Hart Slough Enhancement Feasibility Investigation

Final Report

February 2003

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Executive Summary

The enhancement of Hart Slough and Hart Island has been discussed periodically over the past decade. In 1999, the Skagit County Public Works Department, the Skagit Fisheries Enhancement Group, the Skagit Watershed Council, the Washington Department of Fish and Wildlife, landowners, and other stakeholders met to formally discuss the project. Shortly thereafter, Skagit County applied for and received a grant from the Governor's Salmon Recovery Office to conduct a feasibility investigation and determine alternatives for enhancement of Hart Slough and Hart Island. To guide this effort, Skagit County organized and established a Steering Committee comprised of property owners, local tribes, state resource agencies, and other interested parties and potential stakeholders who have a role / interest in the enhancement of Hart Sough and Hart Island.

This document presents the results of a feasibility investigation focused on exploring potential fish habitat benefits that could be realized by increasing flow into Hart Slough at the inlet and improving flow patterns and access to seasonally available island habitats. The western portion of Hart Slough is a remnant channel of the mainstem Skagit River. During the early 1900's, the Skagit River was re-directed and has subsequently abandoned this channel as the primary conveyance. While the slough remains connected with the mainstem Skagit River, it currently only receives flow through the inlet during high flow events. Improving flow through and enhancing habitat functions within the Hart Slough / Hart Island complex may improve rearing and over-wintering conditions for several salmonid species including coho salmon, cutthroat trout and to a lesser extent steelhead trout, chum, sockeye, and the Endangered Species Act (ESA) listed (threatened) chinook salmon.

Seven alternatives for the enhancement of Hart Slough were proposed for investigation. Of the alternatives investigated, Alternative B was selected as the preferred alternative for achieving the project goal of providing flow throughout the year and optimizing the availability of high quality salmonid rearing habitat. Alternative B involves excavating the upper portion of the existing channel to an elevation (depth) that substantially increases the probability of providing year round flow in the slough. Alternative B provides a substantial benefit to aquatic resources through increased habitat quantity and quality and improved access. Furthermore, Alternative B includes a control structure to regulate flow into the slough and minimize risk to property and infrastructure.

1 Introduction

This document presents the results of a feasibility investigation exploring potential fish habitat benefits that could be realized by enhancing habitat conditions within Hart Slough and on Hart Island. Within Hart Slough, substantial benefits to rearing and over-wintering habitat could be realized by modifying the channel geometry to provide more regular and predictable stream flow to be introduced into the slough. On Hart Island, modifications to the island topography could result in improvements to rearing habitat and provide safe access between the mainstem and refugia during flood conditions. This investigation was initiated to address the lack of rearing habitat in the lower Skagit River and estuary which is one factor believed to be limiting the productive potential of the ecosystem. Enhancing habitat functions within Hart Slough and on Hart Island may improve rearing and over-wintering conditions for several salmonid species including coho salmon, cutthroat trout and to a lesser extent steelhead trout, chum, sockeye, and the Endangered Species Act listed (threatened) Chinook Salmon.

1.1 PROJECT HISTORY

In 1999, the Skagit County Public Works Department, the Skagit Fisheries Enhancement Group, the Skagit Watershed Council, the Washington Department of Fish and Wildlife, landowners, and other stakeholders met to formally discuss the project. Ducks Unlimited completed a partial longitudinal survey of the Hart Slough channel thalweg in 1999 for the Skagit Fisheries Enhancement Group.

In 1999, Skagit County applied for and received a grant from the Governor's Salmon Recovery Office to conduct a feasibility investigation and determine alternatives for enhancement of Hart Slough and Hart Island. In 2001, Skagit County contracted with Inter-Fluve to conduct this study.

1.2 PUBLIC PROCESS / STAKEHOLDER INVOLVEMENT

The successful development and implementation of an enhancement plan for Hart Slough and Hart Island has and will continue to depend largely on the input of the many stakeholders in the Skagit Basin. Recognizing this need, Skagit County organized and established a Steering Committee for this study comprised of property owners, tribes, agencies, and other interested parties and potential stakeholders throughout the watershed who may have a role / interest in the enhancement efforts.

Steering Committee meetings were held throughout the duration of this feasibility study to guide the effort and facilitate public input. The general purpose of the initial meetings was to frame an enhancement approach and action plan. During the course of this investigation, Inter-Fluve presented the results of technical studies and worked with the group to draft a conceptual enhancement plan. The approach and action plan presented in this document is intended to reflect the emerging consensus of the group.

2 Background Information

2.1 DESCRIPTION OF BASIN

The Skagit River originates in British Columbia and flows approximately 35 miles before entering the United States at river mile (RM) 127 and continuing on to its termination point in Puget Sound near Mount Vernon, Washington. Third largest in Washington, the Skagit River basin is the largest in Puget Sound and drains 3,140 square miles, including about 390 square miles in Canada (Johnston 1989). Skagit River flows account for about one-third of the freshwater input to Puget Sound (FWS 1998). The basin is characterized by rugged mountain topography in the central and eastern parts, and by level floodplains and rolling uplands in the western part (Envirosphere 1988). Major tributaries to the Skagit River are the Cascade, Sauk, and Baker rivers. Elevations in the basin range from sea level to 10,000 feet (U.S. Army Corps of Engineers 1973).

2.1.1 Mainstem

Information on mainstem Skagit River habitats summarized here is taken from a comprehensive description by Williams et al. (1975). The mainstem Skagit River provides 96 miles of accessible stream habitat to anadromous salmonids, from the mouth to Gorge Dam. An additional 375 miles of habitat are available in tributaries, including 30 miles in the Cascade River basin and 87 miles in the Sauk River basin. Another 34 miles of suitable salmonid habitat is available to fish hauled above Baker Dam on the Baker River (Williams et al. 1975).

Below Gorge Dam, the Skagit River winds through narrow valleys of the high Cascade Mountain range, within densely forested terrain. Stream reaches contain abundant pool-riffle habitats well suited for salmonids. The Cascade River enters from the east at RM 78.1 near Marblemount, draining high mountain areas with stream habitats desirable to a variety of salmonid species. Below Marblemount, the Skagit River continues through a slightly broader floodplain to Rockport, with excellent pool-riffle habitats. The Sauk River, largest tributary to the Skagit, enters at RM 67.2, just below Rockport. Major tributaries to the Sauk River are the Whitechuck and Suiattle rivers, with headwaters in the rugged, mountainous terrain of the Cascade Range that drains the southernmost parts of the Skagit River basin. Upper portions of the Sauk, Whitechuck and Suiattle watersheds are high gradient and run through canyons with narrow valley bottoms. Lower reaches of these basins contain increasing amount of pool-riffle habitats that provide excellent spawning and rearing conditions for salmonids (Williams et al. 1975). The Skagit and its major tributaries upstream of Sedro-Woolley are protected under the Wild and Scenic Rivers Act. The idea of this act is not to halt development and use of a river; instead, the goal is to preserve the character of a river (www.nps.gov/rivers/about.html).

Below Rockport, the Skagit River valley bottom broadens considerably to include dense deciduous forests and open farmland areas. Agricultural and industrial use along the river increases from Concrete to Sedro Woolley. Despite development, these mainstem reaches provide spawning and rearing habitat for salmonids. The Baker River enters the Skagit River at RM 56.5, near Concrete. Lower Baker Dam, located at RM 1.1 of the Baker River, impounds Lake Shannon. Upper Baker Dam, at RM 9.1, impounds Baker

Lake. Salmon collected in the lower Baker River are transported above Upper Baker Dam and released for spawning.

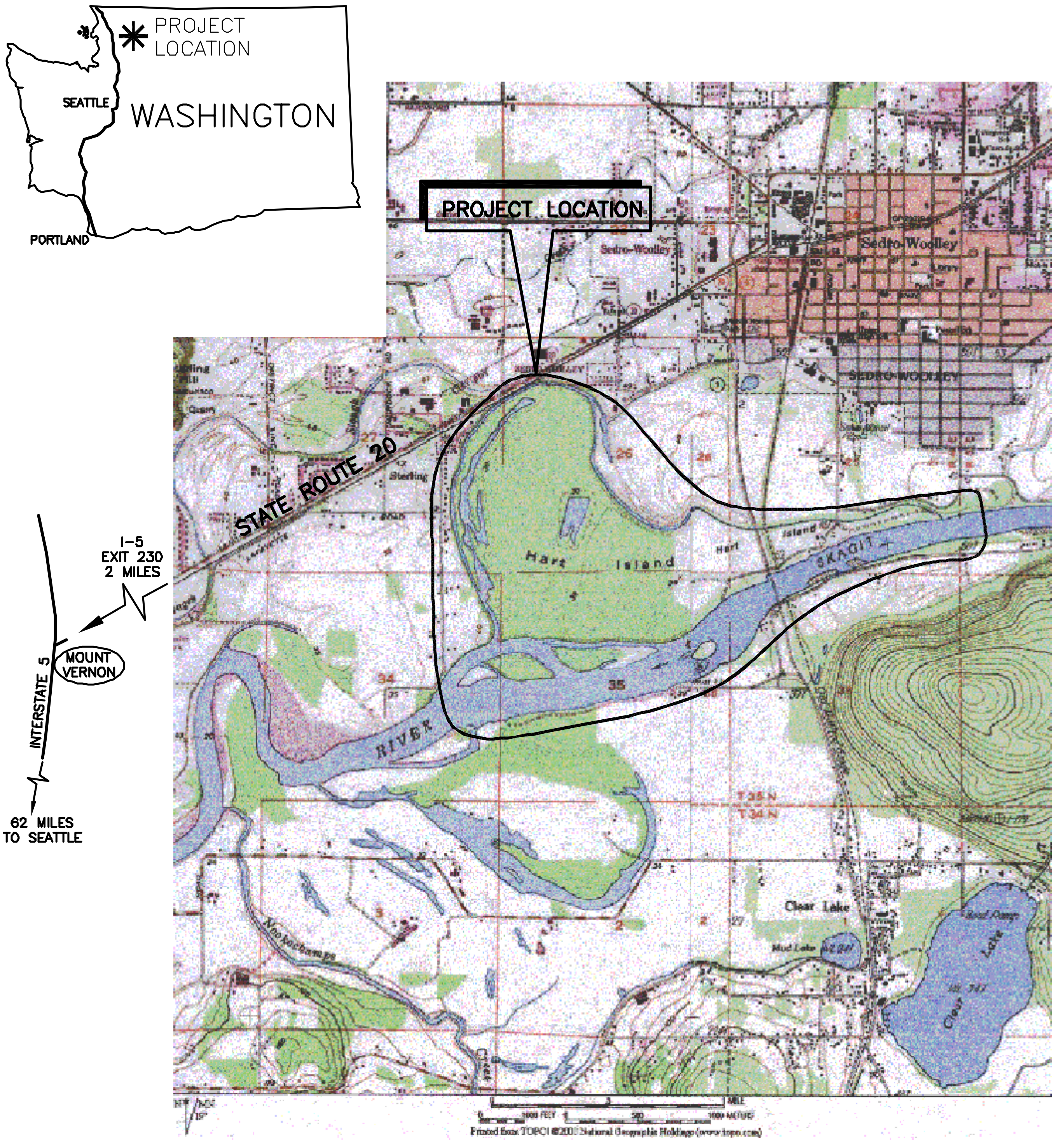
Below Sedro Woolley, the Skagit River meanders through lowland areas, with extensive pool and glide habitats. Floodplains in this portion of the basin have been developed for agricultural, industrial, and residential uses. The lower 19 miles of the Skagit River contain 62 miles of sloughs and over 100 miles of drainage ditches. Dredging is required to maintain various sloughs (U.S. Army Corps of Engineers, 1973). Hart Slough, along with DeBay's Slough, are remnant channels of the mainstem Skagit River within this reach.

The lowermost portion of the Skagit River basin has been developed for agricultural, urban, logging, and flood control uses. The original floodplain is protected with dikes and levees, and now exists as nearly level alluvial bottomlands, most less than 10 feet above sea level. The land is artificially drained by ditches and canals that are protected from flooding by tide gates and pumping into the Skagit River, Skagit Bay, or Swinomish Channel when necessary (WDOE 1996).

The Skagit River divides into two outlet channels, the North Fork and South Fork, about 10 miles above the mouth (FERC 1996). Before emptying into Skagit Bay on the Puget Sound, the Skagit River flows through 90,000 acres of property lying in a floodplain. The extensive Skagit River delta floodplain is approximately 11 miles across an east-west axis, and 19 miles along a north-south axis containing numerous channels, sloughs and drainage ditches.

2.1.2 Hart Slough

Hart Slough / Hart Island are located along the Skagit River, south of the town of Sedro Woolley (Figure 1). The slough is located along the northern side of the Skagit River at approximately RM 21.0 to 23.3. Highway 9 traverses the eastern portion of the slough. Historically, the Skagit River flowed north at this location towards the Seattle and Northern railroad line and then looped back south toward Debay's farm (Figure 2). Hart Island and Hart Slough were created when the Skagit River channel was altered in the early 1900's (see Section 2.2.2). Hart Slough is approximately 4 miles in length and remains connected with the mainstem Skagit River at both the inlet and outlet. Stream flow from Brickyard Creek enters the slough approximately 1.5 miles upstream of the outlet. The lower, approximately 2.5 mile, portion of the slough remains wetted year-round from a combination of groundwater inflow, backwaters from the Skagit River, stream flow from Brickyard Creek, and inflow from the Skagit River at the inlet. The slough currently only receives water at the inlet during high flow events, with approximately 1.5% of the Skagit River mean daily flows (1960 to 2000) occurring at a water surface elevation above that of the slough inlet. During floods, the slough becomes inundated as an active part of the floodplain. Hart Slough has filled in with sediment over time. Beavers actively work the slough evidenced by numerous dams along its length.

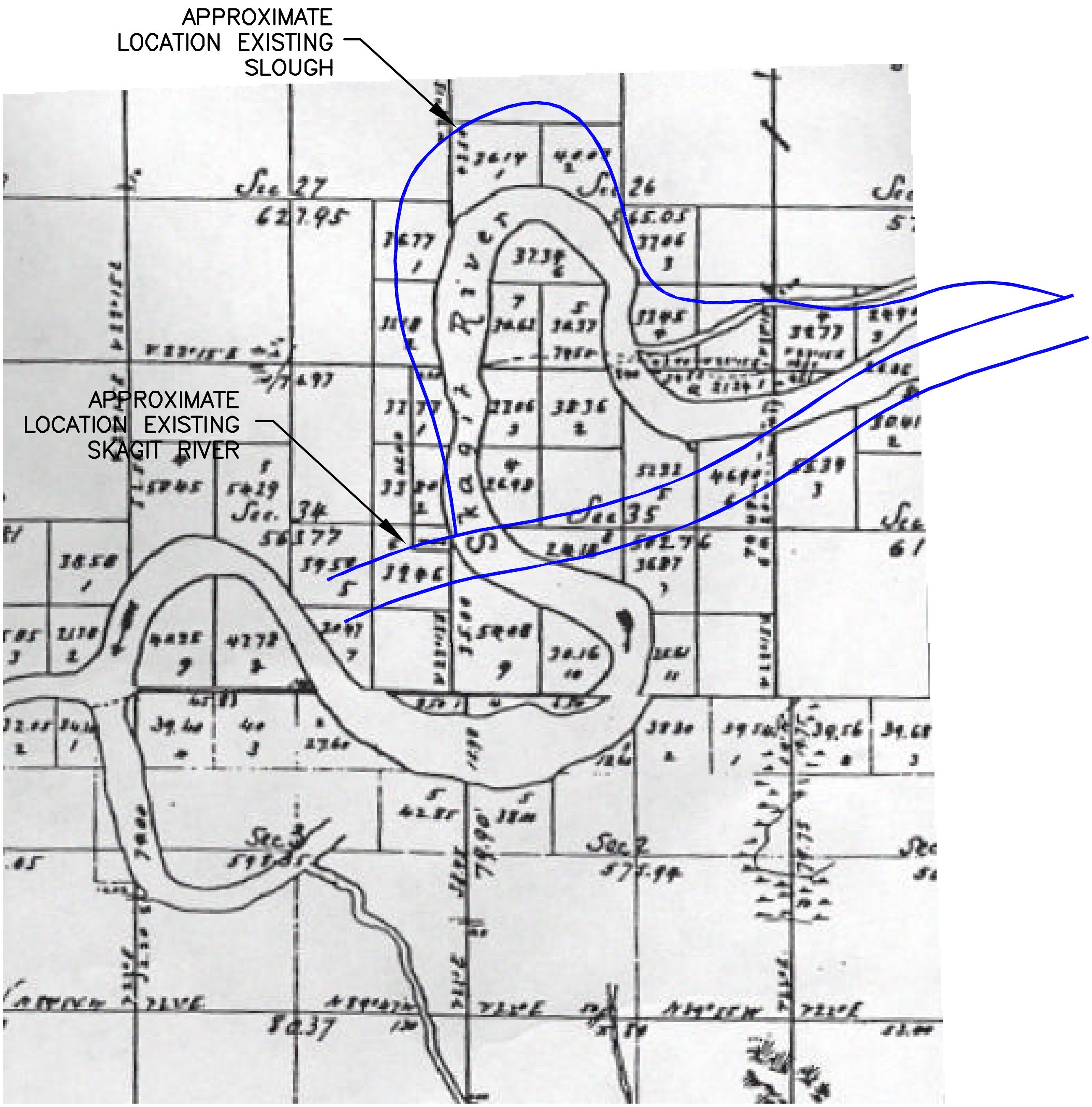


Project Site is near Sedro-Woolley, Skagit County, Washington.

LATITUDE: 122°W 15' 00"
LONGITUDE: 48°N 29' 00"

SOURCE: USGS QUAD: MOUNT VERNON, WA 1981
www.topo.com

FIGURE 1
THE SKAGIT RIVER NEAR HART ISLAND AND HART SLOUGH



DEPARTMENT OF INTERIOR, GENERAL LAND OFFICE, SURVEY GENERALS OFFICE, OLYMPIA, WASHINGTON.

FIGURE 2

MAINSTEM SKAGIT RIVER
1866–1885

2.1.3 Estuarine Areas

Estuarine areas associated with the Skagit delta are a critical habitat component in the production of salmon originating from areas throughout the basin. The Skagit Bay area contains numerous island areas. Mainland shorelines and island beaches provide excellent estuarine characteristics necessary for transition of smolts from fresh to marine waters (Williams et al. 1975). Development and maintenance of navigation channels, combined with flood control, agriculture, and industrial and urbanization in the Skagit delta have resulted in large-scale habitat alterations in the Skagit estuary. The Skagit Bay was formerly a complex floodplain with multiple channels, sloughs, beaver dams, timbered swamps, and marshes. Drift jams up to ¾-mile long occurred in the lower Skagit River. Loss of historical estuarine habitat in the Skagit River is estimated to be 25 percent (Palmisano et al. 1993). Timber snags were removed and channels consolidated for flood control and to facilitate navigation and land development, resulting in loss of productive salmonid rearing areas in the estuary. More than half (56 percent) of historical channels available to salmon in the Skagit River and adjacent deltas are now isolated or inaccessible due to anthropogenic disturbances (SWC 1999). Beechie et al. (1994) found that hydromodification along the Skagit River was the primary factor contributing to habitat loss (73% of summer habitat and 91% of winter habitat), followed by culverts (13% of summer habitat and 6% of winter habitat), and forestry (9% of summer habitat and 3% of winter habitat).

2.2 LAND USE

The first permanent white settlements in the area were established on Fidalgo Island in the late 1850's. Settlement of the tide flats on the mainland soon followed. Clearing and diking of the tide flats created rich farmlands which yielded fine crops of grains and vegetables. In the 1870's, there was a rapid influx of families to the region; schools, churches, farming, logging, and commercial fishing activities were well established. Skagit County was established in 1884 and named after the river and the Skagit Indian Tribe that lived along the riverbanks.

Development in the Skagit River basin began with logging camps established in the 1860's. While the upper Skagit River basin is largely undeveloped, logging and mining have occurred throughout the upper watershed (Pitzer 1978). Railroads were built in the 1890's to support logging, farming, fishing, and mining. Debris jams were cleared from the river to facilitate transport of logs, and marshes were drained for use as agricultural land. Over time, land areas in the lower basin were developed for a combination of residential, commercial, and agricultural uses. Mount Vernon established itself as a major population center for the logging and agricultural community of the late 1800's. Forested lands along the Skagit River floodplain were cleared to support a thriving dairy industry in the area (WDOE 1996). By 1900, habitat modifications combined with over-fishing had reduced salmon stocks in the Skagit River to the point that experimental hatcheries were used to supplement dwindling runs (Skagit County 1996). Today, farming and forest products remain the primary income sources in the lower basin (SCS 1989). Farming, including production of flowers, turf grass, potatoes, and other vegetables is the major land use in the Skagit River delta.

2.2.1 Flood Control / Management

The Skagit River has a long history of flooding. High-water marks have been recorded from time to time, with increasing accuracy, since the first white people settled in the valley in the late 1850's. Prior to that time, documentation of floods relied upon the testimony and tradition of the Native Americans upon certain direct and indirect evidence of high-water marks, and upon flood records elsewhere. Skagit County and the USACOE are currently in the process of conducting a Skagit River Flood Study.

Flood flows have been recorded intermittently since the first gaging stations were established in 1908. Flows on the mainstem Skagit River are currently recorded by the USGS at five sites. As of January 1, 2000, the Skagit River has reached flood stage 66 times since 1900, an average of once every 1.5 years. Over the past 200 years, severe floods in the region were recorded in 1815, 1856, 1897, 1909, 1917, 1921, 1932, 1933, 1935, 1945, 1949, 1951, 1955, 1962, 1975, 1980, 1982, 1984, 1989, 1990, 1995, and 1999.

During high floods, the Skagit River overflows the low divide between the Skagit and Samish River floodplains and the waters from both streams intermingle on the Samish River flood plain. Flood problems of the two streams are, therefore, closely related and both basins are treated as one large basin. The flood plain includes the entire floor of the Skagit River Valley, the deltas and the Samish and Skagit Rivers, and reclaimed tidelands adjoining the Skagit, Samish, and Stilliquamish basins. The flood plain comprises 90,000 acres, including 68,000 acres of fertile farmland downstream, and west of Sedro Woolley. A large portion of the farmland west of Sedro Woolley is protected from small floods by levees, but would be flooded by large floods that overtop or breach levees. While the flood plain is primarily agricultural, it includes a large proportion of the county's urban and rural population, many manufacturing plants, and major transportation routes.

To combat the flooding, landowners along the Skagit River began building dikes as early as 1863. In 1895, the Legislature passed legislation allowing landowners to organize and create public diking districts. These diking districts are independent of any other governmental authority. They have the power of eminent domain, RCW 85.05.070, the power to assess taxes against district properties proportionate to the benefits the properties receive from creation of the dikes, RCW 85.05.075, and the power to issue bonds to fund construction of the dikes, RCW 85.05.078. By 1990, 16 diking districts had been created to maintain approximately 56 miles of levees and 39 miles of sea dike in the Skagit River delta.

Annual peak flows in the Skagit River basin have been reduced through flood control by dams. Pre-development annual peak flows in the lower Skagit River commonly exceeded 200,000 cfs. For instance, flood events in 1815 and 1856 were estimated to be 400,000 and 300,000 cfs, respectively (Kunzler, 1991). Flows in excess of 200,000 cfs have not occurred since dams were constructed and flood regulation was implemented.

2.2.2 Channel Changes near Hart Slough

Prior to 1921, the Skagit River, at the present Hart Island, made a sharp meander north up nearly to where the Seattle and Northern (S & N) tracks ran west to east, and a corresponding meander south near DeBay's farm (Figure 2). A series of events around the turn of the century put in motion several changes in the Skagit River channel in this area. An historic account of these changes is presented below.

In the early 1890's, this horseshoe bend in the Skagit River was rapidly cutting away the bank and approaching the S & N track. In 1897, an appropriation of $35,000 from Congress was granted to cut a new channel through the neck of the peninsula. However, the appropriation came with a rider attached that required waivers of damage from all owners of property abutting the river for five miles down the river below the proposed cutoff. The appropriation lapsed because of the difficulty in obtaining waivers. The river continued cutting into the bend and by 1908 had washed away hundreds of acres of farming land. Leonard Halvorson (pers. comm.) remembers the stories of government engineers blasting a hole through the southern neck of the peninsula during a flood in 1911. They went ahead and implemented this emergency procedure without authorization of the farmers downriver as the rider of 1897 had suggested. The action resulted in a reduction in channel length and an accompanying increase in channel gradient.

Correspondence from the period documents the rapid channel changes that occurred:

"In November of 1911, the river cut a channel across Sterling Bend, but not in a location entirely eliminating the bend. There is now (1912) a fall of about 5 feet in 3,000 feet, or a slope of 8 1/3 feet per mile, where there was formerly a slope of only 2 feet per mile by the channel around the bend." Preliminary Examination Skagit River, WA, Major J.B. Cavanaugh, Corps of Engineers.

"There have been several changes due to the hand of man. The dikes along the river tend to raise the stage for a given discharge by prevention of flow and channel storage in the bottomlands. About November 20, 1911, the river cut across Sterling Bend (aided by dynamite) below the Northern Pacific Bridge at Sedro Woolley. This cause a rapid lowering of the stream bed due to cutting off 2.5 miles of river, and by 1917 three feet less gage height than prior to November 20, 1911." Skagit River Flood Report, James E. Stewart, USGS.

The first time the river cut completely through was during the flood of (December 12-13) 1921 creating what is now the main channel. In 1936, Joe DeBay told Catherine McClintock of the Courier-Times that it was in the big flood year of 1921 when the river began eating the neck of the peninsula and isolating part of his farm as an island with the new channel of the river on the northwest and another channel cutting through on the southeast. Successive floods in 1923 and 1924 deepened the main channel and DeBay Island was formed, with the farm as the dominant feature. Debay Island was essentially a very large mound of silt and sand that formed in the middle of the Skagit River between the town of Sterling and what is now the Francis Road area on the south shore. Recent developments in channel meander patterns and bar developments noted by the U.S. Army Corps of Engineers (Pentech, 2002) indicate that the confluence of Hart Slough and the Skagit mainstem may be impacted by meander development within the next few decades.

2.3 FISHERIES RESOURCES

The Skagit River basin is comprised of a variety of stream types, and nearly all accessible reaches provide suitable habitat for a variety of salmonid species. Most of the anadromous and resident species identified in the Puget Sound region occur in the Skagit River basin (Williams et al. 1975). Salmonids were historically abundant throughout the basin, with nine anadromous species and ten native salmonids present (Table 1). Among these species, bull trout, cutthroat trout, and rainbow trout (steelhead) are the most widely distributed fish, occurring both above and below major dams in the basin. Three exotic salmonids, brook trout, golden trout, and Arctic grayling were introduced to the basin during the 1900's (Envirosphere 1988). The Skagit Salmon Hatchery, operated by the Washington Department of Fish and Wildlife (WDFW) and located near Marblemount, has produced principally fall chinook salmon and coho salmon. Minor plantings of spring chinook salmon, chum salmon, and pink salmon from the hatchery have occurred (Williams et al. 1975). Relatively small numbers of steelhead were produced at the hatchery, most prior to 1963. Since 1995 steelhead production from WDFW hatcheries in the basin have ranged between 400,000 and 500,000. In addition, a steelhead rearing facility located in Barnaby Slough near Rockport produced steelhead smolts for release into the Skagit (Graybill et al. 1979).

Table 1: Primary distribution of 13 salmonid species in the Skagit River basin.

The first 10 species listed are native to the basin; however, non-native stocks have been introduced for many of these species (SCL 1974, WDF et al. 1993, WDFW 1998a, WDFW 1998b, FERC 1998).

Common name (phases in basin)	Scientific name	Primary distributions in Skagit River basin
Chinook salmon (anadromous)	O. tschawytscha	Spring runs in tributaries including Sauk, Suiattle, Cascade Summer/fall runs in mainstem reaches below dams
Coho salmon (anadromous)	O. kisutch	Throughout basin, primarily in tributaries
Chum salmon (anadromous)	O. keta	Primarily mainstem reaches and major tributaries including the Sauk River
Pink salmon (anadromous)	O. gorbuscha	Primarily mainstem reaches of Skagit, Sauk, and Suiattle rivers
Rainbow trout (resident) Steelhead (anadromous)	O. mykiss	Mainstem, tributaries, and headwaters above and below dams
Kokanee salmon (resident) Sockeye salmon (anadromous)	O. nerka	Baker and Shannon lakes Baker River
Bull trout (anadromous and resident)	Salvelinus confluentus	Mainstem, tributaries, and headwaters above and below dams
Dolly Varden (anadromous and resident)	S. malma	Tributaries above and below dams
Cutthroat trout (anadromous and resident)	Oncorhynchus clarki	Mainstem, tributaries, and headwaters above and below dams
Mountain whitefish (resident)	Prosopium williamsoni	Assumed to be distributed throughout the basin
Arctic grayling (resident)	Thymallus arcticus	Upper Granite Lake, a tributary to the Cascade River
Golden trout (resident)	O. aquabonita	Skagit River above dams
Brook trout (resident)	S. fontinalis	Above anadromous fish barriers

2.3.1 Anadromous Fish Species / Habitat Use

Most of the Skagit River basin, up to natural barriers located on tributary streams, is available to anadromous salmonids. Migrations in the Baker River drainage are blocked by the Lower Baker Dam; however, trap and haul facilities there provide fish migrating upstream to spawn access to the upper basin (FERC 1998). Gorge Dam blocks the mainstem Skagit River near the historical upper limit of chinook salmon, reported to be at Goodell Creek, which now empties into Gorge Reservoir (Envirosphere 1988). The primary stream types used by anadromous salmonids in the Skagit River basin are summarized below:

- Spring chinook salmon spawn throughout the basin, using primarily tributary reaches for spawning. Summer and fall chinook in the Skagit River basin are managed collectively as a single stock, and generally spawn in riffles of larger tributaries and the mainstem river. Supplementation of the summer/fall stock by the WDFW occurs at the Skagit Salmon Hatchery near Marblemount (WDF et al. 1993).

