplain and mainstem elevations at several points in the reach (Figure 11). Frequent channel switching puts the mainstem on the left or right margin of the active channel, a situation that has occurred twice in the past three years. The channel switched during the winter of 2005/06, putting the mainstem along the right bank, contrary to the maps prepared with the 2005 LiDAR (Figure 11). The channel occupation grid compiled from aerial photographs dating back to 1933 shows a central core of 100% occupation, contained by margins of old channels with a wide range of occupation percentages ranging from 10% to 80%. The channel occupation grid follows similar patterns to the “flattened” LiDAR basemap in Figure 12. The Jim Creek side channel is the only significant right bank feature to appear on the 1933-1998 grid. The channel occupation grid using GLO (General Land Office) surveys and maps dating back to 1859 shows the mainstem channel along the right floodplain extent in the vicinity of what is now SR 542. Channel occupation in these old meander scars is in the 10%-20% range. Annual channel migration rate since 1933 has averaged 17.1 m (SD = 7.3) over the 10 transects in the reach, with a maximum of 27 m in the middle of the reach (and in the vicinity of the transect that recently avulsed back to the right bank).

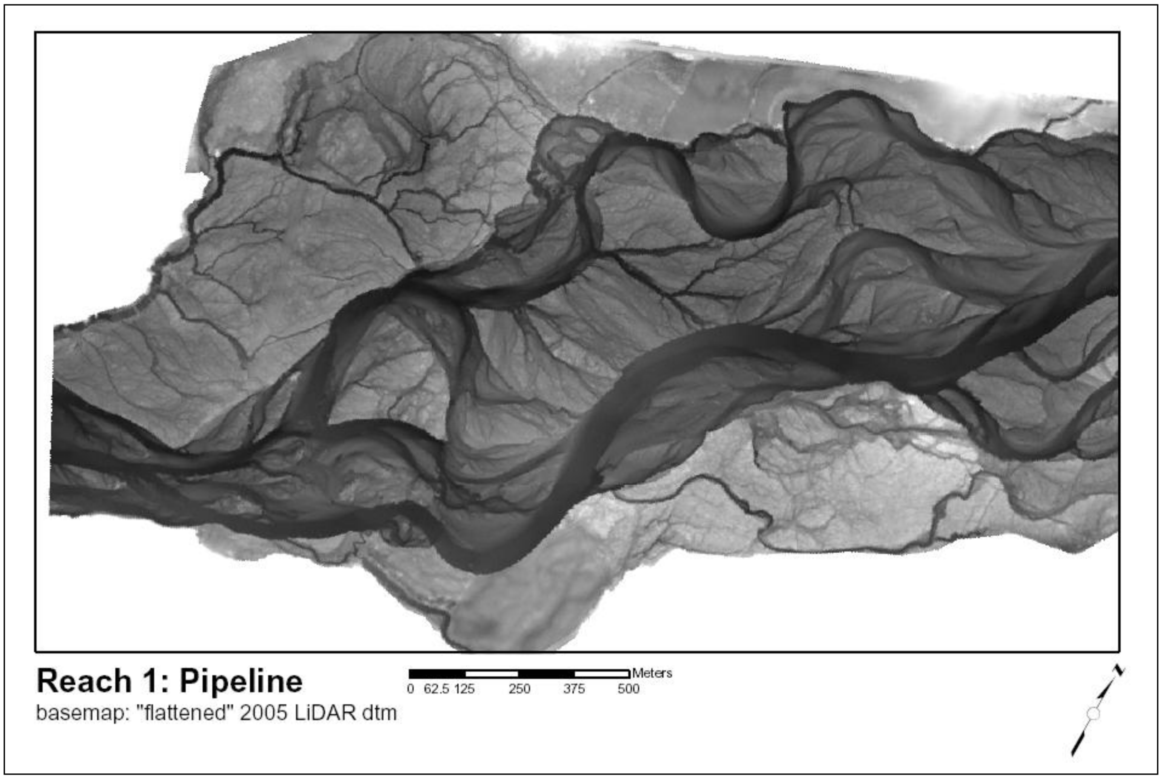

Figure 12. A "flattened" digital terrain model showing channel and floodplain with the effect of channel slope removed. Uplands are not shown. Darker tones are lower elevations, relative to the channel centerline, and generally denote wetted channels and off-channel areas at or near the same elevation as the mainstems. Lighter shades denote floodplains and areas unlikely to be flooded except in extreme events.

The historical aerial photographs from 1933 show the mainstem channel at the lowest end of the reach all the way to the north against the hillslope, where the Jim Creek slough now flows through a maturing alder forest. The channel occupied this area at least until 1950, but by 1955 had shifted south, making the lowest end of Jim Creek an open cobble bar. Apparently the SR 9 highway bridge was shifted west in about 1955 as well. The Jim Creek Flats area—the right bank floodplain downstream of Truck Road Park—was significantly larger in 1933 than it is now, the vegetation was younger, and the active channel was narrower (~230 m) and stayed mostly toward the middle of the floodplain. By 1938 the channel had widened to 280 m and meandered south all the way to Rutsatz Road, just upstream of where the Williams Pipeline crosses today (near the constructed chum spawning channel). By 1938 the Jim Creek Flats area was still extensive and showing signs of maturity, although old meander scars were visible as patterns in the forest canopy. The 1950 and 1955 photos do not show the extensive widening and braiding in the Pipeline reach that are apparent upstream in the Rutsatz reach, although channel island area is greater. By 1967 the pipeline and its cleared corridor are evident, the pipeline having been constructed in ____. In 1976 the mainstem had again claimed the lowest end of the Jim Creek complex, and core areas of what are now large channel islands had begun to form. The 1986 channel width narrowed slightly to under 350 meters, and showed a linear channel edge where riprap was installed to protect the pipeline. By 1994 the current pattern of channel islands was established, although extensive forested island and floodplain areas have been taken out by floods since then.

Reintroducing mainstem flow into the old meander scars and side channels on the right bank appears feasible due to the similarity in elevations, and is being pursued by the Williams Pipeline Company in conjunction with the recent pipeline capacity replacement project. The right bank of the Pipeline Reach in the vicinity of Jim Creek is generally less than 2 m above the mainstem channel, with occasional gaps of only 0.5 m or less (Figure 13). The right bank and mainstem are at approximately the same slope. The left bank is generally about 6 m higher than the mainstem centerline, and the left bank longitudinal profile is steeper than the mainstem (slope 0.00525 vs. 0.00380), indicating that the left bank floodplain was formed under different conditions that exist in the river today, and that the left bank floodplain is much less accessible than the right. The Williams Pipeline restoration project will entail excavation of a gap in a right bank levee that will allow flood flows into the Jim Creek side channel, and control structures downstream of the pipeline corridor to prevent channel head cutting from exposing the buried pipelines. Construction is scheduled for summer 2007.

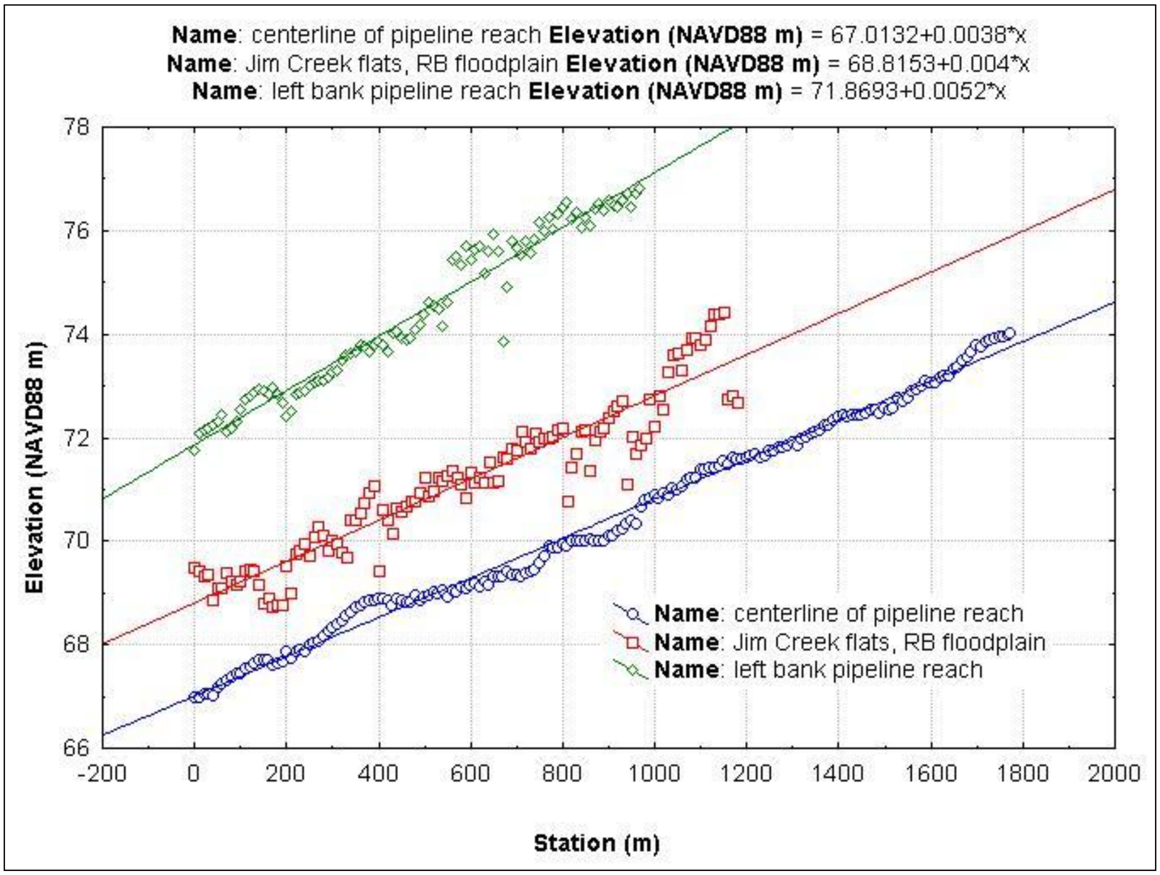

Figure 13. Longitudinal profile plots of the left bank floodplain, right bank floodplain (Jim Creek flats), and channel centerline in the Pipeline reach. The left bank floodplain is substantially higher than the channel centerline, but the right bank floodplain is not. Several low areas in the right bank floodplain provide opportunities for channel avulsion.

Reach 2: Rutsatz

The Rutsatz reach extends from the confluence of the Rutsatz side channels and the North Fork mainstem (RM 38.3) to the Mosquito Lake Bridge above the Middle Fork/North Fork confluence (RM 40.6). The reach is bounded by Rutsatz Road on the left (southeast) bank and Truck Road on the right (northwest) bank. At the Mosquito Lake Bridge the river is restricted to a narrow (~35 m) channel where Mosquito Lake Road pinches the river against bedrock on the right bank (Figure 14). Aerial photos from 1933 and 1938 show a railroad bridge parallel to and just downstream of the Mosquito Lake Bridge. The Washington Department of Ecology (WDOE) has operated a stream gauging station at the Mosquito Lake Bridge since 2002. Landslide and lahar deposits downstream of the North Fork – Middle Fork confluence partially restrict the channel width to about 350 m, whereas downstream of the lahar deposits the channel widens to almost 1 km in some places. Average channel width for 2005 in the Rutsatz reach is 470 m.

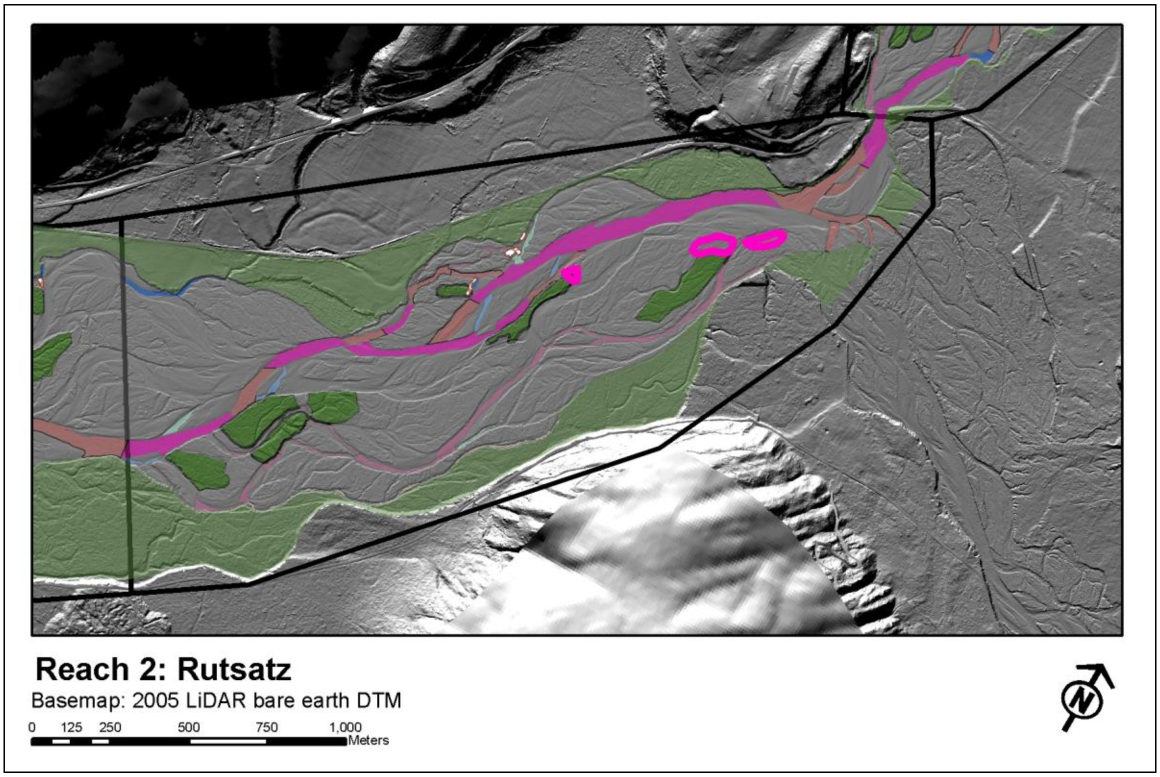

Figure 14. North Fork Reach 2 site map. Legend is same as Figure 11. An extensive network of side channels follows the mainstem in the left portion of the active channel. Several vegetated channel bars (not shown) and channel islands split flow from the mainstem and provide excellent rearing habitat, but in some years the flow split is occluded and the side channels remain dry or intermittent for most of the summer.

Average gradient for the reach is 0.004. The left bank back channel along Rutsatz Road is at a slightly lower gradient than the mainstem centerline (0.0039 vs. 0.0043), and is generally about 3m higher, with few gaps for cross-channel inundation (Figure 15). Water surface slope at the time of the 2005 LiDAR flight ranged between 0.003-0.004 m/m, with a few short riffles at 0.02 slopes.

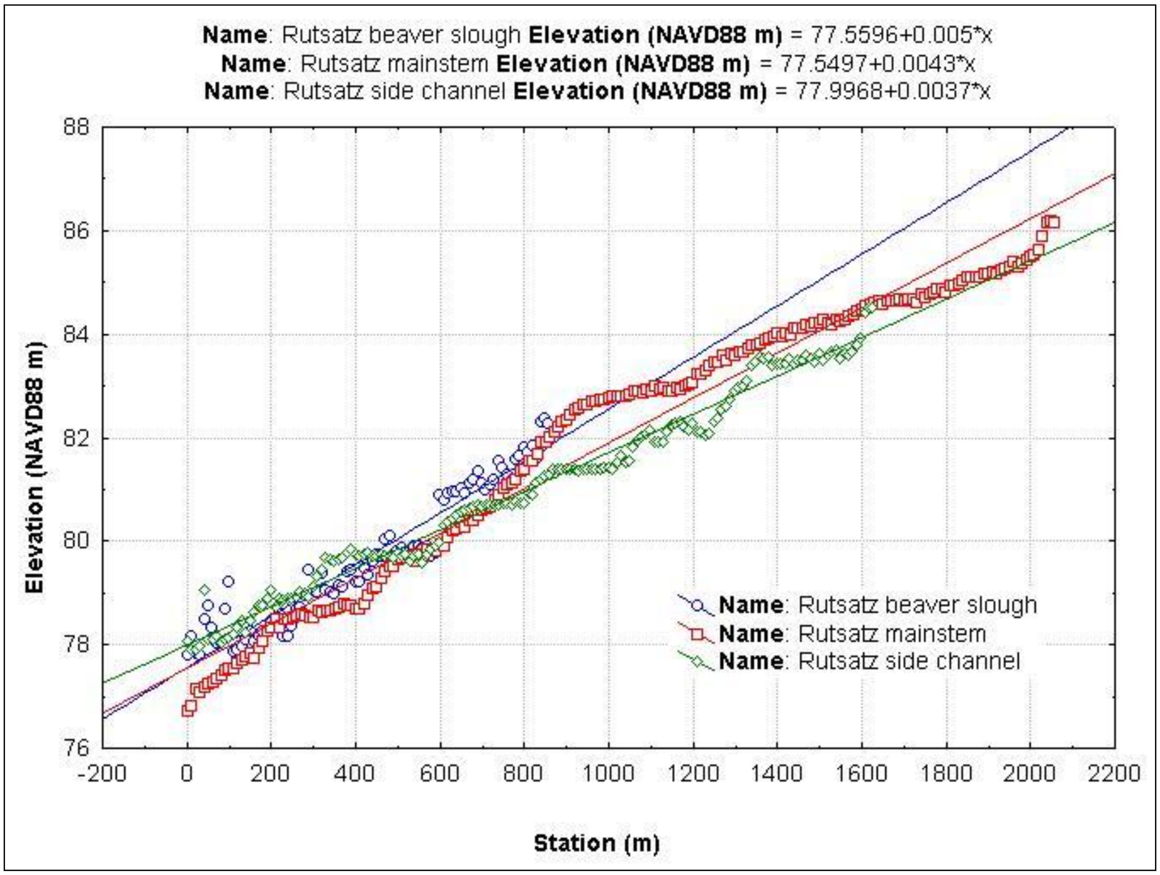

Figure 15. Longitudinal profiles of the Rutsatz Reach. The left bank back channel is higher than the mainstem channel, and therefore would be difficult to reconnect, although substantial rearing habitat could be gained in the process.

Buried logs protruding from the lahar deposit at the North Fork – Middle Fork confluence could be used to accurately date the lahar (using carbon-14 dating techniques). The buried logs might also indicate or constrain the amplitude of channel aggradation and incision over the past 5000 or so years.

An extensive side channel complex on the south side (left bank) of the reach provides extensive spawning for chum and fall chinook. The mainstem and side channels frequently shift in the proportion of flow carried by each, so that the combined side channels sometimes carry up to half of the reach discharge. At other times, such as during the 2005 habitat surveys, substantial parts of the side channel complex carried no flow at all. The channel islands among the side channels, particularly those at the downstream end of the reach, combine many of the most desirable habitat characteristics for off channel areas; that is, tree density and height, canopy coverage, and channel definition are all relatively high. An extensive back channel and beaver slough complex flows across the left bank floodplain and is disconnected from the mainstem except at high flows and at the lowest extent (i.e. at the confluence). The Rutsatz back channel could provide a substantial amount of ideal coho rearing habitat were it connected better to the mainstem. Juvenile fish were rarely spotted in the Rutsatz back channel during the 2005 habitat surveys, but were trapped in the back channel in low numbers.

In the winter of 2001 the mainstem channel avulsed from near its current location towards the north, filling a former channel near the Truck Road park and eroding it further north (i.e. it shifted 80 m further than its historic extent). By autumn 2002 the channel had shifted back to the middle of the channel migration zone and has remained there since. Channel migration has likewise threatened Truck Road at the upstream end of the reach, and high flows typically reach within a few feet of the road, most of which has been lined with large rock.

Less than one percent of the active channel and floodplain in the Rutsatz reach have mature trees greater than 40 m in height. Localized areas of tall vegetation are at the upstream extent of the Rutsatz back channel, near the road and just downstream (southeast) of the large landslide deposit. The majority of floodplain is covered in young forest or pastures.

The historical air photo from 1933 shows a river that appeared to shift frequently and leave behind a maze of complex meander scars and floodplain patches with a wide range of vegetation ages. At the lower end of the reach on the left bank the river had recently carved its way nearly to Rutsatz Road, and on the opposite (right) bank was a maze of vegetated bars and islands of varying maturity. Upstream on the right bank along Truck Road is an abandoned meander scar with a mature floodplain forest between the road and the mainstem. By 1938 the vegetation patterns in the active channel were clearer, with exposed bars and young vegetation offset by distinct channel islands and floodplains. Several areas that are channel islands now (in 2006) were active and wetted channel in 1938. By 1950 the channel had widened significantly, at least at the bottom of the reach, and was highly braided, indicating a large and recent sediment deposit. The next North Fork reach upstream does not appear to have widened and braided in the same photo interval, indicating that the sediment load likely came from the Middle Fork. Also in 1950 the widening put a major split of the North Fork (approximately 1/3 of the reach discharge) hard against the south hillslope and Rutsatz Road, where a groundwater-fed beaver slough exists today. In 1955 the mainstem still occupied the channel where the beaver slough is today, and was still quite braided in the middle, but had migrated at the upstream end to near where it is blocked by Truck Road today. By 1976 the extensive mosaic of channel islands and back channels that we see today had started to form along the left bank, and the channel width as a whole dropped to well under a 350 meter average. In 1980 and 1986 the river moved away from Truck Road. By 1994 the reach exhibited a classic island-braided channel form, with an extensive complex of channel islands interspersed among an array of bars, braids, and multiple side channels.

Proposed projects in this reach include construction of three large logjams and possibly two smaller ones at the upstream end of existing channel islands. The objective of the projects is to split flow and encourage the growth and stability of channel islands to accentuate and accelerate stable side channels suitable for chinook spawning. Land ownership is primarily DNR aquatic lands and Whatcom Land Trust, with some private parties adjacent.

Reach 3: Bell/Kenny

The Bell/Kenny reach extends from the Mosquito Lake Bridge at river mile (RM) 40.7 upstream to the beginning of a short, confined reach at RM 42.9 (Figure 16). Near the downstream end of the reach Bell Creek enters from the right bank, and in the middle of the reach Kenny Creek enters from the left. The reach is a broad, heavily braided alluvial floodplain with several side channels and a few channel islands. The reach is bounded on land by SR 542 to the west and the North Fork road to the east. A pullout along the North Fork road in mid-reach is a popular spot for eagle viewing in the fall.

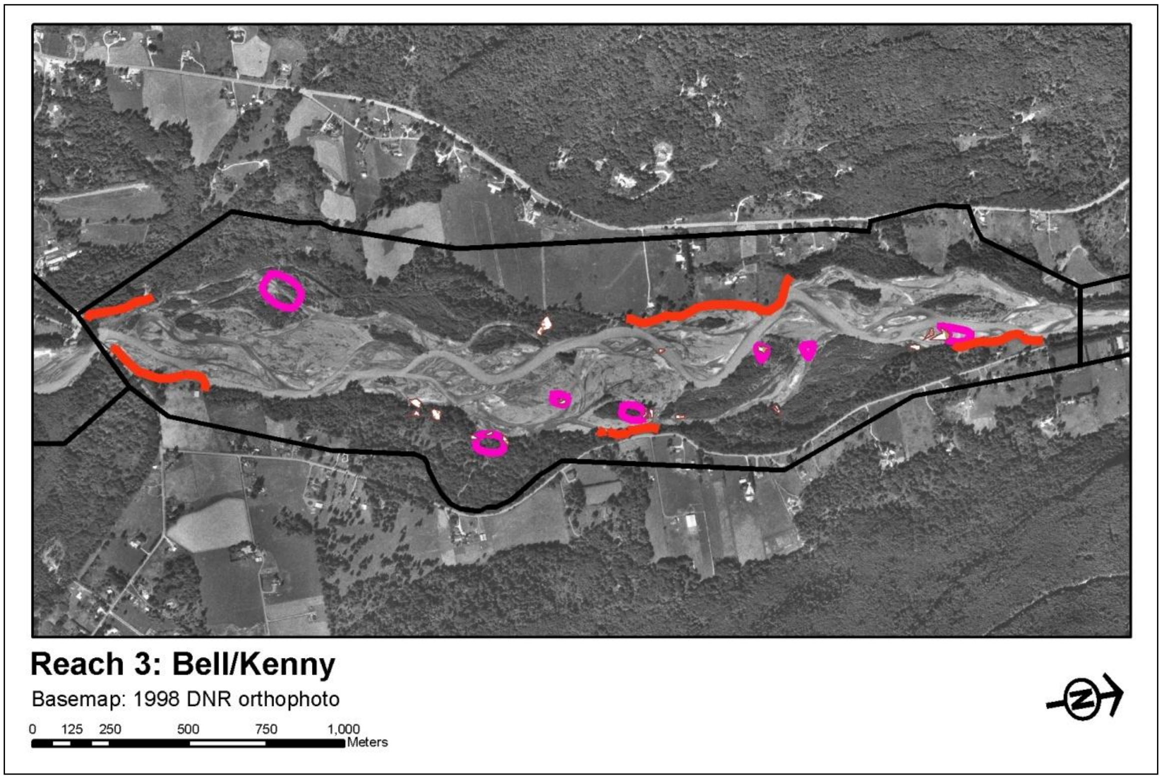

Figure 16. Site map for the Bell/Kenny reach above the Mosquito Lake Bridge. Magenta polygons denote restoration opportunities. Red linear features denote bank hardening.

Mainstem habitats in the Bell/Kenny reach are about 40% glide, 20% riffle, and 5% pool. Of the total wetted area about 21% is off-channel habitat and the remainder is mainstem. The off-channel habitat is divided into two major complexes, one on the right bank in the vicinity of the Bell Creek confluence, and the other on the left bank predominantly upstream of the Kenny Creek confluence. The left bank complex is dominated by extensive beaver sloughs, multiple flood channels in a low floodplain, multiple channel islands, and the Bell Creek confluence. The left bank complex includes an extensive back channel that supports dense chum salmon spawning and occasional scattered chinook spawning. Connections between the left bank back channel and mainstem occasionally shift. Two stable channel islands separate the left bank back channel complex from the mainstem. The back channel was a slough from at least 1998 till 2004, but now is connected at low flow at the upstream end, and via braids lower in the system. The upstream end of the left bank complex was a study site for the chinook incubation assessment (Hyatt and Rabang 2003), and was classified as a slough at that time. Minor wood accumulations are scattered through the reach, particularly in the upper half. Natural logjams are found at the upstream ends of some of the channel islands, including those associated with the left bank back channel. Of the approximately 150 hectares of active channel and floodplain area in the Bell/Kenny reach, only 0.4 hectares (0.3%) have mature timber (>40 m height). The patches of tall trees are on the channel islands upstream of Bell Creek and the North Fork pullout, in the right and left bank back-channel complexes, respectively.

The Bell-Kenny reach is steeper than reaches downstream of the Middle Fork confluence, ranging between 0.0044 to 0.0055 m/m. The left bank floodplain downstream of Kenny Creek is in places 2 m higher than the mainstem, but at the upper and lower extremities of the reach the floodplain and mainstem are at similar elevations. The right bank floodplain, including the Bell Creek confluence and numerous remnant side-channels and beaver sloughs, is generally less than 2 m higher than the mainstem and at several points is lower than the mainstem channel, with several gaps offering clear opportunities for channel connection (). Water surface slopes along the mainstem are generally in the 0.001 - 0.01 range, with a few short riffles greater than 0.01 m/m. Sediment change between 1994 and 2005 shows that the channel lowered by 11 cm.

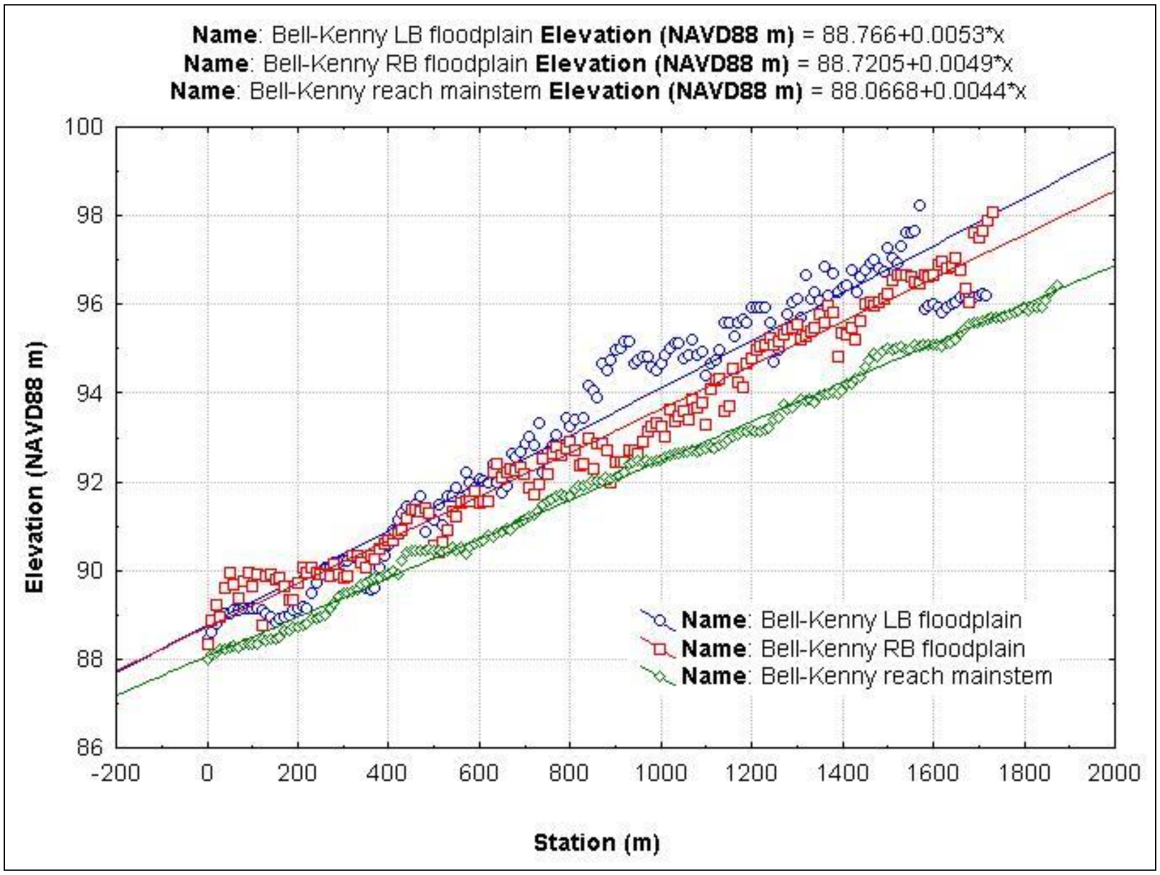

Figure 17. Longitudinal profiles for the Bell/Kenny reach. Intersection and overlap between the mainstem and floodplain profiles indicates opportunities for both channel avulsion and side-channel re-connection.

The 1933 aerial photo of the Bell-Kenny reach shows remarkable similarities with the modern channel. The lower end of the reach, near the Bell Creek confluence, in 1933 was a recently abandoned mosaic of back channels, high flow channels, thinly forested cobble bars, and the lower Bell Creek tributary. By 1938 the area had matured to a floodplain forest, with many of the former channels obscured by forest vegetation. In the 1950s the forest remained, with the North Fork eroding into the floodplain at the upstream end. In the 1960s the river shifted west into the floodplain, but not as far as Bell Creek, nor as far west as the channel margin in 1933. The 1966 channel also shows a substantial channel island towards the left bank, and a large left bank side channel flowing against what is now a hardened bank at the edge of the historical migration zone. By 1976 more than half of the channel island is gone, and the Bell Creek floodplain is mostly open cobble bar with scattered island remnants of the former floodplain forest. The 1986 photo shows a back channel and channel islands upstream of Bell Creek similar to the configuration of beaver ponds there today. The left bank back channel complex has a more varied history, with the beginnings of what are now mature trees showing in the 1938 and, to a greater extent, the 1950 photographs. Both the left and right bank back-channel complexes show channel occupancy rates around 20-40 percent.

Multiple opportunities for restoration exist in the Kenny/Coal reach, however spring chinook spawning in the reach is low and therefore priority for the reach may be low as well. Near the North Fork road pullout an existing channel island could be fortified with LWD at the upstream end where logs have already collected. The channel island is in close proximity (<50 m) to documented spring chinook (and chum) spawning in 2005. At the most upstream end of the left bank side channel the channel entrance could be fortified with LWD to encourage local scour and assure the flow split. Likewise on the braid connecting the mainstem with the back channel, judicious placement of LWD structures could encourage flow into the back channel and possibly create off-channel spawning opportunities attractive to chinook. Near the downstream end of the left bank side channel reinforcements to the existing LWD accumulations could enhance the stability of existing pools, providing useful cover and pool-scouring potential. On the right bank side channel complex the bed elevation of the mainstem and floodplain are very similar, with multiple opportunities for shunting mainstem flow into what are currently small back channels. Additional flow in the existing back channels might encourage chinook spawning in what is a relatively stable habitat (albeit low in the system for spring chinook). The mainstem near the right bank complex currently has a tendency to shift south towards the left bank however, so site-specific topography and hydrologic modeling are recommended to investigate the viability of a right bank project.

Reach 4: Big Rock Canyon

The Big Rock reach is short (<1 km), narrow (<60 m), confined, has not moved substantially in the past 100 years, and appears to provide little opportunity for restoration. Falling between RM 42.9 and 43.7, it is bounded on both banks by boulders and rubble from the Racehorse landslide. Channel migration is virtually nil. Highway 542 provides access to the right bank (about 300 m distant) and the North Fork road closely follows the top of the left bank, affording views of the river. The habitat is predominantly glide (83%), with one long-standing cascade where the river shifts around large, mid-channel, landslide-deposited boulders. Water surface slopes among 100 m mainstem river segments (including the cascades) are less than 0.01, with a reach average of 0.0034. Chinook spawning in the reach is low to nil. There are no side channels. Wood accumulations in the reach are non-existent or ephemeral. Despite a mostly intact riparian zone (few gaps in tree coverage) the trees are no more than medium height, with about 80% less than 25 m. No trees > 40 m in height are within recruiting distance of the river.

Reach 5: Hatchery

The Hatchery reach is long (~3 km), varied, and complex, encompassing several braided sub-reaches, multiple channel islands, three major tributaries, and numerous opportunities for restoration. The reach extends from RM 43.7 to 46.7, from the entrance to Big Rock Canyon upstream to the Bennet-Woodland equestrian farm (Figure 18). The Kendall hatchery is about 2/3 the way up the reach on the right bank. The Bear Creek slough and Racehorse Creek enter about mid-way down on the left bank. Coal Creek enters from the right bank immediately downstream of the Racehorse confluence. Access can be gained to the reach from several points on either bank, most notably from the Kendall hatchery, and from the North Fork road where it turns east at Racehorse Creek.

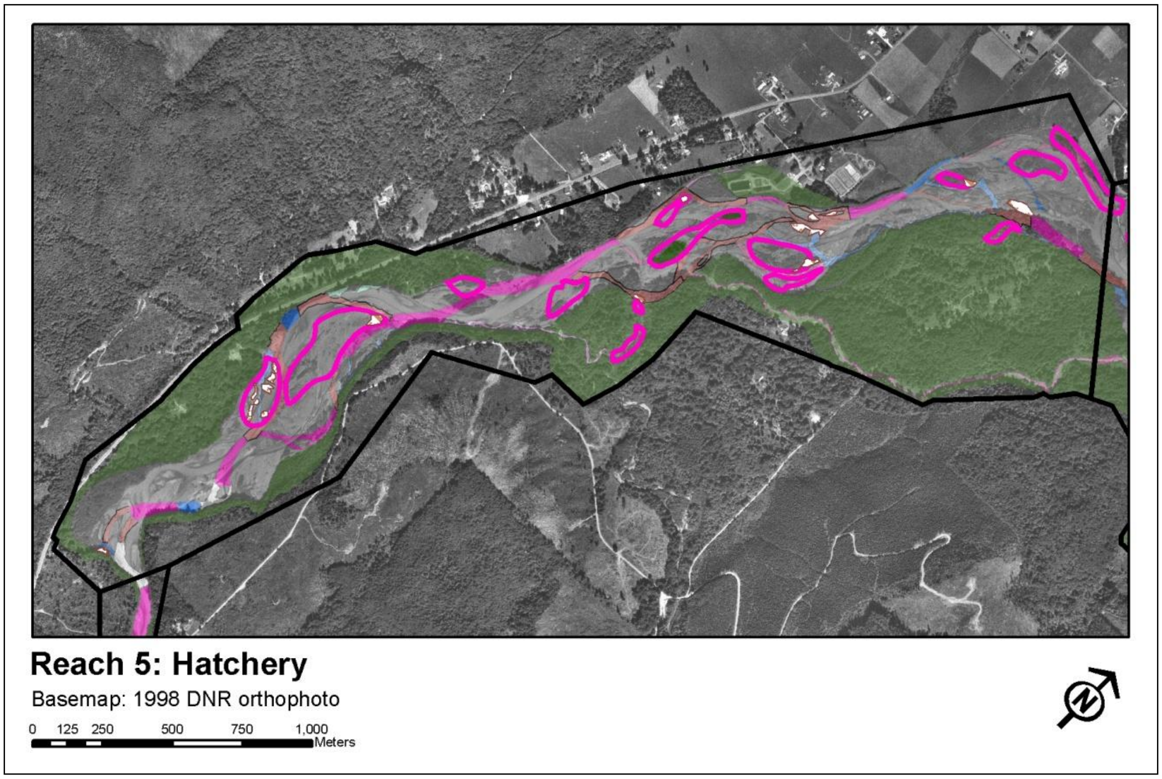

Figure 18. Site map for the Hatchery Reach. Legend is the same as Figure 11. Racehorse Creek enters the photo at bottom center. The Kendall hatchery is in the upper right quadrant. Restoration opportunities (magenta polygons) abound in the reach, although some sites may have a high risk of failure due to flood damage or channel migration.

Mainstem habitat in the reach is primarily riffle (39%) and glide (28%), with a few convergence and lateral scour pools (4%). None of the pools in 2005 were primarily wood-forced, although wood may have been associated with the pools by proximity. Of the wetted habitat area in the reach about 18% is off-channel and the remainder is mainstem. About 4/5 of the Bear Creek side channel is included in the Hatchery reach, with the upstream 1/5 in the adjacent the Farmhouse reach. Chinook spawning in the reach in 2005 was significant, owing in part to proximity to the hatchery. Wood abundance is relatively low for the North Fork at 0.11 key pieces/100m, but several LWD accumulations in strategic locations (e.g. at the upstream end of existing channel islands) were noted during the 2005 habitat surveys. Area of mature timber (>40 m) in the floodplain was average for the North Fork (1.3%), much of which was located on the island formed by the Bear Creek side channel. Floodplain island area is low compared to downstream reaches, but average compared to upstream reaches. The island formed by the Bear Creek side channel was classified as floodplain due to its function, size (56 ha), and stability, and because it was more than twice the width of the active channel. Otherwise the Hatchery reach would compare more favorably with downstream reaches in amount of channel island area.

Water surface slopes in the Hatchery reach average 0.005, and vary locally (in 100 m segments) between 0.001 and 0.01 (that is, no segments greater than 1%). Average width of the active channel is 275 m. The narrowest section of the active channel, at the Coal Creek confluence, is barely 100 m across, while the widest, at the Bennet Woodland farm, is more than 300 m. Avulsion potential is high in the wetlands and former channels on the former Gundy property, now owned by the Whatcom Land Trust. Several linear ponds on that property are naturally-isolated former meanders, and could become flowing channels once again, but re-occupation of those channels is currently subject to natural channel migration processes. Channel occupation values in the active channel generally range between 80-100%, while occupation values in the floodplains typically fall in the 0-20% range, indicating a relatively long-standing distinction between an active braiding channel and its floodplain. Channel migration rate in the entire reach since 1933 averaged about 9 m, with a minimum of 1.18 m near the Coal Creek confluence and a maximum of 18 m at the hatchery.

The air-photo history of the Hatchery reach shows some sub-reaches have remained remarkably stable while others have changed dramatically, especially in the most recent years. The downstream end of the reach at the entrance to the Big Rock canyon has remained largely unchanged in the air-photo record. The Coal Creek confluence has remained the narrowest part of the reach, largely due to the Racehorse Creek landslide deposits and the influx of sediment from both Coal and Racehorse creeks, which enter on opposite sides of the North Fork. The sub-reach at MP 24.7 fluctuates with and without vegetated cobble bars in mid-channel. Likewise a group of channel islands appear and disappear near the Kendall hatchery, as the channel there widens and narrows. The river widened substantially at the upstream end of the reach during the 2003 and 2004 floods, eroding into areas rarely occupied by the channel. Overall channel width increased over the photo record from 150 m to more than 220 m. At the lowest sub-reach, near the SR 542 milepost 24.7 highway bank stabilization site, the floodplain and cobble bar show a classic accumulation upstream of the Big Rock constriction (Figure 19). At that site the river was eroding into the right bank, but was reinforced in 2004 with 1-meter riprap and log structures below the waterline. The logs were anchored by cable to the bank, and were designed to collect sediment at high flows, elevate and roughen the channel, and encourage the river to shift away from the highway, which it has since done. In 2005 a channel island covered in shrubs and open cobble separated the mainstem and highway on the right bank from a braided side channel on the left bank, but since that time the mainstem has shifted to the left bank side channel and vice versa. The river, island, and side channel are all at approximately the same elevation at the upstream flow split, but the (new) river mainstem drops rapidly as it falls away to the left. The relative island elevation rises quickly, and the new side channel (the mainstem in 2005) is flat at first, but soon drops, so that the two channels are distinct. Towards the bottom of the reach the river, side channel, and island are united again at the same elevation.