- Coho salmon spawn in most accessible tributaries to the basin and areas above Baker Dam, where access is provided through a trap and haul program (WDF et al. 1993). However, limiting factors in coho production are also largely related to rearing habitat, such as what Hart Slough could provide (Beechie et al. 1994).

- Pink salmon exhibit a strong cyclic dominance in the Skagit River basin, and spawn during odd years below natural and man-made barriers in the mainstem Skagit River and numerous tributaries. The majority of pink salmon are considered to be of natural origin. Incidental transport of pink salmon above Baker Dam may occur (WDF et al. 1993).

- Chum spawn in the mainstem Skagit River from RM 34-93, frequently in braided channels and sloughs. Some tributary spawning also occurs below barriers. Spawning of chum salmon above Baker Dam is incidental to trap and haul operations (WDF et al. 1993).

- Sockeye salmon in the basin are primarily associated with lake systems and most are confined to the Baker River system, a run considered near extinction in recent years. Few sockeye salmon may spawn in the mainstem Skagit River near Gorge Dam, and in the Sauk River basin (WDF et al. 1993).

- Two races of steelhead occur in the Skagit River basin below barriers. Winter run steelhead enter the river from November to June, spawning the following spring (FERC 1998). Rainbow trout, the resident phase of steelhead, are distributed throughout the basin including the lower river, most tributaries, and reservoirs, and headwater reaches (FERC 1998, Envirosphere 1988).

- Cutthroat trout spawn throughout the Skagit River basin, and use a variety of habitats from fast water to lowland streams. Most sea-run cutthroat spawn in lower tributaries of the Sauk River and northern tributaries downstream of the Sauk River (WDFW 1998b).

- Dolly Varden and bull trout are managed collectively as a single species by the WDFW, due to similarities in appearance and habitat requirements. Both species may spawn in gravel riffles of tributary streams above and below dams, and may migrate to mainstem areas and Puget Sound (WDFW 1998a).

Generalized freshwater life cycles of Skagit River anadromous salmonids are summarized in Table 2.

Table 2: Generalized freshwater life history timing of anadromous salmonids in the Skagit River basin.

Adapted from FERC (1998) with additional information from Williams et al. (1975), WDF et al. (1993), and WDFW (1998a; 1998b).

Species - run	Spawning	Incubation	Juvenile rearing	Peak juvenile out migration	Typical freshwater residency
Chinook:					
Spring	July - Sept	July – Jan.	All year	Mar. – July	11 to 16 months
Summer/fall	Sept. – Nov.	Sept. – Feb.	Dec. – July	Mar. – June	3 to 6 months
Coho	Oct. – Jan.	Oct. – Apr.	All year	Mar. – July	12 to 16 months
Pink	Aug. – Oct.	Aug. – Apr.	Jan. – May	Feb. – May	1 to 3 months
Chum	Nov. – Jan.	Nov. – Apr.	Feb. – June	Feb. – June	1 to 4 months
Sockeye	Sept. – Dec.	Sep. – March	All year	Mar. – July	12 to 15 months
Steelhead:					
Summer	Feb. – June	Feb. – July	All year	Mar. – July	22 to 26 months
Winter	Dec. - June	Dec. – July	All year	Mar. – July	22 to 26 months
Cutthroat trout	Dec. - May	Dec. – June	All year	May – Aug.	22 to 50 months
Dolly Varden / bull trout	Sept. – Nov.	Sept. – Apr.	All year	June – Aug.	22 to 38 months

2.3.2 Resident Fish Species / Habitat Use

Resident fish occupy streams throughout the basin. Information of distribution and abundances of resident fish is spotty, especially for non-salmonid species. Common non-salmonid resident fish in the basin are sculpins, suckers (Catastomidae), and dace (Cyprinidae) (FERC 1998). Although presence of these fish may be noted during surveys for salmonids, specific data are generally not collected by management agencies.

Within the Skagit River basin, rainbow trout exhibit resident and migratory life histories, and occupy mainstem reaches, tributaries, and lakes. Cutthroat trout use life history strategies similar to rainbow trout, and occur in similar habitats. Rainbow trout and cutthroat trout are distributed throughout the basin, including areas above dams, and their presence is most commonly reported in surveys of Skagit River tributaries (FERC 1998). Brook trout were introduced to areas above dams in the early 1900's, and stocking continued at various levels throughout the century (Envirosphere 1988). Arctic grayling were introduced from a Montana stock into Upper Granite Lake of the Cascade River. Mountain whitefish are reported variously throughout the basin; however, comprehensive distribution information is not available (FERC 1998). Resident populations of bull trout and Dolly Varden occur throughout the basin, including areas above dams. Dolly Varden are generally thought to spawn higher in the watershed than bull trout (Kraemer 1994).

3 Study Goals and Objectives

With Steering Committee input, a set of project goals and objectives was developed to address the following primary elements and functions:

- Fish Habitat (with specific emphasis on salmonid rearing and overwintering habitat, flood refugia, and access between the mainstem, slough, and island habitats),
- Hydraulic Connectivity,
- Geomorphic Function (with emphasis on sediment transport),
- Floodplain / Riparian Vegetation,
- Water Quality (with emphasis on temperature),
- Property Ownership / Acquisitions / Easements, and
- Civil Infrastructure (with emphasis on bridges, roadways, and utility crossings).

The Steering Committee established the overall goal for the enhancement of Hart Slough and Hart Island as:

➢ Improve fish and wildlife habitat in Hart Slough and on Hart Island property

Site specific goals and objectives were also established. The goal for Hart Slough is to optimize the availability of high quality, salmonid rearing and overwintering habitat. This goal will best be met by achieving the following objectives:

- Provide a predictable source of year-round flow to the slough

- Provide efficient access between mainstem and slough habitats

- Improve water quality throughout slough (dissolved oxygen, temperature)

The goals for areas on the island (Interior Areas) are:

A) Optimize the availability of high quality, salmonid rearing habitat

Provide additional flow to ponded interior areas

B) Provide flood refuge

Provide efficient access between mainstem and ponded interior areas used as flood refuge and minimize stranding

C) Protect existing waterfowl habitat.

4 Technical Approach to Feasibility Study

The technical approach to characterizing existing conditions and evaluating alternatives relied heavily on the use of topographic and hydrologic information to model and quantify physical attributes of Hart Slough and Hart Island. These physical attributes were then used to make inferences about habitat conditions. The following sections describe the individual components used in the technical analysis.

4.1 Topographic Surveys

The feasibility investigation relied on topographic data collected during three independent surveys conducted between 1999 and 2001. These data were standardized to common datum and used to create the HEC-RAS hydraulic model of study area. The following is a brief description of each of the surveys.

- Ducks Unlimited Survey

This survey was conducted in 1999 by Skagit Surveyors of Sedro Woolley. This survey provided a longitudinal profile of the slough channel from the inlet to Brickyard Yard Creek. Measurements of thalweg depth (channel elevation) were collected at 50-foot intervals through the surveyed reach. Datum used was NGVD 29.

- Aerial Photogrammetric Survey

As part of this feasibility investigation, Inter-Fluve contracted with DeGross Aerial Mapping service to conduct an aerial photogrammetric survey of the western portion of the Hart Island and Hart Slough. The intent of this survey was to provide topographic information to complement existing information. Data generated from the aerial flight (December 2001) included 2-foot contours within the flight coverage and referenced NAVD 88 datum. Data were converted from NAVD 88 to NGVD 29 and merged with information gathered during the Ducks Unlimited Survey. The resulting product was a comprehensive topographic survey of the slough and western portion of the Hart Island.

- Ground Survey

Inter-Fluve conducted additional surveying of channel cross sections at representative and critical locations within the upper 8000 feet of the slough. This reach of slough was not included in the aerial topographic mapping. The sections were used to characterize channel characteristics in the portion of the slough proposed for excavation under several of the alternatives. A total of 6 cross sections were surveyed: 2 near the inlet, 2 near the Third Street Bridge at Janecki Cove, and 2 downstream of State Route 9. Data referenced NAVD 88 datum.

4.2 Hydrologic Analysis

Representative Skagit River flows at Hart Slough for the 2-, 10-, 50- and 100-yr events included in the HEC-RAS model were obtained from the Skagit River Flood Damage Reduction Study (USACOE, 2002). These flows are summarized in Table 3.

Table 3: Peak Skagit River flows used for Feasibility Analysis.

Event	Skagit River peak flow (cfs) at Hart Slough (Source: USACE, 2002)
2-Yr	64,640
10-Yr	127,000
50-Yr	182,671
100-Yr	213,495

Flow and stage frequency analyses for the more frequent, lower discharges were conducted based on existing information. The analysis relied heavily upon the larger data set from the Mount Vernon gage with correlations developed with the Sedro Woolley gage. The minimum instream flow value of 10,000 cfs (instantaneous flow) per WAC 173-503 was used as low flow value for comparison of alternatives. (It should be noted that from WAC 173-503, instream flow minimums vary from 11,000- to 13,000-cfs for the time periods of April through June and October through December 15, for a total of 5.5-months of the year.) An analysis of seasonal flow availability was also conducted to contrast summer and winter flow conditions and associated benefit.

Hydrologic records were obtained from the U.S. Geological Survey (USGS) for stations along the Skagit River in proximity to Hart Slough. Mean daily discharge data were obtained from the USGS gage at Mount Vernon (Gage 12200500, RM 15.7) for the period of record (1940 to present). Similarly, mean daily discharge and stage data were compiled and analyzed for the USGS gage at Sedro Woolley (Gage 12199000, RM 22.3). At the Sedro Woolley gage, discharge data were limited to the period of 1975 to 1980. Stage data only have been collected since 1999.

4.3 HYDRAULIC MODELING

The U.S. Army Corps of Engineer's (USACE) one-dimensional River Analysis System (HEC-RAS) version 3.0 was used to predict hydraulic conditions along the slough including: water surface elevations, flow regimes, and shear stress for each of the alternatives proposed for slough enhancement.

Within the slough, cross sections were generated from aerial topography by DeGross Aerial Mapping and cross sections recorded by Inter-Fluve. All cross sections referenced NGVD 29 datum. Cross sections extended beyond the channel boundaries but did not extend to the limits of flooding for all events. Thus, the model is not intended to predict flood water levels. Rather, this model was developed for the planning level study to provide an equal basis for comparing the alternatives. Hydraulic parameters were generated at 33 cross sections along Hart Slough. For existing conditions and each alternative, the split flow optimization option of HEC-RAS version 3.0 was used to estimate the flow conveyed along Hart Slough for all of the modeled flows.

Cross sections for the Skagit River portion of the model were obtained from an existing UNET hydraulic model provided by the USACE. The UNET model represents the Skagit River from the mouth to river mile 55.35. The Hart Slough area is between river mile 20.9 to 23.3. Locations of the UNET sections along the Skagit River in the vicinity of Hart Slough (river mile 20.0 to 25.2) were identified and copied into the project HEC-RAS model. Between the inlet and outlet of the slough, right overbank portions of the original UNET sections were removed from the model, with overbank flows accounted for in cross sections of the Hart Slough reach.

Eleven Skagit River flows were included in the HEC-RAS model. Flows for the 2-, 10-, 25- 50- and 100-year events along the Skagit River at Hart Slough were provided by the USACE (2002). In addition, six low flow discharges (4,000; 5,000; 6,000; 7,000; 10,000; and, 15,000 cfs) were arbitrary selected to bracket typical low flow conditions near the slough.

Downstream HEC-RAS model boundary conditions for the larger flood events were defined by the water surface elevations predicted by the USACE UNET model. Lower flow boundary conditions and upstream boundary conditions were defined by normal flow depths based on the average channel profile slope.

A number of beaver dams exist along the slough. The heights of these dams limit freely flowing water along the slough for low flows. For Alternative B conditions, slough flows that begin to overtop the dams correspond to Skagit River flows of approximately 11,000- to 12,000-cfs. At higher flows, the dams will be overtopped and will not have as profound an inhibition of Slough flows. From the flow duration curve shown in Figure 5, 12,000-cfs flows along the Skagit River occur approximately 10-percent of the time less frequently than the minimum 10,000-cfs flow conditions considered for this study. Average monthly flows along the Skagit River were calculated from average daily flows recorded at the Mt. Vernon gage over the period of record from October 1, 1940 through September 30, 2000 (Table 6). The monthly average for September was less than 10,000-cfs. The monthly average for August was 11,800-cfs. The monthly average flow for all other months exceeded 12,000-cfs.

The degree to which flow can permeate the beaver dams is, at best, difficult to model. In order to compare each alternative on an equal basis for this feasibility study, and considering that overtopping flows begin for flows slightly greater than the minimum flow considered in this study, the HEC-RAS model was simplified by considering the beaver dams to be “hydraulically transparent” and omitting them from the model. It must be stressed that beaver dams provide very valuable habitat and their physical removal is not intended or suggested.

If necessary, a number of techniques exist for physically conveying low flows (less than overtopping flows) through the beaver dams. One such method to convey water downstream is to place a PVC pipe through the dam with the inlet below the upstream pond surface. The pipe outlet is placed higher than the inlet to submerge the inlet, preventing the sound of running water at the inlet that stimulates the beavers to block the escaping flow. This allows downstream conveyance of water and, with a sufficiently large pipe and low velocities, the upstream and downstream passage of juvenile fish. Design methods enable setting invert elevations at the inlet and outlet to provide the desired level of through flow. For Alternative B conditions approximately 10-cfs passes along the slough during 10,000-cfs Skagit River flows. For 12,000-cfs Skagit River flows interim model results indicate slough flows of approximately 25-cfs. A small number of PVC pipes between 6- and 12-inches in diameter can easily convey these flows.

The existing conditions HEC-RAS model was copied and modified for each alternative. The one exception was Alternative B, which was based on the Alternative A model.

4.4 GROUNDWATER INVESTIGATIONS

A preliminary investigation of groundwater availability was conducted during a one-day investigation on May 10, 2002. This investigation involved a pump / drawdown test at a previously excavated pond on Hart Island. The intent of the test was to provide information on the sustainable groundwater inflow volume present on that date under the prevailing seasonal river conditions. River stage at the Sedro Woolley gaging station was 25.3 feet on the day of the test. Discharge in the river was variable during the 60 days preceding the test ranging between 12,300 and 44,700 cfs, and averaging 19,022 cfs. Due to the limited amount of data, a correlation between river and groundwater conditions is not possible. Observations by local residents (pers. comm. L. Halverson) suggest a 30-day lag time between when changes in river conditions are observed in groundwater levels. It is presumed that there is considerable temporal and spatial variability in this relationship.

In addition to the pump test, a literature review was conducted to determine the extent of knowledge regarding groundwater availability and soil conditions in the study area.

5 Existing Conditions

5.1 EXISTING HABITAT

The quantity, quality, and value of fish habitat in both the slough and the interior areas on the island are temporally and spatially variable, attributed to a combination of both flow and non-flow related factors. The slough and floodplain are low gradient, prone to stagnation during the summer and frequent flooding during other times of the year. The topography of the floodplain and slough habitat in this general area results in poor water quality (elevated temperature, diminished dissolved oxygen) during the summer and sediment deposition during floods. The riparian community along the slough is well established. These conditions provide ideal habitat for beaver, which have been observed throughout the project area. These conditions also provide ideal salmonid rearing habitat, though stranding may be a concern. Improved flow through the project area will increase habitat area, enhance habitat access, and improve water quality during certain critical portions of the year.

5.2 PHYSICAL CONDITIONS

5.2.1 Geology / Soils

The Skagit series consists of deep, drained and protected soils that are naturally poorly drained and subject to flooding. They formed in recent alluvium and volcanic ash on floodplains at elevations ranging from 5 to 50 feet with slopes between 0 to 2 percent. The particle-size control section lacks coarse fragments, averaging less than 15 percent fine and coarser sand, and 18 to 30 percent clay and containing 20 to 50 percent volcanic glass.

In the vicinity of Hart Island, numerous groundwater wells have been installed for domestic and agricultural purposes. Well locations are shown on Figure 3 and listed in Table 4. Soil conditions observed during the installation of these wells provide useful information on soil composition and stratigraphy. These observation records indicate the presence of large deposits of fine-grained materials (primarily sand) in the study area (Table 4).

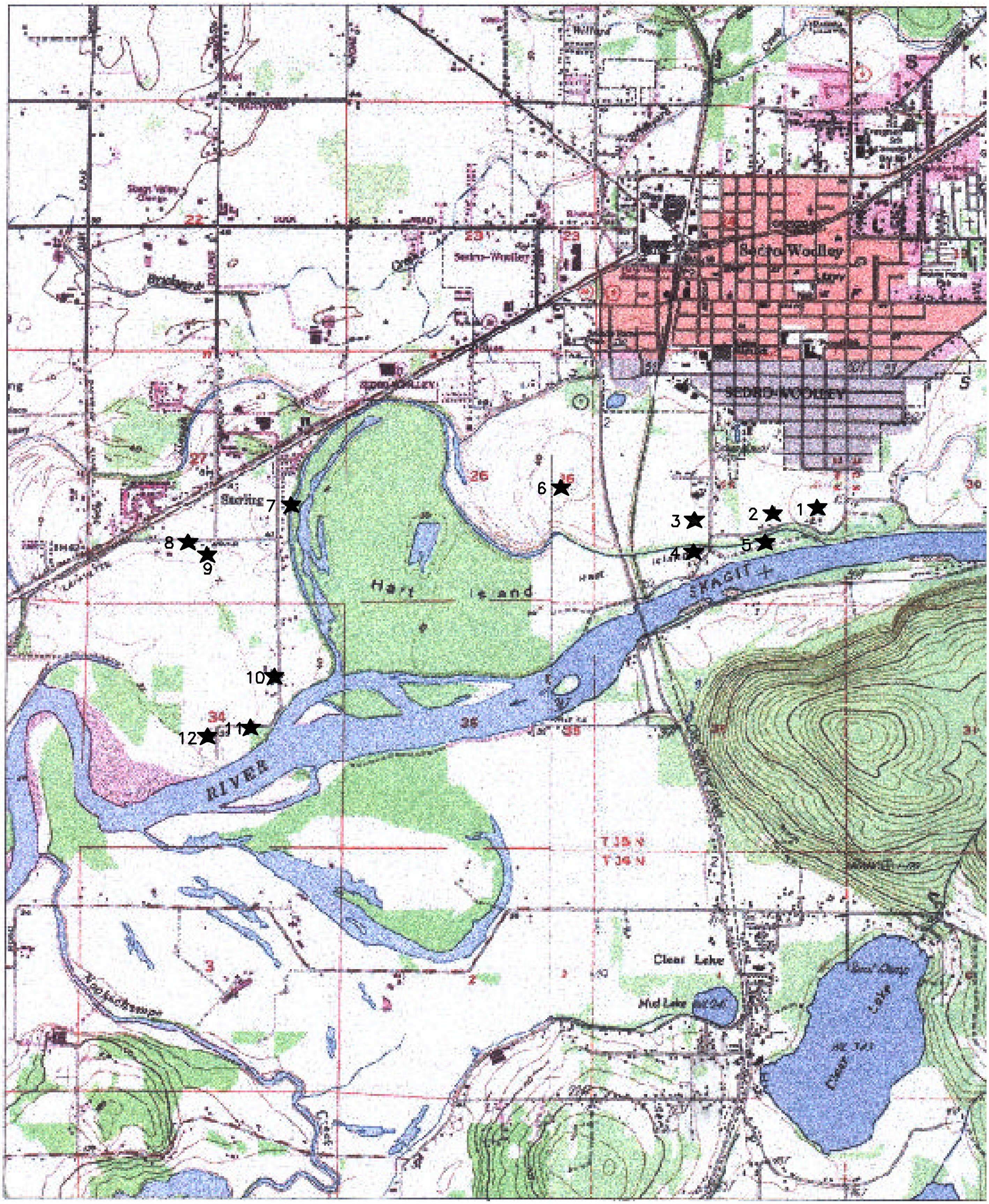
5.2.2 Topography

The Skagit River, near Sedro Woolley, meanders through lowland areas, with extensive pool and glide habitats. Water slope of the mainstem in the study area is generally less than 0.002 feet / feet (Figure 4). Floodplains in this portion of the basin have been developed for agricultural, industrial, and residential uses. Hart Slough, the remnant channel of the mainstem Skagit River, lies in this reach. The energy slope of Hart Slough is substantially lower than the mainstem (Figure 4). The channel invert (thalweg) profile along the slough is also shown on Figure 4.

5.2.3 Hydrology

Annual precipitation in the lower Skagit River basin, near Mount Vernon, averages 32 inches (WDOE 1996). However, precipitation in the Skagit River basin varies both seasonally and with elevation. Most precipitation occurs in late fall to early spring. The summer months of July and August typically have the lowest stream flows. Precipitation above 1,000 feet elevation occurs mostly as snow during winter months. However, heavy winter rainfall associated with high intensity Pacific storms may occur during warm periods after heavy snowfall in the mountains.

The influence of the maritime air masses is pronounced in both the precipitation and temperature regimes, producing a mild but wet climate. During the winter the Skagit Basin, lying directly in the storm path of cyclonic disturbances from the Pacific, is subject to convective showers which are frequently heavy and may follow in quick succession. On the mountain slopes, storm precipitation is heavy and almost continuous as a result of the combination of frontal and oceanographic effects. Skagit River floods result from storms that, moving in from the Pacific Ocean, have their rainfall intensified as the air currents are forced upward over the Cascade Mountains. Temperatures accompanying the storms are often high enough to melt part of the snowpack.



* WELL DESCRIPTIONS IN TABLE 4

USGS, SEDRO WOOLLEY, WA 1975
NO SCALE

HART SLOUGH

FIGURE 3
MAP OF GROUNDWATER WELLS, DROST 1978

Table 4. Soil conditions observed during well installations near Hart Slough, From Driller's Log of Wells, Drost 1978

Figure 3 ID	Local Well No.	Well Depth (feet)	Composition and Depth (ft) of Successive Layers				
			First	*Second*	*Third*	*Fourth*	*Fifth*
1	35N04E-25J01	18					
2	35N04E-25K01	29	Sand (18)	Sand, fine (2)	Gravel (9)		
3	35N04E-25L01	36	Soil and Clay (17)	Sand and Gravel (3)	Gravel and Coarse Sand (2)	Gravel (14)	
4	35N04E-25P01	20					
5	35N04E-25Q01	25					
6	35N04E-26J01	34	Sand, light brown (12)	Sand, light brown - gray, some water (5)	Sand and Gravel, water bearing (6)	Gravel, coarse, water bearing (11)	
7	35N04E-27J01	18					
8	35N04E-27N01	40	Soil (3)	Clay (10)	Sand, coarse (2)	Gravel, coarse (25)	Clay (1)
9	35N04E-27P01	19					
10	35N04E-34G01						
11	35N04E-34K01	14					
12	35N04E-34L01	20					

Figure 4a - Hart Slough Water Surface Profiles

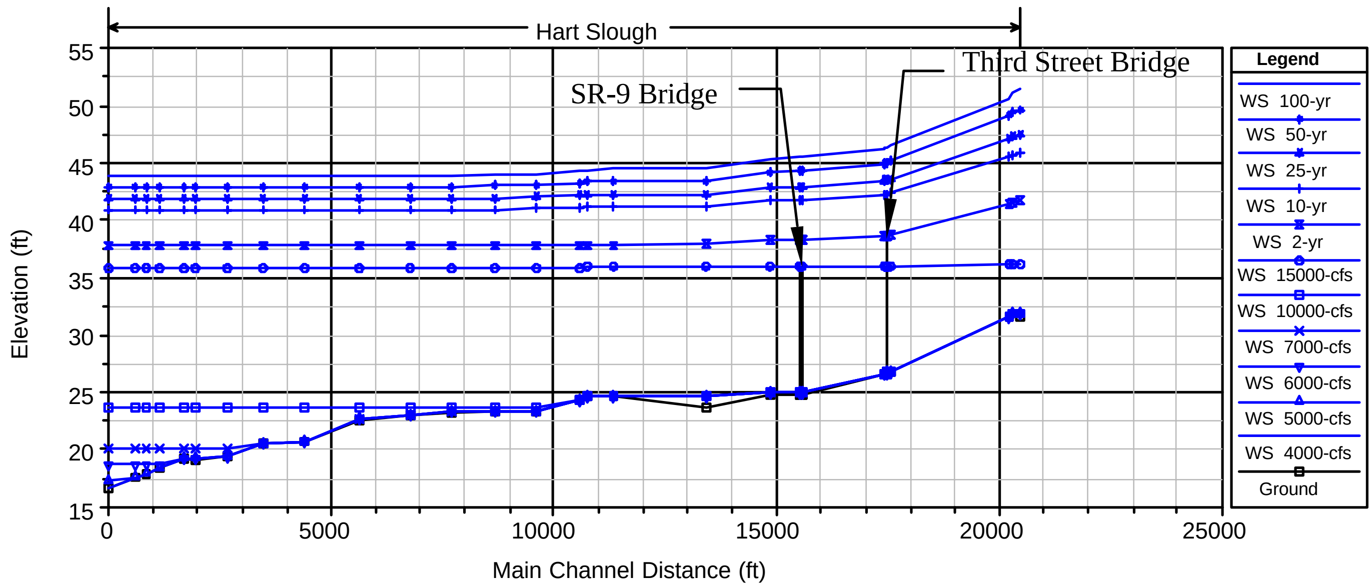
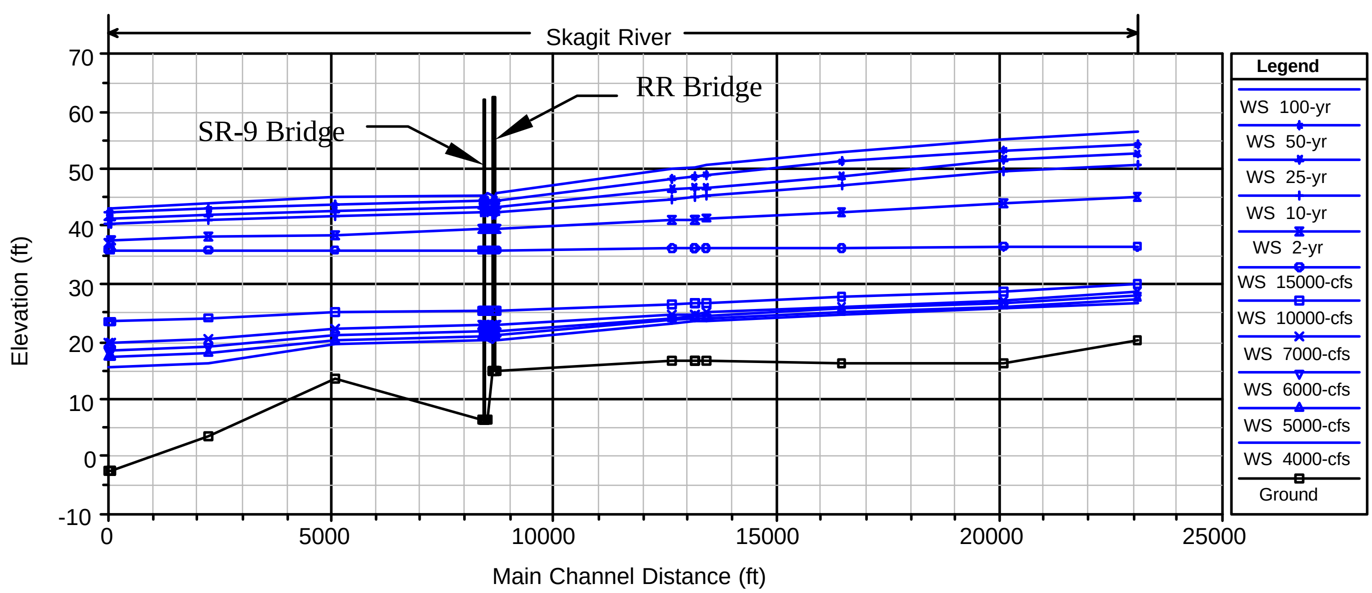


Figure 4b - Skagit River Water Surface Profiles



During the months of November through March when temperatures, particularly at higher elevations, are at or near the freezing point and much of the precipitation occurs as snow, a base flow is maintained in the river. However, sharp increases in river stage, resulting from concentrated 2 to 5 day storms or series of storms, are frequently experienced in this period. These intense storms when accompanied by warm winds and resultant snowmelt produce rapid run-off. During and following these severe storms, river discharges may increase from a relatively low base flow to a discharge of damaging magnitude with 24 to 30 hours duration. Near crest discharges may be maintained for a few hours, followed by a rapid recession. Two or three such increases in stage may be experienced within a period of two weeks. Not all increases in river stage reach flood level, however, and these usually are more frequent and reach higher levels in late October, November, and December.

5.2.3.1 Surface Water

Flows on the mainstem Skagit River are recorded by the U.S. Geological Survey (USGS) at five sites. Discharge data for the USGS gage at Mount Vernon (Gage 12200500, RM 15.7) is particularly relevant to this feasibility investigation because of the long period of record. The average mean annual discharge at this site is 16,520 cfs (Table 5). In terms of monthly flow, the average minimum discharge typically occurs in September while the average maximum discharge typically occurs in June. An analysis of mean daily flow exceedence, including an analysis of seasonal flow variation, was conducted based on existing information (Figure 5).

An analysis of stage frequency at the Sedro Woolley gage was also conducted. The data set was expanded by correlating discharge between the Mount Vernon and Sedro Woolley gages. Figure 6 depicts stage frequency at the Sedro Woolley gage, near the inlet to Hart Slough.

Table 5: Summary statistics for Skagit River at Mount Vernon gaging station.