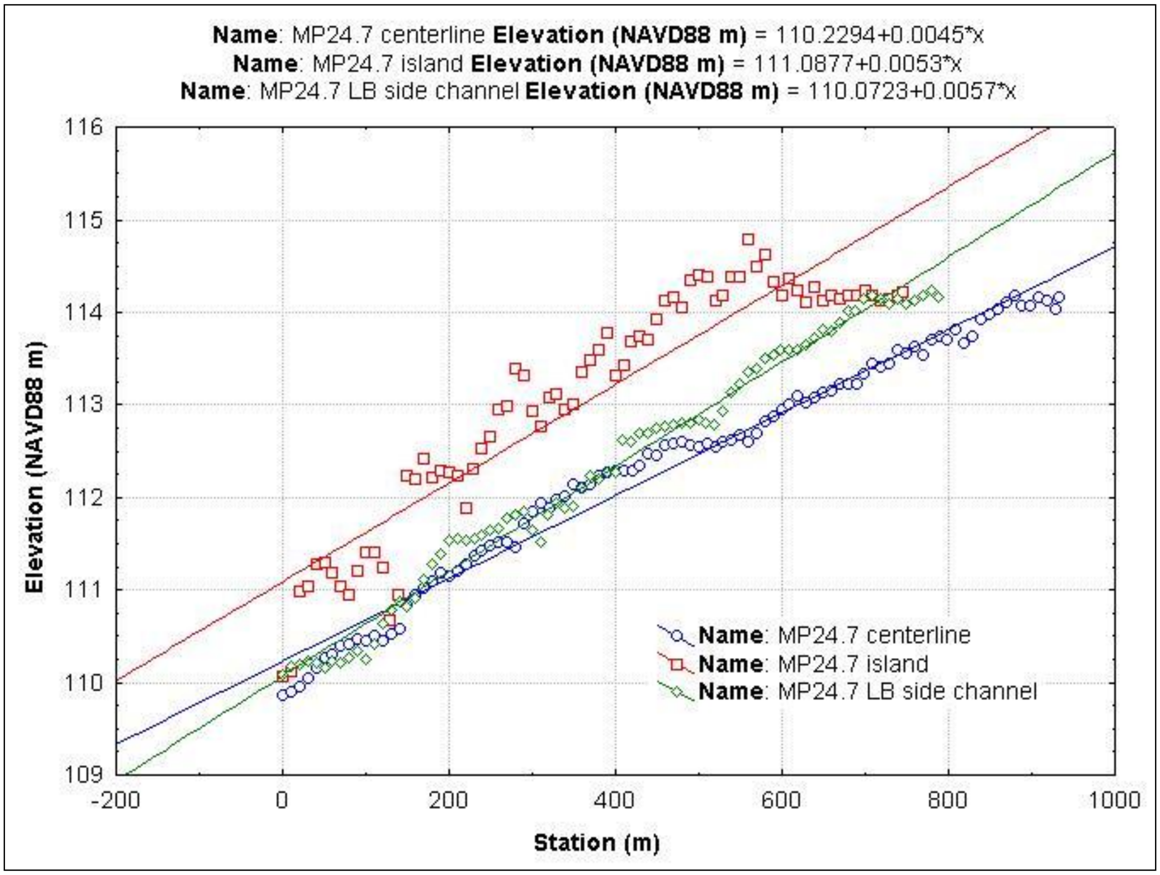

Figure 19. Longitudinal profiles in the lower portion of the Hatchery reach, in the vicinity of the SR-542 instream project at Highway MP 24.7, and downstream of the Coal Creek and Racehorse Creek confluences. The channel island in the middle of the reach is typically less than 2 meters higher than the channels on each side.

A large right bank channel bar just downstream of the MP 24.7 site has some established hardwood and shrub vegetation that could be stabilized by enhancing the logjam at the upstream end, and several smaller logjams on the right bank could be enhanced to encourage stability. The braid at this site, which could become a back channel given time and vegetation growth, offers valuable off-channel spawning and rearing habitat among the existing jams. The site is confined by SR 542 and private holdings on the right bank, and large Holocene landslide deposits on the left bank. Hydraulic analyses should provide insight on the long-term feasibility of logjams and channel islands in the MP 24.7 sub-reach.

The Coal Creek-Racehorse Creek sub-reach shows a marked difference in slopes between the wetted channels and the floodplains (Figure 20). The mainstem centerline and the lowest 700 m of Racehorse Creek have almost the exact same slope (~0.0044), while the cobble bar separating the mainstem from Racehorse Creek and the right bank cobble bar separating the mainstem from Coal Creek have similar, higher slopes (~0.0055). Both cobble bars show gaps where flood flows currently cross over during floods, and where introducing mainstem flow into the side channels may be possible even at low flow.

Given the differences in gradients and the several flood channels on the bars, channel avulsion at these bars is fairly likely.

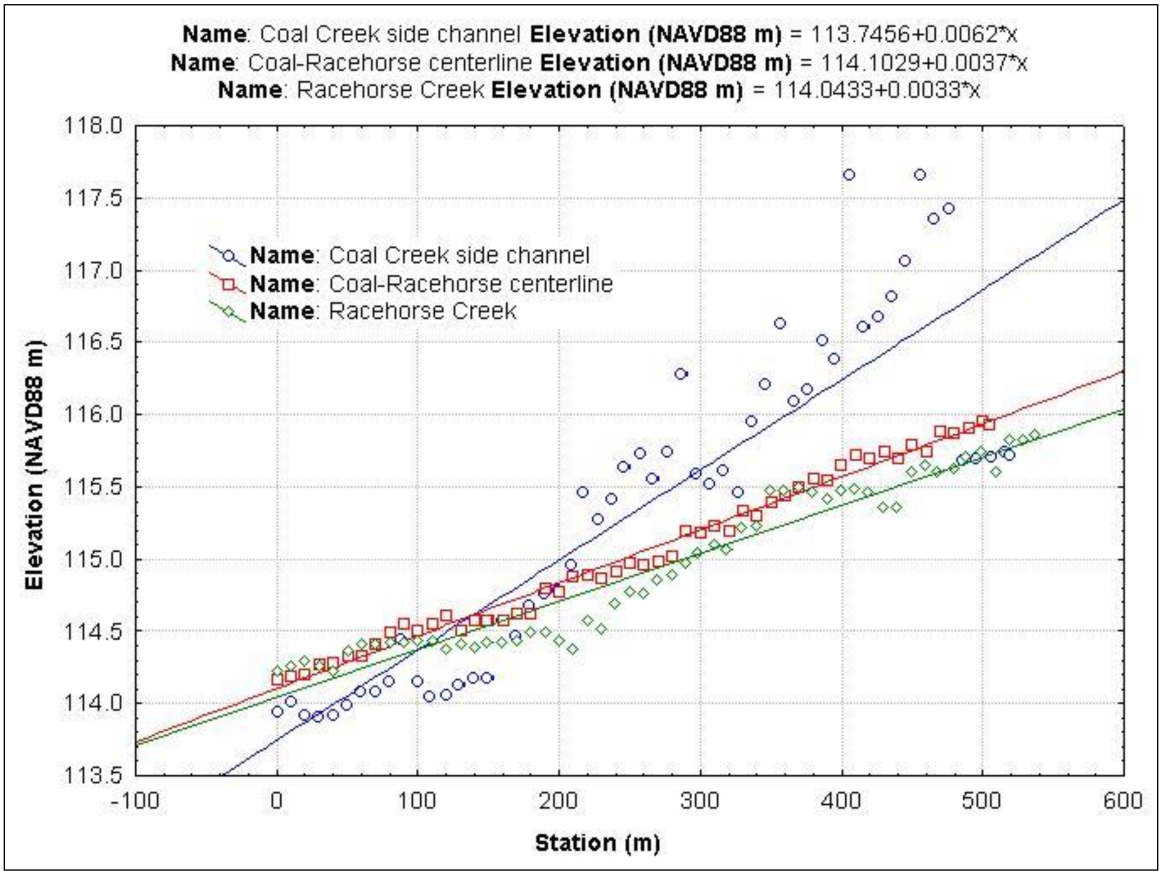

Figure 20. Longitudinal profile for the middle portion of the Hatchery reach, including the confluences of Coal and Racehorse creeks.

The Hatchery site appears poised for an avulsion into a side channel, with some risk of the channel moving further onto the left bank floodplain. The mainstem centerline and side channel show a remarkably consistent (and parallel) slope (~0.0058), considerably steeper than most channel reaches downstream (Figure 21).The mainstem and side channel of course begin and end at the same elevations, but the side channel is consistently about 20 cm lower than the mainstem route throughout almost its entire length. The left bank floodplain undulates between about 1-2m higher than the wetted channels, with gaps where the Bear Creek side channel and minor side channels enter from upstream. Established floodplain islands between the mainstem and side channel present an excellent opportunity to fortify islands in anticipation of continuous channel shifting in this reach.

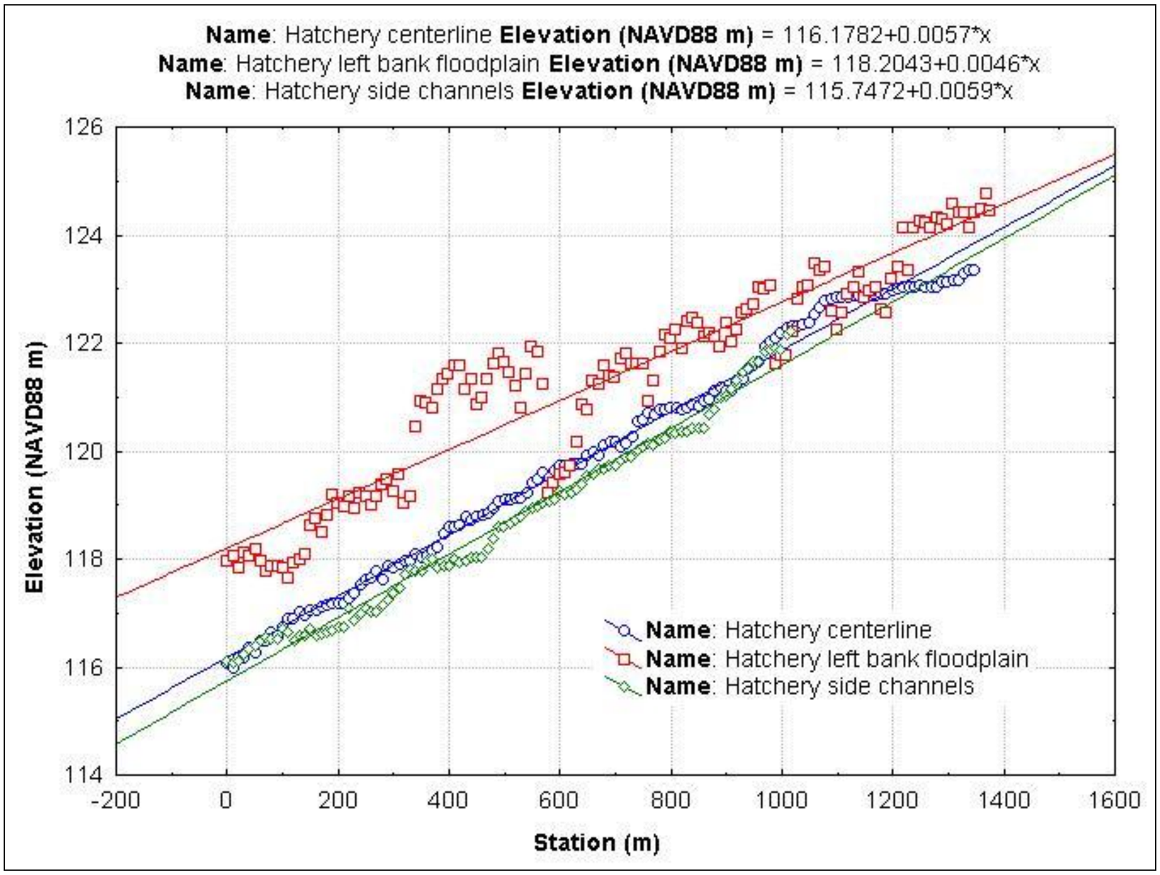

Figure 21... Longitudinal profiles for the upper portion of the Hatchery reach, in the vicinity of the Kendall hatchery and upstream of the Bear Creek side channel.

The Gundy’s Bend sub-reach may also have an ample opportunity to fortify an established channel island in anticipation of avulsion and channel shifting. The mainstem centerline appears to be substantially higher than the right bank side channel for most of its length (Figure 22), with some medium sized forest stands in-between. The left bank floodplain, despite consistent erosion and loss over the past five years, is in most spots about 2m higher than the low flow channel, although avulsion into the wetlands at the downstream end of the bend seems highly possible. Shunting flows attractive to chinook spawning into the right bank side channel (starting upstream in the Farmhouse reach) could substantially expand the spawning habitat available in this reach. In 2005 high densities of spawning chinook were noted at the downstream end of the side channel, which carried less than ~ five cfs at the time, in a pool-like environment where water depths and flows were adequate.

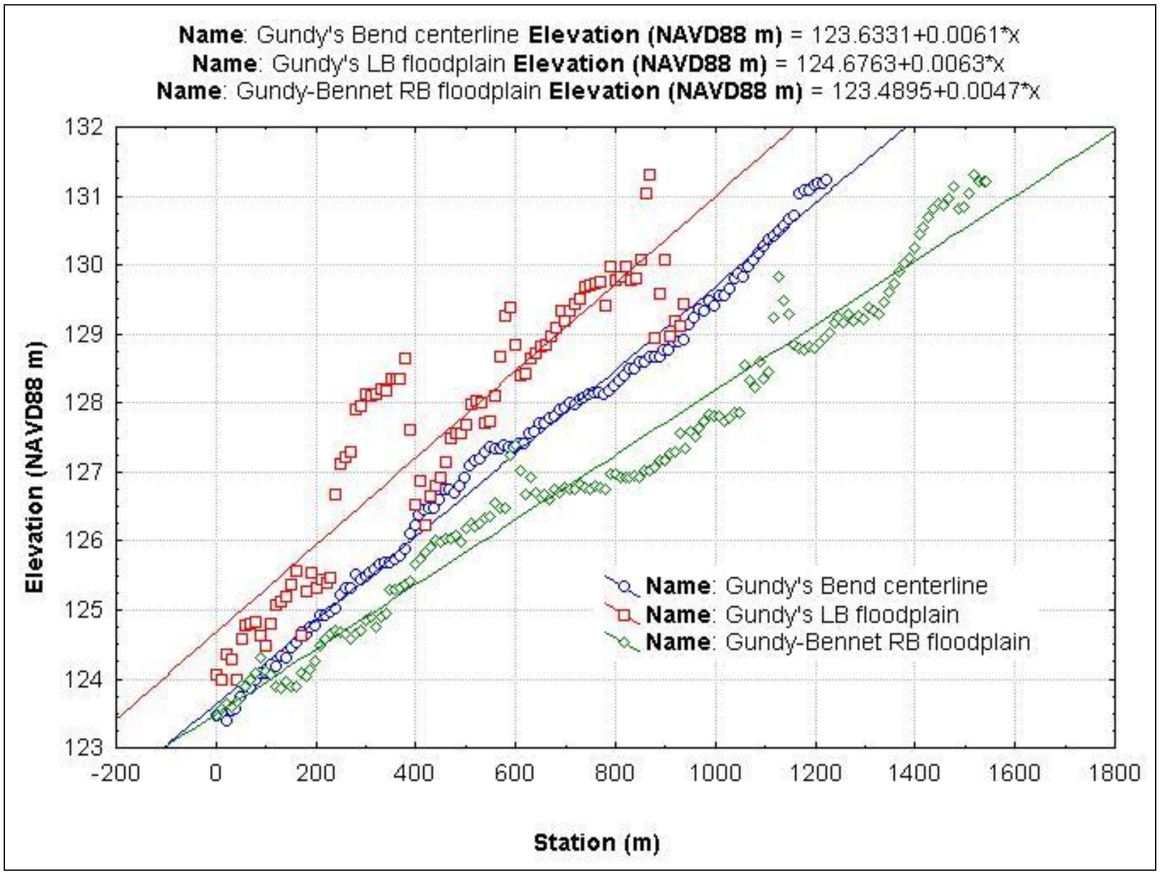

Figure 22. Longitudinal profiles of the most upstream segment of the Hatchery reach, in the vicinity of the Gundy property now owned by the Whatcom Land Trust.

Reach 6: Farmhouse

The Farmhouse reach is among the most active and volatile reaches in the North Fork, with a broad alluvial plain carved by shallow braids that shift multiple times in a given year. The reach extends from RM 46.8 to RM 49.4, from the downstream extent of the Bennet-Woodland equestrian farm to the lower mouth of the small canyon below Maple Creek (Figure 23). The south (left bank) side of the reach is entirely forested, primarily in DNR and Whatcom Land Trust ownership, while the north side is owned by The Glen at Maple Falls (a resort community), a Cowden gravel quarry, and Bennet-Woodland farms. Access to the reach on the north side is through the Bennet-Woodland farm or The Glen. Access from the south side is to hike in from a DNR quarry or to walk up from the Land Trust property at Gundy's bend.

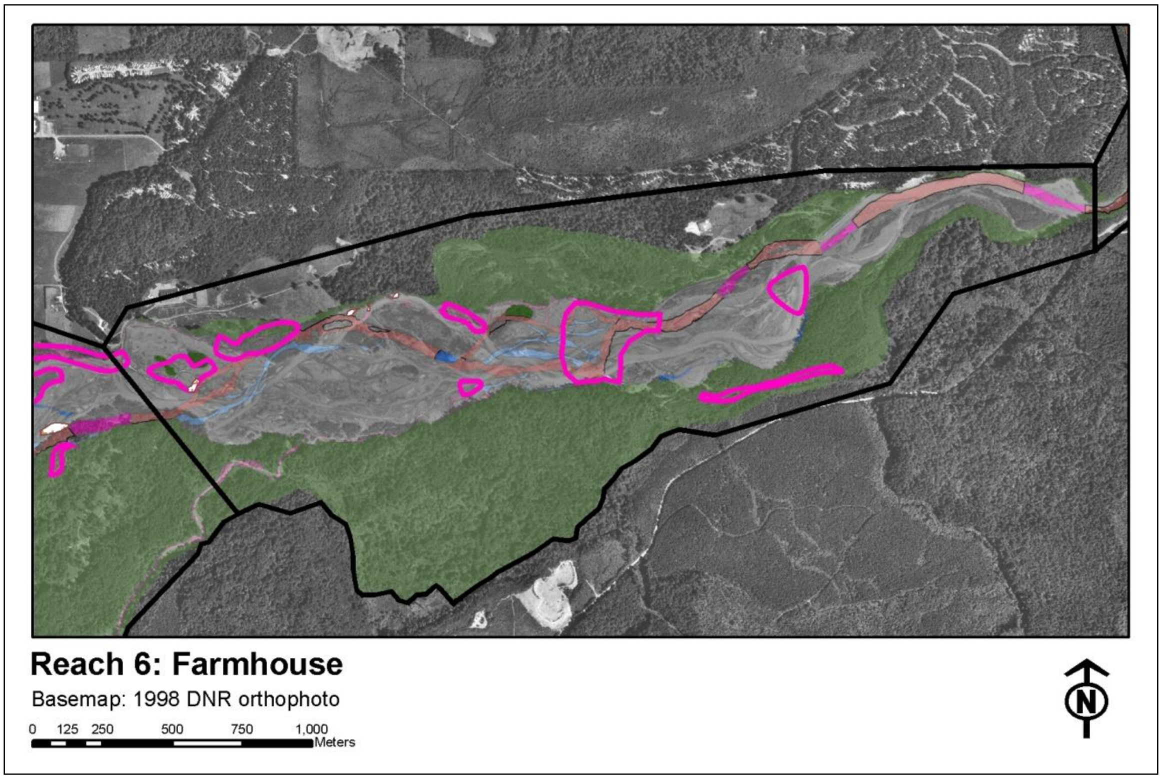

Figure 23. Site map for the Farmhouse reach. The Bennet-Woodland equestrian farm is in the northwest quadrant of the reach (black polygon), and the Glen at Maple Falls is in the northeast quadrant of the photo. Legend is the same as in Figure 11

Mainstem habitat in the Farmhouse reach is predominantly riffle (56%), followed by braid (15%), glide (6%), and pools (<1%). One large convergence pool in 2005 occurred where three mainstem channels were joined, but has since disappeared. Off channel habitat, primarily in the form of back channels, makes up 21% of all the wetted habitat in the reach. The mainstem channel exits Maple Canyon, flows along the base of a high bluff and a large deflection levee at The Glen, and then spills onto the floodplain as multiple channels and braids. These channels shift inter-annually, with little in the way of channel islands or logjams to anchor the channel anywhere on the floodplain. The lower half of the reach includes two significant back-channels, particularly the upstream half of the Bear Creek back channel to the south. A few small channel islands in the downstream half of the reach provide good opportunities for restoration projects, where the islands could be fortified with LWD to encourage long-term growth and expansion. Some of these island and back channel areas have existing LWD accumulations that could be reinforced and embellished to aid stability and function. The Farmhouse reach has one of the lowest concentrations of LWD in the North Fork, due in part to the large active channel area. For each 100m of mainstem channel the 2004 LWD surveys (LNR 2005) counted 0.08 key pieces and 0.71 m^3 of LWD, compared to North Fork averages of 0.30 pieces and 2.73 m^3, respectively. Less than 1% of the floodplain has timber >40 m in height. The majority of the floodplain is bare cobble or vegetation less than 3 m tall. Spring chinook spawning in 2005 was moderate (14 redds), but historically this reach was one of the more active chinook spawning areas in the North Fork (Schuett-Hames et al. 1988c).

The Farmhouse reach is one of the widest on the North Fork (above the Middle Fork), averaging 278 m over the entire reach and varying between 135 m at the upstream end near the Maple Canyon and more than 300 m downstream near the Bennet-Woodland farm. Overall gradient is 0.006, steeper than any of the reaches downstream, and varies locally (by 100 m segments) up to 0.02 but with most segments less than 0.01. Channel migration rates in the lower, more active region of the reach (below The Glen) averages 17 m/yr and ranges between 11.7 and 29.0 m/y. The percentage occupation grid shows a clear band of 100% occupation down the middle of the reach, with several zones of low (<20%) occupation having recently been occupied by the channel, in particular after the 2003 and 2004 floods.

Avulsion potential in the reach is ambiguous. On one hand the active channel is wide, shallow, relatively low-gradient and mostly devoid of logjams, so flood flows do not achieve the depth and elevation that is almost required for finding new paths. On the other hand the floodplain is in most places only 2 m above the wetted channel, and is carved with former meander scars where avulsions, once begun, would likely proceed (Figure 24). The entrance to the Bear Creek side channel, in particular, is lower than most of the Farmhouse reach active channel and could conduct ample flows, shortcutting the Kendall hatchery if mainstem capture were to occur. However, this condition has persisted for several years and through the 67 year flood of record (in 2003), so apparently the hydraulic conveyance in the Bear Creek side channel is insufficient to capture the mainstem.