GAGE	Period of Record	Location RM	Drainage Area (sq. mi.)	Average Annual Discharge (cfs)			Average Monthly Discharge (cfs)	
				Minimum Flow (Yr)	Mean	Maximum Flow (Yr)	Minimum Flow (Mo)	Maximum Flow (Mo)
Mount Vernon	1941-99	15.7	3,093	10,930 (1944)	16,721	22,250 (1997)	9,406 (Sept)	24,803 (June)

The Washington Department of Ecology (WDOE), in March 2001, adopted a rule setting minimum stream flows for most of the Skagit River Basin. According to WAC 173-503-020, the purpose of the rule is to ensure the perennial river and streams of the Lower and Upper Skagit water resource inventory area retain base flows necessary to provide for the protection and preservation of wildlife, fish, scenic, aesthetic and other environmental values, and navigational values. Minimum instream flow values for the lower Skagit River are presented in Table 6. For hydraulic modeling, a minimum flow along the Skagit of 10,000 cfs was used to compare alternatives. 10,000 cfs was selected because this is the theoretical minimum flow along the Skagit River as mandated by the WDOE for this reach of the Skagit River. No expectation is made that a minimum of 10,000 cfs would be available in the Skagit River during periods of low flow.

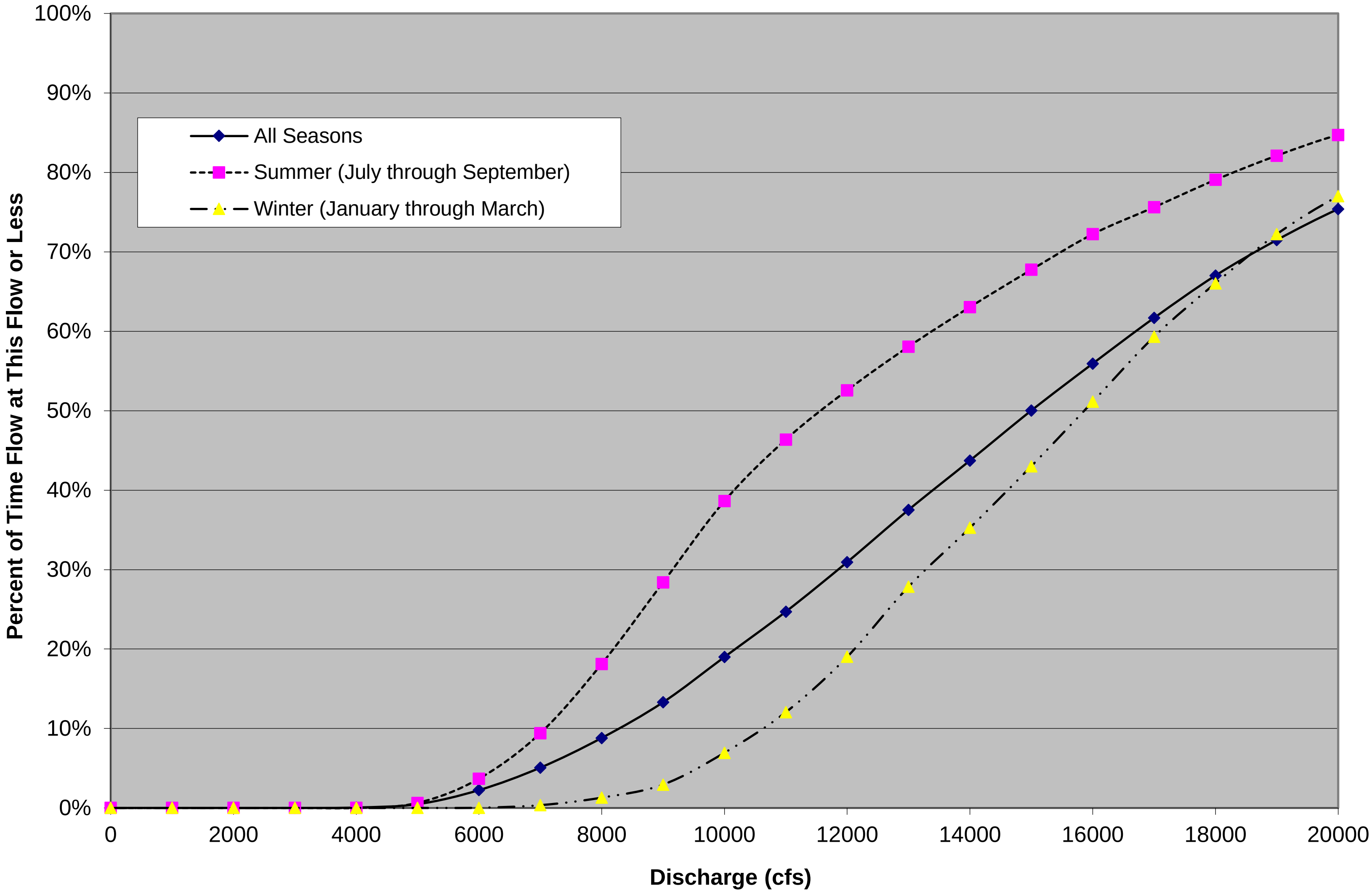


Figure 5. Plot of Skagit River at Mount Vernon Flow Exceedance by Season

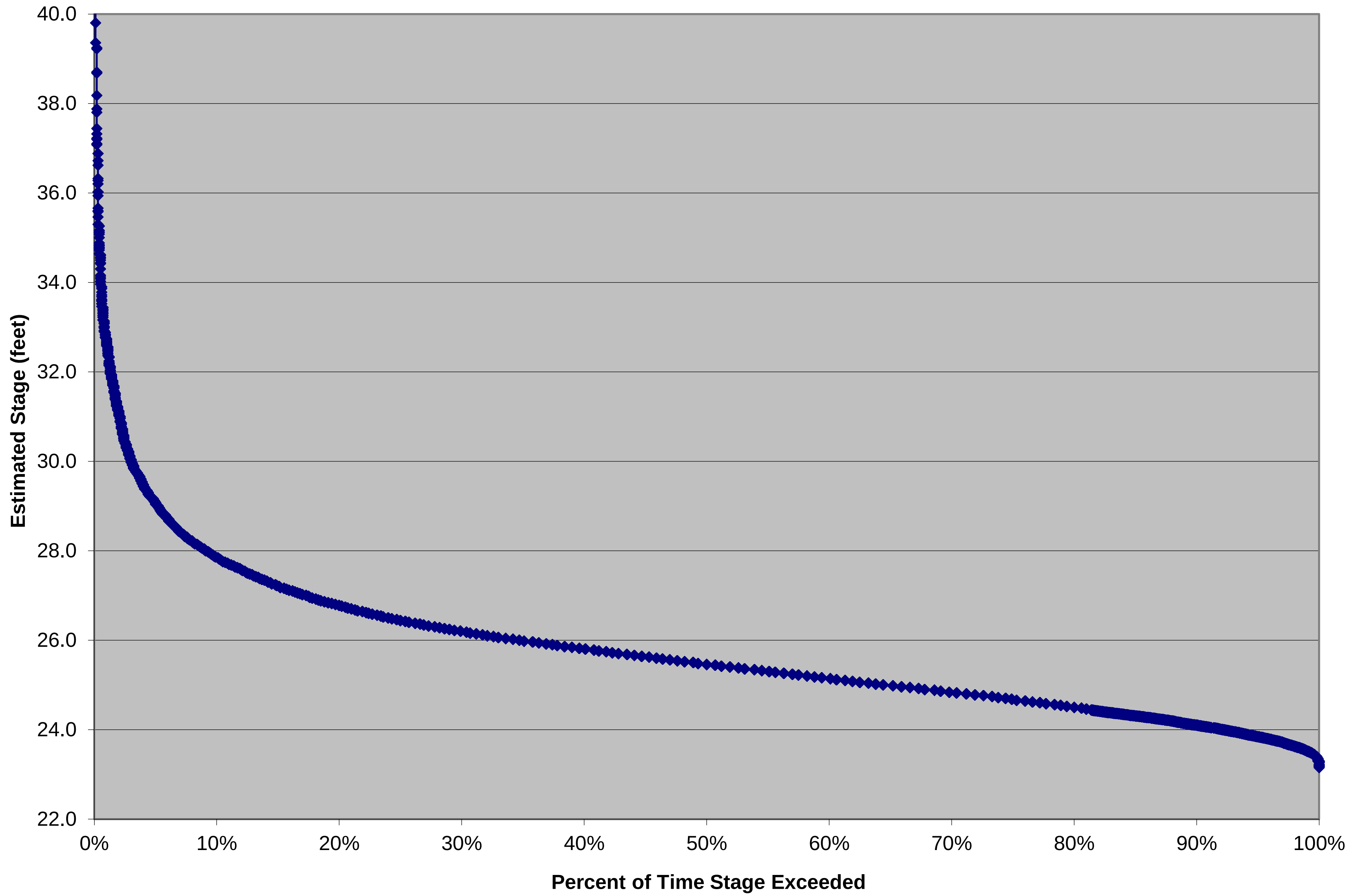


Figure 6. Stage Exceedance for Skagit River near inlet to Hart Slough

Table 6: Established Monthly Instream Flow Targets (WAC 173-503-040)

and Monthly Flow Statistics for the Lower Skagit River (USGS Gaging Station 12200500 Skagit River Near Mount Vernon, Washington).

Month	Day	Minimum Instream Flow (cfs)	Average	Minimum	Maximum
January	1 – 31	10,000	17,597	7,635	27,220
February	1 – 29	10,000	16,827	7,625	31,140
March	1 - 31	10,000	14,358	6,856	27,010
April	1 - 30	12,000	15,050	8,857	23,360
May	1 - 31	12,000	20,590	12,460	35,530
June	1 – 30	12,000	24,803	13,430	43,460
July	1 – 31	10,000	20,432	9,310	37,650
August	1 - 31	10,000	11,801	6,441	21,890
September	1 - 30	10,000	9,406	5,023	17,540
October	1 - 31	13,000	12,317	4,323	23,710
November	1 – 15	13,000	18,229	6,592	52,550
November	16 - 30	11,000			
December	1 – 15	11,000	18,961	8,417	37,930
December	16 - 31	10,000			

5.2.3.2 Groundwater

Ground water in the Skagit River basin occurs principally in the thick, unconsolidated alluvial and glacial deposits (mostly in layers of sand and gravel) underlying the main river valleys. These deposits are found in significant thicknesses only in the bottoms and along the lower sides of the major valleys and predominantly in the western, lowland part of the basin. The unconsolidated deposits occur in the lower part of the basin where sand, gravel, silt, clay, till (locally called “hardpan”) attain thicknesses of 500 feet or more. In the upstream reaches, where the main rivers of the basin are more confined, these water-bearing deposits become thinner and gradually disappear entirely.

Drost and Lombard (1978) studied the general availability of ground water in the basin. Estimated flow volumes are presented in Figure 7. The unconsolidated deposits in the major stream valleys provide sufficient ground water for most domestic and irrigation uses. Except in the extreme western part of the basin, where materials of the delta are finer grained, the highest yields are found in the western lowland where the deposits are thickest. Drost and Lombard (1978) indicate that groundwater flow volumes in the Hart Slough study area exceed 250 gallons per minute (gpm).

A preliminary investigation of groundwater availability was conducted on May 10, 2002. This investigation involved a 6 hour pump draw down test at a previously excavated pond on Hart Island. Pump draw down tests are used to determine the rate of flow of groundwater. The results of this test indicate the presence of a sustainable groundwater flow volume of approximately 360 gpm (0.75 cfs) present on that date under the prevailing river conditions. River stage at the Sedro Woolley gaging station was 25.3 feet on the day of the test. Discharge in the river was variable during the 60 days preceding the test ranging between 12,300 and 44,700 cfs, and averaging 19,022 cfs.

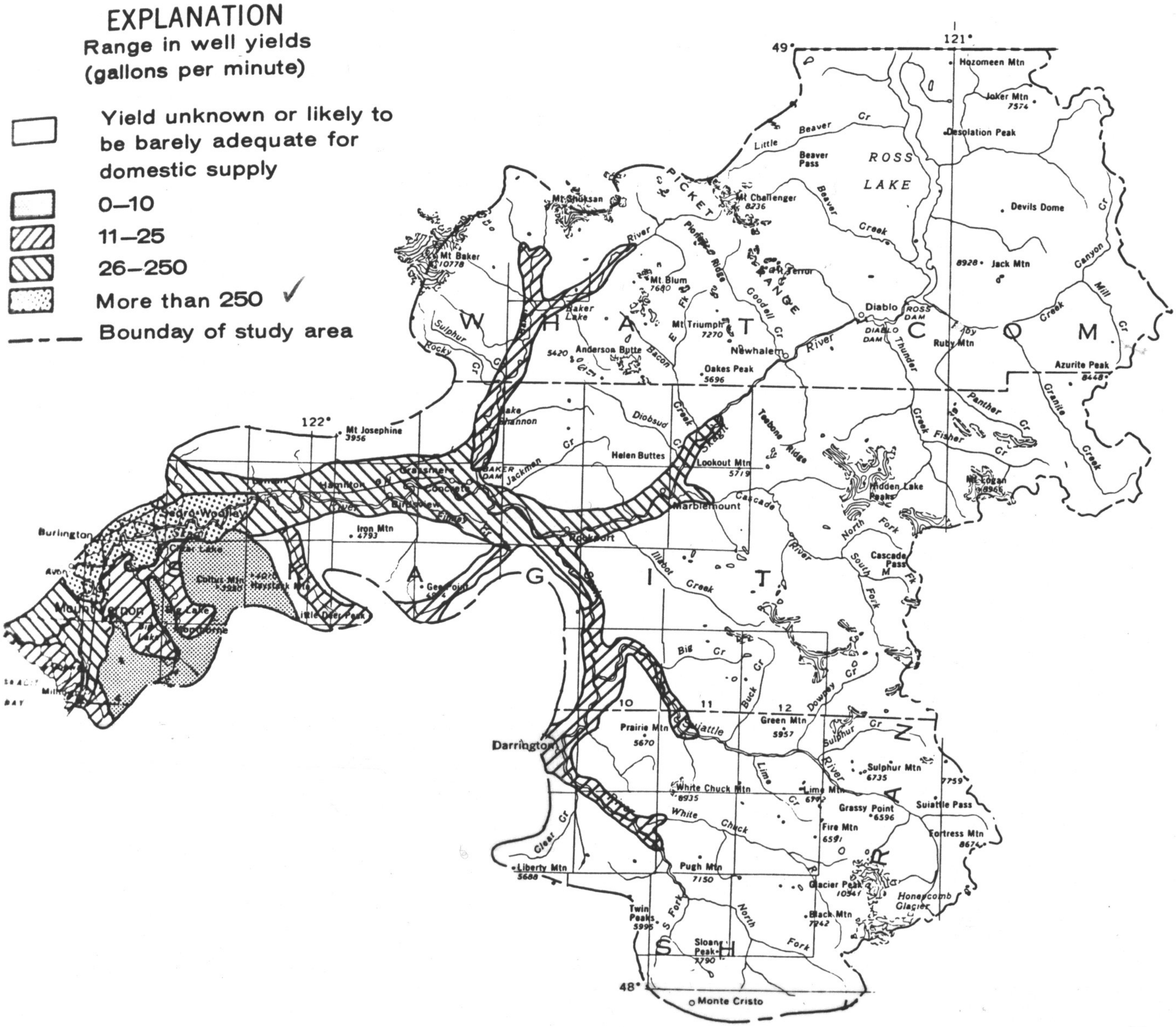


Figure 7. Generalized Groundwater Availability, Drost and Lombard 1978

5.2.4 Hydraulics

As discussed in Section 4.3, the profiles and figures were generated using the HEC-RAS computer program. Graphical data presenting water surface profiles for the existing condition are plotted and presented in the hydraulics Appendix A. Tabular data of HEC-RAS output for existing conditions are also presented in Appendix A. A summary of hydraulic conditions for Alternatives A through D2 is included in Appendix B.

6 Slough Alternatives

6.1 DESCRIPTION OF ALTERNATIVES

Seven enhancement alternatives were proposed for investigation. Limits of various alternatives are shown in Figure 8.

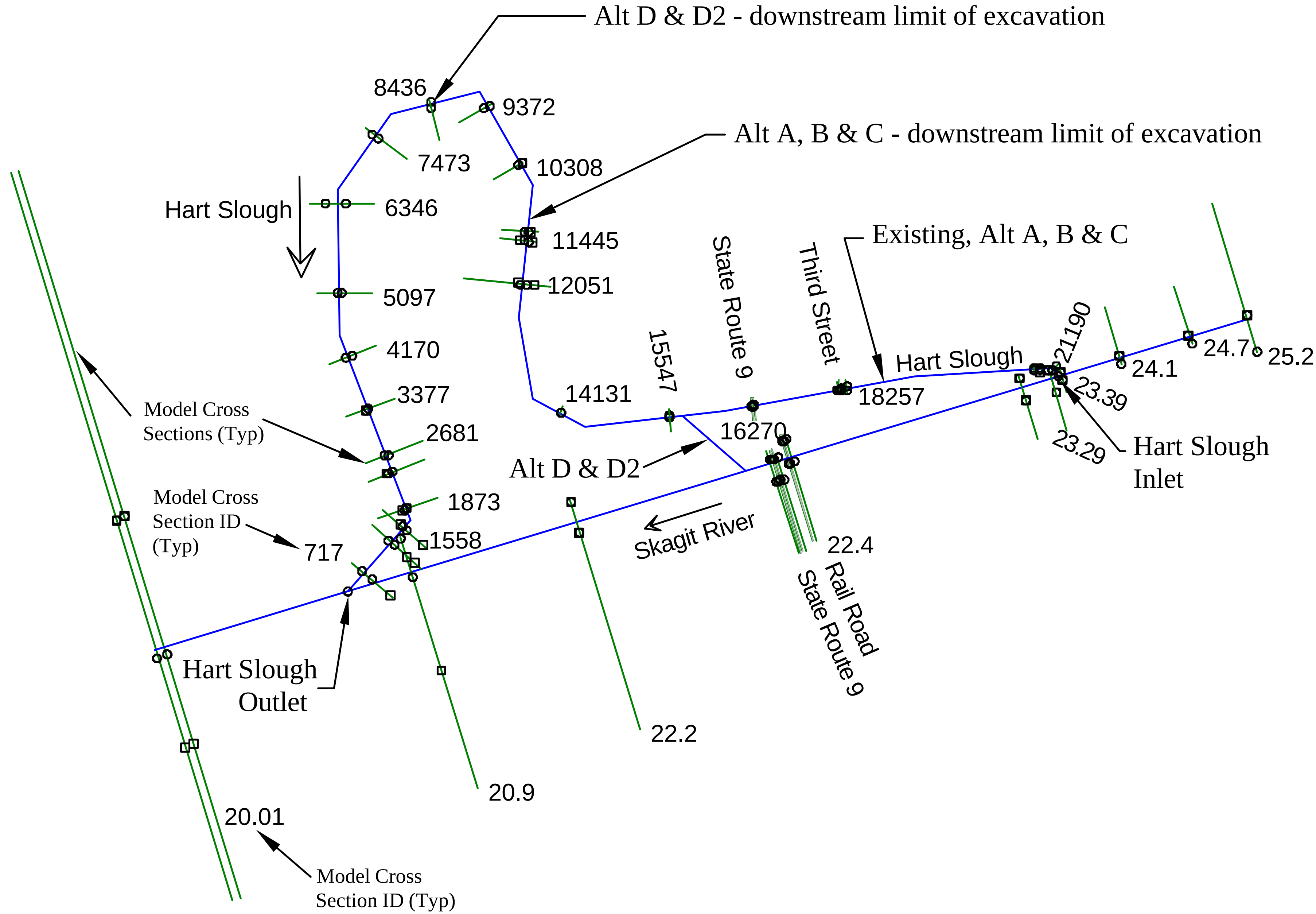
Alternative A involves excavation of the upper reach of the existing channel and channel inlet to a depth (elevation) that allows year round flow (primarily low flow) into the slough from the Skagit River. This alternative required defining the stage / discharge relationship for the Skagit River near the inlet to Hart Slough, upstream of Janecki Cove. With this relationship defined, Alternative A looks solely at excavation required in the slough channel and slough inlet to provide the desired flow from the Skagit River into the slough. Evaluation of the alternative is based on a year round minimum flow of 10-cfs along Hart Slough during low flows of 10,000 cfs along the Skagit River.

Alternative B is conceptually similar to Alternative A in that it includes excavation of the upper slough, but includes a control structure at the head of the slough to regulate flow into the slough rather than an open channel. The primary purpose of the control structure is to limit high flow input to the slough from the Skagit River. This alternative was included out of concern for the potential impact of high flows in the slough on local residences and infrastructure.

Alternative C would provide year round flow from the Skagit River to Hart Slough through a culvert at the upstream terminus of the slough, rather than through an enlarged inlet or control structure as proposed in Alternatives A and B respectively. The site topography will remain similar to existing conditions. As such, the frequency and magnitude of high flows within the slough will be similar to that of the existing conditions, while low flows will be provided by flow through the culvert for Skagit River flows of 10,000-cfs or greater. Alternative C does not include regulation of high flows as Alternative B does.

Alternative D involves the creation of a new open channel located downstream (west) of State Route 9 (Diamond and Broadview Farms Properties) to convey flow from the Skagit River into the Hart Slough. This constructed channel is proposed as an alternative means of conveying water to the slough that limits impacts to Hart Slough upstream of State Route 9.

Figure 8 - HEC-RAS Model Schematic for Existing and Alternative Conditions



Alternative D2 involves burying a culvert to convey water to the slough west of State Route 9 along the same alignment as Alternative D. No open channel would be provided for Alternative D2. Although the concept for Alternative D2 is similar to Alternative C, the locations of the pipe for each alternative differ.

Both Alternatives D and D2 were forwarded to limit impacts to Hart Slough upstream of State Route 9. This will reduce risk to landowners along the upper portion of the slough and because of concerns over the possibility of soil contamination at Art's Wrecking Yard and Riverfront Park.

Alternative E proposes to use a pump station (infiltration gallery) near the inlet to introduce Skagit River water into the slough. No channel modifications are proposed with this alternative.

Alternative F involves the installation of a groundwater well(s) to pump water into the slough. Candidate locations for the well include: adjacent to State Route 9, near Janecki Cove, and near the inlet of the slough. No channel modifications are proposed with this alternative.

6.2 ALTERNATIVES ANALYSIS

The technical analysis for Alternatives A, B, C, D, and D2 relied on the use of hydraulic modeling to assess how changes in channel geometry translate to changes in habitat conditions. Alternatives E and F involved determining the volume of water that could be delivered to the slough on a predictable basis through pumping and assessing potential benefits. No excavation or manipulation of existing channel geometry was included in either Alternatives E or F. The evaluation of these alternatives was based primarily on the added habitat area resulting from each alternative and the assumption that the resultant increase in habitat would result in increase in fish populations. Using methods by Beechie et.al. (1994), estimates of increased annual Coho smolt populations were made. It is assumed that other salmonid species (Chinook, Sockeye, Bull Trout, Cutthroat and Steelhead) would also benefit from this project. Additional benefits would be derived from improved water quality especially during the summer months. By augmenting or providing year round flow in all alternatives, and through topographic alterations in some alternatives, the area of rearing habitat was increased. Resultant habitat area was determined using hydraulic modeling of alternatives and based largely on inundation surface area at various flows modeled. Projected fish populations were calculated using Beechie et al's (1994) value for potential summer Coho smolt production for slough habitat of 0.319 Coho smolts per sq meter (0.03 Coho smolts per sq foot). Using this method, comparison of increased habitat under each alternative was based on the increased numbers of Coho smolts. An additional consideration for evaluating alternatives included reducing the likelihood of stranding of fish. The non-technical analysis / comparison of alternatives was largely subjective and based on professional judgment and stakeholder input.

6.2.1 Methodology for Comparison of Alternatives

Eleven runs of the hydraulic model were generated using the following Skagit River flows: 4000, 5000, 6000, 7000, 10000, 15000 cfs in addition to the 2-, 10-, 25-, 50-, and 100-year events. These flow scenarios for the Skagit River were selected to depict the range of potential conditions within Hart Slough. In this study, we elected to use low (minimum) flow conditions for much of our analysis as they provide the best basis for measuring and comparing differences between alternatives. Both habitat quality and access are currently limited under these low flow conditions. Essentially, this approach provided an even basis of comparison regarding each of the alternative's ability to achieve the goal and assessing benefits. Furthermore, habitat differences between alternatives during overbank flow events are presumed to be very minor. However, benefits to the aquatic resources will likely be realized at all flow levels, despite the fact that the methodology used focuses on low flows.

The 10,000 cfs flow scenario represents the desired minimum flow, per WAC 173 – 503, within the lower Skagit River. As such, the 10,000 cfs Skagit River flow scenario was initially selected as the defining flow for attempting to achieve year-round flow within the slough. For Alternatives A, B, C, D, and D2, channel profile and geometry were manipulated within the model to achieve the goal of providing a minimum flow of 10 cfs within Hart Slough under the 10,000 cfs Skagit River flow scenario.

Hydraulic parameters were modeled at 32 cross sections along Hart Slough for existing conditions and Alternatives A, B and C (Figure 8). Twenty cross sections were used to represent Alternatives D and D2. Due to limitations of HEC-RAS, Hart Slough upstream of the Alternative D and D2 alignment was not included in the model to most accurately represent low flow conditions. Cross sections from the downstream end of Hart Slough to cross section 15,547 near the State Route 9 Bridge were included in the Existing and Alternatives A through D2 models. Representative cross-sections were selected for the purpose of comparing evaluation criteria, discussed below. Data from six representative cross sections were used in the alternatives analysis. These cross sections were:

- Station 2,681: near the outlet from Hart Slough
- Station 8,436: near Brickyard Creek
- Station 12,051 near Houser's Bridge
- Station 15,547: near the State Route 9 Bridge
- Station 18,131: near the Third Street Bridge
- Station 21,190: near the inlet to Hart Slough

The results of modeling for these cross sections under the 10,000 cfs scenario are presented in Appendix B. Select parameters from this analysis were used to quantify habitat benefits and make comparisons between enhancement alternatives. Direct output from the hydraulic model was used to address the evaluation criteria outlined in Section 6.2.2.

6.2.2 Evaluation Criteria

Evaluation criteria included quantitative and qualitative considerations, including consideration of potential increase in fish population (quantified by increase Coho smolt populations). Quantitative criteria were determined primarily using hydraulic models to quantify added habitat, based on the assumption that habitat volume is correlated with increased Coho smolt population (Beechie et al. 1994). Table 7 is a Quantitative Comparison Matrix (Table 7) for comparing and contrasting the quantitative aspects of various slough alternatives.

- Additional Fish Habitat – the net increase in water surface area under low (minimum) flow conditions compared to existing conditions. It should be noted that under existing conditions approximately 10,000-ft of the upper slough either does not convey flow or is dry during low flows. Under the proposed alternatives flow would be conveyed along all or a portion of this upper reach and would provide usable habitat.
- Improvement of Fish Habitat – the flow exchange rate for the additional volume of water present under low (minimum) flow conditions compared to existing conditions.
- Fish Passage (upstream and downstream) – maximum depth at cross sections in the mid and upper portion of the slough under low (minimum) flow conditions compared to existing conditions.
- Water Quality –the velocity associated with the additional volume of water present under low (minimum) flow conditions compared to existing conditions.
- Hydraulic Connectivity – the average depth and area of wetted channel present under low (minimum) flow was computed compared to existing conditions.
- Geomorphic Function (volume of flow during dominant, channel shaping discharge) – the discharge present within the slough under the 2-year Skagit River flow event for each of the alternatives compared to existing conditions.
- Floodplain / Riparian Vegetation Community Connectivity – to quantify increased connectivity, the lateral extent of inundation of floodplain and/or riparian vegetation was determined by the total cross sectional top width of flow present under low (minimum) flow. Top width was computed for each of the alternatives and compared to existing conditions
- Water Surface Elevation – the potential for inundation of adjacent lands at the 2-year flow was evaluated for each alternative.
- Capital / Construction Costs – by estimating from experience and using the MEANS cost catalog.
- Maintenance Requirements / Annual Costs - once the specifics of the feature / modification were determined, a quantitative assessment of maintenance and costs was developed.

Qualitative (non-technical) Criteria – for each alternative, Steering Committee input were used to develop, address, and evaluate the following issues / areas of concern, and are summarized in Table 8:

- Land use issues – are there land use issues that impact the alternative (ex. Sedro-Woolley sewage treatment plant, Riverfront Park, Art's Wrecking Yard).
- Property Ownership – does the alternative require use of private property? City property?
- Land Acquisition – is land acquisition required? How much acreage?
- Easements – are easements necessary? How much acreage?
- Water Rights – are there existing water rights that impact the alternative? Are they transferable / available for purchase?
- Landowner Encroachment – does the alternative impact or encroach upon private property?
- Land Use Restrictions – will additional land use restrictions be imposed?
- Public acceptance

Table 7. Quantitative Comparison Matrix: All Alternatives (10,000 cfs flow scenario)

Goal: Optimize the availability of high quality salmonid rearing habitat	Additional Fish Habitat (square feet)	Potential Increase in Coho Smolt Production per Year, (per methods by Beechie et al 1994)	Improvement to Fish Habitat (change in Q, cfs at Section 8436)	Fish Passage - mid slough (change in maximum depth in feet at station 15547)	Fish Passage - upper slough (change in maximum depth in feet at station 18131)	Water Quality (change in velocity in fps, at station 12051)	Hydraulic Connectivity (avg. depth in feet at 15547)	Geomorphic Function (discharge in cfs during 2-year event)	Floodplain/Riparian Vegetative Community Connectivity (top width in feet, at section 15547)	Floodplain/Riparian Vegetative Community Connectivity (top width in feet, at station 8436)	WSE during 2-year event (immediately u/s of Third Street)	Capital / Construction Costs	Comparitive Incremental Cost of Alternative (Cost of Alternative / one year's increase in coho smolt production)
No Action Alternative: Baseline Condition	n/a	0	0	0.04	0.03	0.01	0.03	1593	4.35	27.25	38.6	n/a	n/a
Alternative A: Excavate Inlet to SR 9	197,126	5914	9.52	1.69	2.02	0.46	1.15	2290	20.66	39.94	39.2	309000.0	$52.25
Alternative B: Excavate Inlet to SR 9 - with control structure	188,854	5666	8.99	1.65	1.97	0.45	1.12	2260	20.44	39.35	39.2	425000.0	$75.01
Alternative C: Buried Pipe (culvert) from inlet to SR 9	199,866	5996	9.87	1.72	2.05	0.47	1.17	3466	20.8	40.43	40.2	624000.0	$104.07
Alternative D: Channel west of SR 9 directly to Skagit	94,148	2824	10.00	2.13	n/a	0.49	1.46	3032	10.55	37.6	38.6	312800.0	$110.75
Alternative D2: Pipe west of SR 9 directly to Skagit	95,956	2879	10.33	2.15	n/a	0.49	1.46	2265	10.68	37.9	38.6	461500.0	$160.32
Alternative E: Pump station at inlet (minimum 10 cfs)	130,680	3920	10	1.5	"0.03"	"0.5"	"1"		"20"	37.6	38.6	82500.0	$21.04
Alternative F: Groundwater well at SR 9, Janecki, or Inlet	43,560	1307	1	"0.25"		"0.05"	"0.1"		4.35	27.25	38.6	25000.0	$19.13

Table 8. Qualitative Comparison Matrix - All Alternatives

Goal: Optimize the availability of high quality salmonid rearing habitat	Land Use Issues Beyond Existing Issues	Property Ownership Issues	Encroachment on Landowners?	Land Acquistion / Easement Required?	Water Rights Issues?	Maintenance Requirements	Liabilities	Perceived Public Acceptance
No Action Alternative: Baseline Condition	n/a	no	no	no	yes	no	no	high
Alternative A: Excavate Inlet to SR 9	yes	no	maybe	yes - maintenance	yes	maybe	yes	low
Alternative B: Excavate Inlet to SR 9 - with control structure	maybe	no	maybe	yes - maintenance	yes	yes	no	medium
Alternative C: Buried Pipe (culvert) from inlet to SR 9	no	no	no	yes - maintenance	yes	yes	no	medium
Alternative D: Channel west of SR 9 directly to Skagit	no	yes	yes	yes	yes	maybe	no	high
Alternative D2: Pipe west of SR 9 directly to Skagit	no	yes	yes	yes	yes	yes	no	high
Alternative E: Pump station at inlet	no	no	yes	yes	yes	yes	no	medium
Alternative F: Groundwater well at SR 9, Janecki, or Inlet	no	no	yes	uncertain	yes	yes	no	medium

RESULTS

6.2.3 No Action Alternative

Modeling results indicate that at a Skagit River flow of 10,000 cfs, no flow currently is routed into Hart Slough at the inlet. The lower reaches of Hart Slough are backwatered by the Skagit with some additional flows entering from Brickyard Creek and other sources. Under this flow scenario, approximately 93 acre-feet of habitat are present along the length of the slough. Average and maximum depths at cross section 15,547 are 0.03 and 0.04 feet, respectively. An estimated top width of 27.25 feet occurs at cross section 8,436. Water velocity under this flow scenario averages less than 0.05 fps. There would be no increase in additional Coho smolts and no cost to implement this alternative.

6.2.4 Alternative A

Modeling results indicate that at a Skagit River flow of 10,000 cfs, roughly 9.5 cfs will be routed into Hart Slough at the inlet under Alternative A. Under this flow scenario, approximately 101.1 acre feet of habitat, including 8.1 acre feet of new fish habitat will be available within the slough with the proposed channel modifications under Alternative A. The increased habitat area will support an estimated 5,914 additional Coho smolts. Average and maximum depth, at cross section 15,547 will be 1.2 and 1.7 feet, respectively. An estimated top width of 39.9 feet is anticipated at cross section 8,436 and 20.7 feet at cross section 15547. Water velocity under this flow scenario will average 0.5 fps. The cost of Alternative A is estimated to be $309,000.

6.2.5 Alternative B

Modeling results indicate that at a Skagit River flow of 10,000 cfs, roughly 9 cfs will be routed into Hart Slough at the inlet under Alternative B. Under this flow scenario, approximately 100.7 acre feet of habitat, including 7.6 acre feet of new fish habitat will be available within the slough with the proposed channel modifications under Alternative B. The increased habitat area will support an estimated 5,666 additional Coho smolts. Average and maximum depth, at cross section 15,547 will be 1.1 and 1.7 feet, respectively. An estimated top width of 39.4 feet is anticipated at cross section 8,436 and 20.4 feet at cross section 15547. Water velocity under this flow scenario will average 0.5 fps. The cost of Alternative B is estimated to be $425,000.

The control structure may impose a constraint to upstream fish passage depending on design and operation.

6.2.6 Alternative C

Modeling results indicate that at a Skagit River flow of 10,000 cfs, roughly 9.9 cfs will be routed into Hart Slough at the inlet under Alternative C. Under this flow scenario, approximately 101.3 acre feet of habitat, including 8.3 acre feet of new fish habitat will be available within the slough with the proposed channel modifications under Alternative C. The increased habitat area will support an estimated 5,996 additional Coho smolts. Average and maximum depth, at cross section 15,547 will be 1.2 and 1.7 feet, respectively. An estimated top width of roughly 40 feet is anticipated at cross section

8,436. Water velocity under this flow scenario will average 0.5 fps. The cost of Alternative C is estimated to be $624,000.

A 38-in by 58-in elliptical concrete culvert placed at the inlet of the slough was included in this option. The invert of the culvert inlet was set at elevation 24.1 and outlet elevation 24.0 to obtain approximately 9.9 cfs along the slough during the 10,000 cfs event. The existing slough channel profile and cross section along the culvert placement was not changed. Some excavation upstream and downstream of the culvert will be necessary to convey this low flow condition.

One disadvantage of this culvert is that it would require some degree of ongoing maintenance to clear accumulated debris and sediment.

6.2.7 Alternative D

Modeling results indicate that at a Skagit River flow of 10,000 cfs, roughly 10 cfs will be routed into Hart Slough at the inlet under Alternative D. Under this flow scenario, approximately 96.3 acre feet of fish habitat including 3.3 acre feet of new fish habitat will be available within the slough with the proposed channel modifications under Alternative D. The increased habitat area will support an estimated 2,824 additional Coho smolts. Average and maximum depth, at cross section 15,547 will be 1.5 and 2.1 feet, respectively. An estimated top width of nearly 38 feet is anticipated at cross section 8,436. Water velocity under this flow scenario will average 0.5 fps. The cost of Alternative D is estimated to be $461,500.

6.2.8 Alternative D2

Modeling results indicate that at a Skagit River flow of 10,000 cfs, roughly 10.3 cfs will be routed into Hart Slough at the inlet under Alternative D2. Under this flow scenario, approximately 96.4 acre feet of fish habitat including 3.4 acre feet of new fish habitat will be available within the slough with the proposed channel modifications under Alternative D2. The increased habitat area will support an estimated 2,879 additional Coho smolts. Average and maximum depth, at cross section 15,547 will be 1.5 and 2.1 feet, respectively. An estimated top width of nearly 38 feet is anticipated at cross section 8,436. Water velocity under this flow scenario will average 0.5 fps. The cost of Alternative D2 is estimated to be $312,800.

A 38-in by 58-in elliptical concrete culvert place at the inlet of the slough was included in this option. The invert of the culvert inlet and outlet were set at elevation 22.5 to obtain approximately 10.3 cfs along the slough during the 10,000 cfs event. The existing topography along the culvert placement would not be changed. Some excavation upstream and downstream of the culvert will be necessary to convey this low flow condition.

One disadvantage of this culvert is that it would require some degree of ongoing maintenance to clear accumulated debris and sediment.

6.2.9 Alternative E

Modeling was not used to quantify potential benefits associated with Alternative E. This alternative relies on the use of a pump station to supply surface flow into Hart Slough at a location near the inlet. Pumped flow would be routed into the existing slough with no changes or modifications to channel geometry. As such, pumping would only be used when Skagit River water surface elevations were below elevation 31.6 feet, the current elevation where flows enter Hart Slough. For comparison purposes, 10 cfs was selected as the volume of flow to be introduced through pumping. It is possible to increase the benefits from pumping by increasing the flow volume. There are potential issues with fish passage depending on location of the pumping facility. Potential benefits were assessed by looking at the baseline condition and focusing the analysis on the lower and mid portions of the slough.

With 10 cfs pumped and routed into Hart Slough at the inlet under Alternative E, approximately 96 acre feet of fish habitat including roughly 3 acre feet of new fish habitat will be available within the slough with the proposed channel modifications under Alternative E. The increased habitat area will support an estimated 3,920 additional Coho smolts. Average and maximum depth, at cross section 15,547 are estimated to be 1 and 1.5 feet, respectively. An estimated top width of nearly 37 feet is anticipated at cross section 8,436. Water velocity under this flow scenario will average 0.5 fps. The cost of Alternative E is estimated to be $82,500.

6.2.10 Alternative F

Alternative F involves the use of groundwater pump(s) to introduce additional flow into the slough. The results of the pump test and other studies done in the study area indicate a limited flow volume (less than 1 cfs) could be achieved through this technique. Given the minimal benefits possible with this technique, this alternative was loosely quantified and dropped from further consideration. The increased habitat area will support an estimated 1,307 additional Coho smolts. The cost of Alternative F is estimated to be $25,000).

6.3 DISCUSSION

Of the seven alternatives for slough enhancement evaluated in this investigation, five (Alternatives A, B, C, D and D2) require channel manipulation / modification. The remaining two alternatives (Alternatives E and F) involve using pumps to deliver water to the existing channel. Of the five alternatives requiring manipulation, three (A, B, and C) are similar in that they involve treatments to the upper reach of the existing channel. Alternatives D and D2 involve creation of an entirely new channel / conveyance west of State Route 9. All alternatives that require channel manipulation involve significant excavation along the length of the slough (Figure 9).

In terms of improvement of aquatic habitat benefit and increased numbers of Coho smolts, Alternatives A, B, and C are similar and exceed all other alternatives (Table 7). Under Alternatives A, B and C, area of habitat would increased by approximately 4.34- to 4.59-acres with a minimum potential increase of between 5,666 and 5,996 Coho smolts. Under Alternatives D and D2, area of habitat would increase by approximately 2.16- and 2.20-acres, respectively, with a potential increaseof approximately 2,824 and

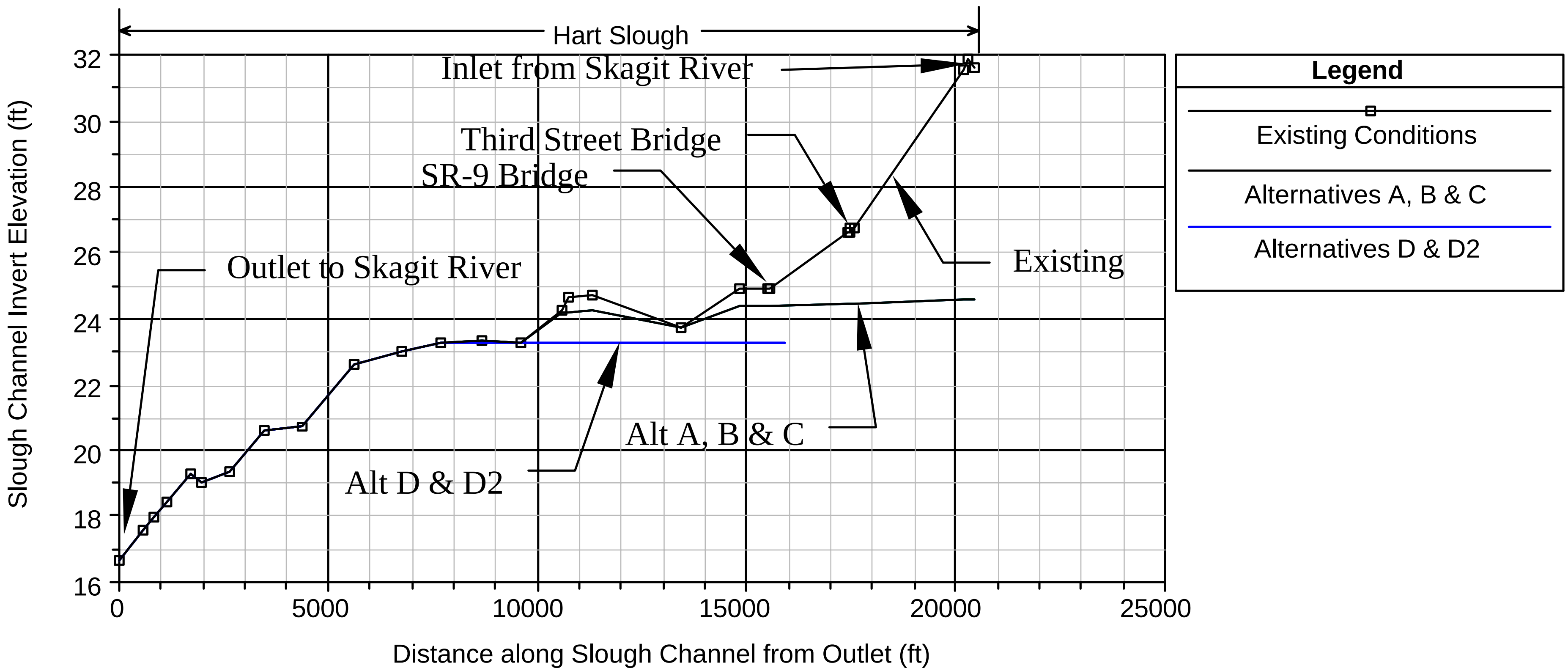
2,879 Coho smolts, respectively. Under Alternatives E and F, area of habitat would increase by approximately 3.00- and 1.00-acres, respectively, with a potential increase of approximately 3,920 and 1,307 Coho smolts, respectively. Alternative A is the least expensive of these alternatives at an estimated construction cost of $309,000 (Table 7). Construction costs for alternatives B and C are estimated at $425,000 and $624,000, respectively. Benefits through the use of a high capacity pump, as proposed under Alternative E, are similar to those of Alternatives D and D2 (Table 7). The cost of Alternative E is significantly less than all alternatives requiring channel modification. Alternative F provides negligible benefit. Although numbers of Coho smolts were estimated and discussed herein, it is assumed that other salmonids (Chinook, Sockeye, Bull Trout, Cutthroat and Steelhead) would also have benefit.

The presence and action of beaver dams will also potentially affect alternatives. The effect of beaver dams on slough flows was described in detail in Section 4.3, Hydraulic Modeling. As described in Section 4.3, in order to evaluate the alternatives on an equal basis, the hydraulic models largely ignored beaver dams. As a result, the actual habitat created in various alternatives will likely differ from modeled results in both quality and volume for the 10,000-cfs condition. As discussed in Section 4.3, beaver dams will inhibit low flows along the slough up to about the 11,000- to 12,000-cfs flow condition at which point the dams will be overtopped and have a less profound impact on slough flows. These overtopping flows occur approximately 10-percent of the time less frequently than the 10,000-cfs condition considered in this study. Options to provide flow conveyance through the beaver dams during non-overtopping low flows include installation of PVC pipes (as described in Section 4.3 Hydraulic Modeling) to promote flow and fish passage, such that modeled habitat and water surface areas at low flow will approximate actual field conditions. These conveyance pipes could be part of an adaptive management approach where the beaver dams are monitored for through flow. If the beaver dams pass insufficient flow during low non-overtopping flow conditions, these pipes could be installed as needed. The number and sizes of pipes needed to meet desired values of slough flows (as discussed in Section 4.3) would lend themselves to installation by hand or with small equipment. Periodic maintenance would be required to clear debris accumulations in order to maintain flow.

Alternatives C and D2 include the installation of long culverts to convey flows to the slough. Disadvantages of the culverts in Alternatives C and D2 include some degree of ongoing maintenance required to clear accumulated debris or sediment. Access along the length of the culvert would be difficult.

Alternative B includes an above ground flow control structure located at the inlet to the slough. Debris will likely accumulate at the structure and would require periodic maintenance for removal. Sediment buildup near the structure is possible but not anticipated to be problematic. Access should be incorporated with the structure for this function. Access to this structure would be much simpler than along the culverts of Alternatives C and D2.

Figure 9 - Hart Slough Invert Profiles



In terms of land use issues / concerns, the upper portion of the slough (upstream of State Route 9) is at greatest potential risk (Table 8). Concerns include risk to landowners associated with a potential increase in the frequency of flooding and increased risk of pollution from possible contaminated soils at Art's Wrecking Yard and Riverfront Park. Alternatives A, B, C, E, and F all involve changes to flow patterns in the upper reach of the slough. Alternatives D and D2, which involve creation of a new conveyance west of State Route 9, other than increased water levels caused by backwater effects from increased flows introduced to Hart Slough from the Alternative D and D2 conveyances, these Alternatives do not have direct impacts along the upper reach of the slough.

Primary concerns are associated with Alternatives A, B, and C as they involve excavation in the upper 10,000 feet of the slough and in the immediate vicinity of the Diamond Property, Janecki Cove, and Art's Wrecking Yard. A stage/discharge rating curve for these alternatives is presented in Figure 10. For a given Skagit River flow / stage, a greater volume of water will be conveyed down the slough under each of Alternatives A, B, and C than under the existing condition. Landowner concerns are largely related to potential changes (increases) in water surface elevation for a given flow event on the Skagit River. The modeled change in water surface elevation associated with each of these alternatives under the 2- and 10-year Skagit River flow events is depicted in Table 9. All alternatives show an increase in water surface elevation of at least 0.5 feet in the vicinity of Janecki Cove and Art's Wrecking Yard during the 2-year event (Table 9). The increase in water surface elevation is greatest for Alternative C (range 1.32 to 1.66 feet) and similar between alternatives A and B (range 0.46 to 0.62 feet). Similar results are presented for the 10-year flow event in Table 9.

Additional concerns of Alternatives A, B and C include sediment deposition and impacts to existing riparian vegetation. Deposition of sediment along the upper reaches of Hart Slough is occurring and is likely to continue. The source of the deposited sediment is from suspended sediments in the Skagit River. No data was identified with which to estimate the amount and size of suspended sediment entrained into the slough from the river at various flows and corresponding depths (elevations). Results of analytical estimates of sediment transport typically differ by orders of magnitude between various equations and between actual field conditions; thus, providing little accuracy in theoretical estimates of rates of deposition. Comparison of cross sectional configurations over time were also considered. However, historical cross sectional data were not available at common locations to directly estimate rates of deposition. Therefore, to gain meaningful insight on rates of sediment deposition along Hart Slough, monitoring cross sections should be established and surveyed following high flows. Deposition depths at the monitoring cross sections can be documented and related to magnitude of Skagit River flows. Flow velocities along the slough for the low flow condition increase for each of the alternatives in comparison to existing conditions. This higher velocity will have greater sediment transporting capability reducing the tendency of deposition. However, somewhat higher flows will also convey additional sediment into the slough. Without a clear understanding of the volume and sizes of sediment entrained during a range of Skagit River flows it is very difficult to make an accurate estimate of the rate of deposition associated with each alternative.

Excavation of the upper slough will damage some existing riparian vegetation along the channel edges. Alternatives A and B would have similar widths of impact to vegetation. Alternative C entails placement of a culvert along the slough alignment and would have less impact on vegetation. Construction methods should attempt to minimize these extents. Implementation of alternatives will include a replanting plan to reestablish damaged vegetation.

Alternatives E and F involve pumping water and are therefore highly regulated. No channel modifications are proposed in alternatives E and F. As such, the level of risk associated with these two alternatives is similar to that present under the existing baseline condition.

As previously discussed, flow into and out of Hart Slough is dependent on Skagit River flows. Benefits to aquatic resources are linked to existing hydrology and life history patterns. This feasibility investigation focused on the low flow portion of the Skagit River flow regime, the portion best suited for making comparisons between alternatives. To fully quantify benefits, seasonal variations in hydrology and species life history patterns must be closely reviewed. From a fish habitat perspective, habitat quality during the summer may be limited primarily by poor water quality associated with insufficient surface- and ground-water inflow. Considering existing seasonal patterns in hydrology, access to high quality rearing (over-wintering) habitat during the winter months is less of a concern due to prevailing river conditions. Therefore, achieving benefits to habitat used during the summer may prove more challenging than achieving benefits to winter habitat.

Table 9 - Alternatives A, B and C: Comparison of Flows along Slough and HEC-RAS Water Surface Elevations

Note: ***Hydraulic model is planning level only. Water surface elevations do not indicate actual flood levels at indicated events and are ONLY for Planning Level comparisons of Alternatives***

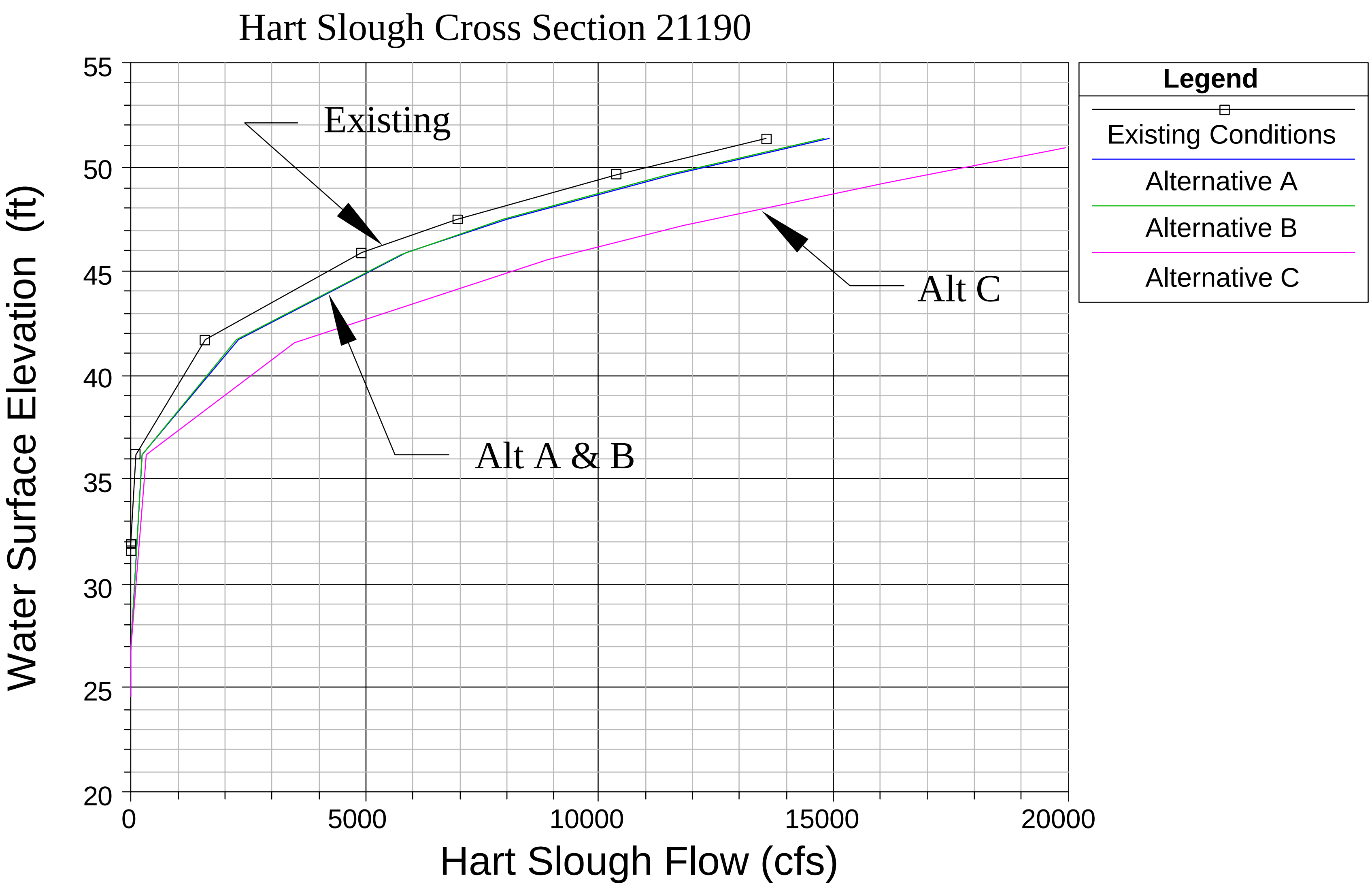
Total Skagit River Flow (cfs), or Event (Tr)	Section	Water Surface Elevation (ft)				Change in WSEL (ft)		
		Existing	Alternative A	Alternative B	Alternative C	Alternative A	Alternative B	Alternative C
2-yr								
Flow along Slough =		1593	2290	2260	3466	697	667	1873
	717	37.71	37.72	37.72	37.72	0.01	0.01	0.01
	1290	37.71	37.72	37.72	37.72	0.01	0.01	0.01
	1558	37.71	37.72	37.72	37.72	0.01	0.01	0.01
	1873	37.71	37.72	37.72	37.73	0.01	0.01	0.02
	2430	37.71	37.72	37.72	37.73	0.01	0.01	0.02
	2681	37.72	37.72	37.72	37.73	0	0	0.01
	3377	37.72	37.72	37.72	37.73	0	0	0.01
	4170	37.72	37.72	37.72	37.73	0	0	0.01
	5097	37.72	37.72	37.72	37.73	0	0	0.01
	6346	37.72	37.72	37.72	37.73	0	0	0.01
	7473	37.72	37.72	37.72	37.74	0	0	0.02
	8436	37.72	37.72	37.72	37.76	0	0	0.04
	9372	37.72	37.73	37.73	37.79	0.01	0.01	0.07
	10308	37.73	37.76	37.75	37.84	0.03	0.02	0.11
	11308	37.8	37.9	37.89	38.14	0.1	0.09	0.34
	11445	37.8	37.91	37.9	38.18	0.11	0.1	0.38
	12051	37.83	37.97	37.96	38.23	0.14	0.13	0.4
	14131	38.02	38.34	38.32	38.93	0.32	0.3	0.91
	15547	38.23	38.68	38.66	39.48	0.45	0.43	1.25
	16235	38.31	38.79	38.77	39.63	0.48	0.46	1.32
	16270	38.31	38.81	38.78	39.65	0.5	0.47	1.34
	18131	38.63	39.23	39.2	40.22	0.6	0.57	1.59
	18166	38.64	39.25	39.22	40.25	0.61	0.58	1.61
	18180	38.63	39.25	39.22	40.26	0.62	0.59	1.63
	18257	38.71	39.33	39.3	40.37	0.62	0.59	1.66
	20926	41.46	41.47	41.42	40.94	0.01	-0.04	-0.52
	21012	41.57	41.54	41.49	41.17	-0.03	-0.08	-0.4
	21190	41.73	41.69	41.68	41.57	-0.04	-0.05	-0.16

Table 9 (cont.) - Alternatives A, B and C: Comparison of Flows along Slough and HEC-RAS Water Surface Elevations

Note: ***Hydraulic model is planning level only. Water surface elevations do not indicate actual flood levels at indicated events and are ONLY for Planning Level comparisons of Alternatives***

Total Skagit River Flow (cfs), or Event (Tr)	Section	Water Surface Elevation (ft)				Change in WSEL (ft)		
		Existing	Alternative A	Alternative B	Alternative C	Alternative A	Alternative B	Alternative C
10-yr								
	Flow along Slough =	4924	5852	5791	8900	929	868	3977
	717	40.94	40.94	40.94	40.95	0	0	0.01
	1290	40.94	40.94	40.94	40.95	0	0	0.01
	1558	40.94	40.94	40.94	40.96	0	0	0.02
	1873	40.94	40.95	40.95	40.96	0.01	0.01	0.02
	2430	40.94	40.95	40.95	40.97	0.01	0.01	0.03
	2681	40.94	40.95	40.95	40.97	0.01	0.01	0.03
	3377	40.94	40.95	40.95	40.97	0.01	0.01	0.03
	4170	40.95	40.95	40.95	40.99	0	0	0.04
	5097	40.95	40.95	40.95	41	0	0	0.05
	6346	40.95	40.96	40.96	41.02	0.01	0.01	0.07
	7473	40.95	40.96	40.96	41.04	0.01	0.01	0.09
	8436	40.96	40.98	40.98	41.09	0.02	0.02	0.13
	9372	40.98	41.01	41.01	41.15	0.03	0.03	0.17
	10308	41.01	41.05	41.05	41.26	0.04	0.04	0.25
	11308	41.15	41.24	41.23	41.63	0.09	0.08	0.48
	11445	41.17	41.28	41.27	41.71	0.11	0.1	0.54
	12051	41.2	41.31	41.31	41.77	0.11	0.11	0.57
	14131	41.27	41.41	41.4	41.91	0.14	0.13	0.64
	15547	41.67	41.91	41.9	42.8	0.24	0.23	1.13
	16235	41.76	42.03	42.01	42.99	0.27	0.25	1.23
	16270	41.77	42.04	42.03	43.01	0.27	0.26	1.24
	18131	42.19	42.54	42.52	43.75	0.35	0.33	1.56
	18166	42.21	42.57	42.55	43.8	0.36	0.34	1.59
	18180	42.24	42.6	42.57	43.83	0.36	0.33	1.59
	18257	42.33	42.7	42.67	43.97	0.37	0.34	1.64
	20926	45.53	45.5	45.45	44.47	-0.03	-0.08	-1.06
	21012	45.73	45.68	45.63	45.06	-0.05	-0.1	-0.67
	21190	45.89	45.86	45.81	45.56	-0.03	-0.08	-0.33

Figure 10. Stage - Discharge Rating Curve at Inlet to Hart Slough



6.4 CONCLUSIONS AND RECOMMENDATIONS

6.4.1 Selection of a Preferred Alternative

Of the alternatives investigated for enhancing Hart Slough, Alternative B is the preferred alternative for achieving the project goal of providing year-round flow and optimizing the availability of high quality salmonid rearing habitat given existing land use issues and concerns. Alternative B has the potential to provide substantial benefit to aquatic resources through increased habitat quantity and quality and improved access while minimizing risk to property.