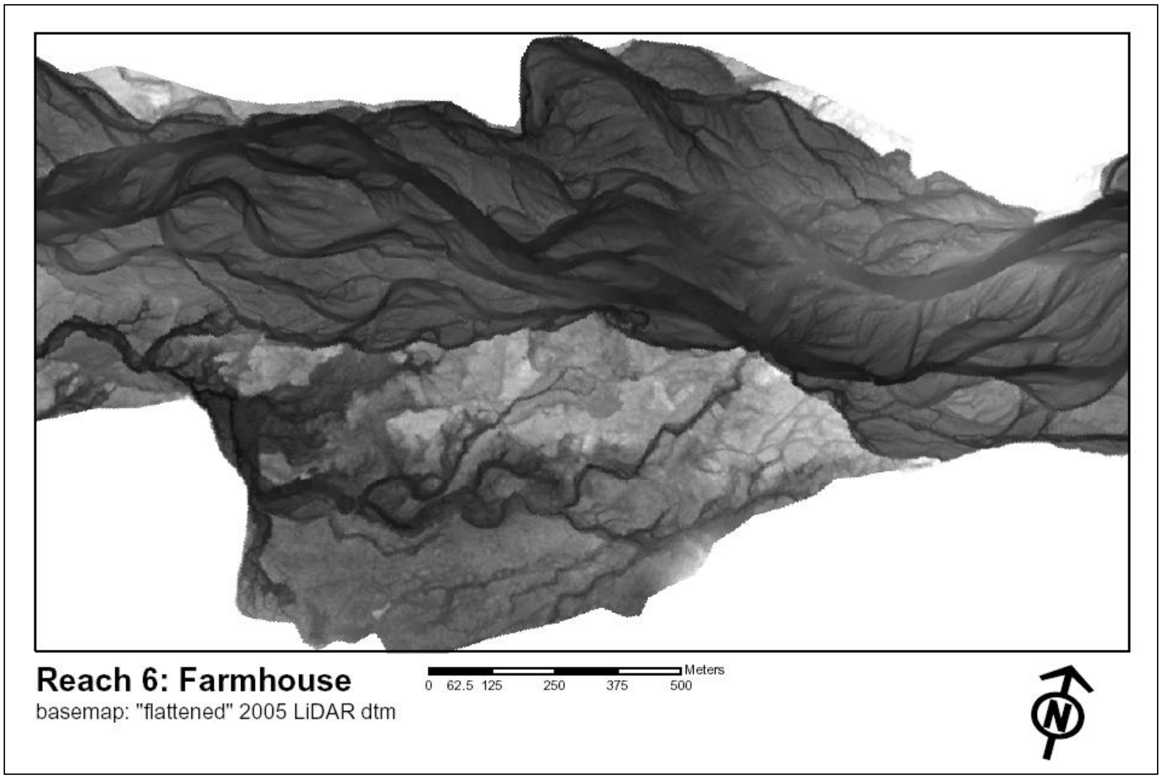

Figure 24. Floodplain “flatchannel” map of the Farmhouse reach, showing off channel drainage paths on both floodplains. The Bear Creek side channel is in the downstream (left) portion of the map on the left bank.

The Farmhouse sub-reach (Figure 25), around the Bennet-Woodland farm, is far steeper than any reach downstream of it, with both the mainstem centerline and the primary braid (which was dry when the LiDAR was flown) at gradients of about 0.007. The primary braid, and to a lesser extent the mainstem centerline, both show a marked stair-step pattern typical of steeper cascade reaches with high sediment loads. The right bank floodplain is low at the upper end where old meanders have been converted to expansive beaver marsh, but is substantially higher than the wetted channel (2-3 m) at the lower end, where the mainstem is eroding rapidly into floodplain horse pastures. The forested left bank floodplain undulates at 1-2 meters higher than the wetted channel, except at the lower end where the Bear Creek side channel branches off from the North Fork mainstem.

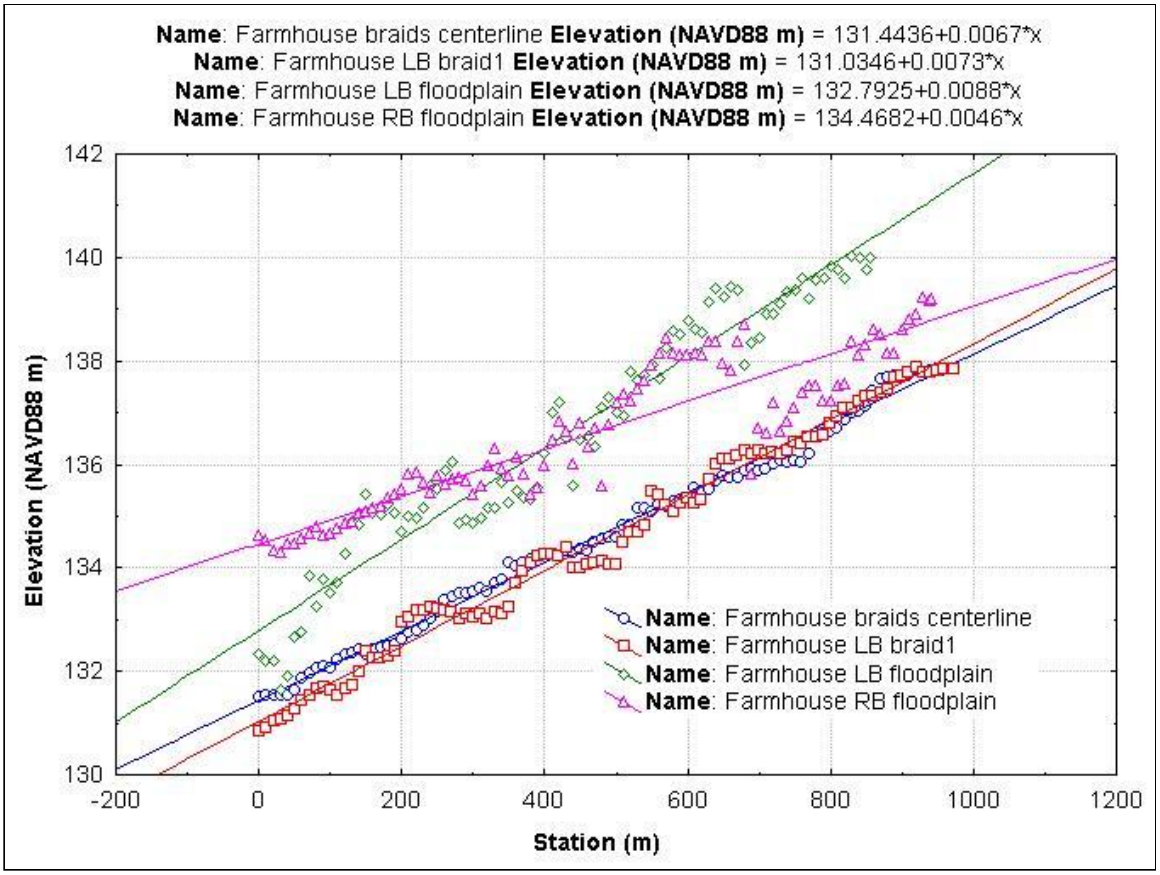

Figure 25. Longitudinal profiles of the lower Farmhouse reach. Both the left and right bank floodplains have low areas where channel avulsions could occur, but the right bank braids could easily be inundated to carry flow sufficient to support spawning chinook.

The Highpoint sub-reach, so-named because the river slopes away in several directions from the nexus where the braids diverge, is possibly the most volatile reach in the North Fork. Each of the shallow braids in this reach shift several times each year, and no single braid can really be considered the mainstem. The channel centerline, like both the floodplains and the braided reach immediately downstream, is relatively steep, averaging about 0.0068. The active channel in this reach is wide, with mid-size forest on each side, and a single-thread mainstem entering the reach. Restoration projects could take advantage of the predictable location of the mainstem channel at The Glen where in-channel structures might be used to interact with and partially train the river.

The air-photo record shows that the channel configuration in the Farmhouse reach has not changed radically over the 1933-2005 period, except that the channel has widened and the floodplain forests have gotten smaller. Average channel width in 1938 was slightly more than 200 m, but expanded to more than 300 m in the 1986 and 1994 photos, and has fallen slightly since then to about 275 m. Each of the photo years shows a fully intact left bank floodplain near the Bear Creek side channel. Extensive erosion at The Glen in the 1976 and 1986 photos was curtailed by a levee evident in the 1998 photos. Large and extensive back channels in the 1976 photos had been partially abandoned by 1986, but vestiges of those channels are still intact in the 2005 LiDAR. The upper end of the reach where the channel exits the Maple Canyon has not changed substantially since 1933.

Two major potential restoration projects present themselves in the Farmhouse reach, one on the upstream end of the reach near The Glen and the other at the downstream extent of the reach at the Bennet-Woodland farm.

At the upstream end of the reach it may be possible to partially stabilize the high point where several channels and braids diverge, and establish one or more semi-stable side channels from what are now braids. Two such stable back channels currently diverge from the High Point reach near the downstream end, both of which have mature forested islands near the divergence points that could be accentuated with LWD. The objective would be to encourage the channel to gravitate to a central corridor for a few years while channel islands form and develop elsewhere. Heavily engineered LWD structures would be used to scour the channel in place and discourage channel migration, while other, smaller structures would be constructed to protect incipient channel islands from flood destruction. Upstream of the reach, near the end of the levee protecting The Glen at Maple Falls, LWD structures could possibly divert mainstem flow into low-lying side channels and braids and could route flow around the High Point and into established back channel habitats. The levee at The Glen, if left intact, could assure that the river location and direction would be known at the upstream end of the project, and the project would benefit in the early establishment years from a predictable river location.

A downstream project near the Bennet-Woodland farm would take advantage of existing channel islands with immature vegetation (alder flats) and existing back channels and braids, accentuating the site with logjams. The objective would be to assure the flow split between the mainstem and the back channel(s), and encourage channel island growth and development by partially shielding the existing islands from destructive flood forces. The project would not be limited to the Farmhouse reach, involving channels and islands in the next reach (Hatchery) downstream.

Reach 7: Maple Canyon

The Maple Canyon reach is a short (510 m), narrow (39 m), confined reach just downstream of the Maple Creek confluence. The canyon depth is ~ 30 m and width at the top is about 100 m. The downstream end of the reach is at about RM 49.4 and the upstream is at RM 49.8. The south side is entirely commercial forest land and the north side is recreational residential at The Glen. Access is gained from a downstream trail at The Glen or from Maple Creek. The canyon is passable on foot only at extremely low flow. Channel gradient is 0.0048 through the reach. Wetted habitat is nearly all (94%) riffle with one mid channel pool forced by an instream boulder near the left bank. Avulsion potential is nil and percent channel occupation is virtually 100% for the entire reach. Historical channel migration rates are slightly more than 1.0 m, well within the measurement error. No restoration opportunities are apparent or necessary for the reach.

Reach 8: Maple Creek

The Maple Creek reach encompasses a short alluvial floodplain between two confined reaches, the Maple Canyon reach downstream and the Mahaffey Canyon upstream (Figure 26). It is short (1800 m), beginning at RM 49.8 and ending at RM 50.6. The left (south) bank is a steep bluff leading up to commercial forests on the side of Slide Mountain, while the right bank is a floodplain pasture planted for future riparian shade. The right bank floodplain, through which Maple Creek flows, is owned by WSDOT and held as a natural reserve. Access to the right bank is through private property adjacent to the WSDOT parcel, or from Highway 542 (crossing private property) at the upstream end of the reach. Access to the left bank, also at the upstream end of the reach, is through private property via DNR holdings. The upstream end of the reach was a scour study site in 2001 and 2002.

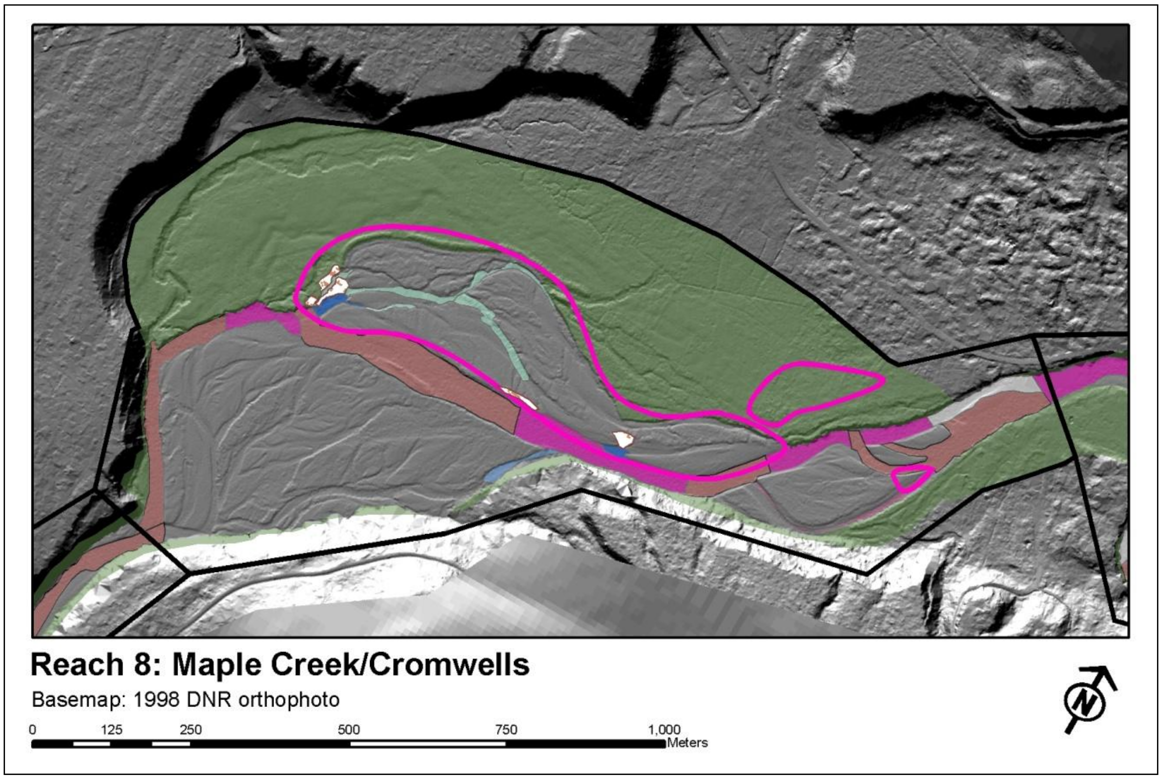

Figure 26. Site map for the Maple Creek reach. Legend is the same as Figure 11.

Mainstem habitat in the reach is primarily riffle (54%) and glide (27%), with one small pool (<1%) and less than 10% of other habitat types. The mainstem water surface is relatively steep (0.0064) and does not appear to offer much suitable spawning or rearing habitat. Off channel habitat makes up 12% of all wetted habitat, primarily in sloughs and back channels, on the right and left banks, respectively. The right bank sloughs near Maple Creek are apparently fed by hyporheic flows from the mainstem and by discharge from beaver ponds on the Maple Creek floodplain. The downstream end of these habitats ends in off-channel pools with ample LWD cover. A restoration project to accentuate these habitats with mainstem flow, making them attractive to chinook for spawning, deserves a more thorough investigation. The left bank side channel splits off at the upstream end of the reach and continues around an incipient channel island, re-entering the mainstem 300 m downstream. Increasing flow into this side-channel could make this off-channel habitat attractive for chinook as well, but access to this part of the left bank is very difficult. Known 2005 spring chinook spawning was in the lower end of Maple Creek itself, and spawner returns from previous years indicate that as a consistent pattern. The Maple Creek reach is one of the few with an ample supply of recruitable large wood. Although only 0.52% of the floodplain has timber > 40 m, a stand of large cottonwoods currently grows adjacent to the mainstem channel, just upstream of the right bank off-channel areas. Several key pieces of LWD occupy the floodplain, resulting in one of the highest LWD loadings in the North Fork (6 m^3/100 m).

Channel pattern in the Maple Creek reach is dominated by a single mainstem with several side channels. Overall channel gradient is 0.006 with all segments in the 0.001 to 0.01 range. Width averages 180 m, with the widest part at the low end of the reach (in the Maple Creek vicinity) and the narrower portion upstream where it is restricted by boulder deposits off Slide Mountain. Width has remained relatively stable over time, ranging from lows of about 105 m in the 1950s and 60s to 182 m in 2005. Channel migration in the reach averaged less than 10 meters since 1933. The channel occupation grid indicates that the right bank cobble bars encompassing the off-channel habitats have been part of the active channel only about 25-35% of the time since 1933. Currently the river mainstem is eroding the right bank at the lower end of the reach.

It is likely that the right bank cobble bar at the lower end of the Maple Creek reach could provide ample off-channel spawning and rearing habitat if more North Fork flow were routed into the existing side channel. The channel is currently fed during summer low flow by a combination of hyporheic trickle from the mainstem and seepage from the beaver marshes on the right bank floodplain. The mainstem and existing side channel gradients are almost exactly parallel (0.0048) and elevations overlap completely, indicating numerous opportunities for introducing mainstem flow to the side channel (Figure 27). Some LWD already exists in the side channel, particularly in a logjam near the confluence, and the right bank riparian zone has both mature trees and conifer plantings established by LNR work crews in about 1998.

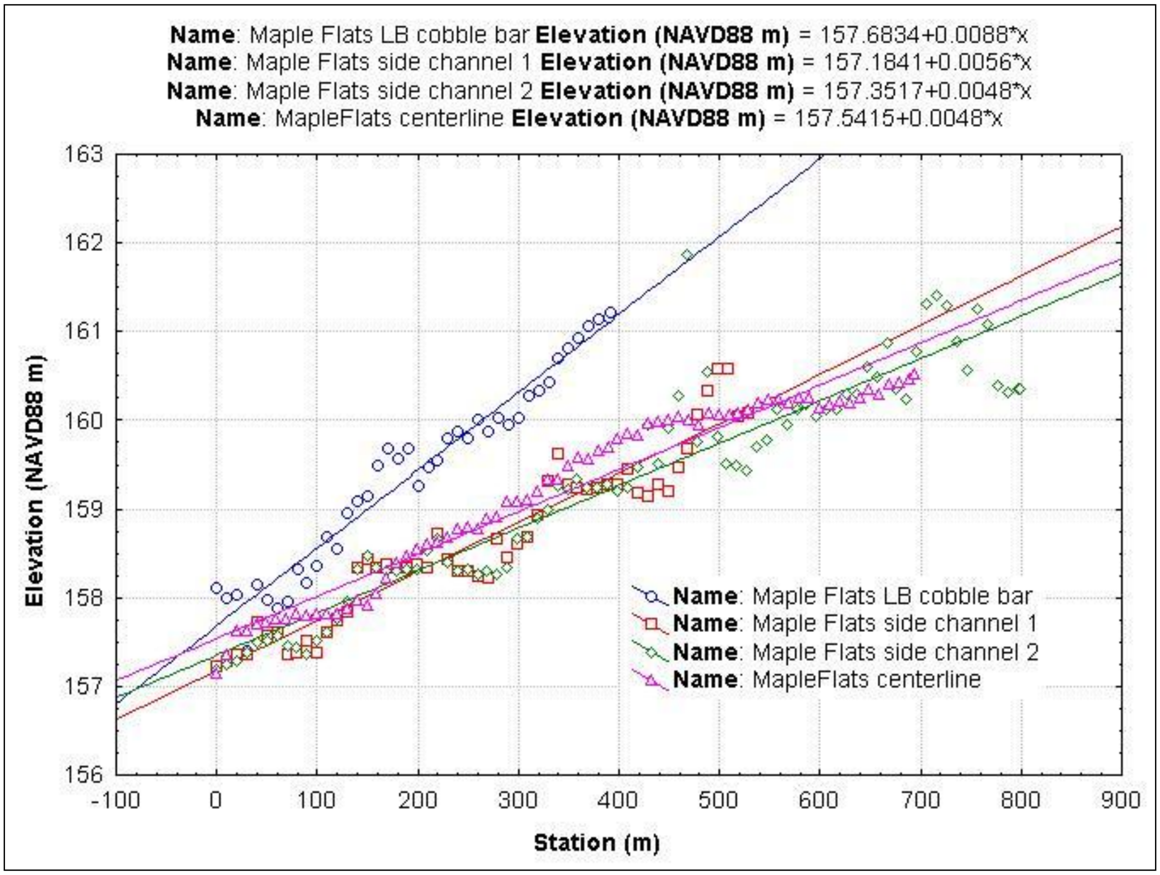

Figure 27. Longitudinal profile for the Maple Creek reach.

At the upstream end of the Maple Creek reach, in the Cromwell sub-reach, the mainstem water-surface centerline shows a distinct step-pool pattern, commonly associated with cascade reaches, and a stream gradient of 0.007 (Figure 28). Thus the reach has sufficient gradient to react quickly to channel modification, and the confined upstream end of the reach suggests predictability in the angle and direction of flows entering the reach. The left bank side channel was a field site during the 2001-2002 redd scour study, but has diminished in width since then. It drops rapidly after diverging from the mainstem, indicating that channel separation could be stabilized by a strategically placed LWD structure. The upstream divergence of the side channel from the mainstem is such that as much mainstem flow as desired (that is, adequate for chinook spawning) could be routed through the side channel, depending again on the placement of the LWD. The side channel is separated from the mainstem by a low cobble island with persistent young alders approximately 10 years old.