6.4.2 Conceptual Design

The preferred alternative (Alternative B) will require considerable excavation to provide flows necessary to improve habitat quantity, quality, and access within slough. To provide year round flow, excavation will be required in upper 10,000 feet of the slough near the inlet (Figure 8). The depth of excavation will be greatest near the inlet (approximately 9 feet) and least at the lower end (Figure 9). The geometry of channel cross-sections will be variable depending on the existing conditions as indicated in Figures 11 and 12. Figure 13 portrays a representative section view of Alternative B after enhancement is completed and riparian vegetation has been re-established. This feasibility investigation focuses on channel elevation and cross-sectional geometry. Specific bank treatments are not presented. Impacts of beaver dams on low slough flows and methods to enhance flow through beaver dams are discussed in Section 4.3, Hydraulic Modeling and Section 6.3, Discussion.

6.4.3 Blending of Alternatives

While Alternative B is the preferred method to enhance habitat conditions, other more “mechanical” options exist to further encourage enhancement especially during low flow conditions. As proposed, Alternative B would provide 10 cfs during summer low flow conditions. Quantifying the benefit to water quality associated with this volume of water is outside the scope of this investigation. Temperature modeling would aid in quantifying this benefit. If deemed appropriate, pumping of surface water may be an option to further improve water quality and enhance summer habitat conditions. This could be accomplished via an infiltration gallery (Figure 14) located near inlet and used during summer only or triggered when Skagit River water surface elevations dropped below the slough inlet elevation. Costs would be significantly less than those presented in Alternative E, which assumed year-round pump operation.

Figure 11 - Cross Section 18180, Existing and Alternative B

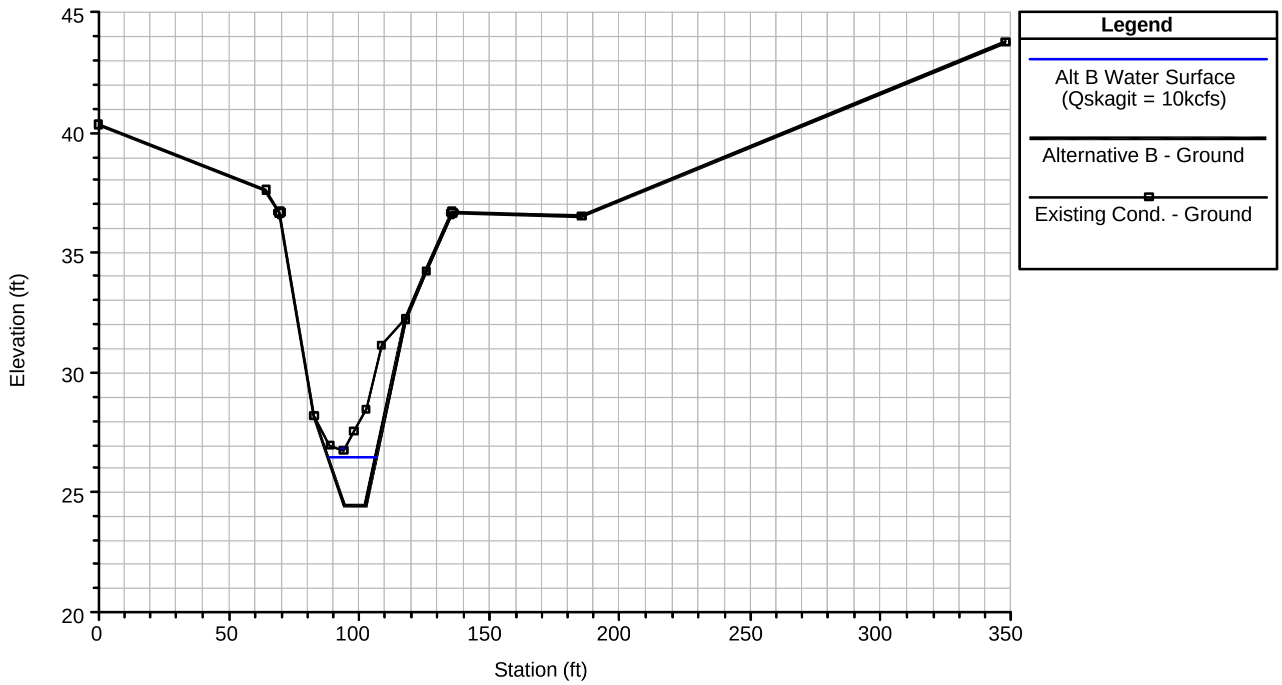
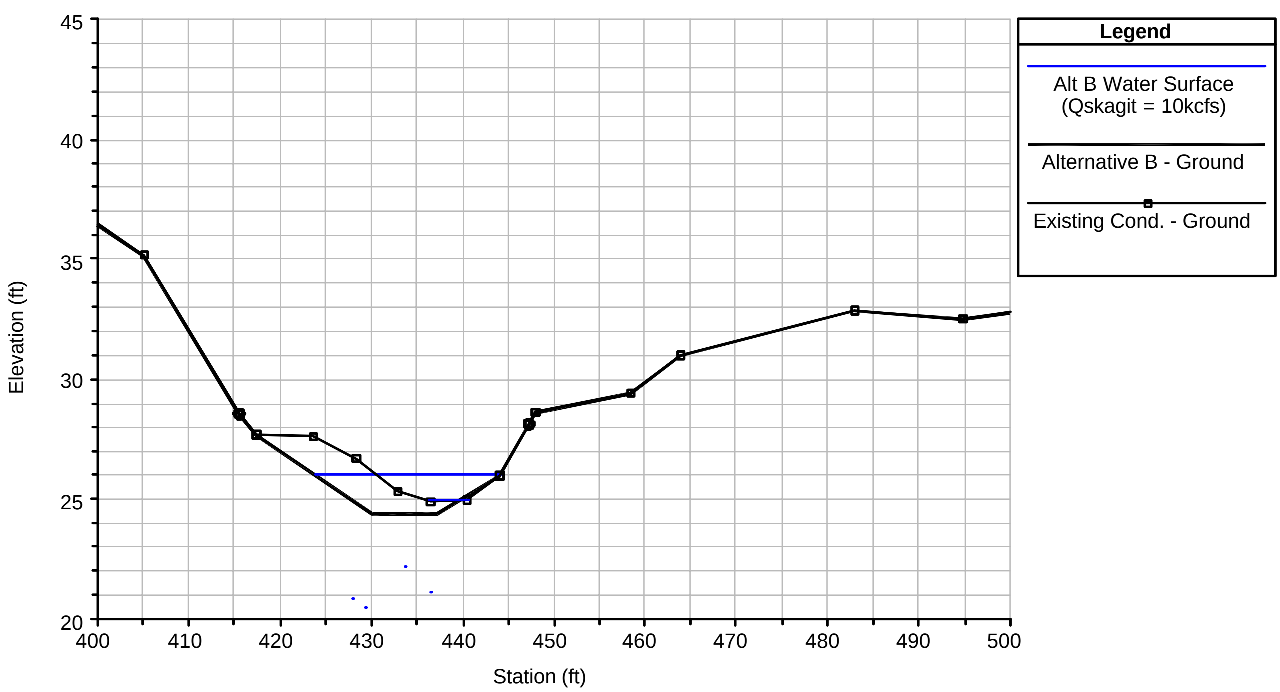
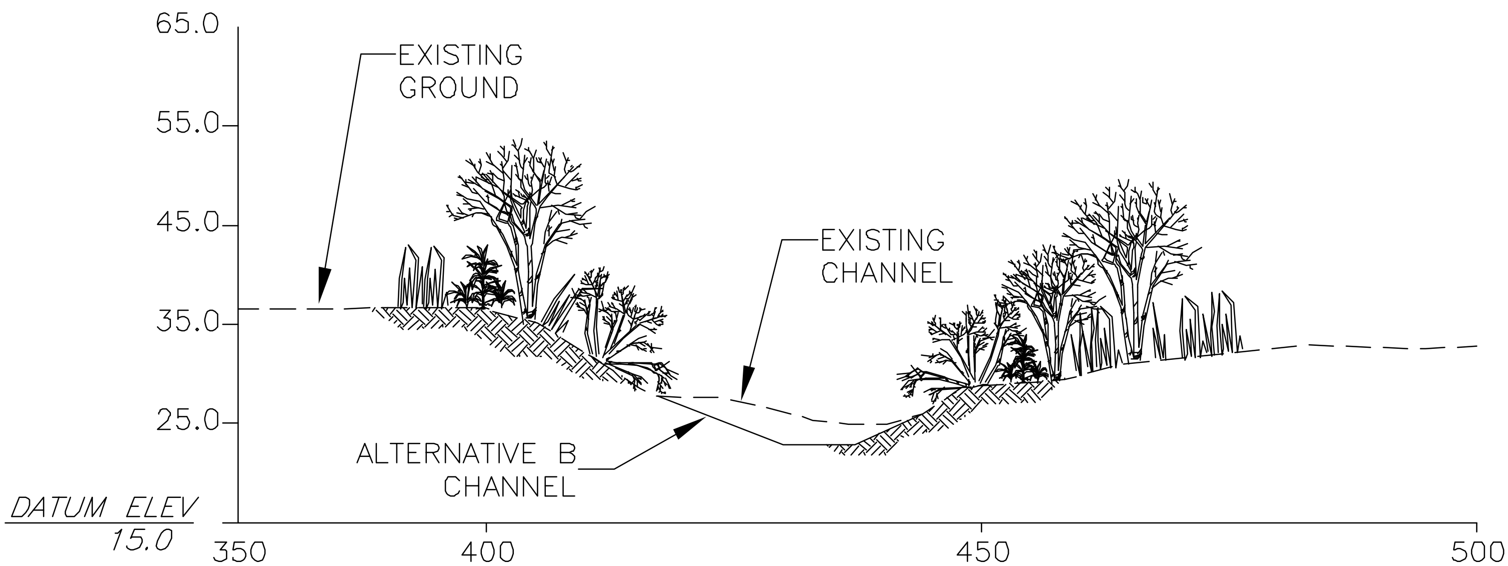
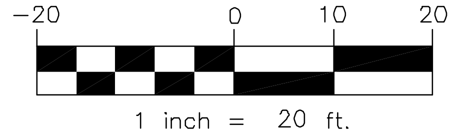


Figure 12 - Cross Section 15547, Existing and Alternative B







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Hood River, OR 97031
541.386.9003
www.interfluve.com

FIGURE 13

HART SLOUGH – ALTERNATIVE B
CONCEPTUAL SECTION VIEW

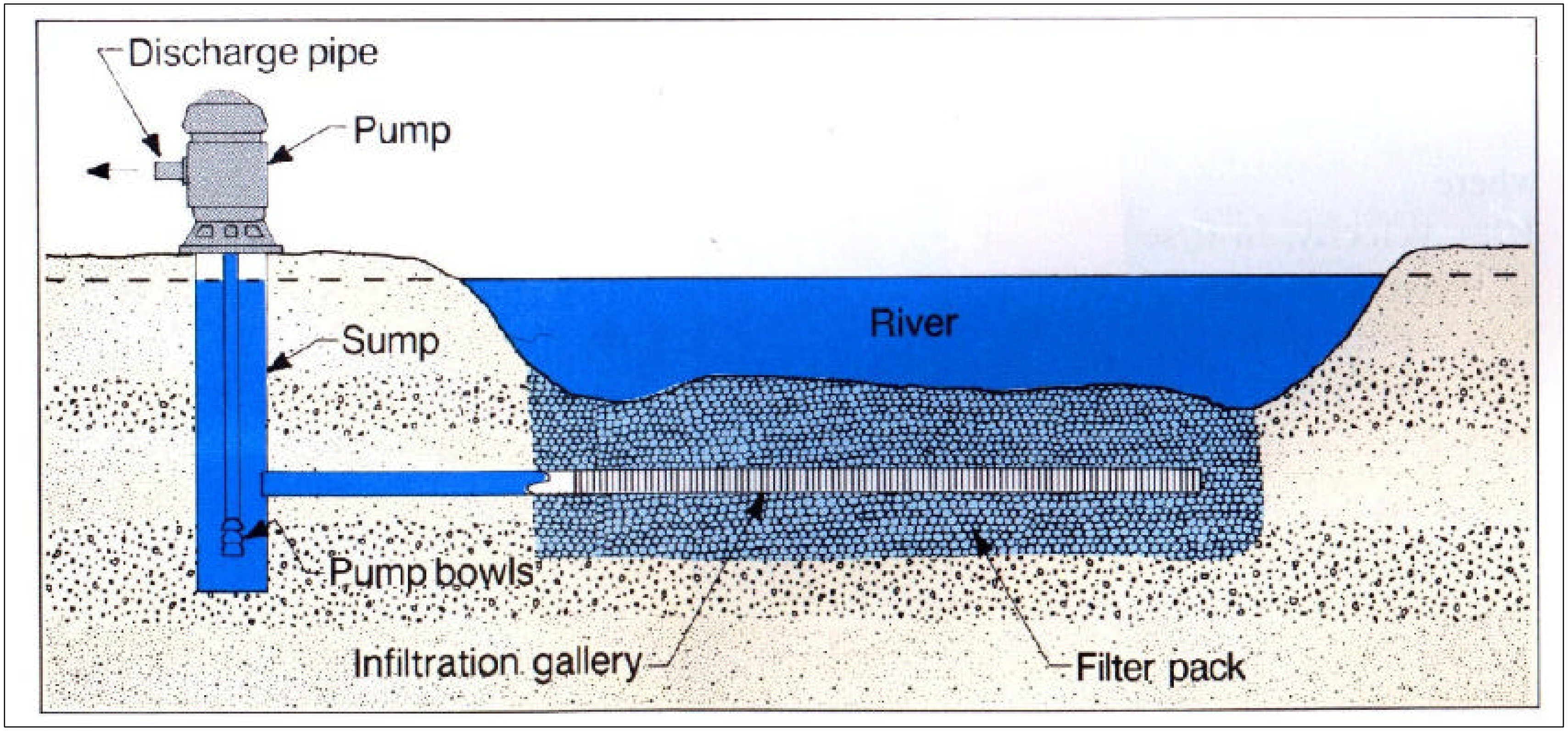


Figure 14 - Conceptual View of Infiltration Gallery

Image source: Fletcher G. Driscoll, 1986. *Groundwater and Wells* , Second Edition. Johnson Division.

7 Hart Island Enhancement Alternatives

The Steering Committee identified additional enhancement goals for the property on Hart's Island. These interior areas are routinely flooded and currently provide limited rearing habitat and refuge during flood conditions. Stranding of fish has been observed at some sites. Goals for the interior areas are:

A) Optimize the availability of high quality, salmonid rearing habitat
- Provide additional flow to ponded interior areas

B) Provide flood refuge
- Minimize stranding in ponded areas used as flood refuge
- Protect waterfowl habitat

7.1 LARGE POND / REMNANT MAINSTEM CHANNEL

Many areas of the island provide refuge for juvenile fishes allowing them to escape mainstem flow conditions. One potentially highly valuable area for both fish and waterfowl is the large pond area that is a remnant of the historic mainstem channel (Figure 15). While this area is inundated to varying degrees throughout the year (from groundwater flow), it currently functions primarily as a refuge during floods. Hart Island begins flooding at about a 2-year event - the slough banks are overtopped by the 2-year event at the upstream and downstream end of the large pond. Thus the large pond provides refuge during events in excess of the 2-year flood when flows overtop the banks of the slough. However, models indicate that the large pond becomes isolated from both the slough and the mainstem as flow and water levels recede. Therefore, no appreciable flow through the large pond is anticipated under existing conditions. Furthermore, as flows recede topographic low points create stranding hazards to fish in the floodplain, as well as in the pond itself. There are two elements to enhance habitat function at this location: 1) the introduction of additional flow through the pond by creating inflow and outflow channels, and 2) improvement of the connection between the mainstem and the ponded areas to provide freely draining conditions that would minimize the risk of fish stranding.

Topographic data indicate that this remnant of the historic channel is favorable to additional flow. The introduction of additional flow would enhance its value as year-round rearing salmonid rearing habitat and as habitat for waterfowl. It may be possible to provide this additional flow by diverting flow from the slough at certain times or under certain flow conditions. Three flow paths were explored for the introduction of water, one near the upper northern end of the pond and two east of the pond in the vicinity of an existing depression. Preliminary analysis indicates that the option of introducing flow near the northern end is most attractive based on site topography. Maintenance of water quality within the pond and control of sediment are key concerns with this alternative. Enhancement options that involve the addition of flow are dependent on what is finally proposed for the slough. At this stage, flow enhancement to the ponded area remains conceptual.

HART SLOUGH

FIGURE 15
LARGE POND ON HART ISLAND
REMNANT OF MAINSTREAM CHANNEL

Improving the connection between the pond area and the mainstem will improve access to rearing area and minimize stranding (Figure 16). Enhancement and definition of this 2500' migration corridor will result in substantial benefit to juvenile salmonids regardless of whether additional flow is introduced into the ponded area upstream. The proposed construction would involve regrading to define a free-flowing and self-maintaining channel between the pond and slough and recontouring of bank topography to direct recede flows into the free-flowing channel. A conceptual profile of the channel in the proposed reach is shown in Figure 17. A typical cross section of the channel in the proposed reach is shown in Figure 18.

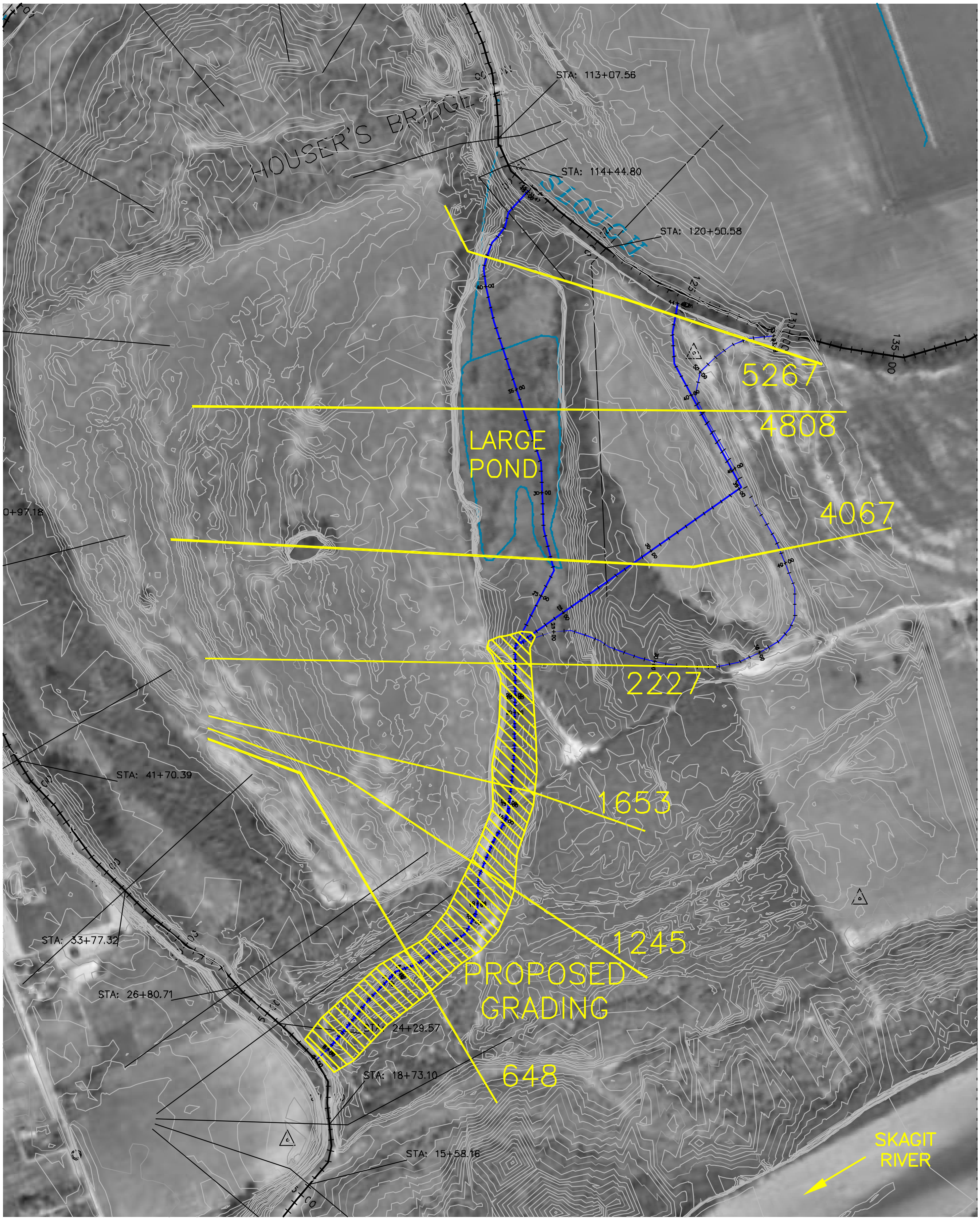
7.2 Regrading of Critical Stranding Areas

Certain portions of Hart Island have topographic depressions that tend to strand fish when floodwaters recede. One area where this problem is especially pronounced is along the western portion of the island, approximately 800 feet east of the slough. This area has been intermittently used for agricultural production and is also inundated at flows less than the 2-year event. Immediate benefits may be realized at this site by regrading the area to reduce the amount of topographic depressions and, thus, minimize fish stranding potential.

The extent of stranding at this location is based on anecdotal documentation of repeated stranding by Leonard Halverson, a field trip to the site under flood conditions, and topographic information collected during the aerial survey. Figure 19 shows the area of concern. Treatment options include regrading the area to remove the topographic depressions and possibly providing fish access via small channels between the potential stranding areas and Hart Slough.

8 Full Restoration Alternative

Much of this feasibility study has focused on the enhancement of existing conditions. Full restoration of the Skagit River in this location would require recreating the historic channel course (Figure 2). While possible, significant modification of the mainstem downstream of State Route 9 would be required to allow flows to recapture the historic meander pattern north of Hart Island and south of DeBay Island. This alternative was not quantified in this study because of high level of risk associated with redirecting flood flows into the historic channel.



HART SLOUGH

FIGURE 16
LARGE POND OUTLET CHANNEL
REGRADING LIMITS

Figure 17. Large Pond Outlet Channel Profile

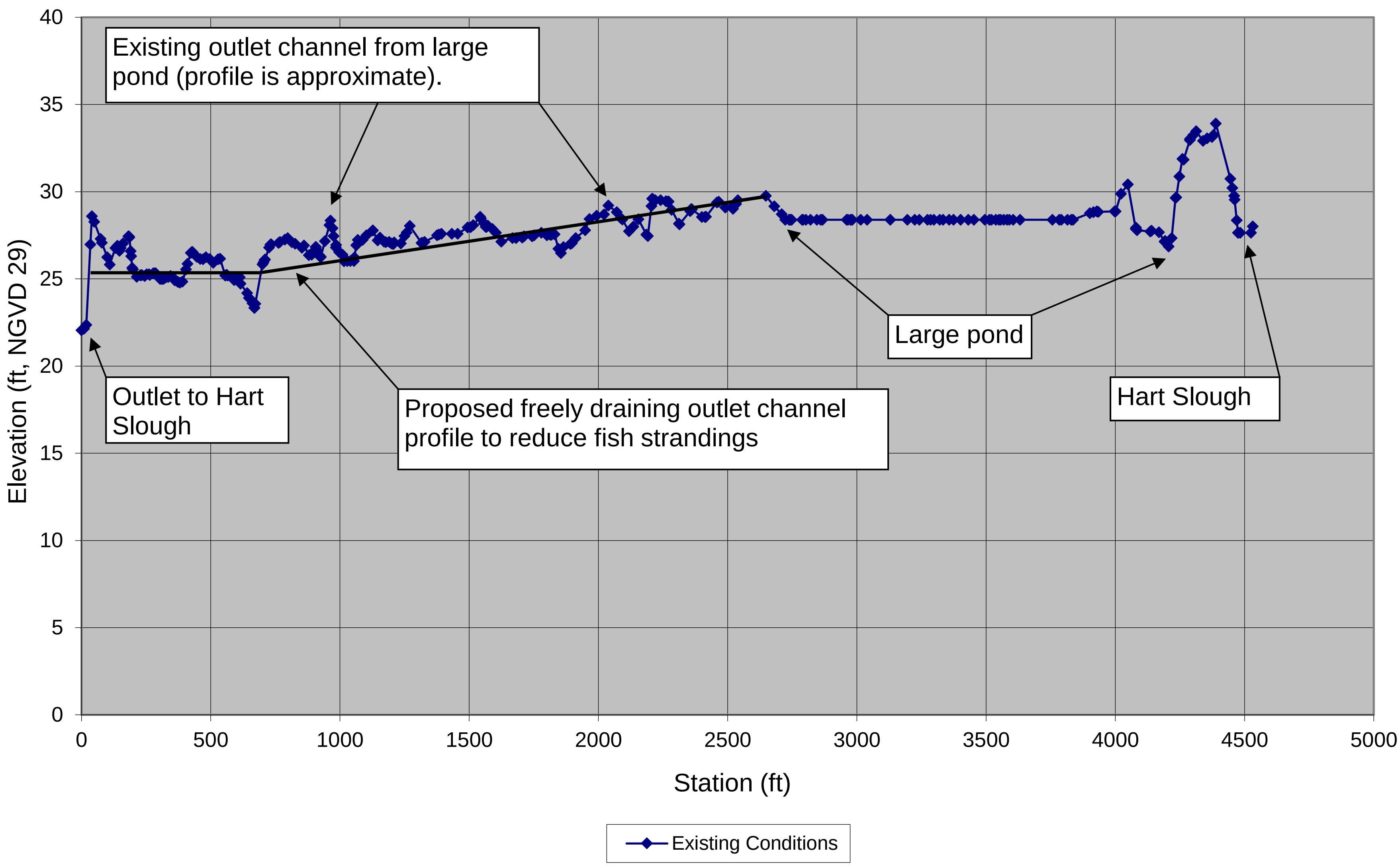
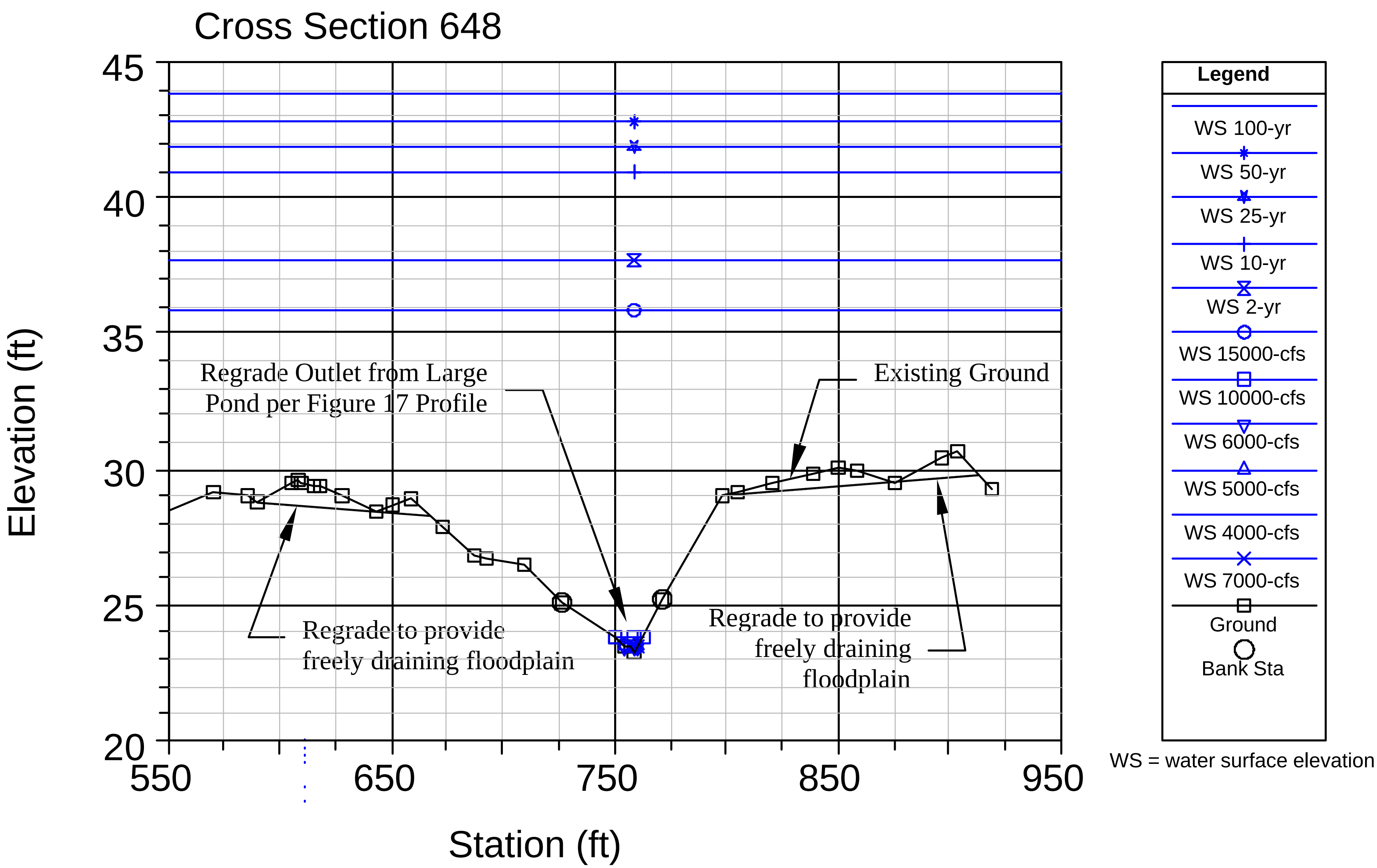
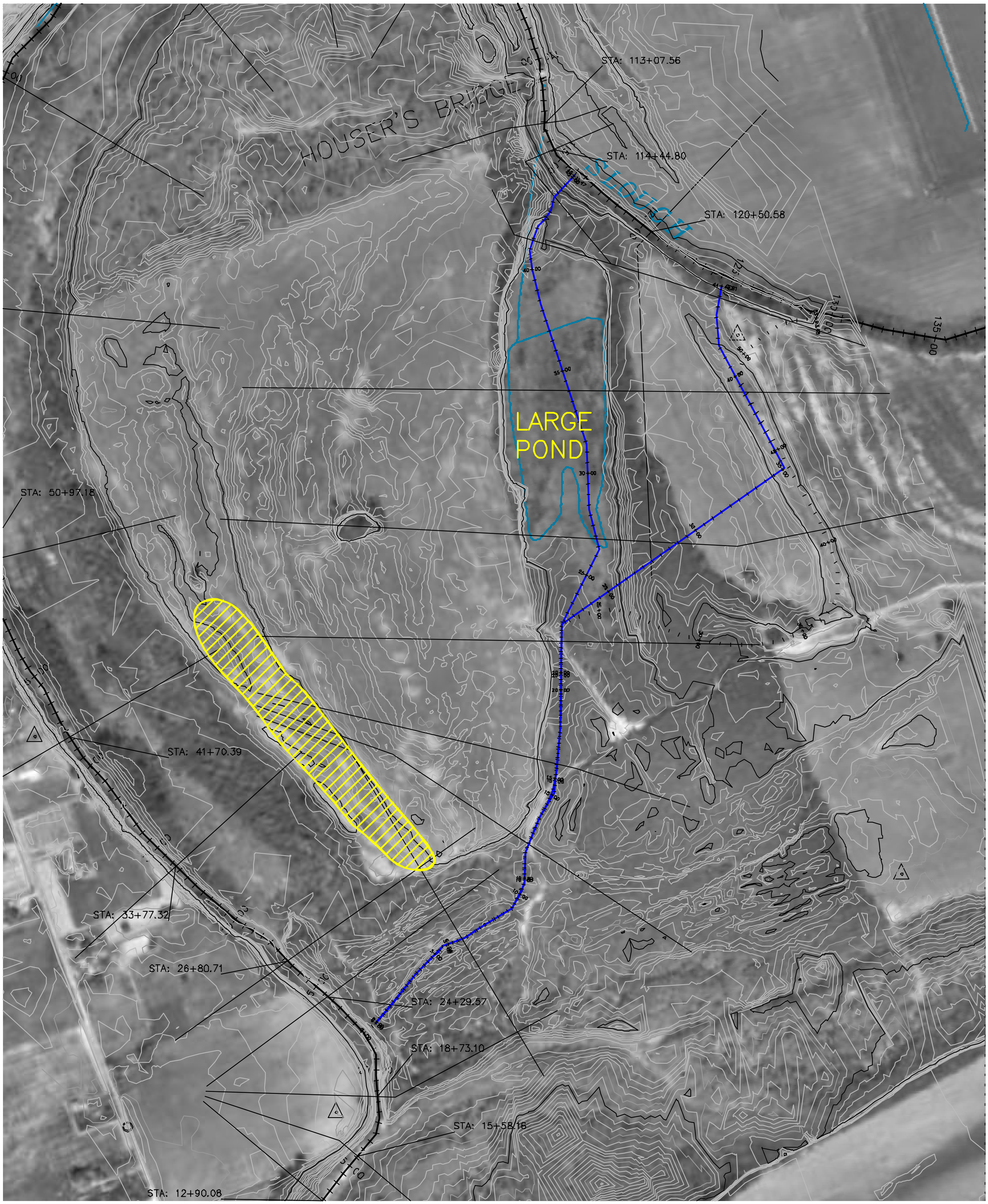


Figure 18. Typical Cross Section of Large Pond Outlet Channel Regrading to Reduce Fish Stranding





HART SLOUGH

FIGURE 19
TOPOGRAPHIC DEPRESSION AT
WEST PORTION OF HART ISLAND

9 Action Plan

This report details the investigations and evaluation of alternatives considered to increase available fish habitat within Hart Slough and thereby enhance and augment fish populations within the Skagit River system. The result of this investigation includes the recommendation of Alternative B for Hart Slough, which involves installation of a structure at the inlet to the slough to augment summer flows and to regulate high flow into the slough, and excavation of the upper reach of the slough to increase habitat area. Recommendations also include consideration of blending components of other alternatives evaluated, such as pumping additional water into the slough to improve water quality. Additional opportunities for habitat enhancement and creation were considered for Hart Island, the land area encompassed by the slough, but will require further investigation to develop recommendations.

While this report explains the alternatives and the basis for its recommendations, implementation of the project will require substantial further efforts. The following action plan lists the recommended actions for moving forward from a recommended alternative to an implemented plan. The action plan is a brief discussion of components including stakeholder involvement, funding, project design, permitting and other implementation requirements and considerations.

9.1 Stakeholder Involvement

Any actions within Hart Slough and the Skagit River in proximity to Hart Slough necessarily affect many landowners and interests, both within the boundaries of the slough and island and within, upstream and downstream on the Skagit. While the recommended alternative is based on considerable consultation and input from stakeholders, there are many details that will require collaboration among stakeholders to resolve. The purpose of stakeholder input is to seek input from all affected parties and to select an alternative to pursue. Stakeholders include property owners, tribes, agencies, enhancement groups, non-profit organizations, and other interested parties throughout the watershed who may have a role or interest in enhancement efforts.

A series of stakeholder meetings are recommended to facilitate this process and include:

1. *Presentation of recommended alternative*. An open meeting of all stakeholders to present the recommended alternative and to distribute the alternatives report.
2. *Selection of an alternative to implement*. Following a comment period of the recommended alternative, a proposal will be presented by Skagit County or other interested entity, to stakeholders which details project components and expected results and impacts of the selected alternative.
3. *Solicit input on project criteria*. A working meeting with participation from stakeholders, design team, and regulatory agency representatives to develop criteria for design.

9.2 Funding

Further development of this project will require additional funding for design and construction. While this report has estimated costs for implementation, a detailed cost and benefit analysis may be required by some potential funding sources. Further detail on cost and benefit analysis may require further investigation and design development. Potential funding sources may include:

- State agencies and programs – Salmon Recovery Funding Board (SRFBoard)
- Federal – U.S. Army Corps of Engineers
- County – Skagit County
- Private – Conservation organizations including National Fish and Wildlife Foundation (NFWF), Puget Sound Energy, Seattle City Light, and Timber companies
- Tribes

9.3 Design

Project design will involve development of and agreement on design criteria, preliminary design, and development of final plans and specifications.

1. *Identify and resolve data gaps*. Prior to design, data gaps should be identified by the design team and resolved. These data gaps may affect the development of design criteria and the design process. *Data gaps may include*:
    - Further detail on fish production potential for summer and winter habitat
    - Sediment inputs to slough and sedimentation evaluation of selected alternative
2. *Design Criteria.* Development of design criteria should include stakeholder input and review to ensure that stakeholder interests and concerns are addressed in the design process.
3. *Preliminary design*. Preliminary design should include a full description and accounting of design components, anticipated results and impacts of implementation, and detailed cost estimate for construction. Preliminary designs should be sufficient in detail to meet permitting application requirements.
4. *Final plans and specifications*. Final plans and specifications are necessary to solicit bids for construction, and to implement construction.
5. *Monitoring and maintenance plan*. Final designs should include a monitoring and maintenance plan. A monitoring plan should be scientifically sound and result in data useful for other projects.

Project design should emphasize consideration of the following design issues and potential maintenance concerns

- Impact to flood potential and channel stability
- Impact of beavers on performance
- Sedimentation
- Design life and maintenance of structures and controls

9.4 PERMITTING AND WATER RIGHTS

9.4.1 Permitting

Permitting any work within the Skagit River system requires substantial time, effort and expense. The permitting process should be initiated at the earliest possible time and may require 12 months to 18 months to complete. Preliminary designs will be necessary at a minimum to submit with permit applications. A number of permits and supporting data will be required including the following:

- Wetland Determination / Wetland Delineation for submittal to U.S. Army Corps of Engineers and Washington Dept. of Ecology
- Section 404 permit - U.S. Army Corps of Engineers
- Section 401 water quality certification - Washington Dept. of Ecology
- Biological Assessment / Biological Evaluation for ESA Consultation with U.S. Fish and Wildlife Service and NOAA Fisheries
- Hydraulic Project Approval permit - Washington Dept. of Fish and Wildlife
- State Environmental Policy Act checklist - Skagit County
- Permits at the local and county level will also be required.

9.4.2 Water Rights

These alternatives were described and discussed with a representative of the Water Resources Program of Washington Department of Ecology (WDOE). Each alternative involves diversion of flows from the Skagit River. Thus, guidance from WDOE was that water rights would be required for each alternative regardless of either condition of consumptive (e.g. seepage) or non-consumptive use and regardless the return of flows back to the Skagit (WDOE, personal communication). New water right applications are presently on a three to four year backlog prior to processing. An option to expedite the water right would be to identify an existing water right and apply to WDOE to have it transferred to the Hart Slough project.

9.5 IMPLEMENTATION

9.5.1 Short-term/Immediate actions

Short-term actions are those necessary to initiate the design process, permitting and to seek funding. Short-term actions should be implemented in the first 6 months of the implementation process and include:

- Stakeholder review and comment of recommended alternative
- Selection of alternative by Skagit County or other entity, and presentation to stakeholders
- Identify data gaps and develop design criteria
- Seek funding for design
- Begin addressing water rights issues.

9.5.2 Long-term actions

Long-term actions are those necessary to complete the project and are typically dependent upon resolution and completion of short-term actions to initiate. Long-term actions are listed roughly in sequential order and may require 12 to 18 months to complete. Long-term actions include:

- Data gap analysis and preliminary design
- Seek funding for implementation
- Submit permit applications and secure necessary permits
- Finalize designs and construction plans and specifications
- Construction contracting
- Construction
- Determining long-tern ownership, operations and maintenance

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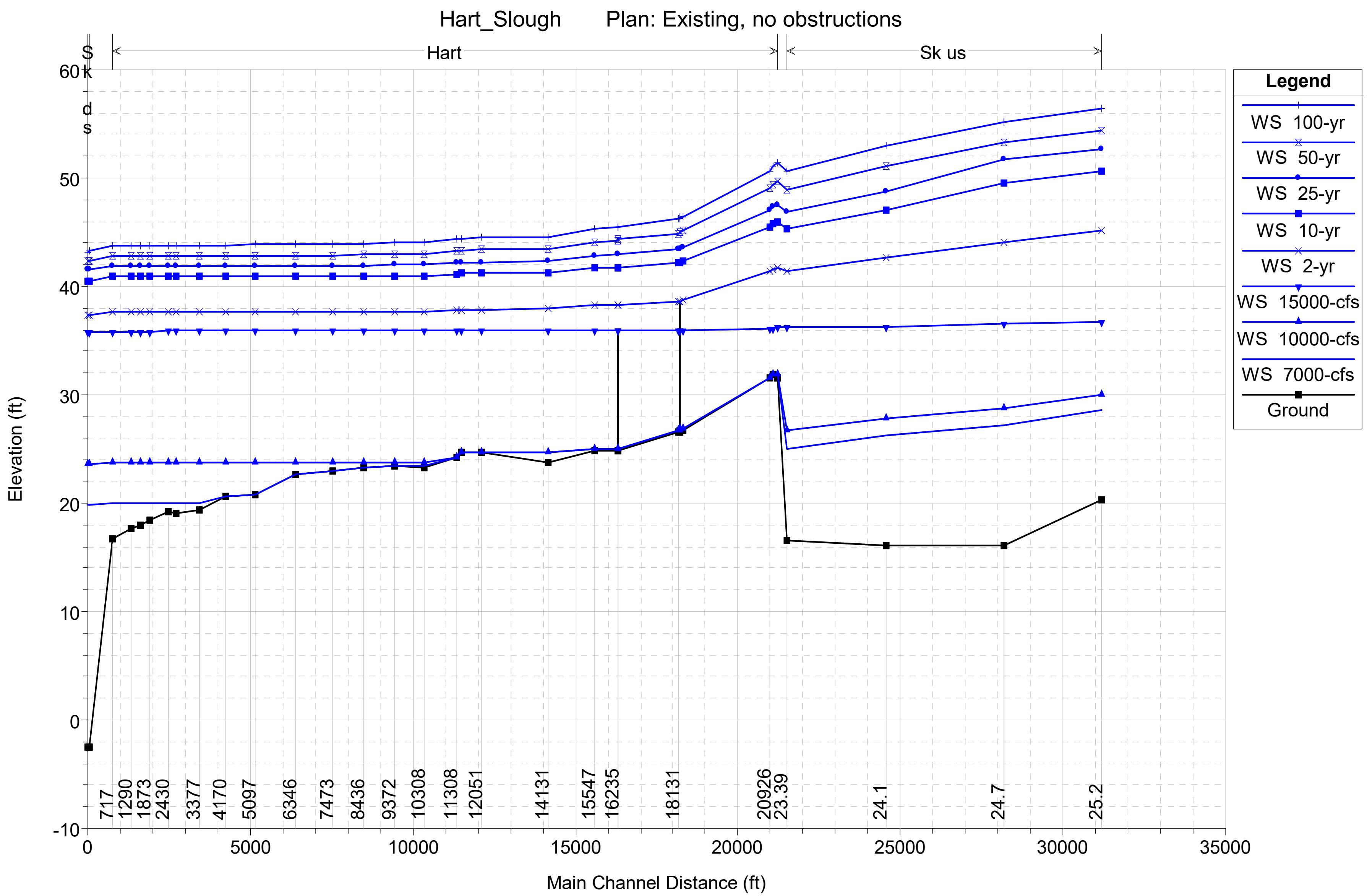
11 Appendices

Appendix A – Summary of Existing Conditions HEC-RAS Model Results
Appendix B – Summary of Existing and Alternative Conditions HEC-RAS Modeling Results.

Appendix A – Summary of Existing Conditions HEC-RAS Model Results



Hart_Slough Plan: Existing, no obstructions
Sk ds
Hart
Sk us
Legend
WS 100-yr
WS 50-yr
WS 25-yr
WS 10-yr
WS 2-yr
WS 15000-cfs
WS 10000-cfs
WS 7000-cfs
Ground
Elevation (ft)
Main Channel Distance (ft)
60
50
40
30
20
10
0
-10
0
5000
10000
15000
20000
25000
30000
35000
717
1290
1873
2430
3377
4170
5097
6346
7473
8436
9372
10308
11308
12051
14131
15547
16235
18131
20926
23.39
24.1
24.7
25.2

Hart Slough - Existing Conditions HEC-RAS Hydraulic Model Summary Results

Reach	River Sta	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl	Max Chl Dpth (ft)	Hydr Depth C (ft)	Shear Chan (lb/sq ft)	Vol Chan (acre-ft)
Hart	717	4000-cfs	0	16.67	16.69	16.69	16.69	0.000001	0	0.46	20.43	0	0.02	0.02	0	28.48
Hart	717	5000-cfs	0	16.67	17.3	16.69	17.3	0	0	16.08	31.3	0	0.63	0.51	0	33.86
Hart	717	6000-cfs	0	16.67	18.75	16.69	18.75	0	0	80.79	57.54	0	2.08	1.4	0	39.39
Hart	717	7000-cfs	0	16.67	20.06	16.69	20.06	0	0	174.63	103	0	3.39	2.06	0	44.92
Hart	717	10000-cfs	0	16.67	23.74	16.7	23.74	0	0	1065.55	391.8	0	7.07	3.45	0	64.8
Hart	717	15000-cfs	103.08	16.67	35.85	17.49	35.85	0	0.01	13393.01	1548.9	0	19.18	12.78	0	203.61
Hart	717	2-yr	1593.28	16.67	37.71	20.42	37.71	0.000001	0.11	16286.28	1548.9	0	21.04	14.65	0	230.16
Hart	717	10-yr	4923.55	16.67	40.94	22.34	40.94	0.000002	0.25	21280.37	1548.9	0.01	24.27	17.87	0	280.8
Hart	717	25-yr	6956.88	16.67	41.88	23.11	41.88	0.000003	0.32	22734.55	1548.9	0.01	25.21	18.81	0	298.11
Hart	717	50-yr	10343.23	16.67	42.8	23.88	42.8	0.000006	0.45	24162.12	1548.9	0.02	26.13	19.73	0.01	311.8
Hart	717	100-yr	13535.92	16.67	43.78	24.49	43.78	0.000009	0.55	25680.07	1548.9	0.02	27.11	20.71	0.01	326.98
Hart	1290	4000-cfs	0	17.59	17.62	17.62	17.62	0	0	0.81	27.78	0	0.03	0.03	0	28.49
Hart	1290	5000-cfs	0	17.59	17.62	17.62	17.62	0	0	0.81	27.78	0	0.03	0.03	0	33.97
Hart	1290	6000-cfs	0	17.59	18.75	17.62	18.75	0	0	42.85	46.37	0	1.16	0.92	0	40.2
Hart	1290	7000-cfs	0	17.59	20.06	17.62	20.06	0	0	122.64	77.21	0	2.47	1.59	0	46.86
Hart	1290	10000-cfs	0	17.59	23.74	17.62	23.74	0	0	735.03	278.95	0	6.15	3.33	0	73.74
Hart	1290	15000-cfs	103.08	17.59	35.85	18.3	35.85	0	0.01	11364.96	1443.31	0	18.26	15.3	0	256.36
Hart	1290	2-yr	1593.28	17.59	37.71	20.95	37.71	0.000001	0.14	14762.4	1859.07	0.01	20.12	17.17	0	290.1
Hart	1290	10-yr	4923.55	17.59	40.94	23.04	40.94	0.000003	0.3	20758.23	1859.07	0.01	23.35	20.39	0	353.17
Hart	1290	25-yr	6956.88	17.59	41.88	23.82	41.88	0.000004	0.39	22504.98	1859.07	0.01	24.29	21.33	0.01	374.09
Hart	1290	50-yr	10343.23	17.59	42.8	24.77	42.8	0.000007	0.53	24221.32	1859.07	0.02	25.21	22.26	0.01	391.34
Hart	1290	100-yr	13535.92	17.59	43.78	25.62	43.79	0.00001	0.63	26045.94	1859.07	0.02	26.19	23.24	0.01	410.3
Hart	1558	4000-cfs	0	17.96	17.99	17.99	17.99	0.000009	0	0.25	19.91	0.01	0.03	0.01	0	28.49
Hart	1558	5000-cfs	0	17.96	17.99	17.99	17.99	0.000009	0	0.25	19.91	0.01	0.03	0.01	0	33.97
Hart	1558	6000-cfs	0	17.96	18.75	17.98	18.75	0	0	32.8	46.58	0	0.79	0.7	0	40.43
Hart	1558	7000-cfs	0	17.96	20.06	17.98	20.06	0	0	102.02	59.52	0	2.1	1.71	0	47.55
Hart	1558	10000-cfs	0	17.96	23.74	17.98	23.74	0	0	601.14	230.2	0	5.78	3.04	0	77.61
Hart	1558	15000-cfs	103.08	17.96	35.85	18.57	35.85	0	0.02	8208.29	957.63	0	17.89	14.98	0	275.53
Hart	1558	2-yr	1593.28	17.96	37.71	21.43	37.71	0.000001	0.19	9997.17	965.3	0.01	19.75	16.84	0	311.63
Hart	1558	10-yr	4923.55	17.96	40.94	23.47	40.94	0.000005	0.41	15423.18	1638.48	0.02	22.98	20.07	0.01	378.78
Hart	1558	25-yr	6956.88	17.96	41.88	24.25	41.88	0.000008	0.52	16963.87	1638.48	0.02	23.92	21.01	0.01	400.9
Hart	1558	50-yr	10343.23	17.96	42.81	25.27	42.81	0.000014	0.71	18479.12	1638.48	0.03	24.85	21.93	0.02	419.31
Hart	1558	100-yr	13535.92	17.96	43.79	26.08	43.8	0.000018	0.85	20089.6	1638.48	0.03	25.83	22.92	0.03	439.52

Hart Slough - Existing Conditions HEC-RAS Hydraulic Model Summary Results

Reach	River Sta	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl	Max Chl Dpth (ft)	Hydr Depth C (ft)	Shear Chan (lb/sq ft)	Vol Chan (acre-ft)
Hart	1873	4000-cfs	0	18.4	18.42	18.42	18.42	0.000023	0.01	0.12	6.26	0.01	0.02	0.02	0	28.49
Hart	1873	5000-cfs	0	18.4	18.42	18.42	18.42	0.000023	0.01	0.12	6.26	0.01	0.02	0.02	0	33.97
Hart	1873	6000-cfs	0	18.4	18.75	18.42	18.75	0	0	2.48	8.09	0	0.35	0.31	0	40.56
Hart	1873	7000-cfs	0	18.4	20.06	18.42	20.06	0	0	17.76	15.32	0	1.66	1.16	0	47.98
Hart	1873	10000-cfs	0	18.4	23.74	18.42	23.74	0	0	111.06	35.11	0	5.34	3.16	0	80.12
Hart	1873	15000-cfs	103.08	18.4	35.86	20.01	35.86	0	0.02	7846.08	1009.8	0	17.46	12.81	0	289.15
Hart	1873	2-yr	1593.28	18.4	37.71	24.68	37.71	0.000002	0.19	9728.74	1018.81	0.01	19.31	14.67	0	327
Hart	1873	10-yr	4923.55	18.4	40.94	28.82	40.94	0.000006	0.38	15328.09	1758.62	0.02	22.54	17.9	0.01	397.18
Hart	1873	25-yr	6956.88	18.4	41.88	30.41	41.89	0.000008	0.49	16983.03	1758.62	0.02	23.48	18.84	0.01	420.18
Hart	1873	50-yr	10343.23	18.4	42.81	30.41	42.81	0.000014	0.65	18612.12	1758.62	0.03	24.41	19.77	0.02	439.46
Hart	1873	100-yr	13535.92	18.4	43.79	30.41	43.8	0.000019	0.78	20343.21	1758.62	0.03	25.39	20.75	0.02	460.59
Hart	2430	4000-cfs	0	19.26	19.28	19.28	19.28	0.000015	0.01	0.15	7.85	0.01	0.02	0.02	0	28.49
Hart	2430	5000-cfs	0	19.26	19.28	19.28	19.28	0.000015	0.01	0.15	7.85	0.01	0.02	0.02	0	33.97
Hart	2430	6000-cfs	0	19.26	19.28	19.28	19.28	0.000015	0.01	0.15	7.85	0.01	0.02	0.02	0	40.58
Hart	2430	7000-cfs	0	19.26	20.06	19.28	20.06	0	0	8.39	13.43	0	0.8	0.62	0	48.15
Hart	2430	10000-cfs	0	19.26	23.74	19.28	23.74	0	0	136.6	86.8	0	4.48	1.57	0	81.71
Hart	2430	15000-cfs	103.08	19.26	35.86	20.67	35.86	0	0.01	8904.34	1085.2	0	16.6	11.83	0	303.66
Hart	2430	2-yr	1593.28	19.26	37.71	24.37	37.72	0.000001	0.16	10935.91	1107.3	0.01	18.45	13.68	0	343.72
Hart	2430	10-yr	4923.55	19.26	40.94	26.99	40.94	0.000004	0.33	16831.75	1710.58	0.01	21.68	16.91	0	417.76
Hart	2430	25-yr	6956.88	19.26	41.88	27.88	41.89	0.000007	0.42	18442.76	1710.58	0.02	22.62	17.85	0.01	441.89
Hart	2430	50-yr	10343.23	19.26	42.81	28.48	42.82	0.000011	0.58	20030.02	1710.58	0.02	23.55	18.78	0.01	462.28
Hart	2430	100-yr	13535.92	19.26	43.8	29.31	43.8	0.000015	0.69	21716.3	1710.58	0.03	24.54	19.77	0.02	484.58
Hart	2681	4000-cfs	0	19.03	19.29	19.05	19.29	0	0	1.7	7.48	0	0.26	0.23	0	28.5
Hart	2681	5000-cfs	0	19.03	19.29	19.05	19.29	0	0	1.7	7.48	0	0.26	0.23	0	33.98
Hart	2681	6000-cfs	0	19.03	19.28	19.05	19.28	0	0	1.65	7.42	0	0.25	0.22	0	40.58
Hart	2681	7000-cfs	0	19.03	20.06		20.06	0	0	9.62	13.18	0	1.03	0.73	0	48.2
Hart	2681	10000-cfs	0	19.03	23.74		23.74	0	0	150.85	80.73	0	4.71	1.87	0	82.53
Hart	2681	15000-cfs	103.08	19.03	35.87		35.87	0	0.01	8432.51	1046.76	0	16.84	12.64	0	312.14
Hart	2681	2-yr	1593.28	19.03	37.72		37.72	0.000002	0.18	10498.27	1301.37	0.01	18.69	14.49	0	353.49
Hart	2681	10-yr	4923.55	19.03	40.94		40.95	0.000005	0.38	15821.64	1729.72	0.02	21.91	17.72	0.01	429.77
Hart	2681	25-yr	6956.88	19.03	41.89		41.89	0.000008	0.48	17451.94	1729.72	0.02	22.86	18.66	0.01	454.55
Hart	2681	50-yr	10343.23	19.03	42.82		42.82	0.000013	0.65	19059.65	1729.72	0.03	23.79	19.59	0.02	475.59
Hart	2681	100-yr	13535.92	19.03	43.8		43.81	0.000018	0.77	20767.28	1729.72	0.03	24.77	20.58	0.02	498.57

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Reach	River Sta	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl	Max Chl Dpth (ft)	Hydr Depth C (ft)	Shear Chan (lb/sq ft)	Vol Chan (acre-ft)
Hart	3377	4000-cfs	0	19.35	19.37	19.37	19.37	0.000024	0.01	0.13	8.69	0.01	0.02	0.02	0	28.51
Hart	3377	5000-cfs	0	19.35	19.37	19.37	19.37	0.000024	0.01	0.13	8.69	0.01	0.02	0.02	0	33.99
Hart	3377	6000-cfs	0	19.35	19.37	19.37	19.37	0.000024	0.01	0.13	8.69	0.01	0.02	0.02	0	40.6
Hart	3377	7000-cfs	0	19.35	20.06	19.37	20.06	0	0	8.33	15.16	0	0.71	0.55	0	48.34
Hart	3377	10000-cfs	0	19.35	23.74	19.38	23.74	0	0	133.03	55.8	0	4.39	2.38	0	84.8
Hart	3377	15000-cfs	103.08	19.35	35.87	20.65	35.87	0	0.01	7681.3	853.41	0	16.52	11.99	0	332.53
Hart	3377	2-yr	1593.28	19.35	37.72	24.34	37.72	0.000002	0.17	9259.71	856.85	0.01	18.37	13.37	0	376.95
Hart	3377	10-yr	4923.55	19.35	40.94	27.53	40.95	0.000007	0.39	12036.64	862.7	0.02	21.59	16.13	0.01	458.72
Hart	3377	25-yr	6956.88	19.35	41.89	27.87	41.89	0.000011	0.52	12851.17	864.36	0.02	22.54	17.07	0.01	485.11
Hart	3377	50-yr	10343.23	19.35	42.82	28.32	42.83	0.000019	0.72	13656.67	865.99	0.03	23.47	18.01	0.02	507.73
Hart	3377	100-yr	13535.92	19.35	43.81	28.63	43.82	0.000023	0.82	17122.16	1444.46	0.03	24.46	18.99	0.03	532.4
Hart	4170	4000-cfs	0	20.59	20.62	20.62	20.62	0.000191	0.02	0.05	3.22	0.03	0.03	0.01	0	28.51
Hart	4170	5000-cfs	0	20.59	20.62	20.62	20.62	0.000191	0.02	0.05	3.22	0.03	0.03	0.01	0	33.99
Hart	4170	6000-cfs	0	20.59	20.62	20.62	20.62	0.000191	0.02	0.05	3.22	0.03	0.03	0.01	0	40.6
Hart	4170	7000-cfs	0	20.59	20.62	20.62	20.62	0.000191	0.02	0.05	3.22	0.03	0.03	0.01	0	48.42
Hart	4170	10000-cfs	0	20.59	23.74		23.74	0	0	113.79	59.59	0	3.15	1.91	0	87.05
Hart	4170	15000-cfs	103.08	20.59	35.87		35.87	0	0.02	7343.86	903.51	0	15.28	11.58	0	356.88
Hart	4170	2-yr	1593.28	20.59	37.72		37.72	0.000002	0.19	9051.79	990.57	0.01	17.13	13.42	0	405.16
Hart	4170	10-yr	4923.55	20.59	40.95		40.95	0.000007	0.42	13191.84	1372.29	0.02	20.36	16.65	0.01	493.8
Hart	4170	25-yr	6956.88	20.59	41.89		41.89	0.00001	0.54	14487.28	1372.29	0.02	21.3	17.6	0.01	522.2
Hart	4170	50-yr	10343.23	20.59	42.83		42.84	0.000018	0.73	15778.25	1372.29	0.03	22.24	18.54	0.02	546.82
Hart	4170	100-yr	13535.92	20.59	43.82		43.83	0.000024	0.88	17137.97	1372.29	0.03	23.23	19.53	0.03	573.6
Hart	5097	4000-cfs	0	20.73	20.76	20.75	20.76	0.000117	0.02	0.06	4.67	0.02	0.03	0.01	0	28.52
Hart	5097	5000-cfs	0	20.73	20.76	20.75	20.76	0.000117	0.02	0.06	4.67	0.02	0.03	0.01	0	34
Hart	5097	6000-cfs	0	20.73	20.76	20.75	20.76	0.000117	0.02	0.06	4.67	0.02	0.03	0.01	0	40.6
Hart	5097	7000-cfs	0	20.73	20.76	20.75	20.76	0.000108	0.01	0.07	4.74	0.02	0.03	0.01	0	48.42
Hart	5097	10000-cfs	0	20.73	23.74		23.74	0	0	101.79	54.1	0	3.01	1.88	0	89.34
Hart	5097	15000-cfs	103.08	20.73	35.88		35.88	0	0.02	7492.15	1015.07	0	15.15	11.48	0	389.97
Hart	5097	2-yr	1593.28	20.73	37.72		37.72	0.000002	0.19	9372.35	1026.01	0.01	16.99	13.31	0	443.53
Hart	5097	10-yr	4923.55	20.73	40.95		40.95	0.000007	0.42	12950.12	1314.65	0.02	20.22	16.55	0.01	541.44
Hart	5097	25-yr	6956.88	20.73	41.89		41.9	0.000011	0.55	14260.77	1470.18	0.02	21.16	17.49	0.01	572.55
Hart	5097	50-yr	10343.23	20.73	42.84		42.85	0.000019	0.74	15712.61	1588.8	0.03	22.11	18.44	0.02	599.89
Hart	5097	100-yr	13535.92	20.73	43.84		43.85	0.000025	0.89	17290.31	1588.8	0.04	23.11	19.43	0.03	629.52