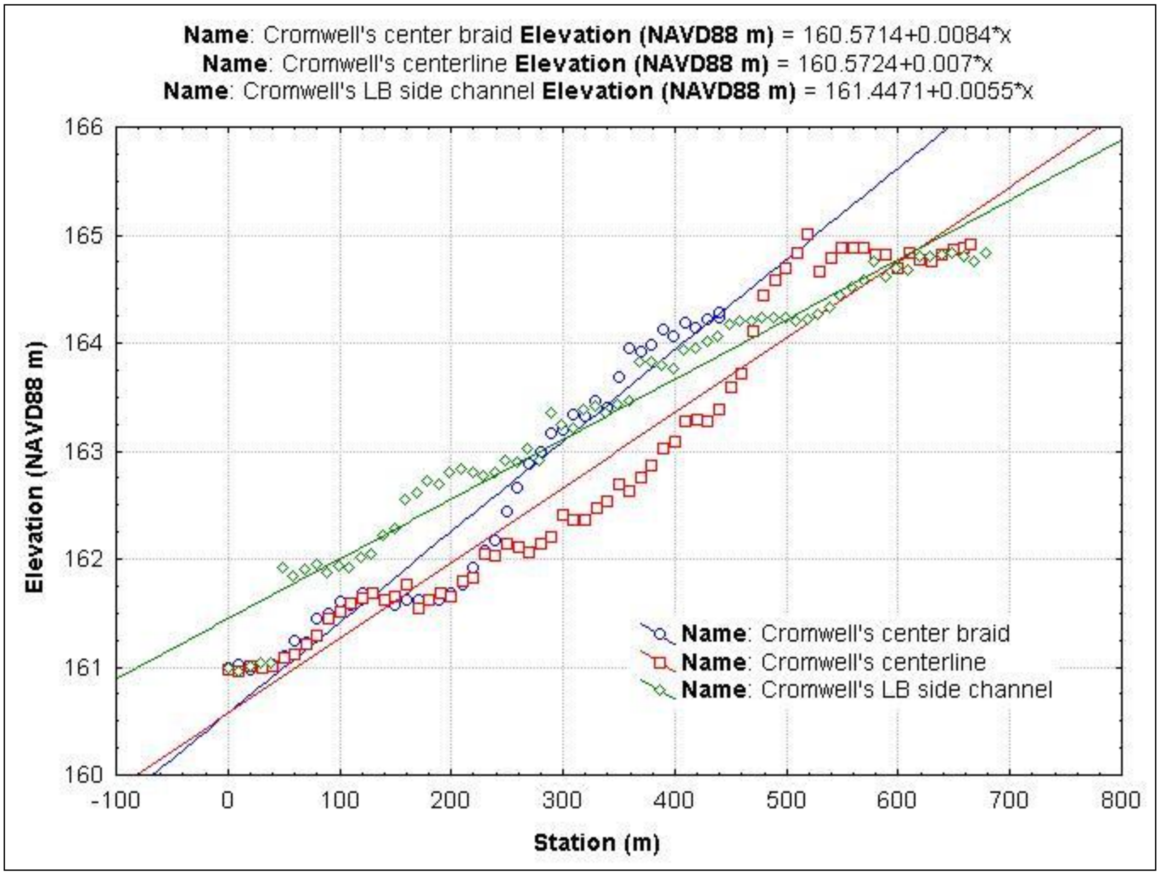

Figure 28. Longitudinal profile for the upper segment of the Maple Creek reach.

Reach 9: Mahaffey Canyon

Mahaffey Canyon is a confined reach where landslide deposits from Black Mountain to the north and Slide Mountain to the south converge at the valley floor, and the Nooksack River has carved a path between and among the channel-restricting boulders, which can be detected on the North Fork LiDAR (Figure 29). The Mahaffey reach has the highest sinuosity in the North Fork. Bluffs on the left (south) bank rise 40 m from the river and continue up as the forested hillside of Slide Mountain. Boulder deposits on the right bank are less than 10 m above the river at normal flow. The reach extends from RM 50.6 to 51.4. The Mount Baker Highway follows the curve of the river, providing access and views, along much of the right bank. Limited access to the downstream end on the left bank is via private property.

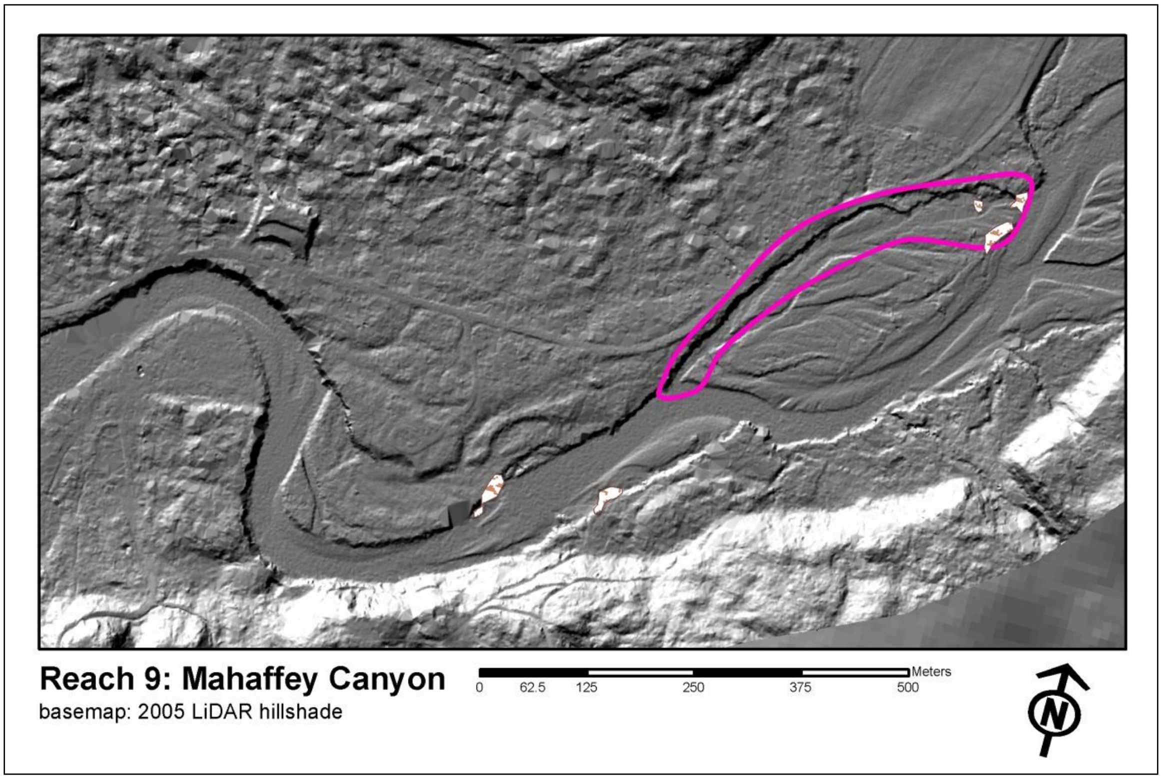

Figure 29. Reach map for the Mahaffey Canyon reach. Legend is same as Figure 11

Wetted habitat in the reach is primarily glide (42%) and riffle (35%), with a strong cascade component (14%) due to the confined channel and large landslide boulders in the channel and on the banks. The reach is devoid of back channels and sloughs, although a prominent braid (comprising 7% of the wetted habitat in the reach) has been stable for several years and could become a back-channel in the foreseeable future. Spring chinook spawning (3 redds) were noted in the braid in 2005, but not elsewhere in the reach. The Mahaffey reach ranked among the lowest in the North Fork (along with Maple Canyon) for LWD abundance in both the LNR and NNR surveys. The reach does however have stands of large (>40 m) timber, and ranked among the highest in percentage of floodplain with mature timber (2%), partly due to the narrow floodplain area.

Channel width in the reach is low (85 m in 2005) and has varied little from its average of 72 m over the 1938-2005 timespan (SD 9.67 m). Gradient is moderate (0.006) compared to adjacent reaches yet has several cascades due to the large (and often angular) boulders from Slide Mountain. Locally the gradient varies from 0.001 to 0.02, but does not exceed 0.02 in any 100 m segment. Sinuosity for the reach is the highest in the North Fork at 1.49 m/m. Avulsion potential in the lower half of the reach is low due to the channel constriction. The mainstem temporarily occupied more than half of what is now the braid, as evidenced by the 1998 aerial photograph, but that path was shortened and steepened (Figure 30) by the mainstem shifting back to the south. Channel occupation in the reach is distinct, with 100% occupation in the existing channel and zero occupation at higher elevations, and only thin margins of intermediate occupation in between. The exception is in the vicinity of the channel braid, just discussed, which shows a channel occupation zone of 38-50 percent. Channel migration among the six transects in the reach has averaged 3.2 m since 1933.

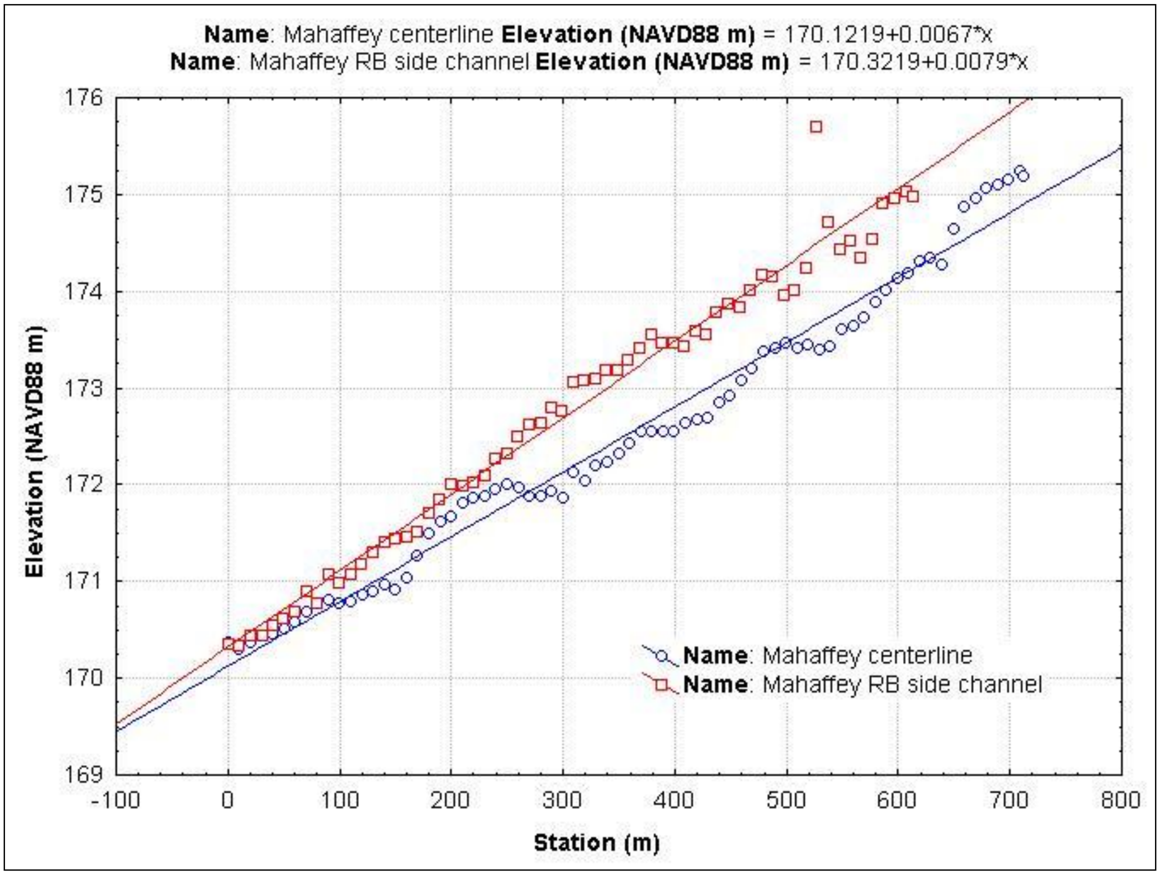

Figure 30. Longitudinal profiles for the Mahaffey reach.

The air photo history show the reach is relatively stable, with the 1933 channel in mostly the same configuration, including certain channel bars. A vegetated channel island in 1933 splits the mainstem from what is now the braid that supports chinook spawning. That vegetated island persisted until 1938, but disappeared by 1955. A footbridge included in the 1986 USGS topographic map crossed the channel at its narrowest point, but was washed away by the October 2003 flood.

The Mahaffey reach provides an opportunity for a very public demonstration of the effectiveness of in-channel restoration using LWD structures. The side channel is considerably steeper than the mainstem (Figure 30), but a LWD bifurcating structure could likely be configured to shunt flow adequate to attract chinook spawning under most flow conditions. Spring chinook were documented using the side channel in 2005. The reach is visible from the Mt Baker Highway, and is frequented by fishermen, families, and others for picnicking, wading, and other recreation. Public access to chinook spawning areas could provide a valuable education component to salmon restoration, but might inhibit spawning at that particular site. The mainstem gradient is 0.0067, with an undulating riffle-glide structure typical of steeper reaches on the North Fork. The downstream end of the reach was formerly a popular take-out spot for river rafters until the access road was gated by the landowner.

Reach 10: Below Boulder

The braided reach below the Boulder Creek confluence encompasses a relatively wide and low right bank floodplain containing several meander scars (Figure 31), despite the fact that the mainstem has been forced over much of its recent history to the left (south) valley wall by frequent debris flows in Boulder Creek. The reach extends from RM 51.4 to about 52.3, from Devine's roadside stand at the downstream end to the Boulder Creek confluence at the top. The reach is largely inaccessible from the left bank but accessible from the right bank at the upstream and downstream ends. Two private parties own most of the right bank, but the mainstem, floodplain, and left bank are controlled by the DNR.

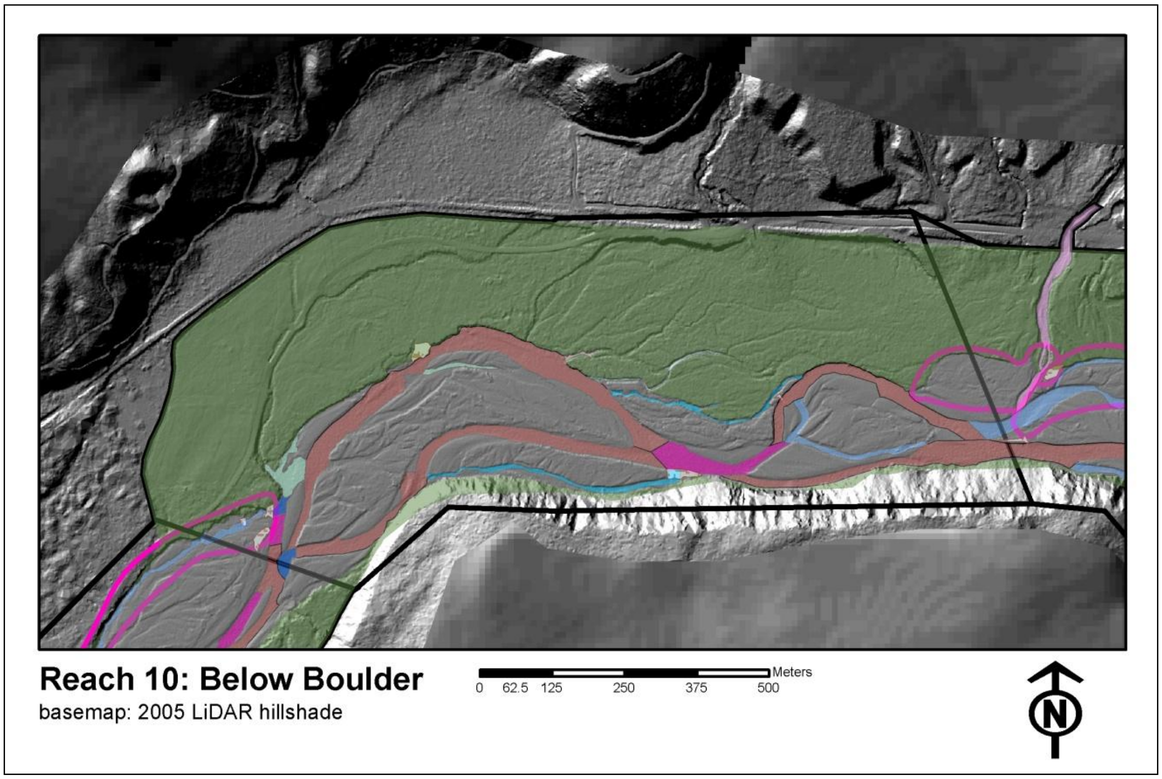

Figure 31. Site map for the Boulder Reach. Legend is same as in Figure 11.

Habitat in the reach is dominated by riffle (71%), with smaller areas of braid (16%) and glide (6%). Although the right bank floodplain has an extensive mosaic of flood and meander scars, most of those off-channel habitats were dry during field surveys, and totaled only 5% of the wetted habitat in the reach. Preliminary hydraulic modeling and digital terrain mapping of the floodplain indicate that these dry, off-channel habitats are only slightly higher than, and could be connected to, the mainstem. A small tributary from the north, Bruce Creek, crosses SR 542 at a culvert known for fish passage failure, but the channel disappears into the floodplain between the highway and the river, as does the water at low-to-moderate flows. The lower end of Boulder Creek consistently attracts spawning spring chinook each year, as did a right bank side channel at the confluence until it was obliterated by channel migration in 2002. The side channel carried flow from Boulder Creek to the mainstem, and was exceptionally popular for chinook and pink salmon spawning, although frequent debris flows from Boulder Creek and flood shifting of the mainstem limited the productivity of the channel. Wood abundance during LNR surveys in 2004 was relatively high, with two jams and nine key pieces placing the reach third among fourteen in the North Fork. However in 2005 large accumulations of wood were not noted in several of the 2004 locations. Mature timber (> 40 m) covers only 0.67% of the floodplain available for channel migration, so much of the wood in the Boulder reach likely comes from the more heavily forested Lone Tree reach immediately upstream.

The Below Boulder reach is, at 166 m in width, average among North Fork reaches, and has been relatively stable (range 140-190 m, SD 16.0) over the past 70 years. Gradient for the reach as a whole is 0.66 m/m, and is relatively homogeneous since all but one 100 m segment is in the 0.002-0.01 category. Avulsion potential is high since virtually all of the right bank floodplain is susceptible to flooding and riddled with former flood and meander scars. The lower half of the floodplain is inundated frequently, and water overtops SR 542 in two locations near Devine's (now defunct) raspberry stand. The upper half of the floodplain is in the historic channel migration zone, having been occupied by the river as recently as 1955, but the downstream half of the floodplain, despite being flood prone and showing clear marks of channel occupation, does not appear in the HMZ. Channel occupation grids of the floodplain area indicate zero to 33 percent occupancy since 1933 (and the same since 1859), with the 100% occupied mainstem area pushed hard against the bluff on the left (south) bank. Channel migration rates for the six transects in the reach average 6.5 m annually since 1933.

The air photo record reveals that the river was all the way against the right (north) bank not long before the 1938 photo was taken (the 1933 air photo series ends at the bottom of the reach and does not extend any further upstream), and that a channel island occupied what is now the right vegetated floodplain. By 1955 the mainstem was entirely on the right side of the floodplain (it appears to have recently wiped out the highway just west of Boulder Creek) and the left bank, what is now the mainstem, was a young floodplain forest with numerous meander scars. By 1976 the situation had reversed, and the river runs along the left bank with young floodplain forest on the right bank. A remnant of older forest forms an island in the middle. Subsequent to the 1976 photo the right bank forest matures into what is observable there today.

At the upstream extent of the reach the Boulder Creek confluence has a history of both frequent channel shifting and heavy spawning use by chinook, pink, and coho salmon. The side channel and lowest reach of Boulder Creek typically gets significant spawning activity in the fall, often to be wiped out by channel shifting during winter floods. Debris flows from upper Boulder Creek present a recurring threat to both the Mt Baker Highway bridge and the salmon redds above and below it. A project on the lower 200 m of Boulder Creek could add a LWD berm on the tributary that would deflect some flows laterally across the alluvial fan and re-create the spawning channel that was so heavily used by fish until 2002. The berm could be constructed in a way that would also direct rock and wood debris from the periodic debris flows downstream and west, parallel to the North Fork mainstem, such that the spawning channel would likely be self-maintaining. Sufficient gradient exists in both Boulder Creek (0.0162) and the proposed side channels (~0.015) to supply and maintain adequate depth, velocity, and substrate suitable for chinook spawning. The spawning channel would be higher in elevation than where the tributary is now, and at a lower gradient due to meandering across the alluvial fan. The tributary currently exhibits a stair-step riffle-glide structure in an odd linear configuration; that is, the riffles and glides are made up of sloped or flat straight units, without the curved and undulating pool-riffle structure typical of cascade reaches (Figure 32).

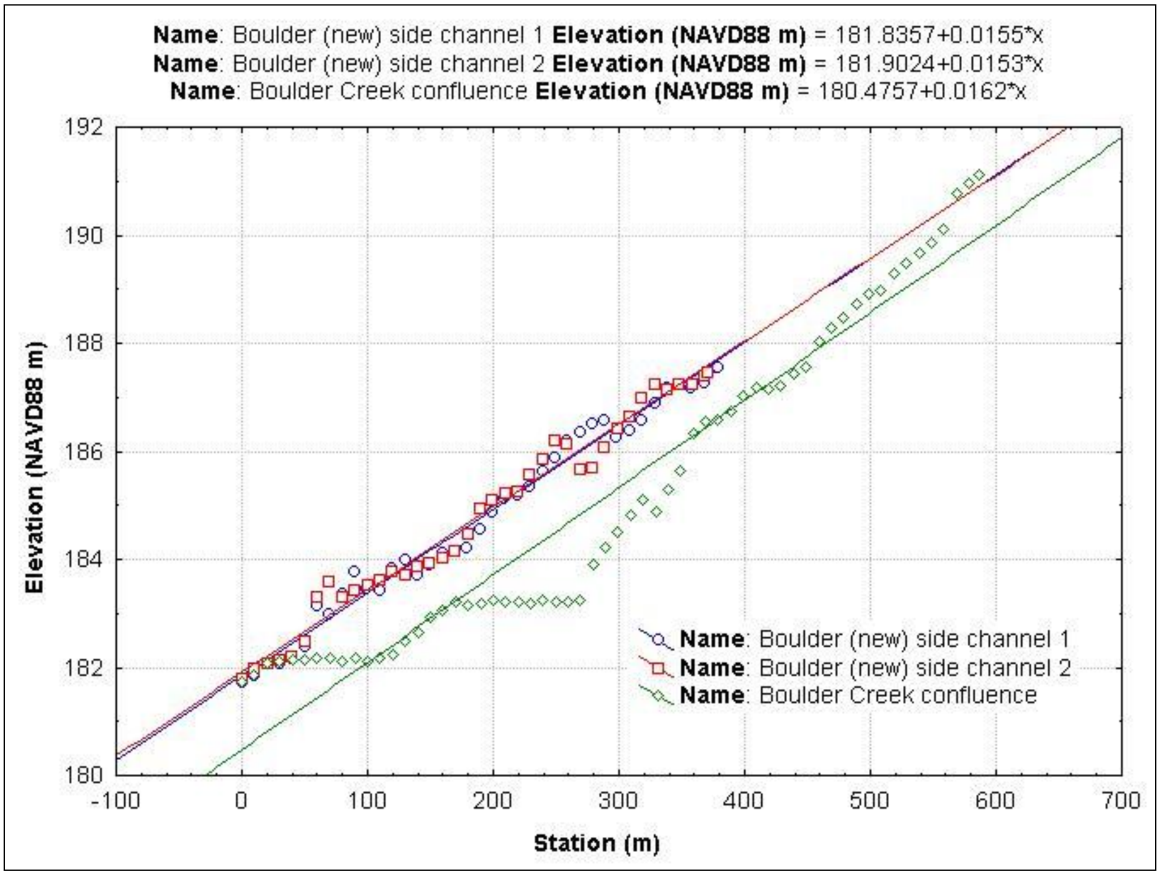

Figure 32. Longitudinal profile of Boulder Creek, with the proposed Boulder Creek side channel profiles superimposed.

Reach 11: Lone Tree

The Lone Tree reach is superlative among reaches in the North Fork in several respects. It has the highest wood loading of all the reaches, the highest proportion of braids, the highest proportion of mature floodplain trees, and is wider than any reach upstream of Maple Canyon. The reach starts at RM 52.3, at the Boulder Creek confluence, and extends up to a pinch point (valley narrowing) at RM 53.3 (Figure 33). It is not only wide, but highly braided, and volatile, and is currently eroding into the left bank floodplain and its mature coniferous forest. The reach is named for a single large cottonwood standing in the middle of the active channel, the sole remnant of what was a channel island as late as 1998. Channel spanning logjams are common in the vicinity, though they shift from year to year. The right bank is accessible from Boulder Creek and from the Puget Sound Energy power line corridor. The left bank is for all practical purposes inaccessible, except by boat, or by wading the river during low flows.

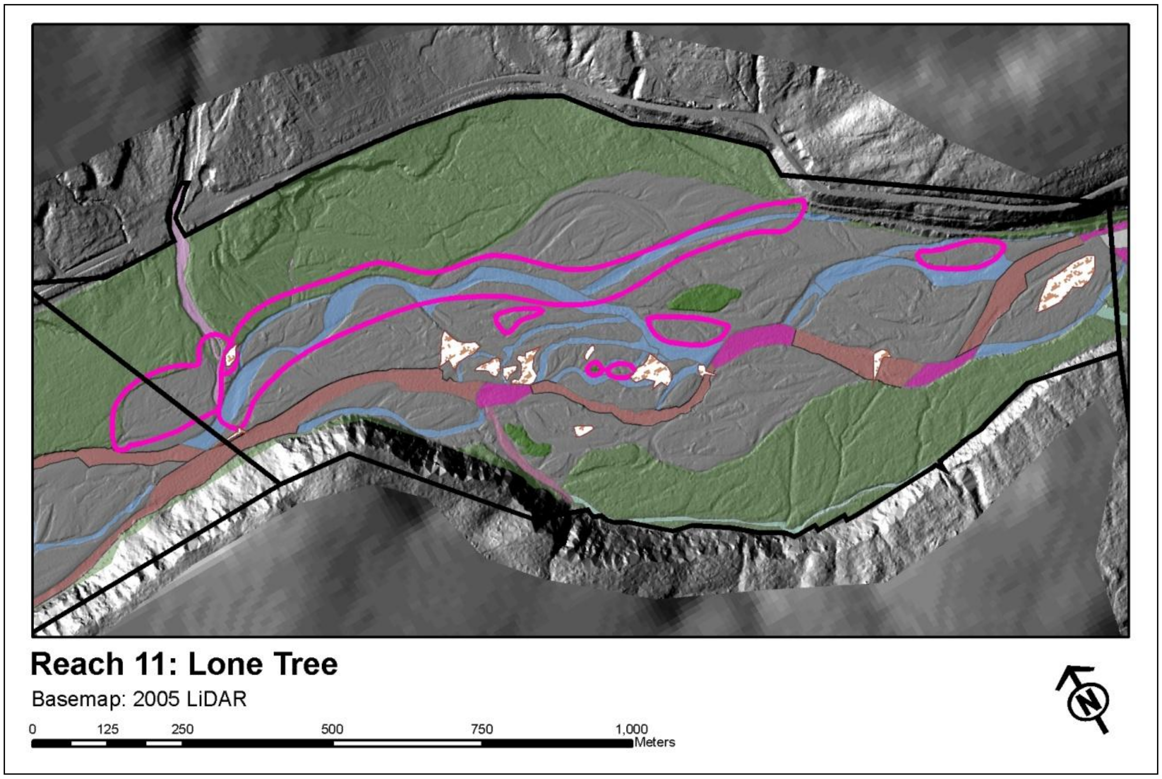

Figure 33. Site map for the Lone Tree reach. Legend is same as in Figure 11.

Habitat in the reach is predominantly braid (34%), followed by riffle (31%), and glide (23%). Off-channel habitat makes up 11% of the wetted area, primarily in sloughs (8%). Several large braids along the right margin of the active channel run along former mainstem channels. These braids are long, wide, shallow, and unshaded, yet could provide productive off-channel habitat with adequate riparian cover. Substrate in the braids is mostly large cobbles and small boulders. Along the left extent of the floodplain sloughs and back-channels run along meander scars created several decades ago. These back channels, which follow the bluffs on the left bank, have ample shade, LWD from mature riparian alders, and substrates with high proportions of organic material. In the middle of the reach the mainstem splits and braids around what was in 1986 a complex of channel islands, which has been reduced to a complex of logjams with interstitial willows. Several LWD pieces in these jams measure between 1.5-2.0 m in diameter and have large rootwads attached. Downstream of the largest LWD pieces are several logjam “rafts” of small and medium pieces spread over a large area. Channel shifting in the reach re-arranges the LWD on a nearly annual basis, yet wood has persisted in the general vicinity over several large floods. The right bank floodplain contains small areas of mature cottonwood (>40 m) next to SR 542 that are not currently accessible to the channel, but the left bank floodplain has extensive stands of large conifers that are frequently recruited during floods. The reach is not known for high chinook spawning activity, but lies between two sites (Boulder Creek and McDonald Creek) where spring chinook spawning was high in 2005.

Geomorphically the Lone Tree reach is one of the more active and volatile in the North Fork. Despite a historical migration zone that does not cover the entire floodplain, distinct meander scars in the 2005 LiDAR and low floodplain elevations indicate that the river has occupied the entire floodplain in the detectable past, although mature conifers on the left bank indicate the channel has not occupied most of that area for more than 100 years. Annual channel migration rate since 1933 has averaged 7.2 m and ranged between 4.3 and 10.8 m. Channel elevation change between 1994 and 2005 was –0.44 m, placing the reach third out of fourteen in the rate of channel incision. Overall mainstem gradient is 0.0078, steeper than any reach downstream. Local gradient (measured in 100 m segments) is generally in the 0.002-0.02 range, with one segment shallower but no segments steeper than 2%. Active channel width in 2005 was at a historical maximum of ~275 m, having risen from ~170 m in 1966. Floodplain island area in the reach peaked in 1986. Avulsion potential is high, given the past history, low floodplains, high density of meander scars, and overlapping profiles among likely avulsion paths (Figure 34). Channel occupation has concentrated in a wide band in the middle of the active channel, but came within 75 m of SR 542 near where it crosses Boulder Creek **[what year?]**, and remained there for some time (29% occupancy). Channel occupancy adjacent to the right bank bluff and the PSE corridor is 100 percent. The aerial photo history shows that the Boulder Creek alluvial fan has generated a lot of activity back at least as far as 1938, pinching the mainstem at the confluence and forcing gravel accumulation upstream. The lower 500 m of the Lone Tree reach on the right bank upstream of Boulder Creek show frequent avulsions, channel scarring, vegetational colonization, and re-channelization over time.

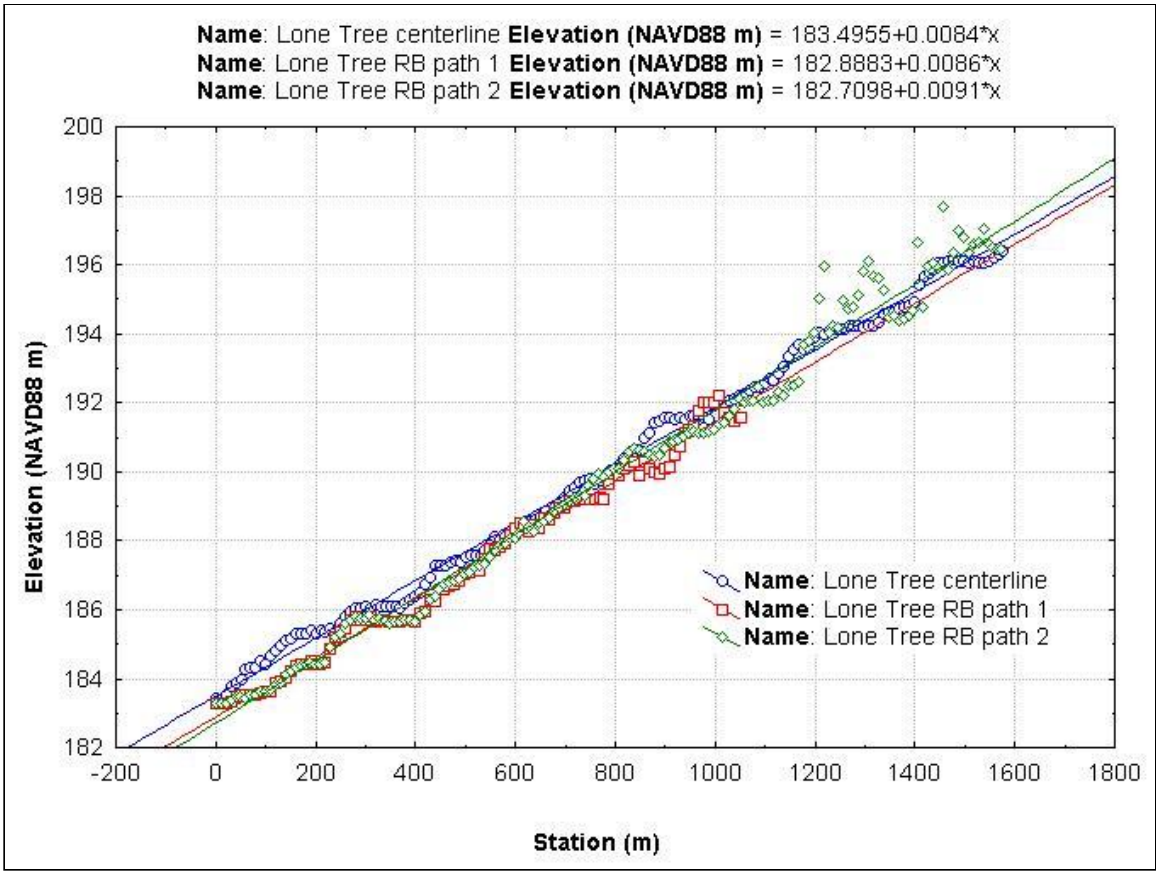

Figure 34. Longitudinal profile of the Lone Tree reach shows a strong overlap in channel and side channel elevations, indicating a high propensity for channel switching and avulsion.

From a restoration perspective, the Lone Tree reach has some of the largest LWD currently in the North Fork, tortuous braiding that shifts frequently, an exceptionally wide active channel, a forested left-bank floodplain that provides ample LWD to the river, and remnant channel islands of medium-sized timber. Restoration in these areas may be ill-advised, as the channel currently exhibits many of the functional characteristics that restoration frequently seeks to achieve. On the other hand, the numerous open and shallow braids could be better defined, and eventually better shaded, with judiciously placed LWD structures. Single logs placed low on the banks and perpendicular to the channel could, with the proper spacing, trap fine sediments and create a seed bed where cottonwood, willow, and alder could naturally become established. The boulder and cobble substrate there now is inadequate for forest establishment, and the open braids are warm and inhospitable waters during much of the year. Gradients among the braids are high (0.0086-0.0091), indicating that flow splitting structures may work to shunt flow into the former meanders. Elevations among the mainstem and side channels are very similar in the highly braided middle of the reach, but differ at the upstream and downstream ends where the LWD is concentrated and channel separation is more distinct. Differences in channel elevations at the upstream end of the reach tend to favor separating and stabilizing channels using LWD structures. That same elevation difference, where braids diverge from the mainstem, would also favor a natural shifting of more flow into the braid during a flood event.

Reach 12: Wildcat

The Wildcat Reach is named for the tributary that enters near the upstream end on the left bank, although McDonald Creek enters near the downstream end and deserves equal emphasis. The reach extends from a landslide-deposit pinch point at RM 53.3 upstream to the Warnick bridge at RM 54.8 (Figure 35). The left side of the channel is accessible from SR 542 at the upstream end near the bridge, but the highway runs along the Warnick Bluffs, a tall (~40 m) unconsolidated cliff, for most of the reach, making the river viewable but not necessarily accessible. The left bank can be accessed from private property upstream. The reach is braided and highly active, with mainstem channels shifting inter-annually. Ownership and control of the active channel is Washington DNR, as are parts of the left bank uplands. The Whatcom Land Trust owns a parcel on the right bank near the Warnick bridge, and has recently purchased nearly the entire left bank floodplain that was owned by the same family for several generations.

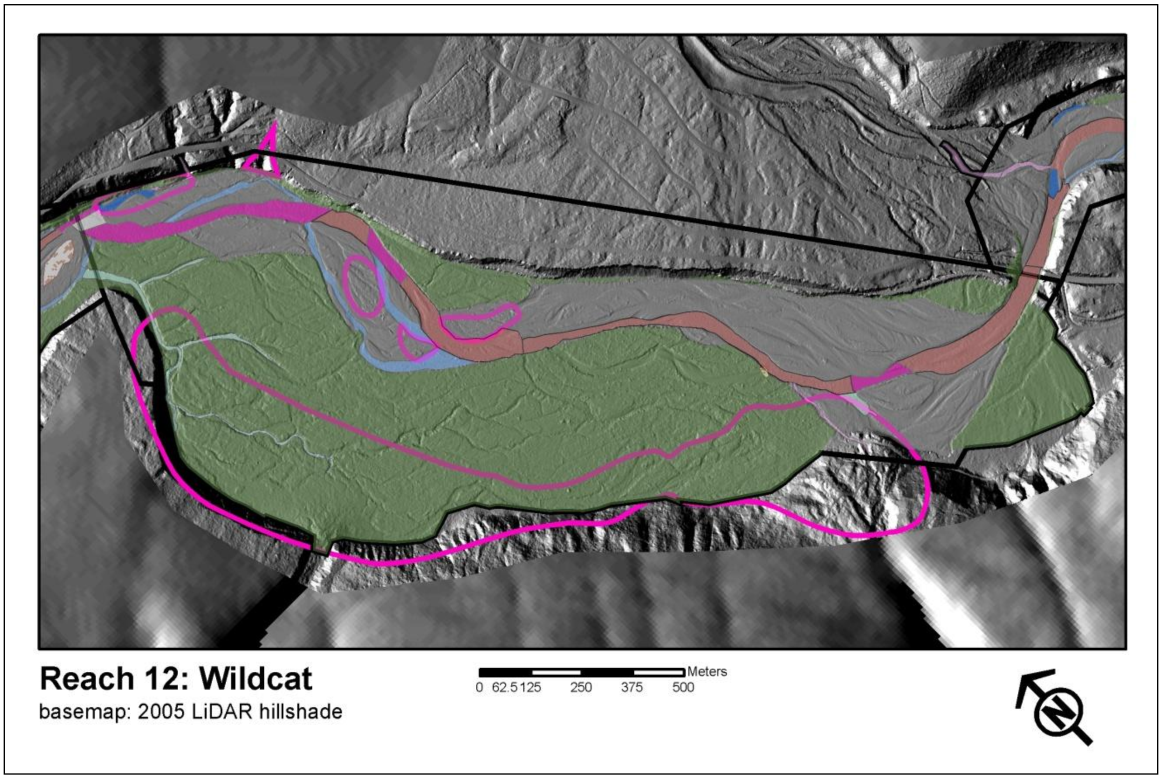

Figure 35. Site map for the Wildcat Reach. Legend is same as in Figure 11.

Habitat in the Wildcat reach is dominated by several long homogeneous riffles (48%), followed by glides (21%) and braids (17%). The mainstem provides limited spawning and rearing habitat for salmonids due to the lack of structure or habitat diversity. Off-channel habitats make up 11% of the wetted area in the reach, predominantly in the extensive McDonald slough complex on the lower left floodplain. In the middle of the

Wildcat reach is an area of extensive braiding where the mainstem shifted between 2002 and 2004, leaving behind an outside meander bend that could over time become an attractive side channel for chinook spawning and rearing. The downstream 500 m of McDonald slough is already known as a perennial chinook spawning site. The reach was mostly devoid of large wood during the 2004 LWD surveys, with only 0.3 pieces and 2.7 m^3 per 100 m of channel. This in spite of the relatively large stands of mature conifer occupying the left bank floodplain. The Wildcat reach ranks sixth among North Fork reaches in area of mature floodplain timber, but four of those reaches are much larger and fall downstream of Maple Canyon; the fifth is the next reach downstream, Lone Tree. Percentage wise the Wildcat Reach ranks fifth in proportion of the floodplain occupied by large (> 40 m) timber, at 1.34 percent, slightly higher than the North Fork as a whole.

Geomorphologically the Wildcat reach is a little less than average in width (175 m), and has remained relatively consistent in width (range: 137-218) except for a peak in 1994. Channel gradient along the mainstem is a relatively steep 0.0091, with local slopes varying widely between 0% and > 2%. The most downstream 100 m segment greater than 2% slope is near the top of the Wildcat reach, and the reach as a whole is steeper than all but one in the study area (the uppermost, Cornell reach). Neither sediment aggradation nor degradation were detectable between 1994 and 2005, and given that the North Fork as a whole degraded 20 cm over that period, the failure of the Wildcat reach to degrade may have been due to sediment emanating from Canyon Creek, immediately upstream. The Wildcat reach is indeed one of the most upstream depositional reaches where sediment from headwater streams, such as Canyon and Glacier creeks, can drop out and accumulate. The annual channel migration rate for the 12 transects in the reach averages 6 meters (SD=1.63). Channel occupancy has concentrated on the right side of the floodplain at a remarkably consistent 100%, despite the myriad meander scars on the left bank floodplain. Channel avulsion potential is high, as several of these flood and meander scars are at consistently lower elevations than the present mainstem (Figure 36). The extensive left bank floodplain is not within the historic meander zone as detected by photographs, but the 1892 GLO maps label the floodplain as “McDonald Island” due to the owner’s homestead on the site. Migration into the right bank is restricted by the 40 m high bluff of the Canyon Creek alluvial fan. Wildcat Creek and McDonald Creek also enter the valley on alluvial fans, albeit much smaller ones than Canyon Creek.