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Reach	River Sta	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl	Max Chl Dpth (ft)	Hydr Depth C (ft)	Shear Chan (lb/sq ft)	Vol Chan (acre-ft)
Hart	6346	4000-cfs	0	22.62	22.65	22.65	22.65	0.000018	0.01	0.17	12.58	0.01	0.03	0.01	0	28.52
Hart	6346	5000-cfs	0	22.62	22.65	22.65	22.65	0.000018	0.01	0.17	12.58	0.01	0.03	0.01	0	34
Hart	6346	6000-cfs	0	22.62	22.65	22.65	22.65	0.000018	0.01	0.17	12.58	0.01	0.03	0.01	0	40.6
Hart	6346	7000-cfs	0	22.62	22.65	22.65	22.65	0.000018	0.01	0.17	12.58	0.01	0.03	0.01	0	48.42
Hart	6346	10000-cfs	0	22.62	23.74		23.74	0	0	35.45	41.84	0	1.12	0.85	0	91.31
Hart	6346	15000-cfs	103.08	22.62	35.88		35.88	0	0.02	7755.23	1402.79	0	13.26	9.64	0	492.26
Hart	6346	2-yr	1593.28	22.62	37.72		37.72	0.000002	0.18	10346.99	1413.88	0.01	15.1	11.47	0	564.62
Hart	6346	10-yr	4923.55	22.62	40.95		40.95	0.000006	0.37	14924.38	1418.36	0.02	18.33	14.7	0.01	695.65
Hart	6346	25-yr	6956.88	22.62	41.9		41.9	0.00001	0.48	16276.93	1419.67	0.02	19.28	15.66	0.01	736.51
Hart	6346	50-yr	10343.23	22.62	42.86		42.87	0.000016	0.65	17640.44	1421	0.03	20.24	16.62	0.02	773.66
Hart	6346	100-yr	13535.92	22.62	43.86		43.87	0.000022	0.78	19061.13	1428.14	0.03	21.24	17.62	0.02	813.52
Hart	7473	4000-cfs	0	22.99	23.02	23.02	23.02	0.000002	0	0.33	11.78	0	0.03	0.03	0	28.53
Hart	7473	5000-cfs	0	22.99	23.02	23.02	23.02	0.000002	0	0.33	11.78	0	0.03	0.03	0	34.01
Hart	7473	6000-cfs	0	22.99	23.02	23.02	23.02	0.000002	0	0.33	11.78	0	0.03	0.03	0	40.61
Hart	7473	7000-cfs	0	22.99	23.02	23.02	23.02	0.000002	0	0.33	11.78	0	0.03	0.03	0	48.43
Hart	7473	10000-cfs	0	22.99	23.74		23.74	0	0	11.45	19.01	0	0.75	0.6	0	91.92
Hart	7473	15000-cfs	103.08	22.99	35.89		35.89	0	0.02	5624.95	780.49	0	12.9	9.01	0	589.3
Hart	7473	2-yr	1593.28	22.99	37.72		37.72	0.000004	0.24	7097.25	827.65	0.01	14.73	10.84	0	680.46
Hart	7473	10-yr	4923.55	22.99	40.95		40.95	0.000016	0.57	10319.1	1161.46	0.03	17.96	14.08	0.01	844.61
Hart	7473	25-yr	6956.88	22.99	41.91		41.92	0.000024	0.73	11473.63	1236.93	0.03	18.92	15.04	0.02	895.26
Hart	7473	50-yr	10343.23	22.99	42.88		42.89	0.000038	0.97	12677.72	1246.42	0.04	19.89	16.01	0.04	942.28
Hart	7473	100-yr	13535.92	22.99	43.89		43.9	0.000049	1.14	13941.92	1306.54	0.05	20.9	17.01	0.05	992.38
Hart	8436	4000-cfs	0	23.27	23.29	23.29	23.29	0.000001	0	0.43	18.22	0	0.02	0.02	0	28.53
Hart	8436	5000-cfs	0	23.27	23.29	23.29	23.29	0.000001	0	0.43	18.22	0	0.02	0.02	0	34.01
Hart	8436	6000-cfs	0	23.27	23.29	23.29	23.29	0.000001	0	0.43	18.22	0	0.02	0.02	0	40.62
Hart	8436	7000-cfs	0	23.27	23.29	23.29	23.29	0.000001	0	0.43	18.22	0	0.02	0.02	0	48.44
Hart	8436	10000-cfs	0	23.27	23.74		23.74	0	0	10.58	27.25	0	0.47	0.39	0	92.16
Hart	8436	15000-cfs	103.08	23.27	35.89		35.89	0	0.03	4004.42	671.39	0	12.62	9.49	0	624.33
Hart	8436	2-yr	1593.28	23.27	37.72		37.72	0.000008	0.36	5270.71	714.52	0.02	14.45	11.32	0.01	722.46
Hart	8436	10-yr	4923.55	23.27	40.96		40.97	0.000028	0.78	7797.41	891.42	0.04	17.69	14.56	0.03	898.94
Hart	8436	25-yr	6956.88	23.27	41.93		41.94	0.000043	1	8693.5	952.4	0.04	18.66	15.53	0.04	953.27
Hart	8436	50-yr	10343.23	23.27	42.91		42.93	0.000071	1.35	9652.79	999.93	0.06	19.64	16.52	0.07	1004
Hart	8436	100-yr	13535.92	23.27	43.93		43.96	0.000098	1.64	10719.42	1116.08	0.07	20.66	17.53	0.11	1057.95

Hart Slough - Existing Conditions HEC-RAS Hydraulic Model Summary Results

Reach	River Sta	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl	Max Chl Dpth (ft)	Hydr Depth C (ft)	Shear Chan (lb/sq ft)	Vol Chan (acre-ft)
Hart	9372	4000-cfs	0	23.36	23.38	23.38	23.38	0.000355	0.02	0.04	3.59	0.04	0.02	0.01	0	28.54
Hart	9372	5000-cfs	0	23.36	23.38	23.38	23.38	0.000355	0.02	0.04	3.59	0.04	0.02	0.01	0	34.02
Hart	9372	6000-cfs	0	23.36	23.38	23.38	23.38	0.000355	0.02	0.04	3.59	0.04	0.02	0.01	0	40.62
Hart	9372	7000-cfs	0	23.36	23.38	23.38	23.38	0.000355	0.02	0.04	3.59	0.04	0.02	0.01	0	48.44
Hart	9372	10000-cfs	0	23.36	23.74		23.74	0	0	5.2	17.57	0	0.38	0.3	0	92.33
Hart	9372	15000-cfs	103.08	23.36	35.89		35.89	0	0.04	3306.53	664.37	0	12.53	8.47	0	650.17
Hart	9372	2-yr	1593.28	23.36	37.72		37.72	0.000013	0.42	4571.7	723.03	0.02	14.36	10.3	0.01	753.55
Hart	9372	10-yr	4923.55	23.36	40.98		40.99	0.000037	0.85	7124.93	868.98	0.04	17.62	13.56	0.03	939.4
Hart	9372	25-yr	6956.88	23.36	41.96		41.98	0.000056	1.09	8024.22	960.79	0.05	18.6	14.54	0.05	996.53
Hart	9372	50-yr	10343.23	23.36	42.97		42.99	0.000088	1.44	9005.67	998.38	0.06	19.61	15.54	0.08	1050.12
Hart	9372	100-yr	13535.92	23.36	44.01		44.04	0.000109	1.67	10066.59	1037.37	0.07	20.65	16.59	0.11	1107.02
Hart	10308	4000-cfs	0	23.28	23.38	23.3	23.38	0	0	1.14	13.31	0	0.1	0.09	0	28.55
Hart	10308	5000-cfs	0	23.28	23.38	23.3	23.38	0	0	1.14	13.31	0	0.1	0.09	0	34.03
Hart	10308	6000-cfs	0	23.28	23.38	23.3	23.38	0	0	1.14	13.31	0	0.1	0.09	0	40.63
Hart	10308	7000-cfs	0	23.28	23.38	23.3	23.38	0	0	1.14	13.31	0	0.1	0.09	0	48.46
Hart	10308	10000-cfs	0	23.28	23.74	23.3	23.74	0	0	6.45	16.41	0	0.46	0.39	0	92.46
Hart	10308	15000-cfs	103.08	23.28	35.9	24.41	35.9	0.000001	0.09	1286.11	231.64	0.01	12.62	8.7	0	671.31
Hart	10308	2-yr	1593.28	23.28	37.73	28.16	37.74	0.000086	1.09	1759.04	396.09	0.06	14.45	10.52	0.06	779.2
Hart	10308	10-yr	4923.55	23.28	41.01	31.39	41.04	0.000161	1.78	4303.4	924.17	0.08	17.73	13.81	0.14	973.13
Hart	10308	25-yr	6956.88	23.28	42.01	32.77	42.04	0.000189	2.02	5223.83	924.17	0.09	18.73	14.81	0.17	1032.7
Hart	10308	50-yr	10343.23	23.28	43.03	34.34	43.09	0.000257	2.46	6173.07	924.17	0.11	19.75	15.83	0.25	1088.79
Hart	10308	100-yr	13535.92	23.28	44.09	35.25	44.16	0.000283	2.7	7151.95	924.17	0.12	20.81	16.89	0.29	1148.29
Hart	11308	4000-cfs	0	24.27	24.3	24.3	24.3	0.000251	0.02	0.05	3.62	0.03	0.03	0.01	0	28.57
Hart	11308	5000-cfs	0	24.27	24.3	24.3	24.3	0.000251	0.02	0.05	3.62	0.03	0.03	0.01	0	34.05
Hart	11308	6000-cfs	0	24.27	24.3	24.3	24.3	0.000251	0.02	0.05	3.62	0.03	0.03	0.01	0	40.65
Hart	11308	7000-cfs	0	24.27	24.3	24.3	24.3	0.000251	0.02	0.05	3.62	0.03	0.03	0.01	0	48.47
Hart	11308	10000-cfs	0	24.27	24.3	24.3	24.3	0.000251	0.02	0.05	3.62	0.03	0.03	0.01	0	92.53
Hart	11308	15000-cfs	103.08	24.27	35.9	25.64	35.9	0.000001	0.07	1744.5	413.89	0	11.63	7.03	0	692.79
Hart	11308	2-yr	1593.28	24.27	37.8	29.22	37.8	0.000048	0.73	2538.03	423.86	0.04	13.53	8.93	0.03	805.9
Hart	11308	10-yr	4923.55	24.27	41.15	32.04	41.17	0.000109	1.37	4206.33	782.32	0.07	16.88	12.28	0.08	1009.13
Hart	11308	25-yr	6956.88	24.27	42.17	32.99	42.21	0.000148	1.68	5127.46	988.55	0.08	17.9	13.3	0.12	1071.53
Hart	11308	50-yr	10343.23	24.27	43.26	34.63	43.31	0.000212	2.12	6212.07	1000.95	0.1	18.99	14.39	0.19	1130.59
Hart	11308	100-yr	13535.92	24.27	44.34	35.23	44.41	0.00024	2.37	7295.42	1000.95	0.11	20.07	15.47	0.23	1193.09

Hart Slough - Existing Conditions HEC-RAS Hydraulic Model Summary Results

Reach	River Sta	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl	Max Chl Dpth (ft)	Hydr Depth C (ft)	Shear Chan (lb/sq ft)	Vol Chan (acre-ft)
Hart	11445	4000-cfs	0	24.64	24.67	24.67	24.67	0.000042	0.01	0.1	6.9	0.01	0.03	0.01	0	28.57
Hart	11445	5000-cfs	0	24.64	24.67	24.67	24.67	0.000042	0.01	0.1	6.9	0.01	0.03	0.01	0	34.05
Hart	11445	6000-cfs	0	24.64	24.67	24.67	24.67	0.000042	0.01	0.1	6.9	0.01	0.03	0.01	0	40.65
Hart	11445	7000-cfs	0	24.64	24.67	24.67	24.67	0.000042	0.01	0.1	6.9	0.01	0.03	0.01	0	48.47
Hart	11445	10000-cfs	0	24.64	24.67	24.67	24.67	0.000042	0.01	0.1	6.9	0.01	0.03	0.01	0	92.53
Hart	11445	15000-cfs	103.08	24.64	35.91	25.94	35.91	0.000001	0.07	1802.67	422.93	0	11.27	7.54	0	696.04
Hart	11445	2-yr	1593.28	24.64	37.8	29.3	37.81	0.000044	0.73	2637.62	470.59	0.04	13.16	9.44	0.03	810
Hart	11445	10-yr	4923.55	24.64	41.17	31.86	41.18	0.000033	0.78	8015.03	1075.77	0.04	16.53	12.81	0.03	1014.73
Hart	11445	25-yr	6956.88	24.64	42.21	32.87	42.22	0.000044	0.94	9129.17	1075.77	0.04	17.57	13.85	0.04	1077.59
Hart	11445	50-yr	10343.23	24.64	43.31	34.28	43.33	0.000065	1.2	10318.19	1075.77	0.05	18.67	14.95	0.06	1137.14
Hart	11445	100-yr	13535.92	24.64	44.41	35.12	44.43	0.000078	1.39	11492.55	1075.77	0.06	19.77	16.04	0.08	1200.12
Hart	12051	4000-cfs	0	24.7	24.72	24.72	24.72	0.000012	0.01	0.14	6.43	0.01	0.02	0.02	0	28.57
Hart	12051	5000-cfs	0	24.7	24.72	24.72	24.72	0.000012	0.01	0.14	6.43	0.01	0.02	0.02	0	34.05
Hart	12051	6000-cfs	0	24.7	24.72	24.72	24.72	0.000012	0.01	0.14	6.43	0.01	0.02	0.02	0	40.65
Hart	12051	7000-cfs	0	24.7	24.72	24.72	24.72	0.000012	0.01	0.14	6.43	0.01	0.02	0.02	0	48.47
Hart	12051	10000-cfs	0	24.7	24.72	24.72	24.72	0.000012	0.01	0.14	6.43	0.01	0.02	0.02	0	92.53
Hart	12051	15000-cfs	103.08	24.7	35.91	26.02	35.91	0.000001	0.08	1410.01	361.2	0.01	11.21	5.92	0	710.14
Hart	12051	2-yr	1593.28	24.7	37.83	29.38	37.84	0.000078	0.85	2135.48	405.19	0.05	13.13	7.8	0.04	828.17
Hart	12051	10-yr	4923.55	24.7	41.2	32.8	41.2	0.000028	0.64	11530.55	2450.26	0.03	16.5	11.18	0.02	1040.08
Hart	12051	25-yr	6956.88	24.7	42.24	34.08	42.24	0.000029	0.7	14078.73	2450.26	0.04	17.54	12.21	0.02	1105.16
Hart	12051	50-yr	10343.23	24.7	43.36	35.05	43.37	0.000037	0.83	16822.46	2450.26	0.04	18.66	13.33	0.03	1167.08
Hart	12051	100-yr	13535.92	24.7	44.46	35.72	44.47	0.000039	0.9	19518.49	2450.26	0.04	19.76	14.44	0.03	1232.4
Hart	14131	4000-cfs	0	23.77	24.72	23.82	24.72	0	0	12.49	24.36	0	0.95	0.51	0	28.87
Hart	14131	5000-cfs	0	23.77	24.72	23.82	24.72	0	0	12.49	24.36	0	0.95	0.51	0	34.35
Hart	14131	6000-cfs	0	23.77	24.72	23.82	24.72	0	0	12.49	24.36	0	0.95	0.51	0	40.95
Hart	14131	7000-cfs	0	23.77	24.72	23.82	24.72	0	0	12.49	24.36	0	0.95	0.51	0	48.77
Hart	14131	10000-cfs	0	23.77	24.72	23.82	24.72	0	0	12.49	24.36	0	0.95	0.51	0	92.83
Hart	14131	15000-cfs	103.08	23.77	35.91		35.91	0.000001	0.15	863.59	145.53	0.01	12.14	10.83	0	746.65
Hart	14131	2-yr	1593.28	23.77	38.02		38.06	0.000154	1.67	1233.31	232.79	0.08	14.25	12.94	0.12	874.93
Hart	14131	10-yr	4923.55	23.77	41.27		41.38	0.000418	3.2	2181.78	317.08	0.14	17.5	16.19	0.41	1104.36
Hart	14131	25-yr	6956.88	23.77	42.29		42.44	0.00057	3.89	2508.59	323.03	0.17	18.52	17.2	0.6	1174.86
Hart	14131	50-yr	10343.23	23.77	43.41		43.65	0.000849	4.96	2869.17	323.03	0.2	19.64	18.32	0.95	1242.64
Hart	14131	100-yr	13535.92	23.77	44.46		44.79	0.001037	5.69	3210.9	323.03	0.23	20.69	19.38	1.23	1313.66

Hart Slough - Existing Conditions HEC-RAS Hydraulic Model Summary Results

Reach	River Sta	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl	Max Chl Dpth (ft)	Hydr Depth C (ft)	Shear Chan (lb/sq ft)	Vol Chan (acre-ft)
Hart	15547	4000-cfs	0	24.91	24.95	24.95	24.95	0.000014	0.01	0.12	4.35	0.01	0.04	0.03	0	29.07
Hart	15547	5000-cfs	0	24.91	24.95	24.95	24.95	0.000014	0.01	0.12	4.35	0.01	0.04	0.03	0	34.55
Hart	15547	6000-cfs	0	24.91	24.95	24.95	24.95	0.000014	0.01	0.12	4.35	0.01	0.04	0.03	0	41.16
Hart	15547	7000-cfs	0	24.91	24.95	24.95	24.95	0.000014	0.01	0.12	4.35	0.01	0.04	0.03	0	48.98
Hart	15547	10000-cfs	0	24.91	24.95	24.95	24.95	0.000014	0.01	0.12	4.35	0.01	0.04	0.03	0	93.04
Hart	15547	15000-cfs	103.08	24.91	35.92		35.92	0.000003	0.2	747.57	357.46	0.01	11.01	9.5	0	760.07
Hart	15547	2-yr	1593.28	24.91	38.23		38.24	0.000125	1.4	1985.1	582.53	0.07	13.32	11.81	0.09	891.2
Hart	15547	10-yr	4923.55	24.91	41.67		41.69	0.000151	1.82	4070.68	630.36	0.08	16.76	15.25	0.14	1124.96
Hart	15547	25-yr	6956.88	24.91	42.8		42.83	0.000182	2.1	4792.76	639.88	0.09	17.89	16.38	0.18	1196.83
Hart	15547	50-yr	10343.23	24.91	44.13		44.19	0.000238	2.53	5646.17	639.88	0.11	19.22	17.71	0.25	1266.18
Hart	15547	100-yr	13535.92	24.91	45.34		45.41	0.000269	2.81	6418.27	639.88	0.11	20.43	18.92	0.31	1338.66
Hart	16235	4000-cfs	0	24.91	24.95		24.95	0.000008	0.01	0.14	4.41	0.01	0.04	0.03	0	29.08
Hart	16235	5000-cfs	0	24.91	24.95		24.95	0.000008	0.01	0.14	4.41	0.01	0.04	0.03	0	34.56
Hart	16235	6000-cfs	0	24.91	24.95		24.95	0.000008	0.01	0.14	4.41	0.01	0.04	0.03	0	41.16
Hart	16235	7000-cfs	0	24.91	24.95		24.95	0.000008	0.01	0.14	4.41	0.01	0.04	0.03	0	48.98
Hart	16235	10000-cfs	0	24.91	24.95		24.95	0.000008	0.01	0.14	4.41	0.01	0.04	0.03	0	93.04
Hart	16235	15000-cfs	103.08	24.91	35.92		35.92	0.000003	0.2	749	358.57	0.01	11.01	9.5	0	764.83
Hart	16235	2-yr	1593.28	24.91	38.31		38.32	0.000117	1.36	2031.46	583.64	0.07	13.4	11.89	0.08	897.14
Hart	16235	10-yr	4923.55	24.91	41.76		41.79	0.000145	1.79	4132.61	631.73	0.08	16.85	15.34	0.13	1132.64
Hart	16235	25-yr	6956.88	24.91	42.92		42.95	0.000173	2.06	4868.43	639.88	0.09	18.01	16.5	0.17	1205.09
Hart	16235	50-yr	10343.23	24.91	44.29		44.34	0.000225	2.47	5744.79	639.88	0.1	19.38	17.87	0.24	1275.11
Hart	16235	100-yr	13535.92	24.91	45.51		45.58	0.000254	2.75	6529.97	639.88	0.11	20.6	19.09	0.29	1348.2
Hart	16250		Bridge													
Hart	16270	4000-cfs	0	24.91	24.97	24.95	24.97	0.000002	0	0.21	4.57	0	0.06	0.05	0	29.08
Hart	16270	5000-cfs	0	24.91	24.97	24.95	24.97	0.000002	0	0.21	4.57	0	0.06	0.05	0	34.56
Hart	16270	6000-cfs	0	24.91	24.97	24.95	24.97	0.000002	0	0.21	4.57	0	0.06	0.05	0	41.16
Hart	16270	7000-cfs	0	24.91	24.97	24.95	24.97	0.000002	0	0.21	4.57	0	0.06	0.05	0	48.98
Hart	16270	10000-cfs	0	24.91	24.97	24.95	24.97	0.000002	0	0.21	4.57	0	0.06	0.05	0	93.04
Hart	16270	15000-cfs	103.08	24.91	35.93	26.49	35.93	0.000003	0.2	753.29	361.9	0.01	11.02	9.51	0	765.07
Hart	16270	2-yr	1593.28	24.91	38.31	30.7	38.33	0.000117	1.36	2035.21	583.73	0.07	13.4	11.89	0.08	897.41
Hart	16270	10-yr	4923.55	24.91	41.77	34.66	41.8	0.000144	1.79	4138.08	631.85	0.08	16.86	15.35	0.13	1132.99
Hart	16270	25-yr	6956.88	24.91	42.93	36.83	42.96	0.000173	2.06	4873.88	639.88	0.09	18.02	16.51	0.17	1205.47
Hart	16270	50-yr	10343.23	24.91	44.3	37.52	44.35	0.000224	2.47	5751.93	639.88	0.1	19.39	17.88	0.24	1275.53
Hart	16270	100-yr	13535.92	24.91	45.53	37.92	45.6	0.000253	2.74	6537.93	639.88	0.11	20.62	19.11	0.29	1348.66

Hart Slough - Existing Conditions HEC-RAS Hydraulic Model Summary Results

Reach	River Sta	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl	Max Chl Dpth (ft)	Hydr Depth C (ft)	Shear Chan (lb/sq ft)	Vol Chan (acre-ft)
Hart	18131	4000-cfs	0	26.62	26.65	26.65	26.65	0.009015	0.13	0.01	0.57	0.2	0.03	0.01	0.01	29.08
Hart	18131	5000-cfs	0	26.62	26.65	26.65	26.65	0.009015	0.13	0.01	0.57	0.2	0.03	0.01	0.01	34.56
Hart	18131	6000-cfs	0	26.62	26.65	26.65	26.65	0.009015	0.13	0.01	0.57	0.2	0.03	0.01	0.01	41.16
Hart	18131	7000-cfs	0	26.62	26.65	26.65	26.65	0.009015	0.13	0.01	0.57	0.2	0.03	0.01	0.01	48.99
Hart	18131	10000-cfs	0	26.62	26.65	26.65	26.65	0.009015	0.13	0.01	0.57	0.2	0.03	0.01	0.01	93.04
Hart	18131	15000-cfs	103.08	26.62	35.94		35.94	0.000006	0.24	542.3	137.26	0.02	9.32	7.94	0	777.3
Hart	18131	2-yr	1593.28	26.62	38.63		38.68	0.000338	2.15	988.35	189.56	0.12	12.01	10.63	0.22	913.22
Hart	18131	10-yr	4923.55	26.62	42.19		42.33	0.000695	3.75	1763.98	245.07	0.18	15.57	14.19	0.6	1153.73
Hart	18131	25-yr	6956.88	26.62	43.42		43.62	0.000896	4.49	2076.81	262.99	0.2	16.8	15.42	0.83	1227.89
Hart	18131	50-yr	10343.23	26.62	44.92		45.21	0.001167	5.46	2477.27	268.08	0.23	18.3	16.92	1.19	1299.97
Hart	18131	100-yr	13535.92	26.62	46.2		46.58	0.001329	6.11	2821.64	268.08	0.25	19.58	18.21	1.46	1374.87
Hart	18166	4000-cfs	0	26.62	26.68		26.68	0.00019	0.03	0.03	1.17	0.03	0.06	0.03	0	29.08
Hart	18166	5000-cfs	0	26.62	26.68		26.68	0.00019	0.03	0.03	1.17	0.03	0.06	0.03	0	34.56
Hart	18166	6000-cfs	0	26.62	26.68		26.68	0.00019	0.03	0.03	1.17	0.03	0.06	0.03	0	41.16
Hart	18166	7000-cfs	0	26.62	26.68		26.68	0.00019	0.03	0.03	1.17	0.03	0.06	0.03	0	48.99
Hart	18166	10000-cfs	0	26.62	26.68		26.68	0.00019	0.03	0.03	1.17	0.03	0.06	0.03	0	93.04
Hart	18166	15000-cfs	103.08	26.62	35.94		35.94	0.000006	0.24	542.85	137.35	0.02	9.32	7.94	0	777.52
Hart	18166	2-yr	1593.28	26.62	38.64		38.69	0.000336	2.15	990.66	189.75	0.12	12.02	10.64	0.22	913.51
Hart	18166	10-yr	4923.55	26.62	42.21		42.35	0.000689	3.73	1770.28	245.44	0.17	15.59	14.22	0.59	1154.12
Hart	18166	25-yr	6956.88	26.62	43.45		43.65	0.000886	4.48	2085.6	263.48	0.2	16.83	15.46	0.83	1228.32
Hart	18166	50-yr	10343.23	26.62	44.96		45.26	0.001149	5.42	2489.41	268.08	0.23	18.34	16.97	1.18	1300.44
Hart	18166	100-yr	13535.92	26.62	46.25		46.63	0.001309	6.08	2835.61	268.08	0.25	19.63	18.26	1.44	1375.36
Hart	18177		Bridge													
Hart	18180	4000-cfs	0	26.77	26.8	26.8	26.8	0.001659	0.07	0.02	0.92	0.09	0.03	0.02	0	29.08
Hart	18180	5000-cfs	0	26.77	26.8	26.8	26.8	0.001659	0.07	0.02	0.92	0.09	0.03	0.02	0	34.56
Hart	18180	6000-cfs	0	26.77	26.8	26.8	26.8	0.001659	0.07	0.02	0.92	0.09	0.03	0.02	0	41.16
Hart	18180	7000-cfs	0	26.77	26.8	26.8	26.8	0.001659	0.07	0.02	0.92	0.09	0.03	0.02	0	48.99
Hart	18180	10000-cfs	0	26.77	26.8	26.8	26.8	0.001659	0.07	0.02	0.92	0.09	0.03	0.02	0	93.04
Hart	18180	15000-cfs	103.08	26.77	35.95	28.35	35.95	0.000021	0.32	318.24	61.9	0.03	9.18	5.14	0.01	777.6
Hart	18180	2-yr	1593.28	26.77	38.63	32.81	38.74	0.000974	2.84	664.38	192.32	0.18	11.86	7.48	0.43	913.63
Hart	18180	10-yr	4923.55	26.77	42.24	37.38	42.42	0.001167	4.04	1614.87	313.48	0.21	15.47	11.08	0.76	1154.29
Hart	18180	25-yr	6956.88	26.77	43.47	38.81	43.69	0.001301	4.58	2017.19	341.05	0.23	16.7	12.31	0.94	1228.51
Hart	18180	50-yr	10343.23	26.77	45.02	40.37	45.31	0.001439	5.22	2556.84	347.88	0.25	18.25	13.87	1.18	1300.65
Hart	18180	100-yr	13535.92	26.77	46.34	41.25	46.69	0.00148	5.62	3017.76	347.88	0.25	19.57	15.19	1.32	1375.6

Hart Slough - Existing Conditions HEC-RAS Hydraulic Model Summary Results

Reach	River Sta	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl	Max Chl Dpth (ft)	Hydr Depth C (ft)	Shear Chan (lb/sq ft)	Vol Chan (acre-ft)
Hart	18257	4000-cfs	0	26.77	26.83	26.81	26.83	0.000085	0.02	0.05	1.61	0.02	0.06	0.03	0	29.08
Hart	18257	5000-cfs	0	26.77	26.83	26.81	26.83	0.000085	0.02	0.05	1.61	0.02	0.06	0.03	0	34.56
Hart	18257	6000-cfs	0	26.77	26.83	26.81	26.83	0.000085	0.02	0.05	1.61	0.02	0.06	0.03	0	41.16
Hart	18257	7000-cfs	0	26.77	26.83	26.81	26.83	0.000085	0.02	0.05	1.61	0.02	0.06	0.03	0	48.99
Hart	18257	10000-cfs	0	26.77	26.83	26.81	26.83	0.000085	0.02	0.05	1.61	0.02	0.06	0.03	0	93.04
Hart	18257	15000-cfs	103.08	26.77	35.96		35.96	0.000021	0.32	318.48	61.93	0.03	9.19	5.14	0.01	778.16
Hart	18257	2-yr	1593.28	26.77	38.71		38.82	0.000927	2.79	679.54	195.95	0.18	11.94	7.56	0.41	914.51
Hart	18257	10-yr	4923.55	26.77	42.33		42.51	0.001112	3.97	1644.95	315.62	0.21	15.56	11.18	0.73	1155.59
Hart	18257	25-yr	6956.88	26.77	43.57		43.79	0.001241	4.5	2053.93	343.45	0.22	16.8	12.42	0.91	1229.95
Hart	18257	50-yr	10343.23	26.77	45.14		45.42	0.00137	5.12	2598.49	347.88	0.24	18.37	13.99	1.13	1302.28
Hart	18257	100-yr	13535.92	26.77	46.47		46.8	0.001417	5.53	3060.59	347.88	0.25	19.7	15.32	1.28	1377.38
Hart	20926	4000-cfs	0	31.54	31.56	31.57	31.56	0.001535	0.05	0.02	1.58	0.08	0.02	0.01	0	29.08
Hart	20926	5000-cfs	0	31.54	31.56	31.57	31.56	0.001507	0.05	0.02	1.59	0.08	0.02	0.01	0	34.56
Hart	20926	6000-cfs	0	31.54	31.56	31.57	31.56	0.001579	0.05	0.02	1.58	0.08	0.02	0.01	0	41.17
Hart	20926	7000-cfs	0	31.54	31.56	31.57	31.56	0.001653	0.05	0.02	1.56	0.08	0.02	0.01	0	48.99
Hart	20926	10000-cfs	0	31.54	31.56	31.57	31.56	0.001882	0.06	0.02	1.52	0.09	0.02	0.01	0	93.05
Hart	20926	15000-cfs	103.08	31.54	36.1		36.13	0.000684	1.2	85.59	31.94	0.13	4.56	2.68	0.11	790.54
Hart	20926	2-yr	1593.28	31.54	41.46		41.57	0.001191	2.91	636.54	146.07	0.2	9.92	6.54	0.47	940.16
Hart	20926	10-yr	4923.55	31.54	45.53		45.77	0.001418	4.38	1272	166.69	0.24	13.99	10.61	0.9	1195.02
Hart	20926	25-yr	6956.88	31.54	47.09		47.42	0.001572	5.05	1532.41	166.69	0.26	15.55	12.17	1.14	1274.36
Hart	20926	50-yr	10343.23	31.54	49.09		49.57	0.001866	6.09	1865.46	166.69	0.29	17.55	14.17	1.58	1353.02
Hart	20926	100-yr	13535.92	31.54	50.66		51.3	0.002113	6.95	2126.81	166.69	0.31	19.12	15.74	1.99	1433.3
Hart	21012	4000-cfs	0	31.9	31.93	31.93	31.93	0.010376	0.14	0.01	0.58	0.21	3.44	0.01		29.08
Hart	21012	5000-cfs	0	31.9	31.93	31.93	31.93	0.010376	0.14	0.01	0.58	0.21	3.44	0.01		34.56
Hart	21012	6000-cfs	0	31.9	31.93	31.93	31.93	0.010376	0.14	0.01	0.58	0.21	3.44	0.01		41.17
Hart	21012	7000-cfs	0	31.9	31.93	31.93	31.93	0.010376	0.14	0.01	0.58	0.21	3.44	0.01		48.99
Hart	21012	10000-cfs	0	31.9	31.93	31.93	31.93	0.010376	0.14	0.01	0.58	0.21	3.44	0.01		93.05
Hart	21012	15000-cfs	103.08	31.9	36.16	33.36	36.17	0.000459	0.98	110.35	62.99	0.11	7.67	2.59	0.07	790.73
Hart	21012	2-yr	1593.28	31.9	41.57	37.31	41.66	0.001023	2.63	653.7	158.07	0.19	13.08	6.21	0.39	940.87
Hart	21012	10-yr	4923.55	31.9	45.73	39.92	45.87	0.00091	3.49	1670.26	232.28	0.19	17.24	10.37	0.57	1196.18
Hart	21012	25-yr	6956.88	31.9	47.35	40.99	47.54	0.000954	3.94	2045.67	232.28	0.2	18.86	11.99	0.69	1275.7
Hart	21012	50-yr	10343.23	31.9	49.45	42.32	49.71	0.001066	4.63	2533.2	232.28	0.22	20.96	14.09	0.91	1354.6
Hart	21012	100-yr	13535.92	31.9	51.11	43.19	51.46	0.00116	5.21	2919.97	232.28	0.23	22.62	15.75	1.11	1435.05

Hart Slough - Existing Conditions HEC-RAS Hydraulic Model Summary Results

Reach	River Sta	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl	Max Chl Dpth (ft)	Hydr Depth C (ft)	Shear Chan (lb/sq ft)	Vol Chan (acre-ft)
Hart	21190	4000-cfs	0	31.59	31.93		31.93	0	0	1.34	6.39	0	0.34	0.21	0	29.09
Hart	21190	5000-cfs	0	31.59	31.93		31.93	0	0	1.34	6.39	0	0.34	0.21	0	34.57
Hart	21190	6000-cfs	0	31.59	31.93		31.93	0	0	1.34	6.39	0	0.34	0.21	0	41.17
Hart	21190	7000-cfs	0	31.59	31.93		31.93	0	0	1.34	6.39	0	0.34	0.21	0	48.99
Hart	21190	10000-cfs	0	31.59	31.93		31.93	0	0	1.34	6.39	0	0.34	0.21	0	93.05
Hart	21190	15000-cfs	103.08	31.59	36.22		36.22	0.000149	0.51	200.35	88.8	0.06	4.63	2.26	0.02	791.35
Hart	21190	2-yr	1593.28	31.59	41.73		41.77	0.000348	1.68	1028.91	192.24	0.11	10.14	7.08	0.15	943.32
Hart	21190	10-yr	4923.55	31.59	45.89		46	0.000526	2.82	1979.91	248.64	0.15	14.3	11.25	0.36	1200.13
Hart	21190	25-yr	6956.88	31.59	47.53		47.67	0.000593	3.27	2386.76	248.64	0.16	15.94	12.89	0.47	1280.24
Hart	21190	50-yr	10343.23	31.59	49.67		49.87	0.000701	3.94	2918.1	248.64	0.18	18.08	15.02	0.65	1359.9
Hart	21190	100-yr	13535.92	31.59	51.37		51.63	0.000785	4.48	3340.31	248.64	0.19	19.78	16.72	0.8	1440.97

Appendix B – Summary of Existing and Alternative Conditions HEC-RAS Modeling Results.

HEC-RAS River: HartSlough Reach: Hart Profile: 10000-cfs

Reach	River Sta	Profile Skagit Flow (cfs)	Plan	Q Total (cfs)	Cum.Volume Channel (acre-ft)	Max Depth (ft)	Avg Depth (ft)	Velocity Channel (ft/s)	Top Width (ft)	X-Sect Flow Area (sq ft)	Min.Channel Elevation (ft)	W.S. Elev (ft)
Hart	21190	10000-cfs	Existing	0	93.05	0.34	0.21	0	6.39	1.34	31.59	31.93
Hart	21190	10000-cfs	Alt A	9.52	101.14	2.2	1.86	0.1	51.37	95.44	24.6	26.8
Hart	21190	10000-cfs	Alt B	8.99	100.67	2.19	1.98	0.74	6.18	12.22	24.6	26.79
Hart	21190	10000-cfs	Alt C	9.87	101.32	2.17	1.84	0.1	51.21	94.3	24.6	26.77
Hart	21012	10000-cfs	Existing	0	93.05	3.44	0.01	0.14	0.58	0.01	31.9	31.93
Hart	21012	10000-cfs	Alt A	9.52	100.9	2.19	1.66	0.47	12.2	20.22	24.59	26.78
Hart	21012	10000-cfs	Alt B	8.99	100.61	2.14	1.62	0.46	12.06	19.57	24.59	26.73
Hart	21012	10000-cfs	Alt C	9.87	101.09	2.17	1.65	0.49	12.16	20.03	24.59	26.77
Hart	20926	10000-cfs	Existing	0	93.05	0.02	0.01	0.06	1.52	0.02	31.54	31.56
Hart	20926	10000-cfs	Alt A	9.52	100.86	2.18	1.7	0.36	15.37	26.16	24.59	26.77
Hart	20926	10000-cfs	Alt B	8.99	100.56	2.13	1.67	0.35	15.21	25.34	24.59	26.72
Hart	20926	10000-cfs	Alt C	9.87	101.04	2.17	1.7	0.38	15.34	26.01	24.59	26.76
Hart	18257	10000-cfs	Existing	0	93.04	0.06	0.03	0.02	1.61	0.05	26.77	26.83
Hart	18257	10000-cfs	Alt A	9.52	98.95	2.07	1.66	0.26	21.7	36.02	24.48	26.55
Hart	18257	10000-cfs	Alt B	8.99	98.71	2.02	1.63	0.26	21.5	34.98	24.48	26.5
Hart	18257	10000-cfs	Alt C	9.87	99.12	2.1	1.68	0.27	21.82	36.66	24.48	26.58
Hart	18180	10000-cfs	Existing	0	93.04	0.03	0.02	0.07	0.92	0.02	26.77	26.8
Hart	18180	10000-cfs	Alt A	9.52	98.9	2.06	1.46	0.36	18.27	26.67	24.48	26.54
Hart	18180	10000-cfs	Alt B	8.99	98.66	2.02	1.43	0.35	18.02	25.8	24.48	26.5
Hart	18180	10000-cfs	Alt C	9.87	99.07	2.09	1.48	0.36	18.42	27.21	24.48	26.57
Hart	18177	10000-cfs		Bridge								
Hart	18166	10000-cfs	Existing	0	93.04	0.06	0.03	0.03	1.17	0.03	26.62	26.68
Hart	18166	10000-cfs	Alt A	9.52	98.89	2.02	1.54	0.36	17.1	26.27	24.48	26.5
Hart	18166	10000-cfs	Alt B	8.99	98.65	1.97	1.51	0.35	16.9	25.44	24.48	26.45
Hart	18166	10000-cfs	Alt C	9.87	99.06	2.06	1.56	0.37	17.23	26.83	24.48	26.53
Hart	18131	10000-cfs	Existing	0	93.04	0.03	0.01	0.13	0.57	0.01	26.62	26.65
Hart	18131	10000-cfs	Alt A	9.52	98.87	2.02	1.46	0.41	16.01	23.39	24.48	26.5
Hart	18131	10000-cfs	Alt B	8.99	98.63	1.97	1.43	0.4	15.8	22.62	24.48	26.45
Hart	18131	10000-cfs	Alt C	9.87	99.04	2.05	1.48	0.41	16.15	23.91	24.48	26.53

HEC-RAS River: HartSlough Reach: Hart Profile: 10000-cfs

Reach	River Sta	Profile Skagit Flow (cfs)	Plan	Q Total (cfs)	Cum.Volume Channel (acre-ft)	Max Depth (ft)	Avg Depth (ft)	Velocity Channel (ft/s)	Top Width (ft)	X-Sect Flow Area (sq ft)	Min.Channel Elevation (ft)	W.S. Elev (ft)
Hart	16270	10000-cfs	Existing	0	93.04	0.06	0.05	0	4.57	0.21	24.91	24.97
Hart	16270	10000-cfs	Alt A	9.52	97.79	1.8	1.33	0.35	20.33	27.02	24.4	26.2
Hart	16270	10000-cfs	Alt B	8.99	97.59	1.76	1.3	0.34	20.07	26.16	24.4	26.16
Hart	16270	10000-cfs	Alt C	9.87	97.94	1.83	1.35	0.36	20.5	27.6	24.4	26.23
Hart	16250	10000-cfs		Bridge								
Hart	16235	10000-cfs	Existing	0	93.04	0.04	0.03	0.01	4.41	0.14	24.91	24.95
Hart	16235	10000-cfs	Alt A	9.52	97.77	1.79	1.25	0.36	21.02	26.27	24.4	26.19
Hart	16235	10000-cfs	Alt B	8.99	97.57	1.75	1.22	0.35	20.78	25.39	24.4	26.15
Hart	16235	10000-cfs	Alt C	9.87	97.92	1.82	1.27	0.37	21.17	26.87	24.4	26.22
D	17300	10000-cfs	Alt D	10	97.08	2.19	1.68	0.32	18.61	31.36	23.27	25.46
D	17300	10000-cfs	Alt D2	10.33	97.18	2.19	1.68	0.33	18.58	31.24	23.27	25.46
D	16300	10000-cfs	Alt D	10	96.37	2.14	1.65	0.33	18.4	30.39	23.27	25.41
D	16300	10000-cfs	Alt D2	10.33	96.47	2.17	1.67	0.33	18.51	30.87	23.27	25.44
Hart	15547	10000-cfs	Existing	0	93.04	0.04	0.03	0.01	4.35	0.12	24.91	24.95
Hart	15547	10000-cfs	Alt A	9.52	97.38	1.69	1.15	0.4	20.66	23.75	24.37	26.07
Hart	15547	10000-cfs	Alt B	8.99	97.19	1.65	1.12	0.39	20.44	22.92	24.37	26.03
Hart	15547	10000-cfs	Alt C	9.87	97.51	1.72	1.17	0.41	20.8	24.31	24.37	26.09
D	15547	10000-cfs	Alt D	10	96.34	2.13	1.46	0.65	10.55	15.36	23.27	25.4
D	15547	10000-cfs	Alt D2	10.33	96.44	2.15	1.46	0.66	10.68	15.63	23.27	25.42
Hart	14131	10000-cfs	Existing	0	92.83	0.95	0.51	0	24.36	12.49	23.77	24.72
Hart	14131	10000-cfs	Alt A	9.52	96.17	2.19	1.36	0.19	37.32	50.87	23.77	25.96
Hart	14131	10000-cfs	Alt B	8.99	96.01	2.15	1.34	0.18	37.03	49.47	23.77	25.92
Hart	14131	10000-cfs	Alt C	9.87	96.27	2.21	1.38	0.19	37.5	51.83	23.77	25.98
D	14131	10000-cfs	Alt D	10	95.56	1.94	1.1	0.31	29.79	32.64	23.27	25.21
D	14131	10000-cfs	Alt D2	10.33	95.64	1.97	1.11	0.31	30.03	33.34	23.27	25.24

HEC-RAS River: HartSlough Reach: Hart Profile: 10000-cfs

Reach	River Sta	Profile Skagit Flow (cfs)	Plan	Q Total (cfs)	Cum.Volume Channel (acre-ft)	Max Depth (ft)	Avg Depth (ft)	Velocity Channel (ft/s)	Top Width (ft)	X-Sect Flow Area (sq ft)	Min.Channel Elevation (ft)	W.S. Elev (ft)
Hart	12051	10000-cfs	Existing	0	92.53	0.02	0.02	0.01	6.43	0.14	24.7	24.72
Hart	12051	10000-cfs	Alt A	9.52	94.46	1.54	0.91	0.46	22.73	20.71	24.23	25.77
Hart	12051	10000-cfs	Alt B	8.99	94.36	1.5	0.89	0.45	22.34	19.96	24.23	25.74
Hart	12051	10000-cfs	Alt C	9.87	94.53	1.56	0.92	0.47	23.01	21.22	24.23	25.79
D	12051	10000-cfs	Alt D	10	94.29	1.69	1.02	0.49	20.04	20.44	23.27	24.96
D	12051	10000-cfs	Alt D2	10.33	94.35	1.71	1.03	0.49	20.25	20.89	23.27	24.98
Hart	11445	10000-cfs	Existing	0	92.53	0.03	0.01	0.01	6.9	0.1	24.64	24.67
Hart	11445	10000-cfs	Alt A	9.52	94.21	1.18	0.73	0.65	19.82	14.54	24.21	25.39
Hart	11445	10000-cfs	Alt B	8.99	94.12	1.16	0.72	0.64	19.49	14.03	24.21	25.37
Hart	11445	10000-cfs	Alt C	9.87	94.28	1.2	0.75	0.66	20.1	14.98	24.21	25.41
D	11445	10000-cfs	Alt D	10	94.01	1.54	0.95	0.51	20.84	19.77	23.27	24.81
D	11445	10000-cfs	Alt D2	10.33	94.06	1.56	0.96	0.51	21.06	20.21	23.27	24.83
Hart	11308	10000-cfs	Existing	0	92.53	0.03	0.01	0.02	3.62	0.05	24.27	24.3
Hart	11308	10000-cfs	Alt A	9.52	94.17	0.98	0.65	0.87	16.71	10.94	24.21	25.18
Hart	11308	10000-cfs	Alt B	8.99	94.08	0.94	0.63	0.87	16.27	10.3	24.21	25.14
Hart	11308	10000-cfs	Alt C	9.87	94.24	1	0.67	0.87	17	11.37	24.21	25.21
D	11308	10000-cfs	Alt D	10	93.95	1.51	1.01	0.49	20.12	20.34	23.27	24.78
D	11308	10000-cfs	Alt D2	10.33	94	1.53	1.02	0.5	20.3	20.77	23.27	24.8
Hart	10308	10000-cfs	Existing	0	92.46	0.46	0.39	0	16.41	6.45	23.28	23.74
Hart	10308	10000-cfs	Alt A	9.52	93.72	1.51	1.12	0.33	25.53	28.54	23.28	24.79
Hart	10308	10000-cfs	Alt B	8.99	93.65	1.48	1.1	0.33	25.23	27.65	23.28	24.76
Hart	10308	10000-cfs	Alt C	9.87	93.77	1.54	1.13	0.34	25.74	29.16	23.28	24.82
D	10308	10000-cfs	Alt D	10	93.44	1.33	1.01	0.41	23.95	24.21	23.27	24.6
D	10308	10000-cfs	Alt D2	10.33	93.47	1.35	1.02	0.42	24.12	24.67	23.27	24.62
Hart	9372	10000-cfs	Existing	0	92.33	0.38	0.3	0	17.57	5.2	23.36	23.74
Hart	9372	10000-cfs	Alt A	9.52	93.15	1.23	0.87	0.38	28.27	24.72	23.36	24.59
Hart	9372	10000-cfs	Alt B	8.99	93.09	1.2	0.86	0.38	27.87	23.84	23.36	24.56
Hart	9372	10000-cfs	Alt C	9.87	93.19	1.26	0.89	0.39	28.55	25.37	23.36	24.62
D	9372	10000-cfs	Alt D	10	92.92	1.16	0.87	0.42	27.67	24.01	23.27	24.43
D	9372	10000-cfs	Alt D2	10.33	92.95	1.18	0.88	0.42	27.87	24.48	23.27	24.45

HEC-RAS River: HartSlough Reach: Hart Profile: 10000-cfs

Reach	River Sta	Profile Skagit Flow (cfs)	Plan	Q Total (cfs)	Cum.Volume Channel (acre-ft)	Max Depth (ft)	Avg Depth (ft)	Velocity Channel (ft/s)	Top Width (ft)	X-Sect Flow Area (sq ft)	Min.Channel Elevation (ft)	W.S. Elev (ft)
Hart	8436	10000-cfs	Existing	0	92.16	0.47	0.39	0	27.25	10.58	23.27	23.74
Hart	8436	10000-cfs	Alt A	9.52	92.54	1.1	0.79	0.3	39.94	31.67	23.27	24.37
Hart	8436	10000-cfs	Alt B	8.99	92.51	1.07	0.78	0.29	39.35	30.51	23.27	24.34
Hart	8436	10000-cfs	Alt C	9.87	92.56	1.12	0.81	0.3	40.43	32.64	23.27	24.39
D	8436	10000-cfs	Alt D	10	92.37	0.98	0.72	0.37	37.6	27.18	23.27	24.25
D	8436	10000-cfs	Alt D2	10.33	92.38	1	0.73	0.37	37.9	27.75	23.27	24.27
Hart	7473	10000-cfs	Existing	0	91.92	0.75	0.6	0	19.01	11.45	22.99	23.74
Hart	7473	10000-cfs	Alt A	9.52	91.99	1.06	0.8	0.54	22.07	17.74	22.99	24.05
Hart	7473	10000-cfs	Alt B	8.99	91.98	1.03	0.79	0.52	21.82	17.19	22.99	24.02
Hart	7473	10000-cfs	Alt C	9.87	92	1.07	0.81	0.55	22.24	18.11	22.99	24.06
D	7473	10000-cfs	Alt D	10	91.9	0.96	0.74	0.64	21.1	15.64	22.99	23.95
D	7473	10000-cfs	Alt D2	10.33	91.9	0.97	0.75	0.65	21.22	15.89	22.99	23.96
Hart	6346	10000-cfs	Existing	0	91.31	1.12	0.85	0	41.84	35.45	22.62	23.74
Hart	6346	10000-cfs	Alt A	9.52	91.3	1.14	0.86	0.26	42.16	36.24	22.62	23.76
Hart	6346	10000-cfs	Alt B	8.99	91.29	1.14	0.86	0.25	42.12	36.14	22.62	23.76
Hart	6346	10000-cfs	Alt C	9.87	91.3	1.14	0.86	0.27	42.19	36.31	22.62	23.76
D	6346	10000-cfs	Alt D	10	91.23	1.13	0.85	0.28	41.95	35.72	22.62	23.75
D	6346	10000-cfs	Alt D2	10.33	91.23	1.13	0.85	0.29	41.96	35.76	22.62	23.75
Hart	5097	10000-cfs	Existing	0	89.34	3.01	1.88	0	54.1	101.79	20.73	23.74
Hart	5097	10000-cfs	Alt A	9.52	89.31	3.01	1.88	0.09	54.15	102.01	20.73	23.74
Hart	5097	10000-cfs	Alt B	8.99	89.31	3.01	1.88	0.09	54.14	101.97	20.73	23.74
Hart	5097	10000-cfs	Alt C	9.87	89.31	3.02	1.88	0.1	54.16	102.04	20.73	23.75
D	5097	10000-cfs	Alt D	10	89.26	3.01	1.88	0.1	54.07	101.66	20.73	23.74
D	5097	10000-cfs	Alt D2	10.33	89.26	3.01	1.88	0.1	54.07	101.68	20.73	23.74
Hart	4170	10000-cfs	Existing	0	87.05	3.15	1.91	0	59.59	113.79	20.59	23.74
Hart	4170	10000-cfs	Alt A	9.52	87.02	3.15	1.91	0.08	59.62	113.95	20.59	23.74
Hart	4170	10000-cfs	Alt B	8.99	87.01	3.15	1.91	0.08	59.61	113.91	20.59	23.74
Hart	4170	10000-cfs	Alt C	9.87	87.02	3.15	1.91	0.09	59.63	113.97	20.59	23.74
D	4170	10000-cfs	Alt D	10	86.97	3.15	1.91	0.09	59.54	113.59	20.59	23.74
D	4170	10000-cfs	Alt D2	10.33	86.97	3.15	1.91	0.09	59.55	113.6	20.59	23.74

HEC-RAS River: HartSlough Reach: Hart Profile: 10000-cfs

Reach	River Sta	Profile Skagit Flow (cfs)	Plan	Q Total (cfs)	Cum.Volume Channel (acre-ft)	Max Depth (ft)	Avg Depth (ft)	Velocity Channel (ft/s)	Top Width (ft)	X-Sect Flow Area (sq ft)	Min.Channel Elevation (ft)	W.S. Elev (ft)
Hart	3377	10000-cfs	Existing	0	84.8	4.39	2.38	0	55.8	133.03	19.35	23.74
Hart	3377	10000-cfs	Alt A	9.52	84.77	4.39	2.38	0.07	55.81	133.11	19.35	23.74
Hart	3377	10000-cfs	Alt B	8.99	84.77	4.39	2.38	0.07	55.81	133.08	19.35	23.74
Hart	3377	10000-cfs	Alt C	9.87	84.77	4.39	2.38	0.07	55.82	133.12	19.35	23.74
D	3377	10000-cfs	Alt D	10	84.73	4.39	2.38	0.08	55.76	132.8	19.35	23.74
D	3377	10000-cfs	Alt D2	10.33	84.73	4.39	2.38	0.08	55.76	132.81	19.35	23.74
Hart	2681	10000-cfs	Existing	0	82.53	4.71	1.87	0	80.73	150.85	19.03	23.74
Hart	2681	10000-cfs	Alt A	9.52	82.5	4.71	1.87	0.06	80.73	150.84	19.03	23.74
Hart	2681	10000-cfs	Alt B	8.99	82.5	4.71	1.87	0.06	80.73	150.81	19.03	23.74
Hart	2681	10000-cfs	Alt C	9.87	82.5	4.71	1.87	0.07	80.73	150.86	19.03	23.74
D	2681	10000-cfs	Alt D	10	82.47	4.71	1.86	0.07	80.69	150.44	19.03	23.74
D	2681	10000-cfs	Alt D2	10.33	82.47	4.71	1.86	0.07	80.69	150.45	19.03	23.74
Hart	2430	10000-cfs	Existing	0	81.71	4.48	1.57	0	86.8	136.6	19.26	23.74
Hart	2430	10000-cfs	Alt A	9.52	81.67	4.48	1.57	0.07	86.79	136.47	19.26	23.74
Hart	2430	10000-cfs	Alt B	8.99	81.67	4.48	1.57	0.07	86.79	136.46	19.26	23.74
Hart	2430	10000-cfs	Alt C	9.87	81.67	4.48	1.57	0.07	86.79	136.48	19.26	23.74
D	2430	10000-cfs	Alt D	10	81.64	4.47	1.57	0.07	86.76	136.08	19.26	23.73
D	2430	10000-cfs	Alt D2	10.33	81.64	4.47	1.57	0.08	86.76	136.09	19.26	23.73
Hart	1873	10000-cfs	Existing	0	80.12	5.34	3.16	0	35.11	111.06	18.4	23.74
Hart	1873	10000-cfs	Alt A	9.52	80.09	5.34	3.16	0.09	35.09	110.96	18.4	23.74
Hart	1873	10000-cfs	Alt B	8.99	80.09	5.34	3.16	0.08	35.09	110.96	18.4	23.74
Hart	1873	10000-cfs	Alt C	9.87	80.09	5.34	3.16	0.09	35.09	110.96	18.4	23.74
D	1873	10000-cfs	Alt D	10	80.06	5.33	3.16	0.09	35.07	110.82	18.4	23.73
D	1873	10000-cfs	Alt D2	10.33	80.06	5.33	3.16	0.09	35.07	110.82	18.4	23.73
Hart	1558	10000-cfs	Existing	0	77.61	5.78	2.61	0	230.2	601.14	17.96	23.74
Hart	1558	10000-cfs	Alt A	9.52	77.58	5.78	2.61	0.02	230.07	600.47	17.96	23.74
Hart	1558	10000-cfs	Alt B	8.99	77.58	5.78	2.61	0.02	230.07	600.47	17.96	23.74
Hart	1558	10000-cfs	Alt C	9.87	77.58	5.78	2.61	0.02	230.07	600.48	17.96	23.74
D	1558	10000-cfs	Alt D	10	77.56	5.77	2.61	0.02	229.89	599.55	17.96	23.73
D	1558	10000-cfs	Alt D2	10.33	77.56	5.77	2.61	0.02	229.89	599.56	17.96	23.73

HEC-RAS River: HartSlough Reach: Hart Profile: 10000-cfs

Reach	River Sta	Profile Skagit Flow (cfs)	Plan	Q Total (cfs)	Cum.Volume Channel (acre-ft)	Max Depth (ft)	Avg Depth (ft)	Velocity Channel (ft/s)	Top Width (ft)	X-Sect Flow Area (sq ft)	Min.Channel Elevation (ft)	W.S. Elev (ft)
Hart	1290	10000-cfs	Existing	0	73.74	6.15	2.63	0	278.95	735.03	17.59	23.74
Hart	1290	10000-cfs	Alt A	9.52	73.71	6.15	2.63	0.01	278.77	734.22	17.59	23.74
Hart	1290	10000-cfs	Alt B	8.99	73.71	6.15	2.63	0.01	278.77	734.22	17.59	23.74
Hart	1290	10000-cfs	Alt C	9.87	73.71	6.15	2.63	0.01	278.77	734.22	17.59	23.74
D	1290	10000-cfs	Alt D	10	73.69	6.14	2.63	0.01	278.52	733.11	17.59	23.73
D	1290	10000-cfs	Alt D2	10.33	73.69	6.14	2.63	0.01	278.52	733.11	17.59	23.73
Hart	717	10000-cfs	Existing	0	64.8	7.07	2.72	0	391.8	1065.55	16.67	23.74
Hart	717	10000-cfs	Alt A	9.52	64.78	7.07	2.72	0.01	391.59	1064.4	16.67	23.74
Hart	717	10000-cfs	Alt B	8.99	64.78	7.07	2.72	0.01	391.59	1064.4	16.67	23.74
Hart	717	10000-cfs	Alt C	9.87	64.78	7.07	2.72	0.01	391.59	1064.4	16.67	23.74
D	717	10000-cfs	Alt D	10	64.78	7.06	2.72	0.01	391.32	1062.84	16.67	23.73
D	717	10000-cfs	Alt D2	10.33	64.78	7.06	2.72	0.01	391.32	1062.85	16.67	23.73