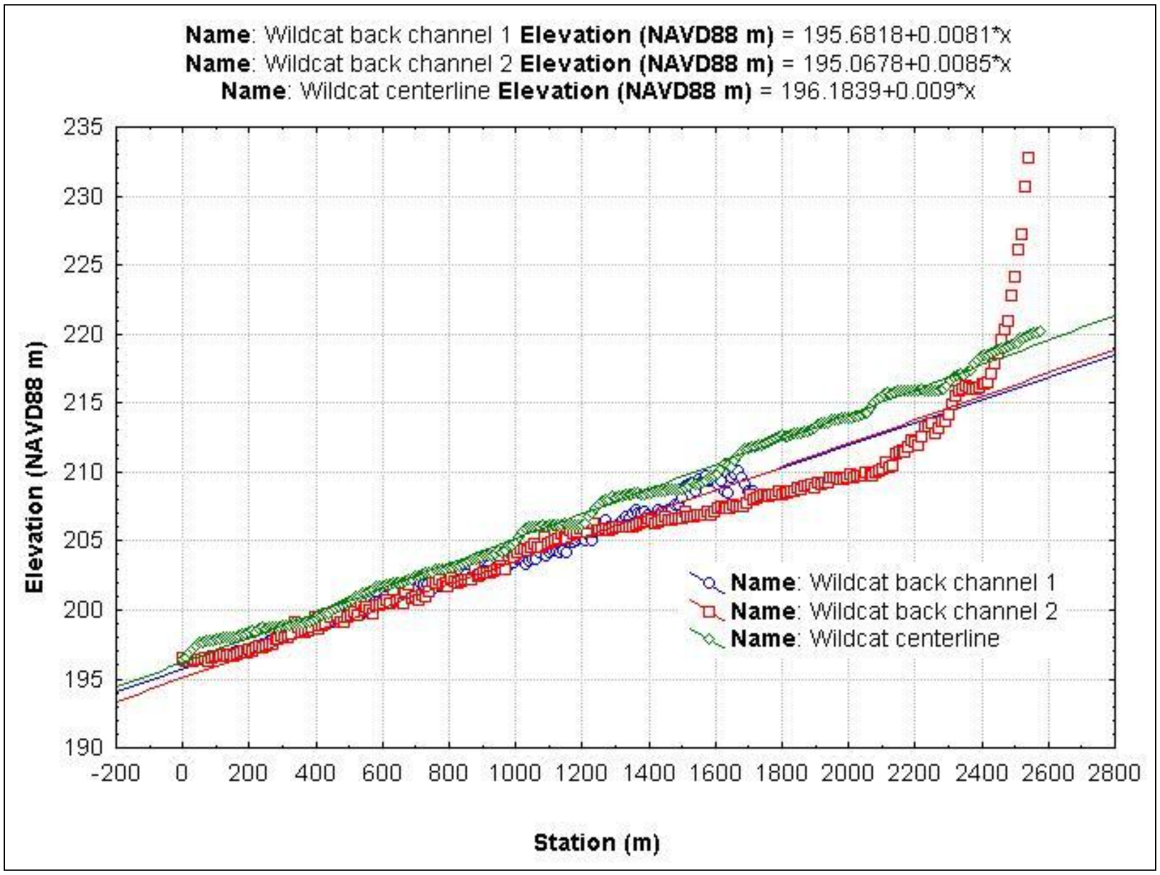

Figure 36. Longitudinal profiles of the Warnick reach.

Until about 1938 a lumber mill operated at Warnick, to the east of the bridge, and was connected to downstream communities by a rail line that ran on cribbing and trestles near the base of the Warnick bluffs. Bridge abutments for the railroad are still visible immediately downstream of the Warnick bridge. The PSE power line corridor also follows part of the old railroad embankment further downstream. The mill closed shortly after the railroad trestle was washed out in 1938 (Jake Steiner, personal communication). The 1955 channel is in much the same configuration as today. The 1976 channel shows more than a half-dozen stable channel islands with maturing vegetation, at both the upstream and downstream extents of the reach. By 1986 the left bank floodplain was dense forest except for the harvest operations going on at the time.

The Wildcat Reach presents a major opportunity to re-create substantial off-channel chinook spawning and rearing habitat where the physical and hydrological conditions permit. The left bank floodplain has a history of timber harvest but still retains sizable trees, numerous meander scars, tributary flows into the back channels, and expansive forested wetlands. Stream gradient along the mainstem is 0.009 and the back channels are ~0.0081, with the mainstem slightly higher in elevation than the floodplain back channels for much of their length (Figure 36). The lower 400m of the back channel currently support moderate densities of chinook spawning. Mainstem channel elevations are significantly higher than the back channels at the upstream end of the reach, providing a possible source for flows into the back channels where the mainstem and back channels are closest. Wildcat Creek itself was rerouted during a debris flow in November 2006, obliterating the DNR bridge and avulsing into a former channel that ends on the floodplain. A minor shift of lower Wildcat Creek could shunt flows into the back channels around what used to be McDonald Island, increasing juvenile rearing habitat several-fold and augmenting flows into McDonald slough.

In the middle of the reach, along the base of the Warnick Bluffs, several of the braids are separated by cobble bars with persistent woody vegetation (mostly alders) in the 7-10 year range. Some of these vegetated bars already have significant amounts of LWD piled at their upstream ends, and are themselves growing on and around large piles of decaying wood. The mainstem in the Wildcat Reach is a steep (0.009), homogenous channel of riffles and braids, with few stable side channels, little LWD, few well-established channel islands, and generally little habitat heterogeneity or structure, despite an expansive left bank forested floodplain with 2-m diameter timber. Little or no known chinook spawning occurs in the mainstem along this reach, despite spawning both upstream and downstream. The river crossover from the left to the right side of the active channel presents an opportunity to break up the monotony of riffles and provide some off-channel spawning and rearing habitat. The mainstem centerline and all three braids are at very similar elevations and gradients (0.0085-0.0099), with hydraulic jumps (cascades) and overflow paths where flows could be directed into side channels with appropriately placed LWD structures. The former outside meander bend at this site, now an open braid on one side but with a mature riparian zone on the other, could likewise benefit from some strategically placed logjams that would encourage channel stability and split flow under a variety of hydrologic conditions (i.e.. both low and high flows).

Reach 13: Canyon Confluence

The Canyon Confluence reach is among the steepest and most volatile reaches of the North Fork, yet due to its confinement between valley walls does not migrate across the same amplitude as the floodplain reaches downstream (Figure 37). The reach extends from the Warnick Bridge at RM 54.8 upstream to a bedrock constriction at RM 55.8. It is bounded on both sides by steep hillsides, and viewable from SR 542 on the left bank, but is most easily accessible from Canyon Creek, which enters the mainstem low in the reach on the right bank. Ownership and control is largely by the Washington DNR, although the high bluff and hilltop on the left bank upstream of the bridge is owned by a private party, the lowest reach of Canyon Creek is owned by Whatcom County Public Works, and a private timber firm owns a large parcel upstream on the right bank.

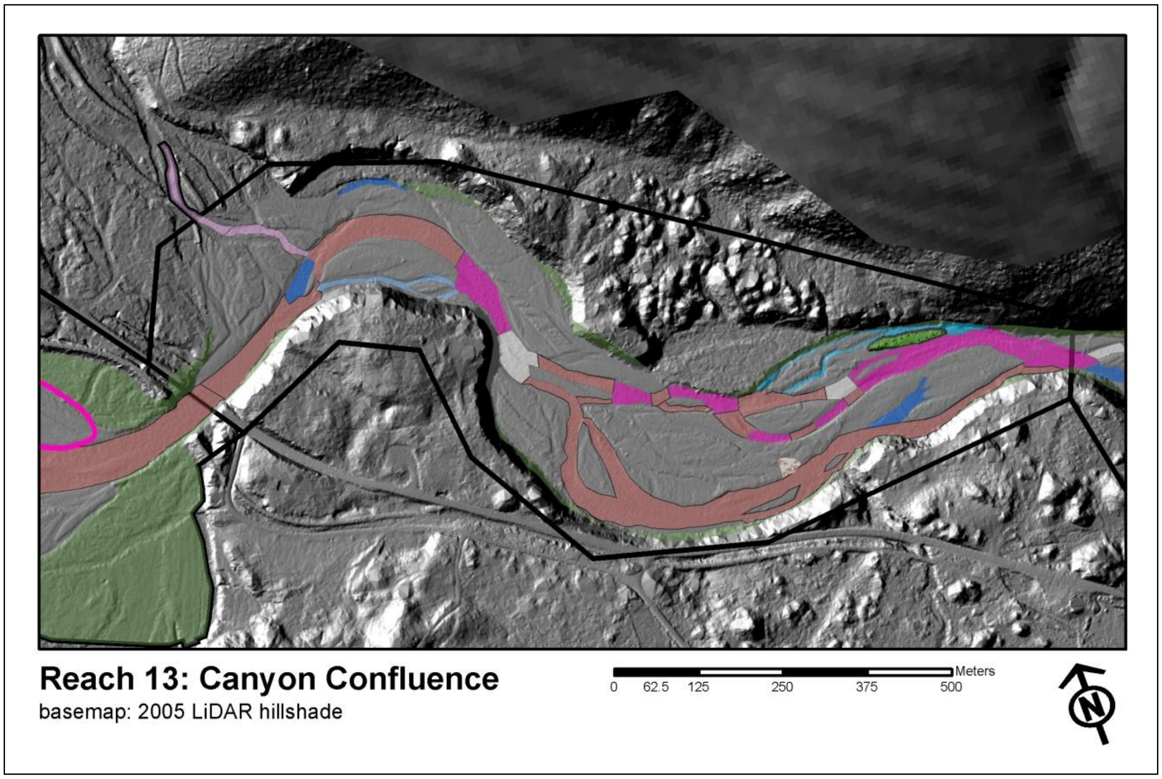

Figure 37. Site map for the Wildcat Reach. Legend is same as in Figure 11.

Habitat in the Canyon reach is dominated by riffles (69%) and glides (19%), with smaller areas of cascades (4%) and braids (2%). Off-channel habitat makes up only about 3% of wetted habitat in the reach, but those areas appeared to be high quality spawning and rearing habitat. Spring chinook spawning in 2005 was relatively high in the reach, with seven redds in one of the smaller reaches (fifth out of fourteen) in the North Fork. The reach is exceptionally low in wood abundance, with only one significant logjam noted in 2005 and only two key-sized pieces noted in 2004. While the surrounding hillslopes contain ample conifer forests, the floodplain contains very little mature timber, with less than 1% of the floodplain in timber > 40 m in height.

Geomorphically the Canyon reach has remained relatively stable in width over time, until recently. The historic average width (1938-1998) was 97 meters, but now stands at 140. The increase in width may be in part due to an emphasis in the 2005 surveys on detecting off-channel areas on the floodplains, or it may be due to flood activity and channel widening, but regardless the channel appears to be almost 45% wider than the recent norm. Differences between the 1994 and 2005 digital terrain models show a –0.19 m change in active channel elevation, indicating a significant channel incision over the past decade. Avulsion potential in the reach is low due to the highly confining valley walls. Annual channel migration since 1938, among the seven transects in the reach, averages 4.1 m (SD = 1.7m). The channel occupation grid shows several channel island areas that have been occupied as active channel for only 30-40 percent of the historical photo period. One of these areas is currently developing as a channel island in the vicinity of semi-protected off-channel habitat, and could indicate a likely area for restoration or enhancement. The upper third of the reach has for most of the photo-period maintained an island-braided character, and may once again if conditions permit.

Reach 14: Cornell Confluence

The Cornell reach is the steepest and furthest upstream reach in the study area, falling between RM 55.8 and 57.3. The reach initially extended further up to RM 57.7 (at the confluence with Glacier Creek), but was shortened to coincide with the historic air photo and map coverages (Figure 38). The reach is braided or island braided for most of its length, with a large pond and wetland complex (Boettiger's Slough) midway down on the left bank floodplain. Access is easiest via Cornell Creek, or from private lands near the town of Glacier. Ownership is primarily private parcels on the left bank, private timber lands on the right bank, and DNR aquatics lands in the channel, with several ecologically sensitive parcels held by the Whatcom Land Trust.

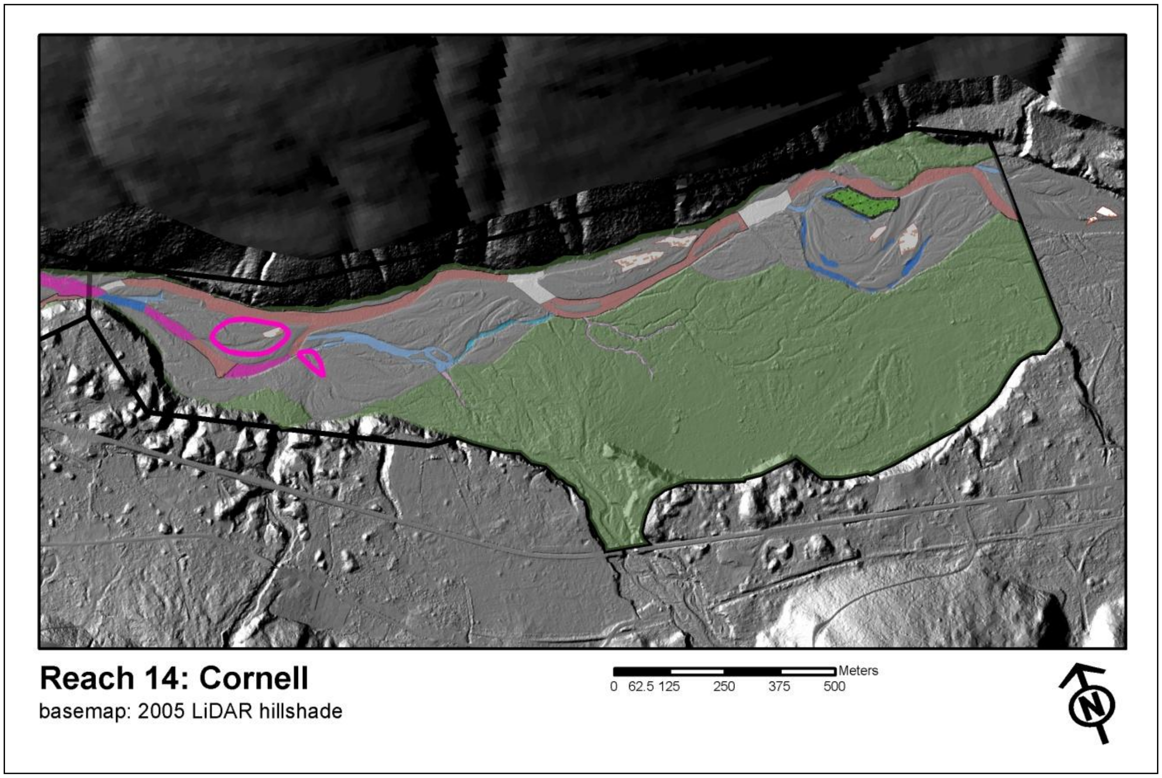

Figure 38. Site map for the Wildcat Reach. Legend is same as in Figure 11.

Habitat in the reach is heavily dominated by riffle (60%), followed by cascade (9%) and glide (8%). The riffles tend to be steep, choppy, whitewater expanses, with a substrate of small boulders completely infilled with fine sediment. The mainstem provides scarce little habitat for spawning and rearing, although the off-channel areas (6% of wetted habitat) are attractive to chinook and are consistently used despite frequent flood disturbance. Boettiger's slough, upstream of the Cornell Creek confluence, is noted for chinook spawning and rearing. In 2005 spring chinook surveys five redds were located at the bottom of the reach in an off-channel pool. Both the 2005 and 2003 LWD surveys noted ample wood in the Cornell confluence reach. The 2003 LNR surveys measured the second highest wood loading in the North Fork, at 7.25 m^3 of wood and 0.81 key pieces per 100m of channel. This despite the third lowest area of mature floodplain timber (0.49%), which compares with the much wider downstream reaches near the Middle Fork confluence.

Geomorphically the Cornell reach is by far the steepest at 0.91 m/m (Figure 39). Channel width is currently at its widest (163 m) since 1938. Historically the reach width has averaged 115 m and ranged as narrow as 85 m. Since 1938 channel migration has averaged 8.3 m/yr (SD = 2.88) at the 11 transects in the reach, with a maximum of 12.5 m/yr at the transect immediately upstream of Boettiger’s slough. Channel occupation in the reach is concentrated in a narrow band along the steep bluff on the right (north) bank, with the extensive floodplain and wetlands to the south essentially un-occupied. Despite this history, a channel avulsion seems likely, since large areas of the floodplain and wetland complex is currently lower than the adjacent active channel. Counteracting the tendency for avulsion is the Cornell Creek alluvial fan, which is responsible for partially damming the river valley and creating the extensive upstream wetlands, and pushing the active channel against the bluffs to the north.

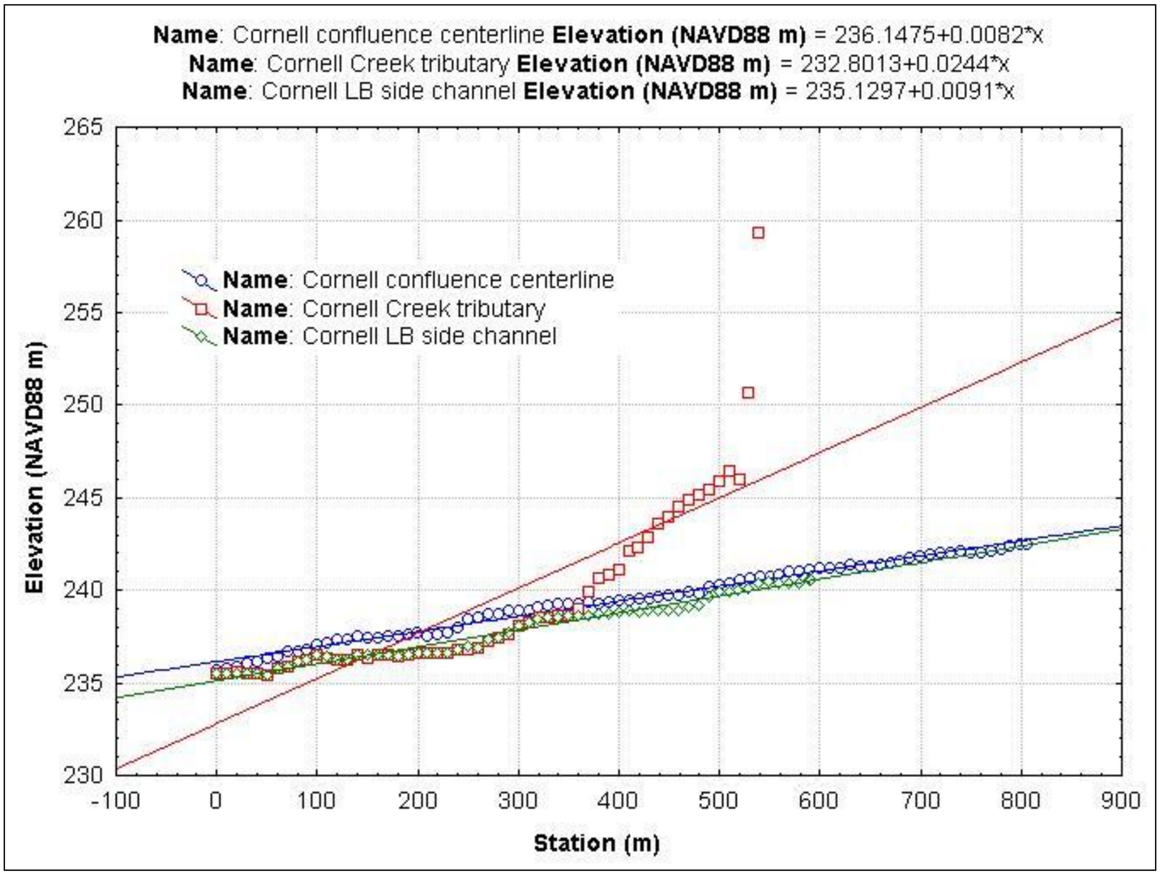

Figure 39. Longitudinal profiles of the lowest extent of Cornell Creek and the mainstem North Fork at the Cornell confluence.

In 1938 much of the left bank floodplain was pasture and the Cornell Creek alluvial fan was forested. The large pond and wetland complex upstream of Cornell Creek was mostly pasture, with fences through the lowest areas (remnants visible today) and a barn in the northwest corner at what is now the edge between the wetland and a mature alder forest. By 1976 the Cornell Creek channel is flushed with recent sediment deposits, and the open-water wetland is starting to form in the pasture against the bluff to the south. The 1986 photo is poor quality, but clearly shows recent widening and sediment deposits in Cornell Creek and expansion of the open-water wetland. By 1994 the current landscape is evident; a large ponded wetland bounded by the south bluff and the Cornell Creek alluvial fan, and floodplain pastures upstream. The 2005 LiDAR shows extensive overflow channels between the wetland and the upstream pastures, but the photo record does not reveal the mainstem occupying these channels.

The Cornell Confluence is a highly volatile reach where frequent channel shifting could be accommodated by establishing an additional channel island downstream of the existing and highly productive Boettiger's Slough. The volatility inherent in alluvial fans should caution against expectations of permanency in the reach however. With that caveat, mainstem and side channel elevations and gradients are conducive to a channel-splitting LWD structure at the upstream end of an existing incipient channel island, augmenting an existing LWD jam, and planting in and around an existing young alder stand. The mainstem elevations are slightly higher than side channel elevations, except at the divergent and convergent ends, so accentuating flow in the tributary-fed side channel would not be difficult. The downstream end of the side channel (at the convergence pool) was noted for heavy spring chinook spawning in 2005, but the upper 95 percent of the side channel was apparently not used. Upstream of the Cornell Creek alluvial fan an area of recent channel widening has left a channel island that could be augmented with LWD to encourage island and side channel persistence. Due to channel constrictions caused by alluvial fans (Cornell, Gallop, and Glacier), few other restoration opportunities exist in the North Fork between Canyon and Glacier creeks.

PROJECT RANKING

The ecological findings presented in the Results section of this report were refined into a list of objectives for reversing the habitat decline in the North Fork. Each of the objectives on the list includes a number of specific strategies that would achieve those objectives. The projects and opportunities identified in the Reach Descriptions were also refined, but into a list of discrete projects that would use the strategies identified above. Those projects were then adopted into a list for immediate project implementation, and ranked according to several criteria. Those criteria included the habitat affected by each project, the risk of project failure due to flood damage or channel migration, and the likelihood that spawning chinook would take advantage of the habitat improvements.

Objectives and Strategies

This report documents disruptions to the habitat forming processes at work in the lower North Fork, and identifies mechanisms whereby that lack of habitat affects the population of North Fork/Middle Fork early chinook. The natural habitat forming processes have been interrupted by a dearth of mature trees in the floodplain and an apparent increase in flood intensity. Reversing habitat declines and re-instating the natural habitat forming processes will require short-term intervention, with the goal a self-maintaining system over the long term. The following objectives and strategies are intended to achieve that goal.

Objective 1: Improve egg-to-fry and juvenile rearing survival by providing stable, off-channel spawning habitat and flood refuge. Reset process of floodplain and channel island formation by providing stable hard points behind which vegetation can establish and mature. Shift braided habitat to protected back-channel habitat by encouraging channel island stability.

- Strategy 1.1. Install stable logs and log structures at the upstream extents and lateral margins of existing or incipient channel islands, to encourage island growth, maturity, and stability. Design structures to collect and trap additional wood during floods.
- Strategy 1.2. Fortify entrances to back channels with stable wood structures that scour a narrow flow aperture, ensuring low-flow inundation but preventing major avulsion into the off-channel habitat.
- Strategy 1.3. Construct log accumulations which encourage fine sediment deposition and tree seedling establishment, and which provides low-velocity areas during floods where pioneer tree species can grow to maturity.
- Strategy 1.4. Augment existing wood accumulations to promote channel island formation.
- Strategy 1.5. Add wood structures to braids and younger back channels to provide instream cover and promote habitat diversity.

Objective 2: Improve habitat conditions in lower tributary reaches and at mainstem-tributary junctions.

- Strategy 2.1. Plant riparian trees to moderate tributary temperatures and increase LWD recruitment potential.
- Strategy 2.2 Encourage formation of protected spawning and rearing habitat by constructing logjams on mainstem floodplains upstream of tributary junctions, where sediment deposition will likely form channel islands and floodplains, and tributary flow can augment side channel habitat.

Objective 3: Restore riparian conditions to provide future LWD recruitment. Shade braids and side channels to reduce heat inputs, particularly where summer discharge is low.

- Strategy 3.1. Plant riparian tree species in understocked areas near channel margins where eventual recruitment is likely. Emphasize areas without bank hardening and where young trees will shade side channels.
- Strategy 3.2. Install ballasted or pinned single logs along margins of mainstem braids where they will encourage fine sediment deposition on channel banks. Return after subsequent floods to plant trees in new sediments if natural seeding is unsuccessful.
- Strategy 3.3. Purchase or otherwise protect existing mature riparian stands to preserve riparian function including LWD recruitment potential.
- Strategy 3.4. Encourage LWD recruitment from mature stands by encouraging river-floodplain interaction and possibly avulsion into mature stands.

Many of the above strategies may take only a few years to show positive effects, while some of the natural processes may take decades to fully recover. In favorable areas of the North Fork floodplain trees can reach diameters of 2-m or more in just over 100 years, and effective key piece size can be achieved in much shorter timeframes. However those riparian zones will likely not mature sufficiently without changes in the active channel to reduce channel migration and volatility. Likewise, restoration projects need to be identified carefully to take best advantage of conditions where they will be most effective. The project list below was generated to take advantage of incipient channel islands, wide channels with shallow flood flows, and existing unprotected side channels. Following this list the projects are ranked according to the habitat gain they provide and the risk of project failure.

North Fork Project List

The projects listed below are derived from the ecological assessment presented earlier in this report, and concentrate on spring chinook spawning and rearing habitat. Other beneficial projects in the analysis area certainly exist. In most cases only rudimentary design work has been performed to verify the feasibility of these projects. Land ownership was documented using only Whatcom County tax assessor records, and not all landowners have been contacted about willingness to participate in instream projects. The project list as a whole is preliminary, and does not imply a readiness to proceed by any party. A GIS shapefile of project locations is available separately, and those locations are outlined on the site maps in the Site Description section.

Rutsatz Reach Island Enhancement

This project includes construction of three large logjams and possibly two smaller ones at the upstream end of existing channel islands. The objective of the project is to split flow and encourage the growth and stability of channel islands to accentuate and accelerate stable side channels suitable for chinook spawning (Objective 1, Strategy 1.2). Land ownership is primarily DNR aquatic lands and Whatcom Land Trust, with some private parties adjacent. The project ranks high in habitat gain due to the long and spacious off-channel habitats downstream that would be inundated by assuring a flow split at this location. Risk is considered low or moderate due to the elevation of the channel island above the surrounding channel. However, few spring chinook spawn this low in the North Fork, and so emphasis on this project is low.

Bell Creek Confluence

The right bank floodplain complex upstream of the Mosquito Lake Bridge includes beaver ponds, side channels, sloughs, the Bell Creek tributary, and forested floodplains in various ages and stages of maturity. During field reconnaissance the site appeared to have potential for shunting mainstem flow into a flood channel and augmenting water to the back channel (Strategy 1.2) near Bell Creek, possibly making the back channel attractive to spawning chinook. During the geomorphic analysis it was shown that the active channel tilts to the left (south) and that shunting water to the right (north) would be hydraulically difficult. Fish use by spawning spring chinook is sparse. Additionally the site ranked as a low priority due to low habitat gain and a high risk from low elevations and high a channel occupancy rating.

Kenny Slough

The Kenny Slough project seeks to stabilize approximately 1200 meters of protected side channel habitat, protect existing channel islands, encourage flow from the mainstem into a braid, and promote riparian growth around the braid, eventually leading to a complex of protected side channels attractive for chinook spawning (Objective 1, Strategies 1.1 and 1.2). Smaller LWD jams above the low-water elevation would be secured by wood pilings and used to augment existing jams and floodplain islands. Riparian planting in fine sediment deposits would accelerate vegetation establishment (Objective 3). Land ownership is primarily public (WSDOT and DNR). Spring chinook do spawn in the reach, but not in the numbers or concentrations observed higher in the watershed.

Coal/Racehorse Confluence Logjam Enhancement

This project seeks to stabilize one large mid-channel bar with established hardwood and shrub vegetation by augmenting the logjam at the upstream end (Objective 1, Strategies 1.1 and 1.3), and encourage stability of the valuable off-channel spawning and rearing habitat by augmenting several smaller logjams on the right bank (Objective 1, Strategy 1.4). The project also seeks to stabilize the productive habitat at the tributary junction by constructing one or more large logjams upstream of the Coal Creek confluence (Objective 2, Strategy 2.2). The site is confined by SR 542 and private holdings on the right bank, and large Holocene landslide deposits on the left bank. Hydraulic and geomorphic analyses are necessary to determine the long-term feasibility of logjams and channel islands in the reach. Risk of project failure is high due to the constricted channel location and low elevation of the incipient channel island.

Hatchery Reach Island Enhancement

This project seeks to stabilize existing side channels adjacent to and immediately downstream of the Kendall Hatchery by augmenting LWD accumulations at the head of two channel islands and several midstream bars (Objective 1, Strategy 1.1). Final design would likely depend on channel configuration prior to construction (channel shifts are frequent). Medium-sized structures could be assembled to promote year-round flow into Smuggler's Slough (Strategy 1.2). Additional work upstream could take advantage of the hardened bank at the hatchery and add LWD structures to split flow into multiple, and possibly more stable, side channels (Objective 1). Land ownership is DNR aquatic lands and the Whatcom Land Trust. Both large and small projects could be identified for this site. A wide range of project costs would cover a variety of project approaches.

Farmhouse Reach

As with the Hatchery Reach, the bend immediately upstream could accommodate a wide range of projects from large to small. At least three vegetated channel islands with small LWD accumulations could be fortified to encourage stable island development (Strategy 1.1). An ephemeral channel split at the top of the reach could be enhanced to provide more year-round flow into a long (~1600 meter) side channel known for chinook and chum spawning and rearing (Strategy 1.2). The project also includes small LWD additions to an area of the side channels (~300 meters) to better define the open braid and promote fine sediment deposition on the banks where woody vegetation could get established (Strategy 3.2). Land ownership is primarily DNR aquatic lands, with two private parties involved (both of whom have cooperated with previous conservation initiatives). Whatcom Land Trust owns nearby parcels suitable for access.

The Glen

The reach adjacent to The Glen at Maple Falls (a gated community), and just downstream of the Maple Falls Canyon, is a wide expanse of channel bars that shift repeatedly in a single flood season. Channel volatility, braiding, and redd scour are high, yet with the wide active channel the flood elevations are relatively low. A high levee on the right bank protects community property at The Glen, but could be used in conjunction with large logjams on the opposite side of the river to both anchor the mainstem where it exits the canyon and then split it into multiple channels downstream (Objective 1). The project would likely begin with three or four large jams at the upstream end of the reach and then continue downstream in subsequent years as the multiple channels adapt to the LWD structures. At least two side channels off this reach, both active chinook spawning sites, could be enhanced with logjams to split flows and encourage year-round inundation (Strategy 1.2). Land ownership is a mixture of The Glen Community Association, Washington DNR aquatic lands, DNR forest lands, and the US Department of the Interior. The ranks high on the amount of habitat that could be affected, but low on risk factors due to the high channel occupancy and low elevation of bars and islands where the project would be constructed.

Maple Creek Mainstem

On the right bank immediately upstream of the confluence of Maple Creek with the North Fork an existing cobble bar separates the mainstem from multiple side channels. Flow in the side channels is from groundwater emergence and tributary flow from beaver marshes on the right bank. If connected to the mainstem by surface flow the side channels could provide chinook spawning and rearing habitat in an area of already high habitat diversity (Strategy 1.2). One or two medium-to-large logjams could effect the flow split and encourage vegetation colonization of the existing bar (Strategies 1.2 and 1.3). An adjacent pasture with an invasion of scotch broom could be included for riparian restoration (Objective 3). Most of the project could be constructed on land owned by the Whatcom Land Trust, although participation by one or two (if the scotch broom pasture is included) private parties may be required. The project ranks low in the amount of habitat that could be gained, but ranks well according to the risk factors, especially if the scotch broom area is included.

Mahaffey's Braid

Alongside the Mount Baker Highway (SR 542) is a braid known for chinook spawning that would provide an opportunity for salmon restoration combined with public access and education. Enhancing existing small LWD jams (Strategy 1.4) would help define the braid against the hardened bank along the highway and encourage vegetation colonization on the cobble bar (Strategy 1.3). Land ownership is one private party and DNR aquatic lands. The project ranks low on habitat gain but high on risk due to channel occupancy. The benefit of public access and education should be weighed against risk to spawning fish (from humans, dogs, etc.) in evaluating the final rank of this project.

Boulder Confluence

Historically the junction of Boulder Creek with the mainstem North Fork included a side channel with flow predominantly from Boulder Creek. The side channel was a preferential spawning area for chinook and pink salmon. Recent debris flows in Boulder Creek have eliminated the side channel, which could be re-constructed and stabilized with two large LWD jams. The objective of the project would be to direct future tributary flows and debris flows downstream (west) along the alluvial fan, instead of taking the shortest route and intersecting the mainstem at a right angle (Strategy 2.2). Land ownership is predominantly DNR aquatic lands, although access would require permission from a private landowner that has expressed a willingness to cooperate. WSDOT has scheduled replacement of the SR 542 bridge over Boulder Creek (~200 meters upstream from the proposed project) for construction in summer 2007. The project ranks low in habitat gain but high in risk factors and fish use.

Lone Tree

Immediately upstream from the Boulder Creek confluence is a site where extensive left bank floodplain forests have been recently captured by the North Fork mainstem, recruiting large quantities of LWD to the channel and occasionally creating channel-spanning logjams. As the mainstem has shifted south to the left bank it has abandoned older, higher channels which now carry flood flows and hyporheic trickles. A project to stabilize existing and former channel islands could be constructed with no in-water work (Strategy 1.1, 1.3). Single log placements along the abandoned braids and sloughs (which still harbor salmon fry) could accelerate fine sediment deposition and eventual vegetation colonization (Strategy 3.2). Land ownership is primarily Whatcom Land Trust and DNR, with access via Whatcom County Parks and Puget Sound Energy. Some construction would be on private property. The site ranks high on habitat gain and high in elevation, but also may have a high risk of channel occupancy.

Wildcat/MacDonald Slough

On the left bank of the North Fork, downstream from the SR-542 (Warnick Bridge) crossing, Wildcat Creek enters the mainstem after flowing over a short, steep alluvial fan. The fan currently directs tributary flowed westward down an abandoned logging road and toward the mainstem, but historically flowed through an extensive floodplain forest to join with McDonald Creek, which enters the North Fork approximately 2200 meters downstream from Wildcat Creek. A road crossing near the bottom of the Wildcat Creek alluvial fan is the current site of the shift, and provides an opportunity to re-direct Wildcat Creek into the historic back channel. Flow augmentation into the floodplain sloughs would substantially enhance the existing rearing habitat. Heavy spring chinook spawning in the downstream reaches of McDonald Creek was noted for 2005 and previous years. The land was recently acquired by Whatcom Land Trust. The project ranks exceptionally high due to a combination of habitat gain, fish use, and risk factors.

Warnick Bluffs

Between the Wildcat and McDonald Creek confluences the North Fork mainstem is mostly homogeneous riffle and glide habitat, with little diversity and virtually no flood refuge or stable spawning habitat. Braids and lightly vegetated cobble bars at a bend in the middle of the reach provide an opportunity for channel enhancement (Objective 1), as does a flood channel through the forest on the left bank (Strategy 1.2). At least five ballasted logjams in the channel bend and one or two more at the top of the flood channel could induce some channel diversity to this high-energy reach (Strategy 1.1, 1.2). Logs and ballast could be delivered by helicopter, minimizing in-water crossings by heavy equipment, or from either the left or right floodplain. The project would be contingent on DNR aquatic lands approval. Large projects at the site are possible. The land was recently purchased (Strategy 3.3) by the Whatcom Land Trust. The project ranks very high in terms of habitat gain, risk factors, and fish use. The WSDOT and USFS intend to pursue a project in the reach for construction in summer 2008.

Cornell/Hedrick

The confluences of Cornell and Hedrick creeks with the North Fork mainstem have historically been sites of high spring chinook spawning activity, but recently that use has been curtailed due to channel instability in the creeks. The Cornell Creek alluvial fan has ample spawning gravel, but tributary discharges percolate through the coarse substrate to the extent that the streams run partially to predominantly sub-surface during much of the spawning season. The Hedrick Creek confluence is often perched by a meter or more at spawning time. It is not known to what extent these problems can be alleviated with a restoration project. Channel islands near the confluences could be constructed similar to elsewhere in the North Fork, and would improve mainstem and side channel habitat, but would not repair the habitat in the lower tributaries. Like the Boulder Creek project, the Cornell/Hedrick projects rank high on height above the channel (a low risk factor) but do not provide as much habitat gain as other instream projects.

Ranking criteria

Objective, numerical scoring criteria for ranking restoration projects are difficult to apply in informative and meaningful ways, and few watershed plans have designed these criteria successfully. For the North Fork project list we used four such ranking screens, alluded to above in the project list.

- First was the area of affected habitat. Using the GIS the wetted channel area influenced by the project was summed by habitat type. The total area of non-mainstem habitats (back channels, sloughs, and braids) was used as an indicator of wetted area that would be affected. In cases where new wetted habitat would be created or inundated by the project, that habitat was digitized into the GIS and used in the calculations as well. This method seemed to favor projects that split flows into long and spacious downstream channels.
- Second was a risk factor related to the elevation of a project site above the wetted channel. The FlatChan grid (see the methods section for an explanation of how this layer was generated) was used in the GIS to average the elevation of 2-m pixels in the project area. The elevations extracted were relative to the mainstem channel at that point, and hence show height above water surface. This method favors channel islands significantly higher than the mainstem, and alluvial fans, where the inundation from floods would be shallower and therefore lower risk.
- Third was the percent of time the project site was occupied by the active channel. The average of the channel occupation grid (again, see the methods section for an explanation of how this layer was generated) for a site was used as an indicator of the time spent as active channel, and therefore the margins of the channel present a lower risk of project failure from flooding or channel migration. Conversely the average channel occupation could be used to indicate the likelihood of the wetted channel interacting with the project structures. Because of this dichotomy the projects were ranked both with and without the channel occupation scores.
- Fourth was the propensity for spring chinook to spawn in the area. Projects below the Kendall hatchery have less frequent and less abundant spring chinook spawning. While these projects were not penalized in the scoring, proponents are cautioned about proposing projects where chinook use is unpredictable or unknown.

For the first three criteria above (habitat gain, height, and channel occupation) the score for the project was extracted in the GIS, and then the projects were ranked from 1 to 14. A low score denoted favorable ranking. The three rankings were summed, and then a final ranking was given based on the summed scores. The scoring table (below) shows that the highest priority projects are Wildcat Slough, Warnick Mainstem, and Lone Tree, if the Kenny/Walbridge site is excluded due to low spring chinook use. If the channel occupation grid is not used for ranking, and the projects below Kendall are excluded for low fish use, then the top three projects are Lone Tree, Wildcat Slough, and Warnick Mainstem. Various priority lists and sequences for project implementation can be drawn from the scores in the table below, as well as from on the ground review of project details and landowner cooperation.

Proj Num	Project Name	Affected Habitat	Habitat rank	Height rank	Occupy rank	Rank Sum	Final Rank	Rank w/o Occupy
1	Rutsatz	6.31	2	4	14	20	5	1
2	Bell Confluence	0.69	12	14	6	32	13	14
3	Kenny/Walbridge	4.44	5	7	5	17	3	6
4	Coal/Racehorse	4.32	6	9	9	24	7	8
5	Hatchery	2.25	9	13	10	32	14	12
6	Farmhouse	3.28	8	12	8	28	12	11
7	The Glen	6.40	1	11	12	24	8	7
8	Maple Creek	0.82	11	8	2	21	6	9
9	Mahaffey's Braid	0.44	13	10	3	26	10	13
10	Boulder Confluence	0.21	14	5	7	26	11	10
11	Lone Tree	5.63	3	3	11	17	4	2
12	Wildcat Slough	3.59	7	2	1	10	1	3
13	Warnick Mainstem	4.62	4	6	4	14	2	4
14	Cornell/Hedrick	0.89	10	1	13	24	9	5

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Appendix A. Areas of wetted habitat by reach in North Fork study area.

ReachName	off channel area	mainstem area	off-channel ratio	back channel	beaver slough	braid	cascade	glide	pool	riffle	slough	total wetted	percent of NorthFk
Pipeline	69568	135972	0.34	0	0	1417	2161	61918	8356	62121	69568	205540	0.09
Rutsatz	63092	188335	0.25	49172	7307	8229	0	97540	486	82080	6613	251428	0.12
Kenny/Bell	37805	183682	0.17	24763	4843	28078	0	97265	12128	46210	8199	221487	0.10
Big Rock Canyon	0	80035	0.00	0	0	0	13307	66728	0	0	0	80035	0.04
Hatchery	58534	269000	0.18	54583	0	28275	10912	91160	11922	126731	3951	327534	0.15
Farmhouse	60134	221766	0.21	57335	0	43500	0	17908	2661	157698	2799	281900	0.13
Maple Canyon	0	24738	0.00	0	0	0	0	0	1596	23143	0	24738	0.01
Maple Creek	12321	87387	0.12	2333	0	1382	3719	27215	1683	53387	9988	99708	0.05
Mahaffey Canyon	0	58850	0.00	0	0	4366	8007	24625	1042	20811	0	58850	0.03
Below Boulder	5467	105501	0.05	0	315	17566	0	7188	1622	79125	5151	110968	0.05
Lone Tree	14098	130030	0.10	3140	0	49695	2365	33173	0	44797	10958	144128	0.07
Wildcat	14823	129038	0.10	0	0	24269	2365	30861	2383	69160	14823	143861	0.07
Canyon	3722	105396	0.03	3722	0	2227	4007	20511	3390	75262	0	109118	0.05
Cornell	6077	101392	0.06	6077	0	15932	9795	8877	2118	64670	0	107469	0.05
totals:	16%	84%		9%	1%	10%	3%	27%	2%	42%	6%		

units are habitat areas in square meters unless otherwise noted. back channels, beaver sloughs, and sloughs are off-channel habitats.

Appendix A2. Proportions of wetted habitat by reach.

ReachName	*back chan*	*beaver*	*braid*	*cascade*	*glide*	*pool*	*riffle*	*slough*
Pipeline	0.00	0.00	0.01	0.01	0.30	0.04	0.30	0.34
Rutsatz	0.20	0.03	0.03	0.00	0.39	0.00	0.33	0.03
Kenny/Bell	0.11	0.02	0.13	0.00	0.44	0.05	0.21	0.04
Big Rock Canyon	0.00	0.00	0.00	0.17	0.83	0.00	0.00	0.00
Hatchery	0.17	0.00	0.09	0.03	0.28	0.04	0.39	0.01
Farmhouse	0.20	0.00	0.15	0.00	0.06	0.01	0.56	0.01
Maple Canyon	0.00	0.00	0.00	0.00	0.00	0.06	0.94	0.00
Maple Creek	0.02	0.00	0.01	0.04	0.27	0.02	0.54	0.10
Mahaffey Canyon	0.00	0.00	0.07	0.14	0.42	0.02	0.35	0.00
Below Boulder	0.00	0.00	0.16	0.00	0.06	0.01	0.71	0.05
Lone Tree	0.02	0.00	0.34	0.02	0.23	0.00	0.31	0.08
Wildcat	0.00	0.00	0.17	0.02	0.21	0.02	0.48	0.10
Canyon	0.03	0.00	0.02	0.04	0.19	0.03	0.69	0.00
Cornell	0.06	0.00	0.15	0.09	0.08	0.02	0.60	0.00